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Geology, geochemistry and tectonic settings of molybdenum deposits in Southwest China: A review

Yong-Fei Yang [a,b,*], Pin Wang [b,c]

[a] Chengdu Center, China Geological Survey, Chengdu 610081, China
[b] Key Laboratory of Orogen and Crust Evolution, Peking University, Beijing 100871, China
[c] Key Laboratory of Mineralogy and Metallogeny, Guangzhou Institute of Geochemistry, CAS, Guangzhou 510640, China

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ABSTRACT

Southwest (SW) China hosts more than 26 Mo (Mo-only, Mo-dominated and Mo-bearing) deposits with a total reserve of >2.5 Mt Mo metal. The region has become one of the most important Mo mineral provinces in China. These Mo deposits are usually fault-controlled, and are located mainly in: (1) Lhasa Terrane, characterized by widely distributed Yanshanian–Himalayan igneous rocks; (2) Qiangtang Terrane, composed by Proterozoic and Early-Paleozoic crystalline basement and Devonian to Jurassic cover rocks; (3) East Kunlun Terrane, comprising Precambrian metamorphic rocks intruded by Paleozoic and Mesozoic granitoid plutons; (4) West Kunlun Terrane, characterized by Precambrian metamorphic basement, Paleozoic metasedimentary rocks, and Early-Paleozoic and Carboniferous–Triassic arc-type plutons; and (5) Yidun arc, composed by Middle and Upper Triassic volcanic–sedimentary successions. The Mo mineralization styles are dominated by porphyry-type, but also contain porphyry-skarn, skarn and porphyry-quartz vein types. Orebodies are vein-type or lensoidal, and are hosted by a variety of metamorphic, volcanic, granitic and sedimentary rocks of different ages. Fluid-rock interactions are exemplified by alteration zonation, which usually grades from an innermost potassic alteration zone, via a silicic/sericite alteration zone, to an outermost propylitic alteration zone. The initial high-temperature ore-forming fluids are magmatic in origin, and contain CO_2-bearing fluid inclusions. The initial ore-forming fluids would have then evolved to low-temperature, low-pressure, low-salinity and CO_2-poor (with meteoric water input) at the late alteration/mineralization stage. Causative granitoids for these Mo deposits have relatively high SiO_2, K_2O and Al_2O_3, and low TiO_2 and MgO, showing a metaluminous to peraluminous high-K calc-alkaline to shoshonitic affinity. These granitoids exhibit significant depletions in Ba, Nb, Ta, P and Ti, and enrichments in Rb, Th, U and K. It is suggested that they were originated from partial melting of a lower rejuvenated crust, as evidenced by their Sr-Nd-Pb isotopic signatures. The Mo deposits in East and West Kunlun were formed in the Triassic (ca. 258–214 Ma), related to the Paleo-Tethys Ocean subduction and the subsequent continental collision. Major Mo mineralization in the Qiangtang and Lhasa terranes mainly occurred during the syn-collisional compression to post-collisional extension transition of the Qiangtang–Lhasa (ca. 43–35 Ma) and India–Asia (ca. 30–14 Ma) collisions, respectively. The Late-Cretaceous Mo mineralization (ca. 88–73 Ma) in the Yidun arc was formed during the late- or post- Lhasa–Qiangtang collision setting, or the intraplate extension led by the post-Himalayan escape tectonics. The wide range of molybdenite Re contents in these major SW Chinese Mo deposits indicates remarkable differences in metal, fluid sources and ages.

1. Introduction

China has the largest molybdenum reserve in the world, with the majority being concentrated in the Qinling–Dabie Orogenic Belt (Li et al., 2007c; Chen et al., 2017a), the eastern part of the Central Asian Orogenic Belt (NE China; Chen et al., 2017b), South China Block (Zhong et al., 2017) and Southwest (SW) China.

* Corresponding author at: Chengdu Center, China Geological Survey, Chengdu 610081, China.
E-mail address: yyf6811@163.com (Y.-F. Yang).

