Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT39-P01 Room:Poster Time:May 2 14:00-15:15

Effects of hydrous rocks on behaviors of subducting slabs

NAKAO, Atsushi[1*] ; IWAMORI, Hikaru[2] ; NAKAKUKI, Tomoeki[3]

[1]Department of Earth and Planetary Sciences, Tokyo Institute of Technology, [2]Institute for Research on Earth Evolution, JAMSTEC, [3]Department of Earth and Planetary Systems Science, Hiroshima University

Introduction: It is widely accepted that Earth's deep mantle contains water in several tens to several hundreds ppm, and that the water causes plate tectonics, volcanoes in subduction zones, deep earthquakes, and large-scale transportation of hydrophilic elements. A number of previous numerical studies on water transportation in the deep mantle are performed. In theses simulations, constant plate velocities and/or fixed plate shapes are synthetically imposed. In this study, we systematically investigated water transportation into the deep mantle and how the water changes the spontaneous behavior of the slab using a numerical model of whole mantle convection without external forces.

Numerical Model: Based on 2-D fluid mechanics simulation (Tagawa *et al*., 2007, *EPS*), the motion of mantle rocks is calculated. Advection of hydrous rocks is calculated using a Marker-And-Cell method, and dehydration/hydration reactions are evaluated by experimentally determined phase diagrams of the hydrous basalt and peridotite (Iwamori, 2007, *Chem. Geol.*). Effects of the hydrous rocks are formularized in constitutive laws (*e.g*. Karato and Wu, 1993, *Science*) and a state equation; therefore, the water transportation and the motion of solid phase are interactive. Only two parameters r (= 0, 0.7, 1.0, 1.93) in constitutive laws (viscosity reduction by hydration) and β (= 0, 1.0, 2.0) in a state equation (density reduction by hydration) are treated as variable, and other settings are equalized.

Results and Discussion: The reaction path (p-T path) of subducting hydrous rocks in each result is the same as that of southwest Japan (Iwamori, 2007), and a hydrous ultramafic layer along the slab surface ($\sim$2000 ppmH_2O in NAMs) is formed beneath $\sim$200-km depth. Large hydration weakening seems essential for back arc spreading because the subducting slab causes tensile stress within the overlying continental plate, and then the expansive deformation is concentrated on the hydrous weak area. Comparing the results with each other, at large r, the subduction rate increases. This is because a hydrous layer reduces viscous resistance above the slab. In contrast, at large β, the subduction rate decreases. This is because the positive buoyancy of the hydrous layer partially canceled to the gravitational instability of the slab. The subduction rate significantly controls the velocity field of the corner flow in the mantle wedge. A rapid corner flow causes strong suction force along the slab surface, which determines the angle of subduction. This also causes effective heat advection from the deep mantle to the back arc, and that contributes rapid, sustainable back arc spreading. The analytical discussion enables us to understand why scenarios differ when r and β are changed. In east Asia, stagnant slabs and back arcs are widely distributed. To realize both, large r and small β are needed. This is because they require strong corner flow, but β declines it. Thus the slab shapes and the period of back arc spreading may constrain scales of hydrous buoyancy and hydrous weakening in the mantle wedge comparing with those in nature.

Keywords: water transportation, free convection, subduction dynamics, plate velocity, big mantle wedge

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SIT39-P02 Room:Poster Time:May 2 14:00-15:15

Regional scale variation of splitting intensity observed in Japanese islands by Hi-net II

OGAWA, Naoto[1*] ; KAWAKATSU, Hitoshi[1] ; TAKEUCHI, Nozomu[1] ; SHIOMI, Katsuhiko[2]

[1]Earthquake Research Institute, the University of Tokyo, [2]National Research Institute for Earth Science and Disaster Prevention

