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Diffusion to dislocation creep transition in upper-mantle from Si grain-boundary diffusion

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Dislocation creep causes non-Newtonian viscosity and seismic anisotropy, whereas diffusion creep causes Newtonian viscosity and no or weak seismic anisotropy. Determination of deformation mechanism in the Earth's interior is thus essential to understand mantle dynamics. Although previous deformation studies on olivine suggested the dislocation to diffusion creep transition with depth in the upper mantle, recent studies suggested possible misinterpretation of those results due to experimental difficulties. Since the olivine creep is considered to be controlled by silicon diffusion, we measured silicon grain-boundary diffusion coefficient in Mg-olivine as a function of temperature, pressure, and water content to estimate the diffusion creep rate. The experimental results show a small activation enthalpy (240-260 kJ/mol), small activation volume (1.8±0.2 cm3/mol), and small water-content exponent (0.22±0.05). The smaller activation energy of grain-boundary diffusion than that of dislocation creep predicts a diffusion to dislocation creep transition in the upper mantle, which is in contrast with the previous model. The Gutenberg discontinuity could be caused by this creep-mechanism transition. The weak seismic anisotropy in lithosphere is interpreted as fossil anisotropy formed at spreading ridges. The dominance of diffusion creep in upper lithosphere accounts for the Newtonian rheology suggested by postglacial rebound.