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


SIT39-01 Room:416 Time:May 2 09:00-09:15

# A new form of the dynamics equation of Maxwellian visco-elastic media

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Dynamical property of the earth's interior down to the core-mantle boundary has so far been considered to be a Maxwellian visco-elastic medium. It behaves as an elastic body for short time-scale phenomena, while on a very long time-scale it shows fluid-like behavior. So the Navier-Stokes equation for viscous fluids is considered to be appropriate for describing mantle convection, and numerical simulations have been made based on the equation.

As a phenomenon for which both elastic body property and viscous fluid property are essential post-glacial uplift has been discussed based on the constitutive equation proposed by Maxwell. However, so far most of studies apply Laplace transform to expressing time evolution, so it is not possible to treat this problem by use of finite difference method, just like general circulation models of atmosphere and oceans. Thus it is not possible to extend numerical simulation of mantle convection to include elastic property of the plate near the earth's surface.

With intention to overcome this difficulty to enable us to conduct numerical simulations of mantle-plate general circulation, a new formulation of dynamics equations for Maxwellian visco-elastic media is attempted in this study

Keywords: Maxwellian visco-elsatic media, visco-elastic medium dynamics, mantle convection, plate-mantle coupling simulation

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SIT39-02 Room:416 Time:May 2 09:15-09:30

# Effects of Al content on water partitioning between Opx and Ol: Implications for lithosphere-asthenosphere boundary

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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. This small amount of water has an important influence on the behaviours of rock systems. A large viscosity contrast of more than two orders of magnitude was detected at depths of 70 km to 100 km beneath ocean and was defined as the lithosphere-asthenosphere boundary [1]. The origin of the lithosphere-asthenosphere boundary remains an enigma. The water distribution in the Earth is critical to the nature of the boundary. For example, Mierdel et al. (2007)[2] 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. Therefore, precise knowledge on the distribution of water among mantle minerals is very important for understanding the Earth's dynamics. The Earth's uppermost mantle is composed mainly of olivine (Ol), orthopyroxene (Opx), clinopyroxene (Cpx), spinel, and garnet. In particular, Ol accounts for a large proportion (60 vol.%) of the Earth's uppermost mantle. In addition, Opx, which contains significantly more water than does Ol in the mantle xenolith, is the second phase of the Earth's uppermost mantle. The FeO content in mantle Ol shows very limited variation in range, whereas the Al content of Opx in the Earth's upper mantle decreases significantly with increasing pressure [3] Therefore, the variation of Al content in mantle minerals can be important for the solubility of water in mantle minerals.

To investigate the partitioning coefficient of water between Opx and Ol ($D_{(Opx/Ol)}$) under low-water concentrations (3 ~ 387 wt. ppm) similar to the Earth's mantle conditions, high-pressure experiments have been conducted at pressures of 1.5-6 GPa and a temperature of 1573 K. The experiments were performed with Kawai-type multi-anvil and piston-cylinder apparatus by using starting materials of natural Ol and synthetic Opx with various Al contents. The water contents were obtained with a vacuum type Fourier transform infrared spectrometer (*Jasco*: FT-IR6100, IRT5000). Water content of minerals was calculated based on Paterson's calibration [4]. IR-spectra of Ol and Al-bearing Opx in this study are similar to those obtained by high-pressure experiments [5] and natural rocks [6], respectively. It is believed that broad bands in IR spectra of natural Opx are due to effect of crystal distortion by large Al substitution. On the contrary, IR-spectra of Al-free Opx are not consistent with those reported by Rauch and Keppler (2002) [7] likely because of the large difference of water fugacity. $D_{(Al-freeOpx/Ol)}$ is ~ 1 at all pressure conditions. However, the water contents of Al-bearing Opx are significantly larger than those of Ol at the same conditions. In addition, the effect of Al concentration in Opx on $D_{(Opx/Ol)}$ becomes larger with increasing pressure. The high Al content in Opx significantly increases $D_{(Opx/Ol)}$ and the trend increases with increasing pressure. $D_{(Opx/Ol)}$ drops sharply at the pressure at which the Al concentration of Opx becomes nearly 0 in the Earth's mantle conditions.

These results imply that viscosity of the upper mantle decreases sharply at depths deeper than those in which orthopyroxene contains no Al. The dramatic change of $D_{(Opx/Ol)}$ may explain the lithosphere-asthenosphere boundary beneath oceans and continents.

