Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS29-P01 Room:Convention Hall Time:May 24 16:15-17:30

Effects of temperature and fluid pressure on the frictional behaviors of glaucophane schist

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The 2011 Tohoku earthquake (Mw 9.0) off the Pacific coast of Japan initiated at 24 km depth along the plate boundary. In order to understand the initiation mechanisms of the earthquake, it is essential to reveal the frictional properties of metamorphic rock which is expected to exist around the epicenters of major earthquakes at the Tohoku subduction zone. Thus, we have conducted friction experiments on glaucophane schist from Franciscan Belt, California at high temperature and high pressure using a gas-medium, high PT deformation triaxial apparatus at AIST. The rock samples were shaped into a cylinder with a precut surface at an angle of 30 degrees. The specimens are drilled through to the slip surface for ?uid conduit and distilled water is used as a pore fluid for wet experiments. Experiments are performed at temperature of 100-300^{o}C, axial loading speed of 0.1-1.0 micron/s, a constant confining pressure of 150 MPa and pore fluid pressure of 1-149 MPa. In this study special attention was paid to how a rate-depend parameter, a-b, in the rate and state friction law changes with temperature and fluid pressure.

Our preliminary results are summarized as follows. At 100^{o}C, a-b value shows positive at low fluid pressure, but it decreases to negative with increasing fluid pressure to effective pressure of 5 MPa. This implies that an earthquake could nucleate even at aseismic plate boundaries when fluid pressure increases significantly to reach very low effective pressure. At 200 and 300 ^{o}C, a-b value shows positive at any fluid pressures and the sliding surface behaves viscoelastically at the rapid change in sliding rate, although a-b at this temperature range is generally thought to indicate negative value. In widely accepted earthquake models of a subduction zone (e.g. Scholz, 1998), a seismogenic zone defines as that the rate-depend parameter becomes negative value at a temperature range of 100-300 ^{o}C. However, this model is based on the experimental results on granite which does not exist at subduction zones. It may be necessary to establish new initiation model of subduction earthquakes that is incorporated into the effect of not only temperature but also fluid or effective pressure on frictional property of metamorphic rocks. More detailed results including microstructural observation will be presented at the meeting.

Keywords: Glaucophane schist, Pore pressure, High temperature and high pressure, Frictional behavior

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Experimental study about compaction of simulated fault gouge

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From the friction experiments using simulated fault gouge, it is known that frictional instability is influenced by microstructure development of the gouge (Byerlee et al., 1978; Logan et al., 1979; Marone and Kilgore, 1993; Onuma et al., 2011). Gouge compacts during an initial stage of shear, subsequently unstable slip occurs when shear proceed (Marone et al., 1990). However, the purely deformation process of gouge to unstable slip in detail is not clear, because the point of measurement is far from gouge layers, and sampling rate is slow. Therefore, we attempted to investigate how gouges behave toward unstable slips using strain gages, and how frictional instability is influenced by confining pressure.

We conducted frictional experiments using simulated fault gouge in a gas-medium apparatus at confining pressures ranging from 140 up to 180 MPa at a constant strain velocity of 10^{-3} /s. A dry quartz powders (0.1 or 0.2 g) were used as simulated fault gouges, and they were placed between two gabbro cylinders, which were 20 mm in diameter, 40 mm in length, and cut by a 50o to their cylindrical axis. To measure localized strain and fault slip, we used strain gages glued directly onto a gouge layer inclined 45o to saw-cut. Another strain gauge was used to measure axial stress. Sampling rate is 2 MHz. In order to investigate how gouge accommodate strains during a compaction stage, we loaded until the axial stress reaches the set points (190, 450, 640, 800 MPa), then stopped load and relaxed stress. The sample was hold at 30?60 seconds and we load until it reaches the next set point. We repeated this loading cycle until unstable slip occurs.

