Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT39-P01 Room:Convention Hall Time:May 24 16:15-17:30

Whole-mantle 3-D velocity structure obtained with ISC, USArray and China seismic network data

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In the last 30 years, global seismic tomography has been used to determine the whole-mantle 3-D velocity structure, which has provided important information on the deep structures of subducting slabs and mantle plumes as well as deep Earth dynamics. Tomographic images under the hotspot volcanoes exhibit low-velocity anomalies, which may reflect hot mantle plumes, while the subducting slabs are generally imaged as high-velocity anomalies (e.g., Zhao, 2004, 2009; Zhao et al., 2013).

In this work, we have tried to determine a more detailed 3-D whole-mantle velocity model using global tomography. To obtain a high-resolution whole-mantle tomography, we adopted a much denser flexible-grid with a grid interval of 50-200 km in depth and ~200 km in the lateral direction. We used a great number of data recorded by the ISC, USArray and China seismic networks. Many previous global-tomography studies have used the ISC data, but the distribution of ISC seismic stations is very non-uniform in the world. By adding the USArray and China seismic data, we could obtain a better result. We used five kinds of P-wave data (P, pP, PP, PcP and Pdiff phases), and adopted a flexible-grid model parameterization, thus the mantle structure under the polar regions can be better determined (Zhao, 2009; Yamamoto and Zhao, 2010; Zhao et al., 2013). By using many kinds of seismic phases, the spatial resolution of the tomographic images has been much improved for the upper mantle under the oceanic regions. The 1-D iasp91 Earth model was adopted to be the starting model for the tomographic inversion. We have used about two million P-wave arrival times from about 13,000 earthquakes which have reliable hypocentral locations.

Our new whole-mantle P-wave tomography shows the subducting slabs clearly as high-velocity anomalies. The old stable continents (e.g., Eurasia, North America, Australia) also exhibit high velocities down to 200-300 km depths in the upper mantle. Low-velocity anomalies are visible in the upper mantle under the circum-Pacific regions, which reflect the hot anomalies under the active arc volcanoes. Under the hotspot volcanoes, low-velocity anomalies exist at some depth ranges in the upper and/or lower mantle. The overall pattern of our present tomography model is the same as that of the previous models, whereas the mantle structures under China and North America are better imaged due to the use of new data.

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Keywords: tomography, slab, mantle plume

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Effect of Al content on water partitioning between orthopyroxene and olivine: Implication for upper mantle dynamics

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Most minerals in the Earth's upper mantle contain small amounts of hydrogen (i.e. "water"), structurally bound as hydroxyl. Water has an important influence on the behavior of rock system. Water significantly affects physical property of minerals (e.g. ionic diffusion rates; (e.g., Goldsmith, 1987), electric conductivity; (e.g., Zhang et al., 2012), viscosity; (e.g., Karato and Jung, 2003)). Because small amount of water plays a key role in mantle rheology, precise knowledge on partitioning of water among mantle minerals is very important to understand the Earth's dynamics. For example, Mierdel et al. (2007) indicated that a high water solubility in aluminous orthopyroxene among mantle geotherm in the Earth's upper mantle would effectively contribute to a stiffening of the lithosphere. Water content of minerals is changed by chemical composition. For example, Al_2O_3 solubility of orthopyroxene (Opx) in the Earth's upper mantle decreases significantly with increasing pressure. In addition, Rauch and Keppler (2002) investigated effect of Al_2O_3 content on water solubility in orthopyroxene. The water solubility in orthopyroxene increases proportionally with increasing Al_2O_3 content. Thus water partitioning coefficient between orthopyroxene and olivine (Ol) may change significantly in the Earth's upper mantle. Therefore it is necessary to investigate the influence of Al_2O_3 in Opx on the partitioning coefficient of water between Opx and Ol under low OH concentration by high pressure temperature experiments.

