Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SCG59-01 Room:106 Time:May 27 16:15-16:30

Slip processes of gels with multiple asperities

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Understanding how multiple asperities rupture is one of the most important questions in both earthquake source physics and tribology. Here we study the elementary slip processes of gels having multiple asperities with in-situ optical observations.

Keywords: asperity, elementary process, gel, fast rupture, slow slip, randomness

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SCG59-02 Room:106 Time:May 27 16:30-16:45

Grain size segregation in a fault gouge

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The structures and textures of fault gouge are believed to provide with rich information on the coseismic slip dynamics of faults. In Chelungpu fault gouge, where the coseismic slip was accommodated in 1999 Chichi earthquake, grain-size segregation is found [Boulier et al. Gˆ3 10, Q03016 (2009)]. This could be an evidence for gouge-fluidization, because grain-size segregation is believed to require sufficient porosity in granular matter. Grain-size segregation is also find grain-size segregation in a laboratory friction experiment with large displacement (˜12m) and under intermediate normal stress (˜2MPa)[Ujiie and Tsutsumi GRL 37, L24310 (2010)]. Here we wish to know whether grain-size segregation occurs as a result of gouge fluidization. To this end, we perform numerical simulation on a simple model of fault gouge, and show that grain size segregation occurs under a condition that may be relevant to faults gouge: the pressure of 1 MPa, the sliding velocity of 1 m/s, and the duration of 0.1 sec. Segregation occurs irrespective of gravitation and it is controlled by nonlinear velocity gradient. More importantly, we find that segregation occurs even if the granular matter possess yield stress, and therefore segregation itself does not imply gouge-fluidization.

Keywords: segregation, fault gouge, nonlinear velocity gradient

Japan Geoscience Union Meeting 2015
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SCG59-03 Room:106 Time:May 27 16:45-17:00

Friction of granular layer at seismic slip rates - Effect of wall disturbances

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A natural fault has the cataclasite core zone, along which shear deformation concentrates. Rheology of these granular matters thus provides us an important insight in considering the nature of friction on faults from a microscopic point of view. In the past two decades, experiments conducted at sub-seismic to seismic slip rates (mm/s to m/s) revealed two remarkable phenomena of high-velocity rock friction; very long critical slip distance (Dc) of the order of 1-10m/s and the considerable weakening due to mechanochemical effects by frictional heating. Recently, Chambon et al.[2006, JGR] conducted friction experiment with very large shear displacement experiment on a thick granular layer, and reported significant slip-weakening behavior active over decimetric slip distances. However, the relation between long Dc observed in a thick granular layer and long Dc in the high-velocity friction is still not clear. We designed laboratory experiments to explore transient responses of a thick granular layer following a step change in slip velocity at seismic slip rates. We use simple particle and choose relatively low normal stress to exclude the possible mechanochemical effects caused by frictional heat. We find that friction coefficient and layer thickness show similar response that is symmetry with respect to velocity changes, and Dc is of the order of 10m. It appears that these responses are attributed to dynamics of granular matter. We report effect of wall boundary disturbance on the transient responses of granular layer.

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SCG59-04 Room:106 Time:May 27 17:00-17:15

Non-equilibrium thermodynamical interpretation for rate- and state-dependent friction law

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The rate- and state-dependent friction law is based on the experimental results of rock sliding friction. This law unifies two types of rock experiment results; the first one is the time dependence of static coefficient of friction (Dieterich, 1972) and the second one is slip velocity dependence of the dynamic coefficient of friction (Dieterich, 1978). This law is reproduced by using two equations called as constitutive law and evolution law.

Several versions of evolution law have been proposed in order to reproduce the experimental data better. However, none of them are completely satisfied.

We analyze this rate- and state-dependent friction law for the velocity-step and the healing tests from a thermodynamic point of view. Assuming a logarithmic deviation from steady-state, both results are reproduced. The proposed system of equations is a unification of the classical models (Dieterich, 1979; Ruina, 1983).

Keywords: friction, constitutive law, non-equilibrium thermodynamics, evolution law

SCG59-05 Room:106 Time:May 27 17:15-17:30

Luminous phenomena due to impact shear fracture of various rocks

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Seismo-electromagnetic (s-EM)/luminous phenomena could be occurred due to dynamic shear deformations/fracture of rocks during not only a main shock but also the fore- and after-shock. In order to understand the source mechanism, the seismic luminous phenomena, a kind of s-EM, from impact shear fractured rocks were conducted using a Sharpy impact tester equipped with a CCD camera at room temperature in ambient atmosphere. In historical documents, luminous phenomona were often eye-witnessed during sector collapse associated with earthquakes, such as Gokken-zan (1701 Hoei EQ), Mayu-yama (1792 Shimabara, Unzen EQ),Ibuki-yama (1909 Kohno EQ). These mountains are consists of not only granite that has been often used in the laboratory tests, but also tuff, pyroclastic, limestone and etc.

