

Rare Earth Elements in alkaline geothermal fluids from Iceland and the East African Rift, Kenya: A data quality and anomaly assessment via the λ polynomial modelling approach

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Discussions of REE distributions are often complemented by including Y (REY). Within igneous and clastic sedimentary environments, the geochemical behavior of Y closely mirrors that of Ho, which is a consequence of their identical ionic charge and similar ionic radii. The lanthanide contraction describes the decrease in atomic radii with increasing atomic number due to the progressive filling of the 4f orbitals, which drives predictable geochemical fractionations. These subtle variations provide valuable geochemical fingerprints. REE typically occur in trivalent (+3) oxidation state, however, Ce and Eu are notable exceptions, exhibiting naturally occurring valence states of +4 and +2, respectively. Chondrite-normalized REY_{CN} patterns are employed to visualize REY distributions, where anomalous concentrations of individual REY manifest as positive or negative deviations from an otherwise smooth trend. These variations in charge are controlled by physicochemical conditions. For example, Eu anomalies can indicate reducing and high-temperature (>250 °C) conditions, whereas Ce anomalies may reflect oxidative scavenging (negative anomaly) or high carbonate alkalinity (positive anomaly) in ambient waters. Consequently, REY serve as powerful geochemical tracers and proxies for physicochemical conditions and geochemical processes. Due to their low abundances in geothermal fluids, achieving high analytical precision is crucial for fully leveraging the information encoded within REY patterns.

Studies on dissolved REY concentrations in alkaline geothermal fluids are limited. Here, we present REY concentration data from otherwise well-studied alkaline geothermal fluids in Iceland and the Kenyan sector of the East African Rift. We achieved high analytical quality by applying a matrix separation and preconcentration protocol. A data quality assessment and anomaly calculations were performed using the λ polynomial modeling approach, originally developed by O'Neill^[1] and recently validated by Ernst et al.^[2]. This represents

the first application of this methodology to geothermal fluids. The modelling results are in good agreement with the measured data, highlighting the good analytical quality as well as the need for matrix separation and preconcentration for measurement of REY in alkaline geothermal fluids.

1. O'Neill, H. St. C. *Journal of Petrology* **57**, 1463–1508 (2016).

2. Ernst, D. M., Vogt, J., Bau, M. & Mues, M. *Sci Rep* **15**, 5360 (2025).