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

SSS29-01 Room:105 Time:May 21 13:45-14:00

Fluid-induced swarm activity as revealed by precisely determined hypocenters and focal mechanisms of earthquakes

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A swarm earthquake sequence is often assumed to be triggered by fluid flow within a brittle fault damage zone, which is supposed to be highly permeable. However, there is little seismological evidence of the relationship between the fluid flow within fault damage zone and the occurrence of swarm earthquakes. Here, we proposed that the 2009 swarm activity at Hakone volcano provide a good example of such fluid-induced activity.

We relocated 1,156 events that occurred in Hakone caldera during the period from August 4 through August 13, 2009 with the double-difference (DD) method (Waldhauser and Ellsworth, 2000). For the relocation of the hypocenters, we used the differential arrival time obtained by both manual picking and wave form cross-correlation analysis. We determined focal mechanisms from the absolute P- and SH-wave amplitudes by adding the P-wave polarities.

We demonstrate that the swarm earthquakes are concentrated on four thin plane-like zones whose thickness is approximately 100 m. One of the nodal planes of the focal mechanisms agrees with the planar hypocenter distribution. The thickness of the plane-like zones is considered to be statically significant, considering the location error of the hypocenters. The value of thickness is consistent with that of fault damage zone for a fault with 1 km length [e.g., Vemilye and Scholz, 1998].

The swarm earthquakes in the initial stage of the activity exhibited a feature of hypocenter migration that can be represented by a diffusion equation. Based on the spatio-temporal distribution of the earthquakes, the hydraulic diffusivity (D) is estimated to be approximately 0.5 to 1.0 m2/s. The values of D are comparable to those estimated in other studies based on the reservoir-induced seismicity, the water injection-induced seismicity, and the spatio-temporal distribution of swarm activities. The observations imply that swarm earthquakes were triggered by diffusion of highly pressured fluid within the fault damage zone.

Keywords: swarm earthquake, fluid, fault damage zone, hypocenter distribution, focal mechanism

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

SSS29-02 Room:105 Time:May 21 14:00-14:15

Fault geometry affecting spatial distribution and evolution of fracture zones

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There are many major, mature faults in Japan which have been in the plate boundary zone for more than 200 Ma. Such mature faults mostly have heterogeneous structures as a result of interactions between multiple faults. In this presentation, heterogeneity of the spatial distribution and characteristics of fracture zones in mature faults is discussed based on detailed and broadscale geological mapping, including the case study in the area around the Atotsugawa Fault, a long-lived active fault in central Japan (Niwa et al., 2008, J. Geol. Soc. Jpn.; Niwa et al., 2011, Eng. Geol.).

Specifically in fault tips and steps, models of pervasive development of fracture zones are proposed (Sibson, 1986, PAGEOPH). First, the occurrence of a compressional step was recognized by means of aerial photograph interpretation and regional distribution of fracture zones. Detailed geological observation suggests that shear planes with NNE-SSW and NW-SE strikes, high-angle oblique to the trend of the Atotsugawa Fault, are characteristically developed in the step. The shear planes with NNE-SSW and NW-SE strikes can be a part of the composite planar fabric such as R_2 surfaces (Davis et al., 1999, JSG) or deformation band (Okubo and Schultz, 2006, Geol. Soc. Amer. Bull.), which are dominantly developed within compressional steps. Fracture zones in the step are characterized by high densities of fractures and intense brecciation of fragments and minerals, but displacements and rotations of fragments are poorly developed. These characteristics are consistent with the previously proposed conceptional models of fracture zone development in steps (e.g. Sibson, 1986, PAGEOPH).

In addition, more broadscale geological mapping was carried out in the western part of the Atotsugawa Fault to elucidate the spatial distribution of the fracture zones. Within 500 m of the fault trace, the number of exposed fracture zones increases sharply and most fracture zones greater than 2 m width are concentrated. The number and width of the exposed fracture zones display almost the same pattern between a compressional step and a long strand, in contrast with several concepts that fracture zones are pervasively developed around a compressional step. Based on rock features and deformation fabrics at meso- and microscopic scales, once fracture zones had formed, epigenetic deformation was concentrated in the older fracture zones.

