Japan Geoscience Union Meeting 2013
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SSS31-01 Room:302 Time:May 21 14:15-14:30

Tsunami generation near Japan by earthquakes in along-strike single segmentation and along-dip double segmentation

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After the 2011 Tohoku-oki megathrust earthquake of Mw9.0, we have proposed a hypothesis that megathrust earthquakes worldwide occur Along-dip Double Segmentation (ADDS) or Along-strike Single Segmentation (ASSS). The former is characterized by the apparent absence of earthquakes in the aligned seismic segments along the Japan trench as opposed to those along the Japan Islands that generate repeated smaller earthquakes (ADDS), where the 2011 Tohoku-oki megathrust occurred. Meanwhile, the latter is by a weak seismic activity before the main event all over the subduction zone, where we find aligned seismic segments along the subduction zone from the trench to the island-arc (ASSS). A typical example of ASSS is the Nankai trough, Japan, where future great earthquakes are expected. The 1960 and 2010 Chile megathrusts occurred in ASSS. In and near Japan, ADDS earthquake activity is restrictively found along the Pacific side of Hokkaido and Tohoku regions and the Hyuganada, Kyushu. The rest of seismic activity near Japan is classified into ASSS. Comparing tsunami magnitude m from local tsunami-wave heights and seismic moment Mo from long-period surface-waves of 61 earthquakes from 1923 in and near Japan, we found that tsunami-wave heights of ASSS earthquakes are almost two times larger than those of ADDS's. This is also confirmed by studying tsunami magnitude Mt evaluated from teleseismic tsunami-wave heights. The reason of this different excitation between ADDS and ASSS is considered to be due to either (1) shallower focal depths for ASSS give rise to larger ocean bottom deformation, resulting in larger tsunami excitation, (2) larger dip-angles of fault planes for ASSS, (3) three dimensional ocean-bottom structures, such as troughs, trenches and continental shelves, or (4) ocean bottom topography nearby causes the focusing of tsunami waves. (1) is the conclusion that we would like to derive. (2) Speaking about the effect of dip angles to the maximum ocean bottom deformations, the difference is about 30% in cases of reverse faults with dip angles of 30 and 60 degrees. (3) Both of earthquakes along the passive margin of the back-arc basin of the Japan sea and along the Nankai trough are classified into ASSS. (4) Both of local and teleseismic tsunami-wave heights do suggest the similar result, rejecting the local tsunami focusing. Therefore, we conclude that the larger tsunami excitation for ASSS earthquakes is due to larger amount of ocean bottom deformations than those for ADDS earthquakes or by the reason of (1) or by both the effects. Asperity for ADDS locates in the shallow part of the subduction zone along the trench, and it ruptures only in the case of megathrust events like as the 2011 Tohoku-oki earthquake. In estimating tsunami wave heights for future earthquakes, we have to take into account of this difference in tsunami excitations in the ADDS or ASSS zone.

Keywords: Along-strike Single Segmentation, Along-dip Double Segmentation, Megathrust Earthquakes, Tsunami Generation, Tsunami Magnitude

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SSS31-02 Room:302 Time:May 21 14:30-14:45

The 2011 Tohoku-oki megathrust earthquake (Mw 9.0) and slip deficit of the past tsunami earthquakes in the region

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The 2011 Tohoku-oki megathrust earthquake of Mw 9.0 generated a devastating tsunami. Gusman et al. (2011) estimated the slip distribution of the earthquake, analyzing tsunami waveforms, GPS data, and ocean bottom deformation, and they indicated that the largest slip was located shallower part of the fault near the trench. That place is the same source areas of tsunamis by significant earthquakes of 869, 1611, 1793 and 1896 (Hatori,1975). This means a slip deficit existed in the region of the 2011 because there was little strain accumulation there if the region released the strain perfectly every time. We aware some of these earthquakes were tsunami earthquakes and there must have been the slip deficit. Seismic moment of an earthquake with some slip deficit is smaller than that of an earthquake without deficit, when the areal sizes of two earthquakes the same. Now the comparison is made to check the above hypothesis that the seismic moment of tsunami earthquakes is smaller than that of ordinary inter-plate earthquakes with a same size of rupture areas.

This is done by studying the scaling relation between seismic moment and rupture area of tsunami and ordinary earthquakes. Standard scaling law for ordinary earthquakes is adopted from Koyama (1977); $\log M_o = 1.5 \log S + 15.12$, where M_o is seismic moment [Nm] and S is rupture area [km^2]. Compared to the relation, we obtained smaller seismic moment for some tsunami earthquakes such as 1992 Nicaragua, 2006 Java, and 2010 Sumatra. Some other tsunami earthquakes such as 1994 Java, 1996 Peru, and 1998 Papua New Guinea are almost the same as the relation. The former are those characterised by low rupture velocity, and the latter are by land-slides or slump of ocean bottoms and may be by a smooth faulting with weak fault heterogeneities.

The 1896 tsunami earthquake occurred in the region of horst and graben structure similar to the 1992 Nicaragua earthquake. This indicates tsunami earthquakes off the Pacific coast of Tohoku are also characterized by low rupture velocity, and there must have been slip deficits.

We conclude that before the 2011 earthquake, the trench side of the rupture zone had a large amount of slip deficit due to repeated ruptures by tsunami earthquakes. Since the 2011 megathrust occurred in Along-dip Double Segmentation, the trench-ward seismic segment has had the potential to generate large moment release due to the slip deficit and the large slip in the trench-ward segment had accompanied with the rupture in the land-ward segment.

Keywords: tsunami earthquake, slip deficit

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SSS31-03 Room:302 Time:May 21 14:45-15:00

Slip deficit distribution using earthquake catalogs

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We tried to make a spatial distribution of the slip deficit beneath subduction trench. Slip deficit is defined by ratio of deficit of seismic or aseismic slip to cumulative plate convergence. Yamanaka & Kikuchi, 2003 showed a spatio-temporal distribution map of seismic slip (nominally asperity map)in the Tohoku district using historical strong motion records. If we assume that asperities slip only by seismic slip, shortness of seismic slip on an asperity relative to plate convergence is defined as slip deficit. To make slip deficit map using their method, we need to define spatial distribution of asperitiesand amount of seismic slip for all historical earthquakes in addition to. subduction velocity.However, strong motion seismogram is not always available for historical earthquakes in the world. Therefore, we tried to make the space-time slip distribution map using Earthquake Catalogs which only equips the hypocenter and magnitude informations instead of record of strong-motion seismogram. Before making the space-time distribution map beneath global subduction trenches, we made the space-time slip distribution map in the Tohoku district and assessed whether this method would be appropriate replacement of strict asperity map. In order to assess the validity of this method, we compared the spatio-temporal distribution map of co-seismic slip beneath the Tohoku district made in the previous studies with that made by our easy method. As a result, although there are some differences in the results between the previous study and our method, they are generally similar. Although there is a room for improving in our method, it can be applied to other subduction zonesin the world.

Keywords: asperity, subduction, the 2011 Tohoku-Oki earthquake, earthquake catalog, slip history

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SSS31-04 Room:302 Time:May 21 15:00-15:15

Estimation of the lower limit of the coseismic slip and the strength in the deeper part near the 2011 mainshock

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Numerous studies have estimated the slip distributions of the 2011 off the Pacific coast of Tohoku Earthquake. However, the reliable slip distribution has not been necessarily clarified. We estimated the lower limit of the coseismic slip region in the deeper part of the fault near the mainshock, using the F-net focal mechanism data and stress changes by the various fault models and then discussed the relation the initial stresses and the slip distributions. Two characteristic focal mechanism distributions after the mainshock were found at the deeper part of the fault off the Miyagi ˜ Iwate Prefecture, where are located in the vicinity of the mainshock hypocenter. The first case is the distribution composed of P-axis with vertical dip angle above the plate boundary and with dip angle parallel in the direction of the plate subduction below the plate boundary in depth of about 40km. The second is located deeper than the first case, which is located about 40-50km at the plate boundary, and is characterized by thrust type events near the plate boundary. We calculated the stress changes by the coseismic slip model that we made artificially, referring to Chiba et al., (2012) using Okada(1992), and then found that above-mentioned features about the focal mechanism distributions appeared equally in the case of the stress changes. The first and second case in the stress change correspond to the parts that the slip gradient is steep and lower limit of the slip, respectively. However, it may be practically expected that focal mechanism distributions after the mainshock are also affected by postseismic slip and initial stresses. We thus examined the dip angle distributions of the P-axis and .axis, which calculated the stress changes with the slip model including the afterslip and initial stress, above the plate boundary. As a result, it was implied that the shear strength in the region deeper than the lower limit of the coseismic slip distribution was high to some extent(> 5˜10MPa), whereas the shear strength in the region with large coseismic slip was weak(< 5MPa).

Keywords: focal mechanism, fault model, stress change, initial stress

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SSS31-05 Room:302 Time:May 21 15:15-15:30

Determination of Stress State in Japan Trench Fast Drilling Project (JFAST)

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The 2011 Mw 9.0 Tohoku-oki earthquake produced a maximum coseismic slip of $>$50 m near the Japan Trench, which could result in a completely reduced stress state in the region. We tested this hypothesis by determining the in-situ stress state of the frontal prism from boreholes of Japan Trench Fast Drilling Project (JFAST) drilled by the Integrated Ocean Drilling Program approximately one year after the earthquake, and by inferring the pre-earthquake stress state. On the basis of the horizontal stress orientations and magnitudes estimated from borehole breakouts, and the increase in coseismic displacement during propagation of the rupture to the trench axis, we concluded that in-situ horizontal stress decreased during the earthquake. The stress change suggests an active slip of the frontal plate-interface consistent with coseismic fault weakening and a nearly total stress drop.

Acknowledgments: This research used data provided by IODP. We thank all drilling and logging operation staff on board the D/V Chikyu during expedition 343.

