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

SSS035-01 Room:IC Time:May 23 16:30-16:45

Afterslip detection from normal-mode data

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Afterslips of large earthquakes from the analysis of normal modes may provide useful information for earthquake source process as its frequency band fills the gap between geodetic data and higher-frequency (> 3 mHz) seismic data. Recent large earthquakes, such as the 2010 Chilean earthquake (M=8.8), the 2004 Sumatra earthquake (M=9.3) and the 2005 Nias (N. Sumatra) earthquake (M=8.6), provide us historically unparalleled opportunities to test such an idea because of availability of broadband seismic instruments.

In this study, we focus on amplitudes of multiplets between 0.2 and 1.85 mHz. There are 20 spectral peaks in this frequency range, some of which are simple multiplets like 0S2 and 0S3 but others consist of more than one multiplet like 1S3+3S1 and 2S5+1S6. Amplitudes of these peaks are the basic information of our approach. We first calculate synthetic seismograms for these peaks and calculate amplitude ratios between data and theory. These ratios as a function of frequency give us insight into the existence of possible afterslips (or multiple sources). If we compute modal amplitude ratios for the 2004 Sumatra earthquake, the amplitude ratios of data to synthetic spectra for the CMT solution is about 2.5 at about 0.3 mHz, i.e. 0S2 (Stein and Okal, 2005). The ratios at frequencies of twenty spectral peaks show systematic, decreasing trend toward 1 at about 2 mHz. The ratio of 1 indicates that the CMT solution is a good solution for seismic data for frequencies higher than 2 mHz.

Application of our technique to the 2010 Chilean earthquake shows that the modal amplitude data are mostly explained by the Global CMT solution with the exception of about 10 percent moment deficit. Amplitude ratios for the CMT solution are about 1.1 at lower frequency end (0.3 mHz). If we search for an additional source to improve the fit these ratios, we get a solution with the moment of about 11 percent of the CMT solution (Mo=1.84x10**29 dyne cm) and the source duration of 80 seconds.

For the N. Sumatra earthquake (Nias) in 2005, the afterslip must have the moment approximately 20 percent of the CMT solution with the rise time of about 100 seconds, although constraints on rise time is not tight.

For the Sumatra-Andaman earthquake in 2004, we modified Tsai et al.'s (2005) five point-source solution and were led to the sixth solution that indicated slow afterslip in the northern part of the Andaman arc.

Somewhat unusual resutls were found for the 2001 Peru earthquake and the 2003 Tokachi-Oki earthquake with no requirement for afterslips. As we know the Tokachi-oki earthquake had afterslips, derived from geodetic data, we must conclude that the afterslip for the Tokachi-oki earthquake occurred very slowly, meaning that the slip was so slow that it did not excite normal modes in the range 0.3-3 mHz.

We will discuss the details of our approach, the underlying assumptions and results for afterslips of large events (Mw >8.0) in the past decade.

Keywords: normal mode, source process, afterslip

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SSS035-02 Room:IC Time:May 23 16:45-17:00

Co- and postseismic deformation associated with the 2010 Maule, Chile, earthquake deduced from PALSAR ScanSAR images

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We investigate co- and postseismic deformation associated with the 2010 Maule, Chile, earthquake using ALOS/PALSAR ScanSAR images. ScanSAR images cover as wide region as 350km and enable detect the entire deformation associated with interpolate earthquakes of M8. The full aperture algorithm is applied to process ScanSAR images and the standard two-pass interferometry follows to produce interferograms. ScanSAR images were acquired several times including April 10, 2008 from the descending orbit, while post-earthquake images were acquired on March 1, April 16, June 1, and December 2. Overlap ratios between these images are not so good, but we obtain fairly good coherence including the pairs spanning the mainshock. The coseismic interferogram for the pair of April 10, 2008 and March 1, 2010 images shows more than 2m range increase which indicate westward motion of the crust. We recognize two peaks of deformations located near Constitucion and Concepcion. Inverting the coseismic interferogram with GPS displacements, we obtain two large slip zones on the plate interface. The maximum slip is estimated larger than 10m. The postseismic interferogram for the pair of March 1 and April 16, 2010, images shows postseismic deformation with the same sense as the coseismic one, but its peak may have shifted landward. This postseismic interferogram includes the coseismic deformation following the largest aftershock with normal faulting mechanism near Valparaiso on March 11.

Keywords: SAR, Maule earthquake, ScanSAR, InSAR, postseismic deformation, coseismic deformation

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SSS035-03 Room:IC Time:May 23 17:00-17:15

Rupture process and coseismic deformations of the 27 February 2010 Maule Earthquake, Chile

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We estimated the spatial and temporal slip distribution for the 27 February 2010 Maule earthquake from teleseismic body wave data. To obtain a stable inversion solution, we used the data covariance matrix from the observation and modeling errors, and incorporated smoothing constraints by using ABIC. The fault rupture can be divided into three stages. For the first 30 s the rupture started as an elliptical crack elongated in the in-plane direction along dip. After 30 s the rupture propagated bi-laterally along the strike reaching the maximum moment release at around 50 s near the hypocenter. Finally the rupture propagated mainly to the north reaching another peak of moment release at 80 s and 130 km north-east from the hypocenter. Main rupture lasted for about 110 s. To evaluate our source model, we calculated the coseismic vertical displacements and compare them with observed uplift/subsidence values measured along the coastline, as well as displacements obtained from strong ground motion and high-sampling GPS records in Concepcion. Our model provides good estimations of the static displacements in the northern source region, but under-estimates the observed coseismic uplifts in the southern region. This result suggests that more coseismic fault slip is required beneath the Arauco peninsula.The main slip in our source model is located in a region near the coastline. This feature is in good agreement with the source model of Delouis et al. (GRL, 2010), but differs from the source model of Lay et al. (GRL, 2010), in which the main moment release is located near the trench. A recent tomographic study conducted in the source area of the Maule earthquake suggests that the updip limit of the rupture zone might be located 30-40 km away from the trench (Contreras-Reyes et al., Tectonics, 2010), in agreement with our source model. On the other hand, the high-frequency radiated seismic energy suggests that the Maule earthquake may be identified as a normal megathrust event having the coseismic slip within the normal seismogenic zone (Newman and Convers, 2010), supporting the rupture near the coast as indicated by our results. The largest slip area of our source model is located near the hypocenter in a region of strong pre-seismic locking as derived from GPS measurements (Moreno et al., Nature 2010). This result supports the idea that slip of future earthquakes in subduction regions might be correlated to inter-seismic coupling.

Keywords: 2010 Chile earthquake, source process, coseismic displacement, strong motion, seismic coupling

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SSS035-04 Room:IC Time:May 23 17:15-17:30

Constraints on the Properties of Subduction-Related Earthquakes Using Array Data

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Recent occurrence of giant earthquakes has been captured by large-aperture arrays such as the High Sensitivity Seismograph Network (Hi-net) in Japan and the Transportable Array component (TA) of the USArray project in the United States. These data provide unprecedented opportunity to constrain properties of these events with the back-projection technique. Unlike conventional finite-fault source modelling, the back-projection method requires very little a priori information, allowing robust estimates of parameters such as rupture speed and spatio-temporal distribution of energy release.

We have analyzed a subset of shallow and intermediate depth earthquakes that occurred between 2001 and 2010 using the back-projection technique applied to the Hi-net and TA data. For some of the events, the spatial and temporal resolution achieved either by the combination of arrays or seismic phases allows detailed imaging of the energy release process of these giant earthquakes. For example, the rupture process of the 2010 Mw 8.8 Maule, Chile earthquake can be obtained using the TA array data. The back-projection results show that this earthquake consists of three segments with very different characteristics. The northernmost segment is characterized by high rupture speed and strong energy release at high frequency. The latitudinal extent of this segment is consistent with that of the 1985 Valparaiso Mw 8.0 Valparaiso earthquake. The central segment is the region around the epicentre which ruptures bilaterally away from the epicentre. The energy release is uneven, and is much stronger to the north than to the south. The northern rupture propagates with a speed of about 2.2 km/s. The boundary between the north and central segments is represented by a gap in rupture and break in aftershock distribution. The timing of the terminus of the rupture of the central segment and initiation of the northern rupture is such that continuous rupture is unlikely, and that dynamic triggering is involved. The third segment is the southernmost segment, and is characterized by very slow rupture speed of 0.8 km/s, and highest relative energy release at low frequency. The central and south segments cover the region that is thought to have broken during the 1835 Charles Darwin earthquake.

Based upon analysis of a number of giant earthquakes, we conclude that dynamic triggering and segmentation of fault are common features. For shallow megathrust events, the locations of breaks in rupture appear to correlate well with change in seismic coupling of the slab interface. The back-projection analysis also indicates that each segment has very different properties. Released energy from segments peaks at various frequencies, implying that seismic hazard assessment requires source studies spanning a wide range of frequencies.

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SSS035-05 Room:IC Time:May 23 17:30-17:45

Source area of the outer-rise normal-faulting earthquake off the east of Chichi-jima Island in December 2010

Koichiro Obana[1*], Tsutomu Takahashi[1], Shuichi Kodaira[1], Yuka Kaiho[1], Mikiya Yamashita[1], Takeshi Sato[1], Tetsuo No[1], Naoto Noguchi[1]

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A M7.4 earthquake occurred off the east of Chichi-jima Island, Bonin Islands, Japan, at 2:19, December 22, 2010 (JST). This earthquake is an outer-rise normal-faulting earthquake occurred within the Pacific plate. According to Japan Meteorological Agency (JMA), the associated tsunami was observed along the Pacific coast of Japan in southern part of northeast Japan and from southern part of Kanto to Okinawa. Outer-rise normal-faulting earthquakes, such as the 1933 Sanriku Earthquake (M8.1), could cause devastating damage by large tsunamis. Furthermore, the earthquakes occurred on September 2009 near the Tonga trench are considered that an outer-rise normal-faulting earthquake and an interplate subduction thrust earthquake occurred at almost the same time and place (Beavan et al, 2010; Lay et al., 2010). Outer-rise earthquakes and interplate subduction thrust earthquakes have cause-and-effect relations between each other. Precise location and shape of fault are necessary to understand mechanism of outer-rise normal-faulting earthquakes. However, the outer-rise earthquakes occur far away from coast. Hence, it is difficult to obtain accurate hypocenter locations of aftershocks. Especially for the earthquake off the east of Chichi-jima Island in December 2010, there is limited number of island seismic stations near the hypocenter. Offshore observations are necessary to obtain accurate aftershock distributions.

R/V Kairei of Japan Agency for Marine-Earth Science and Technology (JAMSTEC) had conducted a seismic survey in Izu-Bonin area during the occurrence of the earthquake off the east of Chichi-jima Island. R/V Kairei stopped the survey temporarily and deployed one ocean bottom seismograph (OBS) in the source area on December 25, 2010, just 3 days after the occurrence of the mainshock. This OBS was recovered on January 6, 2011 during another cruise of R/V Kairei. In addition to this, R/V Kairei deployed four another OBSs in the source area. The recovered OBS succeeded to record the seismic record of aftershocks. Aftershocks were relocated using the seismic record obtained by the OBS and island seismic stations on Chichi-jima (operated by JMA and National Institute for Earth Science and Disaster Prevention) and Haha-jima (operated by JMA).

