Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SIT003-P01 会場:コンベンションホール 時間:5月26日 14:00-16:30

Frequency dependence of attenuation of the inner core beneath the NE Pacific by analyzing broadband seismic waveforms

Frequency dependence of attenuation of the inner core beneath the NE Pacific by analyzing broadband seismic waveforms

入谷 良平[1*], 竹内 希[1], 川勝 均[1]
Ryohei Iritani[1*], Nozomu Takeuchi[1], Hitoshi Kawakatsu[1]

[1]ERI, Univ. of Tokyo
[1]ERI, Univ. of Tokyo

Understanding of the frequency dependence of the inner core attenuation is essential for constraining the physical mechanism responsible for the attenuation that may eventually help us to infer the growth process of the inner core. While Doornbos [1983] and Li and Cormier [2002] suggested a frequency dependent attenuation in the frequency band lower than 2Hz, Souriau and Roudil [1995] suggested that frequency independent attenuation in the few hundred kilometers from ICB. Recently, Souriau [2009] indicated the existence of the anisotropy in the frequency dependence of the attenuation.

In this study, we address the above issue by analyzing the broadband data (0.02 - 2 Hz) recorded by F-net in Japan for 6 events occurred in South America. We employ a nonlinear waveform inversion method based on simulated annealing (SA) [Iritani et al., 2010] with a frequency dependent attenuation filter. SA waveform inversion is the method for estimating attenuation parameters, traveltimes and amplitudes of analyzed phases according to SA algorithm, and is suitable for analyzing data for which several phases are contaminated each other. We compare waveform residuals for the cases when we assumed the frequency dependent attenuation with several different absorption bands. The preliminary results show that the residuals are generally smaller when the analyzed frequency band (0.02 - 2 Hz) is within the assumed absorption band, and tests using synthetic waveforms indicate that this is a robust feature. It suggests that a frequency independent (or weak frequency dependent) attenuation in analyzed frequency band better explains the data. The attenuation of the inner core beneath northeastern (NE) Pacific (equatorial path) appears frequency independent.

キーワード: inner core, attenuation, broadband
Keywords: inner core, attenuation, broadband

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SIT003-P02 会場:コンベンションホール 時間:5 月 26 日 14:00-16:30

非弾性散乱実験による 70GPa までの dhcp-FeHx の Vp 測定
Sound velocity measurements of dhcp FeHx up to 70 GPa by inelastic X-ray scattering

柴崎 裕樹 [1*], 大谷 栄治 [1], 福井 宏之 [2], 境 毅 [1], 鎌田 誠司 [1], 西谷 尚也 [1], 竹村 謙一 [3], 大石 泰生 [4], Alfred Q.R. Baron[4]
Yuki Shibazaki[1*], Eiji Ohtani[1], Hiroshi Fukui[2], Takeshi Sakai[1], Seiji Kamada[1], Naoya Nishitani[1], Kenichi Takemura[3], Yasuo Ohishi[4], Alfred Q.R. Baron[4]

[1] 東北大学, [2] 兵庫県立大学, [3] 物質・材料研究機構, [4] 高輝度光科学研究センター
[1]Tohoku University, [2]University of Hyogo, [3]National Institute for Materials Science, [4]JASRI

The Earth's interior has been directly investigated by seismic wave propagation and normal mode oscillation. In particular, the distributions of density and sound velocity are available to study the Earth's core (e.g. PREM). The inner core, which is solid state, is approximately 3 % less dense than pure iron (a core density deficit), and it is considered that the core consists of iron and light elements, such as hydrogen, carbon, oxygen, silicon, and sulfur.

Hydrogen could be supplied to the Earth's core in the form of iron hydride (FeHx), which could have been formed by reaction between iron and water during the core formation. The compressibility and sound velocity of FeHx has been measured up to 80 GPa by X-ray diffraction (XRD) experiment (Hirao et al., 2004) and up to 52 GPa by nuclear resonant inelastic X-ray scattering (NRIXS) (Mao et al., 2004), respectively. The NRIXS experiment can determine the Debye sound velocity (VD), but can not directly determine the compressional velocity (Vp) and the shear velocity (Vs). In order to calculate Vp and Vs, it is needed to use the the bulk modulus and the density measured by XRD expreiment at high pressure. Therefore, in this study, we directly estimated Vp of FeHx by inelastic X-ray scattering (IXS).

