

The Candelaria-Punta del Cobre Iron Oxide Cu-Au(-Zn-Ag) Deposits, Chile

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Abstract

Several iron oxide-rich Cu-Au(-Zn-Ag) deposits define an approximately 5-km-wide and at least 20-km-long belt along the eastern margin of the coastal batholith near Copiapó, Chile. This belt includes the large Candelaria mine and a group of middle- and small-sized mines in the Punta del Cobre district, which is located about 3 km northeast of the Candelaria deposit. Estimated geologic resources of the belt are on the order of 700 to 800 million metric tons (Mt) at 1.0 percent Cu. The ore occurs in veins, breccia, and stringer bodies, and in replacement bodies that are roughly concordant to bedding. The orebodies are hosted mainly by volcanic and volcanoclastic rocks of the Punta del Cobre Formation and, in places, also occur in volcanoclastic intercalations in the lower part of the overlying Early Cretaceous Chañarcillo Group. Most of the larger orebodies in the belt are located where northwest-trending brittle faults intersect the contact between massive volcanic and volcanoclastic rocks. These northwest faults and a major northeast-trending ductile shear zone control portions of the ore of the Candelaria deposit.

Chalcopyrite is the only hypogene Cu mineral. The Cu-Au ore is characterized by abundant magnetite and/or hematite and by locally elevated concentrations of Ag, Zn, Mo, and light rare earth elements. The ore is hosted mainly in zones with biotite-potassium feldspar \pm calcic amphibole \pm epidote alteration at Candelaria. In the Punta del Cobre district, ore in the deeper parts of the deposits is similarly associated, whereas at shallow levels it occurs in zones of biotite-potassium feldspar, or albite-chlorite \pm calcite alteration.

Mineralization at Candelaria-Punta del Cobre took place under relatively oxidized conditions manifested by the formation of specular hematite. In parts of the district, the pseudomorphic replacement of early specular hematite by magnetite during the main iron oxide formation marks a shift toward more reduced conditions or higher temperatures. The bulk of the magnetite probably formed at temperatures of about 500° to 600°C. The main sulfide stage followed with formation of pyrite and chalcopyrite at temperatures of >470° to 328°C. Subsequent martitization of the magnetite points to a temperature decrease. Cooling of the hydrothermal system is also indicated by the homogenization temperatures of =236°C of saline fluid inclusions in late-stage calcite.

Oxygen isotope combined with microthermometric data suggest that magmatic fluids or nonmagmatic fluids equilibrated with magmatic silicates were dominant during the main copper mineralization. Relatively light oxygen isotope signatures of fluids in equilibrium with late calcite suggest mixing with a nonmagmatic fluid (e.g., basinal brines or meteoric waters) during the late stages of hydrothermal activity. Sulfur isotope ratios of chalcopyrite, pyrite, pyrrotite, and sphalerite from the Bronce, Candelaria, Las Pintadas, Santos, and Socavón Rampa deposits range from $\delta^{34}\text{S}_{\text{CDT}}$ values of -0.7 to +3.1 per mil. This narrow range of sulfur isotope ratios near 0 per mil is consistent with sulfur of magmatic origin. Anhydrite from the Candelaria mine paragenetically overlaps with chalcopyrite. Fluid inclusions in this anhydrite homogenize between 340° and 470°C and it has $\delta^{34}\text{S}_{\text{CDT}}$ values between 14.5 and 17.5 per mil. A $\Delta_{\text{sulfate-sulfide}}$ value of 13.4 per mil for a sample with coexisting anhydrite and chalcopyrite is consistent with sulfide-sulfate fractionation at temperatures on the order of 400°C. Ore lead isotope signatures are homogeneous and similar to those of least altered volcanic host rocks and nearby intrusive rocks. Radiometric ages, including new $^{40}\text{Ar}/^{39}\text{Ar}$ ages for hydrothermal alteration at Candelaria, point to a main Cu-Au mineralization event at Candelaria-Punta del Cobre at around 115 Ma. The ages indicate that ore formation was broadly coeval with batholithic granitoid intrusions and with regional uplift. They further imply that the Cu-Au(-Zn-Ag) deposits formed at shallow crustal levels (<3 km).

The stable isotope data, the presence of previously reported hypersaline CO₂-rich fluid inclusions in the main Cu ore stage and saline fluid inclusions in late-stage calcite, the oxidized character of the first ore-fluid pulses, and the mineralization age coeval with nearby intrusive activity are consistent with, but not unequivocally evidence of, magmatic fluid contribution into the hydrothermal system.