

SIT040-01

会場:104

時間:5月23日 14:15-14:30

反大陸のマントル最下部への集積とD''層の形成

Accumulation of anti-continent at the base of the mantle and formation of the D'' layer

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The continental crust is a unique reservoir of light elements in the solid Earth; it possesses an intermediate composition and is believed to have been created principally along volcanic arcs, which are major sites of terrestrial andesitic magmatism. Mantle-derived arc magmas are, however, generally mafic or basaltic. A simple mechanism to overcome this apparent dilemma and generate andesitic melts in such a setting is through the partial remelting of an initial mafic arc crust by heat supplied from underplating basaltic magmas. An antithesis to the formation of continental crust in this way should be the production of refractory melting residue, here referred to as 'anti-continent'. This anti-continent is likely to detach from arc crust as a result of a density inversion and descend into the upper mantle. High-pressure experiments of two end-member anti-continent compositions with and without olivine cumulates demonstrate that sinking anti-continent is, in contrast to the subducting oceanic crust, always denser than the surrounding mantle, suggesting that it penetrates through the upper-lower mantle boundary, without stagnation, and accumulates at the base of the mantle to form a 200-400 km thick mass known as the D'' layer. Geochemical modeling provides further evidence that this accumulating anti-continent contributes to a deep-seated hotspot source. Therefore, through complementary processes, Earth creates buoyant continents and dense anti-continents at the top and the base of the mantle, respectively, and has recycled portions of anti-continent in mantle plumes.

キーワード: 反大陸, D''層, リサイクル

Keywords: anti-continent, D'' layer, recycle

SIT040-02

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スピン転移にともなう鉄の物性変化 Changes in physical properties of iron on high spin-low spin transition

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The properties of the major constituents of the Earth's inner core, i.e., iron and its alloys, have long been of great interest to geophysicists. Therefore, pure Fe under high pressure has been investigated by numerous theoretical and experimental studies. Under high pressure, the body-centered cubic (bcc) structure transforms into the hexagonal close-packed (hcp) structure, and this structure seems to be stable over a wide range of pressures and temperatures approaching those existing in the inner core. The magnetic state of iron has a major influence on the physical properties of iron and its alloys, including the relative stability of iron polymorphs. Although the magnetic structure of hcp-Fe has been investigated for over three decades, contradictory results from experimental and theoretical studies have been reported. We made use of a high-pressure diamond anvil cell apparatus and first-principles calculations using density functional theory, to investigate the physical properties of hcp-Fe at high pressures and high temperatures.

First-principles simulations were performed using the projector augmented wave implementation of the density functional theory using the Vienna ab initio simulation software package. For the Brillouin zone sampling at 0 K calculations, we used a large number of k-point grids, which provided the convergence of the total energy to within 1 meV/atom. We also used super-cells, gamma-point for the Brillouin zone sampling, a time step of 1 fs for the first-principles molecular dynamics simulations at high temperatures. High-pressure X-ray diffraction experiments were performed using a laser-heated diamond anvil cell. The samples were heated with a laser to overcome any potential kinetic effects on the possible phase transitions. The heated samples were probed using an angle-dispersive X-ray diffraction technique at the synchrotron beam lines. The angle-dispersive X-ray diffraction patterns were obtained on an imaging plate. The pressure was estimated from the observed unit cell volume of NaCl that was used as the pressure-transmitting medium, using the equation of state for B2-NaCl [1].

In high-pressure experiments, no structural phase transition in hcp-Fe was observed up to a maximum pressure of 110 GPa. An interesting variation in the ratio of the cell parameters (c/a) of hcp-Fe as a function of pressure was observed. As the pressure increased up to approximately 50 GPa, the c/a ratio decreased from 1.61 to 1.60. At pressures greater than 50 GPa, the ratio was approximately constant. According to our first-principles calculations, the magnetic moment of iron and the c/a ratio decrease up to approximately 55 GPa, and then the calculated c/a ratio increases slightly with increasing pressure. These calculated results were in good agreement with experimental observations. This indicated that the transition pressure of high spin-low spin state is approximately 50 GPa. As the spin state of iron could be estimated accurately using our calculations, we also calculated elastic properties of different spin states. For example, our calculations predict that the bulk modulus of the high spin state is 10% less than that of the low spin state [2]. Such change in elastic property should be considered to investigate the dynamic of the inner core.

[1] Ono et al. (2006) Structural property of CsCl-type sodium chloride under pressure. *Solid State Communications*, 137, 517-521.

[2] Ono et al. (2010) High-pressure magnetic transition in hcp-Fe. *American Mineralogist*, 95, 880-883.

