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Physics of deep plume melting: komatiitic melt accumulation and segregation in the transition zone

Harro Schmeling (1), Nick Arndt (2), and Svenja Kohl (1)

(1) Goethe University Frankfurt, Institute of Geoscience, Geophysics, Frankfurt/M, Germany (schmeling@geophysik.uni-frankfurt.de), (2) ISTerre, Université Joseph Fourier, Grenoble, France

Komatiites are assumed to be produced in very hot mantle upwellings or plumes. Under such conditions, melting will take place deep within the upper mantle or even within or below the mantle transition zone. Due to its compressibility at such pressures, melt has a higher density than olivine. Whether it would remain buoyant with respect to a peridotitic mantle both above and below the olivine-wadsleyite phase boundary because of the presence of denser garnet remains an open issue, particularly in view of recent X-ray refraction data on molten basalts by Sanloup et al. (2013).

We studied the physics of melting and melt segregation within hot upwelling mantle passing through the transition zone, with particular emphasis on the effect of depth-dependent density contrasts between melt and the ambient mantle. Assuming a 1D plume, we solved the two-phase flow equations of the melt-matrix system accounting for matrix compaction and porosity-dependent shear and bulk viscosity. We assumed a constant ascent velocity leading to a constant rate of melt generation.

In a first model series, the level of neutral buoyancy zneutral is assumed to lie above the depth of onset of melting, i.e. there exists a region where dense melt may lag behind the solid phases within the rising plume. Depending on two non-dimensional numbers (accumulation number Ac, compaction resistance number Cr) we find four regimes: 1) time-dependent melt accumulation in standing and broadening porosity waves that scale with the compaction length, 2) steady-state weak melt accumulation near zneutral, 3) no melt accumulation due to small density contrast, 4) no melt accumulation due to high matrix viscosity. In regime 4 the high mantle viscosity prevents the opening of pore space and the accumulation of melt.

In a second series, the rising mantle crosses the olivine-wadsleyite phase boundary, which imposes a jump in density contrast between melt and ambient mantle. In this case, a sharp melt fraction contrast develops and a large melt fraction accumulates immediately above the phase boundary. In a third set of models, a hot 1D plume head is assumed to move through the transition zone. The top of the plume head remains below the solidus temperature and the melt density is always less than that of the ambient mantle. In this case melt percolates upwards and accumulates near the top of the plume head within a very thin layer, reaching up to 100% melt fraction.

These models show 1) that not only melt density, but also porosity dependent matrix viscosity controls the melt ascent or accumulation, 2) that there are parameter ranges and physical conditions which may lead to the accumulation of very large melt fractions (> degree of melting), 3) that in spite of melt being denser than olivine at some depths, in general these melts escape these regions and continue to percolate upward faster than the rising mantle.