Fracture zones less than 2 m width are sparsely but widely distributed in the study area. Most of them are formed by fracturing and weathering accompanied by displacement along joints, schistosities or lithological boundaries, and lack continuity at geological map scale. From a viewpoint of the microscopic observation, they display brittle fracturing characterized by the development of network-patterned cracks and simple fragmentation without ductile shearing, indicating deformation near the surface, under low confining pressure. Various origins of them are proposed: e.g., subsidiary displacement accompanied activities on the surrounding major faults; dilatation due to the decrease in the confining pressure near the land surface; or the displacement of the weak planar structures caused by non-tectonic movement such as gravitational sliding, etc. Based on the comparison with epicenter distribution in the study area, some of them possibly indicate an evidence of ancient shallow earthquakes at a point distant from the fault trace.

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

SSS29-03 Room:105 Time:May 21 14:15-14:30

EFFECT OF PORE PRESSURE ON THE FRICTIONAL BEHAVIORS OF SERPENTINITE

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Slow earthquakes (e.g., slow slip events, very low frequency earthquakes and non-volcanic tremors) have been detected in subduction zones where relatively young and hot slabs are subducting, such as southwest (SW) Japan. Low velocity anomaly and high Poisson's ratio have been detected in these regions, suggesting a possible role of serpentinite and high pore fluid pressure triggering these events [1,2]. However, the physical mechanisms of slow earthquakes are not fully understood, although the slow earthquakes are characterized by a different scaling law to the regular earthquakes [3].

In this study, we focus on the effect of pore fluid pressure on the frictional behaviors of serpentinite, and discuss a possible role of high pore pressure on the asperity model and enhancement of slow earthquakes at the subducting plate interface.

In order to test frictional behaviors of serpentinite at high fluid pressure, we used a gas confining medium triaxial deformation apparatus at our institute. In this system, serpentinite samples are grinded cylindrical shape with precut at an angle of 30 degrees. One piece of the samples is drilled through to the slip surface for fluid conduit. Stating material is highly dense and isotropic antigorite serpentinite from Nishisonogi metamorphic belts, Nagasaki, Japan. In the experiments, argon gas and distilled water are used as a pore fluid for dry and wet experiments, respectively. Deformation experiments are conducted at a constant rate (0.001 mm/s) at a constant Pc of 150 MPa and room temperature.

At initial stage, shear stress increases lineally with displacement and reaches a steady value after the yield points. We then stepped pore fluid pressure (Pp) to test frictional response on the serpentinite sliding surface. Initial value of Pp ranged from 50 to 145 MPa, and the magnitude of step changes of Pp ranged from 7.8 to 71.0 MPa. Step changes in Pp were accomplished within $<$0.3 s. Shear stress has been sifted simultaneously with Pp steps and reached a new steady state condition. The stress weakening was observed after increasing Pp (decreasing effective pressure), and the stress strengthening was seen after decreasing Pp. The shear stress shows lineally correlation to the effective stress, suggesting that Coulomb's law is applicable for the sliding test due to pore fluid injection and ejection.

The steady-state shear stresses at wide range of Pp were converted to frictional coefficient f. Under dry conditions (Ar gas was used as a pore fluid), friction coefficient is estimated to be ˜0.66, which is similar value of Byerlee's law. However, under wet conditions (distilled water as a pore fluid), the friction coefficient is slightly smaller, f ˜ 0.51, compared to the dry experiments. The difference in frictional coefficient can be caused by charged water on the crystal surface, which might reduce frictional resistance on the sliding surface under wet environments. Molecular dynamics simulation has shown that sheet-structure minerals, such as mica, tend to adsorb more water on grain surface [4].

