Japan Geoscience Union Meeting 2013
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Initial data evaluation of seismometer and tiltmeter installed in the C0002G borehole observatory in the Nankai Trough

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Cable connection between DONET (Dense Oceanfloor Network system for Earthquake and Tsunamis) and C0002G observatory was successfully completed on Jan. 24, 2013. The C0002G observatory has a sensor suite comprising a volumetric strainmeter, tiltmeter, seismometers, pressure gauge, and thermometer, which was installed during IODP Exp.332 on Dec. 2010. After the cable connection, it has become possible to obtain realtime observed borehole data through DONET seafloor cable. In this presentation, we report results of initial data processing especially for seismometers and tiltmeter for future advanced analysis.

We conducted initial data processing including: 1) Power spectral density analysis calculated from 1 hour continuous noise record and comparison results of each sensor. 2) Running spectrum analysis using continuous long-term data and comparison results of each sensor. 3) Estimation of sensor orientation. Details of each processing are described as follows.

1) Power spectral density analysis

We calculate Power spectral density (PSD) using background noise record with length of 1 hour. We obtain PSD plots calculated from each seismic sensor including a broadband seismometer (CMG3TBD, Guralp systems), geophone (GS-11D, Geospace), accelerometer (JA-5H200, JAE) and tiltmeter (LILY, Applied geomechanics). In the obtained PSD, microseisms peaks around 0.3 Hz are clearly visible for all sensors. We then compared obtained results of borehole sensors and DONET seafloor seismometer. Results show that the microseisms peaks of boreholes sensors are smaller than those of DONET seismometers. The difference is 10 dB for horizontal component, and is 3-5 dB for vertical component. For high frequency region, 1-50 Hz, noise-levels of borehole sensors are much smaller than those of DONET seafloor seismometer with the difference of around 20dB. These results imply borehole sensors can capture very small seismic events which cannot be captured by DONET seismometers. We also confirmed that obtained noise-levels are consistent with the results of land experiments which were conducted before installation. For geophone, we conducted the signal coil calibration method, and obtained response parameters which are not changed with those obtained during the land experiments. We then concluded that the borehole seismic sensors were not damaged during the installation.

2) Running spectrum analysis

We calculate running spectrum using long-term data acquired since Jan. 25 2013. We checked long-term stability of each borehole seismic sensor from the results. Results shows common characteristic as the results of 1 hour data. The daily changes of microseisms peaks are clearly visible in the results. Performance degradations of borehole sensors are not found in the results.

3) Estimation of sensor orientation

We applied a cross-correlation method based on Nakano et al. (2012) to teleseismic records to estimate orientation of borehole sensors. We calculate cross-correlation between rotated horizontal waveforms of borehole seismometer and reference horizontal waveforms of DONET seismometer. We calculated cross-correlations for each rotated angle from 0 to 360 degree with a rotation rate of 1 degree. We then obtained the orientation angle of 46 degree from North with clockwise rotation, which has a maximum amplitude of calculated cross-correlation.

The above mentioned results show that seismometer package and tiltmeter installed in C0002G observatory are functional with expected performance which was revealed by the land experiments. Now auto evaluation processes are running to monitor sensor functions on data server. We plan to carry out an advanced check for sensor response using earthquake records. We also plan to analyze very small seismic events which are captured only by the borehole observatory. Furthermore, we plan to perform seismic interferometry analysis applied to continuous noise records and earthquake records for structural monitoring.

Keywords: borehole observatory, seismometer, Nankai trough, data evaluation

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Precision observation of seafloor pressure change on the platform of C0002 borehole observatory in Nankai Trough

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Long-term observation of seafloor and pore pressures off Kii Peninsula is important for the detection of the crustal movement, the monitoring of fluid migration around splay faults and also understanding the pre and post earthquake events in the focal region of the Tonankai earthquake. Pressure measurement contains the instrumental drift in pressure sensors in addition to the pressure changes associated with the crustal movement, fluid migration and etc. In order to remove the drift, the drift rate is estimated by the laboratory experiment. However, for the long-term observation over one year, it is difficult to quantify the behavior of the drift. In this study, we have conducted the precision observation of seafloor pressure change on the platform of C0002 borehole observatory for the development of the in-situ calibration method.

During the IODP Expedition 332 in December 2010, we deployed a long-term borehole monitoring system (LTBMS) with pressure gauges (Paroscientific Inc. 8B7000-2 and 8B7000-1) into C0002 riserless borehole in Nankai Trough to monitor the seismogenic behavior of subduction zone plate boundaries. Seafloor pressure and pore pressure measurements are continuously conducted since the deployment. In this January 2013, the C0002 long-term borehole observatory was connected to the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) for real-time monitoring during the KY13-02 cruise by the R/V Kaiyo. Therefore, the platform of C0002 borehole observatory is good target for the in-situ calibration study.

During the KY13-02 cruise, pressure gauge (Paroscientific Inc. 8B7000-2-005) was deployed on the platform of C0002 observatory by ROV Hyper-Dolphin and precise observation of seafloor pressure change were conducted for one hour. Prior to the cruise, the pressure gauge were precisely calibrated by the laboratory experiment. To reduce the effect of the pressure change, the gauge was pressurized at the target pressure under the seafoor temperature condition and the valve was closed in the laboratory. On the platform after the deployment, the valve was opened for the pressure measurement. Tilt sensor was also attached to the pressure sensor for the tilt calibration. We conducted the measurement twice on January 20 and February 1 for the repeatability evaluation.

The offset of the borehole pressure gauge from the absolute pressure value was 240 hPa. The repeatability of the measurement was 14 hPa within the specification of the pressure sensor(0.005%FS=34.5hPa), which is larger than the laboratory experiment. We found from the in-situ calibration that keeping the pressure condition is important for the precise pressure measurement. We will quantify the effects of the temperature change, tilt of the pressure gauge and the density change of the oil inside the gauge for the precise evaluation. Further, we plan to conduct the in-situ calibration at C0002 borehole observatory to estimate the long-term instrument drift and apply the calibration method to the DONET pressure gauges in Nankai Trough.

Keywords: Seafloor pressure observation, In-situ calibration, Nankai Trough, Borehole observatory, Crustal movement, Pore pressure

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The stress variation along the Nankai Trough observed in the scientific drillings Borehole C0010A and C0004B, NanTroSEIZ

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In NanTroSEZIE Exp. 319, well C0010A was drilled to compare with well C0004B in physical properties, fault zone architecture, and the variations along-strike of Nankai Trough. Based on the seismic reflection data, the character of the mega-spray fault diverges remarkably between C0010A and C0004B. The well conditions of LWD images are collected to 550 meter below sea floor (mbsf). In this paper, we used the stress polygon to analyze the reprocessing LWD images for picking the breakout and tensile fracture azimuth and width in well C0010A and C0004B. The stress state in site C0010A can be modified by the borehole conditions, logging data and the physical properties. The same methods run on the site C0004B and the stable, consistent stress profiles are shown. Several faults were identified by the rotated borehole breakout orientation. The fractures distributions also supported the stress anomaly in the vicinity of the faults. The magnitudes of the horizontal stresses in C0010A vary in the different units comparing to the C0004B. The difference of two sites indicated that the local structure near the Nankai Trough would be the factor to influence the stress state in the boreholes. However, the normal fault stress regime was designed in both boreholes. The low stress level in the shallow portion near the Nakai Trough was obtained in this scientific drilling project.

Keywords: NanTroSEIZE, LWD, Breakout, Tensile fractures, Stress polygon

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Analysis of Fracture Characteristic against Shape of Borehole Breakout

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In general, when fault is formed, the damage zone where includes many fractures will also be formed. Therefore, in previous research, it is known that stress field is disturbed by soft layer which is in fault zone. Thus, we consider that we can identify fractures derived from fault and its scale, shape, and other characteristics with comparing stress state and fracture distribution. Further, I think we can reveal which fracture affects the stress state. Then, I analyze the relationship between dip direction and strike azimuth of fractures and borehole breakout (BO). BO is the failure of borehole caused by stress concentration and it occur two positions separated 180 degree.

I classified the fractures into three patterns by near BOs shape. 1 BO direction is rotating. 2 BOs interval is not 180 degree. 3 No influence against BO shape.

Finally, I found the dip angle of fracture of pattern 2 is little higher than others. But, both dip angle and strike azimuth fractures of 3 distribute all around. So there are other factors affect BO shape. And around damage zone, I estimated from well data, amount of fractures of pattern 2 is much more other areas. I predict that is because the stress is released along fracture, especially near the fault from previous research result.

Keywords: Fracture, Borehole Breakout, Stress state, logging, Nankai Trough, Accretionary Prism

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Unsolving the fault activity off Tokai through 14C dating fossilised Calyptogena .spp shells.

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The Nankai and the Tokai Trough regions are common areas for cold seeps, an area of the ocean floor where Hydrogen Sulphide (H2S), Methane (CH4) and often hydro-carbon rich fluid seepage occurs. These various substances encourage the growth of Calyptogena .spp colonies to flourish at these sites. Naturally, cold seeps occur at tectonically active continental margins and are mostly ephemeral. This suggests that the activities of cold seeps are possibly influenced by the tectonic activity of the diverging plates. Previously attempts were made to reconstruct the cold seep activity history through amino acid racemisation dating. Yet further data is required to show any significant relationship. In order to further study the possible relationship between the cold seep activity and past major fault activity, radioactive 14C dating method will be used to attempt and accurately measure the age of the Calyptogena. spp shells.

Keywords: Tokai Trough, Cold Seeps, Calyptogena .spp, 14C dating, Fault activity

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High resolution shallow structures of the northern marginal fault of the forearc basin off Kumano

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Investigation of shallow deformation structures is significant for understanding of recent tectonic activity. We carried out deep towed subbottom profiling survey by ROV NSS (Navigable Sampling System) during Hakuho-maru KH-11-9 cruise. High resolution mapping of shallow structures was successfully conducted by a chirp subbottom profiling system. ROV NSS also has a capability to take a piston core with a pinpoint accuracy. The studied area is the northern margin of the Kumao Trough. The Kumano Trough is a well developed forearc basin associated with the growth of the accretionary prism that has been examined by IODP drillings. The basin is characterized by pervasive large-scale folds trending ENE-WSW. The northern basin margin is divided into two domains, with water depth differences of 14 m: northern margin at a water depth of 2028 m and southern main basin floor at a water depth of 2042 m, by ENE-WSW trending step. An asymmetric anticlinal fold suggesting activity of a blind fault is recognized beneath this step on multichannel seismic reflection profiles. Subbottom profiles show that reflectors of both fold limbs bend up and thin out toward the fold axis. The northern limb is completely filled by sediments and the southern limb corresponds to the gentle slope between the northern margin and the main basin floor. Acoustically transparent layers are dominant at upper 5 m sequences of the both limbs. These layers seem to correspond to Holocene sediments after approximately 10,000 years ago by adjacent core sample ages. Because bend structures of shallow strata near the fold axis attribute to relative uplift of the fold axis region, vertical displacement for the past 10,000 years is estimated to be 2.5 m. Further deep structures revealed by SBPs show accumulation of displacement with depth. Moreover, MCS profiles suggest strike slip deformation around this anticline based on existence of flower structures. Therefore, it is inferred that the northern marginal fault located below this fold is active for more than 10,000 years at least.