During the holding stages, we detected three different behaviors of stress relaxation of gouge depending on the magnitude of stress: 1) Compression with little drop of stress. The behavior was confirmed at the lowest axial stress of 190 MPa suggesting that the gouge shows elastic rebound at this stress. 2) Extension and subsequent compression during intermediate stress levels (450 and 640 MPa). 3) Great extension with the decrease in axial stress observed at the highest stress (800 MPa). The behavior can be observed during later stages of the repeated loading. During repeated loading, gouge evolves toward unstable slip from behavior 1 to behavior 3 with stress. It is also revealed that the peak stresses when the unstable slip occurred were lower than those in past load cycles. This indicates that during repeated loading, plastic deformation of gouge occurred under high stress and gouge cannot sustain stress even under progressive loading We suggested fracture and slip of gouge particles happened (behavior 3) under high stress after compaction proceed by repeated load (behaviors 1 and 2). Moreover, plastic strain needed for unstable slip decrease with pressure. From the microstructural analysis of simulated fault gouge, the transition from R1 shear to Y shear has been known to cause unstable slip (Logan et al., 1979; Onuma et al., 2011). We propose that the behavior 3 observed in the present study corresponds to formation and slips of R1shears. From the high-speed data acquisition systems using strain gages, we illuminated the mechanical behaviors of gouge toward unstable slip under various confining pressure.

Keywords: simulated fault gouge, compaction, frictional instability

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Properties of comminuted granite subjected to uniaxial compression and direct shear tests

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Properties of comminuted granite subjected to uniaxial compression and direct shear tests.

The comminuted granite articles, formed by the uniaxial compression test showed the particle shapes such as needle, sheet and pillar with irregular and sharp edges. The granite particles formed by the alternated method, were subjected to direct shear tests at 10 mm/30 min. The many particles over several ten microns in diameter were characterized by nearly polygonal shape under normal stress of 4.5 kgf/cm^2. On the other hand, under less than normal stress of 2.25 kgf/cm^2, the shape of particles of more than one micron in diameter slightly changed.

The specimens for the uniaxial compression test were roughly 2 to 5 cm in length and 1.2 to 1.7 cm in diameter. The normal fracture stress was 91˜137 MPa. The specific surface area of the comminuted particle of granite particles was measured by gas adsorption, using the BET method with argon gas.

The specific surface area of the comminuted particles formed by the uniaxial compression tests increased with increasing elastic strain energy density, in roughly linear manner. In the case of the direct shear tests, the degree of the surface area increased, under normal stress, more than 3.375 kgf/cm^2. The results of the comminution experiment tests on granite suggest that the relation between changes in the specific surface area of comminuted particles and the elastic strain energy density is consistent with low comminution energy according to Rittinger hypothesis.

Keywords: Rittinger’s hypothesis, comminuted particles, elastic strain energy density, specific surface area

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What is the factor controlling the increase in vitrinite reflectance along faults?

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The detection of frictional heating along faults is crucial to assessing the level of shear stress during the earthquake. Recent studies suggested that the increase in vitrinite reflectance along faults may result from frictional heating. Commonly, the maximum temperature during frictional heating was estimated using the chemical kinetics model of vitrinite maturation described by a first order Arrhenius law. However, the factor controlling the increase in vitrinite reflectance along faults remains poorly understood. Moreover, the application of the chemical kinetics model for estimation of peak temperature during a short-lived thermal event has not been tested. Here, we conducted high-velocity (1.3 m/s) friction experiments on a mixture of 90 wt% clay-rich powder from the megasplay fault in the Nankai accretionary prism and 10 wt% coal grains from the Kumano forearc basin sediments under wet (water-saturated) and dry (room humidity) conditions. The measurement of vitrinite reflectance and the observation of microstructures were carried out after the experiments. Both wet and dry tests show rapid slip weakening and increase in temperature. The comparison of vitrinite reflectance before and after the experiments indicates that the increase in vitrinite reflectance was observed only in the sample after the dry test, particularly in portions where size of coal is reduced by comminution. In contrast, grain-size reduction is invisible in the sample after the wet test, possibly because of the generation of fluid pressure prior to comminution. The vitrinite reflectance calculated from the commonly used kinetics model is higher than that measured after the experiments, suggesting that the kinetics model tends to overestimate the peak temperature in faults. Our results indicate that vitrinite reflectance is never increased by a short-lived rapid heating alone; comminution is necessary for an increase in vitrinite reflectance. The new kinetic model of vitrinite maturation considering the effects of comminution is need for better estimation of temperature rise along faults.

