

Tohoku University Global COE Program  
“Global Education and Research Center for Earth and Planetary Dynamics”

# **External Review 2011**

**Activity Report of Researchers**

**Solid Earth Research Group**  
**Dynamics of Earthquakes and Volcanism Research Subgroup**

**Tohoku University**



## Members

### Project Members:

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Toru Matsuzawa (\*\*Prof., Seismology, Dr.Sc., 2011.4.1-, Chair of Education Steering Com., -2011.3.31)

Takeshi Nishimura (Assoc. Prof., Phys. Volcanology, D.Sc., Vice-Chair of Public Information Com.)

Haruo Sato (\*\*Prof., Seismology, Dr.Sc., -2011.3.31)

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## Activity Report for External Review (2010-2011)

### Dynamics of Earthquakes and Volcanism Research Subgroup

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# Toru Matsuzawa

Title/Affiliation	Professor / Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University
Specialized Field	Earthquake-generating process
Research Subject	Elucidation of the rupturing process of asperities

## **The Purpose of Research and Outline of Accomplishments:**

The objectives of my research is to elucidate the earthquake generating processes on the plate boundaries, in land areas and in the descending slabs. We found the seismicity is mainly controlled by stress distribution and temperature. We have shown that the 'asperity model' can explain the interplate seismicity very well in the northern part of the northeastern Japan subduction zone, but the model could not explain the infrequent large earthquakes off Fukushima prefecture. The 2011 Tohoku earthquake (M9.0) showed that the hierarchical structure of the asperities is very important to understand the huge interplate earthquakes.

## **Main Results:**

### (1) Lower depth limit of inland earthquakes (collaborative study with A. Omuralieva)

We estimated precise locations of shallow earthquakes beneath the Japanese Islands and three-dimensional seismic velocity structure shallower than 50 km depth. Obtained result shows that the lower limit of the hypocenters (D90) tend to be shallower beneath the volcanoes and deeper in the regions contacting the cold oceanic plates, suggesting the lower limit is basically controlled by the temperature. Moreover, we found that large inland earthquakes tend to occur in the regions with shallow D90.

### (2) Numerical simulations of the interplate earthquakes (collaborative study with K. Ariyoshi)

We investigated the characteristics of small repeating earthquakes, slow-slip events and tremors on the plate boundaries using numerical simulations based on a rate- and state-dependent friction law. In the simulations, migration of the tremors was successfully reproduced and migration speed became faster in the period just before the occurrence of the large interplate earthquakes.

### (3) Stress distribution in the descending slab (collaborative study with S. Kita)

We investigated the stress distribution in the descending slab beneath Hokkaido and Tohoku, Japan and found that aftershocks of large earthquakes are limited by the neutral plane between the down-dip compressional (DC) stress and the down-dip tensional (DE) stress, suggesting that large earthquake ruptures are confined to either the DC or DE stress field, and do not go beyond the neutral plane.

### (4) Seismogenesis in the slab beneath the Hokkaido corner (collaborative study with S. Kita)

We performed seismic tomography beneath the Hokkaido corner and found that a low-velocity

zone having seismic velocities of crust materials exists in the mantle wedge just above the Pacific slab. The low-velocity cold material is thought to be the cause of the local deepening of the seismic belt in the slab crust there.

(5) Interplate coupling distribution estimated from repeaters (collaborative study with N. Uchida)

We compared the slip distribution of the 2011 Tohoku earthquake (M9.0) and small repeating earthquake activities before the main shock. The largest slip of the main shock occurred in a region close to the trench where repeating earthquake activity was quite low. Moreover, the slip was not propagated into the regions where the slip rates estimated from repeating earthquakes were very high. This result indicates that the slip distribution of the huge earthquakes can be roughly estimated from the small repeating earthquake activity beforehand.

(6) Reason why the M9 earthquake occurred on the weak plate boundary (collaborative study with Y. Iio)

Many geophysical observations indicate that the frictional stress on the plate boundary in the northeastern Japan subduction zone was weak and as low as around 20 MPa. We showed that the plate boundary as wide as more than 200km can accumulate the absolute slip deficit of more than 50m even if the strength is as low as 10 MPa.

**International activity:**

Member of the Scientific Organizing Committee for the international symposium "Geofluid Process in Subduction Zones and Mantle Dynamics", Tokyo Institute of Technology, Japan, March 17-19, 2011.

**Published Journal Papers:**

1. Ariyoshi, K., **T. Matsuzawa**, J. P. Ampuero, R. Nakata, T. Hori, Y. Kaneda, R. Hino and A. Hasegawa (2011). Migration process of very low-frequency events based on a chain-reaction model and its application to the detection of preseismic slip for megathrust earthquakes., *Earth Planets Space*, doi:10.5047/eps.2010.09.003, in press.
2. Huang, Z., D. Zhao, N. Umino, L. Wang, **T. Matsuzawa**, A. Hasegawa and T. Yoshida (2010). P-wave tomography, anisotropy and seismotectonics in the eastern margin of Japan Sea., *Tectonophysics*, 489, 177-188, doi:10.1016/j.tecto.2010.04.014.
3. Kita, S., T. Okada, A. Hasegawa, J. Nakajima and **T. Matsuzawa** (2010). 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., *Tectonophysics*, 496, 68-82, doi: 10.1016/j.tecto.2010.10.010.
4. Kita, S., T. Okada, A. Hasegawa, J. Nakajima and **T. Matsuzawa** (2010). Anomalous deepening of a seismic belt in the upper-plane of the double seismic zone in the Pacific slab beneath the Hokkaido corner : Possible evidence for thermal shielding caused by subducted forearc crust materials., *Earth Planet. Sci. Lett.*, 290, 415-426, doi:10.1016/j.epsl.2009.12.038.
5. Uchida, N., **T. Matsuzawa**, J. Nakajima and A. Hasegawa (2010). Subduction of a wedge-shaped Philippine Sea plate beneath Kanto, central Japan, estimated from converted waves and small repeating earthquakes., *J. Geophys. Res.*, 115, B07309, doi: 10.1029/2009JB006962
6. **Matsuzawa, T.** (2010). Strategy for the prediction of the interplate earthquakes., *ZISIN Journal*, 50, 22-26 (in Japanese).

7. Hasegawa, A., J. Nakajima, N. Uchida, F. Hirose, S. Kita and **T. Matsuzawa** (2010). Slab structure beneath the Japanese Islands and earthquake generation, *J. Geography*, 119, 190-204 (in Japanese).
8. Shimamura, K., **T. Matsuzawa**, T. Okada, N. Uchida, T. Kono, and A. Hasegawa (2011). Similarities and Differences in the Rupture Process of the M~4.8 Repeating-Earthquake Sequence off Kamaishi, Northeast Japan: Comparison between the 2001 and 2008 Events, *Bull. Seismol. Soc. Am.*, 101, 2355-2368, doi: 10.1785/0120100295.
9. Okada, T., K. Yoshida, S. Ueki, J. Nakajima, N. Uchida, **T. Matsuzawa**, N. Umino, A. Hasegawa, and Group for the aftershock observations of the 2011 off the Pacific coast of Tohoku Earthquake (2011). Shallow inland earthquakes in NE Japan possibly triggered by the 2011 off the Pacific coast of Tohoku Earthquake, *Earth Planets Space*, 63, 749-754, doi:10.5047/eps.2011.06.027.
10. Uchida, N., and **T. Matsuzawa** (2011), Coupling coefficient, hierarchical structure, and earthquake cycle for the source area of the 2011 Tohoku earthquake inferred from small repeating earthquake data, *Earth Planets Space*, 63, 675-679, doi:10.5047/eps.2011.07.006.
11. **Matsuzawa, T.** (2011), Why could the M9 earthquake occur in the northeastern Japan subduction zone? - Why did we believe it would not occur there?, *KAGAKU*, 81, 1020-1026 (in Japanese).
12. Omuralieva, A., A. Hasegawa, **T. Matsuzawa**, J. Nakajima, and T. Okada (2011). Lateral variation of the cutoff depth of shallow earthquakes beneath the Japan Islands and its implications for seismogenesis, *Tectonophysics*, in press.
13. Hasegawa, A., J. Nakajima, T. Okada, N. Uchida, T. Yanada, S. Kita, D. Zhao, **T. Matsuzawa** and N. Umino (2011). Generation mechanism of earthquakes in subduction zones: A vital role of geofluids in earthquake generation, *J. Geography*, in press (in Japanese).

#### **Symposium Participations (Selected):**

1. **Matsuzawa, T.**, N. Uchida, K. Shimamura, K. Ariyoshi, T. Okada and A. Hasegawa (2010). Aseismic slip and repeating earthquakes on the plate boundary in the northeastern Japan subduction zone., *Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure"*, July 13-15, 2010, Sendai.
2. Omuralieva, A., A. Hasegawa, **T. Matsuzawa**, J. Nakajima and T. Okada (2010). Lateral variation of the cutoff depth of the seismogenic layer beneath the Japanese Islands and its contributing factors., *The Seismological Society Japan 2010 Fall Meeting*, October, 2010, Hiroshima.
3. Uchida, N., **T. Matsuzawa**, J. Nakajima, A. Hasegawa and N. Umino (2010). Subduction of a Wedge-shaped Philippine Sea Plate beneath Kanto, Central Japan, and its Effect on Interplate Coupling., *2010 Western Pacific Geophysics Meeting*, June 22-25, 2010, Taipei.
4. Uchida, N., **T. Matsuzawa**, K. Shimamura, A. Hasegawa, and W. L. Ellsworth (2010), Seismicity on an interplate asperity off-Kamaishi, NE Japan over two earthquake cycles, *AGU 2010 Fall Meeting*, December, 2010, San Francisco.
5. Kita, S , A. Hasegawa, T. Okada, J. Nakajima, **T. Matsuzawa**, and K. Katsumata (2010), Detailed seismic velocity structure beneath the Hokkaido corner, NE Japan: Collision process of the forearc sliver, *AGU Fall Meeting*, December, 2010, San Francisco.
6. **Matsuzawa, T.**, N. Uchida, T. Iinuma, Y. Ohta, S. Miura, T. Okada, J. Nakajima, S. Kita, Y. Yabe, M. Ichiki, N. Umino, and A. Hasegawa (2011), Why the M9 event occurred off the Pacific coast of Tohoku, Japan?, *AOGS 2011*, August, 2011, Taipei.
7. **Matsuzawa, T.**, and Y. Iio (2011). Why could we not anticipate the M9 earthquake? - And why did it occur? -, *The Seismological Society Japan 2011 Fall Meeting*, October, 2010, Shizuoka.

#### **TV and newspaper:**

1. NHK special, MEGAQUAKE, January 10, 2010. This TV program introduced our group's study of small repeating earthquakes.

# Takeshi Nishimura

Title/Affiliation	Associate Professor / Department of Geophysics, Graduate School of Science, Tohoku University
Specialized Field	Volcanology, Seismology
Research Subject	Study of the dynamics of volcanic eruptions

## **The Purpose of Research and Outline of Accomplishments:**

The volcanic fluid behavior in the conduit and reservoir is a key to understand the volcanic eruption dynamics. Since the volcanic fluids deform and oscillate the conduit wall and volcanic edifice, volcanic earthquakes and tremor as well as volcanic deformations are observed at active volcanoes. The objective of this study is to clarify the volcanic fluid dynamics associated with volcanic eruptions and magma ascent processes from the geophysical data. In this fiscal year, I studied mainly the relation of magma upward migration process beneath active volcanoes to volcano deformation. I also conducted tilt and seismic observations at active volcanoes and obtained preliminary results from the data analyses. I further published a book in English on volcanic earthquakes and tremor observed in Japan.

## **Main Results:**

We investigated relations of the magma ascent process to failed eruption of Iwate volcano in 1998, by reconciling the dike intrusion models presented by previous studies. Two simple magma ascent models are tested to explain the observed strain changes caused by dike intrusion. The first model assumes magma ascent without gas bubble growth. This model does not accompany volume changes during ascent, so the predicted strain gradually increases with time. The second model includes gas bubble growth in magma. This model introduces additional buoyancy as magma ascends so that accelerated strain is expected to be observed. The temporal changes in the strains observed at two stations of Iwate volcano are better matched with the first one. We therefore conclude that the 1998 failed magmatic eruption at Iwate volcano is caused by out-gassing of magma during magma ascent. This result suggests that detailed monitoring of magma ascent may enable us to predict whether magma ascent introduce a new eruption or fail to erupt.

We continued tilt observations at Suwanosejima, Kagoshima Prefecture, and Semeru volcano in Indonesia. Tiny inflations of the ground around the active craters are detected by tilt meters about a few hundreds or a few tens of seconds before small vulcanian explosions at the two volcanoes. The amount of inflation increases with the magnitude of volcanic eruptions that are evaluated by the maximum amplitudes of explosion earthquakes. These observational findings may enable us to predict the magnitudes or strength of volcanic explosions by geodetic measurements.

Our book on volcanic earthquakes and tremor that was first published in Japanese in 2006 was published in English in 2011. The book reviews and summarizes the characteristics of the hypocenter distributions, source mechanisms, and activities of the volcanic earthquakes and tremor presented in previous papers published for about 100 years in Japan.

## **Published Journal Papers:**

1. Emoto, K., H. Sato, and **T. Nishimura** (2011). Synthesis and applicable condition of vector wave envelopes in layered random elastic media with anisotropic autocorrelation function based on the



- markov approximation, *Geophys. J. Int.*, (in press)
2. Sawazaki, K., H. Sato, and **T. Nishimura** (2011). Envelope synthesis of short-period seismograms in 3-D random media for a point shear dislocation source based on the forward scattering approximation: Application to small strike-slip earthquakes in southwestern Japan, *J. Geophys. Res.*, 116, B08305, doi:10.1029/2010JB008182.
  3. **Nishimura, T**; Ueki, S (2011). Seismicity and magma supply rate of the 1998 failed eruption at Iwate volcano, Japan, *BULLETIN OF VOLCANOLOGY*, 73, 2, 133-142
  4. Nakahara, H., H. Sato, **T. Nishimura**, and H. Fujiwara (2011). Direct observation of rupture propagation during the 2011 offthe Pacific coast of Tohoku, Japan, earthquake (Mw 9.0) using a small seismic array, *EPS*, 63, 589-594.
  5. **Nishimura, T.** and S. Ueki (2010). Seismicity and magma supply rate of the 1998 failed eruption at Iwate volcano, Japan., *Bull. Volcanol.*, 73, 133-142, doi: 10.1007/s00445-010-0438-8
  6. Emoto, K., H. Sato and **T. Nishimura** (2010). Synthesis of vector wave envelopes on the free surface of a random medium for the vertical incidence of a plane wavelet based on the Markov approximation., *Journal of Geophysical Research - Solid Earth*, 115, doi: 10.1029/2009JB006955
  7. McNutt, SR; **Nishimura, T** (2010). Volcanic tremor during eruptions: Temporal characteristics, scaling and constraints on conduit size and processes, *JOURNAL OF VOLCANOLOGY AND GEOTHERMAL RESEARCH*, 178, 1, 10-18
  8. Murakami, **T**; **Nishimura, T**; Kasai, E (2010). Lowering Reduction Temperature of Iron Ore and Carbon Composite by Using Ores with High Combined Water Content, *ISIJ INTERNATIONAL/JOURNAL OF IRON AND STEEL RESEARCH INTERNATIONAL*, 49, 11, 1686-1693

#### Books:

1. **Nishimura, T.** and M. Iguchi (2011). *Volcanic earthquakes and tremor in Japan.*, Kyoto Univ. Press, 253p.

#### Symposium Participations:

1. K. Pacheco, **T. Nishimura**, and H. Sato (2011) Source mechanism of a very-long-period seismic event observed during the 2000–2002 volcanic activity at Mt. Bandai, Seismological Society of Japan 2011 Fall meeting, October 12-14, Shizuoka, Japan.
2. Yoshida, Y., **T. Nishimura**, and H. Sato (2011) Effusion cycle of a simple analog experiment, Volcanological Society of Japan 2011 Fall meeting, October 2-4, Asahikawa, Japan.
3. Emoto, K., H. Sato, and **T. Nishimura** (2011) Applicable condition of the Markov approximation for elastic wave envelopes in nonisotropic random media, IUGG 2011, Melbourne, Australia.
4. **Nishimura, T.**, M. Iguchi, R. Kawaguchi, Surono, M. Hendrasto and U. Rosadi (2011) Source mechanisms of vulcanian eruptions at Semeru volcano, Indonesia, as inferred from seismic and tilt data analyses, Japan Geoscience Union meeting 2011, May 22-27, Chiba, Japan.
5. Kawaguchi, R., **T. Nishimura**, and H. Sato (2011) Volcano deformation caused by gas slug ascent in an open conduit, Japan Geoscience Union meeting 2011, May 22-27, Chiba, Japan.
6. **Nishimura, T.** (2011). Analyses of transverse component of teleseismic P-waves recorded at Hi-net stations, Japan Geoscience Union meeting 2011, May 22-27, Chiba, Japan.
7. **Nishimura, T.**, M. Iguchi, R. Kawaguchi, M. Surono, Hendrasto and U. Rosadi (2010). Volcano Inflation prior to Gas Explosions at Semeru Volcano, Indonesia., American Geophysical Union 2010 Fall meeting, San Francisco, December 13-17, 2010
8. Emoto, K., H. Sato and **T. Nishimura** (2010). Envelope Synthesis in Layered Random Media with Background-Velocity Discontinuities Based on the Markov Approximation., American Geophysical Union 2010 Fall meeting, San Francisco, December 13-17, 2010

9. **Nishimura, T.**, M. Iguchi, R. Kawaguchi, M. Surono, M. Hendrasto and U. Rosadi (2010). Volcano inflation associated with eruptions at Semeru volcano., JST-JICA program symposium "Multi-disciplinary hazard reduction from earthquakes and volcanoes in Indonesia", Kobe, Japan
10. **Nishimura, T.**, M. Iguchi, R. Kawaguchi, M. Surono, M. Hendrasto and U. Rosadi (2010). Volcano Inflation prior to Gas Explosion Events at Semeru Volcano, Indonesia., Volcanological Society of Japan 2010 Fall meeting, October 9-11, 2010, Kyoto, Japan
11. Kitamura, Y., **T. Nishimura**, H. Sato (2010). Effect of topography on volcano deformation caused by magma in an open conduit by Finite Element Method., Volcanological Society of Japan 2010 Fall meeting, October 9-11, 2010, Kyoto, Japan
12. **Nishimura, T.** (2010). Temporal change of volcano inflation: observed characteristics and its relation to volatile behavior., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-20, July 13-15, 2010, Sendai, Japan
13. **Nishimura, T.**, M. Iguchi, Y. Ohta, Y. Kitamura, H. Aoyama, A. Suzuki, J. Oikawa, H. Nakamichi, H. Yakiwara and T. Tameguri (2010). Tilt observation close to active crater of Suwanosejima volcano., Japan Geoscience Union meeting 2010, May 23-28, 2010, Chiba, Japan
14. **Nishimura, T.** and S. Ueki (2010). Failed eruption of Iwate volcano in 1998: temporal changes of seismicity and magma ascent., Japan Geoscience Union meeting 2010, May 23-28, 2010, Chiba, Japan
15. **Nishimura, T.**, M. Iguchi, T. Yamazaki, R. Kawaguchi, M. Surono, Hendrasto, S. Hidayati, H. Triastuty and U. Rosadi (2010). Tilt observation at Semeru volcano, east Java, Indonesia., Japan Geoscience Union meeting 2010, May 23-28, 2010, Chiba, Japan
16. Anggono, T., **T. Nishimura**, H. Sato, H. Ueda and M. Ukawa (2010). Temporal changes of seismic velocity at Miyakejima associated with 2000 activity based on ambient seismic noise analyses., Japan Geoscience Union meeting 2010, May 23-28, 2010, Chiba, Japan

#### **Medias and others**

1. Science Café of Tohok University Date: July 24, 2010  
Presentation title: Detection of magma motion beneath active volcanoes: science frontier of prediction for volcanic eruptions. Place: Sendai Media Park, Sendai.  
Broadcasting: Sendai CATV television. Science Café of Tohoku University
2. Interview on the steam explosion accident at Onikobe geothermal power plant on October 17, 2010, by several broadcastings and Kahoku newspaper. October, 2010.

# Haruo Sato

Title/Affiliation	Professor / Department of Geophysics, Graduate School of Science, Tohoku University
Specialized Field	Seismology, Solid Earth physics
Research Subject	Study of the inhomogeneous structure of the solid earth

## **The Purpose of Research and The Abstract of Accomplishments:**

The structure of the lithosphere is inhomogeneous reflecting the dynamic evolution of the solid earth. The objective of our research is to study the lithospheric inhomogeneity by using seismological methods. We develop wave scattering theory in random media having rich short wavelength spectra to establish the mathematical foundation for the interpretation of short period seismograms. We also develop a practical method to measure the spectrum of random inhomogeneity from the envelope broadening of short-period seismic waves with travel distance increasing and the coda wave excitation. Information about scattering and absorption is useful for understanding the geodynamic process but also for the quantitative prediction of strong earthquake motion.

## **Main Results:**

### (1) Development of wave scattering theory

1. Sato coauthored a textbook on seismic wave scattering entitled "*Seismic wave Propagation and Scattering in the Heterogeneous Earth (Second edition)*" with M. Fehler and T. Maeda (Springer, 2011, in press).
2. Sato succeeded in theoretically deriving Green's function having coda in a scattering medium from noise correlation, which gives the mathematical foundation for interpreting the coda of observed noise cross-correlation as a measure of crustal velocity structure [Sato, 2010].
3. Margerin and Sato [2011a,b] proved the retrieval of Green's function having coda in a scattering medium from noise correlation is equivalent to the general optical theorem.
4. Emoto et al. [2010, 2011] succeeded in the envelope synthesis in layered random media having a free surface based on the Markov approximation for vector waves.

### (2) Measurements of the lithospheric heterogeneity

1. From the whole S-seismogram analysis of Hi-net data by using the radiative transfer theory, we made a map of scattering strength and intrinsic absorption for short periods in Japan, which clearly shows regional variation of these quantities reflecting tectonic settings [Carcole and Sato, 2010].
2. Regional difference of crustal heterogeneity is revealed from the S wave envelope analysis of crustal earthquakes [Tripathi et al., 2010].
3. Applying the isotropic scattering model with PS conversion to explosion data at Asama volcano, Yamamoto and Sato [2010] found a small mean free path for S waves of the order of 1 km.

## **International activity:**

1. Sato served as the leader of the cooperative research based on the Japan-France bilateral program of JSPS (2009-2010) on "Study on the space-time variation of the earth medium heterogeneity by using multiple scattered seismic waves", where the leader of French side is Prof. M. Campillo.
2. Sato served as a co-convenor (Ludovic Margerin, Carene S. Larmat, Haruo Sato, Roel Snieder) and

a chair of a session “The Role of Scattering in Seismic Interferometry and Time Reversal” at 2010 AGU fall meeting (12/13-17, 2010) in San Francisco, California, USA.

3. Sato served as a member of Executive Organizing Committee for the GCOE symposium on “Dynamic Earth and Heterogeneous Structure” (Sendai City War Reconstruction Memorial Hall, 7/13-15, 2010).
4. Sato had seminars on seismic wave scattering at Colorado School of Mines (Prof. R. Snider) and Boise University (Prof. K. VanWijk) in Sep. 2011.