Keywords: monoclinal fold, flexure, active fault, forearc basin

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Studies of the source depth and the depositional environment of the mud volcano by using of drilling cores in the Kumano

Satoru Muraoka[1*], Juichiro Ashi[1], Arito Sakaguchi[2], Toshiya Kanamatsu[2], Kan Aoike[2], Fumio Inagaki[2]

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Submarine mud volcanoes are formed as conical mounds composed of erupted unconsolidated or partially consolidated sediments from mud diapirs. Hence submarine mud volcanoes have been attracting attention as a tool that can get substance beneath the seafloor without super deep drilling. It is expected to contribute in order to understand the formation of accretionary prisms and the mechanism of large earthquakes. On this view, researchers of mud volcanoes all over the world tried to measure the physical properties of mud volcano's sediments and estimate source depth of mud volcanoes. However, in the Nankai Trough known as a seismogenic zone, the source depth of mud volcanoes developed in Kumano basin have been unsolved.

The purpose of this study is to estimate the source depth and to discuss the formation process by using of shallow drilling cores from two sites (C9004, C9005) at the summit of the mud volcano in the Kumano basin, during CK09-01 using Deep-Sea Drilling Vessel CHIKYU, in March, 2009. We conducted mainly measurements of vitrinite reflectance, porosity, density, nannofossil age dating and anisotropy of magnetic susceptibility.

We estimated the depositional depths of various clasts in the mud volcano from the vitrinite reflectance, the nannofossil age and the geothermal gradient near this study area.

In the result, the source depth was estimated to be approximately 1900 mbsf by maximum burial depth of clasts. Focus of the discussion is about whether the materials of the source depth are derived from the accretionary prism or the forearc basin. It is inferred that the environment of the source was the forearc basin in view of the following two points. 1) Clast densities versus estimated burial are inconsistent with the logging results of the accretionary prism off Kumano. However a density decreases at the boundary between the forearc basin and the accretionary prism, the decay has not appeared in clast densities of the mud volcano. 2) Clay mineral composition of the mud volcano differs from one of the upper accretionary prism indicated from an examination of IODP Expedition 314 by Deep-Sea Drilling Vessel CHIKYU. The abundance ratio of smectite is large in the upper accretionary prism, whereas it is low in the deepest estimated clasts of the mud volcano. These results show that the source of the mud volacano is the forearc basin. Besides, the depth is the deeper, clast ages of the mud volcano are the older by the nannofossil age, but at 1700 mbsf, the age versus the depth indicates the gap of the age. If the source is not the accretionary prism, it would considered that the gap shows the old forearc basin sediments. Therefore, it would appear that the unconformity is developed in the boundary between the present and the old forearc basin near 1700 mbsf. This study suggests that the thickness of the Kumano basin is more than about 2000 m.

We will also discuss particle arrangements within erupted materials to understand grain fabric and its deformation by anisotropy of magnetic susceptibility.

Keywords: mud volcano, mud diapir, vitrinite reflectance, forearc basin, Nankai Trough

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A seismic inversion study for incoming sedimentary sequence in the Nankai Trough, southwest Japan

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The Nankai Trough, off southwest Japan, is a well known convergent margin on where huge earthquakes have been repeated in the cycle of 100–200 years. The next emergence of the disaster is concerned and many scientist have been studying to unveil and assess the dimension and mechanism of earthquakes and tsunamis. Here we show the physical properties distribution in incoming sedimentary sequence in the Nankai Trough. The seismic inversion technique is a method to estimate acoustic impedance of layers on seismic profiles with some drilling well data. We use 3D and 2D MCS profiles which acquired with KR06–02 and KR05–12 cruises and well data which drilled on the cruises of IODP Expedition 322 and 338.

Keywords: Nankai Trough, sediments, inversion, acoustic impedance, seismic reflection, Core-Logging-Seismic Integration

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Influence of Diatomaceous Structure on the Physical Properties - An Example of off San-riku, North Japan -

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During Ocean Drilling Program (ODP) Leg. 186, two sites (Site 1150 and Site 1151) were drilled on the continental slope of the deep-sea forearc basin of northern Japan. Diatomaceous sediments were recovered Site 1150 (39o 10.9'N, 143o 19.9'E) and Site 1151 (38o 45.1'N, 143o20.0'E), and the depth of each site is 1181.60 mbsf and 1113.60 mbsf, respectively. This area is under the influence of the Oyashio current and is one of the highly bio-productive regions of the North Pacific Ocean (Motoyama et al., 2004). The combination of high productivity and active tectonic deformation that often caused high rate accumulating of fossil and organic rich sediments.

The onboard results of porosity measurements show high value (50-70 %) down to 1000 mbsf, and obviously higher than nearby subduction trench, Nankai Trough (Taylor and Fisher, 1993). There is a possibility that diatomaceous shell keep a frame structure from effective stress and load pressure. On another drilling site result, DSDP (Deep Sea Drilling Project) Leg. 19 located 60 km to the north of ODP sites, was reported high value of porosity, but recognized only shallow range (>500 mbsf) (Shephard and Bryant, 1980).

We focused on the relationships between physical property, microstructure, and logging data at deep range(-1000 mbsf). We picked 14 samples to observe microstructure using SEM and measure permeability using flow-pump approach (1.5-4.5 MPa). Logging data were collected using wireline logging (Sacks and Suyehiro, 2003). Based on these results, it is expected that microstructure and logging can be integrated into a general model of core-log correlation.

We observed many pore in and around diatom fossils using SEM even in the sample from deeper than 1000 mbsf, and measured pore size and permeability at each depth. As depth deepen, porosity generally decreased by effective stress and load pressure, and permeability is also decreased. In this site, we recognized diminish as wavy curve in correlation between depth and permeability. Furthermore, wavelength cycle nearly matched resistivity alternation, and promised to have a correlation with lithofacies change.

In this presentation, We show results of microstructure using SEM, measured physical properties, and wireline logging data, respectively.

Keywords: diatom, high porosity, pore size analysis, permeability, logging

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Dehydration of amorphous silica in subduction seismogenic zone

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Generally, a shallow part of a plate boundary megathrust has been considered as aseismic. However, in the 2011 Tohoku-oki earthquake, the seismic fault slip propagated close to the axis of the Japan Trench and caused an extremely large tsunami. It is considered that ductile deformation of unconsolidated sediments is common deformation mechanism prominent in this aseismic region of the shallow part of the subduction zone. Accordingly, it is still unknown how the seismic rupture reached to nearby the trench axis.

The megathrust is characterized by a prominent reflector. Therefore it has been pointed out that the megathrust may host highly pressurized fluids (Kimura et al., 2012). Moreover, based on the result of mineral analysis by Deep Sea Drilling Project (DSDP) in 1977, it is supposed that the subducting sediments mainly consist of vitric diatomaceous and radiolarian silt with pelagic clay intervals.

Opal-A in the vitric diatomaceous silt transform to quartz, and smectite in the pelagic clay to illite. These diagenetic reactions accompany dehydration reactions. The dehydration rates become maximum at 50-60 km horizontally from the deformation front, where the temperature along the megathrust is 100-120?C. This region coincides with the locus with a prominent reflector, and this suggests that the main source of highly pressured fluids is dehydration of sediments (Kimura et al., 2012).

However, few studies have conducted mineral analysis of sediments along the Japan Trench, and detailed dehydration process of hydrous minerals and the reality of fluid pressure have been poorly constrained. Therefore, in this study, we examined by X-ray diffraction whole rock composition of sediments including opal-A, which was recovered from outer rise of the Japan Trench during DSDP Leg56. In this talk, we present calculations of the diageneses of opal-A and smectite, and discuss development mechanism of fluid pressure in the shallow portion of the megathrust in the Japan Trench.

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Keywords: Subduction zone, Silica, Dehydration, XRD

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Core-log integration of a subduction zone megasplay fault -Example from the Nobeoka Thrust Drilling-

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Subduction zone megasplays are known to act as tsunami-seismogenic faults and have been the focus of numerous geological and geophysical research. Reflectance surveys and wave tomography reveal clear outlines of the megasplay in the Nankai Trough, indicating low velocity zone along the thrust and the contrast in physical property and structure between the hanging wall and footwall. Megasplay has been the target of Integrated Ocean Drilling Program (NanTroSEIZE), but the deep portion of the megasplay has not been reached yet. Thus the nature and evolution of megasplay remain to be poorly constrained. On the other hand, however, the fossilized megasplay fault now exhumed on-land, enables to directly observe and study the lithology and structures from the outcrop. The Nobeoka Thrust in Shimanto belt, Kyushu Island, has been studied to be a fossilized megasplay fault, and present well preserved structures of fault zones from the seismogenic regime. To obtain geologic and geophysical datasets to correlate with ocean drilling program, the Nobeoka Thrust Drilling Project was conducted in 2011. 255m of continuous coring and geophysical logging was held, and the main fault core between the hanging wall and footwall was found at 41m depth.

The purpose of this study is to present the results of core-log integration, focusing on the relation among lithology, structure, and physical property along the Nobeoka Thrust, emphasizing the clear contrast between the hanging wall and footwall.

Hanging wall (0-41.3m) is composed of the Kitagawa Group of phyllite of alternating beds of sandstone and shale, while the footwall (41.3˜255m) is composed of the Hyuga Group of foliated cataclasite consisted with scaly shale, tuffacious shale, sandstone, and acidic tuff. The main fault core between the hanging wall and footwall is random fabric cataclasite of ˜50cm thickness, and above and below, the damage zone close to the fault core is characteristic in the hanging wall and footwall. The hanging wall damage zone (32.4-41.3m) is sandstone-rich, with boudinaged and fragmented structures, while the footwall damage zone (41.3-53m) is clay-rich cataclasite with abundant fragments and less mineral veins. 5 lithologic units are classified in the footwall, mainly by the variety of sandstone, silt, and tuff and its structures. Other than the main fault core, several macroscopic fault zones are seen throughout depth in the hanging wall and footwall, which are included in each unit and partly influence the change in lithology and structure there. Tuffacious silt becomes abundant especially from Unit 3, across the fault zone at 112-118m.

Geophysical logging data correlates well with the lithology and structure observed above, and the contrast between the hanging wall and footwall is particularly clear around the main fault core. Footwall presents higher values of neutron porosity (˜7.6%) compared to hanging wall (˜4.8%), while porosity is lowest (˜3.6%) towards/just above fault core. Resistivity is higher at hanging wall (LN˜507, SN˜453, GD˜400 ohm-m), followed by drop near fault core (329,268,315) and stably lower footwall (308,232,310). P-wave velocity is slightly higher at hanging wall and fault core(˜4.3km/sec) compared to footwall (˜4.2km/sec). Temporary drop in natural gamma ray (˜108API) and spontaneous potential (˜39mV) are characteristic towards and just above fault core, while values are nearly constant at hanging wall (˜123API, ˜55mV) and footwall (˜122API, ˜57mV). Density does not vary much throughout depth (˜2.7g/cc).

Curve fitting of number distribution of logging data for each unit, and statistically significant values are obtained from normalized distribution. To understand and estimate the physical property of megasplay fault from logging data, I recalculate values using elastic theory of open cracks assuming the effective pressure to be 55 MPa representing those at in situ values of the Nobeoka Thrust when it was active at depth.