Our experimental results indicate that migration of aqueous fluids in subduction zone setting can cause mechanical weakening on the subducting plate interface. Consequently, asperity on the plate boundary might be controlled by heterogeneous distribution of fluids and its significant role of frictional strength on the serpentinized sliding surface.

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Keywords: Serpentinite, Pore pressure, Friction coefficient, Deformation experiment, Slow earthquakes

SSS29-04 Room:105 Time:May 21 14:30-14:45

Suppression of slip and rupture velocity increased by thermal pressurization: Effect of Dilatancy

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We investigate effect of dilatancy on dynamic ruptures with thermal pressurization (TP), taking into account a power law relationship between permeability and porosity, based on 3-D numerical simulations of spontaneous rupture propagation obeying a slip-weakening Coulomb failure criterion.

Effects of dilatancy on rupture propagation with TP were often investigated in 2-D numerical simulations, or with attention only to behaviors at a single point on a fault plane. Moreover, in the previous simulations, it has never been considered that permeability can change with porosity. Because the hydraulic diffusivity, which controls TP, is proportional to permeability, the changes in permeability along with porosity would affect TP and dynamic ruptures.

To consider changes in porosity and permeability in dynamic ruptures with TP, we solve the thermal and hydraulic diffusion equations with a porosity term by the finite-difference method. Our numerical algorithm for dynamic ruptures is based on the method by Kase and Kuge (2001). Pore pressure from the diffusion equations is included in effective normal stress, while slip velocity and shear stress give the heat source in the diffusion equations. In our model, the frictional heating and the processes of dilatancy occur within the shear zone. We consider both reversible and irreversible changes in the porosity (Segall and Rice, 2006), assuming that the irreversible change is proportional to the slip velocity. Permeability changes with the porosity, according to the power law by David et al. (1994). We put a square fault with the length of 4 km in the infinite medium. The fault is subjected to uniform external stresses.

We reveal that the slip amount decreases with increasing dilatancy coefficient or exponent of the power low, and the rupture velocity is predominantly suppressed by the coefficient. This is observed whether applied stresses are high or low. The deficit of the final slip concerned with the coefficient could be smaller as the fault size is larger.

SSS29-05 Room:105 Time:May 21 14:45-15:00

Monitoring of slip weakening process using transmitted acoustic waves

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To investigate the physical process of slip weakening at subseismic slip rate, Fukuyama et al. (2011, JpGU; 2011, AGU) measured the transmitted acoustic waves during high slip velocity experiments. They concluded that at steady state after the slip exceeds the slip weakening distance, fluctuation of friction, which is typical for the gabbro rock sample at room humidity and room temperature, is controlled by the characteristic size of voids inside the gouge layer. In the experiment, two different proportional coefficients can be found between the friction and transmission coefficient. At beginning before the slip reached the slip weakening distance, the slope was steep, while at the steady state stage, slope became gentle. This difference might be caused by the different process between the weakening and steady state stages. Here, we theoretically investigate this difference. In the scattering theory, Q^{-1} value increases as a function of void size as well as a function of thickness of the gouge layer. In the steady state stage, we assumed that the thickness of the layer does not change. Here, we examine if the steep slope at slip weakening stage can be attributed to the growth of layer thickness or not. We conclude that the steep slope can be explained by the layer growth process. This technique enables us to investigate the generation process of the gouge layer, which might be an origin of the slip weakening process of slip at subseismic slip rate.

