Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS38-01 Room:303 Time:May 23 09:00-09:15

Estimation of slip scenarios of megathrust earthquakes: Application to Central Andes, Peru

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The recent 2011 Tohoku-oki earthquake occurred in a region where giant megathrust earthquakes were not expected. This earthquake proved the difficulty to assess seismic hazard mainly based on information from historical earthquakes. In this study we propose a methodology to estimate the slip distribution of megathrust earthquakes likely to occur in the future, based on a model of interseismic coupling (ISC) distribution in subduction margins obtained from GPS measurements (Chlieh et al. 2011), as well as information of historical earthquakes, and apply the method to the Central Andes subduction region in Peru. Our results indicate that an earthquake of moment magnitude of 8.9 is very likely to occur at this region, as a result of the rapid convergence between the Nazca and South American plates and considering a large slip deficit of 15m since the 1746 earthquake, which is the largest and more damaging earthquake and tsunami in Central Andes according to historical information. The slip model obtained from geodetic data represents the large scale features of asperities within the megathrust, which is appropriate for simulation of long period waves and tsunami modelling. In order to create slip models appropriate for broadband strong ground motion simulations it becomes necessary to introduce small scale complexities to the source slip that allow the calculation of high frequency ground motions. To achieve this purpose we propose a 'broadband' source model in which large scale features of the model are constructed from our geodetic scenario slip, and the small scale heterogeneities are obtained from a spatially correlated random slip model. This spatial heterogeneity of slip is obtained from the spectral amplitudes at high wave-numbers of a Von Karman Pseudo Spectral Density function (PSD) that fits the PSD of our geodetic slip.

Our results indicate that the PSD of a slip model of the (Mw8.8) 2010 Maule earthquake, Chile, (Pulido et al. 2010), is very similar to the PSD of our geodetic scenario slip for Central Andes, suggesting that our methodology might be appropriate to typify megathrust earthquakes at this region.

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Pulido N., Y. Yagi, H. Kumagai, and N. Nishimura, 2011. Rupture process and coseismic deformations of the February 2010 Maule earthquake, Chile, Earth, Planets and Space, 63, 955-959.

Keywords: Megathrust earthquake, earthquake scenario, Seismic hazard estimation, Central Andes, Peru, Nazca plate, GPS

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SSS38-02 Room:303 Time:May 23 09:15-09:30

Was the 1906 great Ecuador-Colombia earthquake (Mw 8.8) a multiple rupture event of three segments ?

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Scince the 2011 off the Pacific coast of Tohoku Earthquake, a multiple segment rupture event is a more important problem in seismology than ever. A suspected example of this type is a great earthquake involving Tokai, Tonankai, and Nankai segments. The 1906 earthquake in the Ecuador-Colombia region is considered to belong to events of multiple segment rupture. Kanamori and McNally (1982) indicated that the rupture zone of the earthquake (Mw = 8.8) included aftershock zones of three medium-sized earthquakes in 1942 (Ms = 7.9), 1958 (Ms = 7.8), and 1979 (Ms = 7.7), judging from this aftershock data. It is, however, difficult to determine the aftershock region in the 1906 event when poor seismological observations were available. Kanamori and McNally (1982) recognized the uncertainty of the aftershock area of this earthquake, although they estimated its seismic moment from the extent of aftershock areas and derived Mw value of the earthquake. The value of Mw is close to Abe's (1979) tsunami magnitude Mt, that is, 8.8.

Abe (1979) estimate Mt of the 1906 earthquake by using far-field tsunami data in Japan and Hawaii. In his calculation the record in Hilo was adopted to be 3.6 m. In this study, we re-examined this value, finding it rather problematic, from the following reasons.

1. The information source of the value comes from an article of a local newspaper, where no numerical observations were presented.
2. According to the article, the tsunami in Hilo covered only streets and railroad tracks, but no substantial damages were reported.

We estimate the scale of the 1906 earthquake based on modern record of the 1979 earthquake. According to Kanamori and McNally (1982), Mw of the 1979 earthquake is 8.2 and Mt is 8.1. We calculate the ratio of the tsunamis amplitude of the 1979 earthquake to that of 1906, estimated from the difference in Mt of two earthquakes with tidal gauge data in Japan. Mt of 1906 earthquake must be about 8.4 to 8.5 at most. Since the 1906 earthquake was not a tsunami earthquake, Mw also must be similar, about 8.5, the value by 0.3 less than Mw by Kanamori and McNally (1982). In this study, the seismic moment of the 1906 earthquake is only about 2.8 times larger than the 1979 earthquake.

If Mw of 1906 earthquake is 8.8 as Kanamori and McNally (1982), the length of the earthquake fault is twice of the 1979 earthquake. The estimated scale is as large as the rupture zones of the three earthquakes. If Mw of 1906 earthquake is 8.5, as suggested in this study the fault length of the earthquake is only 1.4 times of the 1979 earthquake.

In conclusion, we propose that the 1906 earthquake was a multiple rupture event of three segments. The seismic moment of this earthquake seems to be not much larger than but comparable with the other three earthquakes.

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Keywords: Ecuador, Colombia, Multiple rupture, Tsunami

SSS38-03 Room:303 Time:May 23 09:30-09:45

Megathrust Earthquakes in Oblique Subduction Zones Part 1: The Sagmi Trough

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Since the 2011 Tohoku-oki megathrust earthquake, Japan, it has been recognized that there is a variety of megathrust earthquakes occurring in the world not just only the Chilean type megathrust earthquake. In the variation, one end member is the 1960 Chile earthquake and the other is the 2004 Sumatra-Andaman earthquake, while the former is characterized by subduction zone of a young plate forming the Cordilleran orogeny, the latter is by an obliquely subducting plate along a continental margin with active back-arc activity. We study in detail megathrust earthquakes along such oblique subduction zones, considering characteristics of earthquake activities, focal mechanisms, rupture patterns, geometry of subduction zones, types of overriding plates and back-arc activities. Discussions are further made on one of the oblique subduction zones near Japan Islands, the Sagami Trough, in order to derive some information and the possibility of future large earthquakes there from the seismological data at hand. We found that there is a variety of large earthquakes in the oblique subduction zones in the world. Since we have no hand to suspect the future activity of a particular subduction zone, comparative studies on seismic activities in different oblique subduction zones are inevitable.

Keywords: Megathrust earthquakes, Oblique subduction zones, The Sagami Trough, 2004 Sumatra earthquake, 1965 Rat Island earthquake

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SSS38-04 Room:303 Time:May 23 09:45-10:00

Seismic velocity structure around the boundary area of Hyuga-nada and Nankai seismogenic zone

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In the Nankai Trough, three major seismogenic segments (Tokai, Tonankai and Nankai) of megathrust earthquake exist. The Hyuga-nada segment is located on the west of Nankai segment and it was distinguished from these seismogenic segments 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 [e. g., Furumura et al., 2011]. To understand segmentation and synchronization of seismic rupture along the Nankai Trough subduction zone, Japan Agency for Marine-Earth Science and Technology has been carried out a series of wide-angle active source surveys and local seismic observations in the Nankai Trough seismogenic zone.

From the observation data in Hyuga-nada segment, that has been performed from 2008 to 2009, we have clarified the location of subducted Kyushu-Palau ridge as a low-velocity belt with NW-SE strike in the subducted Philippine Sea plate [Yamamoto et al., 2011]. However, because the boundary area between Hyuga-nada and Nankai segments was located in the eastern end of their study area, we could not obtain enough structural information to discuss the difference between Hyuga-nada and Nankai segments.

In this study, we added the observation data in western Nankai segment that has been performed from 2009 to 2010, to the dataset of Hyuga-nada. Then, to discuss the relationship between structural heterogeneities and coseismic rupture pattern around Nankai and Hyuga-nada segments, we performed a three-dimensional seismic tomography for combined dataset.

From our results, high velocity zone is imaged within the continental plate just above the coseismic slip area of 1968 Hyuga-nada earthquake [Yagi et al., 1998]. This high velocity zone is not imaged beneath the coseismic slip area of 1946 Nankai earthquake [Sagiya and Thatcher, 1999]. Besides, uppermost slab mantle in the boundary area of Hyuga-nada and Nankai segments showed relatively higher velocity than that in eastern area. High velocity slab mantle becomes unclear at the eastern side of Cape Ashizuri. This result is consistent with the previous active source studies that showed the P-wave velocity of uppermost slab mantle as 8.0 km/s beneath Cape Ashizuri [Takahashi et al., 2002] and as 7.8km/s beneath Cape Muroto that located about 100 km eastward from Cape Ashizuri [Kodaira et al., 2000]. The existence of high velocity zone in the continental plate and high velocity uppermost slab mantle might be a one of the factor of the boundary area between Hyuga-nada and Nankai segments.

This study 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.

Keywords: Nankai Trough, Ocean bottom seismograph, tomogrsaphy, seismicity

SSS38-05 Room:303 Time:May 23 10:00-10:15

Spatial distribution of random velocity inhomogeneities around the fault zone of Nankai Earthquake

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The Nankai trough is a convergent margin where the Philippine Sea plate is descending beneath the Eurasian plate. There are some fault segments of large interplate earthquakes that are called Tokai, Tonankai, and Nankai earthquakes. According to the studies on earthquake history, their rupture propagation shows various patterns such as a rupture of one segment and nearly simultaneous rupture of contiguous segments. Japan Agency for Marine-Earth Science and Technology (JAMSTEC) conducted seismic surveys at Nankai trough 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 evaluated the spatial distribution of random velocity inhomogeneities from Hyuga-nada to Kii-channel by using velocity seismograms of small and moderate sized earthquakes.

We applied the peak delay time analyses to investigate the random inhomogeneity distribution. Peak delay time is defined as the time lag from the S-wave onset to its maximal amplitude arrival. This quantity reflects the accumulation of multiple forward scattering due to random velocity inhomogeneities, and is quite insensitive to the inelastic attenuation. Peak delay times are measured from the root mean squared envelopes of horizontal components at 4-8Hz, 8-16Hz and 16-32Hz. This study used the velocity seismograms that are recorded by 495 ocean bottom seismographs and 378 onshore seismic stations. Onshore stations are composed of the F-net and Hi-net stations that are maintained by National Research Institute for Earth Science and Disaster Prevention (NIED) of Japan. Minimal value distribution of the peak delay time (e.g., Takahashi et al. 2007) shows that strongly inhomogeneous regions in Nankai trough are located at Hyuga-nada and Kii-Channel. Significantly strong inhomogeneity at Kii-channel is almost located at the subducted seamount (Kodaira et al. 2002). We also conducted the inversion analysis of the peak delay times to investigate the spatial distribution of power spectral density function (PSDF) of random velocity inhomogeneities (e.g., Takahashi et al. 2009). It is assumed that the random inhomogeneities are represented by the von Karman type PSDF. Preliminary result of inversion analysis shows that spectral gradient of PSDF (i.e., scale dependence of inhomogeneities) are the same overt the Nankai trough, but random inhomogeneities at smaller wavenumber shows large values at the southwestern part of Hyuga-nada and Kii-channel. Anomaly at Hyuga-nada is almost located at the subducted Kyushu Palau ridge. Similar random inhomogeneities are imaged near the remnant of ancient arc in the northern Izu-Bonin arc (Takahashi et al. 2011). We speculate these random inhomogeneities reflect the remnant of ancient volcanic activities. These results imply that random inhomogeneities at Kii-channel are possibly related to the subducted seamount, and that random inhomogeneities are useful to discuss the medium characteristics in subduction zone.

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Structural variation and geometry of the Philippine Sea plate of the southwestern Nankai seismogenic zone

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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. It is necessary to understand rupture synchronization and segmentation of the Nankai megathrust earthquake. For a precise estimate of the rupture area of the Nankai megathrust event, it is important to know the geometry of the subducting Philippine Sea plate and deep subduction structure along the Nankai Trough.

Based on our latest structural study of Hyuga-nada region, structural boundary between the oceanic crust of the Shikoku Basin and the crust of the Kyushu Palau Ridge is identified as the western margin of the type of Nankai megathrust event such as the Hoei earthquake occurred in 1707. To understand structural factors controlling coseismic rupture of the Nankai earthquake in 1946, the large-scale high-resolution wide-angle seismic study was conducted in 2009 and 2010. It is also important to obtain structural image and its variation around the deep low frequency earthquakes and tremors area.

In this study, approximately 200 ocean bottom seismographs were deployed for each experiment off the Shikoku Island and the Kii channel respectively. A tuned airgun system (7800 cu. in.) shot every 200m along 13 profiles. Airgun shots were also recorded along an onshore seismic profile (prepared by ERI, univ. of Tokyo and NIED) prolonged from the offshore profile off the Kii Peninsula. Long-term observation was conducted for ~9 months by 21 OBSs off the Shikoku area and 20 OBSs off the Kii channel.

Geometry of the subducting Philippine Sea plate from the Hyuga-nada region to off the Shikoku area, there is no notable variation in the subducting angle or structure around the western margin of the 1946 Nankai earthquake area. However, different structural image around the source area of the deep low frequency earthquakes and tremors is obtained by using the airgun shots recorded at onshore Hi-net (NIED, Japan) data located along prolongation of the offshore seismic profiles. At the western margin of the Shikoku Island, the deep low-frequency earthquakes and tremors are estimated to occur at the subducting plate boundary shallower than the forearc mantle, considering the normal velocity of the forearc mantle.

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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SSS38-07 Room:303 Time:May 23 10:45-11:00

A simple model reproducing complex behavior of a giant earthquake cycle

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The 2011 off the Pacific coast of Tohoku Earthquake is giant earthquake estimated as M9.0 and the source region is expanded from off-Miyagi to off-Fukushima. The magnitude is larger than expected one which is M7-M8 (e.g., The Headquarters for Earthquake Research Promotion, 2002). Some possible causes for reaching M9.0 are proposed in order to understand the mechanism of the earthquake occurrence. They are different on the points: 1) whether the moment of M9 is accumulated before the earthquake occurred, 2) what is the main cause of M9.0 (e.g., spatio-temporal change of frictional parameters, coseismic linkage of several asperities). However some interpretations are misled from the method of data analysis or numerical simulations.

Thus we propose a model based on a simple idea that earthquakes occur frequently at the boundary between asperity and non-asperity area because the incresting rate of the strain energy is large. From this point of view, off-Miyagi M7 source regions can be considered as the boundary not only in the depth direction but also lateral one, considring several data (past and 2011 seismic sources, interseismic activity including repeating earthquake, seafloor geometry, crustal structure, and interseismic slip deficit distribution estimating from GPS data). On the other hand, the source region of the 2011 off the Pacific coast of Tohoku Earthquake (mainly off-Fukushima region) can be assumed at lower incresing rate than that at off-Miyagi. We express this model based on the rate- and state-dependent friction law (Dieterich, 1979). The boundary between asperity and non-asperity in the depth direction is modeled changing the value of A-B from negative to positive, and we set smaller L (characteristic slip distance) at the off-Miyagi M7 source regions than the other surrounding regions in order to reproduce the reccurence of M7 earthquakes.

As the results, we reproduce the recurrence times, the source region, and the rupture propagation of M7 and M9 earthquakes. We analyze the spatio-temporal distribution of slip and shear stress change, and we understand that the moment release rates of M7 earthquakes are comparable to expected one from the plate convergence rate at the final stage of M9 cycle. This suggests that the slip deficit of the area seems to be completely canceled by only M7 events, and it can mislead understanding the whole image of the earthquake cycle using only the data in the last stage of the earthquake cycle. Moreover we analyze afterslip of the M7 events, and we find the area and the cumulated magnitude of the afterslips become larger at the later stage of M9 cycle. In the presentation, we will report the numerical simulation of crustal deformation using this earthquake cycle model.

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SSS38-08 Room:303 Time:May 23 11:00-11:15

Quasi-dynamic earthquake cycle simulation in a layered viscoelastic medium

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Earthquake cycle simulations, based on laboratory-derived rate and state friction laws, have been executed to successfully reproduce historical interplate earthquake cycles at subduction zones. Most of these simulations have assumed half-space homogeneous elastic media. At subduction zones, however, there exists a viscoelastic mantle wedge, which produces several-decades-lasting stress relaxations and postseismic deformations after interplate earthquakes. Tsunami deposit surveys suggested that the 2011 Tohoku earthquake has a recurrence time of several hundred years, and hence such a giant earthquake cycle with a long recurrence time should be affected by viscoelastic stress interactions. And there has been reported the increase of inland earthquake activity before and just after the occurrence of an interplate earthquake. Viscoelastic stress interaction in the mantle wedge would play an important role in these interplate and inland earthquake activity interactions.

In quasi-dynamic earthquake cycle simulations, we first divide a plate interface into N small cells (faults) and numerically obtain slip evolution in each cell by balancing the stress due to slip deficits from all cells with the frictional stress obeying a rate and state friction law. In a viscoelastic medium, the stress is calculated by the hereditary integral of time-dependent SRF(slip response function) and the slip deficit rate. This requires all past slip rate histories in memory and leads to huge memory storage and computations, compared with the elastic case where the stress is obtained by the simple product of the temporally constant elastic SRF and the slip deficit.

We introduced a new method of stress calculation without the heredity integral using memory variables which has been developed in FD calculations of dissipating seismic wave filed in inelastic media (Hirahara et al., 2011). There, we approximate SRF with M relaxation functions, and introduce the M memory variables, each of which satisfies a first-order differential equation in time. Stress is obtained by the product of (the slip deficit - sum of memory variables) and SRF. The slip deficit in elastic cases is replaced by (the slip deficit - sum of memory variables) , and we can keep the same scheme of stress calculation as that in elastic ones. Because of keeping the same scheme, the method for reducing computational costs in elastic cases (Ohtani et al., 2012) works also in viscoelastic ones. In their method, they introduced the H-matrices method to reduce the computational costs of product of the elastic SRF matrix (NxN) and the slip deficit vector (N) from $O(N^2)$ to O(N) - O(NlogN). The stress calculation in viscoelastic cases requires additionally NxM relaxation function parameters approximating SRF and NxM memory variables compared with the elastic cases, and also NxM first order differential equations. This means the extra computational cost is O(NxM), and we found M=2 is generally adequate for approximating SRF.

To examine the performance of our method in viscoelastic cases, we simulate the 2011 Tohoku earthquake cycle in a 2D viscoelastic structure, which consists of a 40-km-thick elastic lithosphere and the underlying Maxwell viscoelastic mantle wedge. We assume a plate interface with the dip of 20 degrees. Following Kato and Yoshida (2011), we set the seismogenic zone with velocity weakening property down to a depth of 55 km on the plate interface extending totally to 100 km depth. We calculate SRFs following Fukahata and Matsu'ura(2005,2006) and Hashima et al.(2008). SRFs in the mantle wedge decay to zero in time, while those in the elastic layer keep some level. This produces slip evolution in the seismogenic zone in the mantle wedge, which is quite different from that in the elastic case, as well as the difference of recurrence time.

