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Enhancing Adjoint Reconstructions of Earth's Mantle with Geochemical Data from Intra-Plate Lavas

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Reconstructing the thermo-chemical evolution of Earth's mantle and its diverse surface manifestations is a grand challenge in the geosciences. Achieving this requires the development of a digital twin -- a dynamic digital representation of Earth's mantle across space and time, constrained by observational data on the mantle's structure, dynamics, and evolution. To this end, geodynamicists are increasingly exploring adjoint-based approaches, which reformulate mantle convection modelling as an inverse problem. In this framework, unknown model parameters are optimized to fit available observational data.

Traditionally, inverse geodynamic models have primarily focused on observations that constrain either the initial (inverse sense) or final (forward modelling sense) state of the system, such as seismic tomography and geodesy. However, additional observational constraints are needed to rigorously reconstruct the mantle's evolution over geological time. Surface plate velocities, their time-dependent behaviour, and plate boundary characteristics provide critical constraints. Another untapped dataset is the geochemistry of intra-plate volcanic lavas, which reflects the depth and temperature of mantle melting at the time of eruption. This geochemical signature provides insights into lithospheric thickness (the 'lid') and underlying thermal structure, extending our ability to constrain mantle evolution into the past.

Here, we present early efforts to incorporate mantle geochemistry into adjoint models of mantle convection using the Geoscientific ADjoint Optimisation PlaTform (G-ADOPT -- https://gadopt.org/). Our synthetic experiments demonstrate that geochemical constraints on temperature and pressure enhance the accuracy of reconstructed mantle flow trajectories, unlocking insights into dynamic processes and interactions previously obscured in mantle retrodiction models. This integration offers the potential for a transformative leap in resolving mantle evolution, illuminating the interplay between deep Earth dynamics and surface processes that shape our planet's geological history.