Japan Geoscience Union Meeting 2011
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SSS029-P01 Room:Convention Hall Time:May 23 14:00-16:30

Finite element modeling of stick-slips on a solid surface with many asperities

Mamoru Hyodo[1]*, Hide Sakaguchi[1], Takane Hori[1]

[1]JAMSTEC/IFREE

Friction is the tangential force resisting the relative motion of solid surfaces or material elements sliding against each other. Since all real surfaces have topography (or roughness) in the microscopic view, they touch at a few points or asperities, when they are brought together. Hence, macroscopic friction is regarded to be the sum of interacting forces at such microscopic asperities. For an contacting asperity, we consider the additional deformation at the area surrounding the asperity. In such a case, depending on the deformation amount, the real area of contact at the asperity will largely increase or decrease. Such a change in contact state at the asperity affects not only the interacting force at the asperity but also the macroscopic friction. Furthermore, it is expected that friction between solid surfaces has a possible dependence on materials, since the deformation of the solid material is strongly depend on their properties (rigidity, viscosity, etc.). The effects of the deformation and property of materials on friction, however, have not been explicitly included in many existing friction laws.

Therefore, in this study, we examine these effects on macroscopic friction through a finite element modeling of stick-slips on a solid surface with many asperities. As a tentative result, the calculation with 50 asperities repeats stick-slips with various sizes, though the maximum number of asperities which break in an event is much smaller than 50. Hence, the macroscopic friction is almost constant, and steady slip motion of two blocks is generated.

In the presentation, we will show the detail of our finite element modeling and calculation results with various material property or asperity distributions.

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Quartz amorphization due to friction and wear : Raman spectroscopic analysis

Yu Nakamura[1*], Jun Muto[1], Hiroyuki Nagahama[1], Takashi Miura[2], Ichiro Arakawa[2]

[1]Graduate School of Science,Tohoku Univ., [2]Dept.Phys.Gakushuin Univ.

Solid state amorphization of minerals is known to occur in hardness indentations, during ball milling, in diamond anvil experiments, and in shock experiments. A production of SiO2 amorphous material is also reported in experimentally created fault gouges [1]. High speed friction experiments of quartz rocks imply extraordinary weakening at seismic rates [2]. Because weakening requires the combined effects of large displacement and high velocity, formation of a thin silica gel layer which comprises of very fine particles of amorphous silica was thought to cause weakening. Therefore, physical process of amorphization is important to better understand weakening of quartz bearing rocks at seismic rates. In this study, we conducted a pin-on-disc experiment to investigate details of amorphization of quartz [3]. Discs were made of single crystals of synthetic and Brazilian quartz. The normal load and sliding velocity were ranged from 0.01 N to 1 N and from 0.01 m/s to 0.25 m/s, respectively. The friction experiments were conducted using quartz and diamond pins (curvature radii of 0.5 ~ 1.5 mm) to large displacement (~80 m) under controlled atmosphere. Raman microspectroscopy (excitation wavelength 532.1 nm) provides lattice vibrational modes, and was used to investigate the degree of amorphization of samples. Raman spectra of frictional tracks on the disc show clear bands at wavenumbers of 126, 204, 356, 394, and 464 cm-1, their bands are restored E(LO+TO), A1, A1, E(TO), A1 vibration modes respectively. However, the bands at 464 and 204 cm-1 gradually broaden to reveal shoulders on the higher-wavenumber side of these peaks. Especially, a new distinguished peak appears at 480cm-1. In an experiment conducted at low stress (125 MPa) to large displacement (~ 80 m), Raman spectra show complete lack of lattice vibrations mentioned above, indicating that quartz lost intermediate range structure of SiO2 during friction experiments. In the presentation, we will present the degrees of the amorphization as a function of normal stress, displacement and sliding velocity.

[1] Yund, R. A., M. L. Blanpied, T. E. Tullis, and J. D. Weeks, 1990, Amorphous material in high strain experimental fault gouges, J. Geophys. Res., 95, 15589-15602.
[2] Di Toro, G., D. L. Goldsby, and T. E. Tullis, 2004, Friction falls towards zero in quartz rock as slip velocity approaches seismic rates, Nature, 427, 436-439.
[3] Muto, J., H. Nagahama, T. Miura, and I. Arakawa, 2007, Frictional discharge at fault asperities: Origin of fractal seismo-electromagnetic radiation. Tectonophysics, 431, 113-122.

