Triple Oxygen (delta O-18, Delta O-17), Hydrogen (delta H-2), and Iron (delta Fe-56) Stable Isotope Signatures Indicate a Silicate Magma Source and Magmatic-Hydrothermal Genesis for Magnetite Orebodies at El Laco, Chile

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Abstract

The Plio-Pleistocene El Laco iron oxide-apatite (IOA) orebodies in northern Chile are some of the most enigmatic mineral deposits on Earth, interpreted to have formed as lava flows or by hydrothermal replacement, two radically different processes. Field observations provide some support for both processes, but ultimately fail to explain all observations. Previously proposed genetic models based on observations and study of outcrop samples include (1) magnetite crystallization from an erupting immiscible Fe- and P-rich (Si-poor) melt and (2) metasomatic replacement of andesitic lava flows by a hypogene hydrothermal fluid. A more recent investigation of outcrop and drill core samples at El Laco generated data that were used to develop a new genetic model that invokes shallow emplacement and surface venting of a magnetite-bearing magmatic-hydrothermal fluid suspension. This fluid, with rheological properties similar to basaltic lava, would have been mobilized by decompression-induced collapse of the volcanic edifice. In this study, we report oxygen, including O-17, hydrogen, and iron stable isotope ratios in magnetite and bulk iron oxide (magnetite with minor secondary hematite and minor goethite) from five of seven orebodies around the El Laco volcano, excluding San Vicente Bajo and the minor Laquito deposits. Calculated values of delta O-18, Delta O-17, delta D, and delta Fe-56 fingerprint the source of the ore-forming fluid(s): Delta O-17(sample) = delta O-17(sample) - delta O-18(sample) center dot 0.5305. Magnetite and bulk iron oxide (magnetite variably altered to goethite and hematite) from Laco Sur, Cristales Grandes, and San Vicente Alto yield delta O-18 values that range from 4.3 to 4.5 parts per thousand (n = 5), 3.0 to 3.9 parts per thousand (n = 5), and -8.5 to -0.5 parts per thousand (n = 5), respectively. Magnetite samples from Rodados Negros are the least altered samples and were also analyzed for O-17 as well as conventional O-16 and O-18, yielding calculated delta O-18 values that range from 2.6 to 3.8 parts per thousand (n = 9) and Delta O-17 values that range from -0.13

to -0.07 parts per thousand (n = 5). Bulk iron oxide from Laco Norte yielded delta O-18 values that range from -10.2 to +4.5 parts per thousand (avg = 0.8 parts per thousand, n = 18). The delta H-2 values of magnetite and bulk iron oxide from all five orebodies range from -192.8 to -79.9 parts per thousand (n = 28); hydrogen is present in fluid inclusions in magnetite and iron oxide, and in minor goethite. Values of delta Fe-56 for magnetite and bulk iron oxide from all five orebodies range from 0.04 to 0.70 parts per thousand (avg = 0.29 parts per thousand, a = 0.15 parts per thousand, n = 26). The iron and oxygen isotope data are consistent with a silicate magma source for iron and oxygen in magnetite from all sampled El Laco orebodies. Oxygen (delta O-18 Delta +4.4 to -10.2 parts per thousand) and hydrogen (delta H-2 = -79.9 to -192.8 parts per thousand) stable isotope data for bulk iron oxide samples that contain minor goethite from Laco Norte and San Vicente Alto reveal that magnetite has been variably altered to meteoric values, consistent with goethite in equilibrium with local delta O-18 and delta H-2 meteoric values of similar or equal to -15.4 and -211 parts per thousand, respectively.

The H2O contents of iron oxide samples from Laco Norte and San Vicente Alto systematically increase with increasing abundance of goethite and decreasing values of delta O-18 and delta H-2. The values of delta H-2 (similar or equal to -88 to -140 parts per thousand) and delta O-18 (3.0-4.5 parts per thousand) for magnetite samples from Cristales Grandes, Laco Sur, and Rodados Negros are consistent with growth of magnetite from a degassing silicate melt and/or a boiling magmatic-hydrothermal fluid; the latter is also consistent with delta O-18 values for quartz, and salinities and homogenization temperatures for fluid inclusions trapped in apatite and clinopyroxene coeval with magnetite. The sum of the data unequivocally fingerprint a silicate magma as the source of the ore fluids responsible for mineralization at El Laco and are consistent with a model that explains mineralization as the synergistic result of common magmatic and magmatic-hydrothermal processes during the evolution of a caldera-related explosive volcanic system.

Palabras clave

KeyWords Plus:KIRUNA-TYPE; LIQUID IMMISCIBILITY; FE-ISOTOPE; APATITE DEPOSITS; TITANIUM OXIDE; ORE; ORIGIN; MELT; BEARING; MANTLE

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