MORB versus OIB genesis: Stratification in mantle composition or in upper mantle melting?

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Geochemical observations of ocean island basalts (OIBs) and mid-ocean ridge basalts (MORBs) indicate that the mantle is heterogeneous on scales much smaller than the size of the upper mantle melting zones. Those materials with higher incompatible-element and volatile contents will begin melting at greater depths than more depleted materials, and thus will tend be sampled more heavily by hotspot melting compared to mid-ocean ridge melting for two main reasons. First, melting beneath hotspots is likely to occur at greater depths, owing to the presence of thick lithosphere (intraplate settings) and/or thick crust (near-ridge settings). Second, if hotspot melting is caused by narrow, buoyant mantle upwellings (e.g., mantle plumes), geodynamic calculations predict that a larger flux of mantle passes through the deepest portion of the melting zone compared to the shallowest portion. Such “plume flow” contrasts with flow beneath mid-ocean ridges, which likely passes a more uniform mantle flux through all depths of the melting zone.

Assuming the traditional isotopic end-member DMM begins melting shallowest and the other end-members (e.g., EM1, EM1, HIMU) begin melting deeper, simple geodynamic models can explain many of the overall Sr, Nd, and Pb isotopic differences between common MORBs and OIBs even in the absense of any difference in the starting (heterogenous) sources. If hotspots arise from deep-seated mantle plumes, the main implication is that the source region for plumes need not be as chemically different from the ambient asthenosphere as traditionally believed. For layered mantle models, this conclusion suggests that any deep mantle layer contributes minimally to the flux of mantle plumes (or to the asthenosphere); for non-layered mantle models, the above conclusion supports the possiblity that mantle composition does not change systematically over its depth.

Differences in melting conditions may also contribute to the differences in the noble gas characteristics between OIBs and MORBs The main requirement for this to be true is that the more primitive material (e.g., FOZO, C) begin melting deeper than the DMM material and, in most cases, shallower than the EM1, EM2, and HIMU components. We thus raise the possibility that rather than reflecting deep sources in the mantle, the key characteristics of OIBs indicate deep melting of a heterogenous mantle, or at least the major portion of the mantle feeding OIB and MORB volcanism.

Scales of thermal anomaly and chemical heterogeneity in the lower mantle

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A sound mantle convection model needs to be able to reconcile seismic tomographic images of superplumes/ upwellings, stagnant slabs and small scale scatters, and geochemical evidence of primitive mantle reservoirs/blobs. To construct a model of this kind, it is essential to quantify the sources to drive the convection, such as thermal and chemical contributions to the density anomaly. This has become possible with our newly obtianed thermoelasticity data for the lower mantle perovskite phase. Quantitative characterization of thermal and chemical effects on velecity and density variations at lower mantle depths are obtained by introducing purtabations to the reference pyrolite model which reproduces radial profiles of P and S wave velocities and density of PREM within 0.5%. From these calculations, partial derivatives of dlnVp, dlnVs, and dln(rho) with regard to temperature, Fe partitioning between perovskite and magnesiowustite, iron contenet, and Mg/Si ratio are obtained. With these coefficients, not only we can compare with seismic observations about the correlations of bulk sound, compressiona and shear wave velocities and density, scales of the thermal and chemical heterogeneities can also be inverted from seismic tomographic results of velocity and density variations. We find that the thermal anomaly inferred by representative seismic velocity variations at the bottom of the lower mantle is moderate compare to the excess temperature required for large plumes.