Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS01-P01 Room:Convention Hall Time:May 19 18:15-19:30

Fluid transport property of sediments near the plate boundary fault at Japan Trench

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The 2011 Tohoku earthquake (Mw 9.0) produced huge fault slip (~50m) on the shallow portion of plate boundary fault. On the basis of previous studies of the rheology of subduction faults and historical observations of seismicity, neither large Mw 9.0 earthquakes near the Japan Trench, nor rupture of the shallow portion of the subduction thrust were anticipated. Thus, questions remain about the dynamic processes during the earthquake, which can be addressed though evaluation of physical properties of the fault zone. Fluid transport properties of fault zones influence pore fluid pressures and how fluids migrate at depth. Permeability of fault rocks and surrounding sediments directly influences (1) the efficiency of the thermal pressurization process during coseismic faulting and (2) the evolution process of pore fluid pressure generated by the chemical dehydration reactions of the subducting sediments along a plate boundary. These processes consequently affect fault dynamics. Thus, we have measured hydraulic property of core samples around the plate boundary materials recovered from the Japan Trench during IODP expedition 343 (JFAST), performing laboratory tests on mudstones from the hanging wall near the plate boundary fault zone (Lithological Unit 4, 714 mbsf and 785 mbsf). Permeability and porosity were measured at confining pressures of 0 to 30 MPa and pore pressures of 0.2 to 0.8 MPa at room temperatures (about 20 degree Celsius). Permeability was determined by a steady-state flow method with NaCl solution (35 per-mil) and distilled water as a pore fluid.

Permeability and porosity for mudstone from 713 mbsf are $3*10^{-17}$ m^2 and 43%, respectively, at 1 MPa effective pressure. These parameters decrease to $2*10^{-18}$ m^2 and 30% with increasing effective pressure to 10 MPa. Specific storage shows from $5*10^{-8}$ to $1*10^{-8}$ Pa^{-1}. A sample from 785 mbsf has measured permeability of $7*10^{-17}$ m^2 and porosity of 40% at 1 MPa effective pressure and $5*10^{-18}$ m^2 and 31% at 10 MPa effective pressure. For both samples, permeability decreased exponentially with a decrease of porosity. Permeabilities at conditions comparable to the in-situ depth (ranging from 10^{-17} m^2 to 10^{-18} m^2) are therefore low enough that processes (1) and (2) are expected to occur. We will model these processes more specifically considering the friction properties of the plate boundary fault, temperature structure at depth and shear-induced permeability change.

Keywords: permeability, JFAST, Tohoku Earthquake, IODP Expedition 343

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Structural heterogeneities around the shallow megathrust zone of the 2011 Tohoku earthquake

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The coseismic rupture area of the 2011 Tohoku Earthquake has estimated over the wide region from the coastline to near the Japan Trench. Several kinds of studies, such as tsunami source inversion [e.g., Fujii et al., 2011], coseismic slip inversion [e.g., Ide et al., 2011], submarine topography change [Fujiwara et al., 2011] and seafloor displacement observation [Sato et al., 2011; Ito et al., 2011; Kido et al., 2011], share the common feature that the largest coseismic slip occurred at the shallow plate boundary in close vicinity to the Japan Trench. However, the structural image just beneath the largest coseismic slip area was unclear since the observation areas of previous ocean bottom seismographs (OBSs) in this region were limited and there were few OBSs near the Japan Trench [e.g., Yamamoto et al., 2011]. To understand the relationship between coseismic rupture behavior and structural heterogeneities, it is necessary to know the seismic velocity structure of the subducted slab crust and mantle near the trench axis.

After the occurrence of 2011 earthquake, some National Universities (Hokkaido, Tohoku, Chiba, Tokyo, Kyushu, and Kagoshima), JAMSTEC, and Meteorological Research Institute together have conducted the aftershock observations along the landward slope of Japan Trench to obtain detail hypocenter distribution [Shinohara et al., 2012]. Tohoku University has performed the other OBS observation off Miyagi prefecture from 2010 to 2011. During this observation, a sequence of foreshocks, the mainshock, and aftershocks of the 2011 Tohoku earthquake were recorded [Suzuki et al., 2012]. In addition, JAMSTEC has conducted the aftershock observation at outer slope of Japan Trench, around the epicenter of a Mw 7.6 earthquake that occurred about 40 minutes after the 2011 mainshock, from May to June [Obana et al., 2012].

