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Late Mesozoic molybdenum mineralization on Hainan Island, South China: Geochemistry, geochronology and geodynamic setting

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ABSTRACT

Hainan Island has become an important molybdenum (Mo) producer in East China, with the proven and measured metal Mo reserves of >0.29 Mt and >0.69 Mt, respectively. The known Mo-related deposits and occurrence which genetically might be attributed to porphyry- and hydrothermal vein types are hosted predominantly within the Cretaceous granitoids. These granitoids belong to high-K calc-alkaline, metaluminous to weakly peraluminous I-type series, and have geochemical affinities to arc-related basalts as defined by SiO_2 (57.40–77.34 wt.%) and K_2O (2.45–6.28 wt.%) contents, A/CNK ratios (mostly 0.86–1.10), depleted K, Ba, Nb, Sr, P and Ti, and enriched Rb, Th, Pb, Zr and La, and LREE-enriched REE patterns ($La/Yb_N = 7.1–66.3$) with pronounced negative Eu anomalies to no Eu anomalies ($Eu/Eu^* = 0.35–1.08$). The highly variable geochemical compositions might be linked to magmatic processes. The LA-ICP-MS U–Pb dating on zircon have revealed three stages of magma emplacement for the Cretaceous Mo-hosting granitoids during ca. 113–108 Ma, ca. 100–94 Ma and ca. 90–70 Ma, respectively. The initial $^{87}Sr/^{86}Sr$ ratios (from 0.70567 to 0.71208) and $\varepsilon_{Nd}(t)$ values (from −3.9 to −6.9) suggest that the host granitoids were sourced from an enriched subcontinental lithospheric mantle that had been metasomatized by fluids and/or melts released from ancient, subducted oceanic crust under an extension-induced setting. This setting is most favorable to variable degree of magma mixing between mantle-derived and crust-derived melts.

With the second event as most important and the third event likely recording the youngest Mo mineralization in East China, the Re–Os dating of molybdenite from two types of Mo deposits on Hainan Island has identified three Mo mineralizing events occurring at ca. 112 Ma, ca. 106–95 Ma and ca. 89–72 Ma. They are consistent with the episodes of the Cretaceous magmatism. The Re concentrations of molybdenites and $\delta^{34}S$ values of sulfides (1.36–5.73‰ and average 4.3‰) commonly indicate that the metal Mo is of hybrid origin between mantle and crust but with variable degree of hybridization. Given that the subduction of the Paleo-Pacific plate beneath the eastern Asian margin dominated the Late Mesozoic tectonism of South China, and that Hainan Island has been a part of the Cathaysia Block since Late Permian, the widespread Cretaceous extension and associated Mo mineralizing event(s) on Hainan Island might be a response to episodic rollback of the subducted slab, which led to the underplating of mantle-derived basaltic melts and associated deep crustal melting. Moreover, this tectono-magmatic scenario likely resulted in the migratory pluses of Mo metallogenesis and the change of metal Mo sources from northeast to southwest Hainan Island.

1. Introduction

Hainan Island, located on the northern margin of the South China Sea (Fig. 1a), has long been known for its Fe- and Au reserves, such as the large-scale, Shilu hematite-rich Fe–Co–Cu ore district (Xu et al., 2013, 2014a, 2015) and the Gezhen- and Baolun-type gold ore deposits (e.g., Hou et al., 1996; Ding et al., 2005), and therefore previous research into metallogenesis on Hainan Island mainly focused on this two ore deposit-types. Recent exploration suggests that there is significant potential for molybdenum (Mo) mineralization on Hainan Island, because eight Mo-related deposits and one occurrence have been identified (Fig. 1b and Appendix A1). Among these, the Luokuidong deposit (Fig. 1b and Appendix A1) is one of the most exciting discoveries in South China, accounting for proven Mo reserves of more than 254,346 tons, with an average grade of 0.05% (HBG: Hainan Bureau of Geology, in press).

