Newsletter of the Global COE program

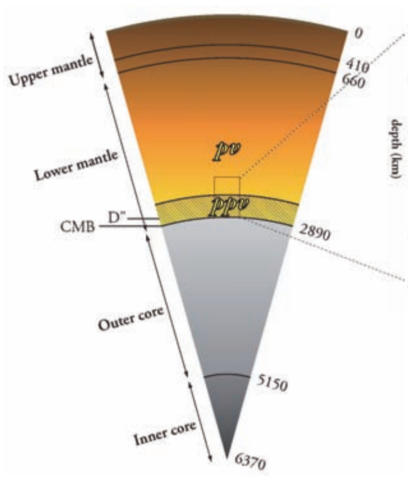
Deep Earth Mineralogy

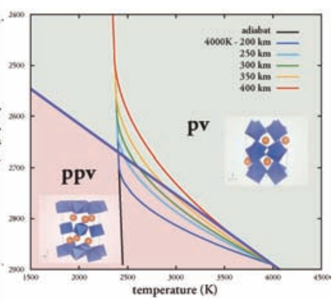
Center for Advanced Experimental and Theoretical Deep Earth Mineralogy
先進的実験と理論による地球深部物質学拠点

No. 5, May 21, 2010

News & Events

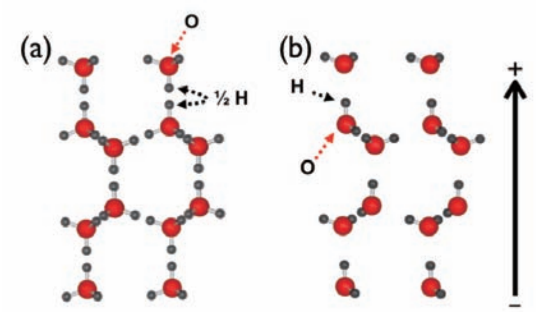
Predicted temperatures at CMB





Prof. T. Tsuchiya of the GRC and Dr. K. Kawai of a JSPS post-doc at Tokyo Inst. Tech. and IPG Paris developed a comprehensive model based on the radial variations of the shear velocity in the D" layer (the base of the lower mantle) and the elastic properties of major candidate minerals at high pressure and temperature, including the effects of post-perovskite phase transitions. This model shows a temperature profile in the lowermost mantle with a temperature of ~3800 K at the core-mantle boundary (CMB). They also concluded that lateral temperature variations of 200–300 K can explain much of the large velocity heterogeneity observed in the D" layer. A single-crossing phase transition model was also suggested to be more favorable in reproducing the observed seismic wave velocity structure than a double-crossing phase transition model. This result was reported in the Proceedings of National Academy of Science (PNAS), USA, issued on 29 December, 2009.

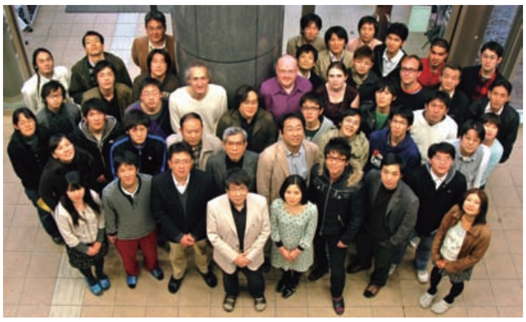
Measurements of hydrogen-ordering in ice XI



Hydrogen-ordering in water ice induces a dramatic change in its properties. Hydrogen atoms in normal ice (ice Ih) are distributed in two crystallographically equivalent sites along the O–O bond (Fig.(a)). In contrast, hydrogen atoms of ice XI, the hydrogen-ordered phase of ice Ih, are located at one site (Fig.(b)) and the crystal structure with ordered hydrogen atoms results in ferroelectricity. Mr. Arakawa (PhD student) and Prof. H. Kagi of Geochemical Lab, Univ. Tokyo, who are the members of the present COE, measured the infrared absorption spectra of ice XI and clarified that the width of the libration mode of ice significantly narrowed with the transition from ice Ih to ice XI (Arakawa et al., Astrophys. J. Suppl. Ser., 184, 2009). Earlier studies suggested that ferroelectric ice (ice XI) may exist in Pluto and Charon, although no direct evidence for ice XI has been reported from astronomical observations. The present results demonstrate that the infrared observation is a potentially important method for searching ice XI in extraterrestrial environments.