キーワード: 鉄, スピン転移, 内核, 高圧実験, 第一原理計算

Keywords: Iron, Spin transition, Inner core, High pressure experiments, First-principles calculations

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酸化・還元環境下における C-Mg-Fe-Si-O 系の相平衡関係：惑星内部への応用 Phase relation of C-Mg-Fe-Si-O system under various oxygen fugacity conditions: Implication for planetary interior

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Many exoplanets have been found recently based on the spectroscopic observation. A carbon-rich circumstellar gas was reported to exist around "beta-Pictoris", which has an exoplanet (Roberge et al., 2006). In such gas, carbon-enriched planet, "carbon-planet" may be formed. Carbon-bearing phase, such as carbide, carbonate, graphite and diamond are likely to compose the carbon-planet interior. Therefore, it is important to investigate phase relations of carbon-rich systems under high pressure conditions. In this study, C-enriched Mg-Si-Fe-O-C system was investigated at high pressure and temperature in order to understand the internal structure of the carbon-planet.

Phase relations were studied based on 2 series of experiments; (I)textural observation and chemical analysis of the recovered sample from 4 GPa and 1873K and (II)in situ X-ray diffraction experiments under high pressure and temperature. For the starting materials, we used several different oxide/metal components, as shown below: (i) MgCO₃ + Fe + Si + C, (ii) (Mg_{1.8},Fe_{0.2})SiO₄ + Fe + SiO₂ + C, (iii) (Mg_{1.8},Fe_{0.2})SiO₄ + Fe + Si + C, (iv) MgO + Fe + SiO₂ + C, (v) MgO + Fe + Si + C. Oxygen fugacity (fO₂) of the sample varies depending on these assemblages due to different O amount in the starting materials. The sample was enclosed in graphite or MgO capsule. MgO capsule enables us to estimate fO₂ in the sample based on the FeO content of the capsule contacting with the samples. Chemical analyses of the recovered samples were performed using an electron microprobe. In situ X-ray diffraction experiments were conducted at 4 and 15 GPa, and up to 1873 K at BL04B1 beamline, SPring-8 synchrotron facility.

Observed mineral/metal assemblages and their compositions vary depending on the redox condition of the sample. The compositions of metallic melt phases changes from Fe-C composition (C = 6.9~8.2 wt.%) in oxidizing conditions ($\Delta IW = -2.4 \sim -1.7$) to Fe-Si composition (Si = 18 wt.%) in the more reducing condition ($\Delta IW < -4.8$). SiC grains were also found in the most reducing condition. The solubility of C into the Fe-melt phase increases with fO₂, whereas the solubility of Si decreases with increasing fO₂. Based on in situ X-ray diffraction experiments at 4 GPa, Fe₃C was formed at 1073 K in the all samples. Fe₃C peak disappeared and FeSi and SiC peaks appeared at 1373 K in the most reducing sample (v), whereas Fe₃C remained in the other samples. Metallic phases in all samples were melted at 1673 K. In the experiment at 15 GPa, FeSi was formed at 1573 K and SiC was also observed at 1673 K in the sample (v). This is indicated that FeSi is stable at high pressure and reducing condition despite carbon-saturated condition. No carbonates was observed under the present experimental conditions. Therefore, carbon-bearing phases correspond to graphite/diamond, SiC and Fe-C alloy or Fe-Si-C alloy in the present redox conditions at 4~15 GPa. The present results may suggest that these carbon-bearing phases consist of carbon-planets interiors.

Keywords: Carbon-planet, Carbide, Silicon carbide, Oxygen fugacity

SIT040-04

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時間:5月23日 15:00-15:15

広帯域波形を用いた波形インバージョンによるインド下最下部マントル構造 Waveform inversion of broadband body wave data for the S-velocity structure in the lowermost mantle beneath India

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We conduct waveform inversion for the radial shear velocity structure of the lowermost mantle beneath India using transverse component body wave waveform data obtained from the ORPHEUS and IRIS arrays in the passband 8?200 s for earthquakes that occurred in 1995-2006 beneath Southeast Asia with epicentral distances of 60?95 degrees. As we use higher frequency data than most previous waveform inversion studies, we make several improvements in the techniques. We introduce a new method for data correction. We also conducted tests to confirm the robustness of the results for several different starting models, and varying other conditions as well. The average S velocity of this region is almost the same as PREM, but we find that the velocity is faster than PREM between 2500?2750 km and slower than PREM between 2750 km? CMB. This suggests that the pv to ppv phase transition occurs in this region. Following Kawai & Tsuchiya (2009), if we assume the composition of D'' is pyrolytic, the thickness of the thermal boundary layer in this region is about 250?300 km.

