

## モホール計画：マントル掘削プロジェクトの概要 The MoHole: Journey to the Earth's mantle

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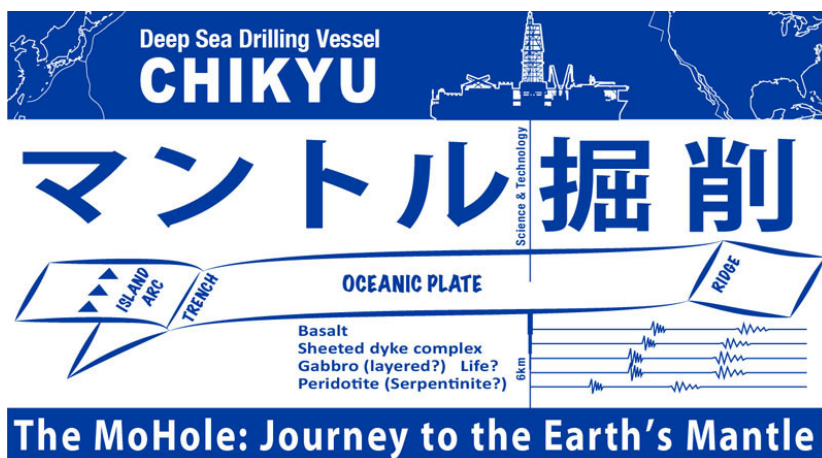
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The MoHole MDP proposal is planned to submit to International Ocean Discovery Program (IODP) in April 2012. This proposal has been compiled based on a series of workshops since 2006 (see <http://www.jp.mohole.org>). The goal of the MoHole project is to drill completely through intact oceanic crust formed at a fast spreading rate into the upper mantle. Full penetration and sampling of intact crust, Moho, and upper mantle in oceanic lithosphere will provide hitherto unattainable information on the composition and melting of the upper mantle, the construction and cooling of the oceanic crust, the chemical exchange between the crust and oceans, and the linkages between these processes including a global carbon cycle. In this contribution, we summarize the current activities and aspects related to the MoHole project.

MDP: Multi-phase Drilling Projects

キーワード: マントル掘削, 海洋プレート, モホ面, 海洋地殻, 最上部マントル  
Keywords: mantle drilling, oceanic plate, oceanic crust, Moho, uppermost mantle



## Temperature stability of polycyclic aromatic hydrocarbons at pressures of 6-20 GPa Temperature stability of polycyclic aromatic hydrocarbons at pressures of 6-20 GPa

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The origin of various deep-seated hydrocarbons was widely discussed in relation to the nature of C-O-H fluid. The estimation of  $fO_2$  conditions in the deep mantle indicate that it can be in equilibrium with reduced fluids and absolute values of  $fO_2$  in mantle rocks can be fluctuated near that for the iron-wustite buffer at the depth below 300 km. Calculations of fluid compositions at these conditions in the simple C-O-H system indicate the dominant CH<sub>4</sub>-H<sub>2</sub>O mixture, with subordinate H<sub>2</sub>, and heavier hydrocarbons. However, some theoretical calculations of equations of state for a range of hydrocarbons indicate their possible increased stability in the deep mantle. According to estimations of Chekalyuk (1967) and Zubkov (2001) some heavy alkanes, alkenes, polycyclic aromatic hydrocarbons (PAH), as well as some C-H-N and C-H-S compounds can become stable in the mantle fluids at the depths of 300-600 km and deeper. These components were found in natural samples - inclusions in deep diamonds and garnets, meteorites, as well as detected in the other planets and satellites and interstellar matters. The most stable hydrocarbons include PAHs, such as naphthalene, phenanthrene, pyrene, etc.

