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

SSS02-P01 Room:Convention Hall Time:May 25 18:15-19:30

Investigation of the Behavior of Shallow Parts of Mega-Thrust Earthquake Faults Based on Dynamic Rupture Simulations

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Recent inter-plate mega-thrust earthquakes, such as the 2011 Off the Pacific Coast of Tohoku earthquake (Tohoku Earthquake, Mw 9.0), the 2010 Maule, Chile earthquake (Mw 8.8) and the 2004 Sumatra earthquake (Mw 9.2), revealed some special features of ruptures, such as very large slip (order of several ten meters) and limited short period seismic radiations close to the trench. However, the mechanical origin of these phenomena has not been clarified yet.

In this study, we carry out simulations of the rupture process of large mega-thrust earthquakes based on dynamic models to understand the behavior of shallow parts of the faults. The model is governed by a slip-dependent friction law (Ida, 1972). The simulations employ the 3D Spectral Element Method (Galvez et al., 2014), which is numerically stable and accurate even for subduction models with low dipping angle. Based on these simulations, we explored some possible hypothesis for the generation of large slip on the shallow parts of the faults: large stress drop and thermal pressurization (e.g., Bletery et al., 2014). The results of our dynamic simulations provide useful clues to understand more generally the behavior of shallow parts of the mega-thrust earthquake faults.

Keywords: Rupture Simulation, Dynamic Model, Mega-Thrust Earthquake, Slip Distribution

Japan Geoscience Union Meeting 2015
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SSS02-P02 Room:Convention Hall Time:May 25 18:15-19:30

Epicenter determination by back-projecting onshore and offshore seismic data along the Japan Trench

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In the Japan Trench subduction zone, we have to pay attention to the uncertainty of hypocenters, especially in focal depths, listed in the existing catalog due to a large distance between hypocenters and the onshore seismic network. In addition, there is a significant reduction in the number of detected events over months after large earthquakes, such as the 2011 Tohoku earthquake. In order to overcome these problems and to understand seismic energy release associated with large earthquakes, it is essential to automatically determine hypocenters by also using offshore seismic data.

Therefore, we have investigated changes in seismicity before and after the 2011 Tohoku earthquake around its southern limit by back-projecting offshore seismic array data. Previous results suggest the large coseismic slip zone of the Tohoku earthquake may not have extended off Ibaraki.

In this study, we try to improve the method for epicenter determination by combining the back-projection results from both onshore and offshore seismic array data, and to discuss the seismic energy release in the source area of the Tohoku earthquake over a wider range. We used the NIED Hi-net data from stations located in the eastern Japan along the Pacific coast as the onshore array, and the 1-Hz ocean bottom seismometer (OBS) data deployed off Ibaraki as the offshore array. We applied a semblance analysis to each array data, and then identified the epicenter from both back-projected semblance values. As preliminary results, we determined some epicenters with higher accuracy even of earthquakes away (∼40 km) from the OBS array. These results indicate that it may be possible that we can put some constraints on the extension of the rupture area of the Tohoku earthquake over a wider range by investigating seismicity and its temporal changes. We continue to develop and improve our method so that the method is applicable to continuous waveform data.

Keywords: back-projection, semblance, onshore and offshore seismic array

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SSS02-P03 Room:Convention Hall Time:May 25 18:15-19:30

Structural characteristics observed on high resolution seismic profiles in the northern Japan Trench axis region