Keywords: slip weakening, transmitted waves, high slip rate friction, gouge layer

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SSS29-06 Room:105 Time:May 21 15:00-15:15

Frictional behavior and BET surface-area changes of SAFOD SDZ gouge at intermediate to high-velocity regimes

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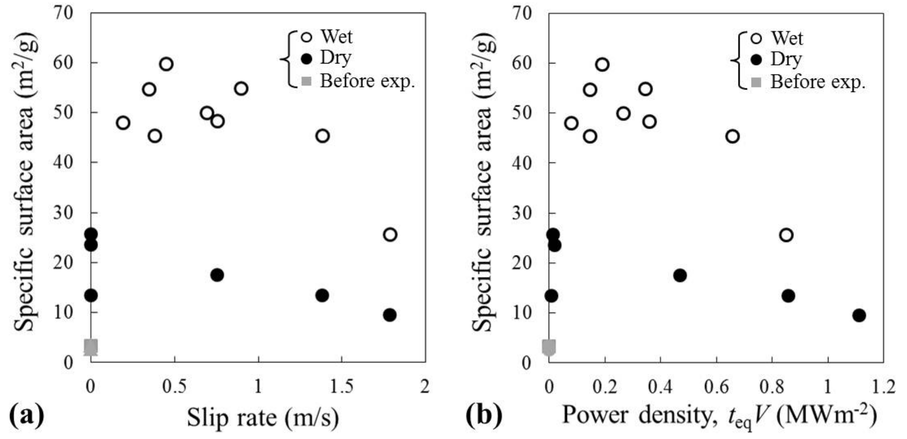
San Andreas Fault Observatory at Depth (SAFOD) Drilling site is located at near the southern end of the creeping section of the San Andreas fault and SAFOD drill cores may provide a clue for the cause of diverse fault motion. We were provided with precious core sample (Phase III core; Hole G-Run 2-Section 8) from southwest deformation zone (SDZ) where creep is confirmed by the borehole casing deformation. Sample for this study was limited to about 6 grams and 6 runs were done at intermediate to high slip rates (10^{-5} to 1.3 m/s) and a normal stress of about 1 MPa and under both dry (room humidity) and wet (with 25 wt% of H_2O added, drained tests) conditions, using a rotary-shear low to high-velocity friction apparatus at Hiroshima University at. One gram of gouge was placed between host rock of Belfast gabbro of 25 mm in diameter with Teflon sleeve outside to contain gouge. Slip rates was decreased first and was increased in step-wise manners to obtain steady-state friction for two runs at intermediate slip rates. Friction coefficient increases from about 0.2 to 0.37 as the slip rate increases from 0.8 x 10^{-5} to 9.7 x 10^{-3} m/s, connecting reported data at the low and high slip rates. Data shows pronounced velocity strengthening at intermediate slip rates which should act as brake for a rupture to grow and this may be a reason for having creep behavior. On the other hand, the steady-state friction markedly decreases at high velocity. Four experiments were conducted at subseismic to seismic slip rate both at dry and wet conditions demonstrating marked slip weakening of gouge at high slip rate. The results agree with reported results for central deformation zone (CDZ). The property of high-velocity weakening may allow earthquake rupture to propagate into the creeping section, as in the case of 1857 and 2004 ruptures, once the intermediate strength barrier is overcome.

BET surface area of gouge (A_{BET}) was measured before and after deformation to determine the energy used for grain crushing. The initial specific surface area (2.6-3.4 m^2/g) increases to 14-24 m^2/g for gouge deformed dry at intermediate slip rates and to 45-60 m^2/g for most gouge deformed at subseismic to seismic slip rates (Fig. 1). The results indicate that about 2 % and less han 1 % of the frictional work is absorbed in grain crushing for dry and wet gouges, respectively, if the fracture surface energy of muscovite (0.38 J/m^2) is used as the surface energy of phyllosilicate-rich SAFOD gouge. Thus grain crushing cannot be an important energy sink during seismic fault motion. The surface area tends to be lower for gouge deformed at high slip rates for both dry and wet gouges. This results and SEM observations of gouge strongly suggests that welding of grains takes place at high slip rate due to frictional heating and counteracts the surface-area increase due to grain crushing. Thus intrafault processes are more complex than in a simple scenario of "grain crushing and surface-area increase" assumed in recent studies. Surface area is greater for wet gouge than for dry gouge suggesting that pore water separating gouge particles suppresses grain welding. Surface-area measurements are useful to monitor the grain-scale processes during fault motion.

