

Towards an integrated theory of geochemistry and geodynamics

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The compositional variability of lavas, melt inclusions and residues sampled from the Earth's mantle is a primary observation constraining dynamic processes at depth. Nevertheless, understanding the dynamic implications of these observations remains a challenge because chemical variability results from at least two scales of processes. At the largest scale, mantle convection produces a chaotic stirring problem that stretches and folds source variations. However, given the extremely small diffusivity of chemical constituents in the solid state, this process neither mixes, fractionates or homogenizes the source. These processes occur at a much smaller scale in the presence of melting and melt transport. The question remains as to how this second scale of process affects chemical variability and ultimately the distributions of composition observed at the surface.

While it might be expected that melt transport leads to enhanced mixing and a reduction in chemical variability, both field evidence and recent calculations suggest that melt transport processes can preserve large chemical variations on small length scales and may actually enhance variability through the development of a channelized melt transport network.

We review observations of chemical variability in lavas and melt inclusions from mid-ocean ridges and show that these systems display large trace-element concentration variability with little obvious spatial correlation on all scales from 1000 km of ridge down to the hand-sample scale measured in melt inclusions. While some of this variability is due to source variations, we suggest that a large component could be the consequence of magma transport in channelized systems. We review field evidence from ophiolites that suggests that "replacive dunites" are a likely candidate for such channels and we describe numerical models that explore channel formation and localization by reactive magma transport.

Given these physical models for channel formation, we explore the chemical consequences of these processes. We show that channelized flow can produce orders of magnitude variation in the concentrations of highly incompatible elements, even for idealized systems with a homogeneous source, constant bulk partition coefficients and equilibrium transport. Most importantly, the full range of variability is found in each channel due to advection of highly depleted melts from the inter-channel regions into the edges of the channels. As these channels may be spaced on scales of 1–100 m in the mantle, this mechanism allows highly variable melts to be delivered to the Moho on very small length scales. We show that the chemical variation produced in the models is consistent with that seen in melt inclusion suites, lavas and residual mantle peridotites dredged from the ridges and sampled in ophiolites. We discuss new models that include the effects of spatially varying partition coefficients and consequences for U-series disequilibrium.