Keywords: friction experiment, amorphization, raman spectroscopic analysis, weakening

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Raman spectroscopic characterization of fault gouge rapidly healed after dynamic weakening

Takehiro Hirose[1*], Mukoyoshi Hideki[2], Kazuo Mizoguchi[3]

[1]JAMSTC/Kochi, [2]Marine Works Japan, [3]Central Research Institute of Electric P

How rapidly fault strength recovers after an earthquake is an important question for understanding the earthquake generation mechanism in seismic cycles. Recent friction experiments at coseismic velocities revealed that the fault can completely regain its strength to pre-slip level within few days (Mizoguchi et al. 2009, BSSA). However the factor causing such rapid fault healing after dynamic weakening is still not understood. We expected that the reformation of a certain type of chemical bond is responsible for fault healing. Thus, we performed high-velocity friction experiments on quartz gouge at a slip velocity of 1.3 m/s, normal stress of 1.0 MPa and displacement of $>$10 m. At this condition, the simulated fault weakened markedly with displacement to friction coefficient of ~0.2. In order to identify the chemical bonds that play a key role in fault healing after dynamic weakening, the slip surface of gouge zone was analyzed immediately after the experiments using a laser Raman microscope. We found a characteristic peak at ~1600 cm-1 in a Raman spectrum detected only from the dynamically weakened gouge at high velocities. This peak corresponds to bending vibrations of a H2O molecule. The peak appeared just after the experiment and its intensity decreased with time. After two days, the peak totally disappeared. Interestingly the time scale of existence of the peak is almost same as that of gouge healing. We propose a hypothesis that the excitation of bending vibrations of a H2O molecule by shear and/or frictional heat during rapid sliding and the degradation of the vibrations after the termination of the sliding results in the dynamic fault weakening and the rapid fault healing, respectively.

Keywords: fault, healing, H2O

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Contact state of simulated fault via electrical resistance

Futoshi Yamashita[1*], Eiichi Fukuyama[1], Kazuo Mizoguchi[2], Takashi Yanagidani[3]

[1]NIED, [2]CRIEPI, [3]None

Earthquake is a frictional sliding of fault. If we can monitor the frictional strength of fault with maintaining the contact state between rocks, therefore, we will obtain valuable information which can help us to understand the frictional property of rocks and the fault sliding mechanisms during earthquake. From the point of view, we focused on electrical property of fault plane. In the previous experiment, we successfully observed decrease in the electrical resistance of simulated fault caused by increase in the normal stress and formation of molten layer. In this meeting, we will show the estimated contact state of simulated fault via the electrical resistance during rotary-shear frictional tests. We adopted an electrometer (Keithley 6514) to measure extreme high resistance of dry rocks. This instrument enables us to measure resistance up to 210 G ohm by impressing high voltage of 250 V. At first, we conducted simple press test. We used two cylindrical gabbros from India as rock samples with the diameter of 25 mm and the length of 30 mm. The rock samples were installed into the rotary-shear frictional testing apparatus (Shimamoto and Tsutsumi, 1994; Mizoguchi and Fukuyama, 2010). The normal stress was changed between 0 and 8 MPa by 0.5 MPa in each step after maintaining the state for 300 s. The electrical resistance of fault should be more than 210 G ohm with the normal stress of 0 MPa, because the electrometer could not work at the stress. The resistance decreased from 90 G ohm at 0.5 MPa to 30 G ohm at 8 MPa accompanying with the increase in normal stress. This can be interpreted that increase in the normal stress enlarged real contact area of the fault, which causes decrease in the resistance. Next, we monitored the resistance of fault during low-velocity frictional test. We used the same rock samples of the press test. The normal stress of 3 MPa and the equivalent slip velocity of 5.3 x 10^{-3} m/s were maintained during the test. Frictional strength, which is defined as the ratio of shear stress to normal stress here, suddenly increased up to 0.8, weakened to 0.2, and fluctuated between 0.2 and 0.6. The electrical resistance drastically decreased from 130 to 8 G ohm after starting the frictional test, and fluctuated between 10 and 30 G ohm after the first decrease. Comparison between changes in the frictional strength and the resistance revealed that the increase in frictional strength synchronized with the decrease in resistance, and vice versa. This observation can be explained by the idea that the increase in real contact area of fault causes the increase in frictional strength as well as the decrease in resistance. Next, we conducted high-velocity rotary-shear frictional test with frictional melting. We maintained the normal stress of 3 MPa and the equivalent slip velocity of 1.3 m/s. The amount of slip distance was attained to 52 m. During one second after starting frictional sliding, the fault showed the first weakening, and after that, the fault showed the second strengthening and weakening associated with the frictional melting introduced by Hirose and Shimamoto (2005). The electrical resistance decreased from 70 G ohm to 3 G ohm just after the start of sliding and continued to decrease up to 1 G ohm. Detailed investigation of the early stage of sliding revealed that rate of the decrease in resistance became greater with transition from the first slip weakening to the second strengthening. This would correspond to the stage that local melting at some asperities stated to connect each other. After that, the frictional strength attained to the second peak, which looks to synchronize with temporal stop of the decrease in resistance. This can be interpreted that the melt patches grew to molten layer in the fault. We also observed step-like decreases in the resistance, which should be associated with growth of the molten layer. We will quantitatively discuss the frictional mechanisms of fault by detail analysis.

