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SIMS zircon U–Pb and molybdenite Re–Os geochronology, Hf isotope, and whole-rock geochemistry of the Wunugetushan porphyry Cu–Mo deposit and granitoids in NE China and their geological significance

Yinhong Wang [a,*], Chunbo Zhao [b], Fangfang Zhang [a], Jiajun Liu [a], Jianping Wang [a], Runmin Peng [a], Bin Liu [a]

[a] State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Beijing 100083, China
[b] Inner Mongolia Mining Company, China National Gold Group Corporation, Xinbaerhuyouqi 021400, China

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ABSTRACT

The geodynamic setting of magmatic rocks and geodynamic mechanism of Cu–Mo–Fe–Sn–Pb–Zn–Ag polymetallic mineralization in northeastern (NE) China are attracting increasing attention. This study explores these issues by providing SIMS zircon U–Pb dating, whole-rock geochemical, Hf isotopic data of magmatic rocks, and molybdenite Re–Os dating exposed in the Wunugetushan porphyry Cu–Mo deposit, NE China. This deposit is located in the western part of the Great Xing'an Range, on the southeastern margin of the Mongol–Okhotsk Orogenic Belt. Molybdenite Re–Os and SIMS zircon U–Pb dating of the host monzogranitic porphyry and the wall rock of biotite granite in the Wunugetushan porphyry Cu–Mo deposit indicate that the ore-formation, host porphyry, and wall rock-emplacement occurred at 180.5 ± 2.0 Ma, 180.4 ± 1.4 Ma, and 203.5 ± 1.6 Ma, respectively, and the mineralization of the Wunugetushan porphyry Cu–Mo deposit occurred during the same period as that of the host monzogranitic porphyry. Geochemically, the Wunugetushan granitoids are characterized by strong LREE/HREE fractionation, and pronounced negative Nb, Ta, and Ti anomalies, with slightly negative Eu anomalies ($Eu/Eu^* = 0.71–0.97$) of the host monzogranitic porphyry and pronounced negative Eu anomalies ($Eu/Eu^* = 0.29–0.32$) of the wall rock of biotite granite. In situ Hf isotopic analyses of zircons from the host monzogranitic porphyry and the wall rock of biotite granite yielded $\varepsilon_{Hf}(t)$ values ranging from 0.5 to 8.2, and from −6.9 to 5.9, respectively. The geochemical and isotopic data for the Wunugetushan granitoids imply that the primary magmas of the host monzogranitic porphyry could have originated by partial melting of a thickened lower crust, with input of mantle components, while the primary magmas of the wall rock of biotite granite could have been derived by partial melting of a thickened lower crust that mixed with ancient crustal materials. Based on the regional geological history, geochemistry of the Wunugetushan granitoids, and new isotopic age data, we suggest that the formation of the Wunugetushan porphyry Cu–Mo deposit was possibly induced in the Early Jurassic during the period of the southeastward subduction of the Mongol–Okhotsk oceanic plate beneath the Erguna Massif.

1. Introduction

The Central Asian Orogenic Belt (CAOB) is one of the largest Phanerozoic accretionary orogenic belts on Earth (Şengör et al., 1993; Jahn, 2004; Safonova, 2009; Xiao and Santosh, 2014), consists of microcontinental blocks, island arcs, oceanic crustal remnants, and continental marginal facies rocks (Coleman, 1989; Hu et al., 2000; Pirajno, 2010; Li et al., 2013; F. Wang et al., 2014a), and has been formed by multiple accretion and arc–continent collision events from the Early Neoproterozoic to the Permian (Windley et al., 2007; Wilhem et al., 2012; Li et al., 2013; F. Wang et al., 2014a). NE China is located in the eastern segment of the CAOB and represents an important area to study the Paleozoic tectonic evolution of the CAOB (Fig. 1a). NE China developed during the Neoproterozoic to Phanerozoic between the Siberian Craton in the north and the North China Craton (NCC) in the south (Jahn, 2004; Jahn et al., 2004a,b, 2009; F.Y. Wu et al., 2011), and evolved from amalgamation of several micro-continental blocks (F.Y. Wu et al., 2011). NE China is characterized by immense volumes of Mesozoic granitoids (Li et al., 2004; Gao et al., 2007; Y.B. Zhang et al., 2008; J.H. Zhang et al., 2010; F.Y. Wu et al., 2011; Xu et al., 2013) and a small quantity of Early Paleozoic granitoids (Miao, 2003; Sui et al., 2006; Qin et al., 2007; F.Y. Wu et al., 2011) and Neoproterozoic granitoids (Y. Wang et al., 2006; Pei et al., 2007; F.Y. Wu et al., 2011).

