

Metal Redistribution in Proterozoic VMS Systems: Insights from Trace-Element Chemistry of Sulfides

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The Bruce and United Verde Volcanogenic Massive Sulfide (VMS) deposits in Arizona represent important Cu-Pb-Zn ore systems, yet the mineralogical and geochemical evolution of their sulfide assemblages remains poorly understood. Located in the Transition zone of central Arizona, these orebodies are hosted in bi-modal Proterozoic volcanic sequences. Metamorphosed to amphibolite (Bruce) and to greenschist (United Verde) facies, respectively, these deposits record a complex geologic history with multiple overprinting events on primary mineralization.

Sulfide mineralization from massive and stockwork zones was characterized using petrography, SEM, EPMA, and LA-ICP-MS on samples from the University of Arizona Economic Geology teaching collection. Primary sulfides include pyrite, chalcopyrite, sphalerite, and galena, with local occurrences of later phases such as arsenopyrite, pyrrhotite, and various Ag-Sb-rich sulfosalts. Trace element data reveal consistent enrichment of Se across sulfide minerals, with notably higher concentrations in stockwork samples. Galena acts as a preferential host for Se, Ag, and Sb, containing up to 5.7 wt.% Se and 2.0 wt.% Ag in stockwork-hosted samples at United Verde. At Bruce, late-stage recrystallized galena hosts tetrahedrite with micro-inclusions of Sb-Bi alloys containing up to 88.8 wt.% Sb and 8.9 wt.% Bi. In contrast, galena hosted in massive sulfides at both deposits yields about 1.0 wt.% Se and 0.01 wt.% Ag.

Pyrite is of particular interest, as variations in porosity and textures relate Se enrichment with fluid events. At Bruce, non-porous pyrite grains from the massive zone contain around 100 ppm Se, while porous pyrite in the stockwork zone exhibits up to 1080 ppm Se, linking Se enrichment to fluid-driven recrystallization and porosity development.

These results highlight a strong relationship between trace-element enrichment and metamorphic fluid mobilization, which are critical to refining mineral-system models and improving exploration strategies for VMS deposits in Arizona and beyond.