In order to investigate the partitioning coefficient of water between Opx and Ol ($D_{(Opx/Ol)}$) under low OH concentration (4~400 ppm), we performed high-temperature and high-pressure experiments using Kawai-type multi-anvil apparatus (SPI-1000) and piston-cylinder apparatus at the Magma Factory, Tokyo Institute of Technology, using starting materials of natural Ol (Ol; KLB-1) and synthetic orthopyroxene with various Al content (Opx; $(Mg,Fe)_{2-x}Al_{2x}Si_{2-x}O_6$ (x=0, 0.0125, 0.025, 0.05)). Powdered minerals were enclosed in Mo foil capsule to form monomineralic layers with more than 300 micron meters in thickness each and put it in a $Au_{75}Pd_{25}$ capsule at pressures of 1, 3, 4.5 and 6 GPa and temperature of 1300^{o}C. Oxygen fugacity was controlled by Mo-MoO_2 buffers. Water contents were obtained with a vacuum type Fourier transform infrared spectrometer (FT-IR6100, IRT5000). Water content of minerals was calculated based on Paterson's (1982) calibration. Run products were polished down to doubly polished slab. After polishing and prior to FT-IR analysis, samples were stored in a vacuum oven at ~120^{o}C over night. Detection limit in the IR spectra at 3200-4000 cm^{-1} is typically less than 1 ppm due to very low back ground of vacuum type FT-IR.

Water partitioning coefficient between Ol and Al-free Opx are $D_{(Al-free\ Opx/Ol)}$ = 0.5~1.8. On the other hand, that between Al-bearing Opx and Ol are $D_{(Al-bearing\ Opx/Ol)} > 7.0$. Thus $D_{(Opx/Ol)}$ increases dramatically by incorporating Al_2O_3 in Opx at given temperature. $D_{(Opx/Ol)}$ also increases with increasing pressure at given Al_2O_3 content in Opx. In other words, the slope of the curve exponential approximation increases with pressure. Under low water fugacity conditions, $D_{(Opx/Ol)}$ stays nearly constant or increases with increasing pressure within the spinel-peridotite stability field. In the garnet peridotite field, however, $D_{(Opx/Ol)}$ decreases dramatically with increasing pressure from about 3 GPa to 6 GPa. Especially, from 4.5 GPa to 6 GPa, this value becomes dramatically smaller (~ 2 order) with increasing pressure. Then, $D_{(Opx/Ol)}$ becomes much smaller than unity in at pressures from 4.5 GPa to 6 GPa. A maximum value in $D_{(Opx/Ol)}$ at 3 GPa. This results indicate that viscosity of the upper mantle might become softer at deeper than 150 km.

Keywords: water partitioning, orthopyroxene, olivine, upper mantle, Al content

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Geometry of subducted slab: three-dimensional visualization of seismic tomographic model

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It is well known that the style of slab subducion in the mantle has a wide variation. Subducted slabs form convective downwelling of the Earth's lithosphere, which play a role in thermal and material transport from the surface into the Earth's interior, therefore describing the style of slab subduction is important to understand mantle dynamics and thermal evolution in the Earth. Seismic tomographic models have been developed to provide clear images of subducted slabs. Most of these images have been presented based on two-dimensional visualization of the models. Subducted slabs are marked by the region of positive values of seismic velocity perturbation continuing from trenches, but their profile cannot be defined quantitatively by a certain value of seismic velocity perturbation, in part because of the intrinsic nature of subducting slab and in part because of uncertainties and errors involved in tomographic model. Two-dimensional view of tomographic model does not depict the slab by a certain value of anomaly but shows spatial variation of seismic velocity, through which one may extract image of the subducted slab. However, it is difficult to understand the three-dimensional geometry of the subducted slab from the two-dimensional view of tomographic model, even if successive slices of the model are provided. This is because the cross-sectional image of a slab depends on the direction and the position of the cross-section, and some subducted slabs continue to each other in very complicated geometry. Seismic tomographic model is originally a three-dimensional scalar field. Three-dimensional visualization of the tomographic model should be more appropriate to illustrate precisely the geometry of the subducted slabs. Most of the previous methods for three-dimensional visualization display the iso-surface of seismic velocity perturbation, which, however, does not give in general natural image of the subducted slab because the slab cannot be delineated by a fixed value of the seismic velocity perturbation as mentioned above. In this study, we propose a new method for visualizing three-dimensionally seismic tomographic model to express the geometry of the subducted slabs. This method is an extension of the two-dimensional contour image in a sense that it can show variation of the seismic velocity perturbations. The mantle domain is divided into small blocks, and by rendering these blocks the three-dimensional tomographic image is obtained. Surfaces of a block are colored with their transparency dependent on the velocity perturbation in the block. The subducted slab is imaged as an assembly of blocks with various degree transparency by this new method, which is a most faithful representation of the slab image contained in the original tomographic model because no interpolation, extrapolation or smoothing is involved in the method. Hence, this method provides a slab image consistent with that obtained from two-dimensional cross-sections. We visualize here some subducted slabs around the Circum Pacific by using the new method to demonstrate that the complicated structures of the slabs difficult to interpret by two-dimensional images are figured out based on the three-dimensional view. The simple visualization proposed here will be useful to describe the geometry of subducted slabs and to clarify the evolutional processes of them.

