3. COE Researcher Reports

Dynamics of the Earth and Planetary Interiors Research Subgroup
Konstantin Litasov

<table>
<thead>
<tr>
<th>Title/Affiliation</th>
<th>COE Associate Professor / Department of Earth Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialized Field</td>
<td>Earth Sciences</td>
</tr>
<tr>
<td>Research Subject</td>
<td>Phase equilibria of peridotite and eclogite with various fluids and deep understanding of spatial-temporal evolution of volatiles in the Earth’s mantle</td>
</tr>
</tbody>
</table>

The Purpose of Research and Outline of Accomplishments and main results:

Most important achievement of 2010 stage include experimental modeling of mantle lithologies (peridotite and eclogite) coexisting with reduced C-O-H fluid at pressures of 3-15 GPa. In these experiments we used double-capsule method and controlled fO₂ using oxygen buffers MMO (Mo–MoO₂) and IW (Fe-FeO). The solidus temperatures were 300-400°C higher than that in the systems with H₂O and CO₂. In turn these solidi were 300-400°C lower than volatile-free ones for peridotite and eclogite systems at 15-20 GPa. The melt compositions in the peridotite and eclogite systems coexisting with reduced C-O-H fluid are characterized by the high SiO₂ contents (44–50 wt.%).

Study of the reactionary interaction between Fe and its compounds with carbonates leaded to following conclusions: 1) Interaction of Fe with carbonates cause formation of Fe₃C. Accordingly diamond formation in the mantle cannot occur in equilibrium with metallic Fe. 2) We observed low solubility of carbon in FeS melt and low solubility of hydrogen in Fe₃C. In addition we observed negligible reactions between carbonate and FeS. 3) According to experiments we suggested Fe-affinity range for light elements at high pressures as FeS > FeC > FeH > Fe.

Phase relations in model carbonate-chloride-bearing eclogite were studied at 7.0–10.5 GPa and 1200–1675°C. In this system melt composition because Si-rich at 1500–1700°C and contain up to 53 wt.% SiO₂. These compositions correspond to Si-rich endmemembr of the fluid/melt inclusions in fibrous diamonds. Therefore, we outlined experimentally affinity of these inclusions to eclogite paragenesis. We completed experimental study of model Cl-bearing Udahnya kimberlite at 2.1-6.5 GPa and 900-1500°C. The obtained phase relations indicate that kimberlite was not in equilibrium with mantle peridotite in the region of magma generation. Primary melt had carbonatite composition and Si-enrichment occurred during reaction of carbonatite melt with surrounding mantle rocks during transport to the surface.

International activity:

In 2010 I presented the results in several international conferences including European Union of Geoscience, General Meeting of International Mineralogical Association, and American Geoscience Union. Two plenary lectures were presented at XVI All-Russian Conference on Experimental Mineralogy (Chernogolovka, Moscow). During October, 2010 I visited Novosibirsk and performed high-pressure experiments in the laboratory of Prof. Y. Palyanov, where we were able to measure composition of C-O-H fluid after experiments using gas...
chromatography. I had a presentation on current progress in collaboration between Tohoku University and Sobolev Institute of Geology and Mineralogy and a lecture on using high pressure techniques in synchrotron radiation facility “SPRING-8” during Seminar for Young Scientists on using of Synchrotron Radiation in Earth Science in the Institute of Nuclear Physics SB RAS (Novosibirsk). I also supervised G-COE intern student Mr. Igor Sharygin (Novosibirsk, Russia). His internship project includes study of mineral dissolution in carbonatite melt with implication to origin of Kimberlite and diamond.

Publications: Journals:


Symposium Participations (selected):


Masaaki Miyahara

Title/Affiliation COE Assistant Professor / Department of Earth Science
Specialized Field High-pressure planetary science
Research Subject Transformation mechanism of high-pressure polymorphs in shocked-meteorites

The Purpose of Research and Outline of Accomplishments:

Olivine dissociates to (Mg,Fe)SiO₃-perovskite (Pv) + magnesiowüstite (Mw) around and below the transition zone of the earth. However, the dissociation mechanism of olivine is still debated. The high-pressure and temperature conditions of the dynamic event recorded in Martian meteorites have been estimated by several previous works, and the estimated conditions given in some reports are beyond the stability filed of ringwoodite. It is likely that olivine in shocked Martian meteorites dissociated to (Mg,Fe)SiO₃-Pv + Mw but overlooked. Accordingly, we scanned olivine grains in the Martian meteorite. We report the first evidence for the dissociation of olivine at high-pressure and –temperature condition induced by a dynamic event on Mars.
Main Results:

TEM observations reveal that micro-texture of olivine dissociation evolves from lamellar to equigranular with increasing temperature at same pressure condition (Fig. 1), agreeing with the observations of synthetic samples recovered from high-pressure and temperature experiments. Equigranular (Mg,Fe)SiO$_3$-Pv and Mw have 50-100 nm in diameter. Lamellar (Mg,Fe)SiO$_3$-Pv and Mw have ~20 and ~10 nm in thickness, respectively. Partitioning coefficient, $K_{Pv/Mw} = [FeO/MgO]_{Pv}/[FeO/MgO]_{Mw}$, between (Mg,Fe)SiO$_3$-Pv and Mw in equigranular and lamellar textures are ~0.15 and ~0.78, respectively. The dissociation of olivine implies that the pressure and temperature conditions recorded in the shock vein and melt pockets during the dynamic event were ~25 GPa but 700 °C at least.

Fig. 1. TEM images of a) equigranular (Mg,Fe)SiO$_3$-Pv and Mw and b) lamellar (Mg,Fe)SiO$_3$-Pv and Mw.