Experimental studies of reduced volatile species, such as hydrocarbons, and their phase relations with mantle silicates are extremely challenging and difficult. To date we have several important contributions from experimental petrology. Composition of C-O-H fluids under controlling oxygen fugacity was measured in samples quenched after piston-cylinder and multianvil experiments (Taylor and Green, 1990; Sokol et al., 2009). They reveal CH<sub>4</sub>- and H<sub>2</sub>-bearing compositions with subordinate H<sub>2</sub>O at 3-6 GPa and 1200-1600°C. Direct observation of methane formation from carbonate and methane dissociation to heavy alkanes was demonstrated in the diamond anvil cell experiments at 5-10 GPa (Scott et al., 2004; Kolesnikov et al., 2009).

We studied temperature stability and decomposition products of a range of PAHs at pressures up to 20 GPa using multianvil high-pressure apparatus and in situ X-ray diffraction at SPring-8. We successfully observed X-ray diffraction patterns of PAHs at high pressure. Disappearance of diffraction lines of PAHs was used as a detection of their decomposition. The decomposition of several PAH, ranging in atomic mass from naphthalene to pyrene and coronene was observed at 550-700°C and 6-9 GPa. Naphthalene and coronene were studied at 15 and 20 GPa and show increasing temperature stability up to about 1000°C. Our data clearly show that PAHs cannot be stable at the average PT-conditions of the upper mantle. Thus, PAHs observed as inclusions in mantle diamond and garnet (e.g. Garanin et al., 2011) must have a secondary origin and formed from lighter hydrocarbons by hydrogen loss with decreasing temperature and pressure.

キーワード: mantle, fluid, hydrocarbon, oxidation state

Keywords: mantle, fluid, hydrocarbon, oxidation state

## 我が国の陸域地下微生物生態系の解明に向けた取り組み Challenges to Explore the Terrestrial Subsurface Biosphere in Japan

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It is becoming increasingly clear that the terrestrial subsurface harbors microbial ecosystems as abundantly and diversely as microbial provinces in the seafloor. As the Japanese arc system is associated with the subduction of oceanic crusts and resulting volcanic fronts, the terrestrial subsurface biosphere is expected to vary from one setting to another. Due to the limited accessibility to the deep subsurface, previous microbiological investigations have been conducted at pre-existing facilities to exploit mineral deposits and fossil fuels. In recent years, the technical framework of site characterizations of potential underground repositories for geological disposal of nuclear wastes are being developed alongside the construction of underground research laboratories (URL). Microbiological studies that utilize the URL have advantages with respect to obtaining high-quality subsurface samples and in-situ physicochemical properties. This presentation is aimed to summarize (1) similarities and differences in subsurface microbial populations previously found to thrive in a variety of geological settings in Japan and (2) technical advances achieved by, and key indigenous and contaminant microbial populations revealed by, research efforts to establish the site-characterization procedures for potential geological repositories.

Keywords: subsurface microbiology, molecular phylogeny, aseptic drilling, underground research laboratory, deep biosphere

## プチスポット火山の揮発成分の重要性 Role of volatiles on petit-spot volcanoes

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The newly found volcanoes, petit-spot, occur in a region of oceanic plate that is susceptible to fracturing prior to plate subduction into the trench off NE Japan and Chile, where the volcanoes locate far from tectonic plate boundaries (e.g., mid-oceanic ridges and volcanic arcs) and hotspots. The magmas produced by these volcanoes originate from the asthenosphere immediately under the plate (Hirano *et al.*, 2006). It is clear that the surface morphology and distribution of petit-spot volcanoes are influenced by cracks in the lithosphere that reach the surface. Monogenetic petit-spot volcanoes located on the NW Pacific Plate are less than 2 km in diameter and yield ages of 1.8, 4.2, 6.0, 6.5, and 8.5 Ma by <sup>40</sup>Ar/<sup>39</sup>Ar datings, suggesting the episodic eruption of magma over a period involving 600 km of plate motion, without any systematic spatial trend in age such that seen along oceanic island/seamount chains moving over a hotspot (Hirano *et al.*, 2010). Moreover, these volcanoes represent 8 million years of activity over a large eruption area but with low volumes of magma production. The petit-spot magmas, therefore, could represent the first discovery of melting product transported directly to the surface from the asthenosphere below an old plate prior to subduction.

