Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SSS035-P01 Room:Convention Hall Time:May 25 14:00-16:30

Changes in Coulomb Failure Function on inland faults in southwest Japan due to subduction events along the Nankai Trough

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The earthquakes on inland active faults in the Kinki region are mainly generated by the east-west compressive stress probably due to the Pacific (PAC) plate subduction. However, because the activity of inland earthquakes increases in the period from 50 years before to 10 years after the occurrence of great interplate earthquakes along the Nankai trough (Hori & Oike, 1999), earthquake generations on these faults are affected by the interplate earthquakes due to the Philippine Sea (PHS) plate subduction. To evaluate the effects quantitatively, we calculate the stress change on the inland active faults in southwest Japan due to the PHS subduction events, such as interplate earthquake, locking, and steady plate subduction.

For this problem, Pollitz & Sacks (1997), Hyodo & Hirahara (2004), and Hirahara (2007) evaluated the viscoelastic effect of great interplate earthquakes at the PHS plate subduction by examining Change in Coulomb Failure Function, dCFF. In these studies, they calculated dCFF due to great earthquakes and locking, among the subduction events.

The long-term (Myr scale) crustal deformation is caused by the mechanical effect due to plate subduction and is obtained by the viscoelastic response function at infinite time (Matsu'ura & Sato, 1989). As for the stress accumulation due to steady plate subduction, Hashimoto & Matsu'ura (2006) explained east-west compression in northeast Japan by steady subduction of the PHS plate and the partial collision of the PAC plate.

Based on the studies, we calculate dCFF on the inland active faults due to the steady plate subduction, using the above-mentioned procedure by Matsu'ura & Sato (1989). We compute the slip response function in an elastic-viscoelastic stratified medium. We employ quasi-static viscoelastic slip response functions for point sources by Fukahata & Matsu'ura (2006). For the plate interface of PHS and PAC plates, we use the structure by Nakajima & Hasegawa (2007) and Nakajima et al. (2009). We set the history of the interplate earthquakes at the PHS plate subduction as the boundary condition; the occurrence time is from historical record and the amount of slip is from time or slip predictable model (Shimazaki & Nakata, 1980). We also consider the east-west compressive stress due to the Pacific plate subduction and the collision of the Izu volcanic arc.

The current result is as follows. First, we calculated the slip response function by the modeled PHS plate. To investigate the validity of the obtained slip response function, we calculated the crustal deformation due to the 1944 Tonankai and 1946 Nankai earthquakes by giving the slip distribution of the events and compared with the geodetic observation data (triangulation, leveling, and sea level data). The computed results are basically consistent with the observation data. Then, we calculated the long-term crustal deformation due to steady subduction of the PHS plate. The computed vertical deformation is generally consistent with the observation of free-air gravity anomaly by Sandwell & Smith (1997). Computing the long-term crustal deformation pattern with various plate thicknesses, we found the vertical deformation pattern considerably depends on the plate thickness. Next, we evaluated dCFF due to great interplate earthquake, locking, and steady subduction. The ratio of dCFF due to steady subduction to the dCFF evaluation varies with the faults, and the stress accumulation pattern also considerably depends on the plate thickness.

We can consider dCFF due to steady plate subduction is the long-term stress accumulation to generate inland earthquake. So, we can evaluate how stress change during the earthquake cycle affects the long-term stress accumulation on inland active faults. We here evaluate the occurrence possibility of each inland earthquake during each great earthquake cycle along the Nankai trough and compare the historical record of inland earthquakes.

Keywords: subduction zone, numerical simulation, viscoelasticity, Coulomb failure function, steady plate subduction, inland earthquake

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SSS035-P02 Room:Convention Hall Time:May 25 14:00-16:30

The 2000 years ago tsunami event in the Kaniga-ike pond innermost the Tosa Bay

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Nankai earthquakes are plate boundary earthquakes associated with the Nankai subduction zone that have been recorded in historical documents a total of nine times since the Tenmu Nankai earthquake in A.D. 684. In order to reveal pre-historical evidence of Nankai earthquakes, we investigated core sediments from ponds and lakes on the coast of southwestern Japanese Islands along the Nankai Trough.

We collected 34 vibrocore samples from the Kaniga-ike pond which located in the center of Tosa Bay area, Shikoku Island. Stratigraphical study and radiocarbon dating of these samples revealed that Kaniga-ike pond recorded 6 tsunami events during last 2000 yeares. Last 4 events correlated with AD 1852 Ansei Earthquake, AD 1707 Hoei Earthquake, AD 1361 Shohei Earthquake or AD 1099 Kowa Earthquake and AD 684 Tenmu Earthquake respectively. Lower two events occurred in AD 300˜600 and about 2000 years ago. The 2000 years ago event formed thick tsunami sequence. Tsunami of AD 1707 Hoei Earthquake recorded over 10m height at the Usa village near by Kaniga-ike pond. The 2000 years ago tsunami sediments is thicker than Hoei tsunami sediments.

Keywords: Nankai earthquake, tsunami sediment

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SSS035-P03 Room:Convention Hall Time:May 25 14:00-16:30

Comparison of two records on the 1854 Ansei Nankai earthquake

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Two records on the 1854 Ansei Nankai earthquake in Kochi prefecture are compared, and it is shown that they are copies of an unknown original record.

Keywords: historical earthquake, Ansei Nankai earthquake, Kochi prefecture

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SSS035-P04 Room:Convention Hall Time:May 25 14:00-16:30

GPS continuous observation in Mindanao, the Philippines (preliminary report)

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Geospatial Information Authority of Japan (GSI) established two GPS continuous observation sites in Mindanao island, Philippines. The establishment of these sites is a part of the project named as "Enhancement of Earthquake and Volcano Monitoring and Effective Utilization of Disaster Mitigation Information in The Philippines", which is supported by JST (Japan Science and Technology Agency) and JICA (Japan International Cooperation Agency), carried out by NIED (National Institute of Earth Science and Disaster Prevention) and PHIVOLCS (The Philippine Institute of Volcanology and Seismology) as the representing organization of Japan and the Philippines.

Two observation sites settled in Butuan and Tandag equip Trimble 4000SSi receivers and LINUX BOX data loggers to obtain and to keep the observation data. The data archived would be used for the analysis to calculate the strain velocity to estimate the temporal variation of plate coupling along the Philippine trench. Those sites are also utilized for the campaign GPS observation, which is carried out by Nagoya university and other collaborating organizations to estimate the spatial distribution of the crustal strain along the Philippine fault and plate coupling along the Philippine trench.

The poster will present the outline of observation sites installation work and preliminary analysis result of the data obtained at those two sites.

Keywords: GPS, Continuous Observation, Crustal Deformation, Plate Coupling, Philippine Trench

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Space-time pattern of great or large earthquakes along the northern Japan to Kurile trenches

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The northern Japan to Kurile trenches have been regarded as a typical subduction zone with spatially and temporally regular recurrence of great interplate earthquakes (Utsu, 1972; 1984). Besides great (M>8) interplate events, however, many large (M>7) interplate, intraslab, outer-rise and tsunami earthquakes have also occurred in this region.

In this study, we depict the space-time pattern of M>7 earthquakes in this region, based on the relocated mainshock-aftershock distributions of all types of earthquakes occurred since 1913. Total number of M>7 events is 72. We classified the types of earthquakes before 1950's based on both relocated hypocenter distribution and seismic intensity distribution maps in Japan. We analyzed teleseismic body waves to estimate coseismic slip distributions of major events after 1960's. As a result, we found that the more complex feature of M>7 earthquake occurrence in this region.

We relocated hypocenters reported the ISC (International Seismological Centre), ISS (International Seismological Summary), and BCIS (Bureau Central International de Sismologie) bulletins by using the HYPOSAT (Schweitzer, 2003) and the Modified Joint Hypocenter Determination (MJHD) method (Hurukawa, 1995). We referred to seismic intensity maps compiled by Utsu (1989) for events before 1926 and those of the Japan Meteorological Agency (JMA) for events after 1926. We estimated coseismic slip distributions by the Kikuchi and Kanamori's (2003) tele-seismic body-wave inversion program. In the inversion, WWSSN long-period seismic waves of events before 1990's and broadband seismic waves of events after 1990's from the IRIS-DMC are used, respectively.

