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Modelling melting rates in upwelling mantle

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Beneath mid-ocean ridges and in mantle hotspots, the upwelling motion of hot crystalline rock results in pressure-release melting. Magma is produced at grain boundaries, which form an interconnected network of low porosity that can allow the buoyant magma to migrate upwards towards the crust.

Melting is driven by the fact that the solidus is pressure dependent; as its overburden pressure reduces the upwelling rock contains more energy than can be sustained as a solid, so it partially melts. As it does so, the less fusible components preferentially move into the magma, so that the composition of the residual rock changes; this in turn alters the solidus, and hence the melting rate.

In this work, we attempt to build simple models that describe the melting process consistently using conservation principles. We assume that reactions occur on a sufficiently fast timescale that the process can be considered to be in equilibrium, and is therefore governed by a phase diagram with pressure-and-composition-dependent solidus and liquidus. We examine simple idealised solidus and liquidus curves for the case of two components, and use the conservation equations to determine the melting rate. The rate is found to be a constant multiple of the overall upwelling rate; that is, the average of the upwelling rates of matrix and melt.

Feedback of the magma flow on the melting (or dissolution) rate has been cited as reason to expect the formation of high porosity channels, which may allow for much faster magma flow and explain the inferred chemical disequilibrium of erupted magma. This feedback is due to an instability associated with enhanced melting (or dissolution) in regions of greater magma flow. We will discuss the implications for such instabilities in the light of the current model, which includes both thermal and chemical considerations.