Japan Geoscience Union Meeting 2014
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SSS32-P01 Room:Poster Time:May 1 18:15-19:30

Re-evaluation of frictional heat recorded in the dark gouge of a megasplay fault at the Nankai Trough

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Because a megasplay fault branching from the deep subduction boundary megathrust in the Nankai Trough is thought to be the source of large tsunamis associated with past Tonankai earthquakes, investigation of the heat signal due to frictional slip recorded in the fault is important for estimating the earthquake slip parameters. We performed X-ray diffraction and infrared spectroscopic analyses of a megasplay fault-rock sample and re-examined previously reported trace-element and isotope compositions, but observed no specific change related to high temperature ($\geq$250 ℃). In addition, although a qualitative increase of the illite content in illite/smectite mixed-layer minerals within the slip-zone sample was previously reported, our kinetic evaluation of illitization, taking into consideration the coseismic temperature change due to frictional heating and heat conduction, revealed that the illitization reaction hardly progresses at temperatures under 250 ℃. Alternatively, we suggest that the illite content in mixed-layer minerals might increase progressively via a comminution – dissolution – recrystallization process during multiple past slips. Accurate assessment of the slip behavior of the megasplay fault could be efficiently obtained by drilling to penetrate the fault zone at a deeper depth of approximately 1.5 km, where records of high temperatures would be detectable.

Keywords: NanTroSEIZE, Tonankai earthquake, fluid-rock interactions, trace elements, X-ray diffraction, infrared spectroscopy

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Roughness of fault surfaces over a length-scale range from nano- to milimeters.

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Geometric complexities of faults are first-order effects that complicate the mechanics of earthquakes and faulting. Here we report on the topographic roughness measurements on two natural fault surfaces with a continuous length-scale range from 1 nm to 3 mm. The fault surfaces observed in this study include (1) the Corona Heights fault in the Castro Area of San Francisco, that has been studied mineralogical and microstructural in detail, and (2) the Itozawa fault in Fukushima prefecture, a normal fault moved just after the 2011 Off the Pacific Coast of Tohoku earthquake. Both fault surfaces exhibit shiny slickensides on which various length and width of slickenlines are observed.

In order to measure fault surface topography with a scale range from 1 nm to 3 mm, we performed line-measurements both parallel and perpendicular to the slickenlines using two scanner devices; a confocal whilte-light scanning microscope (measurable range: 0.15 ˜3000 μm) and a scanning probe microscope (1 ˜50000 nm). The topographic properties of the measured surfaces were expressed either as a Hurst exponent (H) which are calculated from power spectrum density (PSD) of topography data. As a result, the Corona Heights fault and the Itozawa fault exhibit a consistent geometrical property, a linear behavior on a log-log plot where axes are PSD and spatial length scale. A slope of the log-log plot, H, of the Corona Heights fault and the Itozawa fault shows H_N = 0.73 $\pm$0.010 perpendicular to the slickenslide and H_P = 0.81 $\pm$0.012 parallel to it, and H_N = 0.87 $\pm$0.013 and H_P = 0.94 $\pm$0.014, respectively. Smaller H_P than H_N is often reported, that interpreted as surface roughness in the slip direction becomes less pronounced selectively with progressive displacement (e.g., Sagy et al., 2007). Therefore, almost no difference between H_P and H_N in the observed fault surfaces could imply that both faults may be relatively immature due to less total displacement, or otherwise H_P and H_N are undifferentiated with displacement in the length-scale range from 1 nm to 3 mm. Candela et al., (2012) measured roughness of thirteen earthquake fault surfaces and suggested that the fault geometry can be expressed as a single geometrical description (i.e., single H) over a range of scales from 50 μm to 50 km. Our data, at least H_N = 0.81 perpendicular to the slickenlines, is consistent with their universal H_N = 0.81 $\pm$0.04 even for lower length-scale range. Hence, the geometric complexiity of fault surfaces in nature can be maintained over length-scales from nano- to kilometer and be described as the sigle Hurst exponent.

