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Mineralization age and geodynamic background for the Shangjiazhuang Mo deposit in the Jiaodong gold province, China

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ABSTRACT

The Shangjiazhuang Mo deposit is located on the Jiaodong Peninsula in eastern China, which is famous for the ca. 120 Ma "Jiaodong-type" Au deposits with total Au endowment of over 3000 t. In this paper, we discuss the deposit geology, mineralization age, and geochemical features of the host granodiorite of the Shangjiazhuang Mo orebody. Using this information, we aim to clarify the time and geodynamic mechanism for the Mo deposit, which is another constraint to understand the genesis of Au deposits. The Mo mineralization generally occurs as quartz–sulfide veins within the medium-grained Yashan granodiorite. The alteration consists of potassic alteration, silicification, sericitization, chloritization, and carbonatization with a weak unclear zonation. The ore minerals mainly include molybdenite, chalcopyrite, and pyrite. We measured Re–Os isotopes of molybdenite grains, which yielded a weighted mean model age of 116.9 ± 0.81 (MSWD = 1.03) and a well-constrained ^{187}Re–^{187}Os isochron age of 117.1 ± 1.4 Ma (MSWD = 1.6). These ages are slightly younger than the age of Au mineralization on the Jiaodong Peninsula. Rhenium contents of 5.84–29.99 ppm with an average of 16.4 ppm in molybdenites indicate a crustal source. Whole-rock geochemical compositions show that the granodiorite is high-K calc-alkaline and metaluminous to peraluminous. The samples show low Y contents from 8.2 to 10.5 ppm and Sr/Y ratios from 48.2 to 58.8, displaying an adakitic affinity. The Yashan granodiorite has high initial $^{87}Sr/^{86}Sr$ ratios of 0.7101 to 0.7104, low $\varepsilon_{Nd}(t)$ values of −17.6 to −16.7, and zircon $\varepsilon_{Hf}(t)$ values from −24.8 to −17.1, with corresponding Hf model ages of 2.7 to 2.2 Ga. These isotopic data, together with the adakitic affinity of the granodiorite, indicate that the parental magma was derived from ancient crust. Mafic microgranular enclaves (MME) that are contemporaneous with the host granodiorite show SiO_2 contents of 57.98–58.41 wt% and depletion in Nb–Ta. The MMEs show enriched initial $^{87}Sr/^{86}Sr$ ratios of 0.7102 to 0.7106 and low $\varepsilon_{Nd}(t)$ values of −17.3 to −16.3. The MMEs are the products of mixing between the metasomatized lithospheric mantle-derived mafic magma and the ancient crust-derived felsic magma. The Early Cretaceous Mo mineralization (120–110 Ma) is slightly younger than the peak time of Au mineralization (126–120 Ma) on the Jiaodong Peninsula, but have a different spatial distribution which suggests different sources of Au and Mo. The "Jiaodong-type" Au deposits were probably related to the upwelling of metasomatized lithospheric mantle, while the Mo mineralization on the Jiaodong Peninsula may delineate a 120–110 Ma Mo metallogenic belt along the southern margin of the North China Craton with the East Qinling, which is related to the melting of ancient crustal sources. The subduction of the Paleo-Pacific slab and accompanying asthenospheric upwelling triggered upwelling of metasomatized lithospheric mantle, forming "Jiaodong-type" Au deposits. Subsequently, the ponding of mantle-derived magmas resulted in partial melting of ancient crust and associated Mo deposits.

1. Introduction

The North China Craton (NCC) and surrounding areas contain many late Mesozoic Au and Mo ore deposits. The Au deposits are found mainly on the Jiaodong Peninsula and in the Xiaoqinling and Jibei regions. The Mo-bearing deposits are widespread throughout the Yan–Liao, East Qinling–Dabie, Middle–Lower Yangtze River Valley, and Northeast China metallogenic belts (Fig. 1a; Li and Santosh, 2014; Mao et al., 2008, 2011a, 2011b; Shu et al., 2014). The Jiaodong Peninsula, located along the southeastern margin of the NCC, is well known as the largest gold province in China. Compared with the Au mineralization, Mo mineralization on the Jiaodong Peninsula is poorly investigated.

