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In-situ observation of crystallographic preferred orientation of olivine deformed in simple shear: Implications for the

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The characteristics of the seismic anisotropy vary depending on the types of crystallographic preferred orientation (CPO) of olivine. Therefore, the pattern of the seismic anisotropy has been interpreted by taking into account the water- and pressure-induced fabric transitions of olivine in recent studies (Jung and Karato, 2001; Ohuchi et al., 2011). The fabric strength of olivine aggregates is also important when we evaluate the magnitude of the seismic anisotropy in the upper mantle. In the upper mantle, the steady-state fabric strength of olivine is expected to be achieved due to long time-scales of flows.

The dependency of the fabric strength of olivine aggregates on strain has been evaluated in only limited numbers of experimental studies (e.g., Bystricky et al., 2000). Bystrikcy et al. (2000) showed that total shear strains higher than 4 are needed to achieve the steady-state fabric strength of olivine (D-type fabric) at 0.3 GPa and 1473 K. However, it has been difficult to evaluate the detailed process of the development of fabrics because fabrics of recovered samples have been evaluated. Recently, we have developed experimental techniques for in-situ simple-shear deformation experiments using a D-DIA apparatus. In this paper, we briefly show that our recent experimental results on in-situ observations of stress, strain, and fabric developments in olivine samples.

Simple-shear deformation experiments on olivine aggregates at pressures P = 2-3 GPa, temperatures T = 1290-1490 K, and shear strain rates of 3E-4 s-1 were performed using a deformation-DIA apparatus installed at SPring-8. Shear strain (up to 5) was measured by the rotation of a platinum strain-marker, which was initially placed perpendicular to the shear direction. Differential stress, generated pressure, and CPO patterns of olivine samples were determined from two-dimensional X-ray diffraction patterns using software (IPAnalyzer, PDIndexer, and ReciPro: Seto et al., 2010; Seto, 2012). The CPO patterns of olivine in the recovered samples were also evaluated by the indexation of the electron backscattered diffraction (EBSD) patterns.

A-type olivine fabric was developed under dry conditions. The fabric strength increased with strain (<2), and steady-state fabric strength was achieved at shear strains about 2. The [010] axes strongly concentrated to the shear plane normal and its concentration increased with strain. Preferential alignments of the [100] and [001] axes were developed through increase in strain, though concentrations of the [100] and [001] axes were weaker than those of the [010] axes. Development of B-type olivine fabric was observed under wet conditions (~700 ppm H/Si). The fabric strength of B-type sample continuously increased with strain (up to 3). As same as the case of A-type samples, concentrations of the [010] axes were stronger than those of other axes in the B-type sample. Because the concentration of the [010] axes efficiently increases at strains larger than 1, seismic anisotropy (e.g., VSH/VSV) at shear strains = 1 is quite similar to that under the steady-state conditions.

Using the CPO data of the steady-state A-type fabrics, V_{SH}/V_{SV} of the asthenospheric upper mantle is estimated to be 1.027 (note that 70 vol.% of preferred-orientated olivine grains and 30 vol.% of random-orientated orthopyroxene grains are assumed in the calculation). This value is consistent with the global one-dimensional model reported by Visser et al. (2008). The V_{SH}/V_{SV} of the asthenospheric upper mantle is expected to have higher values in the case of B-type fabric (e.g., 1.035), which is harmonious with the global one-dimensional model reported by Panning and Romaniwics (2006). Our results show that seismic anisotropy in the upper mantle is mostly explained by the steady-state olivine fabrics (A- and B-types), and other effects (e.g., shape-preferred orientation of melt, CPO of other minerals) would be limited.

Keywords: olivine, crystallographic preferred orientation, in-situ observation, seismic anisotropy