The experimental conditions are: the impact speed was 4m/s. the impact energy was 25 J. The shutter of the CCD camera was opened for about 1 second between just before and after the impact at the ISO speed of 25,600. In addition to the impact tests, we also conducted both the thermally stimulated electron emission (TSEE) experiments and the thermal desorption mass spectrometry (TDMS) experiments.

As the results, intense luminosity was observed from fracturing rocks including biotite. Limestone and pyroclastic also showed luminous phenomena, but serpentine, ignimbrite and deposits of volcanic ash and sand did not. The mechanism of luminosity will be discussed in terms of ionization/discharge, thermo-luminescence and combustion of flammable gases contained in pyroclastic.

Keywords: luminous pehenomena, shear fracture of rocks, seismo-elecromagnetic, Sharpyi impact test

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SCG59-06 Room:106 Time:May 28 09:00-09:15

Unified understanding of frictional instability based on Rowe's theory on constant minimum energy ratio

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1. Introduction

With respect to frictional instability, many studies on rate and state dependent friction law and the microstructural observations of a gouge layer have been conducted (e.g., Dieterich, 1979; Byerlee et al., 1978). Moreover, Ikari et al. (2011) indicated that frictional parameter (a-b) transits with shear localization. However, the theoretical background for the relationship between frictional parameter and shear localization has not been clear yet. To understand it, we need to assess deformation process of gouges (e.g., shear localization) quantitatively. Here, we focus on Rowe's theory on constant minimum energy ratio (Rowe, 1962) because deformation process of particles is treated quantitatively in terms of energy. We also conduct friction experiments of simulated fault gouge to test the validity of the theory. So, based on the results, we aim to discuss frictional instability and particle deformation quantitatively in terms of analytical dynamics and thermodynamics.

2. Theoretical background

A stability of a system (e.g., a block slider model) depends on a non-linear effect of a damping (e.g., Thompson, 1982). Thus, stable slip is a result of a damping. In contrast, negative damping, or self-excited oscillation leads to unstable slip. The damping is decided by a damping constant; the system is stable when the damping constant is positive. Moreover, it is clear that displacement is controlled by the damping constant from the equation of motion. The damping constant derives from a friction force to a system. So, positive or negative of the damping constant means directions of friction force. Then, we consider that the frictional parameter deriving from coefficient of friction can be described as a ratio of tangential force (friction force) to vertical force. Therefore, frictional parameter has a close relationship with the damping force. Additionally, the relationship between stored energy in a system and energy ratio, or the ratio of input energy to output energy, is obtained from Niiseki and Satake (1981) and Landau and Lifshitz (1976). From these results, the range of energy ratio (K) is clear; in case of $K > 1$, system behave stable. On the contrary, system behaves unstable when $0 \leq K < 1$.

3. Friction experiments

12 friction experiments with simulated fault gouge (quartz) were conducted in a gas medium apparatus (Pc: 140-180 MPa). A geometry of gabbroic split cylinders sandwiching gouge were 20 mm in a diameter, 40 mm in a length and 50 degree precut from their cylindrical axis. The samples with gouge were loaded at a constant strain rate (10^{-3} /s). To obtain energy of gouge in directions of the maximum and minimum compressive stresses, strain gauges were placed. The loading and stop loading periods were repeated 4 times at differential stresses of about 190, 450, 640 and 800 MPa. After that, the sample was loaded again until strains exceeded the measurable range of strain gauges or unstable slip occurred.

4. Results and discussion

From our experiments, output energy can be expressed as a linear function of input energy. So, energy ratio of gouge is constant. Thus, gouge obeys Rowe's theory. However, in detail, the change in energy ratio was observed depending on each stress state. We consider that this change reflects the particle arrangement in each state, because energy ratio is a function of internal friction angle. Moreover, the change in energy ratio indicates the change in the damping constant. Additionally, frictional parameter is equivalent to the direction of friction force decided by a damping force. Thus, the change in the damping constant leads to the change in frictional parameter.

5. Summary

We investigated frictional instability of gouge by theoretical and experimental study. As a result, the physical and energetic background for the relationship between frictional parameter and shear localization become clear by using the damping constant based on Rowe's theory.

