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

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ABSTRACT

South China Block (SCB) is the area including the Yangtze Craton and the Huanan Orogen where scattered Precambrian terranes are usually regarded as segments of Cathaysia Land. It is the third most important molybdenum metallogenic province in China, next to the Qinling-Dabie area and Northeast China, containing 29 Mo-only or Mo-dominated, 9 W-Mo(-Sn-Bi) and 8 Cu-Mo deposits. These 46 deposits are located mainly in: (1) the Lower Yangtze River Belt of the northeastern Yangtze Craton, (2) the Northern Jiangnan Orogenic Belt that is generally considered a Meso-Neoproterozoic magmatic arc complex accreted onto the southeastern margin of the Yangtze Craton, (3) the Wuyi-Yunkai Orogenic Belt characterized by local exposures of Proterozoic metamorphic terranes and the more widespread Sinian (Uppermost Proterozoic) to Triassic sedimentary sequences, and (4) the Southeast Coastal Volcanic Belt characterized by Yanshanian andesitic to felsic volcanic rocks. Their genetic types are dominated by porphyry and skarn mineral systems, with only a few quartz-vein systems. The orebodies form veins, lens, cylindrical shapes, pipes, or irregular in shape, usually controlled by faults at various scales and volcanic-subvolcanic complexes. The host-rocks are variable in lithologies, including granites, porphyries, volcanic breccias and tuffs, clastic sediments and carbonate rocks, but the high-grade orebodies are usually hosted in carbonate-shale sequences. Hydrothermal mineralization processes can be generally divided into four stages, from early to late, they are (1) K-feldspar-quartz veins or veinlets, (2) quartz-molybdenite stockworks, (3) quartz-polymetallic sulfide stockworks, and (4) quartz-carbonate-fluorite veinlets. Fluid-rock interaction as exemplified by wallrock alteration evolved from K-silicate alteration (K-feldspar-quartz-mica), through phyllic (quartz-sericite-chlorite-epidote), to propylitic or argillic alteration, with skarn alteration typically occurring in skarn-type mineral systems. Hydrothermal mineral assemblages vary between two end-members, namely the dry system formed by CO_2-rich fluids and marked by quartz, K-feldspar, fluorite, carbonate and epidote, and the wet system mainly originated from CO_2-poor fluids and composed of biotite, sericite and chlorite. The ore-forming fluids are magmatic in origin and show high-temperature and high-salinity. The melt-fluid systems forming Cu-Mo deposits are more oxidizing than those forming the W-Mo or Mo deposits, as suggested by accessory minerals in granitoids and daughter minerals in fluid inclusions. The Cu-Mo deposits are related to the I-type granitic rocks (adakite-like), whereas the W-Mo and Mo-only systems are related to granitic rocks of S- or A-types, although all of them show high K contents. Available isotope ages show that the Mo and Mo-bearing deposits were predominantly formed in the early Yanshanian Orogeny (170–134 Ma), followed by the late Yanshanian Orogeny (110–92 Ma) and the Caledonian Orogeny (450–410 Ma). The Caledonian Mo-mineralization has been observed only in the Wuyi-Yunkai Orogenic Belt and related to the collision between the Yangtze Craton and the pre-Devonian Huanan Orogen or terranes separated from the Cathaysia Land, linked to the assembly of the Gondwana supercontinent. The Early Yanshanian mineralization affected the entire Huanan Orogen and the eastern Yangtze Craton, and resulted from the syn- to post-collisional tectonism following the closure of eastern Paleo-Tethys. The Late Yanshanian Mo deposits mainly occur in the Southeast Coastal Volcanic Belt and the southeastern margin of the Wuyi-Yunkai Orogenic Belt, and are related to the westward subduction of the Paleo-Pacific plate. The skarn-type mineral systems generally show lower Re contents than the porphyry-type deposits in a same tectonic unit, suggesting that carbonate host-rocks have lower Re contents than the causative porphyries. The Re contents in molybdenites from porphyry or porphyry-skarn Cu-Mo systems are >50 ppm, mainly >100 ppm, suggesting a source

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significantly contributed by the mantle; whereas the Re contents in molybdenites from the Mo-only or W-Mo-dominated deposits are <100 pm, mainly <50 ppm, indicating a genetic relation to the crust-sourced granitic magmatism.

