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Processes of ore genesis at the world-class Yuchiling molybdenum deposit, Henan province, China ☆

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ABSTRACT

The Yuchiling molybdenum deposit is one of the most significant porphyry molybdenum systems in the eastern Qinling of central China. The mineralization is mainly hosted by a porphyritic granite and associated cryptoexplosive breccia. Hydrothermal alteration minerals include K-feldspar, sericite, pyrite, chlorite, epidote, carbonate, kaolinite, fluorite, and gypsum. Ore minerals are dominated by molybdenite and pyrite, with lesser amounts of chalcopyrite, galena, scheelite, wolframite, ilmenite, leucoxene, native gold, sphalerite, and hematite. The $\delta^{34}S$ compositions of sulfide minerals range from −6.0‰ to +4.0‰. The deposit is characterized by four hydrothermal stages: quartz–K-feldspar (stage I), molybdenite–quartz (stage II), pyrite–sericite-quartz (stage III), and quartz–carbonate (stage IV). Microthermometric studies of fluid inclusions show that the fluids evolved gradually during the ore-forming process. Homogenization temperatures, salinities, and minimum pressure estimates for the inclusions from each mineralization stage evolved as follows: (1) stage I: homogenization temperatures = 203.7–525.8 °C, salinities = 2.96–10.49 and 29.66 wt.% NaCl equiv., and minimum pressures = 101.9–196.2 MPa; (2) stage II: homogenization temperatures = 173.6–448.6 °C, salinities = 1.81–9.74 wt.% NaCl equiv., and minimum pressures = 93.1–172.0 MPa; (3) stage III: homogenization temperatures = 130.1–386.0 °C, salinities = 1.40–9.73 and 34.07 wt.% NaCl equiv., and minimum pressures = 95.5–142.5 MPa; (4) stage IV: homogenization temperatures = 170–230 °C and salinities = 0.18–5.71 wt.% NaCl equiv. Various fluid inclusions were observed to contain H_2O, CO_2, CH_4, SO_2, C_2H_2, C_2H_4, C_2H_6, and (or) H_2S, as well as solids that include halite, sylvite, anhydrite, chalcopyrite, hematite, molybdenite, and jamesonite. The $\delta^{18}O$ and δD of the hydrothermal fluids vary from −4.4‰ to +8.5‰ and −81‰ to −61‰, respectively. Microthermometric and stable isotope data indicate that the ore-forming fluids for the Yuchiling molybdenum deposit evolved from early magmatic, to a mixture of meteoric and magmatic water, and finally to a principally late stage meteoric water. A molybdenite Re–Os age of 131.2 ± 1.4 Ma coincides with the early part of the 131–112 Ma period of magmatic and related ore-forming events that are widely recognized in eastern Qinling.

1. Introduction

The eastern Qinling molybdenum (Mo) belt, to the south of the North China craton, is one of the most important Mo belts in China and world-wide, with >8 million tones of Mo reserves (Mao et al., 2008a, 2011; Ye et al., 2006). Due to the abundant resources and unique metallogenic setting, this belt has been the focus of considerable research regarding associated tectonics, geology, geochronology, ore-forming fluid geochemistry, and genesis of the deposits (Huang et al., 1994; Li et al., 2004, 2005; Luo et al., 1991; Mao et al., 2005; Stein et al., 1997; Yang et al., 2010; Ye et al., 2006; Zhang et al., 2001). Most Mo ores in China, such as at the Jinduicheng, Nannihu, Shangfanggou, and Leimengou deposits, are associated with small intermediate–silicic porphyry intrusions of Yanshanian (late Mesozoic) age. Both the metals and intrusions are considered to have deep crustal sources (Lu et al., 2002). The Yuchiling molybdenum deposit is spatially associated with the Early Cretaceous Heyu composite granitic batholith, with the mineralization most closely related to late porphyry granite and associated cryptoexplosive breccia. Li et al. (2012a,b) investigated the geology, geochronology, and fluid inclusion chemistry of the Yuchiling molybdenum deposit. The main points of the earlier studies were to report the age of the Heyu batholith and

