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Re–Os and Sr–Nd–Pb isotope constraints on source of fluids in the Zhifang Mo deposit, Qinling Orogen, China

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ABSTRACT

The Zhifang Mo deposit is located in the northeastern Qinling Orogen along the southern margin of the North China Craton. The deposit represents a quartz-vein system hosted in the Mesoproterozoic Xiong'er Group volcanic rocks. We identify three hydrothermal stages (early, middle and late), characterized by veinlets of quartz–pyrite, quartz–molybdenite–pyrite–chalcopyrite–galena–sphalerite, and quartz–carbonate assemblages, respectively. Five molybdenite samples from the Zhifang deposit yield Re–Os ages ranging from 241.2 ± 1.6 Ma to 247.4 ± 2.5 Ma, with an isochron age of 246.0 ± 5.2 Ma (2σ, MSWD = 7.4), and a weighted mean age of 243.8 ± 2.8 Ma (2σ, MSWD = 5.5). The Re–Os age shows that the Mo mineralization occurred during the Indosinian Orogeny, and suggests that the mineralization is unrelated to the Yanshanian magmatism or the Paleo-Mesoproterozoic volcanic–hydrothermal event.

This study also reports a new Sr–Nd–Pb isotope dataset from ore sulfides in an attempt to constrain the source of the ore-forming fluids. Ten sulfide samples from middle stage of the Zhifang Mo deposit yield $I_{Sr}(t)$ ratios of 0.710286–0.711943, with an average of 0.711004; $\varepsilon_{Nd}(t)$ values between −19.5 and −14.8, with an average of −16.7; and $(^{206}Pb/^{204}Pb)_i$, $(^{207}Pb/^{204}Pb)_i$ and $(^{208}Pb/^{204}Pb)_i$ ratios of 17.126–17.535, 15.374–15.466 and 37.485–37.848, with averages of 17.380, 15.410 and 37.631, respectively. One pyrite from the early stage yield $I_{Sr}(t)$ of 0.722711–0.722855, with an average of 0.722783, which is higher than those of the middle stage sulfides and suggests equilibration with wallrocks. The $\varepsilon_{Nd}(t)$ values are in the range of −17.3 to −16.6 with a mean at −17.0; and $(^{206}Pb/^{204}Pb)_i$, $(^{207}Pb/^{204}Pb)_i$ and $(^{208}Pb/^{204}Pb)_i$ ratios are 17.386, 15.405 and 37.622, respectively. The ore sulfides show higher Pb-isotope ratios, higher $\varepsilon_{Nd}(t)$ and lower $I_{Sr}(t)$ values than the host rocks. The results suggest that the ore-forming fluids had lower $I_{Sr}(t)$, and higher $\varepsilon_{Nd}(t)$ values than the ore sulfides, and were possibly sourced from the Dengfeng Complex. The southward subduction of the North China Craton beneath the Huaxiong Block during the Triassic was possibly responsible for the formation of the Waifangshan orogenic Mo system.

1. Introduction

The Qinling Orogen, located between the southern margin of the North China Craton (NCC) and the northern margin of the Yangtze Craton (Fig. 1), defines a potential metallogenic belt in China hosting one of the world's most important Mo district (Fig. 1c), with estimated reserves of >6 Mt Mo metal, as well as Au, Ag, Pb–Zn, Hg and Sb deposits (Chen et al., 2000; Li et al., 2007; Chen et al., 2009; Mao et al., 2011; Yang et al., 2012). The majority of the Mo deposits in the East Qinling Molybdenum Belt (EQMB, Fig. 1c) are associated with Yanshanian (Jurassic–Cretaceous) porphyry/skarn systems and have been the targets of previous exploration (Hu, 1988; Stein et al., 1997; Zhang et al., 2011; Yang et al., 2012). However, the distribution of most of the Mo deposits in the EQMB along the southern margin of the NCC (Fig. 1c), in association with the Yanshanian granitoids in the Huaxiong Block, has remained enigmatic (Chen et al., 2009). Recently, several new Mo deposits were discovered in the carbonate-, quartz- and fluorite-dominated veins in the Huaxiong Block, such as the Huanglongpu (Xu et al., 2010) carbonatite vein system, Longmendian (Li et al., 2014), Zhaiwa (Deng et al., 2013a,b), Dahu (Li et al., 2011a; Ni et al., 2012, 2014) and Zhifang (Deng et al., 2014b) quartz vein system, and the Tumen (Deng et al., 2013c, 2014a) fluorite vein system. The available molybdenite Re–Os ages show that these veins were formed during different mineralization pulses (Fig. 1c), including the Paleoproterozoic (ca. 1.85 Ga, Li et al., 2011b; ca. 1.76 Ga, Deng et al., 2013a), Neoproterozoic (ca. 0.85 Ga, Deng et al., 2013c), Caledonian (ca. 0.43 Ga, Li et al., 2009), Indosinian

