

A SULFUR, CARBON, OXYGEN, AND STRONTIUM ISOTOPE STUDY OF THE VOLCANIC-HOSTED EL SOLDADO MANTO-TYPE COPPER DEPOSIT, CHILE: THE ESSENTIAL ROLE OF BACTERIA AND PETROLEUM

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Abstract

Strata-bound, manto-type copper deposits of Chile are a major source of copper, and some deposits (e.g., Mantos Blancos, El Soldado) contain as much metal as do large porphyry copper deposits elsewhere. El Soldado (200 Mt @ 1.35% Cu), the largest manto-type copper deposit in the Coastal Cordillera of central Chile, is hosted by the rhyodacite-basalt upper member of the marine Lower Cretaceous Lo Prado Formation. Paragenetic studies indicate that the deposit formed in two stages. The first was a low-temperature stage (stage 1; 130–125 Ma) in which liquid petroleum migrated from underlying carbonaceous shales into the overlying host volcanic rocks and abundant framboidal pyrite developed in a paleopetroleum reservoir. A later hydrothermal stage (stage 2; ca. 103 Ma) introduced copper and replaced earlier pyrite to form chalcocopyrite, bornite, and chalcocite ores. This study presents isotopic data that support bacterial sulfur reduction as the process that formed the essential precursor stage 1 pyrite, and the participation of basinal fluids in the hydrothermal second stage.

A wide range of $\delta^{34}\text{S}$ values for early stage 1 pyrite (–11.1 to +28.0‰) supports the hypothesis that low-temperature, incomplete sulfate reduction from connate seawater sulfate and Fe-enriched oil-field brines took place in a compartmentalized petroleum reservoir by bacterial sulfate reduction. With the exception of a small proportion of Cu-Fe sulfides with $\delta^{34}\text{S}$ values between –2.0 and +2.0 per mil, the bulk of stage 2 Cu-Fe sulfides replaced earlier pyrite and mimic the broad range in $\delta^{34}\text{S}$ values (–12.7 and +19.0‰) of stage 1 pyrite. Sulfur from early pyrite was recycled with no significant homogenization, fractionation, or addition of new sulfur, and indicates the essential role of hydrocarbons and bacteria in the formation of the deposit. The $\delta^{13}\text{C}$ values of gangue calcite vary between –4.2 and –20.2 per mil and reflect a mixing of various proportions of oxidized, pyrobitumen-derived organic and inorganic carbon from the mineralizing fluid. Pyrobitumen in the ores has $\delta^{13}\text{C}$ values of –30 to –26 per mil, consistent with it being a residue of the original liquid petroleum. $\delta^{18}\text{O}$ values of K-feldspar in both ore and barren samples are similar (12.0–12.7‰) and are compatible with the fluids being of metamorphic, rather than magmatic, origin. The similar $\delta^{18}\text{O}$ ranges of calcite (2.7‰) and K-feldspar (0.7‰) suggest that they formed from the same hydrothermal fluid and that the fluid was in equilibrium with the host rocks. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in calcite of 0.7041 to 0.7051 reflect isotopic ratios inherited from the subaerial andesitic rocks that overlay the deposit where the ore-forming fluids are thought to have originated.

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