Keywords: Electrical resistance, Fault, Friction, Frictional melting, High-velocity rotary-shear frictional test

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Influence by teflon contamination on the fault slip behavior during high-speed friction experiments

Nozomu Hirai[1], Go Honda[1*], Wataru Tanikawa[2], Tetsuro Hirono[1]

[1]Osaka University, [2]Kochi Institute for Core Sample Research

There are many natural fault zones including clayey fault gauge. It is important to understand coseismic slip behavior of fault gauge because it has a great influence on frictional strength.

When we conduct high velocity frictional experiments on fault gauge, we generally use a Teflon sleeve which covers the fault to confine the gauge in the fault during shearing. As a preliminary experiment, we conducted high velocity frictional experiments on illite powder samples, using a rotary shear, high speed frictional testing apparatus. We considered the illite powder to be fault gauge. The gauge sample was put between a pair of gabbro cylinders. When we conducted thermogravimetry and differential scanning calorimetry on gauge samples after experiment, the contamination of more than 10wt% Teflon into gauge samples during sharing was recognized. This weight of Teflon contamination increased with increasing normal stress and displacement. Because frictional coefficient of Teflon is low compared with a rock, Teflon contamination into gauge sample is considered to have influence on frictional strength. In order to investigate this influence, we conducted experiments using 0wt%, 10wt%, 20wt%, 30wt%, 40wt%, 50wt% Teflon contaminated beforehand into gauge samples. We evaluated the slip behavior by Teflon contamination from this experiment result.

Keywords: slip behavior, high-velocity friction experiments, teflon, differential scanning calorimetry, thermogravimetry

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Microfracture analysis of damage zone along active faults

Kazuo Mizoguchi[1*], Keiichi Ueta[1]

[1]Central Research Institute of Electric P

Brittle faulting along faults in the crust often results in the fault zone structure characterized by a fault core surrounded by a damage zone. The fault core is narrow localized shear deformation zone consisting of fault gouge, fault breccia and cataclasite. Previous studies showed a clear relationship that the width of the damage zone becomes thick with the net displacement occurred along faults (e.g., Mitchell & Faulkner, 2009). The damage zone width is important for understanding the degree of maturity of a previously unknown fault and its associated seismic hazard. In the damage zone, fractures develop at various scales, from ˜ ?m to ˜ m, and their density typically increases with proximity to the fault core. We examined the spatial distribution of the microfracture density around a newly-found active fault in Takiyama area, east of Tottori plain (Sasaki et al., this 2011 JGU meeting).