Keywords: fault surface, roughness, fractal, Hurst exponent

SSS32-P03 Room:Poster Time:May 1 18:15-19:30

Evolution of fluid transport property by diagenesis in basaltic rocks from the Shimanto belt, Southern Shikoku

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Large slip displacement was observed at shallow portion of the plate boundary fault during 2011 Tohoku earthquake, and this slip has contributed to cause large tsunami. The large displacement was probably caused by dynamic fault weakening at shallow boundary fault, or reduction of fault strength at middle to deeper portion by pore pressure generation. Pore pressure can be generated by chemical dehydration, fluid influx from deeper crust or pore volume reduction associate with permeability reduction at a large subduction plate boundary. In this study, we investigate the change of fluid transport property for basalt during diagenesis process at Nankai Subduction zone.

We collected basalt brocks in the Cretaceous Shimanto accretionary complex of Japan from Okitsu-Kozurutsu site and Kure site in Kochi, Japan. Porosity and P-wave velocity of each basalt at atmospheric pressure are 1.4 % and 2.1%, and 6.4 km/s and 5.9km/s, respectively. We found a slight difference of S-wave velocity for basalts. Permeability was measured by using N2 gas as a pore fluid, and calculated by steady state gas flow method. Permeability was measured at room temperature and under confining pressure that were increased from 1 to 160 MPa in steps.

Gas permeability was decreased with an increase of differential pore pressure at a same confining pressure. This pore pressure dependence implies the Klinkenberg effect, therefore we converted gas permeability to water permeability using the Klinkenberg equation. We did not find a variation of permeability at the lowest effective pressure of 1MPa, and permeability shows from 10^{-15} to 10^{-16} m^2. Permeability in all basalts decreased with an increase of effective pressure, and reaches from 10^{-18} to 10^{-21} m^2. Basalt from Kure site shows the lowest permeability of 10^{-21} m^2 at 100 MPa, and permeability of basalt from Okitsu site shows the largest value of 3×10^{-19} m^2. Permeability reduction with an increase of effective pressure in most samples is described by the power law equation where exponent ranges from -2 to -3. The permeability reduction for the highest permeable basalt was expressed by the theoretical relation that is based on the Hertzian contact theory (Gangi, 1978). Fractures are apparently developed in this sample, therefore the reduction in permeability is influenced more by fracture asperity rather than pore structure.

The permeabilities of basalts in this study are smaller than permeability of basalt in fault zone at Okitsu site (Kato et al., 2004), Juan de Fuca and Tonga-Kermadec (Christensenan and Ramananantoandro, 1988). At present, we did not see clear relationship between the permeability and diagenesis. Most of basalt rock shows very low permeability, therefore they have higher potential to generate a pore pressure by dehydration reaction or influx from depth during subduction at Nankai Trough.

Keywords: permeability, fluid pressure, diagenesis, subduction zone, Nankai Trough earthquake, basalt

SSS32-P04 Room:Poster Time:May 1 18:15-19:30

Effects of thermal cracking on elastic wave velocities and Poisson's ratio of basalt, gabbro and granite

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Marine seismic refraction studies have found that there are high Poisson's ratio regions (>0.35) in oceanic crust at subducting plate. Christensen (1984) performed laboratory measurements of compressional and shear wave velocities (Vp and Vs, respectively) of basalt, which is one of major rocks in oceanic crust, and estimated Poisson's ratio, and suggested that observed high Poisson's ratio can be explained by high pore pressure. This distribution of high pore pressure have been concerned because it should influence fault mechanism of plate boundary at subduction zones. Christensen (1984) used intact rock for the measurements. But there are probably dense cracks near faults in nature. Therefore, to investigate Vp, Vs and Poisson's ratio for fractured rock is important to evaluate distribution of high pore pressure regions by using seismic studies. This study reports the results of measurements of Vp and Vs, and estimations of Poisson's ratio for thermally cracked gabbro, basalt and granite, which are major rocks in oceanic crust and continental crust. Rock specimens were heated at 100 ℃, 300 ℃, 500 ℃ and 700 ℃ to thermally crack them. We performed measurements at atmospheric pressure and dry condition. We also measured Vp and Vs for water-saturated specimens of gabbro and basalt heated at 700 ℃, and compared the results with those under dry condition to investigate the effect of pore fluid on Vp and Vs.