### **Published Journal Papers:**

1. Campillo, M; **Sato, H**; Shapiro, NM; van der Hilst, RD (2011). New developments on imaging and monitoring with seismic noise Foreword, *COMPTEs Rendus Geoscience*, 343, 487-495
2. **Sato, H.**, M. Fehler and T. Maeda (2011b) *“Seismic wave Propagation and Scattering in the Heterogeneous Earth”*, Springer, in press.
3. Margerin, L. and **H. Sato** (2011) Generalized optical theorems for the reconstruction of Green’s function of an inhomogeneous elastic medium, *J. Acous. Soc. Amer.*, DOI: 10.1121/1.3652856, in press.
4. Emoto, K., **H. Sato** and T. Nishimura (2011) Synthesis and Applicable Condition of VectorWave Envelopes in Layered Random Elastic Media with 2Anisotropic Autocorrelation Function Based on the Markov Approximation, *Geophys. J. Int.*, in press.
5. Margerin, L. and **H. Sato** (2011a) Reconstruction of multiply-scattered arrivals from the cross-correlation of waves excited by random noise sources in a heterogeneous dissipative medium, *Wave Motion*, 48, 146-160.
6. Sawazaki, S., K., **H. Sato** and T. Nishimura (2011) Envelope synthesis of short-period seismograms in 3-D random media for a point shear-dislocation source based on the forward scattering approximation: Application to small strike-slip earthquakes in southwestern Japan, *J. Geophys. Res.*, 116, B08305, doi:10.1029/2010JB008182,.
7. Carcole, E. and **H. Sato** (2010). Spatial distribution of scattering loss and intrinsic absorption of short- period S-waves in the lithosphere of Japan on the basis of the Multiple Lapse Time Window Analysis of Hi-net data., *Geophys. J. Int.* 180, doi: 10.1111/j.1365-246X.2009.04394.x
8. Yamamoto, M. and **H. Sato** (2010). Multiple scattering and mode conversion revealed by an active seismic experiment at Asama volcano, Japan., *Journal of Geophysical Research - Solid Earth*, 115, doi: 10.1029/2009JB007109
9. Emoto, K., **H. Sato** and T. Nishimura (2010). Synthesis of vector wave envelopes on the free surface of a random medium for the vertical incidence of a plane wavelet based on the Markov approximation., *Journal of Geophysical Research - Solid Earth*, 115, doi: 10.1029/2009JB006955.
10. **Sato, H.** (2010). Retrieval of Green's function having coda waves from the cross-correlation function in a scattering medium illuminated by a randomly homogeneous distribution of noise sources on the basis of the first-order Born approximation., *Geophys. J. Int.*, 180, doi: 10.1111/j.1365-246X.2009.04432.x
11. Tripathi, J. N., **H. Sato** and M. Yamamoto (2010). Envelope broadening characteristics of crustal earthquakes in northeastern Honshu, Japan., *Geophys. J. Int.* 182, doi: 10.1111/j.1365-246X.2010.04657.x
12. Margerin, L. and **H. Sato** (2010). Reconstruction of multiply-scattered arrivals from the cross-correlation of waves excited by random noise sources in a heterogeneous dissipative medium., *Wave Motion*, doi: 10.1016/j.wavemoti.2010.10.001

**Books:**

1. Campillo, M; **Sato, H**; Shapiro, NM; van der Hilst, RD(eds) (2011), New developments on imaging and monitoring with seismic noise, *COMPRES RENDUS GEOSCIENCE*, 343, 487-652
2. **Sato, H.**, M. Fehler and T. Maeda (2011), *Seismic wave Propagation and Scattering in the Heterogeneous Earth* (2nd Edition), Springer, in press

**Symposium Participations:**

1. **Sato, H.** (2010). Retrieval of Green's function from the cross-correlation function in a scattering medium illuminated by noise sources., Japan Geoscience Union meeting 2010, May 23-28, 2010, Chiba, Japan
2. Anggono, T., T. Nishimura, **H. Sato**, H. Ueda and M. Ukawa (2010). Temporal changes of seismic velocity at Miyakejima associated with 2000 activity based on ambient seismic noise analyses., Japan Geoscience Union meeting 2010, May 23-28, 2010, Chiba, Japan
3. Emoto, K., **H. Sato** and T. Nishimura (2010). Synthesis of vector-wave envelopes in a layered random medium with velocity discontinuities., The Seismological Society Japan 2010 Fall Meeting, October, 2010, Hiroshima, Japan
4. **Sato, H.** and K. Emoto (2010). Envelope Synthesis of Vector Waves in Nonisotropic Random Elastic Media on the Basis of the Markov Approximation., Workshop on "Seismic Waves In Laterally Inhomogeneous Media VII", Teplá Premonstratensian Monastery, June 21-26, 2010, Czech Republic (in Proceeding)
5. **Sato, H.** (2010). Lithospheric Heterogeneity Revealed from the Envelope Analysis of Short-Period Seismograms., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", July 13-15, 2010, Sendai, Japan (in Proceeding)
6. **Sato, H.** (2010). Retrieval of Green's Function Having a Coda Tail from the Cross-Correlation Function in a Scattering Medium on the Basis of the First Order Born Approximation., American Geophysical Union 2010 Fall meeting, San Francisco, December 13-17, 2010

# Dapeng Zhao

Title/Affiliation	Professor / Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University
Specialized Field	Global Seismology, Physical Volcanology
Research Subject	3-D Earth structure, dynamics, seismic and volcanic activity

## The Purpose of Research and Outline of Accomplishments

Using seismological methods to study the seismotectonics, volcanism and mantle dynamics of the Western Pacific and East Asia regions

## Main Results

We used advanced seismological methods to determine the detailed 3-D velocity structure of the crust and mantle under the Western Pacific and East Asia regions. Our results shed new light on the seismotectonics, magmatism, and mantle dynamics in the regions. High-resolution geophysical imaging revealed structural heterogeneities in the source areas of large earthquakes, which may reflect magma and fluids that affected the rupture nucleation of large crustal earthquakes and interplate megathrust earthquakes such as the *Great 2011 Tohoku-oki earthquake (Mw 9.0)*. In subduction zone regions, the crustal fluids originate from the dehydration of the subducting slab. Magmatism in arc and back-arc areas is caused by the corner flow in the mantle wedge and dehydration of the subducting slab. The continental volcanoes in Northeast Asia (such as Changbai and Wudalianchi) seem to be caused by the corner flow in the big mantle wedge (BMW) above the stagnant slab in the mantle transition zone and the deep dehydration of the stagnant slab as well. The Tengchong volcano in Southwest China is possibly caused by a similar process in BMW above the subducting Burma microplate (or Indian plate). The Hainan volcano in southernmost China seems to be a hotspot fed by a lower-mantle plume associated with the Pacific and Philippine Sea slabs' deep subduction in the east and the Indian slab's deep subduction in the west down to the lower mantle. The occurrence of deep earthquakes under the Japan Sea and the East Asia margin may be related to a metastable olivine wedge in the subducting Pacific slab. The stagnant slab finally collapses down to the bottom of the mantle, which may trigger upwelling of hot mantle materials from the lower mantle to the shallow mantle beneath the subducting slabs and cause the slab-plume interactions.

## International activity

- (1) Attended international conferences in Europe (Vienna), China (Guangzhou), Japan (Sendai, Tokyo), Korea (Daejung) and USA (San Francisco) to give keynote or invited lectures there.
- (2) Visited Guangzhou Institute of Geochemistry in China for research collaboration.
- (3) Invited 8 foreign researchers and internship students to Tohoku University for conducting research collaborations and international student educations.

## Honors and Awards

Being selected by **ScienceWatch (Thomson-Reuters)** to be **One of the World Top 10 Seismologists** among the 30,670 researchers during 2000-2010 according to the peer-reviewed publications and citations (<http://sciencewatch.com/ana/st/earthquakes2/authors/>).

## Published Journal Papers:

1. **Zhao, D.**, Z. Huang, N. Umino, A. Hasegawa, H. Kanamori (2011) Structural heterogeneity in the megathrust zone and mechanism of the 2011 Tohoku-oki earthquake (Mw 9.0). *Geophys. Res. Lett.* **38**, L17308.
2. **Zhao, D.**, S. Yu, E. Ohtani (2011) East Asia: Seismotectonics, magmatism and mantle dynamics. *J. Asian Earth Sci.* **40**, 689-709.
3. **Zhao, D.**, Z. Huang, N. Umino, A. Hasegawa, T. Yoshida (2011) Seismic imaging of the Amur-Okhotsk plate boundary zone in the Japan Sea. *Phys. Earth Planet. Inter.* **188**, 82-95.
4. Shao, G., C. Ji, **D. Zhao** (2011) Rupture process of the 9 March, 2011 Mw 7.4 Sanriku-Oki, Japan earthquake constrained by jointly inverting teleseismic waveforms, strong motion data and GPS observations. *Geophys. Res. Lett.* **38**, L00G20.
5. Huang, Z., **D. Zhao**, L. Wang (2011) Stress field in the 2008 Iwate-Miyagi earthquake (M 7.2) area. *Geochem. Geophys. Geosyst.* **12**, Q06006.
6. Jiang, G., **D. Zhao** (2011) Metastable olivine wedge in the subducting Pacific slab and its relation to deep earthquakes. *J. Asian Earth Sci.* **42**, 1411-1423.
7. Tong, P., **D. Zhao**, D. Yang (2011) Tomography of the 1995 Kobe earthquake area: Comparison of finite-frequency and ray approaches. *Geophys. J. Int.* **187**, 278-302.
8. Huang, Z., L. Wang, **D. Zhao**, N. Mi, M. Xu (2011) Seismic anisotropy and mantle dynamics beneath China. *Earth Planet. Sci. Lett.* **306**, 105-117.
9. Padhy, S., O.P. Mishra, **D. Zhao**, W. Wei (2011) Crustal heterogeneity in the 2007 Noto-Hanto earthquake area and its geodynamical implications. *Tectonophysics* **509**, 55-68.
10. Tian, Y., **D. Zhao** (2011) Destruction mechanism of the North China Craton: Insight from P and S wave mantle tomography. *J. Asian Earth Sci.* **42**, 1132-1145.
11. Huang, Z., **D. Zhao**, L. Wang (2011) Frequency-dependent shear-wave splitting and multilayer anisotropy in Northeast Japan. *Geophys. Res. Lett.* **38**, L08302.
12. Cheng, B., **D. Zhao**, G. Zhang (2011) Seismic tomography and anisotropy in the source area of the 2008 Iwate-Miyagi earthquake (M 7.2). *Phys. Earth Planet. Inter.* **184**, 172-185.
13. Huang, Z., **D. Zhao**, L. Wang (2011) Seismic heterogeneity and anisotropy of the Honshu arc from the Japan Trench to the Japan Sea. *Geophys. J. Int.* **184**, 1428-1444.
14. Mishra, O.P., **D. Zhao**, C. Ghosh et al. (2011) Role of crustal heterogeneity beneath Andaman-Nicobar Islands and its implications for coastal hazard. *Natural Hazards* **57**, 51-64.
15. Huang, Z., **D. Zhao**, L. Wang (2011) Shear-wave anisotropy in the crust, mantle wedge and the subducting Pacific slab under Northeast Japan. *Geochem. Geophys. Geosyst.* **12**, Q01002.
16. Lei, J., **D. Zhao**, F. Xie, J. Liu (2011) An attempt to detect temporal variations of crustal structure in the source area of the 2006 Wen-An earthquake in North China. *J. Asian Earth Sci.* **40**, 978-996.

17. **Zhao, D.**, M. Santosh, A. Yamada (2010) Dissecting large earthquakes in Japan: Role of arc magma and fluids. *Island Arc* 19, 4-16.
18. **Zhao, D.**, L. Liu (2010) Deep structure and origin of active volcanoes in China. *Geoscience Frontiers* 1, 31-44.
19. **Zhao, D.**, F. Pirajno, N.L. Dobretsov, L. Liu (2010) Mantle structure and dynamics under East Russia and adjacent regions. *Russ. Geol. Geophys.* 51, 925-938.
20. Wang, Z., **D. Zhao**, J. Wang (2010) Deep structure and seismogenesis of the north-south seismic zone in Southwest China. *J. Geophys. Res.* 115, B12334.
21. Sakamaki, T., E. Ohtani, S. Urakawa, A. Suzuki, Y. Katayama, **D. Zhao** (2010) Density of high-Ti basalt magma at high pressure and origin of heterogeneities in the lunar mantle. *Earth Planet. Sci. Lett.* 299, 285-289.
22. Huang, Z., L. Wang, **D. Zhao**, M. Xu et al. (2010) Upper mantle structure and dynamics beneath Southeast China. *Phys. Earth Planet. Inter.* 182, 161-169.
23. Tian, X., **D. Zhao**, H. Zhang, Y. Tian, Z. Zhang (2010) Mantle transition zone topography and structure beneath the central Tien Shan orogenic belt. *J. Geophys. Res.* 115, B10308.
24. He, R., **D. Zhao**, R. Gao, H. Zheng (2010) Tracing the Indian lithospheric mantle beneath central Tibetan Plateau using teleseismic tomography. *Tectonophysics* 491, 230-243.
25. Wang, J., **D. Zhao** (2010) Mapping P-wave anisotropy of the Honshu arc from Japan Trench to the back-arc. *J. Asian Earth Sci.* 39, 396-407.
26. Huang, Z., **D. Zhao**, N. Umino, L. Wang, T. Matsuzawa, A. Hasegawa, T. Yoshida (2010) P-wave tomography, anisotropy and seismotectonics in the eastern margin of Japan Sea. *Tectonophysics* 489, 177-188.
27. Santosh, M., **D. Zhao**, T. Kusky (2010) Mantle dynamics of the Paleoproterozoic North China Craton: A perspective based on seismic tomography. *J. Geodyn.* 49, 39-53.
28. Kiyosugi, K., C. Connor, **D. Zhao**, L. Connor, K. Tanaka (2010) Relationships between volcano distribution, crustal structure, and P-wave tomography: An example from the Abu monogenetic volcano group, SW Japan. *Bull. Volcanol.* 72, 331-340.

### Books

1. **Zhao, D.**, S. Ueki, Y. Nishizono and A. Yamada (2010), New seismic evidence for the origin of arc and back-arc magmas., In: J. Ray, G. Sen, B. Ghosh (Eds.) *Topics in Igneous Petrology*, pp. 117-132, Springer Press.

### Symposium Participations

1. **Zhao, D.** (2011). Structural heterogeneity and anisotropy in the mantle and core. *Global-COE Symposium "Dynamics of the Earth's Interior"*, February 15-16, 2011, Sendai, Japan
2. **Zhao, D.** (2011). On the origin of intraplate volcanoes in the polar regions. *Polar Research Symposium "Seismology of Blue Earth and White Continent"*, February 24, 2011, Tokyo, Japan
3. **Zhao, D.** (2011). Multiscale seismic tomography and mantle dynamics. *Global Dynamics Symposium*, March 10-11, 2011, University of Tokyo, Japan
4. **Zhao, D.** (2011). East Asia: Seismotectonics, volcanism and mantle dynamics. *Joint Meeting of*



- Japan Earth and Planetary Sciences*, May 22-27, 2011, Chiba, Japan
5. **Zhao, D.** (2011). Mapping seismic heterogeneity and anisotropy in the mantle. *Joint Meeting of Japan Earth and Planetary Sciences*, May 22-27, 2011, Chiba, Japan
  6. **Zhao, D.,** T. Yanada, Y. Yamamoto (2011). On the influence of whole-mantle heterogeneity on teleseismic tomography. *Joint Meeting of Japan Earth and Planetary Sciences*, May 22-27, 2011, Chiba, Japan
  7. **Zhao, D.,** Z. Huang, N. Umino, A. Hasegawa, T. Yoshida (2011). P and S wave tomography of the eastern margin of Japan Sea. *Joint Meeting of Japan Earth and Planetary Sciences*, May 22-27, 2011, Chiba, Japan
  8. **Zhao, D.** (2011). On the earthquake-volcano interactions. *Annual Meeting of Volcanological Society of Japan*, October 2-4, 2011, Asahikawa, Japan
  9. **Zhao, D.** (2011). Seismic imaging of the Western-Pacific subduction zone. *International Workshop "Ocean Mantle Dynamics: From Spreading Center to Subduction Zone"*, October 4-6, 2011, Kashiwa, Japan
  10. **Zhao, D.,** Z. Huang, N. Umino, A. Hasegawa, H. Kanamori (2011). Tomography and mechanism of the 2011 Tohoku-oki earthquake (Mw 9.0). *Annual Meeting of Seismological Society of Japan*, October 12-15, 2011, Shizuoka, Japan
  11. **Zhao, D.** (2011). Seismotectonics, volcanism and mantle dynamics of East Asia. *10<sup>th</sup> International Seminar on Seismology-related Works in Far-East Asia*, October 31-November 1, 2011, Daejung, Korea
  12. **Zhao, D.** (2011). Multiscale seismic imaging of the Western-Pacific subduction zone. *Fall AGU Meeting*, December 5-9, 2011, San Francisco, USA (Invited lecture)
  13. **Zhao, D.** (2011). Tomography of the megathrust zone and mechanism of the Tohoku-oki earthquake (Mw 9.0). *Fall AGU Meeting*, December 5-9, 2011, San Francisco, USA
  14. **Zhao, D.** (2010). Multiscale seismic tomography and mantle dynamics. *Annual Meeting of European Geosciences Union (EGU)* (Keynote lecture), May 2-7, 2010, Vienna, Austria
  15. **Zhao, D.** (2010). Tomographic imaging of the lithosphere and underlying mantle beneath China. *International Symposium on Solid-Earth Sciences*, Guangzhou (Invited lecture), May 14-16, 2010, Chiba, Japan
  16. **Zhao, D.** (2010). Seismic evidence for deep slab dehydration and big mantle wedge in East Asia. *Joint Meeting of Japan Earth and Planetary Sciences*, May 23-28, 2010, Chiba, Japan
  17. **Zhao, D.** and Y. Yamamoto. (2010). Seismic structure and mantle dynamics in the Western Pacific region. *Joint Meeting of Japan Earth and Planetary Sciences*, May 23-28, 2010, Chiba, Japan
  18. **Zhao, D.** (2010). Tomographic imaging of Earth and Moon. *Global-COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure"*, July 13-15, 2010, Sendai, Japan
  19. **Zhao, D.** (2010). Dissecting the seismogenic zones in Japan, China and India. *China-Japan Joint Workshop on Inland Earthquakes* (Invited lecture), November 24-25, 2010, Tokyo, Japan
  20. **Zhao, D.** (2010). Mantle structure and dynamics under the Japan Islands and East Asia: Big Mantle Wedge (BMW) model. *Workshop on Northeast Japan Arc and Back-Arc System* (Keynote lecture), November 26-27, 2010, Tokyo, Japan

# Hiroshi Fujimoto

Title/Affiliation	Professor / Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University
Specialized field	Solid earth planet physics (Seafloor Geodesy) Solid earth planet physics (Geodynamics)
Research Subject	Study on observation of seafloor crustal movements (2003-) Study on dynamics at plate boundaries (2000-)

## The Purpose of Research and Outline of Accomplishments:

### (1) Improvement of geodetic systems for observation of seafloor crustal movement in subduction zones

Sea surface kinematic GPS positioning combined with underwater acoustic positioning (GPS/A) can detect horizontal seafloor crustal movements after repeated observations. Although this is the most promising system for the monitoring of strain accumulation around the plate boundaries, observations by the GPS/A are much less precise and dense than those by the GPS. GPS/A sites are observed only once or twice a year. Marine geophysics group in our research center has been developing systems for better precision within shorter observation time, and a proto-type for continuous observation with a fund from the MEXT, Japan. Our group is also developing an ocean bottom pressure (OBP) recorder network off Miyagi Prefecture with another fund from the MEXT for the monitoring of vertical crustal movements on the seafloor. Our simulation study has shown that the effect of ocean dynamics, one of the most serious problems of the OBP observation, can be fairly well computed and corrected (Inazu et al., 2011).

The occurrence of the 2011 Tohoku-oki earthquake demonstrated the importance of seafloor geodetic observations. Firstly the observed coseismic seafloor crustal movements have become the most critical constraints on the analysis where was the main thrust zone; Kido et al. (2011) detected from GPS/A results an ESE crustal movement of 31 m at some 50 km from the trench axis, and Ito et al. (2011) observed crustal uplift of 5 m at 25 km off-axis. Secondly seafloor geodetic observations will be the most critical observation to solve the question of how the giant earthquake occurred; the key is whether the plate boundary seaward of the up-dip limit is slipping or not. Thirdly distribution of postseismic crustal movement that is important to understand the mechanism of the occurrence of the giant earthquake requires seafloor observations.

The observations of the horizontal and vertical displacements accompanied with the mainshock strongly suggest a huge coseismic slip beneath the frontal wedge on the plate boundary. The estimated magnitude of the slip along the main fault was 80 m near the trench (Ito et al., 2011). Tsuji et al. (2011) demonstrated that a near-vertical branch fault and a related uplift system with a dislocation exceeding 100 m existed before the earthquake within the landward slope of the Japan Trench. Taking into account the difference between two observed vertical displacements across the branch fault, the displacement on the branch fault was probably 1 m (Ito et al., 2011).

It was also confirmed that the attitude of acoustic transponders for the GPS/A system deployed on thick sediment was stable even near M7-class earthquakes in the Nankai Trough (Fujimoto et al., 2011). Our group has shown that acoustic horizontal ranging on the seafloor can be a system for the monitoring of local crustal movements along an active fault.

(2) Study of post-glacial rebound in Southeast Alaska

Reported by Prof. Tadahiro Sato.

**Published Journal Papers:**

1. Ito, Y., T. Tsuji, Y. Osada, M. Kido, D. Inazu, Y. Hayashi, H. Tsushima, R. Hino, and **Hiromi Fujimoto**, Frontal wedge deformation near the source region of the 2011 Tohoku-Oki earthquake, *Geophys. Res. Lett.*, 38, L00G05, doi:10.1029/2011GL048355, 2011.
2. Sato, T., S. Miura, W. Sun, T. Sugano, J. T. Freymueller, C. F. Larsen, Y. Ohta, **H. Fujimoto**, D. Inazu, and R. J. Motyka (2011). Gravity rates and uplift rates observed in Southeast Alaska and comparison with ice unloading model predictions, *JOURNAL OF GEOPHYSICAL RESEARCH*, in press
3. Kido, M., Y. Osada, **H. Fujimoto**, R. Hino, and Y. Ito, Trench-normal variation in observed seafloor displacements associated with the 2011 Tohoku-Oki earthquake, *Geophys. Res. Lett.*, accepted in Nov. 2011.
4. Sato, T., S. Miura, W. Sun, T. Sugano, J. T. Freymueller, C. F. Larsen, Y. Ohta, **H. Fujimoto**, D. Inazu, and R. J. Motyka, Gravity rates and uplift rates observed in Southeast Alaska and comparison with ice unloading model predictions, *J. Geophys. Res.*, accepted in Oct. 2011.
5. Tsuji, T., Y. Ito, M. Kido, Y. Osada, **H. Fujimoto**, J. Ashi, M. Kinoshita, and T. Matsuoka, Potential Tsunamigenic Faults of the 2011 Tohoku Earthquake, *Earth Planet. Space*, 63 (7), 831-834, 2011
6. **Fujimoto, H.** (2011). Progress report on seafloor geodetic observations: GPS/A, OBP, and acoustic ranging, Report of the Coordinating Committee for Earthquake Prediction, in press, 86
7. Inazu, D., R. Hino, and **H. Fujimoto** (2011). Realistic high-frequency global barotropic ocean modeling driven by synoptic atmospheric disturbances. Annual Report of the Earth Simulator Center, April 2010 - March 2011, in press
8. Sato, T., C. F. Larsen, S. Miura, Y. Ohta, **H. Fujimoto**, W. Sun, R. J. Motyka and J. T. Freymueller (2010). Reevaluation of the viscoelastic and elastic responses to the past and present-day ice changes in Southeast Alaska. *TECTONOPHYSICS*

**Papers in Books:**

1. **Fujimoto, H.**, M. Kido, Y. Osada, K. Tadokoro, T. Okuda, Y. Matsumoto, and K. Kurihara, Long-term stability of acoustic benchmarks deployed on thick sediment for GPS/Acoustic seafloor positioning, In: *Modern Approaches in Solid Earth Sciences*, Vol. 8, Springer, doi: 10.1007/978-90-481-8885-7, 263-272, 2011

**Published Reports:**

1. Inazu, D., R. Hino, and **H. Fujimoto**, Realistic high-frequency global barotropic ocean modeling driven by synoptic atmospheric disturbances. Annual Report of the Earth Simulator Center, April 2010 - March 2011, in press.

**Symposium Participations:**

1. **Fujimoto, H.**, M. Kido and Y. Osada (2010). Improvement in the observation system for the GPS/A seafloor positioning., American Geophysical Union 2010 Fall meeting, San Francisco,

December 13-17, 2010

2. Inazu, D., R. Hino and **H. Fujimoto** (2010). Global, barotropic ocean bottom pressure modeling: Sensivity to spatial resolution and boundary conditions., American Geophysical Union 2010 Fall meeting, San Francisco, December 13-17, 2010
3. Kido, M., Y. Osada and **H. Fujimoto** (2010). Temporal variation of oceanic sound speed structure affecting seafloor geodesy., American Geophysical Union 2010 Fall meeting, San Francisco, December 13-17, 2010
4. Osada, Y., M. Kido and **H. Fujimoto** (2010). Observation of seafloor crustal movement using the seafloor acoustic ranging on Kumano-nada., American Geophysical Union 2010 Fall meeting, San Francisco, December 13-17, 2010

# Junichi Nakajima

Title/Affiliation	Associate Professor / Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University
Specialized Field	Seismology
Research Subject	Seismotectonics in subduction zones

## **The Purpose of Research and Outline of Accomplishments:**

The objectives of my research is to investigate seismic activity and seismic structure beneath the Japanese Islands to understand ongoing physical and metamorphic processes related to plate subduction. Recent studies focus on seismogenesis of intraslab earthquakes in the Pacific plate, a unique seismotectonics beneath Kanto as a result of dual plate subduction, and heterogeneous seismic velocity structures around the Atotsugawa fault system in central Japan.

## **Main Results:**

### **An M7.1 intraslab event after the Tohoku-oki earthquake**

We employ seismic tomography to estimate detailed 3D seismic velocity structures in the focal area of an intraslab earthquake (M7.1), which occurred on April 7 and 1 month after the 2011 Tohoku earthquake (M9.0) near its source area. The results show a low-velocity zone around the focal area of the M7.1 event, and that the aftershock activity is limited to the upper 15 km of the oceanic mantle. The lateral extent of the low-velocity zone is comparable to the distribution of aftershocks, suggesting a concentration of fluids in the aftershock area. The angle between the aftershock alignment and the dip of the slab surface is estimated to be  $\sim 60^\circ$ , which is consistent with the dip of an oceanward-dipping normal fault observed at the outer-trench slope. These observations suggest that the M7.1 intraslab event occurred as a result of reactivation of a buried hydrated fault that formed prior to subduction. The upper  $\sim 15$  km of the oceanic mantle may be locally hydrated by bending-related tensional faulting at the outer-trench slope.

### **Stress regime in the Philippine Sea slab beneath Kanto**

We determine the focal mechanisms of earthquakes within the Philippine Sea slab beneath Kanto, and perform stress tensor inversions to investigate the detailed stress field within the slab. The results show a characteristic spatial variation in earthquake-generating stress. Slab stress in northeastern part of the PHS slab is characterized by down-dip tension (DDT), except for the uppermost tip of the seismic portion of the slab where down-dip compression (DDC) stress is dominant. We interpret that DDT is caused by the net slab pull and DDC is attributable to local resistance to subduction at the tip of the slab. In southwestern part of the PHS slab,  $\sigma_1$  and  $\sigma_3$  are generally rotated oblique to the dip of the slab, suggesting that earthquakes occur under stress conditions of neither DDC nor DDT. The rotations in  $\sigma_1$  and  $\sigma_3$  may be related to stress accumulation by the slip deficit along the asperity of the 1923 Kanto earthquake (M7.9).

### **Serpentinized mantle of the Philippine Sea slab beneath Kanto**

We perform travel-time tomography beneath Kanto, Japan, and reveal the existence of serpentinized mantle at

the easternmost portion of the Philippine Sea slab. The western boundary of the serpentinized mantle (serpentine boundary) is sub-vertical and P- and S-wave velocities vary by 15–20% across it over a short distance of ~10 km. Two intraslab earthquakes in 1921 (M7.0) and 1987 (east off Chiba earthquake, M6.7) are inferred to have occurred along the serpentine boundary accompanied by right-lateral movement. A sub-vertical earthquake cluster penetrating the entire Philippine Sea slab is observed along the serpentine boundary, and four earthquakes in the cluster have strike-slip focal mechanisms, similar to that of the 1987 earthquake. Focal mechanisms obtained for past large earthquakes and present-day microearthquakes suggest the concentration of right-lateral deformation along the mechanically weak serpentine boundary. The Philippine Sea slab may have been torn in two along this boundary, with the eastern portion being left behind relative to subduction of the western portion. Assuming that one of the large aftershocks (M7.1) of the 1923 Kanto earthquake (M7.9), which occurred off the Boso peninsula, ruptured the same asperity as did the 1987 earthquake, the slip deficit accumulated along the serpentine boundary during the 64-year interval is consistent with the fault slip of the 1987 earthquake. Interaction between seismic slip along the plate interface and the serpentine boundary can explain the series of M7-class earthquakes before and after the 1923 Kanto earthquake.

