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Isotopic analysis of the super-large Shuangjianzishan Pb–Zn–Ag deposit in Inner Mongolia, China: Constraints on magmatism, metallogenesis, and tectonic setting

Chunhua Liu [a,*], Leon Bagas [a,b], Fengxiang Wang [a,c]

[a] MLR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, 26 Baiwanzhuang Road, Beijing 100037, China
[b] Centre for Exploration Targeting, ARC Centre of Excellence for Core to Crust Fluid Systems, The University of Western Australia, Crawley, WA 6009, Australia
[c] Faculty of Earth Sciences, China University of Geosciences, Wuhan 430074, China

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A B S T R A C T

The super-large Shuangjianzishan Pb–Zn–Ag deposit is a newly discovered deposit located in the Huanggang–Ganzhuermiao polymetallic metallogenic belt of Inner Mongolia, NE China. The deposit's resource includes 0.026 Mt Ag, 1.1 Mt Pb, and 3.3 Mt Zn. The deposit is controlled by a NW-trending ductile shear zone and NE- and NW-trending faults in black pelite assigned to the lower Permian Dashizhai Formation. LREE enrichment, HREE depletion, Nb, Ta, P, and Ti depletion, and Zr and Hf enrichment characterize felsic magmatic rocks in the Shuangjianzishan Pb–Zn–Ag district. The ages of porphyritic monzogranite, rhyolitic crystal–vitric ignimbrite, and porphyritic granodiorite are 254–252, 169, and 130 Ma, respectively. Pyrite sampled from the mineralization has Re–Os isochron ages of 165 ± 7 Ma, which suggest the mineralization is associated with the ca. 169 Ma magmatism in the Shuangjianzishan district.

Zircons extracted from the porphyritic granodiorite yield $\varepsilon_{Hf}(t)$ values of −11.34 to −1.41, with t_{DM2} dates of 1275–1901 Ma. The $\varepsilon_{Hf}(t)$ values of zircons in the rhyolitic crystal–vitric ignimbrite and the ore-bearing monzogranite porphyry are 7.57–16.23 and 10.18–15.96, respectively, and their t_{DM2} ages are 177–733 and 257–632 Ma, respectively. Partial melting of depleted mantle resulted in the formation of the ca. 254–252 Ma ore-bearing porphyritic monzogranite and the ca. 169 Ma rhyolitic crystal–vitric ignimbrite; dehydration partial melting of subducted oceanic crust resulted in the formation of the ca. 130 Ma porphyritic granodiorite. The porphyritic monzogranite was emplaced during the late stages of closure of the Paleo-Asian Ocean during the transformation from a collisional to extensional tectonic setting. The ca. 170 and ca. 130 Ma magmatism and mineralization in the Shuangjianzishan district are related to subduction of the Mongolia–Okhotsk Ocean and subduction of the Paleo-Pacific Ocean Plate, respectively.

1. Introduction

The Xing'an–Mongolian Orogenic Belt (XMOB), is an important component of the Central Asian Orogenic Belt (CAOB), and is a Paleozoic tectonic–magmatic belt that was subjected and reworking by Mesozoic tectonic–magmatic activity that formed numbers of ore deposits (Fig. 1a, b) (Chen et al., 2009; Liu and Nie, 2015; Nie et al., 2014, 2015; Wang et al., 2015a; Xu et al., 2013b, 2014, 2015; Zhang et al., 2010b). The Baiyinnuoer–Haobugao mineralization area is situated in the north-eastern part of the economically important Huanggang–Ganzhuermiao Fe–Sn–Pb–Zn–Cu–Ag polymetallic metallogenic belt (Fig. 2a), which is located in the southern part of the Great Xing'an Mountains (Fig. 1b; Akiyama and Sun, 2001; Hong et al., 2003; Niu et al., 2006; Ouyang et al., 2014; Shao et al., 1998; Sun and Akiyama, 2001; Wang et al., 2001a, 2008, 2009; Zeng et al., 2009, Zeng et al., 2010a, b, Zeng et al., 2011a, b, Zeng et al., 2012, Zeng et al., 2013a, b; Zhou et al., 2010a, 2011). The Huanggang–Ganzhuermiao belt is 200 km long, 50–55 km wide and trends northeast (Fig. 2a). Economically significant deposits have been discovered within the belt (Table 1).

