Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SSS02-01 Room:IC Time:May 25 09:00-09:20

Determining slip near trench in the M 9 Tohoku-oki earthquake using bathymetry differences before and after the rupture

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Many studies of the 2011 M 9.0 Tohoku-oki earthquake indicate very large coseismic slip that breached the trench and induced the devastating tsunami. In order to understand the behavior of the shallow fault during the earthquake, it is important to know the amount of coseismic slip near the trench and how the slip varies in the updip direction. However, a compilation of more than 40 published rupture models derived from various datasets, including seismic, tsunami, and geodetic observations, shows large uncertainties in determining the near-trench coseismic slip. While some models show that the slip peaked at the trench, other models show that it peaked at some distance from the trench and then decreased trenchward. The large uncertainties are due mainly to the lack of very-near-field observations. For example, the most near-trench seafloor GPS/Acoustic site operational at the time of the earthquake is ˜50 km from the trench. However, high-resolution multi-beam bathymetry surveys conducted by JAMSTEC before and ˜10 days after the 2011 earthquake recorded coseismic deformation directly at the trench. In this work, we use differential bathymetry, i.e. bathymetry differences before and after the earthquake, to determine the shallow coseismic slip in the area of the largest moment release. Using a 3D elastic finite element model with actual seafloor and fault geometry of the Japan trench subduction zone, we produce Synthetic Differential Bathymetry (SDB), and compare the SDB with observations. The SDB can well predict short-wavelength features, which correspond mainly to local seafloor slope variations. For longer-wavelength features, our tests using different slip profiles with slip increasing or decreasing to the trench show that the internal elastic deformation of the hanging wall plays an important role in generating bathymetry differences. We use two parameters, the average fault slip over the most near-trench 50 km and a constant gradient of the slip over the same distance, to describe the assigned slip distribution, and search for the slip profile that can best explain the observed differential bathymetry. Bathymetry surveys before the Tohoku earthquake were conducted in 1999 and 2004. Our modeling indicates that a fault slip averaging 65 m over the near-trench 50 km and decreasing by 5 m over the same distance can optimally predict the differential bathymetry from the 1999 and 2011 data. Because the coverage seaward of the trench in the 2004 survey was shorter, causing greater uncertainty in correcting depth bias between surveys, differential bathymetry between 2004 and 2011 is less reliable. Compared to the 1999-2011 data, a smaller average slip (45 m) with a larger trenchward decrease over the most near-trench 50 km is required to explain the 2004-2011 data. Although some uncertainties exist in determining the absolute amount of slip, moderate decrease in fault slip to the trench should be a robust feature, as required by both the 1999-2011 and 2004-2011 data. If some pre-seismic slip and/or short-term afterslip occurred near the trench, the finding of the trenchward decrease of the coseismic slip would be further strengthened. The large coseismic slip but with a small decrease toward the trench suggests that the shallow megathrust may have initially exhibited velocity-strengthening at low slip rates but then changed to dynamic weakening at higher rates. The delay of weakening in the shallow fault may have led to less net coseismic weakening than in the deeper seismogenic zone.

Keywords: 2011 M 9.0 Tohoku-oki earthquake, near-trench coseismic slip, differential bathymetry, elastic finite element model, coseismic weakening

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SSS02-02 Room:IC Time:May 25 09:20-09:35

Small low-frequency tremor coincident with slow slip events near the Japan Trench

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Understanding the changes in rates of transient deformation prior to large earthquakes in subduction zones is critical for predicting impending earthquakes and tsunamis. In the 2011 Tohoku?Oki earthquake, the shallow plate-boundary thrust at the Japan Trench slipped tens of meters to generate a devastating tsunami. Some slow slip events (SSEs) and intense foreshock triggered by SSEs have been reported prior to the megathrust event. At several subduction zones around the world, SSEs have been commonly observed to be accompanied by tectonic tremors. Here, we investigate low-frequency tremor activity accompanying SSEs prior to the 2011 Tohoku?Oki earthquake using ocean bottom seismometers deployed just above the coseismic slip area of the 2011 Tohoku?Oki earthquake before the mainshock occurred. To identify tectonic tremor activity accompanying the SSEs, we used three-component continuous seismograms in an ocean bottom seismometer (OBS) network. We investigated the ratio of two envelopes in order to remove the effects of regional earthquakes and stormy weather, using one station as a reference site. We identified three excitations with durations exceeding three days on the envelope ratio between January 25 and March 9, 2011, prior to the Tohoku?Oki earthquake. Similar excitations of envelope ratio were identified at the beginning of and during the SSEs detected by ocean bottom geodetic observations in 2008. They showed that low frequencies of 5?8 Hz dominated. These observations suggest that the excitations accompanying the SSEs could have been due to small low-frequency tremors associated with episodic SSEs; thus the shallow plate-boundary thrust near the trench could be characterized as a general location of slow earthquakes.

Keywords: low-frequency tremor, slow slip, the 2011 Tohoku-Oki earthquake

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SSS02-03 Room:IC Time:May 25 09:35-09:50

In-Situ Observations of Earthquake-Driven Fluid Pulses within the Japan Trench Plate Boundary Fault Zone

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Transient fluid flow within active faults has long been suspected to be an important process in the earthquake cycle, but has not previously been captured by direct measurements during an episode. Here we report on the signature of fluid pumping events inside the Tohoku Fault associated with individual earthquakes. As part of the Japan Trench Fast Drilling Project (JFAST), a sub-seafloor temperature observatory was installed across the plate boundary fault zone that ruptured during the 2011 Mw 9.0 Tohoku-oki earthquake. In addition to measuring the frictional heat signal from the megathrust earthquake, the high-resolution temperature time series data reveal spatially coherent temperature transients following regional earthquakes. Temperature increases vertically upwards from a fracture zone and decreases downwards, which is consistent with the expected signature of a fluid pulse entering the annulus from the fracture zone. The anomalies are a few hundredths of degree Celsius and occur repeatedly at depths that are independently interpreted to have higher fracture permeability. High-pass filtered data are spatially correlated in areas disturbed by transient fluid advection. Fluid pulses occur in response to over a dozen local earthquakes, including a Mw 5.4 on 14 October 2012, a Mw 5.5 on 11 November 2012, and a Mw 7.3 doublet consisting of two very local intraplate earthquakes on 7 December 2012, and a number of aftershocks of that event. There does not appear to be a response to large far-field earthquakes such as the 28 October 2012 Mw 7.8 Haida Gwaii or 6 February 2013 Mw 8.0 Santa Cruz Islands earthquakes. These measurements provide the first in situ documentation of seismic pumping within the damage zone of an active fault. Near fault measurements such as these may provide insight into drivers of earthquake occurrence. The redistribution of fluid pressures within fault zones, such as observed here in response to earthquakes, is a potential mechanism that may be involved in earthquake triggering.