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the characteristics of the ore-related fluid inclusions, including homogenization temperatures, trapping pressures, and compositions. However, further study of the Yuchiling molybdenum deposit is required to properly constrain the source(s) of the ore-forming fluids and metals, the timing and processes of ore formation, the relationships between mineralization and magmatism, and the specific tectonic setting. In this paper, we will address these issues. To better understand the ore genesis, this study presents new field observations, comprehensive fluid inclusion studies, stable isotope data (S–O–H), and molybdenite Re–Os geochronology for the Yuchiling molybdenum deposit.

2. Regional geology

The Yuchiling molybdenum deposit is located at the intersection of the Huaxiong Uplift and Luanchuan fold belt along the southern margin of North China craton, south of the E–W-trending Machaoying Fault (Fig. 1). The regional strata mainly consist of metamorphic rocks of the Late Archean Taihua Group, volcanic rocks of the Mesoproterozoic Xiong'er Group, and Mesozoic clastic sediments and Cenozoic alluvium. The Taihua Group is principally exposed in the Yangchanggou area, to the southwest of the Yuchiling deposit, and rocks are exposed over an area of 30 km^2. An angular unconformity or fault separates the Late Archean rocks from those of the overlying Xiong'er Group, which is overlapped by strata of the Mesoproterozoic Guandaokou Group in the Daqinggou area. Rocks of the Taihua Group are metamorphosed to amphibolite facies and mainly comprise amphibolite gneiss, amphibolite, biotite-plagioclase gneiss, and intermediate to felsic tuff (or "greenstone") at the top of the sequence. The Late Archean age of the greenstone is broadly defined by $^{207}Pb/^{206}Pb$, Sm/Nd, and $^{40}Ar–^{39}Ar$ isotopic geochronology ranging from 2.9 to 2.5 Ga (Kroner et al., 1988; Li et al., 1987; Ni et al., 2003; Sun and Zhang, 1985; Xue et al., 1995). The Xiong'er Group is mainly comprised of basaltic andesite, andsite, dacite, trachyandesite, and volcanic tuff. Ages from LA-ICP-MS zircon U–Pb dating show that the Xiong'er Group formed between 1.80 and 1.75 Ga (Zhao et al., 2004). The Tertiary rocks include fluvio-lacustrine fine-grained sediments and the Quaternary is mainly composed of sands, gravels, and clay.

The regional structure, characterized by frequent reactivation of the major faults, is dominated by the nearly E–W-trending Machaoying Fault, and the Machaoying Fault is multiplied by NE and NNE-trending fault splays. East–west-trending folds, and E–W- and NE-trending brittle-ductile fault zones are also developed, and the Xiaoqinling, Xiaoshan, and Xiong'ershan metamorphic core complexes occur in the Xiong'er uplift to the north of the Machaoying fault. To the south, along the Luonan-Luanchuan fold-belt, E–W-trending nappe structures are thrust to the south and a series of NE-trending faults are present.

Abundant Archean to Mesozoic magmatism occurred within the area. Caledonian (early Paleozoic) alkaline magmatism is represented by a granite batholith and numerous dikes. During the Indosinian (early Mesozoic), syenite intrusions were emplaced. Felsic magmatism was widespread during the Yanshanian. Mao et al. (2010) reported SHRIMP zircon U–Pb ages of 12 representative granitoid plutons, together with those for one syenite stock, and dolerite, diorite, and granitic dikes in eastern Qinling. The results revealed two main magmatic events, which occurred in the Late Jurassic-Early Cretaceous (158–136 Ma) and the Early Cretaceous (134–108 Ma), respectively, and they are distinguished in Fig. 2. In addition to these ages, new ages have been reported for the Nannihu granite porphyries (146.7–145.2 Ma) (Xiang et al., 2012) Huashan biotite monzonitic granite (129.3–128.7 Ma) (Xiao et al., 2012), Heyu biotite-bearing monzonitic granite porphyry (148–134 Ma) (Gao et al., 2010; Li et al., 2012b), Leimengou granite porphyry (136.2 Ma), and an unnamed quartz porphyry (127.2 Ma) (Chen et al., 2011), The Yanshanian intrusions are associated with magmatic Mo, W, Au, Ag, Cu, Pb, and/or Zn deposits and the undated Qiyugou cryptoexplosive breccia bodies.