The newly discovered Shuangjianzishan deposit is located southwest of Ganzhuermiao between the Baiyinnuoer and Haobugao deposits (Fig. 2a). The Shuangjianzishan deposit was discovered by the Second Regional Survey Team of Inner Mongolia during 1984 while mapping the Wuerji 1:50,000-scale sheet area (L–50–131–C). The Third Inner Mongolia Geological Team carried out a mineral reconnaissance survey in the Linba–Fushan area during 1990, although they did not study Shuangjianzishan in detail. Detailed studies of the deposit were conducted in 2004 with drilling during 2004–2006 in the southern part of the area where two small low-grade Pb–Zn occurrences were discovered. The Chifeng Tiantong Geological Exploration Co. Ltd. started detailed 1:10,000-scale geological mapping and prospecting in the

* Corresponding author.
E-mail address: chunhua91052@126.com (C. Liu).

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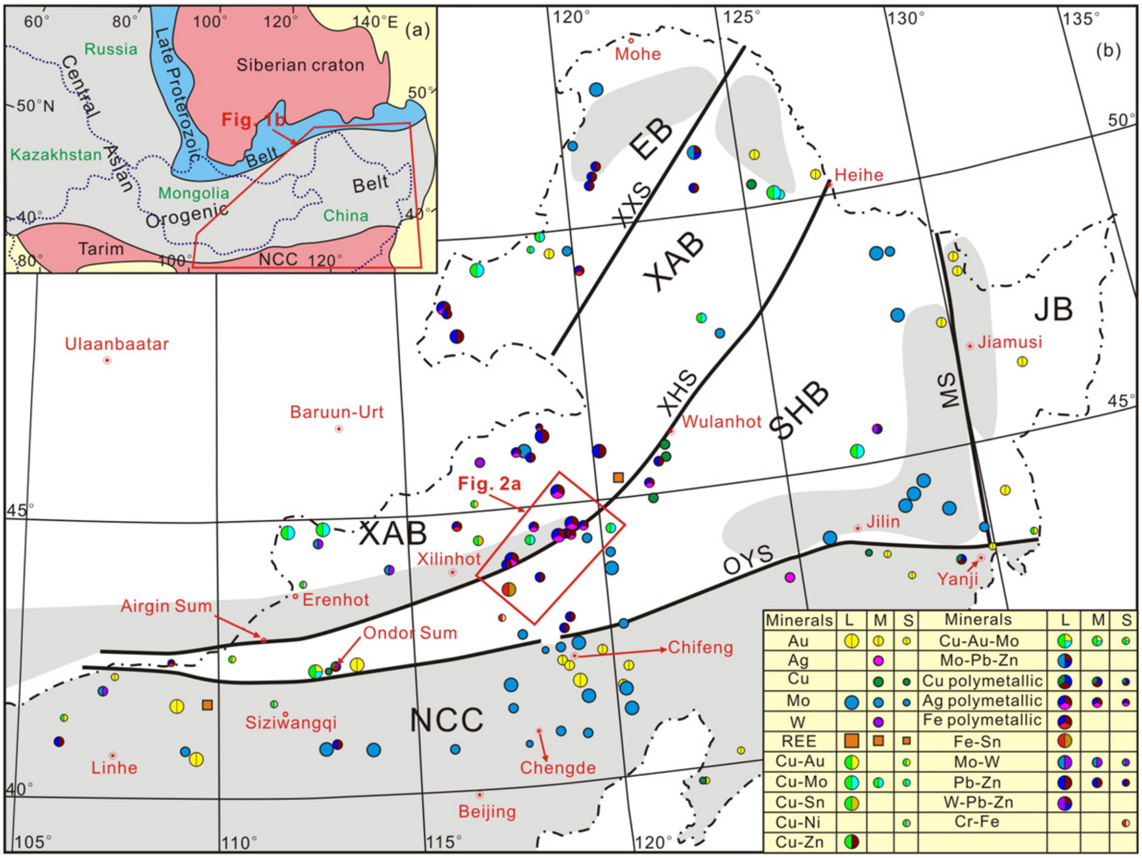