Keywords: Megasplay fault, accretionary prism, Nankai Trough, Physical property

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Physical properties at out of sequence thrust: Nobeoka thrust, Shimanto Belt, Southwest Japan

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To understand information from geophysical survey combining with natural rocks, direct measurement of physical properties on natural rocks is essential. Mega-splay faults cutting whole accretionary wedges in the latest stage of deformation history in subduction zone are commonly observed in seismic profiles. The mega-splay faults are developing around the shallower portion of seismogenic zone along subduction plate interface, and penetrating to ocean floor in transition zone with higher angle of slope topography between outer and inner wedges. Therefore, the mega-splay fault can be a boundary of physical properties of sediments. The on-land analogue of the mega-splay faults is considered to be an out-of-sequence thrust, which cuts paleo-thermal structures. In this study, we measured physical properties of hanging-wall and footwall of the Nobeoka thrust, which is an on-land out-of-sequence thrust. The samples were cored by Nobeoka thrust drilling project (NOBELL).

Nobeoka Thrust is a major geologic boundary between the Northern and the Southern Belts of the Shimanto accretionary complex in Kyushu, Southwest Japan. The paleo-maximum temperature of hanging-wall and footwall is about 320?C and 250?C, respectively. About 70?C difference in temperature is observed at the thrust. The hanging-wall is composed of phyllite. Major component of footwall is tectonic melange of terrigenious sediments and tuff. Damage zone related to Nobeoka thrust is developed in the footwall. Minor faults with carbonate and quartz veins are densely observed in the damage zone. Cataclasite is also identified in the damage zone in some part. Core was drilled about 250m long and Nobeoka thrust is located about 40m of depth in the core. The damage zone is ranging in the depth from about 40m to 110m. We classified samples into three, phyllite in hanging-wall, cataclasite and melange in footwall. 5 samples for each were tested to get physical properties.

We have conducted P-wave and S-wave velocity measurement under controlled effective pressure. Effective pressure ranges from 5MPa to 65 MPa with 5MPa interval. In the laboratory test, change in pore water volume and axial displacement were recorded. Porosity and density were also measured.

Obtained P-wave and S-wave velocities for phyllite, cataclasite, and melange are 4.71-5.01 km/s and 2.78-2.57 km/s, 4.42-4.76km/s and 2.38-2.48 km/s, and 4.48-4.76 km/s and 2.34-2.44 km/s, respectively. Vp/Vs for cataclasite is relatively low (1.85-1.91) than that for others (1.90-1.95). Porosities for phyllite, cataclasite and melange are 1-5%, 2-10%, and 2-8%, respectively. Density is almost constant for all lithologies.

Amplitude variations with offset (AVO) analysis were taken for the estimation of effective pressure. By comparison between AVO parameters from seismic data and the elastic properties, appropriate effective pressure was estimated as about 50 MPa in hanging-wall and about 5 MPa in footwall. Although the coincidence between AVO parameters was not so good, at least, the difference in effective pressure between hanging-wall and footwall is relatively larger. The bad coincidence is probably due to anisotropy of elastic property especially in hanging-wall.

Keywords: out of sequence thrust, Shimanto Belt, velocity

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Detecting time-dependent fluid discharge at the toe of the Nankai Trough accretionary prism

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To detect time-dependent fluid discharge from the toe of the Nankai Trough accretionary prism, the Omine Ridge, we have deployed heat-flow probes since 2010. Observing fluid discharge is a first step to understand seismic activity of subduction zones, because fluid discharge is not only related to fluid drainage from accretionary prisms but also to building-up mechanism of pore fluid pressure at the seismogenic zone of accretionary prisms.

We have deployed two stand-alone heat-flow meters (SAHF) on one of the bacterial mats where fluid discharge is expected and on a normal seafloor near the bacterial mat where no fluid discharge is expected. The 60 cm long heat probe contains five preciously calibrated thermistors at an interval of 11 cm. We have also deployed a temperature meter near one of the SAHFs, which records the temperature slightly above the seafloor. The deployment periods are during Mar 15 and Aug 6 2010, Aug 6 2010 and Sep 11 2012, and Sep 11 2012 and the present. A remotely controlled vehicle, Hyper-dolphin (controlled by R/V Natsushima) and a submersible, Shinkai-6500 (R/V Yokosuka) were used during the deployments and the recovery of the instruments (NT10-05Leg1, YK10-09, NT12-18).

Because the location of deployment is as shallow as 2500 m and is suffered from temperature fluctuations of bottom water due to tides as well as the Kuroshio Current, we deliberately use these fluctuations to obtain fluid flow velocity (Goto et al., 2006). The temperature time series is analyzed using the short-time Fourier transform (STFT) with a given time window (typically, 4 to 5 months). The amplitude ratio (of the deep sensor to the shallow sensor) and phase difference between two thermistors of different depth as functions of frequency simultaneously give Darcy velocity and thermal diffusivity. The phase difference is mainly related to thermal diffusivity; it is small for large diffusivities. Given the phase difference, the amplitude ratio is related to Darcy velocity. For example, the ratio is small for upward flows and large for downward flows with reference to the zero velocity.

We have obtained meaningful difference between the temperature records taken from the two sites: a bacterial mat and a normal seafloor around the bacterial mat. On a normal seafloor, almost zero velocity is obtained with a typical thermal diffusivity observed at this area, 3x10?7 m^2/s. In contrast, on a bacterial mat, upward Darcy velocity of 2?3x10?7 m/s is detected. Preliminary analysis shows that the estimated Darcy velocity is $1x10^{?7}$ m/s in early 2011, smaller than that before and after this period. Anomalous high thermal diffusivity up to twice as a typical value (e.g., $5x10^{?7}$ m^2/s) is obtained at the shallowest 20 cm below the seafloor, although a typical value is obtained at deeper locations than that. This large diffusivity is probably resulted from the formation of the bacterial mat.

Keywords: fluid seepage, accretionary prism, heat flow, subduction zone, long-term monitoring

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Micro-seismicity in incoming Philippine Sea Plate off Kii Peninsula based on ocean-bottom seismographic observation

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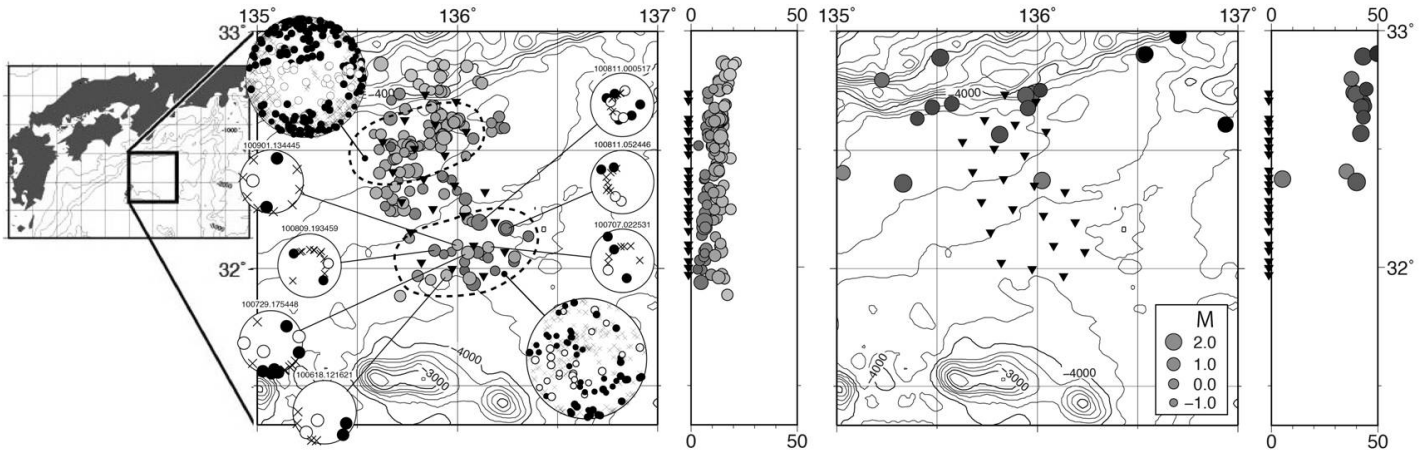
From 2005 to 2008, we repeated ocean-bottom seismograph (OBS) observation to investigate micro-seismicity around the axis of the Nankai Trough off Kii Peninsula, southwest Japan (Yamazaki et al., 2011, Tech.Rep.MRI). This micro-seismicity is not recorded well with land seismic networks. Obana et al.(2005, JGR) distinguished them into two groups; shallow microearthquakes occurring within the oceanic crust of the incoming Philippine Sea Plate (PSP) (around 10 km in depth) and deep ones occurring in the uppermost mantle of PSP (about 15 km to 25 km in depth). Obana et al. also reported that composite focal mechanisms of the shallower microearthquakes showed extensional stress in the direction nearly normal to the trough axis and those of the deeper ones showed compressional stress in the direction normal to the trough axis, indicating ”bending” of the incoming PHP. If so, how far south from the Nankai Trough axis the plate bending stress starts to build up and how it develops?

To investigate this problem, we deployed 24 OBSs, with 8 n.m. (˜15 km) of the spatial interval between every OBS, to the south from the trough axis in 2009. Following the previous two reports last year (Hirata et al., 2012a, JpGU meeting; 2012b, SSJ meeting), we discuss the depth range and focal mechanism of these microearthquakes.

Figure shows hypocenters, located in this study, for the observation period of about three months (left panel of figure). We chose only hypocenters within and nearby the OBS network to plot those in the figure. Shaded circles and closed inversed triangles indicate hypocenters and OBSs, respectively. The events are smaller than M2, and most of them are limited less than M1.5. Almost all of those occur less than 20 km in depth, and thus are confirmed to occur within the oceanic crust and the uppermost mantle. In the southern region of the OBS network, half of the events seems to occur within the oceanic crust and the other half in the uppermost mantle. This feature in the southern region is robust in the examination of various hypocenter determination using six different 1D velocity structures. These events are not recorded on JMA land-based seismic network (right panel). It is difficult to consider the events occur only within this temporary OBS network that was arbitrarily positioned by us. So we guess that similar microearthquakes perhaps occur in wider area outside of the OBS network. Figure also shows composite plots of the P-wave first motion polarity (lower hemisphere projections) for microearthquakes occurring in the northern and southern regions of the OBS network. Open and closed circles indicate downward and upward P-wave first motion, respectively. The composite plots suggest that trough-normal extensional stress is predominant in both the northern and southern regions; in the northern region (near the trough axis), the microearthquakes can be explained by normal faults having trough-normal extensional stress. In the southern region, however, those are seemed to be strike-slip faults. The trough-normal extensional stress is perhaps produced by bending of the incoming Philippine Sea Plate.



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Three-dimensional plate geometry and velocity models for the western Nankai Trough based on structural studies

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Great interplate earthquakes have repeatedly occurred in pairs along the Nankai Trough. In order to reduce a great deal of damage to coastal area from both strong ground motion and tsunami generation, it is necessary to understand rupture synchronization and segmentation of the Nankai megathrust earthquake. For a precise estimate of the rupture zone of the Nankai megathrust event based on the knowledge of realistic earthquake cycles and variations of magnitude, it is important to know the geometry and property of the plate boundary of the subduction seismogenic zone. To improve a physical model of the Nankai Trough seismogenic zone, the large-scale high-resolution wide-angle and reflection (MCS) seismic studies, and long-term observation have been conducted since 2008. Marine active source seismic data have been acquired along grid two-dimensional profiles having the total length of ˜800km per year. A three-dimensional seismic tomography using active and passive seismic data observed both land and ocean bottom stations have been also performed. This study is part of 'Research concerning Interaction Between the Tokai, Tonankai and Nankai Earthquakes' funded by Ministry of Education, Culture, Sports, Science and Technology, Japan. The seismic survey was conducted off the Tokai area including the onshore survey across the eastern Kii Peninsula in 2012, the final year of this project.