Keywords: vitinite reflectance, frictional heating, comminution, Nankai Trough

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Comparison between the resisitiviy profile and fault rock microstructure in fault zones -Case study at Atotsugawa fault-

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[1]Nat'l Res Inst Earth Sci Disaster Prev

Structure and friction characteristic in a fault zone are not homogeneous, and the inhomogeneity is observed as asperity. However, main features of the inhomogeneity in fault zone are not yet sufficiently understood. I consider it is effective to compare geophysical data, such as seismological and/or electromagnetic survey data, and fault rock microstructures and mineral compositions in the fault zone. In this presentation, I report the results of comparison between the resistivity profile by electromagnetic survey across the fault zones (Omura et. al., Seismological Society 2005) and microscopic observation and mineral composition analysis of fault rocks provided by boring into the fault zones (Hirokawa et. al., Joint Meeting 2007), as for Atotsugawa fault, central Japan, where the inhomogeneity is clearly recognized; seismically active region and non-active region are distinctly distributed along the fault trace.

Keywords: resisitivity, electromagnetic survey, fault rock, microstructure, mineral composition, earthquake generation

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Characterization of carbonaceous materials in the Taiwan Chelungpu fault by micro Raman-FTIR spectroscopies

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Coseismic slip during an earthquake induces frictional heating in fault zone. Determination of the temperature recorded in the fault is important for estimating the dynamic shear stress and displacement during the earthquake. Here we performed micro Raman-FTIR spectroscopic analyses of carbonaceous materials from the Taiwan Chelungpu fault, which slipped at the 1999 Chi-Chi earthquake. We also conducted heat experiments and high-velocity friction experiments and analyzed by Raman-FTIR spectroscopies in order to investigate the effects of fast heating rate like frictional heating during earthquake. Based on the results of analyses, we discuss the capability as new temperature proxy during the earthquake.

Keywords: Taiwan Chelungpu fault, carbonaceous materials, Raman spectroscopy, FTIR spectroscopy

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Coseismic reaction of clay minerals in the Taiwan Chelungpu fault

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To investigate the fundamental processes governing earthquakes and the slip behavior, quantitative analyses of mineralogical compositions and physicochemical properties of fault rocks are necessary. There are several methods for evaluation of mineralogical compositions in the fault rocks from these XRD spectra. To evaluate mineralogical compositions with the most suitable methods, we assessd the validity of these methods. Then we determined the quantity of mineralogical compositions of the core samples from the Taiwan Chelungpu fault by the most suitable method.

Keywords: Clay minerals, comminution, XRD, RockJock

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Very low frequency earthquakes off the Pacific coast of Tohoku located by Hi-net high-sensitivity accelerometers

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Various types of slow earthquakes have been reported in several subduction zones, after the discovery of deep low frequency tremor in the Nankai subduction zone (Obara, 2002). These slow earthquakes have lower dominant frequency than those of regular earthquakes. Very low frequency earthquakes (VLFEs) are the slow earthquakes which are dominant around the frequency of 0.05 Hz. Active VLFEs have been reported in the off-Tokachi and Nankai region (e.g., Obara and Ito, 2005; Asano et al., 2008). Recently, Ando et al. (2012) have reported VLFEs in the Ryukyu arc region. Very recent study using ocean bottom seismometers shows that shallow VLFEs in the Nankai region occur around the decollement (Sugioka et al., 2012). These VLFEs close to trench axes are considered as a key to understand the stress accumulation process in the shallow part of the subduction zone. Using F-net broadband seismometers, Matsuzawa et al. (2012) have reported VLFEs off the Pacific coast of Tohoku, where rare VLFEs were reported. In this study, to reveal the details of the VLFE activity in this region, we locate VLFEs using Hi-net high-sensitivity accelerometers which are more densely distributed than F-net seismometers.

