

## Trace Elements in Pyrite in the Lepanto High Sulfidation Epithermal Deposit, Philippines, and Genetic Implications

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High sulfidation deposits are genetically related to magmas and form in two stages: early-stage alteration characterized by silicic and advanced argillic alteration, and late-stage mineralization. The process for the early-stage acidic alteration is unequivocal, caused by condensation of magmatic vapor, whereas the mineralizing process remains in debate, mainly about whether the mineralizing fluids are brine or vapor. In this study we analyze the trace elements in pyrite from the Lepanto high sulfidation deposit, using microprobe and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) elemental mapping methods, based on which we infer the Cu-Au transportation mechanism. The elements investigated are Cr, Mn, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, In, Sn, Sb, Te, W, Au, Tl, Pb, and Bi. For LA-ICP-MS analyses, Fe was the internal standard.

The Lepanto high sulfidation Cu-Au deposit in the Mankayan district, Philippines, has produced >0.9 Mt Cu and >100 t Au. Its link to the underlying Far Southeast porphyry deposit was the first established example of a genetic porphyry-high sulfidation epithermal relationship. Pyrite at Lepanto formed in several stages: (1) The earliest pyrites occur as very fine grained crystals in residual vuggy quartz and advanced argillic-altered rocks, together with fine-grained quartz and advanced argillic minerals including alunite. This pyrite is interpreted to be of the early alteration stage caused by magmatic vapor, with the S<sup>2-</sup> from disproportionation of SO<sub>2</sub> and Fe from local rocks. Such pyrite is featureless after etching. It contains ~10s ppm Pb (less Pb than in some coexisting alunite), ~1 ppm Ag, 10s ppm Cu, and not much else, with a thin rim (<10 μm) that contains anomalous Co (10s ppm), Ni (up to ~100 ppm), and Cu (up to 1,000 ppm) compared to the body of the grain. (2) In and adjacent to the Lepanto fault, which is the main feeder, an overprint of massive silicic alteration on residual vuggy quartz caused the vugs to be filled by later quartz; beyond the orebody, there is only pyrite without other metallic minerals. Etching reveals that the pyrite in this distal position typically has a core and one layer of rim (<10 μm); it is interpreted to be early pyrite overprinted by a distal mineralizing fluid. The core of such pyrite contains minor trace elements, similar to stage 1 pyrite, whereas the margin contains 1,000s ppm to 1% As, 100s ppm Cu, Pb, Te, Co, and Ni, 10s ppm of Sb and Bi, and ~1 ppm Au. The core of such pyrite contains little trace elements, similar to stage 1 pyrite, whereas the margin contains 1,000s ppm to 1% As, 100s ppm Cu, Pb, Te, Co, and Ni, 10s ppm of Sb and Bi, and ~1 ppm Au. (3) Within the main ore zone along the Lepanto fault, coarse-grained pyrite partially replaced by enargite shows strong zoning. It is believed to have formed during initial mineralization. The composition of zones varies, with up to 100s ppm Au, a few % Cu, As, and Sb, 1,000s ppm Pb and Bi, 100s ppm Au, Zn, Ag, Te, Se, Cr, Co, and Ni, and 10s ppm of Cd, In, Sn, and Tl. (4) Some pyrite grains in the orebody have strong zoning and have overgrown enargite grains or filled the interstices between enargite grains. Some of the pyrite zones are selectively replaced by later enargite. Such pyrite is interpreted to be of syn-main mineralization stage. Microprobe analysis of a limited range of elements shows that they are variable in composition, containing up to ~250 ppm Au, ~3% Cu, ~1% As and Pb, 1,000s ppm Sb, and 100s ppm Ag. In summary, the pyrite formed in early-stage alteration contains minor trace elements, whereas the ore-stage pyrite contains abundant Au, Cu, Pb, As, and other elements (Sb, Bi, Ag, Te, Se, Zn, Cr, Co, Ni, Sn, Cd, In, and Tl), with lower concentrations in positions distal to ore. The mineralizing fluids transported and introduced these elements and Fe after acid leaching; therefore, the fluids were likely

brine rather than vapor. This is consistent with the composition of vapors from modern volcanic fumaroles with low concentrations of these elements (e.g., sub-ppb Au and sub-ppm Cu).