Compiling those studies provides a three-dimensional plate geometry and velocity structure models of the western Nankai Trough at the moment. Although their reliability and resolution should be evaluated, these models can be applied to a numerical simulation to examine if the observed rupture zone of the historical event can be reproduced. We will also try to construct more fine-scale model for the entire Nankai Trough area.

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Subducting structure in the northern end of the Nansei-Shoto Trench deduced from MCS profile and topography

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A large number of earthquakes occur at subduction zones and their vicinity, and sometimes a large earthquake with a severe damage occurs there (e.g. 2011 Tohoku-Oki earthquake in the Japan Trench region, Tokai-Tonankai-Nankai earthquake in the Nankai Trough region). The Nansei-Shoto Trench is the subduction zone where the Philippine Sea plate subducting below the Eurasia plate.

Japan Coast Guard carried out the refraction and the multi-channel reflection seismic survey in the northern end of the Nansei-Shoto Trench. The Survey line named ECr11 is perpendicular to the trench-arc-backarc system and traverses the Nansei-Shoto arc between the Yaku-Shima Island and Tokara Islands. ECr11 roughly overlaps the refraction seismic survey profile of Iwasaki et al.(1990) in the area from the forearc to trench. Iwasaki et al.(1990) used explosives and an air-gun array as seismic sources. They deduced ”a huge sedimentary wedge, whose thickness exceeds 12km, overlying the subducted oceanic lithosphere” and the structure of the subducted oceanic plate. To obtain the structure from the shallower part to the deeper part of the subduction zone, we deployed ocean bottom seismographs more closely than Iwasaki et al.(1990), and carried out the refraction and multi-channel reflection seismic surveys along same survey line.

We report the shallower part of the subduction zone in the northern end of the Nansei-Shoto Trench and spatial distribution of active faults deduced from the multi-channel reflection seismic profile (MCS profile) and topography.

Specifications of multi-channel reflection seismic surveys are as follows.

Source: 5.7l (350 inch^3)x3 tuned air-gun array (air-gun cluster)
Shot interval: 50 m
Record device: streamer cable (3,000m length and 240 channel hydrophone (12.5m interval))
Record length: 12 sec

Many lineations that parallel to the Nansei-Shoto Trench locate on the Philippine Sea plate before subducting beneath the Nansei-Shoto Trench confirmed from the MCS profile and the topography. These lineations are deduced the normal faults formed by bending of the Philippine Sea plate that accompanies with subduction.

In the MCS profile, clear reflectors are detected at the top of the subducting oceanic plate. We can trace these reflectors about 80km landward from the trench axis.

Keywords: Nansei-Shoto Trench, Philippine Sea Plate, subduction zone, reflection seismic survey, seafloor topography

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Crustal Deformation Analysis Method with High-fidelity 3D Model and Application to Estimation of Coseismic Slip

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Coseismic slip distribution is estimated by combining crustal deformation analysis in a large scale with the detailed data of the crust and the observation data of crustal deformation. Observation data with high accuracy have been accumulated, not only on the ground (e.g. GEONET: operated by GSI) but also on the seafloor (e.g. DONET: operated by JAMSTEC). In addition, geometry and material data in 1km grid of the crustal structure of the Japanese islands have been developed. However, in spite of the detailed crustal data, crustal deformation analyses have been performed by using simplified crustal structure model like homogeneous half-space. Therefore in this research, by using accumulated data and the technique of high performance computing, we developed a method for generating a high-fidelity 3D finite element (FE) model of crustal structure. A method for crustal deformation analyses with the generated model is also proposed. Then an application of the proposed method to estimation of coseismic slip distribution is shown.

We use FE analysis because it has an advantage in analyzing complex geometry of crustal structure. Assuming crustal structure to be a linear elastic body, we perform static analysis of coseismic crustal deformation due to fault dislocation. For high-fidelity 3D FE model generation, we developed an automatic FE model generation method using background grids by extending the method of (Ichimura et al. 2009). Tetrahedral elements are used near the surfaces to represent the geometries of the crust well, while voxel elements are used in the homogeneous areas, in order to achieve a good balance between reduction of the number of elements and reproduction of the geometry. Our method is verified by comparing the results with the analytical solution in a half-space (Okada, 1985).

To perform this computation fast using an FE model with large degree-of-freedom (DOF), firstly we solved the problem by CG method with a simple preconditioning, parallelizing it by OpenMP. However, this computation took a long time, so we improved the method by introducing adaptive preconditioner and single precision arithmetic. As a result, the computation time is significantly reduced.

As an application example, we estimated coseismic slip distribution in the 2011 Tohoku earthquake using Northeast Japan models. The models are generated by the proposed method, and their DOF are more than 150 million. We applied the estimation method used in (Sato et al. 2010). In comparison of estimation results using our high-fidelity model and conventional homogeneous half-space, significant difference could be seen in the estimation results.

As future work, ambiguity of the geometry and material properties of the crust should be taken into consideration.

Keywords: Inversion analysis of coseismic slip, High-fidelity 3D Crustal Structure Model, Crustal Deformation Analysis

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Application of back-projection method to OBS data for understanding rupture propagation of the 2011 Tohoku earthquake

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The rupture process of the 2011 Tohoku earthquake was remarkably complicated. To discuss what constrains the rupture propagation, it is important to clarify the space and time variation of seismicity before and after the Mw 9.0 event. High-resolution seismicity around the rupture region of the main shock is required for such discussion. We used data from a dense array of 31 ocean bottom seismometers (OBSs) that were deployed before and recovered after the main shock off Ibaraki. The station interval of the array was about 6km. Accurate OBS positions were determined by applying the LSQR algorithm to the acoustic measurements between the vessel and OBS.

In this study, we tried to estimate the initial rupture area by applying back-projection method to these OBS array data.

First of all, we constructed a 3-D velocity structure model off Tohoku by compiling the results of marine seismic surveys (e.g., Mochizuki et al., 2008; Miura et al., 2005) and the tomography under the Japanese islands (Matsubara and Obara, 2011). In this case, P-wave velocities are given to grid points at a horizontal grid spacing of 10km and a vertical grid spacing of 5km. Then, we constructed a travel time field bounded by 35.5N - 40.5N and 141E - 144.5E (about 300km X 540km) with the same grid interval. To refine the theoretical travel time field, we referred to precise hypocenters of aftershocks determined with OBS data from aftershock observations (Shinohara et al., 2012).

After constructing the theoretical travel time field, we measured the array response function to confirm the resolution of the apparent slowness vector arriving at the array, applied a proper frequency filter selected with consideration of the sediment under each OBS, and estimated the initial rupture area of the main shock by projecting semblance values.

Keywords: the 2011 Tohoku earthquake, ocean bottom seismometer, back-projection

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Progress of bending process of Pacific Plate and flattening process of bent slab detected with CMT solusion of JMA

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The hypocenters and forcal mechanisms distribute symmetrically with an axis crossing through the bending head of trench axis toward ocean side. The hypocenter of the East Japan Super Earthquake M9.0 of 2011 March 11 locates on the axis. The seismic free area appeared on the cross point of Japan Trench and the axis after the East Japan Super Earthquake.

The seismic free area surrounded by hypocenters with normal fault type forcal mechanism mainly and lateral fault type in island arc side. The forcal mechanisms are determined with orientations of principal stress axes.

The strengths of 3 principal stress can be calculated with moment tensor and nonDC (double couple) component ratio in CMT(centroid, moment tensor) forcal mechanism solution from Japan Meterological Agency. Normal fault type forcal mechanism can be defined using the strengths into push apart normal fault type of excess compressional stress with negative nonDC component, pull away normal fault type of exess tentional stress with positive nonDC component, and double couple normal fault type without nonDC component.

The normal fault type forcal mechanisms around the seismic free area are refined into push apart type for deeper earthquakes with deeper intial shoch hypocenter (e.g. 2011 March 11 M7.5), and pull away type for shallower hypocenter (e.g. 2012 December 7 M7.3). The depth dependence of excess compressional stress and excess tentional stress is consistent with bending process of oceanic plate along trench. Bending process should induce compressional stress for deeper layer and extensional stress for shallower layer of oceanic Plate. When the compressional principal stress with vertical orientation decreases with shallowing and reachs comparable to intermediate principal stress with horizontal orientation by the bending process, the stress axes exchange and the forcal mechanism changes from normal fault type with horizontal intermediate principal axis to lateral fault type with vertical intermediate principal stress axis. The lateral fault type hypocenters around the seismic free area (e.g. 2011 July 10 M7.3) consisitent with the stress axes exchange.

Oceanic Plate bends along trench and subducts as bent slab. The bent slab flattens under the East Japan coast area and subduct under the west coast of Japan Sea as a flat plane. Reverse fault type earthquakes dominate in the decending slab under the East Japan coast area. The forcal mechanisms with compressional principal axis parallel to the slab surface are classified into collisional reverse fault type of excess compressional stress with negative nonDC component (e.g. 2003 May 26 M7.2) and suctional reverse fault type of execess tentional stress with positive nonDC component (e.g. 2011 April 7 M7.2), which consistent with flattening process of bent slab. Flattening process of descending bent slab should induce compressional stress for extended shallower layer and tention to rip off bent slab.

CMT forcal mechanism solutions reporting by Japan Meteological Agency are usefull for monitoring the progress of bending process of oceanic plate and flattening process of bent slab.

Keywords: CMT solution, bending process, flattening process, Japan Trench, nonDCcomponent, seismic free area

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Ahead of the 3.11, has the greatly east offing pushed the subducting plate really?

Hirofumi Mase[1*]

[1]none

If the temperature of a subducting plate is low, high temperature areas are generated on and under it and they tighten it from both sides by pulling against mutually(1). The stress keeps accumulating because it is not off Miyagi though there is the temperature structure that strain is liberated easily usually off Iwate and Fukushima(2). I presented the model concerning the cutting plane that expresses the range from coast to trench off Miyagi and passes the epicenter of the 3.11(3). I value (4) for the slip distribution and the rupture process of 3.11. I expect that the model will harmonize with (4) and past observation facts. The grounds material used as follows is (5).

We can understand well the features of earthquakes before and after 3.11 by the spatial distribution of focal mechanisms(P6, 1994/01/01-2012/12/31). a)(before 3.11) There are many reverse fault type earthquakes(reverse-type) at the west of the trench axis(Axis) from off Iwate to off Fukushima. At the east, one normal-type off Miyagi stands out. b)(after 3.11, off Miyagi) At the area that centers on the point(Q) of 38deg.N-144deg.E, normal-type overflow around and strike-slip-type of ”Pull” stand out at the west. c)(after 3.11, off Iwate and Fukushima) Reverse-type are generated chiefly at the west of Axis, normal-type chiefly at the east, and they are faced on the boundary of Axis.

A reverse-type(y) and a normal-type(x) occurred about Q recently. The difference at the time of occurrence was a few seconds(2012/12/7M7.3 Sanriku-Oki). The appearance of (y) looks mysterious in the situation that it is located on the LINE that connects remarkable epicenters[(3.11)-(2011/7/10M7.3 strike-slip-type(X))-(x)-Axis,Q-(y)-(2011/3/11M7.5 normal-type(Y))].