キーワード: インド下, 波形インバージョン, 最下部マントル, D''

Keywords: waveform inversion, lowermost mantle, D'', beneath India

SIT040-05

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地磁気ジャークから推定される最下部マンツルの電気伝導度不均質 Lateral heterogeneity of the electrical conductivity in the lowermost mantle inferred from geomagnetic jerks

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Geomagnetic jerks are abrupt changes in the linear trend of the geomagnetic secular variation, and are the surface observable shortest-period components of the geomagnetic field variation of core origin. Hence, the jerks have been studied by many authors to infer dynamics of the core and the electrical conductivity of the lower mantle in the last few decades. Geomagnetic jerks are traditionally studied using time series of the magnetic field recorded in geomagnetic observatories. The uneven distribution of the observatory network precludes the investigation of global distribution of the geomagnetic jerks, and internal origin of the jerks have been questioned by a number of authors. Recently, as a result of continuous satellite measurements since 1999, the magnetic fields and their variations can now be described with high resolution in space and time, and the internal origin of most of the known jerks and their global nature are now firmly established. Since jerks are generated in the core, they will pass through the electrically conducting mantle, before arriving at the surface. Consequently, the geomagnetic field observed at the surface will correspond to a filtered version of the original field generated in the core. Even an 1D electrical conductivity distribution in the mantle exerts screening effects such as delaying and smoothing of signals on the surface observed geomagnetic field. Moreover, a laterally heterogeneous electrical conductivity structure causes more dramatic changes in time and space on the magnetic fields come through the heterogeneous layer. Recent discovery of the postperovskite phase change at the lowermost mantle, and the measurements of the electrical conductivity in the high P and high T condition expected at the bottom of the mantle, predict very high and heterogeneous electrical conductivity structure in the lowermost mantle adjacent to the core surface. Observation of the geomagnetic jerks at the Earth's surface may reveal this possible electrical conductivity heterogeneity in the lowermost mantle. For that purpose, however, we need to estimate the source field in the core.

In the present study, filtering effects of an electrically heterogeneous layer in the lowermost mantle on the short-period variations of the geomagnetic field of core origin are examined by using a newly formulated induction equations in a 3D heterogeneous mantle (Hamano, 2002). As the source field at the core surface, we use the temporal variations of toroidal and poloidal magnetic fields obtained by the high-resolution MHD dynamo models (Sakuraba and Roberts, 2009), in which high frequency variations of magnetic fields such as torsional oscillations are clearly reproduced. Results of the numerical calculation indicate that the heterogeneous layer in the lowermost mantle cause very complicated spatial variations of the surface geomagnetic field reflecting the pattern of the electrical conductivity heterogeneity in the lowermost mantle.

キーワード: 地磁気ジャーク, 地球磁場, 地球ダイナモ, 電気伝導度分布, 最下部マンツル

Keywords: geomagnetic jerks, geomagnetic field, geodynamo, electrical conductivity structure, lowermost mantle

SIT040-06

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太平洋 LLSVP の西縁におけるシャープな水平方向 S 波速度境界 A sharp lateral gradient of shear-wave velocity at the western edge of the Pacific LLSVP

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The western margin of the Pacific LLSVP (Large Low Shear Velocity Province) in the D'' region is investigated. The differential travel times of ScS-S are measured for the rays propagating along nearly the north-south direction, which is considered to be parallel to the strike direction of the western boundary of the Pacific LLSVP. Over 190 high-quality ScS-S differential travel times from 52 events occurred in the North Pacific and Southeast Asia recorded at the broadband stations in Japan and Australia are used. The differential travel times were corrected for the contribution above D'' (250 km above the CMB) using eight global tomography models. The abrupt change in the differential travel times is very clearly observed beneath the region East of Philippine Islands, indicating a sharp lateral boundary in shear-wave velocity across this region. The Vs contrast of up to 4 percent is observed beneath the region from -4 to 4 degrees in latitude and 130 to 140 degrees in longitude, within 400-600 km. We will discuss the possible origin of the structure in terms of the thermal and chemical anomalies.

Keywords: Pacific LLSVP, ScS, D'', lowermost mantle, plume

SIT040-07

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マントル深部での融解現象

Study of melting phenomena under the deep mantle conditions

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It is known that the subducting plate carry the Earth's surface materials (such as the basaltic crust) to the Earth's deep interior. As a result of this process, the mantle is highly heterogeneous in chemical composition. At the core-mantle boundary, there is a possibility that Mid Ocean Ridge Basalt (MORB) exists and it causes the seismic anomalies. Seismological studies indicate the presence of Ultra-Low Velocity Zone (ULVZ) above the core-mantle boundary (Williams and Garnero, 1996). This region exhibits reduction of seismic velocities at least 10% and the thickness of this region is about 5 - 40 km. The most probable cause of the seismic velocity reduction is partial melting of the lowermost mantle.

