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Controls on the formation of porphyry Mo deposits: Insights from porphyry (-skarn) Mo deposits in northeastern China

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Abstract

Porphyry Mo deposits have traditionally been classified into two major classes, arc-related and Climax-type, based on the tectonic setting and chemistry of associated intrusions. Although there is a consensus that porphyry Mo systems were formed by the optimal coincidence of geological processes operating at different scales, it is unclear what key parameter(s) render systems productive and whether the two classes of porphyry Mo deposits are unique in their mode of formation, or if they share fundamentally similar geological processes. These questions are important as a clearer understanding of the optimum conditions for the formation of porphyry Mo deposits is a prerequisite for more efficient exploration.

This contribution presents a detailed assessment of the factors affecting the formation of porphyry Mo deposits through the investigation of barren and mineralized intrusions from the arc-related Songbei-Yangjiazhangzi-Lanjiagou (SYL) ore zone and the Climax-type Hashitu deposit of northeastern China. Our results show that the syn-mineralization intrusions from the SYL ore zone are quite evolved (SiO_2 ~ 75 wt%; Na_2O+K_2O ~ 8.7 wt%) and are characterized by apparent light rare earth element (LREE) enrichments (La_N/Yb_N = 2.7–33.1) and moderate negative Eu anomalies (Eu/Eu* = 0.4–0.7). They show enriched zircon Hf isotopic compositions [$\varepsilon_{Hf}(t)$ = –11.9 to –4.8], indicating their parental magmas were likely derived from an ancient crustal source. Melt inclusions from the SYL syn-mineralization intrusions contain negligible F and Cl. In contrast, Hashitu syn-mineralization intrusions are characterized by weak LREE enrichments (La_N/Yb_N = 2.2–6.9) and strong negative Eu anomalies (Eu/Eu* = 0.02–0.10), with SiO_2 and Na_2O+K_2O contents similar to the SYL syn-mineralization intrusions. They show depleted zircon Hf isotopic compositions [$\varepsilon_{Hf}(t)$ = 3.1–5.0], indicating their parental magmas were likely derived from a juvenile crustal source. Melt inclusions from the Hashitu syn-mineralization intrusions contain up to 0.4 wt% F and 0.03 to 0.09 wt% Cl. However, in both cases, the syn-mineralization intrusions are Mo-poor (1–7 ppm Mo), oxidized (above the quartz-fayalite-magnetite buffer), water-saturated (4.4–7.8 wt% H_2O), and were emplaced at palaeodepths of 3.3 to 8.3 km. These data imply that magma source composition is not a key factor in the formation of porphyry Mo deposits. In contrast, magma oxygen fugacity, water content, and emplacement depth appear to play fundamental roles in the formation of porphyry Mo deposits of both arc-related and Climax-type.

Within individual deposits, no systematic differences between pre- and syn-mineralization intrusions are observed in terms of magma source, fractionation degree, oxygen fugacity, emplacement depth, and volatile and Mo contents. Instead, a crucial apparent difference lies in the geometry of the intrusions, i.e., pre-mineralization intrusions generally occur as flat, ponded bodies, whereas syn-mineralization intrusions commonly develop as small stocks or dikes. Our results, in combination with an examination of other porphyry Mo systems, suggest that the sudden depressurization of magma chambers and subsequent venting of voluminous fluids along focusing structures (such as small stocks or dikes) most likely plays a critical role in the formation of porphyry Mo deposits of both arc-related and Climax-type. The findings of this study indicate that fluid processes in the shallow crust are pivotal for the formation of porphyry Mo deposits and that settings with ideal magmatic-hydrothermal architectures are most likely to develop into productive porphyry Mo systems.

Keywords: Northeastern China, melt inclusions, focused fluid flow, arc-related porphyry Mo deposit, Climax-type porphyry Mo deposit