The IXS experiments and in situ XRD experiments were conducted up to 70 GPa and room temperature. High-pressure conditions were generated using a symmetric diamond anvil cell (DAC) with tungsten gaskets. Hydrogen initially pressurized to 0.18 GPa was loaded to the sample chamber at National Institute for Materials Science, Japan. The IXS experiments were performed at BL35XU beamline of the SPring-8 facility in Japan. We used the Si (9 9 9) configuration, which provides an incident photon energy of 17.794 keV with an energy resolution of 2.8 meV full width at half-maximum (FWHM). The XRD experiments at high pressure were carried out by the angle dispersive method at BL10XU beamline of the SPring-8 facility in Japan. The each XRD pattern of FeHx was collected after each IXS measurement in order to obtain directly the density of FeHx.

Over the range of pressure studied, the diffraction lines of double-hexagonal close-packed (dhcp)-FeHx were observed and there were no diffraction lines of iron. We show FeHx follows Birch's law for Vp above 37 GPa, namely a linear dependence between velocity and density.

キーワード: 非弾性散乱実験, 鉄水素化物, 核, 高圧
Keywords: inelastic X-ray scattering, iron hydride, core, high pressure

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SIT003-P03 会場:コンベンションホール 時間:5 月 26 日 14:00-16:30

非弾性 X 線散乱法を用いた高圧下における Ve3S の VP
Sound velocities of Fe3S at high pressures using inelastic X-ray scattering

鎌田 誠司 [1*], 福井宏之 [2], 大谷 栄治 [1], 境 毅 [1], 柴崎 裕樹 [1], 寺崎 英紀 [1], アルフレッド　バロン [3], 大石泰生 [4], 平尾直久 [4]
Seiji Kamada[1*], Hiroshi Fukui[2], Eiji Ohtani[1], Takeshi Sakai[1], Yuki Shibazaki[1], Hidenori Terasaki[1], A.Q.R. Baron[3], Yasuo Ohishi[4], Naohisa Hirao[4]

[1] 東北大学, [2] 兵庫県立大学, [3] 理化科学研究所, [4] 高輝度光科学研究センター
[1]Tohoku University, [2]University of Hyogo, [3]RIKEN, [4]JASRI

The structure and seismic properties of the Earth's inner core have not been understood well. The observation of compressional wave velocities through the inner core implied that the inner core is anisotropic (e.g., Creager, 1992) and layered (e.g., Ishii and Dziewonski, 2003). Observed compressional velocities are about 3 % faster along the polar axis than in the equatorial plane. The evidence of the layered inner core showed that there is a seismically isotropic or weakly anisotropic layer at the top of the inner core. Although the origins of these anisotropy and layered structure are poorly understood, it has been considered that the anisotropy is caused by the preferred orientation of the crystals in the inner core. The observation of shear wave velocities in the inner core raised an issue because the observed shear wave velocities were unexpectedly low (Cao et al., 2005). Due to lack of the knowledge about elastic properties of the core materials, it is difficult to interpret the observed seismic wave velocities.

There have been a lot of works about the density of Fe and Fe alloys with light elements. However, there have been only a limited number of works for V_P of Fe and Fe alloys with light elements, especially Fe alloys with sulfur. Recently, French group has reported sound velocities of Fe, Fe-Ni, FeS, FeS2, FeO, Fe_3C, Fe-Ni-Si alloys based on an inelastic X-ray scattering (IXS) (Fiquet et al., 2001; Antonangeli et al., 2004; Fiquet et al., 2004; Badro et al., 2007; Fiquet et al., 2009; Antonangeli et al., 2010). In the Fe-S system, V_P of FeS, the end member of the Fe-FeS system, and FeS_2, more sulfur-rich compound, have been studied but these compounds are not appropriate for the inner core materials because Fe-S system has a lot of intermediates such as Fe_3S_2, Fe_2S, Fe_3S under high pressures (Fei et al., 1997; 2000). In addition, under the core conditions, only Fe_3S coexists with hcp-Fe as a subsolidus phase (Kamada et al., 2010). Therefore, it is essential to study the V_P of Fe_3S to understand seismic and chemical properties of the Earth's core.