In this analysis, we adopt a two-step cross correlation technique using a template event to locate VLFEs. An inter-plate regular earthquake is chosen as a template event. At first, we pick candidate events of VLFEs from F-net continuous broadband seismograms which are bandpass-filtered between 0.02 and 0.05 Hz. In the time window of 90 s, an epicenter is located to maximize averaged value of correlation coefficients (CC) within the range of 1 degrees from the template event in the latitudinal and longitudinal direction. If the maximum CC exceeds 0.5, this event is selected as a candidate event. At the next step, using Hi-net high-sensitivity accelerometers, we applied the similar correlation analysis in the finer spatial mesh (intervals of 0.02 degrees) to the candidate events. As regular earthquakes are included in the result, such earthquakes are removed from the list using the catalog of regular earthquakes and amplitude ratio of envelopes in the frequency band from 2 to 6 Hz. CC tends to be high without VLFEs, when surface waves of far-field large earthquakes arrive. Therefore, we excluded the events located in such noisy period, based on the result of the multi array analysis of high-sensitivity accelerometers (Asano et al., 2008). Finally, VLFEs are located, after the manual check of waveforms to remove apparent events caused by microseisms or the coda part of far-field events.

The VLFE activity off Fukushima-Ibaraki is most active in the region off the Pacific coast of Tohoku. In the previous study with F-net data, distribution of epicenters is elongated in the east-west direction. However, this analysis shows that such elongated distribution is apparent and VLFEs occur in the narrower region. Our result shows that, at least, three clusters exist along the trench direction off Fukushima-Ibaraki. VLFE activity in the northern cluster becomes quiescent after the 2011 Tohoku earthquake. On the other hand, VLFEs are activated in the central and southern cluster. This suggests that the northern cluster is located in the slip region of the Tohoku earthquake, and the central and southern clusters are located in the stress accumulation region of the earthquake or afterslip area. This suggests that the monitoring of VLFEs may be useful as an indicator of the slip at the plate boundary. In this correlation analysis, regular earthquakes are also located. Many regular earthquakes occur at the surrounding region of these VLFE clusters. Especially around the central VLFE cluster, the distribution of VLFEs and regular earthquakes seems to be complementary. This may reflect the distribution of inhomogeneous frictional property at the plate boundary.

Keywords: very low frequency earthquake, off the Pacific coast of Tohoku, 2011 Tohoku Earthquake, slow earthquake

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Creep on the Philippine fault in northern Leyte Island

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The Philippine fault is a major strike-slip fault that traverse 1250 km along the Philippine Islands. It is a left-lateral fault and the slip velocity inferred from GPS surveys exceed 20 mm/year. In Masbate and Leyte Islands, located in central Philippines, no earthquakes of M7 or larger are not known for the last 400 years, and fault creeps have been found in a part of Leyte (Tsutsumi and Perez, 2011). In this presentation, we report our results showing evidence of fault creeps along the Philippine fault in Leyte Island and discuss the creep rate.

In our InSAR analysis, we used 20 images acquired from west between February 2007 and January 2011. We used 39 pairs of images having small baselines to form interferograms. We modeled the long-wavelength noise due to inaccurate orbit data and ionospheric disturbances as a bi-linear trend and removed it in such a way that the fluctuations in the displacement time-series are minimized. Namely, the noise components and displacement time-series were obtained simultaneously using least square's method. Finally, we obtained the mean displacement rate from the displacement time-series.

The result of the InSAR analysis shows, in central to northern Leyte, spatial discontinuities in the displacement rate coincident with the traces of the Philippine fault, indicating that the fault is creeping in this part of the Philippine fault. The creep rate is up to 2.5 mm/year in the line-of-sight direction of the satellite, corresponding to 11mm/year in the direction of the fault motion. On the other hand, we had an estimation of 12-26 mm/year from field surveys. The values obtained from InSAR are generally smaller, but the InSAR rates were obtained as mean values within small areas, and this apparent difference does not necessarily contradict with each other. In addition, it may be possible that the difference is simply due to the difference in the analysis periods, and further investigation is needed. In the southern part of Leyte, we have not find so far any evidence of creeps from InSAR or field surveys.