Keywords: JFAST, Japan Trench, Observatory, temperature, hydrogeology

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SSS02-04 Room:IC Time:May 25 09:50-10:05

Study of the ocean physical data acquisition before and after the earthquake using the Argo float

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Tohoku region Pacific Ocean earthquake that occurred on March 11, 2011, resulted in extensive damage to vast areas ranging from the Tohoku to Kanto. However, at the time of an earthquake occurrence, the research vessel which was researching about marine in earthquake hypocenter area adjacent seas is not confirmed, and ocean physical data like water temperature or salinity including ocean sound speed data required for echo sounder etc. cannot be acquired. Therefore, paying attention to the ocean automatic profiling system (Argo system) in this study. Currently, Argo float has deployed about 3600 units in all the world ocean. Thus, it does not require large-scale observation system by research ship or tethered buoy. And we became able to grasp the marine structure of the scale of the earth immediately and easily.

In this study, tried the acquisition of ocean physical data from the Argo data (water temperature, salinity, pressure) which unfolded before and after an earthquake near the focal area. As a result, In this earthquakes associated with the huge tsunami, rapid water temperature change has been confirmed in the vicinity of the sea after the earthquake.

In addition, we analyzed about Sumatra offing earthquake accompanied by a similar huge Tsunami. Data was acquired from two Argo floats which was observation in the seismic center area of ocean in 2005. As a result, a few days after the tsunami occurrence, the thing by which the ocean physical data indicates a profile different from usual was suggested. Thus, to variations in sudden marine environment, Argo system has been shown to be one of the effective database.

Keywords: Tsunami, Earthquake, Underwater sound wave propagation, ARGO system, Ocean physical data, Big Data

SSS02-05 Room:IC Time:May 25 10:05-10:20

Chemical fingerprints of earthquake event deposits in the Japan Trench

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The Japan Trench subduction zone has repeatedly been affected by large earthquakes, as most recently in 2011 by the giant magnitude 9 Tohoku-oki earthquake. The depression of the deep Japan Trench floor (>7500 m water depth) acts as sediment trap, where seismically triggered submarine mass flows are deposited and preserved in the geological record. Sedimentary records, collected east of the Tohoku-oki epicenter in a 60 km north-south transect along the Japan Trench floor axis and from a small basin on the slope, comprise several event deposits, which we test for seismic origin to investigating the earthquake history in this region. Porewater geochemistry and tephrochronological analyses on intercalated ash layers provide an age control and reveal that the records cover the recent 2011 event deposits, historical events, and prehistoric evidence up to ˜62ka ago. Detailed analyses of these records, by using their sedimentological and lithological characteristics, their physical properties as well as their elemental composition (X-ray Fluorescence, XRF) allow to characterize and to identify individual turbidite units.

Three prominent seismo-turbidite sequences, related to the 2011 Tohoku-oki, the AD 869 Jogan and an earlier prehistoric earthquake, are widespread and exhibit in all records the same lithology as well as specific, unique elemental characteristics. In combination with reported rupture areas and incorporated calcareous nanno fossils, the deposited turbidity currents seem to originate from slope areas shallower than ˜4500 m water depth. Further two chemical correlative seismo-turbidites have been deposited solely in an isolated basin in the deep trench and might be related to an historical earthquakes in AD 1454 (or AD 1611) and a prehistoric event ˜2400 years BP. Other turbidite units do not reveal similarities in the elemental characteristics, but may also be the result of seismic triggered slope failures, deposited at locally restricted sites. It is observed that the frequency of turbidite deposition in the deep Japan Trench is higher during the past 1500 years, than during the period from ˜15 ka to 2 ka, and might provide hints on the paleoseismic activity along the Japan Trench off Tohoku.

Keywords: Paleoseismology, Japan Trench, event-stratigraphy

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SSS02-06 Room:IC Time:May 25 10:20-10:35

Linkages between pelagic sedimentation and plate-boundary faulting

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Pelagic sediments may constitute input materials for plate-boundary faults in subduction zones but have been received little attention. Here, we show two examples of the fault localization onto the specific intervals in pelagic sediments. The Japan Trench Fast Drilling Project (JFAST) revealed that the cumulative interplate motion and the large shallow slip during the 2011 Tohoku-Oki earthquake were accommodated by the smectite-rich pelagic clay of less than 5 m thick. Similar ~5 m-thick, smectite-rich pelagic clay layer was recognized in the incoming sediments of the Japan Trench, which is caused by authigenesis and slow sedimentation rate in pelagic environment. Friction experiments revealed that pelagic smectite is weak over a wide range of slip rates, which is consistent with the concentration of interplate motion and coseismic slip. Although coseismic deformations have not been identified, high-velocity friction experiments and permeability measurements on pelagic smectite suggest that thermal pressurization potentially occurred during the shallow coseismic slip. In the coherent chert-clastic sequence of the Jurassic accretionary complex in central Japan, the thrust faults are considered to branch from the plate-boundary fault at temperature of ~220 ℃ in a region of the prehnite-pumpellyite facies metamorphism. The stratigraphy at the base of the thrust sheet (i.e., carbonaceous claystone and black chert in the base, gray chert, and red chert in ascending order) represents the mid-Triassic recovery from the deep-sea anoxic event that occurred across the Permo-Triassic boundary. The thrust faulting is highly concentrated into ~5 cm-thick black cataclasite defined by fragments of black chert in the carbonaceous clay matrix, where total carbon content increases to 8.5 wt%. The cataclasite is sharply cut by a few millimeters-thick, chert-derived pseudotachylyte, which is marked by fault and injection veins, rounded and embayed vein boundaries, cracked quartz clasts, and the presence of muscovite microlites in amorphous matrix. The localization of deformation onto the black cataclasite may represent that carbonaceous claystone is weaker than surrounding siliceous rocks, thereby facilitating concentration of faulting. However, seismic faulting appears to occur in stronger chert rather than carbonaceous claystone, which could result in frictional melting under higher frictional strength. In summary, concentration of pelagic smectite and deposition of carbonaceous clay during deep-sea anoxia control the localization of plate-boundary fault and subduction earthquakes at shallow and deep depths, respectively.

Keywords: pelagic sediments, plate boundary fault, JFAST, pseudotachylyte, chert-clastic sequence

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SSS02-07 Room:IC Time:May 25 11:00-11:15

Toward imaging fault zones of outer rise earthquakes succeeding a large megathrust earthquake in the Japan Trench

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There has been long-standing debate concerning how and where an intra-plate large normal fault earthquake occurred in the oceanic plate seaward of the trench (i.e. outer rise) following a shallow large megathrust earthquake. In the Japan Trench region, the 1933 Showa-Sanriku earthquake are believed to be an outer rise event succeeding the 1896 Meiji-Sanriku megathrust earthquake. Based on those observations, many seismologists have warned a large normal fault earthquake in the Pacific plate seaward of the rupture zone of the 2011 Tohoku-oki earthquake, because no magnitude-8 class outer rise normal fault earthquake has occurred since the 2011 earthquake. Most problematic issue to understand an outer rise earthquake in the Japan Trench region is that there are little information of size and distribution of fault zones of those events. Recent results of active-source seismic studies as well as earthquake monitoring, however, show a possible approach to image fault zone of outer rise normal fault events. We observed, from wide-angle seismic data, P-wave velocity reduction in the uppermost mantle from the outer rise to the trench axis. This may implie mantle serpentinization due to water penetration to the mantle through a bend-related normal fault system (Fujie et al. 2013). Seismic reflection data also show gaps between clearly imaged the Moho reflections (Nakamura et al. 2014). Moreover, aftershock observation of the 2011 Tohoku-oki earthquake in the outer rise shows that normal fault earthquakes are distributed from the crust to ˜40 km deep in the mantle. This suggests that the oceanic lithosphere became under extension stress filed down to 40 km deep after the 2011 event (Obana et al., 2012). Comparing the seismic reflection image and the aftershocks distribution likely indicates that a cluster of the normal fault aftershocks seem to be located in the area where we observe gaps of the Moho reflection. This suggest that the gaps of the Moho reflection can be a structural factor to identify the fault zones of the outer rise normal fault event. In this presentation, we summarize the results of our previous studies and introduce a future plan of the integrated seismic study in the outer rise region.