Keywords: seismic tomographic model, subducted slab, three-dimensional visualization

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GHz Ultrasonic and Brillouin scattering in a Diamond Anvils Cell

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Advances in GHz ultrasonic technology have made it possible to make elastic wave measurements in a diamond anvils cell (DAC). This new technique is a powerful method to explore fundamental problems in earth physics and material science because of the faculties of the DAC to withstand extreme conditions. Combining GHz ultrasonic,Brillouin scattering method, and DAC, we can investigate elastic properties of mantle minerals at the coressponding pressure and temperature condition at the deep mantle.

Keywords: GHz ultrasonic, Brillouin scattering, Diamond Anvils Cell, mantle mineral, elasticity

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Crystal chemistry of oxygen deficient calcium aluminum silicate perovskites

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In last JPGU meeting (SIT41-03), we reported the crystal structure of a low-pressure $Ca_2AlSiO_{5.5}$ oxygen deficient perovskite phase. In this presentation, we further report the crystal structure of low-pressure $Ca_2Al_{0.8}Si_{1.2}O_{5.6}$ phase, another oxygen deficient phase along the $CaSiO_3$-$Ca_2Al_2O_5$ join (Blab et al, 2007).

THe $Ca_2Al_{0.8}Si_{1.2}O_{5.6}$ phase was synthesized at 11 GPa and 1500 ^{o}C 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 and Xue, 2012). 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 of sites and oxygen coordination numbers for Al and Si obtained by NMR were utilized for FOX calculations. After the structure was solved, it 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 a 10-fold superstructure. The space group was found to be C2/c. ^{29}Si MAS NMR spectrum revealed two peaks due to a tetrahedral and an octahedral Si site. ^{27}Al 3Q MAS NMR spectrum revealed a single peak for octahedral Al. Using this information as well as the structure of low-pressure $Ca_2AlSiO_{5.5}$ as guide, the crystal structure was successfully solved.

The crystal structure of the $Ca_2Al_{0.8}Si_{1.2}O_{5.6}$ phase is made of triple-layers of perovskite-like octahedral AlO_6/SiO_6 and double-layers of tetrahedral SiO_4, which are stacked alternatively in the [111] direction of cubic perovskite, forming a 10-fold superstructure. The triple-layers consist of a middle SiO_6 octahedral layer sandwitched by two AlO_6 octahedral layers. This strucutre can be obtained by inserting an octahedral Si layer in between the two AlO_6 octahedral layers of the structure for the low-pressure $Ca_2AlSiO_{5.5}$ phase. The double-layers of SiO_4 in both phases are similar, having deficient oxygens at the middle, with one non-bridging oxygen for each SiO_4 tetrahedron. This is in contrast to brownmillerite or perovskite structures, in which all oxygen are shared by two Al(Si).

