

SIT040-P01

Room:Convention Hall

Time:May 23 10:30-13:00

Melting experiments of the Martian mantle and origin of shergottite

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The basaltic and olivine-phyric meteorites from the Martian surface, shergottites, are known to differ from the Earth's basalts in chemistry. The parent magma of Martian basalts are estimated to be enriched in Fe and depleted in Al. Basaltic rocks are generally considered to originate from liquid part of the mantle material which suffered partial melting. Therefore, these chemical variations in shergottites indicate that the Martian mantle also has Fe-rich and Al-poor composition. Melting experiments on Fe rich mantle have been performed at 1.5-3.0 GPa by Bertka and Holloway (1994) and at 3.0-10 GPa by Draper and his coworkers (e.g., Draper et al., 2001; Wasserman et al., 2001; Agee and Draper, 2004). Parent magmas of shergottite, however, could not be produced by partial melting in this pressure range (Agee and Draper, 2004). Here, we point out that the solidus temperature reported by Borg and Draper (2004) is higher than that by Bertka and Holloway (1994). The difference is more than 150 °C at 3.0GPa, although the chemical composition of starting materials was almost same in the both studies. In this study, we performed melting experiments of Fe-rich Martian mantle between 1.0 and 5.0GPa in more reliable experimental conditions, and discussed the origin of shergottite magma.

The DW Martian mantle composition model which is suggested by Dreibus and Wanke (1985) is used as our starting material in the system SiO₂-TiO₂-Al₂O₃-Cr₂O₃-FeO-MgO-CaO-Na₂O. We reduced the synthesized starting material in a gas mixing furnace, oxygen fugacity at QFM, 1000 °C for 5 h. Pt/Re double capsules are used for all our experiments for reduction of Fe-loss from the sample. We used multi-anvil apparatus for the experiments at 5.0 GPa and piston-cylinder apparatus (Takahashi lab. in Tokyo Tec.) at 1.0 and 2.5 GPa. The experimental conditions are 1300- 1700 °C in temperature and 1-24 h in duration. We used SEM-EDS to analyze the chemical composition and to identify the mineral phases. We also calculated the degree of melting with image-editing software.

In our experiments, the solidus temperature at 5.0 GPa is around 1500 °C and liquidus temperature is 1750 °C, which indicates that the solidus and liquidus temperature of this study is about 100 °C lower than Agee and Draper (2004). At 2.5 and 1.0 GPa, solidus temperature is approximately 1400 and 1300 °C respectively which is a little higher than Bertka and Holloway (1994). Phase relation shows a good agreement with Bertka and Holloway (1994), Agee and Draper (2004) except for spinel stability field that is wider in our experiment up to 1400 °C. The chemical composition of partial melt from our experiments has low in Si content and high in Mg/(Mg + Fe) atomic ratio, compared to the calculated data of the parent shergottite magma by previous studies (e. g., McSween et al., 1988; Schwandt et al., 2001; Harvey et al., 1993). In Al and Ca contents, parent shergottite magma is comparable with the partial melts of DW mantle from our experiments at 2.5 and 5.0 GPa, which is lowest pressure condition of garnet stability field in Martian mantle. Consequently, we estimate that the primitive magma of Mars could be generated between at 2.5 and 5.0 GPa where 200-400km deep in the Martian mantle if the DW mantle is a host material of basaltic shergottites.

Keywords: Mars, mantle, shergottite, partial melting, high pressure and temperature experiments

SIT040-P02

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Density measurement of liquid Fe-C at high pressure and Implication for Earth's Outer core

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Seismological and experimental studies show that the Earth's outer core is approximately 10% less dense than molten iron at corresponding 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, because that the volatility of carbon is only significant at pressures less than 10^{-1} bar and the solubility of carbon in molten iron is large even at 1 bar. Based on the effect of pressure on carbon solubility into iron and thermodynamic calculation, 2-4 wt% carbon is estimated to be in the core. In this study, we measured the density of liquid Fe-3.5wt%C, which corresponds nearly eutectic composition, at 5-9GPa and 1923K using sink/float method. This method is applied using composite density marker which composed of Pt disk core and Al_2O_3 tube mantle. The present results revealed that the effect of pressure on the density of liquid Fe-C. If the density and the bulk modulus(K) are known, the compressional wave velocity, V_P , can be calculated. Therefore, comparing the calculated V_P value of liquid Fe-C with that of the PREM model (Dziewonski and Anderson, 1981), and we evaluated a possibility of existence of carbon in the core. The obtained results revealed that the addition of carbon to liquid Fe decreased the density whereas it did not affect the bulk modulus.