As results, specimens heated at higher temperature tended to have slower Vp and Vs. Density of the specimens was also decreased as heating temperature was increased, and especially the density change was clear from 500 ℃ to 700 ℃. This imply that clack density of specimens was increased with increasing temperature, and this might be the reason why Vp and Vs were decreased. Poisson's ratios obtained in this study (0.05-0.25) were lower than the observed high Poisson's ratio. Vp and Vs for water-saturated specimens were generally faster than those for dried specimens, but output signals tended to be smaller and therefore improvements of the measurements systems and methods to analyze the signals should be necessary.

Keywords: Poisson's ratio, Elastic wave, High pore pressure, Basalt, Gabbro, Granite

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Frictional property of rocks in the Izu-Bonin-Mariana Forearc under high temperature and pressure conditions

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The Kanto region lies atop of three tectonic plates: the North American Plate, the Pacific Plate, and the Philippine Sea Plate. In addition, the collision and subduction of the Izu-Bonin-Mariana (IBM) arc into the Kanto region results in a characteristic tectonic setting as compared with other convergent margins. Due to such complicated plate configuration, the different type of earthquakes including seismic slip (e.g., the Kanto earthquake) and aseismic creep (i.e., slow earthquake of Boso peninsula) occurs at the intra-plate and plate boundaries beneath the Kanto region. Moreover, the different type of events seems to take place side by side at almost same depth (probably nearly same P-T conditions). Although many factors including pore fluid pressure and fault topography can control earthquake generation, this study focus on frictional property of incoming materials to be subducted into the Kanto region in order to examine a hypothesis that the different types of slips arise from different input materials. Thus, we have performed friction experiments on rocks that constitute the IBM forearc using a high P-T gas medium apparatus at AIST.

We sampled five rocks (marl, boninite, andesite, sheared serpentinite and serpentinized dunite) recovered from the IBM forearc by Leg 125, Ocean Drilling Program (ODP Site 784, 786). The rocks were crushed and sieved into 10˜50 μm in grain size. Then, the rock powders were sandwiched between saw-cut alumina cylinders and sheared at temperature of 300^{o}C, confining pressure of 156MPa, pore pressure of 60MPa and axial displacement rates of 0.1 and 1 μm/s. The sheared serpentinite and serpentinized dunite exhibit steady-state friction of 0.55 and 0.35-0.41, respectively and their velocity dependence of friction is positive (velocity strengthening behavior). On the other hand, for marl, boninite and andesite, a periodic stick-slip behavior appears at 1 μm/s. However, contrary to a stick-slip behavior at room temperature in general, rise time of the stick-slip behaviors are quite long (3.9, 9.3 and 10.8 sec, respectively), that could be called as a " slow stick-slip ". Similar slow stick-behavior were observed in halite and serpentinite slipped at high temperatures (Noda and Shimamoto, 2010; Okazaki, 2013), but this is first time to recognize this unique slip behavior in sedimentary and igneous rocks. Although it is difficult to discuss the diverse slip behaviors observed at the Kanto region based on our limited experimental results, we will examine the conditions where the transition between stable and unstable sliding appears using the input materials and explore the generation mechanisms of earthquakes at the Kanto region.

Keywords: Friction, Izu-Bonin-Mariana Forearc (IBM), slow earthquake, stick-slip, earthquake

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Temperature-dependent frictional strength of dolerite in a nitrogen atmosphere and its relation to amorphous material

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Noda et al. (2011, JGR) revealed by rotary shear experiments on dolerite at a normal stress of 1 MPa, a sliding velocity of 1 cm/s and controlled temperatures from room temperature to 1000 ℃, that its frictional strength has a negative correlation with the amount of amorphous phase in wear materials as well as a positive correlation with the amount of iron oxides which increases with increasing temperature by oxidation of the iron-bearing minerals. However, oxidation of iron-bearing minerals as observed in their experiments is unrealistic in fault zones at depths due to the paucity of oxygen there.