The results in this study are summarized as follows. (1) The northern Japan to southern Kurile subduction zone have been divided several regions on the basis of aftershock areas of great interplate events (Utsu, 1972; The Headquarters for Earthquake Research Promotion of Janese government, 2004). Each region has been ruptured by a M8-class interplate earthquake or by multiple M7-class events. A great interplate earthquake (Mw 8.5) occurred offshore Urup Island in 1963 and two large interplate events of Mw7.6 and Mw7.9 recurred in 1991 and 1995 in the eastern and western part of the source region, respectively. From the comparison of the 1963, 1991, and 1995 cosiemic slip distributions, the 1963 southwestern asperity seems to have been re-ruptured by the 1995 event. (2) Focal depth of the 1958 Etorofu earthquake determined by using depth-phases is about 80 km. The deeper focal depth supports the previous study that the 1958 event was an intraslab event (Harada and Ishibashi, 1999). Near Shikotan Island, the 1978 and 1994 intraslab earthquakes occurred on the trench-normal fault plane within the Pacific slab. A M7-class intraslab event may have occurred in 1939 on the same fault plane. M8-class earthquakes offshore the Simushir Island in 1915 and offshore the Urup Island in 1918 may have been intraslab event. (3) In the outer-rise region, M8-class events have occurred in 1933 and 2007 and M7-class events have occurred in 1919, 1963, 1982, and 2009. The 1918 earthquake of M7.7 offshore Urup Island seems to be an outer-rise event from main-shock epicenter location and its remarkable large felt area in Japan. The 2009 earthquake of Mw7.4 within the aftershock area of the 2007 normal-fault event of Mw8.1 have reverse faulting. From comparison of the 2007 and 2009 coseismic slip distributions, the 2007 normal faulting had ruptured a shallower part of the Pacific plate and the 2009 reverse faulting ruptured a deeper part of the plate. Tsunami earthquakes occurred offshore Urup Island in 1963 and offshore Shikotan Island in 1975, respectively.

In this study, we use FORTRAN programs of the HYPOSAT, MJHD method, and tele-seismic body-wave inversion.

Keywords: northern Japan trench - Kurile trench, great or large earthquakes, space-time pattern, hypocenter relocation, coseismic slip distribution, seismic intensity distribution

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SSS035-P06 Room:Convention Hall Time:May 25 14:00-16:30

High-precision hypocenter determinations below the Kumano fore-arc basin based on DONET observations

Masaru Nakano[1*], Takeshi Nakamura[1], Akiko To[1], Shin'ichiro Kamiya[1], Koichiro Obana[1], Yoshiyuki Kaneda[1]

[1]JAMSTEC

Along the Nankai trough, Tonankai and Nankai great earthquakes, which may cause great damages around western Japan, are anticipated to occur in the near future. Kumano fore-arc basin is above the source region of these earthquakes. In this region, various kinds of seismic activities are observed including non-volcanic tremor below the Kii peninsula and very-long-period earthquakes around the Nankai trough. In 2004, the off-Kii Peninsula earthquake (M7.4) occurred in the Philippine Sea plate subducting below the Kumano fore-arc basin. Investigations of seismic activities around this region may contribute to clarify the mechanisms of these earthquakes and tectonic settings along the Nankai trough.

Off the Kii peninsula, Dense Observation Network for Earthquake and Tsunami (DONET) has been developed by Japan Agency for Marine-Earth Science and Technology (JAMSTEC). DONET is a network of ocean-bottom seismic stations, aimed at improving the detection capability and earlier detection of earthquakes and tsunamis in this region. We have already installed 4 DONET stations by October, 2010, and four more stations have been installed in January, 2011. In this study, we determined the hypocenter locations of earthquakes that occurred around Kumano fore-arc basin.

We used data from DONET stations as well as on-line ocean-bottom seismic stations (OBS) installed by the Japan Meteorological Agency (JMA). We assumed a layered velocity structure for the hypocenter determination. The velocity structure is based on the investigation by the Research concerning Interaction between the Tokai, Tonankai and Nankai Earthquakes, a project of JAMSTEC. We picked P and S onsets manually and determined the hypocenter location by using the method of Hirata and Matsuura (1987, hypomh). We did not use data from land stations since the velocity structure is suitable for ocean-bottom seismic stations.

We analyzed data between middle of October 2010 and November 2011. We obtained hypocenters for more than 60 earthquakes which are not listed in the JMA earthquake catalogue. These earthquakes were distributed between the Kumano fore-arc basin and the Nankai trough. This region corresponds to the source region of the 2004 off Kii Peninsula earthquake (Obana et al., 2009). We could not find any significant seismic activity around this region during this period in the JMA catalogue.

The precision of the hypocenter location, especially of the depth, of present study is not enough since we only used data from the stations located close to the land. Adding data from stations located off the coast will improve more the earthquake detection capability and the precision of hypocenter location. Using a 3D velocity structure suitable for this region will also improve the accuracy of the hypocenter location. These improvements will produce an earthquake catalogue which may contribute to the investigations of seismic activity and tectonics around the Kumano fore-arc basin.

Keywords: Nankai trough, Tonankai earthquake, Ocean-bottom seismic observations

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Land-Marine integrated seismic survey in the western Kii Peninsula on subduction of the Philippine Sea Plate

Kimihiro Mochizuki[1*], Aitaro Kato[1], Takashi Iidaka[1], Eiji Kurashimo[1], Masanao Shinohara[1], Ayako Nakanishi[2], Takeshi Sato[2], Koichiro Obana[2], Narumi Takahashi[2], Shuichi Kodaira[2], Yoshiyuki Kaneda[2], Tetsuya Takeda[3], Katsuhiko Shiomi[3]

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The fault segment boundary of the Tonankai and Nankai earthquakes is situated off the Kii Peninsula. This segment boundary region also coincides with a boundary of other tectonic phenomena; a ~30 degree difference in the orientation of the principal stress axis, the lack of low frequency events between this boundary and northeast Shikoku island, and a large downward convex structure of the subducting Philippine Sea Plate with an sudden along-arc depth change beneath the boundary. Ide et al. (2010) suggested a tear in the subducting slab as a possible factor for the formation of this boundary by referring to the locations of past earthquakes and distribution of volcanoes in addition to the above phenomena. Understanding the shape of the subducting slab around this boundary with high resolution is important for clarifying the phenomena, elucidating generation mechanisms of the great earthquakes and their rupture processes. In October, 2010, we conducted a land-marine integrated seismic survey in the western Kii Peninsula. We deployed along a ~200 km long transect from near the Nankai Trough axis to Hannan city, Osaka Prefecture. We conducted airgun-shooting using a research vessel *Kairei* of the Japan Agency for Marine-Earth Science and Technology. We also shot a 300 kg explosive source at a site in Hannan city. We also recorded airgun shooting along a transect beyond the boundary region from the trough axis to near Awajishima Island. We anticipate a good contribution for understanding the shape of the subducting slab around the boundary region from the trough axis downdip to the transition zone of plate coupling strength and revealing characteristics of the plate interface.

This research is supported in part by a grant, *Research concerning Interaction between the Tokai, Tonankai and Nankai Earthquakes*, from Ministry of Education, Cluture, Sports, Science and Technology, Japan.

Keywords: Great earthquake, Subduction zone, Seismic survey, Fault boundary

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Seismic structure survey and ocean bottom earthquake observations in western Nankai Trough, off Shikoku Island

Koichiro Obana[1*], Ayako Nakanishi[1], Tsutomu Takahashi[1], Yojiro Yamamoto[1], Shuichi Kodaira[1], Takeshi Sato[1], Hidetoshi Fujimori[1], Kazuhiko Kashiwase[1], Yoshiyuki Kaneda[1]

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Along the Nankai trough, southwestern Japan, large interplate thrust earthquakes, such as 1946 Nankai and 1944 Tonankai earthquakes, of magnitude 8 class have occurred repeatedly with recurrence intervals of 100-200 years [e.g., Ando, 1975]. Recently, possibility of simultaneous rupture from Tokai to Hyuga-nada along the Nankai trough is suggested. Comparison in the crustal structure and the earthquake activity between Hyuga-nada region and off Shikoku area is important to understand segmentation and synchronization of seismic rupture of megathrust earthquakes along the Nankai trough. The seismic structure survey and earthquake observations in Hyuga-nada were conducted from December 2008 to January 2009. We conducted seismic structure surveys and earthquake observation off Shikoku Island from October 2009 to June 2010. This experiment is a part of ”Research concerning Interaction Between the Tokai, Tonankai and Nankai Earthquakes” funded by Ministry of Education, Culture, Sports, Science and Technology, Japan. In October 2009, 180 ocean bottom seismographs (OBSs) were deployed by R/V Kairei of Japan Agency for Marine-Earth Science and Technology (JAMSTEC) on three along-trough and four across-trough profiles with 5 km intervals. In addition to these OBSs, 21 OBSs for long-term observations were deployed on the profiles with about 20 km intervals. R/V Kairei conducted seismic surveys for crustal structure using the air gun array with a total volume of 7800 cubic inches. The OBSs except for 21 OBSs for long-term observations were recovered by R/V Kaiyo of JAMSTEC in January 2010. The OBSs for long-term observations were recovered in June 2010 by R/V Kaiyo. The data corrected by the OBSs were used for both seismic structure surveys and earthquake observations. The active seismic survey using the OBSs deployed with 5 km interval indicates spatial heterogeneity in crustal structures that could not be imaged by previous seismic surveys [e.g., Takahashi et al., 2002]. The OBSs for long-term observations observed about 120 earthquakes not included in Japan Meteorological Agency (JMA) Earthquake Catalogue during the 9-month observations. In addition to the active seismic surveys, the seismic records of the earthquakes obtained by the OBSs are used for crustal structure imaging.

