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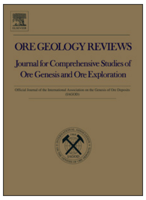

A combined fluid inclusion and isotopic geochemistry study of the Zhilingtou Mo deposit, South China: Implications for ore genesis and metallogenic setting

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ABSTRACT

The Zhilingtou Mo deposit is recently discovered and occurs in the Qin-Hang metallogenic belt, South China. Vein stockworks are hosted in the granite porphyry and the surrounding Paleoproterozoic Badu Group basement. Three stages of mineralization and wallrock alteration were developed: the early stage quartz ± K-feldspar veins with potassic alteration, the ore stage quartz–molybdenite veins with strong phyllic alteration overprinting early potassic alteration, and the late stage quartz–pyrite ± calcite veins with propylitization. Two-phase liquid-rich aqueous (type I) inclusions in the early stage veins show homogenization temperatures (Th) of 366–442 °C, with salinities of 5.3–14.1 wt.% NaCl equivalent. Two-phase gas-rich aqueous (type II) and coexisting halite-bearing (type III) inclusions in the ore stage veins display Th of 335–433 °C and 329–396 °C, and salinities of 0.5–6.2 and 38.6–44.8 wt.% NaCl equivalent, respectively. Type I inclusions in the late stage veins yield Th of 187–282 °C, with salinities 3.5–7.7 wt.% NaCl equivalent. Fluid boiling occurred during the ore stage and probably promoted a rapid precipitation of molybdenite. Laser Raman analysis implies that ore fluids are CO_2-poor. Hydrogen and oxygen isotopes indicate that mineralizing fluids are primarily magmatic in origin, with apparently involvement of external meteoric water in the late stage. Lead isotopes suggest that the metals are sourced from the ore-bearing granite porphyry. Trace elements of the ore-bearing granite porphyry display obvious Nb and Ta depletion, indicating arc magma geochemical affinities. Vein stockworks, intensive phyllic alteration, CO_2-poor ore fluids, and continental arc setting suggest that the Zhilingtou Mo deposit is likely to be an Endako-type porphyry Mo deposit. It is distinctly different from porphyry Mo deposits in the East Qinling-Dabie metallogenic belt in China, which were formed in a post-collisional setting and characterized by intensive potassic alteration and CO_2-rich ore fluids.

1. Introduction

Porphyry deposits are the world's most important source of Mo, accounting for more than 95% of world Mo production (Sinclair, 2007). It is well known that a significant amount of Mo is present as by-product of porphyry Cu–Mo deposits in South America, North America and China such as Chuquicamata, El Teniente, Bingham, Dexing and Wunugetu (Cannell et al., 2005; Li et al., 2012a; Ossandón et al., 2001; Redmond and Einaudi, 2010; Wang et al., 2015b). In addition, a substantial number of large (0.1–0.5 Mt) to giant (>0.5 Mt) porphyry Mo deposits occur in North America and China, such as Climax, Questa, Endako, Shapinggou, Yuchiling and Tangjiaping (Chen and Wang, 2011; Li et al., 2012b; Ni et al., 2015b; Ross et al., 2002; Selby and Creaser, 2001; Wang et al., 2014a; White et al., 1981). Porphyry Mo deposits have been classified into a Climax type and an Endako type (Selby and Creaser, 2001; White et al., 1981). Recent studies reveal that porphyry Mo deposits in the East Qinling-Dabie area might be a new genetic type, i.e., Collision type (Chen and Santosh, 2014; Li et al., 2013; Li et al., 2012b; Mi et al., 2015; Yang et al., 2013). The Climax type is characterized by high abundances of Mo (>0.15 wt.%) and F (0.05–0.15 wt.%), strong potassic alteration, and granitic porphyry (72–77 wt.%) emplaced in an intra-plate extensional environment (Ludington and Plumlee, 2009; Sillitoe, 1980; Sinclair, 2007; White et al., 1981). The Endako type is characterized by relatively low contents of Mo (<0.15 wt.%) and F (<0.05 wt.%), strong phyllic alteration, and granodiorite to granite intrusions (65–77 wt.%) formed in a continental arc setting (Ludington et al., 2009; Selby and Creaser, 2001; Sillitoe, 1980; White et al., 1981). The Collision type is represented by low grade (0.04–0.24 wt.%), fluorine-rich, and a post-collisional setting in response to the collision between the North China and the Yangtze blocks (Chen and Santosh, 2014; Pirajno and Zhou, 2015; Li et al., 2012b; Yang