Keywords: Outer rise earthquake, Japan Trench, Fault, Seismic image, Earthquake monitoring, Megathrust

SSS02-08 Room:IC Time:May 25 11:15-11:30

Proper selection of least squares parameters in tsunami waveform inversion through computational intelligence

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Nature-inspired computational methodologies have been successfully applied to many geophysical optimization problems. One of the advantages of such methods is the ability to avoid local optimum solutions, which is something classical methods fail to do. This is because the methods require no derivative information and thus the search is not restricted by the local gradient of the objective function. This feature is of importance in real world applications, where the optimization problems are often characterized by irregular error surfaces that are sometimes non-differentiable. In the standard tsunami waveform inversion based on the Green's function superposition, the linear assumption allows model parameters to be determined straightforwardly using least squares. Therefore, the use of a more advanced method is unnecessary, unless a different design parameter is introduced leading towards a better solution. To that end, we proposed a utilization of computational intelligence in the tsunami waveform inversion using distinct design parameters.

In this study, a tsunami waveform inversion without the fault model assumption is used to test our proposed method. We develop an optimization method based on a genetic algorithm that further enhanced by a pattern search method to find optimal model parameters for the least squares inversion, which mainly dependent on the spatial distribution. Here, we do not use the method for directly estimating the unknown parameters formulated in the least squares inversion. In addition, we apply the same algorithm to determine the water movement initiation time at specified locations inside the inverse region or tsunami source-influenced area. This is applicable to cases where the transient deformation is not negligible. The results suggest that the method not only leads to better accuracy, but also increases the ability to reveal the underlying physics associated with the tsunami generation process. The method has been applied to both artificial and real event of the 2011 Tohoku-Oki tsunami.

Keywords: Tsunami waveform inversion, Computational intelligence, 2011 Tohoku-Oki tsunami

SSS02-09 Room:IC Time:May 25 11:30-11:45

Rupture dynamics inferred from early stage of the 2011 great Tohoku-oki earthquake

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The occurrence of the 2011 M 9.0, Japan, Tohoku-oki earthquake gives us a unique opportunity to investigate the detailed process of the initiation and propagation of a rupture during a gigantic earthquake. It is observed that the mainshock of the Tohoku-oki earthquake was triggered by the M7 foreshock with time delay of two days occurred near the hypocenter of the mainshock. Therefore, it is expected that the early stage of the mainshock rupture reflects perturbations caused by the foreshock. In order to test this hypothesis, we examine the stress changes during the dynamic rupture propagation of this event. We used the kinematically inverted slip profile obtained by Uchide (2013), JGR, which conducted the multi-scale seismic slip inversion focusing on the first few ten seconds of the mainshock; he showed that the slip profiles around the hypocenter exhibited high-speed rupture propagations. We calculate the dynamic stress changes on the fault plane given the inverted slip profile by applying the 3-D elasto-dynamic boundary integral equation method (Ando and Okuyama, 2010, GRL). The calculated stress changes shows generally the slip weakening behavior consistent with the occurrence of the high speed rupture. The obtained stress change also shows heterogeneous distribution over the fault area, which might reflect the stress perturbation existed before the mainshock.

Keywords: Tohoku-oki earthquake, dynamics, rupture, friction, inversion, simulation

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SSS02-10 Room:IC Time:May 25 11:45-12:00

Characteristics and waveform simulation for dynamic rupture model of the 2011 Tohoku earthquake with deep SMGAs

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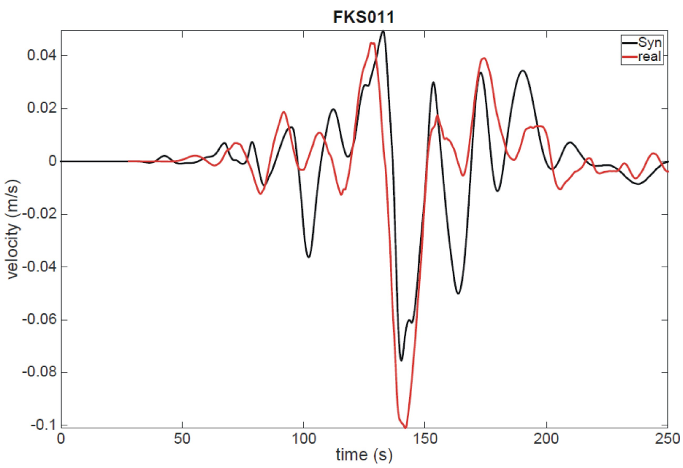
The rupture process of the 2011 Tohoku earthquake is simulated using the spectral element program SPECFEM3D with the recent dynamic rupture module implemented by Galvez et al. (2014). The state-of-the-art unstructured mesh software CUBIT provides a powerful tool to deal with geometrical complexities. We use this capabilities to perform dynamic rupture simulation for the Tohoku earthquake including the non-planar slab interface and tiny angles (<5) found in the trench wedge. Based on this geometry we allocate asperities and SMGAs inspiring by the source inversion results and gradually modify the asperity distribution. To create more slip in the shallow regions, the main asperity has been moved close to the trench. In the deep region we place asperities on the strong-motion generation areas (SMGAs) detected by Kurahashi & Irikura (2013). By a systematic adjustment of stress drops, slip critical distance (Dc), the rupture reproduces final slip recorded by kinematic models (e.g. Suzuki et al.(2011); Lee et al. (2011)).

Moreover, this model also reproduces qualitatively the multi-seismic wave front observed from the strong ground motion and GPS data along the Japanese coast. We take the seismic station (FKS011) and compare the recorded velocity waveform and our 1D synthetic between 20 to 100 seconds period (see Figure). The fitting is remarkable but there are other stations less accurate. For a set of coastal hard rock sites we perform 3D FDM simulations for the JIVSM velocity model and periods 5 to 20sec, and confirm that developed dynamic model reproduce observed wave-packets as amplitude, spectral content and arrival time. Overall, we could resemble the rupture process of the Tohoku earthquake and reproduce qualitatively the recorded multi-seismic wave front detected by the KNET and Kik-net networks.

Acknowledgements. Seismic waveform data of the KiK-net and KNET were used. We are indebt to J.-P. Ampuero and K. Miyakoshi for fruitful discussions. This study was based on the 2014 research project 'Improvement for uncertainty of strong ground motion prediction' by NRA (Nuclear Regulation Authority).

