Mantle heterogeneity in mid-ocean ridge lavas: the melting column as a filter

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Lavas erupted at mid-ocean ridges and ocean islands show chemical variation that cannot be explained by fractional crystallisation alone. Some of this variation must be delivered from the melting regime. Two end-member hypotheses for why lavas, erupted at different times and in different settings, may be chemically distinct are: that there is a spatio-temporal heterogeneity of the mantle source chemistry; or, that there is spatio-temporal heterogeneity of the melt-transport process. The latter may be broadly construed, but typically invokes a channelised system: one in which high-porosity channels enable differential melt transport rates. The former states that chemical variation in the source is transferred to its melt and preserved during segregation.

We use theoretical models to explore the limit to which the source heterogeneity hypothesis can explain basalt chemical variability. Beyond this limit, heterogeneity of melt transport, e.g., channels, is required. We assume melt segregation by laterally uniform (i.e., not channelised) porous flow and ask: under what conditions can variations in source chemistry be delivered by magma to the base of the crust without significant attenuation? Our results indicate that short-wavelength mantle heterogeneity (1–10 km) can be preserved for only the most incompatible elements. Comparing these results to observations from Icelandic lavas suggests that heterogeneity of melt transport is required to explain short-wavelength chemical variability.

We use a theoretical framework for trace element transport through a 1-D melting column. Melting is fractional and transport is in disequilibrium with the mantle matrix. A reaction rate enables the system to evolve toward equilibrium as defined by a bulk partition coefficient D. The melting column is shown to act as a low-pass filter, where the wavelength cutoff depends on partition coefficient. Longer wavelengths of heterogeneity and smaller partition coefficients promote preservation of the heterogeneity signal. This behaviour is explained in terms of the segregation rate of liquid from solid over an interval of the melting column.