SIT06-01 会場:303 時間:5 月 24 日 10:00-10:15

SHOCK-INDUCED PHASE TRANSFORMATION AND METALLIC IRON NANOPARTICLES IN OLIVINE-RICH MARTIAN METEORITES

REYNARD, Bruno[1]* ; VAN DE MOORTELE, Bertrand[1]
REYNARD, Bruno[1]* ; VAN DE MOORTELE, Bertrand[1]

[1]CNRS, ENS Lyon, France
[1]CNRS, ENS Lyon, France

Maps of the magnetic field of Mars display strong magnetic anomalies attributed to crustal remanence. In order to interpret these anomalies, knowledge of the nature of magnetic carriers and magnetic properties of Martian rocks is necessary. In contrast with terrestrial rocks for which the major magnetic mineral is magnetite, studies of the SNC (Shergotty-Nakhla-Chassigny type) meteorites have shown that alternative phases, such as pyrrhotite, dominate the magnetic properties of most basaltic shergottites, while titanomagnetite is the magnetic carrier in nakhlites and a few basaltic shergottites. We studied ultrabasic SNC meteorites using low- and high-temperature magnetic property measurements and mineralogical characterization. It is shown that transformations attributed to shock cause strong modifications of olivine optical and mineralogical properties in chassignites and lherzolitic shergottites. We combined several electron microscopic techniques to fully characterize these mineralogical transformations. The observations point to transformation of olivine to a metastable high-pressure phase, possibly related to metastable transformation of olivine that were recently evidenced by X-Ray diffraction at high pressure. In the meteorites, a reduction or dissociation process of iron in olivine takes place, likely during the shock event and transformation of olivine, causing the formation of metallic precipitates in olivine. Thus, iron may be a significant magnetic carrier in Martian crust, and a precursor phase for iron-rich oxides or hydroxides in the Martian regolith.

キーワード: Martian meteorite, Shock, Olivine, Magnetism, Iron metal
Keywords: Martian meteorite, Shock, Olivine, Magnetism, Iron metal

SIT06-02 　　　　会場:303 　　　　時間:5 月 24 日 10:15-10:30

Contribution of volatile rich material to Earth's accretion
Contribution of volatile rich material to Earth's accretion

DU, Wei[1]* ; IRIFUNE, Tetsuo[1]
DU, Wei[1]* ; IRIFUNE, Tetsuo[1]

[1]GRC, Ehime University; ELSI, Tokyo Institute of Technology
[1]GRC, Ehime University; ELSI, Tokyo Institute of Technology

The planetary formation processes such as accretion and differentiation might have drastically modified the composition of Earth from the building blocks from the orginal so-called chondritic Earth model, especially on the elemental and isotopic compositions of the volatile elements. Recently, heterogeneous accretion model that describes that growth and evolution of Earth in two different stages from volatile-depleted and volatile-rich material was revised based on isotope geochemical studies (e.g. Nudds et al., 2010). However, the exact percentage and the time sequence of this volatile-rich material accretion need to be constrained. For example, models with ~2% carbonaceous chondrite (CI-CM) material added to a dry proto-Earth will result in estimation of carbon content of Earth to be over 500ppm, which could not be explained by the current silicate mantle composition of Earth. In addition, the modeling result needs to be consistent with the siderophile elements concentration in Earth mantle and the oxidation state of Earth mantle changes through the accretion process.

Therefore, we performed experimental studied on Tagish Lake chondrite (CI-CM), a new type of volatile rich carbonaceous chondrite at different pressure and temperature conditions. Our target is to explore the possible effect of the volatile component on Earth composition through the time sequence of Earth growth, the water budge of Earth at different accretion sequences, and other possible later impact.

Our melting experiment at 12GPa shows that the measured solidus temperature of Tagish Lake meteorite is much lower than CV3 meteorite because the existence of the large amount of volatile components; however, the measured liquid temperature is very close to that of CV3 meteorite, indicating the lost of volatile component through higher temperature (2000K) heating process. The experimental method we used works well to keep the volatile components (Carbon and Hydrogen) inside the meteorite sample during heating experiments with temperature lower than 2000K. Whether does the proto-core have carbon or other volatile element will rely on further experiments at higher pressure.

キーワード: Carbonaceous chondrite, Tagish Lake meteorite, Earth accretion, High pressure and high temperature, partial melting, volatile
Keywords: Carbonaceous chondrite, Tagish Lake meteorite, Earth accretion, High pressure and high temperature, partial melting, volatile

SIT06-03 　　　　 会場:303 　　　　　　　　　　 時間:5 月 24 日 10:30-10:45

Synthesis and application of water-bearing large single crystals by slow cooling of hydrous melt at deep mantle pressure

奥地 拓生 [1*] ; Purevjav Narangoo[1] ; 富岡 尚敬 [1] ; Lin Jung-fu[2]
OKUCHI, Takuo[1*] ; PUREVJAV, Narangoo[1] ; TOMIOKA, Naotaka[1] ; LIN, Jung-fu[2]

[1] 岡山大学地球物質科学研究センター, [2]Jackson School of Geosciences, The University of Texas at Austin
[1]Institite for Study of the Earth's Interior, Okayama University, [2]Jackson School of Geosciences, The University of Texas at Austin

The presence of water in the deep mantle of the Earth is an issue of increasing interest in the field of high-pressure mineral physics. An anticipated task for advancing the relevant research is to create homogeneous single crystals of candidate deep-mantle water-bearing minerals of 1 mm or larger in sizes, which is necessary for applying them for the Time-of-Flight (TOF) single-crystal Laue diffraction method at a third-generation pulsed neutron source. In the present study, we applied a significantly slower growth rate over a maximum period up to 24 h to successfully produce these sample crystals. We grew the crystals from a homogeneous silicate melt batch with a volume as large as possible to enable continuous buffering of chemical composition of the crystals. The temperature of the cell slowly decreased during the long heating durations so that the crystals were almost kept in chemical equilibrium with the silicate melt throughout the growth process. This slow-cooling method has been successfully applied at pressures to 24 GPa and at temperatures to about 1800 deg C, respectively, for the crystal growth of deep-mantle hydrous mineral phases. Successfully synthesized crystals include dense hydrous magnesium silicate phase E, hydrous wadsleyite, hydrous ringwoodite, and bridgmanite. These product crystals were confirmed to be inclusion free and crystallographically homogeneous. Compositional homogeneities were better than 3 % among intracrystals and intercrystals within each recovered sample capsule (Okuchi et al., in press). The product single crystals are being used for neutron diffraction as well as for another state-of-the-art mineral physics research requiring high-quality sample crystals (Goncharov et al., in press)

References
Okuchi, T., N. Purevjav, N. Tomioka, J. F. Lin, T. Kuribayashi, L. Schoneveld, H. Hwang, N. Sakamoto, N. Kawasaki, and H. Yurimoto, Synthesis of large and homogeneous single crystals of water-bearing minerals by slow cooling at deep-mantle pressures, Am. Mineral., in press, doi:10.2138/am-2015-5237.
Goncharov, A. F., S. S. Lobanov, X. Tan, G. T. Hohensee, D. G. Cahill, J. F. Lin, S. M. Thomas, T. Okuchi, and N. Tomioka, Experimental study of thermal conductivity at high pressures: implications for the deep Earth's interior, Phys. Earth Planet. Inter., in press.

キーワード: hydrous minerals, single crystal growth, phase E, wadsleyite, ringwoodite, bridgmanite
Keywords: hydrous minerals, single crystal growth, phase E, wadsleyite, ringwoodite, bridgmanite

SIT06-04 　　　　会場:303 　　　　時間:5 月 24 日 11:00-11:15

Silicate Magmas under Compression and Confinement
Silicate Magmas under Compression and Confinement

LEE, Sung keun[1]*
LEE, Sung keun[1]*

[1]Seoul National University
[1]Seoul National University

Upon compression and surface confinement, oxide glasses and melts are expected to be subject to successive structural transitions with multiple densification and confinement mechanisms. Experimental verification of these phenomena remain a major target of glass-melt studies. Here, we provide an overview of the recent progress and insights by solid-state NMR and inelastic x-ray scattering into structures of fluid-bearing multi-component network glasses with varying pressure, composition, and confinement (Lee et al. Rev. Min. Geochem. 78, 139, 2014); Lee Sol. St. NMR. 38, 45, 2010). In contrast to an expected complexity in densification, experimental multi-nuclear NMR results for fluid-bearing multi-component glasses at high pressure demonstrate that the pressure-induced changes in melt structures show a simple trend where the effect composition and pressure can be predicted and quantified with a network flexibility (Lee, Proc. Nat. Aca. Sci. 108, 6847 (2011)]. High-resolution O-17 NMR spectra for binary lead silicate glasses near orthosilicate composition (Pb/Si = 2), as a model system for Mg_2SiO^4 melts, reveal the presence of metal-bridging oxygen (Pb-O-Pb) and thus allow direct quantification of the degree of Mg/Si disorder (Lee & Kim, J. Phys. Chem. C, 119 748, 2015). We also report the structural evolution of andesitic and basaltic melts with varying composition, highlighting the moderate deviation from the degree of Al avoidance among framework cations (Si and Al) and preferential proximity between non-network cations (Ca_{2+},Mg_{2+}) and non-bridging oxygen. Considering all the experimental Al coordination environments available in the literature, together with the current experimental studies, we provide the relationship between the fractions of highly coordinated Al and composition, particularly average cationic potential of non-network forming cations (Park & Lee, Geochim. Cosmochim. Acta, 147, 26, 2014). Finally, as experimental evidence for thickness-induced structural transitions in amorphous oxides is lacking, we report the high-resolution NMR results for the amorphous oxides under confinement where the degree of structural disorder tends to decrease with increasing degree of confinement (i.e., near surfaces) (Lee & Ahn, Sci. Rep. 4 , 4200, 2014).

キーワード: Silicate magmas and melts, High pressure, Nuclear magnetic resonance, Inelastic x-ray scattering, Earth's interior
Keywords: Silicate magmas and melts, High pressure, Nuclear magnetic resonance, Inelastic x-ray scattering, Earth's interior

SIT06-05　　　　　　　　会場:303　　　　　　　　　　　　時間:5 月 24 日 11:15-11:30

中央海嶺玄武岩組成のケイ酸塩ガラスにおける最下部マントル条件までの鉄のスピン状態
Spin state of iron in MORB glass up to the lowermost mantle conditions

前田 郁也 [1*]; 大谷 栄治 [1]; 鎌田 誠司 [2]; 鈴木 那奈美 [1]; 坂巻 竜也 [1]; 平尾 直久 [3]; 大石 泰生 [3];
三井 隆也 [4]; 増田 亮 [5]
MAEDA, Fumiya[1*] ; OHTANI, Eiji[1] ; KAMADA, Seiji[2] ; SUZUKI, Nanami[1] ; SAKAMAKI, Tatsuya[1] ;
HIRAO, Naohisa[3] ; OHISHI, Yasuo[3] ; MITSUI, Takaya[4] ; MASUDA, Ryo[5]

[1] 東北大学大学院理学研究科地学専攻, [2] 東北大学学際科学フロンティア研究所, [3] 高輝度光科学研究センター, [4] 日本原子力研究開発機構, [5] 京都大学原子炉実験所
[1]Department of Earth and Planetary Material Science, Graduate School of Science, Tohoku University, [2]Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, [3]Japan Synchrotron Radiation Research Institute, [4]Japan Atomic Energy Agency, [5]Research Reactor Institute, Kyoto University

The existence of deep magma has been suggested by the studies of physical observations or high P-T experiments subjected to the deep Earth (e.g., Lee et al., 2010; Williams and Garnero, 1996). These melts are considered to contribute to the ultra-low velocity zone on the core-mantle boundary (CMB). However, the presence of the deep magma has been controversial yet because the physical and chemical properties of silicate melts are not understood enough under high P-T conditions.

