

Experimental study of bulk and shear viscosities of partially molten rock analogue

SUZUKI, Ayako^{1*} ; TAKEI, Yasuko¹ ; WATANABE, Shun-ichi²

¹Earthquake Research Institute, University of Tokyo, ²Hydrographic & Oceanographic Dept, Japan Coast Guard

Deformation of partially molten rock is controlled by two independent viscosities: shear viscosity for shear deformation and bulk viscosity for compaction/decompaction. Bulk viscosity and its ratio to shear viscosity, h_b/h_s , play an important role in melt segregation dynamics in the upper mantle (Katz, 2008). However, that value has not been well constrained theoretically nor experimentally especially at small melt fractions. Most numerical studies have used the theoretically predicted value of $h_b/h_s = \sim f^{-1}$, where f is the melt fraction. Takei and Holtzman (2009a) theoretically obtained a constant value of h_b/h_s by taking into account a diffusion creep mechanism. The discrepancy between two models is significant at small melt fractions. There has not been experimentally determined value of h_b/h_s because very few experimental studies have been done about bulk viscosity although shear viscosity has been measured extensively. To discuss the validity of these models based on the experimental data, it is highly important to measure both bulk and shear viscosities by using the equivalent samples. In this study, we measured experimentally these two viscosities as functions of melt fraction using a partially molten rock analogue.

Samples were polycrystalline aggregates of borneol-diphenylamine binary with eutectic temperature of 316K, which has a quite similar equilibrium microstructure to olivine + basalt system (Takei, 2000). Initial melt fraction can be controlled precisely by the concentration of diphenylamine because of its simple eutectic reaction. Before deformation experiments, samples were annealed at 320K for ~ 100 hours in a sealed capsule to make those grain size large enough (~ 0.030 mm), resulted in negligible grain growth during the successive deformation tests at the same temperature.

To measure bulk and shear viscosities, we carried out two separate experiments. For bulk viscosity, compaction experiments were performed under the diffusion creep regime. A cylindrical sample was compacted uniaxially in a rigid sleeve ($e_{zz} < 0$, $e_{xx} = e_{yy} = 0$, where e is the strain). Melt was squeezed out from the partially molten sample into porous metals which contact with the sample at the top and bottom ends until melt fraction becomes nearly zero. Evolution of melt fraction in the sample was calculated from the sample length measured with digital gauge. Apparent viscosities as a function of melt fraction were proportional to $\exp(-af)$ with $a = \sim 30$ at $f > 4\%$, which is quite consistent with the olivine + melt systems (Renner et al., 2003). At $f < 3\%$, deviation of the viscosity from the exponential curve occurs, suggesting the possible effects of permeability and change of rate limiting process of the volumetric creep (Takei & Holtzman, 2009b). For shear viscosity, uniaxial deformation experiments were performed without a horizontal confining pressure ($s_{zz} < 0$, $s_{xx} = s_{yy} = 0$, where s is the stress). Melt fraction was nearly constant during the test. Deformation tests were conducted with some constant load steps under the diffusion creep regime. Apparent viscosity is evaluated from the stress and the strain rate at steady state.

From the two apparent viscosities obtained independently, we can calculate each bulk and shear viscosities as functions of melt fraction. We will test the predictions of models and discuss the possible viscosity ratio of the partially molten rocks in the upper mantle.

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