Japan Geoscience Union Meeting 2012
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SIT41-01 Room:302 Time:May 20 09:00-09:15

Toward modeling the anisotropic velocity structure beneath the Japanese subduction zone (1)

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Study of seismic anisotropy is one of the key problems in seismology because seismic anisotropy has close relationship with mantle dynamics and process of the earth evolution. However, it remains to be fully elucidated. Especially, the spatial distribution is poorly understood. Therefore, we launched modeling of seismic anisotropy structure.

Assuming that the modeling space is composed of weakly anisotropic medium, where hexagonal symmetry axis is in vertical, we estimate three-dimensional (3-D) *P*-wave isotropic velocity and radial anisotropy structures beneath the Japan subduction zone by P-wave travel-time inversion. In this presentation, we show the 3-D distributions of *P*-wave isotropic velocity and radial anisotropy beneath the Tohoku district. On the other hand, there are a lot of observations explained by the existence of horizontal azimuthal anisotropy. Therefore the immediate problem is the validity of the anisotropy assumed in the calculation.

Our ultimate purpose is to propose a comprehensive seismic velocity model including anisotropy beneath the Japan subduction zone and to explain various phenomena generated by anisotropy. Furthermore, based on the anisotropy model, we try to improve the understanding about the dynamics of the subduction zone.

Keywords: seismic anisotropy

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SIT41-02 Room:302 Time:May 20 09:15-09:30

Viscosity structure model around 410-km discontinuity: mineralogical approach

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The 410-km seismic discontinuity has been attributed to the pressure-induced phase transformation from olivine to wadsleyite in an olivine component of mantle peridotite. The phase transformation may induce abrupt change in viscosity at 410 km depth, and the viscosity discontinuity may play an important role in the dynamics of the upper mantle and the mantle transition zone. Attempts have been made to determine viscosity structure of deep mantle by geophysical observations (e.g., aisostasy data of post-glacial rebound and gravity anomaly observations), however, the obtained viscosity-depth profile has been controversial. On the other hand, the viscosity-depth profile of deep mantle can be determined based on experimental data of a deformation experiment at high pressure and temperature. Recently, we made technical developments in the deformation experiment adopting new technique for high-pressure generation, and achieved viscosity measurement at pressure-temperature conditions of the upper part of the mantle transition zone. In order to determine the viscosity at the upper part of the mantle transition zone, we conducted in situ stress-strain measurement of wadsleyite at 13-14 GPa, 1400-1700 K and strain rates of 3.1-15 x 10^{-5} s^{-1} using a deformation-DIA apparatus at BL04B1 beamline of SPring-8. We found that water enhanced plastic deformation of wadsleyite and water dependence of wadsleyite creep strength was larger than that of olivine. Based on the experimental result, viscosity decreases at the 410 km boundary at moderate water content while little viscosity contrast exists at dry condition. Moreover, these experimental results suggest that heterogeneity in water at the mantle transition zone leads large viscosity heterogeneity at the upper part of the mantle transition zone.

Keywords: 410-km discontinuity, wadsleyite, viscosity, creep strength, water, deformation experiment

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SIT41-03 Room:302 Time:May 20 09:30-09:45

Crystal structure of low-pressure $Ca_2AlSiO_{5.5}$ defect perovskite

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$CaSiO_3$ perovskite could dissolve Al_2O_3 component by forming oxygen vacancies. $Ca_2Al_2O_5$ brownmillerite structure can be regarded as an endmember for this dissolution mechanism, as all Si are replaced with Al. As a result, 1/6 of the oxygens are removed, and half of the Al are in tetrahedral coordination. If this is the dominant mechanism for Al dissolution into $CaSiO_3$ perovskite, the perovskite should contain oxygen vacancies, and physical properties such as elastic properties and transport properties would be significantly affected. For the intermediate composition of the $CaSiO_3$-$Ca_2Al_2O_5$ join, $Ca_2AlSiO_{5.5}$ with a rhombohedral perovskite structure was reported (Fitz Gerald & Ringwood, 1991). Later, a lower-pressure form of this phase was also found (Blab et al., 2007). Both phases were regarded to have oxygen-deficient perovskite-related structures, and structural models were proposed (Blab et al., 2007). However, the crystal structures have not been determined to date. Recently, we have demonstrated that a combination of NMR and SDPD (structure determination from powder data) is very powerful technique to solve unknown crystal structures (Kanzaki et al., 2011). In this study, we have applied this technique to the low-pressure $Ca_2AlSiO_{5.5}$ phase.