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The Japan Trench axis area has been intensively investigated since the 2011 Tohoku earthquake because the large slip reached to the vicinity of the trench axis. We have conducted three high resolution seismic cruises in the northern part of the Japan Trench axis region. The trench area between 38 - 40.5 N was covered by 94 E-W seismic lines with 2 - 6 km line interval. A 1200 m-long streamer cable with 192 channel receivers and a cluster gun array with volume of 320 - 380 inch^3 were used for these surveys. Post-stack time migrated sections provide detailed image of sediments above the subducting Pacific plate and its deformation by the bending-related normal faults on the outer trench slope. Thrust faults and possible slope failures are observed landward of the trench axis, beneath the lower most landward trench slope. The deformation style of the sediments in the trench axis shows variation along the trench strike. To the south of the survey area in 38 - 39 N, imbricate thrust-and-fold packages is observed but limited within the vicinity of the trench axis, which could be related to the interaction between the frontal prism toe and horst-graben structure. To the north around 40 - 40.5 N, frontal thrusts and imbricate structure are clearly observed on the seismic profiles through ˜10 - 15 km landward of the trench axis. Around 39.5 N, the trench inner slope is very steep. It is suggested that slope failures have occurred in this area. The trench axis is filled by slump deposits and debris with chaotic acoustic characteristics, which is similar with that in the seaward portion of the frontal prism. Seismic profiles on the outer trench slope show the variation on the thickness of the incoming sediments along the trench strike. It is thick, ˜500 ms, in the northern part of the survey area around 40 - 40.5 N, and it is ˜250 ms in the southern part around 38 N. The thickness is varied in the area between 38.5 - 39.5 N, and is very thin at 39.5 N. Sediments on the trench outer slope basically conformably cover the igneous basement of the Pacific plate and they were deformed by the bending-related normal faults. These normal faults basically coincide with faults identified on the bathymetric map. Graben fill sediments which onlap the original incoming sediments are also clearly observed on the seismic profiles in the outer trench slope. These graben fill sediments have been deposited in several isolated basins. The graben fill sediments could cause underestimation of the fault throw if estimated from bathymetry data, because they mask the throw of the faults located near the depocenter. Similar onlap fill sediments are also observed in a few places in the trench axis.

Keywords: Japan Trench, seismic imaging, incoming sediments, frontal thrust faults, bending-related normal faults

Japan Geoscience Union Meeting 2015
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SSS02-P04 Room:Convention Hall Time:May 25 18:15-19:30

Mechanical and hydrological properties of incoming sediments at the Japan Trench and the weak-decollement evolution

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2011 Tohoku earthquake caused the large tsunami induced by the large fault slip along the subduction plate boundary. Incoming sediments, a part of which changes into weak fault zones or décollement, could control the earthquake behavior of subduction zones. However, what actually controls the formation of a weak fault plane from the non-deformed incoming sediments at a subduction plate boundary is still debated.

There is a high possibility that vertical variations of shear strength and velocity dependence of friction among the incoming sediment contribute to the development of a weak plate boundary fault zone. Permeability is the other important factor to affect the vertical variations of the strength as it controls the generation of excess pore pressure due to dehydration and pore compaction during the subduction.

In the previous reports, the hydrological and mineralogical data about the core of the toe of the wedge have been obtained on the Japan Trench Fast Drilling Project (JFAST), Integrated Ocean Drilling Program (IODP) Expedition 343 (Tanikawa et al., 2013; Kameda et al., 2015). The frictional properties are also revealed (Ikari et al., 2015). On the other hand, there are only a very few frictional and hydrological properties for the input materials at DSDP Hole 436 (Sawai et al., 2014).

Therefore, in this study we measured the frictional strength and fluid transport properties of the core samples retrieved from the input site of the Japan Trench (DSDP Hole 436), and estimated the depth distribution of the strength and permeability.

The core samples we tested were recovered from Hole 436, which is located at the outer rise of the Japan Trench. Tested samples were selected to cover the whole cored depth. We conducted two types of measurements of frictional strength on each sample: normal-stress dependent test and velocity dependent test, by a rotary shear friction apparatus at Kochi Core Center (Shimamoto and Tsutsumi 1994; Hirose and Shimamoto 2005). In addition, we measured fluid transport property by Steady State Flow Method using water as a pore fluid.

Based on the laboratory results, we discuss the possible process to develop the weak fault zone during the subduction. We also compare the data with those of the preceding studies about JFAST samples.

