MEXT Grant-in-Aid for Scientific Research on Innovative Areas

Interaction and Coevolution of the Core and Mantle Toward Integrated Deep Earth Science

International Symposium FY2017 Annual General Meeting

March 26 - 29, 2018
Ehime University

Core Mantle Coevolution

Program

March, 26 (Mon)

9:30-10:20 Reception

10:20-10:30 Opening address Taku Tsuchiya (Ehime Univ.)

Session 1 (Chairperson: Satoru Tanaka, Kenta Ueki)

10:30-11:00
Invited "Rheological weakening of orthopyroxene and the impacts on asthenosphere rheology and the Lehmann seismic discontinuity"
Yanbin Wang (Univ. Chicago)

11:00-11:20
"Development of New Technology for Geoneutrino Directional Measurement"
Hiroko Watanabe (Tohoku Univ.)

11:20-11:40
"Construction of Stochastic Crustal Model for Geoneutrino Observation: Status and Outlook"
Sanshiro Enomoto (Univ. Tokyo)

11:40-12:00
"Current status of neutrino oscillation tomography of the Earth"
Akimichi Taketa (Univ. Tokyo)

12:00-13:30 Break

13:30-14:30 Poster Session

Session 2 (Chairperson: Takashi Yoshino, Seiji Kamada)

14:30-15:00
Invited "Experimental evidence supporting a global melt layer at the base of the Earth' s upper mantle"
Geeth Manthilake (UCA)

15:00-15:20
"Determination of Intrinsic Attenuation in the Oceanic Mantle"
Nozomu Takeuchi (Univ. Tokyo)

15:20-15:40
"The role of dense hydrous magnesium silicates (DHMS) in planet evolution"
Christine Houser (Tokyo Tech.)

15:40-16:00
“First principles investigation of the vibrational properties of hydrous wadsleyite and hydrous ringwoo
Jun Tsuchiya (Ehime Univ.)
16:00-16:20
“He and Ar partitioning between liquid iron and molten silicateunder high pressure”
Zhihua Xiong (Ehime Univ.)

16:20-16:50 Break

Session 3 (Chairperson: Akio Suzuki, Zhihua Xiong)

16:50-17:20
Invited “Large volume presses for imaging, tomography and structural analysis at the PSICHE beamline, synchrotron SOLEIL”
Nicolas Guignot (SOLEIL)
17:20-17:40
“High Pressure Generation in a Kawai-type Multianvil Apparatus Equipped with Sintered Diamond Anvils”
Daisuke Yamazaki (Okayama Univ.)
17:40-18:00
“High pressure generation up to 24 gigapascals using a D-DIA apparatus combined with jacketed anvils”
Tomohiro Ohuchi (Ehime Univ.)
18:00-18:20
“Some recent progress in synthesis, characterization, and applications of NPD”
Tetsuo Irifune (Ehime Univ.)

19:00-21:00 Conference Dinner

March, 27 (Tue)

Session 4 (Chairperson: Tetsuo Irifune, Masayuki Nishi)

9:00- 9:20
“Advancements in Ab Initio Mineral Physics”
Taku Tsuchiya (Ehime Univ.)
9:20- 9:40
“The role of minor elements in conductivity of mantle and core materials: new results in 2017”
Kenji Ohta (Tokyo Tech.)
9:40-10:00
“Crystallographic-preferred orientation of MnGeO3 perovskite”
Yu Nishihara (Ehime Univ.)
10:00-10:20
” Incorporation of nitrogen into the lower-mantle minerals under high pressure and high temperature”
Hiroyuki Kagi (Univ. Tokyo)

10:20-10:50 Break

Session 5 (Chairperson: M Satish-Kumar, Shinnosuke Aoyama)

10:50-11:20
Invited "Terrestrial magma ocean origin of the Moon"
Shun-ichiro Karato (Yale Univ.)
11:20-11:40
"Zr isotope constraints on early Earth differentiation"
Tsuyoshi Iizuka (Univ. Tokyo)
11:40-12:00
"Physical properties of volatile-bearing magmas in the Earth' s deep interior"
Akio Suzuki (Tohoku Univ.)
12:00-12:20
"Origin of geochemical mantle components: Role of spreading ridge, subduction zone, and thermal evolution of mantle"
Jun-Ichi Kimura (JAMSTEC)

12:20-13:50 Break

13:50-14:50 Poster Session

Session 6 (Chairperson: Hidenori Terasaki, Hitoshi Gomi)

14:50-15:20
Invited "Earth' s Correlation Wavefield and new Insights on Structure and Dynamics of the Inner Core"
Hrvoje Tkalcic (ANU)
15:20-15:40
"Ab-initio study of iron diffusion properties in Earth' s inner core"
Sebastian Ritterbex (Ehime Univ.)
15:40-16:00
"Local strong slow S-wave anomalies at western edge of Pacific LLSVP in the lowermost mantle"
Masayuki Obayashi (JAMSTEC)
16:00-16:20
"Mobile broadband seismic observation in Thailand: Its present state and preliminary results"
Satoru Tanaka (JAMSTEC)

16:20-16:50 Break

Session 7 (Chairperson: Katsuhiko Suzuki, Hideharu Kuwahara)

16:50-17:20

Invited "Computational models of magnetic field generation in the Earth"

Andrew Jackson (ETH Zurich)

17:20-17:40

"On penetration of compositional convection into a thermally stable stratified layer in the outer core of the Earth"

Youhei Sasaki (Kyoto Univ.)

17:40-18:00

"Melting experiments on Fe–Si–S alloys to core pressures"

Shigehiko Tateno (Tokyo Tech.)

18:00-18:20

"Melting of iron to 290 gigapascals"

Ryosuke Sinmyo (Univ. Tokyo)

18:20-18:40

"Core isotopic flavors in OIB, without core entrainment"

John Hernlund (Tokyo Tech.)

March, 28 (Wed)

Session 8 (Chairperson: Tetsu Kogiso, Norikatsu Akizawa)

9:00- 9:30

Invited "Shaping mantle volatile concentrations through early heterogeneities and long-term cycling"

Sujoy Mukhopadhyay (UC Davis)

9:30- 9:50

"Stable isotopes as tools for exploring the deep Earth"

M Satish-Kumar (Nigata Univ.)

9:50-10:10

"Determination of the noble gas partition coefficients between metal-silicate melts"

Hirochika Sumino (Univ. Tokyo)

10:10-10:30

"Silicon' s role in the evolution of the Earth' s core and mantle"

George Helffrich (Tokyo Tech.)

10:30-11:00 Break

Session 9 (Chairperson: Taku Tsuchiya, Sebastian Ritterbex)

11:00-11:30

Invited “Thorium and uranium power plate tectonics, but not the geodynamo”

William F McDonough (Tohoku Univ.)

11:30-11:50

“Tungsten isotopic heterogeneity in oceanic island basalts produced by core-mantle interaction”

Takashi Yoshino (Okayama Univ.)

11:50-12:10

“Liquid metal-silicate partitioning of carbon in a magma ocean during the core formation of terrestrial planets”

Hideharu Kuwahara (Ehime Univ.)

12:10-13:40 Break

Session 10 (Chairperson: Hisayoshi Shimizu, Sunil K. Roy)

13:40-14:10

Invited “Chemical Stratification and Magnetic Field Generation”

Laneuville Matthieu (Tokyo Tech.)

14:10-14:30

“Spatiotemporal variations of core-mantle coupling revealed by geomagnetic field data (FY2017)”

Masaki Matsushima (Tokyo Tech.)

14:30-14:50

“Highly precise 182W/184Wisotopic compositions of terrestrial samples”

Katsuhiko Suzuki (JAMSTEC)

14:50-15:20 Comments and Discussion

Core time

Odd-number presentations: 13:30-14:30, March, 26

Even-number presentations: 13:50-14:50, March, 27

P01 "The effects of ferromagnetism and interstitial hydrogen on the equation of states of hcp and dhcp FeHx"
Hitoshi Gomi (Okayama Univ.)

P02 "Grain growth kinetics of lower-mantle materials: Implications for the grain size evolution and the rheology"
Tomoaki Kubo (Kyusyu Univ.)

P03 "Diffusion mechanisms of creep and grain growth of two-phase polymineralic rocks: Implications for rheology of the lowermost mantle"
Atsuro Okamoto (Univ. Tokyo)

P04 "Experimental study on transport properties of liquid iron-silicon alloy at and above the outer core conditions"
Kohei Miyanishi (Osaka Univ.)

P05 "Microstructures of experimentally deformed carbon steels"
Yozora Sakoda (Hiroshima Univ.)

P06 "Deformation of bridgmanite and post-spinel two-layered sample under lower mantle conditions with DT-Cup apparatus"
Fang Xu (IMPMC)

P07 "Toward development of ultrasonic measurement technique under whole lower mantle conditions"
Yuji Higo (JASRI)

P08 "Searching for multi light elements in iron-silicate-water system using high pressure and high temperature experiments: Implications for the Earth's evolution"
Riko Iizuka-Oku (Univ. Tokyo)

P09 "Melting experiments of hydrous peridotite under the top of the lower mantle conditions"
Ayano Nakajima (Tohoku Univ.)

P10 "Al substitution mechanism in anhydrous bridgmanite as a function of Al content"
Masamichi Noda (Ehime Univ.)

P11 "Structures of basaltic glass under high pressure by in-situ X-ray and neutron diffraction investigations"
Tomonori Ohashi (Tohoku Univ.)

P12 "Density measurement of metals at high temperatures using newly designed furnace"
Hidenori Terasaki (Osaka Univ.)

P13 "Silicate melt viscosities at high pressure:Experimental results and its implications"
Longjian Xie (Osaka Univ.)

P14 “Melting of Al-rich phase D up to the uppermost lower mantle and transportation of H_2O to the deep Earth”
Chaowen Xu (Ehime Univ.)

P15 “A recent application of NPD anvils to EXAFS spectroscopy: element-selective elastic properties of Fe-Ni and Fe-Pt Invar alloys”
Naoki Ishimatsu (Hiroshima Univ.)

P16 “Thermal equations of state of $MgSiO_4H_2$ phase H”
Masayuki Nishi (Ehime Univ.)

P17 “High pressure generation using double-stage diamond anvil technique: problems and equations of state of rhenium”
Takeshi Sakai (Ehime Univ.)

P18 “Multiple sulfur isotopes of Archean oceanic crust and granitoids: Implication for the anomalous sulfur budget in the mantle”
Shinnosuke Aoyama (Niigata Univ.)

P19 “Crystallization of metasomatic sulfide melt, and recrystallization of crystalline sulfides constrained by sub-μm-scale investigations for PGE-bearing sulfide inclusion in Tahitian harzburgite xenolith”
Norikatsu Akizawa (Univ. Tokyo)

P20 “Quantitative isotope imaging methods using secondary ion mass spectrometry”
Shoichi Itoh (Kyoto Univ.)

P21 “Behavior of highly siderophile elements in mantle peridotite and its bearing on the primitive mantle composition”
Tetsu Kogiso

P22 “Seismic scatterers in the lower mantle near subduction”
Satoshi Kaneshima (Kyusyu Univ.)

P23 “Observation of multipathing at the western edge of the Pacific Large Low-Velocity Provinc”
Sunil K. Roy (Univ. Tokyo)

P24 “Examination of local geomagnetic jerks using wavelet analysis”
Hisayoshi Shimizu (Univ. Tokyo)

P25 “The evaluation of the chemical variation in a single granitic rock suite revealed by grid sampling toward improving the accuracy of geoneutrino flux”
Kazuki Minami (Univ. Tokyo)

P26 “The new database for composition of the basement rocks of Japanese islands with accurate location information for geo-neutrino modeling”
Kenta Ueki (JAMSTEC)

P27 “Effects of iron on the lattice thermal conductivity of lower mantle minerals evaluated by Ab initio anharmonic lattice dynamics simulations”
Haruhiko Dekura (Ehime Univ.)

P28 “The dependence of mantle convection in super-Earths on the planetary mass”
Takehiro Miyagoshi (JAMSTEC)

P29 “Basic features of the kinematic dynamo action associated with top-down type convection in a rotating spherical shell”
Hinami Taniguchi (Kyushu Univ.)

P30 “Normal mode splitting functions for CMB sensitive modes”
Naoki Suda (Hiroshima Univ.)

P31 “Bayesian Inference of 3-D Lithology Distribution Using a Seismic Tomography Model: Effects of Lithology Mixture”
Nozomu Takeuchi (Univ. Tokyo)

Oral Session

S1-1 Invited

Rheological weakening of orthopyroxene and the impacts on asthenosphere rheology and the Lehmann seismic discontinuity

Feng Shi[1], Tony Yu[1], and Yanbin Wang[1]

[1] Center for Advanced Radiation Sources, The University of Chicago
(wang@cars.uchicago.edu)

Pyroxenes, with roughly equal amounts of orthopyroxene and clinopyroxene, may constitute up to 40% by volume in the upper mantle, second only to olivine, and should impose significant influences on the rheological behavior of the asthenospheric mantle. Here we report high-pressure, high-temperature deformation experiments on polycrystalline orthoenstatite (OEn). Natural crystals with an average composition of $En_{89}Fs_{10}Wo_{1}$ (where En=$MgSiO_3$, Fs=$FeSiO_3$, and Wo=$CaSiO_3$) with ~4 wt% Al_2O_3 were hand-picked from a fresh, coarse-grained spinel lherzolite specimen (Damaping, China), disaggregated and ground into powders with grain size ~25-35 μm. FTIR showed that water contents of the crystals were about 20-30 ppm by weight. The powders were sintered at 3 GPa and 1273 K for 4 h, to form polycrystalline “rocks” 1.2 mm in diameter and 1.2 mm in length. Creep experiments were conducted in the D-DIA apparatus at beamline 13-BM-D of the Advanced Photon Source, Argonne, National Laboratory, at temperatures of 1273-1473 K and pressures up to 8 GPa, with strain rates between 4×10^{-6} and 4×10^{-5} s^{-1}. Ni foils were attached to the samples as strain markers and to help constrain oxygen fugacity. Synchrotron x-ray diffraction and imaging were used to measure stress and strain, respectively, during deformation. Up to 4.5 GPa, the quasi-steady-state stress-strain data can be fitted quite well with a power-law rheology yielding stress exponent n=3.85 and an activation volume V*=13 cm^3/mol. Electron backscattered diffraction (EBSD) was used to quantify crystallographic preferred orientation (CPO) development after creep. The (100) poles are generally aligned with the shortening (axial) direction, while the (001) poles tend to be normal to that direction. This suggests that the dominant slip system is [001](100), consistent with previous studies. Within this pressure range, OEn is significantly weaker than olivine. Model calculations show that, between ~50 and ~150 km depths, effective viscosity of an upper mantle with 20-40% OEn plus olivine is at least one order of magnitude lower than that of a 100% olivine upper mantle. Therefore, the presence of pyroxenes cannot be ignored when modeling mantle viscosity profiles. More importantly, above 4.5 GPa, OEn exhibits an unexpected pressure-induced rheological weakening, with a strongly negative apparent activation volume. This high-temperature rheological weakening occurs at pressures 2-3 GPa lower than the elastic weakening in OEn observed at room temperature [1]. EBSD on samples recovered from above 6 GPa reveals that (001) poles form additional well-defined maxima perpendicular to the axial direction, suggesting new slip directions in the (001) plane. We postulate that the new "slip directions" are activated when OEn is compressed close to a high-pressure structure under differential stress. The high-pressure structure can be either high-pressure clinoenstatite (C2/c) [2], or another monoclinic phase ($P2_1/c$) recently discovered [3, 4]. The latter is structurally closely related to OEn (*P*bca) by losing mirror planes in (001), resulting in twinning. The pressure-induced rheological weakening above 4.5 GPa may be due to an incipient response prior to the transition and is expected to have profound impact on the nature of the asthenosphere. The high-pressure phase transition in OEn, together with weakened pre-transition rheology, may also be a main contributor to the Lehmann seismic discontinuity.

References

[1] Kung *et al.*, In situ measurements of sound velocities and densities across the orthopyroxene → high-pressure clinopyroxene transition in $MgSiO_3$ at high pressure. *Phys. Earth Planet. Int.,* **147**, 27 (2004).

[2] Angel *et al*., Stability of high-density clinoenstatite at upper-mantle pressures. *Nature,* **358**, 322 (1992).

[3] Zhang *et al*., A new high-pressure phase transition in natural Fe-bearing orthoenstatite. *Am. Min.,* **97**, 1070 (2012).

[4] Dera *et al.*, Metastable high-pressure transformations of orthoferrosilite Fs82. *Phys. Earth Planet. Int.,* **221**, 15 (2013).

S1-2

Development of New Technology for Geoneutrino Directional Measurement

Hiroko Watanabe[1]

[1] Research Center for Neutrino Science, Tohoku University (hiroko@awa.tohoku.ac.jp)

Neutrino is an elusive particle and it can penetrate even astronomical objects. While neutrino experiments continue to explore the neutrino propertied, e.g. oscillation nature of neutrino flavor transformation, mass-square differences and mixing angles, we have began to utilize neutrino as a tool to look into the Earth. Anti-neutrinos emitted from radioactive isotopes, geo-neutrinos, bring unique and direct information of the Earth's interior and thermal dynamics.

KamLAND, Kamioka Liquid-scintillator Anti-neutrino Detector, has 1 kton ultra pure liquid scintillator. They reported the first experimental study of geo-neutrino in 2005 [1]. Later the geo-neutrino signals were used to estimate the Earth's radiogenic heat production and constrain the composition models of the bulk silicate Earth [2]. Following the Fukusima reactor accident in March 2011, the entire Japanese nuclear reactor industry has been subjected to a protected shutdown. This unexpected situation allows us to improve the sensitivity for geo-neutrinos [3].

The liquid scintillator detectors have the sensitivity for measuring total amount of geo-neutrinos from the Earth's crust and mantle. However, we do not have the technology to track the direction of incoming geo-neutrinos at present due to the high miss-identification in a neutrino's track reconstruction. The direction-sensitive detector can map out the U and Th distribution inside the Earth and this technic is also applicable to resolving crust versus mantle contributions. Recent progress in studying this this new technology confirmed that a signify improvement is possible in neutrino tracking identification with a combination of ^{6}Li-loaded liquid scintillator and imaging detector. We developed prototype detector to measure 3D image of scintillation light and study the methodology for the image reconstruction. We will present recent status of our prototype detector and achievement of dark noise reduction of pixelated detector.

[1] T. Araki et al., Nature 436, 499 (2005)

[2] A. Gando et al., Nature Geosci. 4, 647 (2011)

[3] A. Gando et al., Phye. Rev. D 88, 033001 (2013)

S1-3

Construction of Stochastic Crustal Model for Geoneutrino Observation: Status and Outlook

Sanshiro Enomoto[1], Nozomu Takeuchi[2], Kenta Ueki[3], and Tsuyoshi Iizuka[4]

[1] Kavli-IPMU, University of Tokyo / University of Washington (sanshiro@uw.edu)

[2] Earthquake Research Institute, University of Tokyo

[3] Japan Agency for Marine-Earth Science and Technology

[4] University of Tokyo

Geoneutrino observation with KamLAND is expected to provide unique insights about Earth's deep chemical composition and thermal dynamics, but for this, proper description of U and Th distributions in the Japan crust is essential. Despite several attempts in the past, no model is satisfactory in terms of objective and quantitative description.

We approached this problem with Bayesian inference of 3D lithology from seismic tomography data, combined with a new rock composition model that removes all biases existed in past treatments, and constructed a truly probabilistic crustal model for the first time (Takeuchi et al, submitted). However, there remains a difficulty on modeling geological special correlations, resulting in a large error in the final flux calculation. Also, if uncertainties and biases exist in the input data of our calculations, such as errors in the tomography model and bias on collecting rock samples, those are not properly propagated to the final results.

