Scales of Heterogeneities in the Hawaiian Plume

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Introduction

Ocean Island Basalts (OIB) are thought to derive from mantle plumes originating from the deeper parts of the Earth’s mantle. Understanding the origin and length scales of the heterogeneities in the deep mantle is fundamental for understanding the long-term processes of differentiation that take place within the Earth. The Hawaiian Islands are the best-studied example of OIB volcanism and their compositions have been explained by combinations of recycled oceanic crust, sediments, ambient and previously depleted mantle within the Hawaiian plume. Here we report new Nd-Pb-Hf isotope data for the isotopically most enriched (Makapuu stage lavas) and most depleted (Kaula rejuvenated lavas and pyroxenite xenoliths) samples from the Hawaiian Islands, in order to constrain the types, length-scales and distribution of heterogeneities in the Hawaiian plume.

Results and Discussion

Nd-Hf and high precision Pb isotopic compositions of lavas and clinopyroxenes were determined on the Thermo-NEPTUNE MC-ICPMS at the Geochemistry facility, NHMFL. The new Kaula lava and pyroxenite data extend towards lower $^{208}\text{Pb}/^{204}\text{Pb}$ and higher $\varepsilon\text{Nd}$ compositions than previously observed in Hawaiian lavas (Fig. 1), with relatively radiogenic $\varepsilon\text{Hf}$ for a given $\varepsilon\text{Nd}$ (not shown). These compositions are consistent with a long-term depleted source. The Mauna Kea-West Maui lavas plot at the extension of the trend defined by rejuvenated volcanism (Honolulu Volcanics, SLC pyroxenites - Kaula lavas and pyroxenites: Fig.1). This trend is semi-parallel to the Pacific MORB field, precluding the involvement of MORB – type mantle as the source of the depleted component and suggests that this component is part of the Hawaiian plume. The new Makapuu data extend towards more enriched Nd isotopic compositions than previously reported in Hawaii. The Makapuu lava Nd-Pb isotopic compositions (Fig.1) suggest mixing between an enriched ($^{208}\text{Pb}/^{204}\text{Pb}$ - low $\varepsilon\text{Nd}$) and a depleted component similar to that identified above.

The Hawaiian lava isotopic variability has been previously explained by mixing of at least four distinct components (Fig 1). If those four components are randomly dispersed within the plume, then during the life-span of a single shield volcano (e.g. ~500Ka for Mauna Kea and ~200Ka for Koolau volcanoes) the lavas should show evidence of variable mixing between these four components. In detail however, data from individual volcanoes form linear arrays that are best explained by binary mixing with unique endmembers for each volcano (Fig. 1), i.e. the lava compositions do not vary randomly. The large number of resulting mixing arrays argues against a simple four-endmember plume model and against finely dispersed small-scale heterogeneities within the plume. Also, the lack of overlap between the different binary mixing endmembers cannot be explained by a concentric zoned plume model or the asymmetrically bilateral plume model. The data suggests vertical heterogeneity within the plume. If vertical streaks are present within the upwelling plume (i.e. “spaghetti” model), then their composition does not vary significantly for ~500Ka (requiring length scales of 30-500km for a 10-100cm/year upwelling rate). However those “streaks” must have a finite length (or short “spaghetti”) in order to reproduce the volcano-to-volcano variability and this argues for multiple components (>4) within the upwelling Hawaiian plume.

Acknowledgements

This work was supported by NSF grant OCE: 0622827 to M.Bizimis.