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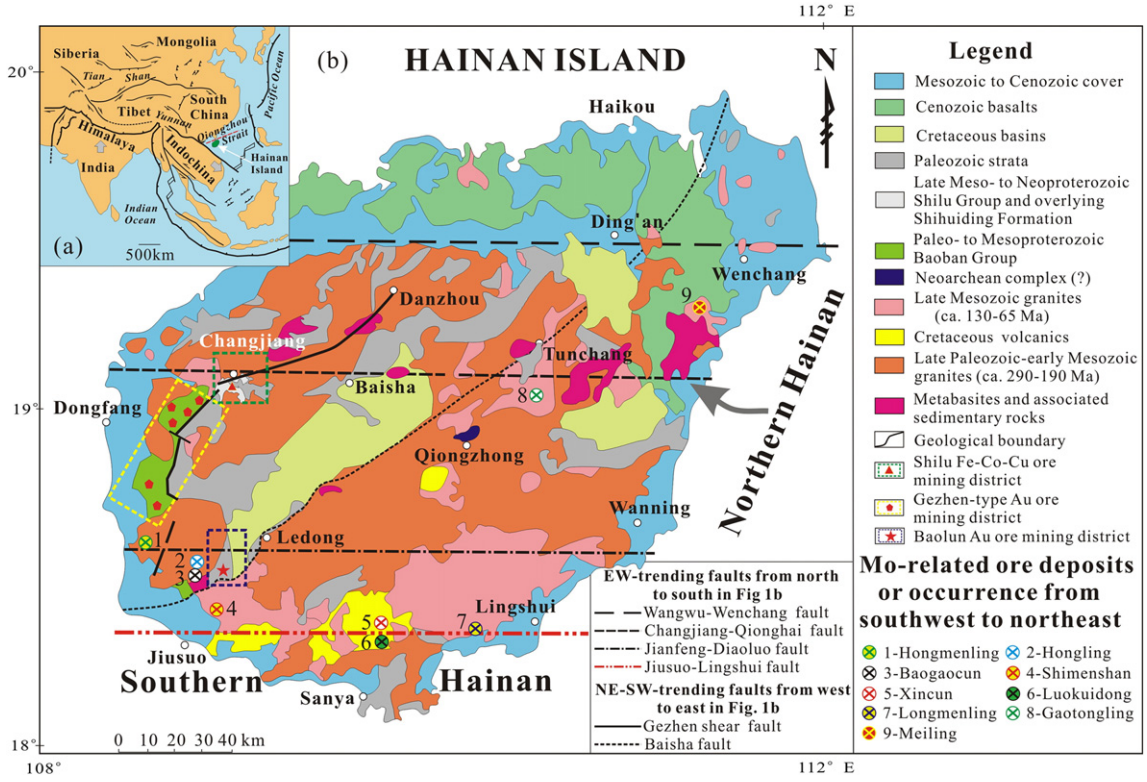

Fig. 1. (a) Location map (modified after Xu et al., 2014a) and (b) geological sketch map showing major stratigraphic and magmatic units, structures and molybdenum (Mo)-related ore deposits or occurrence on Hainan Island (modified after Xu et al., 2013, 2014a).