In order to understand special correlations, we are investigating ~10 cm to ~1 km scale compositional structure, which is usually not discussed in past studies, by systematically collecting rock samples out of a single granite unit. We are also developing a method to evaluate tomography model uncertainties and effects of finite resolutions. For rock sampling biases, statistical methods are being explored to detect the possible bias.

Currently the error of our model prediction is large at ~70%, while the KamLAND geoneutrino observation error has been being reduced and is now at 18%. Depending on the results of the geological correlation structure that we are investigating, we expect that the final model errors could be reduced to a level comparable to the geoneutrino observation errors.

S1-4

Current status of neutrino oscillation tomography of the Earth

Akimichi Taketa[1], Carsten Rott[2]

[1] Earthquake Research Institute, University of Tokyo, Tokyo, Japan (taketa@eri.u-tokyo.ac.jp)
[2] SungKungKwan University, Suwon, Korea

We report the current status of neutrino oscillation tomography.

Next generation large neutrino detectors (Hyper-Kamiokande, IceCube-gen2, ORCA, BIKAL NERPA) are under construction or proposed,and they have capability to measure the average chemical composition of the core and mantle.

The sensitivity estimations of those detector will be reported.The preliminarily result of neutrino oscillation tomography using existing detector is also reported.

S2-1 Invited

Experimental evidence supporting a global melt layer at the base of the Earth's upper mantle

G. Manthilake[1], D. Freitas[1], F. Schiavi[1], J. Chantel[2], N. Bolfan-Casanova[1], M.A. Bouhifd[1], D. Andrault[1]

[1.] Université Clermont Auvergne, CNRS, IRD, OPGC, Laboratoire Magmas et Volcans, F-63000 Clermont-Ferrand, France (geeth.manthilake@uca.fr)

[2.] Department of Earth, Environmental and Planetary Sciences, Case Western Reserve University, Cleveland, OH 44106, USA

The low velocity layer (LVL) atop the 410-km discontinuity has been widely attributed to dehydration melting. In this study, we experimentally reproduced the wadsleyite-to-olivine phase transformation in the upwelling mantle across the 410-km discontinuity and investigated in-situ the sound wave velocity during partial melting of hydrous peridotite. Our seismic velocity model indicates that the globally observed negative Vs anomaly (-4 %) can be explained by a 0.7 % melt fraction in peridotite at the base of the upper mantle. The produced melt is richer in FeO (~ 33 wt. %) and H_2O (~16.5 wt. %) and its density is determined to be 3.56-3.74 g.cm^{-3}. The water content of this gravitationally stable melt in the LVL corresponds to a total water content in the mantle transition zone (MTZ) of 0.22 ± 0.02 wt. %. Such values agree with estimations based on magneto-telluric observations.

S2-2

Determination of Intrinsic Attenuation in the Oceanic Mantle

Nozomu Takeuchi[1], Hitoshi Kawakatsu[1], Hajime Shiobara[1], Takehi Isse[1], Hiroko Sugioka[2], Aki Ito[3], and Hisashi Utada[1]

[1] Earthquake Research Institute, University of Tokyo (takeuchi@eri.u-tokyo.ac.jp)
[2] Graduate School of Science, Kobe University
[3] Japan Agency for Marine-Earth Science and Technology

Quantitative characterization of the physical properties of the oceanic lithosphere-asthenosphere system (LAS) is indispensable to our understanding of plate tectonics. P and S waves traveling through the oceanic LAS are known to have an anomalous feature of long lasting high frequency waves. A large number recordings of the 2011 Tohoku earthquake aftershocks by broadband ocean bottom seismometer arrays deployed in the NW Pacific provided an unprecedented opportunity to quantitatively separate the intrinsic (anelastic) and extrinsic (scattering) attenuation effects on seismic wave propagation in the pure-oceanic paths and to directly infer thermo-mechanical properties of the oceanic LAS.

In this study, we simulated energy transportation of higher frequency seismic waves (~3 Hz) in scattering media and compared the simulated and observed envelopes. The envelopes observed in the NW Pacific are characterized by larger amplitudes especially in S and quasi-exponential amplitude decay with distance. We showed that such features can be explained if and only if we have high intrinsic Q in the lithosphere and low intrinsic Q in the asthenosphere.

The strong intrinsic attenuation in the asthenosphere obtained in this study (~3 Hz) is comparable to that constrained at lower frequency (~100 s) by surface waves and suggests frequency-independent anelasticity, while that in the lithosphere is frequency dependent. This difference in frequency dependence indicates that the strong and broad peak dissipation recently observed in the laboratory exists only in the asthenosphere and sheds new light on what distinguishes the asthenosphere from the lithosphere.

S2-3

The role of dense hydrous magnesium silicates (DHMS) in planet evolution

Christine Houser[1], Cayman Unterborn[2]

[1] Earth-Life Science Institute, Tokyo Institute of Technology (chouser@elsi.jp)
[2] School of Earth and Space Exploration, Arizona State University

As terrestrial planets cool, the stability field of hydrous minerals at high pressure and temperature expands such that terrestrial planets may desiccate with age. We explore scenarios for planets in the neighborhood of Earth in terms of size and composition to determine the fate of surface water as the planet ages. Plate tectonics is the dominant tectonics on Earth and a consistent source of the rock-water chemistry thought to be promote the stability of life. As hydrated oceanic crust and mantle are recycled back into the Earth, a series of dehydration reactions returns most of that water back to the surface. However, under conditions that may exist in the core of the coldest sinking oceanic lithosphere today, Dense Hydrous Magnesium Silicates (DHMS) may be stable into the transition zone and lower mantle. We quantify the extent to which increasing the Mg/Si ratio, cooling the upper mantle, and increasing a planet’s Al content will increase a planet's capacity to draw water down and store it in the mantle based on what is currently known regarding DHMS stability. Once water can be transported into the lower mantle, oceans of water can be efficiently drained within billions of years. For example, using lower bounds of water transport to the mantle for Earth, our surface ocean would drain in 4 billion years.

S2-4

First principles investigation of the vibrational properties of hydrous wadsleyite and hydrous ringwoodite

Jun Tsuchiya[1,2]

[1] Geodynamics Research Center, Ehime University (junt@ehime-u.ac.jp)
[2] Earth-Life Science Institute, Tokyo Institute of Technology

Wadsleyite and ringwoodite are the primary constituent minerals in the Earth's transition zone. Since these minerals are able to retain up to about 3 wt% H_2O in the crystal structures, these phases are known to be the most important water reservoir in the Earth. There have been large numbers of reports about the structure, stability, and physical properties of hydrous wadsleyite and ringwoodite. The vibrational measurements such as FTIR and Raman are the most commonly used for investigating the OH defects in these minerals.

In the case of hydrous wadsleyite, there are major and minor doublets of OH stretching bands, the former exist around 3300 cm^{-1} with $d\nu/dP \sim -10$ cm^{-1} and the latter around 3600 cm^{-1} with almost no pressure dependence. There is a broad consensus that main absorption band is interpreted as the OH stretching modes existing in the M3 vacancy. On the other hand, the minor OH band is not well constrained so far. Since the stable hydrogen defects are usually less mobile in wadsleyite crystal, the determination of minor and metastable hydrogen defects are more important for investigating the transport properties including the electrical conductivity and the deformation properties.

Hydrous ringwoodite, on the other hand, shows very broad OH stretching band around 3200 cm^{-1} at ambient conditions and there is no consensus about the structural explanation of these OH bands nor its high capacity of water storage.

Here I investigated the structural and vibrational properties of hydrous wadsleyite and hydrous ringwoodite using first principles techniques using several different hydrogen defects structures in order to clarify the minor metastable hydrogen positions in wadsleyite and also to shed light on the stability of hydrogen defects in hydrous ringwoodite.

S2-5

He and Ar partitioning between liquid iron and molten silicate under high pressure

Zhihua Xiong[1], Taku Tsuchiya[1]

[1] Geodynamics Research Center, Ehime University, Matsuyama, Japan
(xiong.zhihua.us@ehime-u.ac.jp)

The Earth's core has been suggested as a potential reservoir of noble gases, which can remove the difficulties of their long-term maintenance in the mantle. The fundamental process controlling noble gas sequestering into the core is their partitioning between liquid iron and molten silicate. Unfortunately, limited measurements have only been conducted so far. Experiments conducted by Matsuda et al. [1995] up to 10 GPa showed that the partitioning coefficients of noble gases decrease with pressure, denying the core to be a noble gas reservoir. In contrast, Bouhifd et al. [2013] reported that the helium partitioning coefficient becomes more constant ($\sim10^{-2}$) at P > 10 GPa, suggesting that some helium could be dissolved into the core. However, it is unclear whether this tendency is applicable to other noble gases.

Here we investigate the helium and argon partitioning between liquid iron and molten silicate using the ab initio molecular dynamics method combined with thermodynamics integration technique [Taniuchi and Tsuchiya, 2018]. The partitioning coefficients are computed from the Gibbs free energy changes associated with their exchange reactions. Although more detailed studies on several factors including temperature, pressure, and composition are required, our results in the moment suggest possible partitioning of helium and argon into liquid metal at high pressure. We will try to explain the behaviors from the electronic and structural points of view.

S3-1 Invited

Large volume presses for imaging, tomography and structural analysis at the PSICHE beamline, synchrotron SOLEIL

Nicolas Guignot[1], Geeth Manthilake[2], Eglantine Boulard[3], Andrew King[1], Alisha N. Clark[3,4], Denis Andrault[2], Longjian Xie[5], Daisuke Yamazaki[5], Akira Yoneda[5], Jean-Philippe Perrillat[6], Yann Le Godec[3], Guillaume Morard[3], Alain Prat[7], and Jean-Paul Itié[1]

[1] Synchrotron SOLEIL (guignot@synchrotron-soleil.fr)

[2] Laboratoire Magmas et Volcans, OPGC

[3] IMPMC, Sorbonne Université

[4] Department of Earth and Planetary Sciences Northwestern University Technological Institute

[5] Institute for Planetary Materials, Okayama University

[6] LGLTPE, UCBL Lyon 1

[7] Institut Néel

The PSICHE beamline (synchrotron SOLEIL, France) is focused on the determination of various materials physical properties in-situ at high pressure – high temperature (HP-HT), e.g. thermoelastic properties, viscosity, electrical or thermal conductivity but also phase transitions and structural studies. Imaging, tomography and X-ray diffraction techniques have been specifically designed for large volume presses (Multi-anvil and Paris-Edinburg) operated in white and pink beam modes, focused in the vertical direction for a very high flux or parallel. We present here the different setups and recent experiments and developments to illustrate the possibilities of the beamline.

Our first station is the multi-anvil (MA) apparatus that has proven to be invaluable for experiments where an excellent control over pressure and temperature conditions and a large sample volume are required. Our setup consists of -1/ a 1200 tons load capacity MA press with a (100) DIA compression module - 2/ a CAESAR (combined angle- and energy-dispersive structural analysis and refinement, Wang et al. 2004) XRD setup, which is the ideal tool when accurate structural measurements are required, especially in the case of liquids and amorphous materials -3/ a high resolution imaging system, with framerates up to 2 kHz full-frame and beam sizes up to 10x4 mm2 (HxV). This latter mode is illustrated with recent results obtained on viscosity measurements of forsterite and diopside liquid compositions up to 30 GPa.

The second setup consists of a couple of Paris-Edinburg presses, one with rotational anvils (rotoPEc, Philippe et al. 2016) used to perform full or partial 3D reconstructions of samples at HP-HT conditions. These tools have been used for example to measure the density of liquids and amorphous materials in combination with the CAESAR system. We will also show our very recent efforts to provide a station ready for ultra-fast tomography, opening up the way for time resolved 3D imaging at HP-HT.

References

Y. Wang et al., A new technique for angle-dispersive powder diffraction using an energy-dispersive setup and synchrotron radiation (2004), J. Appl. Cryst., 37, 947–956

J. Philippe et al., Novel portable press for synchrotron time-resolved 3-D micro-imagining under extreme conditions (2016), AIP Conference Proceedings, 1741, 30002

S3-2

High Pressure Generation in a Kawai-type Multianvil Apparatus Equipped with Sintered Diamond Anvils

Daisuke Yamazaki

Okayama University (dy@misasa.okayama-u.ac.jp)

The Kawai-type multianvil apparatus (KMA) has been widely employed to clarify the structure and state of the deep Earth [1]. One of important advantage of the KMA over the diamond anvil cell (DAC) is the capability to compress a large volume sample (>1 mm3) in an octahedral pressure medium under a quasihydrostatic environment owing to squeezing by eight cubic anvils [2]. Moreover, homogeneous and stable heating for sample can be done by adopting an internal heating system, which makes it possible to measure physical and chemical properties of minerals under high pressure and temperature conditions. However, in the conventional KMA, in which tungsten carbide (WC) is used as second stage anvils, the attainable pressure has been limited to ~50 GPa [3]. To extend the pressure range in KMA, the experimental technique for high pressure experiments have been developed using sintered diamond anvil [4].

In this study, the pressure generation tests were conducted in a large volume press (SPEED mk.II) at BL04B1, SPring-8 synchrotron facility. In the experiments, Cr-doped MgO with octahedral edge length of 4.1 mm and BN+TiB_2 which is high transparency for X-ray were used for pressure medium and heater, respectively, for Kawai-type cell assembly. Soft fired pyrophyllite was prepared for gasket. Temperature was monitored by $W_{97\%}Re_{3\%}$-$W_{75\%}Re_{25\%}$ thermocouple whose junction was located in the heater. Before experiment, the sintered starting material of the mixture of $Mg_{0.9}Fe_{0.1}SiO_3$+5wt % Al_2O_3 bridgmanite was prepared. Sample was also mixed with gold in the ration of 1/6 in weight for the standard to estimate the pressure [5] (Tsuchiya, 2003). During compression in the experiments, sample was frequently pre-heated to 800-1100 K at every 5-10 GPa for the relaxation of stress stored in the cell assembly to reduce the probability of "blow out".

The generated pressure finally reached to 120 GPa with press load of 13 MN at an ambient temperature after pre-heating at 800K. Then sample was heated again up to 1673 K to try to observe the phase transition from bridgmanite to post-perovskite. The obtained diffraction pattern under sufficient heating condition was completely indexed as bridgmanite, indicating the stability field of bridgmanite with the composition of $Mg_{0.9}Fe_{0.1}SiO_3$+5wt % Al_2O_3. The present result is consistent with previous study in $MgSiO_3$ (Tateno et. al., 2009) because of a large pressure drop occurred down to 105 GPa in this study. They reported the phase boundary to be 110 GPa at ~1673 K. As a conclusion, the effect of 10 mol % of iron component and 5 wt % of Al_2O_3 is less than 5 GPa on phase boundary shift in pressure.

References

[1] E. Ito, "Theory and practice-multianvil cells and high-pressure experimental methods" Ed: G. Schubert, B. Romanowicz, A. Dziewonski, (Elsevier B.V) pp. 197–230 (2007). [2] N. Kawai and S. Endo, Rev. Sci. Instrum. 4, 425 (1970). [3] T. Kunimoto et al., High Press. Res. 36, 97 (2016). [4] D. Yamazaki et al., Phys. Earth Planet. Inter. 228, 262 (2014). [5] T. Tsuchiya, J. Geophy. Res., 108, 2003JB002446 (2003).

S3-3

High pressure generation up to 24 gigapascals using a D-DIA apparatus combined with jacketed anvils

Tomohiro Ohuchi[1]

[1] Geodynamics Research Center, Ehime Univ. (ohuchi@sci.ehime-u.ac.jp)

Rheological properties of high-pressure polymorphs of olivine are important to understand the cause of seismic anisotropy, viscosity structure, deep-focus earthquakes in the deeper part of the Earth's mantle. Three types of deformation apparatus, namely, the D-DIA type (Wang et al., 2003), the rotational Drickamer apparatus (RDA: Yamazaki and Karato, 2001), and the Kawai-type apparatus for triaxial deformation (KATD: Nishihara, 2008) have been developed to deform high-pressure polymorphs of olivine. Although recent studies by Girard et al. (2015) and Tsujino et al. (2016) succeeded to deform bridgmanite at lower mantle pressures and temperatures using a RDA and a KATD respectively, in-situ D-DIA experiments are still limited to the conditions of lower part of the mantle transition zone (Kawazoe et al., 2016). The main cause disturbing further pressure generation using an in-situ D-DIA apparatus is relatively low toughness of the x-ray transparent anvils made from sintered diamond or cubic BN. In the geometry of cubic-type multianvil apparatus, the available press load needs to be low (usually < 0.6 MN) to avoid the breakage of the x-ray transparent anvils. The advantages of D-DIA apparatus are as follows: i) compatible with acoustic emission monitoring (i.e., many transducers are available) and ii) temperature can be monitored by using a thermocouple. To explore the quantitative deformation experiments at lower mantle conditions, we adopted the 'jacketed' 6-6 type anvils (Yamada et al., 2016) and optimized the cell assembly using preformed gaskets (e.g., Kawazoe et al., 2010). Combining these techniques, I succeeded to generate 24 GPa at room temperatures using a D-DIA apparatus (in the case of truncation edge length = 3 mm). Pressures higher than 20 GPa are also available using the 'jacketed' x-ray transparent anvils. Optimization of the design of 'jacketed' x-ray transparent anvil and cell assembly would lead to quantitative deformation experiments at lower mantle conditions in near future.

S3-4

Some recent progress in synthesis, characterization, and applications of NPD

Tetsuo IRIFUNE[1]

[1] Geodynamics Research Center, Ehime Univ. (irifune@dpc.ehime-u.ac.jp)

We have been working to use ultrahard nano-polycrystalline diamond (NPD) developed by ourselves for advanced studies in deep Earth and related sciences, in collaboration with the GRC members and users of NPD via the PRIUS cooperative research program. Applications to the Kawai-type multianvil apparatus (KMA) using NPD cubes as the second-stage anvils have been limited to about 90 GPa, but its advantages in both higher pressure generation and in situ X-ray observations over the commercially available sintered diamond have been demonstrated. New development of the earlier 6-8-2 system using NPD as the third-stage anvils is currently being pursued for static generation of multi-megabar regime in the KMA.

In addition to the very successful applications to X-ray absorption studies under pressure using the polycrystalline nature of NPD, new technologies in diamond anvil cell (DAC) have been developed. These include rotational DAC for deformation studies, double-stage DAC for higher pressure generation, large DAC for neutron diffraction and X-ray Raman studies, electrode-deposited DAC for electric resistance measurements, a mortar-pestle system for crushing ultrahard materials, etc.

Synthesis of NPD with various grain size and fine structures has also been attempted by using different types of carbon sources and varying pressure and temperature conditions in KMA. Some mechanical tests, such as elastic properties and strength, have also been made on such NPD samples. Preliminary results on synthesis of the NPD samples with various grain sizes and their compressional behaviours will be reported in this talk.

S4-1

Advancements in Ab Initio Mineral Physics

Taku Tsuchiya[1]

[1] Geodynamics Research Center, Ehime University (tsuchiya.taku.mg@ehime-u.ac.jp)

Recent progress in theoretical mineral physics (TMP) based on the density functional quantum mechanical theory has been dramatic in conjunction with the advancement of computer technologies. It is now possible to predict high-*P*,*T* equation of state, phase stability, and thermoelasticity of complex minerals quantitatively with uncertainties that are comparable to or even smaller than those attached in experimental data. The technique is now routinely applied not only for theoretical backup to experiments but also for guide to experiments [1]. Our next grand challenges include new technical developments for high-*P*,*T* thermochemical properties, such as elemental partitioning of both solid and liquid phases [2], and transport properties, such as thermal/electrical conductivity [3,4], and atomic diffusivity [5], within both usual and correlated systems. Chemical partitioning, which we can access using the ab initio thermodynamic integration molecular dynamics method [6], allows us to link mineral physics to geochemistry. lattice thermal conductivity, which is calculated based on the harmonic and anharmonic lattice dynamics theories and Boltzmann's transport equation, is on the other hand a key to clarifying thermal properties of the deep mantle and core. In this talk I will report recent activities in the Ehime Univ. TMP group.

