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 co-seismic 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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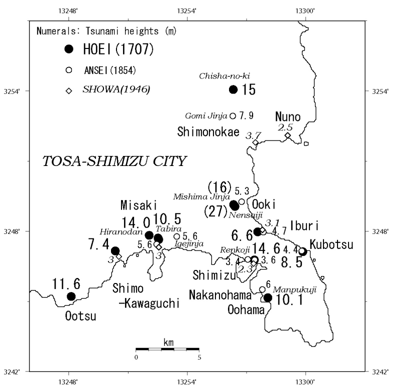
A jointed gigantic earthquake called Hoei earthquake occurred in the jointed regions of south offing of the Tokai and the Nankai districts, the western part of the Japanese Islands. It had been well known that the magnitude of this earthquake is larger than those of the 1854 Ansei Nankai and the 1946 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

Takashi Nakata[1*], Hideaki Goto[2], Mitsuhisa Watanabe[3], Yasuhiro Suzuki[4], Hidekazu Tokuyama[5], Kenji Satake[5], Takashi Kumamoto[6], Azusa Nishizawa[7], Koji Ito[7], Ritsuko S. Matsu'ura[8]

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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

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

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

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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

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

Modeling of permeability structure using pore pressure and borehole strain monitoring

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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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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 NanTro-SEIZE 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

SSS035-29 Room:IC Time:May 24 15:15-15:30

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

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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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SSS035-33 Room:IC Time:May 24 16:30-16:45

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

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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

SSS035-36 Room:IC Time:May 24 17:15-17:30

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

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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

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

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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