The studied fault zone consists of the 1 m thick fault core of the purple-colored clayey fault gouge and the fault breccia with cataclastic foliation, and the surrounding damage zone developed in Cretaceous Kyushozan granite. The boundary plane between the fault gouge and the fault breccia has a strike of N79W and a dip of 87N, corresponding to a fault plane. We collected ten orientated samples 19.4 m to 329 m from the fault core. The samples were coated with epoxy and then thin sections were cut perpendicular to the fault plane and parallel to a horizontal plane because the slip direction is unknown. More than 10 quartz grains per sample were analyzed for the microfracture density measurements. Quartz is suitable to estimate the damage that the rock sample has sustained because quartz without cleavage acts as an isotropic medium for fracturing. We counted the number of microfractures that intersected a line which was drawn from the edge of each quartz grain, through the center point, to the other edge of the grain. The linear microfracture density for each sample is calculated to be the total number of microfractures intersecting the lines divided by the total counting line length. The microfractures we counted are divided into (1) healed fracture (fluid inclusion planes), (2) sealed fracture filled with clay minerals and (3) open fracture. The linear density of open fractures increases as the fault core is approached. The other fractures do not show a clear relationship between the microfracture density and the perpendicular distance from the fault core. In this presentation we will discuss whether such a spatial distribution of microfractures is structural characteristics of damage zone along active faults.

Keywords: active fault, Damage zone, microfracture

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Structural analysis of shear zone developed in Sakaitoge Fault

Satoru Tsuchihashi[1*], Aiming Lin[2]

[1]Graduate school ,Shizuoka University, [2]Graduate school ,Shizuoka University

Active fault zones and their related cataclastic fault rocks formed by seismic faulting at shallow depths within the upper crust are closely related to the long-term seismicity and tectonic history of faults. Studying on deformation structures of active fault zones, therefore, provides important information for accessing the long-term seismic faulting behaviors and understanding the tectonic environment and history of active faults. In this paper, we present a case study on the fault shear zone structures developed along the Sakaitoge-Kamiya Fault, central Japan by field investigation and meso- and microstructural analyses of fault rocks.

The Sakaitoge Fault, the northern segment of the NW-SE trending Sakaitoge-Kamiya Fault zone, extends for about 30 km in the southern Hida Mountains of central Japan. Previous studies show that the total displacement is about 4.5 km, having a left-lateral strike-slip movement sense and that the youngest seismic event occurred in the past 1400 yr (Kano et al., 2001).

Field investigations and meso- and microsructural analyses reveal that the shear-zone of the Sakaitoge Fault is mainly composed of non-foliated cataclasite and foliated cataclasite, fault gouge and fault breccia. The foliations and Riedel shear structures indicate a uniform left-lateral strike-slip sense. The foliations developed in both the cataclasite and the fault gouge shows that the Sakaitoge Fault had been moved in the same shear sense since the formation of cataclasitic rocks.

Keywords: Sakaitoge fault, shear zone, foliation

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Earthquake fossil: ultralcataclastic veins occurred along the Arima-Takatsuki Tectonic Line

Makoto Tanaka[1*], Aiming Lin[1], Kazuhiko Yamashita[1]

[1]Shizuoka university

In this study, we present a case study of veinlet ultracataclastic rocks from the Arima-Takatsuki Tectonic Line (ATTL), southwest Japan. Field investigations and meso-microstructural analyses reveal that numerous veinlet ultralcataclastic rocks, composed of aphanitic pseudotachylyte (Pt) and unconsolidated fault gouge and alluvial deposits, are widely developed within a wide fault zone of ~200 m as simple veins, breccias, and complex networks along the ATTL. These veinlet fault rocks generally show dark, green, gray, brownish-red in color. Microstructurally, all these veins are mainly characterized by a superfine- to fine-grained matrix and angular?subangular fragments ranging in size from sub-micron scale to several millimeters. Powder X-ray diffraction patterns show that all veins are characterized by crystalline materials composed mainly of quartz and feldspar, similar to the host granitic rocks.