[1] M. Nishi, Y. Kuwayama, J. Tsuchiya, T. Tsuchiya, Nature 547, 205 (2017)
[2] Z. Xiong, T. Tsuchiya, T. Taniuchi, under review
[3] H. Dekura, T. Tsuchiya, Phys. Rev. B 95, 184303 (2017).
[4] S. Ohmura, T. Tsuchiya, H. Ichikawa, under review
[5] S. Ritterbex, T. Harada, T. Tsuchiya, Icarus 305, 350 (2018)
[6] T. Taniuchi, T. Tsuchiya, J. Phys. Cond. Mat. 30, 114003 (2018)

S4-2

The role of minor elements in conductivity of mantle and core materials: new results in 2017

Kenji Ohta[1]

[1] Department of Earth and Planetary Sciences, Tokyo Institute of Technology
(k-ohta@geo.titech.ac.jp)

Knowledge about transport properties of Earth-forming minerals is important to understand the evolution and the dynamics of solid Earth. State-of-the-art high-pressure techniques enable us to replicate the Earth's internal conditions, and to reveal various physical properties of minerals at the conditions of the Earth’s interior. In this fiscal year, we mainly performed the following three studies: (1) Lattice thermal conductivity measurements on hydrous wadsleyite and ringwoodite at the pressures corresponding to the mantle transition zone, (2) Thermal conductivity measurements on Fe, Al-bearing bridgmanite and (Mg,Fe)O at the lower mantle pressures, (3) Electrical resistivity measurements on Fe-Si-S alloy and Fe-H alloy. These experimental studies revealed the role of minor elements (hydrogen, iron, aluminum, and sulfur) in the electrical and thermal conductivity of mantle and core materials under high pressure, which would provide for more reliable estimates of electrical and thermal conductivity of deep Earth.

S4-3

Crystallographic-preferred orientation of $MnGeO_3$ perovskite

Yu Nishihara[1], Simon Hunt[2], David Dobson[2], and Yuji Higo[3]

[1] Geodynamics Research Center, Ehime University, GRC (yunishi@sci.ehime-u.ac.jp)
[2] University College London
[3] Japan Synchrotron Radiation Research Institute

Efficiency of material and heat transport in the Earth is largely influenced by flow pattern in the mantle. Flow direction at around the 660 km discontinuity is one of the key to understand the flow pattern of the whole mantle. Recently, Tsujino et al. (2016) determined shear induced crystallographic-preferred orientation (CPO) of $(Mg,Fe)SiO_3$ bridgmanite (Brd), which is the most abundant mineral in the lower mantle, based on high-pressure and high-temperature deformation experiments. They showed that seismic anisotropy in the uppermost lower mantle near subducting slab is reasonably explained by horizontal flow of mantle material. However, Tsujino et al.'s (2016) study consists of very limited number of experimental data due to difficulty in conducting experiments under the lower mantle pressure and temperature condition, and further studies are desirable to assess their conclusion. In this study, we have conducted high-pressure and high-temperature deformation experiments on $MnGeO_3$-perovskite (Pv) which is an analog material of Brd and determined its deformation-induced CPO.

A sintered aggregate of $MnGeO_3$-Pv was synthesized from $MnGeO_3$-Opx and adopted as a starting material of deformation experiments. Deformation experiments were conducted using D111-type deformation device installed at PF-AR, KEK and DT-Cup at UCL. The DT-Cup, developed by Hunt et al. (2014), is a modified Kawai-type multi-anvil apparatus by which well-controlled deformation experiments at pressures higher than 15 GPa can be conducted by driving two second-stage anvils using differential actuators. The D111-type apparatus is an improved version of DT-Cup which can be used under higher press load. Pressure and temperature conditions of experiments were 16 GPa and 1200-1300ºC, and strain rates were $4.5-13.9 \times 10^{-5}$ s^{-1} in shear deformation and 3.7×10^{-5} s^{-1} in uniaxial compression. The CPO of recovered samples were determined using MAUD software by analyzing 2-dimensional diffraction pattern taken with monochromatic X-ray (50 keV) at SPring-8, BL04B1.

Three recovered samples from shear deformation experiments consistently showed CPO pattern with [010] aligned parallel to shear direction, and [100] and [001] weakly aligned sub-parallel to shear plane normal. In a uniaxial compression experiment, [100] strongly aligned parallel to compression direction. These results suggest that dominant slip system of $MnGeO_3$-Pv is [010](100) under the studied conditions. This slip system differs from the dominant slip system of Brd reported by Tsujino et al. (2016), [001](100), whereas Ferre et al. (2007) reported that [010](100) is one of the easiest slip system in $MgSiO_3$-Pv based on first principles calculation. If [010](100) is assumed to be the dominant slip system in Brd, the resultant seismic anisotropy for V_P and V_S is almost identical to that for the [001](100) dominant case. Therefore, present results also suggest predominance of horizontal flow in the uppermost lower mantle near subducting slab as Tsujino et al. (2016) concluded.

Hunt et al. (2014) Rev. Sci. Inst., 85, 085103.
Tsujino et al. (2016) Nature, 539, 81-84.

S4-4

Incorporation of nitrogen into the lower-mantle minerals under high pressure and high temperature

Ko Fukuyama[1], *Hiroyuki Kagi[1], Toru Inoue[2,3], Toru Shinmei[3], Sho Kakizawa[3],
Naoto Takahata[4], Yuji Sano[4] (*presenting author)
[1] Geochemical Research Center, Graduate School of Science, The University of Tokyo
(ko.fukuyama@eqchem.s.u-tokyo.ac.jp)
[2] Department of Earth and Planetary Systems Science, Hiroshima University
[3] Geodynamics Research Center, Ehime University
[4] Atmosphere and Ocean Research Institute, The University of Tokyo

Nitrogen occupies about 80% of the Earth 's atmosphere and it is suggested that nitrogen had an impact on the climate in the early Earth (e.g. Goldblatt et al., 2009). Thus, nitrogen is a very important volatile element in discussing the early Earth evolution process and origin of the life. However, we still cannot fully understand the behavior of nitrogen especially in the deep Earth. For example, nitrogen is depleted compared to other volatile elements in deep mantle (Marty et al., 2012). This is so-called "Missing" nitrogen, which is an important subject in earth science.

In this study, we compared nitrogen incorporation into lower-mantle minerals (bridgmanite, periclase and stishovite) by high-temperature high-pressure experiment using multi-anvil apparatus installed at Geodynamics Research Center, Ehime University under the conditions of 27 GPa and 1600℃-1900℃. In these experiments, we used Fe-FeO buffer in order to reproduce the redox state of the lower mantle. Two types of starting materials: a powder mixture of SiO_2 (quartz) and MgO and a powder mixture of SiO_2, MgO, Al_2O_3 and $Mg(OH)_2$ were used for starting materials. Nitrogen in recovered samples was analyzed using NanoSIMS installed at Atmosphere and Ocean Research Institute.

A series of experimental results revealed that stishovite and periclase can incorporate more nitrogen than bridgmanite. This suggests that periclase, the major mineral in the lower mantle, may be a nitrogen reservoir. Furthermore, the results suggest that stishovite, which is formed by the transition of the SiO_2-rich oceanic crustal sedimentary rocks transported to the lower mantle via subducting slabs, can incorporate more nitrogen than bridgmanite (20 ppm nitrogen solubility reported by Yoshioka et al. (2016)). Our study suggests that nitrogen would continue to be supplied to the lower mantle via subducting slabs since approximate 4 billion years ago when the plate tectonics had begun, forming a “Hidden” nitrogen reservoir in the lower mantle.

S5-1 Invited

Terrestrial magma ocean origin of the Moon

Shun-ichiro Karato1, Natsuki Hosono[2], , Junichiro Makino[3], and Takayuki R. Saitoh[4]

[1] Yale University, Department of Geology & Geophysics (shun-ichiro.karato@yale.edu)
[2] JAMSTEC
[3] RIKEN
[4] ELSI, Tokyo Institute of Technology

Any viable model for the origin of the Moon must explain both the chemical and mechanical characteristics of the Earth-Moon system. The classic model of oblique giant impact explains the large angular momentum and the lack of a large Fe-rich core in the Moon, but it is difficult to explain the similarity in the isotopic compositions without violating the angular momentum constraint. In most of previous studies, they tried to solve this dilemma by modifying the mechanical conditions of collision. However, these models did not give satisfactory explanation because they could explain both chemical and mechanical aspects of the Moon-Earth system only in a very small fraction of the parameter space, and in many cases, the validity of the models for the angular momentum has been questioned. Moreover, none of the previous models explain a higher FeO content of the Moon than Earth. Furthermore, in all previous models, they used a numerical method (SPH (Smoothed Particle Hydrodynamics)) that contains a serious physical problem in treating a density discontinuity.

In this study, we propose a new model to explain both chemical and mechanical aspects of the Moon-Earth system using (i) a new equation of state of silicate melts, and (ii) a modified SPH code where a density discontinuity can be treated correctly. A key to this model is an assumption that the proto-Earth to which a giant impact occurred was covered by a magma ocean. Since the melts and the solids follow completely different equation of state (Jing and Karato, 2011), the degree of heating is much higher for melts and as a consequence, a majority of the materials ejected by a giant impact to form the Moon is from the magma ocean of the proto-Earth. This model provides a natural explanation of the similarities in the isotopic composition and the difference in FeO content between the Moon and Earth with the angular momentum constraint being satisfied.

S5-2

Zr isotope constraints on early Earth differentiation

Tsuyoshi Iizuka[1], Keita Itano[1], and Shinji Yamamoto[2]

[1] University of Tokyo (iizuka@eps.s.u-tokyo.ac.jp)
[2]Yokohama National University

The radionuclide ^{92}Nb decays to ^{92}Zr with a half-life of 37 Ma [1]. Because Nb and Zr can fractionate from each other during partial melting of the mantle and mineral crystallization as well as metal-silicate differentiation, Nb-Zr isotope systematics can potentially place chronological constraints on early planetary differentiation. Considering the initial abundance of 92Nb in the solar system (^{92}Nb/^{93}Nb = 1.7 $\times 10^{-5}$), yet, the possible Zr isotopic variation on the Earth would be highly restricted [2]. For instance, even a 4.53 Ga reservoir having a Nb/Zr ratio four times higher than that of CHUR is expected to display a ^{92}Zr anomaly of only +10 ppm. Such reservoir with an elevated Nb/Zr ratio might be formed if Fe-Ti oxide and sulfide minerals presented as a liquidus phase during differentiation on the infant Earth.

Here we report our search for a Zr isotopic vestige of early Earth differentiation using ancient terrestrial zircons. Zirconium isotopic ratios in single zircon grains were measured using MC-ICP-MS with the desolvating nebulization technique, which allows us to achieve analytical precision of ±<10 ppm. So far, the high-precision Zr isotopic analysis has been applied to detrital zircons with ages up to 4.3 Ga from the Jack Hills in the Yilgarn Craton, Western Australia and igneous zircons from the 4.0–3.6 Ga orthogneisses in the Acasta Gneiss Complex, northwestern Canada. These Acasta rock samples were previously studied for zircon Lu–Hf isotope systematics and the results indicated that their magmatic sources contained Hadean crustal components [3]. Our Zr isotopic data for the Jack Hills and Acasta zircons display no resovable ^{92}Zr anomalies at the level of analytical precision. By combining the Hf isotopic data for these zircon grain, we indicate the development of a 4.5 Ga enriched reservoir on the Earth that had a Lu/Hf of 0.07 and a Nb/Zr less than 0.4. Such reservoir could form via fractional crystallization processes within the shallow or upper mantle.

[1] Holden (1990) Pure Appl. Chem. 62, 941–958. [2] Iizuka et al. (2016) Earth Planet. Sci. Lett. 439, 172–181. [3] Iizuka et al. (2009) Chem. Geol. 259, 230–239.

S5-3

Physical properties of volatile-bearing magmas in the Earth's deep interior

Akio SUZUKI

Department of Earth Science, Graduate School of Science, Tohoku University
(akio.suzuki.c5@tohoku.ac.jp)

Viscosity of magma is an important property, which controls the mobility in the Earth's interior. Therefore, it is important to measure the viscosity of silicate melt at high pressure. Magma is formed by melting of rocks. To reduce the melting temperature of rocks, the volatile components such as H_2O and CO_2 are necessary. Therefore, we investigated the effect of volatile components on the viscosity of magma at high pressure. The viscosity was measured by the falling sphere method using the synchrotron X-ray radiography. Cell assembly and experimental techniques have been described elsewhere (e.g., Suzuki et al., 2002 PCM).

The structure of magma (silicate melt) is characterized by the network of TO_4-terrahedra (T is the network forming cation such as Si and Al). This study shows that the viscosity of polymerized melts is significantly reduced by the volatile component at high pressure. However, we observed that the effect of H_2O and CO_2 on the viscosity of depolymerized melts was very small. Recently, Sakamaki (2017) suggested that the density of melt at deep interior was little reduced by volatile components. Melting experiments have shown that the composition of melts formed by the melting of mantle rocks become basic to ultrabasic with increasing pressure. The structure of such melts is depolymerizd. We have shown that the viscosity of depolymerized melts increased with increasing pressure. Although the melting temperature of rocks is reduced by the volatile elements at high pressure, the density and the viscosity of melt is not reduced. Therefore, it is implied that the mobility of magma in the deep Earth's interior is not affected by volatile components.

S5-4

Origin of geochemical mantle components: Role of spreading ridge, subduction zone, and thermal evolution of mantle

Jun-Ichi Kimura[1], James B. Gill[2], Peter E. van Keken[3], Susanne Skora[4], Hiroshi Kawabata[5]

[1] Dept. Solid Earth Geochemistry, JAMSTEC (jkimura@jamstec.go.jp)

[2] Dept. Earth and Planetary Sciences, UC Santa Cruz

[3] D.T.M., Carnegie Institution for Science

[4] Institute of Geochemistry and Petrology, ETH Zurich

[5] Research and Education Faculty, Kochi University

We explore the element redistribution at mid-ocean ridges (MOR) and subduction zones (SZ) using a numerical model to evaluate the roles of decompression melting at MOR and fluxed melting at SZ of the mantle in Earth's geochemical cycle, with focus on the formation of the depleted and enriched mantle components. Our model uses a trace element mass balance based on an internally consistent thermodynamic-petrologic computation to explain the composition of MOR basalt (MORB) and SZ magmas and their residual mantles and slab components. Model results for MORB-like basalts from 3.5 to 0 Ga indicate a high mantle potential temperature (Tp) of 1650–1500°C during 3.5–1.5 Ga before decreasing gradually to ~1300°C today. The source mantle composition changed from primitive (PM) to depleted as Tp decreased, but this source mantle is variable with an early depleted reservoir (EDR) mantle periodically present. We examine a two-stage Sr-Nd-Hf-Pb isotopic evolution of mantle residues from melting of PM or EDR at MORs. At high-Tp (3.5–1.5 Ga), the MOR process formed extremely depleted DMM. This event coincided with formation of the majority of the continental crust (CC), the sub-continental lithospheric mantle (SCLM), and the enriched mantle components EM1, EM2, and HIMU formed from the slab components at the Archean to early Proterozoic high-Tp SZs and stored in the lowermost mantle now found in ocean island basalts (OIBs) through plume upwelling. During cooler mantle conditions (1.5–0 Ga), the MOR process formed most of the modern ocean basin DMM. Changes in the mode of mantle convection from vigorous deep mantle recharge before ~1.5 Ga to less vigorous afterwards is suggested to explain the thermochemical mantle evolution. These EM and DM components appear to form large domains forming N-S hemispheric lower mantle EM and E-W hemispheric upper mantle DM structures, respectively. Mantle convection appears to be sluggish for these mantle components perhaps due to density stratification of the source materials.

S6-1 Invited

Earth's Correlation Wavefield and new Insights on Structure and Dynamics of the Inner Core

Hrvoje Tkalčić

[1] Research School of Earth Sciences, The Australian National University

(Hrvoje.Tkalcic@anu.edu.a)

We have recently obtained new insights on the Earth's correlation wavefield using the coda of globally recorded large earthquakes, through stacking the cross-correlation of multiple pairs of waveforms. Our method revealed many of the apparent seismic phases sampling the Earth's core that have not previously been observed in either traditional earthquake seismology or previous cross-correlation studies. Some of these seismic phases resemble multiple reverberations through the Earth's core, however we show that they do not correspond to Green's functions, as previously assumed. We propose a principle that explains both apparent arrivals comparable to those expected in the regular seismic wavefield and the previously unobserved and unexplained phases in the correlation wavefield. This insight into the mechanism producing Earth's correlation wavefield has far reaching implications for seismology of the Earth's core since it provides a new view of the seismic wavefield and allows efficient extraction of seismic signals that might lie below the typical noise level in conventional earthquake seismology.

One such signal is the Holy Grail of global observational seismology, the PKJKP waves or shear waves through the Earth's inner core. The observation of shear waves would provide constraints on the rigidity, and more generally, structure and dynamics of the Earth's inner core. I will present the most recent results on Earth's correlation wavefield and report on the search for shear waves in the inner core.

S6-2

Ab-initio study of iron diffusion properties in Earth's inner core

[1]Sebastian Ritterbex and [1]Taku Tsuchiya

[1]Geodynamics Research Center, Ehime University, 2-5 Bunkyo-cho, Matsuyama 790-8577, Japan (ritterbex.sebastian_arthur_willem.us@ehime-u.ac.jp)

Seismic observations provide evidence that the Earth's inner core exhibits global anisotropy (Tanaka and Hamaguchi, 1997; Creager, 1999). This anisotropy is thought to result from the collective alignment of crystals and suggests that the inner core may be subject to plastic deformation. The plastic properties of the inner core are therefore believed to be of paramount importance for understanding inner core dynamics and core evolution.

Under high pressure conditions in the deep Earth, plastic deformation is likely to be governed by diffusion of point defects which may control many mechanisms of plastic deformation including dislocation creep via climb. Understanding the mechanisms of (anisotropic) atomic diffusion is therefore important to gain insight into the creep processes in Earth's inner core.

The inner core is expected to be composed of a solid iron-nickel alloy with some unknown light elements (Mao *et al*., 1998). Using *ab-initio* calculations, we study vacancy diffusion in hcp, bcc and fcc iron at pressure conditions up to the Earth's inner core. Our results demonstrate that pressure suppresses defect concentration but does not strongly affect defect mobilities. We found that some light elements, particularly hydrogen, influence metallic bonding and enhance atomic diffusion. This allows for extrinsic deformation mechanisms in iron at inner core conditions. Here, we will discuss on the diffusion properties of the inner core iron alloy.