In this study, We carried out melting experiments of MORB using a laser heated diamond anvil cell to investigate the melting phase relations of MORB. The phase relations in MORB were investigated from 31 to 156 GPa and 1500 to 4400 K by in situ X-ray diffraction experiments and chemical analysis of the quenched samples using field emission-scanning electron microscope (FE-SEM) and transmission electron microscopy (TEM). In-situ X-ray diffraction experiments were performed at SPring-8 to determine the subsolidus phase assemblage. The MORB composition consists of MgSiO₃-perovskite, CaSiO₃-perovskite, stishovite, and Al-rich phase (likely CaFe₂O₄-type Al-phase) in the upper part of the lower mantle. Stishovite transforms to CaCl₂-type SiO₂ phase above 60 GPa and 2000 K and further to alpha-PbO₂-type phase above 110 GPa. Phase transition of CaSiO₃-perovskite from tetragonal to cubic was also observed with increasing temperature. At 37 GPa, the first consuming phase is likely to be stishovite and the melting temperature is 2700 K. At 118 GPa, the first consuming phase is also alpha-PbO₂-type SiO₂ phase and the temperature is 3700 K.

Keywords: MORB, lower mantle, melting

SIT040-08

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太平洋下マントル最下部の超低速度地帯の形について Constraints on the 3D shape of the ultra low shear velocity zone at the base of the mantle beneath the central Pacific

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Prominent postcursors to S/Sdiff waves with delays as large as 26 s are observed in Northern America for Papua New Guinea events (To et al., 2011). The emergence of the postcursor is explained by placing a laterally localized ultra low shear velocity zone (ULVZ, $dV_s/V_s < -25\%$) on the CMB, which is fully or partially covered by a broad and weak anomaly region ($dV_s/V_s \sim -5\%$). The ULVZ is located beneath the central Pacific.

In the previous study, we limited our focus to an azimuthal range around 60 degrees from the source in Papua New Guinea, where the records show a relatively small azimuthal variation, suggesting a relatively small 3D effect there. We attempted 2D structural modelling along the great circle plane towards stations in southern US. The modelling was limited in 2D, partly due to the sparse station distribution in Midwestern US at the time.

In this study, I investigated USArray station data and further constrained the 3D shape of the ULVZ. The postcursors to S/Sdiff waves are observed at 240 USArray stations for an event, which occurred at Papua New Guinea in 2010. The records from the large number of stations enable me to conduct array analysis. First, I mapped the variation of the incident azimuth of the secondary arrival to the stations. In southern stations, which are located along the azimuth of approximately 60 degrees from the source, the postcursors arrive approximately from the direction of the great circle plane between the source and stations. On the other hand, in northern stations, which are located along the azimuth of 52 degrees from the source, the postcursors arrive from the azimuth of 5 to 10 degrees to the south with respect to the direction of the great circle plane. Second, I compared the observed amplitude of the main S/Sdiff phase with synthetic waveforms created by Direct solution method (Kawai et al., 2006). The comparison shows that the amplitude of the main phase become very small at stations which are located at the distance around 100 degrees and the azimuth of 50 degrees from the source. These observations indicate that the ULVZ, located beneath the central Pacific, is elongated in the east-west direction.

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チャンドラー運動の減衰時間と潮汐変形から推定されるD''層の粘性率 Viscosity of the D'' layer inferred from the decay time of Chandler wobble and tidal deformation

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Viscosity of the D'' layer of the Earth's mantle, the lowermost layer in the Earth's mantle, plays an important role in the dynamics and evolution of the Earth. That is, its rheological properties control a number of important geodynamic and geochemical processes such as chemical interactions between the mantle and core and the nature of the observed ultralow-velocity regions in D'' layer. However, inferring the viscosity of this region is difficult because of the lack of relevant geodynamic observations. A commonly used analysis of geophysical signals in terms of heterogeneity in seismic wave velocities suffers from major uncertainties in the velocity-to-density conversion factor, and the glacial rebound observations have little sensitivity to the viscosity of the D'' layer. In this paper, we show that the decay time of Chandler wobble and semi-diurnal to 18.6 years tidal deformation combined with the constraints from the postglacial isostatic adjustment observations provide a strong constraint on the viscosity of this layer. The decay time of Chandler wobble (30-300 years) indicates the effective viscosity of the D'' layer (~300 km thickness) to be 10^{19} - 10^{20} Pa s, and the tidal deformation with periods less than 20 years suggests the bottom of the D'' layer (~100 km thickness) to be less than 10^{18} Pa s. The viscosity structure may be consistent with the temperature distribution inferred from the double-crossing of seismic rays of the phase boundary between perovskite and post-perovskite. The results have a number of implications including the core-mantle interaction through small-scale convection and the interpretation of the ultralow velocity region in terms of partial melting.