The most important feature of petit-spot lavas is their high vesicularity (up to 60 vol.%) in spite of the eruption under submarine hydrostatic pressure encountered at 6000 mbsl (Hirano *et al.*, 2006). This observation is caused by CO<sub>2</sub>, as the solubility of CO<sub>2</sub> is very low in alkaline magmas (Dixon, 1997) compared with the high solubility of H<sub>2</sub>O (ca. 300 ppm versus 0.5-1.0 wt%, respectively). Because a few percent of melt might be present if small amounts of H<sub>2</sub>O or CO<sub>2</sub> are present in the asthenosphere (Wyllie, 1995), it is anticipated that petit-spot magmas originate in the asthenosphere as incipient partial melts that form as a result of the presence of H<sub>2</sub>O and CO<sub>2</sub>. More recently, carbonatite melt has been proposed as a key material in explaining the electrical conductivity of oceanic asthenosphere (Gaillard *et al.*, 2008; Yoshino *et al.*, 2010). The preliminary observation of high CO<sub>2</sub> contents in petit-spot lavas raises the possibility that CO<sub>2</sub> affects the source components and their melting. Petit-spots on the Pacific Plate, therefore, provide a potential window into the geochemical characteristics and occurrence of partial melting in the asthenosphere.

キーワード: プチスポット, アルカリ玄武岩, 太平洋プレート, アセノスフェア, リソスフェア, 二酸化炭素

Keywords: petit-spot, alkali-basalt, Pacific plate, asthenosphere, lithosphere, carbon dioxide

## Phase relations in peridotite and eclogite systems with H<sub>2</sub>O and CO<sub>2</sub> at 3-27 GPa Phase relations in peridotite and eclogite systems with H<sub>2</sub>O and CO<sub>2</sub> at 3-27 GPa

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Oxidized fluid compounds, H<sub>2</sub>O and CO<sub>2</sub>, dominate in the upper mantle at depths to 100-200 km and have key importance to deep magmatism. The simplified and complex systems with CO<sub>2</sub> or H<sub>2</sub>O alone are studied experimentally up to pressures of 20-32 GPa. The systems, containing both H<sub>2</sub>O and CO<sub>2</sub>, are studied only at low pressures to 3-5 GPa and in few cases to 10-12 GPa under specific conditions. Here we report the results of the experimental study of the systems peridotite-H<sub>2</sub>O-CO<sub>2</sub> and eclogite-H<sub>2</sub>O-CO<sub>2</sub> up to a pressure of 27 GPa. The starting compositions of peridotite and eclogite contained 3 wt% H<sub>2</sub>O and CO<sub>2</sub> each. The experimental details can be found elsewhere.

The association of silicate minerals in the peridotite system includes olivine / wadsleyite / ringwoodite - orthopyroxene / clinoenstatite - garnet. Clinopyroxene occurs only at 3 and 6.5 GPa. Ringwoodite + garnet are stable at 21 GPa; at 1000-1100°C stishovite is added to them. The typical peridotite association of Mg-perovskite-Ca-perovskite-ferropericlasite is stable at 27 GPa. Magnesite is the only carbonate phase over the entire pressure range. The temperature of magnesite stability is 1300°C in the pressure range of 10-27 GPa and it decreases only at lower pressures. Water-bearing superhydrous phase B and phase D were identified only at 21 and 27 GPa and 1000-1100°C. Melts of low melting degrees (from 9 to 33 wt%) in the peridotite system are enriched in SiO<sub>2</sub> and alkalis, which is typical for the peridotite-H<sub>2</sub>O systems, and differ from carbonatitic melts in the systems peridotite-CO<sub>2</sub>. The temperature trends correspond to a decrease in the relative concentration of SiO<sub>2</sub> and alkalis and an increase in the (Mg + Fe)/Ca ratio.

