Petrological and structural analyses of ultrafine-grained ductile shear zone in hydrous peridotite: A case study of the Gongen outcrop in the Sanbagawa belt

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Shear zones are important to cause large tectonic displacement in the Earth's crust and upper mantle. Weakening of mantle minerals is required for subduction boundaries with large displacements to be kept into depths. Grain size reduction of constituent minerals is generally observed in exposed shear zones and is considered as a major mechanism that reduces the rock strength. Therefore, it is important to understand recrystallization and weakening of olivine crystals in wet conditions from observations of natural peridotites.

A case study is carried out on an ultrafine-grained shear zone in the Higashi-akaishi ultramafic body in the Sanbagawa belt, SW Japan. Grain size, intracrystalline misorientation (MO) and crystallographic preferred orientation (CPO) are measured using EBSD maps. FE-SEM observations of dislocation microstructures are made on the samples after oxidation decoration at 900 degree C. Pressure and temperature conditions of the deformation can be constrained as about 3.5 GPa and 700 ℃ based on the syn-deformational mineral assemblage (chlorite is stable and antigorite and phlogopite are unstable) and the pressure-temperature evolution of the body. To evaluate the microstructural observations in terms of olivine rheology, a deformation mechanism map is calculated in the pressure-temperature conditions as a function of stress and grain size. Dislocation-accommodated grain boundary sliding (DisGBS), whose flow law is recently determined in water-saturated conditions, is taken into account for the map.

Olivine grains in samples can be separated into three groups: coarse grain (mm scale), fine grain (100 μm scale) and ultrafine grain (10 μm scale). Coarse grains are characterized by well-developed dislocation walls and large MO indicating dislocation gliding parallel to a– and c-axes. Fine grains have large MOs and high dislocation densities, and show a decrease in concentrations of CPO upon recrystallization (defined by proportion of ultrafine neoblasts). These features indicate a grain-size sensitive flow of DisGBS. Most of ultrafine grains show minor MOs and low dislocation density. The CPOs are weaker than those of fine grains and their concentrations are weaker in more recrystallized domains. Grain sizes and stress estimations for coarse, fine and ultrafine grains are plotted, respectively, within the regimes of dislocation creep, DisGBS creep and DiGBS-diffusion creep in the mechanism map. This is consistent with the above microstructural observations.

In fine grains, dense dislocation walls of various orientations form cellular structures that define sub-grains. They have locally developed to grain boundaries marking neoblasts with minor dislocations. The sizes of the sub-grains and the recrystallized neoblasts are about 2 μm. This value is consistent with an experimentally determined grain size piezometer. Difference in dislocation density between the old and new grains has caused grain boundary migration resulting in growth of ultrafine neoblasts. The typical grain size of about 20 μm is interpreted as a steady-state one determined under co-operation of dislocation and diffusion processes.

The microstructural analyses of this study indicate that grain size reduction in a DisGBS regime was controlled by formation and movement of dislocations. Initial stage of recrystallization possibly induced extensive weakening due to switch of deformation mechanism between two grain size sensitive creeps. However, a subsequent recovery of grain size has inhibited the effect to be moderate. Water-rich condition enhances both dislocation and diffusion processes and, therefore, contribute to the development of the ultrafine-grained shear zone.