Keywords: 2011 Tohoku earthquake, dynamic simulation, slip reactivation



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SSS02-11 Room:IC Time:May 25 12:00-12:15

Possible Rupture Scenario for the Area Off-Ibaragi Prefecture in the 2011 Off the Pacific Coast of Tohoku Earthquake

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The 2011 Off the Pacific Coast of Tohoku Earthquake (Tohoku Earthquake, Mw 9.0) was one of the most devastating earthquakes in Japanese history. It ruptured a very broad area of the plate boundary along the Japan Trench, from the northern end of offshore Aomori prefecture to the southern end of offshore Ibaragi prefecture. The largest aftershock (Mw 7.7) occurred 30 minutes after the main shock offshore Ibaragi Prefecture (Off-Ibaragi area). The rupture of this aftershock was not involved in the rupture of the main shock. It might be useful for the assessment of future seismic hazards to understand what physical mechanism stopped the main shock rupture at the edge of the rupture area of this largest aftershock, and if this area can rupture simultaneously with a future huge earthquake. Some studies have addressed these questions based on structural heterogeneities imaged by tomography in the Tohoku region (Liu et al., 2014) or on compilations of observations of subduction zones around the world. However, more investigations based on numerical simulation studies might be necessary to elucidate the physical mechanisms.

In this study, we have carried out dynamic rupture simulations to understand the mechanisms of rupture arrest of the Tohoku earthquake. The simulations assume a slip-dependent friction law (Ida, 1972) and use the 3D Spectral Element Method (Galvez et al., 2013), which is numerically stable and accurate even for subduction earthquake models with low dipping angle. To set the initial stress conditions for the simulation, we use constraints based on a slip-deficit map inferred from the analysis of GPS data (Ikuta et al., 2012) and the estimates of inter-seismic recurrence time along the Japan Trench by the Headquarter of Earthquake Research Promotion in Japan (2011).

In contrast with the real Tohoku Earthquake, the main shock rupture resulting from our simulation propagated to the Off Ibaragi area, indicating that the initial part of the rupture had enough energy to break through the Off Ibaragi area. Factors that we did not include in this simulation, such as attenuation and smaller-scale features of the megathrust geometry due for instance to subducted seamounts, might have played an important role in the rupture arrest in the southern end of the Tohoku earthquake in 2011.

Keywords: Rupture Simulation, Dynamic Model, The 2011 Off the Pacific Coast of Tohoku Earthquake, Slip Deficit

SSS02-12 Room:IC Time:May 25 12:15-12:30

Structural control on the nucleation of Nankai megathrust earthquakes

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Many large interplate earthquakes (M >7) occurred on the megathrust fault of the Nankai subduction zone, where the young Philippine Sea plate is subducting beneath the Eurasian plate along the Nankai Trough. The landward downdip limit of the Nankai megathrust seismogenic zone is located at a depth of ~30-40 km, marked by the occurrence of episodic tremors and slips. The seaward updip limit is not very distinct, being generally at a depth of ~10 km and correlated with a suite of diagenetic to low-grade metamorphic processes.

To clarify the causal mechanisms of the Nankai megathrust earthquakes, we studied the detailed three-dimensional P and S wave velocities (V), attenuation (Q), and Poisson's ratio (PR) structures of the southwest Japan forearc, using a large number of high-quality arrival time and t*data measured precisely from seismograms of local earthquakes. The suboceanic earthquakes used are relocated precisely using sP depth phase and ocean bottom seismometer data. Our results show the existence of two prominent high-V, high-Q, and low-PR patches separated by low-V, low-Q, and high-PR anomalies in the Nankai megathrust zone. Megathrust earthquakes during 1900 to 2013 nucleated in or around the high-V, high-Q, and low-PR patches, which may represent strongly coupled areas (i.e., asperities) in the megathrust zone. Our results indicate that structural heterogeneities in the megathrust zone, such as the subducting seafloor topography and compositional variations, control the nucleation of the Nankai megathrust earthquakes.

Keywords: Nankai arc, Subduction zone, Megathrust earthquake, slab, fluids

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SSS02-13 Room:IC Time:May 25 12:30-12:45

Hydrous state of the Philippine Sea plate inferred from receiver function analysis using onshore and offshore data

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Exploring fluid distribution in subduction zones is an intriguing topic because it is considered that the fluids affect the occurrence of non-volcanic tremors, slow slip events, microearthquakes, and even the rupture area of the megathrust earthquakes. The fluid generating strong contrast in seismic velocity, many studies have utilized scattered teleseismic body waves, or receiver functions (RFs), to infer the hydrous state in worldwide subduction zones [*e.g., Kawakatsu and Watada*, 2007; *Audet et al.*, 2009]. General consensus among these studies is that subducting oceanic crust hosts abundant fluids, which is supported by overlying positive and underlying negative RF amplitudes. Most of the studies, however, conducted analysis by limiting their study area into two-dimensional vertical sections beneath inland area. Lateral variety and seaward extension of the fluid distribution remains uninvestigated. In this study, we conducted RF analysis using ocean-bottom seismometers (OBSs) and on-land permanent stations deployed around the Kii Peninsula in the southwestern Japan.

OBS vertical component records contain dominant water reverberations, so conventional method fails to estimate correct RFs. We hence developed a method to remove the reverberations using a linear filter, which were constructed from the deconvolution of OBS vertical records by source wavelets. We estimated the source wavelets from stacked traces of on-land station records. Resultant RFs by removing water reverberations with the filter show an improvement on later phase identification, compared with those from conventional method. Using these RFs, we constrained the geometry of the subducting Philippine Sea plate and inferred the hydrous state of the oceanic crust.

Our RF image shows negative RF amplitudes on the plate interface and positive RF amplitudes on the oceanic Moho, which we inferred as hydrous oceanic crust. The hydrous oceanic crust seems to extend seaward to ~5 km depth from our results. We found the RF amplitude reduction on both sides of the oceanic crust at the belt-like region of non-volcanic tremors, while the long-term slow slip patch [*Kobayashi*, 2014] is located at the adjacent place with strong RF amplitudes. This contrasting features suggest that difference in pore fluid pressure or permeability of the plate interface controls the slip behavior of the plate interface. The comparison between microseismicity [*Akuhara et al.*, 2013] and the configuration of the subducting plate modeled in this study reveals that the oceanic crust becomes aseismic as slab subducts deeper, and that the transition depth varies laterally. This may provide some constraints on the process of slab dehydration although detailed simulation of thermal structure is necessary in the future.

Keywords: Subduction zone, fluid distribution, ocean-bottom seismometer, receiver function

SSS02-14 Room:IC Time:May 25 14:15-14:35

Results from IODP Expedition 348: Deep Drilling Above the Plate Interface, Nankai Trough Subduction Zone

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During IODP Expedition 348 from October 2013 to January 2014, Site C0002 was drilled to more than 3000 meters depth into the inner accretionary wedge at the Nankai Trough, setting a new depth record for scientific ocean drilling. It is the first hole to access the deep interior of an active convergent margin. Site C0002 is part of the NanTroSEIZE transect off the Kii Kumano region of Japan, imaged with 3D seismic reflection and drilled on a series of Chikyu expeditions to shed light on the processes around the up-dip edge of seismogenic locking and slip. At Site C0002, riser drilling has passed through the approximately 900 m thick Kumano forearc basin and pierced the underlying Miocene age accretionary wedge. The zone from 865 to 3056 meters below the sea floor was sampled via limited coring, extensive LWD logging, and continuous observations on drill cuttings that all reveal the materials and processes in the deep interior of the inner wedge. Predominantly fine-grained mudstones with common turbiditic sands were encountered, complexly deformed and exhibiting well-developed scaly clay fabrics, variable bedding dip with very steep dips prevailing, and veins that become more abundant with depth. The biostratigraphic age of the sediments in the lowermost part of the hole is thought to be about 9 to 11 Ma, with an assumed age of accretion of 3 to 5 Ma.