Fig. 1. Location of: (a) the Central Asian Orogenic Belt (modified after Chen et al., 2010); and (b) terranes in the Xing'an–Mongolian Orogenic Belt (XMOB), showing outcrops of Precambrian rocks (modified after Xu et al., 2015) and the distribution of Phanerozoic ore deposits (modified after Liu and Nie (2015) and Zeng et al. (2011a, 2012, 2013a, 2015). EB: Erguna Block; XAB: Xing'an–Airgin Sum Block; SHB: Songliao–Hunshandake Block; JB: Jiamusi Block; XXS: Xinlin–Xiguitu Suture; XHS: Xilinhot–Heihe Suture; MS: Mudanjiang Suture; OYS: Ondor Sum–Yanji Suture.

broader Shuangjianzishan area during 2007, and the company delineated mineralized and altered outcrop in a small area in the eastern Xinglongshan part of the district. The company consequently began a 1:10,000 geophysical IP surveys that delineated 10 geophysical anomalies, which lead to the drilling and discovery of Ag-bearing polymetallic orebodies (Sun et al., 2010). By 2010, 46 orebodies were discovered and evaluated, and the resources of 21 orebodies were estimated to contain 181 Mt ore, including 0.026 Mt Ag, 1.1 Mt Pb, and 3.3 Mt Zn (Sun et al., 2010). It is now recognized that this is the site of a super-large Pb–Zn–Ag polymetallic district. With further prospecting and evaluation, it is expected that the measured size of the deposit will increase significantly.

Wu et al. (2014) studied the occurrences of silver in the Shuangjianzishan Pb–Zn–Ag deposit. Within the ore district, the relationship between the Pb–Zn–Ag polymetallic mineralization and the magmatism remain unclear. The age, origin, and evolution of the magmatic activity, and the relationship between the magma and metallogenic fluids are critical for understanding the origin of the deposits and their geodynamic setting. Therefore, in this study we conducted systematic petrographic research on the magmatic rocks in the Shuangjianzishan Pb–Zn–Ag deposit to constrain the ages of magmatism and the origins of the magma by completing whole-rock geochemical analyses, zircon laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) geochronology, and analyses of zircon Hf isotopes. We report on the Re–Os isochron age of pyrite to constraint the age of mineralization at the Shuangjianzishan Pb–Zn–Ag deposit. Finally, we propose a relationship between the magmatism and the Shuangjianzishan Pb–Zn–Ag polymetallic mineralization using detailed geochronology.

2. Regional geological setting

2.1. Regional tectonic evolution

The CAOB is one of the most remarkable global example of accretion and transformation of crustal terranes (Windley et al., 2007; Wu et al., 2011; Xiao and Santosh, 2014; Xiao et al., 2003; Zeng et al., 2012, 2014a). The crustal evolution over the past billion years bears witness to continental margin accretion, and post-collision and intracontinental orogenies accompanied by the strong interaction between crust and the mantle (Xiao et al., 2003).

The southern part of the Great Xing'an Mountains is located in the eastern part of Inner Mongolia, and is part the XMOB in the eastern portion of the CAOB between the Siberian Plate and North China Craton (NCC; Bai et al., 2014). Xu et al. (2014, 2015) proposed an updated division scheme for the XMOB, in which pre-Middle Devonian (>400 Ma) tectonic units are divided into an orogenic belt with four blocks separated by crustal sutures (Fig. 1b). The Huanggang–Ganzhuermiao polymetallic metallogenic belt is situated in the western section of the Xilinhot–Heihe Suture (XHS) (Fig. 1b).

The tectonic evolution of the Paleo-Asian Ocean is characterized by bi-directional subduction along the active southern margin of the Siberia Craton and the northern margins of the NCC and Tarim Craton (Fig. 1b; Chen et al., 2009; Jian et al., 2008; Li et al., 2011, 2015; Xiao et al., 2003, 2008, 2009; Xiao and Santosh, 2014; Xu et al., 2013a; Zhang et al., 2009d). It is generally accepted that closure of the Paleo-Asian Ocean took place along the Solonker Suture (Cao et al., 2013; Chen et al., 2015; Cheng et al., 2014; Hu et al., 2015; Jian et al., 2008, 2010; Li et al., 2013, 2014; Liu et al., 2013; Wang et al., 2013, 2015b;