* Corresponding author at: State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, 29 Xue-Yuan Road, Haidian District, Beijing 100083, China. Tel.: +86 10 8232 2346 (office); fax: +86 10 8232 2970.
E-mail address: wyh@cugb.edu.cn (Y. Wang).

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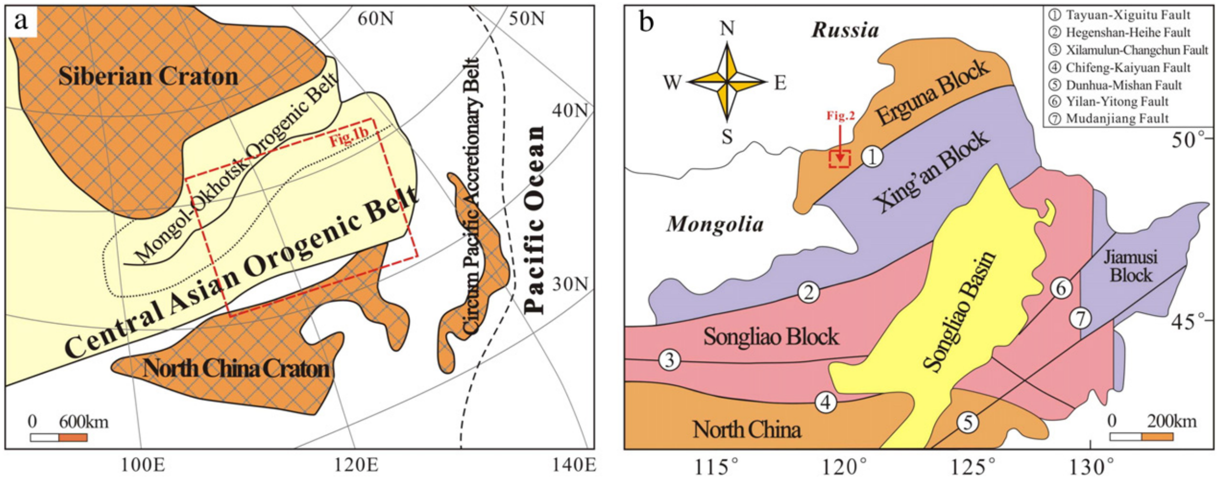

Fig. 1. (a) Tectonic scheme of Northeastern Asian showing the location of the Mongol–Okhotsk Orogenic Belt (modified from Safonova, 2009); (b) Tectonic sketch map of NE China, showing the location of the Wunugetushan porphyry Cu–Mo deposit (modified after J.H. Zhang et al., 2010).

The formation of numerous deposits was closely associated with the Mesozoic magmatic hydrothermal activity in NE China, including the Wunugetushan Cu–Mo deposit (Z.G. Chen et al., 2011; N. Li et al., 2012; Tan et al., 2013), Jiawula Ag–Pb–Zn deposit (Zhai et al., 2013), Chaganbulagen Ag–Pb–Zn deposit (Wu et al., 2010), and Erentaolegai Ag–Mn deposit (Wu et al., 2010).