In this study, we performed the three-dimensional seismic tomography by combining these OBS dataset and land seismic data to obtain the fine hypocenter distribution and velocity structure around the largest coseismic slip zone of 2011 Tohoku earthquake. From the relocation results, we found that some deep intraslab earthquakes occur near the trench and their focal mechanism are normal fault type. Since these earthquakes occurred before the 2011 mainshock showed thrust type [e.g., Gamage et al., 2009], our results suggest the change of stress regime in this region. In the outer-rise area, the hypocenter distribution of the relocated shallow earthquakes has a linear trend along the horst-graben structure. Subducted oceanic crust has some heterogeneous structure around the hypocenter of the 2011 mainshock as follows: (1) relatively low Vs and high Vp/Vs zone at landward side of the mainshock location, (2) high Vs and low-Vp/Vs in the south of mainshock. These structural heterogeneities might represent the heterogeneous distribution of fluid in the oceanic crust and/or existence of subducted seamount. In addition, the velocity of uppermost slab mantle from 143 degree E to the trench axis showed low Vp, Vp/Vs (~1.70) and high Vs ($>$ 5.0 km/s). This feature might reflect the existence of strongly anisotropy in the slab mantle or indicate the locally orthopyroxene enrichment.

This work is supported in part by the Special Coordination Funds for the Promotion of Science and Technology (MEXT, Japan) titled "the integrated research for the 2011 off the Pacific coast of Tohoku earthquake". A part of this study also supported by "Research concerning Interaction between Tokai, Tonankai and Nankai Earthquakes" funded by MEXT, Japan, and the JAMSTEC's rapid response research project for the 2011 Tohoku-oki earthquake.

Keywords: Tohoku megathrust earthquake, seismic tomography, ocean bottom seismic observation, oceanic crust

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Rock-magnetic properties of the plate-boundary thrust material drilled during IODP Expedition 343 (JFAST)

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During IODP Expedition 343, Japan Trench Fast Drilling Project (JFAST), boreholes were drilled through the prism and across the fault that is thought to have slipped during the 11 March 2011 Tohoku-Oki Earthquake. 74 subsamples of the core recovered from hole C0019E were subjected to rock magnetic analyses to identify magnetic minerals, determine the magnetic-grain size distribution and investigate rock magnetic changes related to fault zone processes.

Magnetic hysteresis curves and backfield DC demagnetization curves of isothermal remanent magnetization were measured using a MicroMag 2900 alternating gradient field magnetometer. Hysteresis parameters (Ms, Mr, Hc, Hcr) were calculated and coercivity spectra were obtained as the derivative of DC demagnetization curves. Thermal demagnetization of low-temperature IRM acquired at 10 K and 5 T after zero-field cooling was performed with an MPMS-XL. Thermomagnetic analyses in 0.4 T and ambient pressure were carried out with a Natsuhara NMB-89 thermobalance.

Samples from the sheared scaly clay zone (Lithologic Unit 4: 820-824 m CSF, inferred to be the plate boundary decollement) clearly have low Hc and Hcr (10-13 and 22-24 mT) compared with the lower part of the frontal prism sediment (Lithologic Unit 3: 688-820 m CSF; Hc = 15-52 mT; Hcr = 45-85 mT) and the brown underthrust sediment (Lithologic Unit 5: 824-832 m CSF; Hc = 13-26 mT; Hcr = 45-85 mT), suggesting a difference in magnetic mineralogy and/or grain size. However, there is no obvious variation in magnetic properties within between the decollement zone.

As for the thermal demagnetization curves of low-temperature IRM, the samples from llithologic Unit 3 show loss of magnetization at ~120 K, reflecting the Verwey transition of stoichiometric magnetite. In contrast, the samples from the lithologic Units 4-5 do not show significant loss of magnetization at the Verwey transition temperature. For the thermomagnetic curves, the heating branches of some samples from lithologic Unit 3 have humps above ~400 deg C possibly caused by thermal decomposition of some iron-bearing minerals and formation of magnetic minerals during heating, while the samples from lithologic Units 4-5 do not show any humps on the heating branches. These results imply a difference in magnetic mineralogy between lithologic Units 3 and 4-5 (ie. a difference between hangingwall and fault zone / footwall).

Within Lithologic Unit 4, the lower four samples (822.07-822.48 m CSF) show large magnetization increases in the cooling branches below ~100 deg C which might reflect the formation of magnetic minerals with low Curie temperatures during heating, compared with the upper four samples (821.54-821.78 m CSF). These samples may correspond to material that generated a peak in the on-board magnetic susceptibility log.

In summary, we found minor magnetic signals at the lower part of the sheared clay zone core sample of fault zone processes resulting from localized variation of magnetic mineralogy within the sheared clay zone samples recovered from the hole C0019E, but the origin and process of the minor magnetic variation should be further examined.