Keywords: Earthquake cycle, Simulation, Layered viscoelastic media, H-matrices method, Memory variables

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SSS38-09 Room:303 Time:May 23 11:15-11:30

Historical seismicity explains the dynamic rupture process of the 2011 Tohoku-Oki earthquake

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Many small repeating earthquakes identified in the Tohoku subduction zone imply some kind of irregular structures are maintained for long time, at least longer than the history of the instrumental seismology. However, these structures are not always the source of characteristic earthquakes, nor so-called asperities without rigid definition, which is proved by the 2011 Tohoku-Oki earthquake. Nevertheless, these structures probably constrained the dynamic process of the earthquake. Here we simulate the process using the circular patch model of Ide and Aochi (2005), in which heterogeneous distribution of fracture energy is given by the patch radius.

The distribution of patches is deduced from the historical seismicity in the catalog of Japan Meteorological Agency since 1923. We assume every historical earthquake of M7.8-8.3, M7.2-7.7, and M6.7-7.1 occurred on a patch centered at the hypocenter with the radius of 50, 25, and 12.5 km, respectively. These patches and the source area of the 1896 Sanriku earthquake demarcate the large slip area of the Tohoku-Oki earthquake, which we represent by an ellipse of 260 x 150 km. If we introduce an artificial patch, the patch distribution is sufficient to explain various features of the Tohoku-Oki earthquake.

Following Ide and Aochi (2005) we carried out numerical simulations of dynamic rupture on the patch distribution with a slip weakening friction law using a boundary integral equation method. The result shows (1) downward rupture propagation up to about 30 s, (2) the rupture of the largest patch nucleated by the previous stage and the break of the trench at about 60 s, and (3) successive ruptures of surrounding patches in the deep part of the plate interface, all of which are observed features in many slip models. The rupture stop before breaking patches representing aftershocks. Although the model does not have free surface and the total seismic moment is underestimated, the overall characteristics of moment rate function is reproduced. The calculation also shows that the foreshock on March 9 and its stress disturbance are essential to rupture the largest patch. Without the foreshock, the rupture stops after the stage (1), which corresponds to M7.5-8 earthquake similar to the 1978 Miyagi-Oki earthquake.

Keywords: The 2011 Tohoku-Oki earthquake, dynamic rupture process, fractal patch, seismicity

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SSS38-10 Room:303 Time:May 23 11:30-11:45

Dynamic Simulations for the Seismic Behavior of Shallow Part of the Fault Plane during Mega-Thrust Earthquakes

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Splay faults branching from the plate boundary have been found around the shallow part of plate of mega thrust earthquake. They cause huge vertical displacements being ruptured simultaneously with Mega-Thrust earthquakes. This leads to the huge tsunami. Baba *et al*. (2006) mentioned that splay faults around Kumano-nada were ruptured during the 1944 Tonankai earthquake and the 1946 Nankai earthquake, and these ruptures gave rise to huge tsunami. Additionally, the 2011 Tohoku events produced the huge slips without radiating strong ground motions on the shallow part of the faults. This gets attentions as the distinct features when the rupture of the mega-thrust events reaches to the shallow part of the faults including splay faults. Although various kinds of observations for the seismic behavior (rupture process or ground motion features etc) of splay faults as well as the shallow part of the fault plane from inter plate earthquakes have been reported, the number of analytical or numerical studies based on dynamic simulation is still limited. Wendt *et al*. (2009), for example, revealed that the different initial stress distribution brings huge difference in terms of the seismic behavior (rupture simultaneously or not) and vertical displacements on the surface.

In this study, we have carried out the dynamic simulations in order to get better understandings about the seismic behavior of splay faults as well as shallow part of the plate boundary. We use the spectral element methods (Ampuero, 2009) that can not only incorporate the complex fault geometry but save computational resources. The simulation utilizes the slip-weakening law (Ida, 1972). Even the results of simulation did not reproduce much about the observed features of seismic behavior of shallow part of the plate boundary during the Tohoku events, the parameter studies that vary material parameters, constitute law, and initial stress distribution etc, leads to better understandings about the seismic behavior of shallow part of the plate boundary including splay faults.

Keywords: Megathrust event, Dynamic Simulation, Shallow Part of Fault Plane, Spectral Element Method

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Long-term Changes in Coulomb Failure Function on inland faults in SW Japan due to plate motion and earthquakes

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There are many inland active faults in and around the Kinki region, such as Median Tectonic Line, Neodani, Atotsugawa, and Rokko-Awaji faults. The earthquakes on the faults are mainly generated by the east-west compression, known as Niigata-Kobe Tectonic Zone (NKTZ), which would come from the relative motion between Okhotsk and Amurian plates (Sagiya, 2004). However, because the activity of inland earthquakes increases in the period from 50 years before to 20 years after the occurrence of great interplate earthquakes along the Nankai Trough (Hori & Oike, 1996), earthquake generations on these faults are affected by the interplate earthquakes at the trough. To investigate this problem, Pollitz & Sacks (1997), Hyodo & Hirahara (2004), and Hirahara (2007) evaluated the viscoelastic effect of great interplate earthquakes and interseismic plate locking at the Philippine Sea (PHS) Plate subduction by examining Change in Coulomb Failure Function (dCFF). In these studies, the effect of steady subduction is ignored. However, it generates long-term (Myr scale) crustal deformation, which is obtained by the viscoelastic response function at infinite time (Matsu'ura & Sato, 1989). Hashimoto et al. (2008) explained free-air gravity anomaly in and around Japan by steady subduction of the PHS and Pacific (PAC) plates. We now add the effect of steady subduction and interaction between the inland earthquakes in evaluating stress change on the inland active faults. With this study we evaluate how stress change during the earthquake cycle affects the long-term stress accumulation on inland active faults. We investigate the validity of the model with comparing the historical record of inland earthquakes.

We employ quasi-static viscoelastic slip response functions for point sources in an elastic-viscoelastic stratified medium by Fukahata & Matsu'ura (2006). For the plate interface of PHS and PAC subduction, we use the structure by Hashimoto et al. (2004), because they put priority on minimization of roughness, which is important to calculate the effect of steady subduction. We set history of the interplate earthquakes at the Nankai Trough. The amount of slip is set by Time or Slip Predictable model (Shimazaki & Nakata, 1980). For the global plate motion, we use REVEL 2000 (Sella et al., 2002) based on the GPS data. The maximum compressive strain due to NKTZ east-west compression is set to be 1×10^{-7} strain/yr with the direction of N100E. For the collision of the Izu Arc, the relative plate motion between PHS and AMR plates are decreasing in the Izu and Suruga regions, after Heki & Miyazaki (2001). The geometries of inland faults are after HERP. The effective friction coefficient is set to be 0.3.

For the validity, we first calculated the long-term crustal deformation due to steady subduction of PAC and PHS plates, under the same condition in Hashimoto et al. (2008). The computed results are consistent with the previous work. We then changed the thickness of elastic lithosphere from 40 km to 35 km, which is appropriate for SW Japan. With the thickness the computed crustal uplift pattern is more similar to the observed free-air gravity anomaly than the result of Hashimoto et al. (2008). Thus thickness is set to be 35 km. We then calculated dCFF on the inland faults due to NKTZ east-west compression and steady plate subduction. The dCFF due to NKTZ east-west compression is positive and its value is several kPa/yr, for most active faults. The dCFF due to steady plate subduction are both positive and negative and its value is around several hundred Pa/yr. These results are consistent with that the inland earthquakes in this region are mainly generated by NKTZ east-west compression. Most earthquakes on the faults occur when dCFF is largest-ever, which is consistent with the concept of dCFF. In the presentation, we show the effect of interaction between inland earthquakes.

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

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS38-12 Room:303 Time:May 23 12:00-12:15

Interseismic stress accumulation at the locked zone of Nankai Trough seismogenic fault off Kii Peninsula

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Since 2007, we accomplished drilling, coring and downhole measurements at 13 sites across the Nankai accretionary complex off Kii peninsula using D/V Chikyu. Although the deepest hole is well above the seismogenic fault zone, we found that the stress regime is quite variable across the accretionary prism, and their mechanism is still in discussion.

An important source for such stress variation is the tectonic loading. In order to assess how much stress can possibly be accumulated around the locked zone during one seismic cycle, we conducted a simple 2D plain-strain steady-state elastic model using the finite-element method.

We fixed the geometry of plate interface and prohibited a horizontal displacement at one side (above the plate interface) 200km landward from the trench. Along the plate interface except the locked zone, we allowed free slip only along the fault. The locked zone is defined at 30-100 km landward of the trench, and is assumed as 100% locked (no differential movement). The movement of downgoing lithosphere is given at the landward side boundary 200 km landward of the trench. Since we deal with the total stress accumulation within one seismic cycle, a displacement of 5 m was given as a slab pull. Young modulus in the Kumano forearc basin (1 km thick) is set as 4 GPa taken from sonic log data at Site C0009, whereas that in the underlying domain is set at 50 GPa which would be too high for the accretionary sediment. In that case, estimated stress would be lower than provided below.

Most of the tectonic stress due to 5m of plate convergence is concentrated near the downdip edge of the locked zone. The principal compressional and shear stress on the fault is larger than 5 MPa and 2 MPa, respectively. They roughly agree with the stress drop during the M8 events.

These stresses along the fault, however, gradually decrease seaward to zero level. Tectonic compressional stress near the updip edge is much smaller than near downdip. At Site C0002, it is almost uniform at 0.3-0.5 MPa in the accretionary sediment below the Kumano Basin. In the Kumano basin, the stress further decreases by one order of magnitude.

Since we neglect gravity load, isostatic rebound and horizontal resistance, we cannot estimate the absolute stress level. Thus the results here cannot be compared to the observed downhole stress data, which implies strike-slip regime in the accretionary prism at Site C0002. Still, as mentioned by Wang and He (1999), the fault stress will not deviate too much from its average value. Our results confirm their implication. Furthermore, the small tectonic loading stress suggests that in the shallow part the orientation of principle stress can easily be rotated by near-surface phenomena such as stretching of sediment caused by thrusting of mega splay fault.

Keywords: NanTroSEIZE, stress, locked zone, Young's Modulus, Poisson's ratio

SSS38-13 Room:303 Time:May 23 14:00-14:15

Propagation of slow slip leading up to the 2011 Mw 9.0 Tohoku-Oki earthquake

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Many large earthquakes are preceded by one or more foreshocks, but it is unclear how these foreshocks relate to the nucleation process of the mainshock. On the basis of an earthquake catalog created using a waveform correlation technique, we identified two distinct sequences of foreshocks migrating at rates of 2-10 km/day along the trench axis toward the epicenter of the 2011 Mw 9.0 Tohoku-Oki earthquake. The time history of quasi-static slip along the plate interface, based on small repeating earthquakes that were part of the migrating seismicity, suggest that two sequences involved slow slip transients propagating toward the initial rupture point. The second sequence, which involved large slip rates, may have caused substantial stress loading, prompting the unstable dynamic rupture of the mainshock (Kato et al., 2012, Science).

Keywords: Tohoku-Oki earthquake, slow slip, migration, repeating earthquakes

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS38-14 Room:303 Time:May 23 14:15-14:30

Postseismic deformation of the 2011 Tohoku Earthquake using GPS/acoustic observations

OSADA, Yukihito[1*], KIDO, Motoyuki[1], IINUMA, Takeshi[1], INAZU, Daisuke[1], SATO, Mariko[2], OHTA, Yusaku[1], ITO, Yoshihiro[1], HINO, Ryota[1], FUJIMOTO, Hiromi[1]

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Large interplate earthquake repeatedly occurred in Japan Trench. Recently, the detail crustal deformation revealed by the nation-wide inland GPS network called as GEONET by GSI. However, the maximum displacement region for interplate earthquake is mainly located offshore region. Based on this background, we has been developed a GPS/Acoustic observation (GPS/A) system for the seafloor crustal deformation monitoring. A major earthquake struck in Japan Trench on March 11, 2011, named as the 2011 off the Pacific coast of Tohoku earthquake (here after 2011 Tohoku earthquake). Kido et al (2011) investigated the coseismic seafloor deformation by the GPS/A system. They reported the 15 and 31m coseismic displacements in GJT4, and GJT3, respectively. Both sites moved toward ESE direction, which is opposite direction of the plate subduction. These results suggested the heterogeneity of the coseismic slip distribution in the plate interface [e.g. Iinuma et al. submitted].

After the such large earthquake, the large postseismic deformation is also expected which may be caused by the afterslip for short (~several year) time period. The spatial coverage of the GPS/A sites is still not enough because of we have only two sites in and around the focal area. For more detail information for the postseismic deformation, we has been deployed one more GPS/A site from 2011July. We observed 3 times for the GJT3 for postseismic deformation in 2011 April, August, and October. As the result, we obtained 1.2 m displacement toward the ENE direction in GJT3. It is clearly larger than the displacement expected from the afterslip inferred from inland GEONET time series (http://www.gsi.go.jp/cais/topic110314-index.html). It suggests that the estimated afterslip based on the inland GPS data may underestimate the actual afterslip amount in the offshore region. Iinuma et al. (this meeting) constructed a preliminary afterslip distribution using onshore and seafloor displacement (GPS/Acoustic observations, pressure gauges). They pointed out the large postseismic on the shallow part of plate boundary. We will have more detail discussion for the postseismic deformation in the meeting.

Keywords: Postseismic deformation, seafloor crustal movement, the 2011 off Pacific coast of Tohoku Earthqake

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS38-15 Room:303 Time:May 23 14:30-14:45

Interlocking rupture at the weakly coupled plate boundary for the 2011 Tohoku-Oki megathrust earthquake

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Over the last few decades an asperity model has been developed to characterize the ruptures of large shallow subduction zone earthquakes in context of the strength of plate coupling [e.g., Ruff and Kanamori, 1980; Lay et al., 1982]. The 2011 Tohoku-Oki earthquake (Mw9) ruptured a large portion of the boundary between the subducting Pacific and the overriding Okhotsk plates where the coupling was considered weak and represented by sparsely distributed small asperities [e.g., Tajima and Kanamori, 1985a,b]. Thus, such a great earthquake had not been anticipated for this region in the previous scenario, in which a typical asperity break could produce an event of Mw~7.5 to lower 8, but the driving force of rupture propagation may not be large enough to break through a broad region, as was in the case of the interlocked Mw9 megathrust event in 2011. A typical large event is accompanied by a significant expansion of aftershock activity reflecting stress adjustment into the weakly coupled fault zones outside the ruptured areas.

The 2011 Tohoku-Oki earthquake sequence started with an Mw7.3 foreshock on March 9th. The 2-day aftershock area of this event mainly expanded trenchward until the March 11th main event took place at the western edge of the zone. After the March 11th earthquake ruptured the broad region in t~150 s, however, it is notable that the aftershock area did not show much expansion over time as compared with the 1-day area in spite of the numerous aftershocks (note that we consider the aftershock area to be linked to the main rupture zone, and the large events (M$>$6) in Niigata or Shizuoka, which were apparently induced after March 11 as a separate feature). Unlike the previous large earthquakes in this subduction zone, this expansion pattern is similar to that of the 1964 Mw9.2 Alaskan earthquake which occurred at the boundary between the Pacific and North American plates.

A recent joint seismic tomography model using both P and S wave arrivals provides an indication of the complex variations in physical properties of the fault zone [Gorbatov and Kennett, 2003; Kennett et al., 2011]. In the old subducting Pacific plate in the source region, shear wavespeed variations (dV_S/V_S) dominate variations in bulk-sound speed (dV_{ph}/V_{ph}) (the wavespeed associated with bulk-modulus alone). The variations in the wavespeed structure can be enhanced by examining a measure (R) of the relative variations in dV_{ph}/V_{ph} and dV_S/V_S with respect to the *ak135* reference model [Kennett et al., 1995]. The tomographic images taken on a plane approximately coincident with the March 11 main event fault surface show an anomalous zone of distinct reduction to zero in R, and slightly negative values just up-dip of the mainshock hypocenter. The zone of reduced R is largely associated with a reduction in dV_S/V_S with the effects enhanced by the increase in dV_{ph}/V_{ph}, and appears to have a strong influence on plate coupling over the rupture area. A consistent feature determined for the 2011 March 11 source rupture is the separation of areas associated with dominant high-frequency radiation down-dip and low-frequency up-dip from the hypocenter although the models show notable differences depending on the specific source of information employed. The down-dip edge of the anomalous zone in R corresponds to the separation between the areas of dominant high-frequency radiation and dominant low-frequency radiation. The edges of the anomalous zone we have delineated act as the initiation points for rupture process of the March 2011 sequence starting on March 9 as well as for the 1978 (Mw7.5) and 1981 (Mw7.0) events, and these locations will be where the strongest contrasts exist in physical properties.

In summary we suggest not to preclude a possibility that a weakly coupled plate boundary could produce an interlocked megathrust event as in the case of March 11th main event, given an effective plate coupling.

Keywords: 2011 Tohoku-Oki megathrust earthquake, Weakly coupled plate boundary, Interlocking rupture

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS38-16 Room:303 Time:May 23 14:45-15:00

A plate interface geometry off the southeastern coast of Hokkaido and its relation to source areas of large earthquake

MACHIDA, Yuya[1*], SHINOHARA, Masanao[1], TAKANAMI, Tetsuo[1], NAKAHIGASHI, Kazuo[1], YAMADA, Tomoaki[1], MOCHIZUKI, Kimihiro[1], MURAI, Yoshio[2], AZUMA, Ryosuke[2], HINO, Ryota[3], KANAZAWA, Toshihiko[4]

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In the region off southeastern coast of Hokkaido, Japan, several large interplate earthquakes with magnitudes of 8 have occurred repeatedly due to a subduction of the Pacific Plate. The source regions of the earthquakes are spatially divided into several segments. Revealing a crustal structure in the region is essential to understand the distributions of source region. Seismic experiments using an airgun array and fifty-nine ocean bottom seismometers (OBSs) were performed along 4 profiles in 2006 and 2007. The profiles are located to cross the source regions of the earthquakes and an afterslip area following the earthquake. In this study we investigate relations between the source regions of large interplate earthquakes and an upper surface geometry of the subducting Pacific Plate. Combined the result from the wide angle seismic data with the previous seismic studies, we constructed a precise geometry of an upper surface of subducting Pacific plate in and around the source regions of large interplate earthquake. The depth of the plate interface geometry is not uniform along the trenches. A structure of the island arc crust and the plate interface geometry indicate a folded structure related to the arc-arc collisional tectonics of the Hokkaido region due to oblique subduction of Pacific plate. We found regions with high concentrated stresses on a fault based on the geometry of the plate interface. The areas are comparable with the source regions of the 1952 and the 2003 Tokachi-oki earthquake and the region where large slip was estimated during the 1952 Tokachi-oki earthquake from tsunami waveform inversion. In contrast to the stress concentrated regions, we found a region where the stresses are less concentrated. The afterslip of the 2003 Tokachi-oki earthquakes is distributed to the region. Therefore we suggest that the geometry of the subducting Pacific plate is strongly related to the distributions of source areas in the southernmost Kuril Trench. Due to the difference of the stress acting on the plate boundary, a wide variety of ruptures can occur for M 8 class earthquakes.

