Goldschmidt 2024 Abstract
https://doi.org/10.46427/gold2024.23257

Sulfur-isotope and trace element geochemistry of sulfate and sulfide minerals in the Mountain Pass carbonatite, California, USA

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The Mountain Pass carbonatite stock is a world-class REE deposit that contains an average of 20–30 volume percent sulfate minerals, chiefly barite-celestine. The Mountain Pass carbonatite is a carbonate-sulfate igneous rock, but the source of sulfur has not been constrained. Sulfate minerals likely do not represent the bulk $\delta^{34}S$ of the source of the carbonatite magma, as several sulfide minerals also occur locally and must be accounted for, because sulfur isotopes fractionate between SO_4^{2-} (sulfate) and S^{2-} (sulfide) when in equilibrium. This fractionation can be used to constrain not only the bulk sulfur isotopic composition of the system, but also the oxygen fugacity and temperature of the carbonatite melt.

Trace element and sulfur isotope geochemistry was collected *in-situ* in sulfate (barite, with varying celestine and anhydrite components) and sulfide (pyrite, galena, and chalcopyrite) by LA-ICP-MS. Sulfur isotope fractionation between sulfur phases forms a trend indicating chemical equilibrium; the calculated bulk $\delta^{34}S$ of the carbonatite stock (0.12‰) aligns with typical mantle-sourced S ($\delta^{34}S = 0 \pm 2$‰). A correlation between high Sr or Ca in sulfate minerals and more fractionated $\delta^{34}S$ suggests the barite-celestine or barite-anhydrite transition is related to fractional crystallization and oxidation of the carbonatite melt; increased sulfate-sulfide S isotopic fractionation typically indicates an increase in melt fO_2. Two trends are observed in sulfate-mineral compositions: an increasing-Ca trend and an increasing-Sr trend, implying multiple liquids with different liquid lines of descent. Temperatures calculated from sulfate-sulfide fractionation indicate a carbonatite melt temperature of 200–500°C.

Barite was also investigated in a smaller carbonatite dike (Birthday dike) near the carbonatite stock. This dike lacks sulfide minerals and has elevated $\delta^{34}S$ (6–10‰). Relatively high $\delta^{34}S$, combined with silicification of the dike, may indicate the presence of an external (crustal) sulfur source in forming the Birthday carbonatite dike.