Heterogeneity in mid-ocean ridge sources

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This talk will review some theoretical considerations concerning the melting of heterogeneous sources and the implications for interpretation of melt inclusion data, particularly olivine-hosted inclusions from mid-ocean ridge environments. We have apparently adequate models that assume a locally or globally homogenous source and can explain major and trace element chemistry of basalts and correlations with physical variables like melt flux and axial depth. Such models are the basis of the consensus view of the average thermal and compositional state of the upper mantle and the range of their variability. However, a variety of data (most notably from melt inclusion diversity within samples and suites) and lines of reasoning (such as the need for recycling to maintain fertility of the source) require that heterogeneity exists within particular melting regimes as well as among them. We can classify heterogeneity by scale. There is some small scale (perhaps ~10 cm) below which the source melts as if it were effectively homogeneous and some large scale (perhaps ~ 1 km) above which the source components can be treated as chemically and thermally independent and their melts simply mixed; these scales may be different for different elements and lithologies. The challenge is to develop tools that predict behavior at intermediate scales where incomplete thermal and/or chemical interaction occur and hence standard mixing theory is confounded by complex feedbacks between composition and melting behavior and between melting and equilibration. Additional challenges center on the kinetics of interactions during melt migration through heterogeneous media.

I will review some of the reasons this problem defeats the current generation of melting models, the efforts that have been published by various authors, the theoretical progress that is needed, and the prospects for success.

Magmatism and the evolution of the Earth’s interior

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The flow of liquids relative to solids or other liquids is the only efficient mechanism for obtaining physical separation of chemical components of an initially homogenous material at high pressure. Hence the history of differentiation of the Earth’s interior is essentially the history of magmatic phenomena: core formation involving molten metal, formation and freezing of a silicate magma ocean, and ongoing partial melting of silicate solids. In early history much of this activity took place at very high pressure, in the lower mantle (plausibly, silicate magmatic activity continues today at the core-mantle boundary). In order to define possible evolutionary paths of the young Earth and to learn what evidence might remain today of such early processes we must build well-constrained models of igneous processes at appropriate pressures, temperatures, and compositions. This remains difficult because experimental study of lower mantle igneous petrology lies mostly beyond the pressure capability of multi-anvil devices and beyond the size and homogeneity capability of diamond anvil cells. We must rely on indirect tools: construction of phase diagrams and thermodynamic models from thermochemical and equation of state data contributed by mineral physics and the emerging field of high-pressure melt physics. There are roles in this enterprise for quantum and molecular dynamics computation, shock wave experiments, and a variety of *in situ* applications of synchrotron radiation. Once the major element phase equilibria are well-defined, then it is appropriate to turn to trace elements and the determination of partition coefficients at appropriate pressure, temperature, and major element compositions.

This plenary lecture will review the times and depths in Earth history where magmatic differentiation has determined planetary evolution, some basic thermodynamic tools for defining and understanding behavior in adiabatic environments like convecting mantles and magma oceans, progress in constructing appropriate phase diagrams, and areas of continuing uncertainty.