Keywords: subduction zone, megathrust earthquake, crustal structure, Kuril Trench, Japan Trench, arc-arc collision

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS38-17 Room:303 Time:May 23 15:00-15:15

Complex Space-Time Pattern of Great and Large Earthquakes in the Northern Japan to Kurile Subduction Zones

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The northern Japan to southern Kurile trenches have been regarded as a typical subduction zone with spatially and temporally regular recurrence of great (M>8) interplate earthquakes. The source regions were grouped into six segments by Utsu (1972; 1984). The Headquarters for Earthquake Research Promotion of the Japanese government (2004) divided the southern Kurile subduction zone into four regions and evaluated future probabilities of great interplate earthquakes. Besides great interplate events, however, many large (M>7) interplate, intraslab, outer-rise and tsunami earthquakes have also occurred in this region.

First, we depicted the space-time pattern of M>7 earthquakes along the northern Japan to Kuril trench, based on the relocated mainshock-aftershock distributions of all types of earthquakes occurred since 1913. We relocated hypocenters in the ISC, ISS, and BCIS bulletins by using the HYPOSAT (Schweitzer, 2003) and the Modified JHD method (Hurukawa, 1995). Then, in order to examine more detail space pattern, or rupture areas, of M>7 earthquakes since 1963 (WWSSN waveform data have been available since this year), we estimated cosiesmic slip distributions by the Kikuchi and Kanamori's (2003) teleseismic body wave inversion method. The WWSSN waveform data were used for earthquakes before 1990, and digital teleseismic waveform data compiled by the IRIS were used for events after 1990. Relocated main-shock hypocenters were used as initial rupture points.

As a result, we found complex feature of earthquake occurrence. Each region has been ruptured by a M8-class interplate earthquake or by multiple M7-class events. Offshore Urup Is. is source region of the 1963 Urup earthquake (M 8.5). Large interplate earthquakes occurred in the eastern and western part of the 1963 source region in 1991 (M 7.6) and 1995 (M 7.9), respectively. Their aftershock areas almost re-occupied the 1963 aftershock area. The 1963, 1991, and 1995 coseismic slip distributions show that the southwestern asperity of the 1963 event seems to be re-ruptured by the 1995 earthquake. Giant (the 2011 Tohoku earthquake of M9.0 which occurred just southern region of our study area), great and large interplate earthquakes occurred in the Kurile to Japan subduction zone after 1990s successively. The aftershock areas and coseismic slip distributions clearly show that three seismic gaps (offshore northern part of Aomori pref., offshore eastern Hokkaido to Etorofu Is., and offshore between Urup and Simushir Is.) have remained in this region.

Great intraslab earthquakes occurred in 1958 and 1994. The 1915 and 1918 great earthquakes may have been intraslab events.

Many outer-rise earthquakes and the 1963 and 1975 tsunami earthquakes occurred near the trench axis. The 2009 Simushir earthquake (M 7.4) with reverse faulting occurred within the aftershock area of the 2007 great outer-rise event (M 8.1). The 2007 and 2009 coseismic slip distributions show that the 2007 normal faulting occurred in the shallower part of the Pacific plate and the 2009 reverse intraplate faulting occurred in the deeper part.

Keywords: Northern Japan - Kurile subduction zones, space-time pattern of M>7 earthquakes, hypocenter relocation, teleseismic body-wave inversion, seismic gap

Japan Geoscience Union Meeting 2012
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SSS38-18 Room:303 Time:May 23 15:30-15:45

Characteristics of long-term strain buildup in the Kuril-Japan subduction zone: a global comparison

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Crustal strain is build up in and around a subduction zone in association with interseismic coupling on the plate interface. The elastic component of the crustal strain is released during episodic decoupling events on the plate boundary; the remainder is accommodated as permanent (= inelastic) deformation mainly within the subduction-related orogenic zone. Coseismic deformation is basically elastic, although damped by asthenospheric viscosity and thereby followed by postseismic deformation. Recent GPS observations have made it possible to detect crustal strain precisely and extensively, but are not sufficient in time to cover a whole cycle of strain buildup and release in subduction-related orogens. We propose here that geological methods and data should be used to evaluate inelastic strain buildup quantitatively, thereby to evaluate present-day elastic strain buildup, which may eventually result in gigantic earthquakes.

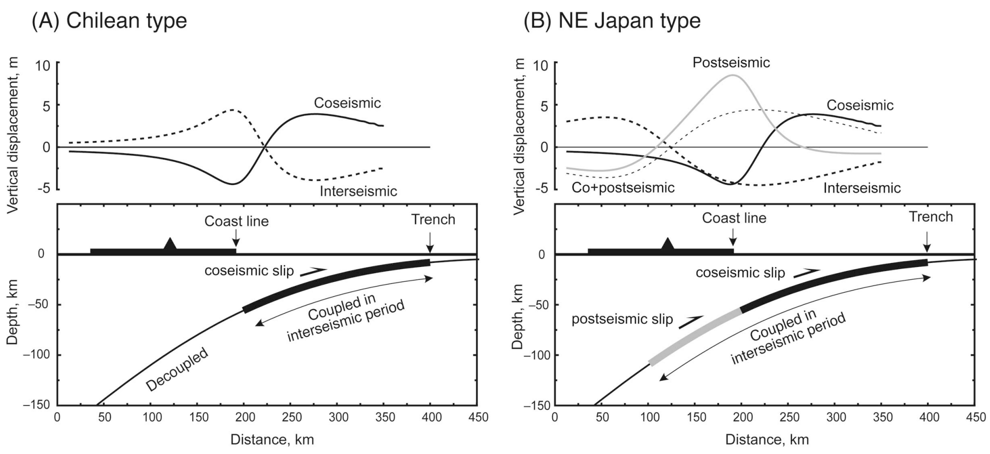
There has been a discrepancy between long-term (geologic) and short-term (geodetic) strain observations in both horizontal and vertical directions over the Northeast Japan (NEJ) arc. Geodetic observations in the past ~100 years have revealed strain accumulation across the NEJ arc at a rate as high as 10^{-7} strain/yr, whereas geologically observed strain rates are one order of magnitude slower. A similar discrepancy exists also in vertical movements; tide gauge records along the Pacific coast have indicated subsidence at a rate as high as ~10 mm/yr during the last ~80 years, whereas late Quaternary marine terraces indicate long-term uplift at 0.1-0.4 mm/yr. The ongoing rapid coastal subsidence is due to dragging by the subducting Pacific plate beneath the NEJ arc. Thus, most of the strain accumulated in the last 100 years at abnormally high rates is elastic, and is to be released by slip on the coupled plate interface. Only a fraction (~10%) of geodetically-observed crustal shortening is accommodated within the NEJ arc as long-term (inelastic) deformation.

Fairly large (Mw 7-8) subduction earthquakes occurred in the past ~100 years on the Kuril-Japan subduction zone, but they had nothing to do with strain release or coastal uplift. The 2011 Tohoku earthquake of Mw 9.0, whose rupture surface encompassed those of previously occurred Mw 7-8 subduction earthquakes, is likely to be such a decoupling event that effectively releases the elastic strain due to plate coupling. Pattern of interseismic subsidence indicates that, at 50~100 km depths down-dip of the 2011 rupture, there still exists a coupled part of plate interface, on which a large amount of aseismic after slip may occur in the coming decades.

A global survey suggests that gigantic (Mw $\geq$ 9.0) subduction earthquakes are classified into two types: the NEJ type and the Chilean type. The Chilean type strain buildup/release process is simple and straightforward in the sense that seismogenic zone (down to a 40-50 km depth) plays everything. The source areas of the 1960 Chile, 1964 Alaska, and 1700 Cascadia earthquakes lack evidence for interseismic deep coupling. Paleoseismological evidence indicates interseismic uplift around the down-dip edge of coseismic rupture, where coseismic subsidence is observed. This implies that the deeper plate interface is basically decoupled in interseismic periods, although subtle postseismic slip could exist on a transition zone down-dip of the coseismic rupture. In contrast, the NEJ type strain buildup/release process seems to be exceptional in that interseismic coupling occurs to a depth as deep as ~100 km. Its decoupling process is two-fold: seismic decoupling occurs only on the shallower plate interface while the deeper interface (50~100 km depths) decouples aseismically following the earthquake. A possible cause for such deep coupling would be thermal; the oceanic lithosphere of the western Pacific is very old and therefore cold, and has subducted beneath the NEJ-Kuril arc.

Keywords: interseismic coupling, decoupling event, elastic strain release, inelastic strain buildup, subduction-related orogen

SSS38-18 Room:303 Time:May 23 15:30-15:45



Japan Geoscience Union Meeting 2012
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SSS38-19 Room:303 Time:May 23 15:45-16:00

Reexamination of the 17th century Kuril multi-segment earthquake

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The magnitude of the 17th century Kuril multi-segment earthquake was estimated to be Mw 8.4 to 8.5, assuming that the distributions of the tsunami deposits in East Hokkaido coasts roughly indicate tsunami inundation areas. However, the tsunami caused by the 2011 off the Pacific coast of Tohoku Earthquake (Mw 9.0) indicated that tsunami inundation areas are wider than distribution of tsunami deposits, suggesting that the Kuril multi-segment earthquake could be larger than Mw 8.5. If the Kuril multi-segment earthquake was larger than Mw 8.5, the tsunami is expected to have been recorded in documents along the Tohoku area. The 1611 Keicho-Sanriku-tsunami is the largest historical tsunami in 17th century along the Pacific Tohoku coast and there is a possibility that the tsunami came from the Kuril trench. Tsunami simulations indicate that the Kuril multi-segment earthquake needs to be as large as Mw 8.9 to generate the tsunami height comparable to those based on histrical records of the 1611 Keicho-Sanriku-tsunami. Further studies of the Kuril multi-segment earthquake are necessary, but the earthquake could be larger than that inferred before.

Okamura, Y. and Namegaya, Y. (2011) Ann. Rept. Active Fault and Paleoearthquake Res., 11, 15-20. (http://unit.aist.go.jp/actfault-eq/english/reports/index.html)

Keywords: giant tsunami, multi-segment earthquake, Kuril trench, 1611 Keicho-Sanriku-tsunami

SSS38-20 Room:303 Time:May 23 16:00-16:15

A fault model of the 1703 Genroku Kanto earthquake inferred from coastal movements, tsunami inundation area and heights

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On December 31, 1703, a large earthquake occurred southern Kanto district, Japan, and was accompanied with coastal movement and tsunami. The earthquake is considered as interplate type along the Sagami trough where the Philippine Sea plate subducts beneath the North American plate.

Previous fault models of the 1703 earthquake are divided into two types. One is the Kasahara's model (Kasahara, 1973, Publications for the 50th anniversary of the great Kanto earthquake, 1923), which represents that the source area extends from Sagami bay to south of Boso peninsula. The other is the Matsuda's model (Matsuda et al., 1978), which represents that the source area extends further off south east of Boso peninsula (fault C). We studied whether fault C is needed for costal movements, tsunami inundation area, and coastal tsunami heights.

We first combined depths of upper surface of the Philippine Sea plate reported by Sato et al. (2005, Science), Takeda et al. (2007, Chikyu Monthly), and Tsumura et al., (2009, Tectonophysics), and 34 sub faults (15 km long and wide) were set on the combined surface. Slip amounts of the sub faults without fault C were inverted from coastal movements estimated from geological and geomorphological surveys (Shishikura, 2003, BERI). As a result, the slip amount of 10 m was estimated in south of Boso peninsula, and that of 5 m was estimated from Oiso to Miura peninsula.

Tsunami inundation area along Kujukuri beach was calculated from the estimated fault model both with fault C (slip amount of 10 m was given) and without fault C. In the former case, the calculated inundation area is similar to that from historical evidences, while in the latter case, the calculated one is quite narrower (Namegaya et al., 2011, An. Rep. Active Fault and Paleoearthq. Res.).

Coastal tsunami heights from Boso peninsula to Izu peninsula were also calculated from both fault models with and without fault C. In the former case, the calculated tsunami heights in the south east of Boso peninsula are similar to those from historical evidences, while in the latter case, the calculated ones are the half of the former case. These results indicate that fault C is necessary for the fault model of the 1703 earthquake.

Keywords: the 1703 Genroku Kanto earthquake, tsunami, coastal movement, Kujukuri beach, fault model

Japan Geoscience Union Meeting 2012
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SSS38-21 Room:303 Time:May 23 16:15-16:30

Crustal movement associated with 1854 Nankai earthquake:Temporal change of damage caused by storm surge and spring tide

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We analyzed historical documents on the 1854 Ansei Nankai earthquake to estimate the crustal movement in Kochi and surrounding areas.

Keywords: Ansei Nankai earthquake, tsunami, storm surge, spring tide, crustal movement

Japan Geoscience Union Meeting 2012
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SSS38-22 Room:303 Time:May 23 16:30-16:45

Evidence for prehistoric large earthquakes in the central Ryukyu Trench ? : Tsunami sediments at the Haneji Inner Bay

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The recent finding of the asperity along the southeastern edge of the main Okinawa Island has suggested huge earthquakes have occurred on the Ryukyu Trench in the subtropic East Asia region. Since documentary evidence of seismic and tsunami events are only available for the past 300 years, long records from continuous sediments are important to clarify the frequency and magnitude.

We have undertaken echo-sounding and coring surveys in the Ryukyu archipelago for the last two years. A preliminary survey was conducted at the Haneji and Shioya bays located along the western coast of the main Okinawa Island. These have semi-closed basin due to the development of coral reefs. It was clarified that the basins were old river channels in the last glacial period and are filled with stably deposited mud layers thicker than 10 meters. Finally, we collected the sediment cores were collected using a Mackeleth piston corer in 2010 and 2012.

The lithology of the cores from the two sites showed a similar pattern, i.e., both sediments are mostly composed of light grey to slightly olived-grey silt with 5 to 10 cm-thick shell fragment assemblage layers intercalated. On the Haneji Inner Bay, the number of this intercalated layer was three at 80, 180, and 280 cm. The lower-most one is the thickest, including coral fragments and rounded pumice. On the Shioya Bay, two layers were recognized at 110 and 280 cm. The 14C dates at the bottom were 2,100 and 1,500 cal yr BP for the Haneji and the Shioya sites, respectively. A linear age-depth model demonstrated that the coral-dominant layers were formed ca. 600-800 cal yrBP, 1300-1500 cal yrBP and 2200-2400 yrBP for the Haneji site and 700-900 cal yrBP and 1400-1600 cal yrBP on the Shioya site, respectively. Hence it could be concluded that the formation emerged almost simultaneously between the two different sites.

It is well known that such layers can be formed by a typhoon or a heavy storm. However, sediments composed of homogenous silt regardless of these catastrophes have been occurred every year on the sites, suggesting that it can exclude such atmospheric events. Hence, these intercalated shell fragment layers (with coral reef fragments and rounded pumice) may be derived from open shallow sea caused by tsumami attacks.

A tsunami simulation model (the width=approx.50 km, the length=200 km, movement=20 m, M=8.5) on the Ryukyu Trench demonstrated that the maximum wave height can be around 15 meters (more than 20-m in case closed-off section of bay) along the east coast of the main Okinawa Island and 8 to 10 meters at the west coast where our sites are situated.

Our result suggests that the possible tsunami deposits found at the Haneji and the Shioya sites may have formed by past huge earthquakes on the Ryukyu Trench. Future efforts should concentrate on investigating not only the recurrence period of the past tsunami events but also the distribution of asperity along the Trench by the observation at the ocean area.

Keywords: central Ryukyu Trenc, large earthquake, tsunami, tsunami sediment

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SSS38-23 Room:303 Time:May 24 09:00-09:15

Heat flow distribution on the floor of the Nankai Trough: Relation to the temperature structure of the seismogenic zone

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The temperature structure of the subducting oceanic plate, generally determined by the seafloor age, is one of the most important factors controlling the subsurface thermal structure of subduction zone. In the Nankai subduction zone, the age of the subducting Philippine Sea plate (Shikoku Basin) significantly varies along the trough, indicating that the thermal structure of the plate interface and the overriding plate accordingly varies along the trough. Surface heat flow observed on the floor of the Nankai Trough is, however, not consistent with the age of the Shikoku Basin. Off eastern Shikoku (off Muroto), the mean heat flow is about 200 mW/m^2, twice as high as the value estimated from the age considering the effect of sedimentation, while it is nearly normal for the age in the area southeast of the Kii Peninsula (off Kumano), around 100 mW/m^2. It is important to investigate the cause of this contrast for estimation of the thermal structure of the subduction zone. We hence have been conducting heat flow measurements on the trough floor between the off-Muroto and off-Kumano areas to examine the transition from high to normal heat flow.

Our previous works showed that in the area west of 136^{o}E heat flow is scattered and the mean value is comparable to that in the off-Muroto area (Yamano et al., JpGU Meeting 2009). The boundary between the western high heat flow and the eastern normal heat flow was not clear because the data was still sparse. In 2011, we conducted heat flow measurements in the Nankai Trough area south of the Kii Peninsula on the cruises KT-11-15 (R/V Tansei-maru) and NT11-23 (R/V Natsushima) and obtained 23 new heat flow data. The results on the Nankai Trough floor revealed that the heat flow distribution shows a rather sharp and distinct change in the vicinity of 136.0^{o}E. In the area west of 136^{o}E, heat flow is highly variable, ranging from 120 to 250 mW/m^2. In contrast, in the area east of 136^{o}E, heat flow decreases eastward from 200 to 100 mW/m^2 in about 50 km with no appreciable scatter. The sharp change at 136^{o}E and high scatter in the western area strongly suggest that the observed heat flow distribution has a shallow origin, probably in the Shikoku Basin crust. 136^{o}E is close to the rupture segmentation boundary between the 1944 Tonankai and the 1946 Nankai earthquakes, across which seismicity on the landward side of the trough significantly changes. It indicates a relationship between the thermal structure of the subducting plate and the seismic activity.

Spinelli and Wang (2008) proposed a model for the high heat flow anomaly on the Nankai Trough floor off Muroto that vigorous hydrothermal circulation in a permeable layer in the subducting oceanic crust efficiently transfers heat upward along the plate interface. If we apply this model to the heat flow transition between the off-Muroto and off-Kumano areas, the permeability structure of the subducting crust, which controls the vigor of fluid circulation, should significantly change at around 136^{o}E. This change may correspond to the transform boundary between the youngest part of the Shikoku Basin formed by spreading in NE-SW direction and the older part formed by E-W spreading. Upward heat transfer by fluid circulation in the subducting crust cools down the plate interface (seismogenic zone of great subduction thrust earthquakes). Variation in the heat flow distribution on the trough floor might therefore reflect along-arc variation in temperature and physical/chemical properties of the seismogenic zone.