The spin state of iron in the silicate melt is one of the important factor to affect the gravitational stability of the deep magma. The iron is one of the abundant element in the Earth and its amount is critical for the density of the silicate minerals and liquids. The iron portioning into the silicate melts was reported at pressures greater than ~76 GPa (Nomura et al., 2011), which might cause the iron-rich dense melt above the CMB region. They suggested the iron partitioning was able to be changed due to the spin crossover of iron (from high-spin to low-spin) occurring around 70 GPa. On the other hand, some recent studies reported no spin transitions in the silicate glass at the pressures corresponding to the Earth's mantle (e.g., Mao et al., 2014; Prescher et al., 2014).

The previous studies about the spin state of iron discussed using the results limited up to the relative lower pressures (~80 GPa) or the simple component glass expected to the actual Earth's composition. Here, we report the results of the iron spin state measurements for the multicomponent silicate glass under high pressure up to about 130 GPa, corresponding to the lowermost mantle depth. The iron spin state was measured using synchrotron ^{57}Fe Mössbauer spectroscopy method, which bring the direct information about the iron spin state.

The starting material was synthesized ^{57}Fe-enriched silicate glass, which represented an average composition of mid-ocean ridge basalt. The glass was prepared by quenching molten mixture of oxides; SiO_2, MgO, Al_2O_3, TiO_2, $^{57}Fe_2O_3$ and $CaCO_3$, K_2CO_3, Na_2CO_3. High pressure experiments were performed using a diamond anvil cell. The silicate glass powder was sandwiched between two NaCl layers which worked as a pressure medium and a pressure scale. We used equations of state for NaCl B1 and B2 phases reported by Matsui (2009) and Fei et al. (2007), respectively. In case of experiments without XRD technique, the pressure was measured based on the pressure dependence of diamond T_{2g} mode presented by Akahama and Kawamura (2004). Energy domain Synchrotron ^{57}Fe Mössbauer spectroscopy was conducted at beamline BL10XU and BL11XU of SPring-8 at room temperature and pressure ranged from 1 atm to 130 GPa. Spectra were collected for 3-11 hours depending on the data qualities. The recorded spectra were fitted with Lorentzian doublets using the MossA software package (Prescher et al., 2012).

The obtained Mössbauer spectra was able to be fitted better supposing two doublet components, which might be derived from high-spin (HS) Fe^{2+} and HS Fe^{3+}. Quadrupole splitting (QS) values of two doublets components were apt to increase from ambient condition to high pressure up to 130 GPa and were suited for the values of the previous studies. On the other hand, the change of the isomer shift (IS) had less pressure dependence.The ratio of ferrous iron to the total iron spiecies, $Fe^{2+}/\sum Fe$ showed an increase tendency up to about 60 GPa. That tendency turned to decreasing at higher pressures up to 95 GPa, and then the ratio seemed to be constant over 100 GPa. The drop of $Fe^{2+}/\sum Fe$ resembled the case of NaFe-silicate glass reported by Prescher et al. (2014) although the onset of decreasing in present study pointed at higher pressure than Prescher et al. (2014).

SIT06-06 　　　　　会場:303 　　　　　　　　　　時間:5 月 24 日 11:30-11:45

Recent progress for stability and water solubility of hydrous and nominally anhydrous minerals in the mantle

井上 徹 [1*] ; 柿澤 翔 [1] ; 蔡 闐 [1] ; 藤野 清志 [1] ; 栗林 貴弘 [2] ; 長瀬 敏郎 [2] ; Greaux Steeve[1] ; 肥後 祐司 [3] ;
坂本 直哉 [4] ; 圦本 尚義 [4]
INOUE, Toru[1*] ; KAKIZAWA, Sho[1] ; CAI, Nao[1] ; FUJINO, Kiyoshi[1] ; KURIBAYASHI, Takahiro[2] ;
NAGASE, Toshiro[2] ; GREAUX, Steeve[1] ; HIGO, Yuji[3] ; SAKAMOTO, Naoya[4] ; YURIMOTO, Hisayoshi[4]

[1] 愛媛大学地球深部ダイナミクス研究センター, [2] 東北大学, [3]JASRI, SPring-8, [4] 北海道大学
[1]Geodynamics Research Center, Ehime University, [2]Tohoku University, [3]JASRI, SPring-8, [4]Hokkaido University

Recently hydrous ringwoodite was found in natural diamond inclusion, which water content was ~1.4-1.5 wt%. This shows that the mantle transition zone is really hydrous condition, at least in some regions. In addition, new dense hydrous magnesium silicate, phase H was newly found by first-principle calculation and experimental studies. Thus the study on the water in the mantle becomes a hot topic again after the finding of hydrous wadsleyite and hydrous ringwoodite.

Our group has been conducting the study for the stability and water solubility of hydrous and nominally anhydrous minerals, and the recent target is the effect of Al. In this process, we found the new Al-bearing hydrous phase in the upper mantle condition. In addition, we found that Al-bearing bridgmanite (Mg-silicate perovskite) can contain significant amount of water. So we are doing those projects to clarify the maximum water solubility in P-T conditions, structure by single crystal X-ray and power neutron diffractions, equation of state and elastic wave velocity. In this talk, we will introduce the recent progress of the water in the mantle based on our projects.

SIT06-07 会場:303 時間:5 月 24 日 11:45-12:15

Seeking constraints on lower mantle composition through nuclear resonance combined with computations

Seeking constraints on lower mantle composition through nuclear resonance combined with computations

MCCAMMON, Catherine[1]* ; DUBROVINSKY, Leonid[1] ; CARACAS, Razvan[2] ; GLAZYRIN, Konstantin[1] ;
POTAPKIN, Vasily[3] ; KANTOR, Anastasia[1] ; SINMYO, Ryosuke[1] ; PRESCHER, Clemens[1] ; KUPENKO, Ilya[3] ;
CHUMAKOV, Alexandr[3]
MCCAMMON, Catherine[1]* ; DUBROVINSKY, Leonid[1] ; CARACAS, Razvan[2] ; GLAZYRIN, Konstantin[1] ;
POTAPKIN, Vasily[3] ; KANTOR, Anastasia[1] ; SINMYO, Ryosuke[1] ; PRESCHER, Clemens[1] ; KUPENKO, Ilya[3] ;
CHUMAKOV, Alexandr[3]

[1]Bayerisches Geoinstitut, Germany, [2]ENS, Lyon, France, [3]ESRF, Grenoble, France
[1]Bayerisches Geoinstitut, Germany, [2]ENS, Lyon, France, [3]ESRF, Grenoble, France

How did the Earth form and how did it differentiate to form the core, mantle, and crust? Part of the answer to these questions resides in the composition of the present day lower mantle, where active discussions regarding how closely it approximates a chondritic composition are still ongoing. Comparison of laboratory measurements of elastic wave velocities of mantle minerals with seismic data constitutes one of the foundations upon which knowledge of the Earth's interior is based, yet it requires a precise knowledge of elastic wave velocities of the dominant lower mantle, bridgmanite, which have up until now been elusive. In situ measurements are important, because some transitions (for example, spin transitions) are not quenchable, and may influence the elastic properties of iron-containing minerals. Nuclear inelastic scattering offers the attractive possibility to determine elastic wave velocities of iron-containing minerals in the laser-heated diamond anvil cell through direct measurement of the partial density of states, although short range ordering and other effects can influence the results. We will present our measurements of elastic wave velocities in bridgmanite as a function of pressure, temperature and composition, and through comparison with ab initio calculations of the partial density of states, discuss the prospects for extracting knowledge regarding the composition and mineralogy of the present day lower mantle.

キーワード: nuclear resonance, elastic wave velocites, partial density of states, ab initio computations, bridgmanite, perovskite
Keywords: nuclear resonance, elastic wave velocites, partial density of states, ab initio computations, bridgmanite, perovskite

SIT06-08　　　　　会場:303　　　　　時間:5 月 24 日 12:15-12:30

Recent Advances in Understanding Elasticity of the Mantle and Core
Recent Advances in Understanding Elasticity of the Mantle and Core

LIN, Jung-fu[1]*
LIN, Jung-fu[1]*

[1]Department of Geological Sciences, The University of Texas at Austin
[1]Department of Geological Sciences, The University of Texas at Austin

Elasticity of the candidate materials at the relevant P-T conditions of the Earth's mantle and core provides critical information in understanding seismic profiles and anisotropies, in building reliable compositional and mineralogical models, and in deciphering geodynamic processes and thermal history of the Earth's interior. Here I will discuss recent advances and research results in using laser and X-ray spectroscopic techniques to investigate the elasticity of candidate mantle and core materials in a high-pressure diamond anvil cell. The use of combined Brillouin and Impulsive Stimulated Scattering (ISS) results permits direct measurements of both Vp and Vs and derivation of full elastic constants of single-crystal ferropericlase and silicate perovskite up to megabar pressures. These results show that Vp of ferropericlase displays significant softening across the spin transition, while Vs is only slightly affected. The derived single-crystal C_{ij} of Bridgmanite at lower mantle pressures display relatively small elastic Vp and Vs anisotropies as compared to the ferropericlase counterpart. Furthermore, research results on the elasticity of single-crystal, polycrystalline, and textured iron alloys at high P-T conditions show that bcc-Fe and Fe-Si alloy crystals display extremely high Vp and Vs anisotropy while hcp-Fe exhibits only a few percent Vp anisotropy. Based on the expansion of the Christoffel equation, a new method to derive full elastic constants (C_{ij}) of single crystals using Vs or Vp alone will also be presented. Using thermoelastic modelling, I will discuss the elastic constants, sound velocities, elastic anisotropies, and seismic parameters of ferropericlase, Bridgmanite, and iron alloys at relevant conditions of the Earth's interior. These recent elasticity results are compared to seismic models to advance our understanding on seismic structures, mineralogical models, and geodynamic processes of the deep Earth's interior.

キーワード: Elasticity, Ferropericlase, Bridgmanite, Diamond Anvil Cell, High Pressure, Lower Mantle
Keywords: Elasticity, Ferropericlase, Bridgmanite, Diamond Anvil Cell, High Pressure, Lower Mantle

SIT06-09 会場:303 時間:5 月 24 日 12:30-12:45

hcp 構造 Fe-Si-H 合金の状態方程式の決定
Compression of hcp Fe-Si-H alloy to 130 GPa

田川 翔 [1*] ; 太田 健二 [1] ; 廣瀬 敬 [2] ; 大石 泰生 [3]
TAGAWA, Shoh[1*] ; OHTA, Kenji[1] ; HIROSE, Kei[2] ; OHISHI, Yasuo[3]

[1] 東京工業大学 地球惑星科学専攻, [2] 東京工業大学 地球生命研究所, [3] 高輝度光科学研究センター
[1]Department of Earth and Planetary Sciences, Tokyo Institute of Technology, [2]Earth-Life Science Institute, Tokyo Institute of Technology, [3]SPring-8, Japan Synchrotron Radiation Research Institute

The light elements in the Earth's core have not been identified yet, but hydrogen is now collecting more attention because recent planet formation theory suggests that large amount of water (e.g. 10 to 100 times seawater) should have been brought to the Earth during the late stage of its formation. Hydrogen is a strong siderophile element and thus it is possibly present in the core. The effect of hydrogen on the property of iron alloy is little known yet. Moreover, the presence of $\sim$ 6 wt.% silicon has been also strongly supported by geochemical and cosmochemical arguments. Here we report hydrogenation of $Fe_{0.88}Si_{0.12}$ (6.5 wt. % Si) alloy and the compression behavior of $Fe_{0.88}Si_{0.12}H_{0.8}$ alloy to 130 GPa at room temperature. $Fe_{0.88}Si_{0.12}$ foil was loaded into a diamond anvil cell (DAC), and then liquid hydrogen was introduced at temperatures below 20 K. The results demonstrate that the octahedral sites of Fe-Si-H alloys are not fully occupied by hydrogen unlike the case of FeH and as a consequence $Fe_{0.88}Si_{0.12}H_{0.8}$ is formed under hydrogen-saturated condition. The compressibility of hcp $Fe_{0.88}Si_{0.12}H_{0.8}$ is similar to that of pure iron. Assuming that liquid and solid alloys have identical density and ideal solution of hydorogen and silicon in the hcp phase, we found that the observed density profile in the outer core may be reconciled with $Fe_{0.88}Si_{0.12}H_{0.4}$. It means that the amount of hydrogen corresponding to about 90 times seawater could be in the Earth's core. This study suggests that Fe-Si-H system is a plausible chemical composition of the core.

