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Disentangling partial melting and crustal recycling signatures in ocean island basalts with multivariate statistics

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Ocean island basalts (OIB) offer critical insights into the mass exchange fluxes between the mantle and the crust. While OIB compositions are often visualized with two-dimensional plots, multivariate methods are increasingly applied to investigate how oceanic basalts reflect mantle heterogeneity. However, these approaches often neglect the compositional nature of geochemical data, where variables are interdependent and inherently sum to a constant (i.e., 1.0). To ensure proper treatment of compositional data, and thus to avoid misleading results, we applied centered log-ratio transformations to a global compilation of OIB major and trace element data. Principal factor analysis of the log-ratio transformed dataset reveals latent variables ('factors') that capture covariance patterns resulting from key geochemical processes. The first two factors correspond to partial melting (F) and the general effects of sediment recycling. Notably, recycled oceanic crust (ROC) does not emerge as a distinct factor, because its geochemical fingerprint is obscured by variable melt degrees. By leveraging the partial melting factor to isolate samples formed under similar melting conditions and reapplying our factor analysis approach, we resolve an ROC factor and two sediment recycling factors (upper continental crust [UCC] and lower continental crust [LCC]), in addition to a depth of melting factor and a factor that reflects the uniqueness of the Hawaiian plume. Visualizing the results in factor space ('factor biplots') provides a novel framework for assessing relationships between these mantle source signatures. The 'HIMU' localities emerge as outliers in a sediment-sediment biplot (UCC vs. LCC), supporting the notion that 'HIMU' signatures are simply due to a deficit of recycled sediment. Additionally, this biplot substantiates that UCC and LCC recycling is governed by a single process— subduction of upper crustal sediments and subduction erosion of the LCC. Relationships among recycled slab components (ROC, UCC, LCC) indicate that sediment and ROC contributions are generally coupled, though UCC is prone to decoupling from ROC during subduction. The Azores, however, display unique bimodal behavior in sediment-ROC biplots, suggesting that their distinct isotopic signatures stem from an absence of LCC, potentially tracing past episodes of weakly compressive subduction.