Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.29220

Magma Degassing vs. Host Rock Leaching – Unravelling the Sources of Sulfur in Geothermal Systems

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Sulfur (S) plays a critical role in volcanic geothermal systems along the Iceland rift, influencing the transport, precipitation, and enrichment of chalcophile metals such as Cu, Fe, Au, and Zn. Sulfur sources include seawater sulfate, host rock leaching, and magma degassing. To date, however, quantifying the individual contributions of each S reservoir to the total S budget of ore deposits remains challenging. Iceland provides a natural laboratory to study S transport and fluxes in young mafic crust by offering easy access to rocks and fluids from geothermal systems within an active rift zone, with numerous boreholes drilled into the upper ~5 km of crust for energy production. Although the Icelandic geothermal systems differ from other hydrothermal sulfide deposits (e.g., epithermal and seafloor massive sulfides) in pressure, phase relations, and surface conditions, they may still provide valuable insights into sulfur transport and fluxes.

Here, we measured whole-rock S contents of hydrothermally altered basalt from active meteoric water-fed and seawater-fed geothermal systems in the Iceland rift. Coupling S contents and the trace element composition of S-bearing minerals with mass balance calculations allowed us to assess the contributions of different S reservoirs to mafic crust.

Basalt from meteoric water-fed geothermal systems contained significantly higher S (up to 14.4 wt.%) than basalt from seawater-fed systems (up to 2.53 wt.%), with enrichment occurring mostly at shallow depths and at temperatures below 250 °C. Notably, Co and Ni concentrations in pyrite exceeded those reported in mafic seafloor massive sulfide deposits, highlighting the ore-forming potential of Icelandic geothermal systems.

Mass balance calculations indicate that in meteoric water-fed systems, sulfur deposition originates from a rock volume roughly five times the size of the enriched area, with circumneutral pH suggesting minimal magmatic input. Conversely, the seawater-fed system shows a smaller discrepancy, implying a more restricted recharge zone, especially when considering seawater-derived S. These findings suggest that S in geothermal systems primarily originates from rock leaching and seawater rather than magmatic sources.