THe low-pressure phase of $Ca_2AlSiO_{5.5}$ was synthesized at 7 GPa and 1500 ^oC for 2H using a multi-anvil high-pressure device. Powder X-ray diffraction pattern for structural analysis was measured at BL19B2 of SPring-8 (for details, see Kanzaki et al., 2011). Local structures around Si and Al were studied by ^{29}Si MAS NMR and ^{27}Al 3Q MAS NMR. The crystal structure was solved using real-space searching program FOX (Favre-Nicolin & Cerny, 2002). The number and coordination of sites for Al and Si obtained by NMR were utilized for FOX calculation. After the initial structure was obtained, the structure was refined using Rietveld method (RIETAN-FP; Izumi & Momma, 2007).

Powder X-ray diffraction pattern of the phase is essentially identical to those reported by previous studies, and the obtained lattice parameters are consistent with those of Blab et al. (2007) with 8-fold superstructure. The space group was found to be C2/c. ^{29}Si MAS NMR spectrum revealed a single peak for tetrahedral Si. ^{27}Al 3Q MAS NMR spectrum revealed a single peak for octahedral Al. These results are in contrast to structure model proposed by Blab et al. (2007), in which both tetrahedral and octahedral Al and Si sites were assumed based on EELS spectra. Using NMR information as constraints, the crystal structure was successfully solved. The crystal structure of the phase is made of perovskite-like double-layer of AlO_6 octahedra and double-layer of tetrahedral SiO_4, stacked alternatively in the [111] direction of cubic perovskite, forming 8-fold superstructure. Oxygen is deficient at the middle of the double-layer of SiO_4, and 1/3 of the oxygens are missing from this oxygen close packing layer. The remaining oxygens are moved to form tetrahedral sites. One notable feature of the structure is that each SiO_4 tetrahedron has one non-bridging oxygen. This is in contrast to brownmillerite or perovskite structures, in which all oxygen are shared by two Al(Si). This new structure reveals another type of oxygen vacancy formation mode other than that of brownmillerite. Based on this structure, this phase is expected to have large anisotropic properties, such as higher compressibility in the c-direction.

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Keywords: Ca2AlSiO5.5, high pressure phase, crystal structure, powder X-ray diffraction, defect perovskite, nuclear magnetic resonance

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SIT41-04 Room:302 Time:May 20 09:45-10:00

P-wave tomography of Northeastern China observed with NECESSArray

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A passive broadband seismic experiment, NorthEast China Extended SeiSmic Array (NECESSArray) has been deployed since 2009 for two years. Northeastern China is a very interesting region because slabs subducting from the south Kuril and Japan trenches are stagnant in the mantle transition zone and extends to northeastern China, and above the stagnant slabs, Sino-Korea craton and unusual volcanism in the continent exist. The relationships between the deep slabs and shallow structures are important clues to understand the tectonic features.

P-wave travel-time picks of the NECESSArray stations were made interactively, while the teleseismic arrival time residuals were extracted using the adaptive stacking method. We picked more than 13,000 event-station pairs. Relative travel-times of P-wave between different stations were measured as a function of frequency using deep events of which P-waves separate in time from depth phases and very shallow events of which P-waves and depth phases are completely coincide. We found strong dispersive effect that is not predicted by our previous three dimensional (3D) P-wave model. We will combine the picked travel times and the frequency depended relative travel times to image a 3D P-wave heterogeneities of the northeastern China. We will present our first model at the meeting. The result shows fin structures of the stagnant Pacific slab. It is It is particularly worth noting that the northern part of the stagnant Japan slab seems to be buckling.

Keywords: Mantle, Mantle transition zone

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SIT41-05 Room:302 Time:May 20 10:00-10:15

Thermal equation of state of CaSiO3 perovskite

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CaSiO3 perovskite (Ca-perovskite) is one of the major constituent minerals in the deep mantle. In the lower mantle conditions, peridotitic mantle and subducted mid-oceanic ridge basalt (MORB) contain ~5 wt% and ~23 wt% Ca-Perovskite, respectively (Hirose et al., 1999, Wood, 2000, Hirose et al., 2005). In addition to MORB, recently, subduction of continental crusts is discussed in relation to the continental growth history. Experimental studies demonstrated that subducted continental crust may also contain Ca-perovskite at the pressure-temperature conditions near the 660-km discontinuity (Wu et al., 2009). Therefore, the density and elastic behavior of Ca-perovskite may be a key to understand the distribution of the subducted materials in the deep Earth. In the present study, we constructed a thermal equation of state of Ca-perovskite based on high-temperature diamond anvil cell (DAC) experiments.