New appointments at GRC

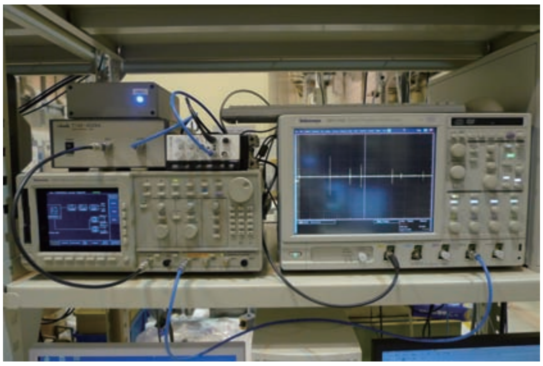
Dr. Matthew L. Whitaker, a former COE Postdoctoral Fellow, has been appointed as a Jokyo (Assistant Professor) at the GRC. Dr. Whitaker has been working on ultrasonic sound velocity measurements at high pressure and temperature under the supervision of Prof. Baosheng Li of the Mineral Physics Institute (MPI), Stony Brook University, who is an official member of the present global COE program. Meanwhile, Dr. Arnaud Metsue arrived at the COE Postdoctoral Fellow position in February 2010, who received his PhD from Univ. Lille-Sciences and Technologies, supervised by Prof. Patrick Cordier, for his first-principles study on modeling of stacking faults. Also joining the GRC is Dr. Haruhiko Dekura, who gained his PhD from Osaka University in solid state physics, and took up the Postdoctoral Fellow position for the GRC branch of Senior Research Fellow Center, Ehime University, in April 2010. At the same time, Dr. Masayuki Nishi, a former PhD student from Kyushu University, joined the GRC as a JSPS Postdoctoral Fellow. Dr. Nishi has been working on kinetics of some high-pressure minerals included in natural diamonds to address the ascending speeds of diamonds in the deep mantle, supervised by both Profs. Takumi Kato and Tomoaki Kubo. The GRC now has 16 faculty staff members, including three COE professors and two tenure-track Senior Research Fellows, as well as 13 Postdoctoral Fellows (including one Research Fellow) working in the field of deep Earth mineralogy.



Global COE
DEEP EARTH MINERALOGY
EHIME UNIVERSITY JASRI, UNIV.TOKYO, SBU

Sound velocity measurement under lower mantle conditions

Dr. Y. Higo of JASRI, who is a former PhD student at the GRC, has set up a new system for measurement of elastic wave velocities at BL04B1, SPring-8. He successfully measured sound velocities at pressures exceeding 25 GPa and temperatures to 1500 K, using a combination of ultrasonic measurements and *in situ* X-ray observations in a large-volume multianvil apparatus. Some GRC members have been extensively working to synthesize high-quality sintered-bodies of various high-pressure phases, including $MgSiO_3$ perovskite, and the ultrasonic technique, originally developed by the research group of SUNY at Stony Brook, will allow them to study the elastic properties of high-pressure phases under the pressure and temperature conditions of the Earth's lower mantle.



External evaluation of the COE program

The annual meeting for reporting activities of the present program on Deep Earth Mineralogy was held on the 15 and 16 of March, attended by the faculty staff members, post-doctoral and research fellows, and students of the GRC and the relevant laboratories, as well as the members of the internal and external evaluation committees, including the president of Ehime University. The outlines on the performance and outcomes from the program were summarized by Profs. T. Irifune, T. Inoue, and T. Tsuchiya of the GRC, followed by reports from the individuals and the principal investigators of each research group in oral and poster presentations. The external committee concluded that the present program has performed well overall in light of its original purposes, and made some constructive comments on future directions for the program, which will be taken into account in conducting the current program.

Spring school for high-pressure neutron studies

A joint school was held at the GRC on the topics relevant to the high-pressure neutron beamline ("PLANET"), which is currently being constructed as one of the beamlines for neutron studies at J-PARC, sponsored by two nation-wide Kakenhi projects (P.I. Profs. T. Yagi and H. Kagi, respectively) and the present COE program. About 50 researchers and students attended the school, where a lecture by Dr. Hattori was given on the current status of the beamline construction and the new facility to be installed in PLANET, followed by an intensive discussion focusing particularly on the design of the new high-pressure apparatus. A visit to the factory of Sumitomo Heavy Industries Co. Ltd. was also organized by Prof. T. Inoue of the GRC, which was attended by many of the participants. Sumitomo is known as the manufacturer of the famous "Sumi-presses", including those at Stony Brook and Bayreuth, and is located in Niihama city, Ehime Prefecture, close to the GRC.

GRC team selected as PU at SPring-8

The GRC high-pressure experiment team was selected as one of five Power Users (PU) among hundreds of research groups working at SPring-8, to which intensive supports are given by JASRI. The main subjects to be studied during the appointed PU term of 5 years are: 1) rheological studies of mantle minerals, 2) sound velocity measurements under lower mantle conditions, 3) phase transitions and P-V-T studies using sintered diamond anvils, and 4) applications of ultra-hard nano-polycrystalline diamond (NPD or HIME-DIA) invented by the GRC to various high-pressure apparatus. Some interdisciplinary studies, such as synthesis and characterization of new hard materials and high-temperature super-conductors, will also be conducted. The team is planning to replace the existing DIA-type guide block system of the 1500-ton multianvil apparatus (SPEED-MkII) with a new large deformation-DIA system (MADONNA) available at the GRC for such advanced studies at BL04B1 in the summer of 2010.

Long-term visiting PhD students from Edinburgh, UK

A PhD student from CSEC (Center for Science at Extreme Conditions), University of Edinburgh, UK, Mr. Shigeto Hirai, stayed and joined in experimental studies at the GRC for about a month from February to March, 2010. He made many successful high pressure and temperature (PT) runs using Kawai-type apparatuses installed at the GRC, Orange-2000 and Orange-3000, driven by 2000 and 3000 tons hydraulic rams, up to about 25 GPa and 1600 K. He succeeded in synthesizing novel materials with perovskite and post-perovskite structures. He also performed some high PT experiments using a diamond anvil cell to study the stability of the newly synthesized materials at higher pressures up to about 60 GPa. He is planning to carry out further characterization and physical property measurements of the synthesized materials at CSEC, University of Edinburgh.