The aftershocks are located northwest to the hypocenter of the mainshock determined by USGS. Aftershocks distributed in a northwest-southeast direction, which is consistent with the mainshock focal mechanism indicating tensional axis oriented northeast-southwest. There are horst and graben structures cutting the Pacific plate by normal faults with strikes almost parallel to the plate boundary near the source area. We discuss that the source area of the outer-rise normal-faulting earthquake based on results of the offshore aftershock observations and crustal structure surveys.

Keywords: outer rise earthquake, normal fault earthquake, OBS, aftershock

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SSS035-06 Room:IC Time:May 23 17:45-18:00

Geometry of the Philippine Sea plate subducting beneath the westernmost Nankai Trough

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

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In the Nankai Trough subduction seismogenic zone, the Nankai and Tonankai earthquakes had often occurred simultaneously, and caused a great event. Possibility of a megathrust earthquake along the Nankai Trough from Tokai to the Hyuga-nada, east off the Kyushu Island, Japan, is recently pointed out.

To know the genuine western end of the Nankai megathrust earthquake, a high-resolution wide-angle seismic survey was conducted in the Hyuga-nada region. Moreover, it is important to know the spatial geometry of the subducting Philippine Sea plate to understand rupture synchronization and segmentation of the Nankai megathrust earthquake.

Layered (or Layered-like) velocity models having velocity interfaces such as Moho are obtained by trial-and-error approach, ray-tracing technique [Zelt & Smith, 1992] combined with first arrival tomography based on the structural images derived from first arrival tomography and reflection traveltime mapping [Fujie et al., 2006]. Previously obtained marine seismic data in the Hyuga-nada region is also used to make precise and detailed geometry of the subducting plate. We also used airgun shot data observed by HI-NET stations located along the prolongation of across-trough seismic profiles to determine deep subduction structure and forearc structure.

The spatial geometry of the Philippine Sea plate was estimated from the layered velocity models. The subducting plate is deformed around the northeastern and southwestern margins of the Kyushu Palau Ridge. Both margins of the Kyushu Palau Ridge may correspond to the western end of the Nankai megathrust earthquake, southwestern end of the 1968 Hyuga-nada earthquake and the 1662 tsunami earthquake, respectively.

This research is part of 'Research concerning Interaction Between the Tokai, Tonankai and Nankai Earthquakes' funded by Ministry of Education, Culture, Sports, Science and Technology, Japan.

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SSS035-07 Room:IC Time:May 23 18:00-18:15

Three dimensional structure of random velocity inhomogeneities in and around the Hyuga-nada region

Tsutomu Takahashi[1*], Koichiro Obana[1], Yojiro Yamamoto[1], Ayako Nakanishi[1], Shuichi Kodaira[1], Yoshiyuki Kaneda[1]

[1]JAMSTEC

High frequency seismic waves (>1Hz) that are impulsively radiated from a point source are collapsed and broadened as travel distance increases. This broadening process can be described by multiple forward scattering in randomly inhomogeneous media. Recent studies on seismic wave scattering and attenuation pointed out the importance of random inhomogeneities and intrinsic attenuation to characterize medium properties [e.g., Takahashi et al. 2009; Carcole & Sato, 2010]. From Dec. 2008 to Jan. 2009, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) deployed 160 ocean bottom seismographs (OBSs) at Hyuga-nada region as a part of "Research concerning Interaction Between the Tokai, Tonankai and Nankai Earthquakes" funded by Ministry of Education, Culture, Sports, Science and Technology, Japan. This study estimates the spatial distribution of the power spectral density function (PSDF) of random inhomogeneities, and examines the relations with crustal velocity structure and seismic activity.

Random inhomogeneities are estimated by the inversion analysis of the peak delay time of S-wave of small earthquakes, where the peak delay time is defined as the time lag from the onset to the maximal amplitude arrival. We assumed the von Karman type functional form for the PSDF. Peak delay times are measured from root mean squared envelopes at 4-8Hz, 8-16Hz and 16-32Hz. Inversion result can be summarized as follows. Random inhomogeneities beneath the Beppu-Shimabara rift zone are characterized by strong inhomogeneities at small spatial scale (~ a few hundreds meter) and weak spectral gradient. Those in the Hyuga-nada region are characterized by the weak inhomogeneities at small spatial wavelength and steep spectral gradient. Note that inhomogeneities at large wavelength (~ a few kilometers) is larger than its surrounding area, which is consistent with the broadened wave trains at 4-8Hz observed by OBSs. Random inhomogeneities in the Hyuga-nada region are similar with those in the frontal arc high in northern Izu-Bonin arc, which is thought to be a remnant arc that is presently inactive [Takahashi et al. JGR in press]. This coincidence implies the existence of subducted Kyushu-Palau ridge in this anomaly of random inhomogeneities, that is also suggested by the seismic refraction survey in this region [Nakanishi et al. 2010 AGU Fall Mtg.]. Source rupture areas of large earthquakes (M>6) in Hyuga-nada region tend to locate around this anomaly of inhomogeneities. We may say that this anomalously inhomogeneous region is a structural factor affecting the seismic activity in Hyuga-nada region.

Keywords: random inhomogeneities, Nankai trough, Hyuga-nada

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Seismic velocity structure around the Hyuga-nada region, western end of the Nankai Trough

Yojiro Yamamoto[1*], Koichiro Obana[1], Tsutomu Takahashi[1], Ayako Nakanishi[1], Shuichi Kodaira[1], Yoshiyuki Kaneda[1]

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In the Nankai Trough, three major seismogenic zones (Tokai, Tonankai and Nankai) of megathrust earthquake exist. The Hyuga-nada region is located on the west of Nankai seismogenic zone and it was distinguished from these seismogenic zones because of the lack of megathrust earthquake. However, recent studies pointed out the possibility of simultaneous rupture of the Tokai, Tonankai, Nankai and Hyuga-nada segments. Thus, the seismological structure in Hyuga-nada region is important to understand segmentation and synchronization of seismic rupture along the Nankai Trough subduction zone. To understand the possibility of seismic linkage of Nankai and Hyuga-nada segments, Japan Agency for Marine-Earth Science and Technology has been carried out a wide-angle active source survey and local seismic observation in the western end of the Nankai seismogenic zone. In the southern west part of observation area, it is considered that the Kyushu-Palau Ridge is subducting. This observation is conducted as a part of ‘Research concerning Interaction Between the Tokai, Tonankai and Nankai Earthquakes‘ funded by Ministry of Education, Culture, Sports, Science and Technology, Japan. From active source survey, Nakanishi et al [2010, AGU] showed that subducting Philippine Sea Plate can be divided into three zones and there is the zone of the thin oceanic crust of the subducting Philippine Sea Plate between Nankai segment and Kyushu-Palau Ridge segment. However, their imaging range is limited in the shallow part of the offshore region. Deep structure of the subducting slab and the structure of arc/ocean transition zone are also important to consider the possibility of the seismic linkage and the location of the boundary among three zones described above.

To extend the seismic image to the coastal area and to investigate the fine structure of subducted slab, we performed a three-dimensional seismic tomography combining the local seismic data recorded on 157 ocean bottom seismographs and 107 land seismic stations. From the result of hypocenter relocation, microseismicity near the trough axis is active on the western part of the ‘thin oceanic crust‘, whereas inactive on the eastern part. Obtained velocity structure of subducted slab crust indicates that the width of ‘thin oceanic crust zone‘ is narrow and it extends to about 30 km in depth of plate boundary. The continental crust just above the coseismic slip zone of 1968 Mw7.5 earthquake shows relatively high velocity. Besides, velocity structure of the uppermost part of the subducting slab mantle shows spatial heterogeneities. In the thin oceanic crust zone, high velocity slab mantle is imaged from near the trough to coastline. On the other hands, in the Kyusyu-Palau Ridge segment, western part of the ‘thin oceanic crust‘ segment, two low velocity zones are imaged in the slab mantle. Because the locations of these low velocity zones are corresponding to the low magnetic anomaly area, we consider that these low velocity zone may be related to the subducted Kyusyu-Palau Ridge. Focal mechanisms estimated from P-wave first motion indicate that the normal fault earthquake is dominant in this region.

Keywords: Nankai Trough, Hyuga-nada, ocean bottom seismograph, seismic tomography, seismicity

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SSS035-09 Room:IC Time:May 24 08:30-08:45

Earthquake recurrence as revealed by tsunami deposit and coral drilling surveys in Sumatra, Indonesia

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We performed coral drilling and tsunami deposit surveys along the western coast of Sumatra Island, Indonesia, to investigate large earthquake recurrence intervals for past several thousands years. Coral drilling surveys were carried out at Pagai Island in September 2009 and Simellue Island in May 2010, and tsunami deposit surveys were done along the north-western coast of Aceh Province, Sumatra Island in December 2009 and March 2010.

About the coral drilling survey, annual bands of coral skeletons in tropical areas could capture the histories of the environments changes and past events with weekly to monthly time resolution and centuries to millennium scale. Our aim is to reconstruct past records of earthquake and tsunami using geochemical and geological approaches on coral annual bands, which is crucial for establishing hazard system in Sumatra regions. We successfully collected modern and fossil coral cores using underwater and land-based drilling from South Pagai Island and Simellue Island. The obtained cores of (total 15 cores with length from 1.5 m to 3 m and diameter of 5 cm) were sliced (5 mm thickness) parallel to the axis of maximum growth direction and x-rayed to observe density banding. The age of ca. 255 (AD1755) was estimated by counting clear annual bands in the longest cores. The growth disturbances corresponding with recent earthquakes (2004 and 2005) were observed in annual bands of modern corals. Geochemical signals of isotopes and elemental analysis found the anomalies on those parts of skeletons. Our future objective is to establish the coral geochemical/geological proxies for earthquake and tsunami using long living coral and fossil cores in order to reconstruct past earthquakes and tsunamis.

About the tsunami deposit survey, we traced the 2004 tsunami layers deposited near the surface and found a clear sand layer at about 1 m beneath the present surface in Calang, Aceh Province, Sumatra. We also found a sand layer at the similar depth in Meulaboh, located about 45 km south from Calang, and this layer was dated to be about 1000 years BP. If these sand layers are tsunami deposits produced by one event of 1000 years BP, the tsunami has to be large enough to affect more than 40 km wide area along the coast. The 2004 tsunami deposits were studied in Lampuuk, northern Aceh Province. The sandy deposits were covered by newly developed soil and still clearly identified in the tsunami inundation area. In Aceh, two tsunami deposits caused by smaller than the 2004 event but large enough tsunamis were found. These sandy tsunami deposits lied between the 1839 and 1510 tephras that might be from Seulawah Agam volcano located about 40 km east from the site.