Keywords: Nankai Trough, heat flow, hydrothermal circulation, temperature structure, Shikoku Basin, seismogenic zone

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SSS38-24 Room:303 Time:May 24 09:15-09:30

Active structures in the margins of the Kumano Trough revealed by deep-tow subbottom profiler

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The Nankai Trough is a convergent margin at which the Philippine Sea plate is subducting to the northwest beneath the Eurasian plate at a rate of about 4 cm/yr. The area off Kumano is characterized by a well-developed forearc basin called the Kumano Trough and a NE-SW trending continuous outer ridge. Multichannel seismic survey data demonstrate that megasplay faults branch from the master decollement ~50 km landward of the accretionary prism toe to form an outer ridge. A NE-SW elongated depression is developed between the outer ridge and the forearc basin. The deep-towed sidescan sonar WADATSUMI revealed a strong NE-SW lineament on the basin floor of the depression and a swarm of normal faults at the southern margin of the forearc basin. Bacterial mats, tubeworms and carbonate crusts are also observed at landward slopes of the depression where the forearc basin strata are partly exposed. Bathymetirc map off Kii Peninsula suggests a dextral displacement of the axis of Shionomisaki Canyon. In order to know the deformation at the southern margin of the Kumano Trough, we carried out deep-tow subbottom survey and pinpoint core sampling by ROV NSS (Navigable Sampling System) during Hakuho-maru KH-11-9 cruise. We introduced a chirp subbottom profiling system of EdgeTech DW-106 for high resolution mapping of shallow structures on this study. The profile crossing the elongated basin does not reveal a fault plane itself but clearly indicates complex geometry of the sedimentary strata. The zone where the sidescan sonar imagery shows a distinct lineament correspond to a small ridge morphology and exhibits sudden dip changes of the strata. Existence of the continuous ridge and deformation of shallow formation suggest recent strike slip displacement along this lineament.

Keywords: forearc basin, active fault, strike slip, cold seep, accretionary prism

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SSS38-25 Room:303 Time:May 24 09:30-09:45

Geometry and physical properties of mega-splay fault in the Nankai Trough

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We have analyzed 3D geometry of mega-splay fault in the Nankai Trough with reflection seismic data-set, and found that the fault surface is not flat but has a complex bended geometry. The surface also show local variety in the dip azimuth and angles, in the thickness distributions, and in the acoustic impedance distributions. These local varieties are harmonious to the local variety in the fault activity estimated from the slope sediment distributions on the ocean floor.

Keywords: Nankai Trough, mega-splay fault, structural geometry, physical properties, geophysical logging, relecetion seismology

Japan Geoscience Union Meeting 2012
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SSS38-26 Room:303 Time:May 24 09:45-10:00

Friction velocity dependence of the shallow parts of faults within the Nankai Trough at a large displacement

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Frictional velocity dependence of clay-rich fault material collected from the Nankai Trough in IODP Exp.316 at the shallow portion of the megasplay system (C0004) and at the frontal thrust site (C0007) were examined in frictional experiments performed at a normal stress of 5 MPa under water-saturated conditions with >250 mm of displacement. Experimental results derived for slip velocities from 0.026 to 2.6 mm/s reveal that there exist both velocity-weakening and velocity-strengthening materials along the megasplay fault. In contrast, all of the tested fault material from the frontal thrust region shows only positive velocity dependence at the same experimental conditions. The frictional coefficient values for slow slip velocities (v = 0.26 mm/s) are relatively low (0.2 to 0.35) for velocity-strengthening samples compared to the values for velocity-weakening samples (0.38 to 0.49). Microstructural analyses reveal that velocity-strengthening samples generally show homogeneous deformation textures in which the entire gouge layer is deformed, whereas velocity-weakening materials show evidence of shear localization in which deformation is concentrated along narrow subsidiary shears.

Results of XRD analysis shows that each of the tested fault rock samples contains clays (smectite, chlorite, illite and kaokinite), quartz, plagioclase and calcite. Low values of friction recorded for the velocity strengthening samples may indicate a higher content of weak clays in the experimental fault layers [e.g., Summers and Byerlee, 1977; Morrow et al., 1992]. However, a semi-quantitative XRD analysis of the clay fraction performed both on the velocity-strengthening samples and the velocity-weakening samples reveals that clay composition are rather uniform and the variations are small among the all examined fault materials.

These results may imply that velocity dependence of friction along the shallow parts of the faults within the Nankai Trough is sensitive to the variation of the clay content of the fault zones. Alternatively, it could be suggested that another property of the fault material, such as the size distribution of the grains within the fault zone also plays an important role in controlling deformation processes of the faults, whereby the velocity dependence of friction could be affected.

Keywords: Nankai Trough, fault, friction, frontal thrust, splay fault

SSS38-27 Room:303 Time:May 24 10:00-10:15

Hydrological and mechanical properties of hemipelagic and turbidite muds from the shallow Nankai accretionary prism

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We found that two mud samples cored from the shallow (ca 1000 mbsf) Nankai Trough accretionary prism at Site C0002 of IODP Exp. 315 are different in origin; one is a hemipelagic mud and the other is a turbidite mud. The hemipelagic mud sample is poorer in quartz and feldspar (36-37 wt%), richer in clay minerals (36-41 wt%), uniformly fine-grained (1.40+-1.25 micrometer), and less porous (11%). In contrast, the turbidite mud sample is richer in quartz and feldspar (52-58 wt%), poorer in clay minerals (29-34 wt%), relatively coarse-grained and poorly sorted (2.27+-3.59 micrometer), and more porous (38%).

At room temperature, in-situ confining pressures of 36-38 MPa and water pressures of 28-29 MPa, the hemipelagic mud sample has a smaller permeability of 2.9x10^{-19} m^2, while that the turbidite mud sample has a larger permeability of 2.3x10^{-18} m^2. Triaxial compression experiments at these conditions and an axial displacement rate of 10 micrometer/s reveal that the former exhibits a smaller peak strength of 14.5 MPa followed by a slow failure lasting for a minute, whereas that the latter exhibits a larger peak strength of 20 MPa followed by a rapid failure within seconds. Friction experiments at these conditions and axial displacement rates changed stepwise among 0.1, 1 and 10 micrometer/s reveal that the hemipelagic mud sample has a much smaller friction (0.25) than the turbidite mud sample (0.56). Although both samples exhibit rate-strengthening behavior, the former's rate-strengthening is more pronounced than the latter. In addition, the latter may possibly exhibit rate-weakening behavior for large displacements.

Such contrasting hydrological and mechanical properties between hemipelagic and turbidite muds have important implications for faulting in the shallow Nankai Trough accretionary prism, which will be discussed.

Keywords: Nankai Trough accretionary prism, mud sediments, hydrological properties, failure properties, frictional properties

SSS38-28 Room:303 Time:May 24 10:15-10:30

Estimation of Peak stress, Fracture energy and Critical distance from natural fault

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New methods based on the technique of calcite twin piezometer can estimate seismic frictional parameters of peak stress, fracture energy (Gc), critical distance (Dc). Though these are fundamental parameters of fault friction, it has been hard to know from a fault rock.

The calcite records paleo-stress as stress dependent intracrystalline deformation of mechanical twinning. Calcite grains, interleaving between rigid grain aggregate, will deform during elastic deformation of the whole body. The record of stress may be preserved by the indicator after elastic rebound of the whole body. This concept was documented by tri-axial sandstone experiment and numerical simulation of discrete element method (Sakaguchi et al., 2011).

This method is applied to natural fault at Pseudotachylyte bearing ancient seismic Okitsu fault, Cretaceous Shimanto complex. High peak stress of 350 MPa was found at center of fault zone, and it drops to 260 MPa with short distance of several 10 m perpendicular to the fault. Such a localized high stress may result in stress-concentration at rupture front. If dynamic fracture energy is close to concentrated strain energy at rupture front, fracture energy can be estimated from paleo-stress and elastic modules of the fault rock. In fault energy model, peak stress, critical distance and fracture energy are plotted at simple triangle diagram. The critical distance can be assumed from other two parameters.

Keywords: seismic fault, paleo-stress, calcite twin, Dc, Gc

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SSS38-29 Room:303 Time:May 24 10:45-11:00

Change in physical properties of sediments in seismogenic depth along subduction zone: The Cretaceous Shimanto Belt

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Changes in physical properties of Sediment along seismogenic subduction interface is important because lead to understand rock strengthening, dewatering and dehydration processes, and mechanisms seismogenesis. The purpose of study is to understand changes in physical properties of sediment with depth along seismogenic subduction interface. The study area is in the Cretaceous Shimanto Belt, western Kochi, southwest Japan using elastic wave velocities combining with paleo-thermal structures. The velocities dependends on porosity basically, but elastic velocities are more seinsitive in the cahnge with depth than that for porosity. In addition, elastic velocities are useful to discuss the aspect ratio of pore geometory with the change in physical properties. Therefore, we focused on the elastic velocties to examine the change in physical properties.

The Cretaceous Shimanto Belt along the eastern coast of Tosa Bay, Shikoku, SW Japan is composed of multiple melange zones and coherent zones. Paleo-temperature estimated from vitrinite reflectance represents a linear increment from north to south in the temperature from about 150?C to 230?C and sharply decreases at the middle part of study area to about 150?C again. Then the paleo-temperature increases again to the south in the footwall. The boundary is interpreted as a fossil mega-splay fault (Sakaguchi, 1999) or Out of sequence thrust (OST). 11 sandstone and 5 mudstone from hanging-wall, and 6 sandstones and 4 mudstones from footwall were analyzed.

The ultrasonic P- and S-wave velocity measurements were conducted under drained condition with constant pore pressure (1MPa) and varying confining pressure to control effective pressure. The effective pressure ranges from 5 to 65MPa with 5MPa intervals. In the following, we used 1) maximum velocities at the highest effective pressure in each sample (Vmax), 2) the differences in velocities with range of effective pressure (dV), and 3) vitrinite reflectance (VR) at the sampling point to discuss the correlations between them.

No correlation was identified between Vmax and VR in sandstones, but we can see a positive correlation between them in mudstones. There is a positive correlation between dV and VR in sandstones, but no correlation was observed in mudstones. Finally, Between Vmax and dV, the positive correlation was seen in Vp but no correlation was identified in Vs for sandstones, whereas the negative correlation was observed in Vs and no correlation was identified in Vs for mudstones. The results shows reverse relationship between sandstones and mudstones in the correlations between Vmax, dV and VR.

The reverse relationship between sandstones and mudstones suggests that evolutions of physical properties for them are totally different along a seismogenic subduction interface. Sandstones were completely lithifed before seismogenic zone and the change in porosity with depth was not identified in the area. On the other hand, lithification of mudstones progressed with depth in a seismogenic zone. dV depends on a relative amount of anisotropic pore. The volume of anisotropic pore increases in sandstone with depth, whereas the volume in mudstones does not change with depth. The correlations between Vp and dVp for sandstones, and between Vs and dVs suggests that the anisotropic pore orients along foliations or bedding of sediments.

Keywords: accretionary prism, velocity, change in physical properties

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SSS38-30 Room:303 Time:May 24 11:00-11:15

A comparison of the modern Nankai megasplay fault and the exhumed ancient megasplay fault, the Nobeoka thrust

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Megasplay fault branched from plate boundary megathrust in subduction zone is located around the border between outer and inner wedges and is considered to cause great earthquake and tsunami such as 1960 Alaska earthquake, 1944 and 1946 Nankai-Tonankai earthquakes, and 2004 Sumatra earthquakes. Therefore, understanding the fault mechanics of the megasplay faults is essential toward assessing their role in the plate boundary processes and seismo-tsunamigenesis. Seismic reflection studies for the megasplay faults in 2D and 3D in the Nankai forearc present the reflector with negative or positive polarities of various amplitude for the megasplay fault, and suggest complicated petrophysical properties and condition of the fault and its surroundings. The Nankai megasplay fault at a depth of ~5km is going to be drilled and cored by Integrated Ocean Drilling Program, NantroSEIZE experiments and is expected for great progress of understanding of the fault mechanics. Deep portion of the megasplay fault and its connection to the plate boundary megathrust is, however, impossible to be accessed by direct drilling. Far and near field geophysical observation is therefore only way to access the modern and active megasplay fault. On-land exhumed and fossilized megasplay faults, on the other hand, give a clue for the fault mechanics when they were active in depth although the exhumation and fossilization process modifies their primary properties due to physico-chemical weathering and crack opening by unloading. Our previous studies from the Nobeoka thrust in Kyushu, southwest Japan present well-preservation of primary faulting processes and clear contrast of physical property between the hanging wall and footwall.

We have conducted the seismic, drilling, coring and logging investigation into the Nobeoka thrust to the depth of ~250 m including ~40m hanging wall and ~210 m footwall. The coring was ~99% recovery and full logging was successful. The result of the logging together with triangular S-wave vibro-seismic array investigation presents a clear contrast between the hanging wall and footwall. The results indicate how the fossilized megasplay fault is useful to investigate the primary properties in depth, excluding the secondary effects associated with exhumation and surface weathering.

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SSS38-31 Room:303 Time:May 24 11:15-11:30

Continuous coring and logging dataset obtained from fossilized megasplay fault

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Mechanics and evolution of large thrust faults along subduction plate boundaries are one of the essential topics in earth sciences because of their potential for causing catastrophic geohazards. Megasplay faults, large landward-dipping thrust fault braching from plate boundary megathrusts, are one of the candidates for the source of large tsunamis. Deep portion (~5200 mbsf) of the megasplay fault in the Nankai Trough is listed for the next drilling target of the NanTroSEIZE project. In such depths, the megasplay fault is recognized as strong reflector of seismic profiles, however, the thickness, architecture, deformation styles of the fault zone is still ambiguous. To evaluate the status of modern megasplay fault before drilling, we projected drilling, coring and logging to the Nobeoka thrust, Japan, a fossilized on-land analog of such megasplay fault and its basic setting has been constrained (Kondo et al., 2005): Nobeoka Thrust Drilling Project (NOBELL).

Drilling operation continued from July to September, 2011. Coring was operated up to 255 m depth with excellent recovery (99.82%). Visual core descriptions including detail sketch, lithological and structural characterization, measurements on 3,787 structural elements, were performed on the whole core. Subsequently, geophysical logging (temperature, spontaneous potential logging, natural gamma-ray, resistivity, P/S-wave velocity, neutron porosity, caliper) and borehole imaging (optical and ultrasonic wave) were operated and continuous dataset from 12 to 252 m-depth were obtained. Cores were stored in Kochi Core Center (KCC) at Kochi University, and gamma-ray density, magnetic susceptibility measurements were performed by a multi-sensor core logger.

Although analyses of core description and logging dataset are now in progress, various cataclasites and slip zones possibly reflecting protolith type and deformation mechanisms, and many spikes on logging data have been recognized. The results of NOBELL would provide new insights on not only the architecture but mechanics and evolution of ancient and modern megasplay faults.

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Simulation of the Complicated Patterns of Great earthquakes along the Nankai Trough: Part 2

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1. Introduction

We have developed and improved a three-dimensional earthquake cycle model on the basis of the rate- and state-dependent friction law. Hirose and Maeda (2011, JpGU, SSJ) numerically simulated great earthquakes along the Nankai trough and produced some occurrence patterns such as (A) all region ruptured, (B) the Tokai region did not rupture occasionally, which is the case of the most recent Tonankai earthquake in 1944, (C) a part of or all part of the Nankai earthquake occurred two to five years after the Tonankai earthquake, and (D) long-term slow slip events (LSSE) in the Tokai region and Bungo channel occurred periodically. They distributed characteristic displacements (L) and effective normal stress (sigma) heterogeneously considering locations of asperities of the 1944 Tonankai and 1946 Nankai earthquakes (Kikuchi et al., 2003, EPS; Murotani et al., 2007, SSJ), subducting ridges beneath the Tokai district (Kodaira et al., 2004, Science) and Hyuganada, the existence of water due to dehydration from the slab (Rice, 1992; Hirose et al., 2008, JGR). In addition, their model simulated also a pattern that only the Tonankai earthquake occurred. However, further inspection is necessary about the reliability of the model because we do not know that pattern in history.

By the way, it is suggested that the shallow region of the plate boundary slipped largely in the 2011 off the Pacific Coast of Tohoku Earthquake (Mw9.0, hereinafter 2011 Tohoku earthquake) (e.g., Yoshida et al., 2011, EPS). So far, it had classically been considered that aseismic slips had occurred constantly and coseismic slips had not occurred in the shallow region of the plate boundary off the Tohoku district (Uyeda and Kanamori, 1979, JGR). However, it was shown that this assumption was wrong by analysis of the 2011 Tohoku earthquake. In this study, taking above points into consideration, we tried to make a model that the shallow zone along the Nankai trough can sometimes slips largely when an earthquake occurs.

2. Method

As for the simulation method, we assumed that the shear stress on the fault obeys a rate- and state-dependent friction law derived from laboratory experiments (Rice, 1993, JGR). We used here the composite law (Kato and Tullis, 2001, GRL). Assuming that equilibrium between shear stress and frictional stress remains quasi statically, we numerically solved differential equations by the fifth-order Runge-Kutta method with an adaptive step-size control (Press et al., 1992). For simplicity, we considered that frictional parameters a and b depend only on depth and that the seismogenic zones for which (a - b) is negative is within the depth range from the Nankai trough to 30 km (cf. Hyndman et al., 1995, JGR). We assumed that a = 0.001 for the entire depth range, and b = 0.0015 for depths from 0 to 30 km. The characteristic displacement L was taken to be 2.0 m at shallower zone than 10 km; 0.5-1.0 m at subducted ridges beneath the Tokai region, Hyunagada, and intermediate region of the 1944 Tonankai and 1946 Nankai earthquakes; and 0.1 m elsewhere. By following the excess pore pressure model suggested by Rice (1992), (sigma) is given by rgz for z <= 5.66 km and 100 MPa for z > 5.66 km, where z is depth, r = 1.8×10^3 kg/m^3 , and g = 9.8 m/s^2. The plate convergence rate we used along the Nankai trough was 6.5 cm/y in the western part of the study area, decreasing eastward from the Kii Peninsula to 1.5 cm/y in the eastern part of the study area (Heki and Miyazaki, 2001, GRL). Difference from the model of Hirose and Maeda (2011, JpGU, SSJ) is as follows: we set negative a-b, large L (= 2.0 m) in the shallower zone than 10 km.

3. Results and discussion

By setting above parameters, we made the model which shows complicated patterns. We simulated great earthquakes which ruptured up to shallow zones once in a few cycles by setting a barrier with large L at shallower zones than 10 km in depth.

Keywords: Nankai trough, great earthquake, simulation, characteristic displacement

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SSS38-P02 Room:Convention Hall Time:May 24 15:30-17:00

The possibility of seismic slip in the shallow and deep extensions of the seismogenic zone in the Nankai Trough

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In the 2011 Tohoku earthquake, it is generally accepted that the strong shakings and large tsunamis are excited by large slip near the trench axis from the analysis of various observation data (e.g. Fujiwara et al., 2011). Also along the Nankai trough, deposits of huge tsunami have been found from the coastal lakes (Okamura, 2011). However, such tsunamis were considered to be caused by concurrent ruptures of asperities laterally located in the seismogenic zone so far.