News & Events

Completion of MADONNA-II at SOSEKI LAB

A new DIA-type apparatus, MADONNA-II, has been installed at the SOSEKI Lab, GRC, in February 2010, sitting next to a larger multianvil press, BOTCHAN-6000. The basic design of MADONNA-II is similar to that of its original version, MADONNA-1500, but the former apparatus is aimed mainly at conducting high-pressure and temperature experiments under lower mantle conditions using sintered diamond anvils while the latter focuses on rheological studies utilizing its deformation-DIA mechanism. The other three multianvil apparatus at the GRC, ORANGE-1000, -2000, and -3000 are used for "ordinary" experiments at pressures up to 30 GPa, as well as for collaborations with external users.

The 3rd International Special Lecture

The third COE International Lecture was given by Dr. Catherine McCammon of Bayerisches Geoinstitut (BGI), Germany, on 9 and 10 February 2010, attended by the students, post-docs, and staff members of the GRC and other relevant laboratories. Dr. McCammon gave two 3-hour lectures entitled as "Transition metal chemistry and the Earth's interior" and "Oxygen fugacity and the Earth's interior", as well as a shorter talk on her recent study on Fe spin-transitions as one of the COE International Frontier Seminar, followed by intensive discussion on these topics with the participants. GRC and BGI hold an agreement about mutual research collaborations and exchange of people, and a PhD student of BGI stayed at the GRC for four months for internships based on this agreement last year. Dr. McCammon also enjoyed staying in Matsuyama for 10 days, visiting Kashima-island in the Seto inland sea and climbing Miyuki-hill behind the campus of Ehime University.

International Frontier Seminer

16th (9 Feburuary)
"Effect of spin transitions on properties and dynamics of the lower mantle"
Lecturer : Dr. **Catherine McCammon** (Staff Scientist, Bayerisches Geoinstitut, Universität Bayreuth, Germany)

17th (19 March)
"The role of mineral physics in modelling geodynamics of the lower mantle"
Lecturer : Prof. **David A. Yuen** (University of Minnesota, USA)

18th (26 March)
"Combined flexural and torsional oscillation methods for laboratory study of viscoelasticity and poroelasticity"
Lecturer : Prof. **Ian Jackson** (Research School of Earth Sciences, Australian National University, Australia)

Forthcoming Events

19th International Frontier Seminar

"Melting of peridotite to 160 GPa"
Lecturer: Prof. **Guillaume Fiquet** (Institut de Minéralogie et de Physique des Milieux Condensés, UMR CNRS 7590, Université Pierre et Marie Curie Paris 6) (Date: end of May, 2010)

2nd TANDEM Symposium at CUG, Wuhan

Following the first TANDEM symposium held in Matsuyama in 2008, the second symposium will be held at one of the National Key Laboratories of China University of Geoscience in Wuhan on 5-7 November 2010. Young scientists and faculty members from various laboratories of TANDEM will gather and have two-day presentations on their latest studies relevant to Deep Earth Mineralogy, followed by an excursion. At the moment, 26 laboratories of 5 Asian countries in this field join TANDEM to enhance research collaborations and exchange of information/people among these laboratories. For further details on the Symposium, see the TANDEM pages of this issue.

An international session at JpGU 2010 Meeting on May 25

An international session entitled "Mineral physics and dynamics of deep mantle" will be held on May 25, as one of the sessions of the Japan Geoscience Union (JpGU) Meeting 2010 in Makuhari during 23 - 28 May. In this session, twenty-nine (22 for oral and 7 for poster) papers from various disciplines on mineral physics and geodynamics of the planetary interiors will be presented by researchers from many countries, with special focuses on (1) thermal/chemical structure, (2) behaviours of fluids and/or hydrous minerals, and (3) rheology of the deep mantle. Those who are interested in deep Earth mineralogy are greatly encouraged to join the discussions in this session. We particularly welcome researchers/students of TANDEM laboratories, to enhance mutual communications and collaborations in Asian countries. Dr. M. Kameyama, Assoc. Prof. of the GRC, will act as the main convener for this session. For further details, see the JpGU website (http://www.jpgu.org/) or directly contact Dr. Kameyama (kameyama@sci.ehime-u.ac.jp).

The 3rd YESA Workshop in September

The 3rd Young Earth Scientist Association (YESA) workshop will be held at the Geodynamics Research Center on 2-3 September, 2010. This workshop aims to have valuable presentation and discussion of recent researches in water and hydrogen. Nowadays, deep Earth water is studied by many research fields, particularly focusing on structure and properties of hydrated magma, and on phase transition of water and hydrogen-bearing substances. In this workshop, we will discuss the properties of hydrogen and water in the Earth and planetary interiors, based on high-pressure experimental studies and numerical simulations. We are still in the preparatory stage of the workshop, but we expect that new interpretations of the physical and chemical properties of hydrogen and water will be suggested, and that their implications for the internal dynamics and evolution in the Earth and planets are discussed at this work shop. We cordially invite many young researchers, including students, to join this workshop. (article by **Shin'ichi MACHIDA**, Leader of YESA this fiscal year 2010-1011)