S6-3

Local strong slow S-wave anomalies at western edge of Pacific LLSVP in the lowermost mantle

Masayuki Obayashi[1], Fenglin Niu[2], and Junko Yoshimitsu[1]

[1] JAMSTEC (obayashi@jamstec.go.jp)
[2] Rice University

Seismic tomography studies have revealed two broad slow shear-wave speed anomalies regions beneath the Pacific and Africa called as LLSVPs (Large Low Seismic Velocity Provinces). There are geographic correlations between the LLSVPs and hotspots, and the LLSVPs could probably play an important role for convection throughout the mantle and thermal structure and evolution of the earth. The LLSVPs have been considered to be heterogeneous in composition since the boundaries between the normal mantle are sharp. To investigate the details of the sharp LLSVP edge we measure ScS–S and SKS–S differential traveltimes in the hypocentral distance of about 60° –90° using Japanese and Chinese seismic networks. We use

We found anomalously large (more than 5 sec) ScS –S travel times accompanying normal SKS –S travel times, suggesting local strong slow region in the vicinity of the ScS bounce points (red circles in Figure 1). Such ScS bounce points locate to the northeast of New Guinea Island extending over 20 degrees in NE-SW direction. However below New Guinea Island, both ScS –S and SKS –S travel times are normal (green circles in Figure 1), indicating abrupt end of the local strong slow anomalies.

We obtained 3750 event-station pairs of ScS –S and 1500 pairs of SKS –S differential travel times and inverted them for lowermost mantle S-wave speed structure. The result shows very strong slow anomalies of more than 5% at western edge of Pacific LLSVP that extend vertically not more than 200 km from the core mantle boundary.

S6-4

Mobile broadband seismic observation in Thailand: Its present state and preliminary results

S. Tanaka[1], W. Siripunvaraporn[2], S. Boonchaisuk[2], S. Noisagool[2], K. Kawai[3], Y. Suzuki[3], Y. Ishihara[1], T. Kim[1], K. Miyakawa[4], N. Takeuchi[4], and H. Kawakatsu[4]

[1] JAMSTEC (stan@jamstec.go.jp)

[2] Faculty of Science, Mahidol Univ.

[3] School of Science, Univ. Tokyo

[4] Earthquake Research Institute, Univ. Tokyo

Thailand is located in an important area to explore deep Earth structure as well as to understand tectonics of the Indochina peninsula. However, the number of broadband seismic stations was not enough to address these issues. Thus, we have conducted a mobile broadband seismic observation in Thailand, named Thai Seismic Array (TSAR), under the support of MEXT Kakenhi, Grant-In-Aid for an innovative area "Core-mantle co-evolution" (2015-2019).

In the period from November 2016 to February 2017, we deployed 40 stations that consisted of 34 CMG-3Ts, 6 STS-2s for broadband seismometers, 40 RT130s for data loggers, whose electric powers were supplied by solar panels and batteries. Although, after the maintenance in February 2018, the number of the station working with full functions are reduced to be only 22 due to water invasion, machine troubles, damages by creatures and human errors, we have succeeded to record valuable seismic records.

Here I show preliminary results on SKS splitting and S-wave velocity structure in the lowermost mantle beneath the southwestern Pacific.

S7-3

Melting experiments on Fe–Si–S alloys to core pressures

Shigehiko Tateno[1], Kei Hirose[1,2], Ryosuke Sinmyo[1,2], and Guillaume Morard[3]

[1] Earth-Life Science Institute, Tokyo Institute of Technology (tateno@elsi.jp)

[2] Department of Earth and Planetary Science, The University of Tokyo

[3] Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, Sorbonne Universités

Melting and subsolidus experiments were carried out on Fe–Si–S alloys (2.2–2.7 wt% Si + 2.0–2.1 wt% S) up to 146 GPa in a laser-heated diamond-anvil cell (DAC). The melting and subsolidus phase relations were examined on the basis of in-situ synchrotron X-ray diffraction measurements and ex-situ textural and chemical characterizations of recovered samples. The subsolidus phase assemblage changed from Fe-rich hexagonal closed-packed (hcp) phase + Fe_3S into a single phase of hcp Fe–Si–S alloy above 80 GPa at ~2500 K. The melting curve was obtained on the basis of the appearance of diffuse X-ray scattering and/or melting texture found in the cross section of a recovered sample. Microprobe analyses of quenched molten samples showed that liquid Fe–Si–S coexisted with Fe-alloy solid being depleted in sulfur but enriched in silicon compared to the liquid. This indicates that the liquid evolves toward a Si-poor and S-rich composition upon crystallization. Our data further suggest that the ternary eutectic liquid composition is Si-deficient and close to the tie line between the eutectic points in the Fe–Si and Fe–S binary systems at each pressure. The composition of Fe–Si–S liquid that accounts for the outer core density is outside the liquidus field of solid Fe at the inner core boundary (ICB) pressure. Accordingly, the solid alloy crystallizing from such outer core liquid must be more enriched in silicon/sulfur than the coexisting liquid and thus cannot form the denser inner core required from seismic observations. Furthermore, liquid Fe–Si–C nor Fe–Si–O does not crystallize a denser solid at the ICB.These reinforce the conclusion that silicon is not an important light element in the core.

S7-1 Invited

Computational models of magnetic field generation in the Earth

Andrew Jackson[1], Kuan Li[1], Andrey Sheyko[1], Philip Livermore[2], Chris Finlay[3]

[1] Institute for Geophysics, ETH Zurich (ajackson@ethz.ch)

[2] School of Earth & Environment, University of Leeds

[3] National Space Institute, Danish Technical University

Earth's magnetic field is generated by fluid motion in the outer core by a process termed self-exciting dynamo action. In this process, electrically conducting fluid flows through a magnetic field, inducing electrical currents that reinforce the original magnetic field. The driving force for this is thought to be thermal convection.

This process can be simulated on the computer in a self-consistent way, albeit in a parameter regime that is somewhat distant from planetary settings. In particular, the values of viscosity used are too large, and the prospects for reducing these viscosities to more appropriate values are remote. Despite this, the approach has met with great success and has demonstrated that magnetic fields can be generated in this way. Many features are quite Earth-like, most likely because the magnetic Reynolds number (the ratio of magnetic induction to magnetic diffusion) is in the correct regime. We will contrast conventional models with a different approach in which both inertia and viscosity are omitted from the equations at the outset. This approach, whilst in its infancy, holds the promise of providing complementary models of planetary magnetic field generation.

S7-2

On penetration of compositional convection into a thermally stable stratified layer in the outer core of the Earth

Youhei Sasaki[1], Shin-ichi Takehiro[2]

[1] Department of Mathematics, Kyoto University (uwabami@gfd-dennou.org)
[2] Research Institute for Mathematical Sciences, Kyoto University

It is suggested from recent high-pressure experiments and first principle calculations that the values of thermal conductivity under conditions of planetary cores are larger than those considered so far. By using 1-dimensional thermal balance models with the updated values of thermal conductivity, generation and existence of a stably stratified layer at the upper part of the Earth's outer core is discussed. However, mixing effect by compositional convection driven by light element release at the inner core boundary is not considered. It is an important hydrodynamic issue for determining structure of the outer core, whether compositional convection erodes and destroy the stable layer or not.

In this study, numerical experiments of two-components Boussinesq fluid system where a light element is injected from the bottom of a thermally stable layer are performed, and development and penetration height of compositional convection is observed.

We propose distribution of power induced by thermal and compositional buoyancy (rate of kinetic energy production) as a measure of occurrence of thermal and compositional convection. The power consists of the terms proportional to heat flux and compositional flux. The region with positive power is considered that convection is active there because kinetic energy can be produced by buoyancy force. On the other hand, in the region with negative power convection is suppressed and stably stratified layer may be produced. Numerical results show that the heights of developed compositional convection are well explained by positive kinetic energy production regions on the assumption that the whole layer is mixed up with convection.

S7-4

Melting of iron to 290 gigapascals

Ryosuke Sinmyo[1,2], Kei Hirose[1,2], and Yasuo Ohishi[3]

[1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan. (sinmyo@eps.s.u-tokyo.ac.jp)
[2]Earth-Life Science Institute, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8550, Japan.
[3]Japan Synchrotron Radiation Research Institute, 1-1-1 Koto, Sayo, Hyogo 679-5198, Japan.

The Earth's core is composed mainly of iron. Since liquid core coexists with solid core at the inner core boundary (ICB), the melting point of iron at 330 gigapascals offers a key constraint on core temperatures. However, previous results using a laser-heated diamond-anvil cell (DAC) have been largely inconsistent with each other, likely because of an intrinsic large temperature gradient and its temporal fluctuation. Here we employed an internal-resistance-heated DAC and determined the melting temperature of pure iron up to 290 gigapascals, the highest ever in static compression experiments. A small extrapolation indicates a melting point of 5500 ± 80 kelvin at the ICB, about 500–1000 degrees lower than earlier shock-compression data. It suggests the upper bound for the temperature at the core–mantle boundary (CMB) to be 3760 ± 180 K. Such present-day CMB temperature combined with the recently-proposed nominal core cooling rate suggests that the lowermost mantle was no longer globally molten, at least in the early Proterozoic Eon, consistent with the recycling of subducted crustal materials originally formed more than 1.5 Gyr ago.

S7-5

Core isotopic flavors in OIB, without core entrainment

John Hernlund[1], Scott Hull[2], Irene Bonati[1], Steve Desch[3]

[1] Earth-Life Science Institute, Tokyo Institute of Technology (hernlund@gmail.com)
[2] School of Earth Sciences, Ohio State University, USA
[3] School of Earth and Space Exploration, Arizona State University, USA

Recent advances in geochemical analysis are better revealing isotopic variations in ocean island basalt (OIB) sources, including relative depletions in $^{182}W/^{184}W$, $^{4}He/^{3}He$, and D/H. While the possibility that these reflect primordial unmixed heterogeneities in the mantle has generated some excitement in the community, such features might easily be explained by core isotopic contamination of the mantle at the core-mantle boundary (CMB). However, lacking a strong coupled enhancement in siderophile element abundance, the possibility of core entrainment directly into the deep mantle has been rejected (e.g., Mundl et al., 2017). On the other hand, several physical processes have been proposed that do not involve entrainment of excess metal into upwelling plumes but still permit ample contamination of the basal mantle by core isotopic flavors. These include: (1) core fluid intrusion via grain-scale decompaction at CMB topographic lows (Kanda & Stevenson, 2006) followed by compaction and expulsion of fluids, (2) upward sedimentation and viscous compaction of solids crystallized in the outer core (Buffett et al., 2000), (3) interaction between a liquid basal magma ocean (BMO) and the top of the core and subsequent accumulation of residues in the CMB region (Labrosse et al., 2007). Mechanism (1) involves ongoing interactions of the lowermost ~1 km of the mantle, the timing and volume of crystals produced by mechanism (2) is highly uncertain but could be ongoing today in the form of SiO_2 crystallization (Hirose et al., 2017), while a BMO mechanism (3) allows for the largest volumes of mantle to be contaminated although the interaction would have been greatest in the early Earth. In any case, it could be that all 3 mechanisms (and others we do not know about) are responsible for imparting a core isotopic flavor to the mantle, but without associated entrainment of excess metal into mantle plumes.

S8-1 Invited

Shaping mantle volatile concentrations through early heterogeneities and long-term cycling

Sujoy Mukhopadhyay[1], Curtis D. Williams[1], Rita Parai[2]

[1] Dept. of Earth and Planetary Sciences, UC Davis, CA 95616, USA (sujoy@ucdavis.edu)
[2] Dept. of Earth and Planetary Sciences, Washington Univ. in St. Louis, St Louis, MO 63105, USA

The origin and incorporation of volatiles within planetary interiors is of fundamental importance in understanding the formation and evolution of terrestrial planets. We will show that high precision neon isotopic measurements in mantle plumes document the presence of nebular gases in the present day deep mantle. Neon isotopic composition of mantle-derived basalts, along with ratios of primordial argon to neon and primordial xenon to neon, indicate that mantle noble gases are a two-component mixture of nebular and chondritic gases. While mantle neon is dominated by the nebular component, primordial argon and xenon are dominated by the chondritic component. The nebular component, best preserved in the neon isotopic ratios, is present in significantly higher proportion in the deep mantle plume source compared to the shallower MORB source. The preservation of distinct reservoirs of primordial noble gases in the present day mantle signifies limited interaction between the plume and MORB sources since Earth's accretion and place constraints on long-term mixing of the mantle.

While some fraction of the chondritic volatiles was introduced into the mantle during accretion, a substantial fraction of the present day inventory is dominated by subduction of chondritic surface volatiles. We will show that the evolving xenon isotopic composition of the atmospheric over the Hadean and Archean can be utilized as a constraint on the timing of initiation of recycling of atmospheric noble gases into the mantle, particularly Xe and water. Forward modeling mantle processing and crust formation rates with the change in atmospheric xenon isotopic composition suggests significant recycling of atmospheric Xe into the deep Earth could not have occurred prior to ~2.5 Ga. Since Xe recycling into the mantle is associated with hydrous phases, water was also not recycled in significant quantities into the Earth's interior prior to the Proterozoic.

S8-2

Nano-mole sulfur, carbon and oxygen isotope measurement system using IRMS MAT-253 for high pressure experiment run products

M. Satsh-Kumar[1], Shinnosuke Aoyama [1], and Miyako Abe[2]

[1] Faculty of Science, Niigata University (Email: satish@geo.sc.niigata-u.ac.jp)

[2] Graduate school of Science and Technology, Niigata University

Geophysical studies and high pressure experimental results have suggested that the Earth's core should contain light elements such as hydrogen, carbon, oxygen, sulfur, or silicon. One potential tool to understand the content of light element in core is the application of mass balance computations on elemental concentration as well as isotopic composition (Wood et al., 2013). Recent studies have suggested the presence of isotope fractionation at high temperature and high-pressure conditions, especially in magma ocean environment and core segregation (e.g., Satish-Kumar et al., 2011; Shahar et al., 2016; Labidi et al., 2016). In order to understand the light element isotope fractionation processes in the deep earth, it is necessary to measure the isotope composition accurately in micro to nano mole scales, because the high pressure experimental run products are small in volume.

At Niigata University, MAT-253 mass spectrometer (Thermo Fisher Scientific) was installed through the MEXT Grant-in-Aid for Scientific Research on Innovative Areas. Carbon and oxygen isotopic composition are measured using CO_2 and sulfur isotopic composition are measured using SF_6 gas. A new micro-volume inlet system was installed and fundamental parameters such as pressure effect and capillary flow effect were tested. Using the micro-volume inlet system the minimum volume required for analysis is 1 micro mole sample gas, and the precession for carbon, oxygen and sulfur isotopic composition are better than 0.1 ‰.

Multiple sulfur isotope measurement system consists of; 1) curie point pyrolyzer for rapid conversion of small volume samples to SF_6 gas (Ueno et al., 2015), 2) gas chromatograph for purifying the SF_6 gas and 3) micro-volume inlet system for introduction of sample gas to ionization chamber. Initial measurements on small volume samples gave precession better that 0.1‰ for both $\delta^{34}S$ and $\delta^{33}S$. However, $\delta^{36}S$ has large errors due to possible contamination by hydrocarbons. Experiments are now being carried out with better vacuum conditions and higher purity carrier gas for refining the precision of $\delta^{36}S$. Sulfur-bearing samples from experimental run products as well as natural samples will be measured for multiple sulfur isotopes for understanding the presence of mass dependent and independent fractionation in mantle reservoirs and possible isotope exchange during core-mantle interaction.

References

Labidi, J., Shahar, A., Le Losq, C., Hillgren, V.J., Mysen, B.O., & Farquhar, J. (2016). Geochimica et Cosmochimica Acta, 175, 181–194.

Satish-Kumar M, So H, Yoshino T, Kato M, Hiroi Y (2011) Earth and Planetary Science Letters, 310, 340-348.

Shahar, A., Schauble, E. A., Caracas, R., Gleason, A. E., Reagan, M. M., Xiao, Y., Shu, J. & Mao, W. (2016) Science 352 (6285), 580-582.

Wood, B.J., Li, J., & Shahar, A., (2013) Reviews in Mineralogy & Geochemistry, 75, 231-250.

Ueno, Y., Aoyama, S., Endo, Y., Matsu'ura, F., Foriel, J., 2015. Chemical Geology, 419, 29–35.

S8-3

Determination of the noble gas partition coefficients between metal-silicate melts

Hirochika Sumino[1], Satoshi Kishi[1], Ryuichi Nomura[2], Kenji Mibe[3], Jackson Colin[4], Hideharu Kuwahara[2], Shigehiko Tateno[5], and Hiroyuki Kagi[6]

[1] Department of Basic Science, Graduate School of Arts and Sciences, The University of Tokyo (sumino@igcl.c.u-tokyo.ac.jp)

[2] Geodynamics Research Center, Ehime University

[3] Earthquake Research Institute, The University of Tokyo

[4] National Museum of Natural History, Smithsonian Institution

[5] Earth-Life Science Institute, Tokyo Institute of Technology

[6] Geochemical Research Center, Graduate School of Science, The University of Tokyo

Analyses of ocean island basalts (OIBs) reveal a geochemical reservoir characterized by unradiogenic, “primordial” noble gas signatures (e.g., high $^{3}He/^{4}He$ and low $^{40}Ar/^{36}Ar$ ratios), likely residing in the deep mantle. There has been much debate about the area holding the “primordial” noble gases deep in the Earth [1], including that the “primordial” noble gasses have been retained in the deepest region of the mantle since 4.4 Ga [2] or in the core since the core-mantle separation [3]. However, the validity of latter strongly depends on the quantity of noble gases the core incorporates during accretion and can hold in the present day.

In order to investigate noble gas partitioning behavior between the core and mantle, noble gases were dissolved into metal-silicate melts under high temperature and pressure conditions, and then the samples were quenched. After the sample synthesis, the noble gas concentrations contained in the each phase were analyzed using an ultraviolet laser ablation apparatus and a noble gas mass spectrometer.

The partition coefficient D, where D = (noble gas in metal phase)/(noble gas in silicate phase), of argon at 1 GPa varied widely from orders of 10^{-4} to to 10^{-1}. This resulted from heterogeneous argon distribution in the metal phase, which seems significantly controlled by contaminant phases, such as silicate inclusions and micro- or nano-argon bubbles. Therefore the lowest D so far determined would yield the best estimate, 7×10^{-5}, which is three orders of magnitude lower than the previous work [4]. On the other hand, D for neon, argon, krypton and xenon at 8 GPa obtained with the samples synthesized with multianvil apparatus were in the order of 10^{-3}, which is consistent with the previous work [4]. At the present time, we have not determined helium partition coefficient in the all pressure range as it was difficult to retain enough amount of helium in high-pressure and temperature apparatus during the experiments. Further experiments are necessary to obtain the noble gas concentration contained in the metal phase in order to determine the partition coefficients at higher pressure, at least 30 GPa with which the elemental partition between iron and silicate melt would have occurred during core formation [5].

[1] Porcelli & Ballentine, *Rev. Mineral. Geochem.* **47**, 411-480, 2002. [2] Mukhopadhyay, *Nature*. **486**, 101-104, 2012. [3] Trieloff & Kunz, *Phys. Earth Planet. Inter.* **148**, 13-38, 2005. [4] Matsuda *et al.*, *Science*. **259**, 788-791, 1993 [5] Righter, *Earth Planet. Sci. Lett.* **304**, 158-167, 2011.

S8-4

Silicon's role in the evolution of the Earth's core and mantle

Helffrich, G[1] (george@elsi.jp), Hirose, K[1,4], Ballmer, M D[1,2], and Shahar, A[3]

[1]Earth-Life Science Institute, Tokyo Institute of Technology, Tokyo 152-8551, Japan

[2]Institute for Geophysics, ETH Zürich, Switzerland

[3]Geophysical Lab, Carnegie Institution for Science, Washington DC, USA

[4]Earth and Planetary Science, University of Tokyo, Japan

As the core forms in a planetary embryo or growing planet, the Fe-rich metal that forms the core dissolves various elements in it. After the core forms and the planetary body cools, those elements may become saturated in the metal and exsolve. Hirose et al. (2017) determined experimentally the saturation limits in liquid Fe of O+Si, two major elements in nebular material. Using a thermodynamic model of the solubility of Si+O, the maximum solubility of Si+O in metal during accretion of an Earth-sized planet is about 2 wt% SiO_2 equivalent in the core (Helffrich et al. 2018a). When it crystallises from core metal, the SiO_2 rises to the top of the metallic core and power dynamo activity in small bodies until its Si+O inventory drops below saturation levels. SiO_2 can even escape from the core into the lowermost mantle, and may survive there to the present day in the form of small-scale seismic scatterers (Helffrich et al. 2018a).