Keywords: Nankai trough, seismic survey, ocean bottom seismograph, seismicity

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SSS035-P09 Room:Convention Hall Time:May 25 14:00-16:30

Seismic Waves from a Slab Earthquake and Velocity Structure in Southwestern Japan

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The nature of interplate megathrust earthquakes can be related to the geometry of the subducting oceanic plate. The Philippine Sea plate, which subducts beneath southwestern Japan and causes megathrust earthquakes along the Nankai trough, has a complicated shape, as shown by many studies (e.g. Nakajima and Hasegawa, 2007). Most of the previous studies suggested a sharp curve in the Philippine Sea plate beneath the Kinki region. Ide et al. (2010) recently proposed a new idea that the Philippine Sea plate is split along the Kii Suido and Hyogo prefecture, causing a step between the western and eastern portions of the plate. Seismic waves traversing in southwestern Japan might be affected by the shape of the Philippine Sea plate.

In this study, we first examined seismograms from a slab earthquake (Mj3.9) beneath the Aki-nada on 11 May, 2010. We used the Hi-net data recorded in southwestern Japan, paying attention to the portions from initial motions of P wave to later phases of S wave. The depth of the earthquake was estimated to be 45 km by JMA. Because we observed the head waves that Ohkura (2000) suggested for slab earthquakes, this earthquake could occur within the oceanic crust of the subducting Phlippine Sea plate. Observed seismograms look different between the western and eastern stations. At the western stations, P waves with apparent velocity of about 8 km/s are significant. We observed later phases of P and S waves, which can be the phases Miyoshi and Ishibashi (2007) interpreted as pPmP, sPmP, and sSmS. Several later phases of P and S waves are also seen at the eastern stations. At the eastern stations, however, P waves with apparent velocity of about 8 km/s are insignificant, and P waves arrive in complicated ways, depending on the station location and distance.

We next computed the theoretical seismograms using the 3-D Gaussian Beam method (Cerveny, 1985; Sekiguchi, 1992). A point source with the double-couple mechanism of F-NET was assumed. We tested some velocity structure models. Based on the results, we discuss how velocity structure including the shape of the Philippine Sea plate can affect seismograms recorded in southwestern Japan.

Acknowledgments: We used data from Hi-net. We thank Shoji Sekiguchi for giving us his code of the Gaussian Beam Method.

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The relationship between velocity structure and the seismic coupling in the Hyuga-nada region, southwest Japan

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In Hyuga-nada region, the Philippine Sea (PHS) plate is subducting beneath the Eurasian (EU) plate (the southwest Japan arc) along the Nankai trough at a rate of about 5 cm per year. In this region, microearthquake activity is very high. Big earthquakes (M7 class) have occurred at intervals of about dozens of years, and so plate coupling varies dozens of kilometers specially. It is important to understand seismic activity, stress field, and structure in such region in order to understand seismic cycle. According to the previous study of Uehira et al. (2007), there is a good correlation between the slip distribution at large earthquakes and the angle between maximum principal axis and the plate boundary in northern part of Hyuga-nada region. We performed extraordinary seismic observations for 75 days from April to July 2006, for 73 days from April to July 2008, and for 77 days from April to July 2009. About 25 pop-up type ocean-bottom seismometers were deployed above hypocentral region in Hyuga-nada using Nagasaki-maru. And three data loggers were deployed on land in order to compensate a regular seismic network. We used these data and permanent stations for this analysis. In order to obtain precise hypocenter distribution, focal mechanisms, and a 3D seismic velocity structure around the Hyuga-nada region, we used Double-Difference (DD) Tomography method developed by Zhang and Thurber (2003). In northern part of Hyuga-nada, Vp/Vs ratio is high along the upper part of PHS slab, and this layer is interpreted as the subducting oceanic crust. On the other hand, Vp/Vs ratio is about 1.73 in southern part of Hyuga-nada, and this is interpreted as the subducted Kyushu-Palau Ridge, old island arc, which is made by granitic rock. More over, there is a difference of Poisson's ratio at mantle wedge. This value is high ($>$ 0.3) in northern part of Hyuga-nada. The high Poisson's mantle wedge is suggesting that the zone probably corresponds to a serpentinized wedge mantle. This results is consistent with weak plate coupling. In southern part of Hyuga-nada, Poisson's ratio at mantle wedge is about 0.25. Uehira et al. (2007) was estimated that plate coupling is strong in southern part of Hyuga-nada, so, this result is consistent with this estimation.

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Preliminary results of logging-while-drilling, IODP Expedition 334, Costa Rica Seismogenesis Project (CRISP)

Saneatsu Saito[1*], Alberto Malinverno[2], Kohtaro Ujiie[3], Paola Vannucchi[4], Nicole Stroncik[5], Expedition 334 Scientists[6]

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Integrated Ocean Drilling Program (IODP) Expedition 334 is the first step in the Costa Rica Seismogenesis Project (CRISP), designed to understand the processes that control nucleation and seismic rupture of large earthquakes at erosional subduction zones. The scientific objectives of this expedition include constraining the architecture and evolution of the plate boundary megathrust, the role of fluids, as well as the nature of the upper plate in a tectonically erosive margin along a drilling transect at two slope sites. One of our goals is to obtain a comprehensive suite of geophysical logs at two sites using state-of-the-art logging-while-drilling (LWD) technology. The principal objectives of the LWD program are to document in situ physical properties (natural gamma ray, density, neutron porosity, resistivity, and annular fluid pressure and temperature), stratigraphic and structural features, compaction state, and hydrological parameters. Electrical resistivity images will be used to determine fracture orientations, to infer stress directions from borehole breakouts, and to orient core samples. We will present preliminary results from LWD measurements that were obtained during Expedition 334 from mid-March to mid-April 2011.

Keywords: IODP, CRISP, LWD, Seismogenic zone

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Interpretation of 3D structure of the Splay Fault at the Nanaki Accretionary Wedge

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We interpreted 3D geometry of the Splay fault, which may cause seafloor earthquakes and submarine landslides, by using three-dimensional seismic data in Nankai trough and evaluated the validity of the interpretation by comparing with synthetic seismograms derived from logging and core data.

Keywords: Nankai Trough, Accretionary Wedge, Spaly Fault, Interpretation of 3D strucutre, Logging data

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What controls the polarity change of decollement reflection along the Nankai Trough?

Jiyoon Lim[1*], Tomoyuki Sasaki[1], Masayuki Higashi[1], Jin-Oh Park[1]

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Understanding of the structure and physical properties of the decollement, which is a plate boundary fault in a subduction zone, is important to elucidate a mechanism of megathrust earthquake generation. Variation of reflection polarity, which is one of the key natures of the decollement, appears to be closely related to fluid flow process in the subduction. In spite of previous seismic reflection studies to show a locality of polarity change of the decollement reflection in the Nankai Trough, its general pattern and causes are still controversial. In this study, we aim to figure out what controls the polarity change of decollement reflection along the entire Nankai Trough. We interpreted multichannel seismic reflection profiles that have been acquired in the Nankai Trough margin by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) since the year of 1997. We focus on three features of the decollement reflection: regional distribution, polarity, and seismic stratigraphy.

