Monitoring magmatic-hydrothermal activity with rare earth elements in crater lakes

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A survey of available data from active, crater-lake hosting volcanic-hydrothermal systems worldwide suggests that REE budgets of the lake waters largely depend on the mode of rock dissolution and on the extent of alteration, processes that are directly related to fluid properties. A rough correlation between REE patterns of lake waters and local rocks testifies that lavas and pyroclastics in the volcanic edifice are the principal source of the REE. In general, the correspondence is closest for highly acidic lakes. Observed fractionation systematics among the REE demonstrate that complete, congruent dissolution is rare and only occurs under extreme conditions.

Alteration minerals, formed during water-gas-rock interaction, exert significant controls on REE budgets as well. We infer that alunite often plays a critical role in regulating the signatures of dissolved REE, even though this mineral is commonly not stable in acidic volcanic lakes. Because the saturation state for alunite is inversely correlated with temperature, the REE signatures of a lake reservoir may be inherited from inflow of water that had interacted with this mineral in hotter parts of the hydrothermal system at depth.

Time-series results on REE concentrations in the ultra-acid and highly dynamic crater lake of Poás (Costa Rica) provide evidence for intermittent effects from alunite in the subsurface system. Strong fluctuations in LREE/HREE ratios, observed over decades of monitoring, probably reflect variations in its stability, induced by shifting hydrothermal conditions. Changes in the REE concentrations sometimes coincided with phreatic eruptive events. Given the secondary character of alunite, its presence or absence may affect the porosity and permeability of volcanic rocks and conduits that act as pathways for upward flowing fluids. Evidence from Poás suggests that the formation of alunite may have a sealing effect that reduces the influx of fluid and heat into a lake. Our findings highlight the potential of REE in crater lakes as a versatile monitoring tool for subsurface processes in underlying magmatic-hydrothermal systems.