Since $Ca_2Al_{0.8}Si_{1.2}O_{5.6}$ and $Ca_2AlSiO_{5.5}$ phases have triple and double octahedral layers, respectively, we could speculate another structure with a single octahedral layer. Such a phase in fact does exits as an ambient pressure phase ($BaCa_2MgSi_2O_8$), although the octahedral layer is made of MgO_6(Park et al., 2011). This structure is a variant of merwinite ($Ca_3MgSi_2O_8$). This suggests that merwinite can also be regarded as a perovskite-related structure. The present study thus revealed that there is a series of oxygen deficient perovskite structures with different numbers of octahedral layers. These phases revealed another type of oxygen deficient local structure that is different from the well-known brownmillerite-type and involves non-bridging oxygens. It might be realized in Al- or Fe^{3+}-containing calcium perovskite solid solutions.

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Keywords: silicate perovskite, oxygen defect, high pressure phase, crystal structure, NMR, $Ca_2Al_{0.8}Si_{1.2}O_{5.6}$

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The effect of potassium on the stability of NAL phase in the lower mantle

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High-Pressure (P) and high-temperature (T) experiments were conducted at P = 33 to 144 GPa and T = 1,800 to 2,700 K in order to examine phase relations on the join $Na_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ - $K_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$. Stable phases were identified in-situ at high P-T in a laser-heated diamond-anvil cell (DAC), based on synchrotron X-ray diffraction measurements. The results show that K-rich new aluminous (NAL) phase forms continuous solid solution on the join $Na_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ - $K_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ at 30 GPa. And, NAL is formed as a single phase up to the lowermost mantle conditions in both $Na_{0.50}K_{0.50}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ and $K_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ compositions. On the other hand, single-phase NAL is found only to 100 GPa at 2,500 K, and NAL coexists with calcium-ferrite type (CF) phase at 120 GPa and 2,300 K in $Na_{0.75}K_{0.25}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$. Considering the NAL phase with $Na_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ composition is stable only up to 45 GPa at 1,850 K, these results clearly indicate that the presence of potassium drastically expands the stability P-T field of NAL. In addition to hollandite, the NAL phase should be an important host of potassium in the deep lower mantle, formed in K-rich materials such as subducted continental crust.

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Phase relations and density changes in mid-ocean ridge basalt (MORB) under the lower mantle condition

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The phase relations and density of a mid-ocean ridge basalt (MORB) composition were investigated at pressures 43 and 53 GPa and at a temperature of 2050 K using multianvil apparatus with sintered diamond anvils. The unit-cell volumes of the samples and the produced pressures were determined using in situ X-ray diffraction measurements at SPring-8, while chemical analyses of the quenched samples were made using transmission electron microscopy (TEM). The observed diffraction lines were assigned to those of five phases, namely MgSiO3-rich perovskite phase (MgPv), CaSiO3-rich perovskite phase (CaPv), stishovite phase (St), calcium ferrite-type phase (CF), and the new alminous rich (NAL) phase. The phase proportions were estimated from a least squares mass balance calculation using chemical compositions of the phases obtained by the TEM analyses. The density of MORB at each pressure and temperature was calculated using the measured volumes, phase proportions, and chemical compositions of the coexisting phases. The present phase relations and phase proportions in MORB are consistent with the results of recent study (Ricolleau et al., 2010) except for the presence of a small amount of the NAL phase even at the pressure of 53 GPa. The calculated MORB densities were then compared with the density profile of PREM. It is demonstrated that MORB is 2.0%~2.8% denser than that of PREM at pressure of 43 GPa and 53 GPa, suggesting that basaltic oceanic crust may subduct to deeper region of the lower mantle.

Keywords: high pressure phase relation, MORB, lower mantle, in situ X-ray diffraction, multi-anvil apparatus

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Double CO_2 laser heating system for high P-T experiments of the deep Earth's materials in a diamond anvil cell

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A laser heated diamond anvil cell (LHDAC) has been widely used for understanding the behavior of materials under the high pressure and temperature conditions of the Earth's and planetary deep interiors. Near IR lasers such as YAG, YLF and fiber lasers, with a wavelength of about 1 micrometer, are generally used for LHDAC experiments. However, they are unsuitable for heating transparent materials including MgO, $MgSiO_3$, SiO_2 and $CaSiO_3$ without metal absorbers. The CO_2 laser with wavelength of about 10 micrometer enables to directly heat these materials. For laser heating system using near IR lasers, the double-sided laser heating technique has been improved to reduce the temperature gradients in the sample. Here, we developed a double-sided heating system using the CO_2 lasers for high P-T experiments of the mantle materials in a DAC.