We separated the Nankai subduction zone into ”stable sliding” and ”stick slip” zones, based on location of the decollement step-down to the subducting oceanic crust. According to the reflection polarity (i.e., normal or reverse) of the decollement, we divided the entire Nankai subduction zone into 5 different regions along Trough. Assuming that the reflection polarity is closely related to incoming sediments, we could recognize 5 different cases in relationship between the decollement reflection polarity and seismic facies. (1) Reverse polarity on the Top of Turbidites, (2)Normal polarity on the Volcanic Ash layer with the Turbidites below, (3)Reverse polarity in the Hemipelagic Mud, (4)Normal polarity on the Kumano Basin, (5)Reverse polarity on the Volcanic Ash with the Hemipelagic mud below. Bedding planes of turbidites shows reverse polarity. It suggest that bedding planes may be used as fluid paths. When the decollement is developed within hemipelagic muddy sediments, it shows reverse polarity. In case of kumano Basin, whole sediments subduct under the accreation prism. The case of off Shiono, and east side of Kumano basin, there are not turbidites and only Vocanic Ash layer and Hemipelagic Mud below. For the dehydrate -smectite to illite- in Hemipelagic Mud, on the vocanic Ash layer with high porosity, the decollement may be easily formed.

Keywords: decollement, polarity, Nankai Trough

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Performance evaluation of the borehole volume strainmeter installed in Nankai Trough

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Long term in situ monitoring of seismic activity, slow slip event, and pore fluid behavior around mega earthquake zone is important for understanding the processes of earthquake generation and strain accumulation. During IODP Exp 332 in December 2010, we have successfully installed borehole volume strainmeter in Nankai Trough for the long term monitoring of mega earthquake zone. Assessing the strain response caused by several externally applied stresses is a crucial step toward evaluating and interpreting the strain data. Especially, in order to detect strain change based on the regional stress field, it is important to verify the performance by comparing with the theory model after removed the effect of the environmental factors. In this study, we installed borehole volume strainmeter which is same type as installed in Nankai Trough, into the 216 mm OD borehole with depth of about 21m in Kamioka mine (Hida city, Gifu) and started the pressure and long term evaluation tests for evaluating the strainmeter performance. Collected strain data showed the drift (about -520 nstrain/day) which can be explained by the temperature change of silicone oil inside strainmeter and the other effect. The drift corrected data clearly showed the earth tidal strain change and corresponds with areal strain change predicted by the earth tidal model. 0.2 - 0.4 Hz microseisms (amplitude 0.15 nstrain) and earthquake with magnitude 5.3 (amplitude 0.38 nstrain) were recorded in the strain data, corresponding with microseisms (amplitude 140 nrad.(X), 180 nrad.(Y)) and earthquake (amplitude 650 nrad.(X), 1350 nrad.(Y)) recorded in tiltmeter installed next to the strainmeter. And the coherency between strain and tilt data was 0.6 - 0.7 at 0.2 - 0.4 Hz (microseisms) and about 0.8 at 0.5 - 1 Hz (earthquake). Further, in order to evaluate strain change associated with pore pressure change, we have conducted the pressure test by pressurizing the bottom of the borehole. As a result, the strain value decreased after the pressurizing (dilatation) and then increased with gradual pressure decay (compression), which may be caused by the opening effect of the borehole wall around the bottom. But the additional test was required to explain relation between strain and pressure change. In this presentation, we will present the performance evaluation of the borehole volume strainmeter installed in Nankai Trough using the strain data collected and will be collected.

Keywords: Tonankai eathquake, Nankai Trough, strain measurement, slow slip, crustal deformation, Kamioka mine

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(May 22-27 2011 at Makuhari, Chiba, Japan)

SSS035-P15 Room:Convention Hall Time:May 25 14:00-16:30

X-ray CT-based hydrogeological core analysis with CFR-PEEK core holder

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Clarifying hydraulic properties in the Earth's crust is required to understand crustal fluid migration, heat and material transport by the fluid, and accompanying water-rock interactions. For this purpose, we have studied an X-ray CT-based numerical method to analyze fracture flows within core samples at in-situ stress conditions. However, a recent study revealed that it was difficult to be characterized by using commercially available core holders, because noise in CT value was not negligible due to relatively high X-ray attenuation. In this paper, we show a new core holder, and some numerical results of fracture flow analyses for a granite sample under confining pressure. We have developed a core holder whose main body is made of a carbon fiber-reinforced PEEK (CFR PEEK), because of the low density of 1.44 g/cc and the high tensile strength of 236 MPa. The main body of the current core holder was designed for 2-inch core samples, and had the wall thickness of 12 mm. A pressure test demonstrated the core holder could be used at confining pressures of $>$ 30 MPa. A medical X-ray CT scan for a granite sample having a saw-cut fracture demonstrated the detection limit of fracture aperture was smaller than 30 microns even with the core holder. Based on a medical X-ray CT scan at 3-10 MPa with the core holder, it was possible to analyze single-phase flow within a granite sample having a tension fracture. The results demonstrated that fracture aperture and resulting permeability distributions within the sample could be measured, and that hydraulic properties of the sample could be evaluated using the permeability distribution, by using the X-ray CT-based numerical analysis, without any direct experiments on permeability.

Keywords: Core Analysis, X-ray CT, CFR-PEEK core holder, Confining pressure, Fracture flow, Permeability

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Structures of mud volcanoes and distribution of methane hydrate in the Kumano Trough using pseudo 3-D seismic processing

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A mud volcano is formed by unconsolidated mud eruption on the earth's surface or the seafloor, and caused by mud diapirism that migrated sediment, fluid, and gas from deep formation. Especially in a deepsea, it is thought that dissociation of methane hydrate near the seafloor promotes diapiric movement and growth of a mud volcano.

The Kumano Trough is one of the forearc basins of the Nankai Trough subduction zone. More than 10 mud volcanoes have been found in the trough floor from previous dives and side-scan sonar surveys. Kumano Knoll 3 (KK3) is one of the mud volcanoes developed in the central part of the Kumano Trough. Previous two-dimensional seismic reflection surveys revealed a pile of 'umbrella structures' beneath the KK3. However, it is not clear that whether this structure was caused by injection of wet-sediments as sills or formations of mud volcanoes by multiple eruptions. Moreover, seismic profiles clearly show methane hydrate BSRs are widely distributed in the trough. In contrast, BSR is discontinuous beneath KK3 suggesting relationships between mud volcano activity and methane hydrate formation.

We conducted pseudo three-dimensional seismic experiment around the KK3 using R/V Tansei-maru on KT-06-19 cruise, and acquired 82 seismic profiles that have about 6 km long lines trending NE-SW in a dense grid with basically 50 m apart during the survey. Data were obtained using consecutively seismic source a GI gun (G250 inch3+I105 inch3) every 50 m. The seismic acquisition systems consist of a 1200 m long streamer cable of 48 channels and 5 compass birds to get precise positions of each CMP. We integrated two-dimensional seismic reflection survey data into three-dimensional seismic profiles by using of corrected position data. In this study, we discuss the formation history and the relationship between the mud volcano and BSRs from three-dimensional precise internal structure of KK3.

Keywords: mud volcano, Kumano Trough, seismic reflection survey, methane hydrate BSR

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Studies on formation mechanism and source depth of mud volcanoes by using of drilling cores in the Kumano Trough

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Submarine mud volcanoes are formed as conical mounds composed of erupted unconsolidated or partially consolidated sediments from mud diapirs which are induced by high pore-fluid pressure and buoyancy developed in the deep underground. Most of them were discovered around subduction zones. Mud diapir that brings deep underground materials to seafloor has an important role for material circulations in subduction zones. Moreover, methane seepages at mound summits are suggested by existences of chemosynthetic biological communities, and accumulation of methane hydrate is expected from core samples and seismic reflection studies. Therefore, mud volcano is also significant in terms of global warming and energy resource.

In order to understand material circulations by mud volcanoes, information about formation mechanism, source layer and its depth is important. In addition, despite mud diapir is generally regarded as rising phenomenon by buoyancy and abnormal high pore pressure, those physical properties are not well investigated. In this study, we discuss the formation mechanism and source depth of mud diapir by using of samples derived form mud volcanoes.

We obtained drilling samples from two sites at the summit of the mud volcano in the Kumano Trough, during CK09-01 using Deep-Sea Drilling Vessel CHIKYU, in March, 2009. Those sites are near the central part of the vent of the mud volcano.

To understand formation process of mud volcano, anisotropy of magnetic susceptibility, vitrinite reflectance, density, geological description of breccia are conducted. Anisotropy of magnetic susceptibility shows particle arrangement within samples to understand sedimentation and deformation fabrics. While muddy sediments usually exhibit the ellipsoidal body characterized by oblate shape, the samples from the mud volcano show prolate shape rather than oblate shape. Moreover, long axis of the ellipsoidal body shows mostly vertical direction. Therefore, we expected that the drilling site is influenced by vertical material flow.