Two years ago 3.11 was generated and (Y) followed 39 minutes later. It shows that the east of (Y) did not move though the LINE became ”Pull” by the rapid subduction. The density in the direction of east and west has decreased about (Y). (X) was generated four months later. It was a strike-slip-type pushed from the south north both. It suggests that the amount of subduction about (X) was larger than it in the south and north of (X). Because the density amends from the south north can be expected, the density reduction in the direction of east and west about (X) is less than it about (Y). At this time, the east of (Y) did not move. Up to the present time, normal-type and strike-slip-type overflow from (X) to Q, normal-type overflow from Q to (Y). Though off Miyagi is the field of ”Pull” from east to west, I guess that the density is high in the west of the boundary of Axis and low in the east. Receiving pressure from the west, reverse-type(y) was generated because the above plate slipped up and east.

Thinking the east of (Y) to be just like an anchor still now might be appropriate. The fact of a) shows the doubt in which pressure from the open sea didn’t exist even just before 3.11. The fact of b)c) shows that the east of Axis is a field of ”Pull” and that the action of force has changed on the boundary of Axis. Because the amount of subduction of the lower plate off Iwate and Fukushima is small by circumstances(2), the east is ”Pull” though the west of Axis is reverse-type and ”Push” already. This harmonizes with the explanations(1) that among powers to act on the subducting plate, one acts from not the east but the lower.

(1)[Mase]http://www2.jpgu.org/meeting/2007/program/pdf/S149/S149-005
(2)[Mase]SSJ/ABSTRACTS/2011MEETING/P3-40
(3)[Mase]SSJ/ABSTRACTS/2012MEETING/P2-75
(4)[Ide]http://www.s.u-tokyo.ac.jp/ja/press/2011/12.html
(5)[JMA]http://www.jma.go.jp/jma/press/1301/10a/1212tohoku.pdf

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A possible M10 event deduced from the lessons of the 2011 Tohoku-Oki earthquake

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After the 2011 Tohoku-Oki earthquake, the immediate threat of megathrust earthquakes in and around Japan has been suddenly advocated by some researchers. One even points out the possibility of a larger event than ever, an event of Magnitude 10. In this study, we discuss whether an event of M10 is realistic or not, from not only statistical aspects of earthquake occurrence or macroscopic scaling laws of seismic sources in a conventional manner (e.g., fault size, the amount of slips) but also the diversity of megathrust earthquakes that was revealed after the occurrence of the 2011 Tohoku-Oki earthquake. From a simple extrapolation of seismicity and macroscopic scaling laws, one event of M10 occurs every 500 years all over the world, with its fault length, width and average slip to be 1,200 km, 600 km and 50 m, respectively. The width may not exceed 200 km very much because of the limitation of an elastic region of a plate boundary in a subduction zone. We therefore need either of (1) average slip as large as 100 m or (2) fault length of more than 1,500 km for a possible M10 event. The average slip may be able to exceed 100 m, considering an area of very large shallow slips associated with the 2011 Tohoku-Oki earthquake, but we must take care that this is possible only for an event of the along-dip double segmentation. This type of events is, however, generally adjacent to segments of weak plate coupling with small coseismic slips. In contrast, an event of the conventional along-dip single segmentation may extend its fault into many adjacent segments. A drawback in this case is that the average slip may not exceed 50 m unless there are several segments of very strong plate coupling, resulting in co-seismic slips lager than those for usual events repeating in each segment. Although a very large strong shallow segment of the double segmentation is a candidate of an M10 event, we cannot find any clear evidence of such a region from the present seismic pattern in the world. The subduction zone in south Chile is the best candidate from its apparent strong plate coupling although it may not occur for a while due to the nearly complete strain release associated with the 1960 earthquake. We consider a very large event will be impossible even if a large portion of subduction zones breaks in the Aleutian trench because of the existence of several segments of weak plate coupling with slow events or aseismic slips in this subduction zone.

Keywords: megathrust earthquake, 2011 Tohoku-Oki earthquake, double segmentation, strong coupling, fault width, average slip

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Investigation of slip parameters and fault slip behavior in the shallow part of subduction zone on the basis of vitrinit

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Enormous earthquakes repeatedly occur in subduction zones, and the slips along megathrusts, in particular those propagating to the toe of the forearc wedge, generate ruinous tsunamis. Quantitative evaluation of slip parameters (i.e., slip velocity, rise time and slip distance) of past slip events at shallow, tsunamigenic part of the fault is critical to characterize such earthquakes. Here we attempt to quantify these parameters of slips that may have occurred along the shallow megasplay fault and the plate boundary decollement in the Nankai Trough, off southwest Japan. We apply a kinetic modeling to vitrinite reflectance profiles on the two fault rock samples obtained from Integrated Ocean Drilling Program (IODP). This approach constitutes two calculation procedures: heat generation and numerical profile fitting of vitrinite reflectance data. For the purpose of obtaining optimal slip parameters, residue calculation is implemented to estimate fitting accuracy. As the result, the measured distribution of vitrinite reflectance is reasonably fitted with heat generation rate (Q) and slip duration (tr) of 16,600 J/s/m2 and 6,250 s, respectively, for the megasplay, and 23,200 J/s/m2 and 2,350 s, respectively, for the frontal decollement, implying slow and long-term slips. To compare these slip behaviors with those in other settings of shallow part of subduction zone, we measured vitrinite reflectance on fossilized analogue faults, exposed in the Miura-Boso accretionary complex (the Shirako fault and the Emi fault), and examined their slip parameters by the above method. The measurement is conducted by using a newly-developed optical microscopy which allows us to 2-dimensional reflectance measurement on polished slab samples. The obtained vitrinite reflectance profiles both show strong anomaly at the slip zones. The reflectance anomaly in the Shirako fault is also recognized at the outside of the slip zone as is the case for the megathrusts in the Nankai trough. The numerical analysis yields slip velocity and slip distance of 0.14 cm/s and 5.17 m, respectively, under the optimal parameters set of = 14,500 J/s/m2 and tr = 3,600 s. On the other hand, the reflectance anomaly at the Emi fault is limited only inside of the slip zone. This condition (i.e. the absence of reflectance anomaly in the host rock) is taken as a constraint to determine and tr for the Emi fault. The estimated slip parameters are then compared with previous reports. The maximum temperature, Tmax, for the Nankai megasplay fault is consistent with the temperature constraint suggested by Hirono et al. [2009]. On the other hand, the calculated temperature contradicts the estimation deduced from clay mineral analysis [Kameda et al., submitted]. This discrepancy might indicate that the Shirako fault has experienced two types of slips; faster slip which caused temperature increase only inside the fault and acceleration of illitization, and slower slip which keep a high temperature state for a while enough to heat up the host rock by thermal conduction. Two constraints are combined to estimate slip parameters for the Emi fault. One is that Tmax is 350-1100 C [Hamada et al., 2011], and another is the absence of vitrinite reflectance anomaly in the host rock. Slip parameter ranges defined by these constraints are relatively faster slip velocity (˜ 1m/s) and shorter displacement (˜ 1m) than those for other faults. These results show large variation of slip parameters in shallow part of subduction zone. Especially, slow slip velocity, long-term rise time and large displacement are recognized in the three fault zones (the megasplay, the frontal decollement and the Shirako fault). These parameters are longer and slower than typical coseismic slip, but are rather consistent with rapid afterslip.

Keywords: slip parameters, vitrinite reflectance, frictional heat

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Frictional heating recoded in virtinite reflectance within coal material concentrated layer: The Cretaceous Shimanto Bel

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Frictional heating recoded in virtinite reflectance within coal material concentrated layer: The Cretaceous Shimanto Belt

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A degree of frictional heating by fault activity is related to effective friction coefficient, normal stress, displacement, slip rate and thickness of fault. So if we can detect the frictional heating along fault, the strength of friction of the fault can be constrained even from natural materials. In this study, we tried to detect the evidence of frictional heating along minor faults developed in on-land accretionary complex using vitrinite reflectance. The frictional heating was also identified along shallow deocollement and mega-spaly fault in Nankai trough by detailed examination of distribution of vitrinite reflectance (Sakaguchi et al. 2011). The similar evidence can be observed in the on-land accretionary complex anywhere.

We have found a coal concentrated layer in the coherent unit, Shimanto Belt, Shikoku, SW Japan. The coal concentrated layer is located in a central part of Nonokawa formation. Thickness of the coal concentrated layer is about 80 cm. Some faults are developed within the coal concentrated layer. Thickness of the faults is about a few mm to 1 cm. The fault branches and undulates at some parts. The coal concentrated layer is appropriate to examine the distribution of vitrinite reflectance. The background value of virtinite reflectance in this area is about 1.1% reported by a previous study (Sakaguchi, 1996).

4 samples from host rocks as background and 6 samples from the coal concentrated layer were collected. Samples from the coal concentrated layer distribute 0 cm, 3 cm, 8 cm, 9 cm, 20 cm, 35 cm from a major fault.

Random oriented vitirinite reflectance (Ro) was measured on polished thin sections. The modal value of Ro in host rocks is about 0.98%, which nicely coincides with the values from the previous study. Variations in Ro in host rocks represent relatively larger than that in the coal concentrated layer, which might be due to rework of the virtinite grains. The modal value of Ro in coal concentrated layer is about 0.92 %, which represent a normal distribution in each histogram except for the samples at 0 cm and 3 cm from the fault. In the samples at 0 cm and 3 cm from the fault, another peak and a weak bulge were observed at 0.2-0.3% higher Ro value. Double peak distribution is clear especially in the sample at 0 cm. Those higher peak and bulge possibly indicate the frictional heating along the fault. Spatial distribution of Ro in the thin sections also shows that vitrinite grains with higher Ro concentrate along the fault zone with thickness of 1cm.

We followed the method by O'Hara (2004), a simple method to estimate temperature by frictional heating from vitrinite reflectance. He used a model to convert temperature from Ro, proposed by Sweeny and Burnmum (1990) with high cooling rate as 0.035 degree C/s and 1.0 degree C/s for heated Ro. On the basis of the model, the higher Ro value corresponds about 460 - 540 degree C. Background value of Ro indicate about 146 degree C. We estimated friction coefficient also following O'Hara (2004)'s method using those obtained temperatures (460-540 degree C in fault zone and 146 in background), fault thickness (1cm, 4cm), displacement (1-5m), normal stress (126.2 MPa assuming 30 degree C/km of thermal gradient, 2650 kg/cm3 of density). The estimated frictional coefficient is about 0.14 in the maximum and about 0.01 in the minimum if the thickness is small and displacement is large. This result indicate very small friction coefficient in the coal concentrated layer. The small friction coefficient can be due to fluidization of nature of coal itself.

Keywords: vitrinite

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Two types of asperities on the Tohoku-oki interplate megathrust

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The 2011 off the Pacific coast of Tohoku Earthquake with a magnitude (M) of 9.0 (the M9 Tohoku-oki earthquake) occurred at an intermediate depth (approximately 17-18 km below the sea level) on the subducting plate interface, whereas the M7-class Miyagi-oki earthquake had been occurred at the down-dip side (35-45 km below the sea level). To clarify the difference in frictional properties between the deep and intermediate-depth seismogenic zones, a strength profile of the NE Japan interplate megathrust was constructed across the source region of the M9 earthquake.

In the model, rheological properties of siliceous sedimentary rocks and subducting seamounts at the top of the oceanic plate were represented by those of wet quartz (+ clay minerals) and gabbro, respectively. Depth-dependent changes of pressure, temperature, and pore pressure ratio were taken into account. At the deep (>35 km) part of the thrust fault, siliceous rocks become ductile due to increasing temperature ($> 250^{o}$), whereas gabbroic rocks are brittle and strong. Thus, the asperity of the M7-class earthquakes is considered as a broken seamount, which is surrounded by siliceous sedimentary rocks. A conditionally stable nature of the surrounding region is explained by frictional behaviors of quartz in the brittle?ductile transition zone. In contrast to the deep M7-class asperity, the M9 asperity (i.e., a region that was strongly coupled before the M9 Tohoku-oki earthquake) occupies a large part of the plate interface because shear strength is relatively insensitive to rock types at the intermediate depth. Depth-varying characteristics of seismic radiation patterns found by Lay et al. (2012) reflect these two kinds of asperities. The along-arc extension of the M9 asperity is constrained by fluid distributions on the plate interface.

