American Mineralogist, Volume 111, pages 173–189, 2026

Controls on metal zonation in porphyry-skarn systems: Evidence from the Tonglushan Cu polymetallic deposit, Eastern China

Xiaolin Wu[1,2], Guiqing Xie[1,2,3,*], Jing Xu[4,†], and Wenyuan Liu[4]

[1]School of Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China
[2]MNR Key Laboratory for Exploration Theory & Technology of Critical Mineral Resources, China University of Geosciences, Beijing 100083, China
[3]MNR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, CAGS, Beijing 100037, China
[4]Zijin School of Geology and Mining, Fuzhou University, 350108 Fuzhou, China

Abstract

Tonglushan is the largest porphyry-skarn Cu polymetallic deposit in the Edong ore district, Eastern China, with proven metal reserves of 86.3 Mt @ 1.78% Cu, 39.4% Fe, 0.94 g/t Au, and 0.13% Mo. The ore bodies exhibit distinct sub-lateral metal zonation, from proximal intrusion to distal carbonate, i.e., porphyry-type Cu-Mo, to skarn-type Cu-Fe-Au, carbonate replacement-type Cu-Zn-Pb-(Au), and distal vein-type Cu-Pb-Zn mineralization. However, the genetic factors governing both the temporal and spatial metal zoning remain uncertain.

Here, we present trace element and S isotope data for sulfide stage (early-stage pyrite and late-stage sphalerite) across various ore types in a well-constrained paragenetic framework. The early stage contains two distinct types of pyrite, including colloform Py0 and euhedral Py1. Py0, observed in both skarn- and carbonate replacement-type ores, is selectively enriched in Cu, Ag, Au, Pb, and Bi relative to later Py1, reflecting a steep temperature gradient process. By contrast, Py1 exhibits increasing concentrations of Co, Ni, As, and Se with increasing distance from the intrusion, but shows depletion in the most distal vein-type ore. Redox exerts the dominant control on this spatial pattern, whereas temperature plays a subordinate role. Values of $\delta^{34}S_{py}$ generally increase from −0.4‰ within the intrusion to 1.5‰ in skarn-type ore, following a decrease to −0.6‰ in carbonate replacement-type ore and −2.15‰ for distal vein-type ore, which is dominantly controlled by temperature. Late-stage sphalerite (Sp2) exhibits systematic spatial trends, with high Fe, Co, and Mn contents in skarn-type ores evolving to elevated Cd, Hg, and Sn concentrations in carbonate replacement- and distal vein-type ores. These trends are controlled by redox and temperature variations, as recorded by Mn/Sn and Fe/Cd ratios. These findings offer valuable insights into the spatial evolution of ore-forming fluids and metallogenic zonation from proximal porphyry to distal vein-type mineralization, providing a potential guide for future mineral exploration.

Keywords: Metal zonation, porphyry-skarn system, Tonglushan, pyrite trace elements