Simulating reactive melt transport in the oceanic mantle lithosphere – a thermodynamic approach

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The oceanic mantle lithosphere is commonly interpreted as the melt-depleted residue left after the extraction of igneous oceanic crust from the upwelling asthenosphere at mid-ocean ridges. This model predicts that a) fractional melts formed in the upwelling mantle are efficiently isolated, aggregated, and extracted to form basaltic crust, and b) the residual lithosphere is upward depleted and its degree of depletion is proportional with the amplitude of decompression. Such a scenario is, however, unrealistic because the lengthscale of heterogeneities observed in oceanic peridotite series is shorter than the depth interval of melt depletion predicted by polybaric melting models, and the concentration of incompatible elements in these peridotites is too high for a given MgO content to result by melt depletion alone (e.g. Elthon 1992). Petrographic observations and geochemical data indicate that melt-rock reaction must be ubiquitous and capable of generating locally diverse peridotite series at oceanic spreading centers and transform faults, and contributes to the compositional diversity of MORBs (e.g. Collier, Kelemen 2010). Whereas the principles governing reactive melt transport are well established by basic theories and models, studies quantifying the physical conditions and mechanisms creating heterogeneities in the oceanic lithosphere are limited (Collier, Kelemen 2010, Kelemen 1990).

To gain a better quantitative understanding of how reactive melt infiltration acts to modify the composition of oceanic mantle lithosphere, here we simulate 1-D melt-rock reactions using Adiabat_1ph (Smith, Asimow 2005) running with the pMELTS thermodynamic database (Ghiorso et al. 2002). In our model, aggregate liquids that result from polybaric near-fractional melting of peridotites upwelling at oceanic spreading centers percolate the mantle section of the overlying thermal boundary layer, reacting with residual harzburgites under constraints of local geothermal gradients and melt/rock ratios. We prescribe the thickness, geothermal gradient and initial composition of the lithosphere using a spreading rate-dependent 2-D thermal model, and handle the process of melt-rock reaction as a combination of continuous fractional crystallization of basalt and harzburgite assimilation under predefined P-T constraints.

We first demonstrate that reactive percolation of basaltic melts through depleted harzburgites readily generates the dunite-(wehrlite)-harzburgite-lherzolite spectrum observed in the abyssal mantle and ophiolites, and that the amplitude of transformations is a function of thermal boundary layer thickness and amount of available melt. We then evaluate the extent to which the major and trace element variability in the melts and oceanic mantle lithosphere can be influenced by different mechanisms of melt transport. Our results

show that, if associated with cooling, distributed porous melt percolation (simulated by incremental addition of the same amount of melt) more efficiently converts harzburgites into fertile lherzolites and creates more pronounced compositional gradients in the abyssal mantle than imparted during channelized melt influx (simulated as batch addition of large amounts of melt) under otherwise identical circumstances. To remain within the MORB trend, reacted melts must be released from dunite channels, before orthopyroxene saturation occurs. Further reaction with harzburgite causes liquids to evolve toward boninite-like compositions. As reaction progresses with decreasing temperature, the chance of such liquids to erupt diminishes rapidly, because reactive melts freeze in rapidly after the point of clinopyroxene precipitation maximum. This prevents such boninite-like liquids to become globally important MORB end-members.

References

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