#### **Along-fault velocity variation and its relation to seismic activity beneath Atotsugawa fault**

We carried out travel-time tomography around the Atotsugawa fault in central Japan. The observed velocities beneath the fault are 10–13% lower than those of the assumed host rocks (pyroxene amphibolite and hornblende-pyroxene gabbro) in the lower crust. Because the seismogenic layer is thickest in the central part of the fault, reaching a depth of ~15 km, we infer that the low-velocity anomaly is caused by aqueous fluids. Fluid fractions in the lower crust are estimated to be 2–3% and ~10%, assuming pyroxene amphibolite and hornblende-pyroxene gabbro, respectively. A distinct low-velocity anomaly is imaged in the central part of the Atotsugawa fault at a depth of 10 km, where seismic activity is very low at the upper 7 km and creeplike movement is observed at the surface. This anomaly is horizontally isolated but vertically connected to the low-velocity anomaly in the lower crust. We interpreted that abundant aqueous fluids supplied from the lower crust are responsible for this anomaly. High pore fluid pressure may enhance the stability of frictional slip, resulting in aseismic or episodic slip along the fault.

#### **Published Journal Papers:**

1. Omuralieva, A.M., A. Hasegawa, T. Matsuzawa, **J. Nakajima**, and T. Okada (2011). Lateral variation of the cutoff depth of shallow earthquakes beneath the Japan Islands and its implications for seismogenesis, *Tectonophysics*, in press.
2. Ito, Y., K. Shiomi, **J. Nakajima**, and R. Hino (2011). Autocorrelation analysis of ambient noise in northeastern Japan subduction zone, *Tectonophysics*, in press.
3. **Nakajima, J.**, A. Hasegawa, and F. Hirose (2011). Stress regime in the Philippine Sea slab beneath Kanto, Japan, *Geophys. Res. Lett.*, 38, L16318, doi:10.1029/2011GL048754.
4. **Nakajima, J.**, A. Hasegawa, and S. Kita (2011). Seismic evidence for reactivation of a buried hydrated fault in the Pacific slab by the 2011 M9.0 Tohoku earthquake, *Geophys. Res. Lett.*, 38, L00G06, doi:10.1029/2011GL048432.
5. Okada, T., K. Yoshida, S. Ueki, **J. Nakajima**, N. Uchida, T. Matsuzawa, N. Umino, A. Hasegawa, and Group for the aftershock observations of the 2011 off the Pacific Coast of Tohoku Earthquake (2011). Shallow

inland earthquakes in NE Japan possible triggered by the 2011 off the Pacific coast of Tohoku Earthquake, *Earth Planets and Space*, 63, 749-754..

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7. Reynard, B., **J. Nakajima**, and H. Kawakatsu (2010), Earthquakes and plastic deformation of anhydrous slab mantle in double Wadati-Benioff zones, *Geophys. Res. Lett.*, 37, L24309, doi:10.1029/2010GL045494.
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9. **Nakajima, J.**, A. Kato, T. Iwasaki, S. Ohmi, T. Okada, T. Takeda, and The Japanese University Group of the Joint Seismic Observations at NKTZ (2010), Deep crustal structure around the Atotsugawa fault system, central Japan: A weak zone below the seismogenic zone and its role in earthquake generation, *Earth Planets and Space*, 62, 555-566.
10. Katayama, I., K. Hirauchi, and **J. Nakajima** (2010), Variability of Subduction Processes beneath Japan, *J. Geography*, 119, 205-223.
11. Hasegawa, A., **J. Nakajima**, N. Uchida, F. Hirose, S. Kita, and T. Matsuzawa (2010), Slab Structure beneath the Japanese Islands and Earthquake Generation (in Japanese with English abstract), *J. Geography*, 119, 190-204.
12. Uchida, N., T. Matsuzawa, **J. Nakajima**, and A. Hasegawa (2010), Subduction of a wedge-shaped Philippine Sea plate beneath Kanto, central Japan, estimated from converted waves and small repeating earthquakes, *J. Geophys. Res.*, 115, B07309, doi:10.1029/2009JB006962.
13. Kita, S., T. Okada, A. Hasegawa, **J. Nakajima**, and T. Matsuzawa (2010), Anomalous deepening of a seismic belt in the upper-plane of the double seismic zone in the Pacific slab beneath the Hokkaido corner: Possible evidence for thermal shielding caused by subducted forearc crust materials, *Earth Planet. Sci. Lett.*, 290, 415-426.
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#### **Symposium Participants:**

1. Ohta, Y., D. Inazu, M. Ohzono, R. Hino, M. Mishina, **J. Nakajima**, Y. Ito, T. Iinuma, T. Sato, H. Fujimoto, K. Tachibana, T. Demachi, Y. Osada, M. Shinohara, S. Miura, Co- and post-seismic deformation of the M7.3 foreshock triggering the 2011 M9.0 Tohoku Earthquake, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.

2. Yoshioka, S., Y. Suminokura, T. Matsumoto, and **J. Nakajima**, 2-D numerical simulations on temperature fields associated with subduction of the Philippine Sea plate in Southwest Japan, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
3. Hayashida, T., F.C. Tajima, **J. Nakajima**, and J.J. Mori, A New 3D Seismic Velocity Model Derived from Waveform Modeling with Tomography Inversion in Southwestern Japan, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
4. Kita, S., A. Hasegawa, **J. Nakajima**, T. Okada, T. Matsuzawa, and K. Katsumata, Precise seismic velocity structure beneath the Hokkaido corner, northern Japan: Arc-arc collision and the 1970 M 6.7 Hidaka region earthquake and the 1982 M 7.1 Urakawa-oki earthquake, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
5. Shikasho, K., T. Okada, **J. Nakajima**, E. Hayami, N. Uchida, T. Matsuzawa, N. Umino, and A. Hasegawa, Seismic high attenuation area beneath the 2008 Iwate-Miyagi Nairiku earthquake (M7.2) and Mt. Chokai in NE Japan, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
6. Iwamori, H., T. Watanabe, M. Nakamura, M. Ichiki, **J. Nakajima**, Y. Ogawa, T. Okada, and T. Matsuzawa, An Integrated Model for Mapping Geofluids, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
7. **Nakajima, J.**, A. Hasegawa, and S. Kita, An intraslab earthquake (M7.1) along a buried hydrated fault in the Pacific plate, triggered by the 2011 M9 Tohoku earthquake, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
8. Hasegawa, A., and **J. Nakajima**, Earthquakes in Japan: A vital role of geofluids in earthquake generation in subduction zones, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
9. **Nakajima, J.**, and G.A. Abers, Seismic imaging of slab structure and its relation to seismicity, Workshop on Ocean Mantle Dynamics: From Spreading Center to Subduction, October 4-6, 2011, Kashiwa, Japan.
10. Ito, Y., K. Shiomi, **J. Nakajima**, R. Hino, Autocorrelation analysis of ambient noise in the northeastern Japan subduction zone, IUGG 2011, June 28-July 7, 2011, Melbourne Convention & Exhibition Centre, Melbourne, Australia.
11. Kita, S., A. Hasegawa, T. Okada, **J. Nakajima**, T. Matsuzawa, K. Katsumata, Detailed seismic velocity structure beneath the Hokkaido corner, NE Japan: Collision process of the forearc sliver, American Geophysical Union 2010 Fall meeting, December 13-17, 2010, San Francisco U.S.A.
12. Abers, G.A., **J. Nakajima**, and P.E. van Keken, Variability in P-T paths in subducting mantle and crust, and its control on the locations of intraslab earthquakes, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
13. **Nakajima, J.**, A. Hasegawa, N. Umino, and T. Demachi, A close link between serpentinization and seismogenesis in the Philippine Sea slab beneath Kanto, Japan, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
14. van Keken, P.E., S. Kita, **J. Nakajima**, A.K. Bengtson, B.R. Hacker, G.A. Agers, Three-dimensional thermal structure and seismogenesis in the Tohoku and Hokkaido subduction system, American Geophysical Union 2011 Fall meeting, December 5-9, 2011, San Francisco U.S.A.
15. Uchida, N., T. Matsuzawa, **J. Nakajima**, A. Hasegawa, N. Umino, Subduction of a Wedge-shaped Philippine Sea Plate beneath Kanto, Central Japan, and its Effect on Interplate Coupling, 2010 Western Pacific Geophysics Meeting, June 22-25, 2010, Taipei, Taiwan.



# Eiji Ohtani

Title/Affiliation	Professor / Department of Earth Sciences, Graduate School of Science, Tohoku University
Specialized Field	Mineral Physics, High Pressure Geochemistry
Research Subject	Dynamics of the earth and planetary interior, High pressure research

## The Purpose of Research and Outline of Accomplishments:

- (1) Core:** Significant progress has been made in the research of the Earth's core. We successfully conducted determination of the melting temperatures of Iron-light elements alloys. We have generated pressures exceeding 250 GPa and  $T > 3500$  K, and clarified that the stable phase of Fe-Si and FeNiSi alloys is hcp phase under the present experimental conditions. We also determined the equation of state of FeNiSi alloys to the pressures exceeding the center of the Earth, 375 GPa, and confirmed that we have generated high temperature, about 700 K at the pressure. Based on the measurements, we estimated the compositional range of the inner core in the Fe-Ni-S system.
- (2) Sound velocity measurement of iron, Fe-Ni-Si alloy, Fe<sub>3</sub>S, and FeH at high pressure by the inelastic X-ray scattering:** We made sound velocity measurement of FeNiSi and Fe up to the pressures up to 145 GPa, Fe<sub>3</sub>S up to 50 GPa, and FeH up to 70 GPa by using inelastic X-ray scattering combined with the diamond anvil cell experiments at BL35XU. Based on the sound velocity of these materials, we obtained the linear relation of the sound velocity-density relation, and estimated the composition of the inner core, which can explain the velocity and density of the inner core.
- (3) Circulation of water and carbon:** Mantle transition zone is a place of accumulation of the subducting plates, and various type of heterogeneities are expected to exist. We have clarified the effect of carbon and hydrogen on melting and magma properties at high pressure. We also clarified the phase and melting relation of peridotite-CO<sub>2</sub> system at high pressure, the density of the CO<sub>2</sub> bearing magmas at high pressure, and applied for the origin of kimberlite magmas. We clarified the phase relations of the carbonated eclogite in the system CaO-Al<sub>2</sub>O<sub>3</sub>-MgO-SiO<sub>2</sub>-Na<sub>2</sub>O-CO<sub>2</sub> to 32 GPa and discussed the nature of carbonatite liquid expected to be formed in the deep mantle.
- (4) Collision and high pressure polymorphs in shocked meteorites:** We have studied the high pressure polymorphs of minerals formed by the shock events in the meteorites. We discovered coesite and stishovite and also discovered seifertite ( $\alpha$ -PbO<sub>2</sub> structured SiO<sub>2</sub>) in lunar meteorite for the first time. These high pressure polymorphs of silica can be used to estimate the intensity of the collision in the early lunar surface such as Lunar Cataclysm. We also studied the evidence of shock events in Martian meteorites, and discovered the decomposition texture of olivine to magnesioferrite and perovskite.

## International activity:

- 1) Collaboration and Exchange with UC Davis:** Ohtani, E. made an invited lecture at Department of Geological Sciences, UC Davis and Advanced Light Source of UC Berkeley "In situ X-ray measurements of density of silicate and metallic melts at high pressure", February, 2010. We are considering further collaboration and exchange of graduate students between Tohoku and UC Davis.

- 2) **Global Network symposium:** Ohtani, E. made an invited talk, Iron-Silicate reaction and silicon as a light element in the core. Ohtani organized the Global-Network symposium on Earth's Dynamics, Akiu, Sendai, Japan, March, 2010. This symposium is organized by the international program committee composed of five major organizations, Tohoku, Lyon, Sobolev, Carnegie Institution, and Academia Sinica.
- 3) **Deep Carbon Cycle Research:** Ohtani worked as a member of the founding committee of Deep Carbon Observatory program funded by Sloan Foundation. Ohtani organized several symposium related to Deep Carbon Cycle, such as a Deep Carbon Cycle session at 2010 JpGU international symposium, 8th Water dynamics/Deep Carbon cycle workshop in March 8-10, 2011. Ohtani also organized a DCC session at 2011 Deep Carbon Cycle in the international symposium at 2011 JpGU international symposium.
- 4) **Lecture at Chinese academy of Science.** Ohtani, E., Invited lecture at Chinese Academy of Science, Beijing, China. Iron-Silicate Reactions and Light Elements in the Core, April, 2010.
- 5) **Invited lecture at Goldschmidt Conference (Knoxville):** Ohtani, E., Application of in situ X-ray observations to melting and melt properties at high pressure, June, 2010.
- 6) **Invited lecture at GCOE Solid Earth symposium:** Ohtani, E., Deep volatile cycle and Light Elements in the Core., July, 2010.
- 7) **Invited talk at SEDI (Study of the Earth Deep Interior) at UC Santa Barbara, July, 2010.** Ohtani, E., Physical and Chemical properties and thermal state of the core and lower mantle.
- 8) **Invited lecture at International Mineralogical Association:** Ohtani, E., Iron-Silicate reaction and Silicon in the Core., September, 2010.
- 9) **CECAM (Centre Européen de Calcul Atomique et Moléculaire), Invited lecture.** Ohtani, E., Composition, Physical Properties, and Thermal State of the Core., October, 2010.
- 10) **Invited lecture at LMU Munchen, October, 2010.** Ohtani, E., Material properties of Earth's materials, and structure, evolution, and dynamics of the mantle and core.
- 11) **Invited lecture at the Deep Carbon workshop at Altai, Russia, August 25-30, 2011.** Ohtani E., Carbon and light elements in planetary cores.
- 12) **Invited lecture at INSA,-Lyon for the ELyT laboratory, summer school at Lyon, September 4-13, 2011. E. Ohtani, Special Lecture for Origin and Evolution of the Earth and Planets**
- 13) **Invited talk at 2011 GSA meeting at Minneapolis, USA, October, 9-12, 2011.** Ohtani E., Sakai T., Kamada S., Fukui H., Shibasaki Y., Baron Alfred Q.R., Tsutsui S., Asanuma H., Phase relations density and sound velocity of Fe-Ni-Si alloys and composition of the inner core.

#### **Award and Honor:**

The medal with Purple Ribbon, November 3rd, 2010.

#### **Published Journal Papers:**

1. Sakamaki, T., **E. Ohtani**, S. Urakawa, A. Suzuki and Y. Katayama (2010). Density of dry peridotite magma at high pressure using an X-ray absorption method., *American Mineralogist*, 95, 144-147
2. Tatsuya, S., **E. Ohtani**, S. Urakawa, A. Suzuki, Y. Katayama and D. Zhao (2010). Earth and Planetary Science Letters, Density of high-Ti basalt magma at high pressure and origin of heterogeneities in the lunar mantle., *Earth and Planetary Science Letters*, 294, 94-100

3. Kamada, S., H. Terasaki, **E. Ohtani**, T. Sakai, T. Kikegawa, Y. Ohishi, N. Hirao, N. Sata and T. Kondo (2010). Phase relationship of the Fe-FeS system in conditions up to the Earth's outer core., *Earth and Planetary Science Letters*, 294, 94-100
4. Terasaki, H., K. Nishida, Y. Shibazaki, T. Sakamaki, A. Suzuki, **E. Ohtani**, T. Kikegawa (2010). Density measurement of Fe<sub>3</sub>C liquid using X-ray absorption image up to 10 GPa and effect of light elements on compressibility of liquid iron., *Journal of Geophysical Research-Solid Earth*, 115, B02202
5. Frost, D. J., Y. Asahara, D. C. Rubie, N. Miyajima, L. S. Dubrovinsky, C. Holzappel, **E. Ohtani**, M. Miyahara and T. Sakai (2010). Partitioning of oxygen between the Earth's mantle and core., *Journal of geophysical research-solid Earth*, 115, B02202
6. Ju, J., K. Huynh, J. Tang, Z. F. Li, M. Watahiki, K. Sato, H. Terasaki, **E. Ohtani**, H. Takizawa, K. Tanigaki (2010). Superconducting properties of SmFeAsO<sub>1-x</sub> prepared under high-pressure condition., *Journal of Physics and Chemistry of Solids*, 71, 4, Sp. Iss. SI, 491-494
7. Miyahara, M., **E. Ohtani**, M. Kimura, A. El Goresy, S. Ozawa, T. Nagase, M. Nishijima and K. Hiraga (2010). Coherent and subsequent incoherent ringwoodite growth in olivine of shocked L6 chondrites., *Earth and Planetary Science Letters*, 295, 321-327, doi: 10.1016/j.epsl.2010.04.023
8. Asanuma, H., **E. Ohtani**, T. Sakai, H. Terasaki, S. Kamada, T. Kondo and T. Kikegawa (2010). Melting of Iron-silicon alloy up to the core-mantle boundary pressure: implications to the thermal structure of the Earth's core., *Physics and Chemistry of Minerals*, 37, 6, 353-359
9. Shimojuku, A., T. Kudo, **E. Ohtani**, T. Nakamura and R. Okazaki. (2010). Effects of hydrogen and iron on the silicon diffusivity of wadsleyite., *Physics of the Earth and Planetary Interiors*, 183, 1-2, 175-182
10. Sakai, T., **E. Ohtani**, H. Terasaki, M. Miyahara, M. Nishijima, N. Hirao, Y. Ohishi and N. Sata (2010). Fe-Mg partitioning between post-perovskite and ferropericlase in the lowermost mantle., *Physics and Chemistry of Minerals*, 37, 7, 487-496
11. Litasov, K. and **E. Ohtani** (2010). The solidus carbonated eclogite in the system CaO-Al<sub>2</sub>O<sub>3</sub>-MgO-SiO<sub>2</sub>-Na<sub>2</sub>O-CO<sub>2</sub> to 32 GPa and carbonatite liquid in the deep mantle., *Earth and Planetary Science Letters*, 295, 1-2, 115-126
12. Shatskiy, A., L. Konstantin, H. Terasaki, T. Katsura and **E. Ohtani** (2010). Performance of semi-sintered ceramics as pressure-transmitting media up to 30 GPa., *High Pressure Research*, 30, 3, 443-450, doi: 10.1080/08957959.2010.515079
13. Litasov, K. D., A. Shatskiy, Y. Fei, A. Suzuki, **E. Ohtani** and K. Funakoshi (2010). Pressure-volume-temperature equation of state of tungsten carbide to 32 GPa and 1673 K., *Journal of Applied Physics*, 108, 5, 053513
14. Dymshits, A. M., A. V. Bobrov, K. D. Litasov, A. F. Shatskiy, **E. Ohtani** and Y. A. Litvin (2010). Experimental study of the pyroxene-garnet phase transition in the Na<sub>2</sub>MgSi<sub>5</sub>O<sub>12</sub> system at pressures of 13-20 GPa: First synthesis of sodium majorite., *Doklady Earth Sciences*, 434, 1, 1263-1266
15. Collerson, K. D., Q. Williams, B.S. Kamber, S. Omori, H. Arai and **E. Ohtani** (2010). Majoritic garnet: A new approach to pressure estimation of shock events in meteorites and the encapsulation of sub-lithospheric inclusions in diamond., *Geochimica et Cosmochimica Acta*, 74, 20, 5939-5957
16. Litasov, K., O. Safonov and **E. Ohtani** (2010). Origin of Cl-bearing silica-rich melt inclusions in diamonds: Experimental evidence for an eclogite connection., *Geology*, 38, 12, 1131-1134, doi: 10.1130/G31325.1
17. Miyahara, M., **E. Ohtani**, M. Kimura, S. Ozawa, T. Nagase, M. Nishijima and K. Hiraga (2010). Melting and subsequent decompression processes recorded in a shock vein of an L6 chondrite., *Meteoritics & Planetary Science*, 45 (Supplement), A140
18. El Goresy, A., M. Miyahara, S. Ozawa, **E. Ohtani**, P. Gillet, P. Beck, G. Montagnac, T. Nagase and K. Hiraga (2010). Liquidus high-pressure assemblages in shocked Martian shergottites: constrains

- to equilibrium peak shock-pressures and consequences to radiometric ages., *Meteoritics & Planetary Science*, 45, A50, (Supplement)
19. Feng, L., M. Miyahara, Y. Lin, **E. Ohtani**, A. EL Goresy, T. Nagase and S. Hu (2010). First evidence for multi shock events on the L chondritic parent body., *Meteoritics & Planetary Science*, 45, A53, (Supplement)
  20. **Ohtani, E** (2010), Application of in situ X-ray observations to melting and melt properties at high pressure, *GEOCHIMICA ET COSMOCHIMICA ACTA*, 74, 12, A775-A775
  21. Sakamaki, T; **Ohtani, E**; Urakawa, S; Suzuki, A; Katayama, Y; Zhao, DP (2010), Density of high-Ti basalt magma at high pressure and origin of heterogeneities in the lunar mantle, *EARTH AND PLANETARY SCIENCE LETTERS*, 299, 3-4, 285-289
  22. Suzuki, A., **E. Ohtani**, R. Ando, H. Terasaki, T. Sakamaki and K. Funakoshi (2010), Viscosity of basaltic magma at high pressure, *Acta Mineralogica-Petrographica*, 6
  23. Ozawa, S., M. Miyahara, **E. Ohtani**, M. Kimura and Y. Ito (2011). Petrography of Yamato 984028 lherzolitic shergottite and its melt vein: implications for its shock metamorphism and origin of the vein., *Polar Science*, 4, 550-557
  24. Terasaki, H., Y. Shibazaki, T. Sakamaki, R. Tateyama, **E. Ohtani**, K. Funakoshi and Y. Higo (2011). Hydrogenation of Fe Si under high pressure., *American Mineralogist*, 96, 93-99
  25. Konstantin, D. L., A. Shatskiy, **E. Ohtani** and T. Katsura. (2011). Systematic study of hydrogen incorporation into Fe-free wadsleyite., *Physics and Chemistry of Minerals*, 38, 1, 75-84
  26. Litasov, K. D., I. S. Sharygin, A. F. Shatskiy, **E. Ohtani** and N. P. Pokhilenko. (2011). Experimental constraints on the role of chloride in the origin and evolution of kimberlitic magma., *Doklady Earth Sciences* 435, 2, 1641-1646
  27. Shibazaki, Y., **E. Ohtani**, H. Terasaki, R. Tateyama, T. Sakamaki, T. Tsuchiya and K. Funakoshi (2011). Effect of hydrogen on the melting temperature of FeS at high pressure: Implications for the core of Ganymede., *Earth and Planetary Science Letters*, 301, 1-2, 153-158
  28. Sakamaki, T., **E. Ohtani**, S. Urakawa, H. Terasaki and Y. Katayama. (2011). Density of carbonated peridotite magma at high pressure using an X-ray absorption method., *American Mineralogist*, 96, 4, 553-557, doi: 10.2138/am.2011.3577
  29. **Ohtani, E.**, S. Ozawa, M. Miyahara, Y. Ito, T. Mikouchi, M. Kimura, T. Arai, K. Sato, and K. Hiraga. (2011). Coesite and stishovite in a shocked lunar meteorite, Asuka-881757, and impact events in lunar surface., *PNAS*, 108, 2, 463-466, doi: 10.1073/pnas.1009338108
  30. Nakamura R., **Ohtani E.**, (2011), The high-pressure phase relation of the MgSO<sub>4</sub>-H<sub>2</sub>O system and its implication for the internal structure of Ganymede. *Icarus*, 211(1), 648-654
  31. Zhao DP., Yu S., **Ohtani E.**, (2011), East Asia: Seismotectonics, magmatism and mantle dynamics. *Journal of Asian Earth Science*, 40, 3, 689-709
  32. Sakai T., **Ohtani E.**, Hirao N., Ohishi Y., (2011), Equation of state of the NaCl-B2 phase up to 304 GPa. *Journal of Applied physics*, 109, 8, doi:10.1063/1.3573393
  33. Miyahara M., **Ohtani E.**, Ozawa S., Kimura M., El Goresy A., Sakai T., Nagase T., Hiraga K., Hirao N., Ohishi Y., (2011), Natural dissociation of olivine to (Mg, Fe)SiO<sub>3</sub> perovskite and magnesiowustite in a shocked Martian meteorite. *Proceedings of the Natural Academy of Sciences of the United States of America*, 108, 15, 5999-6003
  34. Shatskiy A., Borzdov YM., Litasov KD., **Ohtani E.**, Khokhryakov AF., Palyanov YN., Katsura T., (2011), Press less split-sphere apparatus equipped with scaled-up Kawai-cell for mineralogical studies at 10-20 GPa. *American Mineralogist*, 96, 4, 541-548
  35. Sakai T., **Ohtani E.**, Hirao N., Ohishi Y., (2011), Stability field of the hcp-structure for Fe, Fe-Ni, and Fe-Ni-Si alloys up to 3 Mbar. *Geophysical research letters*, 38, L09302