Keywords: BET surface area, Intermediate to high-velocity friction, SAFOD, Energetics of seismic fault motion



Japan Geoscience Union Meeting 2012
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SSS29-07 Room:105 Time:May 21 15:30-15:45

Strain anomalies induced by 2011 Tohoku earthquake observed by means of a dense GPS network in NE Japan

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We evaluated an anomalous crustal strain in the Tohoku region, northeastern Japan associated with a step-like stress change induced by the Tohoku earthquake (Mw 9.0) that occurred off the northeastern Japanese coast in 2011. The source area of the event was extremely large. Hence, the gradient of the observed eastward coseismic displacements at GPS stations had a relatively uniform EW extension in northeastern Japan, suggesting that the induced stress change in this area was uniform. Accordingly, anomalies in the coseismic crustal strain change should reflect the inhomogeneity of rheological crustal characteristics. The deformation anomaly was depicted by subtracting the crustal deformation, which was calculated with a coseismic source model, consisting of two rectangle faults estimated by the observed crustal deformation. The difference in the EW extension anomaly in the forearc and backarc regions possibly indicates a dissimilarity of stiffness, depending on the crustal structure of the Tohoku region. The EW extension in the Ou-backbone range, a strain concentration zone in the interseismic period, was smaller than the predicted extension. This evidence suggests the hypothesis that the viscosity of the lower crust beneath this region is low.

SSS29-08 Room:105 Time:May 21 15:45-16:00

Stress state and deformation mechanism in the Nankai Trough subduction system

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In subduction zones, the updip transition from aseismic to seismic slip behavior with increasing depth is coincident with porosity loss associated with consolidation, lithification, and diagenesis. Porosity decreases from ~80% within incoming sediments to less than 10% in subducted/accreted rocks at burial depths of a few to ~15km, as observed in the ancient accretionary prism outcrops. Stress states are one of the most important factors governing porosity loss, deformation modes, and fault strength, because in subduction systems where tectonic stress is large, sediments are subjected to complicated stress conditions in time and space. In the Nankai Trough, the input sediments on the subducting Philippine plate and shallower sediments in the modern accretionary prism have been recovered during the Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) expeditions. In this study, we aim to understand the evolution of physical properties (porosity, permeability, and P-wave velocity) and sediment deformation in subduction systems by conducting deformation experiments on both the input sediments and the prism sediments from the Nankai Trough. We conducted ~30 uniaxial and triaxial (both triaxial compression and triaxial extension) deformation experiments on sediments recovered from different depths at different drill sites. Cylindrical samples were deformed by controlling confining pressure, axial stress, and pore pressure, and all pressures, axial displacement, and pore volume change were monitored. Permeability, and ultrasonic velocity were also measured during consolidation and deformation.

We deformed samples of Lower Shikoku Basin (LSB) silty-claystone (initial porosity of 44%) from Site C0011 are loaded under a range of different stress paths including isotropic loading, triaxial compression, and triaxial extension by controlling axial stress (up to 70 MPa), confining pressure (up to 70 MPa), and pore pressure (0.5-28 MPa). We find that the evolution of physical properties (porosity, permeability, and P-wave velocity) is dependent on both effective mean stress and differential stress. Differential stress enhances reduction in porosity and permeability and results in an increase in P-wave velocity. The relationship between defined by our experimental data is fit well by a Cam-Clay model, which describes elasto-plastic behavior of sediments. We also find that the input sediments at the reference sites (Site C0011 and Site C0012) are normally consolidated or slightly overconsolidated, whereas the prism sediments are highly overconsolidated. In particular, mudstones of similar age (Miocene) show a progressive increase in the degree of consolidation with a distance from the deformation front. This suggests tectonic stress (i.e., larger horizontal and differential stress within the accretionary prism) enhance further consolidation and porosity loss, and thus induce brittle faulting deformation rather than cataclasitc flow deformation.