[1] D.L. Anderson, (1989) Blackwell Scientific, Boston [2] K. Mierdel et al. (2007) Science, 315, 364-368 [3] M. Obata, (1976) Am. Mineral., 61, 804-816 [4] M. S. Paterson, (1982) Bull. Mineral., 105, 20-19 [5] Q. Bai and D.L. Kohlsted, (1993) Phys. Chem. Minerals, 19, 460-471 [6] K. Grant et al., (2007) Contrib Mineral Petrol, 154, 15-34 [7] M. Rauch, H. Keppler, (2002) Contrib. Mineral. Petrol., 143, 525-536

Keywords: water partitioning coefficient, olivine, orthopyroxene, viscosity, FT-IR, lithosphereasthenosphere

SIT39-03 Room:416 Time:May 2 09:30-09:45

# Acoustic velocities of MgGeO3 gel at high pressure by Brillouin scattering

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Properties of silicate melts are essential for understanding evolution and dynamic behavior of the Earth and terrestrial planets. In the shallow mantle melting processes the density contrast between melts and crystals is well studied, but studies on the deep melting near the core-mantle boundary are still limited due to technical difficulties. The studies of amorphous material, analogs of melt, at high pressure can provide valuable insights about melts in the deep mantle. The Brillouin scattering method is suitable for velocity measurements of amorphous materials. It has been suggested that the change in coordination in the melt or glass structure reflects to the change in acoustic velocity. Thus we conducted sound velocity measurement using the Brillouin scattering method in diamond anvil cell at high pressure. We report in situ high-pressure acoustic velocity measurements of $MgGeO_3$ gel, an analogue of the $MgSiO_3$ melt, revealing the gradual coordination change of Ge from four- to six at least up to 80 GPa. We will conduct experiments at higher pressure in order to confirm the possible Ge coordination change in the gel expected to exist in the terrestrial and extraterrestrial planets.

Keywords: sound velocity measurement, high-pressure experiment, mantle dynamics, silicate melts, super-Earth

SIT39-04 Room:416 Time:May 2 09:45-10:00

# Measurement of differential P-wave travel time between two BBOBSs with Correction for crustal reverberation

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Seismic observations under the ocean are very important to investigate three-dimensional structure of the whole mantle. However, it is difficult to pick up arrival times of P-waves because noise level of broadband ocean bottom seismometer (BBOBS) is in general high in the period range more than 5 sec. Instead of picking arrival times, differential travel times between two BBOBSs have been measured by cross-correlating the waveforms at a period of around 10 sec or more (e.g. Toomey et al. 1998, Tanaka et al., 2009).

The resolution of P-wave tomography become high effectively by taking dispersion of P-wave travel time into account with the finite frequency theory (e.g. Obayashi et al. 2013 JpGU meeting), and its effect is expected to be significant under the ocean where the observations have been sparse. Obayashi et al. (2004) showed dispersion of PP is generated by interference of crustal reverberations under its bounce point. The reverberation under the station also affects a direct P-wave. Especially the effect of the seawater reverberation is significant.

Obayashi et al. (2013) proposed a method of correction for such reverberations to measure differential travel times between any two stations. In this method a waveform is convolved by the response calculated for the crustal structure under the other station.

We applied this method to the BBOBS array at French Polynesia. In the case of the measurement between a BBOBS and a island station, the waveforms of the two stations become similar each other after the correction, suggesting the correction is effective. We report the characteristics of the observed dispersions and the very first result of P-wave tomography using the new observations.

Keywords: crustal reverberation, broadband ocean bottom seismometer, tomography

SIT39-05 Room:416 Time:May 2 10:00-10:15

# Small shear modulus of cubic CaSiO3 perovskite

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Ca-perovskite (CaPv) is considered to be one of the most abundant minerals in the Earth's lower mantle (LM) and was suggested to have distinctly larger shear modulus than MgPv from static calculations and mean-field theory (Karki and Stixrude 1999; Stixrude et al. 2007). In this study the elasticity of cubic CaPv is reinvestigated using density functional constant-temperature first principles molecular dynamics simulations with strict calculation conditions. First, we computed the stable structure of CaPv and found that the cubic phase is more stable than the tetragonal and orthorhombic in the LM P,T condition. The thermal equation of state of CaPv was analyzed using the MD data set, which indicates its thermal properties including Gruneisen parameter quite similar to those of MgPv. Along the adiabatic temperature, CaPv was found to have higher density than the PREM and 12.5% iron-bearing MgPv. Next, we calculated elastic constants of cubic CaPv. Our new results clearly demonstrate that cubic CaPv does not have anomalously large shear modulus suggested by previous calculations with a small computation cell. This is because the cell applied in the previous studies is too small to allow the rotational phonon motion of SiO6 octahedra related to the zone boundary optic phonon instability. Acoustic wave velocities were finally determined from the elastic moduli, indicating no significant differences in velocities between CaPv and iron-bearing MgPv.