36. Terasaki H., Kamada S., Sakai T., **Ohtani E.**, Hirao N., Ohishi Y., (2011), Liquidus and solidus temperatures of a Fe-O-S alloy up to the pressures of the outer core: Implication for the thermal structures of the Earth's core. *Earth and Planetary Science Letters*, 304, 3-4, 559-564
37. Suzuki A., **Ohtani E.**, Terasaki H., Nishida K., Hayashi H., Sakamaki Y., Shibazaki Y., Kikegawa T., (2011), Pressure and temperature dependence of the viscosity of a NaAlSi<sub>2</sub>O<sub>6</sub> melt. *Physics and Chemistry of Minerals*, 38, 59-64
38. Nishida K., **Ohtani E.**, Urakawa S., Suzuki A., Sakamaki T., Terasaki H., Katayama Y., (2011), Density measurement of liquid FeS at high pressures using synchrotron X-ray absorption. *American Mineralogist*, 96, 864-868
39. Miyahara M., **Ohtani E.**, Kimura M., Ozawa S., Nagase T., Nishijima M. and Hiraga K., (2011), Evidence for multiple dynamic events and subsequent decompression stage recorded in a shock vein. *Earth and Planetary Science Letters*, 307, 361-368
40. Asanuma H., **Ohtani E.**, Sakai T., Terasaki H., Kamada S., Hirao N., Ohishi Y., (2011), Static compression of Fe<sub>0.83</sub>Ni<sub>0.09</sub>Si<sub>0.08</sub> alloy to 374 GPa and Fe<sub>0.93</sub>Si<sub>0.07</sub> alloy to 252 GPa: Implications for the Earth's inner core. *Earth and Planetary Science Letters*, doi:10.1016/j.epsl.2011.06.034
41. Tateyama R., **Ohtani E.**, Terasaki H., Nishida K., Shibazaki Y., Suzuki A., Kikegawa T., (2011), Density measurements of liquid Fe-Si alloys at high pressure using the sink-float method. *Physics and Chemistry of Minerals*, doi:10.1007/s00269-011-0452-1
42. Sakai T., **Ohtani E.**, Terasaki H., Kamada S., Hirao N., Miyahara M., Nishijima M., (2011), Phase stability and compression study of (Fe<sub>0.89</sub>, Ni<sub>0.11</sub>)<sub>3</sub>S up to pressure of the Earth's core. *American Mineralogist*, 96, 10, 1490-1494, doi:10.2138/am.2011.3822
43. Kuritani T., **Ohtani E.**, Kimura J., (2011), Intensive hydration of the mantle transition zone beneath China caused by ancient slab stagnation. *Nature Geoscience*, doi:10.1038/NNGEO1250.
44. Miyahara M., **Ohtani E.**, Ozawa S., Kimura M., El Goresy A., Sakai T. Nagase T., Hiraga K., Hirao N., Ohishi Y., (2011), First evidence for natural dissociation of olivine to silicate-perovskite and magnesio-wüstite in a shocked Martian meteorite DAG 735. *Meteoritics & Planetary Science*, 46, SI, 1, A164-A164
45. Bindi, L; Dymshits, AM; Bobrov, AV; Litasov, KD; Shatskiy, AF; **Ohtani, E**; Litvin, YA (2011), Crystal chemistry of sodium in the Earth's interior: The structure of Na<sub>2</sub>MgSi<sub>5</sub>O<sub>12</sub> synthesized at 17.5 GPa and 1700 degrees C, *AMERICAN MINERALOGIST*, 96, 2-3, 447-450
46. Shibazaki Y., **Ohtani E.**, Fukui H., Sakai T., Kamada S., Ishikawa D., Tsutsui S., Baron A. Q., Nishitani N., Hirao N., Takemura K., (2011), Sound velocity measurements in dhcp-FeH up to 70 GPa with inelastic X-ray scattering: Implications for the composition of the Earth's core. *Earth and Planetary Science Letters*, in press
47. Kamada, S; Terasaki, H; **Ohtani, E**; Sakai (2011), Phase and Melting Relationships in the Fe-S System under High Pressures: Application to the Temperature Profile in the Core, *The Review of high pressure science and technology*, 21, 2, 77-83

### Symposium Participations:

1. **Ohtani, E.** (2010). Effect of carbon and hydrogen on phase and melting relations and melt properties at high pressure., Deep Carbon Cycle International Conference in Beijing
2. **Ohtani, E.**, Y. Shibazaki and H. Terasaki (2010). Transport of hydrogen into the deep Earth by slab penetration., JpGU International Symposium 2010, SIT039-12, Chiba, May 23-28, 2010
3. **Ohtani, E.**, T. Sakai, S. Kamada, M. Murakami, H. Fukui and A. Baron (2010). Sound velocity of  $\text{Fe}_{0.83}\text{Ni}_{0.09}\text{Si}_{0.08}$  alloy to core pressures., JpGU International Symposium 2010, SIT042-21, Chiba, May 23-28, 2010
4. Ohtani, E., T. Sakamaki and K. Litasov (2010). Effect of carbon and hydrogen on melting and magma properties at high pressure., JpGU International Symposium 2010, MIS010-12, Chiba, May 23-28, 2010
5. Kuramoto, K., K. Kobayashi and **E. Ohtani** (2010). Toward the structure, origin, and dynamics of the moon and rocky planets., JpGU International Symposium 2010, PPA007-03, Chiba, May 23-28, 2010
6. Kobayashi, K., K. Kuramoto and **E. Ohtani** (2010). Coevolution of surface environments of planets and life., JpGU International Symposium 2010, PPS007-04, Chiba, May 23-28, 2010
7. Ishii, M., **E. Ohtani**, H. Terasaki and K. Litasov (2010). Phase relation of Mercury's interior., JpGU International Symposium 2010, PPS004-22, Chiba, May 23-28, 2010
8. Takahashi, S., **E. Ohtani** and H. Terasaki (2010). Phase relation into the C-rich Mg-Fe-Si-O-C system under various redox conditions: Implication for Carbon Planet., JpGU International Symposium 2010, PPS010-11, Chiba, May 23-28, 2010
9. Shibazaki, Y., **E. Ohtani**, H. Terasaki, R. Tateyama, T. Sakamaki., K. Nishida and K. Funakoshi (2010). Melting relations of FeS-H and Fe-Ni-H systems under high pressure., JpGU International Symposium 2010, SIT036-5, Chiba, May 23-28, 2010
10. Sakai, T., **E. Ohtani**, H. Terasaki, S. Kamada, N. Hirao, E. Sata and Y. Ohishi (2010). Phase stability of subsolidus phases in Fe-Ni-S system at the core pressure., JpGU International Symposium 2010, SIT036-06, Chiba, May 23-28, 2010
11. Shiraishi, R., **E. Ohtani**, T. Kuno, A. Suzuki, N. Doi, A. Shimojuku, T. Kato, K. Kanagawa and T. Kikegawa (2010). Deformation experiment on fayalite using deformation-Cubic Anvil Press with synchrotron X rays., JpGU International Symposium 2010, SIT037-05, Chiba, May 23-28, 2010
12. Nishida, K., **E. Ohtani**, A. Suzuki, H. Terasaki, Y. Shibazaki, R. Tateyama and T. Kikegawa (2010). Equation of state of liquid FeS at high pressure and high temperature., JpGU International Symposium 2010, SIT041-12, Chiba, May 23-28, 2010
13. Shatskiy, A., K. Litasov, D. Yamazaki, T. Katsura and **E. Ohtani** (2010). Incipient fluid migration through the deep mantle by dissolution-precipitation: crystal growth constraints., JpGU International Symposium 2010, SIT042-5, Chiba, May 23-28, 2010
14. Litasov, K., A. Shatskiy, H. Terasaki, **E. Ohtani**, F. Yingwei and K. Funakoshi (2010). Carbon-silicate-Fe metal reactions at high pressures: New experimental constraints on deep volatile cycles., JpGU International Symposium 2010, MIS010-14, Chiba, May 23-28, 2010
15. Fumiko, T., **E. Ohtani** and T. Nakagawa (2010). Seismic evidence of dehydration induced fluids near the 660 Km phase transformation depths beneath stagnant slabs., JpGU International Symposium 2010, SIT039-07, Chiba, May 23-28, 2010
16. Sakamaki, T., **E. Ohtani**, A. Suzuki, S. Urakawa, H. Terasaki, Y. Katayama and K. Funakoshi (2010). Density, viscosity and structure of basaltic magma at high pressure and high temperature., JpGU International Symposium 2010, SIT041-09, Chiba, May 23-28, 2010
17. Takata, N., M. Murakami and **E. Ohtani** (2010). Brillouin scattering and X-ray diffraction of NaCl: a construction of primary pressure scale., JpGU International Symposium 2010, SIT036-P04, Chiba, May 23-28, 2010

18. Suzuki, A., **E. Ohtani**, K. Nishida, R. Tateyama, Y. Shibazaki and T. Kikegawa (2010). Viscosity of  $K_2TiSi_4O_9$  melt at high pressure and high temperature., JpGU International Symposium 2010, SIT041-P04, Chiba, May 23-28, 2010, (poster)
19. Terasaki, H., Y. Shibazaki, T. Sakamaki., R. Tateyama, **E. Ohtani** and K. Funakoshi (2010). Hydrogen solubility onto FeSi under high pressure., JpGU International Symposium 2010, SIT036-P09, Chiba, May 23-28, 2010
20. Nishitani N., **E. Ohtani**, T. Sakai and M. Murakami (2010). Study of melting phenomena under the deep mantle conditions., JpGU International Symposium 2010, SIT036-P05, Chiba, May 23-28, 2010
21. Nishimoto, T., M. Murakami and **E. Ohtani** (2010). Elasticity and equation of state of sodium silicate glass., JpGU International Symposium 2010, SIT041-P05, Chiba, May 23-28, 2010
22. Tateyama, R., **E. Ohtani**, A. Suzuki, H. Terasaki, K. Nishida, Y. Shibazaki and T. Kikegawa, (2010). Density measurement of liquid Fe-Si using sink/float method under high pressure., JpGU International Symposium 2010, SIT041-P09, Chiba, May 23-28, 2010
23. Urakawa, S., H. Terasaki, K. Funakoshi, K. Uesugi and **E. Ohtani** (2010). In situ X-ray tomography observation of connectivity of Ni-S melts in olivine under of high pressure and temperature., JpGU International Symposium 2010, SIT041-P08, Chiba, May 23-28, 2010
24. **Ohtani, E.** (2010). Application of in situ X-ray observation to melting and melt properties at high pressure., The Goldschmidt 2010 Conference, Tennessee, June 13-18, 2010
25. Suzuki, A., **E. Ohtani**, T. Sakamaki, S. Urakawa, Y. Katayama, K. Nishida, R. Tateyama and T. Kikegawa (2010). Density and viscosity of the lunar high-Ti magma at high pressure., Western Pacific Geophysics Meeting, Taipei, June 22-25, 2010
26. **Ohtani, E.**, T. Sakai, S. Kamada, Y. Shibazaki, K. Kobayashi, H. Asanuma and N. Hirao (2010). Melting and phase relations of Fe(Ni)-Si systems to the Earth's core conditions, and their applications to the core., Western Pacific Geophysics Meeting, Taipei, June 22-25, 2010
27. **Ohtani, E.** (2010). Deep volatile cycle and light elements in the core., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", July 13-15, 2010, Sendai, Japan, (oral)
28. Litasov, K., A. Shatskiy, H. Terasaki and **E. Ohtani** (2010). Carbonate-silicate-Fe metal reactions and stability of C-O-H species in the Earth's mantle., Global COE Symposium 2011 "Dynamic Earth and Heterogeneous Structure", July 13-15, 2010, Sendai, Japan, (oral)
29. Terasaki, H., Y. Shibazaki, T. Sakamaki, R. Tateyama, **E. Ohtani**, K. Funakoshi and Y. Higo (2010). The effect of hydrogen on melting of FeSi under high pressure., Global COE Symposium 2012 "Dynamic Earth and Heterogeneous Structure", July 13-15, 2010, Sendai, Japan, (oral)
30. Kuritani, T. and **E. Ohtani** (2010). Transition zone-derived mantle plume above the stagnant Pacific slab and its consequence for intraplate magmatism in northeast China., Global COE Symposium 2013 "Dynamic Earth and Heterogeneous Structure", July 13-15, 2010, Sendai, Japan, (oral)
31. Miyahara, M., **E. Ohtani**, M. Kimura, A. El Goresy, S. Ozawa, T. Nagase, M. Nishijima and K. Hiraga (2010). Coherent and subsequent incoherent phase transformation from olivine to ringwoodite in a shocked L6 ordinary chondrite., Global COE Symposium 2014 "Dynamic Earth and Heterogeneous Structure", July 13-15, 2010, Sendai, Japan, (poster)
32. Nishitani, N., **E. Ohtani**, T. Sakai and M. Murakami (2010). Melting experiments of MORB under the deep mantle conditions., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-08, July 13-15, 2010, Sendai, Japan, (poster)
33. Shatskiy, A., K. D. Litasov, Y. Borzdov, T. Katsura and **E. Ohtani** (2010). Search for the driving forces for fluid migration through the deep mantle., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-09, July 13-15, 2010, Sendai, Japan, (poster)
34. Koike, Y., **E. Ohtani** (2010). Grain growth kinetics in hydrous ringwoodite., Global COE

- Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-10, July 13-15, 2010, Sendai, Japan, (M1, poster)
35. Ozawa, S., M. Miyahara, **E. Ohtani**, M. Kimura and T. Nagase (2010). TEM observations of natural enstatite-majorite phase transition in a shocked meteorite: Implication for interior dynamics of planets., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-11, July 13-15, 2010, Sendai, Japan, (D3, poster)
  36. Kamada, S., **E. Ohtani**, H. Terasaki, T. Sakai, Y. Ohishi, N. Hirao and N. Sata (2010). Melting temperature of Fe-FeS and (Fe, Ni)-(Fe, Ni)S system: Implication to temperature of Outer Core., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-12, July 13-15, 2010, Sendai, Japan, (D3, poster)
  37. Tateyama, R., **E. Ohtani**, A. Suzuki, H. Terasaki, K. Nishida, Y. Shibazaki and T. Kikegawa (2010). Density measurement of liquid Fe-Si using sink/float method under high pressure., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-13, July 13-15, 2010, Sendai, Japan, (M2, poster)
  38. Sakai, T., **E. Ohtani**, H. Terasaki, S. Kamada, N. Hirao, N. Sata and Y. Ohishi (2010). Density of Fe-Ni-S alloy at the pressure of the center of the Earth., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-14, July 13-15, 2010, Sendai, Japan, (poster)
  39. Takahashi, S., **E. Ohtani** and H. Terasaki (2010). Phase relation of C-rich Mg-Fe-Si-O system under various redox conditions., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-15, July 13-15, 2010, Sendai, Japan, (M1, poster)
  40. Ishii, M., **E. Ohtani**, H. Terasaki and K. Litasov (2010). Mineralogy of Mercurian mantle., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-16, July 13-15, 2010, Sendai, Japan, (M1, poster)
  41. Nishida, K., **E. Ohtani**, A. Suzuki, H. Terasaki, S. Urakawa, T. Sakamaki, Y. Shibazaki, Y. Katayama and T. Kikegawa (2010). Equation of state of liquid FeS at high pressure and high temperature., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-18, July 13-15, 2010, Sendai, Japan, (D2, poster)
  42. Shibazaki, Y., **E. Ohtani**, H. Terasaki, R. Tateyama, Y. Sakamaki, K. Nishida and K. Funakoshi (2010). Effect of hydrogen on the melting relations of FeS and Fe-Ni systems under high pressure., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-19, July 13-15, 2010, Sendai, Japan, (D2, poster)
  43. Suzuki, A., **E. Ohtani**, K. Nishida, R. Tateyama, Y. Shibazaki and T. Kikegawa (2010). Viscosity of  $K_2TiSi_4O_9$  melt at high pressure and high temperature., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-20, July 13-15, 2010, Sendai, Japan, (poster)
  44. Shiraishi-Ohnuma, R., **E. Ohtani**, T. Kubo, N. Doi, A. Suzuki, A. Shimojuku, T. Kato and T. Kikegawa (2010). Deformation experiments on fayalite using deformation-cubic anvil press and monochromatic X-rays., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P2-04, July 13-15, 2010, Sendai, Japan, (poster)
  45. Nishimoto, T., M. Murakami and **E. Ohtani** (2010). Elasticity of hydrous sodium silicate glass: Implication for the melt in the Earth's interior., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P2-25, July 13-15, 2010, Sendai, Japan, (M1, poster)
  46. **Ohtani, E.** (2010). Chemical and physical properties and thermal state of the core and lower mantle., The 12th Symposium of SEDI (Study of the Earth's Deep Interior), Santa Barbara, California, July 18-23, 2010
  47. **Ohtani, E.** (2010). Iron-Silicate reaction and silicon in the core., IMA 2010 (The 20th general meeting of the international mineralogical association), Budapest, Hungary, August 21-27, 2010
  48. Sakai, T., **E. Ohtani**, H. Terasaki, S. Kamada, N. Hirao, N. Sata and Y. Ohishi (2010). Compression of Fe-Ni-S alloy up to the pressure of the center of the Earth., IMA 2010 (The 20th



- general meeting of the international mineralogical association), Budapest, Hungary, August 21-27, 2010, (invited)
49. **Ohtani, E.** (2010). Composition, physical properties and thermal state of the core., CECAM 2010 (Computational Mineral Physics: Applications to Geophysics), Zurich, Switzerland, October 11-15, 2010
  50. Litasov, K. D., A. Shatskiy, **E. Ohtani** (2010). Melting phase relations of K- and Na- bearing carbonate at 3-21 GPa with implication to deep carbon cycle., American Geophysical Union 2004 Fall meeting, San Francisco, December 13-17, 2010, (poster)
  51. Shibazaki, Y., **E. Ohtani**, H. Terasaki, R. Tateyama, T. Sakamaki, T. Tsuchiya and K. Funakoshi (2010). In situ X-ray observation of melting temperature of HeS-H system under high pressure: Implications for the core of Ganymede., American Geophysical Union 2005 Fall meeting, San Francisco, December 13-17, 2010, (poster)
  52. Kamada, S., **E. Ohtani**, H. Terasaki, T. Sakai, Ohishi, T. Hirao and N. Sata (2010). Temperature profile of the outer core based on X-ray diffraction of Fe- Fe<sub>3</sub>S and (Fe, Ni)-(Fe-Ni)<sub>3</sub>S system., American Geophysical Union 2006 Fall meeting, San Francisco, December 13-17, 2010, (poster)
  53. **Ohtani, E.**, D. Zhao, T. Kuritani and F. C. Tajima (2010). Deep dehydration and physical and chemical nature of the mantle above the stagnant slab., American Geophysical Union 2007 Fall meeting, San Francisco, December 13-17, 2010, (invited)
  54. Terasaki, H., S. Kamada, T. Sakai, **E. Ohtani**, N. Hirao, N. Sata and Y. Ohishi (2010). Melting relation of Fe-O-S alloy up to the outer core pressure: Implication to temperature of the Earth's core., American Geophysical Union 2008 Fall meeting, San Francisco, December 13-17, 2010, (poster)
  55. Nishihara, Y., T. Ohuchi, T. Kawazoe, D. Spengler, M. Tasaka, T. Hiraga, T. Kikegawa, A. Suzuki and **E. Ohtani** (2010). Rheology of fine-grained forsterite aggregate under deep upper mantle conditions., American Geophysical Union 2009 Fall meeting, San Francisco, December 13-17, 2010, (oral)
  56. Takahashi, S., **E. Ohtani**, H. Terasaki, Y. Ito, Y. Shibazaki, M. Ishii, K. Funakoshi and Y. Higo (2010). Phase relation of C-Mg-Fe-Si-O system under various oxygen fugacity conditions at high pressure and high temperature., American Geophysical Union 2010 Fall meeting, San Francisco, December 13-17, 2010, (poster)
  57. **Ohtani, E.** (2010). In situ X-ray measurements of density of silicate and metallic melts at high pressure., Department of Geological Sciences, UC Davis and Advanced Light Source of UC Berkeley, February, 2010, (invited)
  58. **Ohtani, E.** (2010). Iron-Silicate reaction and silicon as a light element in the core., Global-Network symposium on Earth's Dynamics, Akiu, Sendai, Japan, March, 2010, (invited)
  59. **Ohtani, E.** (2010). Iron-Silicate Reactions and Light Elements in the Core., Chinese Academy of Science, April, 2010, Beijing, China, (invited)
  60. **Ohtani, E.** (2010). Application of in situ X-ray observation to melting and melt properties at high pressure., Goldschmidt Conference (Knoxville), June, 2010, (invited)
  61. **Ohtani, E.** (2010). Deep volatile cycle and Light Elements in the Core., GCOE Solid Earth symposium, July, 2010, (invited)
  62. **Ohtani, E.** (2010). Physical and Chemical properties and thermal state of the core and lower mantle., SEDI (Study of the Earth Deep Interior) at UC Santa Barbara, UC Santa Barbara, July, 2010, (invited)
  63. **Ohtani, E.** (2010). Iron-Silicate reaction and Silicon in the Core., International Mineralogical Union, September, 2010, (invited)
  64. **Ohtani, E.** (2010). Composition, Physical Properties, and Thermal State of the Core., CECAM (Centre Européen de Calcul Atomique et Moléculaire), (invited)

65. **Ohtani, E.** (2010). Material properties of Earth's materials, and structure, evolution, and dynamics of the mantle and core., LMU Munchen, Munchen, Germany, October, 2010
66. **Ohtani, E.,** T. Sakai, S. Kamada, M. Murakami, H. Fukui and B. Alfred (2010). Sound velocity measurement of iron and Fe-Ni-Si alloy at high pressure by the inelastic X-ray scattering., 2010 Annual Meeting of Japan Association of Mineralogical Sciences, Matsue, September 23-25, 2010
67. Miyahara, M., **E. Ohtani,** A. EL Goresy, M. Kimura, S. Ozawa, T. Nagase, M. Nishijima, K. Hiraga, T. Ferroir, F. Gillet, L. Dubrovinsky and A. Simionovici (2010). Fractional crystallization of wadsleyite and ringwoodite from olivine melt in shocked meteorites., 51th The High Pressure Conference of Japan, 1B04, Sendai, October 20-22, 2010, (oral)
68. Takahashi, S., **E. Ohtani,** H. Terasaki, Y. Ito, Y. Shibazaki, M. Ishii, K. Funakoshi and Y. Higo (2010). Phase relation of C-Mg-Fe-Si-O system by in situ X-ray high pressure and high temperature experiment., 51th The High Pressure Conference of Japan, 1B05, Sendai, October 20-22, 2010, (M1, oral)
69. Nishihara, Y., T. Ouchi, T. Kawazoe, D. Spengler, M. Tasaka, T. Hiraga, T. Kikegawa, A. Suzuki and **E. Ohtani** (2010). Experimental study on rheology of olivine at deep upper mantle conditions., 51th The High Pressure Conference of Japan, 1B11, Sendai, October 20-22, 2010, (oral)
70. Terasaki, H., Y. Shibazaki, T. Sakamaki., R. Tateyama, **E. Ohtani,** K. Funakoshi and Y. Higo (2010). Hydrogen solubility into Fe Si under high pressure., 51th The High Pressure Conference of Japan, 1B14, Sendai, October 20-22, 2010, (oral)
71. Takahashi, E., N. Tsujino, H. Terasaki, K. Litasov, **E. Ohtani,** T. Shinmei, N. Nishiyama, T. Irifune and T. Suzuki (2010). On the quality of LaCrO<sub>3</sub> heating elements S2 and S6 by Nikkato CO., 51th The High Pressure Conference of Japan, 1C08, Sendai, October 20-22, 2010, (oral)
72. Sakai, T., **E. Ohtani,** N. Hirao and Y. Ohishi (2010). The equation of state of NaCl-B<sub>2</sub> up to the inner core pressure., 51th The High Pressure Conference of Japan, 3B04, Sendai, October 20-22, 2010, (oral)
73. Kamada, S., **E. Ohtani,** H. Terasaki, T. Sakai, N. Hirao and Y. Ohishi (2010). Melting relationships of Fe-FeS and (Fe,Ni)-(Fe,Ni)S system up to Outer Core conditions., 51th The High Pressure Conference of Japan, 3B06, Sendai, October 20-22, 2010, (D3, oral)
74. **Ohtani, E.,** T. Sakai, H. Fukui, S. Kamada, M. Murakami and B. Alfred (2010). Sound velocity measurement of iron and Fe-Ni-Si alloy at the core pressure., 51th The High Pressure Conference of Japan, 3B07, Sendai, October 20-22, 2010, (oral)
75. Nishida, K., **E. Ohtani,** A. Suzuki, R. Tateyama, Y. Shibazaki, H. Terasaki and T. Kikegawa (2010). Density measurement of liquid Fe-S at high pressure using in situ synchrotron X-ray sink/float method., 51th The High Pressure Conference of Japan, 1P21, Sendai, October 20-22, 2010, (M2, poster)
76. Shibazaki, Y., **E. Ohtani,** H. Terasaki, R. Tateyama, T. Sakamaki, T. Tsuchiya, K. Funakoshi and Y. Higo (2010). In-situ X-ray studied of the melting temperature of FeS-H system: Implications for the core of Ganymede., 51th The High Pressure Conference of Japan, 1P24, Sendai, October 20-22, 2010, (M2, poster)
77. Nishimoto, T., M. Murakami and **E. Ohtani** (2010). Elasticity of hydrous sodium silicate glass: Implications for the melt in the Earth's interior., 51th The High Pressure Conference of Japan, 1P27, Sendai, October 20-22, 2010, (M1, poster)
78. Koike, Y., **E. Ohtani** and R. Shiraishi (2010). Grain growth kinetics in hydrous ringwoodite., 51th The High Pressure Conference of Japan, 1P28, Sendai, October 20-22, 2010, (M1, poster)
79. Shatskiy, A, Y. M. Borzdov, K. Litasov, **E. Ohtani,** Y. N. Palyanov and T. Katsura (2010). Pressless split-sphere apparatus equipped with scaled-up Kawai-cell for mineralogical studies at 10-20 Gpa., 51th The High Pressure Conference of Japan, 3P18, Sendai, October 20-22, 2010, (poster)

