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Compaction Around a Spherical Inclusion in Partially Molten Rock

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Conservation laws that describe the behavior of partially molten mantle rock have been established for several decades, but the associated rheology remains poorly understood. Constraints on the rheology may be obtained from recently published torsion experiments involving deformation of partially molten rock around a rigid, spherical inclusion. These experiments give rise to patterns of melt segregation that exhibit the competing effects of pressure shadows around the inclusion and melt-rich bands through the medium. Such patterns provide an opportunity to infer rheological parameters through comparison with models based on the conservation laws and constitutive relations that hypothetically govern the system.

To this end, we have developed software tools using the automated code generation package FEniCS to simulate finite strain, two-phase flow around a rigid, spherical inclusion in a three-dimensional configuration that mirrors the laboratory experiments. The equations for compaction and advection-diffusion of a porous medium are solved utilising newly developed matrix preconditioning techniques.

Simulations indicate that the evolution of porosity and therefore of melt distribution is predominantly controlled by the non-linear porosity-weakening exponent of the shear viscosity and the poorly known bulk viscosity. In the simulations presented here, we find that the balance of pressure shadows and melt-rich bands observed in experiments only occurs for bulk-to-shear viscosity ratio of less than about five. However, the evolution of porosity in simulations with such low bulk viscosity exceeds physical bounds at unrealistically small strain due to the unchecked, exponential growth of the porosity variations. Processes that limit or balance porosity localization will have to be incorporated in the formulation of the model to produce results that are consistent with the porosity evolution in experiments.