Keywords: high pressure, density, Bulk sound velocity, liquid Fe-C

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Waveform inversion for S-velocity structure in the lowermost mantle beneath the Southern Pacific

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We conduct waveform inversion for the vertical profile of shear velocity in the D'' layer beneath the Southern Pacific. We use the transverse component of relatively long period broadband waveforms (20-200s), obtained from IRIS for earthquakes from 1993 to 2010. We find lower S-velocity relative to PREM in the depth range from 0-150km above the core-mantle boundary (CMB), and higher S-velocity relative to PREM in the depth range from 150-300km above the CMB. This is consistent with a phase transition from perovskite to post-perovskite. The average S-velocity in D'' is the same as or slightly faster than PREM, which is roughly consistent with previous global D'' velocity models.

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Ab initio lattice thermal conductivity of deep mantle minerals

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The core-mantle boundary heat flow depends on the thermal conductivity of the base of Earth's lower mantle. Direct measurement of thermal conductivity of minerals remains technically challenging at the deep mantle condition. On the other hands, *ab initio* computational technique based on the density functional theory (DFT) allows us to examine microscopic process of the transport phenomena including the lattice thermal conduction. Earlier theoretical works calculated the lattice thermal conductivity of MgO with *ab initio* molecular dynamics (MD) simulation or direct evaluation of third-order anharmonic force constants to compute phonon-phonon interaction (Nico de Koker, Phys. Rev. Lett. **103**, 125902, 2009, X. Tang and J. Dong, Proc. Natl. Acad. Sci. U.S.A. **107**, 4539, 2010). However, in these approaches, the simulation cell is often insufficient to accurately calculate the long wave-length phonon-phonon interactions. This leads to a lack of the decay channels for the phonons. For a more reliable way, the anharmonic coupling between phonon modes can be calculated within density functional perturbation theory (DFPT). In this approach, the higher-order force constants are calculated based on the perturbative scheme taking care only of the primitive cell. In this presentation, we show the phonon decay and the lattice thermal conductivity of MgO in the lower mantle conditions.

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Keywords: first principles calculation, lattice thermal conductivity, phonon-phonon interaction, deep mantle minerals

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Hydrous phase in water-saturated MORB at the lower mantle conditions

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Mantle minerals as water reservoir are important issue to consider the structure, dynamics and evolution of the Earth. We investigated the water saturated MORB system under high pressure and high temperature using laser-heated diamond anvil cell (LHDAC) combined with in-situ X-ray diffraction method at AR-NE1, KEK(Tsukuba, Japan). Starting materials were synthetic glass with a MORB component and distilled water. The experimental pressure and temperature range are up to 70GPa and 1700K, respectively. X-ray diffraction experiments were performed using monochromatic X-ray with 30keV and imaging plate detector. Pressures are determined by the equation of state of gold. We found PhaseD exist in the heated sample with coexist phases of Ca-Perovskite, Mg-Perovskite, Stishovite, and CF-Phase, though no significant hydrous mineral has been reported In the previous experiments on dry and wet MORB. The decomposition of phase D was also observed above 60GPa. The appearance of phaseD seems to be related with small intensity from the Mg-perovskite phase. Bulk modulus of each phase was well consistent with the previous reports in the literature. However the absolute volume was slightly different from those in literature. The present results indicate that PhaseD, which could contain up to 19.wt% of water, is one of the candidate minerals as a water reservoir in subducting slab in the lower mantle condition if it was locally in water-saturated condition. The details of experiments and analysis will be presented with analysis of the recovered samples.