Publications:


Symposium Participations:


**Anton Shatskiy**

Title/Affiliation  COE Associate Professor / Department of Earth Science  
Specialized Field  Crystal growth, HP mineral physics  
Research Subject  1) Lattice diffusion of Si, O, H in mantle minerals  
2) Single crystal growth of mantle minerals implication to silicon self-diffusion experiments.

The Purpose of Research and Outline of Accomplishments and results:

In 2010 year I mainly concentrated on two topics. The first is mechanism of H and C transport and segregation in the deep mantle.

Carbon and hydrogen play important role in the mantle processes related to subduction (deep earthquakes due to dehydration of hydrous silicates, arc magmatism) and upwelling (kimberlite, lamproite magmatism, depth > 250 km, metasomatism, and diamond formation). Although an average concentration of H and C in the mantle does not exceed 100 wt. ppm, local mantle regions were extremely enriched in these elements. These are suggested from composition of protokimberlite magma which corresponds to the carbonatitic magma, from CO₂-H₂O fluid inclusions in natural diamond, and mantle xenoliths metasomatically altered by carbonatitic melts. The mechanism of the H₂O and CO₂ transport and segregation at the greater depth is unknown.

Based on our current results on H diffusion in olivine at 13 GPa and literature data a hydrogen and carbon transport by means the solid state diffusion through solid silicate is unrealistic due to very slow diffusion rates (<5×10⁻¹⁰ m²/s allowing diffusion distance of <6 km in 10⁹ yr. at mantle conditions). Moreover, the diffusion is a kind of indirect migration process which leads rather element dissipation than segregation. The well known porous flow (fluid/melt percolation via interconnected pores) transport reliable for the shallow depth (< 50 km) can not be applied for average mantle since the average mantle is the non-porous solid silicate matrix.

Therefore, in 2010 we start to develop new model which enables us to explain transport and segregation of trace amount of H₂O and CO₂ in the mantle. At the mantle conditions water and carbonates are the excellent silicate solvents. Hence the migration of insulated portions of fluid through the solid matrix can proceed by means of the
dissolution-precipitation mechanism. The major driving force for this process would be a concentration gradient of solid silicate in the fluid. This can be caused by pressure or temperature gradient, differences in stable and metastable phase solubility, and stress. The fluid chamber migration rate equals to the silicate components diffusive flux through the fluid. The later is product of diffusion coefficient and applied driving force.

The diffusion of MgSiO$_3$ perovskite in hydrous fluid and water-carbonate melt at 24 GPa and 1500°C and Mg$_2$SiO$_4$ wadsleyite in carbonate melt at 17.5 GPa and 1700°C were measured to be 2×10$^{-7}$, 5×10$^{-9}$, and 2×10$^{-9}$ m$^2$/s, respectively. The measurements were made using scaled-up Kawai-system which we previously developed. The general experimental procedure was the same as we used for the single crystal growth of MgSiO$_3$ perovskite by means of the thermal gradient growth technique. Obtained diffusion coefficients suggest that the dissolution-precipitation mechanism up to 3 order of magnitude faster than solid state diffusion of H$_2$O. However, in our present study the thermal gradient has been employed as a driving force, whereas in the nature, stress would be more reliable. In this connection in this year we start development of the deformation HPHT experiments using D-DIA press installed in PFAR Tsukuba. Simultaneously from the last December we began study of phase relations and P-V-T EOS of alkali and alkali earth carbonates using in situ experiments at PFAR and Spring-8. These data are essential to know stability field of carbonatitic melt in the deep mantle.

The second topic was the regularities of pressure and temperature generation in the Kawai-type multianvil apparatus. The study of the phase relations in the mantle under controlled redox conditions in presence of volatiles (H, C, N, S) is one of the hot topics. However, this study requires large sample volume and therefore it was conducted only at low pressures generally 2-6 GPa (shallow mantle). The diffusion studies of silicate components in fluid/melt and hydrogen in mantle minerals are also needs large sample volume. The choice of the best scaled-up assemblage for a particular experiment at 10-25 GPa is still somewhat arbitrary. Optimizing the high-pressure cell is both time consuming and costly, because each failed experiment destroys several anvils, and a statistically significant number of trials of a given design are required to obtain conclusive results. That largely limits wide application of a scaled-up version of the Kawai-cell for essential use in the field of planetary and material science. During past year we summarized all our data on performance of the Kawai-cell. The essential part obtained using in-situ X-Ray radiography and energy dispersive diffraction has been also included in this analysis. The results were presented as a large paper which is now under reviewing in the Physics of the Earth and Planetary Interior.

Publications:

5. X.P. Wu, B.H. Zhang, J.S. Xu, T. Katsura, S.M. Zhai, T. Yoshino, G. Manthilake, A. Shatskiy, Electrical conductivity measurements of periclase under high pressure and high temperature,


Dynamics of the Earth and Planetary Interiors Research Subgroup (Focus Group)

Takeshi Kuritani

Title/Affiliation  COE Associate Professor / Department of Earth Science
Specialized Field  Petrology, Geochemistry
Research Subject  Dynamics of magmatic processes

The Purpose of Research and Outline of Accomplishments:
1) Geochemical study on Cenozoic basaltic lavas from NE China

The mantle transition zone is considered to be an important water reservoir in the Earth’s interior because of the high water capacity of the transition-zone minerals. Recent studies using electrical conductivity observations have suggested that water distribution in the mantle transition zone is not homogeneous on a global scale, and that the mantle transition zone beneath NE China in particular has a high water content. In this study, we used geochemical data from Cenozoic intraplate basaltic lavas in NE China to elucidate the origin of the remarkably hydrous nature of the mantle transition zone beneath NE China.

