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Two epochs of magmatism and metallogeny in the Cuihongshan Fe-polymetallic deposit, Heilongjiang Province, NE China: Constrains from U–Pb and Re–Os geochronology and Lu–Hf isotopes

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ABSTRACT

The large-sized Cuihongshan Fe-polymetallic deposit is located in the north segment of the Lesser Xing'an range, NE China. The Fe orebodies are dominantly hosted in the contact zone between the alkali–feldspar granite and the dolomitic crystalline limestones or skarns, whereas the Pb–Zn (Cu) and W–Mo orebodies are mostly hosted in the contact zone between the syenogranite and skarns, as well as within the syenogranite. The alkali–feldspar granite and syenogranite yield zircon U–Pb ages of 491.1 ± 2.4 Ma and 199.8 ± 1.8 Ma, with $\varepsilon_{Hf}(t)$ values of −3.7 to −1.3 and 2.5 to 3.9, respectively. Both of them are characterized by high SiO_2 and $Na_2O + K_2O$ content, enrichment in Rb, Th, U and Pb, and depletion in Ba, Sr, Nb, Ta, P, Ti and Eu, indicating an A-type affinity. The Re–Os model ages of the molybdenite range from 198.0 to 202.1 Ma. These data suggest that the Fe-related alkali–feldspar granite was formed by partial melting of the Mesoproterozoic crust in an extensional setting after the final collision between the Xing'an and Songnen Blocks, while the Pb–Zn (Cu) and W–Mo-related syenogranite was probably generated by crystal fractionation from depleted-mantle-derived magmas, which are products of lithospheric delamination.

1. Introduction

Cuihongshan is one of the largest Fe-polymetallic deposit discovered in Heilongjiang Province, NE China. The deposit yields proven resources of 68.35 Mt Fe, 0.09 Mt Mo, 0.12 Mt W, and 0.51 Mt Zn with average grades of 48% Fe, 0.134% Mo, 0.153% W and 3% Zn.

Several recent studies have been carried out on the deposit geology, fluid inclusion characteristics, S isotope composition of the sulfides as well as the U–Pb age of the syenogranite (previously named as monzogranite) (Du et al., 2011; He et al., 2010; Li et al., 2011). It was recognized as a skarn type deposit and the Fe, Pb–Zn (Cu), W and Mo mineralization were considered to be generated in different metallogenetic stages (He et al., 2010; Li et al., 2011; Shao et al., 2011). However, according to the occurrences of the orebodies and the ore characters, a two-epoch metallogenetic model is preferred for the formation of the Cuihongshan deposit: the early-epoch Fe mineralization associated with the alkali–feldspar granite and the late-epoch Pb–Zn (Cu) and W–Mo mineralization related to the syenogranite. In this paper, we present detailed geochemistry, U–Pb geochronology and Lu–Hf isotope data on the ore-forming-related alkali–feldspar granite and syenogranite, together with Re–Os isotopic dating of the molybdenite, in order to characterize the ore-forming stage, and to constrain the tectonic setting for magmatism and mineralization in the Cuihongshan area.

2. Regional geological setting

The Cuihongshan Fe-polymetallic deposit is located in the north segment of the Lesser Xing'an range, east of the Central Asian Orogenic Belt (CAOB). The Lesser Xing'an range is part of the Songnen Block, which straddles the Xing'an Block in the northwest and the Jiamusi Block in the east, separated by the Hegenshan–Heihe Fault and the Jiayin–Mudanjiang Fault respectively (Fig. 1a) (Wu et al., 2000; Yang et al., 2012; Zhou et al., 2010). Regional geological research has suggested that the Lesser Xing'an range is a complex tectonic region that experienced the closure of the Paleo-Asian Ocean in the Paleozoic, the closure of the Mongol–Okhotsk Ocean in the Late Paleozoic–Mesozoic, and the subduction of the Pacific Plate in the Mesozoic–Cenozoic (Li, 2006; Wang and Mo, 1995; Wu et al., 2000; Xu et al., 1994). The complicated geological evolution history has resulted in intense magmatism as well as extensive mineralization of

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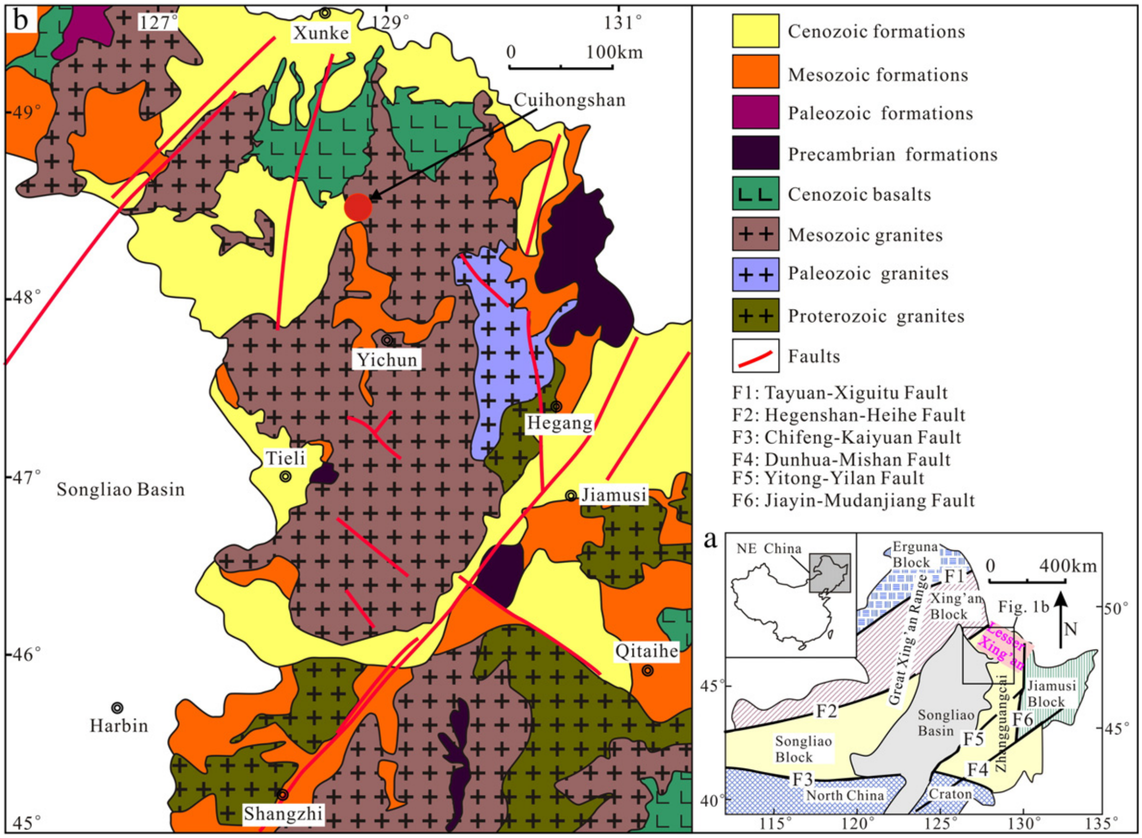

