

The Evolution of a Porphyry Cu-Au Deposit, Based on LA-ICP-MS Analysis of Fluid Inclusions: Bajo de la Alumbrera, Argentina

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Abstract

The chemical and physical evolution of magmatic to hydrothermal processes in the porphyry Cu-Au deposit of Bajo de la Alumbrera (northwestern Argentina) has been reconstructed with a quantitative fluid inclusion study. Fluid inclusion petrography, microthermometry, and single inclusion microanalysis by Excimer laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) are combined to determine the evolution of pressure, temperature, and ore metal concentrations (including Cu and Au) in the fluids. Complementary hydrogen and oxygen isotope analyses are used to further constrain the water sources in the evolving system. The combined data provide a new level of insight into the mechanisms of metal sourcing and ore mineral precipitation in a porphyry-style magmatic-hydrothermal system.

Based on previously reported observations of the igneous geology, alteration geochemistry, and veining history of the subvolcanic porphyries at Alumbrera, the distribution of fluid inclusion types in space and time is documented. Six major inclusion types are distinguished. The highest temperature brine inclusions (up to 750°C; $P > 1$ kbar) are mainly recorded in barren quartz \pm magnetite veins in the core of the alteration system. These polyphase brine inclusions (halite \pm sylvite + multiple opaque and transparent daughter crystals) are interpreted as the most primitive magmatic fluid recorded at the level of the deposit. They are of moderately high salinity (50–60 wt % NaCl equiv) dominated by NaCl, KCl, and FeCl₂, and contain on average 0.33 wt percent Cu and 0.55 ppm Au. Upon cooling and decompression, these saline liquids exsolve a vapor phase, which is preferentially enriched in Cu relative to its main salt components but probably plays a minor role in the formation of this particular deposit because of the inferred small mass fraction of vapor. Cooling and decompression from the highest initial P-T conditions down to about 450°C causes magnetite \pm K silicate alteration but no saturation in Au or Cu sulfides, as recorded by continually high ore metal concentrations in the fluid inclusions. Coprecipitation of Cu and Au as chalcopyrite and native gold (\pm some early bornite) occurs over a narrow range of decreasing fluid temperature. With cooling from $\sim 400^\circ$ to 305°C, the Cu concentration in the brine drops by about one order of magnitude to less than ~ 0.07 wt percent, without a proportional decrease in major salt components. Ore mineral precipitation extracts ~ 85 percent of the Cu and Au from the fluid. It is associated with potassic alteration, as shown by a concomitant decrease in the K/Na ratio of the cooling magmatic brine and by an increase in its Ba and Sr concentrations (elements which are probably liberated in the destruction of calcic igneous minerals).

The fluid chemical data demonstrate that the metal ratios in this and probably many other porphyry-style ore deposits are primarily controlled by the magmatic source of the ore brines. On the other hand, the final hypogene ore grade of the deposit is controlled by the efficiency of ore mineral precipitation. At Alumbrera, metal extraction is governed by the efficiency of cooling a high flux of magmatic fluid within a small rock volume. Dilution of residual magmatic fluids, as recorded by aqueous fluid inclusions of decreasing salinities and temperatures below 295°C, follows after the main stage of copper introduction and is associated with feldspar-destructive (phyllic) alteration. Geometric relationships, fluid analyses, and stable isotope data together indicate that phyllic alteration results from postmineralization hydrothermal activity involving minor mixing between meteoric water, residual brine, and a waning input of magmatic vapor.