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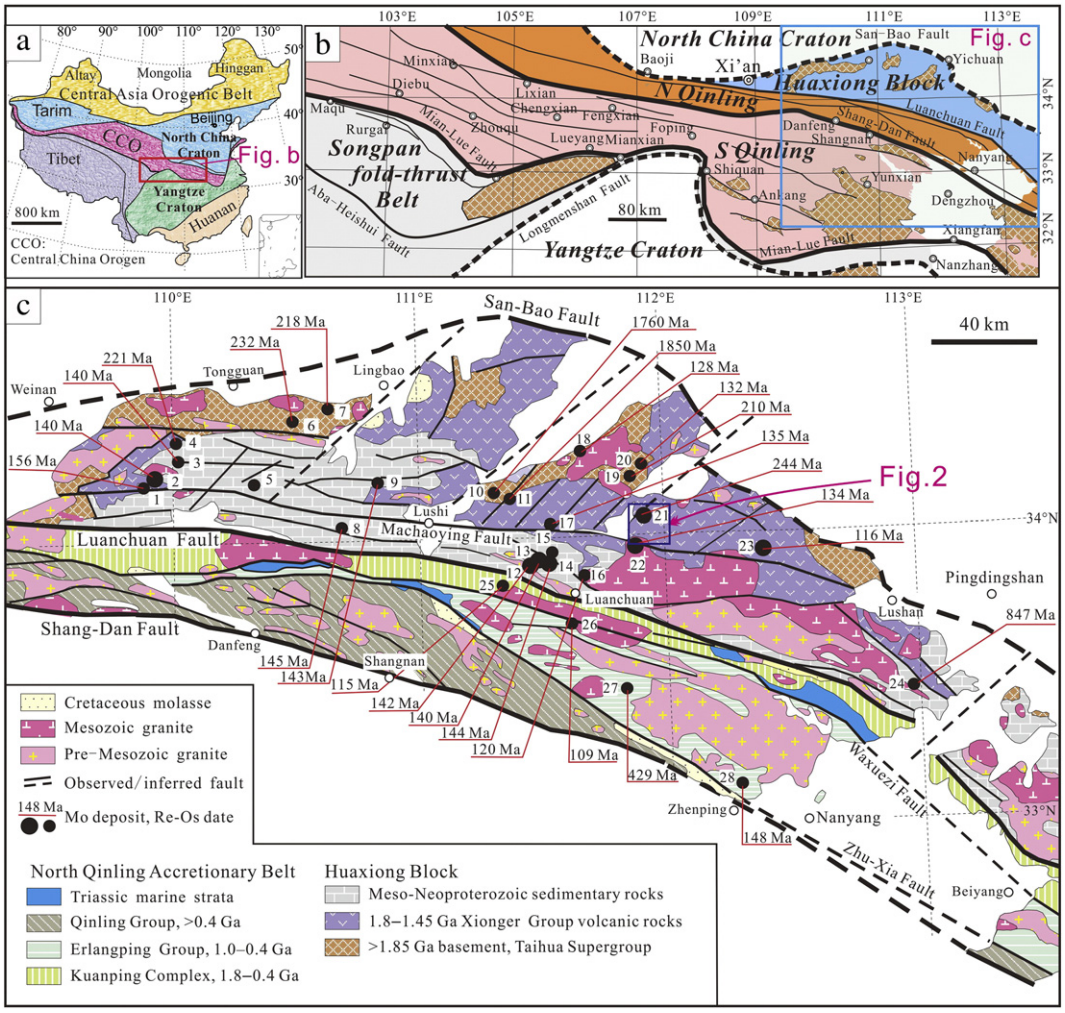

