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Genesis of the Taiyangshan porphyry copper deposit, NW China: Insights from quartz cathodoluminescent textures, fluid inclusion assemblage petrography, and trace element geochemistry hydrothermal quartz

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The Taiyangshan porphyry copper deposit, NW China, is characterized by superposition of multiple generations of quartz growth, commonly punctuated by dissolution, juxtaposed within a single vein. This superposition inevitably obscures temporal relationships between quartz formation, alteration events, and fluid inclusion assemblages (FIAs), and in consequence complicates the interpretation of fluid origin and evolution. We show how cathodoluminescence (CL) imaging of hydrothermal vein quartz, combined with electron probe microanalysis (EPMA), may distinguish three distinct quartz generations (Q1, Q2, and Q3), leading to specification of their fluid inclusion characteristics and thus evolution of quartz vein formation within a porphyry copper system such as that at Taiyangshan.

Quartz ranges from bright blue-CL Q1, typical of veins with early high-temperature potassic alteration, to dark blue-CL Q2 either coinciding with or slightly post-dating chalcopyrite precipitation, to dull red-CL quartz Q3 of fine-grained, anhedral, and recrystallized subgrains. Early bright blue-CL quartz (Q1) crystals, generally at the vein edge close to wallrock, are characterized by oscillatory growth zoning, and exhibit alignment of primary, equant-shaped, brine-bearing FIAs along the banded growth zones. Later dark blue-CL quartz (Q2) crystals are generally euhedral in shape and grow with c-axes pointing inward the vein center. They exhibit well-defined, but rarely preserved, growth zones truncating Q1, and crystal terminations projecting into pyrite and chalcopyrite in the vein center. These vein features clearly indicate that Q2 crystals grow into an open cavity or fracture during ore precipitation. This is evident by coexisting, secondary, irregular-shaped, liquid-rich inclusions and vapor-rich inclusions along fractures transecting Q1 oscillatory growth bands. The coexistence of hypersaline and vapor-rich inclusions moreover provides unequivocal evidence for phase separation during copper mineralization. Dull red-CL quartz (Q3) crystals appear to coincide with or follow sericitic alteration, and cut and encompass preexisting Q1 and Q2 crystals. The Q3 grains contain rare well-defined FIAs, but show scattered, secondary, irregular-shaped, low-salinity aqueous inclusions with small-medium bubbles (10~30 volume percent), accompanying with complex fluid inclusions that have migrated to margins of anhedral Q3 subgrains due to quartz dissolution and recrystallization.

Formation of early blue-CL Q1 and Q2 crystals at high temperatures are consistent with distinct enrichment of Ti compared to Q3. The Q2 crystals are typified by elevated concentrations of Al and K concentrations when compared to Q1 and Q3. The Q3 grains are commonly depleted in abundances of Ti, Al, and K relative to neighboring older Q1 and Q2. The substitution of Ti^{4+} for Si^{4+} in the tetrahedral sites of quartz leads to an increased CL intensity from Q1, to Q2, and then to Q3 corresponding to a decrease in precipitation temperature. Ore deposition, recorded by integrated CL textures, FIAs petrography, and trace element fluctuations in Q2, in the Taiyangshan porphyry copper deposit must have occurred over a significant change in physiochemical conditions. This suggests that phase separation due to fluid cooling/pressure drops during the transition from lithostatic to hydrostatic regimes is critical to copper mineralization. We further propose a complex hydrothermal quartz vein formation history involving multiple fluid incursions under varying pressure and temperature conditions.