キーワード: コアの軽元素, コア形成, 水素, シリコン, 高圧実験, ダイヤモンドアンビルセル (DAC)
Keywords: Light elements, Core formation, Hydorogen, Silicon, High pressure, Diamond anvil cell (DAC)

SIT06-10 　　　　　　　会場:303 　　　　　　　　　　時間:5 月 24 日 14:15-14:45

The Revolutionary Multigrain Crystallography Method for High-Pressure X-ray Diffraction

MAO, Hokwang[1]* ; ZHANG, Li[2]
MAO, Hokwang[1]* ; ZHANG, Li[2]

[1]Geophysical Laboratory, Carnegie Institution of Washington, [2]Center for High Pressure Science and Technology Advanced Research, China
[1]Geophysical Laboratory, Carnegie Institution of Washington, [2]Center for High Pressure Science and Technology Advanced Research, China

For a century, x-ray crystallography has been conducted with one of the two extreme sample conditions: either a single crystal which produces a single set of diffraction spots directly corresponding to the geometric orientation of the crystal, or a powder sample which comprises a huge number of crystals so numerous that the diffraction spots overlap and merge into smooth rings while the geometric relation is completely lost and only the d-spacings information of diffraction planes is observed. High-pressure DAC is not optimized for either condition. Powder x-ray diffraction has the intrinsic limitations when the sample consists of multiple different phases with low symmetry. Diffraction rings cover most of the detector area, and only a couple of low angle diffraction rings are unique to a phase; most other rings overlap with one another and cannot be used for unique identification or accurate determination of crystallographic parameters. New structures and minor phases are often overshadowed by the diffraction of major phases and are impossible to find or identify. Advanced crystallographic software, such as Rietveld and LeBail refinement methods, may get most out of a powder pattern, but cannot overcome the intrinsic limitations. In addition, the common practice of integrating the 2D ring into a 1D peak plot throws away the valuable information of a whole dimension, such as the azimuthal angle of diffraction spot around the ring.

Single-crystal XRD contains orientation and geometrical relationship in addition to d-spacings and thus provides a definitive characterization of the unit cell and symmetry. Unless the crystal is orientated exactly relative to the incident monochromatic x-ray beam to satisfy the Bragg relation, the crystal gives no signal, and the detector remains empty. Rotating the crystal around the w-axis (perpendicular to the incident x-ray beam) can bring the crystal to Bragg condition and occasionally obtain single diffraction spots at a given angle and scanning step. In spite of the advantages, single crystal cannot be sustained through phase transitions and often breaks down into multiple crystals and generate spotty XRD patterns.

Spottiness, that is generally regarded as a flaw in powder XRD, can be turned into great advantages if we can separate individual crystallites and handle them as individual single crystals. The high-brilliance x-ray beam available at synchrotron facilities has made it possible to collect diffraction spots in a powder sample comprised of up to hundreds of submicron crystallites. The newly developed Multigrain Crystallography (MGC) package, which is a suite of programs used for processing and indexing diffraction spots, has been developed to separate and identify the crystallographic orientation of each individual crystallite in the aggregate of hundreds of crystallites. Once separated, the data set for each crystallite can be handled with the standard single-crystal refinement program identical to a stand-alone single crystal, resulting in excellent statistics in refinement and full coverage of the reciprocal space. The MGC method is very powerful in unequivocal determination of symmetry and unit cells, testing different indexing models, picking out minor phases, and resolving strain of individual crystallites, and will very likely replace the powder and single-crystal x-ray diffraction methods as the dominant crystallographic tool for future high pressure-temperature studies in DAC.

キーワード: High pressure X-ray diffraction, Crystallography
Keywords: High pressure X-ray diffraction, Crystallography

SIT06-11 会場:303 時間:5 月 24 日 14:45-15:00

地球中心核形成時における金属-珪酸塩間の化学平衡下の実効温度
Effective metal-silicate equilibrium temperature during core formation

市川 浩樹 [1*] ; Hernlund John[2] ; Labrosse Stephane[3] ; 亀山 真典 [1]
ICHIKAWA, Hiroki[1*] ; HERNLUND, John[2] ; LABROSSE, Stephane[3] ; KAMEYAMA, Masanori[1]

[1] 愛媛大学　地球深部ダイナミクス研究センター, [2] 東京工業大学　地球生命研究所, [3] リヨン高等師範学校
[1]Ehime University, Geodynamics Research Center, [2]Tokyo Institute of Technology, Earth-Life Science Institute, [3]Ecole Normale Superieure de Lyon

It has been long known that the formation of the core transforms gravitational energy into heat and is able to heat up the whole Earth by about 2000 K. However, the distribution of this energy within the Earth is still debated and depends on the core formation process considered. Iron rain in the surface magma ocean is supposed to be the first mechanism of separation for large planets, iron then coalesces to form a pond at the base of the magma ocean. In this process, equilibrium between metal and silicate is achieved within several seconds [Ichikawa et al., 2010].

Experimental studies of metal-silicate partition coefficient show that pressure-temperature conditions for metal-silicate equilibrium are far beyond the liquidus or solidus temperature for several hundred kelvin [e.g. Wade and Wood, 2005]. However, because equilibration was considered to occur in at the surface of metal pond at the silicate solidus, such high temperature equilibration was rejected as implausible. Instead, lower temperature equilibration with variable oxygen fugacity was proposed as an alternative, although the plausibility of the physical mechanisms invoked in this scenario is also questionable.

In this study, we model iron rain and heating of the magma by viscous dissipation to calculate the effective pressure-temperature conditions for partitioning in this scenario based on parameterizations derived from direct numerical simulation results of a 10cm-scale emulsion of liquid iron in liquid silicates. We have found effective temperature is much higher than melting temperature of silicate due to the release of gravitational potential energy.

キーワード: マグマオーシャン, 金属-珪酸塩間の化学平衡, 鉄の雨, 数値計算
Keywords: magma ocean, metal-silicate equilibrium, iron rain, numerical simulation

SIT06-12 　　　　　　　　会場:303 　　　　　　　　　　　時間:5 月 24 日 15:00-15:15

初期地球における深部マグマオーシャンを伴うコアーマントル熱化学進化モデリング

On the core-mantle thermo-chemical evolution with the basal magma ocean in the early Earth

中川 貴司 [1*]
NAKAGAWA, Takashi[1*]

[1] 海洋研究開発機構数理科学・先端技術研究分野
[1]MAT, JAMSTEC

On the recent progress of melt phase relationship such as the density structure of silicate melt in the deep mantle [e.g. Stixrude et al., 2009], the density of silicate melt would be much denser than the silicate solid near the core-mantle boundary (CMB), which has been already proposed from high pressure experiments [e.g. Ohtani and Maeda, 2001]. As a result, the basal magma ocean hypothesis for thermo-chemical structure in the early Earth has been proposed in several years ago, which is based on the concept for the density cross-over between silicate melt and solid in the deep mantle [Labrosse et al., 2007]. In this study, we attempt to include melt-phase relationship in the mantle minerals into a coupled core-evolution model based on numerical mantle convection simulations, which can generate the basal magma ocean in the early Earth. The preliminary outcome from this modeling is that the survival time-scale of the basal magma ocean in the mantle convection system is around 2.0 Gyrs as well as low CMB heat flow (˜5 to 10 TW) at the present time compared to the expected from theoretical core evolution model including the basal magma ocean. On the survival time of basal magma ocean obtained here, the origin of ultra-low-velocity-zone is difficult to generate the partial melting survived over the geologic time-scale, which seems to be explained as the compositional difference (effects of iron) suggested from recent seismological data analysis [e.g. Brown et al. 2015]. On the heat flow across the CMB, it is similar results to cases without assuming the effect of basal magma ocean suggested that the early Earth hypothesis would be still difficult to explain the various diagnostics of Earth's core-mantle evolution over the geologic time-scale.

キーワード: コア熱進化, 深部マグマオーシャン, 融解相関係, マントルダイナミクス, 初期地球
Keywords: Thermal evolution of Earth's core, Basal magma ocean, Melt phase relationship, Mantle dynamics, Early Earth

SIT06-13　　　　　会場:303　　　　　　　　　時間:5 月 24 日 15:15-15:30

Silicate melts of the Earth's mantle
Silicate melts of the Earth's mantle

CARACAS, Razvan[1]* ; SECLAMAN, Alexandra C.[1]
CARACAS, Razvan[1]* ; SECLAMAN, Alexandra C.[1]

[1]CNRS, ENS Lyon, LGLTPE UMR 5276
[1]CNRS, ENS Lyon, LGLTPE UMR 5276

We explore the state of various silicate melts, with different realistic compositions, characteristic for various moments of the crystallization of the magma ocean. Using a starting basis of silica tetrahedra we vary the amount and the quality of the cations, including trace elements.

For this, we employ first-principles molecular dynamics simulations. We perform spin-polarized calculations in the planar augmented wavefunction formalism of the density-functional theory, using the VASP package.

We monitor the dependence with pressure and temperature of various physical parameters, like density, coordination number, magnetic spin, viscosity, etc. We show that the coordination number in the silicate groups increases from 4 to 5 to 6 as we go from ambient pressure to megabar. We estimate the thermal dilatation; from the equations of state we compute the velocities of the compressional seismic waves. We use these results to show that melts can still exist at the base of the Earth's present-day lower mantle as iron-rich pockets. These melts can explain particular features, characterized by low seismic velocities, such as the ultra-low velocity zones. Using the more complex chemistries we provide the first insights into the behavior of the magma ocean during cooling and crystallization.

キーワード: mantle, silicate, melt, spin transition, equation of state, magma ocean
Keywords: mantle, silicate, melt, spin transition, equation of state, magma ocean

SIT06-14   会場:303   時間:5 月 24 日 15:30-16:00

Single-crystal Brillouin Spectroscopy with Laser Heating and Variable q: Design and Results on Olivine
Single-crystal Brillouin Spectroscopy with Laser Heating and Variable q: Design and Results on Olivine

ZHANG, Jin s[1] ; BASS, Jay[2]*
ZHANG, Jin s[1] ; BASS, Jay[2]*

[1]Univ of Illinois & COMPRES, [2]COMPRES & Univ of Illinois
[1]Univ of Illinois & COMPRES, [2]COMPRES & Univ of Illinois

We have developed a novel Brillouin spectroscopy system integrated with CO2 laser heating and Raman spectroscopic capabilities. High-pressure laser heating experiments on liquid water compressed in a diamond-anvil cell up to 2500 +/- 150 K demonstrate the flexibility and performance of the system. Temperature is determined from the grey-body thermal radiation of the heated samples. New single-crystal laser heating Brillouin measurements were made on San Carlos Olivine in the (111) plane at pressures up to ~13 GPa, and T=1300K. We obtain quantitative values for the thermal pressure in the diamond cell. Using KCl and KBr and pressure-transmitting media, we show that pressure gradients in the sample chamber are small at high P-T conditions based on observations of the olivine-wadsleyite transition. This system is additionally designed for continuously varying scattering angles from near forward scattering (0o scattering angle) up to near back scattering (~141o). Our results on the sound velocities of olivine at high pressure-temperature conditions have implications for the nature of the 410 km discontinuity and the olivine content of the transition zone.