1. Introduction

China has the largest molybdenum resources in the world and also has ranked as one of the two largest molybdenum production countries since the 1990s (Barry et al., 2013). The molybdenum deposits in China are mainly found in the Qinling-Dabie Orogenic Belt, the eastern sector of the Central Asian Orogenic Belt (Northeast China), South China Block (SCB) and Himalayan–Tibetan Orogen. Molybdenum mineralization events in China occurred in several periods, from the Paleoproterozoic (e.g., 1.85 Ga Longmendian and 1.76 Ga Zhaiwa Mo deposits in East Qinling, Li et al., 2011; Deng et al., 2013a), through the Neoproterozoic (0.85 Ga Tumen deposit in Qinling; Deng et al., 2013b, 2014), the Paleozoic and Mesozoic in eastern China (Chen et al., 2012c; Zhang and Li, 2014), to the Cenozoic in Tibet (Hou and Zhang, 2015). However, most of the Mo deposits were formed in the Mesozoic, exemplified by those in eastern China (Li et al., 2007; Huang et al., 2011; Mao et al., 2013; Zeng et al., 2013a; Pirajno and Zhou, 2015), including Qinling-Dabie Orogenic Belt (Chen et al., 2000; Chen and Santosh, 2014; Li et al., 2007; Zeng et al., 2013a), Northeast China (Chen et al., 2012c; Zhang and Li, 2014), eastern Tianshan (Wu et al., 2014, 2017) and South China Block (SCB, see below). These deposits were formed in continental collision or intra-continental tectonic settings (Chen et al., 2000; Li et al., 2007, 2013a; Yang et al., 2012, 2013, 2015, 2017), and show 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., 2014; Mi et al., 2015; Yang et al., 2015).

The SCB underwent multistage tectono-magmatic events and is well endowed with resources of W, Sn, Bi, Sb, Cu and Mo. To date at least 46 Mo deposits (including Mo-only, Mo-dominated and Mo-bearing; Table 1, Fig. 1) have been discovered and reported in the SCB, with a total resource of ~1.8 Mt Mo metal and accounting for ~10% of the total Mo resources of China. These Mo deposits are predominantly porphyries, skarns and combinations thereof, formed in a long time span from the Early Paleozoic to Late Mesozoic. Several of these deposits have been studied in geology, geochemistry and geochronology and reported in Chinese literature (e.g., Mao et al., 1995a, 1995b, 1996; Luo et al., 1991; Zhai et al., 1992; Zhou et al., 2008; Xie et al., 2006; Li et al., 2009a, 2009b; Meng et al., 2007; Chen et al., 2011), but only a few deposits have been introduced in English, such as Dexing Cu-Mo (Li and Sasaki, 2007; Mao et al., 2011; Liu et al., 2012b; Hou et al., 2013), Shizhuyuan W-Sn-Mo-Bi (Yin et al., 2002; Lu et al., 2003), Yuanzhuding Cu-Mo (Zhong et al., 2013) and Luoboling Cu-Mo deposits (Zhong et al., 2014).

In this contribution, we summarize the principal geological and geochemical characteristics of the Mo deposits in the SCB, and then discuss their geneses and geodynamic settings.

2. Tectonic framework and evolution

The SCB is the area north to the Xiang-Guang Fault, northwest to the Longmenshan Fault, and southwest to the Ailaoshan–Red River suture zone, respectively, and facing the Pacific Ocean in the southeast (Fig. 1). It is further divided into the Yangtze Craton and Huanan Orogen sutured by the Jiang–Shao Fault (also called Jiangshan–Shaoxing–Pingxiang–Dongxiang Fault or Xiang–Gan–Zhe Suture).

