Precise Measurement of Seismic Wave Velocities under Deep Mantle Conditions

Variations in seismic wave velocities (Vp and Vs) as a function of depth are the most fundamental information to assess the materials in the Earth's deep interior. The elastic wave velocities of minerals have been measured by various methods, such as ultrasonic interferometry, Brillouin scattering, and ultrasonic resonance, but none of these methods have achieved measurements under the conditions of the mantle transition region (P = ~13-24 GPa, T = ~1700-2000 K). We have developed techniques of combined ultrasonic and *in situ* X-ray observations to precisely measure elastic wave velocities in sintered aggregates of high-pressure phases at simultaneous high pressure and high temperature. As a result, we succeeded in such measurements for representative mantle minerals at pressures up to ~19 GPa and temperatures up to ~1700K, equivalent to the P-T conditions of the middle part of the mantle transition region.

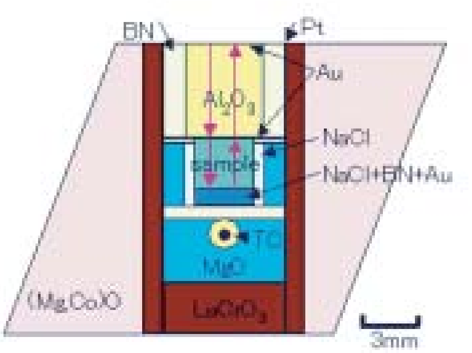

Fig.1. Cross section of cell assemblage used for present ultrasonic/X-ray diffraction measurement at high pressure and high temperature.

We first synthesized the sintered bodies of $(Mg_{0.9}Fe_{0.1})_2SiO_4$ ringwoodite and majorite with a complex chemical composition [1], which are supposed to be the major high-pressure phases in the mantle transition region, using a large (3000-ton) Kawai-type multianvil apparatus (ORANGE-3000) at Geodynamics Research Center, Ehime University. The top and bottom surfaces of the sintered rod samples with dimensions of ~2 mm both in diameter and length were carefully polished, and transferred to the cell assemblage for ultrasonic measurement, as illustrated in Fig. 1. Platinum tube heater was used, and temperature was measured using a W-Re thermocouple, while pressure was measured by the volume change in NaCl using an appropriate equation of state.

Combined *in situ* X-ray and ultrasonic measurements under high pressure and high temperature were conducted at **BL04B1**, using a 1500-ton multianvil press (SPEED-1500). A schematic illustration of the experimental setup and the X-ray optics used is shown in Fig. 2. Travel times for both P- and S-waves passing through the sample were measured by ultrasonic interferometry developed by [2], while the sample length under pressure and temperature was determined from the X-ray image of the sample using a high-resolution CCD camera. At the same time, X-ray diffraction data both from the sample and the pressure marker were acquired, and the produced pressure and the phases present were monitored throughout the run. An example of the ultrasonic echoes observed at almost the highest pressure and temperature is shown in Fig. 3.

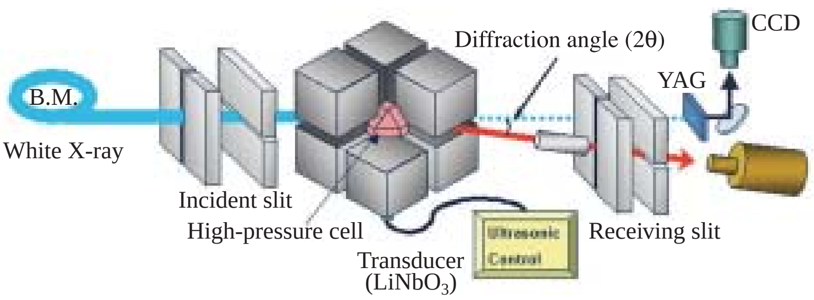

Fig. 2. Schematic illustration of experimental setup for combined ultrasonic and X-ray observations.