キーワード: Elastic properties, Brillouin scattering, Equations of state, Olivine
Keywords: Elastic properties, Brillouin scattering, Equations of state, Olivine

カンラン石の転位移動度の温度圧力依存性の評価
Estimation of dislocation mobility in different slip systems in olivine as a function of pressure and temperature

桂 智男 [1*] ; 王 林 [1]
KATSURA, Tomoo[1*] ; WANG, Lin[1]

[1] バイロイト大学
[1]University of Bayreuth

It is considered that the seismic anisotropy in the upper mantle will be caused by crystallographic preferred orientation of olivine. The seismic anisotropy rapidly decreases below 200 km depth, which is attributed to a transition from A-type to B-type fabric with pressure indicated by deformation experiments. However, stress and strain-rate conditions in deformation experiments are by orders of magnitude higher than in the upper mantle, which may mislead our understandings.

A- and B-type fabrics are produced by the dominant slip systems of (010)[100] and (010)[001], respectively. Hence, the fabric transition implies that the dislocation mobility in (010)[100] will decrease with increasing depth more than in (010)[001]. In order to examine this hypothesis, we determined the dislocation mobility of (010)[100] edge (a-dislocation) and (010)[001] screw (c-dislocation) dislocations at pressures of 0 to 12 GPa and temperatures of 1470 to 1770 K by means of the dislocation recovery technique, in which the dislocation mobility is determined under quasi-hydrostatic conditions. The a- and c-dislocations were produced in (010)[100] and (010)[001] simple shear geometries by 45-degree-edge alumina pistons at a pressure of 3 GPa and a temperature of 1600 K for one hour. TEM observations indicated that 90 % of dislocations produced in (010)[100] and (010)[001] simple shear geometries are a- and c-dislocations, respectively.

The experimental results show: (1) The mobility of a-dislocation is almost identical to or up to 0.5 orders of magnitude lower than that of c-dislocation at ambient pressure. (2) The activation energies of both dislocations are comparable, about 400 kJ/mol. (3) The activation volumes of both dislocations are also comparable, about 2.6 cm3/mol.

The comparable activation energies and volumes suggest that the transition of A-type to B-type fabric by pressure and/or temperature is unlikely. The rapid decrease in seismic anisotropy below 200 km will be due to decrease in flow rate in this depth.

キーワード: カンラン石, 転位, 移動度, 圧力, 温度
Keywords: olivine, dislocation, mobility, pressure, temperature

SIT06-16　　　　　会場:303　　　　　時間:5 月 24 日 16:30-16:45

マントル遷移層と下部マントルの化学組成の実験的制約
Experimental constraints on the chemical compositions of the mantle transition region and the lower mantle

入舩 徹男 [1*]
IRIFUNE, Tetsuo[1*]

[1] 愛媛大学地球深部ダイナミクス研究センター, [2] 東京工業大学地球生命研究所
[1]Geodynamics Research Center, Ehime University, [2]Earth-Life Science Institute

　川井型超高圧実験関連技術の開発により、マントルのより深部における相転移やそれに伴う密度・弾性波速度の精密測定が可能になっている。我々はこのような技術を用いてマントルや沈み込むスラブ関連物質のこれらの性質を実験的に決定し、マントル深部の化学組成に対して鉱物物性により制約を与えてきた。これまでの結果、マントル遷移層はその下部を除いて、上部マントルと同様にパイロライト的化学組成を持つとする結論に至っている。ただし、マントル遷移層下部の弾性波速度はパイロライトでは説明しにくく、何らかの化学組成変化が考えられる。一つの可能性として、この領域にスラブによりもたらされたハルツバージャイト質の物質の存在が考えられる。一方で、最近の肥後らによる下部マントル上部条件での bridgmanite の弾性波速度測定は、ブリルアン散乱法による結果と異なり、この領域においてもパイロライトが主要な構成物質である可能性を示している。この結果は最近の第一原理計算による予測とも一致し、マントルが CI コンドライトに比べて Si に欠乏している可能性を示唆している。

キーワード: 超高圧実験, マントル遷移層, 下部マントル, 鉱物物性, 弾性波速度, パイロライト
Keywords: high pressure experiment, mantle transition region, lower mantle, mineral physics, elastic velocity, pyrolite

SIT06-17   会場:303   時間:5 月 24 日 16:45-17:15

Metallic Fe and its influence on melting in the lower mantle

KARATO, Shun-ichiro[1]* ; GIRARD, Jennifer[1]
KARATO, Shun-ichiro[1]* ; GIRARD, Jennifer[1]

[1] Yale University, Department of Geology & Geophysics
[1] Yale University, Department of Geology & Geophysics

Melting in the deep Earth has important influence on the chemical evolution of Earth. Melting in the deep Earth is largely controlled by the availability of volatile (incompatible) elements that selectively go to the melt. In most of the lower mantle, melting will be difficult without volatiles. However, if a small amount of volatiles is present, melting becomes very easy and partial melting is expected in most lower mantle if volatiles are present.

Such a situation will be dramatically modified, if metallic Fe is present as first shown by Frost et al. (2004). These authors showed that metallic Fe is produced in the lower mantle assembly and that the formation of metallic Fe is not caused by the removal of oxygen but rather caused by the internal transfer of electrons due to the high stability of ferric Fe in bridgmanite. If this reaction occurred throughout the lower mantle, partial melting will be hard.

In this talk, we will present new experimental observations suggesting that the formation of metallic Fe is highly pressure dependent and it occurs only in the shallow lower mantle. The experimental results are the heterogeneous distribution of metallic Fe in a sample assembly in RDA where substantial pressure gradient is present. Metallic Fe is observed only in the low-pressure regions (24-26 GPa), whereas metallic Fe is not detected in the high-pressure regions (>27 GPa). We developed models to explain these observations that also explain varying results of previous studied at different pressures.

We conclude that a substantial amount (~1 % or larger) of metallic Fe is present only in the limited depth region in the lower mantle (660 to ~730 km). A possible implication of this observation to explain seismological observations by Schmandt et al, (2014) will be discussed.

キーワード: melting, lower mantle, volatile elements, metallic Fe
Keywords: melting, lower mantle, volatile elements, metallic Fe

SIT06-18 　　　　　　会場:303 　　　　　　　　　時間:5 月 24 日 17:15-17:30

MgSiO₃ ポストブリッジマナイト相の高温高圧状態方程式
Thermal equations of state of MgSiO₃ post-bridgmanite phase

境 毅 [1*] ; 出倉 春彦 [1] ; 平尾 直久 [2]
SAKAI, Takeshi[1*] ; DEKURA, Haruhiko[1] ; HIRAO, Naohisa[2]

[1] 地球深部ダイナミクス研究センター、愛媛大学, [2]JASRI
[1]Geodynamics Research Center, Ehime University, [2]Japan Synchrotron Radiation Research Institute

MgSiO₃ post-bridgmanite phase exists at the lowermost mantle of the Earth. Thus many studies on the equation of state of the phase were done at the lowermost mantle P-T conditions (Caracas and Cohen, 2008; Guignot et al., 2007; Oganov and Ono, 2004; Ono et al., 2006; Tsuchiya et al., 2004; Mosenfelder et al., 2009). On the other hand, super-Earths which have a few times of the Earth's mass have been found in the extra solar system one after another. MgSiO₃ post-bridgmanite is an abundant silicate phase in such huge terrestrial planet's mantle (Tsuchiya and Tsuchiya, 2011). Although the pressure condition of super-Earth's mantle reaches several hundred GPa, previously reported EoSs of post-bridgmanite by the laser heated diamond anvil cell (LHDAC) experiment were limited up to around 150 GPa. Moreover, the post-bridgmanite is expected to exist in Uranus's and Neptune's rocky cores and also early Earth's proto-core. The direct determination of the compression behavior of post-bridgmanite at multi-megabar pressure is, therefore, important to understand the super-Earth's interior and so on.

Here we report PPv EoSs up to 258 GPa and 2140 K based on the LHDAC experiment and up to 1 TPa and 6000 K by ab initio calculation based on the density-functional theory in the same manner as Tsuchiya et al. (2004). The experimental EoS agrees excellently with the calculated ab initio volume data within 1% up to 400 GPa and 6000 K. The volume differences between the present result and the EoS based on shock experiment data (Mosenfelder et al. 2009) was also 1% at 400 GPa and 300 K. The present EoSs show internal consistency among LHDAC, shock and ab initio data up to 400 GPa within 1% in volume. Our new EoSs are applicable to not only the Earth's core-mantle boundary region but also the super-Earth's mantle and early Earth's proto core.

キーワード: ポストブリッジマナイト, 状態方程式, レーザー加熱式ダイヤモンドアンビルセル, 第一原理計算
Keywords: post-bridgmanite, equation of state, LHDAC, Ab initio calculation

SIT06-19　　　　　　　会場:303　　　　　　　　　　　時間:5 月 24 日 17:30-18:00

核の形成過程と核の化学組成
Core Formation Process and Composition of the Core

大谷 栄治 [1*]
OHTANI, Eiji[1*]

[1] 東北大学大学院理学研究科
[1]Graduate School of Science, Tohoku University

Geochemical and cosmochemical arguments imply that major candidates of the light elements in the core are Si, O, S, and H with small amount of hydrogen. In the early stage of the planetary formation, the core formation process started by percolation of the metallic liquid though silicate matrix (1). The planetesimals which built the Earth could have a composition similar to enstatite chondrite, which contains some amount of sulfur as sulfide such as troilite, CaS, and metallic iron under reducing conditions. Therefore, the in the early stage of the accretion of the planetesimals, the Fe-FeS eutectic liquid could be formed and separated to the core by the percolation process. The major light elements of the core at this stage will be sulfur.

The internal pressure and temperature increased with the growth of the earth, and metallic iron depleted in sulfur was molten. The molten metallic iron can dissolve both Si and O as was experimentally shown by several authors (2). The core forming metallic liquid sunk into the bottom of the magma ocean and was in equilibrium with the magma ocean at high pressure around 40-60 GPa (3). The core separation occurred by the Rayleigh-Taylor instability. The core contains S, Si, and O by this process. If small amount of water was trapped in the magma ocean, most of H can be absorbed by the metallic core by strong partitioning of H into the metallic iron (4), and the magma ocean would have become dry.

The partitioning experiments between solid and liquid iron alloys indicate that S is strongly partitioned into the liquid outer core, whereas O is weakly into the liquid outer core, and Si into the solid inner core. H contents in the outer and inner cores are nearly the same due to similar H contents in solid and liquid iron (4). Based on the partitioning behavior between the outer and inner cores, the equation of state, and sound velocity of iron-light element alloys, the plausible distributions of the light elements in the outer and inner cores are examined.

References: (1) Terasaki, H. et al., Phys. Earth Planet. Inter., 202-1-6, 2012. (2) Kawazoe, T. and Ohtani, E., Phys. Chem. Minerals, 33, 227-234, 2006. (3) Siebert, J. et. al., Science, 339, 1194-1197, 2013. (4) Okuchi, T., Science, 278, 1781-1784, 1998.