To systematically investigate the spatial variation of seismic anisotropy around the Japanese islands, we measured the splitting intensity (SI) of teleseismic SKS and SKKS phases by Hi-net (Ogawa et al., 2013, SSJ). SI is first introduced by Chevrot (2000) as a method of measuring seismic anisotropy; it is based on cross-correlation of polarized waveforms, and can be modeled like the delay time of seismic tomography considering the effect of finite frequency (e.g., Favier and Chevrot, 2003). In this study, we extend our previous work by measuring SI for a large number of dataset recorded by the dense seismic station network, Hi-net. We use data from tilt-meters of Hi-net from October in 2000 to September in 2013. We have selected the recordings of SKS phases for epicentral distances between 90 and 135 degrees and SKKS beyond 105 degrees, and Mw larger than 6.0, resulting in a total number of events to be 189 that is much larger than the previous case. For the actual analysis, we apply a band-pass filter between 0.05 and 0.125 Hz, and the measurement error of each SI will be carefully estimated using a new formulation, as there appears an error in the Chevrot (2000)'s original treatment. The preliminary analysis indicates regional scale variations of SI patterns that apparently depend on the back azimuth of seismic event, which may be influenced by the subducting slabs.

Keywords: seismic anisotropy, splitting intensity

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SIT39-P03 Room:Poster Time:May 2 14:00-15:15

Comparison of phase relations in pyrolite, MORB and harzburgite across 660-km discontinuity

ISHII, Takayuki[1*] ; KOJITANI, Hiroshi[1] ; AKAOGI, Masaki[1]

[1]Depertment of chemistry, Gakushuin University

Pyrolite is the model rock which composes the average upper mantle. It is accepted that 660-km seismic discontinuity is formed by post-spinel transition of pyrolite. MORB (mid-ocean ridge basalt) and harzburgite in slabs subduct to 660-km seismic discontinuity due to their higher densities than pyrolitic average mantle. It has been considered that the density cross-over between pyrolite and slab materials occurs due to post-spinel transition in pyrolite at the 660-km discontinuity, and MORB and harzburgite are trapped around the depth (e.g. Ringwood and Irifune, 1988). Therefore, the phase transition pressures of these mantle rocks are the important parameters to elucidate the dynamics around 660-km seismic discontinuity. We investigated detailed phase relations of pyrolite, MORB and harzburgite with multi-sample cell technique.

The starting materials were prepared from the oxide mixtures of pyrolite, MORB and harzburgite composition after McDonugh and Sun (1995) (excluding MnO, K_2O and P_2O_5), Melson et al. (1976) (P_2O_5) and Michael and Bonatti (1975), respectively. High-pressure and high-temperature experiments by quench method were performed at about 20-28 GPa and 1600-2200C for 2-10 hours using a Kawai-type 6-8 multianvil high-pressure apparatus at Gakushuin University. These samples were packed with pressure calibrants ($MgSiO_3$ or pyrope) in a Re multi-sample capsule with four holes. Temperature was controlled with a LaCrO3 heater and measured with a W5%Re-W26%Re thermocouple inserted in a Cr_2O_3-doped MgO pressure medium. Phases of recovered samples were identified with microfocus-Xray diffractometer and SEM-EDS.

In pyrolite at 1600-2200C, the mineral assemblage of $MgSiO_3$-rich perovskite (Mpv) + magnesiowustite (Mw) + garnet (Gt) + $CaSiO_3$-perovskite (Cpv) is stable at pressure range of 22-24 GPa, and changes to that of Mpv + Mw + Cpv above 24 GPa. The mineral assemblage of ringwoodite (Rw) + Gt + Cpv at 1600C transforms to that of Rw + Mw + Gt + Cpv due to transition of Rw to Gt + Mw at 1800-2000C, and Rw disappears perfectly above 2200C. In MORB, the mineral assemblage of Gt + stishovite (St) + Cpv changes to that of Mpv + St + Al-rich phase + Cpv with continuous post-garnet transition. In harzburgite at 1600C, the mineral assemblage of akimotoite (Ak) + Rw + Gt changes to that of Mpv + Mw by post-spinel transition after the Ak to Mpv transition. Above 1800C, no Ak was observed.