The system consists of two CO_2 lasers, optical systems to focus the lasers and monitor the sample and a spectroradiometric system for temperature measurements. By using lenses designed for the CO_2 laser wavelength, the laser paths are separated from optical paths for collecting thermal radiation and visual observation because the collecting lenses made of SiO_2 glass high absorption of the wavelength. The both side lasers can be controlled separately. Two dimensional image of the sample are observed by CCD camera. Temperatures are measured by using the spectrometer. The heated position was synchronized with observed position by both CCD camera and spectrometer.

We will report the heating experiments of oxide by using developed double-sided CO_2 laser heating system.

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Sound velocity and density measurements of FeSi alloy by laser-shock compression

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It is well known that Earth's core consists of mainly iron (Fe) alloyed with a few percent of light elements. Several light elements (hydrogen, carbon, oxygen, silicon, sulfur, etc.) have been considered as the candidate of the composition of Earth's core, but its composition is still unclear. In order to constrain the core composition, it is important to measure the sound velocity of iron alloys because it can be directly compared with the seismic wave. Silicon (Si) has been proposed as a major light element in the inner core [Mao et al., 2012]. So we measured the sound velocity of laser-shocked FeSi alloy in order to investigate the effect of Si for sound velocity of liquid Fe in the outer core.

The starting sample was prepared by synthesizing from mixture of Fe (99.98% purity) and Si (99.9% purity) slugs at arc furnace. The compositions of Fe and Si are 66.5 wt.% and 33.5 wt.%, respectively. We measured sound velocities and densities of FeSi at high pressure and high temperature conditions at the large laser facility in Institute of Laser Engineering, Osaka University. The sound velocities were measured by the x-ray radiography [Shigemori et al., 2012].

We obtained the sound velocity and density of FeSi at pressures around 700 GPa. It is seen that Si has the effect of increasing the sound velocity of liquid Fe. Comparing our experimental results and PREM model [Dziewonski and Anderson, 1981], Si may be contained up to 17 wt.% at 135 GPa, and up to 6.4 wt.% at 330 GPa in the outer core.

Keywords: laser, sound velocity, outer core, FeSi

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Equation of state of $MgSiO_3$ post-perovskite phase

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Super Earths which have a few times of Earth's mass were found in the extra solar system. $MgSiO_3$ post-perovskite is a most fundamental silicate phase in such huge terrestrial planets. Thus, the compression behavior of $MgSiO_3$ at multi-megabar pressure is important to understand the Super Earth's interior. Here we report the compression behavior of $MgSiO_3$ post-perovskite phase up to 290 GPa.

Mg_2SiO_4 olivine powder mixed with 5 wt.% Au powder was used as a starting material, and $MgSiO_3$ glass powder used as the thermal insulator. We used a symmetric-type diamond anvil cell with the diamond anvils of culet size of 35 and 100 um for high pressure generation. The olivine pellet was coated by thin (150-200 nm) gold layers by conventional sputtering method and loaded into a sample hole that had been drilled in a precompressed tungsten gasket. Sample was annealed by the double-sided laser heating system with fiber laser at each pressure condition to minimize the deviatoric stress in the sample. The unit cell volume of the sample was determined by the synchrotron X-ray diffraction experiment at the SPring-8 BL10XU beamline, Japan. The experimental pressure was determined by the third order Birch?Murnaghan equation of state of gold as reported by Tsuchiya (2003).

$MgSiO_3$ post-perovskite phase was compressed up to 290 GPa. at 290 GPa, the cell parameters are a=2.341(3) A, b=7.570(11) A, c=5.823(3) A, and volume is V=103.19(46) A^3. This volume agrees with the volumes that estimated from ab initio calculations (Tsuchiya et al., 2005; Oganov and Ono, 2004) within 1 %.

Keywords: post-perovskite, Super Earth