キーワード: D''層, 粘性率, チャンドラー運動, 潮汐変形

Keywords: D'' layer, viscosity, Chandler wobble, tidal deformation

SIT040-10

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下部マントルへのスタグナントスラブ崩落の数値シミュレーション Numerical simulations on fall of stagnant slabs into the lower mantle

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Global seismic tomography has recently revealed horizontally lying slabs near the upper and lower mantle boundary beneath the Northwestern Pacific region. Although physical mechanisms that could produce such slab stagnation have been proposed based on numerical simulations, there has been little research into what occurs after slab stagnation. We proposed trench advance and trench jumps as effective mechanisms related to the fall of stagnant slabs into the lower mantle, and our numerical simulations of temperature and fluid flow associated with slab subduction in a 2-D box model confirmed these mechanisms. Our results indicate that a supply of slab material associated with further slab subduction after slab stagnation plays an important role in differentiating further slab stagnation from the falling of slabs into the lower mantle. A shortage of material supply would produce extended slab stagnation near the 660-km boundary for ringwoodite to perovskite + magnesiowustite phase transformation, whereas downward force due to further slab subduction on a stagnant slab would enhance its fall into the lower mantle. The behaviors of falling stagnant slabs were not affected by Clapeyron slope values associated with phase equilibrium transformation within the range from -3.0 to 0.0 MPa/K. Compared with models of normal mantle viscosity, a high-viscosity lower mantle played a role in hindering the fall of slabs into the lower mantle, resulting in complicated shapes and slow falling velocities. Lower mantle viscosity structure also affected slab behavior. Slabs tended to stagnate when a low-viscosity zone (LVZ) existed just below a depth of 660km because friction between the slab and the LVZ was weak there. Slab stagnation around a depth of 660km also occurred when a high-viscosity zone existed below a depth of 1200km and acted as a resistive force against a slab, even if the slab existed in the lower part of the upper mantle.

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Pyrolite と Mg_2SiO_4 のポストスピネル転移：ポストスピネル転移に及ぼす固溶体成分の影響

Post-spinel transitions in pyrolite and Mg_2SiO_4 : Effect of solid-solution components on the post-spinel transition

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地球内部 660 km 不連続面は上部マントル主要構成鉱物である Mg_2SiO_4 のポストスピネル転移により生じていると考えられている。 Mg_2SiO_4 やマントルの平均的な組成と考えられている pyrolite を用いたこの転移圧力は研究者によって様々であり、この転移が真に 660 km 不連続面に対応するか今日でも議論が続いている。本研究での Mg_2SiO_4 と pyrolite を用いた高压実験では、pyrolite の方が約 0.1 ~ 0.5 GPa 低圧でポストスピネル転移が起き、クラペイロン勾配もより緩やかになるという結果が得られた (2010 年度連合大会要旨)。このことから、転移圧力・勾配の低下の原因が Mg_2SiO_4 成分以外の他成分 (Fe^{2+} , Fe^{3+} , Al^{3+}) の影響と予想し、これらの成分がポストスピネル転移に及ぼす効果をマルチセル法により比較した。

出発物質として Mg_2SiO_4 、 $Mg_2SiO_4 : Fe_2SiO_4 = 9 : 1$ (モル比) の混合物 ($Fo_{90}Fa_{10}$)、 Mg_2SiO_4 と $MgSiO_3 : Fe_2O_3 + Al_2O_3 = 85 : 15$ (モル比) を重量比で 6 : 4 とした混合物 ($Fo+En+FeAlO_3$)、 Mg_2SiO_4 と $MgSiO_3 : Al_2O_3 = 85 : 15$ (モル比) を重量比で 6 : 4 とした混合物 ($Fo+En+Al_2O_3$) を用意した。3つの小さな穴が空いた Re カプセルの各穴に Mg_2SiO_4 、 $Fo_{90}Fa_{10}$ 、 $Fo+En+FeAlO_3$ (または Mg_2SiO_4 、 $Fo+En+FeAlO_3$ 、 $Fo+En+Al_2O_3$) を詰め、圧力 22.3 ~ 24.5 GPa、温度 1200 ~ 1600 C の実験条件で、3 時間保持後、急冷回収した。試料中の相の同定には微小領域 X 線回折装置、組成分析には SEM-EDS を用いた。

Mg_2SiO_4 に比べ $Fo_{90}Fa_{10}$ は転移圧力がわずかに上昇し、 $Fo+En+FeAlO_3$ 、 $Fo+En+Al_2O_3$ はより低圧で転移した。 $Fo+En+FeAlO_3$ 、 $Fo+En+Al_2O_3$ のポストスピネル転移反応は、ringwoodite + garnet = perovskite + magnesiowustite (or periclase) である。これらの結果から、 Fe^{2+} は転移圧力を増加させ、 Al^{3+} と Fe^{3+} は低下させていると考えられる。また、クラペイロン勾配を比較すると、 $Fo_{90}Fa_{10}$ は Mg_2SiO_4 と似た傾向を持つのに対し、 $Fo+En+FeAlO_3$ はより緩やかな勾配となり、pyrolite の勾配の傾向とも一致している。このことから、 Al^{3+} が最も転移圧力の低下に寄与していると考えられる。