We also apply our observed experimental relationship between P-wave velocity and stress state to estimate in situ stress state and pore pressure within a well-defined low-velocity zone (LVZ) identified in the outer accretionary wedge [Park et al., 2010]. This LVZ is located at ~3 km depth, immediately above the decollement and extends from 15-35 km from the trench. Our lab data constrain the in situ vertical effective stress to be 7-14 MPa, effective maximum horizontal stress of 28-35 MPa, and excess pore pressure of 23-16 MPa. This corresponds to a value of the pore pressure ratio lambda$*$ = 0.53-0.77. This technique to estimate the in-situ stress from the empirical relationship between P-wave velocity and stress states can be further tested in the future drilling to the deeper accretionary complex and the plate boundary faults.

Keywords: subduction zone, IODP, NanTroSEIZE, deformation

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

SSS29-09 Room:105 Time:May 21 16:00-16:15

Earthquake sequense simulations accounting for brittle-plastic transition

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In understanding sequences of earthquakes from the point of view of mechanics and structural geology on the fault rocks, brittle-plastic transition of rocks is of great importance as evidenced by field observations of repeated overprinting of pseudotachylyte (frictional melting) and mylonitic (ductile) deformations [e.g., Lin et al., 2005]. Near the down-dip limit of the earthquake ruptures which produce such fault rocks, mylonitic deformation which takes place dominantly during interseismic periods probably affects the stress accumulation process in the shallower brittle zone where earthquakes nucleate. Earthquake generation process is often discussed in terms of the rate-dependency of the frictional resistance of a fault [e.g., Tse and Rice, 1986]. On the other hand, the brittle-plastic transitions are typically expressed as a strength profile across the crust [e.g., Goetz and Evans, 1979]. Given the rate-strengthening characteristics of ductile plastic deformation, these two pictures are closely related to each other [e.g., Sholtz, 1988]. Quantitative discussion by actually solving or simulating sequences of earthquakes on a fault accounting for brittle-plastic transition is required to connect mechanics and structural geology on the fault-rocks.

Recent development of an empirical constitutive equation of a shear zone accounting for brittle-plastic transition (friction-to-flow law) [Shimamoto, 2004, JpGU meeting, Noda and Shimamoto, 2012] enables us simulating sequences of earthquakes consistently with the Brace-Goetz strength profile. The fault model [e.g., Kawamoto and Shimamoto, 1997] which is conceptually constructed based on experimental studies is realized in numerical simulations in which both long-term tectonic loading and coseismic inertial effects are fully accounted for [e.g., Lapusta et al., 2000]. By referring the investigation of the texture of experimental specimens [e.g., Hiraga and Shimamoto, 1987], we can discuss expected fault rock structures after simulations of earthquake sequences. We will also discuss the similarities and differences between the earthquake sequences produced by the logarithmic rate- and state-dependent friction law and the rate- and state-dependent friction-to-flow law.

Keywords: Sequence of earthquakes, Brittle-plastic transition

SSS29-10 Room:105 Time:May 21 16:15-16:30

A shock-compression experiment of peridotites: toward a better understanding of focal mechanics of deep earthquakes