Evidence of core-hosted SiO_2 might be found as inclusions in diamonds. Diamonds from the lower mantle are identified through the unusual compositions of the minerals trapped within the diamond (Kaminsky 2012), and often include SiO_2 (stishovite). Though the SiO_2 might have exsolved from high-pressure silicate inclusions reverting to low-pressure forms, the isotopic content of ^{30}Si in the SiO_2 should have a characteristic signature due to metal-silicate fractionation when the metal initially dissolved the Si+O (Helffrich et al. 2018b). This should provide a way to identify core-hosted SiO_2 and provide direct proof that core-mantle interaction occurs.

References. Hirose et al. (2017) *Nature* 543: 99-102; Helffrich et al. (2018a) *J. Geophys. Res.* 123: 176-188; Kaminsky, F. (2012) *Earth Sci. Rev.* 110: 127-147; Helffrich et al. (2018b) *Am. Mineralogist* (in press).

S9-1 Invited

Thorium and uranium power plate tectonics, but not the geodynamo

William F. McDonough[1,2], Scott A. Wipperfurth[2], Meng Guo[2,3], Ondřej Šrámek[4]

[1] Department of Earth Sciences and Research Center for Neutrino Science, Tohoku University, Sendai 980-8578, Japan (mcdonoug@umd.edu)

[2] Department of Geology, University of Maryland, College Park, MD 20742, USA

[3] Institute of Crustal dynamics, China Earthquake Administration, Beijing 100085, China

[4] Department of Geophysics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

Radioactive decay of potassium (K), thorium (Th), and uranium (U) power the Earth's engine, with variations in $^{232}Th/^{238}U$ recording planetary differentiation, atmospheric oxidation, and biologically mediated processes. We report several thousand $^{232}Th/^{238}U$ (κ) and time-integrated Pb isotopic (κ_{Pb}) values and assess their ratios for the Earth, core, and silicate Earth. Complementary bulk silicate Earth domains (i.e., continental crust $^{CC}\kappa_{Pb} = 3.94\,^{+0.20}_{-0.11}$ and modern mantle $^{MM}\kappa_{Pb} = 3.87\,^{+0.15}_{-0.07}$, respectively) tightly bracket the solar system initial $^{SS}\kappa_{Pb} = 3.890 \pm 0.015$. These findings reveal the bulk silicate Earth's $^{BSE}\kappa_{Pb}$ is $3.90\,^{+0.13}_{-0.07}$ (or Th/U = 3.77 for the mass ratio), which resolves a long-standing debate regarding the Earth's Th/U value. Experimental studies find marked differences in the partitioning of U and Th during core formation. We performed a Monte Carlo simulation to calculate the κ_{Pb} of the BSE and bulk Earth for a range of U concentrations in the core (from 0 to 10 ng/g). Comparison of our results with $^{SS}\kappa_{Pb}$ constrains the available U and Th budget in the core. Negligible Th/U fractionation accompanied accretion, core formation, and crust - mantle differentiation, and trivial amounts of these elements (0.07 ppb by weight, equivalent to 0.014 TW of radiogenic power) were added to the core and do not power the geodynamo.

S9-2

Tungsten isotopic heterogeneity in oceanic island basalts produced by core-mantle interaction

Takashi Yoshino[1], Hiroshi Makino[2], Toshihiro Suzuki[2], and Takafumi Hirata[2]

[1] Institute for Planetary Materials (tyoshino@misasa.okayama-u.ac.jp)
[2] Geochemical Research Center, The University of Tokyo

Tungsten isotope composition provide important constraints on the sources of the ocean-island basalts (OIB). If the core formation occurred within the first 60 Myr of the solar system formation, the silicate mantle should be characterized by high Hf/W and positive μ^{182}W, whereas the metallic core has very low Hf/W and negative μ^{182}W. Recently μ^{182}W from modern basalts with high ^{3}He/^{4}He originated from the core-mantle boundary region have shown two distinct features: positive μ^{182}W from Phanerozoic flood basalts indicating a presence of primordial reservoir [1], and negative μ^{182}W from modern OIBs [2]. One possibility to produce this large variation of μ^{182}W is chemical interaction of the mantle with the Earth's outer core.

Here we report tungsten grain boundary diffusion in the lower mantle phases determined by multi-sink method at 25 GPa and temperatures ranging from 1873-2173 K. Grain boundary diffusion of tungsten in postspinel is fast and displays strong temperature dependence. Length scales over which tungsten isotope can be modified significantly at the base of the lower mantle through the whole Earth's history are more than tens of kilometer. Tungsten isotope exchange between core and mantle by grain boundary diffusion processes can generate a large variation of μ^{182}W in modern basalts with high ^{3}He/^{4}He as a function of distance of their source regions from the core-mantle boundary. Modern oceanic island basalts from Hawaii, Samoa and Iceland originated from the modified isotope region with negative μ^{182}W just above the core-mantle boundary, whereas those with the positive μ^{182}W could be derived from the thick Large Low Shear Velocity Provinces (LLSVPs) far from the core-mantle boundary.

References

[1] H. Rizo et al., 2016. Preservation of Earth-forming events in the tungsten isotopic composition of modern flood basalts. *Science* **352,** 809–812.

[2] A. Mundl et al., 2017. Tungsten-182 heterogeneity in modern ocean island basalts. *Science* **356,** 66-69.

S9-3

Liquid metal-silicate partitioning of carbon in a magma ocean during the core formation of terrestrial planets

H. Kuwahara[1], S. Itoh[2], R. Nakada[3], T. Irifune[1]

[1] Geodynamics Research Center, Ehime University [2] Department of Earth and Planetary Science, Kyoto University [3] Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology

Abstract

Elucidating the distribution of carbon in the Earth during core formation is important for understanding mass and composition of the early Earth's atmosphere, and perhaps the composition of the Earth's core. However, the distribution of carbon in the Earth during core-mantle differentiation has not been understood well. Previous studies have conducted high-pressure experiments on liquid metal-silicate partitioning of carbon and found that carbon is highly siderophile (iron loving) [e.g., 1, 2]. However, carbon abundance in the current Earth's mantle is much more abundant than prediction based on experiments [e.g., 1, 2]. In order to explain this discrepancy, the late accretion of sulfur-rich planetesimals has been proposed because carbon is thought to be expelled to mantle if planetesimals had sulfur-rich core [3]. However, this hypothesis is based on experiments for the solubility of carbon in metal and silicate phases using a graphite capsule. Because the solubility ratio of carbon between metal and silicate may not be equal to metal-silicate partition coefficient of carbon, it is necessary to perform metal-silicate partitioning experiments on carbon at undersaturated conditions.

In this study, we conducted high-pressure experiments on liquid metal-silicate partitioning of carbon using a boron nitride capsule and multi-anvil apparatus at 8 GPa and 1923-2123 K. Carbon in quenched metallic liquid and silicate liquid were analyzed by electron probe micro-analyzer and secondary ion mass spectrometry, respectively. The preliminary experimental results show that carbon may not be highly siderophile than previously thought. Although additional experiments are required, preliminary experimental results suggest that the late accretion of sulfur-rich planetesimals, such as a Mercury-like impactor, might not be necessary to explain the current abundance of carbon in the Earth's mantle.

[1] Dasgupta et al., 2013, *Geochim. Cosmochim. Acta* 102, 191-212.

[2] Chi et al., 2014, *Geochim Cosmochim. Acta* 139, 447-471.

[3] Li et al., 2016, *Nat. Geosci.* 9, 781-785.

S10-1 Invited

Chemical Stratification and Magnetic Field Generation

Laneuville M[1] (mlaneuville@elsi.jp), Hernlund J[1], Labrosse S[2],
Lasbleis M[1] and Helffrich G[1]

[1]Earth-Life Science Institute, Tokyo Institute of Technology, Tokyo 152-8551, Japan.
[2]Université de Lyon, École normale supérieure de Lyon, F-69364 Lyon, France.

The existence of a global magnetic field at any point during planetary evolution is key information regarding its internal evolution. The motion in a metallic core required to sustain magnetic activity can be generated by thermal and compositional instabilities, or through mechanical forcing. The first two processes in particular depend strongly on initial state and subsequent cooling history. Accretion of a terrestrial body may lead to chemically and/or thermally stratified layers both in the core itself [e.g., Jacobson et al. (2017)] or at the core-mantle boundary, on the mantle side [e.g., Laneuville et al. (2017)]. In this presentation, we first show how stratified layers form in planetary interiors and discuss the influence it would have on magnetic field generation.

In particular, we consider the case of a stably stratified basal magma ocean on the Earth, and a completely stratified core on Mars. Earth's ~3.45 billion year old magnetic field is thought to be currently sustained by chemical buoyancy due to inner core growth. However, the existence of an ancient field is inconsistent with the estimated young age of the inner core (~1 Ga) and recent measurements of thermal conductivity of iron at core conditions (about twice as large as previously thought). In the case of Mars, there is evidence for an ancient magnetic field within about 500 million years from its formation and no evidence for later activity. Previous models invoked a change in the planet cooling mode in order to stop a thermally driven dynamo [Nimmo and Stevenson, 2000; Roberts et al. (2009)]. In both cases, the existence of a stratified layer may help reconcile models with observations.

References. [1] Jacobson et al. *Earth and Planetary Science Letters* 474 (2017): 375-386. [2] Laneuville et al. *Physics of the Earth and Planetary Interiors* (2017). [3] Nimmo and Stevenson. *Journal of Geophysical Research: Planets* 105.E5 (2000): 11969-11979. [4] Roberts et al. *Journal of Geophysical Research: Planets* 114.E4 (2009).

S10-2

Spatiotemporal variations of core-mantle coupling revealed by geomagnetic field data (FY2017)

Masaki Matsushima[1]

[1] Department of Earth and Planetary Sciences, Tokyo Institute of Technology
(masaki.matsushima@eps.sci.titech.ac.jp)

The dynamo action which generates and maintains the geomagnetic field is driven by fluid flow in the Earth's outer core. A combination of downwelling flow at the core-mantle boundary and upwelling flow at the inner core boundary determines a fluid flow pattern in the outer core. Such a flow pattern is likely to influence generation process of the geomagnetic field. This implies, inversely, that information of the fluid flow in the core can be provided by geomagnetic field data, such as spatial and temporal variations of geomagnetic field. Therefore, spatial and temporal variations of core flow may contain information on spatiotemporal variations of core-mantle coupling. Accordingly, it is important to derive core flow near the core-mantle boundary from geomagnetic field data to reveal spatiotemporal variations of core-mantle coupling. It should be noted that constraint of tangentially magnetostrophic flow is imposed in estimating the core flow, since it is more relaxed than constraint of tangentially geostrophic constraint as adopted by Matsushima (2015). It was concluded, in FY2016, that dynamic effects of the geomagnetic field, such as the Lorentz force, on the modeling of core surface flow are limited. However, core electrical conductivity was assumed to be 3×10^5 S/m smaller than some recent estimates (e.g. Ohta et al., 2016). Hence, effects of core electrical conductivity on core surface flow models are investigated for various values of core electrical conductivity. Spatial distribution of the Elsasser number, which is proportional to core electrical conductivity, suggests that core electrical conductivity can have an effect on the core surface flow through the constraint of tangentially magnetostrophic constraint.

S10-3

Highly precise $^{182}W/^{184}W$ isotopic compositions of terrestrial samples

Asako Takamasa[1], Yusuke Fukami[1], Katsuhiro Suzuki[1]

[1] JAMSTEC (katz@jamstec.go.jp)

^{182}W isotope is a β-decay product of derived from ^{182}Hf with the short half life (8.9 m.y), resulting in extinct ^{182}Hf at present. Both Hf and W are highly refractory elements and thus are accumulated in the early stage of the proto-earth. Hf and W are a lithophile and is a siderophile elements, respectively. This contrast leads to large differentiation of Hf and W during core segregation in the very early Earth system. ^{182}Hf-^{182}W system could give constraints on metal-silicate (core-mantle).

Though the initial studies cannnot detect the anomalies of $^{182}W/^{184}W$ in terrestrial rocks beyond the analytical uncertainties (e.g., Takamasa et al., 2009), improvement of analytical techniques of W isotope analyses allows us to obtain highly precise $^{182}W/^{184}W$ ratios of volcanic rocks, which leads to findings of W isotope anomalies (mostly positive) in old komatiites (2.4 – 3.8 Ga) and young volcanic rocks with positive anomalies of 12 Ma Ontong Java Plateau and 6 Ma Baffin Bay (Rizo et al., 2016) and with negative anamalies of those such as the Loihi basalt.

We developed highly precise W isotope ratio measurement with MC-ICP-MS (Thermo co. Ltd., NEPTUNE PLUS). We have measured W standard solution (SRM 3163) and obtained the isotopic compositions with a enough high precision of ± 5ppm. However, the standard solution, which separated by cation or anion exchange resin, has systematical $^{183}W/^{184}W$ drift of -5ppm. These phenomena was also reported by Willbold et al. (2011). Therefore, we corrected the measured W isotope ratios of samples with the standard solution processed by the same method as that of the samples. This technique leads to the reproducible W isotopic compositions with reproducibility of several ppm. We have obtained the negative $^{182}W/^{183}W$ for the basalts with the high $^{3}He/^{4}He$ isotopic composition from the Loihi, Hawaii, through the developed analytical method. This result is consitent with that of Mundl et al., (2017). As negative anomaly of $^{182}W/^{183}W$ could be created by the early earth core segregation, it is probably a signature of core-mantle interaction.

Poster Session

P1

The effects of ferromagnetism and interstitial hydrogen on the equation of states of hcp and dhcp FeH_x

Hitoshi Gomi[1], Yingwei Fei[2], and Takashi Yoshino[1]

[1] Institute for Planetary Materials, Okayama University, Misasa, Tottori 682-0193, Japan. (hitoshi.gomi@okayama-u.ac.jp)
[2] Geophysical Laboratory, Carnegie Institution of Washington, Washington, District of Columbia 20015-1305, USA.

Hydrogen has been considered as an important candidate of light elements in the Earth's core. Because iron hydrides are unquenchable, hydrogen content is usually estimated from in-situ X-ray diffraction measurements assuming the following linear relation: $x = (V_{\mathrm{FeH}x} - V_{\mathrm{Fe}}) / \Delta V_{\mathrm{H}}$, where x is the hydrogen content, ΔV_{H} is the volume expansion caused by unit concentration of hydrogen, $V_{\mathrm{FeH}x}$ and V_{Fe} are volumes of FeH_x and pure iron, respectively. To verify the linear relationship, we computed the equation of states of hexagonal iron with interstitial hydrogen by using the Korringa-Kohn-Rostoker method with the coherent potential approximation (KKR-CPA). The results indicate a discontinuous volume change at the magnetic transition and almost no compositional (x) dependence in the ferromagnetic phase at 20 GPa, whereas the linearity is confirmed in the non-magnetic phase. In addition to their effects on density-composition relationship in the Fe-FeH_x system, which is important for estimating the hydrogen incorporation in planetary cores, the magnetism and interstitial hydrogen also affect the electrical resistivity of FeH_x. The thermal conductivity can be calculated from the electrical resistivity by using the Wiedemann-Franz law, which is a critical parameter for modeling the thermal evolution of the Earth. Assuming $Fe_{1-y}Si_yH_x$ ternary outer core model ($0.0 \leq x \leq 0.7$), we calculated the thermal conductivity and the age of the inner core. The resultant thermal conductivity is ~100 W/m/K and the maximum inner core age is ranging from 0.49 to 0.86 Gyr.

P2

Grain growth kinetics of lower-mantle materials: Implications for the grain size evolution and the rheology

Masahiro Imamura[1], Tomoaki Kubo[1],

[1] Kyushu Univ. (kubotomo@geo.kyushu-u.ac.jp)

We have conducted grain growth experiments of pyrolitic material at 25-27 GPa and 1600-1950°C using a Kawai-type high-pressure apparatus. Grain growth kinetics data in multi-phase assemblages of Bridgmanite (Brg), ferropericlase (Fp), Ca-perovskite (Capv) and/or majoritic garnet (Mjgt) was obtained and analyzed on the basis of Zener pining and Ostwald ripening processes. The grain size ratio between major (Brg) and secondary phases was roughly constant and estimated to be ~1.4 and ~1.8 at 25 GPa (four phases of Brg, Fp, Capv, and Mjgt) and 27 GPa (three phases of Brg, Fp, and Capv), respectively. The secondary phases are homogeneously distributed at grain boundaries of the major phase of Brg. These results suggest that the Zener pinning and Ostwald ripening of secondary phases by grain boundary diffusion control the grain growth of Brg. In this case, the grain size ratio between primary and secondary phase is described by $d_I/d_{II}=\beta/f_{II}^z$ (d_I: grain size of primary phase, d_{II}: grain size of secondary phase, f_{II}: volume fraction of secondary phase, β and z: Zener parameters). The relationship between d_I/d_{II} and f_{II} obtained in this study is almost consistent with the previous systematic study in the olivine-enstatite system (Tasaka and Hiraga, 2013), in which the Zener parameters of β and z were estimated to be 0.7 and 0.5, respectively. Grain growth kinetics is generally described by $d^n-d_0^n=kt$ (d: grain size, d_0: initial grain size, n: grain growth exponent, k: Arrhenius-type temperature-dependent rate constant, t: time). When assuming the n-value of 4 considering the Ostwald ripening by grain boundary diffusion, the activation enthalpies for the grain growth in Brg, Fp, and Mjgt are estimated to be ~400, ~320, ~530 kJ/mol, respectively.

These kinetic data were used to discuss the grain-size evolution and the rheology of the lower mantle. The grain sizes of Brg in a pyrolitic composition (f_{II}=0.2) were estimated to be ~10-200 μm and ~500-3000 μm in 10^8 years for cold subduciting slabs (800-1400°C) and the surrounding lower mantle (1600-2400°C), respectively. These grain sizes do not change significantly in different chemical compositions of an olivine-like (f_{II}=0.3) and a perovskitic (f_{II}=0.1) lower mantle. These grain sizes are located at the boundary condition between diffusion and dislocation creep mechanisms inferred from diffusivity data, implying that Brg deforms by dislocation creep in high stress conditions expected in the vicinity of subducting slabs and D” layer. Effects of the weaker and secondary phase of Fp with having smaller grain size will also be discussed in the presentation.

P3

Diffusion mechanisms of creep and grain growth of two-phase polymineralic rocks: Implications for rheology of the lowermost mantle

Atsuro Okamoto[1], Takehiko Hiraga[2]

[1] Earthquake Research Institute, Tokyo University (aokamoto@eri.u-tokyo.ac.jp)
[2] Earthquake Research Institute, Tokyo University

The phase (mineral) transition which occurs during downwelling flow to the lower mantle produces micron-size grains. Such fine grains grow to the size observed in the upper mantle rocks (i.e., 1~10 mm) during one cycle of the mantle convection (Solomatov and Reese, 2008). The grain growth is likely to be most significant at the lowermost mantle where temperature is the highest and the duration for the grain growth is the longest. When polycrystalline materials deform by diffusion creep mechanism, their viscosities are proportional to the square or the cube of grain size. Thus, if the lower mantle and D” layer deform by diffusion creep, viscosities of these regions are highly controlled by the grain growth.