Keywords: large earthquake, earthquake recurrence, tsunami deposit, coral drilling, Indonesia

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SSS035-10 Room:IC Time:May 24 08:45-09:00

Location of the eastern end of source area of the 1707 Hoei earthquake (2)

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We discuss the location of the eastern end of source area of the 1707 Hoei earthquake. Yano and Nakanishi (2003) and Nakanishi and Yano (2005) study historical ridge boards (munafuda) preserved in shrines on the western side of the Izu Peninsula, and they find the evidence that the source area of the Hoei earthquake did not extend into the inside of the Suruga Bay. In this paper we present three historical records found in the Suruga Bay area that support the above conclusion on the eastern end of Hoei earthquake.

Keywords: historical earthquake, Hoei earthquake, great earthquake, source area, Nankai trough, Suruga Bay

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SSS035-11 Room:IC Time:May 24 09:00-09:15

The relation of the 1361 Koan earthquake to the damage of Ise Grand Shrine Geku

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The existence of Tonankai earthquake paired with the 1361(the first year of Koan) Nankai earthquake has not made clear so far. We have investigated the occurrence pattern of 1361 Tonankai and Nankai earthquake from historical materials of Ise Grand Shrine.

Jingu Monjo included the letter dated of August 3, 1361 from Tadatou Otugi who was the head of Mibu family showed that a certain earthquake in June 1361 had damaged to Ontsukabashira of Ise Grand Shrine Geku. And the other request letter on Tasukegi from Tadanao who was the chief priest of Ise Grand Shrine indicated that there had been such a serious damage that the pillar and the wall of Geku had been destroyed by the earthquake in the same month when Nankai earthquake had occurred.

The last studies considered, the damage of Ise Grand Shrine Geku was caused by Tonankai earthquake, and there was the possibility that occurred in a few days before Nankai earthquake or simultaneously.

Keywords: Koan Tonankai earthquake, Ise Grand Shrine Geku, Tasukegi

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SSS035-12 Room:IC Time:May 24 09:15-09:30

Factors causing scattered boulders located around Hashigui-iwa, the southernmost of Kii peninsula, Japan

Yuichi Namegaya[1*], Hideaki Maemoku[2], Masanobu Shishikura[3], Tomoo Echigo[4], Asaka Nagai[5]

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A number of boulders are widely scattered on wave-cut benches around Hashigui-iwa, the southernmost of Kii peninsula, Japan. The boulders are not in-situ because almost all the boulders are composed of volcanic rock derived from Hashigui-iwa dike. They are scattered in several meters to about a hundred meters western from Hashigui-iwa dike. Therefore they are considered to be carried to the present locations by external forces, for example, tsunamis and/or storm surges. We studied whether the boulders can be moved by tsunamis.

Hashigui-iwa is facing to Nankai trough, and the boulders were repeatedly attacked by many huge tsunamis, for example, the 1944 Showa To-nankai, the 1946 Showa Nankai, the 1854 Ansei, and the 1707 Hoei earthquake tsunamis. To verify water velocities on the wave-cut benches around Hashigui-iwa, tsunami numerical simulations were carried out including runup effects. Artificial structures of breakwaters and filled grounds were removed from the topography used in the calculations. As a result, the water velocity on the wave-cut beach was estimated more than 4 m/sec in case of the 1707 Hoei earthquake tsunami (Ando, 1975; TECT).

We also carried out field surveys around Hashigui-iwa, and measured the locations and dimensions of the boulders (Maemoku et al., 2010; JPGU). The number of the boulders is more than one thousand, and some of them weigh more than 100 ton. Moreover, we also measured coefficient of static friction between the boulders and the wave-cut benches. The value of the coefficient was estimated to be 0.8. Thus, we found that the water velocity of more than about 4 m/sec, especially more than about 8 m/sec for large boulders, is needed to start sliding.

We compared aero photographs taken above the wave-cut benches in 1975 and 2007, and checked whether the boulders were moved during the 32 years. All the boulders were considered to stay at the same positions except five small boulders. During the years, no large tsunamis attacked, but some huge typhoons attacked. The five small boulders might be moved by the storm surges and/or sever wind waves due to the typhoons, although they might be moved artificially because Hasigui-iwa is a sightseeing area.

The boulders may be scattered by the past tsunamis, for example, the 1707 Hoei earthquake tsunami, and the distribution of the boulders may indicate a history of the past huge tsunamis. Recently, a geological study reported that some of the boulders were overturned due to the 1707 Hoei earthquake tsunami (Shishikura et al., 2011; JPGU this meeting). Our results supports their results.

Keywords: boulders, Hashigui-iwa, wave-cut benches, tsunami, the 1707 Hoei earthquake

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SSS035-13 Room:IC Time:May 24 09:30-09:45

History of multi segment earthquake along the Nankai Trough, deduced from tsunami boulders and emerged sessile assemblag

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To evaluate the history of interplate earthquake caused from the Nankai Trough, we investigated the distribution and ages of tsunami boulders and uplifted sessile assemblages along the southern coast of the Kii Peninsula.

Near the Cape Shionomisaki, the tip of peninsula, drifted boulders are distributed in scattered pattern on wave-cut-bench at Hashigui-iwa which is known as a scenic site. We considered that the most of boulders have been transported by tsunami because they were not moved by storm in recent 30 years. Littoral organisms such as oyster or barnacle attached on some boulders are a good indicator to reconstruct the history of transportation by measuring radiocarbon date. The ages of them show two concentrated periods of 12th-14th century and after AD 1650. The latter transportation event would be correlated to the tsunami associated with the 1707 Hoei earthquake. Although the former event cannot be specified to historical earthquake, recurrence interval of large tsunami event is inferred to be 400-500 years.

We also observed the evidence of repeated uplift events recorded in emerged sessile assemblage around the Cape Shionomisaki. Some well-developed assemblages are characterized by layered structure composed of several vertical layers. Based on radiocarbon dating result, it can be interpreted that each of the layers has been formed by a usual seismo-tectonic cycle with interval of 100-150 years. A whole of assemblage which was developed during 400-600 years was eventually emerged by unusual large uplift associated with multi-segment earthquake such as the 1707 Hoei earthquake. The recurrence interval is consistent with that of large tsunami event deduced from drifted boulders.

Keywords: earthquake, tsunami, crustal deformation, Nankai Trough, Cape Shionomisaki

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SSS035-14 Room:IC Time:May 24 09:45-10:00

Tsunami inundation heights of the 1707 Hoei Earthquake in Tosashimizu city, Kochi prefecture, Shikoku, Japan

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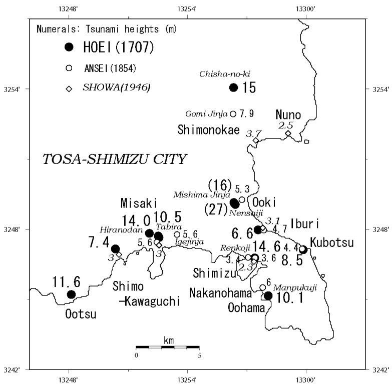
A jointed gigantic earthquake called Hoei earthquake occurred in the jointed regions of south offing of the Tokai and the Nankai districts, the western part of the Japanese Islands. It had been well known that the magnitude of this earthquake is larger than those of the 1854 Ansei Nankai and the 1946 Showa Nankai earthquakes. The number of the points where tsunami heights were measured by reliable instruments on the basis of reliable old documents or legends had not been many. We intended to obtain more data of reliable tsunami heights of this event. In the present study, we measured tsunami heights by using the GPS instrument at the points where the record of sea water inundation limit clearly in nine towns and villages on the coast in Tosashimizu city, Kochi prefecture, Shikoku. We interviewed the specialists of local history of the Tosashimizu citizen library, and several experts of local history at coastal villages. The result is shown in the figure. It was newly clarified that inundation heights of the Hoei earthquake were around 15 meters at four villages, Shimonokae, ooki, Shimizu, and Misaki. We compared the tsunami heights of the Hoei earthquake with those of the 1854 Ansei-Nankai and the 1946 Showa Nankai Earthquakes, and found out that the former is twice of three times of the latter.



Keywords: the 1707 Hoei Earthquake, joint gigantic earthquake, historical earthquake, tsunami, Shikoku

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

SSS035-15 Room:IC Time:May 24 10:00-10:15

A perspective of great earthquakes along the Nankai trough based on newly-made submarine active fault map

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The Nankai trough is a candidate site for the occurrence of large earthquakes of M8 class in near future. The trough has been well studied by many marine geologists, and they have revealed characteristic structure of the plate boundary.

However, fundamental information for prediction of large earthquakes such as the detailed distribution of active faults is not yet well known mainly due to lack of data regarding submarine topography. To make a more precise submarine active fault map along the trough, we have made detailed a submarine topographic s maps and images based on 3-second (about 90m) DEM processed from the original data obtained by Japan Coast Guard since 1986 using multi-narrow beam echo sounder. Then we have made stereo-pair copies of topographic images for interpretation of active faults, similar in manner to how we use air-photo stereo sets for inland active faults. The stereo-pairs allow us to rather easily get 3D images and map active faults on the sea bottom as compared to single ordinary topographic maps. We have also prepared anaglyph images from the stereo-pairs for discussion. As mapped by previous works (Research Group for Active Submarine Faults off Tokai; 1999, Tokuyama and others; 2001, Kimura and Kinoshita eds., 2009), there are several trough-parallel north-dipping thrusts.

Among these the Frontal Thrust and associated splay thrusts are predominant active features. We depicted two candidate active faults for recent large historical earthquakes; 1944 Tonankai and 1946 Tokai. The former one extends eastward from off southeast coast of Kii peninsula across Kumano trough for over 100km, and the latter extends eastward from off southeast coast of Kii peninsula across Shionomisaki submarine canyon and along southern foot of Tosabae, and the outer ridge south of Tosa basin until it reaches far off Ashizuri peninsula. The splay fault extends from southeast of Kii peninsula to south of Muroto peninsula does not coincide with source area of ether 1944 Tonakai or 1946 Nankai earthquake. Several extensive strike-slip faults extend in Tosa basin. We will discuss about relation between newly-found active faults and large historical earthquakes on presentation.