The pressure-volume-temperature (P-V-T) relation of Ca-Perovskite was studied in a DAC with in situ X-ray diffraction method. For high-P-T generation, an externally-heated DAC and laser-heated DAC were used. A membrane gas regulating system was attached to both types of the DAC. Diamond anvils with 150 micron

beveled were used. A starting material was pure CaSiO3 glass mixed with platinum powder which served as a laser absorber and pressure standard. The sample mixture was sandwiched by NaCl pressure medium and was loaded into 50 micron sample chamber in a rhenium gasket. Angle-dispersive X-ray diffraction spectra were collected on a charge-coupled device (CCD) at the BL10XU beamline, SPring-8. Exposure times were 10 seconds. A monochromatized X-ray with a wavelength of about 0.41 A was collimated to 20 micron in diameter. Pressure was calculated from the unit-cell volume of Pt, using the thermal equation of state of Pt (Fei et al., 2004).

We conducted three separate compression runs at BL10XU of SPring-8.The sample was compressed to a certain pressure at 300 K and then the temperature was increased by the laser heating to synthesize Ca-perovskite. After the temperature was reached to a desired temperature, we started compression by increasing the gas pressure in the membrane system. During compression, we kept constant temperature so as to make isothermal compression experiments. We collected the XRD pattern at every 3-4 GPa. The maximum pressure we reached was 127 GPa. In one run, we conducted simultaneous heating of laser and external heating systems. First we increased the temperature by the external heating system to 700 K. Then, the laser was turned on to further increase temperature. This technique allowed us to reduce the temperature gradient in the sample and to attain much more stable heating compared to the laser heating alone.

We fitted thus obtained data to a thermal equation of state. We will present new P-V-T data of Ca-perovskite and discuss its density and elastic behavior at the deep lower mantle conditions.

Keywords: CaSiO3 perovskite, thermal equation state, X-ray diffraction, diamond anvil cell

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SIT41-06 Room:302 Time:May 20 10:15-10:30

Geophysical and mineralogical constraints on the post-spinel transformation: A case study for the Tonga slab

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We investigate the precise depth of the 660 km discontinuity for the Tonga slab, with the aim of determining the Clapeylon slope of the post-spinel transformation. We analyze waveform data from short period seismic networks at western United States and Japan for about 100 deep (h> 500 km) and intermediate-depth (h>200km) earthquakes within a small (nearly 200 km by 200 km) area near 20S. We investigate later phases in a time window from 3 s to 20 s after direct P waves and search for S-to-P converted waves at the 660 km discontinuity, which would represent the post-spinel transformation. We find that immediately below the foci of the deepest earthquakes the discontinuity is depressed down to the depths of 685+-5 km on average. We also observe that the discontinuity dips toward WNW by 10+-3 km within about 70 km laterally. We attempt to constrain the thermal structure near the S to P conversion points based on an assumption that the deepest earthquakes occur around the coldest core of the Tonga slab. The distribution of the hypocenters relocated in this study and previously published tomographic images of the same region indicate that the Tonga slab bends upward when it approaches the 660 km discontinuity and transiently stagnates around the discontinuity, before it ultimately impinges on the lower mantle. By using these observations as the constraints, we numerically model the thermal structure of the Tonga slab. We find that the S-to-P conversion points are located inside and near the bottom of the Tonga slab. We also estimate the temperature around the conversion points as 1200 +- 100 degrees C, which is 300+-100 K colder than the surrounding mantle. As the average depression of the discontinuity (down to 685+-5 km) corresponds to an pressure excess over the global average (660 km) by 1.0+-0.2 GPa, the assumption of equilibrium post-spinel transformation gives an estimate of the Clapeyron slope (C1) of -3.3(+1.3 -2.7) MPa/K. On the other hand the observation of the dip of the discontinuity and the computed temperature variation (by about 200 K) leads to another independent estimate of the Clapeyron slope (C2) of -2.0(+-1.0) MPa/K. The discrepancy between C1 and C2 is marginally significant and can be diminished by considering that the slab materials at the conversion points are currently descending across the phase boundary fast enough and thus the depth of the post-spinel transformation is controlled by nucleation kinetics as well as by the temperature. The nucleation overpressure may be on the order of 0.5 GPa for the post-spinel transformation.

Keywords: post-spinel transformation, 660km discontinuity, Tonga slab, Clapeylon slope, kinetics, seismic array

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SIT41-07 Room:302 Time:May 20 10:45-11:00

Efficient and accurate ab initio calculations on the lattice thermal conductivity: Applications to $MgSiO_3$ Pv and PPv