Grain growth in two-phase rocks, whose microstructure is comparable to that of D” layer, requires diffusion of atoms with a long-distance, which is almost equivalent to the size of the grains. Such diffusion is also a necessary process during diffusion creep. In this study, we examine diffusion mechanisms that control creep and grain growth rates based on experimental results of creep and grain growth of two-phase aggregates. We estimate the flow property of D” layer when its deformation is accompanied with grain growth.

We synthesized highly-dense fine-grained (~1 mm) forsterite + periclase (10 vol%) polycrystals by using vacuum sintering technique (Koizumi et al., 2010). The constituent minerals of the aggregates consist of the similar elements of the D” layer minerals such that the mechanisms controlling its creep and grain growth are expected to be identical to that in D” layer. I performed uni-axial compressional creep experiments on the forsterite + periclase aggregate at atmospheric pressure and high temperature (1150 ~ 1400°C). I also conducted grain-growth experiments at different temperatures ranging from 1300°C to 1450°C for 500h to obtain temperature dependency of grain growth. Hanging the samples fixed with theromocouple at different locations from the central heating zone in the furnace enables to obtain the precise grain growth data from various temperatures even by a single experiment. I observed microstructures of the aggregates after the experiments using scanning electron microscope.

I calculated grain boundary diffusivities from creep and grain growth rates using theoretical models of grain growth and grain boundary diffusion creep (Coble creep), finding both diffusivities are essentially identical. Based on this result, I conclude that the creep and grain growth in forsterite + periclase aggregate is controlled by the common diffusion mechanism. When creep and grain growth rates are determined by a common diffusivity, viscosity of the aggregate during its diffusion creep accompanied with grain growth should follow $\eta = Ct / d$ where η is viscosity, C is a material constant, t is annealing time under constant temperature and d is grain size. I applied this time–grain size–viscometer to the lowermost mantle with substituting 1~10 mm and 100 Myr and obtained $10^{18} \sim 10^{19}$ Pa·s as the maximum viscosity of the lowermost mantle. This value does not contradict with the previous estimate of the very low viscosity (~10^{16} Pa·s) of the lowermost mantle, which is based on the decay time of the Chandler wobble and Earth's tidal deformation (Nakada and Karato, 2012).

P4

Experimental study on transport properties of liquid iron-silicon alloy at and above the outer core conditions

Kohei Miyanishi[1], Toyohito Nishikawa[2], Norimasa Ozaki[1, 2, 3] , Marion Harmand[4], Yuhei Umeda[2], Minoru Hosomi[2], Keisuke Shigemori[1], Youichi Sakawa[1], Takayoshi Sano[1], and Ryousuke Kodama[1, 2, 3]

[1] Institute of Laser Engineering, Osaka University (miyanishik@ile.osaka-u.ac.jp)

[2] Graduate school of engineering, Osaka University

[3] Photon Pioneers Center, Osaka University

[4] IMPMC, Sorbonne Université

Information on the thermal and electrical transport properties of iron alloys under high-pressure and high-temperature conditions corresponding to the earth's outer core is necessary to clarify the convection phenomena of the earth and the cooling history. In particular, the transport properties in the outer core–mantle boundary condition strongly influence the mantle convection, the outer core convection generating the earth's magnetic field, the growth and inner flow of the inner core, and so on. However, there are very few experimental examples concerning high-pressure and high-temperature liquid iron/iron-alloy which correspond to the outer core conditions, and only a few cases have been reported for pure iron [1]. It is required to investigate transport coefficients of liquid iron alloys containing light elements to simulate actual outer core, experimentally. Laser shock compression technique has several advantages to exploring iron-alloys under high-pressure and high-temperature condition. As there is no mechanical restriction on pressure generation, producing the pressure of even TPa is easy, and high heating rate exceeding 10^{15} K / s is possible, and it is a closed system that is not affected by surroundings. Therefore the technique is effective for generation and observation of high-pressure and high-temperature liquid iron-alloys. In this research, we report optical reflectivity, pressure and temperature measurements of laser shock compressed iron and iron-silicon (Fe-Si) alloy at and above the earth's outer core conditions.

Target assemblies containing polypropylene (CH), aluminum, quartz, iron or iron-silicon alloy and magnesium oxide (MgO) window were shock compressed by laser ablation at the GEKKO XII laser facility, the Institute of Laser Engineering, Osaka

University. Iron and iron-silicon alloy were formed by electron beam evaporation on the MgO window. Laser beams with a wavelength of 527 nm were focused onto the target. A focal spot was 1 mm in diameter with a flat-top spatial intensity distribution resulting in a planar shock front. Temporal shape of the laser pulse was approximately a flat-top with a full-width at half-maximum of 2.5 ns. The velocity interferometer system for any reflector (VISAR) measure a particle velocity and a reflectivity at the interface between iron or iron-silicon alloy and MgO. The Ppressure was evaluated using measured particle velocity and a known equation of state of MgO[2]. The optical pyrometer measures the temperature at the interface through the MgO window.

The pressures determined from the measurement results were from 200 to 400 GPa, and the temperatures were up to 15000 K. In the pressure range exceeding 200 GPa, in the case of iron, a decrease in reflectivity was observed as the pressure increased, whereas in the case of the iron-silicon alloy, a continuous increase following a discontinuous decrease in the reflectivity was observed. The decrease in reflectivity of iron suggests a decrease in electronic conductivity due to temperature rise with increasing pressure. On the other hand, the continuous rise seems to indicate an increase in the density of free electrons derived from silicon.

[1] K. Ohta, Y. Kuwayama, K. Hirose, K. Shimizu, Y. Ohisi: Nature, 534, 95-98 (02 June 2016).

[2] S. Root, L. Shulenburger, R. W. Lemke et al.: Phys. Rev. Lett, 115, 198501 (2015).

P5

Microstructures of experimentally deformed carbon steels

Y. SAKODA[1], T. KAWAZOE[1], J. ANDO[1], N. TOMIOKA[2], H. OHFUJI[3] and Y. KODAMA[4]

[1] Department of Earth and Planetary Systems Science, Hiroshima University
(m171210@hiroshima-u.ac.jp)
[2] Kochi Institute for Core Sample Research, JAMSTEC
[3] Geodynamics Research Center, Ehime University
[4] Department of Marine & Earth Sciences, Marine Works Japan Ltd.

The inner core of the Earth is mainly composed of Fe and Ni, in addition to the small amounts of light elements. O, S, and Si are the important candidates of these light elements, and C is also deeply thought to be stored in the inner core. The seismic data suggest that the solid inner core is deformed plastically and convected same as the mantle. Therefore, the study of plasticity of Fe containing the light elements is needed in order to understand the dynamics of the inner core.

Fe-alloy containing C is named “carbon steel”, which is a very useful material for the steel industry. Therefore, its fundamental deformation behavior at ambient pressure is very well understood. One of the interesting phenomena controlling the plasticity of the carbon steel is C concentration on the dislocation line as known as Cottrell atmosphere. This phenomenon contributes to make harder the plastic strength of carbon steel. Meanwhile, the plasticity of the carbon steel at higher pressure conditions has not been studied well so far. Especially, it is not clear whether the Cottrell atmosphere appears or not at higher pressure conditions. In order to understand this point, we conducted the deformation experiments of carbon steels and are currently working on the microstructural observation of the recovered samples.

For the present research, we used the 6-6 multi-anvil apparatus of BGI for the deformation experiments, and the cross-section polisher of GRC and FIB of KCC for the sample preparation, and FE-SEM of GRC and TEM of KCC for the microstructural observation. The used samples were two types of the carbon streels with different C contents (0.22-0.28 wt%C and 0.90-1.00 wt%C). The experimental conditions were 400 °C, 2-6 GPa, and ca. 1.0 x 10^{-6}/s of strain rate.

In our presentation, we will present the details of deformation experiments and preliminary results of microstructural observation.

P6

Deformation of bridgmanite and post-spinel two-layered sample under lower mantle conditions with DT-Cup apparatus

Fang Xu[1]

[1] Institute for Planetary Materials, Okayama University, Tottori, Japan (fang.xu@upmc.fr)

Viscosity jump at 800- to 1200-kilometers depth was reported by geophysical observation recently (Rudolph et al., 2015). Due to the absence of phase transition in the main minerals, chemical deviation is one candidate explanation for the viscosity jump. A perovskitic lower mantle is consist of more than 93 vol.% bridgmanite (Murakami et al., 2012), on the other hand, subducted harzburgite layer contains ~20 vol.% of ferropericlase (Irifune and Ringwood, 1987). Ferropericlase is likely much weaker than bridgmanite may significantly reduce the bulk viscosity of bridgmanite and ferropericlase aggregate (Yamazaki and Karato, 2001). Therefore, the viscosity of bridgmanite and ferropericlase aggregate is critical for us to understand the viscosity profile in the lower mantle.

To identify the bulk viscosity of bridgmanite and ferropericlase aggregate, two-layered sample of bridgmanite and post-spinel (bridgmanite plus ~ 30 vol.% of ferropericlase) aggregates were deformed simultaneously. We prepared starting material of bridgmanite and post-spinel aggregates with grain size of 5-10 micron meter at high pressure and high temperature in a Kawai-type high-pressure apparatus. Then the deformation experiments were conducted in the DT-Cup apparatus which is a development of the Kawai type multi-anvil press (Hunt et al., 2014). We deformed bridgmanite and post-spinel two-layered samples up to strain of ~0.2 at 1500 °C and 25 GPa. As the identical uni-axial stress during deformation, the strengths of bridgmanite and post-spinel are inversely proportional to their strains.

The recovered bridgmanite and post-spinel samples showed virtually identical strain, which indicates similar strengths of them. Lattice preferred orientations (LPOs) of bridgmanite phase in both bridgmanite and post-spinel samples are similar developed, the slip plane of (100) is consistent with the slip system reported by Tsujino et al. (2016). Our result indicates chemical deviation in ferropericlase proportion is unable to be responsible for the viscosity jump in the lower mantle under current condition. The discordance between this study and Girard et al. (2016), who reported a marked softening of post-spinel aggregate with shear strain up to 1.0, highlights the possible importance of large shear strain in controlling the bulk viscosity.

P7

Toward development of ultrasonic measurement technique under whole lower mantle conditions

Yuji Higo[1], Tetsuo Irifune 2[2]

[1] JASRI, SPring-8 (higo@spring8.or.jp)
[2] GRC, Ehime Univ. (irifune@dpc.ehime-u.ac.jp)

Elasticity data on mantle minerals under high pressure and high temperature are critical to interpret the seismic velocity and density profiles in the Earth's deep interior. However, ultrasonic measurements of elastic wave velocities under high pressure and high temperature have been limited to those corresponding to the mantle transition region (<24GPa, <1673K), because of the technical difficulties. Since only a small sample can be used in the experiment under the lower mantle conditions, ultrasonic echoes are very weak and cannot perform a precise elastic measurement. In this study, to overcome this problem, the high-frequency arbitrary waveform generator, post amplifier and high-speed semiconductor relay were installed in BL04B1 at SPring-8. Since this study has just begun, we will introduce the plan for future initiatives.

P8

Searching for multi light elements in iron-silicate-water system using high pressure and high temperature experiments: Implications for the Earth's evolution

Riko Iizuka-Oku[1*] ・ Hirotada Gotou[2] ・ Hiroyuki Kagi[1]

[1] Geochemical Research Center (GCRC), Graduate School of Science, The University of Tokyo (*riizuka@eqchem.s.u-tokyo.ac.jp)
[2] The Institute for Solid State Physics (ISSP), The University of Tokyo

The Earth's outer core is considered to consist of Fe-Ni alloy and some light elements (O, S, Si, H, C). Hydrogen is the most abundant element in the solar system and one of the promising candidates existing in the Earth's core. However, the amount of hydrogen dissolved in the core and its process are still unknown because hydrogen cannot be detected by X-ray and it easily escapes from iron by the release of pressure. Recently, hydrogen content in *fcc*-Fe at high pressure and temperature has been determined using in-situ neutron diffraction measurements at J-PARC [1]. It is suggested the possibility that hydrogen had preferentially dissolved into iron before any other light elements have dissolved in the very early stage of Earth's evolution. It is important to further study the partitioning of the other light elements between iron hydride and silicates. In this study, we focused on sulfur and investigated its effect on hydrogenation.

As a starting material, the powder mixture of iron (#300 mesh), quartz, $Mg(OD)_2$ (or MgO) and S (or FeS) was used. The mixing ratio was slightly changed. High-pressure and high-temperature quench-experiments were carried out using a 500-ton press at ISSP. A multi-anvil 6-6 type (MA6-6) assembly was used with an improved anvil assembly optimized for the neutron experiments [1]. The pressure was increased up to 6 GPa and heated up to 750-1650°C. The quenched samples were analyzed by XRD and SEM-EDS. In-situ X-ray diffraction measurements were also conducted at PF-AR, NE7A and NE5C. The products were identified under high pressure (4-6 GPa) and high temperature (up to 1050°C).

Liquid Fe-FeS was observed in the quenched sample from >1000°C. Liquid iron and solid FeS coexisted in the recovered sample from 950°C. This was in good agreement with the Fe-FeS binary system. In the recovered sample from 750°C, solid FeS and solid Fe coexisted and the iron contained many small vacant holes of a few microns in diameter, indicating the evidence of hydrogen dissolved into iron. From in-situ XRD observations, Fe transformed from *bcc* into *fcc* phase at <500°C. At the same time, dehydration of $Mg(OD)_2$ and formation of FeS were observed. At 850°C, *fcc*-Fe started to melt and FeS and olivine remained in the recovered samples. The results between in-situ and quench experiments were well consistent.

The cell volume of *fcc*-Fe in the Fe-silicate-water system was several % larger than that of pure Fe at the same condition, which suggested the obvious hydrogenation. In the presentation, hydrogen content in *fcc*-Fe and FeS will be discussed to more clarify the formation process of iron hydride and FeS and the effect of sulfur on hydrogenation.

[1] R. Iizuka-Oku, T. Yagi, H. Gotou, T. Okuchi, T. Hattori, A. Sano-Furukawa, Nature Commun. 8, 14096 (2017).

P9

Melting experiments of hydrous peridotite under the top of the lower mantle conditions

A. Nakajima[1], T. Sakamaki[1], T. Kawazoe[2], and A. Suzuki[1]

[1] Tohoku University (ayano.nakajima.r1@dc.tohoku.ac.jp)
[2] Bayerisches Geoinstitut (at present, Hiroshima University)

There are various igneous activities in the Earth. On the surface of the Earth, for example, igneous activities occur in island arcs, mid-ocean ridges, hot spots and petit spots. However, not only on the surface, but also in the interior, melting phenomena are also suggested (e.g., the top of the asthenosphere [e.g., Barazangi & Isacks, 1971 *JGR*]; the bottom of the upper mantle [e.g., Bercovici & Karato, 2003 *Nature*]). In this study, we focused on the melting of hydrous peridotite at the top of the lower mantle because seismological observation indicates the low velocity anomaly [e.g., Schmandt *et al*., 2014 *Science*]. The low-velocity region is expected to be caused by mantle melting due to dehydration decomposition of ringwoodite to bridgmanite and ferro-periclase with a downward flow. Here, we performed melting experiments of peridotite with 6.98 wt % H_2O at 21-26 GPa and 900-1600 °C. As a starting material, a mixture of several oxide powders was used. In this study, Fe_2O_3 was used instead of FeO because the lower mantle is expected to be Fe^{3+}-rich [e.g., McCammon, 1997 *Nature*]. Recovered samples from 1300-1600 °C showed partial melting texture, and clearly demonstrate that mantle melting can be occurred under the experimental conditions. The composition of melt was SiO_2- and Al_2O_3-poor and CaO-rich. Mg/(Mg+Fe) in atomic ratio of the melt (= 0.90) is similar to that of bridgmanite (= 0.89). This result is completely inconsistent with melting experiment under dry condition [e.g., Ito & Takahashi, 1987 *Nature*] but consistent with hydrous melting (Fe^{2+}) [Kawamoto, 2004 *PEPI*]. In addition to decrease in the melting temperature of mantle rock, hydrogen (water) can affect the melt composition such as the partitioning of FeO and MgO between crystal and melt. The density and compressibility of the magma were calculated based on the obtained melt composition. Comparing with seismological model, the melt is lighter than that of the lower mantle. This implies that the melt can be ponded at the top of lower mantle and form the seismological low velocity zone.

P10

Al substitution mechanism in anhydrous bridgmanite as a function of Al content

Masamichi Noda[1], Sho Kakizawa[1], Toru Inoue[1,2]

[1]Geodynamics Research Center, Ehime University, Matsuyama, Ehime, Japan.
(m_noda@sci.ehime-u.ac.jp)
[2]Department of Earth and Planetary System Science & Hiroshima Institute of Plate Convergence Region Research (HiPeR), Hiroshima University, Higashi-Hiroshima, Hiroshima, Japan.

It is considered that two substitution mechanisms, Tschermak substitution and oxygen vacancy substitution, exist in $MgSiO_3$ bridgmanite for the incorporation of Al in anhydrous condition. Kubo and Akaogi (2000) has conducted the phase equilibrium experiment in the system $MgSiO_3$-Al_2O_3, and established the phase diagram up to 28 GPa. However the careful observation in the bridgmanite shows that the chemical compositions are slightly deviated from Tschermak substitution join. The same tendency can be also observed in the run products by Irifune et al. (1996). This result indicates that pure Tschermak substitution bridgmanite cannot be stable even in the $MgSiO_3$-Al_2O_3 join experiment. However, the previous studies used powder samples as the starting materials, so the absorbed water may affect the results. Therefore, we tried to conduct the experiment in the join $MgSiO_3$-Al_2O_3 in extremely anhydrous condition to clarify whether the pure Tschermak substitution bridgmanite can be stable or not. In addition, we also examined the stability of oxygen vacancy bridgmanite in the extremely anhydrous condition for the comparison.

The high pressure synthesis experiments were conducted at 28 GPa and 1600-1700℃ for 1hour using a Kawai-type multi-anvil apparatus. Four different Al content samples were prepared as the starting materials along the ideal substitution line of Tschermak (Al=0.025, 0.05, 0.1, 0.15 mol) and oxygen-vacancy (Al=0.025, 0.05, 0.075, 0.1 mol) substitutions, respectively (when total cation of 2). The glass rods were used as the starting materials to eliminate the absorbed water on the sample surface. The chemical compositions of the synthesized bridgmanite could not be measured by EPMA because of small grain size less than submicron. Therefore the chemical compositions were estimated from the result of the XRD pattern by subtracting the amount of the other phases. The estimated chemical compositions of

Tschermak substitution bridgmanites were consistent with the ideal compositions. On the other hand, oxygen-vacancy substitution bridgmanite was possible to be existed less than Al=0.025 mol on the basis of total cation of 2. These results show that both Tschermak and oxygen-vacancy substitution bridgmanites can exist in low Al content in anhydrous condition. Therefore the deviation from the Tschermak substitution bridgmanite in the previous studies should be due to the absorbed water, and the hydration of bridgmanite should be easy to occur to form hydrous bridgmanite.