COLUMN: Four seasons in Matsuyama

Hiyoku-tsuka, the grave of lovers who died together, which is located along the hill side near Ehime University, is famous for an old cherry tree standing aside the tomb, as well as a sad love story from ancient time. According to Kojiki, the oldest history book in Japan written in the 7-8th century, the first son of the 19th Emperor (Emperor Ingyo) of the 5th century fell in love with one of his younger sisters. The prince, Karuno-miko, was sent to Iyo (the old name of Ehime prefecture, where GRC locates) for banishment because of the forbidden love, and the sister, Sotoori-hime, followed Karuno-miko after having spent several years in the capital with great patience. However, they finally killed themselves stabbing each other at the place where the Hiyoku-tsuka was later constructed. This area is also called Hime-bara (the field of princess), and the cherry tree will be in full bloom in early April, showing its beautiful shape like the incarnation of the pretty princess who died for the tragic love.

New Members

Arnaud METSUE (COE Postdoctoral Fellow)

I joined the GRC in February, after finishing my Ph.D. in Materials Science at the University of Lille (France). My dissertation research focused on the dislocation core properties in mantle minerals. Dislocations are crystalline defects, responsible for the plastic deformation of materials. My research tool is ab initio calculations of atomic structure energies. During my stay at the GRC, I would like to develop new approaches in order to investigate the effects of single-point defects on the physical properties of minerals. My first interest is the study of the effect of iron on the thermodynamic and plastic properties of $(Mg,Fe)SiO_3$ perovskite and post-perovskite phases, which are thought to be the predominant phases in the lowermost part of the mantle. My other interests focus on the discovery of Japanese culture and on the fabulous Japanese food!!

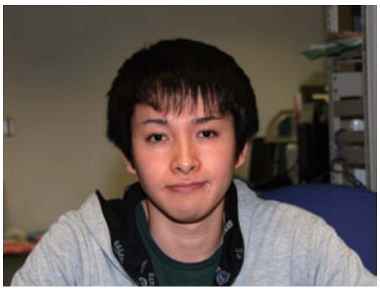
Arata MIYAUCHI (PhD student)

I entered the Ph.D. course this April to begin research on the mantle dynamics of terrestrial planets by using computational fluid dynamics after receiving a Master's degree in the Department of physics at Ehime University. The purpose of my Ph.D study is to clarify the differences in the internal structure of the observed mantle and simulated one. Recent studies of mantle convection showed that large scale convection can be developed by introducing pressure and temperature dependent viscosity and phase transitions. However, coefficients of thermal expansion and thermal conductivity were kept constant in many cases, though they may possibly affect the convection pattern. Therefore, it is necessary to develop a mantle convection simulation model using realistic physical properties of mantle materials, and this is the aim of my research.

Masayuki NISHI (JSPS Postdoctoral Fellow)

My name is Masayuki Nishi and I started working at the GRC in April 2010 as a JSPS postdoctoral fellow. I received a Ph.D. from Kyushu University in March 2010. My doctoral dissertation research focused on examining the transformation kinetics of mantle minerals at high pressure and high temperature conditions. The experiments were mainly conducted using a multi-anvil high-pressure apparatus and time-resolved *in-situ* synchrotron X-ray diffraction measurements. The kinetic data obtained from these experimental studies were used for determination of metastable phase relations of a subducting plate and for the estimation of diamond ascent rate from the deep mantle. My current research interest is chemical diffusion of garnet at the mantle transition zone which is also important for understanding the mineralogy of a subducting plate. I would like to contribute to revealing various reaction processes of mantle minerals.

Futoshi ISOBE (PhD student)



I started my Ph.D. course study in April 2010 after receiving a Master's degree at Ehime University in March of the same year. In my Master's research, I engaged in some technical developments for synthesis of larger nano-polycrystalline diamond (NPD) using a large-volume Kawai-type apparatus (BOTCHAN-6000), which was recently installed at SOSEKI LAB at the GRC. Synthesis of large NPD is an important issue in developing new high pressure technology because NPD has outstanding potential for high pressure anvils. I have succeeded in synthesizing large NPD rods with dimensions of 8mm both in diameter and length which is large enough for applications to various apparatus. I'm working on the challenge of synthesizing larger NPD over 1cm and would like to contribute to the advancement in high pressure technology.

Simulation of core forming process in the magma ocean

Hiroki ICHIKAWA
(COE Postdoctoral Fellow)

We have made 1D numerical simulations of iron rain in the whole magma ocean. Separation of the metal phase from the silicate phase is calculated based on fluid dynamics. The model simultaneously treats partitioning of thermal energy produced from the release of gravitational energy and siderophile elements such as Ni, Co, Mn, Cr, etc. into the mantle and core. It has long been known that the formation of the core transforms gravitational energy into heat and is able to heat up the whole Earth by about 2000 K. However, the distribution of this energy within the Earth is still debated. Iron rain at the surface magma ocean is supposed to be the first mechanism of separation for large planets; iron then coalesces to form a pond at the base of the magma ocean. The time scale of the separation can be estimated from the falling velocity of the iron phase, which is estimated to be about 10 cm/s with iron droplets on the cm-scale.

This process had not been dealt with by numerical simulation because of the large discrepancy between the size of the Earth and the iron droplets.