キーワード: ポストスピネル転移, リングウッドイト, ペロフスカイト, 660km 不連続面, 高压実験

Keywords: postspinel transition, ringwoodite, perovskite, 660km discontinuity, high pressure experiment

SIT040-12

会場:104

時間:5月23日 17:15-17:30

DIA型変形装置を用いたマントル遷移層温度圧力条件下でのウォズリアイトのクリープ強度その場測定

An in situ measurement of creep strength of wadsleyite in a D-DIA apparatus at P-T conditions of mantle transition zone

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In order to study creep strength of wadsleyite at P-T conditions of the mantle transition zone, technical developments have been made by optimization of a multi-anvil 6-6 (MA6-6) assembly for extending P-T conditions of in situ stress-strain measurements in a deformation-DIA (D-DIA) apparatus over 10 GPa and 600 K. Deformation experiments of wadsleyite were conducted using a cubic-anvil apparatus SPEED-Mk.II with a D-DIA system, which was newly installed in 2010, at BL04B1 beamline of SPring-8. We used second-stage anvils made of cubic BN and tungsten carbide with a truncated edge length of 2.5 mm. The stress and the strain of wadsleyite were quantitatively determined at experimental processes including deformation at high P-T conditions using in situ X-ray radial diffraction and radiography, respectively. In the optimization, efficiency of pressure generation was improved to adjust dimensions of a preformed gasket, and materials with low X-ray absorption were adopted for materials of second-stage anvils, columns of an anvil guide and an X-ray window in a LaCrO₃ heater to reduce X-ray absorption. As a result of the optimization, the P-T conditions of the in situ stress-strain measurements in the D-DIA apparatus were extended to 15.3 GPa and 1700 K. Using the developed technique, uniaxial deformation on wadsleyite was achieved to the strain of 19 % at the strain rate of $3.7 \times 10^{-5} \text{ s}^{-1}$ and at 15.3 GPa and 1700 K. In this study, the stress-strain measurements on wadsleyite were succeeded at the P-T conditions of the mantle transition zone and at controlled strain rate. The present study extended the P-T range of the measurements in the D-DIA apparatus from 9.6 GPa in early studies to 15.3 GPa at high temperature corresponding to interior of the earth. The experimental results demonstrate potential of the present deformation system composed of the D-DIA apparatus and the MA6-6 assembly as an important tool to investigate the creep strength of deep mantle minerals under the P-T conditions of an upper part of the mantle transition zone.

キーワード: ウォズリアイト, クリープ強度, マントル遷移層, DIA型変形装置, その場測定, 放射光

Keywords: wadsleyite, creep strength, mantle transition zone, deformation-DIA apparatus, in situ measurement, synchrotron

SIT040-13

会場:104

時間:5月23日 17:30-17:45

全マントル構造不均質の遠地地震トモグラフィーへの影響について On the influence of whole-mantle heterogeneity on teleseismic tomography

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Teleseismic tomography has become a powerful tool to determine the 3-D upper mantle structure under a region covered by a seismic network since this approach was firstly proposed by Aki et al. (1977). A basic assumption of teleseismic tomography is that the lower mantle is homogeneous, thus the use of relative travel-time residuals is assumed to remove the effects of earthquake mislocation and the structural heterogeneities outside of the study area, and the relative travel-time residuals from the teleseismic events only reflect the 3-D structure under the seismic network. However, global tomography studies have revealed various scales of structural heterogeneities in not only the upper mantle but also the lower mantle, such as deep subducted slabs and mantle plumes. Thus the whole-mantle heterogeneities would contribute partially to the observed relative travel-time residuals, and as a result affect the determination of 3-D velocity structure under the study area. However, so far no one has addressed this issue and it is unclear how much the whole-mantle heterogeneity would influence the teleseismic tomography. In this study we have investigated this problem for the teleseismic tomography beneath the Japan Islands. We used about 45,000 P-wave data from 360 teleseismic events recorded by the J-Array and Hi-net stations, in addition to about 230,000 P-wave arrival times from 1180 local shallow and deep earthquakes under the Japan Islands. We calculated theoretical travel times from each teleseismic event to the stations in Japan in a 3-D whole-mantle P-wave velocity model (Yamamoto and Zhao, 2010) and the 1-D iasp91 Earth model. We found that the differential travel time for the two models ($T_{3d}-T_{1d}$) is in the range of -0.3 s to +0.3 s, though it is -0.2 s to +0.2 s for most of the rays, which is equal to or larger than the picking errors of the teleseismic data (0.1-0.2 s). Therefore the effect of whole-mantle heterogeneity on the teleseismic residuals is significant and so it should be corrected. We have taken into account this effect and obtained a better 3-D P-wave velocity structure down to 700 km depth beneath the Japan Islands. Our results show that the Philippine Sea slab has subducted aseismically down to 300-500 km depth under SW Japan. Low-velocity (low-V) anomalies are imaged clearly in the central part of the mantle wedge above the subducting Pacific slab. The low-V zones exist not only under the Honshu land area but also extend westward beneath the Japan Sea. We also imaged low-V zones which seem to be caused by the deep dehydration of the Pacific slab at 300-400 km depths. A low-V zone is revealed at depths of 500-700 km in the mantle beneath the Pacific slab under Southern Tohoku and Kanto, which may reflect an upwelling flow from the lower mantle.