We found that lavas from the Changbaishan volcanic field show remarkably higher EM1-like signature and higher Ba/Th and Pb/U than lavas from the surrounding volcanic fields, and this concentric spatial variation in geochemistry is well correlated with a plume-like structure of the low-velocity anomaly in the upper mantle down to 410 km beneath the Changbaishan area. On the basis of the constraints derived from the lead isotopic compositions of the Changbaishan lavas, it is suggested that there have been at least two superimposed hydration events in the mantle transition zone under NE China: an ancient (>1 Ga ago) hydration probably caused by dehydration of an ancient stagnant slab, and a recent hydration due to dehydration of the stagnant Pacific slab. The
record of the ancient hydration event in the mantle transition zone suggests that the hydrated transition zone has been a long-term (>1 Ga) stable water reservoir in the Earth’s interior.

2) Behaviour of Os in subsuction zones

The Re-Os system has been used as a powerful tool to understand the processes and timescales of the long-term chemical evolution of the Earth. However, behaviors of Re and Os in subduction zones have still been unclear, because arc magmas commonly lost the primary information about the Re-Os system by interaction with the crust en route to the surface. In this study, we examined the Re-Os systematics for a well-characterized suite of relatively primitive alkali basalt lavas from Rishiri Volcano, northern Japan, to elucidate the behavior of Os during arc magma generation.

Rhenium-osmium isotopic analysis of the lavas suggests that the $^{187}$Os/$^{188}$Os ratios of the primary magmas decreased systematically with an increase in the degree of fluid-flux melting of the source mantle. This systematic variation is consistent with the variation expected from the disequilibrium partitioning of Os, rather than the equilibrium partitioning, among the depleted mantle, influxed fluid phases, and primary melts during magma generation. We estimated that the Os in the slab-derived fluids was radiogenic ($^{187}$Os/$^{188}$Os >~1.0), but the concentration was not high (<~100 ppt). The low Os concentration of the fluid may be attributed to the low mobility of Os in the slab-derived supercritical fluid, rather than by the low Os content of the subducting slab from which the fluid was derived.

Publications: Journals:


Symposium Participations:

The Purpose of Research and Outline of Accomplishments:

A factor controlling the style and explosivity of volcanic eruptions is magma degassing. The outgassing from vesiculated magma reduces the driving force of volcanic eruptions; hence, the understanding of the mechanism and rate of the degassing is necessary to predict the style and explosivity of volcanic eruptions. We have investigated the mechanism and the rate of the degassing from silicic magma. Okumura et al. (2008, JGR; 2009, EPSL) revealed the mechanism and rate of the degassing from magma at high temperatures. In this year, we experimentally investigated the degassing from magma at relatively low temperatures. At temperatures <830°C, rhyolitic melt showed brittle behavior when it was sheared at strain rates >10^{-2} s^{-1}. The brittle fractures become efficient permeable pathways and enhance the degassing rate. On the other hand, the brittle fracturing also induces the localization of the shear deformation. Because the shear deformation of vesicular magma results in the enhancement of bubble deformation and coalescence and hence the degassing rate, the localization seems to suppress the enhancement of the degassing rate through bubble networks. Therefore, there is a possibility that the brittle fracturing induces two opposite effects. (Okumura et al., 2010, JGR).

We have also studied the effect of crystals on the degassing. No previous experiments have been performed to investigate the mechanism and rate of the degassing from crystal-bearing magma. To investigate the effect of crystals on the degassing, we performed the decompression experiments and analyzed the microstructure of bubbles and gas permeability of run products. The experimental results showed that the gas permeability of crystal-bearing magma is comparable to those of crystal-free magma when gas bubbles have low contact angle on the crystals. This indicates that the degassing may be enhanced when magma has high vesicularity, i.e., at shallow parts in volcanic conduits. Since there is a possibility that the degassing is enhanced by shear deformation as well as crystal-free magma, the investigation for sheared crystal-bearing magma should be carried out in the future.

All previous studies have investigated bubble and fracture microstructure and gas permeability of quenched samples to understand vesiculation and degassing processes of magma ascending in volcanic conduits. We have constructed in situ observation system to observe magma vesiculation and degassing directly. In this system, magma is vesiculated and deformed in a piston-cylinder type apparatus and observed using X-ray radiography and computed tomography of SPring-8 at high temperature and pressure. In this year, we set up the system, and the vesiculation and degassing will be observed using this system in next years.

Publications: Journals:

Symposium Participations:


Jun Muto

Title/Affiliation: COE Assistant Professor / Department of Earth Science
Specialized Field: Rock Mechanics, Structural Geology
Research Subject: Rheology of crustal rocks

The Purpose of Research and Outline of Accomplishments:

1. Geometrical softening (development of lattice preferred orientation) of crustal rocks
2. Electric signals associated with stick-slip nucleation
3. Rheological profiles of Northeastern Japan

Main Results:

1. The effect of a lattice preferred orientation on the flow strength of quartz aggregates dynamically recrystallized from single crystals of synthetic quartz was investigated using general shear experiments in a Griggs apparatus conducted at shear strains (γ) up to 5 at a temperature of 900 °C, confining pressure of 1.5 GPa, and shear strain rate of 10^-5/s. Three starting orientations of crystal were used, to activate three slip systems: basal <a>, prism [c], and prism <a>. For all three starting orientations, distinct domains of
recrystallized grains develop with c axes parallel to Y of the strain ellipsoid (Ymax), replacing recrystallized grains of other orientations. In addition, strain markers show that strain is highly localized within the Ymax domains, indicating geometrical softening of up to an order of magnitude in effective viscosity. The part of the study is published in J. Geophys. Res.