80. Terasaki, H., S. Urakawa, K. Funakoshi, K. Uesugi, A. Nakatsuka and **E. Ohtani** (2010). 3-D distribution of Fe-Ni-S melts under high pressure and temperature., 51th The High Pressure Conference of Japan, 3P35, Sendai, October 20-22, 2010, (poster)
81. Doi, N., T. Kato, T. Kubo, R. Shiraishi, A. Suzuki, **E. Ohtani**, A. Shimojuku and T. Kikegawa (2010). High pressure decomposition of albite under plastic flow observed by in-situ x-ray diffraction., 51th The High Pressure Conference of Japan, 3P36, Sendai, October 20-22, 2010, (poster)
82. Shiraishi, R., **E. Ohtani**, T. Kubo, N. Doi, A. Suzuki, A. Shimojuku, T. Kato and T. Kikegawa (2010). Deformation experiments of fayalite using monochromatic X-rays., 51th The High Pressure Conference of Japan, 3P38, Sendai, October 20-22, 2010, (poster)
83. Tateyama, R., **E. Ohtani**, A. Suzuki, H. Terasaki and K. Nishida (2010). Density measurements of liquid Fe-Si using in situ synchrotron radiographic sink/float method., 51th The High Pressure Conference of Japan, 3P39, Sendai, October 20-22, 2010, (poster)
84. Ishii, M., **E. Ohtani**, H. Terasaki and K. Litasov (2010). Inner structure of Mercury's mantle., 51th The High Pressure Conference of Japan, 3P41, Sendai, October 20-22, 2010, (poster)
85. Nishitani, N., **E. Ohtani**, T. Sakai and M. Murakami (2010). In-situ X-ray observations of MORB at high-pressure and high-temperature conditions., 51th The High Pressure Conference of Japan, 3P42, Sendai, October 20-22, 2010, (poster)
86. Litasov, K., A. Shatskiy and **E. Ohtani** (2010). Melting phase relations of model alkali carbonatite systems at 3-21 GPa and implication to mantle metasomatism., 51th The High Pressure Conference of Japan, 3P44, Sendai, October 20-22, 2010, (poster)
87. **Ohtani E.**, Ozawa S., Miyahara M., Kaneko S., Ito Y., Mikouchi T., Kimura M., Arai To., Sato K., Hiraga K., (2011) High pressure polymorphs of silica in shocked lunar meteorites and impact events in lunar surface. JpGU Meeting 2011, Chiba, May 22-28. (oral)
88. Nishida K., **Ohtani E.**, Terasaki H., Tateyama R., Shibasaki Y., Suzuki A., Kikegawa T., (2011) Pressure effect on excess molar volume of liquid Fe-S. JpGU Meeting 2011, Chiba, May 22-28. (oral)
89. Nishimoto T., Murakami M., **Ohtani E.**, (2011) Structural change of hydrous sodium, silicate glass under high pressure using Brillouin and Raman spectroscopies. JpGU Meeting 2011, Chiba, May 22-28. (oral)
90. Tateyama R., Nishida K., Terasaki H., Urakawa S., Nakatsuka A., **Ohtani E.**, Katayama Y., (2011) Density measurement of liquid Fe-Si using X-ray absorption method. JpGU Meeting 2011, Chiba, May 22-28. (poster)
91. Ohira I., **Ohtani E.**, Sakai T., Miyahara M., Hirao N., Ohishi Y., Nishijima M., (2011) Mg, Si-bearing delta-AlOOH as a reservoir of water in the lower mantle. JpGU Meeting 2011, Chiba, May 22-28. (poster)
92. Shimoyama Y., **Ohtani E.**, Terasaki H., Nishida K., (2011) Density measurement of liquid Fe-C at high pressure and Implication for Earth's Outer core. JpGU Meeting 2011, Chiba, May 22-28. (poster)
93. Nishitani N., **Ohtani E.**, Sakai T., Miyahara M., Hirao N., Ohishi Y., Nishijima M., Murakami M., (2011) Study of melting phenomena under the deep mantle conditions. JpGU Meeting 2011, Chiba, May 22-28. (oral)
94. Takahashi S., **Ohtani E.**, Terasaki H., Ito Y., Funakoshi K., Higo Y., (2011) Phase relation of C-Mg-Fe-Si-O system under various oxygen fugacity conditions: Implication for planetary interior. JpGU Meeting 2011, Chiba, May 22-28. (oral)
95. Shatskiy A., Litasov K., Katsura T., Yamazaki D., **Ohtani E.**, (2011) Diffusion of silicates in alkali carbonate melt and water fluid, experimental study at 17-24 GPa and 1400-1750 K. JpGU Meeting 2011, Chiba, May 22-28. (oral)

96. Sakai T., **Ohtani E.**, Hirao N., Ohishi Y., (2011) Phase relation of Fe-Ni-Si alloy up to 3 Mbar. JpGU Meeting 2011, Chiba, May 22-28. (oral)
97. Terasaki H., Kamada S., Sakai T., **Ohtani E.**, Hirao N., Ohishi Y., (2011) Melting relation of Fe-O-S ally at the outer core condition. JpGU Meeting 2011, Chiba, May 22-28. (oral)
98. Urakawa S., Nakatsuka A., Terasaki H., Nishida K., Tateyama R., **Ohtani E.**, Katayama Y., Watanabe T., Kikegawa T., (2011) Density and structure of molten iron under pressure. JpGU Meeting 2011, Chiba, May 22-28. (oral)
99. Feng L., Miyahara M., Nagase T., **Ohtani E.**, Hu S., El Goresy A., Lin Y., (2011) Shock conditions and formation mechanism of Akimotoite-Pyroxene glass assemblages in the grove mountains (GRV) 052082. JpGU Meeting 2011, Chiba, May 22-28. (oral)
100. Miyahara M., **Ohtani E.**, Ozawa S., Kimura M., El Goresy A., Sakai T., Nagase T., Hiraga K., Hirao N., Ohishi Y., (2011) Dissociation of olivine to silicate-perovskite and magnesiowustite in the shocked Martian meteorite DaG 735. JpGU Meeting 2011, Chiba, May 22-28. (oral)
101. Kaneko S., **Ohtani E.**, Miyahara M., Sakai T., Kayama M., Nishido H., Oishi Y., Hirao N., (2011) Dynamic event recorded in a lunar meteorite NWA 4734. JpGU Meeting 2011, Chiba, May 22-28. (poster)
102. Ishii M., **Ohtani E.**, Kimura J., Terasaki H., (2011) Partitioning behavior of U and Th between metal and silicate at the Mercury's core mantle boundary. JpGU Meeting 2011, Chiba, May 22-28. (poster).
103. Sakairi T., **Ohtani E.**, Sakai T., (2011) Melting in the Fe-S- Si system at high pressure : Implication for the temperature in the outer core. JpGU Meeting 2011, Chiba, May 22-28. (poster)
104. Kamada S., Fukui H., **Ohtani E.**, Sakai T., Shibazaki Y., Terasaki H., Baron A.Q.R., Ohishi Y., Hirao N., (2011) Sound velocities of Fe3S at high pressures using inelastic X-ray scattering. JpGU Meeting 2011, Chiba, May 22-28. (poster)
105. Shibazaki Y., **Ohtani E.**, Fukui H., Sakai T., Kamada S., Nishitani N., Takemura K., Ohishi Y., Baron A.Q.R., (2011) Sound velocity measurements of dhcp FeHx up to 70 GPa by inelastic X-ray scattering. JpGU Meeting 2011, Chiba, May 22-28. (poster)
106. **Ohtani E.**, Takahashi S., Shimoyama Y., Terasaki H., Suzuki A., (2011) Carbon in Planetary cores, 日 JpGU Meeting 2011, Chiba, May 22-28. (oral)
107. Litasov K., Shatskiy A., **Ohtani E.**, (2011) Melting phase relations n the peridotite and eclogite systems coexisting with reduced C-O-H Fluid at 3-16 GPa. JpGU Meeting 2011, Chiba, May 22-28. (poster)
108. Miyahara M., **Ohtani E.**, El Goresy A., Nagase T., Nishijima M., (2011) The occurrence of a carbon in ureilite of Almahatta Sitta TC3. JpGU Meeting 2011, Chiba, May 22-28. (oral)
109. Shatskiy A., Litasov K., Sharygin I., **Ohtani E.**, (2011) Role of alkali carbonates in the mantle magmatism, metasomatism, and diamond formation. JpGU Meeting 2011, Chiba, May 22-28. (oral)
110. **Ohtani E.**, Kamada S., Sakai T., Terasaki H., Baron A. Q., Fukui H., (2011) Properties of the Iron-light element systems at high pressures and the composition and thermal state of the core. Asia Oceania Geosciences Society 2011 (AOGS), Taipei, August 8-12. (Oral)
111. Litasov K.D., Shatskiy A., **Ohtani E.**, (2011) Melting in the peridotite and eclogite, coexisting with reduced C-O-H fluid at 3-6 GPa. Goldschmidt 2011, Prague, August 14-19
112. Shatskiy A., Litasov K.D., **Ohtani E.**, (2011) Dissolution-precipitation as a possible mechanism of C-O-H fluid/melt segregation in the deep mantle. Goldschmidt 2011, Prague, August 14-19
113. Boborov A.V., Dymshits A. M., Bindi L., Litasov K.D., Shatskiy A., **Ohtani E.**, Litvin Y. A., (2011) Na-bearing majoritic garnets in the system Mg3Al2Si5O12-Na2MgSi5O12 at structural peculiarities. Goldschmidt 2011, Prague, August
114. **Ohtani E.**, (2011) Carbon and light elements in planetary cores. "Deep Carbon Observatory" Deep Carbon Cycle International Workshop (DCO-3), Altai Russia, August 25-30 (invited)

115. **Ohtani E.**, Sakai T., Kamada S., Fukui H., Shibazaki Y., Baron Alfred Q.R., Tsutsui S., Asanuma H., (2011) Phase relations density and sound velocity of Fe-Ni-Si alloys and composition of the inner core. 2011 GSA Annual meeting, Minneapolis, October 9-12, 2011. (invited)
116. **Ohtani E.**, (2011), ELyT school in Lyon 2011, Lyon, September 3-12.
117. Shibazaki Y., **Ohtani E.**, Terasaki H., Tateyama R., Sakamaki T., Nishida K., Tsuchiya T., Funakoshi K., (2011) Melting relation of Fe-S-H system under high pressure: Implication for structure of planets. ELyT school in Lyon 2011, Lyon, September.
118. Naoko Doi, Takumi Kato, Tomoaki Kubo, Masahiko Noda, Rei Ohnuma S., Akio Suzuki, **Eiji Ohtani**, Kikegawa Takumi, (2011) Changes in flow strength induced by the decomposition of polycrystalline albite. AGU Fall Meeting, San Francisco, December 5-9. (poster)
119. Yu Nishihara, Tomohiro Ohuchi, Kawazoe Takaaki, Dirk Spengler, Miki Tasaka, Takehiko Hiraga, Takumi Kikegawa, Akio Suzuki, **Eiji Ohtani**, (2011) Effect of pressure on rhology of fine-grained forsterite aggregate. AGU Fall Meeting, San Francisco, December 5-9 (poster)
120. Hidenori Terasaki, Satoru Urakawa, Kentaro Uesugi, Asumi Nakatsuka, Ken-ichi Funakoshi, **Eiji Ohtani**, (2011) Boundary pressure of inter-connection of Fe-Ni-S melt in olivine based on in-situ X-ray tomography: Implication to core formation in asteroids. AGU Fall Meeting, San Francisco, December 5-9. (Oral)
121. Suguru Takahashi, **Eiji Ohtani**, Hidenori Terasaki, Yoshinori Ito, Ken-ichi Funakoshi, Yuji Higo, (2011) Phase relation of C-Mg-Si-O system under various oxygen fugacity conditions by in situ X-ray diffraction experiments: Implication for planetary interior. AGU Fall Meeting, San Francisco, December 5-9. (poster)
122. Fumiko C. Tajima, Simon C. Stahler, **Eiji Ohtani**, Masaki Yoshida, Karin Sigloch, (2011) Variation of seismic velocity structure around the mantle transition zone and conjecture of deep water transport by subducted slabs. AGU Fall Meeting, San Francisco, December 5-9 (poster)
123. **Eiji Ohtani**, Seiji Kamada, Takeshi Sakai, Hidenori Terasaki, Hiromi Hayashi, (2011) Melting and solid-melt partitioning in iron-light element systems under megabar conditions: Implications for the thermal state of the core. AGU Fall Meeting, San Francisco, December 5-9 (oral)
124. Yuki Shibazaki, **Eiji Ohtani**, Hiroshi Fukui, Takeshi Sakai, Seiji Kamada, Alfred Q. Baron, Naoya Nishitani, Naohisa Hirao, Kenichi Takemura, (2011) Sound velocity measurements of dhcp-FeHx up to 70 GPa using inelastic X-ray scattering: Implications for the abundance of hydrogen in the Earth's core. AGU Fall Meeting, San Francisco, December 5-9 (poster)
125. Takeshi Sakai, Naoya Nishitani, **Eiji Ohtani**, Naohisa Hirao, (2011) The compression study of MgO up to 3Mbar. AGU Fall Meeting, San Francisco, December 5-9. (poster)
126. Seiji Kamada, **Eiji Ohtani**, Hidenori Terasaki, Takeshi Sakai, Yasuo Ohishi, Naohisa Hirao, Masaaki Miyahara, (2011) Melting relationships in the Fe-Fe3S system based on X-ray diffraction up to 180 GPa. (invited)
127. Satoru Urakawa, Asumi Nakatsuka, Hidenori Terasaki, Keisuke Nishida, Yoshinori Katayama, Tohru Watanabe, Takumi Kikegawa, **Eiji Ohtani**, (2011) Structure of pure liquid Fe at high pressure based on in-situ X-ray observation. AGU Fall Meeting, San Francisco, December 5-9 (oral)
128. Seiji Kamada, Hiroshi Fukui, **Eiji Ohtani**, Takeshi Sakai, Hidenori Terasaki, Alfred Q. Baron, Yasuo Ohishi, Naohisa Hirao, (2011) Compressional velocities of Fe3S at room temperature and high pressures using inelastic X-ray scattering. AGU Fall Meeting, San Francisco, December 5-9. (oral)

# Hiroyuki Nagahama

Title/Affiliation	Professor / Department of Earth Sciences, Graduate School of Science, Tohoku University
Specialized Field	Solid earth planet physics Geology Mathematical physics/fundamental theory of physical properties
Research Subject	Study on Fractal Properties of Rock Fractures (1990-) Study on Rheology of Rocks and Lithosphere (1990-)

## The Purpose of Research and Outline of Accomplishments:

- (1) Studies on the rheology of rocks and lithosphere. Rheology denotes the study of deformation and flow of matter. Our efforts are directed towards a better understanding of the mechanical behavior of rocks and to the formulation of more precise mathematical models for their dominant mechanical properties or electromagnetic radiations, mainly friction and wear during slip-sliding, frictional discharge plasma, afterslip associated with interplate earthquakes and viscoelastic behavior of rocks. Subsequent efforts are focused on analyses of the rheology of lithosphere, which is of first-class significance in earth science.
- (2) Studies on preseismic changes in atmospheric radon concentration and crustal strain, and preseismic alteration of atmospheric electric conditions and electromagnetic phenomena due to anomalous radon emanation (Lithosphere-atmosphere-ionosphere interaction). These studies are the source of a renewed interest in the field of earth science.
- (3) Studies on nonlinear dynamics, fractal geometries, differential geometries, chaos (e.g., Lorenz system) and solitons on dislocations, faults, earthquakes and geomagnetic reversals (Rikitake system). Especially we are studying differential geometries (Finsler and Kawaguchi geometries) of seismic ray path in anisotropic media.

## Main Results:

- (1) Skin depth of electromagnetic wave through fractal crustal rocks

Skin depth of electromagnetic (EM) wave depends on frequency of EM wave and electrical properties of rocks and minerals. Based on fractal theory of rocks, we point out that the frequency exponent reflects internal fractal structures (i.e., occupancy, distribution and connectivity) of dielectric/conductive matrices of rocks such as pores, cracks, grain boundaries, inclusions and various fluids. Laboratory measurements of dielectric constant and conductivity of granite and previous studies on various rocks as a function of frequency show that the frequency exponent is an exponent ranging from  $1/4$  to  $1$ . By extrapolation of the skin depth by laboratory measurements at a given frequency into at other frequencies, the skin depth with variation in the frequency exponent becomes longer or shorter than that by previous studies. Moreover, at a given frequency, the skin depth decreases with increasing a fractal dimension of fracture systems. Thus, the skin depth of EM wave through the crust for detecting seismo-EM radiations and through rock salt domes for detecting ultra-high energy neutrinos depends on fractal structures of dielectric/conductive matrices in heterogeneous crust. This study was published by

(2) Differential geometry of viscoelastic models with fractional-order derivatives

Viscoelastic materials with memory effect are studied based on the fractional rheonomic geometry. The geometric objects are regarded as basic quantities of fractional viscoelastic models, i.e. the metric tensor and torsion tensor are interpreted as the strain and the fractional strain rate, respectively. The generalized viscoelastic equations are expressed by the geometric objects. Especially, the basic constitutive equations such as Voigt and Maxwell models can be derived geometrically from the generalized equation. This leads to the fact that various viscoelastic models can be unified into one geometric expression. The fractional time derivatives depend on the difference between the current time and the past time of certain system while the integer-order time derivatives express the local states. In the theory of viscoelasticity, the deformation process is determined by both current and past stress states. Such a memory effect is an intrinsic property of viscoelastic materials and can not always be described by the derivatives with integer order. Moreover, the viscoelastic deformation is geometrically expressed by the time-dependent geometric quantities. Therefore, in this study, we generalize the geometric studies in rheology into fractional cases based on the fractional differential geometry and the time-dependent rheonomic geometry. When the metric and torsion tensors are regarded as the basic quantities of viscoelastic models, the generalized viscoelastic constitutive equation can be constructed from the energy function of geometric objects with fractional orders. In this case, the torsion tensor as a non-Riemannian quantity corresponds to the fractional strain rate. The generalized constitutive equation also induces the geometric descriptions of basic fractional constitutive equations, Voigt and Maxwell models. Thus, the behavior of viscoelastic materials with memory can be understood generally in the framework of the fractional rheonomic geometry. This study was published by Jour. Phys. A: Math. Theor.

(3) Electric potential changes associated with nucleation of stick-slip of simulated gouges

Our friction experiments using simulated gouges detected premonitory changes in electric potential before stick-slip events. These precursor electric signals have been detected both in piezoelectric quartz and non-piezoelectric gabbroic gouges. The changes in the potential were locally detected by electrodes set very close to the fault surface associated with slow slip prior to stick-slip events. The magnitude of electrification is proportional to fault slip associated with gradual stress releases, indicating that the electrification is slip-dependent process. From the detailed microstructural analyses on a representative sample, Riedel ( $R_1$ ) 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  $R_1$  shears in nucleation phases of stick-slip events. Our experimental results imply that natural faults with thicker gouge zones. This study is submitted by Tectonophysics.

(4) Anomalous Radon Concentration Prior to an Earthquake: A Case Study on the 1995 Kobe Earthquake, Japan

The three months before 1995 Kobe earthquake (Mw. 6.8), we observed that anomalous atmospheric radon increased on one of the Rokko fault lines, which was the source of the earthquake. It

has been our goal to reduce the risk to people caused by earthquakes by observing warning signs in radon anomalies. We apply a “critical phenomena model” to the radon data. The anomalous increase in atmospheric radon concentration is studied in detail using the thermodynamic theory on the time-dependent evolution of damage of stressed rock and crustal fluid dynamics prior to catastrophic failure or an earthquake. Effects of radon emissions on atmospheric electrical conditions and preseismic electromagnetic phenomena are discussed in terms of lithosphere-atmosphere-ionosphere coupling. The radon data and other preseismic phenomena are linked to fluctuations in crustal strain before the earthquake. In this book, we show the observation of the atmospheric radon concentration is of great utility in the detection of preseismic anomalies. This study is published by LAP Lambert Academic Publishing. This book will be useful to students and researchers who are interested in precursor phenomena of earthquakes.

We found out that there were severe changes in radon gas before the 9.0-magnitude earthquake struck the northeastern region of Japan on March 11, according to the results of the study made by a research team from the Kobe Pharmaceutical University, Tohoku University and Fukushima Medical University. Changes in the density of radon gas in the atmosphere may predict a possible earthquake. The study cited two cases of 1995 Kobe Earthquake, Japan and 2011 Tohoku Earthquake (Mw = 9.0) showing changes in radon gas before these quakes happened.

Before the Tohoku earthquake, we noted that there were drastic changes in radon gas as dramatic increases happened from June to December 2010 followed by substantial decreases three months prior to the earthquake. Similarly, the research group examined the change of density in radon gas before the 1995 Kobe Earthquake and discovered the unusual increase and decrease in density of the gas just before the earthquake. The levels of density of radon gas may be monitored using facilities in universities and hospitals with indicators. The creation of a “monitoring network to check the changes” could help significantly in predicting earthquakes in the future. The complete results of the study were presented during the conference of the Seismological Society of Japan slated on October 12, 2011 or several newspapers or the national conferences.

#### **International activity:**

1. A Member of Advisory Board of Publications of the Institute of Geophysics, Polish Academy of Sciences

#### **Awards:**

1. Ito, H., Sasaki, O., Iwashita, T., **Nagahama, H.** and Kano, H. (2010). Three dimensional morphometry of planktonic foraminifera chambers., 126. The 117th Annual Meeting of the Geology Society of Japan, 2010, November 18-20, Toyama. Poster award.

#### **Published Journal Papers:**

1. Takahara, K., J. Muto and **H. Nagahama** (2010). Skin depth of electromagnetic wave through fractal crustal rocks. IEEJ Trans., FM (Elect. Eng. Jpn.), 130
2. Yajima, T. and H. Nagahama (2010). Differential geometry of viscoelastic models with fractional-order derivatives., Jour. Phys. A: Math. Theor. 43 doi: 10.1088/1751-8113/43/38/385207
3. Muto, J., **H. Nagahama**, T. Miura and I. Arakawa (2010). Frictional discharges and



- seismo-electromagnetic phenomena due to frictional slip of rocks., *Earth Monthly (Gekkan Chikyu)*. Special Issue: Earthquake Lightning, 32, (8), (in Japanese).
4. Onuma, K., J. Muto, **H. Nagahama** and K. Otsuki (2010). Electric potential changes associated with nucleation of stick-slip of simulated gouges, *Tectonophysics*, 502 (3-4), 20 April 2011, Pages 308-314.
  5. Yajima T., K. Yamasaki, **H. Nagahama** (2011) Finsler metric and elastic constants for weak anisotropic media, *Nonlinear Analysis: Real World Applications* (June 2011) doi:10.1016/j.nonrwa.2011.05.018
  6. Onuma, K; Muto, J; **Nagahama, H**; Otsuki, K (2011). Electric potential changes associated with nucleation of stick-slip of simulated gouges, *TECTONOPHYSICS*, 502, 308-314

#### **Books:**

1. Teisseyre, R., **H. Nagahama** and E. Majewski (2010). *Physics of Asymmetric Continuum: Extreme and Fracture Processes: Earthquake Rotation and Soliton Waves.*, (Paperback, 14 Oct 2010), Springer-Verlag, 293, The 1st Edition. Edition (14 Oct 2010), ISBN-10: 3642087957, ISBN-13: 978-3642087950.
2. Iwasa, N., **H. Nagahama** (2010). Section I, Measurement of environmental radiation, *Education Course Textbook of Tohoku Univ., A Comprehensive Experiment of Natural Sciences 2010*, Text editors of A Comprehensive Experiment of Natural Sciences (eds.), 13-34, Tohoku University Press, Sendai, 301, (in Japanese)
3. Iwasa, N., **H. Nagahama** (2011). Section I, Measurement of environmental radiation, *Education Course Textbook of Tohoku Univ., A Comprehensive Experiment of Natural Sciences 2010*, Text editors of A Comprehensive Experiment of Natural Sciences (eds.), 11-32, Tohoku University Press, Sendai, 2011, (in Japanese).
4. Yasuoka, Y., **H. Nagahama** and T. Ishikawa (2011). *Anomalous Radon Concentration Prior to an Earthquake: A Case Study on the 1995 Kobe Earthquake, Japan, Collected Papers.* LAP Lambert Academic Publishing, ISBN 978-3-8433-8451-3, paperback, 148.
5. Yasuoka, Y., T., Ishikawa, Y., Omori, Y., Kawada, **H., Nagahama, S.**, Tokonami, M., Shinogi (2011 in press) *Handbook of Radon: Properties, Applications and Health*, Editors: Zachary Li and Christopher Feng, *Anomalous Atmospheric Radon Variation before an Earthquake: A Case Study of the 1995 Kobe Earthquake, Japan*, Nova Science Publishers, NY , USA.