At 1600C, post-spinel transition in pyrolite occurred by about 0.5 GPa and 2 GPa lower pressure than that of harzburgite and post-garnet transition in MORB, respectively. The Clapeyron slope of post-spinel transition in harzburgite is larger than that of pyrolite, and both boundaries intersect at 2000C. From the comparisons of density profiles at 1600C, MORB and harzburgite have lower densities than pyrolite by post-spinel transition in pyrolite.

Keywords: post-spinel transition, post-garnet transition, 660-km discontinuity, pyrolite, MORB, harzburgite

SIT39-P04 Room:Poster Time:May 2 14:00-15:15

Melting experiments in the system Fe-Xe and Earth's missing xenon

MORI, Yuko[1*] ; HIROSE, Kei[2] ; TATENO, Shigehiko[1] ; OZAWA, Haruka[3] ; OHISHI, Yasuo[4]

[1]Dept. of Earth & Planetary Sciences, Tokyo Institute of Technology, [2]Earth-Life Science Institute, Tokyo Institute of Technology, [3]Japan Agency for Marine-Earth Science and Technology, [4]Japan Synchrotron Radiation Research Institute,

The abundances of noble gases in the Earth's atmosphere should be consistent with those in CI chondrite. However, xenon in the atmosphere is depleted relative to chondritic abundance, while lighter rare gases, Ne,Ar, and Kr, are less depleted. This is the so-called "missing xenon" problem and its reservoir has been discussed for a long time. Since xenon is too heavy to escape toward outer space, the missing xenon (Xe) might be hidden in the deep Earth.

The potential reservoirs are the mantle and core because xenon has a good reactivity under high pressure. Although extensive studies on the reactions of Xe and various mantle materials have been performed, none of those found a Xe reservoir (e.g., Sanloup et al., 2005; 2011; Brock et al., 2011). On the other hand, the alloying of iron with xenon has been expected based on the fact that Xe becomes metallic above 130 GPa (e.g., Eremets et al., 2000). While first-principle calculations suggested that the solubility of xenon in hcp iron is 0.8 mol% at Earth's core conditions (Lee et al., 2006), experimental study showed that the solid Fe-Xe reaction did not occur at least up to 155 GPa and 3000 K (Nishio-Hamane et al., 2010). Here we performed melting experiments in the Fe-Xe system to 86 GPa and 6450 K.

High pressure and temperature (P-T) conditions were generated in a laser-heated diamond-anvil cell. We used pure iron foil as a starting material. Xe was loaded cryogenically. Angle-dispersive X-ray diffraction (XRD) measurements in-situ at high P-T were conducted at BL10XU, SPring-8. The textural and chemical characterizations of recovered samples were made by using a field-emission-type scannning electron-microprobe (FE-SEM) equipped with energy dispersive x-ray spectrometry (EDS). Both cross section and surface of a sample were carefully examined by combining a focused Ga ion beam (FIB) with FE-SEM.

Any evidence for the reaction was not observed at least up to 83 GPa and 3810 K based on both XRD measurements and chemical analyses. On the other hand, chemical analysis on the sample recovered from 86 GPa and 6450 K, the highest P-T condition achieved in this study, showed Fe alloyed with up to ~1.6 wt.% Xe as tiny grains. This sample had a difference in the texture between heated and unheated regions. We calculated the concentration of Xe in the entire molten area by assuming the heated region and the small grains of Fe-Xe alloy as a cylinder and spheres, respectively. The xenon content was estimated to be 0.02 wt. % for the heated area which is high enough to account for the missing xenon problem (10^{-10} wt.% Xe in the core). The present results could be a clue to solve the "missing xenon" paradox. Since the temperature of the present Earth's core is most likely lower than 6000 K, xenon might be incorporated into the core during Earth's early history at higher temperature.

Keywords: Missing Xe, melting experiments, High pressure and temperature, core

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SIT39-P05 Room:Poster Time:May 2 14:00-15:15

Whole-mantle P-wave radial anisotropy tomography

KITAGAWA, Hiroki[1*] ; ZHAO, Dapeng[1] ; TOYOKUNI, Genti[1]

[1]RCPEVE, Tohoku Univ.