Porosity of the matrix from the mud volcano is almost constant around 50%. In contrast, the porosity from deposits of the normal basin sediment decreases with the depth and show larger values than those of the mud volcano within 20 m below seafloor. Constant value of porosity of mud volcanoes indicates recent eruption without gravitational compaction. On the other hand, the porosity of breccias shows 20-40 %. These values are smaller than those of the surface basin sediment and the matrix of the mud volcano.

Finally, the measured reflectance of vitrinites included in breccias derived from one formation under the seafloor and the age estimated by previous studies give us absolute maximum temperature of breccias. We calculated the depth of one formation by using the value of temperature and the geothermal gradient of this area before mud diapir brought in the formation as breccias. The depth is about 1900 meters under the seafloor. We expect that the source depth of the mud volcano is more depth than 1900 meters depth.

Keywords: mud volcano, mud diapir, accretionary prism, pore fluid pressure, Anisotropy of magnetic susceptibility, vitrinite reflectance

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Heat flow estimated from BSR and IODP borehole data: Implication of recent uplifting of the imbricate thrust zone in the

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New heat flow values were determined in the Nankai Trough forearc slope region of Kii Peninsula from the BSR identified in the 3-D seismic data volume and the thermal conductivity data measured on core samples obtained nearby during IODP Expeditions 315/316. High-resolution images in the shallower portion enabled detection of BSRs in the forearc slope. Comparison of P-wave velocities at drilled sites C0001/ C0004/C0006 and the interval velocity model constrains the uncertainty in BSR depth to <25m and error in heat flow by 5%. Thermal conductivity values were inferred from Vp-K relationship obtained in nearby borehole data, which would involve error of 0.1 W/m/K, or 10 % in terms of heat flow.

BSRs were identified only in the Imbricate Thrust Zone (ITZ) and no BSRs are visible either around the mega-splay fault or in the toe of the accretionary prism. Within the ITZ, the BSR near the axis of anticlines is significantly shallower than those in the adjacent slope zones. We designate the shallow BSR below the ridge axes 'Anticlinal High Value Zone (AHZ)', and designate other BSR 'Basal Low-value Zone (BLZ)'.

BSR-derived heat flow in the BLZ (60-70 mW/m2) is consistent with the general heat flow trend, which gradually decreases landward, from 120-140 mW/m2 in the Shikoku Basin to ˜55 mW/m2 in the Kumano Forearc Basin. Locally, it is lower than values obtained from probe measurements on the forearc slope region (60-90 mW/m2), and is higher than ones obtained at IODP drill sites nearby (47-55 mW/m2). These differences may be caused by the erosion or deposition of slope sediments. The anomalously shallow BSR in the BLZ produces an apparent high heat flow anomaly of 70-90 mW/m2, and a significant discontinuity is identified across the thrust fault complex. The most likely cause is the transient effect of thrust faulting followed by uplift and subsidence, then by the erosion and sedimentation. A one-dimensional time-dependent numerical model confirms that the relaxation time for the BSR depth to be reequilibrated from such a disturbance is 10-100 kyr.

The age of the accretionary prism and overlying sediment would be ˜1Ma or older, as inferred from the ages obtained at mega-splay (Sites C0004/C0008) and at frontal region (Site C0007). Three ridges in the ITZ have been uplifted since ˜1 Ma. Thus the thermal regime and the BSR depth in the AHZ have not yet equilibrated after the uplift due to faulting, resulting in an anomalously shallow BSR depth and higher heat flow. We propose that the anomalously shallow BSR in the AHZ and the BSR discontinuity across these fault zones are caused by thrust faulting activities since ˜1 Ma, followed by uplift and erosion.

Keywords: heat flow, BSR, methane hydrate, NantroSEIZE, thrust fault

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Determination of three-dimensional stress orientation in the accretionary prism in Nankai Subduction Zone, Japan by ASR

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During IODP Expedition 319, the first riser-drilling borehole in ocean was penetrated by D/V CHIKYU at Site C0009 in the Nankai convergent margin, Japan. From 0 mbsf (meters below seafloor) to 1285 mbsf, the borehole crossed the Kumano forearc basin and from 1285 mbsf to the bottom depth of 1604 mbsf, the Nankai accretionary prism.

In a short depth range of 84.20 m from 1509.7 to 1593.9 mbsf, core samples were retrieved by rotary core barrel drilling. We collected 3 whole-round core samples for measurements of anelastic strain recovery (ASR) by the same methods of sample preparation and anelastic strain data acquisition conducted in the previous Stage-1 expeditions of the same NanTroSEIZE drilling program (Byrne et al., 2009; GRL, Vol.36, L23310). Anelastic normal strains, measured every ten minutes in nine directions, including six independent directions, were used to calculate the anelastic strain tensors. All three samples showed coherent strain recovery over a long period more than 1 month. The three samples were from C0009A (3R,1531 mbsf; 4R, 1540 mbsf and 8R, 1577 mbsf, respectively) in lithologic Unit IV interpreted as accretionary prism or deformed slope sediments. All samples are composed of silty clays or hemipelagic muds with relatively high porosities (30%˜).

The ASR measurement results in Kumano Forearc Basin obtained from C0002 (Byrne et al., 2009) showed the maximum stress orientation is nearly vertical and a normal stress regime. However, the ASR results in the accretionary prism from C0009 show that the maximum principal stress axes plunge gently or are nearly horizontal and the stress regimes appear to be strike-slip or thrust (reverse fault) types. The maximum horizontal principal stress orientaions obtained from the ASR tests also show very good consistency with the stress orientaions determined from borehole breakouts in the same borehole and the same depth range (Lin et al., 2010; GRL, Vol.37, L13303). These results suggest that three-dimensional maximum principal stress (Sigma 1) and the stress regimes change with depth and/or formation. Possibly, the depth range around 1500 mbsf may be a transition zone of stress regime from normal faulting above to thrust faulting below.

We gratefully acknowledge the IODP for providing core samples and the supports of the IODP Exp319 scientists, D/V Chikyu drilling crew, and laboratory technicians.

Keywords: NanTroSEIZE, Stress, ASR

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Stress state analyses at the subduction input site, Site C0012, Nankai Subduction Zone, using anelastic strain recovery

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Three-dimensional stress orientation and their stress magnitudes in the basement basalt and overlying sediments at subduction input site, IODP Site C0012 was examined using anelastic strain recovery (ASR) analyses. The ASR results in the sedimentary sequence indicate the maximum principal stress axes were nearly vertical. The stress magnitudes of Sigma 2 and 3 are very close indicating that stress states in the sedimentary sequence are state at rest. On the other hand, ASR results in the basement basalt show that the maximum principal stress axis was nearly horizontal and oriented NE-SW, almost parallel (or slightly oblique) to the trench axis. The minimum principal stress axis plunges steeply SE. The stress state of the basement basalts suggests strike-slip or thrust (reverse fault) regimes, which is very different from state at rest condition, theoretic stress condition on the ocean floor far from subduction zone. The basement basalt in the subduction input at Site C0012 has been experienced trench-parallel shortening. The stress orientation in the basements basalt is consistent with the focal mechanism of the earthquakes occurred the vicinity. The estimated stress magnitude shows small variation between each principal stress, implied that direction of principal stress could be rotated easily in association with tectonic-induced local stress variation. Such stress orientation in the basement basalt therefore apparently formed due to hinge extension on the bending Philippine Sea Plate associated with subduction.

Keywords: NanTroSEIZE, ASR, Stress, Input site

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Permeability structure and permeability evolution of the fault systems in a shallow depth of Nankai subduction zone

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Fault slips during earthquakes can cause the dynamic change in hydraulic properties around fault slip surface, and this change will influence on the fault slip behavior. However, it is not well understood that how much hydraulic property will change due to fault slip including slip velocity dependence on the change of hydraulic property. Here, we measured fluid transport properties at effective pressure of 40 MPa in core samples from the megasplay fault system and the frontal thrust in IODP NanTroSEIZE drilling project Expedition 316. In addition, we estimated the change of hydraulic property in fault rocks by slip deformation using the same core samples.

Permeability and specific storage of the fault zone at the megasplay fault system (Site C0004) and the frontal thrust (Site C0007) shows $7.6*10^{-18}$ m^2 and $8.6*10^{-9}$ Pa-1, and $8.7*10^{-18}$ m^2 and $5.8*10^{-9}$ Pa-1, respectively. Hydraulic diffusivities of both fault zones at shallow depth were about $1*10^{-6}$ m^2/s, which is small enough to cause the dynamic fault weakening by the pore pressure generation. Stratigraphic variation of transport property indicates that the megasplay fault zone can act as a seal to fluid flow, though fault zone at frontal thrust may not.