Based on the meso- and microstructural features of ultracataclastic veins and the results of powder X-ray diffraction analyses, we conclude that i) all veinlet ultracaclastic rocks were generated mainly by crushing, ii) the veinlet and network veins formed repeatedly within the fault-fracture zone via the rapid fluidization and injection of superfine- to fine-grained materials during seismic faulting events; iii) the pseudotachylyte veins formed by crushing but not melting. The present results show that the fluidized ultracataclastic veins record paleoseismic faulting events that occurred within a seismogenic fault zone; consequently, these features are a type of earthquake fossil, as is melt-origin pseudotachylyte.

Reference: Lin, A. (2011). Seismic slip recorded in the fluidized ultractaclastic veins formed along the coseismic shear zone during the 2008 Mw7.9 Wenchuan earthquake, Geology, in press.

Keywords: pseudotachylyte, veinlet fault rock, Arima-Takatsuki Tectonic Line

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High-velocity weakening of the black fine-grained fault rock from the Ghost Rocks Formation, Kodiak Island, Alaska

Masaaki Okita[1*], Akito Tsutsumi[1]

[1]Kyoto University

In Kodiak Island, Alaska, an accretionary complex that has been interpreted as an analogue of paleo-decollement zones exposes (Fisher and Byrne, 1987). Recently, dark gray to black, locally vitreous, ultra-fine grained fault rock (black fault rock, BFR) was reported from the fault zones in the Kodiak accretionary comlex (Ghost Rocks Formation), as a possible rare example of rocks that preserved a record of seismogenic faulting along subduction zones (Rowe et al., 2005). The fault rock is characterized with the following features; In the BFRs, pseudotachylyte occurs as a possible evidence for the operation of frictional melting (Meneghini et al., 2009), and on the other hand, the BFRs contain ductile deformation fabrics, which suggests association of cataclastic flow (liquefaction) process at high slip rates (Brodsky et al., 2009).

In this study, frictional properties of cataclastic melange rock exposed adjacent to the BFRs was investigated using a rotaty-shear frictional testing machine at Kyoto University. The samples for the experiments were collected from cataclastic argillaceous melange rock, which is likely the source of the BFRs. The collected samples were manually disaggregated and sieved in order to eliminate clasts larger than about 0.17 mm. Frictional experiments on the assembled samples were performed at a constant slip velocity of 300 mm/s over a range of normal stresses from 0.4 MPa to 1.0 MPa at dry condition.

At the lowest normal stress of 0.4 MPa, the experimental fault exhibited slip weakening behavior. Upon initiation of slip, shear stress decreased exponentially from initial peak value to residual almost steady-state value after about 20 m displacements. Thickness of the sample monotonically decreased during the run, suggesting a gradual compaction of the sample with the slip. On the contrary, for the tests at higher normal stresses from 0.6 to 1.0 MPa, frictional behavior of the argillaceous rock sample comprises of three stages; weakening stage from initial peak value, which is followed by a rapid friction increasing stage toward the second peak value, and a further gradual friction decreasing stage following the second peak friction. Interestingly to note, the sample started to dilate (expand) following the initial compaction stage. The beginning of the dilation roughly correlates with the onset of the increasing period of shear stress towards the second peak value. Our experimental results suggest that frictional heating plays an important role for the stress increasing behavior of the sample following the initial slip-weakening at normal stresses $>$ 0.4 MPa.

Keywords: rock friction, pelitic rock, Kodiak Island

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Internal and permeability structures of faults developed in the Shimanto accretionary prism in Kochi prefecture

Manami Kitamura[1*], Mukoyoshi Hideki[2], Takehiro Hirose[3]

[1]Hiroshima University, [2]Marine Works Japaan, [3]Kochi Institute for JAMSTEC

Hydrological properties of major faults within accretionary prisms have attracted much attention recently in regard with its role on the earthquake generation processes within a shallow part of subduction zones. However internal and permeability structures of low-angle fault zones in accretionary prism have not been fully understood yet. We thus described the occurrence of large-displacement fault zones in the Cretaceous Shimanto belt in SE Kochi prefecture, and determined their permeability structures by laboratory fluid-flow tests. Among many faults in the research area, large-displacement faults were determined from temperature gap across the fault using a Vitrinite reflectance technique.