Recently, deep sea vessel, Chikyu obtained core data which implies the seismic slip might propagate to the up-dip end of the subduction interface off Kumano along the Nankai trough (Sakaguchi et al., 2011). This suggests that have occurred in the Nankai trough, not only the Showa-type eqs., great eqs. similar to the 2011 Tohoku. While, from model calculations of seismic cycle, by nesting asperity with different fracture energy (hierarchical asperity), both the massive earthquake ruptures up to the trench axis, and the normal earthquake which ruptures only seismogenic zone, may occur in different seismic cycles (Hori et al., 2009). From the above, in order to reconsider the seismic potential along the Nankai trough, we must reevaluate the possible variation of earthquakes there.

We apply the hierarchical asperity model to Nankai trough. To regard the conventional seismogenic zone as a small fracture energy zone, L=5cm is assumed at 10-20km depth. While due to large L=10m in the shallower region, the shallow plate boundary near the trough is modeled as large fracture energy zone.

As results, two types of earthquake with the different value of 0.4 in moment magnitude occur alternately. Hereafter we refer smaller earthquake as S eq., and larger one is L eq.. The interval between S eq. and L eq. is about 170 years, and next S eq. occurs 203 years after the occurrence of L eq..

The S eq. has large slip along the conventional seismogenic zone from Tokai to Hyuga-nada region, and becomes almost similar slip distribution to previously proposed Hoei model (Furumura et al., , 2011). In contrast, during L eq., coseismic slip extends to near the trough axis, and also extends to deeper region until 35km depth where the interpolate coupling is generally considered to be released by occurrences of VLF tremors.

As for vertical deformation expected from slip distributions, for both types of earthquake, the coast of Tosa Bay subsides about 1m similar to historical earthquake. In other regions, hinge line is also placed almost along the Pacific coastline for both eqs.. In Osaka Bay and Setouchi regions, the amount of subsidence in L eq. reaches several meters, since large slip area is extended to deeper than S eq. as mentioned above.

According to the calculations of the tsunami propagation which take the coseismic uplift and subsidence into account, in the case of L eq., tsunami heights of several meters are expected at Setouchi. These amounts of expected tsunami height are comparable to those of the historical records for Hoei event collected by Matsuura (personal communication). On the other hand, in S eq. with a slip distribution similar to the conventional Hoei model, significant tsunami does not reach the Setouchi and Osaka Bay, contradictory to Hoei tsunami data. In addition, the L eq. also predicts a large tsunami at Ryujin pond in Oita Pref. where deposits have been found due to a giant tsunami.

Accordingly, L eq. is consistent with the several observed data which implies the occurrence of huge earthquake along the Nankai trough. However, in L eq., large slip area is distributed from the trench to deeper VLF tremor zone. Hence, it is still unclear whether tsunamis in the pond Ryujin and the Setouchi areas are excited only by local slips such as near the trough, or by large slips over the entire plate interface. We should conduct additional studies to detect the origin of large tsunami and limit the possible models of Hoei type earthquake.

Keywords: Tohoku Earthquake, Nankai Trough, hierarchical asperity, crustal deformation, tsunami

SSS38-P03 Room:Convention Hall Time:May 24 15:30-17:00

Correlation between the interplate coupling and the spherical oceanic lithosphere buckling at subduction zones

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We present a hypothetical model of mechanical stress change on the plate interface due to the slab age increases or decrease after the major spherical buckling.

Here, we assume that the absolute plate motion velocity of the overriding lithosphere is approximately zero at a subduction zone concerned.

Spherical tectonics suggests that, in the case of both edges of the single trench segment having been fixed with the mantle frame, if the slab age is gradually increasing or decreasing, the normal stress on the plate interface, i.e., interplate coupling, will be strengthened or weakened to some extent, respectively.

In the case of the abrupt increase or decrease in the slab age, the spherical slab segment might follow the mechanical buckling theory.

The buckling sequence of the trench segment(s) during morphological transformation is not like as a step function but as a gentle curve of some short period.

This is mainly because of the rheology response for the materials concerned, not only the slab segment itself but also the passive viscous flow regime within the surrounding upper mantle layer as well as the overriding lithosphere.

Keywords: interplate coupling, spherical shell buckling

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SSS38-P04 Room:Convention Hall Time:May 24 15:30-17:00

Large Scale Correlation of Interplate-type Earthquakes in Japan and a Speculative Interpretation

HAYASHINO, Tomoki[1*]

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After gigantic earthquake, 2011.3.11M9.0, it is frequently pointed out that activity of the earth's crust has been enhanced over the entire Japanese archipelogo. Recent big earthquakes(EQs) which took place at faults in continental plates, such as Hyogo-Nanbu EQ(1995, M7.3), Tottori-seibu EQ(2000, M7.3), Niigata-chuetsu EQ(2004, M6.8), Noto-hanto EQ(2007, M6.9), Niigata-jyochuetsu-oki EQ(2007, M6.8), and Iwate-nairiku-nanbu EQ(2008, M7.2), which are extensively distributed on a large scale over Japan, are sometimes discussed in relation to interplate-type EQ 3.11M9.0.

In the present study, the author has investigated long range(i.e., large scale) correlation between Ibaraki-oki interplate-type earthquakes and Hyuganada ones from 1930 to 2010, using the seismic intensity catalog archived by the Meteorological Agency of Japan. Here, earthquakes in two areas are considered to be independent in general, because Ibaraki prefecture is about 1000km distant from Miyazaki prefecture, and the former is belonging to North-American plate, while the latter is located on Firipin-sea plate.

The following results are obtained.

(1) Average event rate between 1930 and 2010 are 0.81 times/year(=4.1/5y) for Ibaraki-oki M>5.7 earthquakes, and 0.45/y(=2.3/5y) for Hyuganada M>5.5 ones.
Both areas seem to show similar time variability, though low statistics.

(2) Define H(high) phase as well as L(low) phase in Ibaraki-oki as the followings,

H phase ; period with 5 or more M>5.7 earthquakes per 5 years
L phase ; period with 4 or less M>5.7 earthquakes per 5 years

Hyuganada has the following M>5.5 earthquakes in each phase of Ibaraki-oki,

Ibaraki-oki	Hyuganada/5years
H phase ;	4.3 +/- 1.0
L phase ;	1.5 +/- 0.4

Although the above correlation is not robust in the present statistics, long range correlation of interplate-type earthquakes would be implied.

In a talk, the author will propose a model which is very speculative, to understand large scale correlation.

Keywords: interplate-type earthquake, time variability, long range correlation

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SSS38-P05 Room:Convention Hall Time:May 24 15:30-17:00

Relations of rupture area of great Kurile earthquakes estimated by tsunami waveform analysis

IOKI, Kei[1*], TANIOKA, Yuichiro[1]

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The Pacific plate subducts about 8cm per year under the Kurile Islands, so many great earthquakes occurred in the Kurile subduction zone. On 13 October 1963, great Kurile earthquake (Mw 8.5, Mt 8.4) occurred off the Etorofu Island. This event was an underthrsut earthquake. The epicenter of the 1963 earthquake is located at 44.8N, 149.5E, depth = 60 km. Also the largest aftershock (Ms 7.2, Mt 7.9) occurred on 20 October 1963. This aftershock generated an unusually large tsunami relative to the size of the seismic waves. The epicenter of the 1963 aftershock is located at 44.7N, 150.7E, depth = 10 km. The 2006 Kurile earthquake occurred northeast of the 1963 Kurile earthquake. The epicenter of the 2006 earthquake is located at 46.6N, 153.2E, depth = 30 km. To examine whether seismic gap exist between 1963 and 2006 earthquakes and to understand source processes of the 1963 main shock and the largest aftershock, slip distributions of the 1963 great earthquake and the largest aftershock were estimated using tsunami waveforms recorded at tide gauges along Pacific Ocean and Okhotsk Sea coast. In the case of the main shock, the total seismic moment was estimated to be 2.4∗10∗∗21 Nm (Mw 8.2). The 2006 earthquake occurred just next to the 1963 earthquake and no seismic gap exists between source areas of the 1963 and 2006 earthquakes. In the case of the largest aftershock, large slip amounts were found at the shallow plate interface near the trench. This largest aftershock was a tsunami earthquake. The seismic moment was estimated to be 1.0∗10∗∗21 Nm (Mw 7.9). On 6 November 1958, the great Etorofu earthquake (Mw 8.3) occurred southwest of the 1963 Kurile earthquake. The epicenter of the 1958 earthquake is located at 44.4N, 148.6E, depth = 80 km. The 1958 great earthquake was defined as a slab event. In this study, dip, depth, slip amount of the earthquake were estimated by tsunami waveforms analysis. Strike and rake of the fault model were fixed. We found that a slab earthquake model of dip = 40 degree, depth = 37.5 km best fit observed and computed tsunami waveforms. The seismic moment estimated by tsunami waveform inversion was 1.7∗10∗∗21 Nm (Mw 8.1). About the 1969 Hokkaido-Toho-Oki earthquake, the earthquake (Mw 8.2) occurred southwest of the 1963 earthquake. The epicenter of the 1969 earthquake is located at 43.2N, 147.5E, depth = 33 km. The 1969 event was an interplate earthquake with the same type event as the 1963 event, but the 1958 event was a slab earthquake. Slip distribution of the 1969 earthquake was estimated from tsunami waveform inversion to investigate relations of locations of the 1969 and 1963 and 1973 earthquake. 1973 Nemuro-Oki earthquake is underthrust earthquake and the epicenter of the earthquake is located at 43.0N, 146.0E, depth = 40 km. The seismic moment of the 1969 earthquake was estimated to be 1.1∗10∗∗21 Nm (Mw 8.0). The 1963 earthquake and 1973 earthquake occurred northeast and southwest of the 1969 earthquake and no seismic gap exists between source areas of these earthquakes.

Keywords: tsunami, great earthquake, Kurile trench

SSS38-P06 Room:Convention Hall Time:May 24 15:30-17:00

M=9.0 Tohoku Earthquake and tsunami; a new interpretation

MARUYAMA, Shigenori[1*]

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M=9.0 Earthquake:

M=9.0 earthquake occurred at 3.11, 2011 and its unusually large magnitude has been discussed since then. Here I propose a different process from the Benioff plane origin, but along a spray-fault that destroyed the fore-arc region. This is a process of tectonic erosion to break the hanging wall of overriding lithosphere, and transport it into deep mantle, presumably in mantle transition zone to develop the 2nd Continents through time.

Origin of spray faults is a manifestation of physically unstable triangular region between material boundary (trench) and physical boundary (spray fault). The tightly connected Benioff thrust dragged down the frontal part of overriding plate to reactivate the spray fault to form M=9.0 earthquake.

Tsunami:

The spray fault occurs right below the trench-slope break which is a turning point of slope change from shallow to deep trench inner wall. Right above the fault, sedimentary basin is present. Huge-scale submarine landslide occurred by the collapse of fulfilled sedimentary basin, which caused the tsunami off Sendai.

The river drainage system on NE Japan is remarkably different from SW Japan. Two major rivers, one from the north and another from the south to transport the eroded sediments on NE Japan meet in Sendai to carry them in the sedimentary basin off Sendai. This basin will periodically collapse, say, every 1000 years, to trigger tsunami.

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SSS38-P07 Room:Convention Hall Time:May 24 15:30-17:00

Have the prior afterslip areas been barriers to the 2011 Tohoku earthquake?

KAWASAKI, Ichiro[1*]

[1]DMUCH, Ritsumeikan U. and TRIES

Common features of rupture expanding process models of the 2011 Tohoku earthquake (eg, Koketsu et al., 2011: Shao et al., 2011: Suzuki et al., 2011: Yoshida et al., 2011: Yagi and Fukahata et al., 2011: Ide et al., 2011) can be summarized as follows

(1) major rupture of slip of 40m to 50m has continued to expand for around 1 minute in an area between N37.5 to N39 longitudinal lines under the continental shelf.

(2) the major rupture to the north has stopped at N39, where was the southern boundary of the afterslip area associated with the 1992 Sanriku-oki earthquake (Mw6.9).

(3) the major rupture to the south has started to cross N39, where was the northern boundary of the afterslip area associated with the 2008 Fukushima-oki earthquake (Mw6.9), while seismic slip has been a few meters, one order smaller than the major rupture.

Questions arise. Why have the major rupture been blockaded at N39? Why has the major rupture been delayed to cross N37.7?

We remember that some afterslips were discovered in Tohoku-oki area in 1990's and 2000's, which are mapped in the figure below. On the other hand, based on numerical simulations invoking with the frictional law of fault slip, Yoshida and Kato (2003) segmented slip area into four modes (K1) - (K4) as a function of (a-b) and Pn (a-b is friction parameter and Pn is the stress normal to a slip plane) and l (inverse of fault stiffness) as

(K1) a-b $<$ 0, l small : asperity.

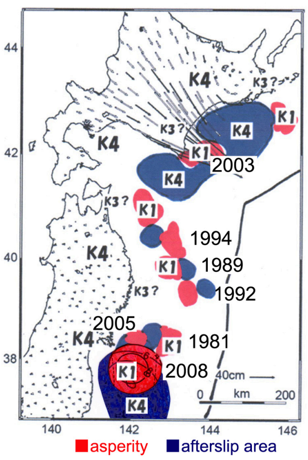
(K2) a-b $<$ 0, l between (K1) and (K3) : stability transition mode, where silent earthquakes recur in the last stage of the seismic cycle.

(K3) a-b $<$ 0, l large : substable sliding mode.

(k4) a-b $>$ 0 : stable sliding mode, where stale sliding is dominant throughout a seismic cycle. When the dynamic rupture occurs in the adjacent asperity, this area act as barrier and if the rupture invade, the rupture is turned into afterslip.

Thus, I would like to propose a hypothesis that the afterslip areas associated with the 1992 Sanriku-oki and the 2008 Fukushima-oki earthquakes have acted as barriers to expansion of major rupture of the 2011 Tohoku earthquake. I also would like to re-emphasize importance of the frictional law of fault slip to understand earthquake physics.

Keywords: 2011 Tohoku earthquake, asperity, afterslip, barrier, friction law



Japan Geoscience Union Meeting 2012
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SSS38-P08 Room:Convention Hall Time:May 24 15:30-17:00

Active faults and large earthquakes around the Japan Trench

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We investigated feature of active sturctures around Japan trench based on 3D anaglyph images. There is an extensive reverse fault ca. 500-km long with long anticlinal bulge on its hanging wall in the landward slope of the trench. The accumulated vertical displacement is over 1,000-3,000 meters, which indicates that the active fault has originated very large earthequakes. The 2011 off the Pacific of Tohoku Earthquake (M9.0) was the same as the previous characteristic earthquakes of the active fault. Other submarine active faults are also recognized close to the hipocentral regions of historical large earthquakes. It is essential to examine submarine active faults im order to make an accureate estimate of future large earthquake. According to the relashionship between historical earthquakes and submarine active faults, there are two large seismic gaps along Janan trench. We need prepare for large earthquakes that may occur in these regions.

Keywords: submarine active fault, large historical earthquake, tsunami, seismic gap, Japan Trench

SSS38-P09 Room:Convention Hall Time:May 24 15:30-17:00

Preliminary report on paleotsunami deposits survey in Higashidori Village, Aomori Prefecture, northern Japan

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[1]Geological Survey of Japan

The rupture area of the 2011 off the Pacific coast of Tohoku Earthquake covers approximately 400 km in length along Japan Trench, and this earthquake raised concerns about future large earthquakes in the north (offshore northern Sanriku) and south (offshore Boso) of the rupture area by changes in balance of stress (Simons et al., 2011). However, there are few historical and geological records to evaluate long-term earthquake history around north and south of Japan Trench. From this perspective, we began geological study of paleotsunami in the Shimokita Peninsula, facing around the boundary between Kuril Trench and Japan Trench.

We found at least three wide-spread sand sheets beneath a narrow valley in Higashidori. The sand sheets are medium to coarse, quartz-rich, and interbedded with clay, peaty clay, or peat. One of the sand sheets was found above a historical volcanic ash B-Tm, of which age shows 10th century. Radiocarbon ages from plant macrofossils just below the sand sheet range 1460-1650 AD and 1480-1650 AD. The other deeper sand sheets were found 200-240 cm and 250-300 cm in depth of the core, but we have not obtained ages yet.

Reference cited;
Simons et al. 2011. The 2011 magnitude 9.0 Tohoku-Oki Earthquake: Mosaicking the megathrust from seconds to centuries. Science 332, 1421-1425, doi: 10.1126/science.1206731.

Keywords: tsunami deposit, Shimokita Peninsula, Japan Trench, Kuril Trench

SSS38-P10 Room:Convention Hall Time:May 24 15:30-17:00

Reexamination of the tsunami trace of Hachijo Island in the 1605 Keicho earthquake

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During the 1605 Keicho earthquake, large tsunami attacked to the large area from Boso Peninsula in Chiba to the Kagoshima bay in Kyushu. Since no strong ground motion was observed during the earthquake it is thought a tsunami earthquake occurred aking the Nankai trough subduction zone.

Because of the Japanese historical backdrop in the beginning of the 17th century, historical records of tsunami damage from this earthquake is very limited. In it, the fact that 57 persons were killed by tsunami in Hachijo Island is an important historical fact, which is based on description of "Hachijo Jikki". Hatori (1975) had pointed out a possibility that the tsunami of a maximum of 10 to 20 m attacked the Hachijyo Island. Since then his opinion has had big influence on the tsunami disaster prevention for Tokai to Kanto area expected for future Nankai Trough earthquake.

The tsunami simulation which assumed the tsunami model for Tokai-type earthquake with fault rupture run from off Tokaido to Suruga bay show the tsunami height at Hachijo Island is about 5-6 m at most. Thus, it is very difficult to reproduce tsunami over 10 m without assuming special phenomenon for the earthquake source model. Actually, Aida (1981)claimed that the extreme tsunami source model which assume that the fault rupture run along the Sagami trough off Boso and Izu Mariana Trench is needed in addition to the ordinary Tokai earthquake model along the Nankai Trough off Tokaido, in order to explain this high tsunami. On the other hand, Yamamoto (1995) scrutinizes the record tradition of the tsunami described in the account of Hachijo Jikki, a map colony position of those days, and the geographical feature of the Island and concluded that the tsunami height of Hachijo Island in the Keicho earthquake was not having reached 10 m. Watanabe (1998) adopted that the height of tsunami during the earthquake is less than 7-8m.

We re-scrutinizated the description of the height of tsunami in the Hachijyo Jikki, and conducted a field survey on 25-27 September, 2011 for reexamination of the Keityo earthquake tsunami. We concluded that the height of tsunami in Hachijyo Island was at most 7-8 m and it did not exceed 10m.