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Although thermal transport property of materials under pressure and temperature is of importance for understanding thermal structure and its thermal history of the Earth, both experimental and theoretical determinations of the thermal conductivity still remain technically challenging particularly at the deep mantle and core conditions. However, ab initio computational method has been recently extended to transport phenomena due to some technical advances. The intrinsic bulk thermal conduction of insulator is caused by lattice anharmonicty owing to phonon-phonon interactions. The key parameter to predict the lattice thermal conductivity, k, is thus the anharmonic coupling strength. Earlier theoretical works calculated k of MgO with various approaches such as molecular dynamics simulation and finite difference method. In those approaches, the sufficient simulation cell size should be taken account for accurate description of the long wavelength phonon scattering, and therefore the computational cost to calculate k tends to be expensive particularly for more complex minerals such as $MgSiO_3$. Actually, to the best of our knowledge, the k of $MgSiO_3$ perovskite (Mg-Pv) or post-perovskite (Mg-PPv) at high-pressure and high- temperature still not established by ab initio calculation. In contrast to those approaches, we evaluate the anharmonic coupling strength based on the density-functional perturbation theory. In this approach, the higher-order force tensors are calculated through a number of phonon decay channels obtained within the perturbative scheme taking care only of the primitive cell. We have been developing a technique for the calculation of the phonon damping function necessary to obtain the phonon relaxation time. Then k is calculated with additional harmonic-level of calculations.

In this presentation, we show that the k of Mg-Pv and Mg-PPv as a function of pressure and temperature. The k of Mg-Pv calculated at ambient condition is found to be in excellent agreement with the experiment (M. Osako and E. Ito, Geophys. Res. Lett. 18, 239, 1991). The current results are applied to evaluate the effective k and the total heat flow at the core-mantle boundary (CMB) with a composite averaging between MgO and $MgSiO_3$. This provides better constraints for the thermal evolution of the Earth.

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Keywords: ab initio calculations, lattice thermal conductivity, phonon-phonon interaction, deep mantle minerals

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SIT41-08 Room:302 Time:May 20 11:00-11:15

Hemispheric variation of the depth dependent attenuation structures of the top half of the inner core

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Previous studies suggested the existence of the hemispheric heterogeneities in the top 100 km of the inner core (ex. Wen and Niu, 2002). However, the depth dependent profiles of the attenuation have not been well constrained because of the poor resolution due to difficulties in analyzing contaminated core phase data. Iritani et al. [2010, GRL, 2011, SSJ] employed a waveform inversion method based on simulated annealing (SA) that enables to analyze complicated waveforms with phase overlapping and applied it to Hi-net and NECESSArray data. The obtained models show similar features that we have definite high attenuation zone around 200 km depth from ICB.

In this study, we collect high-quality core phase data from large number of broadband arrays to obtain the depth dependent profiles of the top half of the inner core in various regions. The resultant data set consists of about 8,500 waveform traces from PASSCAL arrays deployed in a number of places in the world, permanent European stations and USArray. Sampling regions are beneath northeastern Pacific, American and African continent for the western hemisphere of the inner core, and eastern and central Asia for the eastern hemisphere. We apply the same method as Iritani et al. [2010] to these data. In general, the obtained attenuation models for the western hemisphere show the gradually increase from ICB and have a peak around 200 km depth and those for the eastern hemisphere have a high attenuation zone at the top 150 km layer. However, almost all models show common features below 250 km depth and attenuation gradually decreases with depth. We also obtain the averaged structure models for each hemisphere, and similar features are observed. It appears that hemispheric heterogeneities of the inner core are confined in the top 150 - 250 km of the inner core.

Keywords: inner core, attenuation, hemispheric structure

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SIT41-09 Room:302 Time:May 20 11:15-11:30

Sound velocities of laser-shocked iron alloys under Earth's core condition

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When we consider the structure of the Earth's interior, the sound velocity is one of the important physical properties of the interior materials because it can be directly compared with the seismological data which can yield the physical properties of the Earth's interior. Although it needs to measure the sound velocity of the interior material under high pressure and temperature, the sound velocity measurement of the materials on the condition over 200 GPa and 4000 K, such as the Earth's core condition, is technically difficult in static compression technique (e.g. diamond anvil cell: DAC) (1-4). Therefore, in such higher pressure and temperature, dynamic compression technique, such as gas gun, is used. Although some works about the sound velocity of pure iron have been done by gas gun (5-7), it is not enough to discuss about the Earth's core which consists of iron alloy. Although Badro et al. (8) and Fiquet et al. (9) measured compressional sound velocity for some iron alloys (FeO, FeSi, FeS, FeS2, and Fe3C) at room temperature by inelastic x-ray scattering (IXS) at the DAC, the sound velocity data of liquid iron alloy is very few (10, 11).

We performed laser-shock experiments of liquid iron alloys at HIPER system of GXII laser in Institute of Laser Engineering, Osaka University (ILE) (12). We measured the sound velocities of iron alloys (Fe-Si, Fe-Ni-Si) under the Earth's core condition. The sound velocities were measured by side-on radiography (7). We will report the results of the sound velocity measurement for the laser-shocked iron alloys.

Part of this work was performed under the Joint Research of Institute of Laser Engineering, Osaka University.

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Keywords: Sound velocity, Laser, Shock wave, FeSi, Earth's core, Experiment