Keywords: Nankai trough, submarine active fault, large earthquake

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SSS035-16 Room:IC Time:May 24 10:15-10:30

Role of mega-splay faulting in the rupture process of great earthquakes at the Nankai Trough

Takeshi Sagiya[1*], Yoshiko Yamanaka[1]

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The latest megathrust events along the Nankai Trough are the 1944 Tonankai and the 1946 Nankai earthquakes. Although the main rupture zone of these earthquakes is the plate boundary megathrust, several authors have argued a possibility of splay faulting associated with the 1946 Nankai earthquake. The estimated splay fault is located at the western end of the source region of the 1946 earthquake and is characterized by a high-angle reverse faulting. Recently, we have investigated the source process of the 1944 Tonankai earthquake. Eastward rupture propagation stopped on the way and did not extend to Suruga Bay, the eastern end of the Nankai Trough. Through a scrutiny of seismological and leveling data, we obtained a new fault model for the 1944 earthquake. One peculiar feature of this model is that it has a splay fault at its eastern end, branching from the plate boundary megathrust at the depth of about 30km. But this splay fault did not reach to the ground surface and the rupture stopped at the depth of 10-15km. The model can reproduce the leveling profile quite well. The model suggests that mega-splay faulting may have an important role of stopping the dynamic rupture of a plate boundary event. Both the 1944 and the 1946 event seem to have stopped when and where the mega-splay faulting occurred. In both cases, the areas above the splay fault had severe shaking. So the specification of possible location of mega-splay faulting is an important target in terms of seismic hazard mitigation.

Keywords: Nankai Trough, Megathrust earthquake, Mega-splay fault, Tonankai earthquake, Nankai earthquake

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SSS035-17 Room:IC Time:May 24 10:45-11:00

dimension reduction analysis of microseismicity rate in SW Japan

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[1]JAMSTEC

Miroseismic activities ranging from M1 to M2 mean micro-slip of small shear cracks in the rocks of crust and mantle. Considering that the open cracks associated with shear cracks are sensitive of small change of strain and stress and their orientations, microseismicity rate represents number of active shear cracks controlled by shear plane orientation. To infer the hidden states and processes of the plate boundary zone many time series of microseismicity rate of various volumes in the plate and crust should be investigated by means of date mining methods with non-supervised machine learning.

Therefore, the author studied the dimension reduction method by means of principal component analysis to apply for the high dimension vector data sets of time series (1998-2008 data set of JMA1) of microseismicity rate of various volumes of subduction slab of Philippine sea plate and overriding crust of southwest Japan arc as shown in the previous paper (1). The original dimension is 104 and reduced dimension becomes 10. Numbers of time series is took as 120, and thus the sample matrix shows 104 x 120.

Results of dimension reduction of time series of microseismicity rate of the PSP and arc crust represent clearly that the aftershock microseismicity associated with large earthquakes can be sharply dissolved as major PCA components and that the annual periodicity can be observed in the higher order components. It also concluded that the long term changes of several lower order components are identified. The resolved shear stress on microcracks by tidal force may be responsible for the annual periodicity of some PCA components but the long term changes should be derived from the plate motion and related local stress concentration.

1) Toriumi, M., 2009, J.D.R,4.

Keywords: dimension reduction, microseismicity, SW Japan, principal component analysis

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SSS035-18 Room:IC Time:May 24 11:00-11:15

Toward seafloor geodetic monitoring of spatial and temporal variation of the seismic coupling in an offshore seismogenic

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The Hi-net operated by NIED, Japan, and the GEONET operated by Geographical Survey of Japan have demonstrated that dense and high precision seismic/geodetic networks are crucial for the monitoring of seismic activities and spatial/temporal change in strain distribution. Big earthquakes will occur in the subduction zones under the sea, however, and the seismic/geodetic networks on land are not efficient in monitoring the crustal activities in the offshore seismogenic zone. That is why the cabled seafloor observation systems DONET and DONET2 are being constructed, and geodetic methods such as GPS/Acoustic (GPS/A) seafloor positioning, ocean bottom pressure monitoring, and downhole tilt/strain monitoring have been developed.

GPS/A seafloor positioning has become a principal geodetic system for observation of seafloor crustal movement near plate boundaries. There remain, however, substantial differences from GPS observation on land as is mentioned below. Our groups in Tohoku and Nagoya Universities have been working to reduce the differences under the programs supported by the MEXT, Japan, for improvement of the observation system for seafloor crustal movement.

Precision of seafloor positioning by GPS/A is one of key problems. Considering that plate motions are several centimeters per year in most cases, repeatability of a few centimeters by GPS/A is a big difference from a few millimeters by GPS on land. We have estimated that lateral variations in the sound velocity in the ocean can be a key to improve the precision in the positioning and to reduce the required time for the measurement (Kido et al., 2008). GPS/A positioning has coped with the problem by averaging the effects of the lateral velocity variations for one or two days at one site. Therefore, this is a key problem in the way to GPS/A networks, for example, above the seismogenic zones in the Nankai Trough. We have partly succeeded in estimating the lateral variations in the acoustic velocity by using 4-5 precision acoustic transponders (PXPs) (Kido 2007; Kido et al., 2010). We are also trying to estimate later velocity gradient by using a few units of sea surface system (Tadokoro et al., 2010).

Another critical problem of the present GPS/A positioning lies in the campaign style observation to measure the position of an array of acoustic transponders spending one or two days once or twice a year. It is similar to the triangulation observation on land before the age of the GPS, quite different from the semi-realtime continuous observation on land. Chadwell et al. (2009, AGU Fall Meeting) made a step forward for this problem by carrying out a continuous GPS/A observation with a moored buoy on a shallow seafloor. We are also developing a system for continuous observation using a moored small buoy (Fujimoto et al., 2008).

Long-term attitude stability of a PXP deployed on thick sediment has been a basic problem in the GPS/A observation; a tilt of the PXP causes a shift of the acoustic transducer on the top, which is analyzed as a position change of the PXP. While a pillar of a GPS antenna on land is set up firmly on the ground, a PXP is deployed on the seafloor after a free fall from the sea surface. It is a serious problem to detect coseismic crustal movements on the seafloor. M7-class earthquakes occurred in 2004 off Kii Peninsula, Central Japan, gave us a good opportunity to study the problem. By using a JAMSTEC ROV (remotely operated vehicle), we visually observed ten PXPs in 2006, seven of which had been used to detect coseismic seafloor crustal movements of 20 cm or more as was reported by Kido et al. (2006) and by Tadokoro et al. (2006). The diving survey confirmed that all of the seven PXPs stood vertically on the flat sediment, no effects of the earthquakes being recognized (Fujimoto et al., in press).

Keywords: GSP/Acoustic, seafloor crustal movement, seafloor geodesy, seismic coupling, seismogenic zone

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SSS035-19 Room:IC Time:May 24 11:15-11:30

Observation of seafloor crustal movement using the seafloor acoustic ranging on Kumano-nada

Yukihito Osada[1*], Motoyuki Kido[1], Hiromi Fujimoto[1]

[1]Tohoku Univ., Graduate school of science

Along the Nankai Trough, where the Philippine Sea plate subducts under southeastern Japan with a convergence rate of about 40 mm/yr, large interplate thrust earthquakes of magnitude 8 class have occurred repeatedly with recurrence intervals of 100-150 years. About 60 years have passed since the last earthquakes happened in 1944 and 1946. Therefore it is important to monitor the tectonic activities in the Nankai Trough. Since most of the source region of the earthquakes is located beneath the ocean, an observation system is necessary in the offshore source region. We developed a seafloor acoustic ranging system to continuously monitor the seafloor crustal movement. We aim to monitor the activity in the splay faults in the rupture area of the Tonankai earthquake in the Nankai subduction zone. Slips along the active splay faults may be an important mechanism that releases the elastic strain caused by relative plate motion.

We carried out two experiments, a short term (one day) and a long term (four month) experiments, to estimate the repeatability of acoustic measurements of this system. We deployed four PXPs (precision acoustic transponders) with about 600 m (M2-S1 baseline) and 920 m (M2-S2 base line) spacing in the long-term experiment. The standard deviation in acoustic measurements was about 1 cm on each baseline.

In September 2008 we carried out an observation to monitor an active splay faults on Kumano-Nada prism slope. We recovered them in August 2010 to get data of acoustic measurements for 6 month and pressure measurements for 18 month. In March 2009, very low frequency earthquake activity near the experiment area was observed by OBSs which was deployed by JAMSTEC (Obana et al, 2010) and ERI, Univ, of Tokyo (Nakahigashi et al. (2010)). The standard deviation in acoustic measurements was about 1 cm on each baseline. We didn't observe the change of baselines in this system. Therefore we have an assumption that there was no crustal movement that exceeds the detection sensitivity in this event. And we estimated the detection sensitivity of this system on the location of this observation. This results show that this system need more than M5 due to get the dislocation, which is 1cm on this location.

Keywords: seafloor geodesy, seafloor crustal movement, kumano-nada

Japan Geoscience Union Meeting 2011
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SSS035-20 Room:IC Time:May 24 11:30-11:45

Seafloor borehole observatories for monitoring slip events in the Nankai subducting plate boundary.

Eiichiro Araki[1*], Achim Kopf[3], Demian Saffer[2], Kazuya Kitada[1], Toshinori Kimura[1], Masataka Kinoshita[1], Katsuyoshi Kawaguchi[1], Yoshiyuki Kaneda[1], Science Party IODP Exp332[4]

[1]JAMSTEC, [2]Penn State Univ., [3]Bremen Univ., [4]none

Tonankai earthquakes are magnitude 8 class earthquakes known to occur every 100-150 years in the Nankai Trough, south of Japan. The last occurrence was in 1944 and we are concerned about the next occurrence. In order to monitor and watch detailed seismic process in the vicinity of its epicenter, a sea-floor observatory network called DONET was developed and it started observation from 2010. The DONET is consisted of 20 seafloor observatories linked with submarine cable, covering from aseismic seafloor near the trough axis, through the area where episodic slow slip events occur, as well on the Tonankai earthquake rupture zone. Each DONET seafloor observatory was designed to observe ground motion, seafloor pressure, and seafloor water temperature in wide frequency range and wide dynamic range to cover various types of events expected in the area of the DONET network, such as large earthquakes, micro-earthquakes, episodic slow slip events, and seafloor turbidity currents. Some of expected events are very small in amplitude therefore we established very low noise observation environment by completely burying each seismometer in the seabed. By January, 2011, we have successfully installed submarine cable network, and 8 seafloor observatories are operational.

Further low noise and stable observatory may be built using a seafloor borehole penetrating below the sediment on which seafloor observatories stand. During IODP Exp 332 in December 2010, we have successfully installed the first planned seafloor borehole observatories in IODP Hole C0002G. Strainmeter, tiltmeter and seismic sensors were cemented near the bottom of 980 m seafloor borehole to ensure stable environment required for these geodetic measurement, where distance to the Tonankai seismogenic fault is approximately 6 km. The borehole observatory in C0002G is currently measuring pore-fluid pressure in the accrecionary prism, sediment basin, and seafloor. In March, 2011, we plan to start long-term seismic and geodetic observation in the C0002G borehole observatory. We plan for installation of another permanent borehole observatory at IODP Hole C0010A which is located in the south of the C0002G penetrating one of the splay faults in shallower depth. We expect the strainmeter, tiltmeter, and broadband seismometer installed quiet and stable environment in Hole C0002G and C0010A will produce a key observation defining slip behavior of the subducting plate in zone between seismically coupled and decoupled plate interface.

