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Experimental study of bulk viscosity of partially molten rock analogue

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Viscosities of partially molten rock change significantly due to melt fraction. However its quantitative effects have not been well constrained theoretically nor experimentally. Deformation of partially molten rock is controllled 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 (Katz, 2008). Most numerical studies have used the theoretically predicted value of h_b/h_s = ˜f^{-1}, where f is the melt fraction. However, 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. Therefore, the purpose of this study is to measure a pair of the bulk and shear viscosities for the same sample. As the first step of the experimental examination, we measured bulk viscosity experimentally as a function 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 the bulk viscosity, we carried out compaction experiments in which melt was squeezed from the partially molten sample under the diffusion creep regime. A cylindrical sample contacted with a porous metal at the top end was compacted uniaxially in a rigid sleeve (horizontal strain = 0, vertical strain < 0). Melt can flow out into the porous metal until its fraction becomes nearly zero. Evolution of melt fraction in the sample was calculated from the sample length measured with digital gauge. Apparent viscosity is calculated as a function of melt fraction from an instantaneous strain rate and a constant stress. Precise measurements of melt fractions at very small amounts of melt ($f < 1$ %) is crucial to test the predictions of models. Data obtained so far show the viscosity is proportional to exp(-af) with a = ˜30 at $f > 3$ %, 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).

References:
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