The association of silicate minerals in the eclogite system includes garnet and clinopyroxene at 3-10 GPa, garnet and stishovite at 16-21 GPa, and a post-garnet assemblage of Mg-perovskite, Ca-perovskite, stishovite, and Al-phase CF at 27 GPa. Garnet is a liquidus phase melting after clinopyroxene and stishovite with increasing temperature. At 3-10 GPa rutile appears as an accessory phase and at 16-21 GPa Fe-Ti-oxides appear episodically. Dolomite is stable at 3 GPa, but at higher pressures magnesite is the only carbonate phase. The temperature of magnesite stability in the eclogite system is 1100°C in the pressure range of 10-27 GPa, which is lower by 200°C than in the peridotite system. Hydrous phases were not observed even in the lowest temperature experiments.

Low degree melts in the system eclogite-H<sub>2</sub>O-CO<sub>2</sub> are enriched in SiO<sub>2</sub> and alkalis to a greater degree in comparison with the peridotite system, which is also typical for the system eclogite-H<sub>2</sub>O, and strongly differ from carbonatitic melts in the eclogite-CO<sub>2</sub> system. Melts at 16-21 GPa are strongly enriched in Na<sub>2</sub>O (up to 10-16 wt%) in comparison with melts at 3-10 GPa. This is explained by Na<sub>2</sub>O incorporation into omphacite at low pressures and into CF-phase at 27 GPa, whereas garnets at 16-21 GPa contains only up to 1.9 wt% Na<sub>2</sub>O.

Peridotite and eclogite solidi in the studied systems have a flat slope to the pressure axis in the range of 6-27 GPa. Consequently this will result in melting of H<sub>2</sub>O-CO<sub>2</sub>-bearing rocks at intersection of the solidi with PT-profiles of the subduction zones and hotter geotherms, which have a steeper slope to the pressure axis. Magnesite is the only carbonate phase in both systems at pressures above 6 GPa. The temperature of stability of hydrous phases in the peridotite system decreases by 100-200°C in comparison with the peridotite-H<sub>2</sub>O system. Hydrous phases, such as phengite or lawsonite were not observed in the experiments at 6.5 GPa and 900°C in the eclogite system as well. This provides evidence for the fact that addition of carbon or carbonates results in mobilization of structurally bonded hydrogen in peridotitic and eclogitic minerals and decreases the temperatures of melting of hydrous systems.

キーワード: mantle, peridotite, eclogite, volatile, melting, carbon

Keywords: mantle, peridotite, eclogite, volatile, melting, carbon

## 沈み込む海洋堆積物の5GPaまでの溶融関係と上部マントルにおけるC-O-H成分の循環

### Melting phase relation of pelitic sediment to 5 GPa and deep subduction cycling of C-O-H volatiles

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Recycling of C-O-H volatiles in subduction zones is important for understanding the chemical evolution of the Earth's mantle, crust, and long-term surface environments. Downgoing sediments carry an important fraction of water and carbon [1]. Although most water is released in the shallow mantle wedge, some water bound in phengite and most of the carbon bound in crystalline carbonate likely subduct past sub-arc depth (an example of this can be found in the work of Kerrick and Connolly [2]). While experimental data on the melting relations of alumina-rich pelite up to 23.5 GPa have recently been completed [3, 4], those of alumina-poor pelite investigations have been limited to 3 GPa [5, 6]. In order to further understand deep volatile recycling via sediment subduction, melting experiments on an alumina-poor carbonated pelite under water-poor conditions up to 5 GPa have been performed.

Experiments were conducted using piston cylinder (3 GPa) and multi-anvil (4-5 GPa) apparatus with an Au capsule between 800 and 1150 °C. The starting materials HPLC3 (1 wt.% H<sub>2</sub>O and 5 wt.% CO<sub>2</sub> in the bulk) and HPLC4 (0.5 wt.% H<sub>2</sub>O and 5 wt.% CO<sub>2</sub> in the bulk) studied here are deficient in SiO<sub>2</sub> compared with those used in our previous studies [5, 6], which simulates the loss of siliceous hydrous fluid in the shallow part of subduction.