1. Introduction

When studying seismic anisotropy, it is generally assumed that the medium under study has a hexagonal symmetry (i.e., transverse isotropy). In most cases, the axis of symmetry is assumed in the vertical direction (i.e., azimuthal anisotropy) or in the horizontal plane (i.e., radial anisotropy). Seismic anisotropy is induced mainly by the lattice-preferred orientation (LPO) of anisotropic minerals, especially for the olivine in the mantle (e.g., Zhang & Karato, 1995; Tommasi et al., 2000; Kaminski & Ribe, 2001). Studying seismic anisotropy is very important for understanding the structure and dynamics of the Earth's interior (e.g., Silver, 1996). Many previous studies have investigated P-wave azimuthal anisotropy tomography for several regions including the Japan Islands. Recently, Wang & Zhao (2013) studied P-wave radial anisotropy tomography of the Kyushu and Tohoku subduction zones. In this work, we have attempted to conduct global tomography to understand 3-D P-wave radial anisotropy in the whole mantle.

2. Data and method

In this study we used 12,657 earthquakes recorded by 6765 seismic stations which were selected from the ISC-EHB catalog by Yamamoto & Zhao, 2010. About 1.4 million arrival times of P, pP, PP, PcP and Pdiff waves are used in the tomographic inversion. The method of radial anisotropy tomography by Wang & Zhao (2013) is combined with the flexible-grid global tomography of Zhao et al. (2013) to conduct the whole-mantle tomographic inversion in this work.

3. Result

In comparison with the isotropic tomographic model, our anisotropic tomography model results in a smaller root-mean-square travel-time residual, suggesting that the anisotropic tomography model fits the data better. The isotropic component of this model is very consistent with the previous isotropic tomography. In upper mantle, low-velocity anomalies along the Pacific Rim, and high-velocity anomalies under the stable continents are visible. In addition, low-velocity anomalies exist from the surface down to the core-mantle boundary under South Pacific and East Africa, which represent two superplumes. The anisotropic results show that vertical velocity is greater than horizontal velocity under some regions such as South Pacific, which may reflect the mantle upwelling.

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Keywords: tomography, mantle, anisotropy tomography

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SIT39-P06 Room:Poster Time:May 2 14:00-15:15

Melting experiments on the MgO-$MgSiO_3$ system using double CO_2 lasers heated diamond anvil cell

OHNISHI, Satoka[1*] ; KIMURA, Tomoaki[1] ; KUWAYAMA, Yasuhiro[1]

[1]Geodynamics Research Center, Ehime University

Seismological studies suggest the presence of ultralow-velocity zones (ULVZ) near the core mantle boundary (CMB). Partial melting of the lower mantle materials has been proposed to explain these zones, but experimental validation at the appropriate temperature and pressure regimes remains challenging. The melting curve of the lower mantle material is a key to constrain the existence of melt at the base of the mantle. A laser heated diamond anvil cell (LHDAC) provides an enabling tool for determination of melting temperatures of materials under high *P-T* conditions. Although YAG, YLF lasers (the wavelengths are about 1 μm) have been generally used for LHDAC experiments, the use of metal absorber is required to heat silicate materials. However, the thermal absorber may cause a chemical reaction and a temperature gradient in the sample. The accuracy of temperature determination is suffered from the chemical reaction and the temperature gradient. In contrast, the CO_2 laser with the wavelength of about 10 μm can directly heat silicate materials. For the minimization of temperature gradients, double-sided heating system for LHDAC was suggested by Shen *et al*. (1996). This technique using the YAG laser has been widely used to study the behavior of materials under high *P-T* conditions. However, the double CO_2 laser heating system has not been used due to the wavelength of this laser is different from that of visible light.

The requirements for the pressure medium in laser heating experiments are low thermal conductivity and chemical inertness. Ar, which is a noble gas, is one of the suitable pressure mediums. However, loading Ar into the DAC is difficult under room temperature and ambient pressure. Therefore, a simplified method to load Ar into the DAC is required. In this study, I established new experimental technique for the minimization of temperature gradients and chemical reactions and performed melting experiments of the lower mantle materials using LHDAC.

