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Scale and origin of chemical heterogeneities sampled by mantle plumes

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Mantle plumes bring to the surface material coming from the deep mantle. They form flood basalts and ocean island basalts whose chemical and isotopic compositions vary from depleted to highly enriched. Depleted portions of the mantle are due to the formation of continental crust over Earth's history while enrichment of other parts is attributed to recycling of crustal material into the Earth's interior. Large isotopic heterogeneities exist at all scales (worldwide, island chain or even single island) demonstrating that plume sources sample diverse materials and are not very well mixed.

The first large-scale evidence came from the work done by Abouchami et al. in 2005. Using high-precision Pb isotopic data, they showed that lateral zoning in the Hawaiian plume conduit brings up to the surface material from two distinct sources that do not mix while ascending through the mantle. Weis et al. in 2011 suggested that the two sources originate in the deep mantle: one side of the plume samples the LLSVP anomaly present at the core mantle boundary under Hawaii, and the other side samples normal deep mantle material. This exciting conclusion led other authors to suggest a similar origin for features observed in other plumes (e.g., Payne et al. 2013 or Hoernle et al., 2015) but other authors question the systematic link with a LLSVP anomaly to attribute similar bilateral zoning to local internal structures (Chauvel et al., 2012 or Cordier et al. 2016). It remains that lateral zoning is frequent and shows the poor efficiency of mixing during rise in plume conduits.

Clear evidence for poor mixing efficiency also comes from the recent discoveries of remains of Hadean and Archean materials in plume sources: sulfur mass-independent isotopic fractionation has been reported by Cabral et al. (2013) and Delavault et al. (2016) in Polynesian basalts, and ^{182}W anomalies were found by Rizo et al. (2016) and Mundl et al. (2017) in modern ocean island basalts. The presence of sulfur MIF indicates that the material was once present at the Earth's surface prior to 2.45 Ga, implying not only that old surface materials have been recycled in the deep Earth but also that it survived untouched for a long time. The ^{182}W anomalies argue for the presence of undifferentiated Hadean material in some plume sources, a feature that is not easy to reconcile with their trace element and radiogenic isotopes characteristics. Indeed, Hawaii, Samoa and Baffin Island basalts all have modern mantle Ce/Pb and Nb/Th ratios, values that differ significantly from the primitive Earth ratios. In addition, Samoa basalts have very radiogenic isotopic compositions that require involvement of an enriched material in their source. How the two contradictory types of constraints can be reconciled remains to be determined. More generally, how extremely old materials can survive isolated in the mantle for such long periods of time is challenging. Research combining geochemical, experimental and geophysical approaches might be able to provide answers in the future.