The East Qinling–Dabie is the most important Mo belt in the world, with 8.43 Mt of proven Mo metal reserves (Li et al., 2007c; Mao et al., 2011). The Mo deposits in East Qinling–Dabie are mainly associated with Mesozoic porphyry or porphyry-skarn systems formed in a post-subduction collision regime (Chen and Li, 2009; Chen et al., 2000, 2007a, 2009, 2017a; Li et al., 2007c, 2012a, 2013a; Mao et al., 2008, 2010, 2011; Mi et al., 2015; Yang et al., 2016), showing different geological and geochemical features from those in the subduction-related magmatic arc settings such as West Cordillera, North America (Pirajno, 2009; Wang et al., 2014a; Mi et al., 2015; Yang et al., 2016). Therefore, Chen and Fu (1992) and Chen et al. (2000, 2004, 2007a,

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2007b, 2009) proposed a tectonic model for collisional orogeny, petrogenesis, metallogenesis and fluid flow (referred to as the CMF; Pirajno, 2009, 2013).

The NE China lies in the eastern sector of the Central Asian Orogenic Belt (CAOB), accommodating multistage magmatism, crustal growth and mineralization. 69 Mo-only or Mo-dominated and 9 Cu-Mo deposits have been discovered in NE China, with a total resource of 10.5 Mt Mo metal (Chen et al., 2017b; and references therein). The majority of the deposits are porphyry (including breccia pipes) type, followed by the skarn and quartz vein types, formed during Paleozoic and Mesozoic tectono-magmatic events (Chen et al., 2017b; and references therein).

The South China block (SCB) consists of the Yangtze Craton and Huanan Orogen, sutured by the Jiang–Shao Fault (Zhong et al., 2017). The SCB hosts at least 46 Mo deposits (including Mo-only, Mo-dominated and Mo-bearing) with a total resource of ~1.8 Mt Mo metal and accounting for ~10% of the total Mo resources of China (Zhong et al., 2017; and references therein). These Mo deposits are predominantly porphyries, skarns and combinations thereof, formed in a long time span from the Early-Paleozoic to Late-Mesozoic (Zhong et al., 2017; and references therein).

The SW China is mainly composed of the Tibetan Plateau and its surrounding region (Fig. 1), and contains one of the youngest and best known continental collision orogenic belt (Himalaya Orogen; Yin and Harrison, 2000). Two world-famous metallogenic belts have been recognized in SW China: (1) the Gangdese porphyry Cu belt (ca. 19.7–11.5 Ma) (Hou et al., 2009; Qu et al., 2007) in southern Tibet (Rui et al., 2003, 2004; Qu et al., 2003, 2009; Hou et al., 2009); (2) Sanjiang Tethyan polymetallic metallogenic belt (Deng et al., 2014; Hou et al., 2007a), including the Yulong porphyry Cu belt in eastern Tibet (Hou and Cook, 2009; Hou et al., 2006a; Rui et al., 1984; Zaw et al., 2007). Recent years, some important Mo deposits were discovered in SW China (Fig. 1), such as the Sharang (Zhao et al., 2014) and Mingze (Fan et al., 2011) porphyry Mo deposits in Lhasa Terrane; the Narigongma (Yang et al., 2014a) and Lurige (Hao et al., 2013) porphyry Mo-Cu deposit in Qiangtang Terrane; the Lalinzaohuo porphyry Mo deposit in East Kunlun Terrane (Wang et al., 2013); the Kayizi porphyry Mo deposit in West Kunlun Terrane (Liu et al., 2010a); and the Xiuwacu (Wang et al., 2015) and Tongchanggou (Yang et al., 2017) deposits in Yidun arc. These Mo deposits, with a total Mo metal reserve of >2.5 Mt (Table 1), make SW China one of the most Mo productive and prospective regions in China.

In this paper, we describe and summarize the principal geological, age and geochemical features of the major Mo deposits (including Mo-only, Mo-dominated and Mo-bearing deposits) in SW China, and discuss the spatial–temporal distribution and tectonic settings of Mo mineralization, on the basis of an extensive compilation of published and unpublished Mo geological data.

2. Tectonic framework and evolution

2.1. Tectonic framework

Southwest China encompasses the region bounded by the Tarim Basin and Qaidam Basin in the north, by the Longmenshan Fault in the northeast and by the Ailaoshan–Red River suture zone in the east (Fig. 1). From south to north, SW China comprises the northern part of the Himalaya Orogen, the Lhasa Terrane, the Qiangtang Terrane, the Songpan-Ganzi-Hoh Xil Terrane and the Kunlun Terrane, with terrane boundaries marked by the Indus–Yarlung, Bangong–Nujiang, Jinshajiang and Ayimaqin–Kunlun–Mutztagh sutures (Fig. 1B).

