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In-situ iron isotope analyses reveal igneous and magmatic-hydrothermal growth of magnetite at the Los Colorados Kiruna-type iron oxide-apatite deposit, Chile

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ABSTRACT

Iron-oxide apatite (IOA) deposits are mined for iron (Fe) and can also contain economically exploitable amounts of Cu, P, U, Ag, Co, and rare earth elements (REE). Recently, it has been proposed based on trace element zonation in magnetite grains from the Los Colorados Kiruna-type IOA deposit, Chile, that ore formation is directly linked to a magmatic source. The model begins with the crystallization of magnetite microlites within an oxidized volatile-rich (H_2O+Cl) andesitic magma reservoir, followed by decompression, nucleation of fluid bubbles on magnetite microlite surfaces, segregation of a Fe-Cl-rich fluid-magnetite suspension within the magma reservoir, and subsequent ascent of the suspension from the magma chamber via pre-existing structurally enhanced dilatant zones that act as conduits. Emplacement and precipitation of the suspension results in the formation of magnetite grains with core-to-rim features that record a transition from purely igneous to magmatic-hydrothermal conditions within IOA deposits. Here we test this model by using in situ femtosecond laser ablation MC-ICP-MS measurements of Fe isotopes to determine grain-to-grain and intra-grain Fe isotope variations in magnetite grains from the Los Colorados IOA deposit. All in situ δ^{56}Fe values (^{56}Fe/^{54}Fe relative to IRMM-14) plot within the magmatic range (0.06 to 0.50‰), in agreement with previously published bulk Fe isotope analyses in magnetite from the Los Colorados IOA deposit. Different trace element signatures of these magnetite grains indicate an igneous or magmatic-hydrothermal origin, respectively. Although data partly overlap, the assigned igneous magnetites yield on average higher δ^{56}Fe values (0.24 ± 0.07‰; n = 33), when compared to magmatic-hydrothermal magnetites (0.15 ± 0.05‰; n = 26). Some magnetite grains exhibit a distinct core-to-rim trend from higher toward lower δ^{56}Fe signatures. Furthermore, the δ^{56}Fe of the igneous magnetites correlate negatively with trace elements contents typical for igneous formation (Ti, Al, Ga, V, Mn, Zn); igneous magnetites become isotopically heavier with decreasing concentrations of these elements, indicating a trend toward higher δ^{56}Fe in the magnetite with magma evolution. Model calculations of the δ^{56}Fe evolution in melt, magnetite, and fluid further constrain the magmatic-hydrothermal origin of Kiruna-type IOA deposits.

Keywords: Los Colorados, Chilean Iron Belt, Kiruna-type deposits, iron oxide-apatite deposits, iron isotopes, magnetite flotation; From Magmas to Ore Deposits