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Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, asperity, rheology, subduction zone, friction, brittle-ductile transition

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Regulation of maximum earthquake sizes by the lithospheric rheology

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Shallow part of the Earth can be considered to behave as an elastic material such that earthquakes occur, whereas the deeper part deforms viscously. However, it still remains unclear how the seismicity changes with this viscous/elastic transition. On the other hand, the rock consisting the Earth is frequently modeled by a Maxwell fluid which behaves as an elastic material when it deforms at a time scale which is sufficiently shorter than the relaxation time scale. Here we perform shear deformation experiments of quasi Maxwell fluid under different strain rates, and show that the same material can cause earthquakes associated with elastic rebound as well as viscous flow. Around the threshold to cause earthquakes, both earthquakes in which ruptures propagate at a shear wave velocity and viscous relaxation occur simultaneously. The threshold is determined by the strain rate, relaxation time, shear modulus, and the adhesive stress. We construct a scaling applicable to a real faulting system by taking account of the fact that strain rates depend inversely on the faulting length scales. Our scaling predicts that a larger fault can relax the accumulated stress more and the maximum sizes of earthquakes which can occur on Earth becomes around Mw 9. The 2011 Tohoku-Oki Earthquake (Mw 9.0) resulted in a huge coseismic slip, but was insufficient to reconcile all the inter-seismic deformation since the previous earthquake. Our scaling suggests that this earthquake must be around the threshold and some part of the accumulated stress has relaxed viscously prior to the earthquake. Our scaling also explains the fact that only small earthquakes show repeatability and magnitudes of the slow earthquakes are small. Another important feature of our scaling is that the accumulated strain is not proportional to the accumulated stress. For an accurate risk assessment, accumulated stress should be evaluated rather than strain.

Keywords: Viscosity of the shallow Earth, Stress relaxation, Rupture velocity, Tohoku-Oki earthquake

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Frictional properties of sediments on the Cocos Plate collected during the IODP Exp334, CRISP

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Knowledge of the frictional properties of input sediments to subduction zones is fundamental in modeling of the subduction-related faulting processes. However, experimental studies on frictional properties of diverse composition of the input sediments are still limited. On the Cocos plate, which subducts at Middle America Trench offshore Costa Rica, clay, silty clay, and biogenic sediments such as silicic to calcareous ooze are deposited on basalt. They have some tephra layers. In this study, frictional properties of the sediments collected at a reference site of offshore Costa Rica (Site U1381) during the IODP expedition 334 were examined.

The sediments were observed under the microscope and analyzed with X-ray diffraction. The tested samples can be divided into three groups: clastic material, volcanic glasses and biogenic sediments. Frictional experiments were performed at steady slip velocity (v = 0.28 mm/s) to study the shear strength of them, and under a velocity-stepping condition to study the friction velocity dependence of the samples. Experimental results reveal that the shear strength is similar for all the samples at the initiation of the slip. However, the friction values of the silty clastic material reduce to ˜0.2 at the steady state, while those of the volcanic glasses and the biogenic sediments are high at 0.6˜0.8. These results suggest that shear zones are likely to be formed in the uppermost silty clay sediments. The silty clay material shows velocity-strengthening at $0.0028 < v < 2.8$ mm/s. In contrast, the volcanic glasses and the biogenic sediments show velocity-weakening at $0.0028 < v < 0.28$ mm/s and velocity-strengthening at $0.28 < v < 2.8$ mm/s. Stable slip would occur in the silty clay unit. On the contrary, the velocity weakening behavior at slow velocities could provide a condition to initiate unstable fault motion at shallow depths along the fault channel.

Keywords: subdaction zone, frictional experiment, CRISP

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Time-dependent consolidation and reduction in permeability of quartz aggregate due to pressure solution precipitation

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During diagenesis process, incohesive sediments are compacted, lose porosity and permeability, and gain resistance against deformation. Understanding of evolution in the hydrological and mechanical properties during diagenesis is of essential importance in considering deformation of a shallow part of the crust including accretionary prism. Pressure solution precipitation creep is one of the important mechanisms in diagenesis of sediments, and thus has been intensively studied. Previous studies have established microphysical models and the constitutive law during compaction creep [e.g., Shimizu, 1995; Niemeijer et al., 2002]. In the present study, we put our focus on the evolution in the permeability and storage capacity during consolidation due to pressure solution precipitation creep of quartz aggregate.

Recent studies [e.g., Noda and Lapusta, 2013] have pointed out the importance of hydraulic properties on the earthquake generation mechanisms. In particular, permeability plays a cardinal role in thermal pressurization of pore fluid due to frictional heating during high velocity fault slip. An important unknown is whether the host rock (or sediments) fractures with significant increase in the porosity and the permeability or not. Such a property would depend on the degree of consolidation or diagenesis, as well as confining pressure, temperature, and loading condition. In the present study, the focus is put on the effect of time-dependent consolidation or diagenesis on the mechanical and hydraulic properties.

The starting material is commercially available quartzite power the mean grain size of which is about 6 microns. We have prepared the specimens from slurry by sedimentation inside silver tubes which are used as jackets during compaction experiments with gas apparatus at Hiroshima University. The initial specimens have good repeatability in terms of permeability. Compaction experiments are performed with distilled water as pore fluid and at 200 MPa confining pressure, 100 MPa pore pressure, and temperature at most 550 degree C. Permeability and storage capacity are monitored continuously during compaction experiment by pore pressure oscillation technique [e.g., Fischer and Paterson, 1992]. The shortening of the specimen is measured by the hit-point method from time to time.

After the consolidation test, we performed triaxial deformation test at constant load point velocity at room temperature. It turns out that solution-precipitation process extend the elastic limit of the sediment pretty quickly. When the specimen is heated up to 500 degree C by about 100 degree C/ 10 min and cooled down by a similar rate as soon as the temperature reaches 500 degree C, the specimen shows peak strength about 300 MPa in terms of axial compressional stress applied in addition to the 100 MPa effective isotropic pressure. Note that an uncooked sample yields as soon as the axial compressional stress is added. In the present poster, the relations between the shortening and hydraulic properties will be discussed.

Keywords: Diagenesis, Deformation experiment, Fluid-flow experiment

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Measurement of the elastic wave velocity of rocks in subduction zones with the gas medium high pressure apparatus

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The velocity structure of the Earth has been illuminated from the seismological observation (Nakajima et al., 2001) in various places and the quantitative measurement of the seismic wave velocity in laboratory (Nishimoto et al., 2005). The seismic wave velocity is higher at the large coseismic slip area of the Mw 9.0 Tohoku-Oki Earthquake in 2011 than surrounding region (Zhao et al., 2011). This indicates that the rupture of the Tohoku-Oki Earthquake was controlled by structural heterogeneities in the megathrust zone. In order to know the relationship between the velocity anomaly and frictional properties of rocks, we need to measure the elastic velocity of various rocks composing of subduction zones.

In this study, we developed a system of elastic (ultrasonic) wave velocity measurement with the gas medium apparatus which has accurate hydrostatic pressure and can control the temperature and the pore pressure. We can also measure elastic properties such as elastic constants and poisson's ratio in the system by the usage of internal strain gages.

The electric wave velocity was measured by pulse transmission technique employing ultrasonic wave (2 MHz frequency). The wave was recorded by oscilloscope which sampling rate is 10^9 sampling/s. The rock sample and two metal jig pasted piezoelectric transducers of 6 mm diameter were placed in the pressure vessel. The height and diameter of rock samples are about 15-40 mm and 20 mm respectively. We calibrated the system with the metal jig and glass samples whose velocity is known. We measured Vp and Vs of the gabbro and granite during pressurization and depressurization to a maximum confining pressure of 200 MPa. The velocity increased drastically with the increase of the confining pressure up to 100 MPa. After the confining pressure exceeded 100 MPa, the velocity showed gradual increase with pressure. Vp and Vs of the rocks were higher during pressurization than those during depressurization at the same confining pressure, because microcracks that closed at high pressure do not completely reopen during depressurization (Birch 1960). We compared the velocity obtained in this study with the theoretical velocity predicted at a given pressure, temperature and rock composition (Hacker and Abers, 2004). At the confining pressure less than 100 MPa, the measured velocities were significantly lower than theoretical velocities. At pressure higher than 100 MPa, they are consistent with the theoretical velocities. Because the theoretical velocities did not include the effect of microcracks, this indicates that the microcracks closed completely at the pressure higher than 100 MPa. In contrast, the velocity measured with the Piston cylinder-type apparatus in previous studies increased by pressurization until about 400 MPa, and this indicates that the microcracks don't close until higher pressure. Thus the measurement with the gas medium apparatus is suited to measure elastic properties of rocks at shallow part of subduction zones. The elastic wave velocity of rocks increases steadily after microcracks close completely with the increasing pressure. So we can estimate the elastic wave velocity at even more than 200 MPa. In the presentation we will introduce measurement of elastic properties of rocks in subduction zones.

Keywords: elastic wave velocity, gas medium high pressure apparatus, microcrack, rocks in subduction zones, seismic tomography, reflection survey

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Revisit of dynamic critical taper theory for the Japan trench from the topographic point of view

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The March 11, 2011 Tohoku-oki earthquake (Mw9.0) is supposed to have fault rupture extending to the shallow part of subduction zone at the Japan Trench. Various inversion analyses by using, for example, geodetic, teleseismic body waves, strong ground motion or tsunami waveform, show large displacement near the trench axis.Moreover, bathymetric comparison between before and after the earthquake clearly demonstrated that the seafloor on outermost landward slope moved ˜50 m east-southeastward to the trench and uplifted ˜7 to 10 m. Although the mechanism of such fault rupture is not clear, revisiting the structure, deformation and friction properties at the base of the forearc will be key to elucidate this important issue.

Based on bathymetric and seismic reflection data (e.g., angle of slope, dip angle of the subducting plate) and physical states of the wedge and plate boundary (e.g., normal stress, fluid pressure, shear stress and coefficient of friction), Kimura et al. (2012) suggested that middle slope and lower slope of the Japan Trench is in a critical state. Dynamic Critical taper theory proposed by Wang and Hu (2006) improved the Mohr?Coulomb theory to show how stress state changes in terms of seismic cycle. Although the shape of the wedge in the Japan trench is consistent with this theory, stress transition in the shallow region of the trench should be reconsidered.

Because of along-trench variability in the bathymetry and the direction of plate convergence, it is very useful to reconsider relation of taper angle and the friction of the plate boundary at several profiles along the Japan Trench.

In this study, based on Kimura et al. (2012), we used a bathymetric data taken before the Tohoku-oki earthquake and re-examined the relationship between the taper angle and friction of plate boundary in shallow part of the Japan Trench. First, we divided the trench into three segments from south to north, and chose five seismic survey lines from each area, focusing on a specific range from the trench to the splay fault (˜ 20km). By applying the Critical taper theory to the individual cross-section, and based on the assumption that splay fault behaves as a backstop, we discuss stress balance between the interior and base of the wedge, fluid pressure ratio, and effective friction coefficient of the plate boundary.Dip angle of the subducting plate is obtained from images by seismic reflectance surveys, and by studying a broad range in the Japan Trench, we determine the deformation process in the shallow part of the trench.