キーワード: 遠地地震, トモグラフィー, マントル, 不均質構造, スラブ

Keywords: teleseismic events, tomography, mantle, heterogeneity, slab

SIT040-14

会場:104

時間:5月23日 17:45-18:00

IceCube ニュートリノ検出器を用いたニュートリノ・トモグラフィーによる地球内部構造の研究 Neutrino absorption tomography with IceCube detector

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ニュートリノの吸収を用いて地球の内部密度を調べるニュートリノ・トモグラフィーは、地震波測定などの他の測定方法と完全に独立して地球の密度を測定出来る計測法として、長い間実現が待たれてきた。

ニュートリノは電氣的に中性であり、物質とは弱い相互作用でのみ反応する素粒子である。このため、地球本体も殆どが無反応で透過するが、ごくまれに、物質内部の陽子や中性子と反応し、ニュートリノの持つ「香り」と呼ばれる特性に従ってミュオン粒子や電子、タウ粒子などを生成した結果、地球内部で吸収される現象が起こる。

この反応断面積は、ニュートリノのエネルギーが高くなるにつれて大きくなる。また、吸収確率は、ニュートリノが通ってきた経路に沿った物質質量（陽子及び中性子の数）とこの反応断面積により、厳密に求めることが出来る。

このことから、あらかじめ地表での強度が分かっているニュートリノ源があれば、地球を通して飛来するエネルギーの高いニュートリノの数を経路ごとに調べることで、それぞれの経路での地球の平均密度を求める事ができる。

ニュートリノ・トモグラフィーの強みは、地球内部の温度や物質組成などに依らず密度が独立に求まる点にある。

一方で、その実現には主に次のような問題があった。

1) 10TeV 以上のエネルギーを持つニュートリノが数多く必要になる点

2) ほとんど物質と反応しないニュートリノを大量に検出するための、大容量のニュートリノ望遠鏡が必要である点

1) については、現状では大気ニュートリノが殆ど唯一の選択肢である。しかし、大気ニュートリノは数十 TeV 以上の地表での強度がまだ正確に測定されておらず、この領域の強度を推定するモデルも数多く存在する。また、大気ニュートリノは大量に地表に降り注いでいるとはいえ、10TeV 以上のエネルギーをもつものの数は少ない。このため、長期の観測が必要になる。

3) については、少なくとも1立方キロメートルの検出領域を持つニュートリノ望遠鏡が必要である。現在、この条件を満たすものは、2011年1月に完成した IceCube のみである。

IceCube ニュートリノ望遠鏡は、南極点の氷河面下 1500メートルから 2500メートルにかけて設置された、チェレンコフ光検出器である。

1本のストリングと呼ばれるケーブルに、60個の光電子増倍管をベースに開発された検出器が設置されている。2005年に1ストリングから運用を開始し、以降毎年15本から20本のストリングを設置しつつ、データの取得も行っている。北半球に送られたデータは、大気ミュオンなどのバックグラウンドイベント除去の後、純粋に地球内部を通過して到達したニュートリノ起源のイベントのみ抽出され、地球外ニュートリノの探索や大気ニュートリノスペクトラムの測定に用いられる。2007年（ストリング22本）及び2008年（ストリング40本）で、合計約20000のニュートリノイベントが観測された。

今回、この20000イベントを用いて、それぞれのニュートリノの到達角度ごとの頻度を得た。更に、このデータを、いくつかの地球内部モデルを組み込んだモンテ・カルロ・シミュレーションの結果と比較した。

結果は、Preliminary Reference Earth Model を組み込んだシミュレーションが、統計誤差の範囲内でデータと良く一致した。これは、地球のコアによるニュートリノの吸収を示唆する、ニュートリノ・トモグラフィーにおける最初のデータであると言える。

