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Effects of grain-scale microstructure on the mechanical properties and dynamics of solid-liquid two-phase system

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Mechanical and transport properties of solid-liquid two-phase systems strongly depend on the microscopic geometry of the liquid phase. The microscopic geometry of liquid that are texturally equilibrated under hydrostatic stress is relatively well known. However, effect of shear stress on the liquid geometry is poorly understood, and is a subject of intensive studies. The purpose of my talk is to show that microscopic behavior of the liquid phase at the grain size scale significantly influence the macroscopic dynamics of the solid-liquid system. In order to investigate the effect of microstructural process on the macroscopic dynamics, an internal state variable describing the microstructural process is introduced into a two-phase flow theory.

The present approach consists of (1) deriving viscous constitutive relations of solid matrix as functions of a microstructural state variable, and (2) solving them together with the mass and momentum conservation equations for the two-phase system under a given boundary condition. Contiguity, which describes grain-to-grain contact geometry, is the essential microstructural factor determining the mechanical properties of granular media (Takei, 1998; Takei and Holtzman, 2009). Hence, contiguity provides an appropriate internal state variable for partially molten rocks. Recent experimental studies on partially molten rock (Daines and Kohlstedt, 1997) and partially molten rock analogue (Takei, 2005, 2009) demonstrate the development of microstructural anisotropy under stress, which is well described in terms of contiguity. The constitutive relations predict that a significant softening occurs in the direction of the least compressive stress (sigma3) and that, because of this anisotropy, strong coupling occurs between shear and isotropic components of stress. An important consequence of this coupling is significant enhancement of the interaction between shear deformation and melt migration: melt migrates up the stress gradient in the solid, and melt spontaneously segregates into the melt-rich bands which form at a low-angle to the shear plane (Takei and Holtzman, 2009). Both of these phenomena have important geological implications because they can significantly reduce viscosity and shear wave velocity even with a small amount of melt and develop high permeability channels for the melt ascent. These results were obtained for rotary shear and uniform simple shear systems. For more realistic geological settings, the effect of viscous anisotropy on melt migration was roughly estimated by using the corner flow ridge and subduction models of Spiegelman and McKenzie (1987). It was demonstrated that the melt phase is attracted to the position of high stress in the plate boundary. The attracted melt will significantly soften the matrix, change the stress concentration pattern, and hence change the melt flow pattern. Therefore, the next important step will be a numerical approach to simulate such interactive evolution between mantle flow and melt migration. This study has developed basic tools for such simulation.

Keywords: micro-macro, solid-liquid two phase system, structural sensitive, viscous anisotropy, fluid migration, lubrication