SSS38-P11 Room:Convention Hall Time:May 24 15:30-17:00

Possibility of a hyper earthquake in Southwestern Japan

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Recently it has been recognized that the subduction zone along the Suruga and the Nankai troughs in SW Japan has a potential for an M9-class earthquake, which will be much larger than the 1707 Hoei earthquake. In this assumption, while the source area comprises many fault segments including a deeper part of the subduction zone, the maximum dislocation on the fault is postulated to be smaller than that of the 2011 Tohoku earthquake (M=9.0). However, there is a possibility that the largest earthquakes along the subduction zone may involve a dislocation as large as the Tohoku event, several tens of meters. In order to investigate such a possibility we should invoke data from geological and/or archeological fields, since historical records on earthquakes for the last 1000 years must be insufficient. Based on data of coastal terraces formed in the last 6000 years, I report it is likely that huge events took place repeatedly in the relevant region. Three or four remarkable terraces have been formed at the coasts on the peninsulas, Omaezaki, Shiono-Misaki, and Muroto-Misaki, along the subduction zone (Fujiwara et al., 2004; Shishikura., 2008; Maemoku, 2001). Since the vertical displacements between the terraces are large and the average interval is longer than that proposed for the Hohei-type evets, the terrace forming events should be different from the Hoei-type earthquake. The reported ages of the terraces at Siono-Misaki and Muroto-Misaki are similar to each other. They were formed 4500-4800 years ago, 2700-3000 years ago, about 1800 years ago, and several hundreds years ago. Although the ages of the terraces at Omaezaki are not given accurately, the number of the terraces agrees with those at the other two sites. It is likely that the events forming the terraces are not local phenomena but regionally wide ones. Moreover, there are similar terraces in a wide area in SW Japan. These crustal movements suggest a possibility that hyper earthquakes with large fault areas and dislocations have repeated in SW Japan as well as the Tohoku region of Japan.

Keywords: subduction zone, terrace

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Two historical tsunami deposits recognized in the core sediments along the Hamana River on the Enshu-nada coast, Central

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The Lake Hamana is located along the Nankai trough, where interplate earthquakes have often occurred repeatedly (Shizuoka Pref., 1996). We analyzed diatom fossil assemblages of samples taken from the Arai No. 1 core (Fujiwara *et al.*, 2010). As the result, two historical tsunami deposits are recognized. Radiocarbon ages indicate that the lower deposited at the AD1498 Meio earthquake and the upper at the AD1707 Hoei earthquake or AD1854 Ansei earthquake.

The Arai No.1 core was excavated in a small flood plain between the Peistocene marine terraces and the Holocene sand dunes in the southern part of the Lake Hamana. This plain is consisted of an abandoned channel of the former Hamana river and back-marshes. According to the core stratigraphy (Fujiwara *et al.*, 2010), this core sediment is composed of channel deposit of the former-Hamana river (lower 3.45 m of the core) and a swamp deposit (upper 2.9 m of the core). The upper 0.9 m part of the channel deposit is sandy sediments with many molluscan fossils. Radiocarbon ages taken from this lowland suggest that the upper part deposited around the Meio earthquake (Fujiwara *et al.*, 2010). We performed diatom analyses about the 33 subsamples taken from the core in interval of 2-41 cm. Subsamples were treated based on Kosugi(1993).

Diatom assemblages enabled to be classified the core sediments into 5 diatom zones. The Zone I (3.54, 3.70 and 3.34 ? 3.52 m depth) is characterized by dominance of brackish-marine species such as *Cocconeis scutellum* and *Achnanthes hauckiana*. In the Zone II (2.53 to 3.32 m depth), however, *C.scutellum* and *A. hauckiana* decrease less than 10 % respectively, and *Staurosira construens* increases up to 20-50% with other fresh water species such as *Synedra tabulate* and *Cocconeis placentula*. The Zone III (1.36 - 2.40 m depth) and the Zone IV (1.16 - 0.96 m depth) is resemble each other with abundance of *S. construens* and *Pinnularia* spp. The Zone V (1.27 - 1.33 m depth) is corresponding to the muddy layer between the swamp deposits (1.25-1.33 m depth) and characterized by the spike of marine species of *Thalassiosira* sp. occupying approximately 10-40 %. This muddy layer is recognized successively in horizontal direction in eastern part of the lowland.

The Zone II shows obvious increasing of fresh-marine diatom species instead of brackish-marine species. This indicates that environmental change from river mouth to fresh-brackish marsh or pond. Stratigraphy and radiocarbon ages show that this environmental change occurred rapidly after the Meio earthquake. On the other hand, the dominance of outerbay diatom speacies in the Zone V indicates that marine water flowed into the fresh water marsh from the Pacific Ocean due to a tsunami current. Radiocarbon ages around the core indicate that the zone V was formed at the AD1707 Hoei earthquake or AD1854 Ansei earthquake. The Zone V shows similar core faces to the fore-end of the tsunami deposit of the 2011 Tohoku earthquake (Fujiwara *et al.*, 2011). The upper tsunami deposit including the Zone V has 8 cm thickness at least, therefore it suggests that inundation limit of the tsunami flows was further inland than the Arai No.1 core site.

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Keywords: Lake Hamana, Tsunami deposit, Meio earthquake, Diatom fossil assemblage, Nankai trough

Japan Geoscience Union Meeting 2012
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SSS38-P13 Room:Convention Hall Time:May 24 15:30-17:00

Petrophysical properties of fossilized seismogenic megasplay fault

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To understand the evolution and fault mechanism of subduction zone megasplay fault branching from plate boundary, Nobeoka Thrust Drilling Project (NOBELL) was carried out in 2011. Nobeoka Thrust is known to be a fossilized megasplay fault (out-of-sequence thrust) in ancient accretionary complex, located onland in Kyushu, Japan. In this project, coring and wireline logging were conducted down to 255m in total depth across the Nobeoka Thrust. Continuous logs of resistivity, density neutron porosity, natural gamma ray, and optical/sonic images were successfully acquired along the borehole wall.

In this study, we focus on the interval of 20-60m, including the main fault core (at 41m), and compare the physical properties among hanging wall, footwall, and fault core, correlating logging datasets and core description. Structure of hanging wall is characterized by phyllite and relatively stable foliation. Stronger deformation and boudinage can be seen from ~38m toward fault core. Random fabric cataclasite characterizes fault core, while cataclasite / foliated cataclasite are spread throughout footwall.

Footwall presents higher values of neutron porosity (4.6-10.5%) compared to hanging wall (2.3-8.7%), while porosity is lowest (3.2-10.2%) around fault core. Resistivity is higher at hanging wall (SN: 138-622 ohm-m), followed by drop near fault core (151-203 ohm-m) and stably lower footwall (163-323 ohm-m). P-wave velocity is highly fluctuated and slightly higher at hanging wall and higher values at fault core (3.3-5.0m/s) and values are stable at footwall (3.8-4.6m/s). Local decreases in natural gamma ray (91.9-134 API) and spontaneous potential (39.4-57mV) are characteristic around fault core, while values are nearly constant at hanging wall (81-158 API, 18.7-64.2mV) and footwall (91.1-152 API, 53.3-59.7mV). Density log is fluctuated and does not show significant changes throughout depth (2.4-2.9g/cc).

Crossplots of these logging data are useful to examine relationship between the logs and extract different responses with depth. A resistivity-porosity plot clearly illustrates that the fault core, hanging wall, and footwall show different trend. We also apply empirical formulas (such as Archie's formula and Wyllie's formula) to evaluate relationship between physical properties and internal structure and characterize hydrological properties. Permeability derived from porosity and resistivity show highest values around fault core, despite the lowest porosity value at the interval. These results provide important suggestions to understand structural and hydrological properties associated with fault activities and to connect modern and ancient seismogenic megasplay faults.

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SSS38-P14 Room:Convention Hall Time:May 24 15:30-17:00

Illite crystallinity of the borehole samples penetrating the Nobeoka thrust, Miyazaki prefecture, SW Japan

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A borehole penetrating the Nobeoka thrust was drilled at Nobeoka city, SW Japan as analogue of NanTroSEIZE project. The Nobeoka thrust is a fossilized OOST in the Shimanto belts, Cretaceous and Paleogene accretionary complex in SW Japan. Total drilling length was 255m and continuous core samples were recovered. The borehole runs through the Nobeoka thrust at the depth of 41.7m. The hangingwall is Kitagawa group mainly consist of phyllite and the footwall side is melange of Hyuga group (*Kondo et al., 2005*).

In the present study, we present preliminary results of X-ray diffraction analysis of the fragmented core samples. Constituent minerals are mainly quartz, plagioclase, illite, chlorite and calcite. The mineral assemblages are almost the same from the top to the bottom. We determined illite crystallinity (illite crystallinity, IC), one of the indicator of paleotemperature, using oriented samples.

IC values in the hangingwall range from 0.163 to 0.185^o, those in the main thrust zone range from 0.678 to 0.701^o, and those in the footwall ranges from 0.369 to 0.550^o. The IC values show clear difference among the hangingwall, the main thrust zone and footwall. The paleotemperatures, calculated after the conversion formula (*Mukoyoshi et al., 2007*), are 315-319^{o}C in the hangingwall, 209-213^{o}C in the thrust zone and , 240-277^{o}C in the footwall. Vitrinite reflectance analyses indicate that the maximum temperatures of the hanging wall and footwall are approximately 320and 250^{o}C, respectively (*Kondo et al, 2005*), which agree to our results.

On the other hand, the samples in the main thrust zone indicate a larger IC values and lower paleotemperatures. The later faulting and alteration under lower temperture probably affected only on the main thrust zone, though the mineral assemblages do not show remarkable change.

Keywords: Fault, Borehole core, Accretionary Complex

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Stress analysis on various deformation features in on-land accretionary complexes: Shimanto Belt, Shikoku, SW Japan

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At an accretionary subduction zone, sediments are deformed by underthrusting, accretion, and earthquake. Corresponding deformation features are identified in on-land accretionary complexes such as tectonic melanges, shear veins, underplating faults, out of sequence thrusts, and localized faults with pseudotachylyte. Those deformation features are formed under different stresses and stages. Furthermore, those changes in stress and stages of deformation reflect change in physical properties and fluid pressures along subduction interface, which is strongly related to architecture and strength of accretionary wedges and seismic behavior. The purpose of this study is to understand the time-spatio changes in deformations and stress along subduction interface from on-land accretionary complexes.

The study areas are Yokonami melange (Cretaceous) and Mugi melange (Cetaceous and Paleogene). Both are in Shimanto Belt, Shikoku, Southwest Japan. They are composed mainly of sandstone blocks and black shale matrix with minor basalt, chart and tuff. The localized slip zones, the Goshikino-hama fault for Yokonami melange and the Minami-awa fault for Mugi melange, are identified at the northern boundary of the melange zones. Shear veins are well developed both in the melange zones. Slicken lines and slicken steps are well preserved on the shear vein surfaces. In the Mugi melange, underplating faults at the bottom of the oceanic basements are well exposed. Fluidization was reported along the underplating fault.

For stress analysis, we used Multiple inverse method (MIM, Yamaji, 2000) and Hough inversion method (HIM, Yamaji, 2006). Examined deformation features are 1) shear veins in Yokonami melange, 2) faults at the Goshikino-hama fault, 3) shear veins in Mugi melange, and 4) underplating fault in Mugi melange. Comparing between MIM and HIM, we found that the MIM provided a better result on the basis of misfit analysis. Therefore, we use stress from MIM. Further, we use one stress for each deformation feature with the smallest misfit in the following discussion.

To compare the results of stress, the stress orientations are reconstructed by rotations of fault planes to be horizontal because the averaged orientation of foliation is varied between deformation features and those fault planes would be horizontal at the time of deformation. The obtained stresses are as following. 1) A low angle N-S compression with 0.32 of stress ratio for shear veins in Yokonami melange, 2) a low angle NE-SW compression with 0.22 of stress ratio for the Goshikinohama fault, 3) a low angle NNE-SSW compression with 0.05 of stress ratio for shear veins in Mugi melange, and 4) a low angle E-W compression with 0.45 of stress ratio for underplating fault, where stress ratio is defined as ($sigma_2$ - $sigma_3$)/($sigma_1$ - $sigma_3$). The orientations of stresses for 1), 2) and 3) are similar to each other. On the other hand, the stress orientations and stress ratio for 4) is completely different from others.

Effective frictional coefficient (M') was also examined by the lowest ratio between normal and shear stresses on fault planes as suggested by Angelier (1989). M' are related to frictional coefficient M and fluid pressure ratio lambda as following equation.

M' = M(1 - lambda)

Obtained effective frictional coefficients for each deformation feature are 1) 0.11-0.48, 2) 0.49-0.79, 3) 0.14-0.35, and 4) 0.05-0.23. M' for the Goshikino-hama fault is relatively high, indicating decrease of fluid pressure at the time of fault activity. Others have relatively low M'. Shear veins have a much of precipitated quartz and calcite. Those minerals suggests that large amount of fluid are existed for the deformation. The lower M' for underplated fault can be explained by the fluidization along the fault that was reported by previous study.

Keywords: paleostress, subduction zone, accretionary complex, melange, underplating fault, effective frictional coefficient

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Development of geo- and fault-thermometer using a raman spectoroscopy tecqbuque on carbonaceous material

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In order to develop geothermometer of low-grade metamorphic rocks, we examined Raman spectrum of poorly-ordered carbonaceous materials (CM) with different metamorphic temperatures. The CM samples used in this study were collected from the Miocene Hota complex (50^{o}C) (Yamamoto et al., 2005), the Cretaceous Shimanto complex (150^{o}C and 230^{o}C) (Mukoyoshi et al., 2006) and the Jurassic Ashio complex (300^{o}C) and measured the Raman spectra. In addition, the CM is also matured by frictional heating of a fault even during short-periods coseismic sliding (several seconds' process) (e.g., O'Hara et al 2006). Such maturation of CM can be used for a fault-thermometer to estimate frictional heat along a fault during an earthquake. Thus, we performed laboratory friction experiments on CM to determine how the Raman spectra of the CM change with frictional heat. The experiments were conducted simulated gouge (a mixture of 90 wt% quartz and 10 wt% vitrinite) at slip velocities of 0.0013-1.3 m/s, normal stress of 1.0 MPa and displacement of 15 m under anoxic, nitrogen atmosphere, while measuring temperature in the gouge zone by thermocouples.

Here, we present our preliminary attempt for developing a geothermometer using Raman spectra of CM. On poorly-ordered carbonaceous materials, first-order Raman spectrum often decomposed into four peaks of a Raman shift (G peak at about 1580cm^{-1}, D1 peak at about 1350cm^{-1}, D2 peak at about 1620cm^{-1}, D3 peak at about 1500cm^{-1}) (e.g., Bayssac et al., 2002; Aoya et al., 2010). In our amorphous CM (coal) samples we recognized other three peaks on the D1 peak around 1150 cm^{-1}, 1220 cm^{-1} and 1450 cm^{-1}. The first-order Raman spectra of our coal samples, in particular low-temperature samples, are hard to fit with decomposed four peaks using the LabSpec program due to the influence of faint shoulders on D1. However, the Rama spectra can be fit well when we used the above seven peaks. In this study, we define an area ratio of D1/[decomposed seven peaks] as R6. The correlation between R6 and T is given by

T (^{o}C) =10.9*exp(11.9*R6) (R^2=0.99)

These correlations can be used for a potential geothermometer for low-grade metamorphosed sediments, in the temperature range of 50-300^{o}C. We will present a potential fault thermometer using Raman spectra of CM in the meeting.

Keywords: raman spectroscopy, vitrinite reflectance, carbonaceous material, geothermometry, frictional heat, fault rock

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Sensitivity analyses of slip parameter estimation to hydrological and thermal properties

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Sensitivity analyses of slip parameter estimation to hydrological and thermal properties

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Abstract
Enormous earthquakes repeatedly occur in subduction zones, and the slips along megathrusts, in particular those propagating to the toe of the accretionary prism, generate ruinous tsunamis. Although quantitative evaluation of slip parameters (i.e., slip velocity, rise time and slip distance) of past slip events for the shallow, tsunamigenic part of a fault is a critical component of characterizing such earthquakes, it is very difficult to constrain these parameters. Here we quantify these parameters for slip events that occurred along the shallow part of a megasplay fault and a plate boundary decollement in the Nankai Trough, off Japan. We applied a kinetic approach to profiles of vitrinite reflectance data obtained from Integrated Ocean Drilling Program (IODP) cores that intersected the slip planes of the two thrusts, and identified extremely slow and long-term slips in the megasplay fault and the frontal decollement.

The chemical kinetic method is useful to evaluate fault temperature and slip parameters. This has been introduced into various natural faults, however, this contains uncertainly due to its sensitivity to temperature which is dependent on various natural properties complicatedly. Therefore, we also discussed the effect of temperature dependence of thermal property or dynamic weakening mechanism for temperature calculation. We assessed the sensitivity of the calculation results to the measured thermal property and dynamic weakening effect caused by thermal pressurization.

Keywords: fault material, slip parameter, parameter sensitivity

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Relationship between compressional-wave velocity and porosity of sediments along subduction plate interface

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Evolution of physical properties of sediments along subduction interface has an effect on wedge strength, wedge geometry, dewatering and dehydration processes, and seismic behavior. Sediments have initially more than 70% of porosity prior to subduction. Through underthrusting and accretion, porosity of sediments decreases by compaction and cementation to be lithified sediments. The purpose of this study is to understand evolution of physical properties from a state before subduction to a state within a wedge using a relationship between compressional-wave velocity and porosity.

In this study, we obtained new data for sediments from a reference site in IODP NanTroSEIZE, Expedition 333, sites in Expeditions 315 and 316. In addition to that, we have complied velocity-porosity relationships obtained by previous studies from NanTroSEIZE (off Kumano) (Hashimoto et al., 2010, 2011, Raimbourg et al., 2011), ODP Leg 190 (off Shikoku) (Hoffman and Tobin, 2004) and ODP Leg 170 (off Costa Rica) (Gettemy and Tobin, 2003).

Locations of sites are as following: For off Kumano, Site C0011 in Expedition 333 is in reference site (prior to subduction), Site C0006 is located at toe of accretionary prism, C0004 is located on a Megasplay fault, Site C0001 is located at landward of C0004 and ocean-ward of Kumano basin, and C0002 is located in the Kumano basin above the seismogenic zone. For off Shikoku, Site 1173 and Site 1174 are located in reference sites, off Muroto and Off Ashizuri, respectively. For off Costa Rica, Site 1039 is located 1.5km of ocean-ward of deformation front (reference site), Site 1043 and Site 1040 are located in 0.6km and 1.7km landward from deformation front, respectively.

Velocity measurement procedure in this study to obtain new data is as following: In the velocity measurements, two pumps (Teledyne ISCO 1000D syringe pump) were used to control pore fluid pressure and confining pressure. The pore pressure of 1000kPa was kept under drained conditions. Confining (effective) pressure was increased stepwise in the measurements. Velocity measurements were conducted under isotropic pressure conditions. Confining pressure was pressurized in tens seconds and kept for more than 8 hours for next step to obtain equilibrium conditions between effective pressure and sediments strain. About 8 steps were conducted for each sample. A in situ effective pressure was approximated for each sample from the accumulation of the bulk density of sediments and hydrostatic pore fluid pressures at the depth of recovery. The maximum effective pressure for each test was up to about 2.5 times of in situ effective pressure. Lead zirconate titanate (PZT) shear wave transducers (500kHz) were used in a source-receiver pair to measure wave speed. PZT in a shear orientation generates a weak compressional mode in addition to its primary shear mode.