#### **Symposium Participations:**

1. Omori, Y. and **H. Nagahama** (2010). Nocturnal evolution of atmospheric radon concentration under near-surface meteorological conditions., *EGU General Assembly 2010*, EGU2010-7481 May 2-8, 2010, Vienna, Austria
2. Omori, Y., **H. Nagahama**, Y. Ishikawa, A. Kimura, M. Nagayama and T. Sekine (2010). Linear relations among atmospheric radon concentration, air temperature, and net radiation in nighttime, and their implications., *The 19th Symposium on Boundary Layers and Turbulence*, August 2-6, 2010, Keystone, USA
3. Omori, Y., I. Tohbo, **H. Nagahama**, Y. Ishikawa, M. Takahashi, **H. Sato** and T. Sekine (2010). Variation of atmospheric radon concentration with bimodal seasonality on the Oshika Peninsula, Miyagi prefecture., *11th Workshop on Environmental Radioactivity*, March 1-3, 2010, Tsukuba Japan
4. Omori, Y., **H. Nagahama**, Y. Ishikawa, M. Takahashi, **H. Sato** and T. Sekine (2010). Dependence of nocturnal increase in atmospheric radon concentration on a heat-related parameter., *Japan Geoscience Union meeting 2010*, AAS001-P19, May 23-28, 2010, Chiba, Japan
5. Onuma, K., J. Muto, **H. Nagahama** and K. Otsuki (2010). Electromagnetic phenomena prior to stick slip and microstructural evolution in simulated gouges., *Japan Geoscience Union meeting*

- 2010, May 23-28, 2010, Chiba, Japan
6. Onuma, K., J. Muto, **H. Nagahama** and K. Otsuki (2010). Electric voltage variation by nucleation of stick-slip of simulated gouges., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", July 13-15, 2010, Sendai, Japan
  7. Ito, H., O. Sasaki, T. Iwashita, **H. Nagahama** and H. Kano (2010). Three dimensional morphometry of planktonic foraminifera chambers., The 117th Annual Meeting of the Geology Society of Japan, 126, November 18-20, 2010, Toyama, Japan
  8. Muto, J., K. Takahara and **H. Nagahama** (2010). Skin depth of electromagnetic wave through fractal crustal rocks., The 117th Annual Meeting of the Geology Society of Japan, O-135 November 18-20, 2010, Toyama, Japan
  9. **Nagahama, H.** and T. Yajima (2010). Geometry of seismic wave propagation in high-order spaces., The 117th Annual Meeting of the Geology Society of Japan, O-135 November 18-20, 2010, Toyama, Japan
  10. Kawada, Y., Yajima, T. and **H. Nagahama** (2010). Fractional order viscoelasticity and theoretical progress in rheological constitutive law for rocks., American Geophysical Union 2010 Fall meeting, MR41A-1977, San Francisco, December 13-17, 2010
  11. Nakamura, Y., J. Muto, **H. Nagahama**, T. Miura, I. Arakawa (2011) Quartz amorphization due to friction and wear : Raman spectroscopic analysis, Japan Geosciences Union Meeting 2011, May 22-27, 2011, Chiba, Japan
  12. Ito, H., O. Sasaki, T. Iwashita, **H. Nagahama**, H. Kano (2011) The quantitative analysis method of three dimensional morphometry by segmentation of planktonic foraminifera chambers, Japan Geosciences Union Meeting 2011, May 22-27, 2011, Chiba, Japan
  13. Endo, E., O. Sasaki, **H. Nagahama** (2011) Availability of morphological analysis using X-ray computed tomography in microfossil study: Example of planktonic foram, Japan Geosciences Union Meeting 2011, May 22-27, 2011, Chiba, Japan
  14. Kaneko, H., J. Muto, **H. Nagahama** (2011) Development of intrafolial folds at deeper extension of seismogenic fault, Japan Geosciences Union Meeting 2011, May 22-27, 2011, Chiba, Japan
  15. Bando, Y., A. Kumamoto, N. Nakamura, **H. Nagahama** (2011) Electric wave absorptions in Reiner Gamma by lunar radar sounder (LRS) on Kaguya orbiter, Japan Geosciences Union Meeting 2011, May 22-27, 2011, Chiba, Japan
  16. Nakamura, Y., J. Muto, **H. Nagahama**, T. Miura, I. Arakawa, I. Shimizu (2011) Physical processes of quartz amorphization due to friction, American Geophysical Union 2010 Fall meeting, San Francisco, December 5-9, 2011, USA
  17. Endo, T., O. Sasaki, **H. Nagahama** (2011) Three-dimensional morphoanalysis of planktonic foraminifera by high-resolution X-ray computed tomography, R20-O-9, 2011 Joint Annual Meeting of Japan Association of Mineralogical Society of Japan, Sep. 9-11, Mito Japan.
  18. **Nagahama, H.**, T. Yajima, K. Yamasaki (2011) Finsler geometry approach to seismic rays in anisotropic media, R17-O-2, 2011 Joint Annual Meeting of Japan Association of Mineralogical Society of Japan, Sep. 9-11, Mito Japan.
  19. Nakamura, Y., J. Muto, **H. Nagahama**, T. Miura, I. Arakawa (2011) Quartz amorphization due to Pin-on-disk friction experiment, R17-O-3, 2011 Joint Annual Meeting of Japan Association of Mineralogical Society of Japan, Sep. 9-11, Mito Japan.
  20. **Nagahama, H.**, Y. Yasuoka, T. Suzuki, Y. Homma (2011) Radon variation in the air before the 2011 Tohoku Earthquake (Mw = 9.0), The seismological Society of Japan 2011, Fall Meeting, Oct.12-15, Shizuoka, Japan.

### **Newspaper & Radio**

1. Were there severe changes in radon gas before the 9.0-magnitude earthquake struck the northeastern region of Japan on March 11?, October 5, 2011, The Sankei Shinbun & Sankei Digital  
URL: <http://news.goo.ne.jp/article/sankei/world/ecoscience/snk20111005117.html>  
URL: [http://news.biglobe.ne.jp/domestic/1005/san\\_111005\\_0651280442.html](http://news.biglobe.ne.jp/domestic/1005/san_111005_0651280442.html)  
URL:<http://sankei.jp.msn.com/affairs/news/111005/dst11100511420004-n1.htm>
2. Radon gas may predict earthquakes, October 5, 2011, Majirox news
3. Recent Study Shows Radon Gas in the Air May Predict Earthquakes, October 6, 2011, The Tokyo Times.
4. There were severe changes in radon gas before the 9.0-magnitude earthquake struck the northeastern region of Japan on March 11. Radon gas may predict earthquakes, October 13, AM7:30,.  
Takeru Morimoto satand-by. TBS RADIO 954kHz
5. Why could we predict the 9.0-magnitude earthquake struck the northeastern region of Japan on March 11?, , October 30, 2011, The Sankei Shinbun & Sankei Digital  
URL:<http://sankei.jp.msn.com/affairs/news/111030/dst11103018200011-n1.htm>  
URL:<http://sankei.jp.msn.com/affairs/news/111030/dst11103018200011-n2.htm>  
URL:<http://sankei.jp.msn.com/affairs/news/111030/dst11103018200011-n3.htm>

# Toshifumi Imaizumi

Title/Affiliation	Professor / Department of Earth Sciences, Graduate School of Science, Tohoku University
Specialized Field	Tectonic geomorphology
Research Subject	Active tectonic study based on mapping and evaluating surface and sub-surface faulting

## The Purpose of Research and Outline of Accomplishments:

Coseismic behavior of active fold and thrust belts is crucial for prediction of the magnitudes and locations of future earthquakes and thus for appropriate evaluation of their future seismic hazards. The purpose of this study is to clarify the structure of surface and sub-surfaces fault, based on geomorphic, geologic and seismic reflection survey.

## Main Results:

The 2008 Iwate-Miyagi Nairiku earthquake ( $M_w$  6.9) struck an area where no active fault was known prior to the earthquake. The earthquake was shallow and large enough to produce scattered and discontinuous surface ruptures. To better understand the source processes and seismotectonic setting of the earthquake, we mapped the coseismic surface ruptures observed at Oshu and Ichinoseki Cities, Iwate Prefecture.

The otherhand, we made the seismic reflection profiles along the Iwai River in the source area of the 2008 Iwate-Miyagi Nairiku earthquake. Surface ruptures appear to be associated with a reverse slip on west-dipping faults imaged by seismic reflection profiling, which originated as Miocene normal faults and have been reactivated as reverse faults since the Pliocene. Some of the ruptures appeared along preexisting tectonic scarps, although these scarps are short and discontinuous.

## Published Journal Papers:

1. Kato, N., H. Sato, **T. Imaizumi**, S. Koshiya, T. Ishiyama, S. Toda, E. Kurashimo and N. Hirata (2010). Seismic profiles along the Iwai River in the surcearea of the 2008 Iwate-Miyagi Nairiku Earthquake., *Gekkan Chikyū* (Earth monthly), 32, (in Japanese)
2. Tsutumi, H., N. Sugito, S. Koshiya, T. Ishiyama, **T. Imaizumi**, N. Marushima and D. Hirouchi (2010). Surface rupture of the 2008 Iwate-Miyagi Nairiku Earthquake observerd at Oshu and Ichinoseki cities, Iwate Prefecture., *Northeast Japan. Journal of Geogaphy*, 119, (in Japanese with English abstract)
3. Ishiyama, T., N. Kato, H. Sato, T. Suzuki, S. Toda and **T. Imaizumi** (2010). Tectonic geomorphology and shallow subsurface structure of the Kakuda-Yahiko fault, central Japan., *Gekkan Chikyū* (Earth monthly), 32

# Takeyoshi Yoshida

Title/Affiliation	Professor / Department of Earth Sciences, Graduate School of Science, Tohoku University
Specialized Field	Igneous Petrology, Tectonics
Research Subject	Late Cenozoic Magmatism in the northeast Honshu Arc, Japan

## The Purpose of Research and Outline of Accomplishments:

Three prominent tectonically indexed stages of volcanic activity are recognized in the NE Honshu arc, Japan. These are, continental margin (66-21Ma), back-arc basin (21-13.5Ma), and island-arc stage (13.5-0Ma). We are integrating recent geological and petrological studies and synthesizing to present the tectonic and magmatic evolution of the late Cenozoic NE Honshu arc. Interactions between the NE Honshu arc and the surrounding plates and the related magmatism appear to have been the main controls on the tectonic evolution including transition of the regional stress field and the subsidence history of the sedimentary basin of the NE Honshu arc. The change in the magmatic compositions mainly reflects the thermal structure of the mantle and overlying crust and the distribution of the source materials via the change of magma segregation depth. Change in the structure of magma plumbing system and the mode of volcanic activity reflects an intracrustal stress regime controlled mainly by plate motion. Changes in the eruption volumes are related to both the thermal structure and the regional stress regime. These relations result from a close link between tectonic and magmatic evolution of the island arc.

## Published Journal Papers:

1. Yamada, R; **Yoshida, T** (2011). Relationships between Kuroko volcanogenic massive sulfide (VMS) deposits, felsic volcanism, and island arc development in the northeast Honshu arc, Japan *MINERALIUM DEPOSITA*, 46, 431-448
2. Zhao, D., Huang, Z., Umino, N., Hasegawa, A. and **Yoshida, T.** (2011). Seismic imaging of the Amur-Okhotsk plate boundary zone in the Japan Sea, *PHYSICS OF THE EARTH AND PLANETARY INTERIORS*, 188, 82-95
3. Prima, O. D. A. and **T. Yoshida** (2010). Characterization of volcanic geomorphology and geology by slope and topographic openness., *Geomorphology*, 118, doi: 10.1016/j.geomorph.2009.12.005
4. Nunohara, K., **T. Yoshida**, R. Yamada, S. Maeda, K. Ikeda, Y. Nagahasi, A. Yamamoto and T. Kudo (2010). Geology and geologic structures around the area of hypocenter of the 2008 Iwate-Miyagi Nairiku earthquake., *Chikyu Monthly*, 32, 6
5. Kudo, T., **T. Yoshida**, A. Yamamoto, M. Kawamura and R. Shichi (2010). Crustal structure of the northeast Honshu arc revealed from detailed gravity anomalies., *Chikyu Monthly*, 32, 6
6. Huang, Z., D. Zhao, N. Umino, L. Wang, T. Matsuzawa, A. Hasegawa and **T. Yoshida** (2010). P-wave tomography, anisotropy and seismotectonics in the eastern margin of Japan Sea., *Tectonophysics*, 489, doi: 10.1016/j.tecto.2010.04.014
7. Kuritani, T., **T. Yoshida** and Y. Nagahashi (2010). Internal differentiation of Kutsugata lava flow from Rishiri Volcano, Japan: Processes and timescales of segregation structures' formation., *Volcanology and Geothermal Research*, 195, doi: 10.1016/j.jvolgeores.2010.06.003
8. Yamada, R. and **T. Yoshida** (2010). The characteristics of the particular occurrence of rare-metals associated with base-metal deposits in the northern Tohoku district, Japan., *Resource Geology*, 60 (3)

9. Yamada, R., **T. Yoshida**, T. Kakegawa, F. Nara and Y. Ogawa (2010). Several constraints of indium enrichment associated with base-metal deposits in the vicinity of northern Tohoku district., *Resource Geology*, 60 (3)

**Symposium Participations:**

1. Prima, O. D. A. and **T. Yoshida** (2010). Delineation of Late Miocene to Pleistocene Caldera Rims from Gravity and Aeromagnetic Data., The 6th International Conference on Remote Sensing (REMOTE'10) in Proceedings, Selected Topics in Power Systems and Remote Sensing, 239-243, April 28-29, 2010, Kuala Lumpur, Malaysia
2. Prima, O.D.A. and **Yoshida, T.** (2010) Delineation of late Miocene to Pleistocene caldera rims from gravity and aeromagnetic data. Selected Topics in Power Systems and Remote Sensing, 239-243
3. Yamada, R. and **Yoshida, T.** (2011) Relationships between Kuroko volcanogenic massive sulfide (VMS) deposits, felsic volcanism, and island arc development in the northeast Honshu arc, Japan. *Mineral Deposita*, DOI 10.1007/s00126-011-0362-7.
4. Zhao, D., Huang, Z., Umino, N., Hasegawa, A. and **Yoshida, T.** (2011) Seismic imaging of the Amur-Okhotsk plate boundary zone in the Japan Sea. *Physics and the Earth and Planetary Interiors*, 188, 82-95.

# Michihiko Nakamura

Title/Affiliation	Associate Professor / Department of Earth Sciences, Graduate School of Science, Tohoku University
Specialized Field	Petrology, Volcanology
Research Subject	Mechanism of Volcanic Eruptions; Microstructure of fluid-bearing rocks

## **The Purpose of Research and The Abstract of Accomplishments:**

Volcanic eruptions are representative of the dynamic activity of the Earth. A striking feature of the volcanic activity is its wide variety of eruption styles. They are different among volcanoes and eruptions of a volcano, and even changes within an eruption event. An important issue of modern physical volcanology is to first find out and define the bifurcation points of eruption styles in the course of magma ascent and emplacement, and then clarify the mechanisms of bifurcations. Besides scientific interests, it provides a basis for predicting transitions of activity in volcanic crises. Among some key processes, we have been focusing on the outgassing mechanism of highly viscous, silicic magmas that often cause violent explosive eruption as well as relatively quiet lava dome growth. In such magmas, shear induced fracturing is believed to be an important process for outgassing. We have carried out for the first time experimental studies on fracturing of a vesicular magma and healing of fractures under high temperature and a confining pressure, and clarified their mechanisms from a viewpoint of material science.

Growing number of evidences from melt inclusions in phenocrysts and obsidian pyroclasts indicate that shallow and H<sub>2</sub>O-rich magmatic system is often flushed with relatively CO<sub>2</sub>-rich deep-derived fluid. In order to understand the effect of this “CO<sub>2</sub>-fluxing” on the volatile behavior in subvolcanic systems, we performed hydrothermal experiments on the reaction between H<sub>2</sub>O-rich melt and CO<sub>2</sub>-rich fluid. Other projects on the Sakurajima activity, and the microstructure of fluid bearing rocks have been on-going.

## **Results:**

1. We performed torsional deformation experiments on columnar rhyolites that simulated flow of rhyolites in shallow volcanic conduits. We showed that the deformation was localized and finally resulted in brittle failure, followed by a slip at the fractured interface, which prevented further brittle failure and shear-induced bubble coalescence in the remaining parts of the sample. We infer that repeated fracturing and healing processes are necessary for effective degassing of the entire magma.
2. The healing of magmatic fractures is considered essential to repetitive seismicity and the closure of degassing paths during emplacement of lavas. To estimate the healing time of magmatic fractures, we performed healing experiments of the contact interface of rhyolitic melts at 850°–1000°C. The interface became coherent in atomic scale and finally disappeared, which was characterized by the homogenization of water content across the contact via diffusion. We defined this closure interval as healing time and determined this based on a diffusion model. The microscopic healing time was strongly dependent on temperature and roughness of the interface, being consistent with the period of actual seismicity. It is prolonged sufficiently to permit the formation of millimeter thick bubble-free obsidian layers along fractures in vesicular lavas through bubble resorption due to diffusive degassing.
3. We found chemically-driven bubble growth during the interaction, which has a potential to trigger volcanic eruptions.

### Published Journal Papers:

1. Yoshimura, S. and **M. Nakamura** (2010). Fracture healing in a magma: An experimental approach and implications for volcanic seismicity and degassing., *Jour. Geophys. Res.*, 115, B09209 doi: 10.1029/2009JB000834
2. Okumura, S., **M. Nakamura**, T. Nakano, K. Uesugi and A. Tsuchiyama (2010). Shear deformation experiments on vesicular rhyolite: Implications for brittle fracturing, degassing, and compaction of magmas in volcanic conduits., *Jour. Geophys. Res.*, 115, B06201, doi: 10.1029/2009JB006904
3. Yoshimura, S. and **M. Nakamura** (2010). Chemically driven growth and resorption of bubbles in a multivolatile magmatic system., *Chem. Geol.*, 276, 18-28
4. Ohuchi, T., **M. Nakamura** and K. Michibayashi (2010). Effect of grain growth on cation exchange between dunite and fluid: implications for chemical homogenization in the upper mantle., *Contrib. Mineral. Petrol.*, 160, 339-357, doi: 10.1007/s00410-009-0481-7
5. **Nakamura, M.**, S. Tamura, Y. Ito, S. Okumura, M. Iguchi and D. Miki (2010). Incubation processes for the Taisho eruption of sakurajima volcano - Constraints from the mineral chemistry of magnetite -, *Annuals of Disas. Prev. Res. Inst. Kyoto Univ.*, 53 B  
Yoshimura, S., **Nakamura, M.**, Carbon dioxide transport in crustal magmatic systems, *Earth Planet. Sci. Lett.*, 307, 470-478, 2011.

### Symposium Participations:

1. **Nakamura, M.**, S. Okumura and S. Takeuchi (2010). Permeability development of volcanic pyroclasts: experimental constraints., *Japan Geoscience Union Meeting, Makuhari, Japan, May23-28, 2010.*
2. **Nakamura, M.** (2010). Bifurcations of eruption processes: An overview with a case study of the Asama volcano., *Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure"*, July 13-15, 2010, Sendai, Japan
3. Okumura, S., **M. Nakamura** and T. Nakano (2010). Experimental constraints on the permeable gas transport in ascending magmas., *Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure"*, July 13-15, 2010, Sendai, Japan
4. Yoshimura, S. and **M. Nakamura** (2010). Bubble growth and resorption driven by chemical interaction in the H<sub>2</sub>O-CO<sub>2</sub>-rhyolite system., *Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure"*, July 13-15, 2010, Sendai, Japan
5. Okumura, H. and **M. Nakamura** (2010). Crystallization kinetics in the system Ab-Qtz-H<sub>2</sub>O: Implications for the formation of pegmatitic texture., *Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure"*, July 13-15, 2010, Sendai, Japan
6. **Nakamura, M.**, T. Kichise, Y. Yasui and T. Nagahashi, (2010). Voluminous juvenile lithic fragments in the pumice-fall deposit of the 1108 eruption of Asama volcano: Evidence of repeated compaction and fragmentation in the shallow conduit., *American Geophysical Union 2010 Fall meeting, MR41A-1977, San Francisco, December 13-17, 2010*
7. Okumura, S., **M. Nakamura**, T. Fujioka, A. Tsuchiyama, S. Takeuchi, T. Nakano and K. Uesugi (2010). Evolution of microstructure of bubbles and gas permeability in sheared rhyolite., *American Geophysical Union 2010 Fall meeting, MR41A-1977, San Francisco, December 13-17, 2010 (Invited)*
8. **Nakamura, M.**, Otsuki, S., Miki, D., Iguchi, M., Nanolites in volcanic ash: a clue to understand gas pocket processes in the on-going Sakurajima eruption, *Japan Geosciences Union Meeting 2011, May 22-27, 2011, Chiba, Japan (Invited)*
9. Yoshimura, S., **Nakamura, M.**, Carbon isotope evolution in magmatic systems by CO<sub>2</sub> fluxing, *Goldschmidt Conference 2011, August 14-19, 2011, Prague, Czech Republic (Invited)*



# Akio Suzuki

Title/Affiliation	Associate Professor / Department of Earth Sciences, Graduate School of Science, Tohoku University
Specialized Field	Experimental Petrology, Mineral Physics
Research Subject	Physical properties of silicate and metallic liquid under high pressure

## The Purpose of Research and Outline of Accomplishments:

Knowledge about viscosity of silicate melt is valuable for understanding the activity of magma in the Earth's interior. We have carried out series of experiments using an X-ray radiography system and a high pressure apparatus installed at the synchrotron radiation facilities. The viscosity was determined by the falling sphere method.

## Main Results:

We constructed a new beamline (NE7A) at KEK, Tsukuba, for high pressure experiments. Using a large volume press equipped with an X-ray imaging and diffraction system, we carried out in situ falling sphere viscometry of silicate melts and in situ buoyancy test for density measurements of metallic liquids. For example, the viscosity of a silicate melt of composition  $\text{NaAlSi}_2\text{O}_6$  was measured at pressures from 1.6 to 5.5 GPa and at temperatures from 1,350 to 1,880C. We found that the viscosity of the  $\text{NaAlSi}_2\text{O}_6$  melt decreased with increasing pressure up to 2 GPa. The pressure dependence of viscosity is diminished above 2 GPa. By using the relationship between the logarithm of viscosity and the reciprocal temperature, the activation energies for viscous flow were calculated to be  $(3.7 \pm 0.4) \times 10^2$  and  $(3.7 \pm 0.5) \times 10^2$  kJ/mol at 2.2 and 2.9 GPa, respectively.

In addition to the viscosity measurement, we carried out 1) the density measurement of silicate and metallic liquid by X-ray absorption method and in situ sink/float method, 2) the development of the diamond/SiC composite as an X-ray transparent anvil material, and 3) the deformation experiment using the D-CAP deformation apparatus and X-ray radiography system.

## Published Journal Papers:

1. Nishida, K; Ohtani, E; Urakawa, S; **Suzuki, A**; Sakamaki, T; Terasaki, H; Katayama, Y (2011) Density measurement of liquid FeS at high pressures using synchrotron X-ray absorption AMERICAN MINERALOGIST, 96, 5-6, 864-868
2. **Suzuki, A**; Ohtani, E; Terasaki, H; Nishida, K; Hayashi, H; Sakamaki, T; Shibazaki, Y; Kikegawa, T (2011), Pressure and temperature dependence of the viscosity of a  $\text{NaAlSi}_2\text{O}_6$  melt PHYSICS AND CHEMISTRY OF MINERALS, 38, 1, 59-64
3. Litasov, K. D., A. Shatskiy, Y. Fei, **A. Suzuki**, E. Ohtani and K. Funakoshi (2010). Pressure-volume-temperature equation of state of tungsten carbide to 32 GPa and 1673 K., Journal of Applied Physics, 108 doi: 10.1063/1.3481667
4. Sakamaki, T., E. Ohtani, S. Urakawa, **A. Suzuki** and Y. Katayama (2010). Density of dry peridotite magma at high pressure using an X-ray absorption method., American Mineralogist, 95
5. **Suzuki, A.** (2010). High-pressure X-ray diffraction study of  $\epsilon$ -FeOOH., Physics and Chemistry of Minerals, 37 (3)
6. Arima, H., T. Hattori, K. Komatsu, J. Abe, W. Utsumi, H. Kag, **A. Suzuki**, K. Suzuya, T.

- Kamiyama, M. Arai and T. Yagi (2010). Designing PLANET: the neutron beamline for high-pressure material science at J-PARC., *Journal of Physics: Conference Series*, 215
7. Nishida, K., E. Ohtani, S. Urakawa, **A. Suzuki**, T. Sakamaki, H. Terasaki and Y. Katayama (2010). Density measurements of liquid FeS at high pressure using synchrotron X-ray absorption. *American Mineralogist*, *American Mineralogist*, 96; 5-6; 864-868; doi: 10.2138/am.2011.3616
  8. Doi, N., T. Kato, T. Kubo, R. Shiraishi, **A. Suzuki**, A. Shimojuku, K. Nishida, E. Ohtani and T. Kikegawa (2010). An in-situ X-ray diffraction study on the high-pressure decomposition reaction of albite under differential stresses., *Photon Factory Activity Report 2008 (KEK Progress Report 2009-3)*, 26, B
  9. Tateyama, R., **A. Suzuki**, E. Ohtani, H. Terasaki, K. Nishida, Y. Shimazaki and T. Kikegawa (2010). Density measurements of liquid Fe-S at high pressure using sink-float method. , *Photon Factory Activity Report 2008 (KEK Progress Report 2009-3)*, 26, B
  10. Nishida, K., **A. Suzuki**, E. Ohtani, H. Terasaki, T. Sakamaki, Y. Shibazaki, H. Hayashi, M. Funayama and T. Kikegawa (2010). Density measurements of liquid FeS at high pressure using X-ray absorption image., *Photon Factory Activity Report 2008 (KEK Progress Report 2009-3)*, 26, B
  11. Shiraishi, R., E. Ohtani, T. Kubo, **A. Suzuki**, N. Doi, A. Shimojuku and T. Kikegawa (2010). High pressure deformation experiments using deformation-cubic anvil, D-CAP 700, with synchrotron X rays., *Photon Factory Activity Report 2008 (KEK Progress Report 2009-3)*, 26, B
  12. **Suzuki, A.**, E. Ohtani, K. Nishida, R. Tateyama, H. Terasaki, Y. Shibazaki, R. Shiraishi and T. Kikegawa (2010). Viscosity of lunar high-Ti magma at high pressure., *Photon Factory Activity Report 2008 (KEK Progress Report 2009-3)*, 26, B
  13. Shibazaki, Y., E. Ohtani, **A. Suzuki**, T. Sakamaki, K. Nishida and H. Hayashi (2010). Phase relation of the Fe-Ni-H system under high pressures and high temperatures: application to the thermal structure of the Earth's core., *SPring-8 User Experimental Report No.24 (2009B)*
  14. Ohtani, E., S. Urakawa, **A. Suzuki**, H. Terasaki, Y. Katayama and T. Sakamaki (2010). Density measurement of silicate melts by X-ray absorption method under high pressures and high temperatures., *SPring-8 User Experimental Report No.23 (2009B)*
  15. **Suzuki, A.**, E. Ohtani, R. Ando, H. Terasaki, T. Sakamaki and K. Funakoshi (2010). Viscosity of basaltic magma at high pressure., *Acta Mineralogica-Petrographica*, 6

#### Symposium Participations:

1. **Suzuki, A.**, E. Ohtani, K. Nishida, R. Tateyama, Y. Shibazaki and T. Kikegawa (2010). Viscosity of  $K_2TiSi_4O_9$  melt at high pressure and high temperature., *Japan Geoscience Union meeting 2010, SIT041-P04 (international session) May 23-28, 2010, Chiba, Japan*
2. **Suzuki, A.**, E. Ohtani, T. Sakamaki, S. Urakawa, Y. Katayama, K. Nishida, R. Tateyama and T. Kikegawa (2010). Density and viscosity of lunar high-Ti magma at high pressure., *2010 Western Pacific Geophysics Meeting, V33C-05 June 22-25, 2010, Taipei*
3. **Suzuki, A.**, E. Ohtani, K. Nishida, R. Tateyama, Y. Shibazaki and T. Kikegawa (2010). Viscosity of  $K_2TiSi_4O_9$  melt at high pressure and high temperature., *Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", P1-20 July 13-15, 2010, Sendai, Japan*
4. **Suzuki, A.**, E. Ohtani, R. Ando, H. Terasaki, T. Sakamaki and K. Funakoshi (2010). Funakoshi, K., Viscosity of basaltic magma at high pressure., *IMA2010, 20th General Meeting of the International Mineralogical Association, 5SE08] August 21-27, 2010, Budapest, Hungary*
5. **Suzuki, A.** (2010). Compression behavior of InOOH-type oxyhydroxide., *5th Asian Conference on High Pressure Research Matsue, Japan, November 8-12, 2010*

# Motoyuki Sato

Title/Affiliation	Professor / Center for Northeast Asian Studies, Tohoku University
Specialized Field	Applied Electromagnetics
Research Subject	Radar remote sensing for environment studies

## **The Purpose of Research and Outline of Accomplishments:**

We are pursuing the application of advanced electromagnetic technologies and radar/remote sensing methodologies to the environmental and resources studies of the Northeast Asian region and development of the applied electromagnetic methodologies. Survey in the Northeast Asian region aims at various subjects, including ground water resources, permafrost, oil and energy resources, mineral resources and biology. Microwave remote sensing (SAR), Ground Penetrating Radar (GPR), Electromagnetic survey techniques and Polarimetric borehole radar have been used for these measurements.

