Upper mantle dynamics expressed in hotspot and mid-ocean ridge basalt chemistry

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The fact that the mantle is heterogeous on scales much smaller than the size of upper mantle melting zones, and the likelihood that the different source components begin melting at different depths both allow for the possibility that 3D variations in upper mantle flow can contribute to geochemical variations in erupted magmas. One example is the spatial variations observed along hotspot-influenced ridges. If a ridge-centered hotspot is fed by a narrow, buoyant upwelling (e.g., mantle plume), then compared to the non-influenced portions of the mid-ocean ridge, the hotspot will tend to more heavily sample those materials that begin melting deepest. The main reason is that the flux of mantle through the deepest portion of the melting zone is predicted to be larger than the flux through the shallower portions. Such “plume flow” contrasts with normal mid-ocean ridge flow, which is likely to be more uniform at all depths of the melting zone. Assuming that the isotopic end-member DMM begins melting shallowest and the other end-members begin melting deeper, our models predict that a large percentage of the variation in Sr, Nd, and Pb associated with the Iceland-Mid-Atlantic Ridge system can be caused by the transition from plume-like flow beneath Iceland to normal mid-ocean ridge flow far from Iceland, even without any variation in the mantle source.

Another example pertains to the geochemical differences between Hawaiian shield and rejuvenated or secondary lavas. We propose that the secondary volcanism forms due to decompression caused by lithospheric upwarping at the flexural arch surrounding volcanic shields. Such an origin is supported by the observation that on- and off-shore secondary volcanism has most frequently occurred at distances from growing shields (200-400 km) that coincide with the likely locations of rising flexural arches. Models predict that mantle is drawn upward beneath the arch at a rate that is largest near the top of the melting zone and decreases with depth. Arch melting will thus tend to more heavily sample the shallower melting, DMM-like components in a heterogeneous Hawaiian hotspot mantle. In contrast, shield lavas are likely to form in the presence of rapid, deep mantle plume flow, as described above, which tends to sample EM or HIMU components. Calculations show how such processes can produce the differences in the average Sr and Nd compositions between the two volcanic stages.

Spatial and temporal isotopic variability in ocean island volcanism: The noble gas story

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Extremely unradiogenic helium and neon isotopic signatures are preferentially found in the largest active ocean island hotspot provinces such as Hawaii, Iceland and Galapagos. Unradiogenic mantle noble gas isotopes have generally been interpreted as indicating deep, relatively undegassed mantle sources, but this has been challenged by researchers who do not believe relatively undegassed reservoirs can be accomodated within whole mantle convection models. The spatial and temporal variability within ocean island provinces and volcanoes provide important constraints on the dynamics of mantle upwelling and convection. The least radiogenic helium isotopes are found within the most active sectors of ocean island provinces (e.g., Loihi seamount, central Iceland, and Fernandina) supporting a global relationship between heat, melting, and unradiogenic noble gases. Correlations between helium and neon isotopes suggest that this relationship extends to neon. The best examples of temporal noble gas isotopic evolution are provided by Hawaiian lava flows where time scales and stratigraphy are relatively well constrained. The lowest $^{4}He/^{3}He$ ratios are always found in the shield building tholeiites (e.g., for Haleakala, Mauna Loa, Hualalai, as well as newer data sets from Mauna Kea and Koolau volcanoes). Mauna Loa data indicates that the shield building stage of Hawaiian volcanoes is mostly characterized by unradiogenic helium, implying that this also represents the bulk of the upwelling/melting mantle. These considerations, and the correlations between helium and the other elements, show that large volumes of mantle with unradiogenic noble gases are required. This cannot be explained by dispersed upper mantle sources; the lower mantle, or at least mantle below the 670km discontinuity, is the most likely site for unradiogenic noble gases. Temporal isotopic evolution, as observed at Hawaii, has not been well documented elsewhere, but this may relate to the lack of appropriate sampling. This is important because temporal evolution can be obscured in global geochemical compilations and can complicate mixing relationships.