Keywords: JFAST, Stress, Breakout

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SSS31-06 Room:302 Time:May 21 15:30-15:45

Anelastic deformation during the 2011 Tohoku earthquake: The role of extensional faulting in the generation of a tsunami

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The 2011 Tohoku-oki earthquake (Mw 9.0) ruptured a wide area along the plate interface (~450 km in the trench-parallel direction) and generated a particularly large tsunami. On the basis of geodetic and geophysical data as well as tsunami records, large slip along the plate interface (~60 m) was estimated to have occurred near the trench off Miyagi. However, the mechanisms of large displacement along the plate interface near the trench are not well understood. Prior to the 2011 Tohoku-oki earthquake, the plate interface near the Japan Trench was thought to be too weak to accumulate strain and, because of this presumed weak lithology, the frontal prism was expected to deform aseismically. Here we identify a series of faults in seismic reflection profiles acquired within and outside of the tsunami source area and examine dynamic changes of the fault traces on the seafloor by comparing observations made during submersible dives before and after the 2011 earthquake, in order to identify characteristic geological structures and dynamic fault activity within the overriding plate in the tsunami source area. During the seafloor observations, we also repeatedly measured heat flow to evaluate the activity of the fault system.

Observations of seafloor morphologies and environments made before and after the 2011 Tohoku-oki earthquake reveal open fissures, generated during the earthquake, where the fault trace is interpreted on seismic profiles to intersect the seafloor. Anomalously high heat flow was observed at a landward-dipping normal fault in August 2011, five months after the earthquake, but by August 2012 heat flow measured at the same station had decreased to close to the background value, which suggests that the normal fault ruptured during the 2011 earthquake. These seafloor observations and measurements demonstrate deformation that was both extensional and anelastic within the overriding continental plate during the 2011 earthquake. Seismic profiles as well as seafloor bathymetry data in the tsunami source area further demonstrate that landward-dipping normal faults (extensional faults) collapse the continental framework and detach the seaward frontal crust from the landward crust at far landward from the trench. The extensional and anelastic deformation (i.e., normal faulting) observed in both seafloor observations and seismic profiles allows the smooth seaward movement of the continental crust. Seaward extension of the continental crust close to the trench axis in response to normal faulting is a characteristic structure of tsunami source areas, as similar landward-dipping normal faults have been observed at other convergent plate margins where tsunamigenic earthquakes have occurred. We propose that the existence of a normal fault that moves the continental crust close to the trench can be considered one indicator of a source area for a huge tsunami.

Keywords: 2011 Tohoku-oki earthquake, Tsunami mechanisms, seafloor observations, normal fault, anelastic deformation, heat flow

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SSS31-07 Room:302 Time:May 21 15:45-16:00

Vertical seafloor deformation associated with the 2011 Tohoku-Oki earthquake

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The 2011 Tohoku-Oki earthquake was preceded by a large (Mw7.3) interplate earthquake which gave rise to evident afterslip and intensive aftershock activity. Although the studies on the afterslip and aftershocks suggested that the slow slip propagated towards the hypocenter of the mainshock of the Tohoku-oki earthquake, no clear evidences of the acceleration of fault slip related to the nucleation of the mainshock have been presented. In this report, we will present the results of reanalysis of the eight ocean bottom pressure records obtained around the hypocenter to inspect if there were any fluctuations of fault slip prior to the occurrence of the mainshock, other than the afterslip of the M7.3 earthquake. By removing short-term variation common to all of the records, assuming that the common component is caused by non-tidal physical oceanographic pressure variation, noise level of the pressure records was considerably reduced. The processed pressure records show that rates of seafloor deformation decayed gradually or were almost constant until the mainshock occurrence, but no remarkable accelerations exceeding noise level, ˜ 2 cm. The noise level of the pressure data corresponds to vertical displacement caused by slip along the plate boundary with amount of ˜ 20 cm and we conclude that the Tohoku-oki mainshock was not associated with a preslip larger than this amount within a couple of hours prior to the initial break of the mainshock. In the presentation we will report on the postseismic deformation following the M-9 mainshock.

Keywords: seafloor geodesy, Tohoku-oki earthquake

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SSS31-08 Room:302 Time:May 21 16:15-16:30

Seismic reflection character and spatial distribution of the Nankai shallow decollement with tsunami potential

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One of the biggest features of the subduction-zone processes is tsunami earthquake that generate tsunamis disproportionately large for their seismic energy. Tsunami earthquakes have been reported in the subduction zones worldwide: for example, 1896 Sanriku, 1946 Aleutian, 1992 Nicaragua, and 1994 Java. Most of the tsunami earthquakes appear to propagate along shallow decollement up to near trench. However, the tsunamigenic decollement is not clearly identified and its nature is largely unknown. Here we report seismic reflection character and spatial distribution of the tsunamigenic, shallow decollement along the Nankai subduction zone, southwest Japan. Seismic reflection profiles along and across the Nankai Trough reveal clear shallow plate-boundary fault (i.e., decollement) with variation of negative and positive polarity reflections. Very-low-frequency earthquakes suggesting slow seismic slip and shear failure occur around the decollements with tsunami potential. Although fluid-poor decollement with positive polarity reflection too may have tsunami potential, fluid-rich decollement with negative polarity reflection could be much easier to slip due to elevated fluid pressure leading to low effective normal stress so that it is conditionally stable. On the whole, the fluid-rich decollement is identified off Shikoku Island and Cape Shiono. The fluid-poor decollement is recognized off Kii Channel. Alteration of the fluid-rich and fluid-poor decollements is observed off Kumano Basin. The huge, fluid-rich decollement zone off Shikoku Island is almost consistent with tsunami source area of the 1605 Keicho event. On seismic reflection profiles, we also identify three distinct turbidites underthrusting along the shallow decollement immediately beneath the Nankai accretionary wedge. Deep sea turbidite subduction may affect formation of the fluid-rich decollement with much more tsunami potential.

Keywords: Nankai Trough, decollement, seismic reflection, spatial distribution, tsunami

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SSS31-09 Room:302 Time:May 21 16:30-16:45

Estimation of effective pressure in Nankai accretionary margin using physical properties of sediments

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Effective pressure within accretionary wedge and along decollement in subduction zone affects both on strength of sediments in wedges and friction strength along decollement or mega-splay faults. Those strengths control widely wedge architecture, stress state, and seismic behavior. Therefore, estimation of effective pressure is critical to understand wedge state and seismicity in subduction zone.

In this study, we estimate effective pressure along decollement from shallow to deep up to shallow seismogenic zone, and also along mega-splay fault in Nankai trough combining physical properties of sediments with information from seismic profiles in Nankai Troguh.

For shallow decollement, from deformation front to ~25 km landward, we followed Tobin and Saffer (2009) to estimate effective pressure. They used velocity-porosity relationship obtained from sediments only in the toe and reference sites. Porosity was converted from velocity along decollement obtained by seismic data in Nankai Trough. The porosity was converted to effective pressure based on porosity-effective pressure relationship at reference site. We have newly made porosity-velocity relationship with additional data from rocks in Shiamnto Belt to cover wider range of porosity. The estimated effective pressure based on the newly modified porosity-velocity relationship represents less than 10 MPa, which is very consistent with the result of Tobin and Saffer (2009).

For deeper decollement, about 5 km depth, effective pressure was estimated using elastic properties of hanging-wall and footwall bounded by fossil seismogenic fault in Mugi melange, Shimanto Belt. The elastic properties were measured in laboratory under controlled effective pressure. Amplitude variations with offset (AVO) analysis were taken for the estimation. By comparison between AVO parameters from seismic data and the elastic properties, appropriate effective pressure was estimated as about 15MPa in hanging-wall and about 10 MPa in footwall.

Finally, for deep mega-splay fault, ~8-10km deeper portion, effective pressure is also estimated by elastic properties of hanging-wall and footwall bounded by Nobeoka thrust, Shimanto Belt. AVO analysis was also conducted to compare AVO parameters from seismic data and the elastic properties. The estimated effective pressure is about 50 MPa in hanging-wall and 5MPa in footwall although the coincidence between AVO parameters was not so good. The bad coincidence is probably due to anisotropy of elastic property especially in hanging-wall. At least, the difference in effective pressure between hanging-wall and footwall is larger than other portions.

Distribution of effective pressure in subduction zone from shallow to deep was examined in this study. About 5-15 MPa of effective pressure are distributed along shallow to deep decollement up to shallower portion of seismogenic zone. 5MPa in footwall and about 50MPa in hanging-wall of effective pressure are obtained along deep mega-splay fault. This low effective pressure in footwall both in decollement and mega-splay fault lead to low friction along those faults. This estimation is for the modern state based on the seismic data.

Keywords: Nankai Trough, effective pressure, physical properties, velocity, porosity

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SSS31-10 Room:302 Time:May 21 16:45-17:00

Accumulation process of earthquake-induced turbid layer in the Nankai Trough accretionary prism

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While massive seafloor turbid layers were observed at slope basin of Nankai Trough off Kumano in the proximity of an epicenter of the 2004 Earthquake (Mw 7.4) during submersible observation immediately after the earthquake, they were not recognized at the same observation site after 6 years of the event. This phenomenon is considered to have been resulted from rapid deposition of large amounts of sediments within a relatively short time. We can investigate paleoearthquakes based on estimations of sedimentation age after careful assessment of whether the depositions are caused by earthquakes or not. It is inferred that these deep-sea turbid phenomena are accompanied by relatively high sedimentation rate and characterized by a typical accumulation processes, but the picture remains unsolved. We aim to investigate the possible mechanism of suspended layers generated just after an earthquake and their accumulation and sedimentation processes, which also contribute to evaluation of samples studied for paleoenvironment and paleooceanography.

We used the data derived during KY04-11, KH-10-3 and KH-11-9, and the data on ROV NSS (Navigable Sampling System). We also used high-resolution images obtained from a chirp subbottom profiler (SBP) surveys, and interpreted geological structure of the basin in detail.