Fig. 1. (a) Tectonic framework of NE China (modified from Wu et al., 2000, 2007). (b) Simplified geological map of the Lesser Xing'an range (modified from Zhang et al., 2010a).

precious metals and nonferrous metals in this area (Ge et al., 2007; Han et al., 1995; Mao et al., 2003).

The stratigraphic sequence outcropping in this area can be generally divided into four units: 1) the Precambrian crystalline basement composed predominantly of the Paleoproterozoic Dongfengshan Group and Zhangguangcailing Group; 2) the Paleozoic submarine sedimentary cover including Cambrian, Ordovician and Permian strata; 3) the Mesozoic continental volcanic sedimentary rocks; 4) the Cenozoic sandstones, conglomerates and alkaline basalts (Fig. 1b). The Precambrian and Paleozoic formation are scattered across the Lesser Xing'an range. The Precambrian metamorphic rocks are dominated by marbles, phyllites, schists, amphibolites, gneisses and granulites (Han et al., 1995; Yang et al., 2012), unconformably overlain by the Paleozoic marine formation. The Cambrian strata, which host numerous skarn type Pb, Zn, W and Mo deposits (Zhao et al., 2009), consist of carbonates and terrigenous clastic rocks. The Ordovician strata can be divided into two lithological sequences: the lower sequence consisting of intermediate-acidic volcanics and the upper sequence consisting of slates, sandstones and conglomerates (Han et al., 1995). In comparison, the Permian strata are mainly made up of sandstones, conglomerates and intercalated limestones (Yang et al., 2012; Yin and Ran, 1997; Zhang et al., 2010b). The Mesozoic terrestrial formation contains terrigenous clastic and volcanic rocks which are extensively distributed throughout the Lesser Xing'an range (Sun et al., 2013; Wu et al., 2007).

Apart from the volcanic rocks, the Lesser Xing'an range is also characterized by widespread plutonic rocks formed at various times: 1) Late Proterozoic granodiorites and alkali–feldspar granites with Rb–Sr and Sm–Nd ages of 614–672 Ma (Yin and Ran, 1997); 2) Early Paleozoic granodiorites, tonalites, monzogranites and alkali–feldspar granites (Han et al., 1995); 3) Late Paleozoic alkali–feldspar granites and alkaline granites (Sun et al., 2001); 4) Early Mesozoic moyites and alkali–feldspar granites; 5) Late Mesozoic quartz diorites, granodiorites and granite porphyries. The Late Proterozoic and Late Paleozoic granites only outcrop sporadically in this region. While the relatively extensive Early Paleozoic granites distribute as an overall SN trending belt in the east of the Lesser Xing'an range. The Mesozoic granites, however, cover the maximum area of the Lesser Xing'an range. According to previous studies, the Mesozoic volcanic and plutonic rocks are considered as products of lithospheric delamination in response to the subduction of the Paleo-Pacific Plate (Ge et al., 2007; Wu et al., 2005, 2007), or alternatively related to the extension after the final closure of the Paleo-Asian Ocean (Mao et al., 2003, 2005; Qi et al., 2005).

3. Geology of the Cuihongshan deposit

The only exposed stratum in the Cuihongshan area is the Lower Cambrian Qianshan Formation, which consists predominantly of dolomitic crystalline limestones, sandstones, siltstones and slates (Fig. 2a and b). The stratum was intruded by the alkali–feldspar granite and the syenogranite. The alkali–feldspar granite (Fig. 3a) is distributed in the north section and south section of the mining district. It was intruded by the syenogranite (previously named as monzogranite, Fig. 3b, Li et al., 2011; Shao et al., 2011), which mainly outcrops in the west section and the east section. Both the alkali–feldspar granite and the syenogranite occur as stocks and they are locally separated by the NNE and near WE trending faults.

The mineralizations in Cuihongshan and adjacent areas are constrained by a series of NE trending composite folds, which are cut-off by NW trending faults (Shao et al., 2011). The orebodies in the Cuihongshan deposit are predominantly controlled by three types of structures: the intrusive contact zone between the plutonic rocks and wall rocks; the interformational fracture zones within the