キーワード: 形成過程, 微惑星, マグマオーシャン, 軽元素, 外核, 内核
Keywords: formation process, planetesimal, magma ocean, light element, outer core, inner core

SIT06-20 　　　　　会場:303 　　　　　　　　　　　時間:5 月 25 日 09:00-09:15

衝撃を受けた隕石中のシリカ高圧相とその意義
High-pressure polymorphs of silica in shocked meteorites and their implications

宮原 正明 [1*]
MIYAHARA, Masaaki[1*]

[1] 広島大学理学研究科地球惑星システム学専攻
[1]Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University

A high-pressure polymorph of silica is one of most unambiguous evidences for an impact event. Natural coesite and stishovite were discovered from impact craters on the Earth for the first time. Some meteorites are heavily shocked. Recent our studies reveal that high-pressure polymorphs of silica occur in many kinds of meteorites. Stishovite and coesite were identified from a lunar meteorite, Asuka 881757 for the first time (Ohtani et al., 2011). Subsequently, α-PbO$_2$ type silica, seifertite along coesite and stishovite were found from a lunar meteorite, NWA 4734 (Miyahara et al., 2013). In addition to lunar meteorites, we also identified stishovite from a lunar return sample, Apollo 15299 breccia (Kaneko et al., 2014). Considering radio-isotope chronology, the high-pressure polymorphs of silica are closely related with the late heavy bombardment and subsequent meteoroid impacts on the Moon. Miyahara et al. (2014) identified coesite and stishovite from eucrite which was expected to originate from 4 Vesta, which raised an objection about howardite-eucrite-diogenite delivery model to the Earth. Coesite and stishovite are also found from enstatite and carbonaceous chondrites (Weisberg et al. 2010; Kimura et al., 2014) although their parent-bodies are expected to be less shocked. Now the existences of coesite and stishovite in shocked meteorites appear to be ubiquitous. Therefore, high-pressure polymorphs of silica, which were overlooked, will become a new clue for clarifying a dynamic event in the solar system. On the other hand, the pervasive existence of coesite in shocked meteorites is enigmatic. The phase transition from quartz to coesite is not easily achieved in a transient high-pressure condition due to a high kinetic barrier (e.g., Mosenfelder and Bohlen, 1997). Coesite occurs in a silica grain entrained in a shock-melt vein or melt-pocket. Most coesite are un-oriented fine-grained assemblages accompanying silica glass. Coesite in shocked meteorites may crystallize from silica-glass or melt subsequent to amorphization or melting. Coesite probably has a high nucleation rate in silica-glass or melt.

Reference
Kaneko S. et al. (2014) Discovery of stishovite in an Apollo 15 sample and impact record on the Moon. Japan Geoscience Union Meeting 2014, PPS22-10.
Kimura M. et al. (2014) Shock vein in an enstatite chondrite, Asuka 10164. 77th Annual Meteoritical Society Meeting, 5100pdf.
Mosenfelder J.L. and Bohlen S.R. (1997) Kinetics of the coesite to quartz transformation. Earth and Planetary Science Letters 153, 133-147.
Miyahara M. et al. (2013) Discovery of seifertite in a shocked lunar meteorite. Nature Communications, doi: 10.1038/ncomms2733.
Miyahara et al. (2014) Discovery of coesite and stishovite in eucrite. Proceedings of the National Academy of Sciences U.S.A., doi: 10.1073/pnas.1404247111.
Ohtani E. et al. (2011) Coesite and stishovite in a shocked lunar meteorite, Asuka-881757, and impact events in lunar surface. Proceedings of the National Academy of Sciences U.S.A., 108, 463-466.
Weisberg M.K. and Kimura M. (2010) Petrology and Raman spectroscopy of high pressure phases in the Gujba CB chondrite and the shock history of the CB parent body. Meteoritics & Planetary Science 45, 873-884.

キーワード: シリカ, 高圧相, 隕石
Keywords: silica, high-pressure polymorph, meteorite

高圧下における MgO-FeO-SiO2 系のリキダス相関係 下部マントルにおけるマグマオーシャンの結晶化への応用
Liquidus phase relations in MgO-FeO-SiO2 system at high pressure: Implications for the solidification of magma ocean

森下 玲 [1*] ; 野村 龍一 [2] ; 廣瀬 敬 [2]
MORISHITA, Akira[1*] ; NOMURA, Ryuichi[2] ; HIROSE, Kei[2]

[1] 東京工業大学大学院理工学研究科地球惑星科学専攻, [2] 東京工業大学地球生命研究所
[1]Department of Earth and Planetary Sciences, Graduate School of Science and Engineering, [2]Earth-life Science Institute, Tokyo Institute of Technology

Seismological observations show the presence of large anomalies in the lowermost mantle such as LLSVP and ULVZ, both of which should be denser than surrounding mantle and thus gravitationally stable. The origins of such anomalies are still under debate, but they could be related to a basal magma ocean (BMO) that may have formed in early history of the Earth; the LLSVP represents iron-rich solids crystallized from the evolved BMO, and the ULVZ is a residual melt left after extensive solidification of the BMO.

Here we performed high-pressure melting experiments on the MgO-FeO-SiO$_2$ ternary system in a laser-heated diamond-anvil cell (DAC). Chemical and textural characterization of recovered samples were made using dual beam scanning microprobe (FIB + FE-SEM) (Versa 3D) and field-emission-type electron probe microanalyzer (FE-EPMA). The cross section of the sample showed a round portion with non-stoichiometric composition at the center (the hottest part), which represents quenched partial melt. And, such quenched melt was surrounded by a layer of solid phase(s) of (Mg,Fe)SiO$_3$ bridgmanite, (Mg,Fe)O ferropericlase, and SiO2 stishovite. Together with previous theoretical calculations of eutectic melt compositions in MgO-SiO$_2$ binary system and experimental results on FeO-SiO$_2$ and (Mg,Fe)$_2$SiO$_4$ systems, the liquidus phase relations in the MgO-FeO-SiO$_2$ ternary system were determined at 36 GPa. We also estimated those at 135 GPa considering the increase in iron content in bridgmanite with increasing pressure.

These results indicate that residual melt of the BMO should have evolved toward iron-rich and silica-poor with solidification. Fractional crystallization in the BMO leads to a very small fraction of residual melt that is strongly enriched in FeO, which is very dense in the lowermost mantle. The knowledge of chemical evolution of the BMO help understand the nature of the LLSVP and the ULVZ.

キーワード: マグマオーシャン, マントル進化
Keywords: magma ocean, mantle evolution

SIT06-22 　　　　　　　 会場:303 　　　　　　　　　　　　　　 時間:5 月 25 日 09:30-10:00

A coordinated study on structures of liquids/glasses using synchrotron radiation in Paris-Edinburgh and the diamond cell

WANG, Yanbin[1]* ; YU, Tony[1] ; PRAKAPENKA, Vitali[1] ; PRESCHER, Clemens[1] ; KONO, Yoshio[2] ;
JING, Zhicheng[3] ; ENG, Peter[1] ; STUBBS, Joanne[1] ; SHEN, Guoyin[2]
WANG, Yanbin[1]* ; YU, Tony[1] ; PRAKAPENKA, Vitali[1] ; PRESCHER, Clemens[1] ; KONO, Yoshio[2] ;
JING, Zhicheng[3] ; ENG, Peter[1] ; STUBBS, Joanne[1] ; SHEN, Guoyin[2]

[1]CARS, Univ. Chicago, USA, [2]HPCAT, CIW, USA, [3]Case Western Reserve Univ., USA
[1]CARS, Univ. Chicago, USA, [2]HPCAT, CIW, USA, [3]Case Western Reserve Univ., USA

Structures of geo-liquids at temperature and pressure conditions of the deep interior of the Earth fundamentally control the physical properties of these liquids, which, in turn, profoundly influence chemical and thermal evolution of the Earth. We have developed a suite of monochromatic x-ray diffraction techniques using both a Paris-Edinburgh press (PEP) and a diamond anvil cell (DAC) at the GSECARS beamlines. With two high resolution Si (111) and (311) monochromators, a multi-channel collimator (MCC) assembly, and two Kirkpatrick-Baez focusing mirrors, we have an exciting opportunity for liquid and glass structure studies in both the PEP and the DAC. A new PEP anvil geometry has been adopted which is capable of generating pressures in excess of 15 GPa on 0.5 mm diameter samples. Cell assemblies have been developed and temperatures up to 2000 C have been maintained over hours. A simple analysis shows that with a finely collimated or tightly focused incident beam of 0.05 mm, a collimation depth of 0.5 mm can be achieved at two-theta angles above ~10 degrees with the MCC. The PEP is mounted on the general-purpose diffractometer (GPD) in 13-ID-C, with the sample located at the center of the six-circle diffractometer, which allows scanning an area detector (e.g., MAR CCD) to cover maximum Q range up to 30 Å $^{-1}$,with x-ray energies above 60 keV. Ultrasonic acoustic velocity measurements can be conducted in-situ at high pressure and temperature to study elasticity of liquids using either the PEP or other large-volume, high-pressure devices. Applying a similar diffraction setup for the DAC technique, we can now study structural evolution of super-cooled liquids (glasses) to pressures in excess of 150 GPa both at room temperature and high temperatures. With a focused incident beam on the order of 0.03 mm, the MCC effectively reduces unwanted Compton scattering of the diamond anvils by a factor of 10, thereby allowing more accurate extraction of x-ray total scattering signals from tiny samples. Furthermore, online Brillouin spectroscopy allows acoustic velocities to be measured under the same pressure and temperature range. We will present results on structural responses and densification mechanisms of a number of silicate liquids and glasses at high pressures. Implications for melt dynamics in the Earth's interior will be discussed.

キーワード: synchrotron, high pressure, liquid structure, diffraction, early earth, mantle dynamics
Keywords: synchrotron, high pressure, liquid structure, diffraction, early earth, mantle dynamics

SIT06-23　　　　　　会場:303　　　　　　　　　　　時間:5 月 25 日 10:00-10:15

200GPa までの SiO$_2$ - Al$_2$O$_3$ ガラスの音速測定
Acoustic wave velocity measurements of SiO$_2$ - Al$_2$O$_3$ glasses up to 200GPa

大平 格 [1*] ; 村上 元彦 [1] ; 大谷 栄治 [1]
OHIRA, Itaru[1*] ; MURAKAMI, Motohiko[1] ; OHTANI, Eiji[1]

[1] 東北大学大学院理学研究科地学専攻
[1]Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University

　　Determination of the structure and physical properties of silicate melt under high pressure and high temperature is an important key to understand the stratified structure of the Earth through the global magma ocean in early Earth, and the gravitational stability of melts in Earth′s deep mantle. Natural silicate melts mainly consist of SiO$_2$ with various chemical components. Al$_2$O$_3$ is one of the most abundant components in natural silicate melts after SiO$_2$ (e.g., Mysen, 2005). Thus, it is essential to understand the effect of Al$_2$O$_3$ on the density and the structure of silicate melts under the high pressure and high temperature condition corresponding to the Earth′s mantle. However, the density and the structure of silicate melts under the whole mantle condition are poorly understood, and it is unclear whether an aluminous silicate melt is buoyant or not in a certain mantle condition.

　　In this study, in-situ high-pressure acoustic wave velocity measurements of SiO$_2$-Al$_2$O$_3$ glass were performed up to around 200 GPa using Brillouin scattering spectroscopic techniques to understand the effect of Al$_2$O$_3$ on pressure-induced structural changes in silicate glasses, as the analogue of silicate melts, under the whole mantle pressure conditions. We used both SiO$_2$ + 3.6 mol% Al$_2$O$_3$ glass (SA1) and SiO$_2$ + 20.0 mol% Al$_2$O$_3$ glass (SA2) as a starting material, synthesized using container-less liquid phase processing at the SPring-8 BL04B2.

　　The results below 30-40 GPa showed that the acoustic wave velocity of SA1 and SA2 increases with increasing Al$_2$O$_3$ content at a certain pressure, showing that the difference of bulk modulus (K) and shear modulus (μ) occurs depends on Al$_2$O$_3$ content in SiO$_2$-Al$_2$O$_3$ glasses. It is suggested that K, μ and of SiO$_2$ - Al$_2$O$_3$ glasses become large with progressing depolymerization in this pressure range.

