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Accessory Mineral Geochemistry as a Proxy for Metallogenic Potential in the Chinese Northwestern Tianshan

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The porphyry–skarn Fe–Cu–Mo polymetallic mineralization in the Chinese Northwestern Tianshan is genetically linked to late Paleozoic felsic intrusions formed during subduction (390–350 Ma) and collision (315–280 Ma) events. This study employs zircon and apatite geochemistry of felsic rocks to unravel magmatic evolution and mineralization mechanism. Results show that subduction-related intrusions exhibit elevated water content (avg. 6.6 wt.%), higher oxygen fugacity (ΔFMQ = −1.61 to +2.13, avg. +0.17) and X_{Cl}/X_F ratios (avg. 0.122), which collectively favor the formation of large porphyry–skarn deposits. Notably, intrusions associated with porphyry Cu-Mo deposits display higher oxygen fugacity (ΔFMQ = +0.63) but lower Cl content (avg. 0.319 wt.%) compared to those linked to skarn Fe-Cu deposits (ΔFMQ = +0.18; Cl content avg. 0.512 wt.%). In contrast, collision-related intrusions are characterized by lower water content (avg. 2.6 wt.%), lower oxygen fugacity (ΔFMQ = −2.15 to +1.18, avg. −0.38) and diminished X_{Cl}/X_F ratios (avg. 0.003), correlating with poor mineralization potential.

Magmatic water content and oxygen fugacity are primarily controlled by tectonic settings. During subduction, slab dehydration and melting enriched the mantle wedge with water and oxidized components, imprinting these features onto magmas generated through crust-mantle interactions. These magmas retained high water and Cl concentrations, facilitating efficient metal (e.g., Fe, Cu) transfer into exsolved fluids and subsequent mineralization. Conversely, collision-related magmas underwent extensive differentiation under high thermal flux from asthenospheric upwelling, leading to water depletion, lower oxygen fugacity, and F enrichment in residual melts. Chlorine preferentially partitioned into aqueous fluids during exsolution, while fluorine remained in the melt. Consequently, Cl-rich subduction magmas promoted fluid-mediated metal transport, whereas F-rich collision magmas inhibited porphyry–skarn mineralization. This study underscores that hydration state, oxygen fugacity, and halogen ratios are critical factors controlling metallogenic efficiency, with tectonic setting, magmatic differentiation, and fluid exsolution synergistically regulating magma compositions and mineralization potential.

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