Keywords: frictional instability, simulated fault gouge, friction experiments, a gas-medium apparatus, Rowe's theory on constant minimum energy ratio

SCG59-07 Room:106 Time:May 28 09:15-09:30

Effect of liquid viscosity on the shaking condition required for the granular medium fluidization

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A liquid-immersed two-layered size-graded granular medium, where the upper layer forms a permeability barrier against the upward percolating liquid, is shaken vertically. A gravitational instability occurs above a critical acceleration (Γ_c) and its amplitude grows. We have previously reported the results of experiments for the water-immersed case (Yasuda & Sumita, 2014). Here we proceed to study the viscosity dependence by conducting experiments for the case in which the liquid is more viscous such that the Stokes velocity is smaller by a factor of 17, and shake it for a corresponding longer time span. We vary the acceleration and frequency of the shaking by 2 and 3 orders of magnitude, respectively, and find that fluidization occurs most efficiently at a frequency band centered around 100 Hz. Importantly, the high viscosity (HV) case has a smaller Γ_c. In addition the instability of the HV case has a shorter wavelength, and when scaled using the Stokes velocity, the growth rate is faster. The critical acceleration becoming minimum at 100 Hz can be interpreted as follows. For a flame structure to form, a sufficient amount of liquid should accumulate at the 2-layer boundary. A combined condition of energy and jerk of shaking exceeding their critical values, can explain this frequency dependence. A smaller critical acceleration for the HV case can be interpreted as a result of viscous lubrication. To confirm this, we conducted shear stress controlled fluidization experiments of the jammed particles using a rheometer. We indeed find that the fluidization occurs under a smaller shear stress for the HV case. Our experimental situation in which the gravitational instability occurs can be approximated as a thin low density, low viscosity layer underlying a thick high density, high viscosity (with a viscosity which is $\times\ \epsilon$ that of the low viscosity layer) layer. For this situation, linear stability analysis for viscous fluids indicate that the wavelength (λ) scales as $\lambda \propto \epsilon^{1/3}$. Our experimental results suggest that ϵ becomes smaller for HV case such that λ becomes shorter. A smaller ϵ value for HV case is consistent with our result indicating that fluidization occurs under a smaller acceleration.

Our experiments indicate that if shaken for a sufficiently long time, fluidization of the HV case occurs under a smaller acceleration because of viscous lubrication. This implies that fluidization of magma is more susceptible to fluidization than the water-saturated case. This may be relevant to liquefaction of magma and earthquake triggering of volcanic eruption.

Reference

Yasuda, N., Sumita, I. 2014, Shaking conditions required for flame structure formation in a water-immersed granular medium, Progress in Earth and Planetary Science, 1:13.

Keywords: earthquakes, liquefaction, fluidization, magma, triggered eruption, shaking experiments

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Understanding characteristics of the granular compaction by analyzing visualized stress chain

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Granular material is defined by an ensemble of many solid grains. Although the grains composing granular material are solid, granular material sometimes behaves like fluid [1]. The rheological property of granular matter is very complex in general. Granular matter deeply relates to various phenomena occurring on the earth and planetary environments. For example, an avalanche or a liquefaction of ground caused by vibration such as earthquake relates to the complex nature of granular behavior. In this study, we focus on the granular compaction induced by vibration. Granular compaction is a peculiar phenomenon observed in various granular related behaviors, it is usually defined by the increase of the packing fraction of a granular bed.

To reveal the granular behavior, researchers have carried out various experiments. As a result, deeper understandings for the granular behaviors have been obtained. However, these understandings have not yet been perfect. In general, image analyses and data acquisition by sensors are used to investigate the granular behavior. For example, we can measure the packing fraction or the particle velocity in granular material from the former method [2]. In addition, the data such as pressure or acoustic wave on granular material can be obtained from the latter method [3]. However, we cannot completely understand the characteristics of individual particles from these macroscopic quantities. By using photoelastic discs, recent studies succeed in measuring the force applied to particle at each contact point and the stress distribution in a bulk granular material, so-called stress chain in the case of two dimension [4].

In this study, we carry out the experiment of tapping-induced granular compaction using photoelastic discs for granular material to understand granular compaction. In the experiment, we add vertical tapping to photoelastic discs piled layer in two-dimension (2D) experimental vessel. For this experiment, we use 2D experimental vessel made of acrylic plates and fill it with bidisperse photoelastic discs. To lead to the granular compaction, we tap the experimental vessel by using an electromagnetic vibrator. We systematically vary the tapping condition, the duration of tapping impulse and applied maximum acceleration. As a result, the degree of granular compaction varies depending on tapping condition. By taking and analyzing pictures of this 2D experimental vessel in the bright and dark fields at initial and tapped states, we obtain following results.

(1) Although both the packing fraction and total internal forces in the granular pile increase by the tapping, the latter saturates more quickly than the former.

(2) The applied forces on each particle become large, but the total length of the stress chain is almost constant during the granular compaction caused by tapping.