Any Earth-sized numerical model cannot directly incorporate the effect of iron droplets. We made a parameterization based on a direct numerical simulation of a 10cm-scale emulsion of liquid iron in liquid silicates [Ichikawa et al., 2010] and incorporated it into our Earth-sized model. The evolution of the thermal and chemical structure during the separation of the iron phase is calculated by using this model.

As a result, the maximum temperature, which exceeds the peridotite melting temperature by several thousand Kelvin, is obtained at the boundary between the metal ponds (or the core if the whole planet is liquid) and the silicate layer. This result indicates the chemical equilibrium between metal and silicate would take place at a much hotter condition than the silicate melting temperature. These results are consistent with P-T conditions where silicate equilibrated with metal that is estimated from the partitioning of siderophile elements [Wade and Wood, 2005]. Furthermore, we estimated the depth of the magma ocean as 2000-3000km by chemical distribution.

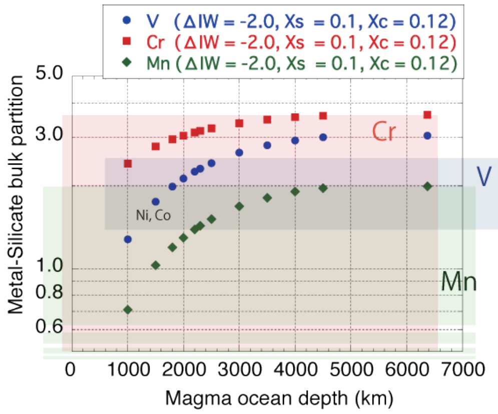


Fig. 1. The relation between metal-silicate bulk partition of V, Cr, and Mn and the depth of the magma ocean. The shaded regions in the figure denotes the likely range for each element evaluated from core-mantle bulk partitioning. The results of a 2000-3000km magma ocean depth are consistent with the core-mantle bulk partition.

Simple-shear deformation of olivine under the upper mantle conditions

Tomohiro OHUCHI
(COE Postdoctoral Fellow)

Plastic deformation of olivine plays an important role in controlling the dynamics in the upper mantle. The lattice-preferred orientation (LPO) of olivine developed by dislocation creep is known to be the cause of the anisotropic elastic properties of upper mantle materials. It has been reported that water has significant effects on the LPO of olivine (e.g., Jung and Karato, 2001). Recently, Raterron et al. (2007) conducted a series of deformation experiments on forsterite single crystals at pressures of 2.1−7.5 GPa and temperatures of 1373−1677 K, and reported that the dominant slip direction changes from b = [100] to [001] at > 5 GPa. Both pressure and water, therefore, is expected to affect the LPO of olivine in the deeper upper mantle. However, the influence of pressure and water on the LPO of olivine (and other minerals) has not been fully evaluated at pressures of > 4 GPa.

In order to explore the pressure-induced fabric transition of minerals and the effect of water on the LPO of minerals at high pressures, we have initiated a series of experimental studies on the effect of pressure and water on the LPO of olivine under upper mantle conditions using the multi-anvil assembly 6-6 (MA6-6) system combined with a deformation-DIA apparatus. We successfully conducted the experiments of the simple-shear deformation of anhydrous and hydrous olivine at P = 3−7 GPa and T = 1473−1773 K for a range of shear strain rates 1E-5 to 1E-4 /s (Fig. 1).

Our experimental results showed that the type-A LPO of olivine, where the olivine [100] axis and (010) plane are subparallel to the shear direction and the shear plane, respectively, was dominant under anhydrous conditions (Fig. 1). The type-B LPO of olivine, which is characterized by the olivine [001] axis subparallel to the shear direction and the (010) plane subparallel to the shear plane, was dominant under hydrous conditions (Fig. 1). These observations suggest that water content is one of the most important parameters controlling the fabric transition of olivine not only in the uppermost mantle but also in the deeper part of the upper mantle.

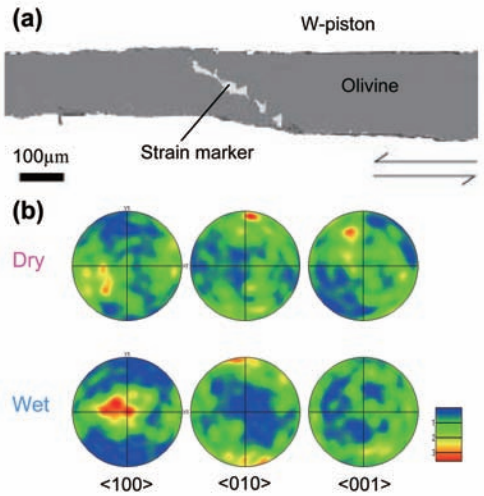
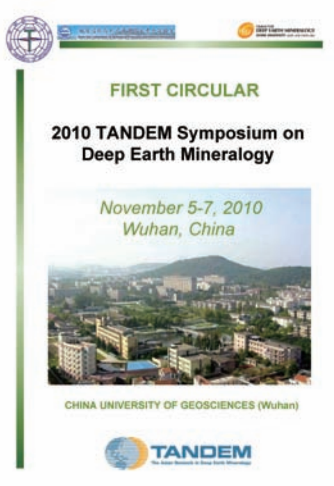


Fig. 1. (a) A representative backscattered electron image of a deformed olivine sample. Note that the strain marker was rotated ~50° (i.e., shear strain of ~120%). Arrows represent the shear direction. (b) Pole figures showing the LPO of deformed olivine samples at 5 GPa and 1573 K under dry and wet conditions.

