



Hypogene, Volcanic-hosted Copper Mineralization at Lince-Estefanía, Michilla District, Northern Chile

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The Lince-Estefanía Cu deposit, hosted by the La Negra Formation, has long been considered as a type example of the Michilla District, northern Chile. The district is located in the Coastal Range, ~100 km north of Antofagasta, at an elevation of ~900 m. The geology of the deposit includes a >1,000-m thick sequence of andesite flows and breccias, intruded by several pulses of structurally controlled microdiorite and andesite dikes along a dominant N65°E direction. Mineralization occurs in mantos in highly porous vesicular andesitic lava and flow breccia, and in the matrices of discordant hydrothermal breccia bodies preferentially developed along the microdiorite-andesite contacts. A larger concentration of mineralization in the mantos is typically present in the vicinity of the breccia bodies, suggesting a genetic connection between them. Chalcocite-digenite, covellite and bornite are the main sulfides, and are locally accompanied by minor amounts of chalcopyrite and pyrite. Chalcocite-digenite amounts for ~90% of the hypogene sulfide mineralization in the deposit. Atacamite and chrysocolla are the main supergene products. Native copper and silver occur locally. Mineralization probably took place between 159.9 ± 0.7 and 137.4 ± 1.1 Ma, which is the range of ages obtained for the various microdiorite dikes in the district. A post-mineralization andesite dike has returned an age of 118 ± 14 Ma.

New data on the textural relationships among the dominant sulfide assemblages suggest that hypogene mineralization developed in at least three main stages. An early stage, dominated by pyrite, was followed by an intermediate stage of chalcopyrite and bornite, and by a late stage with chalcocite-digenite and subordinate bornite. All hypogene sulfides occur dominantly as amygdule fillings, in veinlets, in the matrices of both hydrothermal and volcanic breccias, and as fine-grained disseminations in volcanic country rocks. At the deposit scale, pyrite is more abundant towards its margins and dominates in the deepest levels (below the 250 m level). Chalcopyrite typically overgrowths and cuts through earlier-formed pyrite crystals and occurs as exsolution lamellae within bornite grains. Chalcopyrite is present below the 500 m level. Exsolution textures between bornite and chalcocite-digenite of the late stage, together with microprobe data that have determined the chemical composition of the chalcocite-digenite assemblage to vary between $\text{Cu}_{1.8}\text{S}$ and $\text{Cu}_{1.95}\text{S}$ ($\text{Cu}_{1.9}\text{S}$ average), strongly suggest that the latter is hypogene in origin. In contrast, secondary chalcocite is typically associated with hematite, displays replacement textures by covellite and possesses a chemical composition in the range of $\text{Cu}_{1.69}\text{S}$ to $\text{Cu}_{1.77}\text{S}$.

Hydrothermal alteration is characterized by an early, copper-barren, propylitic event (epidote-chlorite-calcite-quartz) and a younger, transgressive, albite-specular hematite event with which the bulk of the hypogene copper mineralization is spatially associated.

New microthermometric data from fluid inclusions within quartz crystals associated with hypogene chalcocite mineralization constrain the temperature range of the hydrothermal fluids responsible for copper mineralization between 200 and 380°C. Associated salinities fall in the range of 9 to 21 eq. wt% NaCl. These ranges are similar to those from other deposits in the district (e.g., Buena Vista: 214-360°C; 16-21 eq. wt% NaCl). The lack of evidence for boiling in the inclusions from both deposits suggests that the hydrothermal fluids were channeled through conduits that did not reach the paleosurface, under conditions of lithostatic pressure greater than fluid pressure.