We therefore conducted rotary shear experiments on the same dolerite at the same normal stress, sliding velocity and temperature conditions with Noda et al. (2011) in a nitrogen atmosphere with the oxygen content of 0.1 %, and compared the results with those of Noda et al. (2011). We collected mechanical data during stable sliding of 20 m after the presliding of 100 m at each experimental condition. Sieved wear materials smaller than 250 μm were then used for quantitative X-ray diffraction analyses.

Steady-state friction coefficient was ˜0.47 at room temperature and 200 ℃, ˜0.7 at 400 and 600 ℃, and ˜0.9 at 1000 ℃. Steady-state was not reached at 800 ℃ due to intense fracturing of samples. The amount of amorphous phase in wear materials shows a change with increasing temperature similar to that for experiments in the air (Noda et al., 2011); ˜65 wt% at room temperature, ˜70 wt % at 200 ℃, ˜70 wt% at 400 ℃, ˜45 wt% at 600 ℃, ˜15 wt% at 800 ℃, and 0 wt% at 1000 ℃. In contrast, the amount of iron oxides does not show a noticeable change with increasing temperature.

Experiments by Noda et al. (2011) in the air showed a negative correlation between frictional strength and the amount of amorphous phase at temperatures lower than or equal to 800 ℃. Our experiments also show an overall tendency of increasing frictional strength and decreasing amount of amorphous phase with increasing temperature. However, steady-state friction coefficient differs by more than 0.2 between room temperature and 400 ℃, while the amount of amorphous phase differs by only ˜5 wt% between these two temperatures. In addition, the amount of amorphous phase differs by ˜15 wt% between 400 and 600 ℃, whereas steady-state friction coefficient is almost the same at these two temperatures. This implies lack of a direct relationship between frictional strength of dolerite and the amount of amorphous phase in wear materials. Study on what controls the temperature-dependent change in frictional strength of dolerite is now in progress.

Keywords: Dolerite, Frictional strength, Wear material, Nitrogen atmosphere, Rotary shear experiment

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Observation of 2-D rupture propagation for stick-slip events during large-scale biaxial frictional experiments

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Pre-slip was expected to occur prior to large earthquakes, since a pre-slip model was proposed by Ohnaka and Kuwahara (1990) based on their rock frictional experiments. The pre-slip accelerates toward an unstable sliding event. However, such phenomena have never been clearly observed for natural earthquakes. Ohnaka and Kuwahara (1990) observed a 1-D strain distribution along a sample surface, and estimated the apparent rupture propagation speed. In addition, the fault was narrow, and the rupture growth might be affected by free surfaces at the edge of the sample, though the free surface effect is not so common for natural earthquakes. Therefore, we closely observed two-dimensional rupture propagation on a wider fault during rock frictional experiments.

We carried out meter-scale rock frictional experiments (Fukuyama *et al*., 2013), and investigated rupture propagation of stick-slip events and some of their characteristics, using AE (acoustic emission) and strain records. The fault consisted of an interface of two Indian gabbro blocks. Their width and height were 0.5 m, and the length of upper and lower blocks were 1.5 m and 2.0 m, respectively. The arrays of strain gauges and AE sensors were installed within the lower block in order to understand two-dimensional rupture propagation. Twenty four sets of AE sensors and biaxial strain gauges were attached 60 mm below the sliding surface at intervals of 150 mm parallel to the slip direction and at intervals of 75 mm perpendicular to the slip direction. We analyzed time series of strain and AE data, and found stick-slip events accompanied with slow and accelerating strain decrease that propagated at a speed much slower than elastic wave speed.

This study was supported by NIED research project "Development of monitoring and forecasting technology for crustal activity" and JSPS KAKENHI Grant Number 23340131.

Keywords: stick-slip event, rupture propagation, large-scale biaxial frictional experiment

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The experimental study about frictional instability of fault gouges in terms of Rowe's energy ratio

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1. Introduction

The stress-dilatancy relationship for granular materials in a dense packing state was introduced by Rowe (1962). He used the energy ratio (K), which was the ratio of rate of energy dissipation in the direction of minimum principal stress to energy supply in that of maximum principal stress. According to the concept, K shall be a minimum and constant value (Rowe, 1962). However, there are many questions about the physical meaning of K. Therefore, the Rowe's low has not been applied much for fault mechanics until now. Nevertheless the stress-dilatancy relation is related to the onset of frictional instability, it has not been clear yet. So, we conducted friction experiments using simulated fault gouges in order to confirm whether Rowe's law can be applied to fault situation or not.