News & Events

The 2nd TANDEM Symposium on Deep Earth Mineralogy

Date: 5-7 November, 2010
Venue: China University of Geosciences (Wuhan), China
Registration: ~30 September



We are delighted to invite you to attend the symposium during November 5-7, 2010 in Wuhan, China. We look forward to your participation at this meeting and the reports of your recent interesting research results. Detailed information and important dates can be found in the First Circular. Please mark your calendar and distribute the information to the colleagues, students and postdocs in your laboratory/institution who might be interested. We had a very successful 1st symposium in Ehime University, Matsuyama, Japan two years ago. We will make the 2nd symposium a joyful reunion for all TANDEM members and friends in Wuhan.

Now the 1st circular and the abstract format are distributed via TAMDEM mailing list and can be seen on the website, http://deep-earth-mineralogy.jp/tandem/index.html.

Second circular including updated information about the conference will be advertised in the summer of 2010 in the web site above and the mailing list.

Organizing Committee:
Zhenmin JIN, China Univ. of Geosciences, Wuhan, China
Tetsuo IRIFUNE, Ehime Univ., Japan
Yuansheng DU, China Univ. of Geosciences, China
Changqian MA, China Univ. of Geosciences, China
Yanbin WANG, GSECARS, Univ. Chicago, USA
Shan GAO, China Univ. of Geosciences, Wuhan, China
Laishi ZHAO, China Univ. of Geosciences, Wuhan, China
Hongfei ZHANG, China Univ. of Geosciences, Wuhan, China
Junfeng ZHANG, China Univ. of Geosciences, Wuhan, China

Call for internships at GRC, Ehime Univ.

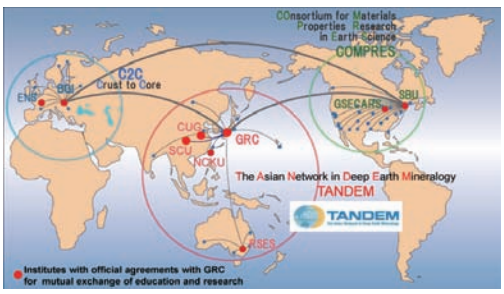
The GRC of Ehime University will invite a few master-course (or equivalent) students for long-term internship program (up to about two months) in deep Earth mineralogy. Successful applicants should have a strong intention to enroll in either the special PhD course in Deep Earth Mineralogy (for Asian students) at the GRC or the ordinary PhD course in the Graduate School of Science and Technology, Ehime University for this and next fiscal year (the entrance exams will be held this coming August, May 2011, and August 2011). Most of the students in both of these PhD courses will be financially supported (up to about 140000 yen/month) and exempted from the tuitions and the enrollment fee. The successful applicants can choose one of the following topics for internships to be conducted during the period from early August to late March 2011: 1) High-pressure experiments using the multianvil apparatus or diamond anvil cell, 2) Numerical simulations in mineral physics using first-principles calculations and those in geodynamics based on fluid dynamics theory, which are supervised by the faculty members of the GRC. The GRC will financially support the travel and living expenses during the period of the internship. For further details: contact Dr. Akira Yamada (yamada@sci.ehime-u.ac.jp).

Visits of TANDEM lab representatives to GRC

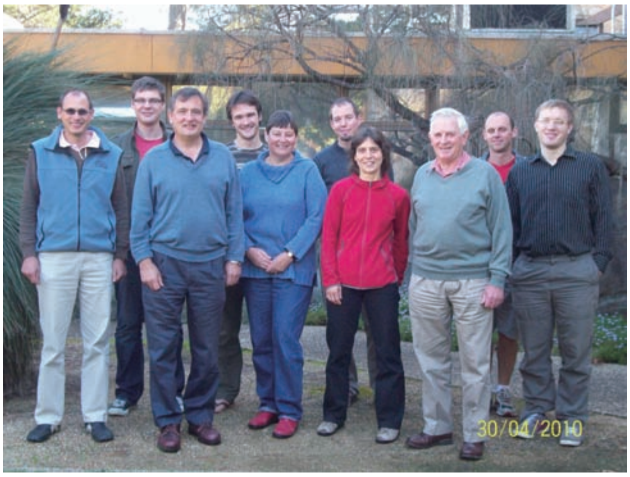
Prof. Zenmin Jin, the representative of the National Key Lab, CUG in Wuhan, visited the GRC during the period of 12-15 March, accompanied by his wife and Dr. Yao Wu of the same laboratory. Prof. Jin and Dr. Wu discussed with some of the faculty staff members of the GRC about the details of the second TANDEM symposium to be held in Wuhan this coming November. Meanwhile, Prof. Ian Jackson, the representative of RSES, ANU, also visited the GRC on 25-27 March and gave a talk as one of the International Frontier Seminars. Dr. Yoshio Kono, a COE Research Fellow at GRC, will visit Prof. Jackson's lab for a few months based on the mutual agreement of exchange of people between the two institutes and supported by the COE long-term overseas internship program.