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SSS035-21 Room:IC Time:May 24 11:45-12:00

The development and evaluation of sensors for long-term borehole monitoring system at C0002 site in Nankai Trough

Toshinori Kimura[1*], Eiichiro Araki[1], Hiroyuki Takayama[2], Kazuya Kitada[1], Masataka Kinoshita[1], Yasuhiro Namba[1], Masanori Kyo[1]

[1]JAMSTEC, [2]JMA

In this presentation, we report the development and evaluation of sensors for Long-Term Borehole Monitoring System (LTBMS) installed at C0002 site, the first LTBMS observatory in the Nankai Trough. The suite of LTBMS sensors includes a broad-band seismometer, volumetric strainmeter, tiltmeter, geophone, accelerometer and thermistor array. The set of sensors was designed to collect broad-band dynamics with wide dynamic range to understand the mechanism of mega-earthquake occurred along the plate boundary faults. The purpose of this study is to develop high accuracy and reliable sensors that can obtain valuable scientific data and to develop sensors that have anti-vibration mechanism that is sufficient to resist against Vortex Induced Vibration (VIV) caused by the strong ocean current, ”Kuroshio”.

In our development scheme for sensors, broad-band seismometer, CMG3TB, tiltmeter, LILY and thermistor digitizer, SAHF were developed by customizing general products. The volumetric strainmeter was developed from scratch. We developed some printed circuit boards (PCBs) for telemetry, A/D conversion and calibration. Geophone, GS-11D and accelerometer, JA-5H200 were integrated to our PCBs. We added anti-vibration mechanism to all sensors.

After development was completed, noise evaluation, vibration and shock test were conducted using tiltmeter, geophone, accelerometer and thermistor digitizer. The purpose of these tests is to confirm that our anti-vibration mechanism is working well by comparison of sensor response before and after vibration and shock tests. Noise evaluation test was conducted in Matsushiro Seismological Observatory of JMA. Because of the very low-noise and stable environment, minimal change of amplitude or phase response that occurred during vibration and shock test can be detected. We can also confirm long-term stability of sensors. The vibration test was conducted with a sweep vibration from 3 to 15 Hz in frequency, and from 0.25 to 2.0 G in acceleration calculated from accelerometer data measured on IODP Exp. 319. The shock pulse test was conducted with 90 G shock pulse and 2 ms pulse width. After these tests were completed, we installed all sensors to Matushiro Seismological Observatory and re-start noise evaluation test. As for the volumetric strainmeter, we only conducted vibration test using each small components. As for the broad-band seismometer, vibration test was conducted by Guralp Systems Ltd. in U.K. with same parameters as our test. After delivered, noise evaluation test was conducted in Matsushiro.

Power spectral density (PSD) was calculated using background noise for sensor evaluation. We confirmed that PSD plots have same response before and after these tests. The peak of microseism around 0.2Hz can be clearly confirmed in the PSD plot of the geophone,and tiltmeter. In the PSD plot of accelerometer, a peak in microseism was not found because the accelerometer was adjusted for strong motion. However, there were no differences of internal noise level before and after these tests. The broad-band seismometer was also installed to same place after delivered. PSD plots of broad-band seismometer, geophone, accelerometer and tiltmeter were compared with reference sensor, CMG3T general package. Finally, we confirmed that the responses of these sensors have good coherence with that of the reference sensor and this result is consistent with each specification of sensors.

After final noise evaluation test was completed, all of sensors were loaded to D/V Chikyu. In IODP Exp. 332, these sensors were installed to C0002 site successfully. These sensors are planned to connect to a seafloor recorder and to start continuous recording in KY11-04 cruise by R/V Kaiyo. In this presentation, we report the preliminary result of KY11-04 cruise and evaluation of acquired data as well.

Keywords: Long-term borehole monitoring system, Nankai Trough, development of sensors, vibration and shock test, noise evaluation test

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SSS035-22 Room:IC Time:May 24 12:00-12:15

Modeling of permeability structure using pore pressure and borehole strain monitoring

Yasuyuki Kano[1*], Hisao Ito[2]

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The methods to determine permeability underground are hydraulic test utilizing borehole and packer or core measurement in laboratory. Another way to know the permeability around a borehole is to examine responses of pore pressure to natural loading such as barometric pressure change at surface or earth tides. Using response to natural deformation is conventional method for water resource research.

The size of measurement is different between in-situ hydraulic test, response method, and core measurement. It is not clear that the relationship between permeability values form each methods for an inhomogeneous medium such as a fault zone. Knowledge of inhomogeneity is essential to understand permeability structure around a fault zone.

Supposing the measurement of the response to natural loading, we made a model calculation of permeability structure around fault zone. The model is 2 dimension and constructed with vertical high-permeability layer in uniform low-permeability zone. The upper and lower boundaries are drained and no-flow condition. We calculated the flow and deformation of the model for step and cyclic loading by numerically solving a two-dimensional diffusion equation. The model calculation shows that the width of the high-permeability zone and contrast of the permeability between high- and low- permeability zone control the dominance of the low-permeability zone. We applied the the model calculation to the results of in-situ packer test, and natural response of water level and strain monitoring carried out in the Kamioka mine.

The model calculation shows that knowledge of permeability in host rock is also important to obtain permeability of fault zone itself. The model calculations help to design pore long-term pressure monitoring, in-situ hydraulic test, and core measurement using drill holes.

Keywords: fault zone, permeability structure, deep drill hole, pore pressure

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SSS035-23 Room:IC Time:May 24 12:15-12:30

Seismic structural and stratigraphic variations of subduction inputs along the Nankai Trough

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

[1] AORI, University of Tokyo

The Nankai Trough subduction zone, where the Philippine Sea Plate subducts beneath the Eurasian Plate to the NNW, is known as one of the best-suited convergent plate margins for studying subduction zone earthquakes. Historically, large earthquakes along the subduction zone have occurred with a recurrence interval of 100-200 years. The Nankai subduction zone may be divided into four or five discrete domains marked by the megathrust earthquake rupture, each of which roughly corresponds to a geologically well-defined forearc basin. Previous works indicate variations in upper plate geometry and plate-boundary decollement character along the Nankai Trough. Wedge taper angle of overlying accretionary prism varies significantly along the Nankai subduction zone. Reflection polarity of plate-boundary decollement has also a regional variation: for example, reverse for Muroto transect, and normal for Kumano transect. Those variations of the Nankai subduction-zone processes may be attributed to variations of subduction inputs composed of oceanic crust and overlying sediments of the Philippine Sea plate.

In order to figure out structural and stratigraphic variations of subduction inputs along the Nankai Trough, we interpreted a number of 2D and 3D seismic reflection data which have been acquired by JAMSTEC since 1997. For lithologic and age controls of each seismic reflection unit, we used Ocean Drilling Program and Integrated Ocean Drilling Program NanTroSEIZE drilling results. Based on seismic reflection characteristics, we identify 5 major seismic units from top to bottom: (1) trough turbidite fill, (2) upper Shikoku Basin sediments consisting of hemipelagic mud and volcanic ash, (3) middle Shikoku Basin sediment of volcaniclastics, (4) lower Shikoku Basin sediments consisting of turbidites and hemipelagic mud, and (5) oceanic crust of basalt. In particular, we recognize 3 different turbidte sediments within the lower Shikoku Basin (LSB) unit: LSB-T1, -T2, and ?T3. The shallow LSB-T1 is widely distributed in the east Nankai Trough including offshore Kumano Basin, with pinch-out off Cape Muroto of Shikoku Island. The middle LSB-T2 is confined to a region off Cape Ashizuri of Shikoku Island. The deep LSB-T3 shows a local distribution off Kumano Basin. Variation of oceanic basement highs appears to have influenced the turbidite sedimentation along the Nankai Trough. In this talk, we will present seismic structural and stratigraphic variations of the subduction inputs and then discuss its implications for the Nankai plate-boundary fault behavior.

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SSS035-24 Room:IC Time:May 24 12:30-12:45

S-wave velocity structure in the accretionary prism beneath the Kumano Basin, Nankai Trough, Japan, revealed by vertical

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The Kumano Basin is a forearc basin located on the landward slope of the Nankai Trough. It lies directly above the large co-seismic slip area of the 1944 Tonankai earthquake (M 8.1) and directly above the megasplay fault. Although a number of surface seismic surveys have been acquired in this area to reveal seismic signatures characterizing an asperity of megathrust earthquakes, S-wave velocity structure remains almost unknown. In 2009, we conducted a walk away vertical seismic profiling (VSP) experiment using a large, 7,800 cu. in. airgun array as a sound source and an array of 16 three-component downhole seismometers as receivers, during the IODP Exp. 319. P-to-S converted waves were successfully observed on the horizontal component of the downhole seismic records. Refracted S waves that were converted at the seafloor from P waves have arrival times that are explained by assuming Vp/Vs values of 1.73 in the old accretional sedimentary layer overlain by the unconsolidated basin sediment with $Vp/Vs > 2.0$. The obtained Vp/Vs ratio, or equivalent Poisson's ratio, is somewhat smaller than the value estimated in the Ashizuri region, southwestern end of the Nankai subduction system, although the observed Vp values are almost the same in the two regions. The lower Poisson's ratio in the old accreted sediment suggests that the layer is highly cemented and therefore impermeable. The existence of the impermeable layer in the hanging wall side of the mega-splay fault could increase pore pressure along the fault zone where VLF earthquakes are observed frequently.

Keywords: IODP, VSP

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SSS035-25 Room:IC Time:May 24 14:15-14:30

High resolution shallow structures of splay faults in the Nankai subduction zone off Kumano revealed by ROV NSS

Juichiro Ashi[1*], Yasuyuki Nakamura[2], Takeshi Tsuji[3], Yasutaka Ikeda[4], Hironori Otsuka[1], KH-10-3 shipboard scientists[1]

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Structures of the accretionary prism off Kumano were well investigated by dense seismic reflection survey. IODP Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) has been conducted based on these data. However, subbottom profiling (SBP) and surface sediment samplings were limited due to steep and complex topography under strong Kuroshio Current. We carried out deep-tow subbottom survey and pinpoint core sampling by ROV NSS (Navigable Sampling System) during Hakuho-maru KH-10-3 cruise. A pilot vehicle of NSS is equipped with four thrusters, observation cameras and a hook for a heavy payload. We introduced a chirp subbottom profiling system of EdgeTech DW-106 for high resolution mapping of shallow structures on this study.

Megasplay faults at shallow depth around IODP drilling sites were well imaged by 3D seismic survey. One of three SBP data shows a fault plane at a depth deeper than 10 meter below a seafloor. Surface sediments exhibit continuous stratification although reflectors are weak above this blind fault. Chaotic sediments are often observed at a base of a fault scarp suggesting slumping or sliding. Active cold seep at each fault scarp was recognized at the prism slope 30 km southwest of the IODP sites. One of fault scarps at a water depth around 3300m is characterized by dense traces of bivalves suggesting diffusive methane flux through thin sediment cover above a fault. SBP reveals a blind fault at the depth deeper than 10m below seafloor. Above the upper termination of this fault, chaotic sediments are found below a stratified cover sequence of five meters thick. It is suggested that diffusive methane flux occurs through such thin sediment cover. We installed a long-term heat flow meter for monitoring of cold seep activity.