In this study, Fe_3S was synthesized from a mixture of powdered Fe and FeS using a muti anvil apparatus. A symmetric diamond anvil cell was used to generate high pressures. Inelastic X-ray scattering experiments were performed at the beamline 35XU of SPring-8, Japan (Baron et al., 2000; 2001). The present results follow the Birch's law. The slope of the law of Fe_3S (1.1) is smaller than that of FeS_2 (3.0) reported by Fiquet et al. (2004) and that of of FeS (1.7) reported by Vocadlo (2007) and Badro et al. (2007). The slopes of Birch's law for iron sulfides are decreasing with increasing a mean atomic mass of an iron sulfide. This suggests that sulfur might make the slope of Birch's law steeper with increasing the amount of sulfur.

キーワード: 非弾性 X 線散乱法, 音速, Fe3S, 内核
Keywords: Inelastic X-ray scattering, Sound velocity, Fe3S, inner core

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SIT003-P04 会場:コンベンションホール 時間:5 月 26 日 14:00-16:30

高圧下における Fe-S-Si 系の融解：外核の温度への応用
Melting in the Fe-S-Si system at high pressure : Implication for the temperature in the outer core

坂入 崇紀[1*], 大谷 栄治[1], 境 毅[2]
Takanori Sakairi[1*], Eiji Ohtani[1], Takeshi Sakai[2]

[1] 東北大学大学院理学研究科地学専攻, [2] 東北大学国際高等融合領域研究所
[1]Faculty of Science, Tohoku University, [2]IIAIR Tohoku University

Based on seismological studies, it has been commonly accepted that the Earth's outer core is composed of molten iron-nickel alloy with light elements. S and Si are plausible candidates of the light elements. This is because Si is one of the most abundant elements in the Earth, iron sulfides are found universally in iron meteorite, and Si, S are depleted in mantle relative to C1 chondritic materials.

The temperature of the inner core boundary (ICB) is the melting temperature of the core material. Therefore, the melting relationship in the Fe-S-Si system at high pressure and high temperature is indispensable to estimate the thermal structure of the Earth's core.

The melting experiments in the Fe-S-Si system were performed by using a laser-heated diamond anvil cell and melting temperatures were determined based on following two procedures: (1) the change of laser heating efficiency, (2) textual observations of recovered samples using SEM.

The changes of heating efficiency were observed up to 60 GPa. The present data were fitted by the Simon's equation. Assuming that S and Si are the light elements in the Earth's core, the temperature at the ICB was estimated to be 4970(340) K from this study, and the temperature at the core-mantle boundary (CMB) was estimated to be 3800 K by considering the adiabatic temperature gradient in the outer core.

Keywords: Fe-S-Si, Earth's core, high pressure, LHDAC

Japan Geoscience Union Meeting 2011
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SIT003-P05 会場:コンベンションホール 時間:5 月 26 日 14:00-16:30

MHD geodynamo model including effect of length-of-day variation
MHD geodynamo model including effect of length-of-day variation

宮腰 剛広 [1*], 浜野 洋三 [1]
Takehiro Miyagoshi[1*], Yozo Hamano[1]

[1] 海洋研究開発機構
[1]IFREE, Jamstec

Correlation of geomagnetic field variation with length-of-day variation has been pointed out. For example, Hamano (1992) argued relation between geomagnetic field variation and length-of-day variation associated with Milankovitch cycle. However, there are no geodynamo models which take effect of length-of-day variation into consideration.

In this paper we show MHD geodynamo model including effect of length-of-day variation. The Yin-Yang dynamo model (Kageyama and Sato 2004, Kageyama et al. 2004) was developed to include this effect. In a momentum equation, rotation speed in Coriolis force term changes as time goes on by sin function. In addition, a new term concerning time differential of rotation speed is added. The Ekman number and Rayleigh number are 1.9E-5 and 1.5E8, respectively. Prandtl and magnetic Prandtl numbers are both unity. For reference, we initially solved without rotation speed variation and confirmed magnetic dipole moment is the largest one than other higher moments, and magnetic energy in the outer core is several times larger than the kinetic energy at saturated state. Our simulation results show that the length-of-day variation causes oscillation of magnetic energy, kinetic energy, and magnetic dipole moment. At the typical case, the amplitude of rotation speed variation is 2 percent. When the variation period is the same as magnetic diffusion time, the magnetic and kinetic energy, and magnetic dipole moment oscillate in that period. The amplitude of magnetic energy oscillation is about plus minus 25 percent. When the period is 1 percent of magnetic diffusion time, both the kinetic energy and magnetic dipole moment oscillate in that period. In this case the amplitude of magnetic dipole moment oscillation is about plus minus 0.7 percent.
Keywords: geodynamo, length-of-day variation