講演では、本年初頭に完成した IceCube（ストリング88本）で10年間データを取得した場合に得られると予想される地球の密度分布についても議論する。

また、大気ニュートリノスペクトラム、解析手法、検出器キャリブレーション及び icecube 直下の岩盤の密度の系統誤差が解析に与える影響を考察し、更にこれらの系統誤差を減らすための計画についても議論する。

[研究協力] 米ウィスコンシン大学 IceCube グループ

キーワード: ニュートリノ トモグラフィ, アイスキューブ
Keywords: Neutrino absorption tomography, IceCube

SIT040-15

会場:104

時間:5月23日 18:00-18:15

上部マントルにおける水素と olivine の反応

Reaction of hydrogen molecule and olivine under high pressure and high temperature condition

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水素は宇宙で最も多く存在する元素であり、現在でも地球深部のマントルや核に水素が存在していると考えられている。マントル中の水素は微量であっても鉱物の物性や融点に大きな影響を与える重要な物質である。マントル中の水素を含む流体の組成は酸化還元状態によって変化する。地殻やマントル上部は比較的酸化的であり、水流体として存在する。一方でマントルは深部に向かうにつれて還元的になり、上部マントル最下部やマントル遷移層では水、水素分子、メタンとして存在している。マントルダイナミクスや物質循環を検討する上で水に加えて水素、メタンとマントル鉱物との反応を調べるのが重要な課題となる。Olivine はマントルの主要構成鉱物であり、水が olivine に与える影響に関しては多くの研究が行われている。水が olivine の融点を大きく低下させることが明らかになっている。一方で、水素分子と olivine の反応に関する報告は十分でない。本研究では水素が olivine に与える影響を明らかにすることを目的として olivine と水素を出発物質とする高温高压実験を行った。

マントルでカンラン石は鉄を 10%程度含むことが知られているが、本研究では水素がカンラン石に与える影響をより明確にするため、鉄を含まない forsterite-水素系を出発物質とした。圧力の発生はレバー式ダイヤモンドアンビルセルを、圧力の測定にはルビー蛍光法を用いた。加熱には CO₂ レーザーを用いた。加熱の温度圧力条件は 10.8 GPa-15.2 GPa, 1500-1600K である。室温下に急冷後、減圧過程において光学顕微鏡観察、粉末 X 線回折、Raman 分光、SEM, TEM を用いて試料の評価を行った。

加熱後、加熱領域の茶色から黒色への色の変化が観察された。加熱後の XRD パターンから、加熱領域で olivine の MgO と SiO₂ への分解が観察された。無水条件および、H₂O と共存する条件では同様の分解反応は観察されないことから、水素が影響を与えたと考えられる。

キーワード: 上部マントル, 水素, かんらん石, レーザー加熱ダイヤモンドアンビルセル

Keywords: upper mantle, hydrogen, olivine, laser heated diamond anvil cell

SIT040-16

会場:104

時間:5月23日 18:15-18:30

マルチモード表面波トモグラフィーによるオーストラリア地域の3次元S波速度及び異方性モデル

Radially Anisotropic Shear Wave Structure of Australian Region from Multi-mode Surface Wave Tomography

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We developed a new three-dimensional shear wave speed model for the upper mantle beneath the Australian region from multi-mode surface waves. A large number of phase speed data from both Love and Rayleigh waves are extracted from three-component seismic records of seismic stations in the Australia and its surrounding region over the period between 1990 and 2008, using the networks reporting to IRIS, as well as portable seismic arrays deployed by the Australian National University.

We used a fully automated technique of multi-mode dispersion measurements with a nonlinear waveform fitting based on a direct model-parameter search using the Neighbourhood Algorithm. Over 6,000 paths for both Love and Rayleigh waves are collected to cover the entire Australian continent, which allow us to extract lateral heterogeneity as well as radial anisotropy with extended horizontal and vertical resolution. The path-specific phase speeds are inverted to produce multi-mode phase speed maps incorporating approximate finite-frequency effects via the surface-wave influence zone, within which surface waves can be considered to be coherent in phase. A 3-D radially anisotropic shear wave speed model is then derived from simultaneous inversions of local dispersion curves of multi-mode Love and Rayleigh waves.

The new 3-D model shows a good correlation of fast shear wave speed anomalies with regions of Archaean and Proterozoic cratons in the western and southern Australia down to a depth of about 200 km. Owing to the enhanced vertical resolution with the higher mode information, the subduction of the Australian plate in the north beneath Indonesia has also been mapped clearly. Three-dimensional distribution of radial anisotropy indicates faster SH anomaly than SV beneath the central and western Australia down to about 300 km depth, indicating possible effects of strong shear motion in the lithosphere-asthenosphere boundary beneath the continent.

キーワード: 表面波, トモグラフィー, 異方性, 大陸, オーストラリア

Keywords: surface wave, tomography, anisotropy, continent, Australia