Based on the result of the SBP profiles acquired at the slope basin, we classified the deposition structure into acoustic transparent layers and the acoustical high amplitude layer. The thickness of upper transparent layer is 2 m. The layer is considered to have been originated from earthquake-induced turbid layer. A ripple-like structure was observed on the seafloor of the slope basin from the NSS deep sea video footage. The crest of the ripple-like structure is considered to have been developed parallel to the bathymetry, which suggests that it seems to be an evidence of traveling down of sediment gravity flows along the slope. In addition, since the ripple-like crest structure originates from two directions in NE-SW and NW-SE, several basin-wards incoming sediment flows from surrounding slope basin areas are presumed. Moreover considering the slope basin, the sediment source region that could supply sediments based on the bathymetrical map, deposition rate and seismogenic interval, the acoustic transparent layer observed in this basin is considered to have been deposited during single earthquake event. In addition, clay fabrics of the sediment samples obtained during KT-06-7 Cruise observed by a scanning electron microscope (SEM) were characterized by a "granular structure" formed by high-concentrated mud fluids, which suggests that the occurred suspended layer is composed of high-concentrated state substances. Thus, thick sediment layer is eventually expected after completed settling of suspended layer. The comparison of the measured water depth in 2004 and 2010/2011 resulted that the suspended layer was estimated to be at least 2.5 m. Since no significant differences exist between the thickness of the acoustic transparent layer recognized in SBP profile and the one of coseismic turbid deposit layer derived from the results of particle settling experiments and seafloor observations, the transparent layer is considered to have been originated from turbid layer.

From these results, the upper acoustic transparent layer in the slope basin is considered to have been formed by the 2004 event, which suggests that sediment layer with the thickness of 2 m can be deposited after M7 class earthquake. Moreover, this study proposes the possibility for determining the presence and absence of turbid sediment in the sedimentary basin based on high-resolution SBP data, which contribute to reconstruct the histories of paleoearthquakes.

Keywords: earthquake-induced sediment, gravity flow, slope basin, turbid layer

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SSS31-11 Room:302 Time:May 21 17:00-17:15

ACORK off Muroto: Tidal response and overpressure observed from borehole pore pressure monitoring in the Nankai Trough

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Pore pressure and hydrological properties play key roles in governing coupling and slip behavior along the subducting plate interface. During the KR12-17 cruise, five dives were completed using ROV KAIKO onboard R/V KAIREI during Nov. 4-8, 2012, to retrieve pore pressure data and interstitial fluid samples from ACORKs at ODP Holes 808I and 1173B situated landward and seaward of the deformation front in the Nankai Trough off Cape Muroto. Since their deployment during ODP Leg196 in 2001, we now have over 11-year-long continuous pressure records. Data from most monitoring depths show systematic variations in average pressure, and in formation pressure response to seafloor tidal loading.

In 2005 and 2009, we observed significant decrease in the amplitudes of pressure response to semi-diurnal tidal loading at Hole 808I. We suggest that this is due to the reduction of hydraulic diffusivity around ACORK casing.

Venting of fluid from ACORK mouth at Hole 808I (up to 1 L/min.), coming from the decollement, has been continuing for long, but was terminated by closing the valve in 2011. As opposed to our expextation the pressure decreased instantaneously by a few kPa, followed by a slow pressure recovery. Termination of the flow could also have terminated the supply of advective heat, resulting in the thermal contraction of the casing and thus in the pressure decrease. This inference is supported by the 2-D cylindrical numerical simulation.

Keywords: Nankai Trough, ODP, Borehole monitoring, decollement, seismogenic zone, pore pressure

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SSS31-12 Room:302 Time:May 21 17:15-17:30

Development of seafloor and seafloor borehole observatory network in the Nankai Trough for monitoring earthquake and slo

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A seafloor seismo-geodetic observation network using a submarine cable called ”DONET” (Dense Ocean-floor Network for Earthquake and Tsunamis) is currently under development in and around the epicenter of the Tonankai earthquake in the Nankai Trough. The purpose of the observation system development is to study mechanism of seismogenesis of large earthquakes in subducting oceanic plate.

Observation of ground deformation and earthquake above the seismogenic plate interface in the Nankai Trough seafloor should give a very important data to model the system of the coupling at the plate interface in the seismogenic cycles. In the development of the DONET, observation of seafloor ground deformation is important target. We planned ground deformation observation in the DONET in two methods, one using a seafloor height measurement based on the seafloor pressure data, and the other using geodetic sensors installed in a seafloor borehole where the surrounding media is more consistent and stable with less effect from oceanographic disturbances.

Our installation of the DONET seafloor observation network started in March 2010 with seafloor seismometer and seafloor pressure gauges, completing in July 2011 with 20 seafloor observatory in the seafloor. In the installation of the seafloor seismometers, we took care to bury the seismometer in the seabed using a caisson penetrated into the sediment to minimize effect from current flow in the seafloor for broadband wide-dynamic range seismic observation. In February 2013, we further improved the installation by filling the gap between the seismometer and the caisson with sand. After filling sand, we confirmed improvement in the seismic background noise level in many of the observatories.

In observing long-term ground deformation with seafloor pressure measurement, instrumental drift of the pressure gauge can be larger than the pressure change expected from seafloor deformation. Our measure on the instrument drift is to implement repeated calibration of the pressure gauges in the seafloor. We had an experimental calibration of the seafloor pressure gauge in January 2013 by JAMSTEC R/V Kaiyo.

Development of seafloor borehole observation network was planned as a part of IODP scientific drilling in the Nankai Trough. We successfully constructed the first long-term seafloor borehole seismogeodetic observatory in IODP C0002G hole in December, 2010. After confirming the proper function of the borehole instruments in 2011-2012 periods, we finally connected DONET cable to the borehole observatory in January 24, 2013. Currently we perform continuous real-time observation with the borehole observatory in IODP C0002G hole connected to the DONET. Observed records of the borehole strainmeter, tiltmeter, pore-fluid pressure gauges, and broadband seismometer showed clear signature of ground deformation from oceanic tide, tsunami, and long-period ocean gravity waves. We continues observation with the combined seafloor and seafloor borehole observation systems to analyze earthquakes and slow slip phenomena in the seismogenic plate boundary in the Nankai Trough.

Keywords: the Nankai Trough, seismic observation, ground deformation monitoring, borehole, seafloor pressure, seafloor cable

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SSS31-13 Room:302 Time:May 22 09:00-09:15

Analyses of mineral composition and carbonaceous material in the megasplay fault of the Nankai Trough

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We analysed the mineral composition by XRD and carbonaceous material by vitrinite reflectance measurement, micro FTIR and micro Raman spectroscopies.

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Segmentation of hypocenters and 3-D velocity structure around the Kii Peninsula

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Around the Kii Peninsula, the rupture boundary of the Tonankai and Nankai earthqueks is located. In addition, there can be seen along-strike segmentations in hypocenters, P-wave anisotropy, low frequency earthquake (LFE) distribution and subduction depth of the Philippine Sea (PHP) Plate. To investigate these segmentations, 3-D velocity structure and hypocenters were determined by using ocean bottom seismometers (OBSs) deployed from 2003 to 2007 and on-land stations.

To begin with, we determined station corrections which compensate travel time delays due to the sediment layers based on traveltime misfits. A double-difference tomography method was adapted to obtain 3-D velocity structures and a grid search method was used to increase the number of determined hypocenters. In addition, we performed calculations of waveform cross-correlation coefficients (CC) in order to improve relative hypocenters and to detect similar event clusters. Waveforms recorded by OBSs are problematic in that their frequencies tend to be monotonic due to the sediment layers. To overcome this problem, a new method was developed which determines thresholds of CC at every station statistically.

As a result, geometry of the PHS Plate was estimated. It has been discovered that Vp/Vs ratio is segmented within the oceanic crust and at the bottom of the overriding plate, which coincides with the LFE distribution. In the western Kii segment, Vp/Vs ratio is low within the oceanic crust and LFE cluster with small amount of cumulative slip is located. It is considered that the pore fluid pressure is relatively low in this segment. In the eastern Kii segment, because no LFEs occur and Vp/Vs ratio is high, the pore fluid pressure must be comparable to the lithostatic pressure, so the plate interface may be at the state of stable slip.

Similar segmentation has also been seen in hypocenters. In the western Kii segment and its west side segment, most earthquakes occur in the oceanic crust and mantle, respectively. In the western Kii segment, fewer earthquakes occur. Moreover, variation of the depth can also be seen where earthquakes do not occur within the oceanic crust, which can be considered to reflect difference of the thermal structure.

As a result of cluster analysis based on waveform similarity, we found a fault sequence in the oceanic mantle and an inter-plate earthquake cluster at the southern tip of the Kii Peninsula. The inter-plate earthquakes occur at the landward edge of the strong plate coupling zone. Long term observations of these inter-plate earthquakes might provide insight into the state of plate coupling during inter-seismic periods.

Keywords: subduction zone, Kii Peninsula, ocean bottom seismometer, hypocenters, 3-D seismic velocity structure, similar event cluster

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SSS31-15 Room:302 Time:May 22 09:30-09:45

Spatial distribution of random velocity inhomogeneities at western Nankai trough

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Major interplate earthquakes at Nankai trough show various rupture patterns, for example, the individual rupture of one segment or nearly simultaneous or successive ruptures of contiguous segments. Lithosphere structures around the Nankai trough are intensively studied by using active and passive seismic sources to elucidate their relation with seismicity and segment distribution. From 2008, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) conducted seismic surveys at Nankai trough as a part of "Research concerning Interaction Between the Tokai, Tonankai and Nankai Earthquakes" funded by Ministry of Education, Culture, Sports, Science and Technology, Japan. This study applied the peak delay time analysis [e.g., Takahashi et al. 2009] to estimate the spatial distribution of random inhomogeneities in the crust and uppermost mantle. Peak delay time is defined as the time lag from S-wave onset to the maximal amplitude arrival. This measurement mainly reflects the accumulated effect of multiple forward scattering, and is insensitive to the medium inelasticity. We measured peak delay times from the RMS envelopes of horizontal components at 4-8Hz, 8-16Hz and 16-32Hz. This study used the velocity seismograms that are recorded by 665 ocean bottom seismographs, 20 DONET stations, and 532 onshore seismic stations. Onshore stations are composed of the F-net and Hi-net stations that are maintained by National Research Institute for Earth Science and Disaster Prevention (NIED) of Japan. It is assumed that the random inhomogeneities are represented by the von Karman type power spectral density function (PSDF). Inversion analysis shows that medium at the Nankai trough is characterized by weak inhomogeneities with steep spectral gradient. That means inhomogeneities at smaller wavelength (˜ a few hundred meters) are significantly weak. Long wavelength component of inhomogeneities, meanwhile, shows some anomalies along the Nankai trough. Strong inhomogeneities at large wavelength are imaged at Hyuga-nada and Kii-channel. Similar strong random inhomogeneities are found beneath west Shikoku at 20-60km depth and around the Cape Shionomisaki at 20-60km depth. Strong inhomogeneities at west Shikoku and Cape Sionomisaki are located in non-volcanic tremor zones. Similar random inhomogeneities were found in high-microseismicity area in Hokkaido, and existence fluid was pointed out by velocity structure analysis [Kita et al. 2010]. These results suggest that random inhomogeneity is an important medium property related with seismicity and geofluid distribution.