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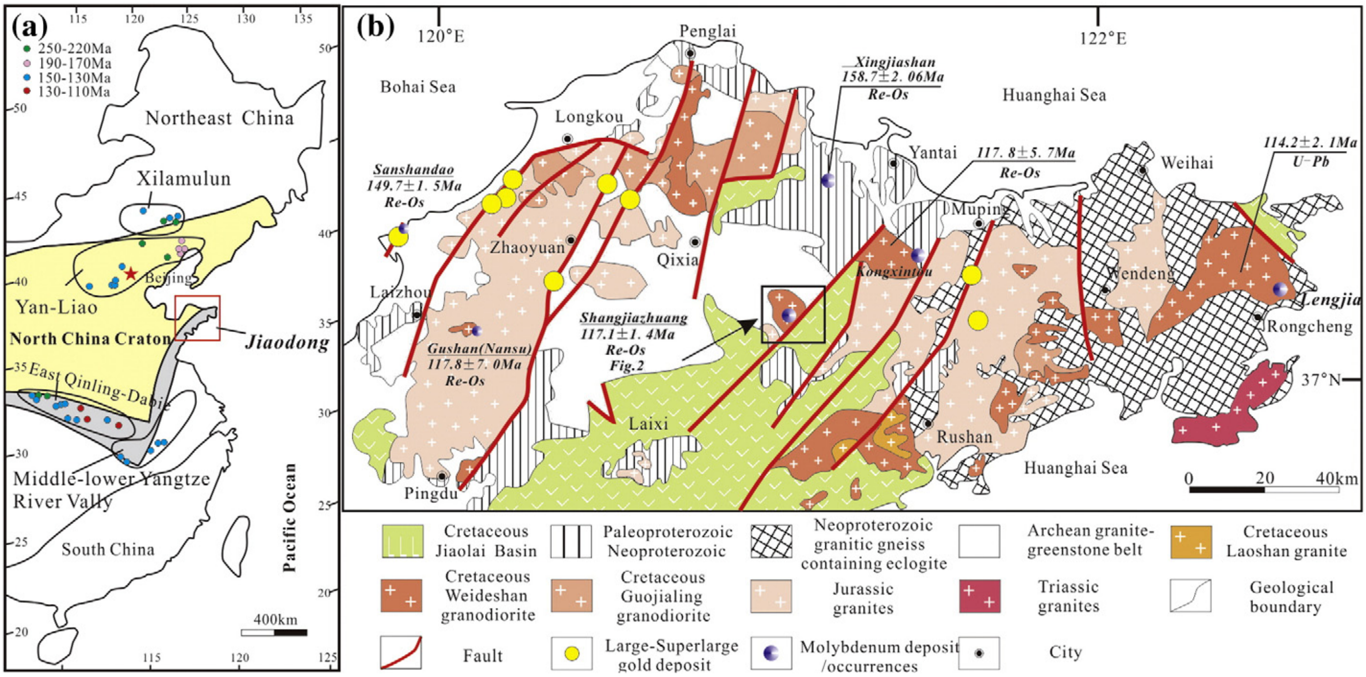

Fig. 1. (a) Spatial and temporal distribution of Mesozoic Mo-bearing deposits in eastern China (modified after Shu et al., 2014). (b) Simplified geological map of the Jiaodong Peninsula, showing the distribution of major tectonic units, Mesozoic igneous rocks, faults, and Au and Mo deposits (modified after Song et al., 2015). The Shangjiazhuang Mo deposit is located at the junction between the Jiaobei uplift and the Jiaolai basin.