We bracketed the solidus temperatures of 800-850 °C at 3 GPa and 900-950 °C at 5 GPa for HPLC3, and of 850-900 °C at 3 GPa and 900-950 °C at 5 GPa for HPLC4. Subsolvus phases include cpx, garnet, quartz/coesite, rutile, phengite, and calcite<sub>ss</sub> for both HPLC3 and HPLC4 at 3-5 GPa. The subsolvus phases also include water vapor and K-feldspar for HPLC3 and HPLC4, respectively; this indicates the differences of the near-solidus melting reactions between the vapor-present (HPLC3) and vapor-absent (HPLC4) conditions. The near-solidus melts at 3-4 GPa for HPLC3 and 3 GPa for HPLC4 are hydrous rhyolitic, whereas those at 5 GPa are Ca- and K- rich carbonatitic for both materials. Excess water vapor decreases the temperature in comparison to the vapor-absent solidus at 3 GPa where the hydrous silicate is stable at near-solidus temperatures. On the other hand, excess water vapor does not affect the temperature in comparison to the vapor-absent solidus at 5 GPa where the carbonate melt is present at near-solidus temperatures.

Comparison of the melting boundaries up to 5 GPa with slab surface temperatures as a function of depth [7] predicts that the extrapolated solidus temperatures of hydrous carbonated pelite might intersect the *P-T* trajectory of Central America (Nicaragua) where carbonated sediments similar to the composition studied here may be subducting at 180-200 km depth. The seismic low-velocity zone in the mantle wedge, located from the subducting slab at 180-200 km depth to the arc volcanoes of Nicaragua [8], might be responsible for the transport of the sedimentary carbonated melt from the deep upper mantle.

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Keywords: subduction zone processes, sediment melting, deep water cycle, deep carbon cycle, C-O-H volatile recycling, arc magmatism

## Origin of kimberlite magma: experimental constrains

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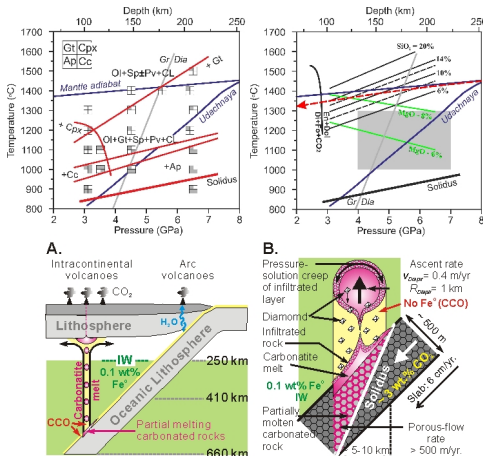
In this presentation we discuss the compositional trend of parental kimberlite melt (Fig. 1,2), possible source regions, mechanism of the magma segregation and ascent (Fig. 3). The dissection based on our recent experimental data on the melting phase relations in the Udachnaya East kimberlite (UEK) which is unique sample of unaltered kimberlite rock (Fig. 1). The rates of the melt segregation and ascent estimated using our experimental data on diffusivity of silicate component in carbonatite melt.

Figure 1. Experimental phase diagram of unaltered Udachnaya East kimberlite (UEK). Ol ? olivine; Sp ? Al-spinel, Pv ? perovskite, Gt ? garnet; Cpx ? clinopyroxene; Ap ? apatite; Cc, Ca-carbonate, CL ? carbonatite melt. Blue lines show mantle adiabat and Udachnaya geotherm from McKenzie et al. (2005). Graphite-diamond (Gr-Dia) transition line is shown for comparison.

Figure 2. The UEK melt composition vs. P-T trend of ascent (Red dashed arrow). Grey field show approximate PT-estimations from mantle xenoliths and diamond inclusions.