First, a double-sided heating system using CO_2 laser was developed by separating optical elements. This system consists of the heating system using two CO_2 lasers which have the high power (100 W), the observation systems and the temperature measurement system. By using lenses designed for the CO_2 laser wavelength, the laser system is separated from observation and temperature measurement system. Two dimensional images and radiation spectrums are observed by Charge Coupled Device (CCD) camera and spectrometer, respectively.

Second, a simplified method to load Ar into the DAC was developed by the cryogenic technique. In this technique, Ar is cooled using liquefied N_2 until it forms a liquid, and the liquefied Ar is loaded into the sample chamber of the DAC. Cu was used to enhance cooling efficiency.

Finally, I performed melting experiments of the lower mantle materials using the double CO_2 lasers heated diamond anvil cell and Ar as the pressure medium. I used forsterite (Mg_2SiO_4) and mixtures of MgO and $MgSiO_3$ as the starting material. After the complete pressure release, the sample was recovered from the DAC and examined by FE-SEM. From the surface texture of recovered samples, I discussed melting temperatures of the lower mantle materials under high *P-T* conditions.

The double CO_2 laser heating and loading Ar methods developed in this study could powerful tool for determination of melting temperatures of the lower mantle materials.

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SIT39-P07 Room:Poster Time:May 2 14:00-15:15

Ultra high pressure generation using the double-stage diamond anvil cell

SAKAI, Takeshi[1*] ; YAGI, Takehiko[1] ; OHFUJI, Hiroaki[1] ; IRIFUNE, Tetsuo[1] ; OHISHI, Yasuo[3] ; HIRAO, Naohisa[3] ; SUZUKI, Yuya[4] ; KURODA, Yasushi[4] ; ASAKAWA, Takayuki[4] ; KANEMURA, Takashi[4]

[1]Geodynamics Research Center, Ehime University, [2]Earth-Life Scinece Institute, Tokyo Institute of Technology, [3]Japan Synchrotron Radiation Research Institute, [4]HITACHI High-Technologies

1 TPa region is still far frontier for the high pressure physics. The maximum pressure generated by diamond anvil cell is about 400 GPa (Akahama and Kawamura, 2010). On the other hand, recently Dubrovinsky et al. (2012) reported the generation of 640 GPa using double stage diamond anvil cell. This new technique makes 1TPa reagion a realistic goal for static compression experiments. But there are some technical difficulties such as a second-stage anvil's shape controllability, shift under pressure, and the difficulty of a sample filling. These problems depress the reproducibility of experiment.

In this study, second-stage microanvils were made by focused ion beam system from the nano-polycrystalline diamond (NPD) or single crystal (SC) diamond. Micro manufacturing using focused ion beam system enables us to control anvil shape, process any materials (NPD, SC and also sample), and fill the sample between the second-stage anvil gap precisely. Using this method, we generated up to 340 GPa. This method has a high reproducibility of the experiment. Thus, we can optimize the experimental parameters such as an anvil shape, confining pressure and so on.

Keywords: nano-polycrystalline diamond (NPD), microanvil

SIT39-P08 Room:Poster Time:May 2 14:00-15:15

Ab initio molecular dynamics study on a phase separation in liquid Fe-O

OHSUMI, Masanao[1*] ; TSUCHIYA, Taku[1] ; ICHIKAWA, Hiroki[1]

[1]Geodynamic Research Center, Ehime University

The Earth's outer core is mainly composed of liquid Fe-Ni alloy. The density of the outer core is, however, ~10% smaller than this alloy. The density deficit indicates that substantial amount of light elements are present in the outer core [Birch, 1964]. Recent seismological observations proposed that seismic wave velocity is ~3% slower than PREM below a few hundred kilometers of the CMB [Helffrich and Kaneshima, 2010]. The low-velocity anomaly is considered to be cause by stratification. However, mechanisms of the stratification have not been clarified yet. One possible cause is phase separation into Fe-rich and light element-rich liquid. Oxygen is one of the most important light elements, because an iron-oxygen phase separation was observed experimentally at low-pressure condition [Tsuno et al., 2007]. This immiscible behavior is, however, still unclear at the outer core pressure.