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Keywords: critical taper, slope, the Japan trench

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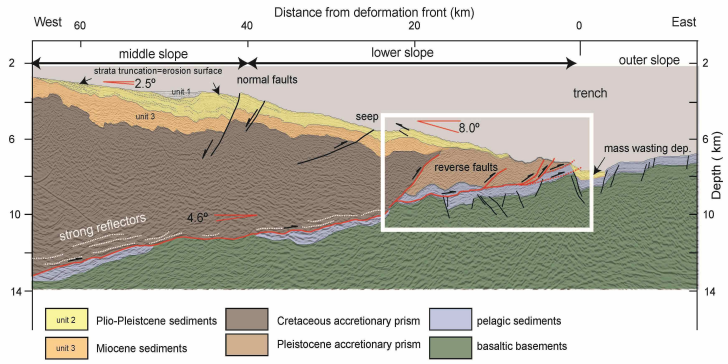

Sesimic profile along MY 102 modified from Tsuji et al. (2011).

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Relation between Stress Perturbation of the Virtual Fault Models of Intra-plate Eq. and the 1605 Keicho Eq.

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1.Introduction

We have developed and improved a three-dimensional earthquake cycle model on the basis of the rate- and state-dependent friction law. Hirose and Maeda (2011, JpGU, SSJ; 2012, JpGU) numerically simulated great earthquakes along the Nankai trough and produced some occurrence patterns applying heterogeneous frictional parameters and effective normal stress.

However, we could not simulate a pattern that a rupture occurred on only a shallow portion of the plate boundary like the 1605 Keicho earthquake (Furumura et al., 2010, SSJ) even after taking into consideration stress perturbations of inland earthquakes (Hirose & Maeda, 2012, SSJ).

2.Virtual fault models of intra-plate earthquakes

There is the Zenisu ridge with a strike of NE-SW south off Tokai district. We can observe background seismicity and some M6-class earthquakes around the area. In the same area, Kaizuka (1972, Kagaku) pointed out existence of the Nishi-shichitou fault with left-lateral and a strike of N-S. In addition, M7.1 and M7.4 intra-plate earthquakes occurred southeast off Kii peninsula in 2004. Such intra-plate earthquakes may become a trigger of the Keicho type earthquake.

In this study, we try to simulate the Keicho type earthquake taking into consideration stress perturbations of intra-plate earthquakes around the trough, using the method same as Hirose & Maeda (2012, SSJ). We will report our result in the session.

Keywords: Nankai trough, Keicho earthquake, Simulation, stress perturbation, intra-plate earthquakes

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Numerical simulation of Nankai Earthquake, Hyuga-nada Earthquakes, and slow slip events in Bungo Channel

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We numerically simulated cycles for occurrences of seismic and aseismic events in the region from Hyuga-nada to off Shikoku of southwest Japan with the 3D geometry of the Philippine Sea plate. In this study, we model Nankai Earthquake, three large earthquakes in Hyuga-nada, and slow slip events (SSEs) in the Bungo channel using the composite law, which is a type of rate- and state-dependent friction law. We put the seismogenic zone for the Nankai Earthquake from off Kii peninsula to cape Ashizuri. And we set frictional properties at source area of SSE and the Hyuga-nada earthquakes to satisfy a condition of slow slip and unstable slip, respectively.

As a result, these earthquakes and SSEs occur, whose recurrence intervals roughly correspond to observation data. In our simulation, the Nankai Earthquake and the northern Hyuga-nada earthquake mostly occur independently. And once or twice for a thousand years, rupture of the Nankai Earthquake extends to the Hyuga-nada region. When shallow area at off cape Ashizuri is locked, rupture of the Nankai Earthquake does not extend to the westward. Coseismic slip or afterslip frequently occurs after the Nankai Earthquake in the source area of SSE in the Bungo channel. Then, SSEs in the Bungo channel do not occur after the Nankai Earthquakes for a while, and it repeatedly occurs before the next Nankai Earthquake.

By using these results, it is possible to describe the correlation among occurrences of Nankai Earthquake, Hyuga-nada Earthquake, and Bungo channel SSEs. But these phenomena have not been observed in the past. Therefore, it is required to include a discussion of modeling hypothesis and uncertainty of frictional properties.

Acknowledgments

This work was partly supported by the project ”Evaluation and disaster prevention research for the coming Tokai, Tonankai and Nankai earthquakes” of the Ministry of Education, Culture, Sports, Science and Technology of Japan. The Earth Simulator was used for all simulations.

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Two alternative regimes in Nankai seismic cycles caused by depth dependent distribution of fracture energy

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Great earthquakes have occurred repeatedly along the Nankai Trough in southwestern Japan with recurrence intervals of 100?200 y. The magnitudes of Nankai earthquakes have varied throughout this recurrence history, with many studies to date asserting that an event's magnitude is controlled only by the number of broken segments arranged along the Nankai Trough. However, evidence for seismic slip on the shallowest part of the decollement has been found in cores from boreholes drilled along the trough. In fact, slip on the shallowest part of the plate interface became larger during the 2011 Tohoku earthquake, causing a devastating tsunami. Moreover, recent evidence suggests that large tsunami with recurrence intervals of several hundred years have occurred along the Nankai Trough. Therefore, it is now essential to reconsider the scenario of Nankai Trough earthquakes, including the possibility of seismic slip on the shallow subduction interface. Recently, model calculations of the interplate seismic cycle have been conducted using rate- and state-dependent friction laws. In these calculations, assuming heterogeneous distribution of fracture energy in the seismogenic zone and its shallower extension, both massive earthquakes with slips up to the trough axis and ordinary earthquakes in the seismogenic zone can occur in different seismic cycles. Here, we apply a similar heterogeneous distribution of fracture energy in the shallower plate interface of the Nankai Trough. In the model, we represent the difference in fracture energy by the difference in the characteristic slip distance L. To model the conventional seismogenic zone as a zone of low fracture energy, we set L to be 0.05 m at depths of 10?20 km. Conversely, the shallow plate boundary near the trough is modeled as a zone of high fracture energy. By applying various values of L (0.05m<L<10m) in the shallower region, we explain the effect of gaps in fracture energies on resultant seismic cycles. For small gaps in fracture energies (0.05m<L<2.25m), the rupture in the every earthquake propagates up to the top of plate interface. In cases of relatively high fracture energies on the shallow interface (i.e. L >= 2.25 m), however, two types of earthquake with different moment magnitude occur alternately. The recurrence interval of the larger type (i.e., that with the greater slip distance) is about 370 y, which is comparable to the recurrence interval of larger tsunami deduced from recent geological findings. Large coseismic slip (i.e., more than 10 m) extends to the trough axis during the larger types. In contrast, the smaller one, whose seismic slip is distributed only along the seismogenic zone, occurs after ~200 y of the larger one. These results indicate the depth dependent distribution of fracture energy could be a factor which controls the large variation of seismic cycles along the Nankai Trough.

Keywords: numerical simulation, earthquake generation cycle, subduction zone, fracture energy heterogeneity, rate- and state-dependent friction laws

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Dynamics of decollement formation during accretion and mechanism of great earthquake generation in subduction zones

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In the previous studies, necessary conditions for decollement formation have been considered as the existence of weak layers due to material heterogeneities, fluid pressure anomaly, etc. Further, in the multiple decollement formation, as called decollement step-down, the newer decollement would be formed deeper than the older one. However, our numerical experiments of accretionary prism formation demonstrate that decollement can be formed without material heterogeneity, and the newer decollement is formed above the older one. We will explain the mechanism of the above processes, and propose new paradigm for the dynamics in accretion and decollement formation. Furthermore, we will discuss earthquake generation mechanism based on our dynamical model for accretion formation.

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Dynamic Simulation of the Seismic Behavior on the Shallow Part of the Fault during Mega-Thrust Earthquakes Part.3

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The recent mega-thrust earthquakes, such as the 2011 Tohoku-Oki earthquake (M9.0), the 2004 Sumatra earthquake (M9.2) and the 2010 Chile earthquake (M8.8) showed some distinct features. For example, huge slips on the order of several ten meters on the shallow part of the fault without radiating short-period seismic waves (strong ground motions) are detected. Another is that the deep part of the fault radiates strong ground motions (e.g. Lay et al., 2012). The feature of seismic behavior especially shown on the shallow part of the fault has been highlighted if the rupture of the mega-thrust earthquakes reaches to the shallow part. Although various kinds of observations for the seismic behavior (rupture process and ground motion characteristics etc.) on the shallow part of the fault plane during the mega-trust earthquakes have been reported, the number of analytical or numerical studies based on dynamic simulation is still limited.

In this study, we carried out the dynamic simulations in order to get better understandings about the seismic behavior on the shallow part of the fault during mega-thrust earthquakes. We used the two-dimensional spectral element method (Ampuero, 2009) that can incorporate the complex fault geometry into simulation as well as to save computational resources. The simulation utilizes the slip-weakening law (Ida, 1972). In the simulation, we investigated the seismic behavior with changing some parameters such as the critical slip distance (Dc), the material parameters, and the rupture directivity in addition to the stress drop whose results are shown in Tsuda et al. (2012). The results of simulations are useful to get better understandings about the seismic behavior on the shallow part of the fault during the future mega-thrust earthquakes along the Nankai Trough, Japan.

Keywords: mega-thrust earthquake, shallow part of fault plane, seismic behavior, dynamic simulation, spectral element method

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3-D numerical modeling of temperature, fluid flow and heat flow associated with subduction of the PHS plate in SW Japan

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Constructing a three-dimensional numerical model, we investigated temperature, fluid flow and heat flow distributions associated with subduction of the Philippine Sea plate subducting beneath the Amuran plate, southwest Japan. We modeled realistic three-dimensional shape of the Philippine Sea slab by an inversion analysis using ABIC, using the geometry datum obtained by high resolution of P-wave tomography and seismic reflection study. Subducion velocity was set to be 4 cm/yr during a period from 7 to 3 Ma in the direction parallel to the strike of the Kinan Seamount Chain, and 6.32 cm/yr for the last 3 Myr obliquely in the current convergent direction. The results showed the patterns of temperature distribution, fluid flow and surface heat flow distributions in southwest Japan after 7 Myr of subduction. We found that the cooling effect brought by the Philippine slab is remarkable in the portion on descent slope of the slab with a larger composite subduction angle. The distribution of interplate temperature on the slab upper surface appears similar to the geometry of slab upper surface, indicating a corresponding relation between them.. Flow velocity of the mantle substance near the upper surface of the Philippine Sea slab is lower than that of the slab, and oblique subduction resulted in convection in oblique direction beneath the Osaka Bay where a dip angle of the slab is much larger than that beneath Shikoku. Subduction velocities on ascent and descent slope gradients are different, for they have a different composite subduction angle. Surface heat flow distribution is also affected by the slab shape. The cooling effect became large with increasing subduction time and slab length. To fit the observed surface heat flow distribution better in the model domain, we changed thickness of the continental plate and pore pressure ratio related to frictional heating on the plate interface, and evaluated the simulated results using the least square method. As a result, we suggest that thickness of the continental plate larger than 30 Myr. Pore pressure ratio larger than 0.95 is better for fitting the observation data. High heat flow anomalies in Shikoku and the Kii Peninsula and the low anomaly along the Seto inland sea exist according to the comparison to the results of simulation.