P11

Structures of basaltic glass under high pressure by in-situ X-ray and neutron diffraction investigations

Tomonori Ohashi[1], Tatsuya Sakamaki[2], Takanori Hattori[3], Asami Sano-Furukawa[3], Ken-ichi Funakoshi[4], and Akio Suzuki[2]

[1] Department of Earth and Planetary Materials Science, Tohoku University (tomonori.ohashi.s8@dc.tohoku.ac.jp)

[2] Department of Earth Science, Graduate School of Science, Tohoku University

[3] Japan Atomic Energy Agency (JAEA)

[4] Comprehensive Research Organization for Science and Society (CROSS)

Structure determinations of basaltic glass have been conducted under high pressure using X-ray diffraction (XRD) and neutron diffraction (ND) techniques. The total structure factor, $S(Q)$ suggests that the position of the first sharp diffraction peak (FSDP) shifts to higher-Q region with increasing pressure. This shift indicates the intermediate-range structure of glass becomes compact. The radial distribution function, $G(r)$ shows the shrinkage of the average T-T length, and no detectable change of the average T-O length with increasing pressure (T means tetrahedrally coordinated cations, such as Si^{4+} and Al^{3+}). This result implies that drastic shrinkage of network structure involving a decrease in the mean T-O-T angle is the dominant structural evolution under experimental pressure conditions. Moreover, the second sharp diffraction peak, SSDP (Elliot, 1995) was observed in $S(Q)$ from the ND experiment. The intensity of SSDP enhanced, while that of FSDP weakened with increasing pressure. These trends indicate the disordering of the intermediate-range order (Salmon, 1994) and the ordering of the extended-range order (Salmon et al., 2005), respectively. $G(r)$ of ND also indicates no extension of the T-O bond in the present study. Considering the T-O extension reported in basaltic liquid (Sakamaki et al., 2013), this difference seems to be due to thermal effect. Also, $G(r)$ of ND represents the Mg-O and Fe-O distances show increase two times at about 2.0 and 6.0–6.9 GPa. These changes is might be caused by the increase in their coordination numbers due to the polymerization of TO_4 tetrahedron. On the other hand, Ca-O and Na-O distances are less sensitive to the pressure. Since the Mg/Fe-O distance is shorter than the Ca/Na-O distance, the Coulomb force between Mg/Fe and O ions is larger than that of Ca/Na and O ions. Hence, Mg and Fe cations are easier to combine with non-bridging or isolated O anions than Ca and Na cations.

P12

Density measurement of metals at high temperatures using newly designed furnace

Hidenori Terasaki[1], Asaka Kamiya[1]

[1] Department of Earth and Space Science, Osaka University
(terasaki@ess.sci.osaka-u.ac.jp)

Density and thermo-elastic properties at high temperatures and ambient pressure are fundamental information for describing an equation of state. In order to study the thermo-elastic properties of solid and liquid alloys at high temperatures, we developed a high temperature furnace designed for density and sound velocity measurements. The furnace is composed of a heating element of carbon fiber composite, which enables to heat up to 2173 K, and of two windows for optical observation. A buffer rod can descend down to the sample during heating. The density and sound velocity are measured based on volume measurement and pulse-echo overlap method, respectively. Here, we report a set-up of the instrument and results of density of iron and nickel solids at 1073–1773 K. The effect of temperature on the density were measured for γ-Fe (fcc), δ-Fe (bcc) and γ-Ni (fcc). The measured densities of γ-Fe and γ-Ni are consistent with previous results within a difference of ~1.5 % and ~0.5 %, respectively.

P13

Silicate melt viscosities at high pressure: Experimental results and its implications

Longjian Xie[1], Akira Yoneda[1], Geeth Manthilake[3], Daisuke Yamazaki[1], Yuji Higo[2], Yoshinori Tange[2], Nicolas Guignot[4], Denis Andrault[3]

1. Institute for Planetary Materials, Okayama University (longjianxie@s.okayama-u.ac.jp)
2. Japan Synchrotron Radiation Research Institute
3. The Laboratoire Magmas et Volcans
4. Synchrotron SOLEIL

It is believed that the early Earth experienced several episodes of magma-ocean, with a major one just after the giant Moon-forming impact. In this framework, the viscosity of the silicate melts is a key to understand the dynamics of the magma ocean and the recrystallization processes.

We succeeded to extend the experimental measurements of silicate-melt viscosity up to about 30 GPa and more than 2500 K, by devising an *in-situ* falling sphere method coupled with boron-doped diamond heater and ultra-fast cameral (1000 f/s) in the multi-anvil apparatus. We determined viscosities of molten forsterite, enstatite and diopside from 5 to 30 GPa and at temperatures just above their liquidus; reproducibility of the measurements is within a few percents. Experimental uncertainties were estimated by Monte Carlo method based on the uncertainties of pressure, temperature, falling sphere velocities and sphere size.

The viscosity of the melt with forsterite composition increases with increasing pressure along the liquidus, while those of enstatite and diopside melt compositions decrease with increasing pressure. Melt viscosities of the three compositions are found very low, in the range of 0.01 to 0.1 Pa.s, at mantle pressure conditions. The extremely low viscosity implies a short life-time for the magma ocean (1-6 thousand years) and, potentially, a fractional crystallization.

P14

Melting of Al-rich phase D up to the uppermost lower mantle and transportation of H_2O to the deep Earth

Chaowen Xu1[1], Toru Inoue2[1, 2]

[1] Geodynamics Research Center, Ehime University, 2-5 Bunkyo-cho, Matsuyama 790-8577, Japan 1 (416755386@qq.com)

[2] Department of Earth and Planetary Systems Science & Hiroshima Institute of Plate Convergence Region Research (HiPeR), Hiroshima University, 1-3-1 Kagamiyama, Higashi-Hiroshima 739-8526, Japan 2

We have investigated the stability of the Al-rich dense hydrous magnesium silicate phase D in MgO-Al_2O_3-SiO_2-H_2O (MASH) system between14 and 25 GPa at 900-1500 ºC. Al-rich PhD has a very wide stability region from 900 ºC and 14 GPa to at least 1500 ºC and 25 GPa. With pressure increasing, Al-rich PhD decomposes to phase Egg and then to δ at above hot subduction at transition zone. Al-rich PhD is also determined by X-ray diffraction and Raman spectroscopy at ambient condition. Compared with Al-free PhD, unit-cell volume of Al-rich PhD is little larger, but the Raman spectra resemble some of Al-free PhD.

The wide stability region determined in this study makes Al-bearing PhD an important storage site for water in transition zone, suggesting that it can deliver a certain amount of water into the lower mantle along hot subduction and even the normal mantle geotherm P-T condition. Therefore, dehydration of Al-bearing PhD may be responsible for a series of observed seismic discontinuities from transition zone to uppermost lower mantle, and even deep earthquakes in some typical places.

P15

A recent application of NPD anvils to EXAFS spectroscopy: element-selective elastic properties of Fe-Ni and Fe-Pt Invar alloys

N. Ishimatsu[1], M. Kousa[2], S. Iwasaki[2], H. Maruyama[1], N. Kawamura[3], M. Mizumaki[3], R. Nomura[4], S. Kakizawa[4], T. Irifune[4] and H. Sumiya[5]

[1] Grad. Sch. Sci., Hiroshima Univ. (ishimatsunaoki@hiroshima-u. ac.jp)
[2] Fac. Sci., Hiroshima Univ.
[3] JASRI/SPring-8
[4] GRC, Ehime Univ.
[5] Advanced Materials R&D Laboratories, Sumitomo Electric Industries

Nano-polycrystalline diamond (NPD) anvils have been applied recently in high pressure research using X-ray absorption spectroscopy (XAS) [1,2]. This is because the nanometer-sized polycrystallization in NPD anvils enables to obtain glitch-free X-ray absorption spectra. NPD anvils drastically improve the experimental conditions of XAS, which has previously used conventional single-crystal diamond (SCD) anvils. Distorted spectra due to the glitches from the SCD anvils have been an inevitable problem of XAS. To demonstrate how NPD anvils are useful when XAS is measured for high pressure research, we present our recent study of extended X-ray absorption fine structure (EXAFS) for Fe-Ni and Fe-Pt Invar alloys.

The zero or negative thermal expansion observed in $Fe_{65}Ni_{35}$ and $Fe_{72}Pt_{28}$ alloys is well known as Invar effect, however, the microscopic origin of the Invar effect is not fully understood yet. In this study, we determined element-selective elastic properties of these alloys by EXAFS spectra, and examined a possible theory of the Invar effect based on the non-collinear spin structure model [3]. Our analysis using the glitch-free EXAFS spectra has revealed differences in the element selective elastic properties: Fe bond is more compressive than Ni bond, and both bulk moduli become hard in the pressure-induced paramagnetic phase. We also discuss the comparison between the local bond length probed by EXAFS and the average interatomic distance determined by XRD measurements.

[1] N. Ishimatsu et al., J. Synchrotron Rad. **19**, 768-772 (2012).
[2] T. Irifune et al., Nature (London), **421**, 599–600 (2003).
[3] M. Schilfgaarde, I. A. Abrikosov, and B. Johansson, Nature (London) **400**, 46-49 (1999).

P16

Thermal equations of state of $MgSiO_4H_2$ phase H

Masayuki Nishi[1,2], Jun Tsuchiya[1,2], Takehiro Arimoto[1], Sho Kakizawa[1], Takehiro Kunimoto[1], Yoshinori Tange[3], Yuji Higo[3], Tetsuo Irifune[1,2]

[1] Geodynamics Research Center, Ehime University (nishi@sci.ehime-u.ac.jp)
[2] Earth and Life Science Institute, Tokyo Institute of Technology
[3] Japan Synchrotron Radiation Research Institute

Phase H ($MgSiO_4H_2$) is the high-pressure form of dense hydrous silicate, which could deliver surface water into the lower mantle. Thus, it plays a significant role in the water cycle in the Earth's interior. Here we have determined the thermal equations of the state of phase H using in situ X-ray diffraction measurements in conjunction with a multi-anvil apparatus. Analysis of the data based on the Mie-Grüneisen-Debye model using third-order Burch-Murnaghan equations at a reference pressure of 35 GPa yielded the following results: $V_{ref,}$ = 49.61±0.01 (Å^3), K_{ref} = 344.6±4.1 (GPa), K_{ref}' = 3.05±0.32, θ_{ref} = 974±146 (K), γ_{ref} = 1.8±0.1, and q = 1.79±0.55. The compressibility of phase H observed in this study agrees well with that derived from theoretical calculations in pressure regions where hydrogen bond symmetrization is predicted. Furthermore, it was recognized that the volume and compressibility between phase H and δ-AlOOH were similar.

P17

High pressure generation using double-stage diamond anvil technique: problems and equations of state of rhenium

Takeshi Sakai[1], Takehiko Yagi[2], Tetsuo Irifune[1,3], Hirokazu Kadobayashi[1], Naohisa Hirao[4], Takehiro Kunimoto[1], Hiroaki Ohfuji[1], Saori Kawaguchi-Imada[4], Yasuo Ohishi[4], Shigehiko Tateno[3] and Kei Hirose[3,5]

[1] Geodynamics Research Center, Ehime University (sakai@sci.ehime-u.ac.jp)
[2] Geochemical Research Center, Graduate School of Science, The University of Tokyo
[3] Earth-Life Science Institute, Tokyo Institute of Technology
[4] Japan Synchrotron Radiation Research Institute
[5] Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo

We have developed a double stage diamond anvil cell (ds-DAC) technique for reproducible pressure by precisely fabricating 2nd stage anvils using a focused ion beam system [1]. We used 2nd stage micro-anvils made of ultra-fine (< 10 nm) nano-polycrystalline diamond with various shapes and dimensions synthesized from glassy carbon at high pressure and temperature. The X-ray diffraction patterns from the rhenium sample always showed very broad peaks due to large pressure gradients in the culet of the micro-anvils. Deconvolution of the broad 101 diffraction peak results in compression of rhenium to $V/V_0 = 0.633$ for the smallest d-spacing. The calculated pressure for this minimum volume varies from 430 to 630 GPa, depending on the choice of the equation of state of rhenium. We conclude that the most likely pressure achieved for the minimum volume of rhenium is in a range of 430–460 GPa based on a calibration using the platinum pressure scale to 280 GPa and the latter value of 630 GPa is unreasonably high, suggesting that the pressures in an earlier study for the equation of state of rhenium would have been significantly overestimated.

Reference

[1] T. Sakai et al., 2018. High pressure generation using double-stage diamond anvil technique: problems and equations of state of rhenium. *High Pressure Research*, DOI: 10.1080/08957959.2018.1448082. (in press)

Multiple sulfur isotopes of Archean oceanic crust and granitoids: Implication for the anomalous sulfur budget in the mantle

Shinnosuke Aoyama[1], Yuichiro Ueno[2,3,4]

[1] Niigata University (aoyama@geo.sc.niigata-u.ac.jp)

[2] Tokyo Institute of Technology

[3] Earth-Life Science Institute

[4] Japan Agency for Marine-Earth Science and Technology

Non-mass dependent sulfur isotopes are found in the Archean rocks, probably owing to the low oxygen concentration in atmosphere at that time (e.g., Farquhar et al., 2000). While most of the sulfide minerals in Archean sedimentary rocks show positive $\Delta^{33}S$ (and negative $\Delta^{36}S$) anomaly, volume, occurrence and anomaly of Archean sulfate deposits, which exhibit negative $\Delta^{33}S$ (and positive $\Delta^{36}S$) anomaly, is limited. This suggests that the presence of missing Archean sulfur reservoir somewhere. In general, seawater sulfate is fixed in the oceanic crust in the forms of sulfate minerals (e.g., gypsum) during hydrothermal circulation and sulfide minerals (e.g., pyrite) by microbial and inorganic sulfate reduction processes. Therefore, Archean greenstone is one of the potential candidates compensating for the missing. Another candidate is Archean granitoid, because Archean granitoid may be generated by slab melting (Martin et al., 2005). However, multiple sulfur isotopes of those igneous rocks are poorly studied. In order to evaluate the missing sulfur Archean reservoir, we have measured multiple sulfur isotopes of Archean greenstone exposed in North Pole Dome and Archean granitoid in Mount Edgar Complex, Pilbara craton, Western Australia.

We newly introduced Degree of Anomaly Contribution (DAC) value. The DAC value was simply calculated by multiplication of the total volume, average sulfur concentration and average sulfur isotopes anomaly in specific material. DAC value of total Archean sulfate deposits is three magnitudes lower than that of Archean sedimentary sulfide, clarifying the missing. On the other hand, Archean greenstone and granitoid are two magnitudes lower than that of Archean sedimentary sulfide. We concluded that the missing is owing to the Archean oceanic crust subducted into the mantle, which is comparable DAC value assuming similar subduction rate to modern and similar sulfur concentration and isotopes anomaly to Archean greenstone. This suggests approximately 8vol.% of the mantle has sulfur isotopes anomaly, evidenced by sulfur isotopes anomaly in modern OIB (Cabral et al., 2013; Delavault et al., 2016).

P19

Crystallization of metasomatic sulfide melt, and recrystallization of crystalline sulfides constrained by sub-µm-scale investigations for PGE-bearing sulfide inclusion in Tahitian harzburgite xenolith

Norikatsu Akizawa[1], Akira Miyake[2], Yohei Igami[2], and Tetsu Kogiso[3]

[1] Atmosphere and Ocean Research Institute, The University of Tokyo
(akizawa@aori.u-tokyo.ac.jp)
[2] Graduate School of Science, Kyoto University
[3] Graduate School of Human and Environmental Studies, Kyoto University

Platinum-group elements (PGEs) in mantle peridotites have been targeted as geochemical tracers of core–mantle evolution, as they are highly siderophile. Meanwhile, ascending melts produced by partial melting of the mantle potentially disturb PGE composition recorded during early Earth's history. To fully facilitate the PGE as the geochemical tracer of core–mantle evolution, mineralogical and geochemical characteristics of metasomatic PGE host minerals, such as platinum-group minerals (PGMs) and base-metal sulfides (BMSs), should be properly investigated in metasomatized mantle peridotites.

A sub-micrometer-sized PGE-bearing sulfide inclusion in harzburgite xenolith from Tahiti island (Society Archipelago) was investigated down to the scale of sub-micrometer, employing transmission electron microscope with energy dispersive X-ray spectrometer (TEM-EDS). The sulfide inclusion is of metasomatic origin as it is enveloped by carbonaceous glass (21.2 at% C), and forms inclusion array with other sulfide–carbonaceous glass inclusions in host clinopyroxene crystal. The Tahitian harzburgite xenolith is, therefore, sufficient appropriate material for elucidating metasomatic behavior of PGEs during carbonatitic metasomatism in the mantle.

With the mineralogical and geochemical investigations by the TEM-EDS, the sulfide phases were identified: Fe-rich monosulfide solid solution (MSS), Ni-rich MSS, Fe-rich pentlandite, Ni-rich pentlandite, sugakiite, heazlewoodite, chalcopyrite, and Cu-Ir-Pt-Rh-thiospinel (cuproiridsite–malanite–cuprorhodsite). Considering empirical evidence, the first crystallization product from metasomatic sulfide melt was primary MSS below 1,000 ºC. The primary MSS was recrystallized into the sulfides at low temperatures down to 500 ºC, below which Ni-rich pentlandite and heazlewoodite can coexist. During the recrystallization process, most of Cu contained in the primary MSS was absorbed into the sugakiite (6.9 at% Cu). The other Cu-rich sulfides such as chalcopyrite (25.7 at% Cu) and Cu-Ir-Pt-Rh-thiospinel (15.1 at% Cu, 26.5 at% Ir, 8.2 at% Pt, and 1.2 at% Rh) were crystallized directly from evolved Cu-rich sulfide melt after the primary MSS crystallization below 760 ºC. Hence, the PGE was preferentially partitioned into the evolved Cu-rich sulfide melt. The preferential partitioning of PGE into the evolved Cu-rich sulfide melt is attributed to high metal/sulfur ratio (~1.2). The coupling mobility of Ir, Pt, and Rh might function in the case of metasomatic activity involving carbonatitic melts in the mantle. Since the primary MSS was first crystallized at ca. 1,000 ºC through carbonatitic melt involvement, and cooled down to ca. 300–500 ºC before entrainment to the surface via host nephelinite–alkali basalt magmas, the genesis of the carbonatitic melts were not attributed to magmatism of the host nephelinite–alkali basalt, or rather might be related to plume-derived magmatism.

P20

Quantitative isotope imaging methods using secondary ion mass spectrometry

Shoichi Itoh[1]

[1] Dept. Earth Planet. Sci., Kyoto University (sitoh@kueps.kyoto-u.ac.jp)

Direct ion imaging with secondary ion mass spectrometry (SIMS) has been developed in various fields, such as Material sciences, Earth and planetary sciences, life sciences. Especially, quantitative direct ion imaging techniques has recently developed using stigmatic direct ion imaging methods (e.g., Nittler, 1999; Yurimoto et al., 2003).

In this study, we try to develop the stigmatic secondary ion imaging methods using Cameca ims-4fE7 SIMS at Kyoto University. The imaging detector system consists of micro-channel plate (MCP), florescent screen and Cooled 16bit charged-coupled device (CCD) camera (BU-LN52 Bitrun Co.). This conventional imaging system needs to estimate the calibration parameter with conversion from ion to electron, and from electron to photon.

In principle, each micro-channel of MCP would be different conversion parameter for electron converted from secondary ions. Therefore, in order to estimate the qualitative ion imaging using this system, we need to estimate the error of this conversion parameter in different location of each channel.

In this talk, we introduce the estimation of calibration parameter between the light output count rate read by CCD camera and the count rate of secondary ions incident on MCP with different experimental session. We will estimate the error of each nonlinear exponent parameter for five places (50 x 50 pixels) and these different parameters cause the error of about 5%. We will discuss it in detail with quantitative isotope imaging with application of high-pressure experiments.

