Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.36087

The Chemical Geodynamics of Mantle Plumes

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Mantle plumes, buoyant upwellings from deep within the mantle, are the source of most ocean island basalts (OIB). Consequently, OIB are a window into deep mantle composition, and provide crucial insights into Earth's inner structure, dynamics, and the mass exchange fluxes between its surface and interior. In recent years, it has become increasingly evident that mantle plumes are thermochemical anomalies. It has also become apparent that variably melt- and incompatible element-depleted peridotite is required to explain the Nd isotope ratios of olivine-hosted melt inclusions [1], the Ce-Nd-Hf isotope systematics of OIB [2,3], and the Nd-Hf isotope ratios of plume-derived peridotites [4]. In this study, we employ a forward model to simulate plume melting to further assess the nature of global plume sources. Our findings confirm that global OIB trends in various 2D Sr-Ce-Nd-Hf-Pb isotope ratio diagrams fan out from isotope ratios that represent mixtures of melts from heterogeneous peridotite and recycled oceanic crust, plus variable amounts and types of recycled continental crust. The location of OIB trends in such 2D isotope ratio diagrams indicates that almost all plume sources must be dominated by heterogeneous melt- and incompatible element-depleted peridotite. Therefore, the perception of thermochemical plumes shifts from predominantly thermal upwellings of unprocessed ("primitive") peridotite, containing relatively large amounts of recycled crust, to compositionally distinct upwellings dominated by highly processed peridotite, characterized by coupled composition and density variations, with moderate temperature excess. Melts from isotopically heterogeneous peridotite, along with melts from minor recycled crust components, control the spectrum and covariation of various isotope ratios in OIB (or absence thereof), including those of the rare gases ($^{4}He/^{3}He$) and short-lived decay systems ($^{142}Nd/^{144}Nd$, $^{182}W/^{184}W$). Moreover, variably buoyant peridotite may account for complex plume geometries, and temporal variations in plume volume flux [2,4], and may thus influence the geospatial variation and temporal fluctuation of plume isotope signatures conveyed by OIB.

References: [1] Stracke et al. (2019) Nature Geoscience, 12, 851–855; [2] Béguelin et al. (2025) AGU Advances, 6(2), e2024AV001434; [3] Stracke and Salters (2025) Geochem., Geophys., Geosys., 26, e2025GC012463: [4] Sanfilippo et al. (2024) Nature Geoscience, 17, 1046–1052