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The determination of the enstatite phase boundary by in-situ X-ray observation: Implications for the nature of the X-discontinuity

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Many seismological studies have reported some discontinuities at depth of 200-340 km in the Earth's upper mantle. The discontinuities observed at ˜210 km depth are called as "Lehman discontinuity" and those at ˜300 km depth are called as "X-discontinuity" (e.g. Revenaugh and Jordan, 1991; Duess and Woodhouse, 2002; 2004; Williams and Revenaugh, 2005). Both seismic discontinuities are not distributed ubiquitously in the mantle but dispersed locally and their origins have not been understood.

We shed light on the origin of the X-discontinuity in this study. Some researchers proposed that the X-discontinuity is caused by a phase transformation from orthopyroxene (Opx) to high-pressure clinopyroxene in the mantle (e.g. Revenaugh and Jordan, 1991; Woodland, 1998; Kung et al., 2004; 2005; Miyake and Kawano, 2005). In order to examine this hypothesis, we carried out in-situ X-ray observation experiments at high-pressure and high-temperature on the enstatite, $MgSiO_3$, which is a major end-member of Opx, and determined the orthoenstatite/high-pressure clinoenstatite phase boundary.

A multi-anvil high-pressure apparatus "SPEED-Mk.II" installed at BL04B1, SPring-8 was used for in-situ X-ray observation experiments. We carried out two types of experiments, "in-situ observation experiments" and "in-situ quench experiments". In the former experiments, we have determined stable phases at given P-T condition by in-situ observation of phase transformation after increasing or decreasing pressure (or temperature). In the latter experiments, pressure and temperature were held at target conditions and the stable phases were determined from diffraction patterns and analyses on quenched samples using Raman spectroscopy (JASCO-NRS-2000C). $MgSiO_3$ gel powder was employed as a starting material in both experiments. In addition, mixture of orthoenstatite and low-pressure clinienstatite crystals was used in "in-situ quench experiments" to check reversal transformation. Pressure was determined by using equation of state of MgO by Speziale et al. (2001). The experiments were conducted at pressures of 5.7-9.4 GPa and temperatures of 600-1600 ^oC, and the stable phases of $MgSiO_3$ were determined at 22 different P-T conditions. Based on the results of experiments, the phase boundary was determined to be P (GPa) = 0.0029T (^oC) + 4.42. The phase boundary determined in this study is ˜1 GPa lower in pressure than that determined by previous study based on quench experiments (Pacalo and Gasparik, 1990).

Duess and Woodhouse (2004) summarized the relationship of observed depth of the X-discontinuity and velocity perturbations (delta-v_s). We plot the Opx phase boundary determined in this study on the depth-delta-v_s plots by Duess and Woodhouse (2004). The X-discontinuity (at 240-340 km) has no obvious Clapayron slope in all regions. However, some of the observed X-discontinuity at shallower depth (240-290 km) overlaps with the Opx phase boundary. Thus, the Opx phase transformation may be partly responsible for the X-discontinuity. The X-discontinuity at deeper depth (290-340 km) might be due to the coesite/stishovite phase transformation in SiO_2. This phase transformation is known to occur at ˜1 GPa higher in pressure than the Opx transformation (e.g. Zhang et al., 1996). At depth of the X-discontinuity (240-340 km), very few amount or none of Opx and SiO_2 phase exist in the primitive mantle composition such as pyrolite (Irifune and Isshiki, 1998). Therefore, the X-discontinuity would be the indicator of the chemical heterogeneity, such as presence of harzburgite or eclogite, in the upper mantle.