Fig. 1. Maps showing (a) the major tectonic subdivisions of China, with the location of Qinling Orogen; (b) tectonic framework of the Qinling Orogen; and (c) distribution of Mo deposits in the East Qinling Mo Belt, with the location of the Waifangshan Mo ore district (modified from Chen et al., 2009, and references therein; Deng et al., 2014b). Names of numbered deposits: 1 — Balipo; 2 — Jinduicheng; 3 — Shijiawan; 4 — Huanglongpu; 5 — Mulonggou; 6 — Majiawa; 7 — Dahu; 8 — Yechangping; 9 — Yinjiagou; 10 — Zhaiwa; 11 — Longmendian; 12 — Shangfanggou; 13 — Nannihu; 14 — Sandaozhuang; 15 — Majuan; 16 — Zhuyuangou; 17 — Shiyaogou; 18 — Shapoling; 19 — Huangshui'an; 20 — Leimengou; 21 — Waifangshan Mo ore district; 22 — Yuchiling; 23 — Donggou; 24 — Tumen; 25 — Saozhoupo; 26 — Shimengou; 27 — Yindonggou; 28 — Qiushuwan. Abbreviation: CCO, Central China Orogen (includes the Kunlun, Qilian, Qinling, and Dabie orogenic belts).

(ca. 0.24 Ga, Gao et al., 2010) and Early Cretaceous (Chen et al., 2009). Thus, the origin of the EQMB, and the timing and mechanisms of formation of the pre-Yanshanian Mo-deposits remain as important aspects to be investigated.

More than ten quartz vein-type Mo deposits have been discovered through geochemical survey by the No. 5 Party of Henan Bureau of Geological Exploration for Non-ferrous Metals in the Waifangshan area of the EQMB. These are the Zhifang, Fantaigou, Qianfanling, Xiangchungou, Kangjiagou, Badaogou, Shitishang, Dazhuanggou, Maogou and Daxigou deposits (Fig. 2). These veins yield an estimated reserve of more than 0.1 Mt Mo metal and expected resources up to 0.5 Mt, constituting the Waifangshan quartz vein-type Mo ore district (Bai and Xiao, 2009). These deposits have attracted several investigations (Chen, 2006, 2010; Gao et al., 2010; Lu et al., 2011; Mao et al., 2011; Deng et al., 2014b). Among these, the Zhifang Mo deposit has been considered as the representative, and geologically most studied. However, controversy surrounds the ore genesis based on geological characteristics such as: (1) the stratiform deposit associated with late Yanshanian magmatic hydrothermal system (Wen et al., 2008); (2) the stratabound deposit related to Paleo-Mesoproterozoic volcanic hydrothermal system (Bai and Xiao, 2009); and (3) the orogenic-type deposit (Chen, 2006; Deng et al., 2014b). Moreover, the source of the ore-forming fluids and metals, as well as genetic mechanism remains unclear.

Molybdenite Re–Os dating offers a useful technique to determine the timing of mineralization (Stein et al., 2001a; Conliffe et al., 2010). The isotopic data from the ore minerals and genetically associated sulfides can be used to evaluate the nature and source of the ore-forming fluids (Jiang et al., 1999; Voicu et al., 2000; Kempe et al., 2001; Yang and Zhou, 2001; Chen et al., 2004; Barker et al., 2009; Pirajno, 2009; Zhang et al., 2009; Ni et al., 2012, 2014). In this contribution, we report new Re–Os geochronology and Sr–Nd–Pb isotope data from a comprehensive study of the Zhifang Mo deposit, and discuss the genetic type of the ores and the sources of ore-forming fluids.

2. Regional geology

The Qinling Orogen is the central portion of the E–W-trending Central China Orogen Belt (CCOB) that evolved from the northernmost Paleo-Tethys Ocean and was finally built up by the Mesozoic collision between the NCC and Yangtze Craton (Fig. 1; Zhang et al., 2001; Chen et al., 2009; Dong et al., 2011a,b; Wu and Zheng, 2013; Zheng et al., 2013; Chen et al., 2014; Diwu et al., 2014; Li et al., 2015). The Qinling Orogen is composed of four tectonic units from north to south: the Huaxiong Block representing the reactivated southern margin of the NCC, the northern Qinling accretion belt, southern Qinling fold belt, and a foreland fold–thrust belt (e.g., Songpan fold belt) along the