Extensive studies focused on Au mineralization have been carried out on the Jiaodong Peninsula. Gold mineralization occurs either as massive gold–quartz–pyrite veins (Linglong–type) or as shear zone–hosted disseminated sulfides in fractured granitoids (Jiaojia–type) in the northwestern part of the Jiaodong Peninsula. Gold deposits in brecciated Paleoproterozoic metamorphic rocks or in Cretaceous sediments along the northern periphery of the Jiaolai basin are described as Pengjiakuang–type (Deng and Wang, 2015). These Au deposits are strictly controlled by NNE–NE trend faults and belong to "gold-only" deposits which carry no economic base metals (Deng et al., 2015; Phillips and Powell, 2015). Precise $^{40}Ar/^{39}Ar$ ages of hydrothermal muscovite and sericite indicate Au mineralization during the Early Cretaceous. These data include 130 ± 4 Ma for the Dayingezhuang deposit (Yang et al., 2014a), 121.3 ± 0.2 Ma for the Cangshang deposit (Zhang et al., 2003), 121.0 ± 0.4 Ma to 119.2 ± 0.2 Ma for the Jiaojia, Xincheng, and Wangershan deposit (Li et al., 2003), 120.9 ± 0.4 Ma to 119.1 ± 0.2 Ma for the Pengjiakuang deposit and 109.3 ± 0.3 Ma to 107.7 ± 0.5 Ma for the Rushan deposit (Li et al., 2006a). An age of 117 ± 3 Ma was reported for the hydrothermal zircons from Jinqingding deposit using the SHRIMP U–Pb method (Hu et al., 2004). Combined geochronological data with relative timing relationships between Au mineralization, Guojialing granitoids, and dykes, the majority of the Au deposits was deposited during a short interval between ca. 126 and 120 Ma (Goldfarb and Santosh, 2014). The fluid inclusion data are laterally and vertically consistent. Most Au deposits formed at 250–350 °C from CO_2–H_2O ore fluids with calculated salinities of 6–13 wt% NaCl equiv (Qiu et al., 2002). Wen et al. (2016) reported that the characteristics of ore fluids are consistent within the 4000 m vertical interval for the Sanshandao deposit. Published isotope data also show no notable differences between studied deposits. $\delta^{34}S$ values range from 4‰ to 13‰ (Li et al., 2015). Oxygen and hydrogen isotope measurements have been carried out on ore–related minerals such as quartz, sericite, and potassium feldspar. Calculated $\delta^{18}O$ (SMOW) values of fluids mainly range from 0.08‰ to 8.85‰ while the δD (SMOW) values of fluid inclusion waters mainly range from −106.48‰ to −48‰ (Deng and Wang, 2015). Reported Rb–Sr and Sm–Nd isotope data of hydrothermal minerals show that most initial $^{87}Sr/^{86}Sr$ values are higher than 0.7110 and $\varepsilon_{Nd}(t)$ values are strongly negative within the range −16.1 to −25.2 (Deng et al., 2015; Li et al., 2013b). The He–Ar isotopic system indicates involvement of mantle–sourced fluids (Deng and Wang, 2015). As these data can be interpreted in many ways, the classification and formation mechanisms of these deposits have always been controversial. Fan et al. (2003) and Tan et al. (2015) favored the magmatic origin of the ore fluids, inferring that the fluids were sourced from the mafic dikes. Qiu et al. (2002) classified the Au deposits as orogenic Au deposits associated with the Pacific Plate subduction. Li et al. (2013b) argued that fluids derived from felsic magmas and meteoric water may constitute a major portion of the ore fluids and mantle derived fluids are also involved. Recently, these Au deposits were defined as the "Jiaodong–type" Au deposits (Li et al., 2015). Goldfarb and Santosh (2014), Goldfarb and Groves (2015) discussed the sub–crustal fluid/metal source of these Au deposits and subduction–related models were used to explain the Au formation. Obviously, more information is needed to constrain the Au formation especially the problematic fluid/metal source.

Compared with other Mo metallogenic belts, Mo mineralization on the Jiaodong Peninsula is relatively small in resource. Mo mineralization ages are consistent with related granitoids and indicate two episodes of mineralization, during Jurassic (ca. 160–150 Ma) and Early Cretaceous (ca. 120–110 Ma, see details in Section 6.1). Goss et al. (2010) reported four granitoid batholiths with zircon SHRIMP U–Pb ages of 118 Ma to 113 Ma. They were believed to form by partial melting of the lower or middle crust due to mafic magma underplating (Goss et al., 2010). Archean basement rocks were involved and interaction between mantle–derived mafic magma and felsic crustal magma happened to some degrees. The Gushan granite, which is located in the Jiaobei terrane, was emplaced at ca. 120 Ma. Ancient NCC lower crust melting, mafic–felsic magma interaction and continuous assimilation were envisaged to explain the formation of the granite (Li et al., 2012c). What is most interesting is that these Mo deposits are slightly younger than the peak time of Au mineralization. Moreover, these deposits are related to granitoids and are spatially separate from the faults–controlled "gold–only" Au deposits. These spatial and temporal differences between Mo and Au mineralization provide important insight for better understanding the formation of Early Cretaceous Mo and Au mineralization.