3. Deposit geology

The Yuchiling Mo deposit is located in the area of Tongzi village in the southern part of Song county, Henan province, between

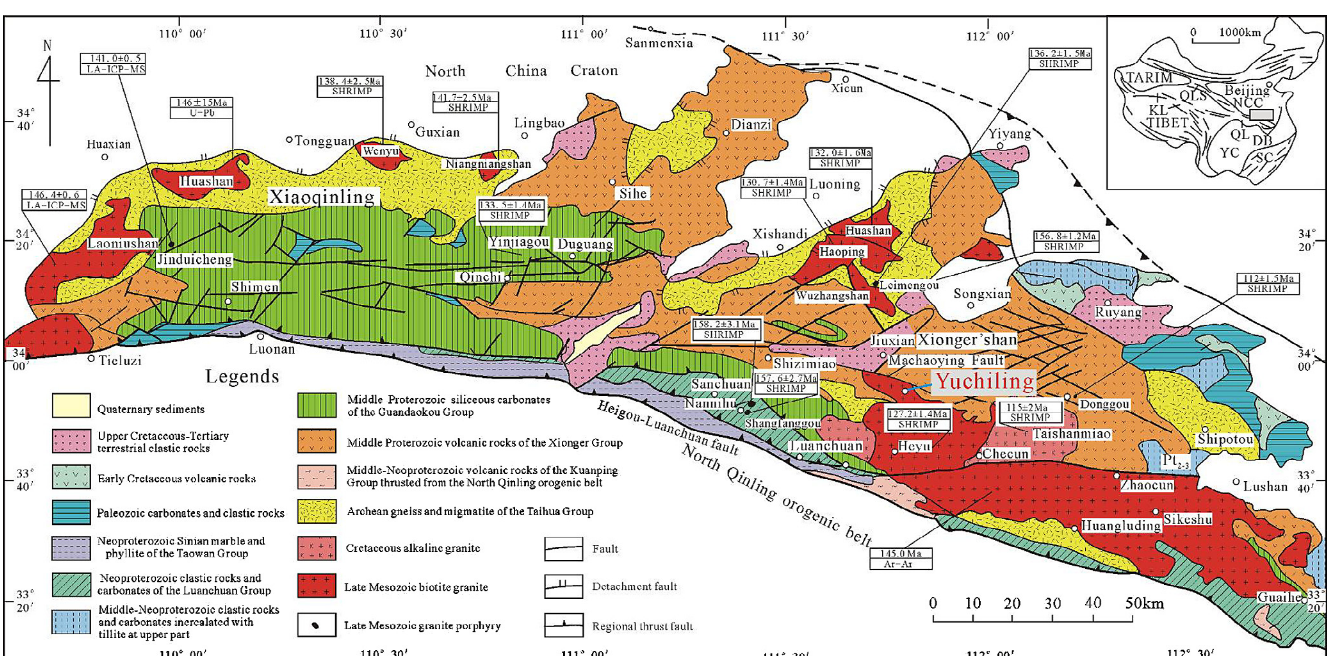

Fig. 1. Simplified geology of the eastern Qinling region and giving age data and methods. Inset shows the position of the eastern Qinling and other tectonic units in China (taken from Mao et al., 2010). YC, Yangtze Craton; NCC, North China Craton; KL, Kunlun orogenic belt; DB, Dabie orogenic belt; QL, Qinling orogenic belt; SC, South China (Cathaysia Block).