We used the core samples from the fault zones to estimate the permeability change by sliding deformation. To simulate fault gouge material, the fault breccia and fractured siltstone samples were roughly crushed with an agate mortar and pestle and sieved to retain only grains of less than 0.2 mm diameter. A 1g sample of gouge, which has about 1 mm thickness, was placed between a pair of quartz rich sandstone cylinders from India (12 ~ 14 % of porosity, 10^{-15} ~ 10^{-16} m^2 of permeability) of about 25 mm diameter and 20 mm length. A gouge layer was shared by rotating the one of the cylinders to produce the fault slip. To evaluate the shear-induced permeability change, permeability was measured in the ascending order; 1) A pair of sandstone cylinders, 2) Simulated fault rocks before friction test (sandstone cylinders and a gouge layer), 3) Simulated fault rocks after friction test. Friction tests were performed on the gouge samples by using the high-speed rotary-shear testing apparatus in Kochi Core Center. Friction tests were performed at 1.5 MPa of normal stress and 150 rotation (about 8m slip displacement). We performed friction test at 3 different conditions; a) high-velocity sliding at 1m/s with fully water saturated, b) low-velocity sliding at 0.013 m/s with water saturated, and c) high velocity sliding at 1m/s with dry (unwetted) condition. Simulated gouge layer showed $2*10^{-18}$ m^2 ~ $4*10^{-19}$ m^2 in permeability, and the gouge permeability was one order of magnitude smaller than bulk permeability. Permeabilities in both fault gouges were decreased after sliding in wetted condition, and permeability reduced much larger in low velocity friction test than that in high velocity friction. On the other hand, permeability after sliding deformation in dry condition was increased.

We assume that shear compaction and fining of grain size by shear deformation around the slip surface reduced permeability of gouge layer. However, in high velocity friction, permeability reduction was prevented by the expansion of gouge layer due to thermal pressurization mechanism. It is supposed that permeability enhancement by dry friction experiment was a result of thermal cracking and thermal expansion of gouge layer.

Keywords: Nankai Trough, NantroSEIZE, permeability, permeability evolution, fault zone, thermal pressurization

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Mineral compositions and microstructures of accretionary mud samples cored at Site C0002 of the IODP Exp. 315

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We report the results of X-ray diffraction analyses and microstructural observations on mud samples cored by D/V "Chikyu" from the shallow Nankai-Trough accretionary prism during the IODP Exp. 315, which was conducted from November 16 to December 18 in 2007. We also discuss their relations to the failure and permeability properties of these samples which will be reported separately by Takahashi et al. in this session.

We analyzed two mud samples cored from about 945 and 1049 mbsf at Site C0002. Their in situ temperatures estimated from the geothermal gradient measured are 40-44 degrees C, while their in situ pressures estimated from depth-dependent densities and in situ pore pressures calculated assuming hydrostatic pressures are 36-38 MPa and 28-29 MPa, respectively. Triaxial compression experiments and permeability measurements conducted at room temperature and in situ confining and pore pressures revealed contrasting failure and permeability properties of these two samples (Takahashi et al., this session). We have done X-ray diffraction analyses and microstructural observations of these two samples in order to investigate what are responsible for the contrasting failure and permeability properties.

Keywords: Nankai-Trough accretionary prism, mud sample, mineral composition, microstructure, failure property, permeability

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Frictional response of sediments to earthquake ruptures: Insight from friction experiments on samples from NantroSEIZE

Mukoyoshi Hideki[2*], Takehiro Hirose[1], Wataru Tanikawa[1], Tadai Osamu[2], Weiren Lin[1]

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In order to evaluate the frictional response of sediments against rapid sliding associated with rupture propagation along faults in the accretionary prism, we have conducted friction experiments on clay-rich sediments from IODP Expedition 316, Nankai Trough. Recent high-velocity friction experiments demonstrated that frictional resistance of simulated faults increases rapidly at the onset of sliding of over slip distance of more than several centimeters (the initial frictional barrier), that is followed by prolonged slip-weakening (e.g. Sone & Shimamoto, 2009). The sediments from the Nankai trough also exhibit similar mechanical behaviors at slip velocity of 1.3 m/s and normal stress of 1.0 MPa. In this study special attention is paid to the initial frictional barrier at the onset of rapid sliding, as it may be a significant factor controlling how earthquake ruptures propagate from the depth into the shallow accretionary prisms.

In the experiments, we slid a simulated fault gouge at a constant slip rate of 0.1 mm/s and then suddenly increase slip rate to 1.3 m/s with different acceleration of from 0.13 to 13 m/sˆ2. In all runs, friction coefficient is 0.6-0.7 at slip rate of 0.1 m/s and then increases by 2-10% over distance of several centimeters as a fault starts accelerate. Amplitude of the initial frictional barrier and hardening distance seem to depend on acceleration. When a simulated fault overcomes the initial barrier, friction coefficient gradually decreases with slip toward the steady-state value of 0.1˜0.2. In order to evaluate whether the initial barrier can affect rupture propagation, we estimate a ratio of the frictional work consumed on fault during the initial hardening stage to the frictional work during the slip weakening. The ratio is about ˜0.01 at acceleration of 0.13 m/sˆ2, but tends to increase with acceleration to ˜0.1 at 13 m/sˆ2. The result suggests that as the rupture speed increases, the effect of initial frictional barrier at the onset of rapid faulting could not be negligible; large initial barrier may arrest the rupture propagation. The effect of initial barrier must be incorporated into the analysis of earthquake rupture propagation in subduction zones.

Keywords: fault, friction, NantroSEIZE, Expedition 316, earthquake

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Deformation experiments of serpentinite using gas apparatus: Implication for slow earthquakes in subduction zone

Keishi Okazaki[1*], Ikuo Katayama[1], Miki Takahashi[2], Koji Masuda[2]

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Slow earthquakes (e.g. slow slip events, very low frequency earthquakes and non-volcanic tremors) have been detected in southwest (SW) Japan. Most slow earthquakes in the subduction zone of SW Japan occur with the depth range from 35 to 45 km (Obara, 2002), where is slightly deeper than seismogenic zone of Nankai megathrust earthquake. In these depths of SW Japan, low velocity anomaly and high Poisson's ratio have been reported, and it suggest that the corner of mantle wedge are locally serpentinized, where the subducted Philippine Sea plate is dehydrated (Tsuji et al., 2008, Kamiya and Kobayashi, 2000). In addition, the effective normal stress at source region of tremor in SW Japan is an order of 100kPa (Nakata et al. 2008), which indicates that tremor source regions in SW Japan maintains high pore fluid pressure. To compare the strength of olivine, serpentine is week material and behaves semi-brittle deformation at shallower depth, thus, it is considered that serpentine prevents from generating earthquakes. In summary, the region of slow earthquakes activity involves areas of (1) presence of serpentine, (2) high pore fluid pressure zone and (3) semi-brittle deformation.

This study focuses on the deformation behavior of serpentine under high pore pressure and hydrothermal conditions. Experiments were conducted using the high-temperature and high-pressure gas confining medium apparatus at Hiroshima University. Stating material was used highly dense and isotopic antigorite serpentinite from Nishisonogi metamorphic belts, Nagasaki, Japan, which porosity is about 0.2 to 0.3 %. We performed preliminary deformation experiments at confining pressure of Pc = 10 MPa, pore pressure of Pp = 0 MPa under room temperature. The sample shows brittle failure at differential stress of 500MPa and axial strain of 0.02. The residual stress was almost 0MPa. In another run, at Pc = 200 MPa, Pp = 190 MPa and temperature of 400 C, shows brittle failure at 340 MPa at axial strain of 0.016. The residual stress was 280 MPa. The stress-weakening rate of the former experiment was up to 1200MPa/s, whereas the stress-weakening rate of the experiment under hydrothermal condition was 2.7 MPa/s. These preliminary data indicates that the high pore pressure plays important role one the failure strength of serpentinites, and we will report more results on the mechanical data of serpentinite under high pore pressure and hydrothermal conditions.

