The Geochemistry of Magnetite and Apatite from the El Laco Iron Oxide-Apatite Deposit, Chile: Implications for Ore Genesis

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Abstract

The textures of outcrop and near-surface exposures of the massive magnetite orebodies (>90 vol % magnetite) at the Plio-Pleistocene El Laco iron oxide-apatite (IOA) deposit in northern Chile are similar to basaltic lava flows and have compositions that overlap high- and low-temperature hydrothermal magnetite. Existing models-liquid immiscibility and complete metasomatic replacement of andesitic lava flows-attempt to explain the genesis of the orebodies by entirely igneous or entirely hydrothermal processes. Importantly, those models were developed by studying only near-surface and outcrop samples. Here, we present the results of a comprehensive study of samples from outcrop and drill core that require a new model for the evolution of the El Laco ore deposit. Backscattered electron (BSE) imaging, electron probe microanalysis (EPMA), and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) were used to investigate the textural and compositional variability of magnetite and apatite from surface and drill core samples in order to obtain a holistic understanding of textures and compositions laterally and vertically through the orebodies. Magnetite was analyzed from 39 surface samples from five orebodies (Cristales Grandes, Rodados Negros, San Vicente Alto, Laco Norte, and Laco Sur) and 47 drill core samples from three orebodies (Laco Norte, Laco Sur, and Extension Laco Sur). The geochemistry of apatite from eight surface samples from three orebodies (Cristales Grandes, Rodados Negros, and Laco Sur) was investigated. Minor and trace element compositions of magnetite in these samples are similar to magnetite from igneous rocks and magmatic-hydrothermal systems. Magnetite grains from deeper zones of the orebodies contain >1 wt % titanium, as well as ilmenite oxyexsolution lamellae and interstitial ilmenite. The ilmenite oxyexsolution lamellae, interstitial ilmenite, and igneous-like trace element concentrations in titanomagnetite from the deeper parts of the orebodies are consistent with original crystallization of titanomagnetite from silicate melt or high-temperature magmatic-hydrothermal fluid. The systematic decrease of trace element concentrations in magnetite from intermediate to shallow depths is consistent with progressive growth of magnetite

from a cooling magmatic-hydrothermal fluid. Apatite grains from surface outcrops are F rich (typically >3 wt %) and have compositions that overlap igneous and magmatic-hydrothermal apatite. Magnetite and fluorapatite grains contain mineral inclusions (e.g., monazite and thorite) that evince syn- or postmineralization metasomatic alteration. Magnetite grains commonly meet at triple junctions, which preserve evidence for reequilibration of the ore minerals with hydrothermal fluid during or after mineralization. The data presented here are consistent with genesis of the El Laco orebodies via shallow emplacement and eruption of magnetite-bearing magmatic-hydrothermal fluid suspensions that were mobilized by decompression-induced collapse of the volcanic edifice. The ore-forming magnetite-fluid suspension would have rheological properties similar to basaltic lava flows, which explains the textures and presence of cavities and gas escape tubes in surface outcrops.

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