(3) The degree of granular compaction strongly depends on the applied maximum acceleration rather than the number of tapping or the duration of the tapping pulse.

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Keywords: granular matter, stress chain, granular compaction, photoelasticity

SCG59-09 Room:106 Time:May 28 09:45-10:00

Transition between frictional sliding and viscous flow in magmatic fractured zone

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Silicic magma intruded into shallow parts of volcanic conduits experiences shear localization and shear-induced brittle fracturing, resulting in the formation of a magmatic fault along conduit wall. Once the fault is formed, the frictional behavior of the fault controls the magma ascent process. The weak magmatic fault lubricates magma plug in the conduit, which results in rapid magma ascent and hence explosive volcanism. In contrast, if the fault heals during magma ascent, the ascent is controlled by viscous flow. In the viscous flow, magma is sheared, which causes efficient outgassing though shear-induced bubble coalescence and elongation. Thus, the healing of the fault may results in non-explosive volcanism. Here, we observed torsional deformations of a rhyolitic melt and a magmatic fault gouge in-situ at temperatures of 800-900 ℃ using synchrotron radiation X-ray radiography. The torsional deformation rate was set to be 0.1 to 10 rpm, corresponding to equivalent slip velocities of 2×10^{-5} to 2×10^{-3} m s^{-1} and shear strain rates <1 s^{-1}. The experimental temperature is greater than the glass transition temperature; hence, the experiments were conducted for supercooled rhyolitic melts. In experiments for rhyolitic melts, we observed brittle fracturing and formation of magmatic fault along a rotational piston. The fault did not heal under the constant deformation rate. In experiments for the magmatic fault gouge, the magmatic fault showed a frictional sliding as well as viscous flow; the deformation is controlled by the viscous flow under higher temperature, low deformation rate, and high normal stress. Based on the experimental results, we propose the ratio of timescales of fault healing and deformation as a criterion for transition between frictional sliding and viscous flow. The experimentally calibrated transition criterion infers that frictional sliding is predominant from several hundred meters in the conduit during explosive eruption on silicic volcanism; this may explain the rapid magma ascent without efficient outgassing. In contrast, once the fault heals, magma ascent may decelerate, resulting in effusive eruptions. In addition, the repeated magma fracturing, sliding, and healing would be a possible explanation for the cyclic behavior of magma ascent.

Keywords: Silicic magma, Viscous flow, Frictional sliding, X-ray radiography

SCG59-10 Room:106 Time:May 28 10:00-10:15

Shear-induced instability of an aging suspension

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In general, magma is one of typical examples of complex fluids. First of all it is a multi-phase mixture of contrasting physical properties. The volume fraction can easily change with the environmental conditions so that interactions between the constituent phases are highly variable. The characteristics make the magma complex. Rheology is an intrinsic property characterizing the complex fluid. Magma also exhibits non-Newtonian behaviors such as the existence of yield stress [M. Saar et al., 2001], shear-thinning [H. Sato, 2005], thixotropy, which is a kind of aging property [H. Ishibashi and H. Sato, 2007], and shear localization [S. Okumura et al., 2013, A. Hale and H. Muhlhans, 2007] under certain conditions. Consequently magma flow is expected to be unstable by control of complex rheology and it might be related volcanic oscillation phenomena such as volcanic tremor. However there are few studies, which focus on flow behaviors caused by the complex characteristics of magma rheology so far since it is difficult to control flow in magma and obtain reproducible results at high pressure and high temperature.

For this reason, instead of using real magma but by using analog material this study aims to reveal possible control of complex rheology in magma flow dynamics. We particularly focus on shear-induced instability of the suspension such as shear-banding phenomena to drive unstable and oscillatory flows. As an analog material we utilized an aging suspension of fine silica particles (Ludox TM-40, Aldrich) with salt water. The suspension is known to have yield stress, aging behavior and thixotropic natures [Moller et al., 2008], which can be an analog for the magma complexity. A series of rheological experiments with the use of a rheometer (AR1000, TA Instrument) and 1D and 2D ultrasonic speckle velocimetries (USV) [S. Manneville, 2004] have achieved to observe global rheology and local velocity profiles in the flow simultaneously. By results from the experiments under various conditions changing applied shear rate and aging time, we conclude that the flow behavior can be divided into three types; fluidization, unstable shear banding, and stable shear banding. In the cases of fluidization and unstable shear banding, shear stress fluctuates when the width of shear band and slip velocity show large shift. In this way, it was revealed that fluctuation of shear stress could occur in this kind of suspension and both shear-banding and wall-slip are responsible for driving the shear-induced global instability.