Keywords: active fault, splay fault, cold seep, accretionary prism

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SSS035-26 Room:IC Time:May 24 14:30-14:45

Heat flow anomaly and cold seep activity in the vicinity of the splay fault off the Kii Peninsula

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We have been conducting heat flow measurements in the area southeast of the Kii Peninsula (off Kumano) for investigation of the thermal structure of the Nankai subduction zone, especially the temperature distribution along the plate interface. The observed heat flow generally decreases landward reflecting the influence of subduction of the Philippine Sea plate, while highly scattered values, 50 to 100 mW/m^2, have been obtained on the accretionary prism slope about 15 to 25 km landward of the deformation front, where the megasplay fault system intersects the sea floor. Possible causes of the scatter are: influence of bottom water temperature variation (BTV), advective heat transfer by fluid flow along active faults, and deformation or movement of surficial sediments such as slumping. The latter two factors may be closely related to the activity of the splay faults.

To study the relation between the scattered heat flow and the splay faults, we conducted closely-spaced heat flow measurements and deployed long-term temperature monitoring systems on the prism slope off Kumano on KH-10-3 cruise of R/V Hakuho-maru in August 2010. We made 11 successful heat flow measurements with an ordinary deep-sea probe at two sites. One site (HF-1) is located in the vicinity of a prominent fault and close to the existing scattered data. The temperature profiles obtained at HF-1, where the water depth is 2600 to 2700 m, are apparently affected by BTV. It indicates that part of the scatter may be attributed to the influence of BTV. At the other site (HF-2), where the water depth is 3000 to 3300 m, no appreciable effect of BTV was found in the temperature profiles. HF-2 is also located around a branch of the splay fault system, along which cold seeps were discovered through submersible surveys. Heat flow measured along the fault is higher than values obtained at stations away from the fault, suggesting that heat flow is locally high along faults due to upward pore fluid flow, though a more intensive survey is necessary for examination of this tendency.

We deployed temperature monitoring instruments using NSS (Navigatable Sampling System) at two stations in the close vicinities of biological communities along branches of the splay fault system. The instruments have 2-m long probes with six or seven sensors and can record temperature profiles in surface sediments for one year or longer. One station is close to the heat flow measurement site HF-2. The other is at about the same location as the station where we conducted temperature profile monitoring with 60 to 70-cm long probes in 2001 to 2002 and in 2003 to 2004. Analysis of the temperature records obtained in the previous experiments shows that heat flow is very high (over 100 mW/m^2) and pore fluid flows upward in bacterial mats. Along the same fault, temperature profile monitoring with shorter (60-cm long) probes has also been conducted about 300 m away from this site since March 2010. Temperature records with these instruments, particularly with longer probes, will allow us to detect slower pore fluid flow and temporal variation of flow, which might be associated with very low frequency earthquakes.

Keywords: Nankai Trough, accretionary prism, splay fault, heat flow, cold seep, long-term monitoring

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Coseismic rupture to the up-dip end of plate subduction zone, the result of IODP NanTroSEIZE Exp316

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Seismic faulting along subduction-type plate boundaries plays a fundamental role in tsunami genesis. During the Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTro SEIZE) Stage 1, the updip ends of plate boundary subduction faults were drilled and cored in the Nankai Trough (offshore Japan), where repeated large earthquakes and tsunamis have occurred, including the 1944 Tonankai (Mw = 8.1) earthquake. Samples were obtained from the frontal thrust, which connects the deep plate boundary to the seafloor at the toe of the accretionary wedge, and from a megasplay fault that branches from the plate boundary decollement. The toe of the accretionary wedge has classically been considered aseismic. Non-destructive X-ray fluorescence core-imaging scanner, X-ray diffraction and the vitrinite reflectance geothermometry reveal that the two examined fault zones underwent localized temperatures. This suggests that frictional heating occurred along these two fault zones, and implies that coseismic slip must have propagated at least one time to the up-dip end of the megasplay fault and to the toe of the accretionary wedge.

Keywords: Plate subduction, Seismogenic zone, Tsunami, Vitrinite, XRD, XRF

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A material record of slow slip in the shallow accretionary prism

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Recent geophysical observations have shown a great variation in seismicity in a shallow accretionary prism, from the coseismic slip of a large earthquake such as the 1944 Tonankai earthquake to slow slip of VLF in Nankai Trough. During the Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTro SEIZE) Stage 1, the frontal thrust and a megasplay fault were drilled and cored. The measurements of vitrinite reflectance geothermometry were performed within these two major slip zones and revealed the occurrence of the temperature anomaly along the faults. We combined the data with core-scale structure and interpolated the vitrinite reflectance (Ro) applying Steinman function. The smoothed data showed that broad peaks exist within certified slip zones and the peak positions locate in black narrow zones in each fault. We simulated Ro distribution using temperature alteration model and a kinetic method of thermal maturation of vitrinite. The results show that the range of the Ro distribution is expanding relative to the width of heat generate region and the long-term heating (~100 s) is needed for the proceeding of the maturating reaction rim. Therefore, we concluded that the measured Ro distributions indicate that the slow slip occurred in the shallow accretionary prism.

Keywords: slow-slip, vitrinite refrection, kinetics

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Failure and permeability properties of accretionary mud samples cored at Site C0002 of the IODP Expedition 315

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Very low frequency earthquakes have recently been found in the accretionary prism along the Nankai Trough (Ito and Obara, 2006), which has been ascribed to slow-slip faulting along out-of-sequence thrusts (OSTs). Thus faulting along the OSTs presumably varies from slow slips to seismic ruptures. What controls such difference in seismic faulting along the OSTs? Both intrinsic and extrinsic factors are likely responsible; intrinsic factors include material and physical properties of sediments (e.g., clay-mineral contents and permeability), while extrinsic factors include physical conditions (e.g., pressure, pore-water pressure and temperature). We will here discuss on pore-water diffusivity possibly affecting the duration time for stress drop after failure.

We have conducted triaxial compression experiments and permeability measurements to investigate what factors affect styles of brittle failure in accretionary sediments. We used mud samples cored from c.a. 1000 mbsf at site C0002 of the IODP Expedition 315 (#51R06 and #65R02). At room temperature, we first measured the permeability of the specimens of two samples with 20 mm in diameter and 40 mm in length, then deformed them at a constant axial displacement rate of either 1 micron/sec and 10 micron/sec, and at in situ confining and pore-water pressures, i.e. at the confining pressure Pc of 36 MPa and the pore-water pressure Pp of 28 MPa for the sample #51R06 (944 mbsf), while at Pc of 38 MPa and Pp of 29 MPa for the sample #65R02 (1049 mbsf).

Permeability measurements revealed that sample #51R06 is less permeable (k ~ 10^{-20} m^2) than the sample #65R02 (k ~ 10^{-19} m^2). Both samples showed a continuous porosity reduction during the deformation, implying a continuous compaction. However, the duration time required for stress drop after failure of the sample #51R06 was almost 10 times longer than that of the sample #65R02. Because the less permeable sample requires more time for pore water to diffuse throughout the sample, it also requires more time for pore-water pressure to stabilize after failure. Thus the duration time required for stress drop after failure is possibly affected by pore-water diffusivity. We will also discuss on mineral compositions and microstructures of the two samples which are relevant to the difference in their failure and permeability properties.

Keywords: post-failure curve, permeability, diffusivity

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Frictional properties of megasplay fault materials in the Nankai subduction zone for intermediate slip velocities

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Knowledge of frictional properties of fault materials for a wide range of velocities is essential for understanding mechanical behavior of faults. Here, we present results from a series of frictional experiments over a range of slip velocities from 0.0026 to 260 mm/s, with $>$ 250 mm of displacements on clay-rich fault materials from the major splay fault within the Nankai accretionary complex (a megasplay fault zone) for water saturated condition.

All of the samples tested in this study were collected at Sites C0001 and C0004 during the IODP expedition 316. Friction experiments were conducted on the samples using a rotary-shear, intermediate- to high-velocity friction testing machine. The experimental fault is composed of a 24.9 mm diameter granite cylinder assembled with an intervening thin layer of gouge (initial gouge thickness were 0.5 or 1.0 mm). A PTFE (Teflon) ring surrounds the fault in order to avoid gouge expulsion during rotation. The collected samples were disaggregated, oven dried at 50 degrees centigrade for 24 hours and then sieved in order to eliminate clasts larger than about 0.17 mm. Distilled water of 0.5 ml in volume was added to the 0.5 mm-thick gouge layer (1.0 ml for 1.0 mm gouge) in order to prepare saturated (wet) condition of the experimental gouge layer. The assembled gouge has been axially pre-compacted at the test condition (5 MPa) for half an hour.

Experimental results reveal that there are both velocity-weakening and velocity-strengthening fault materials for slip velocities from 0.026 to ~26 mm/s. The velocity weakening behavior could provide a condition to initiate unstable fault motion at shallow depths along the splay fault. On the contrary, velocity strengthening behavior may affect to stabilize the propagation process of earthquake nuclei that emerges in the velocity weakening portion along the fault. For velocities v $>$ 260 mm/s, friction of all samples decreases dramatically with increase of the slip velocity.

The tested samples contain clays, quartz, plagioclase and calcite [Expedition 316 Scientists, 2009]. Variation of the clay content and composition of the clays may play an important role controlling the frictional velocity dependence of the megasplay fault at shallow depth conditions. For example, lithological unit that includes abundant ash layers would be a candidate of smectite-rich horizon, and this type of compositional variation along the fault may contribute to produce patch-like distribution of the frictional velocity dependence along the splay fault.

Keywords: frictional properties, Nankai Trough, Splay fault

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Alteration pattern of ocean floor basalt at NanTroSEIZE Site C0012: implication for the rheology of subduction thrust

Asuka Yamaguchi[1*], Jun Kameda[1], Yujin Kitamura[2], Saneatsu Saito[2], Gaku Kimura[1], Pierre Henry[3], Toshiya Kanamatsu[2], MOE Kyaw Thu[2], Scientists the Expedition 333[4]

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The IODP Expedition 333, a part of NanTroSEIZE project, was operated during December 2010 to January 2011. To recover cores of oceanic crust as the material of subduction input, three holes were drilled at Site C0012, located at the top of Kashinozaki Knoll on the Philippine Sea Plate just before subduction in the Nankai Trough. Basalts are recovered from 525.7 to 626.44 m CSF in Hole C0012G. They are composed of pillow lavas and massive lavas. Plagioclase and pyroxene (clinopyroxene) phenocrysts in altered volcanic glasses with various amounts of vesicles show intergranular to subophitic textures. Alteration is entirely strong: i.e., olivine phenocrysts were completely replaced by saponite, and groundmasses (volcanic glasses) were mostly altered to saponite and celadonite. Moreover, plagioclases were replaced by zeolites and clay minerals in some places. Green- and orange-colored alteration halos develop along red-colored Fe-oxyhydroxide veins below 563 m CSF. The green and orange alteration halos were overprinted by pyrite precipitation accompanying with strong saponitization (occurs in 525.7 to 563, 601, 613 to 615 m CSF). The two stages of alteration reflect the changes in fluid redox state. Fe-oxyhydroxide veins with orange alteration halos might be formed by near-axis open-system oxidizing fluid circulation, whereas strong saponitization with pyrite might be formed by closed-system reducing fluid circulation after oceanic crust was covered with sediments and separated from seawater (Alt, 2004).