　　At the pressures from 30-40 GPa to 100 GPa, the velocity increase with pressure is more gradual. Above 100 GPa, the sharp increase in the velocity gradient were observed in both SA1 and SA2. The pressure at which the sharp increase in the velocity gradient occurs are 130 ± 5 GPa in SA1, and 116 ± 9 GPa in SA2, and these values are smaller than those of SiO$_2$ glass and MgSiO$_3$ glass (Murakami and Bass, 2010; Murakami and Bass, 2011). The pressure condition at which the change of the velocity gradient occurs in SA1 are 10 GPa lower than that in SiO$_2$ glass and 3 GPa lower than that in MgSiO$_3$ glass. Moreover, such pressure condition in SA2 are 24 GPa lower than that in SiO$_2$ glass and 17 GPa lower than that in MgSiO$_3$ glass. This result may suggest that Si ions have a coordination number greater than 6 in both SA1 and SA2 around above mentioned pressures, and Al$_2$O$_3$ could lower the pressure condition for the formation of the Si-O coordination numbers higher than 6. The results suggest that an aluminous silicate melt is likely to become dense at much shallower depth than CMB.

キーワード: ケイ酸塩ガラス・メルトの構造, ブリルアン散乱法, 音速測定
Keywords: Structure of silicate glasses and melts, Brillouin scattering, Acoustic wave velocity measurement

SIT06-24　　　　　　会場:303　　　　　　　　　　　時間:5 月 25 日 10:15-10:30

高圧力条件における高密度ケイ酸塩ガラスの放射熱伝導率
High-pressure radiative conductivity of dense silicate glasses with implications for dark magmas

村上 元彦 [1*]
MURAKAMI, Motohiko[1*]

[1] 東北大学大学院理学研究科
[1]Graduate School of Science, Tohoku University

The current structure of Earth's interior is believed to have developed through dynamic differentiation from a global magma ocean in the early Earth. Elucidation of the heat-transport properties of silicate melts in the deep Earth is fundamental to understanding the evolution and structure of Earth's interior. The possible presence of dense, gravitationally stable, silicate melts at the bottom of the current mantle, as a remnant of a deep magma ocean, has been proposed to explain observations of anomalously low seismic velocities above the core-mantle boundary. Thus, heat flux through the core-mantle boundary (CMB) region would strongly depend on the thermal conductivity, both lattice-vibrational and radiative , of such dense silicate melts, as well as that of constituent minerals of the lower mantle. However, the thermal properties of such silicate melts under relevant high-pressure conditions are poorly understood, while there have been several experimental studies on the thermal conductivity of lower mantle minerals such as magnesium-rich silicate perovskite (bridgmanite) and ferropericlase. Direct measurements of thermal conductivity on silicate melts under ultrahigh-pressure conditions remain a great challenge and are currently beyond experimental capabilities. Alternatively, silicate glasses have been studied as analogues for quenched silicate melts, to simulate high-pressure melt behavior. Previous experimental works on silicate glasses have, however, been still limited to lower pressure condition, which is far below the pressure condition of the bottom of the mantle.

Here we report in-situ high-pressure optical absorption and synchrotron Mossbauer spectroscopic measurements of iron-enriched dense silicate glasses, as analogues for dense magmas, up to pressures of 85 GPa. Our results reveal a significant increase in absorption coefficients, by almost one order of magnitude with increasing pressure to about 50 GPa, most likely due to gradual changes in electronic structure. This indicates that the radiative thermal conductivity of dense silicate melts may decrease with pressure and so may be significantly smaller than previously expected under the CMB conditions. Such dark magmas heterogeneously distributed in the lower mantle would result in significant lateral heterogeneity of heat flux through the CMB.

SIT06-25　　　　　　　　会場:303　　　　　　　　　　　　時間:5 月 25 日 10:30-10:45

ブリッジマナイトの単結晶弾性と下部マントルの地震波速度異常の関連性
Single-crystal elastic property of bridgmanite and seismic anomalies in the lower mantle

福井 宏之 [1*] ; 米田 明 [2] ; 鎌田 誠司 [3] ; 大谷 栄治 [4] ; Baron Alfred[5]
FUKUI, Hiroshi[1*] ; YONEDA, Akira[2] ; KAMADA, Seiji[3] ; OHTANI, Eiji[4] ; BARON, Alfred[5]

[1] 兵庫県立大学大学院物質理学研究科, [2] 岡山大学地球物質科学研究センター, [3] 東北大学学際科学フロンティア研究所, [4] 東北大学大学院理学研究科地学専攻, [5] 理化学研究所バロン物質ダイナミクス研究室
[1]Graduate School of Material Science, University of Hyogo, [2]Institute for Study of the Earth's Interior, Okayama University, [3]Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, [4]Department of Earth and Planetary Materials Science, Graduate School of Science, Tohoku University, [5]Materials Dynamics Laboratory, RIKEN

Single crystal elasticity of bridgmanite is essential information to understand the seismic velocity structure of the lower mantle from the viewpoint of chemical and thermal structures. We have performed inelastic x-ray scattering measurement at BL35XU of SPring-8 on 100-micron size $(Mg,Fe,Al)(Si,Al)O_3$ single crystals synthesized by thermal gradient method. Analysis of the obtained spectra gives single crystal elastic stiffness constants. The cation substitution is seen to cause the anti-correlation between the bulk sound and shear wave velocities as well as to enhance the elastic anisotropy of bridgmanite, and consequently allows us to make a quantitative model that is consistent with seismological observations.

キーワード: ブリッジマナイト, X 線非弾性散乱, 単結晶弾性, 陽イオン置換, 下部マントル, 弾性波速度異常
Keywords: bridgmanite, inelastic x-ray scattering, single crystal elasticity, cation substitution, lower mantle, seismic anomaly

SIT06-26 　　　　　会場:303 　　　　　時間:5 月 25 日 11:00-11:30

Melting and core formation during accretion of the Earth
Melting and core formation during accretion of the Earth

RUBIE, David[1*] ; DE VRIES, Jellie[1] ; NIMMO, Francis[2] ; MELOSH, Jay[3] ; JACOBSON, Seth[4] ;
MORBIDELLI, Alessandro[4]
RUBIE, David[1*] ; DE VRIES, Jellie[1] ; NIMMO, Francis[2] ; MELOSH, Jay[3] ; JACOBSON, Seth[4] ;
MORBIDELLI, Alessandro[4]

[1]Bayerisches Geoinstitut, Bayreuth, Germany, [2]2) UCSC, Santa Cruz, USA, [3]3) Purdue University, West Lafayette, USA, [4]OCA,
Nice, France
[1]Bayerisches Geoinstitut, Bayreuth, Germany, [2]2) UCSC, Santa Cruz, USA, [3]3) Purdue University, West Lafayette, USA, [4]OCA,
Nice, France

The most significant differentiation event in the history of the Earth resulted in the formation of the Earth's iron-rich core and silicate mantle. Core formation involved the segregation of metal from silicate for which high temperatures were required. At least the metal, and probably also the silicate, had to be in a molten state for segregation to occur efficiently. Although the decay of short-lived isotopes provided sufficient heat for the core-mantle differentiation of early-formed planetary bodies, this heat source was only effective during the initial 2-3 My of Solar System history. The heat required for core-mantle differentiation of the Earth was derived primarily from high-energy collisions with other planetary bodies that culminated in the Moon-forming giant impact.

In order to study the compositional evolution of the growing planets, we have combined N-body accretion simulations with a model of multistage core formation (Rubie et al., 2015, Icarus 248, 89-108). Impacts of embryos and planetesimals with growing proto-planets are considered to result in large-scale melting, magma ocean formation and an episode of core formation. Metal-silicate equilibration at high pressure and temperature results in equilibrated metal and silicate compositions that are determined by mass balance combined with element partitioning data. The evolving compositions of the mantles and cores of the terrestrial planets can thus be modelled simultaneously. Model parameters are constrained by fitting the final composition of the mantles of Earth-like planets to the composition of the Earth's primitive mantle. However, current results are based on the simplifying assumption that metal-silicate equilibration pressures are always a constant fraction (typically around 0.7) of the proto-planet's core-mantle boundary pressure.

In order to further develop the model of Rubie et al. (2015), we are now calculating the depth of melting for each impact in the N-body simulations, which enables the P-T conditions of metal-silicate equilibration to be specified. Full three-dimensional models of planetary collisions are computationally too time-consuming for the large number (hundreds to thousands) of impacts in the N-body accretion simulations. Two-dimensional models cannot be used for non-vertical impacts due to their assumed symmetry in the third dimension. Therefore, a parameterised model is used which describes the amount and depth of melting based on the energy needed to melt a dunite mantle together with the energy provided by the impact. The available energy depends on the impact angle and velocity as well as on the impactor mass and the material properties of the impactor and the target.

A deep melt pool, formed by a collision between bodies of similar size, will spread over the planet's surface to form a global magma ocean as the result of isostatic readjustment. Subsequent planetesimal impacts may occur while this magma ocean is still present, in which case metal-silicate equilibration will take place near its base. With a simple cooling model, an estimate can be made of the depth of the magma ocean as a function of time. Using this method, equilibration temperatures and pressures are calculated for each impact. This approach is being used to constrain the accretion history and the presence or absence of a dense insulating atmosphere during the early history of the Earth.

キーワード: magma oceans, giant impacts, differentiation, high pressure
Keywords: magma oceans, giant impacts, differentiation, high pressure

Hydrostaticity and Equation of states of NaCl, KCl, KBr up to 70 GPa at room temperature
Hydrostaticity and Equation of states of NaCl, KCl, KBr up to 70 GPa at room temperature

鎌田 誠司 [1*] ; 前田 郁也 [2] ; 高畑 明拓 [2] ; 天池 洋平 [2] ; 大谷 栄治 [2] ; 平尾 直久 [3] ; 大石 泰生 [3]
KAMADA, Seiji[1*] ; MAEDA, Fumiya[2] ; TAKAHATA, Akihiro[2] ; AMAIKE, Yohei[2] ; OHTANI, Eiji[2] ;
HIRAO, Naohisa[3] ; OHISHI, Yasuo[3]

[1] 東北大学学際科学フロンティア研究所, [2] 東北大学理学研究科地学専攻, [3] 高輝度光科学センター
[1]FRIIS, Tohoku Univ., [2]Dept, Earth Sci., Grad. School of Sci. Tohoku Univ., [3]JASRI

Recently, the high pressures and temperatures corresponding to the inner Earth's core have been achieved due to the progress of the experimental techniques (e.g., Tateno et al., 2010). To understand the physical properties of the Earth's core, it is essential to perform high pressure and temperature experiments. Fiquet et al. (2001) reported first results on sound velocities of Fe by an inelastic X-ray measurement over 100 GPa. Antonangeli et al. (2004) and Ohtani et al. (2013) also reported sound velocities of Fe over 100 GPa. Fiquet et al. (2001) reported slow sound velocities above 100 GPa due to preferred orientation of iron. They concluded the preferred orientation was caused by a uniaxial compression using a diamond anvil cell and slow sound velocities propagated along c-axis were observed. Therefore, hydrostatical compression is essential to avoid texturing of the samples and understand physical properties under high pressure.

To produce hydrostatic condition under high pressures, some liquid pressure media have been used, such as 4:1 (in volume ratio) Methanol Ethanol mixture (ME), 16:3:1 (in volume ratio) Methanol Ethanol Water mixture (MEW). Those materials are solidify at around 10 GPa. Therefore, the hydrostatic conditions are limited up to 10 GPa. Noble gases are also used as pressure media. He is solidified at 12 GPa and Ne is solidified at 5 GPa. They show hydrostatic behavior up to 40 and 20 GPa, respectively. Although they are good material to produce hydrostatic compressions, ME and MEW are reactive under high temperature and the noble gases require a special equipment to load them into a sample chamber. In this study, we employed alkali halides (NaCl, KCl, KBr) as pressure media, which are relatively soft and are expected to produce pseudo hydrostatic condition.

