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

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.

SSS38-06 Room:303 Time:May 23 10:15-10:30

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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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

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

SSS38-11 Room:303 Time:May 23 11:45-12:00

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 $1\text{x}10^{-7}$ 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

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

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

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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

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.

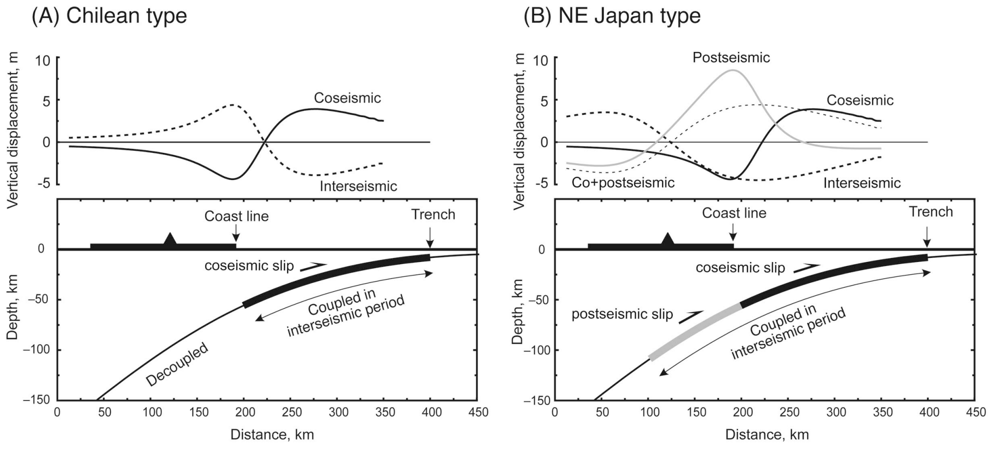
There has been a discrepancy between long-term (geologic) and short-term (geodetic) strain observations in both horizontal and vertical directions over the Northeast Japan (NEJ) arc. Geodetic observations in the past ~100 years have revealed strain accumulation across the NEJ arc at a rate as high as 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

Japan Geoscience Union Meeting 2012
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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

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

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

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

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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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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.