Keywords: aging, rheology, suspension, shear band

SCG59-11 Room:106 Time:May 28 10:15-10:30

Fundamental aspects of the thermo-elasticity in the columnar joint formation

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Columnar joints form as a result of unidirectional propagation of cooling and the consequent thermal contraction. So far in interpreting the columnar regular structures at nature, two hypotheses are assumed about the fracture threshold and propagation direction: 1) fractures take place at a certain temperature, that is, at the isothermal surface corresponding to the yield strength (fracture threshold hypothesis). 2) fractures propagate perpendicular to the isothermal surface (propagation direction hypothesis). However, those hypotheses have not been proved on the basis of the thermo-elastic theory. In this paper, we analytically show, using the thermo-elastic theory in 2D, that these two hypotheses are correct under the specific circumstances. Firstly we derive the relation between the stress field and temperature field in terms of principal stress difference, stress invariant and temperature. From the relation, we understand that the principal stress difference contributing to the crack initiation is exactly equivalent to a certain temperature when the minimum principal stress is small enough. The temperature corresponding to the crack initiation, which is determined by the yield strength, defines the fracture isotherm or crack front. Secondly we derive the direction of maximum extension on the fracture isotherm as function of azimuthal angle. If the stress is completely released in the region where fracturing already occurred and cracks are present, that is, where temperature is less than fracturing temperature, then the shear stress on the fracture isotherm must be zero, and one of principal stress is perpendicular to the fracture isotherm and another principal stress is along the fracture isotherm. These geometric relations naturally mean that the direction of maximum extension is perpendicular to the fracture isotherm. Numerical calculations well explain morphological features derived from our analog experiments, indicating that two hypotheses work correctly in real systems.

Keywords: columnar joint, thermo-elasticity, thermal stress

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SCG59-12 Room:106 Time:May 28 10:30-10:45

Analogue experiments of reproducing morphological features of entablature in columnar joints

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There are various types of morphological features in columnar joints, i.e. column width, column configurations (straight or curved) and the directions of developed columns. We have conducted analogue experiments by use of potato starch and water mixture to reproduce morphological characteristics of entablature and we have found the following two results: 1) when the desiccation rate increases instantaneously on the half way of columns development, the number of columns increases by column nucleation, 2) the direction of developing columns is perpendicular to the isopleth surface of the same water concentration with the exception under particular circumstances of stress field. In order to observe the time evolution of column development in the case of the spatially inhomogeneous desiccation rate, we used the X-ray CT (MCT 225 made by Nikon, owned by Fukuoka Industrial Technology Center) at a certain interval of time during the development of columns. We prepared potato starch and distilled water mixture with the same mass 150g each in a plastic cylindrical container. The light source (60 W lamp) is located at 3 cm above the surface of mixture thereby the thermal heterogeneity on the surface is made due to the highest desiccation rate just below the lamp and the lowest desiccation rate at the edge of circular sample surface. We took the X-ray CT images every 2 or 3 hours during the daytime to observe the change of water distribution by the gray scale intensity together with crack developments in the mixture with time. As a result, there is a higher brightness area like a crescentic shape at upper part of the mixture, which indicates lower concentration of water than at lower part, before the initial generation of cracks on the surface of the mixture. The area in which cracks develop coincidently take a similar crescentic shape. The lower area below the crack front indicates homogeneous brightness. The crack front advanced to the depth with keeping its crescentic shape and cracks developed not perpendicular to the crack front, indicating the discrepancy with the theoretical prediction for the crack direction under the simple condition. This discrepancy may be caused by the mechanical effect at the edge of the plastic container. In addition, we conducted the experiments in the case of drying from 3 non-parallel surfaces which provide spatially homogeneous desiccation rate each. We put the mixture into a triangular prism shaped metal frame. Two sides are dried through the membrane (surface B and C) and the other top side is dried directly on the air (surface A). We conducted experiments in the cases that the angle θ between surfaces B and C is 60 degree and 90 degree each. As a result, when θ is 90 degree, columnar joints developed from surface A, B and C simultaneously merge in the center of the mixture with curved structure which are fan-like structure at the edge of the triangle. From the comparison with the theoretical results, the characteristics of curved structure can be explained by the condition that a crack propagates perpendicular to the iso-concentration surface. We will investigate the interaction of columns developed from different directions in terms of angles between the desiccation surfaces as a parameter.