We focused on two fault zones with inferred displacement of >2 km; one is developed in a sequence boundary between basalt and pelitic breccias, and the other is in a melange zone. These fault zones are composed of cataclasite and clay-rich gouge zones. As total thickness of the fault zones is less than a few meters, fault slip is localized into thin gouge zones with average thickness of ~3 cm. The ratio of fault thickness to displacement of the fault zone is ~10^-5, that is far low as compared with worldwide displacement-thickness scaling relationship (10^-3 to 10^-1; e.g., Shipton et al. 2006). Fluid-flow experiments at effective pressures up to 100 MPa showed that permeability of the hanging wall was relatively low (10^-18-10^-20 m^2 at effective pressures of >50 MPa), while it is higher by 1-3 orders of magnitude in the footwall and fault zones. The permeability structures imply that high pore fluid pressure could be sustained within the fault zone, which may promote the thrust movement. Furthermore, the relatively thin fault zones with respect to displacement may be due to low strength of such low-angle faults that are energetically easy to propagate in a shallow part of subduction zone without forming a wide damage zone.

Keywords: fault, accretional complex, permeability

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Fluid-rock interaction in the fault gauge of the Median Tectonic Line

Noriko Matsuta[1*], Tsuyoshi Ishikawa[2], Tetsuro Hirono[1], Go Honda[1], Yoshiro Nishio[2], Kazurou Kawamoto[3]

[1]Earth and Space Science, Osaka Univ., [2]JAMSTEC Kouchi, [3]Oshika museum of Japan MTL

Frictional heating during coseismic slip induces transient fluid-rock interaction and fluid transfer. In order to understand these physicochemical process and mechanism, we performed geochemical analyses of major- and minor-element concentrations and Sr isotope. The fault gouge samples used were collected from the Anko outcrop, Nagano prefecture, of the Middle Tectonic Line. Using the fluid-mobile trace element spectrum, which is sensitive to fluid-rock interaction at high temperatures, we estimated that the black gouge experienced frictional heating of approximately 150 degree Celsius. This temperature signal probably indicates that frictional heating have occurred in the gouge together with high amount of coseismic fluid transfer.

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Spontaneous dynamic rupture propagation with thermal pressurization: Phase transitions of pore fluid

Yumi Urata[1*], Keiko Kuge[1], Yuko Kase[2]

[1]Dept. Geophysics, Kyoto University, [2]MEXT

We investigate whether or not an increase in pressure and temperature of pore fluid due to thermal pressurization (TP) can cause phase transition of pore water, on the basis of 3-D numerical simulations for spontaneous dynamic ruptures. Mizoguchi et al. (2007) conducted friction experiments and observed a decrease in friction owing to the phase transition of water from liquid to vapor. Although effect of TP has been investigated using numerical simulations (e.g., Urata et al., 2008), the phase transition of pore water controlling TP has never been considered. In this study, we discuss possibility of the phase transition and its effects on dynamic ruptures. Our numerical algorithm is based on the finite-difference method by Kase and Kuge (2001). Pore pressure and temperature are calculated by the formulations of Bizzarri and Cocco (2006), and simply compared to a water phase diagram. Any processes of the phase transitions are not included in our simulations. We put a vertical strike-slip square fault with the length of 6 km. The fault is subjected to external normal and shear stresses. We examine cases when the external stresses are either uniform or depth-dependent. Under the uniform stresses, initial values of stresses, pore pressure, and temperature are uniform and independent of depth, whereas the values increase with depth under the depth-dependent stresses. The values of the uniform stresses correspond to those at a depth of 3 km in the depth-dependent stresses.

Judging from the temperature and pressure of pore water, liquid pore water is likely to change to supercritical water in most part of the fault under the uniform stresses, whether TP works or not. On the other hand, under the depth-dependent stresses, liquid pore water is likely to change to supercritical water in deeper portions than about 2 km. In both cases, TP promotes the transition. The phase transition from liquid to vapor is not likely to occur. According to PROPATH[1)], the transition from liquid phase to supercritical one can cause changes in viscosity, compressibility, and thermal expansion of water, which can affect TP. The changes due to the transition would have two opposite effects on TP; suppressing a rise of pore pressure from temperature increase, and decreasing hydraulic diffusivity. We include the changes due to the transition in numerical simulations of dynamic ruptures and investigate whether or not the phase transition of pore water causes TP to be more effective.