Porosity and P-wave velocity ranges about 27 ? 65% and 1.5 ? 2.6 km/s in this study. The P-wave velocity from Raimbourg (2011) is relatively about 1.0 km/s higher at corresponding porosity comparing with that from Hoffuman and Tobin (2004) and Hashimoto et al., (2011).

Sediments were classified into two, simply compacted sediments (reference site and slope sediments) and wedge sediments. Different trend in Vp-porosity relationships were observed for the classified sediments. For compacted sediments, Vp-porosity relationships are along the global empirical relationships (Erickson and Jarrard 1988) and within the area between normal and highly compaction curves. On the other hand, some of Vp-porosity relationships for wedge sediments represent trends with higher velocity at a porosity. Such trend was observed for wedge sediments from Site C0001, C0002 and even from Costa Rica. Those higher Vp trend in Vp-porosity relationship for wedge sediments can be explained by shear strain of sediments and or cementation.

Keywords: compressional-wave velocity, porosity, subduction plate boundary, accretionary complex

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X-ray CT imaging and hydrologic characterization of fractured core samples under stress

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Analyzing fluid flow within naturally fractured samples under in-situ stress conditions is desirable. The present study first focuses on the feasibility of a precise 3D numerical modeling coupled with X-ray computed tomography (CT), which enables simple analysis of heterogeneous fracture flows within core samples, as well as the measurement of porosity and permeability. A numerical modeling was developed and applied to two fractured granite core samples having either an artificial single fracture or natural multiple fractures. With a linear relationship between the CT value and the fracture aperture, 3D distributions of the CT value for the samples were converted into fracture-aperture distributions in order to obtain fracture models for these samples. The numerical porosities reproduced the experimental porosities within factors of approximately 1.3 and 1.1 for the single fracture and the multiple fractures, respectively. Using the fracture models, a single-phase flow simulation was also performed. The numerically obtained permeabilities reproduced the experimental permeabilities within factors of 1.3 and 1.6 at for the single fracture and the multiple fractures, respectively. Consequently, a precise numerical modeling coupled with X-ray CT is essentially feasible. Furthermore, the development of preferential flow paths (i.e., channeling flow) was clearly demonstrated for multiple fractures, which is much more challenging to achieve by most other methods.

The method was then applied to two granite core samples having either a mated artificial or a mated natural fracture at confining pressures of 5 to 50 MPa. Numerical results were evaluated by a fracture porosity measurement and a solution displacement experiment using NaCl and NaI aqueous solutions. The numerical results coincided only qualitatively with the experimental results, primarily due to image noise from the aluminium liner of the core holder. Nevertheless, the numerical results revealed flow paths within the fractures and their changes with confining pressure, whereas the experimental results did not provide such results. Different stress-dependencies in the flow paths were observed between the two samples despite the similar stress-dependency in fracture porosity and permeability. The changes in total area of the flow paths with confining pressure coincided qualitatively with changes in breakthrough points in the solution displacement experiment. Although the data is limited, the results of the present study suggest the importance of analyzing fluid flows within naturally fractured core samples under in situ conditions in order to better understand the fracture flow characteristics in a specific field. X-ray CT-based numerical analysis is effective for addressing this concern.

Finally, a novel core holder with a carbon fiber reinforced polyetheretherketone (CFR PEEK) body has been proposed and developed. Medical CT scans for granite and sandstone samples containing a saw-cut fracture revealed that the core holder had no adverse influence on image quality due to the small X-ray attenuation. Moreover, with medical CT scans using the new core holder, a numerical analysis of single-phase flow was successfully completed on a fractured granite sample at confining pressures of 3-10 MPa, where real fracture porosities and permeabilities could be predicted within factors of 1.2-1.3 and 1.4-1.5, respectively. Although the maximum available confining pressure and sample size are currently limited due to the design, the novel core holder with the CFR PEEK body enables CT scans on fractured samples under confining pressure without image noise problem. Consequently, with the new core holder or a core holder having similar X-ray attenuation, the X-ray CT based numerical analysis can be successfully conducted on naturally fractured samples under confining pressure, which should contribute to better understanding of fluid flow characteristics in the crust.

Keywords: X-ray CT, hydrological characteristics, fracture, core sample, stress

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Seismic inversion of the incoming sedimentary sequence in the Nankai Trough off Kumano Basin, southwest Japan

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Huge earthquakes have been repeated in the cycle of 100–150 years in the Nankai trough. The south western Japan have been struck terrible shakeups and tsunamis by these earthquakes. In these days the next emergence of the earthquake becomes one of the most serious issue in Japan. Therefore detailed description of geological structure is urgently needed to understand mechanism of the seismogenic zone of this area. Moreover, this area is getting attentions of scientists as the most surveyed subduction zone with accretionary prism in the world and recently becomes an important research target of IODP (Integrated Ocean Drilling Program). The seismic inversion technique is an inversion method to estimate physical parameters of layers on seismic profiles: in this method a seismic profile is modeled as convolution of measured physical properties with an estimated wavelet, and actual physical properties are estimated by the modeled seismic profile if the convolved profile shows good fitting with the observed one. We use 3D MCS (3D Multi-channel Seismic reflection survey) data which was acquired on KR06–02 research cruise in 2006, and measured physical properties of borehole logging and sediment cores by IODP Expedition 319 and 322 cruises in 2009. This study aims to challenge CLSI (Core–Logging–Seismic Integration) on the sediments layer of the Nankai trough.

Keywords: Nankai trough, Multi-channel Seismic reflection, sediments, seismic inversion

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Shallow structure and evolution of active faults with strike-slip in a forearc basin, eastern Nankai Trough

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Accretionary prisms and forearc basins are developed in the Nankai Trough, SW Japan. Many active faults are recognized and classified into five fault systems in the eastern Nankai Trough. The Enshu Faults System, the most landward one, runs over 200 km along the northern edge of the Tokai, Enshu and Kumano forearc basins. Structural investigation of this area is important for earthquake disaster mitigation as well as understanding of oblique subduction tectonics. However, activity and distributions of faults has not been well clarified.

The Enshu Faults System has a general trend of ENE-WSW, on the basis of swath bathymetry and side-scan sonar imagery, and shows dextral strike slip inferred from displacement of the canyon axis across the landward-most fault. Seismic reflection profiles partly exhibit landward dipping faults. These observations suggest that this area is tectonically affected by oblique subduction of the Philippines Sea Plate.

We picked continuous reflectors and divided the formation into five units on the multichannel seismic profiles obtained by JOGMEC, and carefully studied thickness changes of the units across the faults, which reflect fault activities. Approximate positions of faults are estimated by discontinuities of seismic reflectors although fault planes are hardly recognized. Moreover, geometry of formations beneath the lineaments identified on the sidescan sonar imagery suggests existence of flower structures along fault zones. The formation thicknesses above the acoustic basement occasionally change across these fault zones. In most cases, the formation thickness seaward of the fault zones is thicker than that landward of them suggesting transpressive deformation. However, time and space distribution of unit thickness changes imply that fault displacements are not uniform along each fault zone. In order to know the recent fault activity, we carried out deep towed chirp subbottom profiler survey. In the base of the steep slope corresponding to the strong lineament, the shallow sedimentary sequence exhibits seaward divergent shape of reflectors. These depositional styles indicate recent activity of crustal movement by faulting although a fault plane is not recognized in the shallow sediment. In contrast, the dimmed seismic reflectors with tiny displacements were observed in the upper part of the slope. Shallow extension of the fault planes and existences of cold seep previously observed by a submersible survey suggest that these fault systems are still active at present.

Keywords: Oblique subduction, Strike-slip fault, Active fault, flexure

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Accumulation process of earthquake-induced turbid layer in the slope basin -An example from the Nankai Trough off Kuman-

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Earthquake shaking is one of triggers for submarine slope failures and causes sediment redeposition in the base of the slope. Sedimentary section of the slope basin in an accretionary prism continuously and well records past activity of earthquakes for a long term and with a high accuracy. Therefore, it is one of useful proxy to understand coseismic geological phenomenon. However, it is inferred that earthquake-induced turbid mud settles out so fast. In this study, because sedimentation processes on earthquake-induced sediment are not well illustrated so far, I am anaryzing settling processes of earthquake-induced turbid mud in deep sea.

Muddy deposits in a deep-sea region generally show slow sedimentation rate. The velocity is several mm to several dozen mm per one thousand years. However, the observation by ROV "NSS" during KH-10-3 cruise (*R/V Hakuho-maru*) illustrated that thick turbid layers in the prism slope completely settled six years after the 2004 off Kii peninsula. Therefore, it is inferred that earthquake-induced turbid mud settles out during short period. Two turbid layers specifying different degrees of turbidity are composed of upper dilute suspension layer and bottom dense suspension layers. The measured water depth at the slope basin in 2010 shows high variation suggesting seafloor undulation. In contrast, the measured water depth in 2004 by NSS during KY04-11 cruise (*R/V Kaiyo*) was very constant. This observation indicates that the measured water depth corresponds to the upper boundary of a dense suspended layer as a pseudo-seafloor.

A chirp subbottom profiler (SBP) surveys were carried out during the KH-10-3 and KH-11-9 cruises. We successfully obtained high resolution structural images down to a maximum of about 30m. Sedimentary reflectors of the slope basin are mostly flat-lying and laterally coherent. Moreover, three transparent layers are developed at a depth shallower than about 10 meter below a seafloor. Observation of dense turbid layers after the 2004 earthquake and existence of distinct transparent layers in the slope basin suggest periodic accumulation of earthquake-induced turbid layer.

Keywords: turbid layer, redeposition, earthquake-induced sediments, sedimentary structure

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Closely-spaced heat flow measurements in the vicinity of the splay fault on the the Nankai accretionary prism

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Heat flow measurements have been conducted in the Nankai Trough area southeast of the Kii Peninsula (off Kumano) for investigating the thermal structure of the target area of IODP seismogenic zone drilling (NanTroSEIZE). Combining the data obtained with ordinary heat-flow probe and long-term monitoring instruments with those estimated from gas hydrate BSRs, the overall pattern of heat flow distribution was delineated. Heat flow is around 100 mW/m^2 on the floor of the Nankai Trough and decreases landward to 40 to 60 mW/m^2 in the forearc basin (Kumano Trough), which should reflect the thermal structure of the seismogenic zone and the overriding plate. On the slope of the accretionary prism, however, highly scattered values (60 to 100 mW/m^2) were obtained about 15 to 25 km landward of the deformation front, where the megasplay fault system approaches and intersects the surface. Possible causes of the scatter are: localized fluid flow along active faults, recent deformation near the surface including submarine landslides, bottom water temperature variation (BTV), and topographic disturbance.

To study the relation between the scattered heat flow and tectonic activities around the splay fault, we conducted closely-spaced heat flow measurements at two sites on the prism slope on KH-10-3 and KH-11-9 cruises of R/V Hakuho-maru in 2010 and 2011. One site is located around a prominent 400-m high scarp associated with a branch of the splay fault, At the foot of the scarp, biological communities have been found, indicating cold seepage activity along the fault. The observed heat flow is higher on the seaward side of the scarp and lower on the landward side. The highest values were measured at the foot of the scarp. The overall heat flow distribution across the scarp is attributable to the effect of bathymetric relief, whereas the local high at the foot of the scarp might arise from upward fluid flow along the fault. The other site is located around a U-shaped slump scar topography on the middle part of the prism slope and measurements were made along a line crossing the scar. The obtained data show no significant heat flow variation across the scar. It suggests that submarine landslide corresponding to the scar is not a very recent event.

We also conducted long-term temperature monitoring with pop-up type instruments and obtained bottom water temperature records for 15 months at two stations with water depths of 2550 and 3340 m. The record at the 2550-m station shows large BTV over 0.3 K, similar to the one previously obtained at about the same water depth. BTV with this amplitude has significant influence on temperature distribution in surface sediment. The BTV observed at the 3340-m station is much smaller, less than 0.1 K, and cannot cause appreciable variation in heat flow measured at the surface. Half of the existing scattered heat flow values were measured at sites shallower than 3000 m and may have been affected by BTV. We need to collect more long-term water temperature records at depths around 3000 m for evaluation of influence of BTV and for measurement of undisturbed heat flow.

Keywords: Nankai Trough, heat flow, accretionary prism, splay fault, cold seep, submarine landslide

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Back-ground seismicity within the Philippine Sea Plate off Shiono-misaki based on ocean-bottom seismographic observation

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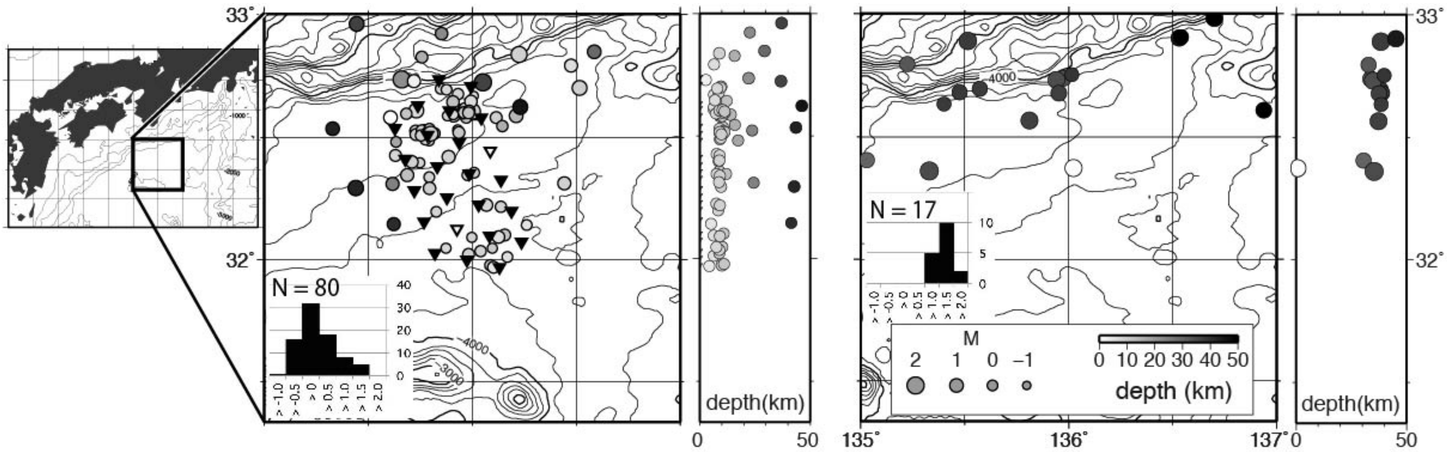
From 2005 to 2008, we repeated short-term ocean-bottom seismic (OBS) observation four times to confirm ambient micro-seismicity at depths between about 10 km and 25 km beneath the axis of the Nankai Trough off Cape Shiono-misaki in Kii Peninsula, southwest Japan (Yamazaki et al., 2011, Tech. Rep. MRI). This micro-seismicity is poorly recorded by land seismic networks. Obana et al.(2005, JGR) distinguished them into two groups; shallow microearthquakes occurring within the oceanic crust of the incoming Philippine Sea Plate (PSP) (around 10 km in depth) and deep ones occurring in the uppermost mantle of PSP (about 15 km to 25 km in depth). They also reported that composite focal mechanisms of the shallow microearthquakes showed extensional stress in the direction nearly normal to the trough axis and those of the deep ones showed compressional stress in the direction normal to the trough axis, indicating "bending" of the incoming PHP. If so, how far south from the Nankai Trough axis the plate bending stress starts and how it develops?

To investigate this problem, we conducted OBS observations to the south from the trough axis between mid June 2009 and mid September 2009. The OBS network consisted of 24 short-term OBSs (4.5 Hz, 3-comp.) with a spacing of about 15 km (8 n.m.). We recovered 22 OBSs after a three-month long development. Deployment and recovery of the OBSs were done with R/V Ryofu-maru of JMA. After a linear correction of internal OBS time stamp, we picked arrival times of P-waves, S-waves and PS converted waves, which the picking of last phases is required for finding a set of initial station correction (i.e., sediment layer correction). Then we determined hypocenters assuming an appropriate one-dimensional velocity structure estimated based on a nearby seismic refraction experiment (Kodaira et al., 2000, Science). Next averaged differences between observed travel time and estimated travel times (O-C times) for each OBS were calculated. The averaged O-C times were then added to the previous station correction values, and the hypocenters were relocated. We repeated this procedure two times.

Figure shows preliminary hypocenters located in this study for the first 30 days of the observation period. Open circles and closed inversed triangles indicate hypocenters and OBSs, respectively. Hypocenters deeper than 30 km occur only outside the OBS network, indicating that their depths are not constrained. Within the OBS network, we find that the smallest earthquakes with magnitudes less than 1, which are defined as "ultra-microearthquakes(UMEs)", occur around 10 km in depth (upper panel of figure). JMA land-based seismic network does not detect the activity (lower panel). The OBS network was arbitrarily positioned and UMEs are probably a widespread feature of the seismicity in the incoming plate. So we propose that similar UMEs occur in wider area outside of the present OBS network. Among the two groups of microearthquakes reported by Obana et al., the deep microearthquake activity in the uppermost mantle within the present OBS network can be identified in the northern region of the OBS network (near the trough axis) but not in the southern region (toward the outer-rise). This suggests that microearthquakes in the uppermost mantle of PHP only occur near the trough axis and farther landward.



Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS38-P25 Room:Convention Hall Time:May 24 15:30-17:00

Fine-scale Seismicity of the subducting PHS plate around the Kii Peninsula

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Introduction

In southwestern Japan, the Philippine Sea (PHS) plate subducts along the NNW direction beneath the Eurasian plate. This plate has been known for its complex shape, less seismic activity and occurrences of megathrust earthquakes. Although many seismological studies have been done, their resolutions at the ocean area are still poor, mainly because these studies are based on on-land observations. Mochizuki et al. (2010) investigated the seismicity around the Kii peninsula using ocean bottom seismometers (OBSs), and revealed stepwise changes of seismic characteristics along the Nankai trough. In this study, we do not only extend the study area of Mochizuki et al. (2010) using on-land observations, but we applied waveform cross correlation analysis to relocate hypocenters with better resolution. As a result, we obtained some linear alignment of earthquakes.

Data

We deployed at most 27 long-term OBSs for repeating one-year observations around the Kii peninsula by changing sites among 32 locations from November, 2003 to November, 2007. In addition, we included arrival time data from 45 land stations during the same period.

Relocation and Tomography Method

We first located events using P and S-wave first arrival times. During this process, we assumed station-specific 1-D velocity structures, and determined the station corrections simultaneously to compensate for systematic errors mainly originating from slow S-wave velocities in the sediment layers. We located 3931 events, which included microearthquakes that were not listed in the JMA catalog. Then, we applied a Double-Difference tomography method [Zhang and Thurber, 2003] to the above results and obtained relocated hypocenters and 3-D velocity structures for both P- and S-waves. Because of the limited seismic activity in this area, it is important to make full use of the present marine data set. Therefore, we applied non-linear grid search method [Lomax et al., 2009] to the events whose hypocenter was not stably determined through the above processes. This method searches hypocenters and origin times using 3-D grid velocity model so that the Equal Differential Time (EDT) likelihood function can be maximum. We obtained 1059 events by this grid search. Finally, we calculated waveform cross-correlation for measuring arrival time differences, and applied the Double-Difference tomography method again.

