

Physicochemical Conditions of Ore-Forming Fluids at Filo del Sol Deposit, NW Argentina: New Insights from Laser Ablation Split Stream S Isotope and Trace Element Chemistry

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Filo del Sol (FDS) is a high-sulfidation Cu-Au-Ag epithermal system superimposed on porphyry Cu-Au mineralization in the recently defined Vicuña metallogenic belt, between the world-class Maricunga and El Indio Cu-Au-Ag belts in the Central Andes. The physicochemical conditions of the ore-forming fluids at FDS remain unknown. We present new petrographic observations combined with in situ S isotope and trace element chemistry collected simultaneously by laser ablation multicollector inductively coupled plasma mass spectrometry (MC-ICP-MS) and quadrupole (Q)-ICP-MS split-stream analyses in sulfides, sulfosalts, and sulfates. In FDS, pyrite is ubiquitous and exhibits a diversity of textures and trace-metal compositions that correspond with paragenesis. Although the porphyry environment is dominated by a first generation of nonporous Cu-rich pyrite, the epithermal comprises porous and colloform Au-Ag-rich pyrites that post-date a second generation of nonporous Cu-Au-Ag-poor pyrite. In contrast, several generations of enargite are only identified using combined in situ S isotope and trace element analysis. Sulfide/sulfosalts-sulfate isotopic pairs associated with porphyry mineralization indicate high temperature of ~500°C and H₂S-dominated fluid, whereas mineral pairs from the epithermal stage revealed more complex physicochemical conditions at 300° to 400°C. The progressive shift toward $\delta^{34}\text{S}$ -depleted compositions from nonporous Cu-Au-Ag-poor pyrite (avg $\delta^{34}\text{S}$ of -7.1‰) to porous and colloform Au-Ag rich pyrites (avg $\delta^{34}\text{S}$ from -8.5 to -10‰) suggest an ore-forming fluid path toward lower temperatures and/or more oxidizing conditions. The occurrence of cinnabar associated with billingsleyite (Ag sulfosalt) at shallower levels yielding extreme $\delta^{34}\text{S}$ -depleted compositions from -42 to -23‰, combined with alunite-pyrite and alunite-enargite pairs in isotopic disequilibrium, argue for supergene processes at low temperatures and oxidizing conditions. Collectively, we show the power of coupled in situ S isotope and trace element analyses in high-spatial investigations to resolve geochemical changes of mineral assemblages, while preserving information about microscale crosscutting relationships and the relative timing of cryptic ore-forming events.