## **Main Results:**

### 1. Development of ground penetrating radar technology for Humanitarian Demining

Since 2002, we have developed a new hand-held land mine detection dual-sensor ALIS, which is equipped with a metal detector and a GPR, with a sensor tracking system, which can record the GPR and Metal detector signal with its location. Deployment of ALIS in Cambodia started in 2009. Two sets of ALIS have been operated in Cambodia, and more than 70 antipersonnel mines have been detected. This operation has been conducted by Cambodian Mine Action Center (CMAC), and we are acquiring all the GPR and Metal detector record which is stored in PC equipped in ALIS. We receive the detailed report on the detected objects, and we are analyzing the field data to improve the performance of ALIS.

### 2. Development of GB-SAR for landslide monitoring

17 people were killed and 6 people are still missing by the Iwate-Miyagi Nairiku Earthquake occurred in June 2008. In 2009, we started a feasibility study of Ground –Based Synthetic Aperture Radar (GB-SAR) for continuous monitoring of Land slide at the same area. There was a huge-scale landslide at Arato-zawa area, Kurihara-city, and now we are planning to settle a GB-SAR system together with University of Florence, Italy. We investigated the site for set up the equipments, and discussing the continuous monitoring system with Kurihara-city. The system starts the continuous land slide monitoring from November 2011. Interferometric SAR information will be provided to Kurihara city for early warning.

### 3. Microwave remote sensing for North and East Asia by ALOS/PALSAR

ALOS is an earth observation satellite which has been operated by JAXA since 2006. It is equipped with a L-band full-polarimetric SAR(Synthetic Aperture Radar) sensor PALSAR, and is the only one system in the world which is acquiring the data regularly. We are developing methodologies for classification of the objects by using the polarimetric information. New classification methodologies have been proposed and validated by ALOS/PALSAR data.

### Published Journal Papers:

1. Hayashi, N. and **M. Sato** (2010). Design and evaluation of Vivaldi antenna for ground penetrating radar with focusing on surface current along antenna conductor., IEICE Technical report, 110 (347), AP2010-122

### Symposium Participations:

1. **Sato, M.** (2010). ALIS Evaluation test by CROAMC and CMAC in 2009., The 7th mine action Symposium entitled "Humanitarian Demining 2010", April 27-29, 2010, Sibenik, Croatia
2. Chen, S. W. and **M. Sato** (2011). PolInSAR Complex Coherence Estimation Based on Similarity Test of Covariance Matrix., POLinSAR 2011 Workshop, January 24-28, 2011, Frascati, Italy
3. **Sato, M.**, Y. Yokota (2010). Radar Remote Sensing for Earth Observation., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", July 13-15, 2010, Sendai, Japan
4. **Sato, M.** (2010). Evaluation test of ALIS in Cambodia for humanitarian demining., Defense and Security Symposium, April, 2010, Orlando, FL, USA
5. **Sato, M.** (2010). ALIS: GPR for Humanitarian demining and its evaluation in Cambodia., IEEE AP-S symposium
6. **Sato, M.** (2010). Evaluation test of ALIS Hand-held Dual sensor in Cambodia., The ANTEM/AMEREM 2010, July 5 - 9, 2010, Ottawa, Canada
7. **Sato, M.** (2010). Imaging Algorithm of ALIS Hand-held Dual sensor., The ANTEM/AMEREM 2010, July 5 - 9, 2010, Ottawa, Canada
8. **Sato, M.**, A. Gaber, Y. Yokota, M. Grasmueck and P. Marchesini (2010). CCD Camera and IGPS Tracking of Geophysical Sensors for Visualization of Buried Explosive Devices., 2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN), 15-17, September 15-17 2010, Zurich, Switzerland, (poster)
9. **Sato, M.** (2010). Deployment of GPR System ALIS for Humanitarian Demining in Cambodia., 13th International Conference on Ground Penetrating Radar, June 21-25, 2010, Lecce, Italy (poster)
10. Kim, D. H., **M. Sato** and T. Ito (2010). Dynamic Monitoring of Fracture Extension in Unconsolidated Sand Specimen by GPR., 13th International Conference on Ground Penetrating Radar, 828-833, June 21-25, 2010, Lecce, Italy
11. Yokota, Y., A. Mase, **M. Sato**, T. Tokuzawa, K. Kawahata, Y. Nagayama and H. Hojo (2010). Ultra Wide Band Radar Reflectometer for Density Profile Measurement of High Temperature Plasmas., 13th International Conference on Ground Penetrating Radar, June 21-25, 2010, Lecce, Italy
12. **Sato, M.** (2010). GPR Evaluation Test for Humanitarian Demining in Cambodia., IGRSS2010,
13. Hayashi, N. and **M. Sato** (2010). 3D subsurface visualization by suppressing ground reflection and direct wave with bistatic GPR., 2010 IEEE International Geoscience and Remote Sensing Symposium, Proceedings (in DVD), July 25-30 2010, Honolulu, Hawaii, USA
14. **Sato, M.** (2010). Evaluation Tests of ALIS Hand-held Dual sensor in Cambodia., 2010 Asia-Pacific Radio Science Conference, FP. 2, September 22-26, 2010, Toyama, Japan
15. Kim, D. H. and **M. Sato** (2010). GPR Monitoring of Fracture Extension induced by hydraulic fracturing., 2010 Asia-Pacific Radio Science Conference, FP. 2, September 22-26, 2010, Toyama, Japan
16. H. Liu, J. Chen and **M. Sato** (2010). UWB measurement of dielectric permittivity of lossy media., AP-RASC 2010 in Proc. FP-1, September, 2010, Toyama, Japan
17. **Sato, M.** (2010). Deployment of Dual Sensor ALIS for Humanitarian Demining in Cambodia., The 123rd Society of Exploration Geophysicists of Japan Conference, September 29, 2010, Sendai, Japan
18. **Sato, M.** (2010). Survey of automobiles buried by land slide in Kurikoma area by RTK-GPS EMI.,

- The 123rd Society of Exploration Geophysicists of Japan Conference, September 29, 2010, Sendai, Japan
19. Kusano, S., M. Watanabe, **M. Sato** (2010). A new decomposition applied to azimuthally inclined objects., The 123rd Society of Exploration Geophysicists of Japan Conference, September 30, 2010, Sendai, Japan
  20. Yokota, Y. and **M. Sato** (2010). Development of wide band antenna for ground based synthetic aperture radar., The 123rd Society of Exploration Geophysicists of Japan Conference, September 29 - October 01, 2010
  21. Kim, D. H. and **M. Sato** (2010). Monitoring of water diffusion in the subsurface by cross-hole radar with an optical sensor array., The 123rd Society of Exploration Geophysicists of Japan Conference, 29, 107-110, September 29-October 1, 2010, Sendai, Japan
  22. Hayashi, N. and **M. Sato** (2010). Subsurface visualization by using bistatic type ground penetrating radar., The 123rd Society of Exploration Geophysicists of Japan Conference, 135- 138, September 29, 2010, Sendai, Japan
  23. Liu, H., N. Hayashi and **M. Sato** (2010). Coherence measure analysis of multi-offset GPR data., The 123rd Society of Exploration Geophysicists of Japan Conference, 143-146, September 29, 2010, Sendai, Japan
  24. Liu, H. and **M. Sato** (2010). Design of GPR antenna array for pavement Survey., The 123rd Society of Exploration Geophysicists of Japan Conference, 147-150, September 29, 2010, Sendai, Japan
  25. Kim, D. H. and **M. Sato** (2010). GPR monitoring of the fluid movement induced by hydraulic fracturing in unconsolidated sand., The 123rd Society of Exploration Geophysicists of Japan Conference, 41, 155-157, September 29-October 1, 2010, Sendai, Japan
  26. K. Mansour and **M. Sato** (2010). Comparison of electromagnetic scattering from flat and rough single rock fracture models., The 123rd Society of Exploration Geophysicists of Japan Conference, 139-142, September 29, 2010, Sendai, Japan
  27. Kim, D. H. and **M. Sato** (2010). GPR Monitoring of Fracture Extension induced by hydraulic fracturing., The 16th Formation Evaluation Symposium of Japan, October 7-8, 2010, Chiba, Japan
  28. K. Mansour and **M. Sato** (2010). FDTD simulation of electromagnetic wave scattering from a rough surface synthesized by Fractal theory., The 16th Formation Evaluation Symposium of Japan in Proceeding, October 7-8, 2010, Chiba, Japan
  29. **Sato, M.**, K. Tseedlum and D. Amarsikhan (2010). GPR and Polarimetric SAR Observation of Environment of Mongolia., XVII International Symposium of Kherlen Geological Expedition, Ulaan Baatar, Mongolia, October 15-16, 2010
  30. Kusano, S., M. Watanabe, **M. Sato** (2010). proposal of a new algorithm of the three-component decomposition for azimuthally inclined objects., ALOS PI Symposium, November 16, 2010, Tokyo, Japan
  31. Chen, S. W., **M. Sato** (2010). A Novel Method For Polarimetric SAR Image Speckle Filtering and Edge Detection., The 4th Joint PI Symposium of ALOS Data Nodes for ALOS Science Program, 55, November, 2010, Tokyo, Japan
  32. **Sato, M.** (2010). Disaster Mitigation by Electromagnetic Methodologies:What we have learned from Humanitarian Demining., 25th SIP Symposium, November 24-26, 2010, Nara, Japan
  33. Yokota, Y. and **M. Sato** (2010). Archaeological Survey by accurate GPR., 25th SIP Symposium, November 24-26, 2010, Nara, Japan

# Noriyoshi Tsuchiya

Title/Affiliation	Professor / Graduate School of Environmental Studies, Tohoku University
Specialized Field	Geofluid Science
Research Subject	Water - Rock Interaction

## The Purpose of Research and Outline of Accomplishments:

I have been to Antarctica from Nov 2009 to Feb 2010 as an expedition leader of Earth Science Research Expedition in the Sør Rondane Mountains, which is part of 51st Japanese Antarctic Research Expedition (JARE-51). Earth Science Research Expedition in the Sør Rondane Mountains involved geology, geomorphology and meteorite search parties. I have performed geological survey in the entire area of the Sør Rondane Mountains, East Antarctica. Geology party collected more than 1.5 ton rock samples which were metamorphic and igneous rocks. Expedition was successfully completed, and we could come back to Japan safely. I studied the role of geofluid for high grade metamorphics and collected many types of igneous rocks to identify geochemical characteristics of magma process in the Sør Rondane Mountains.

After Great East Japan Earthquake, I and our research group have studied on Tsunami Deposit and Soil. We investigated arsenic and other heavy metal concentration in the Tsunami deposit, and we already published contamination map of arsenic and heavy metals in Tsunami disaster area.

## Published Journal Papers:

1. Zhang, S., Jin, F., Zeng, X., Hu, J., Huo, Z., Wang, Y., Watanabe, N., Hirano, N., and **Tsuchiya, N.** (2011), Effects of general zero-valent metals power of Co/W/Ni/Fe on hydrogen production with H<sub>2</sub>S as a reductant under hydrothermal conditions. , International Journal of Hydrogen Energy, 36, 8878-8884.
2. Watanabe, N., T. Ishibashi, N. Hirano, Y. Ohsaki, Y. Tsuchiya, T. Tamagawa, H. Okabe, and **N. Tsuchiya** (2011), Precise 3D Numerical Modeling of Fracture Flow Coupled With X-Ray Computed Tomography for Reservoir Core Samples. [SPE (Society of Petroleum Engineers) Journal, 16 (3), 683-691.
3. Setiani, P., J. Vilca ´ez, N. Watanabe, A. Kishita, **N. Tsuchiya** (2011). Enhanced hydrogen production from biomass via the sulfur redox cycle under hydrothermal conditions., International Journal of Hydrogen Energy, 36, 10674-10682.
4. Takeda, A; Yamasaki, S; Tsukada, H; Takaku, Y; Hisamatsu, S; **Tsuchiya, N** (2011). Determination of total contents of bromine, iodine and several trace elements in soil by polarizing energy-dispersive X-ray fluorescence spectrometry, SOIL SCIENCE AND PLANT NUTRITION, 57, 1, 19-28
5. Yamasaki, S; Matsunami, H; Takeda, A; Kimura, K; Yamaji, I; Ogawa, Y; **Tsuchiya, N** (2011). Simultaneous Determination of Trace Elements in Soils and Sediments by Polarizing Energy Dispersive X-ray Fluorescence Spectrometry, BUNSEKI KAGAKU, 60, 4, 315-323
6. Batkhashig, B., **N. Tsuchiya** and B. Greg (2010). Magmatism of the Shuteen Complex and Carboniferous subduction of the Gurvansaikhan terrane, South Mongolia., Journal of Asian Earth Science, 37

7. Okamoto, A., H. Saishu, N. Hirano and **N. Tsuchiya** (2010). Mineralogical and textural variation of silica minerals in hydrothermal AEow-through experiments: Implications for quartz vein formation., *Geochimica Cosmochimica Acta*, 74
8. Abe, J., **N. Tsuchiya**, S. Furukawa and N. Hirano (2010). Properties of H<sub>2</sub>O and CO<sub>2</sub> AEuids in contact with quartz under supercritical conditions revealed by IR spectroscopy., *Water-Rock Interaction*, 13
9. Hirano, N., K. Yamamoto, A. Okamoto and **N. Tsuchiya** (2010). Observation of quartz fracturing under the hydrothermal condition using visible type autoclave., *Water-Rock Interaction*, 13
10. Saisyu, H., A. Okamoto and **N. Tsuchiya** (2010). Precipitation of silica minerals in hydrothermal AEow-through experiments., *Water-Rock Interaction*, 13
11. **Tsuchiya, N.**, Y. Ogawa, R. Yamada, S. Yamasaki, C. Inoue, T. Komai. J. Hara, Y. Kawabe, T. Shiratori and S. Kano (2010). Geosphere environmental informatic universal system for evaluation of geological pollution on heavy metals., *Water-Rock Interaction*, 13
12. Ogawa, Y., S. Yamasaki and **N. Tsuchiya** (2010). Application of a Dynamic Reaction Cell (DRC) ICP-MS in Chromium and Iron Determinations in Rock, Soil and Terrestrial Water Samples., *Analytical Sciences*, 26
13. Tagami, K., S. Uchida, A. Takeda, S. Yamasaki and **N. Tsuchiya** (2010). Estimation of Plant-Unavailable Iodine Concentrations in Agricultural Fields., *Soil Chemistry*, 74 (5)
14. Matsunami, H; Matsuda, K; Yamasaki, S; Kimura, K; Ogawa, Y; Miura, Y; Yamaji, I; **Tsuchiya, N** (2010). Rapid simultaneous multi-element determination of soils and environmental samples with polarizing energy dispersive X-ray fluorescence (EDXRF) spectrometry using pressed powder pellets, *SOIL SCIENCE AND PLANT NUTRITION*, 56, 4, 530-540

# Fumihiko Imamura

Title/Affiliation	Professor / Disaster Control Research Center, Graduate School of Engineering, Tohoku University
Specialized Field	Tsunami Engineering
Research Subject	Study on Prediction of earthquake and tsunami hazards

## The Purpose of Research and Outline of Accomplishments:

We aim to develop the numerical method to predict a tsunami inundation as well as wave height along the coast by using the data of earthquake and tsunami observed by GPS buoy and so on in real time for the case of the past tsunami of the 1896 Sanriku. The methods of database is discussed by taking consideration of available input data, CPU time and its accuracy for estimating the tsunami behaviors along the coast.

After the 2011 Tohoku earthquake followed by the tsunami, we added the purpose to evaluate the tsunami impact on the coast and tsunami source, and continue to develop the numerical method to predict a tsunami inundation as well as wave height along the coast by using the data of earthquake and tsunami observed by GPS buoy and so on in real time for the case of the past tsunami of the 1896 Sanriku and 2011.

## Main Results:

The system to estimate the tsunami inundation is proposed by collecting seismic and tsunami information observed in real time, and selecting suitable cases from all scenarios in the database. The system includes the function to re-select better one by referring the tsunami heights and arrival time observed by GPS buoy, which was applied to the case of 1896 Sanriku offshore tsunami, and showing good performance. The process on accuracy change in time is also studied by adding available observation data of the tsunami.

We carried out the field survey of the 2011 Tohoku earthquake tsunami in order to estimate the impact on the coast by measuring the tsunami runup and inundation heights, which all data can be completed on the web site of <http://www.coastal.jp/tjt/>. By using the obtained data and monitored data by the tidal station and GPS sensors and sea bottom pressure gauges, the faults model of the tsunami source could be investigated then the tsunami source model of TOHOKU Univ. model vers1.0 was proposed by adding the source off Sanriku North area.

## International activity:

### (1) Activity in AGU

- Serving as CIP Committee on International Participation ,AGU(American Geophysical Union), November 2008-present

### (2) Activity of International Journal

- Serving as Editorial Board member for Journal of Waterway, Port, Coastal, and Ocean Engineering, ASCE, April 2005- present and Journal of Earthquake and Tsunami (JET), World Scientific, March 2007- present.

### (3) Activity of the president of JSNDS

- Serving as president of the Japan Society for Natural Disaster Science, April 2008-May 2011



#### Awards:

1. The 2009 Best Paper Award by JSCE (Japan Society of Civil Engineers) in May 2010 ; S. Koshimura, T. Oie, H. Yanagisawa and **F. Imamura**, Developing fragility functions for tsunami damage estimation using numerical model and post-tsunami data from Banda Aceh, Indonesia, Coastal Engineering Journal, 51, 3, 243-273, 2009
2. The 2009 Publication Award by JSCE (Japan Society of Civil Engineers) in May 2010 ; TSUNAMI, World Scientific Publishing Company 2009, S. Murata, **F. Imamura**, K. Katoh, Y. Kawata, S. Takahashi and T. Takayama
3. The Geological Society of Japan Best Paper Award ; Sugawara, D., Minoura, K., Nemoto, N., Tsukawaki, S., Goto, K., **Imamura, F.**, 2009, Foraminiferal evidence of submarine sediment transport and deposition by backwash during the 2004 Indian Ocean tsunami. Island Arc, 18, 513-525, 2009, DOI: 10.1111/j.1440-1738.2009.00677.x
4. The 2010 Coastal Engineering Journal Award (Japan Society of Civil Engineers) in November 2011 ; Anawat Suppasri, **F.Imamura** and Koshimura, Effects of the rupture velocity of fault motion, ocean current and initial sea level on the transoceanic propagation of tsunami, Coastal Engineering Journal, Vol.52, No.2, pp.107-132, 2010, DOI; 10.1142/S057853410002142

#### Published Journal Papers:

1. Muhari, A., **F. Imamura**, D. Hilman, S. Diposaptono and H. Latief, J. Post and F. A. Ismail (2010). Tsunami Mitigation efforts with PTA in west Sumatra province., Journal of Earthquake and Tsunami, 4 (4), doi: 10.1142/ S1793431110000790
2. Yanagisawa, H., S. Koshimura, T. Miyagi and **F. Imamura** (2010). Tsunami damage-reduction performance of a mangrove forest in Banda Aceh, Indonesia inferred from field data and a numerical model., J. Geophys. Res., 115, doi: 10.1029/2009JC005587
3. Goto, K., T. Kawana and **F. Imamura** (2010). Historical and geological evidence of boulders deposited by tsunamis, southern Ryukyu Islands, Japan., Earth-Science Reviews, 201
4. Goto, K., T. Shinozaki, K. Minoura, K. Okada, D. Sugawara and **F. Imamura** (2010). Distribution of boulders at Miyara Bay of Ishigaki Island, Japan: A flow characteristic indicator of tsunami and storm waves., Island Arc, 19
5. Goto, K., K. Miyagi, T. Kawana, J. Takahashi and **F. Imamura** (2010). Emplacement and movement of boulders by known storm waves -Field evidence from the Okinawa Islands, Japan., Marine Geology, 269
6. Abe, I. and **F. Imamura** (2010). Study on the evaluation of tsunami inundation in real time with database and its accuracy., Conference of Coastal Engineering, JSCE B2-66
7. Anawat, S., S. Koshimura and **F. Imamura** (2010). Developing the tsunami fragility curves for structural destruction along the Thailand coast., Proc. of International session of Conference of Coastal Engineering, JSCE, 1
8. A.Suppasri, S. Koshimura, and **F. Imamura**(2011), Developing tsunami fragility curves based on the satellite remote sensing and the numerical modeling of the 2004 Indian Ocean tsunami in Thailand, Nat. Hazards Earth Syst. Sci., 11, 173-189, doi:10.5194/nhess-11-173-2011
9. Maeno, F., and **F. Imamura** (2011), Tsunami generation by a rapid entrance of pyroclastic flow into the sea during the 1883 Krakatau eruption, Indonesia, J. Geophys. Res., 116, B09205, doi:10.1029/2011JB008253,2011

**Books:**

1. **Imamura, F.** (2010), Tsunami to survive from Tsunami, Advanced series on ocean engineering, 32, World Scientific, ISBN-13 978-981-4277-47-1, 302p (Co-authored)

**Symposium Participations:**

1. **Imamura, F.** (2010), The 3rd International Tsunami Field Symposium (Organizing), April 10-16, 2010, Sendai, Japan

# Hisashi Nakahara

Title/Affiliation	Assistant Professor / Department of Geophysics, Graduate School of Science, Tohoku University
Specialized Field	Seismology
Research Subject	Generation and propagation of short-period seismic waves

## The Purpose of Research and Outline of Accomplishments:

Short-period seismic waves carry rich information about not only propagation process in the heterogeneous Earth and but also earthquake source process. The objectives of my research are to investigate the characteristics of short-period seismic waves and to develop practical methods to extract information about sources and propagation media.

In this fiscal year, I studied the source process of the March 11 Tohoku-Oki earthquake using short-period seismograms recorded at our seismic array located about 130km away from the epicenter. I also studied the propagation of short-period seismic waves in terms of theory and application.

## Main Results:

We recorded strong ground motions from the March 11 Tohoku-Oki earthquake (M9.0) with our small-aperture seismic array deployed at Oshika Peninsula in Miyagi Prefecture. Applying a seismic array technique to the records, we detected four subevents suggesting a complex rupture of the earthquake.

In terms of propagation of short-period seismic waves, we semi-analytically formulated radiative transfer of P- and S-wave energies in two-dimensional scattering media. This model predicts that the ratio between P- and S-wave energies is equilibrated after multiple conversion scatterings between P- and S-waves. The equilibrated energy ratio is found to be controlled by P- and S-wave seismic velocities.

We also studied partitioning of seismic coda energy into horizontal and vertical directions of motion. The partitioning is found to be stabilized in later coda of local earthquakes and to be controlled by a subsurface seismic velocity structure. Confirming the results at borehole stations in Japan, we proposed a method to estimate a subsurface velocity structure using the coda partitioning. This stability is a benefit of the coda-based method. We also studied statistical fluctuations in seismogram envelopes. The statistics can be explained well by the Nakagami-m distribution which has been used in the field of radio-wave propagation. Based on the statistics, we newly developed a maximum likelihood method to estimate coda Q and the Nakagami-m parameter. This study indicated an importance to discriminate the statistical fluctuations in seismogram envelopes and physical fluctuations reflecting regional differences in scattering coefficients.

## Published Journal Papers:

9. **Nakahara, H.**, H. Sato, T. Nishimura, and H. Fujiwara (2011). Direct observation of rupture propagation during the 2011 off the Pacific coast of Tohoku, Japan, earthquake (Mw 9.0) using a small seismic array, *Earth, Planets, and Space*, 63, 589-594.
10. **Nakahara, H.**, and L. Margerin (2011). Testing equipartition for S-wave coda using borehole records of local earthquakes, *Bull. Seismol. Soc. Am.*, 101, 2243-2251.
11. **Nakahara, H.**, and K. Yoshimoto (2011). Radiative transfer of elastic waves in two-dimensional

isotropic scattering media: Semi-analytical approach for isotropic source radiation. *Earth, Planets, and Space*, 63, 459-468.

12. **Nakahara, H.** and E. Carcole (2010). Maximum-likelihood method for estimating coda Q and the Nakagami-m parameter, *Bull. Seismol. Soc. Am.*, 100(6), 3174-3182 doi:10.1785/0120100030.

