The effect of water on seismic attenuation of upper mantle olivine and its implications for origin of the sharp lithosphere-asthenosphere boundary

*Chao Liu[1], Takashi Yoshino[1]

1. Institute for Planetary Materials, Okayama University

Seismological observations have shown attenuation of seismic waves in the asthenosphere (Dziewonski and Anderson, 1981; Takeuchi et al., 2017) and a sharp drop of seismic velocity at the lithosphere-asthenosphere boundary (LAB) (Kawakatsu et al., 2009; Rychert et al., 2009). Such a sharp change in shear wave velocity was caused by the difference of their physical properties between the lithosphere and asthenosphere rather than the thermal gradient (Karato et al., 2015; Kawakatsu et al., 2009). The presence of partial melt, reduced grain size or increased water content have been previously proposed as the origin of the geophysically observed anomalies in the oceanic asthenosphere (e.g., Anderson and Sammis, 1970; Hirth and Kohlstedt, 1996; Faul and Jackson, 2005; Yoshino et al., 2006; Jackson et al., 2010; Karato, 2012). Although partial melting has been considered as the most popular model, from the petrological point of view, such a sharp velocity drop at the LAB (~60 km) in the old oceanic upper mantle (120 Myr) is difficult to be explained by partial melting (Hirschmann, 2010).

To figure out the effects of water and grain size on seismic attenuation, attenuation factor Q^{-1} and Young's modulus of polycrystalline forsterite with variable grain sizes and water contents were measured by cyclic loading with oscillation periods ranging from 0.5 to 1000 s. The in situ X-ray radiographic observation was obtained in a deformation DIA press with a short-period cyclic loading system at the bending magnet beamline BL04B1 at SPring-8, Japan (Yoshino et al., 2016).

The results show that Q^{-1} increases with decreasing grain size and increasing the water content of forsterite, whereas Young's modulus decreases with decreasing grain size and increasing the water content of forsterite. To distinguish the effects of water content and grain size on attenuation quantitatively, all the Q^{-1} data were globally fitted by the modified power-law function (Jackson et al., 2002; Karato and Jung, 1998): $Q^{-1}=Ad^{m}\tau^{\alpha}C^{r}\exp(-\alpha\Delta H/RT)$, where Q^{-1} is a quality factor for attenuation, d is a grain size (μm), τ is a period (s), C is a water content (ppm wt. H_2O), ΔH is an activation enthalpy, R is the gas constant and T is the temperature (K). A= 121(50) $s^{-\alpha}$ μm^{m} (ppm wt. H_2O)^{r}, m= 0.28(3), α= 0.221(7), ΔH = 407(22) kJ.mol^{-1} and r= 0.33(6). The exponents of grain size (um) and water content (ppm wt. H_2O) exponent 0.28(3) and 0.34(6), respectively. The effect of grain size on attenuation is consistent with the previous study (Jackson et al., 2002). The shear modulus was calculated from the Young modulus assuming constant bulk modulus by the relationship of them: $G=3KE/(9k-E)$ (where G is shear modulus, E is Young's modulus and K is bulk modulus). Although the unrelaxed velocity contributed from unrelaxed shear modulus is still controversial (Karato, 2012), seismic velocities were calculated based on the relationship between shear wave velocity and shear modulus: $V_s= (G/\rho)^{1/2}$ (where V_s is shear velocity, G is shear modulus, and ρ is the density). Assuming that only shear modulus contributes to shear wave velocity, the effect of water on velocity is as follows: the samples with a higher water content of 147 ppm wt. H_2O shows a 10% lower shear modulus than of that with the water content of 77 ppm wt. H_2O at the temperature of 1100°C and the period of 1 s; then it could results in a 10% velocity drop of the sample with relative lower water (From $Vs= (G/\rho)^{1/2}$, so $dV_s/V_s= dG/G$). Even if we consider the effect of grain size on attenuation, the water could potentially be one possible factor to produce the seismic anomalies observed at the LAB.

Keywords: cyclic loading, in situ X-ray observation, lithosphere-asthenosphere boundary (LAB), seismic attenuation, upper mantle