Keywords: Nankai Trough, random media, scattering

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On the anomalies of distribution of Green's function amplitudes for M9 source in Nankai trough

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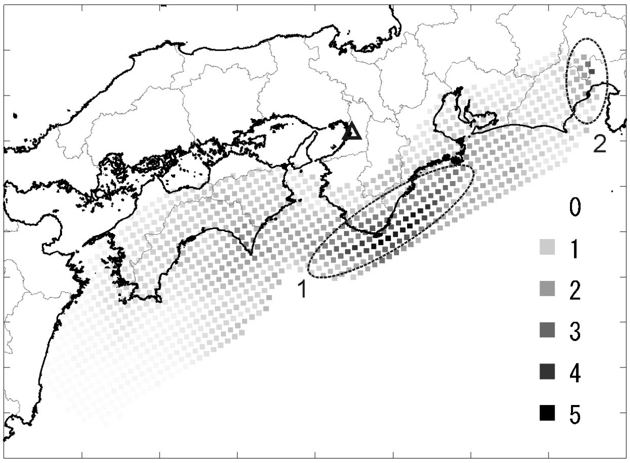
Effect of various areas (asperities or SMGA) in source of a megathrust subduction zone earthqauke on the simulated long-period ground motions is studied. For this case study we employed source fault model proposed by HERP (2012), for future M9-class event in Nankai trough. Velocity structure is 3-D JIVSM model developed for long-period ground motion simulations (Koketsu et al., 2012). Target site is located in center of Osaka basin. Green's functions for large number of subsources (>1000) were calculated by the finite-difference method using reciprocity approach. Depths, strike angles and dip angles of subsources are adjusted to the shape of upper boundary of the Philippine sea plate in the JIVSM model.

Results for period range 4-20sec are shown in the Figure below. Figure shows distribution of peak amplitudes of Green's functions, calculated at the target site in Osaka basin (marked by triangle). Darker colors indicate subsources producing larger amplitudes in Osaka, while lighter colors indicate smaller amplitudes. Strongly nonuniform distribution is observed, with two areas of anormal large amplitudes: (1) large elongated area just south of Kii peninsula and (2) a smaller area north of Suruga bay. Elongation of both areas fit well 10-15km isolines of depth distribution of the Philippine sea plate, while target site is located on a perpendicular to these isolines. For this reason, preliminarily we suppouse that plate shape may have critical effect on the simulated ground motions, through a cumulative effect of subsource radiation patterns and specific strike and dip angle distributions.

Keywords: Megathrust earthquake, Source modeling, Green's function, Long-period ground motions, Reciprocity method, Nankai trough



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SSS31-17 Room:302 Time:May 22 10:00-10:15

Spatiotemporal relation of inland earthquakes in southwest Japan to interplate earthquakes along the Nankai trough

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There are many inland active faults in and around the Kinki region. The earthquakes on the faults are mainly generated by the E-W compression caused by the relative motion between North American and Eurasian plates (Sagiya, 2004). However, because inland earthquakes increases in the period from 50 years before to 10 years after the occurrence of great interplate earthquakes along the Nankai trough (Utsu, 1974; Hori & Oike, 1996), earthquake generations on inland faults are affected by the interplate earthquakes. We have evaluated stress change on many inland faults in this region. Our result predicts reverse faulting increases before interplate earthquakes along the trough, and strike-slip faulting increases after the interplate earthquakes. In this presentation we examine the validity of the prediction by spatiotemporal pattern of historical earthquakes.

In the computation we obtained quasi-static viscoelastic slip response functions in an elastic-viscoelastic stratified medium by Fukahata & Matsu'ura (2006). We employed plate interface of Philippine Sea plate subduction by Hashimoto et al. (2004). Amount of slip is set by Time or Slip Predictable models (Shimazaki & Nakata, 1980). The relative motion is after Heki & Miyazaki (2001). The compressive strain rate due to EW compression is $0.3\text{x}10^{-7}$ (yr^{-1}) with the direction of N100E. The geometries of inland faults are after HERP.

The results already presented are summarized as follows. The E-W compression is the primary cause of the long-term stress changes in this region, and forms general trend of strike of inland faults. The elastic changes in Coulomb Failure Function (dCFF) due to interplate earthquakes are mostly negative on reverse faults and mostly positive on strike-slip faults. This is because this region dragged to the SSE direction due to interplate earthquakes. As a result, dCFF are negative on N-S trending reverse faults and positive on NW-SE trending left-lateral and NE-SW trending right-lateral strike-slip faults. The calculated dCFF on source faults of 9 historical inland earthquakes at last 500 years are consistent with the historical records, because dCFF are the highest-ever at the occurrence in most cases. The computed dCFF on 73 inland faults are consistent with the historical earthquake pattern, presented in the first paragraph. These results suggest the inland reverse faulting increases before interplate earthquakes, whereas strike-slip faulting increases after interplate earthquakes. Recently, this relation is obtained in the seismic observation in the northern Tohoku region before and after the 2011 great Tohoku-oki earthquake (Asano et al., 2011).

Focal mechanism of inland earthquakes corresponds to the fault mechanism in and around the Kinki region, as a reflection of the local stress fields (Townend & Zoback, 2006; Terakawa & Matsu'ura, 2010). That is, there occur reverse earthquakes in the SW Chubu and central Kinki regions, and strike-slip earthquakes in the western Chubu and NW Kinki regions, corresponding to the fault mechanism. Conversely, mechanisms of inland earthquakes in a certain region can be roughly assumed by fault mechanisms. With our prediction, we can expect the inland earthquakes increases in the reverse fault region before interplate earthquakes, whereas the inland earthquakes increase in the strike-slip fault region after interplate earthquakes.

Based on the concept, we examined the spatiotemporal pattern of inland earthquakes. The expectation is notably consistent with the earthquake occurrence in the reverse fault region. On the other hand, in the strike-slip fault region, consistency of expectation is good in the western Chubu region (occurrence rate increases after interplate earthquakes) and not good in the NW Kinki region (occurrence rate increases before interplate earthquakes). As a whole, our result for inland earthquake occurrence is supported by the spatiotemporal pattern of historical inland earthquakes.

Keywords: subduction zone, the Kinki region, interplate earthquake along the Nankai trough, Coulomb failure function, historical earthquake, inland earthquake

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The results of researches on the seismic linkage among mega thrust earthquake seismogenic zones around the Nankai trough

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The recurrence of Nankai trough mega thrust earthquakes is the very severe problem
to Japan. Therefore, MEXT of Japanese government has started to the research project on the estimation of seismic linkage around the Nanakai trough mega thrust earthquake seismogenic zones. This project is composed of three research subjects as the observational research, simulation research and disaster mitigation research.

In results of observational research subject, the precise structures and seismicity around the western part of the Nankai trough are obtained. Especially, precise structures and characteristics of off Hyuga seismogenic zone including Kyushu-Palau

Ridge are obtained from refraction seismic surveys. Around off Hyuga, low frequency detected by the new analytical method. Furthermore, we have carried out observations of earthquakes and crustal deformations around off East Japan seismogenic zone from before 2011 East Japan earthquake, so, results of off East Japan observations indicated crustal activities among the pre shock, the main shock and aftershocks at 2011 East Japan. As results of simulation research subject, the crustal deformation database has been constructed and tsunami sediments were sampled and analyzed for the estimation of historical large tsunami recurrences. And some simulation technologies have been developed for advanced simulation researches including recurrence cycle simulations and data assimilations. .

Finally, in disaster mitigation research subject, precise seismic wave and tsunami propagations have simulated for the reliable hazard estimation. Furthermore, for the disaster mitigations and improvements of regional disaster measures, we have discussed with local governmental people and lifeline industrial people at some regional disaster prevention research societies. Results from this project contributed to the new estimation of maximum Nankai tough seismogenic zones, tsunamigenic zones and damages by Japanese Cabinet office.

Keywords: Nankai trough, Mega thrust earthquake, Seismic linkage

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SSS31-19 Room:302 Time:May 22 11:00-11:15

Preliminary results of IODP Expedition 338: Scientific aspects

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The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) is a multi-disciplinary scientific project designed to investigate fault mechanics and seismogenesis along subduction megathrusts through reflection and refraction seismic imaging, direct sampling, in situ measurements, and long-term monitoring in conjunction with laboratory and numerical modeling studies. As part of the NanTroSEIZE program, operations during Integrated Ocean Drilling Program (IODP) Expedition 338 were planned to extend and case riser Hole C0002F, begun on Expedition 326 in 2010, from 856 meters below the sea floor (mbsf) to 3600 mbsf. Riser operations extended the hole to 2005.5 mbsf, collecting a full suite of logging- and measurement-while-drilling (LWD/MWD), mud gas and cutting data. However, due to damage to the riser during unfavorable winds and strong current conditions, riser operations were cancelled. Hole C0002F was suspended at 2005.5 mbsf, but left for re-entry during future riser drilling operations, which will deepen the hole to penetrate the megasplay fault at about 5000 mbsf.