Results

We obtained the seismic velocity structure of the subducting PHS and overriding Eurasian Plates and seismicity from around the Kii Peninsula to the Nankai Trough axis. The dip angle of subduction increases from west to east. The seismicity in the slab varies between the east and west. In the west, earthquakes occurred in shallow part of the slab mantle (30~35 km depth), while they did not occur in the east. We found some linear alignments of earthquakes in this western shallow mantle. These alignments are oriented in NNE-SSW. We also revealed a large alignment of intra-slab earthquakes just below the Nankai trough. It is oriented N-S and dipping southwards.

Keywords: PHS plate, seismicity, subduction, OBS, waveform cross-correlation, tomography

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Daily monitoring of shear wave velocity and anisotropic structure using the reflected wave extracted from BBOBS data

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Temporal variation at subsurface structure has been recently detected by using seismic interferometry. This would be achieved by extracting waves propagating between two stations, and measuring the temporal variation of the extracted wave. For example, with the extracted surface wave, Brenguier et al. (2008) found that a velocity reduction and its relaxation occurred at and after the 2004 Parkfield Earthquake. Nakata et al. (2011) detected velocity changes between two stations deployed in vertical array, which was caused by the 2011 Tohoku-oki Earthquake. Moreover, reflection profile underneath a seismic station can be obtained by auto-correlation function of seismic noise. Chujo et al. (2011) constructed the reflected P wave from auto-correlation function of seismic records observed at BBOBS, and detected a temporal velocity change due to the 2005 Miyagi-oki Earthquake. In this study, we try to extract the reflected S wave by using horizontal components of BBOBS data, and also investigate whether temporal variation of the shear wave velocity and its anisotropic structure occurs or not.

We used 2 BBOBS deployed on the accretionary prism at the Nankai trough. The time period of the observation is from 2008/8 to 2009/9. This period contains the time in which the very low frequency earthquakes (VLFs) are active.

We applied a bandpass filter of 1-3 Hz to two horizontal components. The amplitude of the records was disregarded by keeping one-bit signal. We then synthesized the waveform by rotating two horizontal components with a step of 5 degrees, and calculated auto-correlation functions (ACFs) with a time length of 600 sec. The ACFs stacked for 1 day were prepared for approximately 400 days. Note that the ACFs of the waveform for all directions allow us to extract the reflected S wave with different polarization directions.

Our results show that the S wave reflected at the bottom of the accretionary prism can be seen in the ACFs for all directions. Interestingly, the travel time of the reflected S wave is varied as a function of polarization directions, which is considered to be the effect of anisotropic structure between the station and seismic discontinuity. The velocity change between the fast and slow S wave is approximately 3-4 %. Moreover, such reflections can be constructed with 1 day stacking of noise, allowing us to daily monitor the S wave velocity and its anisotropic structure. However, no temporal variations could be found at or after the VLF activity on 2009/3. In the presentation, in addition to the above result, we will also report that the temporal variation of travel time of the reflected S wave due to the 2011 Tohoku-oki Earthquake is observed by using BBOBS data deployed in the outer-rise.

Keywords: seismic interferometry, monitoring, accretinary prism, anisotropy, shear wave velocity

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Slow slip events and large thrust earthquakes triggered by afterslip in the Hyuganada region

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Slow slip events were detected after the December 1996 earthquake in the deeper region of the postseismic slip area with a recurrence interval of approximately 2 years with the durations of 0.5-1 year [Yarai et al.]. Three slow slip events have been detected since 2005.

We proposed a model of numerical simulation for the coexistence of afterslip for ˜M7 earthquake and slow slip events in the Hyuganada region of Japan with the 3D geometry of the Philippine Sea plate [Nakata et al., 2011, SSJ]. While coseismic events are reproduced by the slip law, recurrence of slow slip events are qualitatively reproduced by using the slowness law even in the velocity range of afterslips and slow slip events, in addition to characteristic slip distances larger than seismic source. In our simulation, afterslip triggered a slow slip event, which was unidentified in geodetic observation. After the triggered slow slip event, spontaneous slow slip events occurred in the same area. Furthermore, a large earthquake was triggered in the slow slip event area by postseismic slip.

In this study, we compare the spatial and temporal distributions of stress, strength, and slip velocity before a triggered slow slip event and an earthquake with a sampling interval of one day. As a result, the triggering of either a slow slip event or an earthquake through postseismic slip is determined by slight differences in stress and strength around the source.

Acknowledgments

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

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Progress of borehole seimo-geodetic observation above the rupture zone of the Tonankai earthquakes.

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Sensitive seismic and geodetic sensors were installed in seafloor boreholes drilled near the rupture zone of the Tonankai earthquakes to construct high-quality seismo-geodetic observatories in the seafloor. Three or more borehole observatories are planned in the area and these observatories are planned to connect to dense ocean floor network for earthquakes and tsunamis (DONET) for realtime long-term seismo-geodetic observation in the rupture zone of the Tonankai earthquakes and off-shore side of the zone. The construction of the borehole observatories began in 2009 at IODP C10 site where we installed temporal pore-fluid pressure sensor. In December, 2010, we installed the first permanent seafloor borehole observatory in the area in IODP C2 site with borehole sensors such as volumetric strainmeter, tiltmeter, broadband and strong motion seismic sensors, pore-fluid pressure sensors, and thermometers. It was necessary to check performance of the installed borehole sensors in the C2 observatory before starting long-term observation. Originally an ROV cruise was planned in March, 2011, which was cancelled due to the earthquake in March 11, 2011. With some delay, we were still able to check the performance of all the borehole sensors through ROV visits in JAMSTEC R/V Natsushima cruises NT11-09 in July 2011 and NT12E01 in January 2012. All sensors were checked and these performed well in the seafloor borehole. The data from the borehole broadband seismometer in the C2 observatory showed the borehole is 10-20 dB quieter in some of seismic frequencies, suggesting good observation environment for seismo-geodetic observation is established in the borehole. Pore-fluid pressure sensors in the C2 observatory were checked at the time of installation and continued continuous observation since the installation. We have not still started continuous observation with other sensors but we plan to start long-term observation in near future and we are also preparing connection of the C2 observatory to the DONET cable in January 2013.

Keywords: borehole, seismic, geodecy, Tonankai earthquake

SSS38-P29 Room:Convention Hall Time:May 24 15:30-17:00

Operation and Construction of Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET/DONET2)

KANEDA, Yoshiyuki[1*], Katsuyoshi Kawaguchi[1], Eiichiro Araki[1], Hiroyuki Matsumoto[1], Takashi Yokobiki[1], Shuhei Nishida[1], Jin-Kyu Choi[1], Masayuki Hoshino[1], Masaru Nakano[1], Takeshi Nakamura[1], Keisuke Ariyoshi[1], Narumi Takahashi[1], Shin-ichiro Kamiya[1], Toshitaka Baba[1]

[1]JAMSTEC

DONET (Dense Oceanfloor Network System for Earthquakes and Tsunamis) is a real time monitoring system conducting long-term and extremely precision observation in the seafloor. Broad-band seismograph, strong motion seismograph, hydrophone, differential pressure gauge, quartz pressure gauge, and precision thermometer, are installed in multiple seafloor observation points. They are connected with landing station by submarine cable so that observed data is acquired in real time. It was completed to establish all of the 20 observation point was planned as DONET1 in August 2011, and currently going well in operation of real-time observation in the sea depth of a range from 1,900m to 4,300m, in Kumano-nada off Kii Peninsula. The data is used in research and analysis that will contribute to the sophistication of an early earthquake and tsunami warnings and to understand the Nankai trough seismogenic zone via physical phenomena around the shallow plate boundary such as slow slip and low frequency events.

On the other hand, it is insufficient just maintenance of observation network in the Kumano-nada which is the source region of the Tonankai earthquake, to capture the process of a series from the Tonankai earthquake to the Nankai earthquake. Especially when the Tonankai earthquake occurred ahead of the Nankai earthquake, it is essential to extension of the observation network to the west for evaluation of the time lag between the Tonankai and the Nankai earthquakes. Accordingly in JAMSTEC, a subsequent project has started to construct a new earthquake and tsunami observation system from west off the Kii peninsula to off Muroto coastal area since 2010 (DONET2). DONET2 has 350km backbone cable length and 7 nodes and 30 observation points is a larger system than the current DONET, DONET2 of 10KV high voltage enable to deploy a wider observation network. Currently, we decided outline of the cable route of DONET2 and then bathymetric survey, the seafloor visual inspection are ongoing even as design of the landing stations.

We will introduce the operation of DONET and progress of DONET2.

Keywords: DONET, DONET2, real time monitoring system, Tsunami, Nankai trough, Nankai earthquake

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Investigation into source depth of mud volcano in the eastern Mediterranean: A case study of Medee-Hakuho Mud Volcano

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Present-day geodynamic framework in the Eastern Mediterranean Sea and the surroundings is characterized by a complex pattern of active thick-skin crustal tectonics resulting from various plate and microplate interactions [e.g., McKenzie 1972]. Moreover, thick impermeable barrier of the Messinian evaporates exists below the entire Eastern Mediterranean foredeeps exceeding 3 km in thickness [e.g., Polonia et al. 2002]. These geological frameworks result in the Mediterranean Ridge (MedRidge) differing from other accretionary complexes around the world, coupled with formation of mud volcano and brine lake.

Ten-day PENELOPE Cruise in January/February 2007 (KH-06-4 Leg06 survey of the R/V Hakuho-Maru) made detailed mapping and piston/multicores sampling at newly-discovered Medee brine lake and its westward neighboring Medee-Hakuho Mud Volcano (MHMV) in the western branch of the MedRidge. The MHMV has an almost circular dome structure in diameter of ~7km and reaching ~130m high showing very gentle slope, standing on the backstop boundary thrust in water depths of 2260 m. It was initially roughly-recognized during Medee Cruise conducted in 1995 on the basis of its distinct backscatter intensity. The MHMV is interpreted to be active because of existence of many pebbles in the obtained core samples and the high backscattering characteristics.

Little has been clarified the relationship between undergoing collisional tectonics and mud volcanism, although these processes are strongly associated [Kopf 2002]. Mud volcanism in the Eastern Mediterranean Sea is known to be present on contiguous belt along the MedRidge, which is referred to as the “Mediterranean Ridge mud diapiric belt” [Limonov et al. 1996], but mud fields in the western branch of the MedRidge remain poorly solved. This study includes vitrinite reflectance (VR) measurement of the clasts from the pinpoint piston cores obtained from MHMV by means of ROV NSS (Navigable Sampling System), in order to evaluate experienced maximum paleotemperature of the clasts. Some nannofossil ages of the clasts from the MHMV core show ~100 Ma corresponding to the period when Hellenic subduction initiated [Stampfli and Borel 2002]. The subduction system in the eastern Mediterranean has developed dramatically since the period [Ring et al. 2010]. Preliminary results show high VR values suggesting these clusts come from deeper areas as compared with reported results from mud volcano at Kumano Trough [e.g., Muraoka et al. 2011]. Estimating the sediment source and burial depth of MHMV will contribute to qualitatively indicate elevated pore pressure in this subduction zone, or presumably to reveal characterization of the mud volcano coupled with brine lake at the prism-backstop contact.

Keywords: Eastern Mediterranean, Mediterranean Ridge, accretionary prism, mud volcano, vitrinite reflectance

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The source depth of the mud volcano develoed in the Kumano Trough

MURAOKA, Satoru[1*], ASHI, Juichiro[1], KANAMATSU, Toshiya[2], SAKAGUCHI, Arito[2], AOIKE, Kan[2], INAGAKI, Fumio[2]

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

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

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

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

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

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

Keywords: mud volcano, mud diapir, vitrinite reflectance, subduction zone, Nankai Trough

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Subduction structure revealed by seismic experiments at the southern Ryukyu Trench

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The Ryukyu Trench (Nansei-Shoto Trench), extending to the east-south of the Ryukyu Arc, is formed by subduction of the Philippine Sea Plate below the Arc. Although great earthquakes have been rarely observed around the Ryukyu Arc and plate coupling at the Ryukyu Trench had been believed to be weak, enormous disasters were induced by earthquakes. Yaeyama Earthquake (M7.4) occurred in 1771 induced large tsunami, which killed more than 11,000 people of the Ryukyu Islands. It is important to determine structure models of a subduction zone to understand mechanism of earthquakes even in a weak plate coupling area.

Although the length of the Ryukyu Trench is longer than the Japan Trench and the Nankai Trough, number of seismic surveys conducted around the Ryukyu Trench to obtain structure models of the subduction is much less than those around the two trenches. Only several structure models of the Ryukyu Trench and the subducting Philippine Sea Plate in shallow area have been constructed until present. In this meeting, we will report a new structure model of the southern Ryukyu Trench at where Japan Coast Guard has been conducted seismic survey.

In 2009, we conducted a seismic reflection experiment with 3,000 m multi-channel streamer cable and a seismic refraction experiment with ocean bottom seismographs (OBSs) on a survey line named ECr5 which runs across the Ryukyu Arc, the Hateruma Basin and the Ryukyu Trench from north to south to the east of the Ishigaki Island. Total volumes of airgun arrays for the reflection and the refraction experiments are 1,050 $inch^3$ and 6,000 $inch^3$, respectively.

To construct a P-wave velocity structure from the OBS records, a ray tracing method with graph theory was used for first arrivals and various reflected signals including reflected signals from the top of the subducting plate and its Moho. A depth scale of the constructed structures was converted to two-way travel time to lay the structure over the multi-channel seismic profile for further interpretation.

Characteristic features of our structure model are follows.

1) Backstop structure is located below an edge of the Hateruma Basin.

2) Thickness of an accretional prism is thicker than 10 km.

3) Approximate subduction angle of the Philippine Sea Plate is 5 degree at shallow (<20 km) part and is 25 degree at deep (20-35 km) part.

4) Large fault connecting to the plate boundary at a depth of 15 km reaches to seafloor with an approximate angle of 40 degree.

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The geological structures to the south of the Yaeyama Islands deduced from submarine topography and MCS reflection data

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The Nansei-Shoto Trench is where the Philippine Sea plate is subducting beneath the Eurasian plate. In the southern part of the Nansei-Shoto Trench, the Yaeyama earthquake accompanied a large tsunami killed about 12,000 people in 1771. However, few numbers of structural studies in this region have been carried out compared to those in the Japan Trench and the Nankai Trough regions.

In order to understand characteristics of earthquake occurrence in the Nansei-Shoto Islands, we need the topographical and geological information about Nansei-Shoto Trench.

Japan Coast Guard has been carried out bathymetric, seismic refraction, and multi-channel seismic (MCS) reflection surveys around the Nansei-Shoto Islands. We conducted a seismic survey on an N-S survey line across the forearc basin to the south of the Yaeyama Islands in 2009.

The landward slope of the trench to the south of the Yaeyama Islands is an accretionary wedge with a width of about 50km. To the south of the Yonaguni Island, a linear right-lateral fault with WNW-ESE direction exists at the boundary between the forearc basin and the accretionary wedge (Lallenamd et al.1999.).

On the MCS profile across the right-lateral fault to the southeast of the Ishigaki Island, a flower structure is confirmed around the boundary between the accretionary wedge and the forearc basin. A strong reflector corresponding to a plate boundary is recognized beneath the forearc basin region. This reflector is confirmed to extend to about 50km north from the escarpment at a depth of 20km from the sea surface.

Keywords: Nansei-Shoto trench, Multi-Channel Seismic profile, submarine topography

SSS38-P34 Room:Convention Hall Time:May 24 15:30-17:00

Subbottom structures in the region causing the huge tsunami during the 2004 Sumatra-Andaman Earthquake

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On 26th December 2004, the Sumatra-Andaman Earthquake (Mw 9.2) nucleated offshore northwestern Sumatra Island and then ruptured the megathrust for over ˜ 1,300 km mostly to the north along the Sunda Trench. The great tsunami spread over the Indian Ocean and more than the 220,000 people died. Several international marine geological and geophysical surveys have been conducted in this area, especially the Sunda Trench and the Aceh Basin areas. Based on the results from the surveys, five working hypotheses have been proposed for the tsunami source fault model. Among them, Hirata et al. (2008, 2010) suggested that the secondary tsunami source is located around the Middle Thrust of Sibuet et al. (2007). If the 2004 coseismic rupture reached the seafloor along the Middle Thrust, seafloor deformation contributing the great tsunamis would be recorded in the shallow part of the sediment layer.

To image the detailed shallow structure and to map distribution of active faults, we conducted a high-resolution Multi-Channel Seismic (MCS) survey with ship-board Subbottom Profiler (SBP) in the areas during KH-10-5 cruise (using R/V Hakuho-Maru). KH-10-5 MCS survey was carried out in November 2010. Total length of the survey lines was ˜484.3 nautical miles. In this MCS survey, a GI gun with a total volume of 150 cubic inch (G: 45 cubic inch, I: 105 cubic inch) and 1200m-long, 48 ch streamer cable were used (steaming at 4 knots, 10 seconds shot interval).

The survey provided fine structural images down to 1.5 sec (TWT) in the trench and to a maximum of 2.0 sec (TWT) in the forearc high region. In the trench region, many landward-vergences (seaward-dipping) faults were identified. These faults reach the seafloor. In general, the trench region seems to suffer active deformation. Additionally, the landward-vergences uplift and deform the oceanic and trench-fill sediments of the Sunda trench. This deformation system has developed the kink folding systems and has also played the role of the accretionary process. In the forearc high area, many of faults and folds were also recognized. A number of ridges in this area are made by many thrust-anticlines. Between the anticline ridges, the syncline and the syncline (or piggyback) basins are also recognized. The sedimentary layers of syncline basins can be usually imaged down to a maximum of 0.5 sec (TWT) below the seafloor. In the deep part of these basins, sediment is often tilted landward. These tilted layers form a proto-deformation related to the shortening of the forearc and the development of the anticline ridges. In contrast, the shallow part of these basins is mostly flat-lying and laterally coherent. It indicates that the recently deformation activity of this area is relatively low. Along the Middle thrust, however, we found evidence in both MCS and SBP data of recent deformation in the near-surface layer. This active deformation area is almost coincident with the position of the predicted secondary tsunami source fault predicted by Hirata et al. (2008). However, only the high-resolution MCS and shipboard SBP data alone cannot decide if this deformation was activated coseismically during the 2004 event. Also, the deeper structure of the Middle Thrust could not be recovered by our MCS data. Additional survey will be required, such as the high-resolution deep-tow SBP and piston coring will be required in near future as well as a large-scale MCS survey with lager volume air-gun and much long streamer.

Keywords: 2004 Sumatra-Andaman Earthquake, Tsunami, Subbottom structure, High-resolution Multi-Channel Seismic survey