Keywords: LHDAC, MORB, Hydrous minetals, PhaseD, Lower mantle, KEK

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Mg, Si-bearing delta-AlOOH as a reserver of water in the lower mantle

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Earth's lower mantle is mainly composed of MgSiO₃-perovskite. Additionally, subducting slabs transport water stored in hydrous minerals into the lower mantle. It has been considered that almost hydrous minerals decompose and dehydrate at the lower mantle. On the other hand, delta-AlOOH can be stable up to the CMB condition and be as a reserver of water transported into the deep lower mantle (e.g., Sano et al., 2008). However, it is unknown whether delta-AlOOH can coexist with MgSiO₃-perovskite in the lower mantle or not. In this study, we performed high pressure and temperature experiments in the hydrous MgSiO₃-Al₂O₃-H₂O system, and we evaluated the possibility of the coexistence of delta-AlOOH and MgSiO₃-perovskite in the lower mantle.

We synthesized a gel-sample, of which composition was 70 mol.% MgSiO₃-30 mol.% Al₂O₃. H₂O contents of the starting gel samples were 1.5 wt.% or 7.0 wt.%.

High pressure and temperature conditions were generated using a laser heated diamond anvil cell. X-ray diffraction experiments were performed at high pressure after quenched from 2000 K at BL10XU, SPring-8. The present results showed that delta-AlOOH and MgSiO₃-perovskite coexist up to 68 GPa at 2000 K. Chemical analyses of recovered samples were performed using STEM-EDS (JEM-3000F). The recovered sample from 68 GPa and 2000 K showed that MgSiO₃-perovskite coexisting with delta-AlOOH contains 3.1(12) mol.% Al₂O₃ and this delta-AlOOH contains about 50 wt.% MgSiO₃. In contrast, MgSiO₃-perovskite in the dry MgSiO₃-Al₂O₃ system can contain at least 25 mol.% Al₂O₃ (e.g., Liu, 1977). Present results revealed that the Al₂O₃ content in MgSiO₃-perovskite in the hydrous system is dramatically less than that in MgSiO₃-perovskite in the dry system because of the existence of delta-AlOOH. Moreover, the Al₂O₃ content in the hydrous system is less than that in MgSiO₃-perovskite in the pyrolite composition. This suggests that delta-AlOOH can coexist with MgSiO₃-perovskite in the lower mantle composition.

Therefore, it can be concluded that delta-AlOOH coexists with MgSiO₃-perovskite in the lower mantle if the lower mantle contains at least 1.5 wt.% water even along the lower mantle geotherm.

Keywords: Earth's lower mantle, MgSiO₃-perovskite, delta-AlOOH

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Influence of iron on the plastic properties of MgSiO₃ post-perovskite: a first-principle study.

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The D'' layer is one of the most enigmatic part of the Earth's interior and has major implications for its dynamics. This layer is characterized by a strong and inhomogeneous seismic anisotropy. This latter could be produced by combining the single-crystal elastic anisotropy and crystal preferred orientation (CPO) of (Mg,Fe)SiO₃ post-perovskite phase. Some experiments have been done on the plasticity of poor-Fe-bearing and pure MgSiO₃ post-perovskite and lead to textures of deformation dominated by the (100) and (110) slip planes (Merkel et al., 2007) and by the (001) slip plane (Miyagi et al., 2010). On the other hand, theoretical calculations on the dislocations mobility on pure MgSiO₃ (Carrez et al., 2007; Metsue et al., 2009) suggested a texture dominated by the (010) slip plane. These results cannot explain the seismic observations in the whole D'' layer. Consequently, in order to understand the seismic anisotropy of the whole D'' layer, one should determine the effects of incorporated elements, such as iron, on the plastic properties of the post-perovskite phase.

In this study, we present the results of an atomic-scale computational study on the plastic shear of pure and Fe-bearing MgSiO₃ post-perovskite at 120 GPa. We determine the response of 4 potential slip planes, (100), (010), (001) and (110), under a plastic shear through the calculation of the Generalized Stacking Faults (GSF) energies. The values of the GSF energy are obtained by shearing half of an infinite crystal over the other half for every slip plane, similarly to our previous studies for the post-perovskite phase (Carrez et al., 2007; Metsue et al., 2009). The calculation of the GSF energies provides also an estimation of the ideal shear stress (ISS); the maximum resolved shear stress that a perfect crystal can suffer without plastically deforming (Paxton et al., 1991). The GSF energies are determined with ab initio calculations based on the internally consistent LDA+U technique (Tsuchiya et al., 2006) to describe accurately the local interactions between the d-states in Fe. The U parameter is optimized at 120 GPa by using the linear response theory based on the constrained total energy variational principle (Cococcioni and de Gironcoli, 2005, Phys. Rev. B). In this study, Fe is incorporated as substitutional single-point defects close to the glide plane. Iron is treated with different oxidation states (+2 or +3) and different spin states (low or high). As a main result, we show that the incorporation of iron in the post-perovskite phase leads to a decrease of the ideal shear stress for all slip systems. In addition, the slip systems that exhibit the lowest ISS are the same in pure and Fe-bearing MgSiO₃ post-perovskite.