2. In order to understand the seismo-electromagnetic signals, we conducted friction experiments using simulated gouges to detect premonitory electric signals before stick-slip events. The magnitude of electrification is proportional to fault slip, indicating that the electrification is slip-dependent process. From the microstructural analyses, Riedel (R1) shears known to be formed during stable sliding were the most densely developed around the electrode pair which detected the precursory voltage changes. This indicates that local increases in the voltages were likely caused by frictional electrification due to slow slip on R1 shears in nucleation phases of stick-slip events. Our experimental results imply that natural faults with thicker gouge zones would require greater precursory slips, resulting in larger electric signals in the nucleation phase of earthquakes. The part of the study was presented at GCOE symposium “Dynamic Earth and Heterogeneous Structure” and submitted to Tectonophysics.

3. Based on recent results on rock mechanics and geophysical observations, I constructed rheological (strength and viscosity) profiles across the northeastern Japan lithosphere. The profiles well explain patterns of present-day geodetic strain accumulation and shallow seismicity. Experimentally derived flow laws also predict the presence of weak zones by mechanisms likely operated in the lithosphere (e.g., partial melting and shear zone development). The strain localization into weak zones explain the lower estimates of viscosity (10^{19}-10^{20} Pas) from post-seismic creep after a large inland earthquake. The part of the study was presented at GCOE symposium “Dynamic Earth and Heterogeneous Structure” and international symposium of subduction dynamics at Earthquake Research Institute (Invited, Tokyo) and submitted to Tectonophysics.

Publications: Journals:

Symposium Participations:
5. Muto, J. Rheology of the island arc crust based on current understanding on rock deformation.
Tohoku University GCOE symposium “Dynamic Earth and Heterogeneous Structure” July 2010.


Saeko Kita

Title/Affiliation: COE Fellow / Research Center for Prediction of Earthquakes and Volcanic Eruptions

Specialized Field: Seismology

Research Subject: Study for understanding of the generation of the intraslab earthquakes

The Purpose of Research and Outline of Accomplishments:

[A] Existence of interplane earthquakes and neutral stress boundary between the upper and lower planes of the double seismic zone beneath Tohoku and Hokkaido, northeastern Japan [Kita et al., Tectonophysics]

Using data from the recently constructed nationwide dense seismic network, we determined the hypocenters and focal mechanisms of many intermediate-depth intraslab earthquakes within the Pacific slab beneath northeastern Japan. The results show that in addition to the upper and lower planes of the double seismic zone, a considerable number of intraslab earthquakes also occur between the two planes. This interplane earthquake activity is not homogeneously distributed in space, being high beneath eastern Hokkaido and the fore-arc regions of southeast and central Tohoku. The focal mechanisms of the interplane earthquakes tend to be of the down-dip compressional type (DC) in Tohoku and the Hokkaido corner, but down-dip tensional type (DE) in eastern Hokkaido. Upper plane earthquakes are characterized by DC-type stress while lower plane earthquakes are DE-type in both Tohoku and eastern Hokkaido. The existence of interplane earthquakes enables estimation of the position of the neutral plane between the upper-plane DC stress and the lower-plane DE stress. We did so by applying stress tensor inversions to focal mechanism data obtained in the present study and Japan Meteorological Agency (JMA) data. The results show that the neutral plane is located about 22 km beneath the upper plate interface beneath Tohoku, but only about 10 km beneath the upper surface beneath eastern Hokkaido. This difference in the location of the neutral plane may be due to the difference in buoyancy force exerted by the less dense metastable olivine wedge that is a result of the oblique plate subduction beneath Hokkaido. Comparison of large intraslab earthquakes beneath the two regions shows that their aftershock areas are limited by the neutral plane, suggesting that large earthquake ruptures are confined to either the DC or DE stress field, and do not go beyond the neutral plane.
[B] Precise structure of two island arcs and deformation of the descending Pacific slab beneath the 
arc-arc type collision in the Hokkaido corner, NE Japan [Kita et al., in preparation]

Using both of data from a nationwide dense seismic network and those from a dense temporary 
seismic network, we precisely investigated the three-dimensional seismic velocity structure beneath the 
Hokkaido corner to examine the collision of two forearcs in this area. Inhomogeneous seismic velocity 
structure was clearly imaged in the Hokkaido corner at depths of 0-120 km. The results show that a 
high-velocity anomaly of P- and S- waves with a volume of 20 km x 90 km x 35km was detected just 
beneath the Hidaka metamorphic belt at depths of 0-35 km. The highest velocity value in the anomaly 
corresponds to those of the uppermost mantle material (e.g. peridotite). The location of the anomaly is also 
consistent with that of the Horoman-Peridotite. On the other hand, a low-velocity anomaly of P- and S- 
waves with a volume of 80 km x 100 km x 50 km is distributed to the west of the Hidaka metamorphic belt 
at depths of 35-90km. This low-velocity anomaly, whose velocity value corresponds to those of crustal 
material, seems to be continuously distributed from the continental crust of the NE Japan forearc. This 
observational fact does not support the expectation of the previous studies that the delaminated lower-crust 
materials of the Kuril forearc sliver descends into the mantle wedge due to the collision. We also examined 
the characteristics of seismicity and focal mechanisms of events in the slab beneath this region, and revealed 
the possibility of deformation of slab due to the effect of the collision.

Awards:
Commendation from the Geological Society of Japan for continuously activities of young earth science 
reseachers (as one member of core group of New year school (NYS) of earth system and evolution), 
September 2010.