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Generation of earthquakes that infers fault motions in deep earth remains unsolved problems of solid earth sciences. Frictional melting is well expected at fault planes at high confining pressure and the formation of melt layers will result in a rapid release of cumulated stress leading to a large earthquake (e.g., Kanamori et al, 1998). The occurrence of ultramafic pseudotachylyte in exhumed mantle-derived peridotite mass testifies such mechanism does occur in the upper mantle (Ueda et al, 2008). Conventional friction melt experiment using a rotary high-speed shear testing apparatus cannot be directly applied to the deep earthquakes because of the technical limitation to the confining pressure, which is typically below tens of mega Pascal. We have started a new experimental project using a powder propellant gun at the Shock Wave and Condensed Matter Research Center of Kumamoto University. With this machine it is possible to apply the uniaxial shock stress to samples up to 10~20 GPa by impacting flyer plate with a speed of 1 to 2 km/s. We have performed several shots using natural peridotites and olivine single crystals and observe that multiple shear planes being generated in the samples after such intense compression although any clear textural evidence that indicates frictional melting has not yet been detected. Reviewing the instrumentation and the experimental strategies, we will report some preliminary results of the microstructural observation of shock compressed samples, including an olivine single crystal.

Keywords: shock melting, deep earthquake, frictional melting, peridotite, earthquake source mechamics

SSS29-11 Room:105 Time:May 22 09:00-09:15

Drilling the Alpine Fault: Preliminary project report

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The Alpine Fault, which is dextral-reverse delineates at the Australia-Pacific plate boundary on the west side of the south island, New Zealand. It causes large earthquakes at every 200-400 years (most recently 1717, with expected Mw $<$7.9). Quaternary fault motions have been determined from landscape features and the deformed rocks around the fault have been investigated in numerous exposures (e.g., Norris and Cooper, 2007, AGU). Recently, microstructures and deformation mechanisms of deformed rocks around the fault have been discussed based on the fabric analyses of quartz (Toy et al., 2008, JSG). It has been proposed that anomalous seismic wave speeds apparent in large-scale seismic transects result from fluid presence within the fault rocks (Stern et al., 2001, Geology). Exhumation occurs rapidly (6-9 mm/yr) from depths of as much as 20-30 km (Little et al., 2005, GJI), yielding young samples.

The drilling project of the Alpine Fault (Deep Fault Drilling Project; DFDP) mainly focus on (1) evolution of a orogenic system, (2) transition between brittle and plastic deformation mechanisms, and (3) seismogenesis and the habitat of earthquakes. The following themes have been identified on which to focus; (a) stresses, fluid pressures, permeabilities, and temperatures adjacent to the Alpine fault, (b) strain localization within the fault core and surrounding damage zone, and the deformation mechanisms related to these, (c) the seismic velocity structure at centimeter to kilometer scales, (d) the deformation mechanisms of minerals (developments of crystallographic preferred orientation; CPO) and reactions (e.g, chloritic alteration), (e) interactions between metamorphic fluids and fault rocks, (f) the thickness of the active slip zone and accompanying damage zone, (g) possibility of episodic slow slip or low-frequency tremor, and (h) developments of pseudotachylyte and element motilities. The Japanese team are involved in (c), (d), and (h) in detail.

The Alpine Fault drilling project has been in planning since 2008, and the drilling started in January 2011. The first phase (DFDP-1), which targeted to drill to 150 m, finished in February 2011, and the samples have already been provided to scientists. Work has now begin on DFDP-2, during which it is planed to drill to 1500 m through the Alpine Fault. DFDP-2 has financial support from the as International Continental Scientific Drilling Program (ICDP). In this presentation, we outline this drilling project.

Keywords: ICPD, J-DESC, contributions of Japanese team

SSS29-12 Room:105 Time:May 22 09:15-09:30

Internal structures and high-velocity frictional properties of Longmenshan fault zone: the current status of researches