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et al., 2013). Additionally, the Collision type Mo deposits in the East Qinling-Dabie metallogenic belt contain a large number of CO_2-rich ore fluids (Chen and Wang, 2011; Li et al., 2012b; Ni et al., 2015b; Yang et al., 2013). Research over the last 30 years on porphyry Mo deposits has focused mainly on Climax and Collision type deposits (Chen et al., 2000; Chen and Wang, 2011; Klemm et al., 2007; Li et al., 2012b; Ni et al., 2015b; Seedorff and Einaudi, 2004; Stein and Hannah, 1985; Wang et al., 2014a), with limited research on Endako type deposits (Selby and Creaser, 2001; Whalen et al., 2001).

The Zhilingtou Mo deposit is located in the Qin-Hang metallogenic belt in South China, which was generally thought to be a large Cu–Au polymetallic ore district (Fig. 1), including several large (>0.5 Mt Cu; >20 t Au) or giant (>2.5 Mt Cu; >100 t Au) ore deposits such as Dexing porphyry Cu–Au deposits (9 Mt Cu and 107 t Au), Yongping Cu deposit (1.6 Mt Cu), Yinshan Cu–Au–Pb–Zn–Ag deposit (1 Mt Cu and 138 t Au), Jinshan Au deposit (180 t Au), and Dongxiang Cu Deposit (0.5 Mt Cu) (Cai et al., 2011; Ni et al., 2005; Wang et al., 2013a; Wang et al., 2015b; Wang et al., 2012; Zhao et al., 2013). Recently, several Mo deposits such as Zhilingtou, Shizitou, Tongcun, Xiongjiashan, Yanglin, Jinzhuping, Meizikeng, Yangchuliang, Lingjiao and Shipingchuan have been discovered in this belt (Fig. 1) (Chen and Zheng, 2008; Dong, 2010; Meng et al., 2007; Wu and Yang, 1999; Xu, 2012; Zhang et al., 2009; Zhang et al., 2013b). Therefore, the Qin-Hang metallogenic belt not only is a large Cu–Au metallogenic belt, but also is a great prospect for Mo deposits. In the past, there were numerous studies on Cu–Au deposits in this belt (Liu et al., 2011; Mao et al., 2011; Wang et al., 2015b; Wang et al., 2012; Wang et al., 2013b; Zhang et al., 2013a; Zhao et al., 2013). For instance, a combined geochronology, geochemical and isotopic study on ore-bearing porphyries in the Dexing and Yinshan deposits suggested that they were formed by remelting of the Neoproterozoic subduction-modified lithosphere in a non-arc setting (Wang et al., 2015a; Wang et al., 2012) rather than direct melting of the paleo-Pacific plate in a subduction zone (Zhang et al., 2013a). The systematic fluid inclusion study at the Yinshan deposit indicates a transition from porphyry to epithermal regimes, implying the possibility that porphyry-style ore bodies may exist at even deeper zones (Wang et al., 2013a). Zhao et al. (2013) proposed that the Jinshan deposit is a typical orogenic gold deposit in response to the Neoproterozoic Jiangnan Orogeny instead of a Yanshanian epithermal deposit (Mao et al., 2011). However, only few superficial studies have been carried out on Mo deposits in this region (Chen and Zheng, 2008; Dong, 2010; Meng et al., 2007; Wu and Yang, 1999; Xu, 2012; Zhang et al., 2009; Zhang et al., 2013b).

This paper presents the geology, fluid inclusion microthermometry, Raman analysis, H–O–Pb isotopes, and whole-rock compositions in the Zhilingtou Mo deposit to constrain the source of ore fluids and metals, the evolution process of ore-forming fluids, the metallogenic setting, and the genetic type of ore deposit.

