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Effect of viscous anisotropy on melt migration dynamics of partially molten rocks: Coupling between shear and isotropic components

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A modeling approach was performed to quantify the effects of grain scale microstructural anisotropy on the macroscopic elastic and viscous properties. Based on the results, I provide a quantitative method for mapping between elastic and viscous anisotropies and also demonstrate the importance of grain scale microstructural anisotropy as a cause of larger scale melt redistribution.

Mechanical constitutive relations of partially molten rocks are derived based on a microstructural model with granular configuration. It is shown that both elasticity and viscosity depend on the grain-to-grain contact geometry, and that anisotropy of the contact geometry results in the anisotropy of these properties. By constraining the model with observations of contact geometry in experimentally deformed partially molten rocks (or rock analogue), direction and amplitude of viscous anisotropy are calculated under a given stress direction. The obtained viscosity tensor has off-diagonal components that define a coupling between shear and isotropic components, which do not exist in an isotropic viscosity tensor. One of the most remarkable consequences of this coupling is the enhancement of interaction between shear deformation and melt migration, which is demonstrated by solving the governing equations of solid-liquid two-phase system under some simple boundary conditions. In an example of a simple shear zone under constant stress conditions, perturbation in melt fraction sub-parallel to the shear plane can grow due to the effect of viscous anisotropy on melt pressure. This process can produce the segregation observed in experiments and suggested by field observations. In a second example of rotary shear deformation, melt migrates up stress gradients in the solid framework: in other words, shear stress gradients can drive compaction. Such melt redistribution over distances greater than grain scale would significantly increase effective permeability and matrix deformability (lubrication), causing interaction between melt migration and deformation relevant to the scale of plate boundaries. Mapping between elastic and viscous properties enables us to test the possible occurrence of such interactions in the Earth.