Major element and volatile heterogeneity in the Earth's mantle and generation of oceanic basalts

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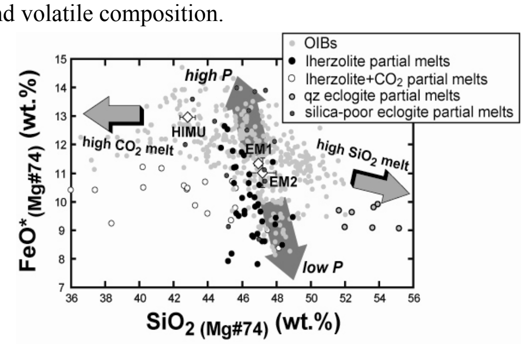
The compositions of oceanic basalts provide a window into the geochemical and petrologic complexity of the Earth's convective mantle. But the information on mantle heterogeneity comes mostly from long-lived radio isotopes and the global scale major element heterogeneity of basalt source regions remains less clear. Here I evaluate major element compositions of ocean island basalts (OIBs) and constrain the relative role of source heterogeneity versus conditions of melting in the major element array of OIBs.

Basalts with 8wt.%≤MgO≤16wt.% from 120 individual volcanic centers of 30 ocean island groups were corrected for fractionation by adding or subtracting olivine. The lithospheric thicknesses at the time of magmatism were estimated based on plate model and by subtracting eruption age of individual islands from the present-day sea-floor age. The relations between average major element compositions and plate thicknesses suggest that lithospheric thicknesses provide a strong control for islands situated on thinner plates or near ridges. But the fractionation corrected SiO_2, FeO*, CaO/Al_2O_3, Na_2O/TiO_2 are too variable for basalts erupted on older, thicker lithospheres. Comparison with the experimental partial melts of putative mantle lithologies indicates that melting of a fertile peridotite at variable P-T alone cannot reproduce the extrema of the major element compositions that anchor the global OIB trends and two additional higher Fe# components, one rich in SiO_2 and the other rich in CO_2 seem necessary (see figure). Ocean islands on thicker lithospheres randomly sample these additional components and suggest that the Earth's mantle is heterogeneous in its major element and volatile composition.



Volatile-induced metasomatic melting in terrestrial planets

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Melting is the principal cause of chemical differentiation of planetary interiors and release of volatiles to exosphere. Adiabatic decompression of mantle materials past the silicate solidus is the primary mode of melting in the Earth's mantle but flux of volatiles such as H_2O and CO_2 can have a significant impact in causing deeper melt generation. Metasomatic flux melting in the mantle wedge is well appreciated but the framework of volatile-induced metasomatic melting for the convective upper mantle, beneath ridges and intraplate ocean islands is less clear.

Experimental petrology of subducting lithologies suggests that the CO_2/H_2O (wt. ratio) of the fluid flux released from the slab to mantle wedge is <1. In contrast, nominally anhydrous, carbonated convecting mantle with sub equal amounts of trace H_2O and CO_2, likely releases melt flux with CO_2/H_2O of ~10-30. Buoyantly rising melts such as these react with the overlying mantle and stabilize volatile-rich, silica-undersaturated basaltic magmas, which evolve in composition with depth. The signal of this deeper flux melting is subtle in mid-oceanic ridges and can only be captured in the distribution of incompatible element ratios (CO_2/Nb, La/Sm) in enriched basalts. However, evidence of deeper metasomatic melting is much more pronounced in the ocean isalnds, where the presence of thick lithosphere puts a cap on the extent of shallow melting (e.g., Hawaii, Cape Verde, Cook-Australs). In these settings, even the major element compositions (e.g., SiO_2, CaO, CaO/Al_2O_3) of basalts may carry imprints of volatile-induced metasomatic melting.

The mechanism of basaltic melt generation and volatile release outlined here can proceed without a significant component of mantle upwelling, as long as there are instabilities (e.g., plate flexure and small-scale convection at the base of the lithosphere) to trigger the initial production of a volatile-rich melt. Magmatism on Earth, especially beneath petit spots and beneath thick lithospheres, may have a significant component of volatile-induced metasomatic melting. Composition of Wishstone class rocks from the Gusev crater perhaps suggest a similar melting scenario for Mars. The presence of a thick, stagnant lid in Venus also presents a suitable tectonic setting where volatile-induced metasomatic melting may contribute significantly to magmatic resurfacing.