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Sediment fabric record in the trench axis formed during the 2011 Tohoku-oki earthquake

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The rupture of the 2011 Tohoku-oki earthquake propagated to the trench. Kodaira et al., (2012) revealed that the several ten meters scale displacement of the lower landward slope of Japan Trench occurred during the earthquake. Meantime an uplifted seafloor appeared in the trench axis, and the seismic reflection image beneath the trench floor reveals a thrust up structure. These observations are important keys to understand the slip of the 2011 Tohoku-oki earthquake. In order to detail the dynamics of the slip, surface sediments around the trench deposited before and after the earthquake were studied. Surface sediment cores were collected in the upheaval and un-upheaval areas from the trench axis, and the foot of the lower landward slope using piston and gravity cores. Cores from the trench axis consist mainly of coherent hemiplegic layers. On the other side, the sediment cores in the foot of the lower landward slope is characterized by mass-transport deposits and inclined layers of hemipelagite interbeded with silt/sand layers. Anisotropy of magnetic susceptibility (AMS), which is sensitive to soft sediment deformation, was studied to detect the sediment deformation. AMS from the trench axis shows fairly foliated magnetic fabric parallel to bedding planes, and parameters of AMS suggest that no lateral compression is recorded in the surface sediment. Instead, their sediment magnetic fabric in the trench sediment involve information of paleo-current of turbidites. On the other hand, AMS from the foot of lower landward slope is characterized by randomly orientated magnetic fabric indicating chaotic depositions, and inclined magnetic fabric indicating layer tilting downslope. Those fabric patterns in the slope suggest that the surface sequence were slid toward the trench. Preliminary interpretation on those data is that AMS reveal no compressional environment in the seafloor surface but sediment transporting information. If the upheaval structure in the trench axis formed during the earthquake, it should controlled the sedimentation pattern in the trench axis. It is expected that analysis of the sedimentary fabric in the area document such pattern. It will provide an unique information to understand the deformation during the slip in the trench axis. In this presentation, we will present detail properties of sedimentation on the basis of magnetic fabric.

Keywords: the 2011 Tohoku-oki earthquake, Japan Trench, turbidite, mass-transport deposits, Magnetic fabric

SSS01-P05 Room:Convention Hall Time:May 19 18:15-19:30

Seismic imaging in the Japan Trench axis area off Miyagi, northeastern Japan

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On March 11, 2011, the M9 great Tohoku megathrust earthquake ruptured the plate boundary at the Japan Trench off eastern Honshu, Japan. Several seismological, geodetic and tsunami wave inversion studies indicate a large magnitude of slip (30-60m) occurred on the shallow portions of the plate boundary. Differential bathymetric and seafloor geodetic studies also document large coseismic displacement near the trench. Thus, it is important to understand the detailed structure of the shallow portion of the subduction zone and the trench axis area of the Japan Trench to evaluate mechanisms of deformation and the geometry of the structures that accommodated shallow slip.

We conducted a high resolution reflection seismic survey in the vicinity of the Japan Trench axis off Tohoku in October-November, 2011. The high-resolution seismic profiles we obtained successfully image the detailed structure around the Japan Trench axis, and were used for site selection of the rapid response drilling program for IODP Expedition 343 (JFAST). We identify four seismic units in the study area: an acoustically transparent frontal wedge (Unit I), a sequence of parallel continuous reflections interpreted as sediments on the incoming plate (Unit II), a sequence of relatively strong reflections correlated to chert recovered in DSDP Site 436 (Unit III), and acoustic basement of the Pacific plate (Unit IV). The incoming Pacific plate sediments, including the basal chert layer (Units II and III), have been offset by normal faulting during plate bending seaward of the trench. Mapping of the relief on the igneous oceanic basement (Unit IV) shows that the trench axis in the survey area is located in a graben. The relief observed on the basement landward of the trench is related to the subduction of horsts and graben formed seaward of the trench. The hemipelagic/pelagic sediments (Unit II) overlying the basal chert layer (Unit III) are imbricated at the trench axis. The detachment surface is located slightly above the top of the chert-rich layer (Unit III) in the trench axis graben. We observe a seaward-dipping reflection branching off the top of the chert-rich layer (Unit III) at the edge of a horst block at the base of the landward trench slope. This reflection short-cuts the horst-graben normal fault, and soles into a horizon slightly above the top of chert-rich layer (Unit III) in the trench graben. This reflection is interpreted as a part of the decollement in the lowermost Japan Trench inner slope, and was likely generated by an increase of the loading and failure of the underthrust hemipelagic/pelagic sediments. The imbricate structure of the graben-fill sediments could have been developed by a combination of aseismic deformation as well as repeated megathrust earthquakes which caused failure and slip along the seaward dipping decollement. These data clearly image structures resulting from deformation and sediment subduction at the Japan Trench in the region that ruptured during the March 11, 2011 great Tohoku earthquake.