Keywords: Japan Trench, subduction zone, frictional property, hydrological property

Japan Geoscience Union Meeting 2015
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SSS02-P05 Room:Convention Hall Time:May 25 18:15-19:30

Frictional properties of subducting oceanic sediments and rocks at a shallow Japan Trench condition and slow slip rates

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We conducted triaxial friction experiments on gouges of subducting oceanic sediments and rocks at a confining pressure of 81 MPa, a pore pressure of 76 MPa, a temperature of 27.5 ℃, and a constant slip rate of 1.155 μm/s. Samples used are basalt of the Philippine Sea plate cored from IODP Site C0012 off Kii Peninsula, chert of the Pacific plate cored from IODP Site C0019 near Japan Trench off Tohoku, and pelagic and hemipelagic clays of the Pacific plate cored from DSDP Site 436 off Tohoku. Experimental confining pressure, pore pressure and temperature are those supposed at the plate boundary fault zone near Japan Trench drilled through during the IODP Exp. 343. Confining and pore pressures were estimated from the density log profile obtained during the Exp. 343 and assuming a hydrostatic condition, respectively, while temperature was a value recorded in a hole at Site C0019 after 7 months of drilling. The steady-state friction coefficient after a displacement of ≈ 5 mm was ≈ 0.65 for basalt and chert, ≈ 0.4 for hemipelagic clay, and ≈ 0.1 for pelagic clay. Thus the frictional strength of pelagic clay is unusually low, which is ascribed to its abundance in clay minerals (≈ 89 wt%), particularly smectite (≈ 63 wt%). This implies that a décollement is likely formed in the pelagic clay layer at Japan Trench off Tohoku, which was in fact found to be true by drilling during the IODP Exp. 343. We will also show the results of friction experiments at a slip rate of 11.55 μm/s, and discuss the velocity dependence of steady-state friction as well.

Keywords: friction, basalt, chert, pelagic clay, hemipelagic clay, Japan Trench

Japan Geoscience Union Meeting 2015
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SSS02-P06 Room:Convention Hall Time:May 25 18:15-19:30

Clay minerals in the Nankai Trough accretionary sediments as a function of depth

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We investigated how clay minerals in the Nankai Trough accretionary sediments change in content with depth from ≈ 950 mbsf (meters below seafloor) to ≈ 3030 mbsf at IODP Site C0002 off Kii Peninsula. Quantitative XRD analyses reveal that the content of smectite relative to total clay minerals decreases with depth from ≈ 76 wt% to ≈ 40 wt %, while those of illite and kaolinite increase with depth from ≈ 10 wt% to ≈ 30 wt%. Borehole temperature measurement at this Site revealed the temperature at 900 mbsf to be 38 ℃, while the temperature at ≈ 3000 mbsf has been estimated to be ≈ 100 ℃ based on the temperature and heat flow data at ≈ 900 mbsf and logging-while-drilling bit resistivity data. Thus the observed changes in contents of clay minerals likely reflect a temperature increase with depth.

Keywords: clay minerals, accretionary sediments, Nankai Trough

Japan Geoscience Union Meeting 2015
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SSS02-P07 Room:Convention Hall Time:May 25 18:15-19:30

Borehole stability discussion of NanTroSEIZE main-site, C0002

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Three IODP expeditions run for the Nankai subduction zone had accomplished in 2014. Chikyu carried out the drilling operations and collected much valuable data including LWD, core samples and wireline loggings. This site is planned to drill 7 kilometers recovering the fault zone material and on-site experiments data. In the beginning, C0002A borehole was drilled from 1964.5mbrf (0 mbsf) to 3336 mbrf without any problem. The drilling was complete in one week on 18th October 2007. This riser-less drilling used seawater (1.03S.G) for drilling mud. In this riser-less drilling, we can observe the clear breakout in entire borehole from shallow to deep. Due to the difficulties of drillings in the following expeditions, next stage of drilling in this site, exp.338, was started in the first of October 2010, C0002F kept drilling 12.24-inch LWD borehole to 3973 mbrt (20005.5 mbsf) and changed to drill in riser-less due to the BOP line leakage, C0002F was abandoned at this depth by suddenly increasing wind. Exp.348 faced the difficulties in very early stage (in the C000F cementing section). The sidetrack borehole, C0002P, overcame the high fractures zones and highly tilted structure to reach the center of inner accretionary wedge. Very few breakout occurred in both riser drillings, the big amount of cutting recovered indicated the weak formation collapsed and enlargement of borehole radius. However, these drillings could not pass through the fault zone yet. In this research we listed the related drilling parameters in these boreholes and construct the borehole stability model to explain the possible reason of drilling difficulties. Depending on 2-D stress model in each borehole. The major reason maybe the high and over mud weights apply on the borehole in the low principal stress environments.

