EGU21-10321
https://doi.org/10.5194/egusphere-egu21-10321
EGU General Assembly 2021

Toward the Better Understanding of Shear Localization in the Lower Mantle Caused by the Strength Contrast between Bridgmanite and Ferropericlase: the Role of Stress/Strain Rate Heterogeneity in Diffusion Creep Regime

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Localized deformation is a possible scenario that may explain the preservation of geochemical heterogeneity in the lower mantle. Recent experimental studies (e.g., Girard et al., 2016) showed that Fp (ferropericlase), which is a weak and volumetrically minor phase (~20 %), accommodates a large fraction of strain of its mixture with Br (bridgmanite), which is a stronger (approximately order of 2 - 3) and volumetrically major phase (~60-70 %). Localized deformation of the Fp phase within this two-phase mixture may provide an important insight to the long-standing question of the mechanical differentiation process between the weak boundary layer and the relatively unmixed volume in the lower mantle. Since the dominant deformation mechanism in the lower mantle is thought to be the diffusion creep, and the deformation state is mostly simple shear, it is important to understand how the deformation by diffusion creep occurs in a mixture of Fp-Br under the simple shear.

In the context of multiscale modeling methodology, we approach a grain's length scale deformation where a single 2D elliptic Fp grain is embedded in the infinite Br matrix medium. These two phases are treated as linear viscous incompressible materials where deformation occurs by the fluxes of atoms (vacancies) caused by the applied boundary normal stress gradient. We conducted a theoretical analysis to investigate the nature of the diffusion-induced deformation of the Fp grain under the simple shear. We focused on the following issues: (i) when the two-phase mixture deforms under the far-field simple shear, what the local stress and strain rate fields within the Fp inclusion are, (ii) how the local stress gradients induce the diffusion fluxes of vacancies of the Fp grain, and (iii) the dependences of diffusion creep of the Fp to its shape (changing with the strain) and its viscosity contrast against the Br.

To investigate the internal stress states, we used the Eshelby's inhomogeneous inclusion theory translating its elastic formulations to the linear viscous ones using the Hoff analogy. This approach provides the stress, strain rate, and vorticity within a 2D elliptic Fp grain embedded in Br (3 orders of magnitude greater viscosity than Fp) matrix subjected to the far-field simple shear. From these mechanical states, the lattice diffusion within Fp grain and its influences on the rheology were found by using the Finite Element method solving the Fick's laws of diffusion. This study shows that the diffusion creep rate increases as the ellipse elongates and rotates. As the Fp ellipse elongates (i.e., its aspect ratio increases), the local shear stress in the Fp increases, and the stress is somewhat concentrated near the small radius tips, which induces the strong diffusion fluxes due to the high normal stress gradients. These theoretical and numerical results support that the strain localization under diffusion creep regime can occur and be a possible mechanism that created the localized mantle flow particularly where the shear deformation is dominantly applied.