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Simulation-Informed Inversion of Intra-Plate Melt Geochemistry: Lithospheric Thickness, Plume Temperature, and Source Enrichment

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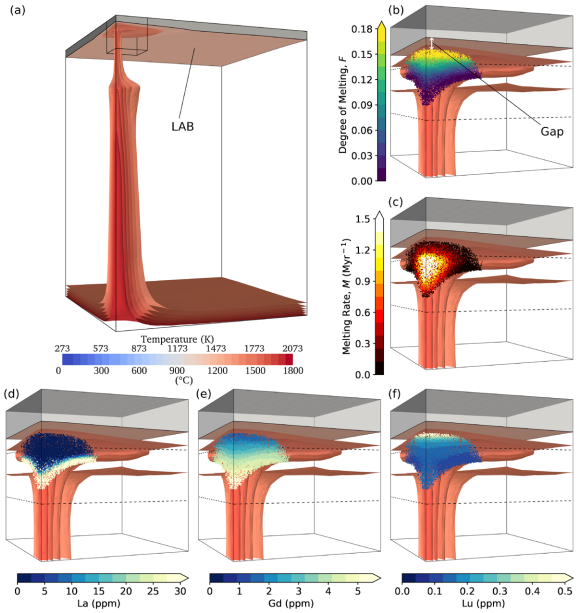

Intra-plate volcanic rocks - the surface expression of mantle plumes - exhibit large variations in major- and trace-element geochemistry that reflect both melting conditions and mantle source composition. We have developed an inversion framework to jointly estimate lithospheric thickness, plume excess temperature, and source enrichment from the geochemistry of intra-plate melt, primarily ocean island basalt (OIB). This approach proceeds in three steps: (i) we run 3-D coupled geochemical–geodynamical simulations to predict trace-element concentrations as functions of lithospheric thickness and plume excess temperature; (ii) using optimal transport theory, we interpolate these discrete predictions to produce continuous maps of melt region geometry, melting rate, and composition across our thickness–temperature space; (iii) we invert for lithospheric thickness and temperature conditions that minimise the misfit in rare earth element (REE) concentrations between source-corrected model predictions and fractionation-corrected OIB observations, aided by an empirical relationship between Al_2O_3 and lithospheric thickness that mitigates any temperature-pressure trade-off. Our inferred thicknesses and temperatures are generally consistent with independent petrological and seismic estimates. Notably, temperature estimates covary with buoyancy flux and $^3He/^4He$ ratios, indicating that plume temperature modulates the extent to which heterogeneous mantle components are entrained and sampled. In addition, we present examples that capture the temporal variations in the intra-plate melt conditions across an island chain. By explicitly accounting for realistic melt region geometries and source variability, the framework complements classic thermobarometry, REE inversion, and seismic inversion approaches, providing a pathway to assimilate geochemical signals into time-dependent models of Earth's thermo-chemical evolution.