Keywords: columnar joints, analogue experiment, entablature, morphological features

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SCG59-13 Room:106 Time:May 28 11:00-11:15

Experimental study on the rheology of ice-rock mixtures: Implications for cosmoglaciology

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Icy bodies in the solar system have various shapes, bulk densities, and surface features. Icy satellites have a wide range of bulk density, 300 to 3000 kg/m^3, and those with small density have a residual porosity in their interiors while those with high density are composed of ice-rock mixtures. The shape of icy satellites is determined by the ratio of the stress by gravity and the material strength, that is, icy body has spherical shape when the internal stress is beyond the material strength. Furthermore, glacial features and large-scaled faults are observed on Mars polar regions and the surfaces of giant icy satellites such as Europa. Such the variations of shape and density and the tectonics of the surface features on Mars and icy satellites are controlled by the rheology and the failure stress of constituent.

Many researchers examined the rheology of H_2O ice. Particularly, they examined the effects of temperature and grain size on the flow law by laboratory experiments and field observations. However, icy bodies in the solar system are composed of ice-rock mixtures with various rock contents and small icy bodies are porous because of their small densities. Furthermore, the surface temperature can be estimated from the radiative equilibrium temperature while the internal temperature must be higher than the surface temperature. But it is very difficult to estimate the internal temperature distribution. Therefore, in order to clarify their evolutions and tectonics of Mars and icy satellites, we must examine the rheology of ice-rock mixtures in the wide range of rock content, porosity, and temperature. In this study, we did deformation experiments of ice-rock mixtures and examined these effects on the flow law systematically.

The samples were prepared by mixing ice particles with the diameter smaller than 710 μm and amorphous silica beads with the diameter of 1 μm. We prepared two kinds of samples. One is a frozen sample (f.s.) which is made by mixing ice particles, silica beads, and liquid water. The silica volume fraction of the f.s. was from 0 to 0.63 vol.%, and the porosity was 0%. The other is a pressure-sintering sample (p.s.s.) which is made by the compaction of ice particles and silica beads. The silica mass content of the p.s.s. was 0, 30, and 50 wt.%, and the porosity was changed from 0 to 25%. We did uniaxial compression tests under constant strain rate from 8.7×10^{-7} s^{-1} to 8.3×10^{-4} s^{-1} in the cold room at ILTS, Hokkaido University. The temperature was set from -10 to -25 ℃.

We examined the flow law expressed as $d\epsilon/dt = A_0 \exp(-Q/RT)\sigma_{max}{}^n$, which σ_{max} is the maximum stress on the stress-strain curve and $d\epsilon/dt$ is the strain rate. The dependence of the silica content was different between f.s. and p.s.s.. The σ_{max} increased with the increase of the silica content in the case of f.s. while it decreased in the case of p.s.s.. On the other hand, the σ_{max} decreased with the increase of the porosity or the temperature for both samples. From these results, we obtained the parameters, A_0, Q, n, on the flow law. The power n and the activation energy Q depended on only silica content, and the n at the silica volume fraction larger than 0.15 became twice larger than that of pure ice (n=3). The Q increased with the increase of the silica content. The A_0 depended on the silica content and the porosity, and the empirical equation, $A_0 = B\exp(\alpha\phi)$, which ϕ is the porosity, and B and α are constant depending on the silica content, could be obtained.

Next, we examined the deformation modes, ductile deformation or brittle failure. As a result, the f.s. at the silica volume fraction larger than 0.29 showed brittle failure at the temperature lower than -20 ℃. The temperature at the brittle-ductile boundary of the mixtures was 30-50 ℃ higher than that of pure ice at constant strain rate.

Keywords: Mars polar regions, icy satellites, ice-rock mixtures, porosity, flow law, brittle-ductile boundary

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SCG59-14 Room:106 Time:May 28 11:15-11:30

Elasticity, anelasticity, and viscosity of a polycrystalline material at near-solidus temperatures

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For a quantitative interpretation of seismic structures in the earth's interior, understanding of rock anelasticity over a broad frequency range is needed. There are high-Q^{-1} and low-V regions in the upper mantle. To interpret them, it is important to understand effects of melt on anelasticity.

Anelasticity of mantle rock or rock analogue at seismic frequencies have been measured intensively. We use polycrystalline aggregates of organic "borneol" as rock analogue to accurately measure the anelastic properties over a broad frequency range. A sample made from borneol + diphenylamine binary system partially melts at T_m = 43 ℃ and its equilibrium microstructure is quite similar to that of olivine + basalt system.