China is currently the largest Mo producer in the world with most of the metal Mo reserves located in East China, where reserves of metals Mo, W, Sn, Bi and Sb rank among the largest worldwide (USGS, 2011). The major types of Mo ore systems in East China contain porphyry, porphyry–skarn, skarn, and hydrothermal vein, which produced the giant East China Mesozoic metallogenic province and its constituent metallogenic belts or regions (Mao et al., 2011a). Mao et al. (2011a) and Zeng et al. (2013) suggested that the majority of the Mo deposits in East China formed during the Mesozoic between 240 Ma and 80 Ma, and might be linked to multiple tectono-magmatic events, involving far-field-subduction, plate collisions, crustal thickening, post-collision collapse, and extension/rifting or lithospheric thinning, and associated crust–mantle processes (Hua et al., 2003; Zhou et al., 2006). Over the last century, the majority of studies have focused on the Mo deposits as isolated units at the ore-field scale, rather than research involving all the coeval Mo ore deposits at the regional scale (e.g., Mao et al., 2011a,b; Li et al., 2012; Zeng et al., 2013). Especially, most of the published, Chinese and international papers have contributed to the genesis and associated tectonic settings of Mo ore deposits in the South China, Middle-Lower Yangtze River Valley, East Qinling–Dabie, Interior of North China Craton, Yan–Liao and Northeast China (Mao et al., 2011a). Consequently, the importance of Mo mineralization on Hainan Island has been underestimated. It is necessary to place more emphasis on the Mo-related deposits on Hainan Island, in order to evaluate the nature of the Mo mineralization, and more importantly to pinpoint the link between the Mo mineralizing events and the Mesozoic tectonic development of East China. In this contribution, we carried out analysis on geochemistry and Nd–Sr isotopes of host rocks, and sulfur isotope of sulfide minerals, as well as LA-ICP-MS U–Pb dating on zircon from host rocks and Re–Os dating on molybdenite from the Mo-related deposits on Hainan Island. The aim of the paper is to precisely and accurately define the timing of granitic magmatism and associated Mo mineralization, and to elucidate the Mo metallogenetic events and their corresponding geodynamic settings.

2. Geological setting

South China comprises the Yangtze Block in the northwest and the Cathaysia Block in the southeast (Li et al., 2002a). Traditionally, Hainan Island has been regarded as the southwestern extent of the Cathaysia Block, adjacent to the northern Indochina Block (Fig. 1a; Li et al., 2002a, 2008a,b; Metcalfe, 2013). Except for the unconfirmed Devonian and Jurassic (HBGMR, 1997), the stratigraphy is dominated by Paleozoic successions that outcrop as isolated units dispersed over the island, whereas Precambrian strata are relatively rare and mostly occur in western Hainan Island (Fig. 1b). Hainan Island is covered mostly by Permian to Cretaceous intrusive and extrusive rocks which comprise ca. 50% of the land area (Fig. 1b). Based on zircon SHRIMP, LA-ICP-MS and conventional U–Pb, mica (biotite, muscovite and sericite) and amphibole K–Ar and Ar–Ar, and whole rock Rb–Sr dating methods (Wang et al., 1991; Hou et al., 1996; Li et al., 2006; Wang et al., 2011, 2012; Zhang et al., 2011a; Tang et al., 2013; Jiang and Li, 2014; HBG, in press; and references therein), the intrusions can be grouped into the Late Carboniferous to Permian (ca. 300–250 Ma), the Triassic (ca. 250–200 Ma), the Middle to Late Jurassic (ca. 173–150 Ma) and the Cretaceous (ca. 131–70 Ma). Two sets of fault systems dominate the tectonic configuration of Hainan Island, the NE-trending Gezhen and Baisha faults occurring from west to east, and the E-trending Wangwu–Wenchang, Changjiang–Qionghai, Jianfeng–Diaoluo and Jiusuo–Lingshui crustal scale faults passing through the island from north to south (Fig. 1b). Because of its unusual tectonic setting, i.e., situated at the intersection of the Eurasian, Indian–Australian and Pacific plates (Fig. 1a), Hainan Island was subjected to complex tectonic development accompanied by multiple deformation, magmatism and metamorphism which led to many metalliferous ore deposits containing Fe, Co, Cu, Pb, Zn, Au, Ag, W, Sn and Mo (Xu et al., 2013).

The suggested position of the Cathaysia Block including Hainan Island (Li et al., 1995, 1999) before the late Mesoproterozoic assembly of the Rodinia supercontinent, implies that a united, Paleoproterozoic or older crystalline basement (Li et al., 2008a; Wang et al., 2015)