Physical properties suggest that the inner wedge from 1600 to 3000 mbsf has quite homogeneous properties. P wave speeds from sonic logs increase with depth to approximately 1600 meters, but are constant to slightly decreasing with depth from 1600 to 3050 meters. We hypothesize that this change in trend indicates the onset of elevated pore fluid pressure, but structural and lithologic factors may also play a role. A borehole leak-off test (LOT) and a series of borehole pressurization and injection tests were also performed, which we synthesize to estimate the least principal stress, Shmin. Furthermore, downhole pressure while drilling (PWD) measurements recorded during borehole packoff events provide information on the maximum principal stress, SHmax. Taken together, the LOT and PWD observations suggest that the inner wedge at about 2000 meters depth is currently in a strike-slip stress regime, despite its position as the hanging wall of a main plate boundary thrust.

Keywords: accretionary wedge, seismogenic zone, subduction, Nankai Trough, physical properties, in situ stress

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SSS02-15 Room:IC Time:May 25 14:35-14:55

Seafloor monitoring for dynamics and stress state of the seismogenic plate interface in the Nankai Trough

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Stress and pore-fluid pressure are considered to be key parameters governing behavior of seismogenic plate interface. Direct observation of these parameters is difficult, but we are trying to establish seafloor observation techniques that let us infer these parameters at the seismogenic plate interface in the Nankai Trough, south of Japan.

In the Nankai Trough, we started development of real-time seafloor observation network (called DONET) since 2010. The network aims monitoring of seismic activity in the seismogenic subducting plate boundary in the Nankai Trough where repeated occurrence of large earthquakes in the history. The DONET will distribute more than 50 observatories in the rupture area of Tonankai and Nankai earthquakes. Currently, the network is continuously monitoring micro earthquakes and very low frequency earthquakes in the vicinity of them with 20+ sites. This enables us to look into stress state and its temporal change in the crust through their mechanisms. Very low frequency events were observed below the DONET network after off Tohoku events in March, 11, 2011 (Toh et al, 2011). We consider monitoring of such events is very important to know current status of the interface in preparation for the next earthquake.

The DONET observatories are also monitoring seafloor water pressure using Quartz pressure gauges, which are able to detect seafloor level change as small as 1 cm. We plan to use the networked seafloor pressure observation to detect crustal deformation due to slip in the plate interface. As the pressure gauge has instrumental offset drift in long-term, it is currently difficult to evaluate small ground deformation using pressure data over month period, but we are developing techniques to calibrate seafloor pressure gauge to compensate effects of the instrumental drift so that we can identify long-term change of the seafloor level as small as 1 cm also in such long-term. When such techniques are developed, we expect to identify where in the subducting seismogenic plate interface accumulate slip deficit for the next large earthquake.

We consider pore-fluid pressure near the plate interface may control slip in the plate interface. Observation of pore-fluid pressure in the crust is already in practice using seafloor boreholes drilled in scientific drilling programs (ODP Leg 196, and IODP expeditions 332) here in the Nankai Trough. Existing borehole pore-fluid pressure observations in the Nankai Trough, are reaching up to 1 km below the seafloor. Therefore, it is very effective way to observe pore-fluid pressure in seaward end of the plate interface, but in deeper interface where seismogenic slip occurred in the last large earthquake in the Nankai Trough, existing technology is still out of reach to the interface itself and we need to develop deep borehole observatory penetrating it in the future.

Monitoring characteristics of seismic waves traveling near the target seismogenic plate interface may provide another way to estimate stress state and pore-fluid pressure. Brenguier et al., (2014) suggested that the crustal seismic wave velocity would have strong relationship with status of pore-fluid in crust. Seismic anisotropy is also known to indicate background stress state. We were encouraged from these facts to conduct a series of experiments to observe characteristics of seismic wave velocity in the Nankai Trough seismogenic plate boundary and its temporal change using the DONET and borehole observatory. Using airgun seismic source and the network of seismometers, seismic velocity of the crust is measured precisely. By repeating, we expect to identify its change. To begin with, we conducted an airgun shooting cruise in March, 2013 to survey anisotropic structure of the area, confirming observed seismic anisotropy around IODP site C0002 in accordance with known stress from borehole breakout. Next experiment is planned in March, 2014 to evaluate our ability to identify change in seismic velocity.

Keywords: seafloor observation, seismogenic zone, stress, seismic anisotropy, temporal change, borehole

SSS02-16 Room:IC Time:May 25 14:55-15:15

Estimation of in-situ stress and strength along the Nankai Trough subduction megathrust

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Understanding the mechanics that underlie the spectrum of fault slip behaviors observed along subduction megathrusts requires a sound investigation of depth-varying in-situ stress conditions, absolute fault strength, and fault rheology. The porosity reduction of sediments with progressive burial plays an important role in deformation style in the shallow portion of subduction zones because the deformation mode and strength of porous rocks are largely dependent on both porosity and pressure. Here, we report on results of triaxial deformation experiments on (1) modern sediments currently subducting at the Nankai Trough; and (2) tectonic melange near the Nobeoka thrust in the exhumed Shimanto complex, which is an ancient out-of-sequence-thrust or plate boundary, to provide constraints on the stress state and strength along the plate boundary.

For the mudstone core samples (porosity of 43%) recovered from the Nankai Trough in the IODP NanTroSEIZE project, we conducted triaxial compression and extension tests under a range of loading paths at room temperature, and measured sonic velocity and porosity during the tests. We then used these data to develop empirical relations between sonic velocity, porosity, and stress, in order to estimate in situ stress along the megathrust plate boundary from P-wave velocities defined by seismic survey data. Different loading paths do not affect the relationship between P-wave velocity and porosity, but they do affect the relationship between porosity and effective mean stress: at the same effective mean stress, sediments are more compacted with increasing differential stress. Based on expected in situ stresses and pore pressures for a range of possible scenarios under different loading paths, we suggest that the Kumano basin is loaded in a uniaxial stress condition, whereas the prism and underthrust section are most likely loaded along a near critical stress condition with lateral compression. We find that the Kumano Basin is likely to be hydrostatically pressured, whereas the prism and underthrust section in the vicinity of the plate boundary are moderately overpressured ($\lambda *$= ˜0.5 in average) and significantly overpressured ($\lambda *$= ˜0.85 in average).

