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Hydrothermal mineral seal formation in acidic volcanic systems: flow through experimental constraints on fluid evolution and pore closure

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Gas driven volcanic eruptions at intermediate volcanoes are commonly associated with active hydrothermal systems and transient permeability changes beneath vent areas. Although hydrothermal minerals are inferred to form seals that restrict fluid flow, the rates, geochemical pathways, and fluid signatures associated with seal development remain poorly constrained.

We conducted a series of flow through experiments passing crater lake fluid from Ruapehu volcano, New Zealand, through crushed andesitic rock with grain sizes of 0.3 to 0.5 mm and 0.7 to 2.0 mm across a temperature gradient from room temperature to 200 °C at 23 bar and a fixed flow rate of 1 ml h^{-1}. The reactor configuration simulates downwelling acidic fluids with pH approximately 2 entering hotter fumarolic conduits. Effluent fluids were analysed for major and trace elements, and evolving saturation states were evaluated using thermodynamic modelling.

Within 60 days, progressive mineral scale formation developed along the thermal gradient, reducing permeability and leading to significant pressurisation prior to mechanical failure. The dominant secondary phases include alunite and anhydrite, with subordinate sulfur and accessory phosphate phases, forming primarily between 150 and 180 °C. This assemblage closely resembles hydrothermal minerals observed in ejecta from past gas driven eruptions.

Effluent fluid chemistry shows systematic shifts during seal formation, including temperature dependent decreases in dissolved Ca, Al, and sulfate and measurable deviations from equilibrium model predictions. These trends reflect coupled dissolution and precipitation processes and evolving aqueous speciation under acidic conditions.

Our results provide experimental constraints on hydrothermal mineralisation in acidic volcanic systems and demonstrate that mineral seal formation generates a distinct and reproducible geochemical signature. These findings have broader implications for hydrothermal system monitoring, particularly where permeability evolution is governed by temperature dependent mineral precipitation.