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Synchrotron radiation study on rheological properties of minerals during high-pressure transformations

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Phase transformations of minerals have an important role on the rheology of subducting slabs. Flow properties and the dominant mechanism of deformation are possibly affected through changes of the crystal structure, grain size and polycrystalline texture during the transformation. In the peridotite layer of subducting slabs, the olivine-spinel and the post-spinel transformations are major reactions, which are thought to be origin of the 410 and 660 km seismic discontinuity in the mantle, respectively. In this study, to investigate effects of these transformations on rheological behavior of the subducting slabs, simultaneous deformation and transformation experiments were conducted using analogue reaction systems. Flow stress and transformed fraction were quantitatively obtained by in-situ X-ray observations during the constant strain rate deformation using deformation-DIA (D-DIA) apparatus.

High-pressure transformations of fayalite (Fe_2SiO_4) and albite ($NaAlSi_3O_8$) were used for the analogue of the olivine-spinel and the post-spinel transformation in $(Mg,Fe)_2SiO_4$, respectively. High-pressure deformation experiments were conducted using D-DIA apparatuses at the NE-7 of PF-AR and BL04B1 of SPring-8. The plastic deformation and high-pressure transformation processes were simultaneously observed by time-resolved two-dimensional X-ray diffraction (2DXRD) measurements using monochromatic X-ray (energy 50 keV). 2DXRD patterns were used to obtain the transformed fraction and the differential stress of the sample that was estimated from the distortion of the Debye ring. Plastic strain of the sample was measured from the X-ray radiography images. The microstructure and crystallography of recovered samples were observed using a FE-SEM with an EBSD system.

The olivine-spinel transformation experiments in polycrystalline fayalite were conducted at 973 and 1173 K under quasi-hydrostatic and non-hydrostatic (the samples deformed with the strain rate of $5*10^{-5}\ s^{-1}$) conditions. Overpressure needed for the transformation under non-hydrostatic condition at 973 and 1173 K (2.9 and 0.6 GPa) was smaller than under quasi-hydrostatic condition (3.8 and 1.5 GPa). In deformed sample, creep curves indicated that the sample became harder with increase of the spinel fraction. This observation suggests that the olivine-spinel transformation under relatively small overpressure and high-temperature condition would not cause the slab weakening.

Both the post-spinel transformation and the albite decomposition are eutectoid reactions with having an alternating fine lamellar structure. To investigate the creep behavior during eutectoid transformation, two kinds of polycrystalline starting materials, parental albite and decomposed jadeite + quartz aggregate, were prepared. High-pressure deformation experiments were conducted at 2-4 GPa, 873-1073 K and the strain rate of 10^{-6}-$10^{-5}\ s^{-1}$. The microstructures of recovered samples as well as the flow and kinetic data suggest sequential variation of the creep mechanism from dislocation creep of the transformed eutectoid colony followed by the grain-size sensitive creep in the degenerated eutectoid structure. This study demonstrated that the creep behavior during the eutectoid transformation involves various processes than previously thought. The slabs may not be weaken promptly after entering into the lower mantle when the size of eutectoid colony is enough large, and keep their strength (or harden) over a period of time depending on the degeneration kinetics of the colony.