Using these samples, forced oscillation tests have been performed to measure anelasticity as a function of frequency f, temperature T, grain size d, and melt fraction ϕ. McCarthy et al. (2011) showed that polycrystal anelasticity follows the Maxwell frequency (f_M) scaling, by demonstrating that all attenuation spectra $Q^{-1}(f)$ obtained under various experimental conditions collapse onto a single master curve $Q^{-1}(f/f_M)$. However, this result was obtained from the data at $f/f_M < 10^5$, which is lower than the seismic frequencies normalized to f_M in the upper mantle ($10^6 \leq f/f_M \leq 10^9$). Recently, Takei et al. (2014) measured Q^{-1} of rock analogue up to $f/f_M \sim 10^8$ and showed that the Maxwell frequency scaling is not fully applicable to $f/f_M > 10^4$. They showed that the deviation from the master curve increases with increasing homologous temperature T/T_m (T_m: solidus temperature) and/or grain size. Based on their results, they speculated that at near-solidus temperatures high Q^{-1} and low V can occur even without melt. However, their data were limited to $T/T_m \leq 0.93$. Data at $T/T_m > 0.93$ are needed to examine the detailed behavior at the onset of melting.

In this study, we prepared 4 samples made from borneol + diphenylamine binary eutectic system with different grain sizes and melt fractions. Anelasticity of these samples was measured at near-solidus temperatures ($0.88 \leq T/T_m \leq 1.01$). In order to clarify the mechanism of anelasticity, mechanical data over a broad frequency range are needed. Therefore, in addition to forced oscillation tests, ultrasonic tests and creep tests were conducted to measure elasticity and viscosity at the same temperature conditions.

The samples were pre-annealed at supersolidus temperatures to prevent the rapid grain growth at the onset of melting. This improvement enabled us to measure elasticity, anelasticity, and viscosity at near-solidus temperatures and examine how these properties behave at the onset of melting. We found that although the ultrasonic velocities are discontinuously reduced by the poroelastic effect of melt, anelasticity and viscosity changed continuously with temperature even at the onset of melting. Based on these data, an empirical formula of the relaxation spectrum X was obtained as a function of nondimensional variables f/f_M and T/T_m. A preliminary appreciation of the formula to the upper mantle suggests that high Q^{-1} and low V can occur at near-solidus temperatures even without melt. It also suggests that seismic attenuation changes continuously even at the onset of melting, whereas seismic velocity changes discontinuously due to the poroelastic effect of melt.

In this study, the temperature dependence of anelasticity could be captured at near-solidus temperatures, but dependences on the grain size and melt fraction couldn't be captured. This is because the samples that experienced partial melting show various hysteresis effects, and the hysteresis effects masked these effects. Our next step is to investigate effects of grain size and melt fraction on anelasticity by using samples that do not experience partial melting and hence are free from the hysteresis effects.

Keywords: anelasticity, seismic attenuation, melt

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Experimental study on the oblique collisional disruption on porous gypsum target

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Introduction

High-velocity impact among small bodies in the solar system could originate asteroidal bodies and EKBOs and so on through collisional disruptions. Then, the collisional disruption is one of the most important physical processes to clarify the formation and evolution of the small solar system bodies. The degree of collisional disruption is quantitatively defined by an impact strength, and it has been studied for various materials, then it is found that it depends on a porosity. Because the shock wave rapidly attenuates in a porous target, so the impact damage is well concentrated near the impact point (Arakawa et al.2009). Recently, many porous asteroids were found by the explorations, then it is important to understand the impact phenomenon for the porous asteroids. Okamoto and Arakawa (2009) conducted high-velocity impact experiments on porous gypsum targets, but they carried out them only for a head-on impact. However, oblique impacts would be dominant in the collisions among solar system bodies. Therefore, we conducted high-velocity oblique impacts for porous targets and examined the effect of impact angles on the collisional disruption.

Experimental method

The impact cratering experiments were conducted by using a two-stage light-gas gun at Kobe University. We used a polycarbonate sphere with the diameter of 4.75mm and the density of 1.2g/cm^3 for a projectile. A spherical gypsum target was prepared and it has the diameter of 70mm, the porosity of 61%, the tensile stress of 1.0MPa and the bulk sound speed of 1.19km/s. The impact velocity, V_i, was 4.0km/s and 7.0km/s. The impact angle, θ, was changed from 15 to 90-degree, where the head-on impact was defied as the impact angle 90-degree. The impact fragments during the disruption process were observed by a high-speed video camera to measure the ejection velocity of these fragments. In addition, we recovered impact fragments after the shot and measured the mass of each fragment to construct the mass distribution of these fragments.

Result

In order to study the degree of the collisional disruption quantitatively, we studied the relationship between the mass of the largest fragment normalized by the original target mass (m_l/M_t) and the energy density, $Q_t = 1/2V_i{}^2m_p/M_t$, where m_p, M_t are the mass of the projectile and target respectively. Our result for a head-on collision (θ=90) was almost consistent with a previous study for porous gypsum targets (Okamoto and Arakawa 2009). While, it was surprised that m_l/M_t did not change or was almost constant when the impact angle was changed from 90-degree of a head-on collision to 45-degree of a oblique collision. However, ml/Mt was significantly changed to be almost for θ of 15,30-degree at 4km/s and θ of 15-degree at 7km/s because an impact crater was formed instead of the catastrophic disruption.