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Keywords: post-perovskite, first-principle calculations, Stacking fault

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High-pressure transitions of subducted continental crust at around 660-km discontinuity

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It has been suggested that subducted slabs carry crust materials to the deep interior of the earth, and give a variety of influences on mantle dynamics. The slab materials are composed of oceanic crust, harzburgite and peridotite. But it is suggested that continental crust and terrigenous and pelagic sediments may be subducted to the deep mantle with the slab. High-pressure phase relations of upper continental crust (UCC) have been studied from the uppermost mantle to the upper part of lower mantle (Irifune et al., 1994, Wu et al., 2009), but phase relations at around 660-km discontinuity of the interior of the earth have not been researched in detail yet. In this study, we have examined high-pressure phase relations of UCC at around 660-km conditions.

UCC sample was prepared by mixing SiO₂(66.07), TiO₂(0.50), Al₂O₃(15.21), K₂O(3.40), FeO(4.50), MgO(2.20), CaO(4.20) and Na₂O(3.90), where numbers in parentheses are contents in wt%. High-pressure experiments were made at 20.1-28.0 GPa and 1200-1800C with a Kawai-type 6-8 multianvil high-pressure apparatus. UCC and pressure marker (one of Mg₂SiO₄, MgSiO₃ and MgAl₂O₄) were packed in two holes in a Re capsule, kept simultaneously at desired pressure-temperature conditions for 2-3 hours, quenched and recovered after the run. Phase identification of each sample was made with a microfocus X-ray diffractometer, and compositional analyses of them were made with a SEM-EDS.

The assemblage of garnet (Gt) + clinopyroxene (Cpx) + KAlSi₃O₈-hollandite (Hol) + stishovite (St) + CAS phase (CAS) is stable to 21 GPa at temperatures higher than 1400C, and the assemblage of calcium ferrite (CF) + St + Gt + Ca-rich perovskite (Cpv) + CAS is stable in a range of 21-24 GPa. Gt and CAS decompose completely and CF + Hol + St + Cpv is stable at pressures higher than about 24 GPa. At 1200C, CAS does not exist. At pressures higher than 23-24 GPa, recovered samples were easily crushable. The fact indicates that Hol (II) probably transforms to Hol (I) during decompression. We will conduct mass-balance calculations from the compositions, compare a density with pyrolite mantle and discuss the influence on movement of the materials in the mantle.

Keywords: continental crust, 660km discontinuity, slab, high pressure experiment, pyrolite

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A numerical model of three-dimensional mantle convection with long-lived cratonic lithosphere

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The continental lithospheric mantle assists in the long-term survival of continental crust at Earth's surface and has a thick root or keel that extends hundreds of kilometers into the upper mantle. Geochemical and geochronological studies have revealed that some old cratons have survived at the Earth's surface for periods of more than three billion years despite later tectonic disturbances. The cratons are the keel of the continental lithosphere, and continental assemblages referred to as supercontinents have probably cyclically formed several times during Earth's history (see Yoshida and Santosh, 2011, Earth-Science Reviews).

However, in the numerical modeling of mantle convection, it is a challenging task to construct a numerical model to realize the longevity of cratonic lithosphere. Here, the dynamic role of a weak (low-viscosity) boundary zone (WBZ) between cratonic and oceanic lithospheres in the longevity of the cratonic lithosphere is investigated. The WBZ is assumed to consist of weak materials, deforming with time by mantle convection force. The three-dimensional numerical model presented herein makes it possible to model the cratonic lithosphere that survives for a sufficiently long geological timescale. An important factor in the longevity of cratonic lithosphere is the localized rheological (viscosity) contrast between the cratonic and oceanic lithospheres, i.e., the presence of a weak (low-viscosity) boundary zone (WBZ) that surrounds the cratonic lithosphere. The WBZ protects the cratonic lithosphere from being stretched by the surrounding convection force. This implies that the mechanical contrast between floating cratonic and oceanic lithospheres has played a significant role in the longevity of cratonic lithosphere itself throughout Earth's history. In addition to the presence of a WBZ, the higher viscosity of the cratonic lithosphere itself effectively contributes to the stability of the cratonic lithosphere.