2. Methods

The friction experiments using simulated fault gouges were conducted in a gas-medium apparatus. The confining pressure was ranging from 140 to 180 MPa. We used a cylindrical gabbroic forcing blocks (20 mm in a diameter, 40 mm in a length, and cut by a 50 degree from their cylindrical axis) and quartz gouges were sandwiched by them. The sample sustained loading initially and holding at several values of axial stresses at 190, 450, 640 and 800 MPa. The strain rate was 10^{-3} /s. In order to measure strain, three strain gauges were glued onto a gouge layer through the Teflon jacket. Another one was placed to a forcing block in a vertical direction and far from a gouge layer. Data were recorded at 2 MHz.

3. Results and Discussion

From our friction experiments, we obtained K of gouges at different confining pressures. K is given by the ratio of rate of energy dissipation in σ_3 direction to energy supply in σ_1 direction, so it can be represented by the ratio of output energy to input one. We obtained strain of σ_3 direction from three strain gauges glued onto a gouge layer. Similarly, σ_1 and strain of σ_1 direction were obtained from another gauge. σ_3 was the confining pressure. Our results showed that the output energy was the linear function of input one. K increased with confining pressure and showed a certain constant value at each loading and holding stage. Moreover, the change in K was remarkable at the final loading stage. In other words, the output energy increased suddenly because gouge particles began to slip. So, the change in K is large under high stress, including just before unstable slip. It matched shear localization (e.g. Logan et al., 1992; Marone, 1998).

Because K is represented by a function of internal friction angle, we suggest that the change reflects the process of microstructural development. It implied that the statistical particle arrangements of gouges changed at each stress level. After gouges become a closest packing state at the peak stress, the grain size reduction (GSR) of gouges occurs leading to the development of shear structure. Under GSR occurrence, K became a new state. From previous study, it is known that the microstructural development has a close relation with frictional instability (e.g. Logan et al., 1992; Marone, 1998; Onuma et al., 2011). During progressive shear, the angle of R1-shear developed in gouges decreases with cumulative slip (Gu and Wong, 1994). Hence, the change in K, that is to say the change in internal friction angle must be connected with not only microstructural development but also frictional instability.

4. Summary

From our experiments using simulated fault gouges, we obtained relationships among microstructural development, frictional instability and energy ratio of it. We confirmed that the Rowe's law could be applied to simulated fault gouges. Therefore, we can assess frictional instability in terms of the energy ratio based on Rowe's law. Systematic laboratory observation provides better understanding on energetical or microstructural consideration on the shear localization and seismogenic process.

Keywords: frictional instability, simulated fault gouge, Rowe's minimum constant energy ratio, friction experiments

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Temporal evolution of slip event probability -Case study of slow slip off the Boso Peninsula and the Yaeyama Islands

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Spatially-isolated slip events (earthquakes and slow slip events) have occurred quasi-periodically especially at plate interfaces (e.g., Nadeau and McEvilly [1997], Matsuzawa et al. [2002], Rogers et al. [2003]). This fact suggests that the concept of simple elastic rebound at the plate interfaces is true at a certain level.

Of course, the recurrence intervals of the slip events have no periodicity in a strict sense. Probably it is because the slip events never repeat in the same pattern. Earthquakes with dynamic processes especially tend to have this trend. In fact, an earthquake event occurred beyond the expected period from the previous earthquake sequence (Bakun et al. [2005]). Moreover, seemingly spatially-isolated events can be strongly affected by nearby huge earthquakes (e.g., Uchida and Matsuzawa [2013]). Thus it is difficult to discuss the event recurrence quantitatively based on deterministic physical models. Reseacheres alternatively used probability distribution to evaluate the recurrence intervals.

