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 deposits are an important source of iron and rare earth elements globally and despite being mined for over 100 years, there is no consensus on how these systems formed. Most iron oxide - apatite systems are Proterozoic in age, except for the Andean deposits which are Cretaceous in age. In this study, we investigate the Pliocene age El Laco iron oxide deposit to determine which of the existing hypotheses for ore genesis of iron oxide - apatite deposits (including magmatic-hydrothermal replacement of volcanic and hypabyssal rocks, magmatic liquid immiscibility, or by precipitation from a magmatic-hydrothermal fluid) best explains this enigmatic deposit. We use several micro-analytical techniques to investigate the chemistry of iron oxides and apatite from Laco Sur and Laco Norte because the chemical signature of these mineral phases can provide insight into the ore fluid history, which can then be used to make inferences about how the deposit was formed. Energy dispersive X-ray (EDX) mapping and electron probe microanalyses reveal the presence of three iron oxide phases at El Laco: magnetite, hematite and an iron hydroxide (e.g., goethite). The concentrations of titanium and vanadium in magnetite and hematite are consistent with both a magmatic (igneous) and magmatic-hydrothermal origin for these minerals. When the concentrations of calcium, manganese and aluminum are considered along with those for titanium and vanadium, the chemistry of the minerals is consistent with magnetite/ hematite from several different hydrothermal ore environments; porphyry, skarn, Kiruna, iron oxide copper gold and banded iron formations. Both the goethite and hematite are believed to be the result of alteration of primary magnetite and these reactions occur on time scales of >100,000 years after primary mineralization. Based on petrographic evidence and field observations, the apatite at Laco Sur is believed to be late stage and does not constrain conditions present at the time of magnetite mineralization. Analyses indicate that the apatite is end-member fluorapatite; and individual grains are strongly zoned with respect to sulfur, and contain up to >1 wt.% sulfur. The cores of some grains are relatively depleted in sulfur while the rims are enriched, and vice versa for other grains. The trace element signature of the iron oxide phases and apatite, therefore, highlights the importance of magmatic-hydrothermal fluids for ore formation at El Laco; however, more work needs to be done to further constrain the ore forming processes at the deposit.