There appears to be a relationship between the horizontal size and longevity of the cratonic lithosphere. The results of the present study are consistent with the fact that there are no Archean cratons of sizes larger than the scale of mantle convection in present-day Earth. Cratons that are sufficiently smaller than the convection scale are likely stable over the long geologic timescale, even if the continental keel is extensively eroded by younger magmatic and subduction-erosion processes.

Keywords: mantle convection, numerical simulation, cratonic lithosphere, supercontinent, plate motion, rheology

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Melting experiment of hydrous upper mantle and origin of Mg- and Si-rich cratonic mantle

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Mantle peridotite xenoliths from kimberlite pipes, which derived from the deep upper mantle up to ~250km depth from Archean cratons, give us some direct information about the geochemical evolution of crustal and mantle materials in interior of our planet. These peridotite xenoliths sometimes have unusual chemical, modal, and textural compositions (e.g., Boyd, 1989; Boullier and Nicolas, 1975). Garnet peridotites from more than 80 km in depth have quite different chemistry from shallow mantle, such as oceanic and arc area (e.g., Dick et al., 1984; Boyd, 1986; Arai, 1994). For example, in oceanic peridotites from mid-ocean ridges, the chemical variation of shallow mantle can be explained by process of partial melting of pyrolitic lherzolite and subsequent melt extraction at depth of 30-80 km. The estimated maximum degree of melting (~30 %) of residual peridotite and the chemical feature of the constituent minerals, that was depleted in incompatible element (SiO₂, Al₂O₃, CaO) with respect to compatible elements (MgO, Cr₂O₃), indicate that the partial melting occurred at almost dry condition. On the other hand, the cratonic peridotites mainly consist of olivine, orthopyroxene, garnet and clinopyroxene, and characterized the extremely high amount of orthopyroxene (= high amount of SiO₂ component) with high Mg# (= Mg/(Mg + Fe) atomic ratio) (e.g., Boyd, 1989). These high-Si and -Mg harzburgite/lherzolite could not explain as residue of dry partial melting and melt extraction process (Walter, 1998). Here, based on melting experiments at high pressure, we suggest possibilities of the Si- and Mg-rich cratonic peridotites as residues by partial melting of pyrolitic lherzolite at hydrous condition at depth of 200-300 km.

Starting material is a pyrolite + H₂O. The powder of Al₂O₃, SiO₂, CaCO₃, Fe₂O₃, TiO₂, Cr₂O₃, Na₂CO₃, K₂CO₃, and NiO was mixed, and degas at 1273 K and the ambient pressure in atmosphere. Then it was melted at 1773 K and quenched to form glass in the reducing furnace where the oxygen fugacity was controlled to QFM buffer. Finally, powder of MgO and Mg(OH)₂ is added to be the water contents of starting material as 2wt% and 8wt%. Experiments were performed by using multi Anvil type high-pressure apparatus (ORENGE 1000) of the Ehime University at the temperature of 1273-1872 K at the pressure of 5GPa and 7GPa.

In our experimental conditions, All products show a partial melting. The residual mineral assemblage is olivine + opx + cpx + garnet at lower temperature. At the experiments with 2 wt% H₂O, the solid phases resolved to liquid as a next order, cpx, garnet, opx and olivine. On the other hand, the experiments of 8 wt% H₂O the stability field of opx become wider with increasing pressure. It is noted that the liquidus phase not become olivine but opx at 7GPa. Actually, the opx/ol ratio of cratonic mantle xenoliths is known to be higher than that of mantle xenolith in other regions, and our results imply that water greatly influenced continental generation in the early earth. If our conclusion is correct, the Earth's mantle is very heterogeneous in water content, and water was one of the important components for formation of continental craton at early Earth.

Keywords: hydrous pyrolite, high pressure and temperature experiments, continent, craton, partial melting