Keywords: Ca-perovskite, elasticity, lower mantle, first principles

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SIT39-06 Room:416 Time:May 2 10:15-10:30

# Seismic Constraints on an Enstatite Chondrite Earth

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Recently, Javoy et al., EPSL, 2010 suggested the possibility that Earth had an initial enstatite chondrite composition due to their similar oxygen isotopes. Currently, the calculations of the bulk silicate Earth (BSE) are based on the assumption that the initial Earth began with a composition very close to that of a carbonaceous chondrite. Thus, it is necessary to evaluate whether the 1D seismic properties of the Earth are more consistent with an initial enstatite or chondritic composition. The BSE of an enstatite chondrite Earth (ECE) is different from that of a carbonaceous chondrite since the magnesium/silicon ratio is much lower for the former, resulting in a lower mantle that is almost devoid of Mg. Hence, the primitive lower mantle of an ECE consists mostly of iron-rich perovskite and pure silica. The seismic velocities of these phases are much slower than Mg-perovskite which, by itself, is faster than PREM (the slower MgO phase is necessary to match PREM velocities). However, the present-day lower mantle would be a mix of the primitive upper mantle (ie. pyrolite) and the Mg-depleted lower mantle. The latest mineral physics results are used to calculate possible 1-D seismic profiles of the Earth associated with these two scenarios and to compare with those observed for the Earth today.

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SIT39-07 Room:416 Time:May 2 10:30-10:45

# Thermal property modeling of the core-mantle boundary

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Lattice thermal conductivity of minerals under pressure and temperature is a key property to understanding dynamics and evolution of the Earth's interior. We recently established an efficient ab initio technique for calculating the thermal conductivity of silicate minerals with complex structure and chemistry (Dekura, Tsuchiya, Tsuchiya, PRL, 2013). Calculated lattice thermal conductivity of MgSiO3 perovskite agreed satisfactorily with experimental values at room temperature, and post-perovskite was found to have thermal conductivity quite different from perovskite's, indicating that the D" discontinuity is not only the phase transition boundary but also the conductivity boundary. Using the obtained results, we determine the effective conductivity of the lower mantle and estimate the energy flow across the core-mantle boundary (CMB). Our results demonstrate that the CMB heat flux could change significantly from place to place by reflecting temperature heterogeneity located atop the core. A large CMB heat flow recently suggested from the outer core side can be reconciled only by considering polycrystalline assemblages yielding high-thermal conductivity.

Keywords: First principles computation, Thermal conductivity, CMB heat flow

SIT39-08 Room:416 Time:May 2 11:00-11:15

# Waveform inversion for localized 3-D seismic velocity structure in the lowermost mantle beneath the Western Pacific

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We infer 3-D localized shear velocity structure in the lowermost 400 km of the mantle at the western edge of the Pacific large low shear velocity province (LLSVP) by applying waveform inversion to transverse component body-wave waveforms from the F-net seismic array in Japan. Our dataset consists of relatively long period (12.5-200 s) broad-band seismic waveforms of Tonga-Fiji deep focus and intermediate deep earthquakes. We conduct several tests to confirm the robustness of the inversion results. We find two low velocity zones at the bottom of the target region, with a high velocity zone in the middle, and a low velocity zone above the high velocity zone and contiguous with the two deeper low velocity zones at a depth of 200-300 km above the CMB. This supports the idea that the Pacific LLSVP may be an aggregation of small upwelling plumes rather than a single large thermochemical pile.

