Geochemical and seismological constraints on the locations and geometries of deep mantle reservoirs

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Significant effort has been made to characterize the diversity of geochemical components sampled by oceanic hotspot volcanoes and mid-ocean ridges, and progress has been made to identify the origin of these geochemical components. However, the locations of the key mantle domains sampled at hotspots—EM1 (enriched mantle I), EM2 (enriched mantle II), HIMU (high ‘μ’, or high $^{238}\text{U}/^{204}\text{Pb}$), and an ancient, high $^3\text{He}/^4\text{He}$ component—remain poorly constrained. In turn, the lack of spatial constraints on the locations and geometries of these reservoirs limits understanding of how geodynamic processes (e.g., subduction, mantle convection) operate to modify the Earth’s interior.

We provide an updated compilation the most extreme EM (lowest $^{143}\text{Nd}/^{144}\text{Nd}$) and HIMU (highest $^{206}\text{Pb}/^{204}\text{Pb}$) compositions in lavas from 46 oceanic hotspots with available data, and the highest $^3\text{He}/^4\text{He}$ compositions from 44 hotspots globally. We examine the geographic distributions of hotspots hosting extreme geochemical components at the Earth’s surface. We also explore how tilted plume conduits relate the geochemical distributions in hotspots at the Earth’s surface with the two inferred Large Low Shear Wave Velocity Provinces (LLSVP) in the deep mantle.

We find that the most extreme EM signatures are identified in southern hemisphere hotspots, and northern hemisphere hotspots exhibit more geochemically-depleted compositions. Critically, hotspots with the most extreme HIMU compositions show a very different distribution, and are found in, or near, the tropical latitudes. The EM and HIMU domains thus exhibit a clear spatial separation in the deep Earth.

In order to evaluate whether EM and HIMU domains are spatially associated with the LLSVPs, we compare the magnitude of EM and HIMU signatures with minimum hotspot distances from the LLSVP margins. While EM-hosting hotspots show a clear geographic affinity for the LLSVPs, new data make it apparent that HIMU-hosting hotspots show no geographic association with the LLSVPs, further supporting to the spatial decoupling of EM and HIMU mantle domains.

Hotspots hosting ancient high $^3\text{He}/^4\text{He}$ domains exhibit a spatial relationship with the LLSVPs (doi:
suggesting that the EM and high $^3$He/$^4$He domains may coexist in the LLSVPs. While the degree of the EM signature exhibits no relationship with hotspot buoyancy flux, maximum high $^3$He/$^4$He values correlate with hotspot buoyancy fluxes, consistent with the hypothesis that high $^3$He/$^4$He mantle reservoirs are hosted in dense regions in the LLSVPs sampled by only the hottest and most buoyant plumes.

These results raise several key questions. First, if subduction of oceanic crust and sediment generate HIMU and EM reservoirs, then why are they spatially separated? Why are EM2 domains concentrated in the southern hemisphere, and why are they limited to being inside or near the LLSVPs? Why are EM and high $^3$He/$^4$He domains both geographically associated with the LLSVPs, and are they spatially separated within the LLSVPs so that the low $^3$He/$^4$He of the former does not overprint the high $^3$He/$^4$He of the latter? If elevated $^3$He/$^4$He originates in the core, consistent with negative $^{182}$W anomalies in high $^3$He/$^4$He lavas, why are high $^3$He/$^4$He plumes associated with the LLSVPs?