For the tectonic melange samples (porosity of 2%) from the footwall of the Nobeoka thrust fault in the NOBELL project, we conducted triaxial compression tests along a conventional tri-axial loading path, where confining pressure is kept constant and axial stress is progressively increased. The cylindrical specimens were deformed at an axial displacement rate of 0.5 μm/s, corresponding to strain rates of 1.6×10^{-5} s^{-1}, and at a temperature of 250 ℃ and an effective pressure (Pe) of 120 MPa (confining pressure of 200 MPa and pore pressure of 80 MPa) or 20 MPa (confining pressure of 200 MPa and pore pressure of 180 MPa). The temperature was chosen based on the estimated temperature (250-300 ℃) at which the melange were formed [Kondo et al., 2005]. The two different effective pressures of 120 MPa and 20 MPa correspond to estimated stress conditions at ˜8 km (geothermal gradient of ˜30 ℃/km), for hydrostatic and 90% of lithostatic pore pressures, respectively. The experimental results show that the melange samples deform in a brittle manner at Pe = 20 MPa. The strengths reach a peak at 80-90 MPa, followed by strain weakening to residual strengths of 40-60 MPa. At Pe = 120 MPa, on the other hand, the foliated cataclasite deforms in a hybrid brittle-ductile mode, with a steady-state strength of ˜300 MPa. Because the brittle-ductile transition of the melange samples lies on the extrapolation of critical loading on the Nankai mudstone samples, the melange samples in the ancient prism may provide a good analog for the mechanical behavior of underthrust rocks at seismogenic depth in the modern Nankai Trough. The strength of these clay-rich sediments increases as they compact with depth, but is not as high as that of sandstones or carbonates.

Keywords: Nankai Trough, subduction zone, IODP, NanTroSEIZE, Nobeoka thrust, melange

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Estimation of sediment friction coefficient from heating upon APC penetration during the IODP NanTroSEIZE

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During the Nankai Trough Seismogenic Zone Experiments (NanTroSEIZE) of the Integrated Ocean Drilling Program (IOD), the advanced piston corer temperature (APCT) tool was used to determine in situ formation temperatures while piston coring down to ~200 m below sea floor. When the corer is fired into the formation, temperature around the shoe abruptly increases due to the frictional heating. The temperature rise due to the frictional heat at the time of penetration is 10 K or larger. We found that the frictional temperature rise increase with increasing depth, and that its intersection at the seafloor seems non-zero.

Frictional heat energy, which is basically proportional to the temperature rise, is the product of the shooting length D and the shear stress (tau) between the pipe and the sediment. Assuming a coulomb slip regime, the shear stress is shows as: tau = tau0 + m*(Sv-Pp), where tau0 is the cohesive stress, m the frictional coefficient between the pipe and the sediment, Sv the normal stress at the pipe, PP the pore pressure). This can explain the non-zero intersection as well as depth-dependent increase for the frictional heating observed in the APCT data. Assuming a hydrostatic state and by using the downhole bulk density data, we estimated the friction coefficient for each APC-T measurement. For comparison, we used the vane-shear strength measured on core samples to estimate the friction coefficients.

The frictional coefficients were estimated as ranging 0.01 ? 0.06, anomalously lower than expected for shallow marine sediments. They were lower than those estimated from vane-shear data, which range 0.05 to 0.2. Still, both estimates show a significant increase in the friction coefficient at Site C0012, which dominates in the hemipelagic sediment in the Shikoku Basin. The anomalously low values suggest either fluid injection between the pipe and the sediment during the measurement, uncertainty in converting the observed temperature rise to the frictional heat generation, etc. Further investigation is planned for other drillsites.

Keywords: IODP, NanTroSEIZE, APC-T, Friction coefficient

SSS02-18 Room:IC Time:May 25 15:30-15:45

Origin of mega-splay fault in subduction zone - out-of-sequence thrust or evolution gap in subduction

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Mega-splay fault in subduction zone is a major seismogenic fault in subduction zone and separates outer and inner wedges of the forearc in many places. Origin of the mega-splay fault, however, is not so clear and is ambiguously considered to be out-of-sequence thrust in accretionary prism or accidental result of thrust branching from the plate boundary mega-thrust.

The out-of-sequence thrust model assumes that terrigenous sediments supply and relative plate convergence are constant, and the prism grows constantly. The prism grows by in-sequence thrusting at the deformation front, with out-of-sequence thrusting occurring in the inboard of the prism and maintaining the critical taper. The resulting accretionary prism can thus thicken until it obtains the thickness of continental crust of ~30 km and more with association of exhumation of high grade metamorphic rocks to keep the critical taper.

If we attempt to apply this out-of-sequence thrust model to the mega-splay fault in the Nankai margin and tectonic boundary faults in ancient accretionary prisms of southwest Japan, the model implies that the northern Shimanto Belt was continuously followed by the growth of the southern Shimanto Belt and modern Nankai accretionary prism without any serious break since Late Cretaceous time to present.

The tectonic history of southwest Japan, however, presents several complications of the events, such as global change in relative convergence with subduction of several different oceanic plates such as Farallon, Kula, Philippine Sea, Pacific and other anonymous plates, intermittent sediment supply to the trench in Late Cretaceous and Palaeogene times as suggested by many researchers.

Given that one or some combination of these tectonic scenarios may have controlled the onset and evolution of the main tectonic boundaries and setting of the mega-splay fault in the forearc. Present mega-splay fault in the Nankai Trough may be related to the onset of new tectonic framework at ~2Ma and present inner wedge appears to have related to the onset of new subduction in the Nankai Trough at ~6Ma. Thus, out-of-sequence thrust interpretation for the origin of the megasplay fault should be avoided.

SSS02-19 Room:IC Time:May 25 15:45-16:00

Plate geometry, splay fault and tsunamigenic earthquake in the southernmost Ryukyu trench

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In the last few decades, a series of megathrust earthquakes and their ensuing tsunamis worldwide required us to reassess seismic potentials in subduction zones. A typical example in controversy is the Ryukyu subduction zone, extending 1,200 km from Kyushu, SW Japan, to Taiwan collision zone (e.g., Lin et al., 2014). Along this subduction zone, historical evidence for great interplate earthquakes (M>8) has been poorly documented and ongoing back-arc rifting along the Okinawa trough implies that the plate coupling is weak (Peterson and Seno, 1984). In more recent years, a variety of seismic activities including large earthquakes with M>7 (Engdahl and Villasenor, 2002), repeating slow-slip events (Heki and Kataoka, 2008) and very low frequency earthquakes (Ando et al., 2012) were found indicative of spatial variation in frictional property along the plate boundary and surrounding faults. Historically, the Yaeyama earthquake in 1771 with M˜8 is thought to have ruptured a shallow portion of the plate interface and generated devastating tsunami with a maximum run-up height of ˜30 m, causing approximately 12,000 fatalities (Nakamura, 2009). Although these documentations imply that a diversity of seismogenic processes along the Ryukyu subduction zone, fundamental structural features associated with plate subduction are not well understood. Moreover, the slab geometry itself is poorly constrained due to the sparse seismic observation networks.

In order to improve our understanding seismic potentials and structure controlling the seismogenic process in the Ryukyu subduction zone, we started a new 8-year project that consists of four two-dimensional active-source seismic experiments and extensive passive-source seismic observations covering the entire Ryukyu arc. In 2013, active-source seismic data were collected in the southernmost Ryukyu trench that crosses the potential source region of the 1771 Yaeyama earthquake (Nakamura, 2009). For refraction/wide-angle reflection analyses, seismic wave from air-gun shots were recorded at a total of 60 ocean bottom seismographs with approximately 6-km spacing on a ˜390-km-long profile. On the same line, multichannel seismic (MCS) reflection profiling using the ˜6-km-long, 444-channel streamer cable was also carried out.

