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Cobalt enrichment and metallogenic mechanism of the Galinge skarn iron deposit in the Eastern Kunlun metallogenic belt, western China

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Cobalt enrichment mechanisms in skarn deposits remain poorly constrained despite their increasing importance as critical metal resources. Here we investigate the timing, mineralogical controls, and geochemical processes governing cobalt occurrence in the Galinge skarn iron deposit (Eastern Kunlun metallogenic belt, western China) using a combination of in situ garnet U–Pb geochronology, major and trace element analyses of sulfarsenides and sulfides, and high-resolution X-ray element mapping.

Garnet U–Pb dating yields a lower intercept age of 237.1 ± 0.3 Ma, consistent with previously reported phlogopite ^{40}Ar–^{39}Ar ages (234.1 ± 3.7 Ma), indicating that skarn formation and cobalt mineralization occurred during the Middle Triassic. Cobalt in the Galinge deposit occurs both as independent cobalt minerals (skutterudite and cobaltite) and as isomorphic substitutions within arsenopyrite, pyrrhotite, sphalerite, pyrite, magnetite, and chalcopyrite. Quantitative analyses reveal strongly heterogeneous cobalt distributions among ore minerals, with mean Co contents decreasing in the order: arsenopyrite (34,003 ppm) > pyrrhotite (1,158 ppm) > sphalerite (471 ppm) > pyrite (194 ppm) > magnetite (7 ppm) > chalcopyrite (2 ppm). Negative correlations between Co + Ni and Fe in arsenopyrite indicate coupled substitution of Co–Ni for Fe, whereas weak correlations between Co and Fe or Cu in pyrite and chalcopyrite suggest more complex and partial substitution mechanisms. In sphalerite and alabandite, negative correlations between Co + Fe and Zn or Mn imply substitution of Co–Fe for Zn–Mn, while pyrrhotite shows no systematic compositional control on cobalt incorporation.

We propose that during the early skarn mineralization stage, cobalt was transported predominantly as $CoCl_4^{2-}$ complexes and precipitated as skutterudite through reactions with $H_3AsO_3^0$, followed by transformation to cobaltite. The sequential precipitation of skutterudite and cobaltite reflects evolving fluid conditions characterized by increasing pH and a decreasing reduced As/S ratio, respectively. These results provide new mineral-scale constraints on cobalt enrichment processes in skarn systems and highlight the critical role of fluid chemistry in controlling cobalt mineralization.