[1)] PROPATH Group, PROPATH : A Program Package for Thermophysical Properties, version 13.1, 2008.

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Numerical models of slow slip events in Shikoku based on observed distribution of tremor and plate configuration

Takanori Matsuzawa[1*], Bunichiro Shibazaki[2], Hitoshi Hirose[1], Kazushige Obara[3]

[1]NIED, [2]Building Research Institute, [3]ERI, University of Tokyo

Recent studies revealed that slow slip events (SSEs), low-frequency tremors, and very low frequency earthquakes occur in several subduction zones. In the subduction zone of the Nankai trough from Shikoku to Kyushu, shallow very low frequency earthquakes are found along trench axis, and episodic low-frequency tremor and short-term SSEs (ETSs) are found at the deeper extent of the locked region of megathrust earthquakes. In addition, long-term SSEs repeatedly occur in the Bungo channel, and locate at the shallower extent of the ETS region. We successfully reproduced recurrence of short- and long-term SSEs in the flat plate model (Matsuzawa et al., 2010, JGR). Recently, we also reproduced recurrence and segments of short-term SSEs in the Kii-Tokai region, incorporating the actual distribution of tremor and the shape of the subducting Philippine Sea plate. In this study, we aim to reproduce the recurrence of short- and long-term SSEs in the Shikoku region, incorporating the actual distribution of tremor and the shape of the plate.

The ETSs occur at the transitional zone of friction from brittle behavior of megathrust earthquakes to ductile deformation of stably subducting plate. To model such transitional frictional property, we adopted a rate- and state-dependent friction law with cut-off velocities based on the experiment of halite (Shimamoto, 1987), as in Shibazaki and Shimamoto (2007). In the ETS and long-term SSE region, high Vp/Vs is reported (Shelly et al., 2006; Matsubara et al., 2009), which implies high pore pressure. Therefore, we assumed low effective normal stress in those regions. We modeled the shape of the subducting Philippine Sea plate based on Shiomi et al. (2008) and Baba et al. (2006). In our numerical simulation, the plate interface is modeled by ~65,000 triangular meshes within a semi-infinite elastic medium. In our model, we defined ETS regions with transitional frictional property, based on the actual distribution of tremor (Obara et al., 2010). Outside of the ETS regions below the locked region, velocity-strengthening friction is assumed. A long-term SSE region is introduced in the Bungo channel as a low effective normal stress region, as modeled in Matsuzawa et al. (2010). Assuming the above frictional parameters and the shape of the subducting plate, we calculated the temporal evolution of slip on the plate interface.

In our numerical result, recurrences of short- and long-term SSEs are reproduced. The typical scale of activities is larger in western Shikoku than that in eastern Shikoku, as observed in tremor. Our numerical simulation also reproduced the observed characteristics that the major tremor activity usually starts from the deeper part of ETS region (Obara et al., 2011). However, there exist differences between observation and our simulated results. For example, transient slow events are found between the ETS region and the locked region of megathrust earthquakes in central Shikoku, though no transient event has reported at that region. Comparison of such differences may lead us to a more realistic numerical model, and may be a key to further understanding of subduction processes.

Keywords: slow slip event, numerical simulation, Shikoku, seismic cycle

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Slow and rapid slip in sliding friction between polymer gel and plexiglass

Tetsuo Yamaguchi[1*], Takane Hori[2], Hide Sakaguchi[2]

[1]Dep. Appl. Phys, Univ. Tokyo, [2]JAMSTEC

When a soft and sticky gel is slid against a hard substrate, spatio-temporal stick-slip motions and the power-law statistics (GR law) are often observed. In this presentation, we report our experimental studies on sliding friction between silicone gel and plexiglass with various degrees of viscoelasticity in silicone gel.

The system shows slow slip events in viscous gels and rapid events

for less viscous gels, and the size-duration relation follows M0 to T ^(1/2) for viscous gels. We will also report more detailed analysis by modeling and vislization of the contact area.