#### **Symposium Participations:**

17. **Nakahara, H.** (2011) Envelope inversion analysis for estimating short-period energy radiation from the 2011 off the Pacific coast of Tohoku earthquake (M9.0), Seismological Society of Japan 2011 Fall meeting, October 12-14, Shizuoka, Japan.
18. Yoshimoto, K., **H. Nakahara**, and H. Sato (2011) Seismic basement structure beneath the Kanto Plain inferred from the seismic interferometry of SI sensor records, Seismological Society of Japan 2011 Fall meeting, October 12-14, Shizuoka, Japan.
19. **Nakahara, H.**, and L. Margerin (2011) Testing equi-partition in S-wave coda using borehole seismograms, Japan Geoscience Union meeting 2011, May 22-27, Chiba, Japan.
20. **Nakahara, H.**, H. Sato, T. Nishimura, and H. Fujiwara (2011) Direct observation of rupture propagation during the 2011 off the Pacific coast of Tohoku, Japan, earthquake (Mw 9.0) using a small seismic array, Japan Geoscience Union meeting 2011, May 22-27, Chiba, Japan.
21. **Nakahara, H.**, and K. Yoshimoto (2010) Radiative transfer of elastic waves in 2D isotropic scattering media, Seismological Society of Japan 2010 Fall meeting, October 27-29, 2010, Hiroshima, Japan
22. **Nakahara, H.**, and L. Margerin (2010) A test of equi-partition hypothesis for S-wave coda using borehole records of local earthquakes, The meeting of the Americas 2010, August 8-12, Foz do Iguass, Brazil.
23. **Nakahara, H.**, and L. Margerin (2010). Observation and modeling of energy partitioning for S-wave coda using borehole records of local earthquakes., Global COE Symposium 2010 "Dynamic Earth and Heterogeneous Structure", B2-07, July 13-15, 2010, Sendai, Japan
24. **Nakahara, H.**, and E. Carcole (2010). Measurement of statistical fluctuations in seismogram envelopes based on the Nakagami-m distribution, Japan Geoscience Union meeting 2010, May 23-28, 2010, Chiba, Japan

# Huang Zhouchuan

Title/Affiliation	COE Fellow / Research Center for Prediction of Earthquakes and Volcanic Eruptions
Specialized Field	Seismology
Research Subject	Seismic tomography and anisotropy

## The Purpose of Research and Outline of Accomplishments:

We aim to study high-resolution seismic structure and anisotropy beneath Northeast Japan using seismic tomography and shear-wave splitting analysis so as to understand the subduction dynamics.

## Main Results:

We determined three-dimensional seismic images beneath the Northeast Japan arc that extends from the Japan Trench to the eastern margin of Japan Sea. Strong heterogeneities were revealed in the forearc mega-thrust zone. Large interplate earthquakes are found to occur mainly in the high-velocity (high-V) zones where the subducting Pacific plate and the overriding Okhotsk plate are strongly coupled. Extensive low-V anomalies were found in the middle of the mantle wedge, which may be caused by a combination of fluids from the slab dehydration and mantle-wedge corner flow. The low-V zones extend upward to the Moho beneath the volcanic front with significant along-arc variations.

Our results of seismic tomography and shear-wave splitting analysis suggest the existence of multi-layer anisotropy beneath Northeast Japan. In the mantle wedge, the fast velocity directions (FVDs) are generally normal to the trench, which are caused by the subduction-driven preferred orientations of minerals (mainly olivine) and melts. In the subducted Pacific slab, the FVDs are parallel to the trench, which may reflect the preferred orientations of the faults and cracks in the slab or the fossil anisotropy when the plate formed at the mid-ocean ridge.

## Published Journal Papers:

1. **Huang, Z.**, D. Zhao, L. Wang (2011). Seismic heterogeneity and anisotropy of the Honshu arc from the Japan trench to the Japan Sea. *Geophys. J. Int.*, 184, 1428-1444.
2. **Huang, Z.**, D. Zhao, L. Wang (2011). Shear wave anisotropy in the crust, mantle wedge, and subducting Pacific slab under northeast Japan. *Geochem. Geophys. Geosyst.*, 12, Q01002.
3. **Huang, Z.**, D. Zhao, L. Wang (2011). Frequency-dependent shear-wave splitting and multilayer anisotropy in Northeast Japan. *Geophys. Res. Lett.*, 38, L08302.
4. **Huang, Z.**, D. Zhao, L. Wang (2011). Stress field in the 2008 Iwate-Miyagi earthquake (M 7.2) area. *Geochem. Geophys. Geosyst.*, 12, Q06006.
5. **Huang, Z.**, L. Wang, D. Zhao, N. Mi, M. Xu (2011). Seismic anisotropy and mantle dynamics beneath China. *Earth Planet. Sci. Lett.*, 306, 105-117.

# Takahiro Miwa

Title/Affiliation	COE Fellow / Research Center for Prediction of Earthquakes and Volcanic Eruptions
Specialized Field	Volcanology
Research Subject	Dynamics of volcanic eruption, Development of volcanic ash monitoring

## **The Purpose of Research, Outline of Accomplishments and Main results.**

### ***Monitoring of volcanic ash***

Volcanic ash is emitted by almost every types of volcanic eruption, circulates in the earth and affects on environment with local and global scale. Especially airborne ash particles from ongoing eruption plumes are suitable candidates to get continuous monitoring of volcanic activity. Such particles, carried by wind, can be safely sampled at kilometers from active vents, and their features (shape, component, chemical composition and etc) hold clues about the process and progress of volcanic eruptions. However, continuous monitoring of volcanic ash has not been realized during ongoing eruption. In order to realize the monitoring, we need to clarify the feature of ash particle relating with progress of the eruption and construct easy method for characterization of the features.

We performed petrological analysis on volcanic ash from vulcanian eruptions at Showa crater of Sakurajima volcano, Japan, to reconstruct the temporal variation of the eruptive process (Miwa et al. 2011JPGU). The falling ashes are collected every 5-10 minutes and petrologically analyzed. The analysis revealed that number fraction of volcanic glass with low-crystallinity in falling ash, from deeper part of conduit, 1) increases with the progress of single eruption and 2) rapidly increases few hours before pumice eruption which shows larger magnitude. These results show that the crystallinity of volcanic ash is key-feature for monitoring of progress of ongoing eruption. The analysis of crystallinity of ash by traditional method (image analysis and etc) is very time consuming. So, we started to construct an easy method, based on optical feature, for characterization of crystallinity of the ash.

### ***Termination of volcanic eruption***

How does an ongoing eruption terminate, and how do we predict it? An understanding of the control mechanism for the duration and end of an eruption is fundamentally important for predicting the termination. The Sakurajima volcano in Japan has had repeated vulcanian explosions during the last fifty years without any transition in the eruption style. The understanding of vulcanian eruptions of a short duration without transition to any other eruption style is expected to provide information on the condition and mechanism of the termination of volcanic eruptions.

We estimate the temporal variation of decompression rate of magma during the vulcanian eruption to reveal the cause of their short duration (Miwa and Geshi, 2011IUGG and submitted to JVGR). The modeling of the formation process and measurements of the extension-cracked crystal in pumice reveal that a decompression rate of magma during the later phase of the eruption ranges from  $7.0 \times 10^3$  to  $7.8 \times 10^4$  Pa/s. The comparison of decompression rates in the initial and late phases show that the rate decreases to one-tenth of the initial value within a few tens of seconds during vulcanian eruption and this rapid drop of

decompression rate (ascent speed of magma) stems the eruption.

### **Symposium Participation**

1. **Miwa, T.**, Geshi, N. and Shinohara, H., Time-series analysis of volcanic ash from vulcanian eruptions at Showa-crater of Sakurajima volcano, Japan. JPGU Meeting 2011, May 22 - 27, 2011, Makuhari, Japan.
2. Oikawa, T., Furukawa, R., Nakano, S., Geshi, N., Nishiki, K., **Miwa, T.**, Shinohara, H., Hoshizumi, H., Tomiya, A. and Tanaka, A., Fallout tephra of the eruption of Shinmoedake in Kirishima Volcanoes after January 28th, 2011. JPGU Meeting 2011, May22-27, 2011, Makuhari, Japan.
3. **Miwa, T.** and Geshi, N. Drop of decompression rate of magma terminates volcanic eruptions. IUGG 2011, June 28 – July 7, 2011, Melbourne, Australia.

# 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.



**Published Journal Papers:**

1. **Tian, Y., D. Zhao** (2010) Destruction mechanism of the North China Craton: Insight from P and S wave mantle tomography, submitted to *J. Asian Earth Sci.*

# 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 seismic velocity structure beneath the Hokkaido corner, northern Japan: Arc-arc collision and the 1970 M 6.7 Hidaka and the 1982 M 7.1 Urakawa-oki earthquakes [Kita et al., under review in JGR]

Using travel time data from both a nationwide dense seismic network and a dense temporary seismic network, we obtained a precise three-dimensional seismic velocity structure beneath the Hokkaido corner. A considerably inhomogeneous seismic velocity structure was clearly imaged at depths of 0 to 120 km in the region. The results indicate that a broad low-velocity zone of P- and S-waves having velocities of crust materials is confirmed in the west of Hidaka main thrust at depths of 35 to 90 km. The images also indicate that several smaller-scale high-velocity zones were found at depths of 0 to 35 km, striking approximately N-S and inclined east-northeastward at a high angle of 40 to 60°. All of these anomalous high-velocity zones are located in the deeper extension of the Neogene thrust faults. The clearest high-V zone is located beneath the Hidaka metamorphic belt, being in contact with the eastern edge of the broad low-V zone. Moreover, the boundary between the clearest high-V zone and the broad low-V zone corresponds to the fault

plane of the 1970 Mj 6.7 Hidaka earthquake. The western boundary of another small high-V zone at depths of 20 to 30km within the broad low-V zone corresponds to the fault plane of the 1982 Mj 7.1 Urakawa-oki earthquake. The present observations suggest that these two large anomalously deep big inland earthquakes occurred at sharp material boundaries under the NE-SW compressional stress field caused by the ongoing arc-arc collision process.

#### **Awards:**

1. 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.

#### **Submitted Journal Papers:**

1. **S. Kita**, A. Hasegawa, J. Nakajima, T. Okada and T. Matsuzawa, Precise seismic velocity structure beneath the Hokkaido corner, northern Japan: Arc-arc collision and the 1970 M 6.7 Hidaka and the 1982 M 7.1 Urakawa-oki earthquakes, under review (JGR).

#### **Published Journal Papers:**

1. **S. Kita**, T. Okada, A. Hasegawa, J. Nakajima and T. Matsuzawa, Existence of interplane earthquakes and neutral stress boundary between the upper and lower planes of the double seismic zone beneath Tohoku and Hokkiado, northeastern Japan., *Tectonophysics*, doi 10.1016/j.tecto.2010.10.010, 2010b.
2. A. Hasegawa, J. Nakajima, N. Uchida, F. Hirose, **S. Kita** and T. Matsuzawa, Slab Structure beneath the Japanese Islands and Earthquake Generation, *Journal of Geography*, 119, 2, 190-204, 2010.
3. J. Nakajima, A. Hasegawa, and **S. Kita**, Seismic evidence for reactivation of a buried hydrated fault in the Pacific slab by the 2011 M9.0 Tohoku earthquake, *Geophys. Res. Lett.*, doi:10.1029/2011GL048432, 2011.
4. Ohta Y., S. Miura, M. Ohzono, **S. Kita**, T. Iinuma, T. Demachi, K. Tachibana, T. Nakayama, S. Hirahara, S. Suzuki, T. Sato, N. Uchida, A. Hasegawa, and N. Umino, Large intraslab earthquake (2011 April 7 M7.1) after the 2011 off the Pacific coast of Tohoku earthquake (M9.0): Coseismic fault model based on the dense GPS network data, *Earth Planets Space*, in press.

#### **Symposium Participations:**

1. **S. Kita**, T. Okada, A. Hasegawa, J. Nakajima and T. Matsuzawa, Difference in location of the neutral plane of stress in the Pacific slab between Hokkaido and Tohoku, 2010 JPGU meeting, Makuhari-Messe, May 2010.
2. **S. Kita**, A. Hasegawa, J. Nakajima, T. Okada and T. Matsuzawa, Detailed seismic velocity structure 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.
3. **S. Kita**, T. Okada, J. Nakajima, T. Matsuzawa, A. Hasaegawa and Y. Tsuji, Upper-plane seismic belt in the double seismic zone and seismic velocity struture 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.
4. **S. Kita**, T. Okada, J. Nakajima, T. Matsuzawa, A. Hasegawa, Detailed seismic velocity structure beneath the Hidaka metamorphic belt in Hokkaido: Collision process of the forearc sliver, 2010 SSJ fall meeting, Hiroshima International Hall, Oral, October, 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.
6. **S. Kita**, T. Okada, J. Nakajima, T. Matsuzawa, A. Hasegawa, K. Katsumata, Detailed seismic velocity structure beneath the Hokkaido corner, NE Japan: Collision process of the forearc sliver, 2010 AGU fall meeting, Oral, December 2010.
  7. **S. Kita**, T. Okada, J. Nakajima, T. Matsuzawa, A. Hasegawa, K. Katsumata, Precise seismic velocity structure beneath the Hokkaido corner: Arc-arc collision and the 1982 Urakawa-oki earthquake, 2011 JPGU meeting, Makuhari-Messe, Oral, May 2011.
  8. **S. Kita**, Precise seismic velocity structure beneath the Hidaka region, northern Japan: Arc-arc collision process and M7 class big earthquakes, Workshop on Ocean Mantle Dynamics from spreading center to subduction zone, AORI, University of Tokyo, Poster, October, 2011.
  9. **S. Kita**, T. Okada, J. Nakajima, T. Matsuzawa, A. Hasegawa, K. Katsumata, Precise seismic velocity structure beneath the Hokkaido corner, northern Japan: Arc-arc collision and the 1970 M 6.7 Hidaka region earthquake and the 1982 M 7.1 Urakawa-oki earthquake, 2011 AGU fall meeting, Poster, December 2011.

#### **Outreaches:**

1. **Saeko Kita**, My study of seismology and carrier history, Lunch time for women high school students in the 2010 Tohoku University Open Campas, Poster, July 2010, <http://www.sci.tohoku.ac.jp/docs/world-wide/oc2010.pdf>
2. **Saeko Kita**, Present situations of one young woman seismologist in Japan - study and carrier pass-, Lunch time for women high school students in the 2011 Tohoku University Open Campas, Poster, July 2011.

# 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 ( $\gamma$ ) 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  $\langle a \rangle$ , prism  $[c]$ , and prism  $\langle a \rangle$ . 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 ( $R_1$ ) 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  $R_1$  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 published in 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 published in Tectonophysics.

### Published Journal Papers:

1. **Muto, J.**, G. Hirth, R. Heilbronner and J. Tullis (2011) Plastic anisotropy and fabric evolution in sheared and recrystallized quartz single crystals. *J. Geophys. Res.*, B02206, doi:10.1029/2010JB007891.
2. Onuma K., **J. Muto**, Nagahama, H. and Otsuki, K. (2011) Electric potential changes associated with nucleation of stick-slip of simulated gouges, *Tectonophysics*, 502, 308-314.
3. **Muto, J.** (2011) Rheological structure of northeastern Japan lithosphere based on geophysical observations and rock mechanics. *Tectonophysics*, 503, 201-206.

### Symposium Participations:

1. Onuma, K., **J. Muto**, H. Nagahama and K. Otsuki, Electromagnetic phenomena prior to stick slip and microstructural evolution in simulated gouges. JpGU meeting 2010 (Makuhari).
2. Nishikawa, O., **J. Muto** and K. Otuski, Intense pulverization of quartz single crystal associated with possible super-shear stick-slips, JpGU meeting 2010 (Makuhari).
3. Onuma, K., **J. Muto**, H. Nagahama and K. Otsuki, Electric voltage variation by nucleation of stick-slip of simulated gouges. Tohoku University GCOE symposium "Dynamic Earth and Heterogeneous Structure", July 2010.
4. Nishikawa, O., **J. Muto** and K. Otuski, Pulverization of quartz single crystal induced by possible super-shear stick-slips. Tohoku University GCOE symposium "Dynamic Earth and Heterogeneous Structure", July 2010.
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.
6. **Muto, J.**, Rheology of the island arc lithosphere by current understanding on rock deformation (**Invited**), Workshop on lithosphere dynamics: collaboration of geophysics and geology, July 2010 (Earthquake Res. Inst).
7. **Muto, J.**, K. Takahara and H. Nagahama, Skin depth of electromagnetic wave through fractal crustal rocks. Geol. Soc. Jpn. Ann. Meeting, September 2010 (Toyama).
8. **Muto, J.**, Rheological structure of Northern Honshu, Japan: Fault reactivation and post-seismic creep (**Invited**). TheERI International Symposium on "Subduction systems: structure, seismicity and geodynamics", November, 2010.
9. **Muto, J.**, Deformation of the northeastern Japan arc inferred from rheology of rocks and minerals (**Invited**). Miner. Soc. Jpn. Ann. Meeting, September 2011 (Mito).
10. Nakamura, Y., **J. Muto** and H. Nagahama, T. Miura and I. Arakawa, Quartz amorphization due to friction and wear : Raman spectroscopic analysis. Geol. Soc. Jpn. Ann. Meeting, September 2011 (Mito).
11. Kaneko, H., **J. Muto** and H. Nagahama, Development of intrafolial folds at deeper extension of seismogenic fault. JpGU meeting 2011 (Makuhari).
12. Katayama, I., S. Azuma and **J. Muto**, Strength discontinuity of oceanic moho. Miner. Soc. Jpn. Ann. Meeting, September 2011 (Mito).
13. **Muto, J.** and M. Ohzono, Rheological profile of the northeastern Japan: Toward precise modeling of post-seismic deformation of 2011 Tohoku Earthquake, Seismol. Soc. Jpn. Ann. Meeting, October 2011 (Shizuoka).

# Satoshi Okumura

Title/Affiliation	COE Assistant Professor / Department of Earth Science
Specialized Field	Volcanology
Research Subject	Dynamics of Volcano Eruptions, Experimental Studies on Magma Degassing

## 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  $< 830^{\circ}\text{C}$ , rhyolitic melt showed brittle behavior when it was sheared at strain rates  $> 10^{-2} \text{ s}^{-1}$ . 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.

## Published Journal Papers:

1. **Okumura, S.**, M. Nakamura, T. Nakano, K. Uesugi, A. Tsuchiyama (2010) Shear deformation experiments on vesicular rhyolite: Implications for magma fracturing, degassing, and compaction of magma in volcanic conduits, *J. Geophys. Res.*, 115, B06201, doi:10.1029/2009JB006904.

2. **Okumura, S** (2011) The H<sub>2</sub>O content of andesitic magmas from three volcanoes in Japan, inferred from the infrared analysis of clinopyroxene. *European J. Mineral.*, in press.

#### **Symposium Participations:**

1. **Okumura, S.**, M. Nakamura, K. Uesugi, Microstructure of bubbles and gas permeability in crystalline magmas, Chiba, Japan, Japan Geoscience Union Meeting 2010, May 23–28, 2010.
2. Nakamura, M., **S. Okumura**, S. Takeuchi, Permeability development of volcanic pyroclasts: experimental constraints, Chiba, Japan, Japan Geoscience Union Meeting 2010, May 23–28, 2010.
3. Fujioka, T., **S. Okumura**, M. Nakamura, K. Uesugi, Open-system degassing and compaction of flowing magma: constraints from torsional deformation experiments, Chiba, Japan, Japan Geoscience Union Meeting 2010, May 23–28, 2010.
4. Sato, T., M. Nakamura, **S. Okumura**, M. Igushi, D. Miki, Pre-eruptive volatile contents of magma and eruptive dynamics on the 1914 eruption of Sakurajima volcano, Chiba, Japan, Japan Geoscience Union Meeting 2010, May 23–28, 2010.
5. **Okumura, S.**, M. Nakamura, T. Nakano, Experimental constraints on the permeable gas transport in ascending magmas, Sendai, Japan, G-COE symposium 2010: Dynamic Earth and Heterogeneous Structure, July 13–15, 2010.
6. **Okumura, S.**, M. Nakamura, A. Tsuchiyama, T. Nakano, S. Takeuchi, K. Uesugi, Open-system degassing from silicic arc magmas, Matsue, Japan, The 2010 Annual Meeting of Japan Association of Mineralogical Sciences, September 23–25, 2010 (invited).
7. **Okumura, S.**, N. Hirano, Carbon emission from volcanoes, Kyoto, Japan, The Volcanological Society of Japan 2010 Fall Meeting, October 9–11, 2010.
8. **Okumura, S.**, M. Nakamura, T. Fujioka, A. Tsuchiyama, S. Takeuchi, T. Nakano, K. Uesugi, Evolution of microstructure of bubbles and gas permeability in sheared rhyolite, San Francisco, USA, 2010 American Geophysical Union Fall Meeting, December 13–17, 2010 (invited).
9. **Okumura, S.**, M. Nakamura, K. Uesugi, T. Nakano A. Tsuchiyama, In-situ observation of flowing magma at high temperature and pressure, Chiba, Japan, Japan Geoscience Union Meeting 2011, May 22–27, 2011.
10. **Okumura, S.**, M. Nakamura, T. Nakano, K. Uesugi, Anisotropy of bubble microstructure and gas permeability in sheared magma, Chiba, Japan, Japan Geoscience Union Meeting 2011, May 22–27, 2011.
11. **Okumura, S.**, M. Nakamura, K. Uesugi, T. Nakano, In situ observation of brittle fracturing and gas transport in silicic magma, Mito, Japan, The 2011 Annual Meeting of Japan Association of Mineralogical Sciences, September 9–11, 2011.
12. **Okumura, S.**, K. Okazaki, I. Katayama, Magma permeability measurement at high temperature and high pressure by pore-pressure oscillation method, Asahikawa, Japan, The Volcanological Society of Japan 2011 Fall Meeting, October 2–4, 2011.



# Yukihito 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:

### 1. Seafloor acoustic ranging system

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 PXP's (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.

### 2. GPS/Acoustic observation

Large earthquakes repeatedly occurred around northeastern Japan associated with subduction of the Pacific plate. In Japan crustal movement have been estimated by nation-wide GPS network on land, but large displacement occur in ocean areas. Therefore our group has been developed a GPS/Acoustic observation (GPS/A) system for the observation of the seafloor crustal movement. Our group started the seafloor geodesy using GPS/A from 2004. All sites (GJT3, GJT4) are the landward of Japan Trench. We estimated the slip vector associated with the plate motion to be about 5 cm West at GJT4 and about 3 cm WSW GJT3 until the 2011 off the Pacific coast of Tohoku Earthquake (M9.0). This result agrees roughly with back-slip model (Suwa et al., 2001). This earthquake occurred on 11 March 2011 off the Pacific coast of Tohoku

district, northeastern Japan. Kido et al. (2011) reported 15 m and 31 m of co-seismic displacement at west- and east-side points, respectively, both in the ESE direction. Large post-seismic deformation is expected due to the magnitude of the main rupture ( $M_w=9.0$ ). According to GPS network analysis by Geological Survey Japan, maximum  $\sim 2.2$  m of cumulative deformation due to post-seismic slip after about 140 days was reported on land.

### **Main Results:**

#### **1. Seafloor acoustic ranging system**

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.

#### **2. Seafloor acoustic ranging system**

Kido et al. (2011) reported 15 m and 31 m of co-seismic displacement at west- and east-side points, respectively, both in the ESE direction. Large post-seismic deformation is expected due to the magnitude of the main rupture ( $M_w=9.0$ ).

### **Published Journal Papers:**

1. Fujimoto, H., M. Kido, **Y. Osada**, K. Tadokoro, T. Okuda, Y. Matsumoto and K. Kurihara, Long-term stability of acoustic benchmarks deployed on thick sediment for GPS/Acoustic seafloor positioning, In: Y. Ogawa et al. (eds.) *Accretionary Prisms and Convergent Margin Tectonics in the Northwest Pacific Basin*, Springer, in press.
2. **Osada, Y.**, M. Kido, and H. Fujimoto. A long-term seafloor experiment using an acoustic ranging system: precise horizontal distance measurements toward detection of seafloor crustal deformation, submitted to *Ocean Engineering*.
3. Ito, Y., T. Tsuji, **Y. Osada**, M. Kido, D. Inazu, Y. Hayashi, H. Tsushima, R. Hino, and H. Fujimoto, Frontal wedge deformation near the source region of the 2011 Tohoku-Oki earthquake. *Geophysical Research Letters*, 38, (2011), L00G5
4. Tsuji, T., Y. Ito, M. Kido, **Y. Osada**, H. Fujimoto, J. Ashi, M. Kinoshita, and T. Matsuoka, Potential Tsunamigenic Faults of the 2011 Tohoku Earthquake. *Earth, Planets and Earth*, 63(7), (2011), 831-834.
5. Kido, M., **Y. Osada**, H. Fujimoto, R. Hino, and Y. Ito, Trench-normal variation in observed seafloor displacements associated with the 2011 Tohoku-Oki earthquake *Geophys. Res. Lett.*, doi:10.1029/2011GL050057.

### **Symposium Participations:**

1. **Osada, Y.**, M. Kido and H. Fujimoto, A long-term seafloor experiment using seafloor acoustic ranging system, GCOE 2010 symposium: Dynamic Earth and Heterogeneous Structure.
2. Fujimoto, H., M. Kido, and **Y. Osada**, Improvement in the observation system for the GPS/A seafloor positioning, AGU Fall Meeting, 2010.
3. Kido, M., **Y. Osada** and H. Fujimoto, Temporal variation of oceanic sound speed structure affecting seafloor geodesy, AGU Fall Meeting, 2010.
4. **Osada, Y.**, M. Kido and H. Fujimoto, Observation of seafloor crustal movement using the seafloor acoustic ranging on Kumano-nada, AGU Fall Meeting, 2010

5. **Osada, Y.**, M. Kido and H. Fujimoto, Observation of seafloor crustal movement using the seafloor acoustic ranging on Kumano-nada, UT 2011 & SSC11, 2011.
6. **Osada, Y.**, M. Kido and H. Fujimoto, Development of a seafloor acoustic ranging system, OES22, 2011.