Geophysical Research Abstracts
Vol. 17, EGU2015-14532, 2015
EGU General Assembly 2015

The geochemical geometry of mantle plumes

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Lavas erupted at oceanic hotspot volcanoes exhibit tremendous isotopic variability, which indicates that the mantle sources of the hotspots are highly heterogeneous geochemically. A key question is how the surface expression of hotspot lavas relates to the spatial distribution of the geochemical components within upwelling mantle plumes. Significant progress has been made in recent years relating the geographic distribution of geochemical heterogeneities in hotspot lavas to parallel volcanic lineaments that define the traces of oceanic hotspot tracks. For example, a well known geographic separation of parallel volcanic lineaments at Hawaii – the Loa and Kea trends – are also isotopically resolved. In addition to the Hawaiian example, clear patterns relating the geographic distribution of geochemical components along hotspot tracks are emerging from a suite of global hotspots, and these patterns suggest that geochemical heterogeneities are highly organized within upwelling mantle plume conduits.

At the Samoan hotspot, the Pb-isotopic compositions measured in lavas reveal several geochemical groups, and each group corresponds to a different geographic lineament of volcanoes. Each group has a geochemical signature that relates to each of the canonical low 3He/4He mantle endmembers: EMII (enriched mantle 2), EMI (enriched mantle 1), HIMU (high U/Pb) and DM (depleted mantle). In Pb-isotopic space, the four geochemical groups each form an array that trends toward a common component (thus forming an "X-shape" in Pb-isotopic space). The region of isotope space where the 4 Pb-isotopic array intersect is defined by the highest 3He/4He (up to 34 Ra, or ratio to atmosphere) in the Samoan hotspot. In Pb-isotopic space, 3He/4He decreases monotonically along each of the Pb-isotopic groups away from the common region of convergence. In order to quantify the relationship between He and Pb isotopes, 3He/4He is plotted versus distance from the common component in Pb-isotopic space, and a clear relationship emerges from the dataset. This observation supports a hypothesis where several low-3He/4He components are embedded within (and mix with) a plume matrix that is composed of the high 3He/4He component. In this way, the four distinct Pb-isotopic groups do not mix efficiently with each other, thereby preserving the four distinct arrays in Pb-isotope space. However, the low 3He/4He components do mix with the high 3He/4He plume matrix, thereby generating the clear relationship between He and Pb isotopes.

These mixing relationships provide a clear picture of the geochemical geometry of the Samoan plume. However, owing to the sparse datasets that link high-precision Pb-isotopic measurements with 3He/4He measurements on the same sample, it is not yet clear whether the geochemical geometry observed in the Samoan plume is feature that is common to mantle plumes globally.