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Disastrous Wenchuan earthquake (12 May 2009, Mw 7.9) was accompanied by surface ruptures of about 280 km in EW extension mostly along existing Longmenshan fault system (e.g., Lin et al., 2009, Tectonophysics). Wenchuan Earthquake Fault Scientific Drilling (WFSD) has started about two years ago under the leadership of Z. Xu and this was the third rapid drilling into seismogenic fault immediately after a large earthquake, following the drilling into the Nojima and Chelungpu faults. Compared with the latter two, a big advantage of studying the Longmenshan fault system is that deep exhumed fault zones such as low-temperature mylonites are exposed on surface (e.g., Xu et al., 2008, Episodes). One has a chance to construct a fault model for shallow to deep portions of the fault by combining studies of coseismic surface ruptures, shallow drill cores and exhumed fault rocks that formed at depths. WFSD drilling is still underway although initial results from series researches were reported at AGU fall meeting in 2010. Unfortunately, however, WFSD drill cores are not released for physical property measurements as yet. Thus Institute of Geology, CEA drilled five shallow holes into the Beichuan-Yingxiu fault and studied fault zones at several surface outcrops. We report here internal structures of fault zones as studied at Hongkou, Pingxi and Xiaojiaqiao outcrops and from Shenxigou shallow drill core. All gouge from those fault zones exhibit dramatic slip weakening at high velocities and we compare experimental results for fault gouges from those locations to delineate heterogeneity in frictional properties of faults. Fault gouge exhibits considerable variation even from the same fault outcrop. WFSD data will be included if cores are available in the near future.

Keywords: Longmenshan fault, Wenchuan earthquake, Fault rheology, High-velocity friction, Fault rock, Earthquake mechanism

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Amorphization of clay minerals by thermal and mechanochemical processes, and its implications for seismic faulting

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Amorphous nanoparticles on the slip surface have been paid much attention since they give significant influences on the frictional properties. They are considered to be formed by combined processes including mechanical, chemical and thermal ones. It is well known that clay minerals are easily transformed into amorphous materials mechanochemically by grinding. We performed experimental studies on amorphization of kaolinite and saponite, common clay minerals under a surface environment.

Heat treatment: Crystalline kaolinite was completely decomposed and transformed into amorphous phase after 1 hour heating at 600 degrees Celsius and also after 1 minute heating at 1000 degrees Celsius. Saponite was completely decomposed and transformed into enstatite after 5000 minutes at 680 degrees Celsius and after 60 minutes at 800 degrees Celsius. The activation energy of amorphization of kaolinite was estimated to be 98kJ/mol.

Mechanochemical process: Dry grinding experiments of crystalline kaolinite and synthetic saponite using a planetary ball mill were conducted. Amorphization is completed after 3 hours milling (400 rpm) for kaolinite and 9 hours for saponite. Aggregates of nanoparticles were observed with FE-SEM. The injection energy during the experiment is estimated to be 9550 kJ/kg for kaolinite and 28700 kJ/kg for saponite.

The maximum temperature on a fault surface could be as high as 1000 degrees Celsius by frictional heating. The fracture energy in large earthquakes is estimated to be 1000 to 10000 kJ/kg. Thus kaolinite can be transformed into amorphous phase in faulting. Saponite is less easily amorphized than kaolinite. This is concordant with the observation at Taiwan Chelungpu fault core (Hirono et al., 2008).

Keywords: clay minerals, amorphous, mechanochemical, frictional heating, faulting

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Mechanochemical effect on chemical reactions during earthquake slip

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Transient frictional heating in a fault zone during earthquake slip induces various chemical reactions. In the case of the Chelungpu fault in Taiwan, which slipped during the 1999 Chi-Chi earthquake, material within the slip zone was reported to be relatively low in inorganic carbon (mainly calcite), smectite, and kaolinite contents, compared with the surrounding rocks. These characteristics have been attributed to friction-induced thermal decomposition of calcite, dehydration of interlayer water and dehydroxylation of smectite, and dehydroxylation of kaolinite, and the released gas and fluids from such reactions have a strong role in dynamic fault weakening, similar to that of thermal pressurization. However, mechanochemical effect by coseismic slip is not fully considered on such process. Here we performed high-velocity friction experiment of clay mineral, and analyzed the samples after the experiments using TG-DSC, XRD, ATR-IR, and particle size analyzer. In this presentation, we show the preliminary result and discuss the mechanochemical effect on the chemical reaction during earthquake slip.