Keywords: IODP, NanTroSEZIE, LWD, borehole stability, stress

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SSS02-P08 Room:Convention Hall Time:May 25 18:15-19:30

Incoming materials for an erosional subduction zone, offshore Osa Peninsula, Costa Rica

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Bulk mineral assemblages of sediments and igneous basement rocks on the incoming Cocos Plate at the Costa Rica subduction zone were examined by X-ray diffraction (XRD) analyses on core samples. These samples are from Integrated Ocean Drilling Program (IODP) Exp. 334 reference Site U1381, ~5 km seaward of the trench, cored as part of the Costa Rica Seismogenesis Project (CRISP).

Drilling recovered approximately 100 m of sediment and 70 m of igneous oceanic basement. The sediment includes two lithologic units: hemipelagic clayey mud (unit 1) and siliceous to calcareous pelagic ooze (unit 2). The hemipelagic unit is composed of clay minerals (~50 wt.%), quartz (~5 wt.%), plagioclase (~5 wt.%), calcite (~15 wt.%) and ~30 wt.% of amorphous materials, while the pelagic unit is mostly made up of biogenic amorphous silica (~50 wt.%) and calcite (~50 wt.%). The igneous basement rock is composed of plagioclase (~50-60 wt.%), clinopyroxene (~>25 wt.%), and saponite (~15-40 wt.%). Saponite is more abundant in pillow basalt than in the massive section, reflecting the variable intensity of alteration. Fluid expulsion models shows that sediment compaction during shallow subduction causes the release of pore water while peak mineral dehydration occurs at temperatures of approximately ~100 ℃. The subducting sediment has the potential to generate fluid overpressure at distances of between 5 and 70 km landward of the trench.

Keywords: erosional subduction zone, CRISP, XRD

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SSS02-P09 Room:Convention Hall Time:May 25 18:15-19:30

Change in stress state in an on-land accretionary complex : implication for large stress drop with subduction earthquake

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Stress state in subduction zone is one of critical information to understand wedge architecture controlled by physical properties of wedge, friction on decollement, and fluid pressure ratios within and below wedge. Accretionary complexes are developed mainly by horizontal compressional stress in subduction zone, which indicates that the wedge development occurs under compressional critical state. Major geological features have been reported such as fold and thrust, and duplex structure. However, not only the compressional features, but also the bedding parallel extensional features such as normal faults are also recognized within accretionary complex. Because those extensional features are not commonly expected in subduction zone, we have not paid much attention on such extensional features. Recently, the extensional aftershocks were identified after the Tohoku-Oki earthquake suggesting that the stress state can be switched from horizontal compression to extension in subduction zone with seismic cycles. Because accretionary complex should be experienced by numerous number of earthquake events, such stress switch can be also recorded within accretionary complexes. That means that the normal faults within accretionary complexes are also possible to be related to the stress switch with seismic cycle. The purpose of this study is to understand the relationships between reverse and normal faults in on-land accretionary complex, whether the activations of reverse and normal faults can be expected in the same pressure-temperature conditions.

The study area is Kayo Formation in the Shimanto accretionary complex in Okinawa Island. Beautiful outcrops are well exposed along coastline. Paleomaxim temperature from vitrinite reflectance has been reported by previous study ranging from about 250-300?C. Fold and thrust structures of more than 50 m width are well observed. Within the fold and thrust zone, normal faults of 10 m width are also identified. On the basis of careful observations, horizontal thrusts cut normal fault in some areas, which suggests that the normal faults was activated before thrusting. Normal faults also cut the reverse fault in some places. The cross-cutting relationships suggest that the normal and reverse faults were activated in a short period.