Figure 3. Extraction of carbonatite melt from subducting slab. A. General view. B. close view. Since carbonatite melt rapidly infiltrates surrounding rocks, the diapir ascent rate would be controlled by pressure-solution creep in the melt impregnated layer, i.e. by silicate diffusion via intergranular melt films rather than by solid state diffusion. We expect that even small, 1 km in radius, diapirs could rise with the rate of about 0.5 m/year.

キーワード: mantle, kimberlite, carbonatite, experiment  
 Keywords: mantle, kimberlite, carbonatite, experiment



## Sao Luiz 超深部ダイヤモンドの成長環境と炭素循環 Deep carbon and growth environment of superdeep diamonds from Sao Luiz, Brazil

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Diamonds are one of the natural samples providing us with direct information on materials in the deep earth. Some of diamonds from Sao Luiz, Brazil, are known to originate from the transition zone and lower mantle from the existence of ferropericlase and back-transformed magnesium perovskite as inclusions.

The dominant inclusions in diamonds from studied here are CaSi-perovskite and AlSi-phases. MgSi- and CaTi-perovskites, ferropericlase, native iron, coesite and zircon have also been found. Raman shift of coesite show high residual pressure (>3 GPa). CL image has revealed the complex growth history for most diamonds, reflecting their formation in several stages.

Some samples contained microinclusions and FTIR analyses showed that water and carbonates are not major components of diamond-forming fluids. To identify the microinclusions, TEM observations were carried out on a foil of carbonado (0.1 micron thick) made from a polished diamond specimen after Au-coating. The foil was fabricated with a Ga ion beam using a focused ion beam (FIB) instrument (JEOL JEM-9310FIB). The foil was observed with a TEM (JEOL JEM-2010) under an accelerating voltage of 200 kV. We first found out euhedral inclusions of several tens nanometers in size. At present, the chemical composition or mineral species of these nano-inclusions are not clarified. However, the presence of these nano-inclusions will be a key to understand the growth process.

Based on these microscopic observations coupled with carbon isotopic distribution obtained from SIMS measurements, deep carbon cycle inferred from the growth history of the super deep diamonds will be discussed.

キーワード: ダイヤモンド, 下部マントル, 炭素循環, 包有物  
Keywords: diamond, lower mantle, carbon cycle, inclusions



## Diamonds in Almahatta Sitta 2008 TC3 ureilite Diamonds in Almahatta Sitta 2008 TC3 ureilite

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Near Earth Object (NEO) 2008 TC3 impacted the Earth around northern Sudan on October 7, 2008. Its remnant was recovered immediately and called Almahatta Sitta as a meteorite. Almahatta Sitta is a first meteorite we could trace during a falling into the Earth after we found it in the space by astronomic observation. Almahatta Sitta TC3 consists mainly of coarse-grained and fine-grained ureilite. Both of them contain a carbon material. Here, we report the occurrence of the carbon material in the coarse-grained ureilite (MS-170-14).

Based on low-magnification BSE images, the carbon materials in the coarse-grained ureilite (MS-170-14) have two different textures; i.e., a) granular-like and b) booklet-like. The former is much dominant occurrence as a carbon material compare to the later. Most carbon materials filling cavities and fractures between the olivine grains show granular-like texture. The granular-like texture has concave and convex portions, which would be differences on resistance between them to polishing. Raman spectroscopy analyses indicate that the convex portions consist mainly of diamond. The main diamond Raman band stays within narrow range (1333.7 cm<sup>-1</sup>). High-magnification BSE image show that many diamonds (a dimension > 2-3 micro m) have hexahedron- or octahedron-like shape, which would correspond to euhedral {001} or {111} diamond, respectively although their shaped are not perfect. The concave portions embedding the diamonds consist mainly of graphite. Interlayer C-C stretching vibration (E<sub>2g2</sub>) originating from graphite (G-band = ~1586 cm<sup>-1</sup>) was confirmed by Raman analysis. In addition to G-band, strong and broad peak around 1358 cm<sup>-1</sup> appears. This is a so-called D-band and is inherent in deformed graphite. TEM images show that most diamonds are single crystals. Some deformation textures are observed in the diamond. Some isolated graphite portions exist in the diamond. These features would be due to a dynamic event after diamond formation. These single diamonds having hexahedron- or octahedron-like shape are not found from ureilites up to now, and would not be formed from graphite through martensitic transformation mechanism by a dynamic event. It is likely that these diamonds were formed by chemical vapor deposition (CVD) process.

