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Quantification of grain boundary sliding and grain rotation during diffusion creep of mantle rocks

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Existence of an anisotropy in the seismic wave velocity in Earth's upper mantle have been known for decades (Tanimoto and Anderson 1984). The seismic anisotropy is often explained by the crystallographic preferred orientation (CPO) of rock-forming minerals, which have anisotropic elasticity. In general, the CPO of olivine produced during dislocation creep is considered to be the primary cause of the anisotropy. Recently, our team showed that the CPO of olivine is produced even during diffusion creep (Miyazaki et al. 2013). However, the mechanism of the CPO development under diffusion creep is still not clear. The purpose of this study is to understand the mechanism in submicron scale by observations of samples surface after the sample deformation where the fine-scale strain markers were imposed.

We used a vacuum sintering technique to synthesize cylindrical samples which were composed of fine-grained forsterite plus 20 vol. % diopside (a combination that we denote Fo80Di20) and forsterite plus 35 vol. % enstatite (En). We polished the lateral side of the sample. Subsequently we imposed grooves on such surface with using a focused ion beam. These marker lines were parallel to the compression axis of sample deformation. We conducted uniaxial compression creep experiments at atmospheric pressure, temperatures of 1300oC and strain rates of 10^{-5} -10^{-4} s^{-1}. After the compression creep experiment, we observed the marker lines under scanning electron microscope (SEM) with field emission gun (JEOL 6500F installed at Nano-Manufacturing Institute, University of Tokyo) to observe how the markers were displaced after the deformation. Such observations allow to quantify the amount of grain boundary sliding and grain rotation due to a plastic deformation of the sample.

We succeeded to observe the marker lines after the deformation. Significant grain boundary sliding was detected from the offsets of the markers at numbers of grain boundaries. No distortion of the markers within the grains was found indicating the absence of intragranular deformation process such as a glide of dislocations. We quantified the grain rotation finding that the rotation angle increases with strain. The average angles in the sample of Fo80Di20 with strain of 3%, 7% and 14% were 1.2^o, 3.9^o, 6.5^o, respectively. We also found larger rotation angle of the grains in Fo80Di20 than in Fo65En35. Fo80Di20 is composed of anisotropic grains of Fo whereas Fo65En35 has isotropic grains, which may explain the difference in the grain rotation between the samples. The shape of anisotropic grains is crystallographically controlled resulting in a development of longer and straight grain boundaries. We assumed that grains were easier to glide at such boundaries resulting in development of CPO during diffusion creep (Miyazaki et al. 2013), which is an modified model of grain rotation during grain boundary sliding creep (Beere 1978). Our present result seems to support our CPO model.

Keywords: grain rotation, grain boundary sliding, CPO, creep