The Himalaya Orogen was formed by the India–Asia collision from the end Cretaceous to Eocene (Mo et al., 2008). The orogen comprises the Lesser Himalayan Metasedimentary (LHM) and Higher Himalayan Metasedimentary (HHM) series and the Tethyan Himalayan Sequences (THS), with boundaries that include the Main Boundary Thrust (MBT), Main Central Thrust (MCT) and South Tibet Detachment System (STDS) (Fig. 1B). Most parts of the THS are located in China, and comprise Paleozoic–Cenozoic sedimentary sequences deposited on the Indian passive continental margin (Li et al., 2015a). The THS sedimentary sequences are characterized by deep-water, distal-margin shale, chert and turbidites in the northern part, and shallow-water carbonates and

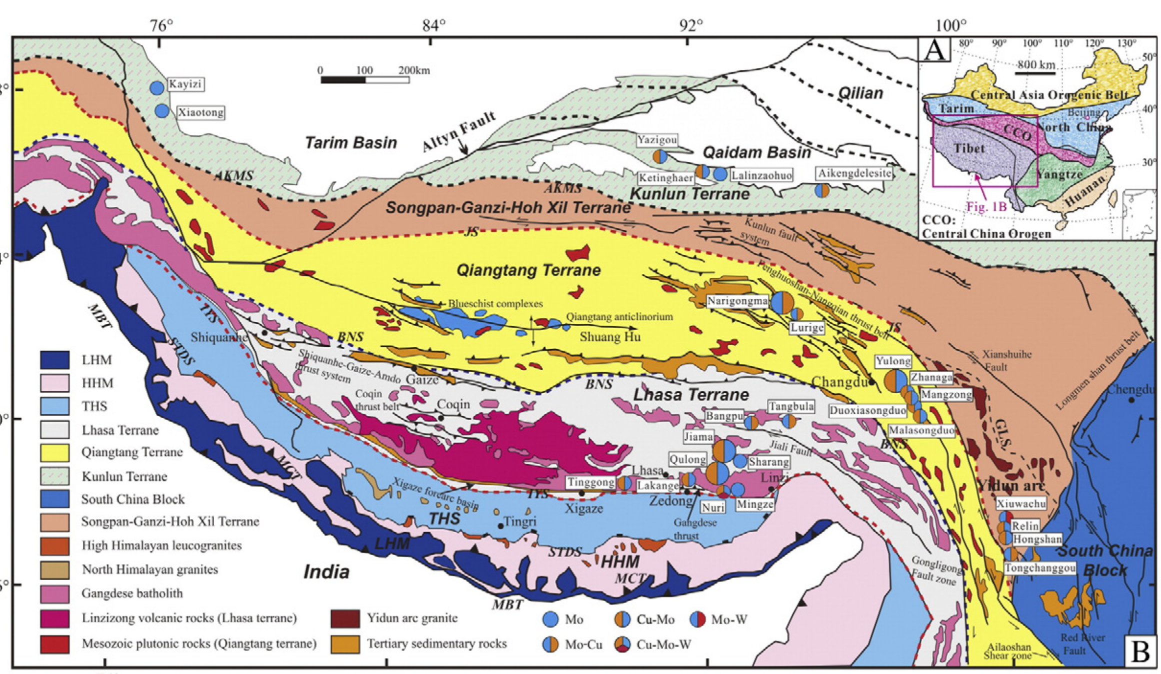

Fig. 1. Simplified geologic map of the Tibetan Plateau and its surrounding region, showing the distribution of major Mo deposits. Abbrev: MBT, Main Boundary Thrust; MCT, Main Central Thrust; LHM, Lesser Himalayan Metasedimentary series; HHM, Higher Himalayan Metasedimentary series; STDS, South Tibet Detachment System; THS, Tethyan Himalayan Sequences; IYS, Indus–Yarlung suture; BNS, Bangong–Nujiang suture; JS, Jinshajiang suture; GLS, Ganzi–Litang suture; AKMS, Ayimaqin–Kunlun–Mutztagh suture.
(Modified after Qin, 2012.)