Using this data set, we succeeded in imaging the plate boundary down to ˜30 km depth. The dip angle of the slab increases from ˜5 degree closer to the seafloor to ˜20 degree at greater depths. In the fore-arc region, we found a fault branches from the plate boundary to the seafloor and they form a low-velocity accretionary wedge in between. This splay fault and accretionary wedge almost overlap the source region of the 1771 Yaeyama earthquake proposed by Nakamura (2009) and thus may have played a role in tsunami generation. The slab contacts with the overriding wedge mantle at depths greater than ˜25 km. This region shows greater reflectivity at the plate boundary and is also coincident with repeating slow-slip events (Heki and Kataoka, 2008). These results probably suggest a changing frictional property along the plate interface with increasing depths.

Keywords: Ryukyu subduction zone, Philippine Sea plate, Accretionary wedge, Reflection/refraction analysis

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SSS02-20 Room:IC Time:May 25 16:15-16:35

Unlocking the secrets of slow slip at the Hikurangi subduction margin

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The northern Hikurangi subduction margin, New Zealand is the site of the shallowest well-documented slow slip events (SSEs) on Earth. Due to the close proximity of the SSE source area to the seafloor at the offshore Hikurangi margin (<5-15 km), it has become an important international target for a variety of geophysical studies to understand the offshore physical mechanisms that lead to slow slip. The centerpiece of these efforts is a series of IODP proposals to undertake riserless (Joides Resolution) and riser (Chikyu) drilling, and CORK observatory installation on a transect spanning the shallow Hikurangi SSEs. We understand that if scheduling of riserless drilling (and observatory installation) occurs, it is likely for 2017. We will discuss the plans and scientific objectives for both riser and riserless drilling, and borehole observatories. We will discuss other ongoing experiments at the northern Hikurangi margin, including an upcoming heatflow survey, and recent seafloor geodetic (Absolute Pressure Gauges) and OBS deployments to undertake near-source investigations of SSE deformation and related seismicity of the shallow (<10 km depth) subduction thrust (the HOBITSS project). We will also present preliminary analysis of slip distribution and seismicity (using onshore data) from a large SSE that occurred in October 2014 directly beneath the HOBITSS network.

Keywords: subduction, slow slip events, GPS, scientific drilling, seafloor geodesy, New Zealand

SSS02-21 Room:IC Time:May 25 16:35-16:50

Physical property and Microstructure across the Seismic reflectors in the Upper plate of the Costa Rica Subduction zone

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Costa Rica subduction zone offshore Osa peninsula is known as an erosive margin characterized by active seismicity, subduction of the Cocos Ridge, active fluid seeps, and mud volcanoes. To understand the geologic processes of this margin, Integrated Ocean Drilling Program (IODP) Expedition 334 and 344 have drilled into the overriding Caribbean plate and the subducting Cocos plate offshore Osa in 2011 and 2012. Velocity structures acquired from previous seismic reflection surveys indicate that the upper plate is composed of a few hundred meters to ~2 km thick slope sediments overlying consolidated high velocity material (~3.5-4.3 km/s), bounded by distinct seismic reflectors (von Huene et al., 2000). The nature of the seismic reflectors and the lithology of the consolidated material beneath the slope sediments had been unknown and were considered to be the uplifted basement or old accreted material (e.g. Vannucchi et al., 2013) before Expedition 344 drilled deeper into the middle slope. The unconformity between the slope sediments (Unit 1) and consolidated materials (Unit 2 and 3) were penetrated at Site 1380, across zones that correlate with seismic reflectors. Unit 2 and 3 consists of lithified, low porosity sediments compared to Unit 1, but the age gap between Unit 1 and 2 is very small (<~0.49 m.y.), indicating rapid sedimentation rate (NN18 zone, ~600 m/m.y.) despite the unconformity (Harris et al., 2013). The process for the formation of the unconformity and the physical property transitions are yet to be clarified. In our study, to understand the tectonic and depositional history and the processes of subduction erosion occurring at the Costa Rica subduction zone, we evaluate the depositional, tectonic, and geochemical factors that account for the consolidation nature and the formation of the seismic reflectors in the upper plate, by conducting microstructural observations, particle size analysis, X-ray fluorescence analysis, X-ray diffraction analysis, and resistivity measurements using the samples from Site 1380.

The microstructures of the samples observed through the microscope tend to develop dense and cohesive textures in the low porosity sediments of Unit 2 and 3, and particle size changes across several unconformities. Particle size decrease with depth in Unit 2 and finer sediments form well-sorted structures that may account for the porosity decrease. The cross correlation between measured particle size and shipboard porosity show negative correlation especially at Unit 2, indicating that larger sized particles form smaller or fewer pores which may be due to finer particles filling pores between larger particles. The microstructures of the sediments occasionally exhibit foliated fabrics that are partially distributed. From the X-ray fluorescence and X-ray diffraction measurements, Al, K, Ti tend to concentrate in the higher porosity sediments of Unit 1, whereas Si, Ca, P, Mg, Na, and Mn concentrate in the lower porosity sediments of Unit 2 and 3, which are consistent with the transition in mineral composition marked by the increase in analcime and chlorite and the decrease in clay abundance in Unit 2 and 3. The crossplots between porosity and element concentration show negative correlations in Mg, Na, and Mn with porosity, suggesting that the minerals rich in these elements may relate with the consolidation and/or form the pore-filling materials or cements in Unit 2 and 3.

The depositional effect of grain size sorting, the tectonic effect of formation of foliated fabrics, and the geochemical effect of mineral precipitation and/or cementation are indicated to be the factors that characterize the unconformity, consolidation state and the seismic reflectors. In our presentation, we further investigate each effect to constrain the geologic processes occurring across the unconformity and seismic reflectors that form the upper plate structure of the Costa Rica subduction zone.

Keywords: Costa Rica subduction zone, seismic reflector, IODP, Costa Rica Seismogenesis Project, physical property, microstructure

SSS02-22 Room:IC Time:May 25 16:50-17:05

Rupture process of the 2014 Iquique, Chile earthquake estimated from tsunami waveforms, teleseismic, and GPS data

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We applied a new method to compute tsunami Green's functions for slip inversion of the 1 April 2014 Iquique earthquake using both near-field and far-field tsunami waveforms. Inclusion of the effects of the elastic loading of seafloor, compressibility of seawater, and the geopotential variation in the computed Green's functions reproduced the tsunami travel-time delay relative to long-wave simulation, and allowed us to use far-field records in tsunami waveform inversion. Multiple time window inversion (Satake et al., BSSA, 2013) was applied to tsunami waveforms iteratively until the result resembles the stable moment-rate function from teleseismic inversion. We also used GPS data to perform a joint inversion of tsunami waveforms and co-seismic crustal deformation (Gusman et al., EPSL, 2012). According to results, the major slip region with a size of 100 km $\times$ 40 km is located down-dip the epicenter at depth ˜28 km, regardless of assumed rupture velocities. The total seismic moment from the slip distribution estimated by the joint inversion is 1.24×10^{21} Nm (Mw 8.0) (Gusman et al., GRL, 2015). This seismic moment is slightly smaller than 1.88×10^{21} Nm (Mw 8.1) from a teleseismic waveform inversion.