To estimate the pressure temperature conditions of reverse and normal faults, fluid inclusion analysis was conducted. Both reverse and normal faults are accompanied by shear veins composed of quartz. Only water inclusions were observed in the veins. The homogenization temperature for the veins from reverse and normal faults ranges from about 165 ?C to about 235?C and modal value ranges from about 175?C to about 195?C. There is no difference between the fault types. Density of water calculated to range from about 0.87 to about 0.89 on the basis of the homogenization temperature. Combining with the isochore lines (equal-density line in pressure vs temperature space) and the paleomaximum temperature of 250-300?C from vitrinite, paleo-maximum pressure ranges from about 140MPa to 190MPa, which is corresponds to the geothermal gradient of about 40-50?C/km. As describe above, the cross-cutting relationship between normal and reverse faults suggest that the their activations were in a short period enough to consider a constant geothermal gradient. Therefore, the same homogenization temperature of fluid inclusion between veins from reverse and normal faults indicates that the both faults were activated under the same pressure-temperature conditions. This result also suggests that the coexistence of reverse and normal fault in accretionary complex can reflect the stress switch by stress drop with seismic cycles similar of that observed in Tohoku-Oki earthquake.

Keywords: Accretionary complex, stress, temperature pressure conditions, fluid inclusion

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SSS02-P10 Room:Convention Hall Time:May 25 18:15-19:30

Coseismic stress of ancient seismic fault of Median Tectonic Line at Mie Matsusaka, Japan

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Introduction

The frontal stress of propagating fault increases from initial state (τ1) to peak state (τp), and stress will drop to residual level (τ2) (Kanamori and Rivera., 2004). The value of these stress are still uncertain in natural fault. The calcite-twin piezometer (Sakaguchi et al., 2011), enables paleo-stress estimation in this process. We applied this method to Median Tectonic Line (MTL) at Mie Matsusaka, Japan. Extra high stress that concern with τp is expected at central part of fault zone. Low stress level will be appeared at area distance from fault center, and this may show τ1 of the crust. Seismologic analysis revealed that the value of stress drop (τ1-τ2) is several MPa in many fault, and the residual stress of τ2 can be constrained from value of τ1 of the crust. We propose an one case study of quantitative stress evaluation in natural fault.

Matsusaka-Iitaka core sample

The MTL, length of $>$1000km is a boundary between the Ryoke and Sanbagawa Belts. The drilling core sample of 600m in length was obtained for groundwater observation at Iitaka area, Mie Matsusaka. This hole penetrates the MTL at 473.9m in depth. This site is composed of the granite and crystalline schist, and some of Protomylonite and Ultramylonite are developed (Shigematsu et al., 2014). Many calcite veins are occurred in these fault zones, and twenty one of calcite bearing samples are measured to estimate ancient stress.

Results

As a result, the highest twin density of 340.28/mm was found at central part of the MTL at depth of 473.3m, and the lowest twin density of 142.4/mm was found at 242.65m in depth. In other parts, high calcite twin-density are found at the branch faults from MTL. The values of the calcite twin-density are 277.3/mm at 340.28 to 358.08m in depth and the 208.1/mm at 213.1 to 248.32m in depth. In particular, Twin density tends to remarkably raised, towards at central part of MTL around depth of 450˜470m. The estimated paleo stress of the central part of MTL is approximately 490 (+/- 15) MPa, obtained from the calcite-twin density of 331.7/mm. This high stress may shows the τp of the MTL in this site. The lowest stress of 320 (+/- 15) MPa of this study was found at 242.65m in depth. Since this low stress was obtained around the branch fault, the value of τ1 of the crust probably lower than 320 MPa.

Keywords: coseismic, Initial state, peak state, residual level, calcite twin piezometer, twin density