## 玄武岩マグマと揮発性物質：リソスフィアとアセノスフィアの起源への適用 Properties of basaltic magmas and volatiles: application to origin of the asthenosphere-lithosphere boundary

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MOR basaltic volcanism is the most voluminous magmatic activity and produces oceanic floors and drives plate motion on the surface of the Earth. Thus the physical properties of magmas including the effect of CO<sub>2</sub> and water on the properties are essential for account for the magmatic activity of the Earth.

We have conducted the density and viscosity measurements of basaltic magma under the upper mantle conditions. We observed a rapid increase in basaltic magma density at pressures around 3-5 GPa, and the compression curve cannot be expressed by the Birch-Murnaghan equation of state. This result implies that density contrast between the magma and the surrounding mantle disappears at the depths >100 km in the upper mantle. The viscosity of the magma shows a minimum in the same pressure range. The change in these physical properties of magma will be caused by the structural change of the melts such as coordination increase of Al at high pressure, which is consistent with the previous NMR measurements of the glass (Allwardt et al., 2007). The effect of volatiles on the density of magmas has also been studied under the upper mantle conditions, and it revealed that the effect of CO<sub>2</sub> is small compared to that of water. If volatile associated with the melts in the asthenosphere is mainly CO<sub>2</sub>, we can expect disappearance of the density difference between the magma and surrounding rocks under the volatile bearing conditions.

We will discuss the relation between the change of the physical properties of basaltic magma and the processes in the oceanic lithosphere and asthenosphere including a Petit spot activity (Hirano et al., 2006), small-scale sublithospheric convection (SSC) (Ballmer et al., 2010), melt retention observed in seismology (Kawakatsu et al., 2009).

キーワード: 玄武岩マグマ, 密度, 粘性, 揮発性物質, リソスフィア, アセノスフィア

Keywords: basaltic magma, density, viscosity, volatiles, lithosphere, asthenosphere

## Density and magnetic properties $\text{Fe}_7\text{C}_3$ to 1.7 Mbar with implications for carbon in the Earth's inner core

## Density and magnetic properties $\text{Fe}_7\text{C}_3$ to 1.7 Mbar with implications for carbon in the Earth's inner core

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The global carbon cycle may involve iron carbide  $\text{Fe}_7\text{C}_3$  as a major component of the Earth's inner core. Testing the hypothesis of a carbon-rich inner core requires knowledge on the phase stability, density, and sound velocities of  $\text{Fe}_7\text{C}_3$  under the corresponding pressure and temperature conditions. Here we report new x-ray diffraction spectra of  $\text{Fe}_7\text{C}_3$  compressed to 1.7 Mbar, well into the pressure range of the Earth's core. In combination with parallel measurements on  $^{57}\text{Fe}$ -enriched  $\text{Fe}_7\text{C}_3$  using the synchrotron Mossbauer spectroscopy. Our data reveal two discontinuities in the compression curve, which we attribute to magneto-elastic coupling associated with pressure-induced second-order transitions. On the basis of the equation of state fitted to the XRD data above 60 GPa, we found that  $\text{Fe}_7\text{C}_3$  provides a good match for the inner core density, supporting the notion that carbon is by far the largest reservoir of carbon inside the Earth.