Publications:
earthquakes and neutral stress boundary between the upper and lower planes of the double seismic 
zone beneath Tohoku and Hokkaido, northeastern Japan., Tectonophysics , doi 


Symposium and Meeting Participations:
natural plane of stress in the Pacific slab between Hokkaido and Toho, 2010 JPGU meeting, 
Makuhari-Messe, May 2010.

of the arc-arc collision zone beneath the Hidaka metamorphic belt in the Hokkaido, NE Japan, 
G-COE Symposium 2010 Dynamic Earth and Heterogeneous Structure, Sendai, Sendai City War 
Reconstruction Memorial Hall, Poster, July 2010.

belt in the double seismic zone and seismic structure in the Pacific plate beneath NE 
Japan: Evidence for dehydration embrittlement as a cause of intraslab earthquakes, the 
Geological Society of Japan 117th academic meeting, Toyama University, Invited, Oral, September 
2010.

5. S. Kita, Detailed seismic velocity structure beneath the Hidaka metamorphic belt in Hokkaido: Deformation process of the forearc material and descending slab, the workshop for JTABS project, JAMSTEC, Shinbashi-branch, Oral, November 2010.


Outreaches:

Tian You

Title/Affiliation COE Assistant Professor / Department of Geophysics

Specialized Field Seismology

Research Subject (1) P- and S-wave tomography of North China Craton
(2) Seismic imaging under the western United States

The Purpose of Research and Outline of Accomplishments:
(1) The eastern part of the North China Craton (NCC) was reactivated and its lithosphere was destructed during the Mesozoic to Cenozoic. Many destruction models, such as delamination, thermal erosion, chemical metasomatism and hydro-weakening have been proposed mainly through geochemical and geologic observations. We determined detailed P and S wave velocity and Poisson’s ratio structures under NCC, which show different structural patterns in the different blocks of NCC. Our seismic images provide important new constrains on the evolution mechanism of the NCC. We consider that the deep subduction of the Pacific plate under East Asia caused local or regional scale lithospheric delamination which first took place along some special locations such as the Trans-North China Orogen (TNCO), Dabie-Sulu and Yanshan orogenic belts in early Mesozoic or Paleoproterozoic. As a result, asthenospheric upwelling led to widespread magmatism in and around the eastern part of NCC. Hence the thermal erosion and/or chemical metasomatism might be a main dynamic mechanism for the lithospheric evolution of eastern NCC during the Mesozoic to Cenozoic. The TanLu Fault Zone and TNCO may have acted as two main conduits for the asthenospheric upwelling, which have played an important role in the Mesozoic–Cenozoic destruction of the pre-existing Archean lithospheric mantle.

(2) We used more than one million travel time data recorded by the EarthScope/USArray transportable array to determine a detailed three-dimensional (3-D) P-wave velocity structure of the crust and mantle down to 1000 km depth under the western United States (U.S). Our tomographic images show a very heterogeneous
structure in the crust and upper mantle under the western U.S. Prominent high-velocity anomalies are imaged beneath Idaho Batholith, central Colorado Plateau, Cascadian Subduction zone, stable North American Craton, Transverse Ranges, Southern Sierra Nevada and in the Mantle Transition Zone and lower mantle, and prominent low-velocity anomalies are imaged beneath Snake River Plain (~200 km) and Yellowstone region (~1000 km), which may reveal a small-scale convection beneath the western U.S. Some oblique and less-significant low-velocity anomalies extend to 1000 km depth beneath the Yellowstone region, suggesting that the Yellowstone hotspot may be lower-mantle origin. The Juan de Fuca slab is characterized as a high-velocity anomaly in the western edge portion of the study area. The slab shape and its subducted depth vary in the latitude direction. In the southern parts the slab may have extended down to >600 km depth. A “slab hole” is revealed beneath Oregon (42°N-43°N), which shows up as low-velocity anomalies at depths of ~50-300 km. The formation of the slab hole may be related to the Newberry magmatism. The removal of flat subducted Farallon slab may trigger the vigorous magmatism (low-velocity anomalies beneath the Basin and Range and southern part of Rocky Mountain) and also resulted in the uplift (Colorado Plateau and Rocky Mountain) in this region.

Publications:


Yukihiro Osada

Title/Affiliation  
COE Assistant Professor / Department of Geophysics

Specialized Field  
Solid earth planet physics (Seafloor Geodesy)

Research Subject  
Study on observation of seafloor crustal movements

The Purpose of Research and Outline of Accomplishments:

Along the Nankai Trough, where the Philippine Sea plate subducts under southeastern Japan with a convergence rate of about 40 mm/yr, large interplate thrust earthquakes of magnitude 8 class have occurred repeatedly with recurrence intervals of 100-200 years. About 60 years have passed since the last earthquakes happened in 1944 and 1946. Therefore it is important to monitor the tectonic activities in the Nankai Trough. Since most of the source region of the earthquakes is located beneath the ocean, an observation system is necessary in the offshore source region. We developed a seafloor acoustic ranging system to continuously monitor the seafloor crustal movement. We aim to monitor the activity in the splay faults in the rupture area of the Tonankai earthquake in the Nankai subduction zone. Slips along the active splay faults may be an important mechanism that releases the elastic strain caused by relative plate motion.

We carried out two experiments, a short term (one day) and a long-term (four month) experiment, to estimate the repeatability of acoustic measurements of this system. We deployed four PXPs (precision acoustic transponders) with about 600 m (M2-S1 baseline) and 920 m (M2-S2 base line) spacing in the long-term experiment. The standard deviation in acoustic measurements was about 1 cm on each baseline.