Contingency riserless operations included coring at Site C0002 (200-505, 902-940 and 1100.5-1120 mbsf), LWD at Sites C0012 (0-709 mbsf) and C0018 (0-350 mbsf), and LWD and coring at Sites C0021 (0-294 mbsf) and C0022 (0-420 mbsf). These sites and drilling intervals represent key targets not sampled during previous NanTroSEIZE expeditions, but relevant to comprehensively characterize the alteration stage of the oceanic basement input to the subduction zone, the early stage of Kumano Basin evolution, gas hydrates in the forearc basin, and the recent activity of the shallow megasplay fault zone system and submarine landslides.

Preliminary scientific results of Expedition 338 include:

1. LWD, mud gas monitoring and analyses of cuttings from the deep riser hole characterize two lithological units within the inner wedge of the accretionary prism at Site C0002, separated by a prominent fault zone at ~1640 mbsf. Internal style of deformation, downhole increase of thermogenically formed gas, and evidence for mechanical compaction and cementation document a complex structural evolution and provide unprecedented insights into the mechanical state and behavior of the wedge at depth.

2. Multiple samples of the boundary between the Kumano Basin section and the underlying accretionary prism at Site C0002 shed new light on this unconformity, the interpretation of which was debatable from previous samples and data. New samples suggest that variable erosional processes were active on small spatial scales.

3. Geochemical data characterize the gas-hydrate bearing zone (200-400 mbsf) in the Kumano Basin at Site C0002 as a zone of disseminated methane-dominated hydrate of microbial origin.

4. Operations at Site C0012 included 178.7 m of detailed LWD characterization of the oceanic basement, indicating an upper ~100 m zone of altered pillow basalts and sheet flow deposits, and a lower, presumably less altered basement unit.

5. Cores recovered at Site C0021 improve our understanding of submarine landslides in the slope basins seaward of the splay fault. LWD data acquired at Sites C0018 and C0021 characterize in situ internal structures and properties of mass-transport deposits (MTDs) which relate to the dynamics and kinematics of submarine landslides.

6. LWD resistivity images from Hole C0022A, located in the slope basin immediately seaward of the megasplay fault, show a conductive horizon where the tip of the megasplay fault is inferred from the 3D seismic data. Although the fault itself was not sampled at Hole C0022B, structural and porosity data from cores as well as interstitial water data suggest that the conductive horizon is possibly the splay fault tip.

Keywords: NanTroSEIZE, accretionary prism, forearc basin, megasplay fault, submarine landslide, subduction input

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SSS31-20 Room:302 Time:May 22 11:15-11:30

Preliminary structural geology results of IODP Expedition 338

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Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Expedition 338 took place from October 1, 2012 to January 13, 2013. This expedition was originally planned to extend riser Hole C0002F from 856 to ~3600 mbsf. However, riser operations at Hole C0002F were suspended at 2005.5 mbsf because the riser pipe was damaged by unfavorable wind/current conditions. Contingency riserless operations including coring at Site C0002 (200-505, 902-940, and 1100.5-1120 mbsf), LWD at Sites C0012 (0-709 mbsf) and C0018 (0-350 mbsf), and LWD and coring at Sites C0021 (0-294 mbsf) and C0022 (0-420 mbsf) have been performed instead of deepen Hole C0002F. Here we report the preliminary results of Expedition 338 shipboard structural studies.

During Expedition 338, two types of sample material were used for structural geology analyses: (1) cuttings (1-4 mm and >4 mm size fractions) sampled at 5-10 m intervals between 865.5 and 2004.5 mbsf during riser drilling of Hole C0002F, and (2) cores recovered from intervals of 200.0-1112.84 mbsf at Holes C0002H, C0002J, C0002K, and from intervals of 0-419.5 mbsf at Hole C0022B. For the cuttings from Hole C0002F, deformation structures such as vein structures, carbonate veins, slickenlined surfaces, and minor faults, were observed as well as high number of drilling-induced deformation structures. Between 1550.5-1675.5 mbsf, up to 10% of investigated cuttings show slickenlined surfaces. This is correlatable with the high fracture concentration interval identified by LWD resistivity images. Abundant bedding, faults and deformation bands are observed in the cores retrieved from Holes H, J, K and L at Site C0002. Deformation structures are rarely observed in cores from the upper part of the Kumano Basin deposits (Unit II), while they are numerous in cores from the lowermost part of the Kumano Basin sediments (Unit III) and from the accretionary prism sediments (Unit IV). At Site C0022, orientations of bedding dip and minor faults appear to change across the possible splay fault. The existence of highly fractured or disturbed material and claystone with planar fabrics suggest that the interval of 100-101 mbsf is a plausible candidate for the location of the splay fault at Site C0022.

Keywords: IODP Expedition 338, NanTroSEIZE, Site C0002, Site C00021, Site C00022

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SSS31-21 Room:302 Time:May 22 11:30-11:45

What determines Mw7 or Mw8?

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Variations in earthquake magnitude and recurrence intervals of fault behavior need to be understood in the context of regional tectonics. Convergent margins may be divided into two end-member types that are termed erosive and accretionary plate boundaries (e.g. von Huene and Scholl, 1991; Clift and Vannucchi, 2004). The Nankai accretionary margin has a 1300-year historical earthquake record with a recurrence interval of 100-150 years (Ando, 1975). In contrast, the Middle America trench offshore Costa Rica represents an erosive margin characterized by magnitudes as high as 7.6Mw, with a recurrence interval of several decades.

CRISP (Costa-Rica Seismogenesis Project) Program-A has carried out the first step toward deep riser drilling by characterizing the shallow lithologic, hydrologic, stress, and thermal state of this area (Vannucchi et al., 2011; Harris et al., 2013). CRISP drilling of Exp. 344 reveals that the shallow upper plate crust is composed of terrigenous sediment accumulated at a high rate. The Costa Rica seismogenic zone is characterized by the subduction of young oceanic crust with high heat flow and active fluid flow (Spinelli and Wang, 2008; Spinelli and Harris, 2011; Harris et al., 2010). These characteristics are similar to the Nankai seismogenic zone (Kinoshita et al., 2008). Some differences exist between both margins including the convergence rates, the thickness and composition of incoming sediments, and physical properties of the crust. Among them, P-wave velocity within the upper plate of the Costa Rica margin (Stavenhagen et al., 1998) is much higher than at the Nankai margin (Nakanishi et al., 2002). In frictional stick-slip systems, the recurrence interval and event displacement varies with the stiffness of the system. We propose that the characteristic magnitude of large subduction earthquakes and recurrence intervals are influenced by the stiffness of the upper plate. This hypothesis may be best tested at the Nankai and Costa Rica margins.

Keywords: Large subduction earthquake, seismogenic zone drilling, accretion and erosive margin

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SSS31-22 Room:302 Time:May 22 11:45-12:00

Preliminary results of stress and strain analyses, IODP Expeditions 334 and 344, Costa Rica Seismogenesis Project (CRISP

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The Costa Rica Seismogenesis Project (CRISP) is designed to understand the processes that control nucleation and seismic rupture of large earthquakes at erosional subduction zones. Integrated Ocean Drilling Program (IODP) Expeditions 334 and 344 penetrated the middle slope at Sites U1378 and 1380, the upper slope at Sites U1379 and U1413, the frontal prism at Site U1412, and input sites at Sites U1381 and U1414.

Stress and strain analyses using anelastic strain recovery (ASR), fault kinematics, and anisotropy of magnetic susceptibility (AMS) have been conducted in the middle and the upper slope. Based on ASR analyses during Expedition 334, a clear difference in present-days stress state between the slope sediments and the basement were identified at Site U1379: A normal-fault stress regime characterizes the slope sediments, whereas a strike-slip regime corresponds to the basement. On the other hand, the stress-states in the slope sediments at Sites U1378 and U1380 are characterized by a strike-slip regime that has Sigma 2 oriented vertically. The Sigma 1 direction is oriented NNW-SSE, which corresponds to the SHmax direction identified in the logging while drilling (LWD), parallel to the present GPS direction. In contrast to the present-day stress state, the ancient stress and strain based on onboard fault kinematics during both expeditions and AMS were controlled by direction of plate subduction (Sigma 1 oriented to the vertical, whereas Sigma 2 oriented NW-SE). The spatial and time variations in stress state along the CRISP transect plausibly correspond to the stress variations during earthquake cycles. Preliminary ASR and AMS results will be incorporated into this study.

Keywords: Stress, Costa Rica, CRISP, Earthquake cycle

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SSS31-23 Room:302 Time:May 22 12:00-12:15

Fluid-rock interaction and resultant rupture of great earthquake -An exercise from fossilized seismogenic plate boundary

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Recent investigations of exhumed and fossilized plate boundary thrusts and megasplay faults strongly suggest that unraveling the physico-chemical dynamics of fluid-rock interaction and resultant rupture of great earthquake and tsunami is the scientific target of the seimogenic plate boundary processes, which is accessible only by Chikyu-deep riser drilling. The expected result of drilling into the active and living fault in depth will be a great step of science.

Technological advantage of the Chikyu Riser drilling is no doubt for its ability of deep hole with coring, logging and observatory installation. A main target of IODP was direct drilling into the sesimogenic plate boundary thrust in the Nankai Trough of subduction zone. After the first proposal for the NantroSEIZE many new discoveries have been reported from subduction zones, e.g. deep low frequency earthquakes, shallow low frequency earthquakes, high velocity slip even along the plate boundary decollement and on-going stress build-up within the hanging wall accretionary prism. However, unfortunately the deep target of IODP has not been reached yet.

Before drilling into the seismogenic deep splay fault and plate boundary thrust, we have conducted investigation of exhumed and fossilized splay fault of the Nobeoka thrust and plate boundary fault rocks recorded as melange in the Shimanto belt, Japan.
The Nobeoka thrust was once buried at the depth more than 10 km in subduction zone. Combining with inspection of surface exposure, drilling with logging for physical properties and borehole imaging was operated to compare the one dimension data set with the three dimensional occurrences of the fault zone.