In January 2013, we carried out another seismic survey around the JFAST drill site using larger volume of sounding sources, longer streamer cable, and ocean bottom seismographs. Preliminary processed data provide seismic profiles with enhanced quality in the deeper portion. We will also present the velocity model deduced from the analysis of these seismic data.

Keywords: seismic image, Japan Trench, Tohoku earthquake

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New approaches to advanced GPS/A geodetic observation on the seafloor

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(1) A plan for better positioning in shorter time
The 2011 Tohoku-oki earthquake was accompanied with exceptionally large coseismic slips near the trench axis, where land-based GPS has little resolution on the seismic coupling on the plate boundary. Then we have added 20 GPS/A observation sites along the Japan Trench for the Japanese geodetic group with a fund from the MEXT Japan. The Japan Coast Guard has also added 9 observation sites along the Nankai Trough. Although there still remains a big difference from the GPS networks on land, the extension of the GPS/A observation was a big progress. On the other hand, it requires more ship time. We have to solve this problem to fill the gaps such as the area near the Nankai Trough axis. Since we have spent half a day or a full day at a site for GPS/A observation, the first thing we should do is to reduce the time at a site.

We have estimated from our observation results that a breakthrough for the problem would be measurement of horizontal gradients of sound speed in the surface layer of the ocean. The group of Nagoya University had proposed to carry out acoustic positioning by using a few moored buoys. We have found that an important point in such positioning lies in nearly simultaneous acoustic ranging from two surface units apart at certain distance to four precision acoustic transponders (PXPs). Then we can roughly measure a sound speed gradient in the direction connecting the two surface units. The value in any direction can be obtained by changing the positions of the surface units. After some trials to get know-hows, we can reduce the observation time to get a repeatability of a few centimeters. If three surface units are available, a precise position can theoretically be obtained at each acoustic positioning. The Japan Trench area is one of the major fishery fields in the world, and many fishery nets longer than 10 km are extended there. We hope to carry out experiments at an appropriate site to validate this method consulting with fishermen.

(2) An approach to semireal-time continuous observation
Real-time continuous observation is the final goal of seafloor geodetic observation. A realistic target for the moment will be to get daily or weekly positions of the seafloor. There are two major problems in the way to semireal-time continuous GPS/A observation. Firstly GPS/A observation needs sea surface vehicles for the GPS positioning. A self-navigating buoy called Wave Glider can sail at about 1.5 knot with the power of surface waves of the ocean. It can survive in the rough seas associated with typhoons. We estimate that two sets of Wave Gliders or a pair of moored buoy and a Wave Glider can solve the first problem.

The second problem is precise GPS positioning. The kinematic GPS method we have used needs sending the GPS data from the sea surface unit to a land station. This requires satellite data transmission at least 4800 baud, for which we are studying a solution with a group of the JAXA. Recently we have found a tentative solution. Yamamoto et al. (this meeting) evaluated the stability of the kinematic solution of a station on land with the corrected signal by the StarFire system in October 2012. They confirmed that the standard deviation of the horizontal solutions is less than 1.5 cm. And also, the obtained time series is within 2 cm from the daily position by the GIPSY-OASIS II software version 6.1.2, which we use for the kinematic GPS positioning.

The battery capacity of the PXPs newly deployed in 2012 can respond about 20 times every day in a long-term observation. We expect that three surface units can get several centimeters of repeatability. Although the daily cost for the StarFire and the Iridium is much less than that for ship time, one week will be the minimum interval, if the observation continues for a year or longer. We need less expensive satellite data telemetry to get daily GPS/A positions for long time.

Keywords: seafloor geodetic observation, GPS/A, Tohoku-oki earthquake, seismic coupling, horizontal gradient of sound speed, daily position

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS01-P07 Room:Convention Hall Time:May 19 18:15-19:30

Precursory Seismic Activity Surrounding the High-Slip Patches of the 2011 Mw9.0 Tohoku-Oki Earthquake

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The 2011 Tohoku-Oki earthquake (Mw9.0) was preceded by foreshock activity that occurred north of the main-shock epicenter two days earlier. The epicentral area of the foreshock activity is almost the same as that of the prominent seismic activity in 1981 [Ando and Imanishi, 2011; Shao et al., 2011a]. The question arises, why did the 1981 event not trigger an event like the 2011 Tohoku-Oki earthquake? The time difference of 30 years is negligible in comparison with the long time required for the slip deficit of more than 40 m. In order to address this problem, we investigated the long-term seismicity pattern with reference to the slip distribution of the Tohoku-Oki earthquake. We used the earthquake catalogue compiled by the Japan Meteorological Agency (JMA) for the past 90 years since 1923. We assume that the variation of frictional strength on the megathrust, as suggested by the slip distribution of the Tohoku-Oki earthquake, would manifest itself in the spatio-temporal distribution of seismic activity.