Keywords: Philippine fault, Leyte Island, fault creep, InSAR

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Time dependent changes of pore pressure before and after the 2011 Tohoku earthquake

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Changes in well water level, streamflow and chemical composition changes of ground water accompanied by earthquakes have been widely observed. Groundwater monitoring is especially important for understanding of mechanism of earthquake-related change.

We are monitoring continuous pore pressure and atmospheric pressure with a recording interval of 1 second at the Kamioka mine, Gifu Prefecture, central Japan. Pore pressure decreased after the 2011 Tohoku earthquake (M 9.1) on 11 March. In general, causes of the pore pressure changes include meteorological effects, Earth tide and crustal deformation. Here, we focused on the Earth tide response before and after the earthquake. The observed data during the period from April 2005 to December 2011 were divided into time windows of one month (744 hour). The tidal analysis program, BAYTAP-G (Tamura, 1995) is used to extract tidal responses of pore pressure from the divided data. Amplitudes of M_2 and O_1 components decreased after the Tohoku earthquake, which can possibily be due to: (1) the increase of the permeability (2) the elastic coefficient change of the rocks. We estimated the hydraulic diffusivity supposing that the cause of the tidal amplitude change is the increase of the permeability. This yields an increase of the diffusivity from 0.03m^2/s to 0.09 m^2/s. Increase of the hydraulic diffusivity is consistent with pore pressure reduction. But in actually, the effects of the elastic coefficient changes of the rocks cannot be excluded. We analyzed the data before and after the 2007 Noto Hanto Earthquake (M6.9) and apparent amplitude changes cannot be detected. These results imply that only large deformations caused by very large earthquakes, such as the Tohoku earthquake, cause changes of the hydraulic diffusivity and the elastic coefficient.

Keywords: pore pressure, hydraulic diffusivity, Tohoku earthquake, Earth tide

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Dissolution process of quartz grains damaged by earthquake slip

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We evaluated the dissolution process of quart grains damaged by milling.

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Seismogenic fault lubrication by graphite: Evidence from graphite-bearing pseudotachylyte and cataclasites

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We report the occurrences of basal-slip graphite derived from pseudotachylyte in the upper sequence of Hidaka metamorphic belt, Hokkaido, Japan. Melt-induced textures such as biotite microlites, shell textures of Fe-oxide, spherulites and vesicles in Fe-oxide are observed in the graphite-bearing pseudotachylyte. These matrix have two important features. Firstly, hydrous minerals, biotite and muscovite, have completely disappeared and albite, quartz and oxide minerals including graphite have survived as fragments. These results suggest that pseudotachylyte was generated at least above 650 - 700 degree Celsius by dehydration melting of biotite and muscovite. Secondly, graphite shows lower degree of graphitization than those in the cataclasite, and is closely associated with other oxide minerals along the shear planes, and their aggregations have striation and smooth surface. In particular, the deformed graphite in the pseudotachylyte matrix records valuable information of degree of graphitization during seismogenic faulting. However, the Fe-oxide spherules have formed in the matrix by the oxidation during melt-quenching, where a part of original graphite might have been converted to CO_2 by oxidation. In the Micro-Raman spectroscopy and XRD study, graphite in the pseudotachylyte show amorphization by basal slip. The Lc values decrease from over 40 nm to 9-15 nm and the scatter plots between R1 ratio and G band FWHM display a different trend with higher R1 ratios than that in the host rocks. In addition, HRTEM observations indicate that microstructures are mainly observed in interlayer delamination of stacking. Moreover, carbon isotopic composition of graphite in both host rocks (delta ^{13}C = -24.8 to - 25.9 per mil) and pseudotachylyte-bearing cataclasite (delta^{13}C = - 22.5 to - 27.8 per mil) show clearly biogenic isotope signatures, and considered to have formed through metamorphism and deformation process of organic matter in sedimentary rocks. Thus, these data suggest that the differences of crystal size by slip rate might be the driving force of deformation process.

Therefore, the presence of small amount of graphite by residual assimilation during frictional melting has the potential for fault lubrication. Our finding of deformed striated graphite is a direct evidence of fault lubrication on the slip surface during seismogenic faulting.

Keywords: pseudotachylyte, graphite, frictional melting, amorphization, lubrication