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Insights from in situ S isotope analysis in apatite from iron-oxide apatite deposits

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Recent studies have suggested that water-poor, sulfate(±chloride-carbonate)-rich hydrosaline liquids play a key role in the formation of iron oxide-apatite (IOA) deposits. These liquids are interpreted as essential agents for the transport of Fe and P, thereby contributing to their enrichment in IOA systems. The origin of such water-poor hydrosaline liquids remains uncertain; however, recent work indicates that they may form by direct melting and assimilation of evaporite-bearing rocks by the ore-associated magma.

Evaporite rocks generally display high $\delta^{34}S$ values of ~10 to >30‰ throughout geologic time, rendering their involvement in IOA deposit formation traceable through the S isotope signature of ore minerals. Apatite is ubiquitous in IOA deposits and represents one of the main hosts of S in these systems.

We performed in situ $\delta^{34}S$ analysis by LA-ICP-MS/MS on apatite from IOA deposits worldwide, spanning a broad geologic age range (Proterozoic to recent) and diverse mineralization styles. Apatite grains were first imaged by SEM-BSE and characterized by EPMA to select samples suitable for $\delta^{34}S$ analysis. Relatively S-poor apatite (typically <700 ppm S) were excluded due to the reduced analytical accuracy of $\delta^{34}S$ measurements of low-S apatite by LA-ICP-MS/MS.

Apatite preserves primary oscillatory zoning, patchy alteration, and locally homogeneous textures. Sulfur isotope data from seven IOA districts show deposit-mean $\delta^{34}S$ values (±1σ) ranging from -1.5 to 16.3‰ with Cerro Mercado, Mexico: -1.5±1.9‰, Laco-Salar, Chile: 3.1±1.7‰, El Laco, Chile: 7.9±2.0‰, Hierro Acari, Peru: 10.2±1.4‰, Gaocun, China: 14.5±2.5‰, Nihe, China: 15.0±1.6‰, and Makou, China: 16.3±2.2‰.

These preliminary results suggest the contribution of multiple S sources to IOA ore formation. Lighter isotopic compositions (-1.5 to 10‰) are consistent with a magmatic S signature, whereas $\delta^{34}S$ values >10‰ likely require the involvement of external sedimentary S. High $\delta^{34}S$ values (>10‰) measured in Hierro Acari, Gaocun, Makou, and Nihe occur both in primary growth zones and altered grains, emphasizing the need for further investigation into possible overprinting of the S isotope composition by late fluids and the role of evaporite assimilation in IOA ore formation. Analyses from additional deposits will expand this dataset and help refine the S isotope signature of apatite in IOA systems.