Even though surface weathering and cracking with exhumation, the results of coring, logging, and borehole imaging present the condition of the fault in the depth of plate boundary. They show porosity less than several percentages with contrast between the hanging wall and footwall, which are well correlated with electric resistivity, and elastic wave velocities of Vp and Vs. They are systematically changes with the development of discrete slip zones in the shear zone and define a quantitative damage zone. Abundant mineral precipitation is characteristic in the fault and presents a catalog of fault rocks from friction melt of pseudotachylyte to fluidized fault rock suggesting various fault mechanisms of dynamic weakening.

REE pattern of carbonate vein precipitated along the slip surfaces and extensional cracks suggests that fluid flow along the fault, which might be co-seismic, would be under reductive condition but inter-seismic fluid appear to be oxidized condition. The change in chemical property appear be from rupture-related fluid-rock interaction along the plate boundary.

Exploration of the fossilized plate boundary to deep living ones is the revolving jump like autopsy to modern open-heart surgery in medical science. The drilling into various plate boundaries with different subduction parameters is quite essential.

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SSS31-24 Room:302 Time:May 22 12:15-12:30

Changes in illite crystallinity in the Nobeoka thrust fault zone SW Japan, ancient megaspray fault in a subduction zone

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The Nobeka thrust is a fossilized OOST in the Shimanto belts, Cretaceous and Paleogene accretionary complex in SW Japan. A bore hole penetrating the Nobeoka thrust was drilled at Nobeoka city, SW Japan as analogue of NanTroSEIZE project. Total drilling length was 255 m and continuous core samples were recovered. The borehole runs through the Nobeoka thrust at the depth of 41.3m. The hangingwall is mainly phyllite of Kitagawa group and the footwall is cataclacite of Hyuga group (Kondo et al., 2005).

The depth interval between 29m and 78.4m is suffered intense cataclasis due to Nobeoka thrust. Quartz and carbonate veins are enriched in this interval except 41.3-52 m depth interval. We identified from 41.3m to 41.8 m to be a main thrust zone. We also recognize fault breccia at 114m depth.

We collected fragmented core samples from every three meters and analyzed constituent minerals by powder X-ray diffraction. Quartz, plagioclase, illite, chlorite, calcite are main constituent minerals from the top to the bottom. Ankerite sometimes occurs as a vein mineral. Here, we focus on the illite with special reference to fault activity.

We measured IC values (FWHM of illite 001 peak) of 65 samples from the top to the bottom. They show remarkable change between hanging-wall and footwall.

IC values range from 0.14^o to 0.22^o above 38m depth they increase from 0.18^o to 0.30^o in the damaged zone between 38m and 41.0m depth. They range from 0.43^o to 0.58^o just above the Nobeoka thrust between 41.0 to 41.3 m depth. They range from 0.49^o to 0.59^o in the fault core between 41.3m and 41.8m depth, They range from 0.38^o to 0.62^o in the footwall. Here, we focus on the changes in IC values in the hanging-wall.

IC values increase near the Nobeoka thrust. In the damaged zone, the samples are divided into two groups, A and B. In the group A, IC value and peak intensity show negative correlation, whereas, IC values are low and peak intensity is high in the group B. In the fault core, carbonate and clay minerals are enriched and plagioclase content is decreased by intense hydrothermal alteration. The alteration temperature may be lower than the maximum plaetoemperature of Kitagawa group (320 degrees centigrade). This alteration may affect the high IC values in the fault core and the zone just above the fault.

Cray minerals are easily amorphitized by pulverization. IC values should increase during pulverization. We conducted pulverization experiment of illite rich core samples by planetary ball mill. The IC values increased with decresing peak intensity, in a similar relations as that of group A.

Therefore, the increase in IC values in the damaged zone of the Nobeoka thrust result from two processes, which are pulverization (group A) and hydrothermal alteration(group B).

Keywords: cray mineral, megaspray fault, illite

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SSS31-25 Room:302 Time:May 22 14:15-14:30

Frictional behavior of incoming pelagic sediments to the Tohoku subduction zone

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The 2011 Tohoku earthquake (Mw 9.0) off the Pacific coast of Japan produced huge slip (~50 m) on the shallow part of the megathrust fault (e.g., Fujiwara *et al*., 2011), resulting in destructive tsunamis. Although the multiple causes of such large slip at shallow depths is expected, the frictional property of sediments around the megathrust, especially at coseismic slip velocities, may significantly contribute to large slip along the fault. We thus investigate the frictional properties of pelagic sediments to be subducting beneath the Tohoku region at seismic velocities and large displacement toward understanding the rupture processes to cause large slip at the shallow portion of the subduction plate boundary.

We have conducted friction experiments on incoming pelagic sediments on the Pacific plate (DSDP, Leg56, Site 436, Core 38 (358 mbsf) and Core 40 (378 mbsf)). The site locates about 100 km northeast from the Hole C0019E drilled during the IODP Expedition 343 (J-FAST). Core 38 is diatom-rich clayey sediment, while Core 40 contains mainly smectite which could correspond to black-colored sheared clay in the plate boundary fault zone recovered during Expedition 343. Experiments are performed at slip velocities of 2.5 x 10^{-4} to 1.3 m/s, normal stresses of 0.8 to 2.0 MPa and slip displacement of ~16 m under brine saturated conditions, using a rotary-shear friction apparatus. One gram of gouge was placed between rock cylinders of sandstone or gabbro of 25 mm diameter with Teflon sleeve outside to contain gouge. Both gouge sample and host rock were saturated with brine before the experiments.

In both Cores 38 and 40, a typical slip weakening behavior appears at slip velocity of 1.3 m/s; friction coefficient of the sediments rapidly increases at the onset of sliding (initial peak friction) and then progressively decreases to $<$0.1 with displacement. However, at low velocities there is significant difference in friction level between two. Steady-state friction coefficient of Core 40 is remarkably low ($<$ 0.2) over a wide range of slip rate (2.5 x 10^{-4} to 1.3 m/s). In contrast, steady-state friction of Core 38 is high values of ~0.6 at low velocities, but decreases to $<$0.1 toward seismic slip velocity of 1.3 m/s. This marked difference in frictional strength between two sediments could be attributed to smectite content and initial grain size: clay minerals align preferentially along most shear planes in Core 40, whereas fracturing and subsequent shear enhanced compaction seems dominant deformation processes in Core 38. In addition, peak friction of Core40 is far smaller than that of Core38 and steady-state friction of Core 40 is smaller than that of similar studies conducted on other fault gouge (e.g., Mizoguchi *et al*., 2007; Ujiie and Tsutsumi, 2010). These results suggest that the incoming pelagic zone in Core 40, possibly source material of the current plate boundary fault zone, is energetically very easy for earthquake ruptures to propagate at shallow portion of the Tohoku subduction zone, leading to large slip near the trench.

Keywords: Tohoku earthquake, High-velocity friction, Pelagic sediments

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SSS31-26 Room:302 Time:May 22 14:30-14:45

Mechanical properties of the shallow Nankai Trough accretionary sediments

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We report the results of triaxial compression and friction experiments of mudstone, sandstone and tuff samples, which are cored from the shallow (1000-1500 mbsf) Nankai Trough accretionary prism at Sites C0002 and C0009 of IODP Expeditions 315 and 319, at confining pressures, pore water pressures and temperatures close to their in situ conditions.

Triaxial compression experiments at these conditions and an axial displacement rate of 10 micron/s reveal that failure strength is 300 MPa for a sandstone sample, 48 MPa for a tuff sample, 20 MPa for a silty mud sample, and 14 MPa for a clayey mud sample. Another silty mud sample did not fail, and deformed ductilely at strength of ~15 MPa. The sandstone sample is strongly lithified by being cemented by calcite and dolomite, which makes this sample's failure strength very high. The ductilely deformed silty mud sample seems not lithified enough to fail. Failure strength of the other three samples shows a negative correlation with the content of clay minerals, i.e. it increases with decreasing content of clay minerals.

Friction experiments at these conditions and axial displacement rates changed stepwise among 0.1, 1 and 10 micron/s reveal that frictional strength, too, has a negative correlation with the content of clay minerals; steady-state friction coefficient is $>$0.8 for the sandstone sample with ~5 wt% clays, ~0.7 for the tuff sample with ~15 wt% clays, ~0.55 for the silty mud samples with ~30 wt% clays, and ~0.25 for the clayey mud sample with ~40 wt% clays. Slip-dependent frictional behavior also shows a correlation with the content of clay minerals; sandstone sample, tuff and silty mud samples, and clayey mud sample exhibit slip-hardening, quasi steady-state slip, and slip-softening, respectively. All samples showed an increase in friction when sliding velocity was increased or vice versa, i.e., velocity strengthening. We also found that the velocity dependence of friction has a correlation with the content of clay minerals, suggesting an increasing contribution of flow with increasing amount of clay minerals.

Thus the mechanical properties of shallow accretionary sediments differ basically according to the content of clay minerals, which would have important implications for deformation and faulting in the shallow Nankai Trough accretionary prism.

Keywords: fracture experiment, permeability, velocity dependent of friction

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SSS31-27 Room:302 Time:May 22 14:45-15:00

Dynamic weakening of smectite-rich faults at intermediate velocities and its importance for rupture propagation

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Shallow portion of the subduction interface had long been assumed to be aseismic and releasing stress by creep. However, the 2011 Tohoku-oki earthquake clearly demonstrated that the subduction zone earthquakes can propagate to the surface and causes devastating tsunamis resulted from large seafloor displacements. Recent high velocity friction experiments and dynamic modeling are revealing dynamic weakening processes and rupture propagation to the shallow aseismic regions (Faulkner et al., 2011, GRL; Noda and Lapusta, 2013, Nature). Here we provide frictional properties of smectite-rich, synthetic fault gouges (bentonite-quartz mixtures) under the various slip velocities to understand the processes of interseismic loading and coseismic weakening. Experiments were conducted under the normal stress of 2 MPa and slip rates of 30 um/s to 1.3 m/s, using rotary-shear, low- to high-velocity friction testing apparatus. Synthetic fault gouges were saturated with deionized water and placed between gabbro host rock (slider). At the low slip rates of 30 to 150 um/s, friction coefficient remains constant values without visible slip weakening or hardening for any fraction of mixtures. On the other hand, friction becomes unstable at the slip rates of few mm/s, and exhibits noticeable slip weakening at the slip rates faster than 22 mm/s. Intense slip weakening can be observed from 20 to 35 % bentonite mixtures in particular. The velocity, which starts to appear dynamic weakening, comes from 1-2 order of magnitude lower than previous study (Di Toro et al., 2011, Science). According to the slide-hold-slide test, specimens after the slip weakening recover its strength logarithmically with time, but not correspond with temperature decay. Additionally, slip weakening can not be observed from the experiments with highly permeable host rock. These results suggest that the dynamic weakening at the velocity range of mm/s can be attributed to mechanically and/or thermally activated pressurization of pore fluids. These experimental results can explain high friction at interseismic loading and dynamic weakening associated with coseismic rupture. Dynamic weakening at intermediate velocity may assist rupture propagation to the shallow portion of the subduction interface.

