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Melting and reactive flow of a volatilized mantle beneath mid-ocean ridges: theory and numerical models

Tobias Keller and Richard F Katz
University of Oxford, Foalab, Earth Sciences, Oxford, United Kingdom (tobias.keller@earth.ox.ac.uk)

Laboratory experiments indicate that even small concentrations volatiles (H_2O or CO_2) in the upper mantle significantly affect the silicate melting behavior [HK96,DH06]. The presence of volatiles stabilizes volatile-rich melt at high pressure, thus vastly increasing the volume of the upper mantle expected to be partially molten [H10,DH10]. These small-degree melts have important consequences for chemical differentiation and could affect the dynamics of mantle flow. We have developed theory and numerical implementation to simulate thermo-chemically coupled magma/mantle dynamics in terms of a two-phase (rock+melt), three component (dunite+MORB+volatilized MORB) physical model. The fluid dynamics is based on McKenzie's equations [McK84], while the thermo-chemical formulation of the system is represented by a novel disequilibrium multi-component melting model based on thermo-dynamic theory [RBS11]. This physical model is implemented as a parallel, two-dimensional, finite-volume code that leverages tools from the PETSc toolkit.

Application of this simulation code to a mid-ocean ridge system suggests that the methodology captures the leading-order features of both hydrated and carbonated mantle melting, including deep, low-degree, volatile-rich melt formation. Melt segregation leads to continuous dynamic thermo-chemical dis-equilibration, while phenomenological reaction rates are applied to continually move the system towards re-equilibration. The simulations will be used first to characterize volatile extraction from the MOR system assuming a chemically homogeneous mantle. Subsequently, simulations will be extended to investigate the consequences of heterogeneity in lithology [KW12] and volatile content. These studies will advance our understanding of the role of volatiles in the dynamic and chemical evolution of the upper mantle. Moreover, they will help to gauge the significance of the coupling between the deep carbon cycle and the ocean/atmosphere system.

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