Keywords: Waveform inversion, Western Pacific, Mantle convection, Lowermost mantle, Plume cluster

SIT39-09 Room:416 Time:May 2 11:15-11:30

# Compressional sound velocity and density measurements of hcp-Fe under core conditions

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Sound velocity measurements of Fe and Fe-alloy at high temperature and high pressure are necessary to understand the Earth's inner core. Despite seismological observations providing density-sound velocity data of Earth's core, there are few experimental reports about sound velocity of hcp-Fe at ultrahigh pressure and temperature conditions. In order to push forward with research, we have developed a portable laser-heating system for diamond anvil cell, which is called COMPAT (Fukui et al., 2013). We have succeeded in measuring the sound velocity of hcp-iron up to 160 GPa and 3000 K by inelastic X-ray scattering measurements combining with a laser-heated diamond anvil cell. The obtained pressure and temperature dependence of the sound velocity suggest that compressional sound velocity of hcp-Fe at inner core boundary (330 GPa and 5500 K) is higher than that of Earth's inner core. Thus, we can conclude that the light elements or combination of the light elements and nickel in the inner core decreases both density and compressional sound velocity of hcp-Fe simultaneously under the inner core conditions.

Reference

Fukui et al., 2013. A compact system for generating extreme pressures and temperatures: An application of laser-heated diamond anvil cell to inelastic X-ray scattering. Review of Scientific Instruments 84, 113902; doi: 10.1063/1.4826497.

Keywords: Earth's core, sound velocity, density, high pressure and high temperature, inelastic X-ray scattering, laser-heated diamond anvil cell

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SIT39-10 Room:416 Time:May 2 11:30-11:45

# The P-V-T equation of state of liquid pure Fe and Fe-light elements alloys by ab initio molecular dynamics simulations

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The equation of state (EoS) of pure Fe and Fe-light elements alloy liquids were calculated by means of ab initio molecular dynamics simulations at the outer core $P$-$T$ conditions. In the outer core, many light elements, such as carbon, nitrogen, oxygen, hydrogen, sulfur, and silicon, have been proposed as possible constituents. The concentrations of these elements have been strongly debated for years. In this study, internally consistent thermodynamic and elastic properties of pure Fe and Fe-light elements alloys, in particular density, adiabatic bulk modulus, and P-wave velocity were analyzed in order to clarify the effect of light elements incorporation on seismically observable data. Then the results were compared with the seismological data of the Earth's outer core to confine the plausible compositions of the outer core. The new EoS model of liquid iron alloys as a function of pressure, temperature and fraction of light elements may serve as fundamental data for the composition model of the Earth's core.

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# Simultaneous measurement of liquid Fe-C density and sound velocity at high pressure

SHIMOYAMA, Yuta[1*] ; TERASAKI, Hidenori[1] ; TAKUBO, Yusaku[1] ; URAKAWA, Satoru[2] ; KUWABARA, Souma[1] ; KATAYAMA, Yoshinori[3]

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The cores of terrestrial planets, such as Mercury, Mars and Moon are considered to contain some light elements. The effect of light elements on density and bulk modulus of liquid iron is necessary for estimating of these core compositions. Sound velocity of liquid iron alloys is also important for identifying light elements in the core by comparison with observed seismic data.

In this study, we have measured density and sound velocity of liquid Fe-C at SPring-8 beamline BL22XU. Density was measured using X-ray absorption method (Katayama et al., 1993) and sound velocity was measured using pulse-echo overlapping method (Higo et al., 2009). Experimental conditions were 1.2-2.9 GPa and 1650-1850 K. Obtained density values of this study were consistent with our previous results (Shimoyama et al., 2013). In sound velocity measurement, we could observe clear sample wave signal. Measured compressional wave velocity of liquid Fe-C was found to increase with pressure.

Keywords: Density, Sound velocity, liquid Fe-C

SIT39-12 Room:416 Time:May 2 12:00-12:15

# Sound velocity and density measurement of liquid FeSi alloy by laser-shock compression

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The internal structure of the earth is estimated by observing seismic wave. Comparing seismic wave observations and experimental data of sound velocity of iron(Fe), the composition of the Earth's core is not pure Fe. Several light elements (hydrogen, carbon, oxygen, silicon, sulphur, etc.) have been considered as the candidate of the composition of the 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 condition.

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 13.1 wt.% at 135 GPa, and up to 5.5 wt.% at 330 GPa in the outer core.

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

# Effects of hydrous rocks on behaviors of subducting slabs

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**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 $\beta$ (= 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$2000 ppm$H_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 $\beta$, 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 $\beta$ are changed. In east Asia, stagnant slabs and back arcs are widely distributed. To realize both, large $r$ and small $\beta$ are needed. This is because they require strong corner flow, but $\beta$ 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

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

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

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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

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

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

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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

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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

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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 $\mu$m) 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 $\mu$m 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.

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

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

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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

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

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

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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

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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 $\varepsilon$-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

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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