Keywords: slow slip, laboratory experiment, polymer gel, scaling law

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Formation of graphite during high-velocity friction experiment under H_2 atmosphere

Kiyokazu OOHASHI[1*], Raehee Han[2], Takehiro Hirose[3], Kentaro Omura[4], Tatsuo Matsuda[4], Toshihiko Shimamoto[5]

[1]Graduate School of Sci, Hiroshima Univ., [2]KIGAM, Korea, [3]KCC, JAMSTEC, [4]NIED, [5]China Earthquake Administration

Graphite-bearing brittle faults are often found within the non-carbonaceous host rocks such as granite or marble (e.g., Nojima fault; Arai et al., 2002). Precipitation of graphite from C-O-H fluid system is widely accepted under the high P/T conditions of lower crust. However, it is considered to difficult to awake graphite precipitation under the upper crustal conditions, and formation process along the shallow fault zone is still not understood. Meanwhile, in last several years, experimental studies clearly suggested that mineralogical transformation took place in a few tens of seconds during coseismic fault slip (e.g. Han et al., Oohashi et al., 2011). Thus, we conducted high-velocity friction experiment under the C-O-H atmospheric conditions to determine if graphite forms from non-carbonaceous host rocks during rapid sliding.

Experiments were conducted using rotary-shear, low- to high-velocity friction apparatus under H_2 gas atmosphere, and Carrara marble (99% calcite and very small amount of silicate) is used for the host rock. Rock to rock experiments (bare surfaces) were conducted at normal stress of 2.0 MPa and slip rate of 1.3 m/s under the H_2 purged atmosphere. After the friction experiment, we can observe patches of blackish material on the slip surface, whereas the slip surface deformed under the air/Ar atmosphere maintains original white color. According to laser Raman spectroscopic analysis, two broad peaks correspond to the fundamental peaks of the graphite (or carbonaceous material) at a wavenumber of 1350^{-1} and 1590 cm^{-1} were detected from the patches of blackish material.

The Carrara marble used for the experiment is very pure and composed of 99% calcite, thus, it is unlikely that graphite appeared from carbonaceous material originally presents in the rock. Additionally, no visible color change was observed prior and after the HV friction experiment under the air and Ar atmospheres. Hence, the appearance of solid carbon is attributable to the atmospheric difference during the experiments. Possible explanation is formation of graphite via gas phase reaction of following chemical reaction: $2H_2+CO_2->C+2H_2O$. Salotti et al. (1971) conducted reaction experiment of calcite at the temperature of 500 degrees celcius, gas pressure of 13.8 MPa and duration of 6 hours under C-O-H atmosphere, and demonstrated formation of well-crystallized graphite on the surface of calcite. Although two of these conditions were not met in our high-velocity experiments with gas pressure of 0.1 MPa and duration of less than hundreds of seconds, temperature must have exceeded 500 degrees celcius since calcite decomposed into CaO and CO_2 (decomposition temperature of calcite: $>$720 degrees celcius). The reaction is temperature dependent so this is why the reaction accomplished at these experimental conditions. This result suggests that if rapid faulting occurs within the calcareous rocks (e.g., marble, limestone and rock rich in carbonate vein) under the reducing environment (H_2 or CH_2 atmosphere), graphite forms in response to frictional heating.

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Keywords: Nojima fault, Graphite, Carbonate minerals, High-velocity friction, Mechano-chemical reaction

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Relationship between dehydroxylation reaction of clay minerals and their inner structure and frictional property

Tetsuro Hirono[1*], Go Honda[1], Wataru Tanikawa[2]

[1]Osaka University, [2]JAMSTEC Kochi

Transient frictional heating during earthquake slip induces dehydroxylation of phyllosilicate minerals. As this reaction is endothermic and releases H2O, it may affect dynamic fault weakening and the energetics of earthquakes. To elucidate this question, we measured thermal property, chemical kinetic parameters, and frictional property of dehydrated clay minerals (montmorillonite, illite, and kaolinite), and observed the inner structure under scanning electron microscope. We then discuss the relationship among the reaction, structure (fabrics), and frictional property, and also argue their implications on dynamic fault weakening and energetics during an earthquake.

Keywords: clay mineral, dehydroxylation