2. Geological setting

The South China Block (SCB) consists of the Yangtze Block in the northwest and the Cathaysia Block in the southeast (Fig. 1). The SCB was formed during the Neoproterozoic Jiangnan Orogeny along the Qin-Hang zone (Zheng et al., 2008; Zhou et al., 2009). The northwestward underthrusting of the Cathaysia Block beneath the Yangtze Block along the Qin-Hang belt caused strong metamorphism and crustal melting within the Cathaysia Block during the Early Paleozoic (Faure et al., 2009). The SCB underwent one compressional event in the Triassic, which occurred in response to the collision between the Indochina and South China blocks (Carter et al., 2001; Lepvrier et al., 2004) and between the South China and North China blocks (Chen and Santosh, 2014; Dong et al., 2011; Li et al., 2001). The northwestward subduction of the paleo-Pacific plate beneath the South China Block took place since the Early Jurassic (Maruyama et al., 1997; Wang et al., 2012; Zhou et al., 2006). During the Early Cretaceous, the coastal region of the SCB was in a subduction-related continental arc setting (Liu et al., 2014; Zhou et al., 2006).

The Zhilingtou Mo deposit is located in the Southwest Zhejiang, Cathaysia Block. The basement rocks of the Cathaysia Block in this region are predominantly the Proterozoic Badu, Longquan and Chencai Groups (Li et al., 2010; Shu et al., 2011; Yu et al., 2012). Zircon U–Pb dating results indicate that sedimentary protoliths of the Badu Group were deposited in an arc-related basin at ca. 2.5 Ga. The Badu Group thus represents the oldest rocks known in the Cathaysia Block (Yu et al., 2012). Meta-sedimentary and meta-volcanic rocks of the Longquan Group of Zhejiang Province are equivalent to rocks of the Mesoproterozoic Tieshajie Group of Jiangxi Province and the Mamianshan Group of Fujian Province in both age and rock type (Li et al., 2005; Shu et al., 2011). Meta-sedimentary and meta-basaltic and ultramafic rocks of

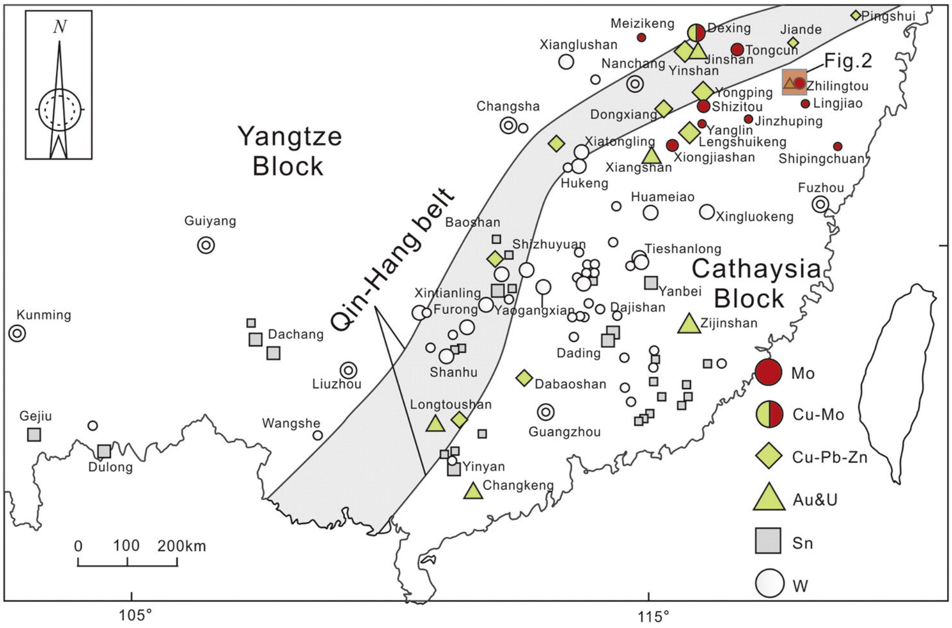

Fig. 1. Spatial distribution of the major mineral deposits in the Qin-Hang metallogenic belt in South China and the location of the Zhilingtou Mo deposit (modified after Ni et al., 2015a).

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