Keywords: Smectite, Fault gouge, Friction experiment, Dynamic weakening, Thermal pressurization, Tsunamigenic earthquake

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SSS31-28 Room:302 Time:May 22 15:00-15:15

Megathrust-zone heterogeneity and megathrust earthquakes

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We investigated the detailed 3-D seismic structure of the crust and upper mantle under the NE Japan and SW Japan arcs and its implications for the generation of large megathrust earthquakes. We used P and S wave arrival times from earthquakes under the forearc region under the Pacific Ocean and back-arc region under the Japan Sea which are relocated precisely using sP depth phases. P and S wave arrival-time data from many relocated aftershocks of the 2011 Tohoku-oki earthquake (Mw 9.0) are added to determine the updated 3-D Vp and Vs models of the Tohoku forearc region.

Significant structural heterogeneities are revealed in the interplate megathrust zone under the Tohoku forearc. Three low-velocity (low-V) anomalies exist off Sanriku, off Fukushima and off Ibaraki. There is a correlation between the velocity variation and the distribution of large thrust-type earthquakes ($M > 6.0$) that occurred from 1900 to 2011, including the foreshock, mainshock and aftershocks of the 2011 Tohoku-oki earthquake. The low-V patches in the megathrust zone may contain subducted sediments and fluids associated with slab dehydration, thus the subducting Pacific plate and the overriding continental plate may become weakly coupled or even decoupled in the low-V areas. In contrast, the high-velocity (high-V) patches in the megathrust zone may result from subducted oceanic ridges, seamounts and other topographic highs on the Pacific seafloor that become asperities where the subducting Pacific plate and the overriding continental plate are strongly coupled. Thus tectonic stress tends to accumulate in these high-V areas for a relatively long time during subduction, leading to the nucleation of large and great earthquakes in those areas. The off-Miyagi high-V zone, where the Tohoku-oki mainshock and its largest foreshock occurred, corresponds to the area with large coseismic slip (> 25 m) during the Tohoku-oki mainshock. This indicates that the off-Miyagi high-V zone is a large asperity in the megathrust zone that ruptured during the Tohoku-oki mainshock. These results indicate that the rupture nucleations of the large events in the 2011 Tohoku-oki earthquake sequence, including the mainshock and major foreshocks and aftershocks, were controlled by the structural heterogeneities in the interplate megathrust zone and the over-riding continental plate.

Detailed 3-D Vp and Vs models of the entire Southwest Japan arc from the Nankai trough to the Japan Sea are determined for the first time using a large number of high-quality arrival-time data from local earthquakes. Our results show that strong lateral heterogeneities exist in the interplate megathrust zone under the Nankai forearc. Large interplate earthquakes mainly occurred in or around high-V patches in the megathrust zone. These high-V patches may represent asperities formed by the subducted oceanic ridges and seamounts. Low-V zones in the megathrust zone may contain sediments and fluids associated with slab dehydration and so become weakly coupled areas. Our results also show that the coseismic slip distributions of some megathrust earthquakes are not limited in the high-V patches (asperities) where the ruptures initiated. Because of the weak interplate coupling in the low-V areas, the rupture of an interplate earthquake could unimpededly pass through the low-V anomalies and so result in a great megathrust earthquake.

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Keywords: subduction zone, great earthquakes, structural heterogeneity, seismic tomography, forearc, fluids

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SSS31-29 Room:302 Time:May 22 15:15-15:30

3D modeling of the cycle of megathrust earthquakes in the southern Kuril subduction zone considering high speed friction

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Studies on deposits of prehistoric tsunamis indicate the occurrence of destructive earthquakes (Mw 8.4) along the southern Kuril trench subduction zone (Nanayama et al., 2003). Intervals between inferred outsized tsunami events average nearly 400 years, but range widely from about 100 to 800 years (Sawai et al. 2009).

Recent studies on fault zones show that considerable weakening can occur at a high slip velocity because of pore-fluid pressurization via frictional heating or thermal weakening processes (Noda and Lapusta, 2010; Di Toro et al., 2011, Tsutsumi et al., 2011). Shibazaki et al. (2011) performed 3D quasi-dynamic modeling of the great Tohoku-oki earthquake cycle by considering high-speed friction. The present study models the megathrust earthquake cycle along the southern Kuril trench subduction zone, considering weakening of friction by thermal pressurization at high slip velocity.

We investigate the model considering a rate- and state-dependent friction law and thermal pressurization by using a spectral solver (Noda and Lapusta, 2010) to calculate the temperature and pore pressure evolution on a fault plane. Asperities for the 1952 Tokachi-oki earthquake (Mw 8.1) and the 1973 Nemuro-oki earthquake (Mw 7.8) are considered. The Geospatial Information Authority of Japan (2012) suggests that there is a slip deficit region at the shallower subduction interface between the two source regions, and in this respect, we set a larger asperity near the trench. We set the frictional properties of velocity weakening within the asperities and that of velocity strengthening outside of the asperities. Results show that when a rupture occurs around the large asperity near the trench, significant thermal pressurization occurs, resulting in large and fast slips. This rupture propagates to the stable creeping region and to the asperities of Mw 8 earthquakes. We examine conditions where observed recurrence intervals are reproduced. In cases where the recurrence interval of megathrust earthquakes is around 400 years, the size of the megathrust earthquakes reaches Mw 8.8.

Keywords: the southern Kuril subduction zone, megathrust earthquakes, earthquake cycle, high-speed friction

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SSS31-30 Room:302 Time:May 22 15:30-15:45

Strength drop as a detectable short-term precursor: feasibility of acoustic monitoring at a natural scale

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On the basis of the revised RSF proposed by Nagata et al. (2012), we reinvestigated frictional stick-slip cycles of earthquake faults. Simulation results showed a fairly large strength drop in the preslip period, which is localized within a few years preceding the earthquake. This suggests a possibility of earthquake forecast by monitoring the strength drop of a natural fault by acoustic methodology. In laboratory, Nagata et al. (2008, 2012) conducted rock friction experiments in a double-direct-shear apparatus, where they simultaneously measured P-wave transmissivity across the frictional interface to monitor the state of contact (= strength). The acoustic transmissivity |T| was found to reflect changes in the contact state very well. However, a critical problem is that how the acoustic monitoring can be realized at a natural scale. The present paper discusses its feasibility based on the earlier studies on the acoustic method for monitoring mechanical properties of imperfectly welded interfaces (Kendall and Tabor, 1971; Schoenberg, 1980).

We started from the laboratory experiment of Nagata et al. (2008) of the order of strength 10MPa, fc_lab = 1MHz and L_lab = 1micron, where fc is a cutoff frequency and L is a characteristic slip distance of the interface. We theoretically derived that I times greater strength and J times greater L lead to fc = (I/J)fc_lab. For our simulation values of I=10 (100MPa strength) and J=10^5 (L=10cm), fc can be estimated as 100 Hz. Recently reported large L=1m (J=10^6) (Hori and Miyazaki, 2011; Kato and Yoshida, 2011) and weak strength of 10MPa (I=1) (Hasegawa et al., 2011) for the 2012 Mw9.0 Tohoku earthquake, fc could be as low as 1 Hz. We think that the frequency range between 1 to 100 Hz is seismically observable. In fact, the explosion reflection surveys conducted over the plate boundary on the forearc slope of the Japan Trench successfully revealed the intensity distribution of plate boundary PP reflection around 5 - 20 Hz (Fujie et al., 2002; Mochizuki et al., 2005). Because acoustic reflection |R| is theoretically related to |T| (Schoenberg, 1980), acoustic monitoring of strength via |R| looks feasible at a natural scale. Note that though expected change of |T| in the preslip period would depend on the ratio of the change to the absolute value (Nagata et al., 2012), and the ratio is arbitrary in the simulations (only the change from an arbitrarily chosen reference value is necessary). The ratio could be more than 50% if a weak fault is considered in our simulation, and it would be easily detected by seismic reflection surveys.

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SSS31-31 Room:302 Time:May 22 16:15-16:30

Paradox of seismicity in subduction zones: Background seismicity and mega-earthquakes

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Since earthquakes release elastic strain accumulated by long-term plate motion, we expect that fast plate subduction yields frequent occurrence of earthquakes. This intuitive expectation is supported by observation. A background seismicity rate estimated by applying the ETAS model in a finite area of subduction zone correlates with the velocity of relative plate motion. Especially a strong correlation exists for subduction zones in the south western Pacific including the Mariana and Tonga-Kermadec subduction zones. Despite high seismicity, no earthquake larger than M9 has been known in these regions and the Mariana subduction zone was considered as a representative region where no mega-earthquake occur in early comparative subductology. In total, these regions have a potential to yield one M9 earthquake every decade, if we assume the complete coupling and the independent occurrence of large earthquakes. On the other hand, there are many regions where seismicity is extraordinary lower than the expectation by the above proportionality. These include the Nankai, Ryukyu, Cascadia, and southern Chile subduction zones, all of which are also known as the area of "slow earthquake", i.e., tectonic tremor and slow slip events, and as the high-risk area of mega-earthquakes. Therefore, apparently high seismicity implies low risk of mega-earthquakes, and vice versa. Slow aseismic process seems to be a key to reconcile this paradox. Actually, the above fact is not new, and vaguely and regionally recognized by many researchers. However, I emphasis that it is an important paradox in earthquake science, that should be considered globally and quantitatively.

