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Cooperation of dislocation gliding and grain boundary sliding in hydrous peridotite

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Deformational behavior of olivine in mantle wedge strongly affects subduction dynamics and geological processes at convergent margins (mantle flow, volcanism, earthquakes and orogeny). Many experimental works are addressed on the deformation under wet conditions. However, there are some difficulties in extrapolating the results to the conditions in subduction zones, especially for temperature conditions. A recent experimental study showed that a mechanism of grain boundary sliding (GBS) can be prevailing in polycrystalline olivine with interstitial hydrous melt, suggesting that a superplastical flow due to GBS of olivine possibly affects on a coupling between mantle wedge and subducting slab. Our EBSD analyses of natural hydrous peridotite revealed transitional structures due to cooperation of GBS and dislocation gliding. Here we present results of microstructural analyses that constrain a GBS flow law under wet conditions.

We used three dunite samples with different proportions of olivine porphyroclasts (SGB) (about 20, 40 and 60%), representing the various degrees of recrystallization. They were exposed at the Gongen outcrop that belongs to the Higashi-akaishi ultramafic body in the Sanbagawa metamorphic belt. All the samples include mm-sized planar grains of amphibole that define the strain geometry of samples. Strain shadows of chlorite and phlogopite around amphibole porphyroclasts indicate water-rich conditions during deformation. Geothermometry for fine Opx and Cpx in the matrix suggests deformational temperature of 700-770 oC. Pressures are inferred to be in a range of 1-2 GPa.

Using well indexed EBSD maps for these samples, olivine grains are separated into two fractions with and without significant internal misorientation (MO): we call them as wSGB and w/oSGB grains respectively. Then, we analyzed grain size, axial ratio and crystallographic preferred orientation (CPO) for each fraction and internal MOs of representative porphyroclasts using MTEX and HKL software.

The olivine CPO of wSGB is stronger in a more recrystallized sample and shows a weak concentration of a-axis parallel to amphibole lineation. On the other hand, the CPO of w/oSGB is weak and independent of the extent of recrystallization. Grains with SGB are elongated (aspect ratio = 2.0) whereas those without SGB are close to equant. Frequency distributions of grain sizes for wSGB and w/oSGB can be approximated as distinctive log-normal distributions and the mean values are $10^{2.3}$ micron for wSGB and $10^{2.0}$ micron for w/oSGB.

These observations suggest that larger grains are dominated by intracrystalline deformation with a dislocation mechanism. Sub-grain structures in porphyroclasts are consistent with [100] slip in {0kl} planes. On the other hand, smaller grains have been deformed under a mechanism without CPO strengthening. Almost equant shapes of olivine grains and high frequency of quadruple junctions of grain boundaries are consistent with GBS mechanisms rather than diffusion creep. Recrystallizing porphyroclasts is associated with nucleation of neoblasts in support of grain boundary migration, implying that diffusional processes have accommodated displacements among grains.

We interpreted that the microstructures of the hydrous dunite record a mechanism transition from dislocation gliding to diffusion-accommodated GBS due to grain size reduction. The critical grain size for mechanism transition lies between representative grain sizes of wSGB (200 micron) and w/oSGB (120 micron). Differential stress is estimated as 30-130 MPa based on recrystallized grain size piezometers. These values are, however, inconsistent with an extrapolation of an experimentally determined GBS flow law. This indicates that some refinement of the flow law parameters are required in order to discuss deformational mechanisms in cold thermal conditions expected for subduciton zones.

Keywords: olivine, microstructure, rheology, grain boundary sliding, hydrous peridotite, subduction zone