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3D Compressible Melt Transport with Adaptive Mesh Refinement

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Melt generation and migration have been the subject of numerous investigations, but their typical time and length-scales are vastly different from mantle convection, which makes it difficult to study these processes in a unified framework. The equations that describe coupled Stokes-Darcy flow have been derived a long time ago and they have been successfully implemented and applied in numerical models (Keller et al., 2013). However, modelling magma dynamics poses the challenge of highly non-linear and spatially variable material properties, in particular the viscosity. Applying adaptive mesh refinement to this type of problems is particularly advantageous, as the resolution can be increased in mesh cells where melt is present and viscosity gradients are high, whereas a lower resolution is sufficient in regions without melt.

In addition, previous models neglect the compressibility of both the solid and the fluid phase. However, experiments have shown that the melt density change from the depth of melt generation to the surface leads to a volume increase of up to 20%. Considering these volume changes in both phases also ensures self-consistency of models that strive to link melt generation to processes in the deeper mantle, where the compressibility of the solid phase becomes more important.

We describe our extension of the finite-element mantle convection code ASPECT (Kronbichler et al., 2012) that allows for solving additional equations describing the behaviour of silicate melt percolating through and interacting with a viscously deforming host rock. We use the original compressible formulation of the McKenzie equations, augmented by an equation for the conservation of energy. This approach includes both melt migration and melt generation with the accompanying latent heat effects. We evaluate the functionality and potential of this method using a series of simple model setups and benchmarks, comparing results of the compressible and incompressible formulation and showing the potential of adaptive mesh refinement when applied to melt migration.

Our model of magma dynamics provides a framework for modelling processes on different scales and investigating links between processes occurring in the deep mantle and melt generation and migration. This approach could prove particularly useful applied to modelling the generation of komatiites or other melts originating in greater depths.

Keller, T., D. A. May, and B. J. P. Kaus (2013), Numerical modelling of magma dynamics coupled to tectonic deformation of lithosphere and crust, Geophysical Journal International, 195 (3), 1406–1442.

Kronbichler, M., T. Heister, and W. Bangerth (2012), High accuracy mantle convection simulation through modern numerical methods, Geophysical Journal International, 191 (1), 12–29.