In September 2008 we carried out an observation to monitor an active splay faults on
Kumano-Nada prism slope. We recovered them in August 2010 to get data of acoustic measurements for 6 month and pressure measurements for 18 month. In March 2009, very low frequency earthquake activity near the experiment area was observed by OBSS which was deployed by JAMSTEC (Obana et al, 2010) and ERI, Univ, of Tokyo (Nakahigashi et al. (2010)). The standard deviation in acoustic measurements was about 1 cm on each baseline. We didn’t observe the change of baselines in this system. Therefore we have an assumption that there was no crustal movement that exceeds the detection sensitivity in this event. And we estimated the detection sensitivity of this system on the location of this observation. This results show that this system need more than M5 due to get the dislocation, which is 1cm on this location.

Main Results:
We developed the seafloor acoustic ranging system. This system on seafloor has shown a reliable result during trial experiment. We carried out a long-term (four month) experiment, to estimate the repeatability of acoustic measurements of this system. The standard deviation in acoustic measurements is about 1 cm on each baseline.

Publications:  Journals:

Symposium Participations:

Climate Change Research Subgroup

Kohtaro Hosoda

Title/Affiliation  COE Assistant Professor / Center for Atmospheric and Oceanic Studies, Graduate School of Science
Specialized Field  Satellite Remote Sensing of Ocean
Research Subject  Estimation of sea surface temperature from space-borne microwave and infrared radiometers

The Purpose of Research and Outline of Accomplishments:

Near-real-time observations of sea surface temperature (SST) are essential for monitoring and
prediction of atmosphere and oceans. They provide fundamental weather information required by the modern society for stable production of agricultural and fishery industries and navigation safety of ships. Since satellite-based observations can produce high-spatial-resolution and wide coverage SST images within several minutes, the provided data by many satellites have been widely used for operational and research purposes. The purposes of my research are the development and advancement of the estimation algorithm for SST from these satellite-based sensors.

The achievements of our research in this year consist of the algorithm developments for two radiometers mounted on NASA’s Aqua satellite. One is the algorithm for a visible and infrared radiometer, MODIS. Another developed algorithm is one for the AMSR-E, a microwave radiometer, which was built by the Japanese space agency (JAXA).

Main Results:

1. Algorithm development for SST estimation from Aqua/MODIS observations in global ocean.

   This study is a extension to global ocean of our previous work: Hosoda et al.(2007, J. Oceanogr.), in which an appropriately-estimating model was selected for estimating SST from MODIS in the western North Pacific. We compared four candidate models for atmospheric correction, which were suggested in 1980s and 1990s. Other previous studies have concluded that a model (WVSST) using water vapor in the atmosphere, which can be estimated from microwave radiometers, has little performance for estimating SST. On the other hand, our research showed that WVSST using water vapor data from Aqua/AMSR-E is the best performance model. Discussions in the previous studies were based on the water vapor values estimated from an interpolation or a weekly-averaged product. Our study revealed that the simultaneous data of water vapor is a key for infrared remote sensing of SST.

2. A study on SST estimating algorithm from microwave radiometer Aqua/AMSR-E

   This is a continuing study from the last year. The improving point is that the atmospheric pressure data at sea level (SLP), which were estimated from the atmospheric re-analysis product by the Japanese Meteorological Agency (JMA/GANAL), were included as one of input parameters for estimating SST. While a few microwave remote sensing algorithms for cloud parameters employed SLP for atmospheric correction, most studies have not included the SLP as an estimation parameter. Including SLP in the estimating algorithm for SST showed that the estimation was improved by about 50%. This study suggests that the SLP could also improve the estimation of surface parameters, SST.

Publications: Journals:

Shusaku Sugimoto

Title/Affiliation
Fellow of "Japan Society for the Promotion of Science"/International Advanced Research and Education Organization
Institute for International Advanced Interdisciplinary Research

Specialized Field
Physical Oceanography

Research Subject
Air-sea interaction in the North Pacific

The Purpose of Research and Outline of Accomplishments:
The western boundary current region of the North Pacific is characterized by vigorous heat release related to turbulent heat flux (sum of sensible and latent heat flux) from the ocean to the atmosphere during winter and one of extremely large turbulent heat flux release region in the world’s oceans. The purpose of this study is to investigate relations between the upward turbulent heat flux and sea surface temperature in the western boundary current region, and to assess contributions of sea surface temperature in determining the turbulent heat flux, using the daily observational dataset.

Main Results:
Variations of turbulent heat fluxes in 16 winters from December 1992/February 1993 to December 2007/February 2008 in the North Pacific are investigated. Turbulent heat fluxes are calculated from the bulk formula using daily variables of the Objective Analyzed air–sea Flux (OAFlux: Yu et al. 2008) dataset and
bulk coefficients based on the Tropical Ocean and Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment (TOGA/COARE) bulk flux algorithm 3.0. The winter turbulent heat fluxes over the Kuroshio/Oyashio Confluence region have largest temporal variances in the North Pacific. The relative contributions among observed variables in sea surface temperature, surface air temperature, and surface wind speed causing turbulent heat flux variations in the Kuroshio/Oyashio Confluence region are assessed quantitatively by performing simple experiments using combinations of two types of variables: raw daily data and daily climatological data. Results show that the sea surface temperature is primarily responsible for the turbulent heat flux variations: a huge amount of heat is released in the state of the positive sea surface temperature anomaly. Using the satellite-derived sea surface temperature and sea surface height datasets with high spatial and temporal resolutions, it is found that the sea surface temperature anomalies in the Kuroshio/Oyashio Confluence region are formed through activities of the anticyclonic (warm) eddies detached northward from the Kuroshio Extension: SSTs take positive (negative) anomalies when the eddy kinetic energy level becomes higher (lower) there, associated with more convoluted (straight) Kuroshio Extension path.