キーワード:  $\text{Fe}_7\text{C}_3$ , inner core, carbon, magnetic transition, x-ray diffraction, synchrotron Mossbauer spectroscopy

Keywords:  $\text{Fe}_7\text{C}_3$ , inner core, carbon, magnetic transition, x-ray diffraction, synchrotron Mossbauer spectroscopy

## 高温高圧下における Fe-C メルトの密度 Density measurement of liquid Fe-C at High pressure and high temperature

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Seismological and experimental studies show that the Earth's outer core is approximately 10% less dense than molten iron at the core pressure and temperature conditions, implying that some light elements exist in the core. Carbon is one of the plausible candidate of the light element in the core. Based on the effect of pressure on carbon solubility into iron and thermodynamic calculation, 2-4wt% carbon is estimated to be in the core. In this study, we measured the density of liquid Fe-3.5wt%C using X-ray absorption method at BL22XU, SPring-8 synchrotron facility, and clarified the pressure and temperature dependency of the melt in 1.8-6.5 GPa and 1600-2299 K range. The present results revealed that the melt becomes more compressible in the pressure range of 4-6 GPa at 1800 K. This change of the compressibility suggests existence of a structural change of the Fe-C melt in this P-T range. Therefore we cannot ignore the effect of the structural change of the liquid Fe-C in order to consider an abundance of carbon in Earth's outer core.

キーワード: 高温高圧, 密度, X線吸収法, Fe-C 融体

Keywords: high pressure, Density, X-ray absorption, liquid Fe-C

## その場 X線回折実験による $\text{Fe}_3\text{C}$ の融解関係の決定 Determination of melting relation of $\text{Fe}_3\text{C}$ by in-situ X-ray diffraction experiments

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The carbon cycle in the Earth's interior (Deep Carbon Cycle) is one of the outstanding topics in Earth science. Carbon may be contained in the Earth's core. The Earth's core is regarded as an Fe-Ni alloy but the density of the core is lower than that of pure Fe at pressures and temperatures corresponding to the core conditions. Therefore, the Earth's core is supposed to contain light elements and carbon is one of the candidate of the light elements to explain the density deficit of the Earth's core. Until now, many studies on physical and chemical properties of Fe-carbides have been carried out at high pressure. Especially, the recent studies on melting of  $\text{Fe}_3\text{C}$  were reported by Nakajima et al. (2009) and Lord et al. (2009). Nakajima et al. (2009) reported the melting temperature of  $\text{Fe}_3\text{C}$  up to around 30 GPa based on textual observations, the chemical analysis of the quenched run products, and in situ X-ray diffraction experiments using a Kawai-type multi anvil apparatus. Lord et al. (2009) reported melting temperatures of  $\text{Fe}_3\text{C}$  up to 70 GPa, which was determined by the temperature plateau during increasing laser power using a laser-heated diamond anvil cell. However, there are obvious discrepancies between the melting curves of  $\text{Fe}_3\text{C}$  reported by Nakajima et al. (2009) and Lord et al. (2009). In this study, the melting temperatures of  $\text{Fe}_3\text{C}$  were determined based on in situ X-ray diffraction experiments. This study aims to reveal the uncertainty of the melting temperature of  $\text{Fe}_3\text{C}$  and discuss the behaviours of carbon in the Earth's core.

We have performed experiments using a diamond anvil cell combined in situ X-ray diffraction experiment at BL10XU beamline, SPring-8 synchrotron facility. An NaCl powder and a rhenium foil were used for the insulator and gasket, respectively. Melting of the sample was determined by disappearance of the X-ray diffraction peaks as described in previous works (e.g. Campbell et al., 2007; Morard et al., 2008; Kamada et al., 2010).

We determined the melting relation of  $\text{Fe}_3\text{C}$  up to 70 GPa by in situ X-ray diffraction experiments. The melting temperature (both solidus and liquidus) of  $\text{Fe}_3\text{C}$  is close to Nakajima et al. (2009) up to 30 GPa but becomes close to that reported by Lord et al. (2009) at higher pressure conditions. The present experiments revealed that  $\text{Fe}_3\text{C}$  was stable as a subsolidus phase at least up to 70 GPa. This indicates that  $\text{Fe}_3\text{C}$  is a potential candidate of the Earth's inner core.

Keywords: Deep carbon cycle, Earth's core, Fe-Carbide, in situ X-ray diffraction experiment