Strong saponitization encountered in the topmost 40 m of ocean floor basalt may play important role for the rheology of subduction thrust, especially stepping-down of the decollement. Saponite releases water in response to temperature rise, and is progressively converted to chlorite (Kameda et al., submitted). In subduction zones, this dehydration reaction can build up high fluid pressure within highly saponitized part of oceanic crust so that can reduce effective strength at the topmost part of subducting basalt. If this mechanism works efficiently, inversion of effective strength between sediments and oceanic crust occurs at some depth of subduction zone. Here we point out the possibility that such strength inversion result in the step-down of the decollement to oceanic crust, which is figured out by seismic profiles of modern subduction zones (e.g. Park et al., 2002; Kimura et al., 2010) and geology of on-land accretionary prisms (Kimura and Ludden, 1995). A compile of metabasalts in on-land accretionary complexes indicate that oceanic crusts are often underplated to accretionary prism as slab-like bodies with thickness of less than 300 m (mostly $<$100 m) (Kimura and Ludden, 1995). This characteristic thickness could be controlled by the thickness of saponitization just below the sediment. Although seismic fault rocks have been discovered from basalts in on-land accretionary complexes (Ujiie et al., 2007), frictional properties of altered basalt are not very much considered so far. Experimental investigation on altered basalt is needed to quantify the role of subducting basalt in seismogenic zones.

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Prograde clay minerals reactions along an ancient frontal thrust

Jun Kameda[1*], Yuzuru Yamamoto[2], Yohei Hamada[1], Gaku Kimura[1]

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Fossil imbricate thrusts branching from an ancient decollement in the Miura-Boso accretionary prism are exposed in the southern parts of the Miura and Boso peninsulas in central Japan. A clay mineralogical analysis on the fault rocks of one of the imbricate thrust faults, the Shirako fault (Boso Peninsula), revealed a local progress of transformation reactions over intact surrounding rocks; illitization of mixed-layer illite-smectite (I-S), thickening and/or ordering of discrete illite and chlorite packets, and partial degradation of kaolinite. Shape of I(001)-S(001) reflection in the X-ray diffraction pattern together with mean crystallite thickness suggests that illite content in I-S within the fault gouge increases by ~10 % from the host rock samples. Local temperature anomaly possibly caused by frictional high-velocity slips appears a favorable reason to have promoted these prograde reactions in the clay assemblage, rather than factors such as rock deformation or specific fluid composition. A thermal model coupled with kinetic simulation on illitization in I-S suggests that the reaction is facilitated by several repetitions of high-velocity slips with peak temperature >400 ?C. Such slips along the Shirako fault might have been potentially tsunamigenic events.

Keywords: accretionary prism, tsunami, semectite, illite

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Behavior of clay minerals in fault zones - amorphization and recrystallization of kaolinite

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Nanoparticles in fault zones are recently paid much attention since they give significant influences on the frictional properties (Ma et al., 2006). Nanoparticles are considered to be formed not only bay mechanical grinding but also by mechanochemical processes. Amorphous nanoparticles were found in Iida-Matsukawa fault, Central Japan (Ozawa and Takizawa, 2007). It is well known that clay minerals are easily transformed into amorphous phase by mechanochemical processes. In nature, Kaolinite is selectively decomposed in Chelungpu fault, Taiwan (Hirono et al., 2008). We performed experimental studies on amorphization and recrystallization of kaolinite.

Amorphization: Dry grinding experiment using a planetary ball mill. Some portion of kaolinite is transformed into amorphous phase after several 10 minutes milling. Aggregates of nanoparticles were observed with FE-SEM. Changes in size distribution of nanopores were also detected by measurement of positronium life time. The injection energy during these experiments is considered to be comparable to M7 earthquake. Heat treatments were also performed. Starting materials were completely decomposed and transformed into amorphous phase after 1 hour heating at 600 degrees C and also after 1 minutes heating at 1000 degrees C.

Recrystallization: Starting amorphous materials were provided by heating experiment (600 degrees C, 1 hour heating). Starting materials were hydrothermally treated in 0.01N hydrochloric acid solution (pH3) at temperatures between 140 to 250 degrees C. Degree of recrystallization was determined semi-quantitatively using peak area of kaolinite (002) by X-ray diffraction. About 10% of starting materials were crystallized after a few hours at 250 degrees C, after 1 day at 200 degrees C and after 4 days at 170 degrees C. The estimated recrystallization rate revealed that the starting material might be recrystallized after several hundred years at room temperature.

Kaolinite can be transformed into amorphous material both by heating and mechanochemical process during seismic slip. The amorphous materials can be recrystallized during interseismic interval.

Keywords: fault, clay mineral, kaolinite, mechanochemical, amorphization

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Geochemical evaluation of co-seismic fluid-rock interaction and frictional melting in fault zones

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In this paper, we report recent progress on geochemical method for evaluating co-seismic fluid-rock interactions and frictional melting in fault zones on the basis of change in trace element and isotope compositions of fault rocks. Analyses of rocks from Taiwn Chelungpu fault and faults in accretionary complexes of Emi and Shimanto show clear evidence for co-seismic fluid-rock interaction at high temperatures ($>$350 deg. C). For the Shimanto samples from the Kure region, which are considered to represent rocks of ancient spray fault at 2.5?5.5 km depth, the signals of fluid-rock interactions overlap with highly elevated incompatible element concentrations, indicating that the high-temperature fluid-rock interactions were followed by frictional melting. These results demonstrate that co-seismic fluid-rock interactions widely occur within seismic faults and trace element and isotope compositions of fault rocks are useful indicators of fluid-rock interactions as well as frictional melting. For better understanding of the co-seismic fluid-rock interactions using this method, experimental determination of solid-fluid distribution coefficients for key elements such as Li, Rb, Cs and Sr and kinetic parameters at temperatures over 350 deg. C are required.

Keywords: fault rocks, geochemistry, earthquake, fluid-rock interactions, trace elements, isotopes

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Change in deformation mechanisms from pressure solution to brittle faulting at shallow subduction interfaces: lithificat

Yoshitaka Hashimoto[1*], Natsuko Yamano[1], Mika Yamaguchi[1], Mio Eida[1]

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Tectonic melanges predominantly composed of sheared, fluid saturated, trench-fill sediments, and have been considered to be formed along subduction plate boundaries. Those tectonic melanges can include a wide range of seismic deformations as well as aseismic deformations, as geological evidences. While pseudotachylytes are the direct evidence for seismogenic faults, the change in deformation mechanisms from pressure solution cleavage to brittle faulting is also a significant geological evidence for variety of displacement along subduction plate boundaries. In this study, we focused on pressure solution cleavages and micro-faults within melange zones to understand processes in shallow brittle-ductile transition along subduction interfaces.

Occurrences commonly observed in tectonic melanges that the extension cracks only formed in sandstone blocks and injected by shale matrices in part suggest that competence contrast existed at the time of the melange formation. The matrix flow might be accommodated by dissolution-precipitation creep, representing pressure solution cleavages. Observation by secondary electron microscope (SEM) shows that the pressure solution cleavages are composed of relatively heterogeneous size of grains of illites with authigenic pyrite.

Micro-faults are also commonly observed in melagne zones almost parallel to melage foliation but clearly cut the shale matrices in some parts. Most of micro-fault are accompanied with mineral veins composed of quartz and/or calcite, and slicken lines and mirror surface are also commonly found on the fault surface, indicating the fault displaced in brittle manner. SEM observations provide that the mirror surface are composed of very fine grained (<1 micron) clinochlore with homogenize grain size.

Pressure temperature conditions for melange formation and micro-faults using fluid inclusion thermometry from some melange zones, corresponding ˜100 degree C - ˜210 degree C / ˜80MPa - ˜150 MPa, and ˜180 degree C - ˜250 degree C/ ˜150MPa - ˜300 MPa, respectively. The brittle-ductile transition can ranges from ˜180 degree C to ˜210 degree C in temperature. Those results indicate that the deformation mechanisms are divided by P-T conditions with the transition zones and change can be one-way to deep in broad sense. In addition to that, the authigenic minerals were also distinguished with the deformation mechanisms.

Change in deformation mechanisms can be related to lithificaion, strain rate and fluid pressure. In the way from ductile to brittle, from shallow to deep, lithification can be a significant process. In this process, pressure solution is a role to make shale matrices lithified. In the brittle-ductile transition zones, the heterogeneous lithification state can be existed.

Change in strain rate can affect on the deformation mechanisms in the transition zone. The seismic cycle model by Wang and Hu (2006) expects a change in strain rate along subduction interface and a change in stress within the front of accretionary wedges. Stress changes reported from Yokonami melange and the Nobeoka thrust (Eida and Hashimoto, Yamaguchi et al., this meeting) indicate the consistency with the model. The seismic cycle model can adapt not only to accretionary margins but also to erosional margins such as Costa Rica.

Keywords: deformation mechanisms, accretionary complex, seismogenic zone along subduction interface, seismic cycle, tectonic melange

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Faulting process and its heterogeneity on Chelungpu fault during ChiChi earthquake revealed by TCDP Hole C cores

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The Chelungpu fault is an active fault generated a large earthquake (magnitude 7.7) in Chi-Chi, central Taiwan, in 1999. Taiwan Chelungpu fault Drilling project (TCDP) drilled two vertical holes (hole A and B) and one side-track hole from the hole B (hole C). The samples from the hole C preserve whole structures including a possible primary slip zone (PSZ) and other older slip zones. Identification of the slip zone by recent earthquake is important to understand slip mechanism with combining seismic data and geological data. In this presentation we first show microstructures and discuss recent slip zone and its slip mechanism. Furthermore we discuss heterogeneity on the fault surface by comparing slip zone in hole C with those in holes A and B.

Based on detailed observation, we divided 12 cm fault zone of the hole C into thin 16 layers. All layers are classified into gouge composed of quartz, feldspar and clay minerals. Results of microstructural observation suggest that the most bottom layer in the 12 cm fault zone is related to ChiChi earthquake slip layer. Characteristics of the bottom layer is that the slip layer has 2 cm width and its slip zone is localized within thin 2mm zone.