Journals:

Symposium Participations:
Origin and Extinction of Life Research Subgroup

Yoshihiro Furukawa

Title/Affiliation: COE Assistant Professor / Department of Earth Science
Specialized Field: Astrobiology, Geochemistry
Research Subject: Abiotic organic synthesis, Amino acid polymerization

The Purpose of Research and Outline of Accomplishments

Origin and chemical evolution of organic compound on the early Earth has been under intensive investigation to reveal the origin of life. I have been investigating such abiotic chemical reactions essential for the origin of life: 1) reactions in meteorite impact to ocean as a synthesizing process of the organic compounds, 2) reactions of amino acids to form peptides.

Main Results

1) Syntheses of organic compounds and their precursors under ocean impact conditions

Chemical reactions in ocean impacts have potentials to form various organic compounds. Simulating impact conditions, the organic compounds synthesized from inorganic compounds so far were an amino acid, amines, and carboxylic acids. Recently, I synthesized various hydrocarbons, alcohols, and an aldehyde with shock-recovery experiments simulating ancient ocean impact conditions. I investigated the factor controlling the yields of such organic compounds in this year and we found the variations of yields depending on the type of meteorite.

In order to understand the reaction mechanisms in ocean impact events, a graduate student and I have been investigating the intermediate products of organic compounds: carbon monoxide, hydrogen, ammonia, and hydrogen cyanide. We found the formation of these compounds from inorganic elemental substances (graphite, nitrogen, iron, and nickel) and water. In addition, the factors controlling the yields of hydrogen cyanide and ammonia were revealed in this year.

In addition to the synthesis of organic compounds, I have investigated the formation of serpentine from olivine in impact conditions. In this study, I performed the formation of serpentine in impact condition for the first time.

2) Peptides formation under sub-seafloor conditions

The next step of chemical evolution, from amino acids to protein, is polymerization of amino acids. Sub-seafloor environments are considered to be one of the possible places for abiotic polymerization. However, few study have been performed as to the polymerization of amino acids under sub-seafloor conditions. Caraboleters and I were demonstrated high temperature and pressure experiments of valine, glycine, alanine, and methionine simulating sub-seafloor diagenetic conditions. We successfully synthesized hexamer of valine, which have never been synthesized simulating the early Earth conditions. Effects of pressure on the amino acids decomposition and peptides formation were also precisely investigated in this study.

Conference Participations

1) International conferences
   1. Furukawa, Y., Sekine T., Oba M., Kakegawa T., and Nakazawa H., Variety of organic compounds
synthesized by ocean impacts on the early Earth, Astrobiology Science Conference 2010, 26-29 April 2010, League City, TX, USA, (Speaker).


2) Domestic conferences


Media Coverage
1) Britannica Book of the Year 2010
Our research on the organic synthesis by impact on the early Earth was covered by “Britannica Book of the Year 2010” as a highlighted study in Earth Science in 2009 (Furukawa et al., Nature Geoscience, 2009).

Tsubasa Otake
Title/Affiliation COE Assistant Professor / Department of Earth Science
Specialized Field Hydrothermal geochemistry, Stable isotopes
Research Subject Origin of life, Polymerization of amino acids

The Purpose of Research and Outline of Accomplishments:
(1) Mechanisms of iron oxide transformations in hydrothermal systems

Redox evolution of atmosphere and ocean is of great interest since it is liked to the evolution of biosphere, particularly the timing of emergence of oxygenic photoautotrophs (i.e., cyanobacteria). The redox state of atmosphere and ocean in Archean era (3.8 – 2.5Ga) has been estimated by several geologic records, one of which has been oxidation states of Fe in Fe-rich chemical sediments called Banded Iron Formations (BIFs). However, to better understand the oxidation state of Archean ocean, we need to take into account the effect of diagenetic/metamorphic transformation of iron-bearing minerals in BIFs. Therefore, objective of the researches was to investigate mechanisms of iron oxide transformations under various hydrothermal conditions (e.g., 100 – 250°C).

The main results obtained in the experiments were: (1) at the lower temperatures (e.g., 100 – 150°C), transformations between magnetite and hematite occur though a redox-independent reaction by addition/leaching of Fe^{2+} ion into/from the minerals, and (2) at the higher temperatures (e.g., > 200°C), the
iron oxide transformations are involved with the change in redox state of Fe. These results suggest that iron oxides in BIFs were likely to be formed in disequilibrium with the Archean ocean due to the transformations during diagenesis, and that iron oxides in BIFs are not direct indicators for the redox state of Archean ocean. These results were published from Geochimica et Cosmochimica Acta this year.

(2) Oligomerization of amino acids under high pressure conditions

A problem in determining the origins of life on Earth has been the polymerization of amino acids, a process that is necessary in the formation of peptides. The problems stemmed from the instability of amino acids and the difficulty of advancing the reactions in a water-rich environment (e.g., a seafloor hydrothermal system). Instead, we investigated the stability of powders of amino acids and their oligomerization reactions under high temperature (180 - 400°C) and pressure (1.0 - 5.5 GPa) conditions, based on a hypothesis that polymerization of amino acids may have occurred during diagenesis/metamorphism of marine sediments at convergent margins on the early Earth.

The results showed that amino acids, both glycine and alanine, were stable under the high pressure conditions. They were oligomerized up to pentamer, which has never been reported for alanine in the absence of any catalysts. Yields of peptides at a fixed temperature and reaction time were higher under the higher pressure conditions, indicating applying pressure does not suppress the formation of peptides from amino acid monomers. Elemental, IR, and isotope (N and C) analyses of the run products indicate that deamination is a key process when determining the stability of amino acids and peptides under high pressure conditions. Therefore, a possible NH₃-rich environment in marine sediments on the early Earth may have further stabilized amino acids and peptides by preventing the deamination reaction. These results suggest that diagenetic/metamorphic environments of marine sediment in sub-seafloors are needed to consider as where played an important role for the prebiotic peptide formation. The results were presented by several international and domestic conferences, and the manuscript for publication will be submitted to Astobiology in early next year.