Keywords: numerical simulation, temperature, fluid flow, heat flow, Philippine Sea plate, Southwest Japan

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Rock magnetism of Tsunami boulders and its implication to emplacement history.

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In Ishigaki Island of Japan, there are several tens of erratic boulders, consisted of hermatypic coral. They had been emplaced due to the 1771 Meiwa Tsunami and/or prehistorical Tsunamis, called Tsunami boulder. These boulders that originally had attached to the reef edge emplaced to the shoreline or reef flat. To reveal the age of ancient Tsunami attacks, recent studies have conducted radiocarbon dating to Tsunami boulders and the result showed the population of five tsunamis since about 2000 years ago. Therefore, each Tsunami event might have transported or rotated Tsunami boulders more than once. However, radiocarbon dating cannot discriminate subsequent rotations. To solve this problem, we propose the paleomagnetic strategy. When coral grows, the coral magnetized parallel to the Earth's magnetic field due to the presence of magnetosome or detrital magnetite. If boulder have fine-grained magnetite, it is easy to acquire the secondly magnetization. Thus, the boulder obtains the new magnetization as it moves and rotates. This new magnetization is called viscous remanent magnetization (VRM) and increases progressively with age like vector composition. Using progressive thermal demagnetization (PTD), these vector components are erased young to old. Therefore, PTD can visualize the point of magnetic vector component changed and this point indicates the presence of Tsunami event. Furthermore, Neel's theory gives the formula that natural VRM acquired at low temperature over a long time disappears at a high temperature in a short time. This formula predicts multiple Tsunami age is determined from rotation record of each boulder. Our result showed multiple points of vector component changed during 383K to 413K. This result consist with emplacement mode of "Bari-ishi" which have been emplaced by 1771 Meiwa Tsunami. Our paleomagnetically-dated ages agree well with the population of radiocarbon dating. Furthermore, the ages calculated by the demagnetization temperature of VRM are close to ages of radiocarbon dating, although remanence-carrying mineral should be a single domain magnetite. To reveal the magnetic mineralogy, we conducted Lowrie-Fuller test, X-ray diffraction, high-temperature hysteresis to determine the Curie point. These allow us that the magnetic mineral of Tsunami boulder is of single domain magnetite. Therefore, our paleomagnetic strategy is valid for revealing the multiple transportation history of Tsunami boulder at Ishigaki Island.

Keywords: Tsunami boulder, paleomagnetism, viscous remanent magnetization, Neel's theory, single domain

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Hearing survey of the tsunami generated by the 1911 great earthquake(M8.0) occurred around Kikai-jima, Japan

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The great earthquake(M8.0) occurred around Kikai-jima, Japan in 1911 and the weak tsunami was known to attack Amami-oshima (Imamura, 1913). However, it is recently revealed that there are some traditions of tsunami height more than 5m in Kikai-jima and Amami-oshima. Then, we conducted hearing survey at Kikai-jima, Amami-oshima, Kakeroma-jima, Uke-shima, Yoro-shima and Takara-jima in 2011-2012 for understanding the actual conditions of tsunami.

Number of collected information on tsunami is 34 at Kikai-jima, 19 at Amami-oshima and 2 at Kakeroma-jima, many of which are oral traditions from parents or grandparents. Characteristics of tsunami are summarized as follows :

1. Height of tsunami was more than 5m at the west coast of Kikai-jima. On the other hand, it was low at the east coast.
2. Height of tsunami was more than 5m at Amami-oshima, which was larger at the east coast generally in comparison with that at the west coast.
3. There was no severe tsunami damage at Kakeroma-jima, Uke-shima and Yoro-shima.
4. Ebbing tide was observed at Kikai-jima, the middle and the northern part of Amami-oshima. (There is no information on the first motion of tsunami at the southern part of Amami-oshima.)

The present hearing survey reveals that the 1911 tsunami is reasonable size for earthquake magnitude of 8.0. The tsunami simulation shows the collected information on tsunami is explained well by the model that the tsunami is generated by the thrust fault located at the north-northeast off Kikai-jima.

Keywords: great earthquake, tsunami, plate boundary, Nansei-shoto, Kikai-jima

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Nankai Earthquake recurrences recorded in lacustrine sediment from eastern Shikoku

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We collect total nine cores from Kamoda-oike , western Shikoku. These core samples cover 0-6,500 years in Late Holocene time. Only one thick tsunami sediment obtains in the interval which composed of brown colored plant material-rich mud. This tsunami sand layer which shows 2000yBP to 2300yBP in age, yield light gray colored, well sorted and well rounded sand.

Historical records among 1,000 years interval are not written in any archives around this pond even 1707 Hoei Nankai Earthquake. This pond may have sedimentary potential in which tsunami sediment records huge tsunami only.

Keywords: tsunami sediment, Nankai earthquake, Nankai Trough, tsunami record

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Nankai Earthquake recurrences recorded in lacustrine sediment

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We collected total nine cores from Sugari-oike facing the Kumano-nada Sea. The cores cover 0-3500 years in interval through the latest Holocene time. Total eighteen tsunami sand layers found in light-brown colored plant-rich material. Several tsunami sediments can be correlated to the historical records such as the Ninna Tonankai (AD 887 year) and Tenmu Tonankai (AD 684 year). Among 1000 years interval, we can recognize five-layers
in top 200 cm cores. The other hand, three tsunami layers yield in these cores which correspond 2000, 2300 and 2500 years respectively.

Relative intensity of tsunami is difficult to know because of paleoenvironmental condition are not stable because of having several tsunami-pass inlet.

Keywords: Nankai Earthquakes, Tsunami sediments, Sukari O-ike

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Re-examination of large 20th century earthquakes along the southern Japan trench -The 1927 and 1953 off Boso earthquakes

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We re-examine hypocenters, focal mechanisms and fault models for large earthquakes off Boso region along the southern Japan Trench. The relocated epicenter of the 1927 Boso earthquake, from newly collected S and S-P times, is about 100 km to the west of that of Japan Meteorological Agency (JMA).

Off Boso, several large earthquakes (e.g., the 1953 Boso earthquake) and tsunami earthquakes (e.g., the 1677 Empo earthquake) have occurred, but their recurrence periods are not well known. Two earthquakes, one on August 18, 1927 with Mjma 6.4 and Mt 7.4, and the other on November 25, 1953 with Mjma 7.4 and Mt 7.8, have different epicenters and tsunami source areas. While the 1927 epicenter was located southeast of the 1953 epicenter, the 1927 tsunami source was estimated northwest of the 1953 tsunami source (Hatori,1975). We identified the locations of tide gauge stations in 1920's, and recalculated the tsunami travel time. The tsunami source area was located a little southwest of that of Hatori (1975). To relocate epicenter, we collected seismic waveforms and original arrival time reports from the local meteorological observatories of the 1927 earthquake, and re-examined those S-P times. At some observatories, the value reported as a preliminary tremor in 1927 was not S-P but L-P time. Even if there were no report from a local meteorological observatory, there were some observatories where seismic waveform records remain, and P and S wave arrival times were written on them. Re-examined S-P time distribution of the 1927 earthquake looks similar to that of the 1953 earthquake. The 1927 epicenter is estimated at 141.2-141.7E and 34.1-34.2N, while that of JMA (2004) is 142.4E and 33.8N. The 1953 epicenter by JMA is 141.4E, 34.2N.

Keywords: Off Boso earthquake, Hypocenter location, Tsunami simulation

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Fault model of the 17th century great earthquake off Hokkaido estimated from tsunami deposit data

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Historically great underthrust earthquakes occurred off east Hokkaido. On the other hand, tsunami deposits by prehistoric tsunami have been found on the coast of east Hokkaido, Japan. These tsunami deposits were found at far inland away from tsunami inundation area by historic great earthquakes. The elevations of the location where tsunami deposits were found are also much higher than estimated heights of historic tsunamis. The recurrence interval of events is about 400 ~ 600 years. The latest event occurred early 17th century because that the latest tsunami deposits can be seen just under the volcanic ash caused by the 1667 Tarumae eruption. Large tsunami of the 17th century was generated by the earthquake that ruptured the area of Tokachi-Oki and Nemuro-Oki regions.

We estimated fault model of the 17th century earthquake by using both lowland tsunami deposit data and elevations of the location where tsunami deposits were found near the coast at highland. A finite-difference scheme was used to solve the non-linear long-wave equations with a moving boundary condition. The computed tsunami inundation and heights were compared to tsunami deposit data at 11 locations on the coast of east Hokkaido. Satake et al. (2008) estimated the fault model of the 17th century earthquake. This fault model was estimated to compare lowland tsunami deposit data and computed tsunami inundation area. This fault model of large rupture area of the plate interface was needed to explain the large tsunami inundation. Additionally, the fault model of very large slip amount at shallow part of the plate interface near the trench is needed to explain the high tsunami height near the coast. Therefore, fault model was added at the plate interface near the trench.

The result shows that lowland tsunami deposit data were explained by a tsunami inundation caused by a large rupture area at deep part of the plate interface. Elevations of the location where tsunami deposits were found near the coast were explained by very large slip amount at shallow part of the plate interface near the trench. The total seismic moment of the 17th century earthquake was calculated to be $1.7*10^{22}$ Nm (Mw 8.8) by assuming that the rigidity is $4*10^{10}$ N/m^2. The 2011 Tohoku earthquake also ruptured the large area off Tohoku and very large slip amount was fond at shallow part of the plate interface near the trench. It is possible that the 17th century great earthquake was the same type of the 2011 Tohoku earthquake.

Keywords: great earthquake, tsunami, Hokkaido

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Preliminary report on submarine active-fault landforms in the Sagami Trough, revealed by 0.5-arcsecond-mesh DEM

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We have conducted submarine-topographic surveys using multi-beam echo sounder in the Sagami Trough, in order to produce 0.5-arcsecond-mesh DEM, which is necessary for detailed analysis of submarine active-fault landforms.

This study was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, under its Observation and Research Program for Prediction of Earthquakes and Volcanic Eruptions.

Keywords: Submarine active fault, Fault-related landform, Historical earthquake, Multi-beam echo sounder, Sagami Trough

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3D bathymetric image of the Sagami Trough and the Boso Triple Junction area

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A triple junction is a place where complex interactions of plates occur. The Pacific plate, the North American plate and the Philippine Sea plate collide at the junction of the Japan Trench and the Izu-Bonin Trench, and the Sagami Trough. At these trenches and their vicinity, a collision of plates builds up strain and causes intraplate and interplate earthquakes. Those imprints may have been preserved in the topography.

To understand the seafloor topography of the triple junction and its vicinity, especially spatial distribution of active submarine faults, we made detailed seafloor topographic images based on 150m DEM processed from the original data obtained by Japan Coast Guard and JAMSTEC.

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Reexamination of the late Quaternary crustal movements in the Sanriku Coast, Northeast Japan, based on geomorphological

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The 2011 off the Pacific coast of Tohoku Earthquake (Mw 9.0) was accompanied by wide crustal subsidence (max. 1.2 m) along the Saniku coast on the Northeast Japan forearc, about 150 km distant from the axis of Japan Trench. This fact led us to qualitatively and quantitatively reexamine the component of coseismic, post-seismic and inter-seismic crustal movements in cumulative long-term uplift of the coast on the forearc. In order to achieve this aim, we conducted geomorphic analysis, drilling survey, and analysis of boring cores along the Sanriku Coast.

Keywords: Pleistocene, Holocene, crustal movement, marine terrace, Sanriku Coast