Comparing our results from the hole C samples and previous studies about the holes A and B, slip layer activated by Chi-Chi earthquake is heterogeneious on the fault zone. Slip zone in the hole C is localized in 2 mm with adjoining drag structure with grain segregation and that in hole B is also 2 mm thick showing a layering structure with grain segregation and dewatering structure (Aubourg et al., 2010 presentation in WPGM T33B-03; Chou et al., 2010 poster in WPGM T31A-061). In contrast, slip zone in the hole A is 2 cm thick and shows ramdom fabric (Boullier et al., 2009). These structures may be compared with experimental studies under high speed and dry or wet conditions (Ujiie et al., 2010 presentation in JPGU SSS019-15; Boutareaud et al., 2008) with fluid pressurization in the slip zone. We show possible slip mechanisms and the heterogeneity of PSZs in HoleA, B and C, by comparing PSZs microstructures in Chelungpu fault with those formed in experiments.

Keywords: ChiChi earthquake, CheLungPu fault, Accretionary complex of Taiwan

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Preliminary results of IODP Expedition 334, Costa Rica Seismogenesis Project (CRISP)

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The Costa Rica Seismogenesis Project (CRISP) is designed to understand the processes that control nucleation and seismic rupture of large earthquakes at erosional subduction zones. CRISP involves the only known erosional end-member of convergent margins within reach of scientific drilling. With a low sediment supply, fast convergence rate, abundant seismicity, subduction erosion, and a change in subducting plate relief along strike, CRISP offers excellent opportunities to learn causes of earthquake nucleation and rupture propagation. This project investigates the seismogenic processes common to most faults and those unique to erosional margins. Integrated Ocean Drilling Program Expedition 334 is based on a part of CRISP Program A, which is the first step toward the deep riser drilling through the seismogenic zone. Scientific objectives of this expedition include constraining the architecture and evolution of the plate boundary megathrust and 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. These slope sites might also serve as pilot holes for potential future proposed riser drilling to reach the aseismic/seismic plate boundary. We will present preliminary results of Expedition 334 that is conducted on March 15-April 13, 2011.

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Characteristics of slip and stress due to interaction between fault segments

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As a method of a long-term earthquake prediction, Shimazaki and Nakata (1980) proposed two recurrence models to explain the quasi-periodic nature of repeating earthquakes: the time-predictable and slip-predictable models. It remains difficult, however, to successfully apply either the time- or slip-predictable model to most of major earthquakes. This is partly because the stressing rate is assumed to be constant in both the models; the condition cannot be applied to real large earthquakes due to intermittent slip in the surrounding area as seen for Miyagi-oki earthquakes. We have performed a two-dimensional numerical simulation to elucidate the physical processes governing earthquake behavior when significant stress perturbations are produced by interaction between fault segments. Our model involves two seismogenic segments separated down-dip on a subduction plate boundary and incorporates a rate- and state-dependent friction law. Our simulations show that slip amounts in the seismogenic segment increase in all of the co-, pre- and post-seismic stages when an earthquake occurs shortly after another earthquake in the other seismogenic segment. Conversely, when earthquakes occur in a single seismogenic segment several times in succession while the other segment remains locked, all three pre-, co-, and post-seismic slip amounts become smaller. These results imply that precursory changes do not necessarily occur at the same level on every occasion. In cases of multiple rupturing, the co-seismic slip of the later earthquake in a pair is approximately characteristic when frictional stability in the aseismic segment between the two seismogenic fault segments is strong enough to produce different rates of seismicity on each segment. We also try to interpret the 2004 Sumatra earthquakes by applying the simulation results, and discuss the variation of preseismic stress changes and rupture initiation points.

Keywords: Perturbation of earthquake cycle, Constant stress drop model, Characteristic slip model, Preseismic slip, the 2004 Sumatra earthquake, Numerical simulation

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

SSS035-39 Room:IC Time:May 24 18:00-18:15

Numerical experiment of sequential data assimilation for crustal deformation between Tonankai and Nankai earthquakes

Takane Hori[1*], Mamoru Hyodo[1], Shin'ichi Miyazaki[2]

[1]JAMSTEC, [2]Kyoto Univ.

A possible estimation procedure for the time interval between the forthcoming Tonankai (Tokai) and Nankai earthquakes is sequential assimilation for the crustal deformation data which will obtain from hour to hour following the occurrence of the Tonankai (Tokai) earthquake. We demonstrate the numerical experiment of the assimilation using the surface deformation calculated from the results of earthquake generation cycle simulations along the Nankai trough. For the observation noise, we use the real ocean bottom pressure gauge data excluding the tidal modulation at a station of the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) in the Tonankai source area . As a data assimilation method, we use Sequential Importance Sampling (SIS) which is a kind of particle filter. Data assimilation is done sequentially every 5 hours. As the data increase, the estimated time interval between Tonankai and Naknai earthquakes becomes closer to the "true" time interval. How early the true value is estimated depends at least on the noise level and crustal deformation pattern. It is important to note that the real noise level of the pressure gauge data of DONET including the long-term drift is small enough to distinguish the simulated crustal deformation patterns for the different cases in the time interval.

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SSS035-40 Room:IC Time:May 24 18:15-18:30

Fast computational methods for large- and multi-scale earthquake cycle simulations

Kazuro Hirahara[1*], Makiko Ohtani[1], Mamoru Hyodo[2], Takane Hori[2]

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Recently, we have developed several methods for reducing memories and computational times in earthquake cycle simulations based on a rate and state friction law. In this talk, we give the need and a brief summary of the methods for reduction and their characteristics.

Model sizes in earthquake cycle simulations have become large as in the case of the Nankai trough (Hori,2006). We need to simulate earthquake cycles including earthquakes with different sizes and long- and short-term slow slips, leading to a multi-scale simulation. Toward predictive simulations for future earthquakes, we need to apply data assimilation methods to estimate initial conditions of variables as well as frictional parameters with uncertainties, which requires a large number of forward and backward computations. In simulations, dividing the plate interface into N smaller cells, the multiplicative computation of N∗N slip response function matrix (SRFM) and slip deficit rate vector (SDRV) frequently appears. The memory and the computational time are O(N∗N). The large- and multi-scale predictive simulations with N amounting to a million orders as in the Nankai trough model requires huge memories and computational times. Therefore, indeed, we need the speed-up of the computations with less memory.

In this study, we compare three methods for computing the product of SRFM and SDRV; Fast Fourier Transform (FFT), Fast Multipole Method (FMM) and Hierarchical Matrices (H-matrices) method. FTT has been used in earthquake cycle simulations (e.g., Kato,2008). The memory and the computational time are O(N) and O(NlogN). FFT, however, requires cyclic boundary conditions. At subduction zones, such conditions cannot be assigned in the dip directions because of the free surface. FMM was developed for rapid evaluation of the long-ranged forces in N-body problem in astrophysics and has been widely applied to a variety of problems. In earthquake cycle simulations, however, FMM has not so far been applied except for the studies in Tullis and Beeier (2008) and ours. It enables the faster evaluation with a multipole expansion of the slip response function, which allows one to group sources and receivers that lie close together and treat them as if they are a single source or receiver. The memory size and the computational time are O(N). Hirahara et al.(2009) developed the code for the multiplication in an infinite homogeneous elastic medium based on FMM formulation of Yoshida et al.(2001) and tree-structure algorithm of Liu and Nishimura(2006). FMM does not require any cyclic boundary conditions, but the functional forms suitable for multipole expansion. However, any suitable functional forms have not been obtained for the dip slip faulting on the dipping interface in the semi-infinite homogeneous elastic medium (Ohtani et al.,2010). H-matrices, which are efficient low-rank compressed representations of dense matrices, enable rapid arithmetic operations with less memory (Hackbusch,1999). Ohtani et al.(2011) implemented H-matrices in the code of Hori (2006) and examined the performance up to N of 10∗∗6. With the proper ranges of parameters controlling the accuracy, the memory is O(N), and the computational time is O(N) in the range of N smaller than 10∗∗5 and O(N)-O(NlogN) in the larger N range. Application of H-matrices requires only the slip response function decays with the distances between source and receiver cells, but not limitations of functional forms. In fact, Ohtani et al.(2011) use slip response function in a triangular cell in the semi-infinite homogeneous elastic medium. So far, we have examined only the case of homogeneous elastic medium. H-matrices would enable us to simulate earthquake cycles in a more realistic heterogeneous medium at subduction zones, by constructing SRFM with FEM.

Keywords: Large- and multi-scale earthquake cycle simulatio, Fast computation methods, Fast Fourier Transform Method, Fast Multipole Method, H-matrices

Japan Geoscience Union Meeting 2011
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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

Yosuke Shikakura[1*], Yukitoshi Fukahata[2], Kazuro Hirahara[1]

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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

Hiromi Matsuoka[1*], Makoto Okamura[1]

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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

Japan Geoscience Union Meeting 2011
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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

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

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

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

Tetsuro Imakiire[1*], ENYA Toshiharu[1], Fumiaki Kimata[2], Teresito C. Bacolcol[3]

[1]Geospatial Information Authority, [2]Nagoya University, [3]Philippine Inst. of Volcanology & Seism

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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SSS035-P05 Room:Convention Hall Time:May 25 14:00-16:30

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

Tomoya Harada[1*], Kenji Satake[1], Katsuhiko Ishibashi[2]

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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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SSS035-P08 Room:Convention Hall Time:May 25 14:00-16:30

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]

[1]JAMSTEC

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

Tetsuya Fukuda[1], Keiko Kuge[1*]

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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

Kenji Uehira[1*], Hiroshi Yakiwara[2], Tomoaki Yamada[3], Kodo Umakoshi[4], Shigeru Nakao[2], Reiji Kobayashi[2], Kazuhiko Goto[2], Hiroki Miyamachi[2], Kimihiro Mochizuki[3], Kazuo Nakahigashi[3], Masanao Shinohara[3], Toshihiko Kanazawa[3], Ryota Hino[5], Masaji Goda[6], Hiroshi Shimizu[1]

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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.

Japan Geoscience Union Meeting 2011
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SSS035-P11 Room:Convention Hall Time:May 25 14:00-16:30

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

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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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SSS035-P13 Room:Convention Hall Time:May 25 14:00-16:30

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

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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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[1]JAMSTEC

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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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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SSS035-P16 Room:Convention Hall Time:May 25 14:00-16:30

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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[1]AORI, [2]JAMSTEC

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

Weiren Lin[1*], Timothy B. Byrne[2], Yuhji Yamamoto[3], Yuzuru Yamamoto[4], Masataka Kinoshita[4]

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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

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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/s^2. 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/s^2, but tends to increase with acceleration to ~0.1 at 13 m/s^2. 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

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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

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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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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

Mika Yamaguchi[1*], Yoshitaka Hashimoto[1], Asuka Yamaguchi[2], Gaku Kimura[2]

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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