International activity:
Fieldtrip to South Africa (Archean Barberton Greenstone Belts) September 28th – October 6th

Publications from peer reviewed journals:

Conference Presentations:
2. Sakamoto, Y., Otake, T., and Kakegawa, T. Geological and geochemical study of Archean BIFs (3.2 Ga) at the Fig Tree Group and Moodies Group in the Barberton Greenstone Belt, South Africa. Japan Geoscience Union Meeting 2010, Makuhari, Japan.
4. Otake, T. Theoretical study of multiple sulur isotope effects and their mass dependency during


Symposium Participations:
“Problems on Chemical Evolution and Evolution of early life” in the 3rd Astobiology Workshop, Tokyo, Japan.

Masahiro Oba
Affiliated Department: COE Assistant Professor/ Department of Earth Science
Specialized Field: Organic Geochemistry
Research Project: Analysis of paleoenvironments by organic geochemistry

Main Results:
• Short-term OAEs coinciding with foraminiferal extinctions in the late Cenomanian

The ocean anoxic event (OAE) that occurred near the Cenomanian-Turonian (C-T) boundary is the most extensive among the mid-Cretaceous OAEs and is characterized by stepwise extinctions in marine biota. Recently, some reports from organic geochemical studies have estimated the dissolved oxygen changes in the photic zone using molecular fossils. But, there are no discussions in those studies on the relationship between the extinctions and the anoxic condition of water column. We report coincidence of two peaks of organic compounds showing short-term OAEs and double planktonic foraminiferal extinctions in the late Cenomanian. This indicates that those extinctions were due to short-term OAEs, which we discovered for the first time in this study.
(In Oba, M., Kaiho, K., Okabe, T., Lamolda, M.A., and Wright, J.D., Short-term anoxia coinciding with rotaliporid extinctions during the Cenomanian–Turonian transition in the middle-neritic eastern North Atlantic inferred from organic compounds. Geology, submitted.)

• A smooth negative shift of organic-carbon isotope ratios at an end-Permian mass extinction horizon in central pelagic Panthalassa.

The end-Permian mass extinction is associated with a global perturbation in the carbon isotopic composition of carbonates and organic matter, but such changes are not well documented from pelagic deep-sea sediments. One of the most continuous pelagic deep-sea Permian/Triassic boundary (PTB) sections, the Am-2 section, is exposed in the accretionary complexes of Japan. New data for organic carbon isotope ratios (δ^{13}C_{org}) were obtained from 36 samples from section Am-2. The δ^{13}C_{org} excursion curve exhibits a
negative shift of 2.0‰ in the low-latitude, pelagic Panthalassic Ocean at the end of the Permian, which coincides with a radiolarian extinction. The $\delta^{13}$C$_{org}$ values of pelagic, deep-sea Panthalassic sections and those of shallow-water sections from Panthalassic seamounts exhibit a smooth, negative shift that lacks temporary increases like those reported from Paleotethyan PTB sections. Absence of temporary $\delta^{13}$C$_{org}$ increases at the PTB in Panthalassa may reflect less algal and bacterial blooming in pelagic Panthalassa compared to the shallow-water Paleotethys.

Publications: Journal:

Planetary Evolution Research Group

Hitoshi Miura

Title/Affiliation: COE Assistant Professor / Department of Earth Science
Specialized Field: Planetary Science, Crystal Growth
Research Subject: Theoretical modeling of crystal growth in space

The Purpose of Research and Outline of Accomplishments:

Chondritic meteorites contain many kinds of primitive materials being considered to have experienced significant thermal processes in early solar nebula, e.g., evaporation, melting, and crystallization. It is very important to elucidate the thermal processes because it closely relates to the environment in which planets were formed. We investigate the formation mechanism of these primitive materials in the early solar nebula based on the numerical simulation techniques. The main target is the crystallization process at far from equilibrium state, which is common in the early solar nebula environment.

Main Results:
1. We studied evaporation and re-condensation process of silicate dust particles caused by planetesimal bow shock. The micron-sized particles evaporate behind the shock front. The vapor cools rapidly in the distance from the planetesimal, then solid particles condense from the supersaturated vapor. We found that the condensation occurs when the vapor cooled far below the equilibrium condensation temperature by a few hundred K or more, depending on the size of planetesimal causing the bow shock. The condensed particles should have sizes and morphologies similar to fine olivine crystals observed in matrix of chondritic meteorite.
2. The solidification textures of chondrules have been considered to relate to the crystal growth process inside a chondrule melt droplet. We numerically simulated pattern formation of a supercooled forsterite melt droplet using a phase-field method and reproduced the rapid crystal growth along the droplet (rim formation).
We also analytically derived the condition for the rim formation as a function of the cooling rate.

**International activity:**

1. Lecturer for Experimental practices course in the 14th International Summer School on Crystal Growth (ISSCG-14), August 1st-7th, 2010 at Dilian, China.

**Publications:**


**Journals:**


**Symposium Participations (International and the first author, only):**

1. H. Miura, E. Yokoyama, K. Nagashima, K. Tsukamoto, and A. Srivastava, For understanding of fundamental process of chondrule melt crystallization, 7th Annual Meeting and Geosciences World Community Exhibition, Hyderabad International Convention Centre, India, July 5-9, 2010 [invited]