The tsunami arrival time and polarity reversal observed at far-field DART stations can be accurately reproduced by solving shallow water equations and applying the phase velocity correction to the simulated waveforms (Watada et al., JGR, 2014). The slip distribution of the 2014 Iquique earthquake from our joint inversion method can accurately explain the tsunami waveform in the near-field as well as in the far-field. We propose the tsunami phase velocity correction to be included as a standard procedure in inversion methods when using far-field tsunami waveforms.

The teleseismic inversion with different rupture velocities (1.5, 2.0, and 2.5 km/s) yielded similar moment rate functions which all peaked at ˜35 s, but their spatial slip distributions are different. On the contrary, the joint inversion gives a stable spatial slip distribution for different rupture velocities. Among the slip distributions from the teleseismic inversions with the three different rupture velocities, the one for 1.5 km/s is most similar to the slip distribution from the joint inversion of tsunami waveforms and GPS data in terms of large slip area. Thus, the velocity of 1.5 km/s may better represent the rupture process of the 2014 Iquique earthquake (Gusman et al., GRL, 2015).

Keywords: Rupture process, Tsunami waveforms, GPS data, Teleseismic body waves, Tsunami dispersion, Joint inversion

SSS02-23 Room:IC Time:May 25 17:05-17:20

Tsunami Hazards from secondary sources in the Makran Subduction Zone, northwestern Indian Ocean

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We present evidence for hazards from secondary tsunami sources in the Makran subduction zone (MSZ), NW Indian Ocean, by analyzing two tsunami events of November 1945 and September 2013 in this region. We revisited the source of the 27 November 1945 tsunami in the MSZ by analyzing two observed tsunami waveforms in Karachi and Mumbai and coastal deformation data. However, the source model based on far-field tsunami waveforms (Heidarzadeh and Satake 2014, Pure Appl. Geophys., doi: 10.1007/s00024-014-0948-y) produces a maximum coastal runup height of 5-6 m in the near-field; almost half of the observed runup height of 12-15 m. This finding combined with the reports of failure of the trans-oceanic submarine communication cables during this earthquake and tsunami may indicate possibility for submarine landslides triggered by the main shock. Another possibility can be large slip due to splay faults which branch from the plate boundary during large earthquake since many splay faults are present in the seismic profiles of the MSZ. These secondary tsunami sources cannot be estimated from far-field tsunami data. The recent tsunami on 24 September 2013 in the Makran region was triggered by an inland Mw 7.7 earthquake. While the main shock and all aftershocks were located inland, a tsunami with a dominant period of around 12 min was recorded on nearby tide gauges and a DART station. We examined different possible sources for this tsunami including a mud volcano, a mud/shale diapir, and a landslide/slump through numerical modeling (Heidarzadeh and Satake 2014, Geophys. J. Int. 199, 752-766). Only a submarine landslide/slump with a source dimension of 10-15 km and a thickness of around 100 m, located 60-70 km offshore Jiwani (Pakistan) at the water depth of around 2000 m, was able to reasonably reproduce the observed tsunami waveforms. In terms of tsunami hazards, analysis of the two tsunamis shows that the MSZ is posed to potential tsunami hazards from secondary sources such as submarine landslides and splay fault branching from the plate boundary.

Keywords: Northwestern Indian Ocean, Makran subduction zone, Tsunami, Splay faluting, Landslide, Tsunami secondary sources

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Microfault classification and difference in roughness with seismic cycles exampled from the Chelung-pu fault, Taiwan

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Change in stress with seismic cycle was strongly related to stress drop. Just after Tohoku-Oki earthquake, the stress orientation was changed from horizontal compressional stress to vertical compressional stress. The change in stress orientation with seiscmic cycle can be detected also in paleostress using slip data from microfault close to seismic faults in on-land accrationary complex. In addition, after the change in paleostress is detected, we can classify the microfault into two. One is related to the stress state before earthquake and another is related to the stress state after earthquake. Furthermore, we also observed the classified microfault directly. In this study, we examined the paleostress in the Chelung-pu fault, Taiwan, which was a seismogenic fault at the time of the Chi-Chi earthquake, 1999 and then we analyzed roughness of the classified micro-faults.

We have conducted paleostress analysis using multiple inversion method for slip data from microfault in cores drilled in Taiwan Chelung-pu Fault Drilling Project (TCDP). Two stress orientations were classified; one is the horizontal maximum principal stress and another is the others are the horizontal minimum or intemediate principal stresses in the compressional stress orientation at the time of the Chi-Chi earthquake, which is the switch in stress orientation similar to that in Tohoku-Oki earthquake. Combining the estimated stress orientations with stress polygons, the stress magnitude for each stress state was constrained. Stress magnitude for the horizontal compressional stress is larger than that for the horizontal extensional stress, which support the idea that the change in stress state can be related to seismic cycles.

On the basis of the stress inversion results, we classified the microfaults into that related to horizontal compressional stress and that related to horizontal extensional stress. We have collected samples of microfault for each stress state and identified that the roughness of the fault surfaces is different between them. Relief of slicken lines on microfault for horizontal compressional stress is deeper than that for horizontal extensional stress. To examine the topography of microfault surface quantitatively, we have conducted topographical analysis using a confocal microscope. Power Spector Density (PSD) was obtained from topographical data. Higher PSD value was detected in the samples for horizontal compressional stress than that for horizontal extensional stress. The slope angle of trend in PSD vs wavelength is shallower in horizontal compressional stress than that in vertical compressional stress. The differences in roughness of microfault surface can be related to the difference in stress magnitude as identified above.

Keywords: paleostress, seismic cycle, microfault, roughenss

SSS02-25 Room:IC Time:May 25 17:35-17:50

Dynamic weakening of smectite-bearing faults at subseismic slip rates

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The hydrous clay mineral smectite, which is pervasive in sediments on subducting oceanic plates, is thought to weaken and stabilize subduction thrust faults. However, these frictional properties of smectite alone cannot explain the large coseismic slip in the vicinity of a trench. Here, we performed friction experiments to demonstrate the rate dependence of friction at slip rates from 30 μm/s to 1.3 m/s for water-saturated smectite-quartz mixtures with various smectite contents, so as to shed light on the frictional response of smectite-bearing faults at intermediate to high slip rates. At slip rates of 30 to 150 μm/s, the friction coefficients decreased gradually from 0.5-0.6 to 0.1 with an increase in smectite content from 20 to 50 wt%. In contrast, at slip rates higher than 1.3 mm/s, friction exhibited marked slip weakening, resulting in low friction coefficients of 0.1-0.05, even for low smectite contents (roughly $<$30 wt%). Drastic slip weakening occurred at smectite contents of 10-30 wt% at slip rates of ˜10 mm/s, which is one to two orders of magnitude lower than the slip rate at which slip weakening was observed in previous experiments on various rock types. The intermediate-velocity weakening could be attributed to a rise in pore pressure caused by both shear-enhanced compaction and microscopic thermal pressurization of pore fluids. This process could weaken the fault even below seismic slip rates, leading to an acceleration of fault motion and potentially facilitating large coseismic slip and a stress drop in the vicinity of a trench.

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Keywords: marine sediments, friction experiment, velocity weakening, decollement, megasplay fault, tsunamigenic earthquakes