A foil made from powdered Au was used as a pressure scale (Fei et al., 2007) and a laser absorber. The foil was embedded between alkali halides pellets which served as pressure media and thermal insulators. A symmetric diamond anvil cell was used to generate high pressure. A double-sided laser heating method using fiber lasers was used for annealing the Au foil under high pressures for 10 min. Experimental pressure was imposed to the sample every a few GPa step and its X-ray diffraction (XRD) patterns were taken at room temperature. At 50 GPa and 70 GPa, the sample was annealed in order to reduce stress in the chamber. XRD patterns were taken before and after annealing. All XRD patterns were taken at BL10XU of SPring-8, Japan (Ohishi et al. 2008). The diameter of the X-ray beam was collimated to be 20 μm. The volume of Au at ambient pressure was measured to be 67.69(5) $\mathring{A}^3$ (a=4.0755(9) $\mathring{A}$) at the BL10XU, SPring-8. The gold volume obtained here was used for V_0 in the equation of state for Au to calculate experimental pressures.

We have obtained XRD patterns from the samples between 1 and 70 GPa and annealed the samples at 2000 K at 50 and 70 GPa. KCl, KBr, and NaCl transformed from B1 to B2 phase at 2.6, 2.8, and 32.6 GPa, respectively. The standard deviations of the pressure distributions in the chamber decreased slightly due to the transformations. The pressure standard deviations increased from 0.1 GPa at 1 GPa to 0.2 GPa at 20 GPa. After further compressions, the pressure distributions of Au in NaCl was almost constant but those in KCl and KBr increased up to 0.8 GPa and 1.2 GPa, respectively. After annealing at 50 GPa, the pressure distributions slightly reduced in KCl and KBr but they increased in NaCl. The compression behaviors of KCl and KBr are in good agreement with Dewaele et al. (2012) and those of NaCl are consistent with Dorfman et al. (2012).

Keywords: equation of state, hydrostatic compression, alkali halides, high pressure

Jadeite in shocked meteorites: various textures and formation processes
Jadeite in shocked meteorites: various textures and formation processes

小澤 信 [1*] ; 宮原 正明 [2] ; 大谷 栄治 [1] ; 伊藤 嘉紀 [1] ; 鈴木 昭夫 [1] ; 木村 眞 [3] ; Koroleva Olga N. [4] ;
Litasov Konstantin [5] ; Pokhilenko Nikolay P. [5]
OZAWA, Shin[1*] ; MIYAHARA, Masaaki[2] ; OHTANI, Eiji[1] ; ITO, Yoshinori[1] ; SUZUKI, Akio[1] ;
KIMURA, Makoto[3] ; KOROLEVA, Olga N.[4] ; LITASOV, Konstantin[5] ; POKHILENKO, Nikolay P.[5]

[1]Department of Earth Science, Graduate School of Science, Tohoku University, Sendai 980-8578, Japan, [2]Department of Earth
and Planetary Systems Science, Graduate School of Science, Hiroshima University,, [3]Faculty of Science, Ibaraki University,
Mito 310-8512, Japan, [4]Institute of Mineralogy, UB RAS, Miass, 456317, Russia, [5]V. S. Sobolev Institute of Geology and
Mineralogy, SB RAS, Novosibirsk, 630090, Russia
[1]Department of Earth Science, Graduate School of Science, Tohoku University, Sendai 980-8578, Japan, [2]Department of Earth
and Planetary Systems Science, Graduate School of Science, Hiroshima University,, [3]Faculty of Science, Ibaraki University,
Mito 310-8512, Japan, [4]Institute of Mineralogy, UB RAS, Miass, 456317, Russia, [5]V. S. Sobolev Institute of Geology and
Mineralogy, SB RAS, Novosibirsk, 630090, Russia

Introduction

Collision of materials is one of the most fundamental processes in planet formation of the early solar system. Heavily-shocked
meteorites sometimes contain high-pressure minerals, which provide important constraints on the nature of the impact events.
Jadeite is a high-pressure mineral identified in various types of meteorites such as H, L and LL chondrites, and Martian meteorites
[1-8]. Here, we show various occurrences of jadeite observed in shocked meteorites, and discuss the conditions and mechanisms
of jadeite formation.

Results and Discussions

Heavily-shocked ordinary chondrites (H, L and LL) were mainly observed in our studies. They consist of chondritic host-rock
and pervasive shock-induced melt veins (SMVs). Jadeite is usually identified in fragments of the host-rock entrained to the
SMVs. Albitic feldspar grains in these fragments have been replaced by jadeite plus amorphous material.

A variety of texture was observed in jadeite-bearing grains of Sahara 98222 L6 chondrite, such as "particle-like", "stringer-
like", and "polycrystalline-like" phases [4]. Similar textures were also reported in jadeite-bearing grains of other L and
H ordinary chondrites [5], and shocked rocks from Ries crater, Germany [7]. Detailed TEM observations by Miyahara et al.
[5] clarified that these jadeite-bearing grains consist of massive or network-like assemblages of jadeite crystals and interstitial
amorphous (or poorly-crystallized) materials. Bulk chemical compositions of the jadeite-bearing grains are almost identical to
that of albitic feldspar in the host-rocks. Therefore, the jadeite described above is considered to have formed by solid-state
reactions.

On the other hand, we recently found a new occurrence of jadeite in Chelyabinsk LL5 chondrite [8]. Needle-like or skeletal-
rhombic crystals of jadeite coexist with amorphous material. The bulk chemical compositions of the jadeite-bearing grains are
different (more K-rich) from that of albitic feldspar in the host-rock. In addition, jadeite-rich part is enriched in Na, whereas the
amorphous part is highly enriched in K. The significant element migrations appear to be difficult in solid-state reactions during a
short duration of an impact. Thus, jadeite in Chelyabinsk meteorite is considered to have crystallized from feldspathic melt.

It is experimentally revealed that albite dissociate into jadeite plus silica phase over 3 GPa, and jadeite can be stable at 3-19
GPa as a liquidus or subsolidus phase [9-14]. The two types of jadeite formation (from solid or melt) were probably caused by
different temperature conditions. For the jadeite formed by solid-state reactions, the temperature is considered to have been lower
than at least 1400 ℃, the melting temperature of albite at 3 GPa [10,11]. For the jadeite formed from melt, the temperature could
have been higher than 1400 ℃. The different textures and chemical compositions of the jadeite-bearing grains reflect different
P-T-t (Pressure-Temperature-time) conditions during the impact events on different parent bodies of the meteorites.
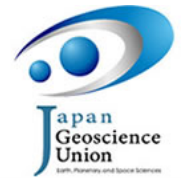
References

[1] Kimura et al. (2000) Meteorit. Planet. Sci. 35, A87-A88.
[2] Kimura et al. (2001) Meteorit. Planet. Sci. 36, A99.
[3] Ohtani et al. (2004) Earth Planet. Sci. Lett. 227, 505-515.
[4] Ozawa et al. (2009) Meteorit. Planet. Sci. 44, 1771-1786.
[5] Miyahara et al. (2013) Earth Planet. Sci. Lett. 373, 102-108.
[6] El Goresy et al. (2013) Lunar Planet. Sci. Conf. 44, 1037.

SIT06-P02 　　　　会場:コンベンションホール 　　　　時間:5 月 25 日 18:15-19:30

[7] James (1969) Science 165, 1006-1008.
[8] Ozawa et al. (2014) Sci. Rep. 4, 5033.
[9] Birch & LeCompte (1960) Am. J. Sci. 258, 209-217.
[10] Boyd & England (1963) J. Geophys. Res. 68, 311-323.
[11] Bell & Roseboom, Jr (1969) in Pyroxenes and Amphiboles: Crystal Chemistry and Phase Petrology,151-161.
[12] Liu (1978) Earth Planet. Sci. Lett. 37, 438-444.
[13] Yagi et al. (1994) Phys. Chem. Min. 21, 12-17.
[14] Tutti (2007) Phys. Earth Planet. Int. 161, 143-149.

キーワード: jadeite, meteorite, impact, high-pressure mineral, shock melt vein, formation mechanism
Keywords: jadeite, meteorite, impact, high-pressure mineral, shock melt vein, formation mechanism

Viscosity and structure of anorthite melt under high pressure and high temperature conditions
Viscosity and structure of anorthite melt under high pressure and high temperature conditions

坂巻 竜也 [1*] ; 河野 義生 [2]
SAKAMAKI, Tatsuya[1*] ; KONO, Yoshio[2]

[1]Department of Earth and Planetary Materials Science, Tohoku University, [2]HPCAT, Geophysical Laboratory, Carnegie Institution of Washington
[1]Department of Earth and Planetary Materials Science, Tohoku University, [2]HPCAT, Geophysical Laboratory, Carnegie Institution of Washington

The viscosity and structure of the anorthite ($CaAl_2Si_2O_8$) melt has been measured up to 6.1 GPa and 2173 K using the in-situ falling sphere method with X-ray radiography for viscosity and energy-dispersive X-ray diffraction technique for structure at beamline 16-BM-B of the Advanced Photon Source. The viscosity of the melt decreases with pressure up to 4 GPa, and then increases. The viscosity and its pressure dependence of anorthite melt are smaller than albite melt, which is also fully polymerized melt. Obtained structural information support the difference in viscosity behavior between anorthite and albite melts. Anorthite melt shows a smaller shift of the first sharp diffraction peak (FSDP) in the structure factor, $S(Q)$, to higher-Q with pressure than albite one, indicating the pressure-induced structural shrinkage of an intermediate-range order is small. The radial distribution function, $G(r)$, of anorthite melts exhibits the longer T-O distance, which is the length between tetrahedrally coordinated cations and oxygen. The TO_4 tetrahedra are the most fundamental units in the silicate melts, and the T-O distance reflects strength of the units. Thus, anorthite melt initially shows the low viscosity due to longer T-O distance. On the other hand, a pressure dependence of T-T distance in anorthite melt is smaller than albite one, and T-O-T angle is also small.

キーワード: viscosity, structure, anorthite melt, albite melt,, high pressure
Keywords: viscosity, structure, anorthite melt, albite melt, high pressure

The effect of Ni and C on sound velocity of liquid Fe at high pressure
The effect of Ni and C on sound velocity of liquid Fe at high pressure

Kuwabara Soma[1] ; 寺崎 英紀 [1*] ; Shimoyama Yuta[1] ; Nishida Keisuke[2] ; Higo Yuji[3] ; Takubo Yusaku[1] ;
Shibazaki Yuki[4] ; Tahara Masaki[4] ; Igarashi Mako[4] ; Sakamaki Tatsuya[4] ; Tange Yoshinori[3] ;
Kondo Tadashi[1]
KUWABARA, Soma[1] ; TERASAKI, Hidenori[1*] ; SHIMOYAMA, Yuta[1] ; NISHIDA, Keisuke[2] ; HIGO, Yuji[3] ;
TAKUBO, Yusaku[1] ; SHIBAZAKI, Yuki[4] ; TAHARA, Masaki[4] ; IGARASHI, Mako[4] ; SAKAMAKI, Tatsuya[4] ;
TANGE, Yoshinori[3] ; KONDO, Tadashi[1]

[1]Department of Earth and Space Science, Osaka University, [2]Department of Earth and Planetary Science, The University of
Tokyo, [3]Japan Synchrotron Radiation Research Institute, [4]Department of Earth and Planetary Materials Science, Tohoku University
[1]Department of Earth and Space Science, Osaka University, [2]Department of Earth and Planetary Science, The University of
Tokyo, [3]Japan Synchrotron Radiation Research Institute, [4]Department of Earth and Planetary Materials Science, Tohoku University

Nickel is a highly plausible element in the terrestrial core together with iron. However, the effect of Ni on elastic properties of
liquid Fe at high pressure has not been reported. It is important to study the effect of Ni together with light elements on the sound
velocity of liquid Fe to give a constraint on the liquid core composition of terrestrial planets by comparing with the observed
seismic data. In this study, we focused on the effect of Ni and C on the P-wave velocity and elastic properties of liquid Fe up to
6.5 GPa.