Keynote lecture at NDNC2010 in Suzhou

Prof. T. Irifune of the GRC was invited as a keynote lecturer at the 4th International Conference on New Diamond and Nano Carbons (NDNC2010) held in Suzhou, near Shanghai, China. This conference is held for presentations and discussions on sciences and technologies on diamond and various nano-carbons (nanotubes, grapheme, fluerene, etc), as well as on diamond-like carbons and other hard materials. Prof. Irifune gave a 30-minute keynote talk on the nature and application of nano-polycrystalline diamond (HIME-DIA), firstly synthesized at the GRC.



Experimental Research in Earth Materials at the Australian National University



From left to right: Joerg Hermann, Guilherme Mallmann, Hugh O'Neill, Cassian Pirard (Ph. D. student), Kay Provins (administrator), David Buchs (visitor), Anja Rosenthal (Ph. D. student), David Green (visitor), Dean Scott (technician) and Aleksey Sadekov (Ph. D. student). Missing: Greg Yaxley, John Mavrogenes, Laure Martin, Oliver Nebel, Robert Rapp, David Clark (technician) and Ph. D. students Jeremy Wykes, Huijuan Li, and Jesse Jones.

Experimental research into chemical and mechanical aspects of the behaviour of geological materials is undertaken by the experimental petrology and rock physics groups within the Research School of Earth Sciences. Experimental facilities include piston-cylinder, multi-anvil, hydrothermal and internally heated gas apparatus for high-pressure-temperature studies of phase equilibria, rheology and seismic properties, along with controlled atmosphere furnaces. Analytical capability includes an electron microprobe, laser ICPMS, Fourier transform infrared spectrometry (FTIR), and light and electron microscopy, including SEM-based electron backscattered diffraction (EBSD) and TEM. The research activities involve a substantial number of Ph. D and undergraduate students and are supported by specialised technical staff. The current interests of the senior research staff are summarised in the following paragraphs.

Joerg Hermann is experimentally investigating the nature and composition of subduction zone fluids, taking advantage of new developments such as the UHP piston cylinder technique (up to 6.5 GPa) and large, cold sealed silver capsules for hydrothermal experiments at very high pressures. Special emphasis is placed on the influence of accessory phases on the trace element compositions of subduction zone fluids, which are analysed in the experimental runs by Laser-Ablation ICP-MS. Other experimental studies focus on different ways how volatiles (H_2O, CO_2, Cl and F) are recycling through subduction zones.

Greg Yaxley is working on constraining the nature of metasomatic processes operating in the deep cratonic mantle, the stability of diamond, and the petrogenesis of highly silica-undersaturated magmas such as kimberlites. Based on studies of spinel and garnet peridotite xenoliths, the oxygen fugacity of the Earth's upper mantle is heterogeneous. There is an observed overall decrease from values within 1 or 2 log units of FMQ in the upper most lithosphere to several log units below FMQ near the base of the cratonic lithosphere at 150 - 200 km depth. Such low values in the deep cratonic mantle are consistent with diamond and CH_4-rich fluid stability. However, superimposed on this overall trend is frequently observed evidence of oxidation associated with metasomatism, which may be of sufficient magnitude to destabilise diamond. Dr. Yaxley's experimental program aims to investigate the nature of partial melting of peridotite in the presence of CHO under the reduced oxygen fugacities near the base of the cratonic lithosphere, using fO_2 buffering techniques and analysis of experimental fluids by gas chromatography.

John Mavrogenes' research is broadly focussed on the chemical processes responsible for the formation of ore deposits, including 1) Evolution of high-temperature volcanic gases: metal (Au, As, Sb, Se) solubilities and speciation (complexes of S and Cl); entrapment and analysis of low-density synthetic fluid inclusions; formation of enargite gold deposits, 2) Formation and modification of PGE deposits: diffusive re-equilibration and evolution of PGE-bearing sulfide melts during cooling, 3) The petrochemistry of the Windimurra-Narndee (Western Australia) layered mafic intrusions, 4) Evolution of polymetallic melts in high grade metamorphic terranes, including the effects of halogens on sulfide melting, and 5) Analysis of magnetites in support of the bornite model.

Hugh O'Neill's research focuses on applying physical chemical measurements to understanding the origin and evolution of the Earth and the terrestrial planets. He is especially concerned with studying the accretion and early differentiation of the Earth and how this influences the Earth's composition, and the subsequent mantle processes that lead to partial melting and the production of basaltic magmas. His longstanding interest in measuring the thermodynamic properties of minerals and melts at high temperatures and pressures has recently been extended to experimental measurements of trace-element partitioning and diffusion.

Ian Jackson and John Fitz Gerald are continuing to collaborate in the use of seismic-frequency torsional forced oscillations to measure shear wave speeds and attenuation in upper-mantle materials. Particular emphasis is currently being given to the influence of dislocations (Ph. D. student Robert Farla) and water, improvements to experimental technique, and more robust modelling of the variations of shear modulus and attenuation resulting from high temperature viscoelastic relaxation. This work has a vital microstructural dimension involving light microscopy, SEM-based EBSD, TEM, and FTIR. Collaborative work with Uli Faul (Boston University) involves the influence of trace elements on the rheology of fine-grained polycrystalline olivine prepared in house from synthetic (sol-gel) precursors. Another major project is the development of complementary flexural-oscillation methods for the measurement of Youngs modulus and associated strain energy dissipation. This approach, being undertaken in collaboration with Doug Schmitt and Ph. D. student Heather Schijns of the University of Alberta, is being pursued primarily for studies of cracked and fluid-saturated crustal rocks but is also potentially applicable to phase-transforming materials including partial molten rocks.