The Yangtze Craton is mainly covered by the coal-bearing Phanerozoic sedimentary sequence, with the basement rocks exposed along the margins. The basements rocks in the southeast margin of the Yangtze Craton consist of Mesoproterozoic volcanic-sedimentary rocks and constituting the Jiangnan Orogenic Belt, or a Mesoproterozoic accretionary arc (Fig. 1), yielding isotope ages generally in the span of 1.8–0.85 Ga (e.g., Guo et al., 1980; Hu and Xu, 2008; Pirajno, 2013). The Huanan Orogen is divided into the Wuyi-Yunkai Orogenic Belt (WYOB) in the west and the Southeast Costal Volcanic Belt (SCVB) separated by the Lishui–Dapu Fault (Lishui-Zhenghe-Dapu-Haifeng Fault). The SCVB is characterized by Yanshanian volcanic and granitic rocks, with a total lack of Paleozoic rocks; by contrast, the WYOB is marked by widespread pre-Devonian, Late Paleozoic to Triassic rocks, in places associated with Yanshanian volcanic and granitic rocks. The locally recognized Precambrian (Neoproterozoic in general) rocks within the pre-Devonian basement, such as the Badu Complex in Zhejiang and the Baoban Complex in Hainan (Pirajno, 2013 and references therein), can be interpreted either as fragments of the previously called Cathysia Land (Grabau, 1924; Shu, 2012) or as accretionary continental terranes amalgamated onto the Yangtze Craton (Hu and Xu, 2008) (Fig. 1).

The SCB underwent multiple tectonic-magmatic-metallogenic events since the Proterozoic period (Pirajno, 2009, 2013; Shu, 2012). Many researchers (e.g., Pirajno and Bagas, 2002; Charvet et al., 2010; Shu, 2012; Wang et al., 2013) suggested that the Huanan Orogen (Cathysia Land) firstly collided with the Yangtze Craton in the early Neoproterozoic (1.0–0.8 Ga), then separated from the latter due to Rodinia breakup in Neoproterozoic (0.8–0.68 Ga), and ultimately re-docked with the Yangtze Craton during the period of Late Ordovician–Silurian (Caledonian Orogeny). The amalgamated SCB collided with the North China Craton and Indochina Block in the Triassic, and subsequently overrode the paleo-Pacific plate since the Middle Jurassic, resulting in the formation of abundant magmatic rocks and associated mineral systems. However, this model disagrees with the fact that the Precambrian rocks are very limited in the Huanan Orogen, and thus another group of geologists (e.g., Guo et al., 1980; Hsü et al., 1988, 1990; Hu and Xu, 2008) proposed that the Huanan Orogen evolved from a geosyncline or an archipelago filled by Sinian (Late Neoproterozoic) to Triassic volcanic-sedimentary sequence with thickness of up to 20 km (Guo et al., 1980; Xiao and He, 2005; Hu and Xu, 2008), instead of a hypothetical Cathaysia Old Land (Grabau, 1924; Shu, 2012) formed in Early Precambrian.

The eastern SCB is characterized by Yanshanian (Jurassic to Cretaceous) magmatic rocks and mineral deposits (Pirajno and Bagas, 2002; Zhou et al., 2006; Chen et al., 2007a; Mao et al., 2013), but the tectonic setting is a long-time controversial issue. The early Yanshanian (mainly Jurassic) tectonic setting has been debated between several models including: (1) a back-arc basin-and-range province related the westward subduction of the Pacific plate (Gilder et al., 1996; Zhong et al., 2014); (2) a syn- to post-collisional setting related to the continental collisions of the SCB with the North China Block and Indochina Block since the ending Triassic, and with the hypothesized Dongnanya continent since the end of the early Jurassic (Hsü et al., 1988, 1990; Chen et al., 2007a); (3) post-orogenic delamination of the lower crust (Wang et al., 2004, 2006a, 2006b); and (4) a wide magmatic arc resulting from the westward flat subduction of the paleo-Pacific plate (Zhou et al., 2006; Mao et al., 2013; Zhou and Li, 2000; Li and Li, 2007; Wang et al., 2013). Hitherto, the westward subduction model of the paleo-Pacific plate is the most popular one to understand Early Yanshanian tectonics in the eastern SCB. Subsequently, the subduction zone of the paleo-Pacific plate is interpreted to have migrated eastward to the ocean since Cretaceous (or Late Cretaceous), resulting in an extensional setting along the margin of the overriding Eurasia continental plate (Shu, 2012; Zhong et al., 2014), accommodating the development of rift basins filled with molasses and shoshonitic