In this study, we calculated liquid Fe-O alloy at the outer core condition by means of *ab initio* molecular dynamics simulations. First, we analyzed local structures of liquid Fe-O alloy to detect signs of phase separation. Second, we evaluated its excess enthalpy. Both indicate that the liquid was well-mixed. Finally, we computed P-wave velocity in liquid Fe-O alloy. P-wave velocity was found to increase with increasing the oxygen concentration. All these results suggest that the simple enrichment process is less suitable to explain the low-velocity anomaly.

Keywords: ab initio molecular dynamics simulation, phase separation, liquid Fe-O alloy

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SIT39-P09 Room:Poster Time:May 2 14:00-15:15

In situ X-ray observations of phase transitions in MgCr2O4 to 30 GPa using Kawai-type multianvil apparatus

KUNIMOTO, Takehiro[1*] ; IRIFUNE, Tetsuo[1] ; FUJINO, Kiyoshi[1]

[1]Ehime University

Phase relations in $MgCr_2O_4$ (magnesiochromite) have been studied up to 30 GPa and 1600 ℃, using a large volume Kawai-type multianvil apparatus and in situ X-ray diffraction measurements system installed at SPring-8/BL04B1. $MgCr_2O_4$ spinel dissociates into $Mg_2Cr_2O_5$ (orthorhombic type) + Cr_2O_3 (eskolate) at 9 GPa and 1200 ℃, and then reunion to higher pressure phase ($CaTi_2O_4$ type) at 22 GPa and 1200 ℃. Moreover, another high-pressure phase was observed above $CaTi_2O_4$ type structure phase, and this phase was unquenchable to ambient condition. In addition, pressure-induced phase transition in $MgCr_2O_4$ was confirmed without decomposition under cold compression process. In this cause, Magnesiochromite is directly transformed to high-pressure phase through the mixture of spinel and high-pressure phase. In this study, $CaFe_2O_4$ type and ε-phase, which reported in earlier studies in $MgAl_2O_4$ were not observed. The Birch-Murnaghan equation of state was used for least-squares fitting of the volume data (assuming K_0' =4). Thus, determined zero-pressure bulk modulus (K_0) of the $CaTi_2O_4$ type $MgCr_2O_4$ was 195 GPa.

In this presentation, we will discuss further details of high-pressure phase relation and physical properties of high-pressure phases in $MgCr_2O_4$ series.

Keywords: Magnesiochromite, in situ X-ray diffraction measurement, Kawai-type multianvil apparatus, phase transition

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SIT39-P10 Room:Poster Time:May 2 14:00-15:15

Sound velocities of laser-shocked Fe-Ni alloys under Earth core conditions

SAKAIYA, Tatsuhiro[1*] ; YOKOYAMA, Naoya[1] ; HOSOGI, Ryota[1] ; KONDO, Tadashi[1] ; TERASAKI, Hidenori[1] ; SHIGEMORI, Keisuke[2] ; HIRONAKA, Yoichiro[2]

[1]Graduate School of Science, Osaka University, [2]Institute of Laser Engineering, Osaka University

When we consider the structure of 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 (1) which can yield the physical properties of the Earth's interior. Cosmochemical data and the composition of iron meteorites suggest that Earth's core contains mainly Fe-Ni alloy with 5-25 wt.% Ni. Although Lin et al. (2) and Kantor et al. (3) measured compressional sound velocities of Fe-Ni alloys at room temperature by inelastic x-ray scattering (IXS) at diamond anvil cell (DAC), the sound velocity data of liquid Fe-Ni alloys is very few (4).

We performed laser-shock experiments of liquid Fe-Ni alloys at HIPER system of Gekko-XII laser in Institute of Laser Engineering, Osaka University (5). Sound velocities were measured by side-on radiography (6, 7). We obtained sound velocities of Fe-Ni alloys at pressures up to 770 GPa. The sound velocity of Fe-Ni alloy was about 10% lower than that of liquid Fe at inner core boundary (ICB) pressure.

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Keywords: sound velocity, laser, shock wave, iron alloy, Earth's core, experiment