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Lunch-time gathering of staff and students involved in experimental research in rock physics group. *From left to right:* Harri Kokkonen (technician), John Fitz Gerald, Ian Jackson, Robert Farla (Ph. D. student), Heather Schijns (Ph. D. student), Emeritus Professor Mervyn Paterson, Hayden Miller (technician).

The Research Group of the Physics of the Earth's Interior (HACTO), Institute for Study of the Earth's Interior, Okayama University

Institute for Study of the Earth's Interior (ISEI) is one of the research centers of Okayama University located in the small town, Misasa in Tottori prefecture, Japan, and it was reconstructed in 1985 from the Institute for Thermal Spring Research. The Research group of the physics of the Earth's interior (HACTO, Highly Advanced Compression for Terrestrial Objects) aims to study the structure, dynamics, and evolution of the solid Earth through experimental studies for the constituents of the Earth's interior. In order to understand more accurately the Earth's interior, we are determining the various physical properties of the mantle and core materials and results are compared with geophysical observations. We are focusing on the following topics: 1) Equation of the state and phase equilibria of mantle minerals; 2) Determination of the electrical properties of mantle minerals; 3) Technical development for ultra high-pressure generation; 4) Determination of the elastic and plastic properties of the materials in the Earth's interior.

Our group is one of the oldest multi-anvil labs in Earth science since 1969. During its long history, we contributed to the high-pressure Earth science field, for example, the first attempt of synthesizing a large-sized perovskite crystal, determinations of spinel-postspinel and alpha-beta phase boundaries in olivine, electrical conductivity measurement under high pressure, ultra high-pressure generation using sintered diamond anvils. We have the current world record of high pressure generation using a Kawai-type multianvil press at nearly 100 GPa. We have published 6 Nature and 5 Science papers through its history. We also have developed some special techniques to measure elasticity, plasticity and thermal conductivity.

In our lab, we installed several high pressure apparatus, such as: USSA-5000 split sphere press, USSA-1000 split sphere press, UHP-2000/20 DIA-type press, piston cylinder apparatus, and the “6-axis” press.

With the USSA-5000 press, we can apply the maximum press load to 2000 tonf at present and we are now trying to expand it to more than 3000 tonf. By using 46 mm tungsten carbide cubes as second stage anvils for the octahedral high pressure assembly, we are able to generate pressures and temperatures up to ~25 GPa and 2500 K. By using this technique, we successfully synthesized a large single crystal (>1 mm) of $MgSiO_3$ perovskite.

The concept of the USSA-1000 press is the same as that of the USSA-5000, except the second stage anvil size is fixed to 32 mm. Therefore, sample size in USSA-1000 press is much smaller than that in USSA-5000 press although the maximum pressure and temperature conditions are almost identical. USSA-5000 and 1000 presses are mainly used for synthesis of high pressure materials, determination of phase boundaries, observation of phase equilibrium, measurement of rheological properties, electrical properties, and thermal properties.

In the UHP-2000/20 DIA-type press, a unique system for deformation is equipped to the normal DIA-type press. By using this press, we can deform the samples at high pressure and temperature (to ~3 GPa and 2000 K) by driving a cylindrical piston which is set in the bottom anvil of a DIA type guide block. We measure electrical conductivity coupled with rheological properties under the deviatric stress field.

The new “6-axis” apparatus was developed 1) to achieve an ideally uniform compression of the cubic anvil assembly and 2) to minimize frictional loss of applied load in the guide block. The movement of the six anvils is monitored and controlled by the servo system. Therefore, it is possible to keep the cubic space (ex. Kawai-type high pressure assembly) within accuracy of 1 μm during compression and decompression. This press is mainly used for experiments higher than ~50 GPa employing sintered diamond cubes as second stage anvils. We are expected to generate pressure higher than 100 GPa with further technical development and study for mineral physics applicable to the lowermost mantle.

In addition to the research at our own laboratory, we frequently use the synchrotron facility, SPring-8, to conduct in situ X-ray observation at high pressure and temperature to clarify the pressure effect on the physical properties of high pressure materials, determine phase equilibria of unquenchable phases, and so on.

We have carried out collaboration research programs with researchers from Kyoto University, Hiroshima University, Toyama University, Tokyo Institute for Technology, Okayama University of Science, and University of Hyogo. Moreover, we are building our laboratory to be an international laboratory. A lot of scientists/students from all over the world, China, Chinese Taipei, France, Korea, Russia, etc. have visited our laboratory for research and our members (including students) are/were also from foreign countries, e.g., Bangladesh, China, France, Russia and Sri Lanka. Currently our group is composed of 4 faculty (including a professor emeritus), 2 post-doctors, 4 graduate students and technical staffs.

We appreciate cooperation with the members of TANDEM, and welcome researchers and students to visit our laboratory and work together.

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