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A modified genetic model for multiple pulsed mineralized processes at the giant Qulong porphyry Cu-Mo mineralization system

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Abstract

Porphyry copper deposits are economically significant sources of Cu and Mo, formed when metal-rich fluids precipitate at shallow levels, exsolving from underlying magmatic reservoirs at depth. However, the origin and evolution of these metal-rich fluids, whether through episodic enrichment from multiple pulses or a single continuous fluid-release event, remain a subject of controversy. To gain deeper insights into these processes, data on cathodoluminescence (CL) imaging, in situ trace elements, and Sr isotopes of newly discovered scheelite (Sch 1, Sch 2, and Sch 3) found in three generations of vein types within the giant Qulong porphyry Cu-Mo mineralization system are presented. The anhedral Sch 1 occurs in quartz + magnetite + anhydrite + chalcopyrite veins, exhibiting no obvious zoning in the CL image. These scheelite samples show high concentrations of Mo, Nb, Ta, and $^{87}Sr/^{86}Sr$ ratios ranging from 0.70688 to 0.71109. Moreover, they demonstrate enriched rare earth elements (REE) and negative Eu anomalies in the chondrite-normalized pattern, indicative of their formation in relatively oxidized metal-rich fluids during the early high-temperature alteration stage. Among the discovered scheelite varieties, the most volumetrically significant is the subhedral Sch2, which occurs in veins composed of quartz + pyrite + chalcopyrite. In its central region (Sch 2a), Cu-rich cores are dispersed, surrounded by an oscillatory Cu-poor mantle and rim (Sch 2b and 2c), as observed in the CL image. When compared to Sch 1, Sch 2 exhibits lower levels of REE, Nb, Ta, Mo, and $^{87}Sr/^{86}Sr$ ratios (ranging from 0.70502 to 0.70578), but higher Cu concentration and positive Eu anomalies. The gradual decrease in Cu content from the core to rim in Sch2, along with its rim's intergrowth with sulfide, suggests the precipitation of Cu during the second pulse of fluids. Euhedral Sch 3 is found in relatively moderate-temperature mineral assemblages within quartz + galena + sphalerite + molybdenite veins. It displays an oscillatory pattern with a Mo-rich core (Sch 3a), an extremely Mo-rich mantle (Sch 3b), and a Mo-poor rim (Sch 3c) in the CL image. Sch 3 shows lower REE, Cu, and Pb contents but variable Mo concentrations in different domains while consistently recording $^{87}Sr/^{86}Sr$ ratios ranging from 0.70498 to 0.70542. These characteristics indicate the precipitation process of Mo and Pb during the third pulse of fluid evolution. The observed shift in mineral assemblages, metal contents, and Sr isotopic components from Sch 1 to Sch 3 reflects the occurrence of different fluid pulses within a cooling porphyry Cu-Mo mineralization system. Overall, the three generations of scheelite found at the Qulong porphyry Cu-Mo deposit indicate the occurrence of multiple pulsed flows of magmatic fluids, revealing a more complex fluid evolution for porphyry Cu deposits than previously recognized. Notably, Sch 1 exhibits relatively high $^{87}Sr/^{86}Sr$ ratios, similar to the post-ore mafic porphyries, which are higher compared to Sch 2 and Sch 3, showing $^{87}Sr/^{86}Sr$ ratios similar to the pre- and syn-ore host granite and porphyry. This result implies that mafic magma has significantly contributed to the formation of the first pulse of magmatic fluids, whereas syn-ore granitic magma contributed to the ore fluids responsible for forming the veins containing Sch 2 and Sch 3 in the later stage. Therefore, we propose that volatiles from mafic magma, injected into the porphyry metallogenic system, play a crucial role in the formation of porphyry Cu deposits. Additionally, for the first time, the presence of Cu-Mo-W metal endowment in the porphyry Cu deposits of the Gangdese magmatic belt is identified, providing valuable new insights into the metallogeny of porphyry Cu deposits and offering promising opportunities for tungsten exploration in the collision zone.

Keywords: Scheelite, porphyry copper deposits, Cu-Mo-W mineralization, in-situ Sr isotope, cathodoluminescence imaging, recharge of mafic magma, Gangdese

Introduction

The formation of porphyry Cu deposits (PCD) through magmatic-hydrothermal processes has been well established and is supported by geologic, geochemical, and isotopic studies (Seedorff et al. 2005; Sillitoe 2010; Buret et al. 2017). These studies have revealed that metals are released from magmatic fluids (>600 °C), driven by heat exsolved from deep-seated subvolcanic intrusions at a paleodepth of 5–10 km. Eventually, these metals precipitate as sulfides of chalcopyrite and molybdenite in the shallow crust at depths of 1–3 km (Heinrich 2007; Sillitoe 2010; Kouzmanov and Pokrovski 2012). However, despite this

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