The Wunugetushan porphyry Cu–Mo deposit, located on the southeastern margin of the Mongol–Okhotsk Orogenic Belt and approximately 22 km southwest of Manzhouli City in NE China, has attracted the interest of many geologists in terms of ore deposit geology (Wang and Qin, 1988; Zhang, 2006; Tan, 2011; N. Li et al., 2012), geochronology (Wang and Qin, 1988; Qin et al., 1999; Li et al. 2007a; Z.G. Chen et al., 2011), and isotopic geochemistry (Z.G. Chen et al., 2008; Li et al., 2012; Tan et al., 2013). However, the timing of ore formation and geodynamic setting remain controversial. The age of mineralization has previously been inferred from whole rock Rb–Sr dating of the intrusion related to mineralization at 130 to 140 Ma (Wang and Qin, 1988) and from U–Pb zircon ages for host rock and K–Ar ages of hydrothermal sericite at 180 to 190 Ma (Qin et al., 1999). Li et al. (2007a) and Z.G. Chen et al. (2011) argued that the Wunugetushan Cu–Mo deposit was formed at 170 to 180 Ma based on Re–Os isotope dating of molybdenite and $^{40}Ar/^{39}Ar$ ages of host porphyry. The Wunugetushan Cu–Mo deposit was considered to relate to a magmatic event induced by the ridge subduction (Wang and Qin, 1988; Zhao and Zhang, 1997; Qin et al., 1999; Zhang et al., 2001; Sun et al., 2010, 2011; Zhou and Wilde, 2013). Limited geochemical data indicated that the host porphyry was derived from lower crust (Wang and Qin, 1988). However, other geologists argued that the Wunugetushan Cu–Mo deposit was associated with magmatic activity in continental rifts (Xu et al., 1998; Lü et al., 2001) and continent–continent collisions (Mao et al., 2003; Li et al., 2007b; Z.G. Chen et al., 2011). Moreover, the ore-forming mechanism has not been adequately constrained until now, largely due to a lack of detailed geochemical data for the deposit. This paper provides new geological and geochemical evidence that can contribute to the debate and help resolve genetic aspects of the Wunugetushan Cu–Mo porphyry deposit. Here, we report SIMS zircon U–Pb dating, whole-rock geochemical data, Hf isotope, and Re–Os isotopic data for the Wunugetushan deposit, and discuss their petrogenesis, the porphyry Cu–Mo mineralization, and the crust–mantle interaction process based on the detailed field geological surveys and laboratory petrographic tests. Furthermore, our new data on the Wunugetushan porphyry Cu–Mo deposit may provide strong constrains on the geodynamic setting of the Wunugetushan granitoids and associated Cu–Mo mineralization.

2. Geological setting

2.1. Regional geology

NE China is composed of a Paleozoic orogenic collage that has traditionally been considered to be the eastern segment of the CAOB (F.Y. Wu et al., 2011; Xu et al., 2013). The Paleozoic tectonic evolution of NE China was dominated by the closure of the Paleo-Asian ocean and the amalgamation of micro-continental blocks (including the Erguna, Xing'an, Songliao, and Jiamusi blocks) (Şengör et al., 1993; F.Y. Wu et al., 2011), whereas the Mesozoic tectonic evolution of NE China was characterized by the overprinting of the circum-Pacific and Mongol–Okhotsk tectonic systems (Xu et al., 2009; Meng et al., 2011; Xu et al., 2013; Tang et al., 2014). Meanwhile, NE China is one of the important producers of Cu, Mo, Fe, Sn, Pb–Zn, Au and Ag in China, and develops various kinds of metallogenic system (Zhai et al., 1999; Mao et al., 2003; Deng et al., 2011; Zhai et al., 2011; Goldfarb et al., 2014).

The Xing'an–Mongolia orogenic belt and the North China Craton are separated by the Chifeng–Kaiyuan fault. The Tayuan–Xiguitu, Hegenshan–Heihe, and Mudanjiang faults separate the Xing'an–Mongolia orogenic belt from northwest to southeast into the Erguna, Xing'an, Songliao, and Jiamusi blocks (Fig. 1b; J.H. Zhang et al., 2010). Located primarily on the Xing'an and Erguna blocks, the northern part of the Great Xing'an Range in NE China is known for large exposures of Mesozoic granites and volcanic rocks (Fan et al., 2003; Ge et al., 2005; F. Wang et al., 2006; Ge et al., 2007; L.C. Zhang et al., 2008), and also is an important polymetallic metallogenic belt hosting different types of hydrothermal deposits (Liu et al., 2001; Mao et al., 2003; D.G. Zhai et al., 2009; Wu et al., 2011b, c; Liu et al., 2012; Zhou et al., 2012; D.G. Zhai et al., 2013), mainly including porphyry, skarn, and epithermal ore deposits that are spatially and temporally associated with the Mesozoic felsic magmatism (Zhao and Zhang, 1997; Mao et al., 2003; F. Wang et al., 2006; Zhai et al., 2013).

The regional stratigraphy of the northern part of the Great Xing'an Range in NE China can be divided into four tectonic units: the Precambrian metamorphic basement represented by continental blocks of various affinities; the Early Paleozoic metamorphosed volcanic and sedimentary rocks consisting of schist, sandy slate, marble, and andesite; the Late Paleozoic metamorphosed volcanic and sedimentary rocks with lower metamorphic grades and more extensive exposures compared to the Early Paleozoic units; and the Jurassic and Cretaceous continental, intermediate-acidic volcanic and sedimentary rocks (Wu et al., 2011a; Zhou et al., 2012; Zhai et al., 2014).