An investigation of the chemistry of magnetite and apatite from the El Laco iron oxide-apatite deposit, Chile

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Iron oxide-apatite (IOA) deposits are hypothesized to represent the roots of iron oxide-copper gold (IOCG) systems. These deposits are important sources of iron, copper, gold, uranium, and rare earth elements. The origin of IOA and IOCG systems is heavily debated, and there are five hypotheses that attempt to explain deposit formation. These include precipitation from basinal brines and/or metamorphic fluids, magmatic-hydrothermal replacement of hypabyssal and volcanic rocks, precipitation of an iron oxide melt formed as a result of magmatic liquid immiscibility, and precipitation from a magmatic-hydrothermal fluid. In this study, we investigate the geochemistry of magnetite and apatite from the El Laco IOA deposit in order to gain insights about the formation of this enigmatic ore deposit. We used energy dispersive X-ray spectroscopy (EDS) element mapping and electron probe micro-analyses (EPMA) to investigate the geochemistry of magnetite at five ore bodies at the El Laco Deposit: Laco Norte, Laco Sur, San Vicente Alto, Rodados Negros, and Cristales Grandes. We also use EDS element mapping, cathodoluminescence imaging, and EPMA to investigate the geochemistry of apatite from three of the localities: Laco Sur, Rodados Negros, and Cristales Grandes. The analyses reveal multiple iron oxide phases (magnetite, hematite, and goethite) in samples at the deposit. The chemistry of magnetite plots across multiple fields on the [Al+Mn] vs [Ti+V] magnetite discriminant diagram. Magnetite from Cristales Grandes and Rodados Negros plots in the porphyry, IOCG, and Kiruna fields; magnetite from San Vicente Alto plots in the IOCG field; and magnetite from Laco Norte and Laco Sur plot in the IOCG, skarn, and banded iron formation fields. These data are consistent with growth of magnetite from a cooling magmatic hydrothermal fluid. The apatite at the three localities is fluorapatite with $X_F = 0.8$ and $X_{Cl} = 0.1$. Apatite grains from Cristales Grandes and Rodados Negros contain rare earth element phosphate and iron phosphate inclusions. Further, some apatite grains from Rodados Negros are zoned in cathodoluminescence images, and this zonation corresponds to increasing Cl concentrations in these zones of the apatite grains ($\sim X_{Cl}=0.3$). While the F, Cl, and OH concentrations of the apatite grains are consistent with apatite that grew in equilibrium with a silicate melt, the apatite hosted inclusions and variations in magnetite chemistry suggest that hydrothermal fluids played an integral role in the formation of the deposit.