SIT003-P06 会場:コンベンションホール 時間:5 月 26 日 14:00-16:30

水星核マントル境界における金属/珪酸塩間の U 及び Th の分配挙動
Partitioning behavior of U and Th between metal and silicate at the Mercury's core mantle boundary

石井 美帆 [1*], 大谷 栄治 [1], 木村 純一 [2], 寺崎 英紀 [1]
Miho Ishii[1*], Eiji Ohtani[1], Jun-Ichi Kimura[2], Hidenori Terasaki[1]

[1] 東北大学大学院理学研究科, [2] 海洋研究開発機構地球内部変動研究センター
[1]Graduate School of Science, Tohoku Univ., [2]JAMSTEC

Mercury has a dipole magnetic field which was discovered by Mariner 10. But its origin has not been proven clearly yet. The most appropriate model for producing the dipolar magnetic field is core dynamo, which requires a high electrical conductive fluid in the interior (Elsasser, 1956). However, the size of Mercury is small enough to have completed internal cooling. Thus, any other heat source is needed to maintain the molten Mercury's core. One of the most plausible heat sources in the core is radioactive elements such as U and Th. In this study, in order to confirm the possibility of the existence of radioactive elements in the core, partitioning experiments of U and Th between Fe-alloy liquids (Fe-S, Fe-Si and Fe-S-Si) and solid silicate were conducted at the Mercury's core/mantle boundary condition (7 GPa, 1500 ^{o}C). High pressure experiments were performed using multi-anvil apparatus. Chemical analysis for major elements was performed using SEM-EDS, and for trace elements (U and Th) were performed using LA-ICP-MS at JAMSTEC.

Observed silicate assemblages were Olivine, Opx and Garnet, and their compositions were different depending on the coexisted metal compositions. Olivine was not observed in the experiments contained Fe-Si and Fe-S-Si metal.

As Garnet is considered to contain more U and Th compared to other coexisting silicate minerals, we measured the partitioning of U and Th between Garnet and metals. The amounts of U and Th in Garnet were two orders of magnitude higher than those in metal phases, suggesting that U and Th show the lithophile character at the experimental condition. The partitioning coefficients (D) of U and Th between metal/Garnet were almost 0.05 and 0.009, respectly. We estimated the effects of pressure, temperature, oxygen fugacity and light elements contents in metal on D by comparing with the previous works (Wheeler et al., 2006; Malevergne et al., 2007).

キーワード: 水星, 核マントル境界, 分配挙動, U, Th
Keywords: Mercury, core mantle boundary, partitioning behavior, U, Th

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SIT003-P07 会場:コンベンションホール 時間:5 月 26 日 14:00-16:30

Quasi-geostrophic thermal convection and zonal flows in the outer core.
Quasi-geostrophic thermal convection and zonal flows in the outer core.

Philippe CARDIN[1*], Celine GUERVILLY[1]
Philippe CARDIN[1*], Celine GUERVILLY[1]

[1]ISTerre, Grenoble, France
[1]ISTerre, Grenoble, France

Highly developped regimes of thermal convection in a rapidly rotating sphere are still very difficult to compute and analyse. Most of the numerical dynamos models of the geodynamo are based on convective flows but the Rayleigh number is generally kept not very far from the onset of convection according to available computational resources as fully developped regimes of thermal convection need very fine grids and small time steps. Here, we develop a new numerical model where the velocity field is computed on the equatorial plane using a quasi geostrophic approximation while the heat equation (and the induction equation) is solved in the spherical domain. This approach is particularly powerful to compute thermal convection for low (magnetic) Prandtl number and our results agree with 3D numerical calculation of Jones et al (2000) and Zhang et al (1994) at the onset.

We have perfomed calculations for E = 10^{-8}, Pr = 0.01 and Ra = 50 Ra_c. The flow is then made of Rossby waves interacting with vortices and large azymuthal flows. Non linear mixing of potential vorticity lead to strong zonal flows which dissipate the kinetic energy of the flow in the Ekman layers. We observe many jets (until 5) with prograde zonal jets at the center of the sphere (where the convection is less active) and in the outer part (with a necklace of spiralling Rossby waves). Some prelimanry kinematic dynamo calculations have also been performed.

キーワード: thermal convection, dynamos, zonal flows
Keywords: thermal convection, dynamos, zonal flows