Keywords: serpentinite, subduction zone, deformation experiment, slow earthquake, brittle-ductile transition, high pore pressure

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Progressive change of Clay microstructure during burial consolidation

Kiichiro Kawamura[1*]

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Progressive change of microfabrics of deep-sea sediments during early diagenesis was analyzed using two drill cores collected from the Sites U1305 and U1306 of the Integrated Ocean Drilling Program Expedition 303 in the Labrador Sea in the northwest Atlantic Ocean. Microfabrics were analyzed by scanning electron microscope and micro X-ray CT (SP-microCT). Different microfabrics in three layers were distinguished in both cores: Surface layer-1 with general void ratio $>$ 2.5, subjacent layer-2 with void ratio 2.5 ? 1.5, and deep layer-3 with void ratio $<$ 1.5. Microfabrics of the sediments changes downward (toward deeper part), as well as magnetic susceptibility anisotropy. Microfabrics in the surface layer-1 is non-directional and characterized by the presence of many macropores larger than 10 micron meters in diameter. Clay platelets in this layer are linked to each other with edge-to-edge or high-angle edge-to-face (EF) contact. In the underlying layer-2, contact relations of clay platelets change to low angle EF type. Coarse siliciclastic fractions of this layer show horizontal preferred orientation, most probably due to overloading. Sizes of macropores decrease to several micron meters in diameter. In the lowest layer-3, clay platelets take horizontal preferred orientation to form shaly texture, according to further compaction. In conclusion, it can be said that the microfabrics of deep-sea sediments was quickly evolved to take horizontal, parallel preferred orientation by burial compaction, as far as concerned the sediments of the Labrador Sea floor. Furthermore, I will show an example of microfabrics around Japan.

Keywords: Scanning Electron Microscope, X-ray CT, Anisotropy of Magnetic Susceptibility, Freeze-Dry, Thin section

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Paleostress from calcite twins and stress change with seismic cycle: Yokonami melange, Cretaceous Shimanto Belt, Kochi

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A model that the stress within accretionary wedges can change with seismic cycles has suggested by Wang and Hu (2006). The model indicates that compression stress within wedges is expected at co-seismic slip due to higher shear friction along decoellement and extensional stress can be existed in inter-seismic period because of low friction due to higher pore pressure along decollement.

Paleo-stress has been examined using regionally distributed micro-faults as well as calcite twins by stress inversion method. Because calcite twin density is considered to reflect paleo-maximum differential stress, the stress estimated from calcite twin might be at the time of the maximum differential stress, therefore at co-seismic period. In this study, we have compared between paleo-stresses for micro-faults in relatively regional melange zone, for micro-faults around seismogenic fault and for calcite twins within the mineral veins along micro-faults to examine the stress change between them.

The study area is the Yokonami melange, the Cretaceous Shimanto Belt, Kochi, SW Japan. Lithologies are mainly composed of sandstone blocks surrounded by shale matrices representing tectonic melange textures with minor varicolored shale, red shale, cherts and basalts. The Susaki formation and the Shimotsui formation are observed in the north and the south of the Yokonami melange, respectively. Those formations are coherent unit including mainly of sandstone and mudstone. The both boundaries are faults. Pseudotachylytes were found in the northern boundary fault (the Susaki fault), suggesting that the fault was a seismogenic fault. We obtained mineral veins along micro-faults as oriented samples. The micro-faults clearly cut the melange fabrics, indicating that the micro-faults were formed after melange formation. Distribution of the micro-fault suggests that the underplating was after the micro-fault formation. Temperature and pressure conditions for the micro-fault formation are about 200 degree C and about 180MPa, respectively on the basis of fluid inclusion thermometry.

In this study, we have treated the calcite twins as a micro-fault. Axes of calcite crystals and e-poles for calcite twin were measured by universal stage. From that, we can obtain the slip directions and twin plane orientations. We used HIM (Hough inversion method) by Yamaji et al. (2006). We can estimate the stress orientation and stress ratio by the method. Stress ratio (F) is defined as ($sigma_2$ - $sigma_3$) / ($sigma_1$ - $sigma_3$).

Also, we have examined stresses for the micro-faults distributing throughout the Yokonami melange and around the northern boundary of seismogenic fault (the Susaki fault).

Calcite twin data were measured from 20 samples from 200m of northern part of Yokonami melange. Total number of data from calcite twin is 829. The stresses from all twin data shows axial compression with F = 0.0446 and axial extension with F = 0.9125. The stresses from each sample also represent axial compression and extension stresses. On the other hand, the stress from micro-fault throughout the Yokonami melange indicates triaxial stress with F = 0.6071 and NW horizontal $sigma_1$.

The most of stresses from calcite twins for each sample shows higher angle of $sigma_1$ with axial compression of stress ratio. The stress from the all calcite twins indicates also a vertical maximum principal stress. This stress is consistent with the stress from micro-faults around the Susaki faults. Because the stress from Yokonami melange indicates almost horizontal maximum principal stress with triaxial stress ratio, both stresses from calcite twins and micro-fault around the Susaki fault are totally different from the stress from the Yokonami melange. This result suggested that the stresses from Susaki fault and calcite twins might reflect co-seismic stress and the stress from Yokonami melange might be for inter-seismic stress. Change in stress in seismic cycle can be identified in this study.

Keywords: calcite twin, paleo stress, subduction zone, seismic cycle, accretionary complex, seismogenic fault

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(May 22-27 2011 at Makuhari, Chiba, Japan)

SSS035-P27 Room:Convention Hall Time:May 25 14:00-16:30

Numerical simulation of silica diagenesis in subduction zones

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A bedded chert in accretionary complex is a sedimentary rock composed mainly of pelagic sediments such as radiolarian ooze, and its major component is SiO_2. Silica in chert are transformed from amorphous silica into quartz via cristobalite phase during diagenetic process (Opal A->Opal CT->Quartz). In the process, structured water of silica minerals is dehydrated as much as 21.7% by volume (Mizutani, 1970). This water, can be supplied to deep plate boundary in subduction zone, and can generate an excess pore pressure which drops effective stress and rock strength. This process is important when concerning plate boundaries especially inside old plate subduction zones such as Japan trench, because pelagic sediments are deposited thickly on old oceanic plates. In the Kamiasou unit, Mino belt, red bedded chert is formed partly with white chert layer, which is a fossilized conduit of dehydrated water from silica . In this study, we perform numerical analysis the ratio of Opal A, Opal CT, and Quartz, the amount of dehydrated water, and the dehydration rate through silica diagenesis varing depth and temperature in order to estimate the formation condition of white chert layer. For this calculation, we chose kinetic parameters reported by Mizutani(1970), and observed values of sedimentation rate, geotherm, subduction angle and subduction rate in modern Japan Trench. As a result, we estimated the formation condition of white chert layer in the Inuyama area by calculating the depth and temperature where the phase transition and dehydration of silica diagenesis is significantly advanced.

Keywords: chert, diagenesis, subduction, kinetics

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Change in stress with seismic cycles identified at an out of sequence thrust: The Nobeoka thrust, Shimanto Belt, Kyusyu

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Seismic surveys along Nankai trough have revealed that the out-of sequence thrusts (OSTs) are commonly developed within the accretionary wedge branching from seismogenic subduction plate boundaries. The OSTs are also recognized in on-land accretionary complexes as large thrust faults cutting paleo-thermal structures. The Nobeoka fault is one of the OSTs recognized in on-land accretionary complex, the Shimato Belt, Kyusyu. The fault bounds the northern and the southern Shiamnto Belt and the gap in paleo-thermal temperature is up to 70 degree C.

The Nobeoka thrust strikes almost EW at coastline close to Nobeoka city. The Cretaceous Makimine formation and Paleogene Kitagawa formation are located at the hanging wall of the fault, comprising mainly of pelitic schist. The footwall of the fault is the Paleogene Hyuga formation composed mainly of shale. A lot of micro-faults are well developed just below the thrust for a few hundred meters to the south. Those micro faults are considered to be related to the Nobeoka thurst because slip direction and sense of the micro-fault is consistent with that of the Nobeoka thrust. The micro-faults are commonly accompanied with mineral veins of quartz and ankerite. Yamaguchi et al. (2010) suggested that the differences of mineral veins are possibly related to the seismic cycle.

In this study, we conducted stress inversion analysis for the micro-faults to examine the change in stress, which might be related to the seismic cycle.

We divided the micro-fault into two as a micro-fault with quartz vein and that with ankerite veins. From the micro-fault, we obtained the slip direction from slicken lines and slip sense by slicken steps. We used HIM (hough inversion method) by Yamaji et al. (2006) to estimate the stress for each. The stress ratio (F) is expressed as (sigma2 - sigma3) / (sigam1 ? sigma 3).