The slip distribution of the Tohoku-Oki earthquake we obtained from the coseismic displacements of the GEONET and sea-bottom stations is characterized by a low-slip zone sandwiched between the two patches of high slip (20m) along the Japan Trench. The epicenters of the foreshock activity are distributed over the boundary between the low-slip zone and the two high-slip patches (LHSB seismic zone), where other prominent activity had been accommodated during the past 90 years. The main-shock initiated near the junction of the northern edge of the southern high-slip patch and the mid-asperity seismic zone that divides the southern high-slip patch into two parts. The main-shock was able to rupture the western half of the southern high-slip patch, which is located down-dip of the main-shock epicenter, because the stress increased by the foreshock activity surpassed its strength. However, we infer that it is not only because the foreshock activity was the largest to have ever occurred in the LHSB seismic zone, but also because the western half of the southern high-slip patch had been sufficiently weakened by surrounding events since 2003. A substantial reduction of its strength might have been caused by the 2003 M6.8 event in the mid-asperity seismic zone and the 2005 events in the area of characteristic events such as the 1936 and 1978 Off-Miyagi earthquakes. The afterslip of the 2008 and 2010 events off the coast of Fukushima prefecture might also have contributed to weakening the western half of the southern high-slip patch. The last significant stress change was caused by the foreshocks that occurred along the northern edge of the southern high-slip patch one day before the main-shock.

The following rupture of the eastern half of the southern high-slip patch, which is located up-dip of the main-shock epicenter and includes an area of slip greater than 60 m, was probably made possible because that portion had also been sufficiently weakened by the surrounding events since 2003. The contribution of the 2003 activity extending along the southern edge of the center of the southern high-slip patch may be important because no prominent activity had occurred there before. A couple of moderate-sized events on the eastern edge of the southern high-slip patch might also have made important contributions. We infer that the foreshocks occurring along the northern edge of the southern high-slip patch also played an important role for weakening of the center of the southern high-slip patch. Lastly, the main-shock was able to expand to its large size by rupturing the center of the southern high-slip patch. The magnitude of the slip caused the subsequent ruptures of adjacent areas including the northern high-slip patch. The doughnut-shaped seismicity pattern that formed around the center of the southern high-slip patch is considered to be due to the presence of an extremely strong area on the megathrust.

Keywords: Off the Pacific coast of Tohoku Earthquake, Tohoku-Oki earthquake, Pacific plate, subduction zone, precursory seismic activity, foreshock activity

SSS01-P08 Room:Convention Hall Time:May 19 18:15-19:30

Aftershock seismicities of three great earthquakes and their implications for lithospheric deformation

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Assessment of influence of great earthquakes on reginal seismicity is high priority for seismic hazard mitigation. However, the properties of aftershock seismicity have not been fully understood. Since 2004, there were three great earthquakes with magnitudes greater than 8.8, which are the 26 December 2004 M9.1 Sumatra-Andaman earthquake, the 27 February 2010 M8.8 Maule earthquake, and the 11 March 2011 M9.0 Tohoku-Oki earthquake. In this study, we investigate the seismicities and focal mechanism solutions of earthquakes in the three regions that belong to active convergent plate boundaries. The seismicities and focal mechanism solutions of the earthquakes before and after the great earthquakes during 2000-2012 are investigated by time period, focal depth, and faulting type. It is observed that the numbers of events increase abruptly right after the great earthquakes, and decrease gradually with time. Thrustal earthquakes occur dominantly in the regions. It is observed that a large number of strike-slip events occur in the Sumatra-Andaman region after the great earthquake. On the other hand, thrustal earthquakes are still most dominant in the Maule region after the great earthquake. Also, we find large numbers of shallow-focus normal-faulting events in the Tohoku-Oki region after the great earthquake. It is intriguing to note that all three regions present shallow-focus normal-faulting earthquakes that are clustered around the slab boundaries with large slips. Thrustal earthquakes are found to be clustered around the slip edges. The observation suggests that the ambient stress field changes by the slip amount. The occurrence of normal-faulting earthquakes in large slip regions can be explained as a result of lithospheric elastic rebounds of plates after the great earthquakes.

Keywords: aftershock, seismicity, focal mechanism, b value, lithospheric deformation