P21

Behavior of highly siderophile elements in mantle peridotite and its bearing on the primitive mantle composition

Tetsu Kogiso[1] and Norikatsu Akizawa[2]

[1] Graduate School of Human and Environmental Studies, Kyoto University
(kogiso@gaia.h.kyoto-u.ac.jp)
[2] Atmosphere and Ocean Research Institute, The University of Tokyo

Concentrations of highly siderophile elements (HSE: Ru, Rh, Pd, Re, Os, Ir, Pt and Au) in the Earth's mantle are controlled by differentiation processes involving metal and sulfide phases, and therefore give us key insights into the core-mantle differentiation in early Earth's interior and core-mantle interaction during the Earth's history. The HSE abundances of hypothetical primitive mantle have been estimated on the basis of HSE concentration data of fertile lherzolite samples and their covariations with other components like Al_2O_3 that are thought to indicate the extent of melt extraction. However, primary causes of the covariations of HSE with other components in mantle peridotites are not well understood yet, indicating potential large uncertainty in the estimated values of the primitive mantle HSE composition. Concentrations of HSE in mantle peridotites are controlled by mainly partial melting and metasomatism, but it is generally difficult to distinguish the effects of these two processes, because it is not clear how and to what extent HSE are mobilized with silicate melt and aqueous-carbonaceous fluid phases. Recent submicrometer-scale analyses of HSE in natural peridotites have revealed that HSE are mainly hosted by base-metal sulfides (BMS) and platinum-group minerals (PGM) in peridotite. High-temperature/high-pressure experimental works have also revealed that BMS are likely to be molten along a normal mantle geotherm whereas some PGM phases such as Ir-Os alloy persist in residual solids. These studies anticipate that peridotites that experienced large extent of melt extraction would show HSE abundance patterns highly depleted in "incompatible" HSE like Pt, Pd and Re. However, HSE patterns of natural peridotite samples do not always show clear correlations with melt extraction indicators. Our submicrometer-scale petrologic and mineralogical observations of a Tahitian peridotite xenolith revealed that carbonaceous melt could mobilize incompatible HSE together with some of "compatible" HSE like Ir. It is thus suggested that the behavior of HSE in melting and metasomatic processes of carbon-bearing peridotite systems should be considered in estimating the HSE abundances in the primitive mantle.

P22

Seismic scatterers in the lower mantle near subduction

Satoshi Kaneshima

Dept. of Earth and Planetary Sciences, Faculty of Science, Kyushu University, Motooka, Nishi-ku, Fukuoka, JAPAN

We investigate the distribution of S-to-P scatterers in the lower mantle beneath subduction zones, where seismicity extends down to the bottom of the upper mantle and where downwelling mantle flows probably dominate. We find many strong S-to-P scatterers shallower than 900 km, at all of the subduction zones around Pacific; Peru to Bolivia, Tonga-Fiji, Vanuatu, Bismarck, Indonesia, Philippine-Mindanao,Mariana, Izu-Bonin, Japan Sea, Kuril, and Okhotsk. Prominent shallow lower mantle scatterers are found also beneath southern Spain where the deepest seismicity occurs indicating the subduction of an oceanic lithosphere. Anomalous later phases in the P coda often arrive along off-great circle paths, and with positive and nearly zero slowness relative to direct P. Most of them thus cannot be S-to-P conversion at a globally horizontal discontinuity, but are more adequately interpreted as a scatterer. The delay times of the S-to-P waves after P waves vary from 20 s to greater than 100 s, and the number of observations markedly drops above about 50 s. The number of S-to-P scatterers decreases below about 900 km, although there are certain numbers of deeper S-to-P scatterers. S-to-P scatterers deeper than 2000 km are not observed. Many of the scatterers are fairy pronounced, characterized with a much larger amplitudes than the anomalous phases arriving earlier and probably representing "S660P" waves. This indicates that the elasticity jumps at the scatterer are larger and occur more abruptly than the post-spinel transformation.

P23

Observation of multipathing at the western edge of the Pacific Large Low-Shear-Velocity Province

Sunil K. Roy[1,2], Nozomu Takeuchi[1], D. Srinagesh[2], M. Ravi Kumar[2,3], and Hitoshi Kawakatsu[1]

[1]Earthquake Research Institute, The University of Tokyo, Tokyo – 1130032, Japan (sunilroy@eri.u-tokyo.ac.jp)
[2]CSIR-National Geophysical Research Institute, Hyderabad – 500007, India
[3]Institute of Seismological Research, Gandhinagar – 382009, India

The waveforms of five deep earthquakes from the Fiji-Tonga subduction zone recorded by a seismic array in India reveal a secondary pulse just after the Sdiff phase. We obtained 51 observations for this pulse, in the distance range of 102.0° to 115.1°. The pulse is sharper on the northern part compared to the southern part of the array, with a azimuthal variation. The relative arrival time of the second pulse varies from 3.0 to 9.9 s with respect to the first pulse, with its arrival getting delayed from north to the south along the seismic array, albeit the south array being closer to the earthquake sources. At present, we choose to interpret the first pulse in terms of the Sdiff phase whose ray path reaches the CMB inside the Pacific Large Low-Shear-Velocity Province (LLSVP) and then passes along the vertical side of the LLSVP. The second pulse is probably the direct S and its diffracted at the top of the LLSVP. The ray path goes into the LLSVP but bottoms above the CMB. It appears that the second wave seems to have stronger amplitudes when the ray bottoms inside the LLSVP and the sharp vertical boundary lies after the bottoming point. We attempt to model the relative timing of the first and secondary pulses as well as the absolute arrival times of the first pulse by incorporating varying thickness and shear wave velocity on either sides of the boundary. At the time of the presentation, we plan to show our velocity model including azimuthal variability, to explain the observed data.

P24

Examination of local geomagnetic jerks using wavelet analysis

Hisayoshi Shimizu[1]

[1] Earthquake Research Institute, University of Tokyo (shimizu@eri.u-tokyo.ac.jp)

Detection of geomagnetic jerks, sudden variation of secular acceleration of the geomagnetic field components, has been tried using wavelet analysis by considering that a geomagnetic jerk is a singularity in time-series. It has been confirmed that geomagnetic jerks occurred globally around 1968 and 1978 (Alexandrescu et al., 1995).

Observation of geomagnetic field using satellites allowed identifying local geomagnetic jerks of 2003 and 2007 (e.g. Chulliat et al., 2010), whose signatures are seen strongly in south Atlantic region in secular acceleration map. We attempted to analyze the two local geomagnetic jerks by applying a wavelet analysis on time series of magnetic field at geomagnetic observatories. The analyzing wavelet is the same as that used by Alexandrescu et al. (1995). The two local geomagnetic jerks were successfully identified in wavelet transform at Mbour (MBO, Senegal), but only the one around 2007 was identified in that at Chambon la Foret (CLF, France). The global jerks and local jerk around 2003 at MBO showed similar regularity. However, the regularity of the local jerk around 2007 at MBO and CLF is higher than that of the other jerks. These results might imply that the generation mechanism of the local geomagnetic jerk around 2007 is different from those occurred globally around 1969 and 1978 and locally around 2003.

References:

Alexsandrescu, M. et al., 1995, JGR, 100, 12,557-12,572.

Chulliat, A. et al., 2010, GRL, 37, L0730.

The evaluation of the chemical variation in a single granitic rock suite revealed by grid sampling toward improving the accuracy of geoneutrino flux

Kazuki Minami[1], Kenta Ueki[2], Tsuyoshi Iizuka[3], Sanshiro Enomoto[4], and Hiroyuki K.M. Tanaka[1]

[1] Earthquake Research Institute, University of Tokyo (kminami@eri.u-tokyo.ac.jp)
[2] Japan Agency for Marine-Earth Science and Technology
[3] University of Tokyo
[4] University of Washington

Geoneutrino, which is emitted in decay of radioactive elements in the earth, was firstly observed on the KamLAND (Araki et al., 2005). In the past decade, enough data is observed by KamLAND to estimate the U-Th abundances in the core or mantle (The KamLAND Collaboration, 2011). Geoneutrino enables us to conduct direct estimation of the U-Th abundances in the earth. In order to obtain the U-Th abundances with high accuracy based on the geoneutrino data, it is important to estimate the U-Th distributions in the crust near the KamLAND (Enomoto et al., 2007). Takeuchi et al. (in review) showed U-Th distributions in the Japanese crust using the new method, which combined the three-dimensional lithology model inferred from seismic velocity structure and the rock composition model.

The new compositional model enables us to infer the geoneutrino flux from the Japanese crust. However, calculated geoneutrino flux from the Japanese crust has large uncertainties. One reason of the uncertainty is derived from wide compositional variations of the U-Th concentrations in one geological unit. These wide compositional variations make it difficult to estimate the uncertainty of the typical U-Th concentration values in one geological unit, which leads to the large uncertainty of geoneutrino flux. If the U-Th distributions in a single rock suite are known, the large uncertainties of 70% on geoneutrino flux from the Japanese crust can be reduced to 30% at a maximum.

In order to understand the distributions of element concentrations in a single rock suite or the relationship between sample size and the U-Th concentrations, we sampled granitic rocks from Inada granite, Kasama city, Ibaraki prefecture. Inada granite is 60Ma (Arakawa and Takahashi, 1988) medium-grained granite (Takahashi et al., 2011) in the Ryoke Belt (Ishihara, 1977). We conducted grid sampling in two stone quarries. Precise locations were obtained by a high-precision GNSS receiver. Several 2-centimeter cube were cut from one rock sample and each cube was analyzed by XRF analysis. From obtained data, the relationship between the compositional variation and sample size are discussed.

P26

The new database for composition of the basement rocks of Japanese islands with accurate location information for geo-neutrino modeling

. Kenta Ueki[1], Satoru Haraguchi[1], Mika Mohamed[1], Shunsuke Horiuchi[1] and Hikaru Iwamori[1,2]

. [1] Japan Agency for Marine-earth Science and Technology
(kenta_ueki@jamstec.go.jp)
. [2] Department of Earth and Planetary Sciences, Tokyo Institute of Technology

With the aim of determining the amount of radioactive elements contained in the earth's core and mantle with high precision using the world's highest precision geoneutrino data obtained with KamLAND, Takeuchi et al. (submitted) constructed the 3D lithological model of the Japanese crust. Based on the lithological map, Takeuchi et al. (submitted) constructed the 3D U-Th distribution map in the Japanese crust, and evaluated flux of the crustal origin geoneutrino at KamLAND using the 3D U-Th distribution map. Takeuchi et al. (submitted) showed that information regarding the spatial correlation of U-Th concentration of a rock type of interest is necessary to obtain the flux of the crustal origin geoneutrino with the higher precision. Geochemical data with the precise sample locality is necessary to obtain information on such spatial correlation.

For the purpose, we construct a new dataset for the chemical composition of the basement rocks of the Japanese crust with the accurate location information. The database is called "DODAI" and was presented by Haraguchi et al. (submitted). It consists of 1618 data points including U-Th concentration, the accurate location coordinates, geological information and sample description at present. Concentrations of multiple elements are included in this dataset. We present U-Th concentrations and its geographical systematics of various rocks in the database, as well as its variations among various rock types.

Using the dataset, we can analyze spatial correlations of rock compositions between various rock suites or rock types in various spatial length. Using the information on spatial correlations, we can obtain quantitative geoneutrino probability density function (pdf) derived from Japan arc crust.

P27

Effects of iron on the lattice thermal conductivity of lower mantle minerals evaluated by *Ab initio* anharmonic lattice dynamics simulations

Haruhiko Dekura[1], Taku Tsuchiya[1,2]

[1] Geodynamics Research Center, Ehime University (dekura.haruhiko.mf@ehime-u.ac.jp)
[2] Earth-Life Science Institute, Tokyo Institute of Technology

Determination of lattice thermal conductivity (κ_{lat}) of lower mantle (LM) minerals is a key to understanding the dynamics and evolution of the earth's deep interior. Some recent experimental studies have shown that κ_{lat} of MgO and $MgSiO_3$ are substantially reduced by Fe incorporation (Manthilake et al., 2012; Goncharov et al., 2015; Ohta et al., 2017; Hsieh et al., 2017); Okuda et al. (2017) reported very weak effects on $MgSiO_3$ at lowermost mantle pressure. So, experimental results are still largely scattered and effects on Fe in κ_{lat} remains unclear. We recently established an *ab initio* technique to compute κ_{lat} of Fe-free systems based on the density-functional theory (DFT) combined with fully solving the phonon Boltzmann transport equation, which was successfully applied to MgO (Dekura and Tsuchiya, 2017). In this study, the technique is extended further to Fe-bearing systems, $(Mg,Fe)SiO_3$ bridgmanite (Brg) and (Mg,Fe)O ferropericlase (FP), combined with the internally consistent DFT+*U* technique (Wang et al., 2015). Calculations demonstrate strong solid solution effects in both Brg and FP. The effects of Fe are found to be caused mainly by the substantial changes in harmonic properties.

P28

The dependence of mantle convection in super-Earths on the planetary mass

Takehiro Miyagoshi[1], Masanori Kameyama[2], Masaki Ogawa[3]

[1] JAMSTEC (miyagoshi@jamstec.go.jp)
[2] Ehime University (kameyama@sci.ehime-u.ac.jp)
[3] University of Tokyo (cmaogawa@mail.ecc.u-tokyo.ac.jp)

A large number of super-Earths, which are terrestrial exoplanets with larger mass than the Earth's, have been discovered in this century. Physics of mantle convection in super-Earths is one of the most important keys for understanding the habitability of them because it controls the surface tectonics and material circulation such as carbon dioxide in the planets. In Miyagoshi et al. (2014, 2015), we show that the strong effect of adiabatic compression, or the large dissipation number in massive (ten times the Earth's mass) super-Earths significantly affects thermal convection in their mantle.

In this paper, following these results, we conduct numerical simulations of thermal convection in the mantle of super-Earths of various mass. All of the dissipation number, the Rayleigh number, the depth-dependence of the thermal expansivity and the reference density change in accordance with the planetary mass. We found that the effects of adiabatic compression become conspicuous when the planetary mass exceeds about *Mp*=4 where *Mp* is the planetary mass normalized by the Earth's. The vigor of hot plumes ascending from the core-mantle boundary becomes significantly weak when the planetary mass exceeds the threshold. The thickness of the lithosphere becomes about twice from *Mp*=1 to 10 while the magnitude of flow velocity of convection is almost independent of *Mp* although the Rayleigh number increases as *Mp* increases. These results give important suggestions to discuss the operation of plate tectonics in super-Earths.

P29

Basic features of the kinematic dynamo action associated with top-down type convection in a rotating spherical shell

Hinami Taniguchi[1], Futoshi Takahashi[2]

[1] Kyushu University (hinami.taniguchi.725@s.kyushu-u.ac.jp)
[2] Kyushu University

Terrestrial planets which maintain their intrinsic fields have convection driven by either thermal or compositional, or both kind of buoyancy in the cores. In case of the Earth, it is believed that compositional convection, which is fed by light element ejection from the ICB upon inner core growth, is currently dominant and powers the geodynamo. On the other hand, the geodynamo would be driven by thermal convection alone in the past mostly fueled by removal of core heat through the CMB by mantle convection: namely "top-down" type convection. Although it is well known that the velocity field powered by these driving forces and the resultantly generated magnetic fields are different from each other, the reason why they are distinct is not evident. In this study, the basic feature of the top-down type of dynamo action is investigated by numerically solving a kinematic dynamo problem.

We consider an electrically conducting fluid contained in a rotating spherical shell, in which a stationary flow given by linear stability analysis for top-down convection exists. Ekman number E_k is adopted in the range of 2×10^{-4} to 10^{-3}. The induction equation is solved by time-marching with an initial axial dipole field given as a seed. In this results, the critical magnetic Reynolds number R_{m_c} shows a positive correlation with E_k in a regime of relatively low E_k. A possible interpretation of the relation arises from the fact that the helicity of convection increases with decreasing E_k. Then, the enhanced helicity could make it easier to regenerate the poloidal magnetic field. The efficient generation of the poloidal field might result in decrease of R_{m_c}.

P30

Normal mode splitting functions for CMB sensitive modes

Naoki Suda

Hiroshima University (nsuda@hiroshima-u.ac.jp)

Observations of long-period free-oscillation spectra provide constraints on the Earth's internal structure on scale lengths of a few thousand kilometers. Lateral heterogeneity in the Earth's interior has been obtained as 'splitting function coefficients' from analyses of normal-mode spectra using least-squares inversion. Splitting function coefficients are linearly dependent upon the Earth's internal structure. Although most studies on splitting function coefficients were done in 1990s (e.g. Resovsky & Ritzwoller 1998), accumulation of high-quality seismic records of large earthquakes urged new studies (e.g. Deuss et al. 2013). Even in those new studies, however, obtained are mostly splitting function coefficients for elastic structure; those for anelastic structure have not yet been fully obtained.

In this study I obtained splitting function coefficients not only for elastic structure but for anelastic structure. The target modes are 1S8, 1S9 and 1S10, which are sensitive to structure near the core-mantle boundary. I measured apparent complex frequencies of these modes by applying the Sompi method to records from broadband seismic stations for large earthquakes. Then splitting function coefficients were obtained by using a non-linear inversion method. Although I obtained only 'self-coupling' coefficients in this study, the effect of full coupling between multiplets (Deuss & Woodhouse 2001) was included in computations of theoretical apparent complex frequencies of the target modes in the inversion process.

From intensive synthetic tests, it was confirmed that spherical harmonic degree-2 of anelastic lateral heterogeneity could be resolved by using the observed data. I obtained consistent patterns of lateral heterogeneity with degrees 2, 4 and 6 among the three modes for elastic structure. The degree-2 patterns for anelastic structure are well correlated between 1S8 and 1S9. The patterns for elastic structure are correlated with the recent results of Deuss et al. (2013) and the pattern derived from S40RTS (Ritsema et al. 2011). The patterns for anelastic structure showed low attenuations beneath Indonesia and central Atlantic regions, which do not correlate with the low-velocity anomalies.

P31

Bayesian Inference of 3-D Lithology Distribution Using a Seismic Tomography Model: Effects of Lithology Mixture

Nozomu Takeuchi[1], Kenta Ueki[2], Tsuyoshi Iizuka[1], and Sanshiro Enomoto[1,3]

[1] University of Toyo (takeuchi@eri.u-tokyo.ac.jp)

[2] Japan Agency for Marine-Earth Science

[3] University of Washington

We present a method to infer 3-D lithology distribution using a seismic tomography model. We first assume a prior probability map of lithology, $P^{(\boldsymbol{x})}(i)$, the probability that rock at location $\boldsymbol{x}$ is type i. This prior probability allows us to take local lithological features into account. In this study, to apply our method to calculate the flux at Kamioka, Japan, we use the lithology of the Hidaka metamorphic belt in Hokkaido, northern Japan, as the prior. The crustal section of the Hidaka metamorphic belt is expected to represent a typical example of crustal lithology in the Japan arc system.

We then update the probability using Bayes theorem. We refer to a seismic tomography model to get the P velocity data at $\boldsymbol{x}$, v^{obs}, and compute the posterior probability map $P^{(\boldsymbol{x})}(i|v^{obs})$, which constrains i to those rock types for which the P velocity is likely to be around $v^{obs(\boldsymbol{x})}$. Note that, in contrast to previous studies, we did not use seismological models with somewhat *ad-hoc* segmentations of, for example, upper, middle and lower crusts. The use of the tomography model obtained in a reproducible manner allows us to evaluate the errors of the seismological data straightforwardly. To compute the posterior probability map, $P^{(\boldsymbol{x})}(i|v^{obs})$, we develop an appropriate Bayesian velocity-lithology translator. We refer to laboratory experiments by Christensen and Mooney (1995) for P velocities of various rock types in the crust. We also develop an appropriate method to take lithology mixture into account and discuss the differences in the obtained models with and without that effect.