As velocity is basically defined by sample length divided by travel time, we can determine Vp and Vs as functions of pressure and temperature from the observed data sets. Figure 4 shows an example of such variations for the ringwoodite sample, which shows that both of these velocities increase with pressure but significantly decrease with increasing temperature. From these data, we are able to derive elastic moduli and their pressure/temperature derivatives quite precisely, which can be used to tightly constrain the mineralogy and chemistry of the mantle transition region, which have been controversial for many years (e.g., ref. [3]). Further extension of the pressure and temperature conditions toward those of the lower mantle is currently being pursued, which should yield comprehensive understanding of the constitution of the whole mantle.

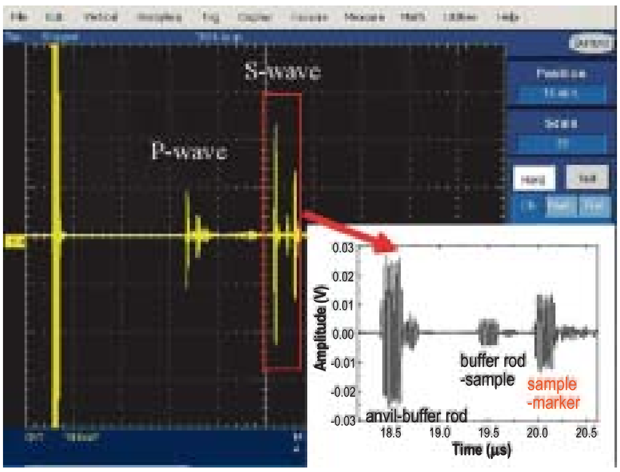

Fig. 3. Example of observed ultrasonic echoes at high pressure and high temperature.

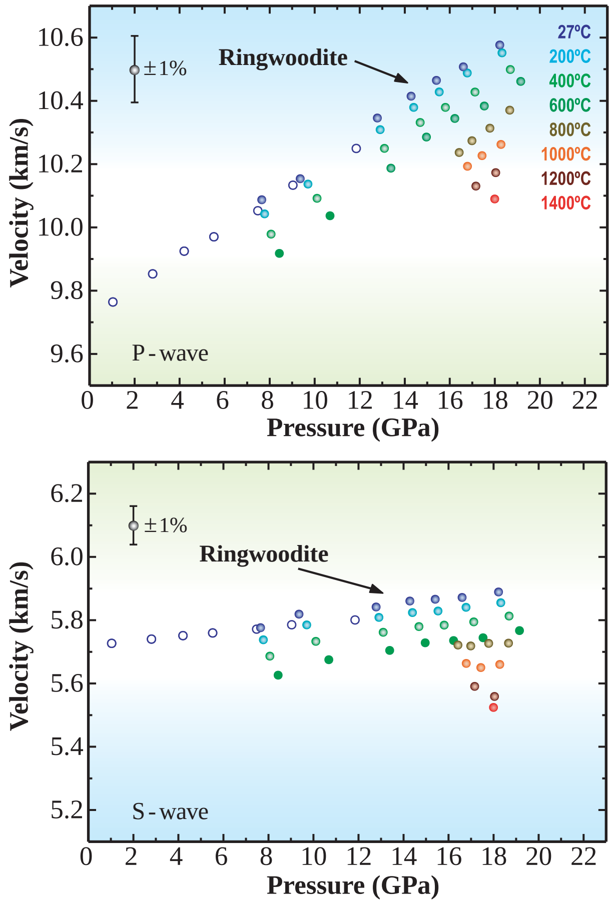

Fig. 4. Example of variations in Vp and Vs in sintered ringwoodite sample with pressure and temperature.

Yuji Higo*, Toru Inoue and Tetsuo Irifune

Geodynamics Research Center, Ehime University

*E-mail: higo@sci.ehime-u.ac.jp

References

[1] T. Irifune: Phys. Earth Planet. Inter. **45** (1987) 324.
[2] B. Li *et al.*: Phys. Earth Planet. Inter. **143** (2004) 599.
[3] D.L. Anderson and J.D. Bass: Nature **320** (1986) 321.