High pressure experiments were carried out using 1500 ton Kawai-type multi-anvil press at BL04B1 beamline, SPring-8
synchrotron facility. P-wave velocity (V_P) was measured using pulse-echo overlap method. Used sample compositions were
Fe-10wt%Ni and Fe-10wt%-4wt%C. The sample pellet was sandwiched by single crystal sapphire buffer rods for the V_P measurement. The experimental pressures and temperatures were determined based on lattice volumes of MgO and BN, which were
used as a pressure marker, combined with their equations of state. The measurements were performed up to 6.5 GPa and 2100 K.

Obtained VP of liquid Fe-Ni is located slightly lower and aligned almost parallel to the V_P curve of liquid Fe as a function
of pressure. This suggests that alloying 10 wt% of Ni into liquid Fe slightly decrease the V_P but little influence on the bulk
modulus and its pressure dependence. Alloying C slightly increases the V_P of liquid Fe and it is also found that the effect of
temperature on the V_P is not negligible. In the presentation, we will compare these results with the reported results of other light
element such as S in the sound velocity-density relation (Birch plot) and discuss a clue to constrain the core composition of small
terrestrial planets.

キーワード: Sound velocity, Fe alloy, Core, High pressure
Keywords: Sound velocity, Fe alloy, Core, High pressure

高温高圧下における Fe-S-Si 系の融解関係
Melting relationships in the Fe-S-Si system at high pressure and temperature

坂入 崇紀 [1*] ; 大谷 栄治 [1] ; 境 毅 [2] ; 鎌田 誠司 [1] ; 坂巻 竜也 [1] ; 平尾 直久 [3]
SAKAIRI, Takanori[1*] ; OHTANI, Eiji[1] ; SAKAI, Takeshi[2] ; KAMADA, Seiji[1] ; SAKAMAKI, Tatsuya[1] ;
HIRAO, Naohisa[3]

[1] 東北大学大学院理学研究科, [2] 愛媛大学地球深部ダイナミクス研究センター, [3] 公益財団法人高輝度光科学研究センター
[1]Graduate school of Science, Tohoku Univ., [2]Geodynamics Research Center, Ehime Univ., [3]JASRI

It is widely accepted that the Earth's core is mainly composed of iron and contains light elements to account for its density deficit. Alloying with light elements significantly affects the physical properties of iron and depresses its melting temperature. Therefore, the melting relation of the Fe-light elements system is the key to clarify the thermal structure of the Earth's core. Although there are many candidates for light elements in the core, sulfur and silicon are considered to be the major light elements. Some geochemical models predicted that sulfur and silicon could be present not only in the core of the Earth but also in the core of other terrestrial planets such as Mars and Mercury. In spite of the importance of the effect of sulfur and silicon on the physical properties of iron, there are few previous reports and the melting relationships in the Fe-S-Si system at high pressure were not revealed in details. To better understand the properties of the planetary cores, we investigated the melting relationships of the Fe-S-Si system under high-pressure conditions.

Here, we report the phase relationships and melting temperatures in the Fe-S-Si system up to 60 GPa. Melting experiments were performed in the pressure range of 20-60 GPa and the temperature range of 1300-2500 K using a double-sided laser-heated diamond anvil cell combined with X-ray diffraction technique. The sample compositions used in this study were $Fe_{80.1}S_{12.7}Si_{7.2}$ (Fe-8wt.%S-4wt.%Si) and $Fe_{74.4}S_{18.5}Si_{7.1}$ (Fe-12wt.%S-4wt.%Si). In situ X-ray diffraction experiments were conducted at the BL10XU beamline of the SPring-8 facility. The melting detection was based on disappearance of the X-ray diffraction peaks of the sample. On the basis of X-ray diffraction patterns, we confirmed that iron-silicon alloy which hcp and fcc structure and Fe_3S are stable phases under subsolidus conditions. Because of dissolution of silicon into iron, the boundary of fcc and hcp phase of this study shifts towards higher pressure compared to that of pure iron. Both solidus and liquidus temperatures are significantly lower than the melting temperature of pure Fe and increases with pressure in this study. In addition, the present melting curve is lower than the melting temperature of the Fe-Si system reported by Asanuma et al. (2010) and slightly lower than the eutectic temperature of the Fe-Fe_3S system (Kamada et al., 2012) and that of the Fe-O-S system (Terasaki et al., 2011). In order to draw the melting curve as a function of pressure, we fitted the present results using the Simon's equation. The obtained fitting parameters are T_{mR} =1277(6), a=116.1(21) and c=1.06(2) for the solidus and T_{mR} =1582(13), a=127.9(48) and c=1.00(3) for the liquidus. Because sulfur and silicon are the candidates for the light elements in the cores of Earth, Mars, and Mercury (e.g., Malavergne et al., 2007), the present results on the solidus and liquidus temperatures can be applicable to the core formation processes in the Earth, Mars, and Mercury.

Keywords: Core, Melting relationships, Diamond Anvil Cell, Light elements, Fe-S-Si system

超音波法を用いた固体鉄の高温高圧下での弾性波速度測定
Sound velocity measurements of solid iron under high pressure and high temperature using an ultrasonic method

柴崎 裕樹 [1*] ; 西田 圭佑 [2] ; 肥後 祐司 [3] ; 五十嵐 愛子 [4] ; 田原 政紀 [4] ; 坂巻 竜也 [4] ; 寺崎 英紀 [5] ;
下山 裕太 [5] ; 桑原 荘馬 [5] ; 田窪 勇作 [5] ; 大谷 栄治 [4]
SHIBAZAKI, Yuki[1*] ; NISHIDA, Keisuke[2] ; HIGO, Yuji[3] ; IGARASHI, Mako[4] ; TAHARA, Masaki[4] ;
SAKAMAKI, Tatsuya[4] ; TERASAKI, Hidenori[5] ; SHIMOYAMA, Yuta[5] ; KUWABARA, Souma[5] ; TAKUBO, Yusaku[5] ;
OHTANI, Eiji[4]

[1] 東北大学学際科学フロンティア研究所, [2] 東京大学大学院理学研究科, [3] 高輝度光科学研究センター, [4] 東北大学大学院理学研究科, [5] 大阪大学大学院理学研究科
[1]Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, [2]Department of Earth and Planetary Science, The University of Tokyo, [3]Japan Synchrotron Radiation Research Institute, [4]Department of Earth and Planetary Material Sciences, Tohoku University, [5]Department of Earth and Space Science, Osaka University

The Earth's interior has been directly investigated by seismic wave propagation and normal mode oscillation. Based on those observations, the distributions of density and sound velocity of the Earth's interior have been estimated (e.g. PREM). The core, which is located at the center of the Earth, is believed to consist of metallic iron with a certain amount of light elements, such as hydrogen, carbon, oxygen, silicon, and sulfur. A large number of experiments on the compressibility of iron and iron-light element alloys have been carried out in order to constrain the abundances of the light elements in the core. In the past fifteen years, the sound velocities of the iron and iron alloys have also been measured intensively at high pressure. Although the sound velocity consists of longitudinal (V_P) and transverse (V_S) components, most discussions about the core composition have been based on the only V_P data because of the technical issues of the high-pressure experiments. In order to estimate the abundances of the light elements more correctly, the precise measurement of V_S as well as V_P is necessary. In this study, we measured the V_P, V_S, and density of solid iron under high-pressure and high-temperature conditions using an ultrasonic method, and X-ray radiography and diffraction techniques.

Simultaneous ultrasonic measurements, and X-ray radiography and diffraction experiments were carried out at BL04B1 beamline, SPring-8 in Japan. High-pressure and high-temperature were generated using a 1500-ton Kawai type multi-anvil apparatus installed at BL04B1 beamline. The experimental conditions were up to 7 GPa and 800 K (stability field of bcc-Fe). The Fe powder or rod was used as the sample. Ultrasonic V_P and V_S measurements were performed using the pulse reflection method. P- and S-wave signals with a frequency of 57 MHz and 30 MHz, respectively, were generated and received by a 10 degree Y-cut $LiNbO_3$ transducer. The sample was first compressed to the target pressure and heated up to the maximum temperature in each press load in order to reduce the deviatoric stress. Then, we got the ultrasonic data, X-ray radiography image, and X-ray diffractions from the sample and the pressure marker (MgO + hBN) at each about 150-200 K temperature step on decreasing temperature.

Our high-pressure V_P and V_S data are good agreement with the previous ambient-pressure results measured using the same ultrasonic method [Dever, 1972]. In contrast, our V_P data are slightly smaller than the results obtained by high-energy resolution inelastic X-ray scattering (HERIX) technique [Liu et al., 2014]. The values of both V_P and V_S at high temperature are lower than the linear relationship of a velocity-density, i.e., Birch's law, at room temperature, which is the same trend as the previous HERIX result [Liu et al., 2014].

Keywords: high pressure, planetary core, iron, sound velocity

SIT06-P07 　　　　会場:コンベンションホール　　　　時間:5 月 25 日 18:15-19:30

Synthesis of unsaturated hydrocarbons at the core-mantle boundary

BELONOSHKO, Anatoly[1] ; LITASOV, Konstantin[2]* ; LUKINOV, Timofiy[1] ; ROSENGREN, Anders[1] ; BRYK, Taras[3]
BELONOSHKO, Anatoly[1] ; LITASOV, Konstantin[2]* ; LUKINOV, Timofiy[1] ; ROSENGREN, Anders[1] ; BRYK, Taras[3]

[1]Department of Theoretical Physics, Royal Institute of Technology, Stokholm, Sweden, [2]VS Sobolev Institute of Geology and Mineralogy, Novosibirsk, Russia, [3]Institute for Condensed Matter Physics, Lviv, Ukraine
[1]Department of Theoretical Physics, Royal Institute of Technology, Stokholm, Sweden, [2]VS Sobolev Institute of Geology and Mineralogy, Novosibirsk, Russia, [3]Institute for Condensed Matter Physics, Lviv, Ukraine

The origin of life on Earth converges to the problem of the origin of first organic molecules, so called 'blocks of life'. The synthesis of complex organic molecules with C-C bonds is possible under conditions of reduced activity of oxygen or at a surface of catalyst via Fischer-Tropsch reaction (Kenney et al., 2002; Lobanov et al., 2013). It is clear, however, that such conditions should have sustainably existed to provide continuous flow of large quantities of organic material. We found, performing *ab initio* molecular dynamics simulations of the C-O-H-Fe system, that such conditions exist no deeper than at the core-mantle boundary of the Earth. H_2O and CO_2 can be delivered to the CMB by subducting slabs. Indeed, carbon and hydrogen can be also emitted from the core itself. The mixture of H_2O and CO_2 subjected to high pressure (130 GPa) and temperature (around 4000 K) does not lead to synthesis of complex hydrocarbons. However, when metallic Fe is added to the system, C-C bonds emerge. Being lighter than the material in the mantle, the hydrocarbons can rise towards the surface via mantle plumes as a part of fluid or melt component, providing the 'blocks of life' for further synthesis of complex organic molecules. Stability of hydrocarbon molecules and their possible mobility as a light component of the plume was argued in recent study of peridotite and eclogite systems with reduced C-O-H fluid (Litasov et al., 2014).Thus, the iron core not only protects Life on Earth creating the magnetic field, but may also create the Life. This means that search for Life on other planets can also be oriented towards the planets with iron cores.

キーワード: high pressure, core mantle boundary, ab initio molecular dynamics, C-O-H fluid, hydrocarbons, iron
Keywords: high pressure, core mantle boundary, ab initio molecular dynamics, C-O-H fluid, hydrocarbons, iron