When we examine the event recurrence by the probability distribution approach, one of the most important point is actual event probabilities at the time of event occurrences. There has been little discussion on this point. We address it, focusing on slow slip events with shorter recurrence intervals. We select the Boso-oki slow slip events (Hirose et al. [2012]) and the Yaeyama-oki slow slip events (Heki and Kataoka [2008]). The probability distribution of the event recurrence intervals is the Poisson distribution. We evaluate the event probability as the subtraction of cumulative probability of zero occurrence from 100%. The cumulative probability reverts back to 100% at the time of an event. The mean recurrence interval as a parameter of the Poisson distribution is the sample average from the forepassed events. The above settings allow us to calculate the temporal evolution of the event probabilities off the Boso Peninsula and the Yaeyama Islands. **We can validate the calculated results** by comparing with the actual event occurrences.

In the result off Yaeyama Islands, the event numbers that occurred at a stage with the smaller probability than 50% are five out of the total numbers twenty six. About 80% of the events occurred with the event probability >50%. Besides, off the Boso Islands, the event numbers during a stage of the smaller probability than 50% are two out of the total numbers five. The two events followed the 2011 Tohoku earthquake. This fact may reflect the effect of the stress perturbation due to the Tohoku earthquake, as suggested by Hirose et al. [2012]. In summary, few slow slip events occur with the event probability <50%, in the probability evaluation based on the Poisson distribution. We additionaly find that the event probability at the time of an event off the Yaeyama islands has increased gradually.

Keywords: Repeating slow slip event, Event probability, Statistical approach, Off Boso Peninsula, Off Yaeyama Islands

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Numerical modeling of concurrent occurrence of shallow very low frequency earthquakes and long-term slow slip events

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Concurrent occurrences of shallow very low frequency earthquakes (VLFEs) and long-term slow slip events (SSEs) are found in the Bungo channel (Hirose et al., 2010, Science). This region is located at the western rim of the area where a large slip of megathrust earthquake is expected. Thus, the understanding of such behaviors will help us to reveal the preparation process of megathrust earthquakes. We aim to numerically reproduce the concurrent slip at the shallow VLFE and the long-term SSE region.

In our numerical model, a subducting plate interface is modeled as a flat plane within a semi-finite elastic medium. Frictional stress on the plate interface is given by a rate- and state-dependent friction law with cut off velocities (e.g., Matsuzawa et al., 2010, JGR). To reproduce long-term SSEs, a region with a cutoff velocity of $10^{-6.5}$ m/s and low effective normal stress is assumed below the depth of 10 km. In terms of shallow VLFEs, result of rock experiments shows that velocity-weakening and strengthening behaviors are found at low and high slip velocity, respectively (Saito, et al., 2013, GRL). In addition, it is estimated that a radius of shallow VLFEs is 5-10km from seismic data analysis (Ito and Obara, 2006, GRL). Based on these results, we assume circular regions for VLFEs with a cutoff velocity of 10^{-4} m/s and a radius of 6 km. In addition, we pose a stable sliding region beside the long-term SSE region, as more stable sliding behavior is expected in the Hyuganada region where shallow VLFEs frequently occur even in the period without long-term SSEs. In this study, some cases are calculated to examine the effect of the distribution of frictional parameters. Model 1 is a model based on the above assumptions. Model 2 is a model without a stable sliding region beside the long-term SSE region. In Model 3, the top of the long-term SSE region is set to the depth of 18 km.

In the numerical results of these three models, recurring slip at shallow VLFE and long-term SSE regions are reproduced. Concurrent occurrence of shallow VLFEs and long-term SSEs are reproduced in Model 1 and 2, while the concurrent occurrence is not clear in Model 3. In addition, slip events at the VLFE region are also found during the period without long-term SSEs in Model 2, while most of slip events at the VLFE region are found with long-term SSEs in Model 1. Our results suggest that the top of the long-term SSE region are close to the VLFE region, and the model with stable sliding region beside the long-term SSE region (Model 1) is more preferable to reproduce observed results than the model with fully locked surrounding region (Model 2).

Keywords: very low frequency earthquake, slow slip event, numerical simulation, Bungo Channel