Keywords: subduction zone, seismicity, ETAS, slow earthquake

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SSS31-32 Room:302 Time:May 22 16:30-16:45

Similarity and variability of great earthquakes in world's subduction zones

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Because recurrence interval of giant (M~9) earthquake is typically several hundred years, data of past earthquakes are limited from a particular subduction zone. However, we can increase our knowledge by studying the subduction zones in the world. For five giant earthquakes with M=9 or larger occurred in the world since the 20th century, instrumental data such as seismic waves, tsunamis, or geodetic data were used to estimate the slip distribution and similarities. For older earthquakes, historical documents or paleoseismological data such as coastal movement (subsidence or uplift), tsunami deposit, or turbidite can help to estimate size and recurrence of past earthquakes. They show the variability of past earthquakes: giant (M~9) earthquakes occurred in the source regions of recurrent M~8 earthquakes, hence it is dangerous to assume characteristic earthquake model (Satake and Atwater, 2007).

For the post 20th century earthquakes, i.e., the 1952 Kamchatka (Mw 9.0), 1960 Chile (Mw 9.5), 1964 Alaska (Mw 9.2), 2004 Sumatra-Andaman (Mw 9.1) and 2011 Tohoku (Mw 9.0) earthquakes, the slip distributions have been estimated from inversion of tsunami and geodetic data. The results show that the largest slip is twice to four times larger than the average slip, and the asperity (defined as the area with more than 1.5 times the average slip) consists 16-32 % of the total fault area. The scaling relations among seismic moment, fault area, asperity area, average slip obtained for M~8 earthquakes can be applied for the M~9 earthquakes (Murotani et al., 2013).

Paleoseismological studies around the Pacific ocean have revealed the recurrence interval of giant earthquakes. In southern Chile where the 1960 earthquake occurred, historical records indicated that the recurrence interval was ~ 100 years, but recent studies of tsunami deposit (Cisternas et al., 2005) show that the penultimate event occurred in 1575 and the recurrence interval is ~ 300 years. In north America, along the Cascadia subduction zone, no great earthquakes have been recorded in historical records. Numerious paleosesimological stuides on coastal subsidence, tsunami deposit or offshore turbidite have shown that more than 40 great earthquakes occurred in the Holocene, but the number of giant earthquakes (M~9) is about a half, or the average recuccence interval is ~ 500 years (Goldfinger et al., 2012). Along the Kuril trench, the great earthquakes that left tsunami deposits occurred with ~ 500 year interval, and the most recent one occured in the 17th century (Nanayama et al., 2003). Tsunami deposit studies in Sendai plain showed that the recurrence interval of giant earthquake similar to the 869 Jogan and 2011 Tohoku earthquakes is 500 to 800 years (Sawai et al., 2012). Similar paleoseismological studies have been made in countries around the Indian Ocean such as Thiland, Indonesia, or India, and they show that tsunamis similar to the 2004 Indian Ocean tsunami occurred several hundread ago. The tsunami deposits in Thailand show that the average recurrence interval is ~ 500 years (Prendergast et al., 2012.)

Keywords: great earthquakes, tsunami, paleoseismology, subduction zone

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SSS31-33 Room:302 Time:May 22 16:45-17:00

Tsunami source models of the 2011 Tohoku and 1896 Sanriku earthquakes

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We estimated the tsunami sources of the 2011 Tohoku earthquake and 1896 Meiji Sanriku tsunami earthquake by modeling the tsunami waveform data and tsunami height data along the coasts.

The spatial and temporal slip distribution of the 2011 Tohoku tsunami source was inverted from 53 tsunami waveforms recorded at ocean bottom pressure gauges, GPS wave gauges, and coastal wave and tide gauges (Satake et al., 2013, BSSA). The result shows that fault slip started near the hypocenter and very large (> 25 m) slip occurred on the deep plate interface near the hypocenter within ~ 2.5 min, then huge (up to 69 m) slip occurred at the shallow part near the trench axis and propagated to the north. The final slip distribution shows that the slip increases toward the trench axis. The average slip on a 550 km long and 200 km wide fault is 9.5 m, and the total seismic moment is 4.2 x 10^{22} Nm (Mw = 9.0). The slip distribution can be decomposed into a shallow slip near the trench axis (Mw = 8.8) and a deeper slip on the plate interface (Mw = 8.8).

The shallow slip near the trench axis is similar to the proposed model of the 1896 Sanriku tsunami earthquake (Tanioka and Satake, 1996, GRL), which is inferred from the tsunami records at three tide gauges (Hanasaki, Ayukawa and Choshi). The maximum tsunami height observed at tide gauges was 1.2 m at Ayukawa, which is much smaller than the observed one for the 2011 tsunami (> 8 m), while the maximum tsunami height (~ 40 m) along the Sanriku coast was similar to the 2011 tsunami. The tide gauge records and the coastal tsunami heights from the 1896 Sanriku earthquake can be explained by halving the slip of the 2011 source model on the northern subfaults along the trench axis (200 km x 50 km). The seismic moment is ~ 3 x 10^{21} Nm (Mw = 8.2). While the average slip of ~ 9 m is similar to the previous estimates (Tanioka and Seno, 2001, GRL), the slip increases toward south. This indicates that both the 1896 and 2011 earthquakes had similar slip distribution along the trench axis.

Keywords: 2011 Tohoku earthquake, 1896 Sanriku earthquake, Slip distribution, Tsunami waveform data, Tsunami height along coast

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SSS31-34 Room:302 Time:May 22 17:00-17:15

The feature of the Tsunami height according to type of the coastal landforms - in the case of the 2011 Tohoku Earthquake

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Along the Sanriku shoreline, a lot of the Thsunami height dates have been measured by the 2011 Tohoku Earthquake Tsunami Joint Survey Group (2012) in the field survey and Tsunami damage area maps were made by interpretation of the aerial photographs taken just after the earthquake (Tsunami Damage Mapping Team, Association of Japanese Geographers, 2011). Also, we can access historical Tsunamis dates (1896, 1933, 1960).

We classified according to the type of coastal landforms and then compared the 2011 Tohoku Earthquake Tsunami to historical tsunamis. In the result, in short wavelength Tsunami case, a tsunami height in bordering open ocean areas is higher than in bordering inner bay. On the other hand, in long wavelength Tsunami case, a tsunami height in bordering open ocean areas is similar as bordering inner bay. In the 2011 Tohoku Earthquake Tsunami case, we can show the tsunami height with features of both the short wave and the long wave in the northern and the southern area, and the middle area has only the long wave feature. The areal distribution correlates with the tectonic geomorphology in sea bed.

This study leads us in understanding of the detail subduction earthquakes in poor observation equipment area and geological period.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, coastal landform, Meiji Tsunami, Wavelength of Tsunami, Ocean-Trench Earthquake

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SSS31-35 Room:302 Time:May 22 17:15-17:30

Holocene event deposits detected from Kushimoto, Wakayama prefecture, along the Nankai Trough

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We found several Holocene event deposits in Kushimoto where tsunami has been repeatedly attacked due to mega-thrust earthquakes along the Nankai Trough. Analyzing the drilling cores up to 9 m in depth, mean recurrence interval of event is estimated to 400-600 years. This result is consistent with our previous studies of tsunami boulders and uplifted sessile assemblages in outskirts area.

Drilling survey site is in the campus of Kushimoto-Koza high school located in tombolo of 500 m in width and 5.8 m in altitude. Obtained core samples show that at least 7 layers of fine-coarse sand are intercalated into humic silt-clay. Based on the lithofacies, it is inferred that sand has been intermittently transported into marsh or lagoon.

In the depth of 7.4 m, we found volcanic ash layer which is probably K-Ah tephra (ca 7300 yr BP). Radiocarbon samples in the depth of 4.1 m and 3.2 m were dated to 5570-5320 yrs BP and 4150-3980 yrs BP respectively. Archeological layer of late Yayoi period (1800 years ago) was also found in the depth of 1.8 m. Because seven sand layers were deposited between 5400 yrs BP and 1800 yrs BP, mean recurrence interval of event can be estimated to 400-600 years.

Cause of event deposits found in this survey is tsunami or storm, but its distinction is difficult. To identify tsunami deposit, it is necessary to consider synchronism with crustal movement reconstructed by microfossil analysis.

Keywords: Nankai Trough, Kushimoto, Holocene, tsunami, deposit

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SSS31-36 Room:302 Time:May 22 17:30-17:45

Revisiting the unusual uplift of the Kikai Island at northern Ryukyu Islands, Japan

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After the 2011 Tohoku-oki tsunami, reevaluation of the maximum earthquake and tsunami along the coastal area of Japan is the important issue for the future disaster prevention. In this sense, understanding the historical and pre-historic earthquake and tsunami events is the straightforward way to prepare the future disaster countermeasures. In this study, we evaluated the possible maximum earthquake event at the northern Ryukyu Islands (Amami-Oshima and Kikai Islands), Japan based on the geological and geomorphological evidence and then conducted the numerical modeling of the seismotectonic uplift and tsunami. Kikai Island marks one of the highest uplift rates in the world. Namely, the island was intermittently uplifted about 1-4 m of 1,500-2,000 years interval during the Holocene by the seismic event and the latest one was occurred at about 1,550 years ago (e.g., Webster et al., 1998). On the other hand, there is no evidence of such remarkable uplift at the east coast of the Amami-Oshima Island (approx. 30 km away from the Kikai Island). Moreover, coastal boulders deposited on these islands' reefs were of storm wave origin without any tsunami origin, suggesting no remarkable tsunami was affected to these coasts during past 2,300 years. These evidences can be used as the geological and geomorphological constraints of the seismic event at 1,550 years ago. Our preliminary numerical modeling of the seismotectonic uplift revealed that the above-mentioned constraints were explained reasonably by the high-angle reverse faults rather than the row-angle thrust type fault at the plate boundary.

Keywords: earthquake, uplift, tsunami, Kikai Island