Two stress orientations and three stress orientations are observed in the results for ankerite veins and quartz veins, respectively. For ankerite veins, SE oriented and relatively higher dipping sigma3 with axial extension of F and SE oriented and relatively lower dipping sigma1 with axial compression are identified. For quartz veins, SE oriented and relatively higher dipping sigma3 with axial extension, NE oriented and almost horizontal sigma1 with triaxial stress ratio, and NW oriented and lower dipping sigma1 with axial compression are observed. After examination to detect reasonable stresses from them, we concluded that the NW-SE oriented and lower dipping sigma1 with axial compression is the most adequate stress for ankerite and quartz veins.

In comparison between the two stresses for ankerite veins and quartz veins, the angle of sigma1 is relatively higher in quartz veins and the stress ratio is also larger for quartz veins. Those differences between them are pretty well consistent with the dynamic Coulomb model suggested by Wang and Hu (2006). The model predicts that the stress within accretionary wedge can be change with seismic cycle, horizontal sigma1 with axial compression at the co-seismic slip and relatively higher dipping sigma1 with relatively triaxial stress in inter-seimsic period.

The result from the study can be explained by the dynamic Coulomb wedge model.

Keywords: out of sequence thrust, stress inversion method, seismic cycle, subduction plate boundary, accretionary complex

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Microscopic analysis of shear-concentrated zone and its surroundings, in the brittle damage zone of the Nobeoka Thrust

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Investigation of the microscopic structures inside the brittle damage zone in the footwall of the Nobeoka Thrust was examined. The Nobeoka Thrust in Kyushu, southwest Japan, is a fossilized out-of-sequence thrust, bounding the northern and southern Shimanto Belts of the Cretaceous-Tertiary accretionary complexes. Microscopic analysis was examined focusing on boudinage, which was one of the most typical structures in the study area. Boudinage is the disruption of layers, bodies or foliation planes within a rock mass in response to bulk extension along the envelope surface(Goscombe et al.,2003).

Coefficiency ratios of viscosity for the black shale and brown silt rock were calculated, using Smith(1977)'s equation. Viscosity was smaller for black shale than for brown silt rock, and the difference was greater inside the shear-concentrated area than the surrounding area.

XRD and EPMA analysis was performed for black shale and brown silt rock, and both results show that the conversion of smectite into illite occurred more strongly in the black shale than in brown silt.

The results indicate the relationship between the viscosity coefficient and the procession of diagenesis in clay minerals. The difference of viscosity was greater in the shear-concentrated area. However, the details of how viscosity and procession of diagenesis are related, are still unclear, and investigation from further analysis such as with XRD is necessary.

Keywords: Nobeoka Thrust, boudin, viscosity ratio

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Simulation of the Complicated Patterns of Great earthquakes along the Nankai Trough

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Hirose and Maeda (2010, SSJ) numerically simulated that the Tokai region did not rupture during the most recent Tonankai earthquake in 1944, and that long-term slow slip events (LSSE) in the Tokai region and Bungo channel occurred periodically, by using a three-dimensional earthquake cycle model on the basis of the rate- and state-dependent friction law. By assuming large characteristic displacements for areas where ridges are being subducted beneath the Tokai district [Kodaira et al. (2004, Science)] and Hyuganada, they developed a model for which recurring ruptures of both the Tonankai and Nankai segments occur approximately every 110 years, but rupture on the Tokai segment occurs on average during only every second earthquake cycle. Their modeling also successfully reproduced the recently observed recurring LSSE by assuming low normal stress and small characteristic displacement in areas where the LSSE occur. Their simulation showed that the amplitudes of the LSSE increased following earthquakes that did not rupture the Tokai segment.

However, in their model, great earthquakes along the Nankai trough always initiate off Kii Peninsula and the ruptures then propagate bilaterally; that is, the Tonankai and Nankai segments always rupture at the same time. These simulated results are not completely consistent with the complicated historical record of great earthquakes along the Nankai trough. On the other hand, the Tokai segment ruptures every second time the Tonankai segment ruptures because large L plays a role of barrier. In this study, we attempt to simulate intervals between the ruptures of the Tonankai and Nankai segments by introducing large L in area of the subducted Kinan seamount chain which may play a role of barrier.

As for the simulation method, we assumed that the shear stress on the fault obeys a rate- and state-dependent friction law derived from laboratory experiments. We used here the composite law [Kato and Tullis (2001, GRL)]. Assuming that equilibrium between shear stress and frictional stress remains quasi statically, we numerically solved differential equations by the fifth-order Runge-Kutta method with an adaptive step-size control [Press et al., 1992]. For simplicity, we considered that frictional parameters a and b depend only on depth and that the seismogenic zones for which (a ? b) is negative is within the depth range from 10 to 30 km [cf. Hyndman et al., 1995]. We assumed that a = 0.001 for the entire depth range, and b = 0.00165 for depths from 10 to 30 km. The characteristic displacement L was taken to be 0.1 m, except for 0.5 m at subducted ridges beneath the Tokai region, Hyunagada, and Kinan seamount chain, and 0.019-0.035 m at area of the LSSE. We believe that the dehydration process is especially active in the subducting slab beneath area of the LSSE [Hirose et al. (2008, JGR)], so we used smaller effective normal stresses (30-60 MPa) at the plate interface beneath area of the LSSE than the 100 MPa we used elsewhere. The plate convergence rate we used along the Nankai trough was 6.5 cm/y in the western part of the study area, decreasing eastward from the Kii Peninsula to 1.5 cm/y in the eastern part of the study area [Heki and Miyazaki (2001, GRL)].

The results show that a great earthquake that ruptures the Tonankai segment occurs about every 110 years, then after a few years a Nankai earthquake occurs. Furthermore the rupture propagates into the Tokai segment for only every second earthquake. By setting the large L which plays a role of barrier at the Kinan seamount chain, we can simulate the time interval between the Tonankai and Nankai earthquakes. However, the simulation holds the interval time at every earthquake cycle and does not produce the pattern like the 1707 Hoei earthquake which ruptured all segments along the Nankai trough at the same time. We will try to make a model which is consistent with the complicated historical record of great earthquakes along the Nankai trough.

Keywords: Nankai trough, Great earthquake, Simulation

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Efficient numerical approach for dynamic earthquake cycle simulation

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Recently, a simulation of the earthquake cycles is calculated based on the full-dynamic governing equations because the dynamic earthquake cycle simulation gives the different solution compared to the conventional quasi-static simulations (e.g. Lapusta and Liu, 2009). The dynamic simulation requires 1) the accuracy around the fault region, 2) representation of the inhomogeneous crust structure and 3) short to long scale calculations. Satisfying the above requirements is still in progress. I present some achievement and the progress to construct the framework to simulate the dynamic earthquake cycle simulation.

Keywords: dynamic earthquake cycle simulation, numerical method, finite element method

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A model of three-dimensional seismic structure in the source area of the Tokai-Tonankai-Nankai earthquake

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Previous studies with the seismic survey have shown that the seismic structure around the Nankai-Suruga Trough has a strong spatial heterogeneity, associated with the accretionary prism, plate boundary, subducting ridges, and mantle wedges (e.g., Kodaira et al., 2005). This means that we need to use a realistic three-dimensional structure model for seismic data analysis. We here construct the three-dimensional oceanic structure model around the trough, consisting of the accretionary prism, subducting oceanic layers 2 and 3, and oceanic mantle, mainly for the purpose of hypocenter determination, tomography, seismic wave propagation, and earthquake cycle simulation. We compile the geometry of each layer from the results of reflection and refraction seismic survey (e.g., Nakanishi et al., 2002), JMA hypocenter lists, and receiver function analysis (e.g., Shiomi et al., 2004), by using the gridding algorithm with continuous curvature splines in tension (Smith and Wessel, 1990). We also compile the recent results of seismic survey by the subproject 1 of the research on evaluating seismic linkage around the Nankai Trough into our model. The P wave velocity and the Poisson's ratio in each layer are provided referring to the JMA velocity model (Ueno et al., 2002), the classification of crustal type (Christensen, 1996) and the analysis results of the PPS converted waves (Takahashi et al., 2002). The model covers an area with the latitude of 28 to 37 degrees and the longitude of 128 to 142 degrees, which includes the source area of the Tokai-Tonankai-Nankai earthquake, and extends to a depth of 200 km. Our model is formatted with the netCDF type for each layer so that it is easy to edit and clip the data. In order to verify our constructed model, we simulate seismic wave propagation with the FDM (Nakamura et al., 2011) and compare synthetic data with observed one. In this presentation, we show the three-dimensional structure model and demonstrate it as a realistic one for seismic analysis.

Keywords: Nankai Trough, Tokai-Tonankai-Nankai earthquake, seismic structure model, seismic survey