In the case of oblique impacts, the kinetic energy effectively used for the impact disruption could be that originated from the normal velocity component of the projectile. Thus, we could calculate the effective energy density defined as $Q_c = 1/2V_i{}^2m_p\sin^2\theta/M_t$ and found that our result at the impact angle θ from 90 to 45-degree was not inconsistent with the previous study (Okamoto and Arakawa 2009). Therefore, the normal velocity component might be important for oblique impacts in these angles. However, Q_c did not work well at the impact angle smaller than 45-degree at 4km/s an 30-degree at 7km/s. This result indicates that not only normal component of the impact velocity but also the tangential component of the impact velocity might affect the impact disruption.

Keywords: collisional disruption, oblique impact, porosity

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Granular convection and its application to asteroidal resurfacing timescale

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Recently, planetary explorations by space probe have observed various surface geomorphologies that are covered with regolith and boulders on the asteroids. In particular, landforms resulting from the regolith fluidization and sorting by impact-induced global seismic shaking were found on the asteroid Itokawa [1]. As a possible mechanism for the regolith fluidization, granular convection was proposed [1]. In addition, the regolith migration and resurfacing resulting from the granular convection might be consistent with the relatively young surface age (1 ? 8 Myr) of Itokawa [2, 3]. In fact, when the granular matter such as regolith is subjected to the vertical vibration, the granular convection can be readily generated (e. g. [4]). Although the gravity dependence of the convective velocity has to be investigated to discuss the possibility of regolith convection under the microgravity condition such as asteroid Itokawa, only a few researches concerning this problem have been performed so far [5].

We performed systematical experiments of the granular convection with glass beads under the steady vertical vibration. Although the direct control of gravity is quite difficult in laboratory experiments, we instead employ the scaling approach to figure out the gravity dependence of the granular convective velocity. As a result, we found that the granular convective velocity is almost proportional to the gravitational acceleration [6]. This experimental result suggests that the convective velocity would be very low under the microgravity condition. The low convective velocity would result in the long timescale of regolith migration. In order to examine the feasibility of the regolith convection on Itokawa, the resurfacing timescale induced by regolith convection should be compared with the surface age or the lifetime of Itokawa. In this study, we aim at developing a model of resurfacing process induced by granular convection. The model allows us to estimate the resurfacing timescale not only Itokawa but also on the general asteroids covered with regolith.

In the model, we divide the resurfacing process into three phases as follows:

1. Impact phase: An impactor intermittently collides with a target asteroid.
2. Vibration phase: The collision results in a global seismic shaking.
3. Convection phase: The global seismic shaking induces the regolith convection on the asteroid.

For the impact phase, we estimate the frequency of impact events per year by using the model of impactors' population in the main belt asteroids (MBA) [7]. To compute the vibration strength induced by each impact, we utilize the global seismic shaking model [8] for the vibration phase. For the convection phase 3, we use the scaling of the granular convective velocity [6] in order to relate the vibration strength and the regolith convective velocity. Combining these three phases, we compute the resurfacing timescale T as a function of the diameter of target asteroid D_a.

We assume the specific parameter values based on previous work [1, 7, 8] to compute T. As a result, we find T= 9 Myr for the Itokawa-sized asteroid, and this value is comparable to the surface age of Itokwa measured by the returned sample (1 ? 8 Myr) [2, 3]. In addition, T= 9 Myr is much shorter than the mean collisional lifetime of Itokawa (about 170 Myr [7]). This indicates that the regolith convection is able to resurface the asteroid almost within its lifetime.

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Keywords: granular convection, regolith fluidization, asteroid, resurface

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Granular flow field around an obstacle and clogging at a bottleneck outlet

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Granular materials in the flowing state can form an arch structure at the bottleneck. Due to the arch formation, particles suddenly clog to arrest the flow. It has been empirically known that the clogging phenomenon cannot occur when the size of bottleneck is larger than approximately six times of diameter of particles [1]. Even in this flowing state without clogging, the flow rate would not be steady but vary depending on various parameters. In addition, the occurrence frequency of clogging could be decreased by inserting obstacles into the flow fields. Therefore, the effect of obstacles in the flow field must be an important key for the better understanding of granular clogging phenomenon. Furthermore, it is expected that the understanding of these phenomena will be helpful for structural design of buildings to control the flow of evacuating people. In this case, the flow of evacuating people can be regarded as a kind of granular flow. The nonlinear behaviors of granular matter such as the sudden clogging and arch formation could also relate to various geophysical phenomena, e.g., landsliding and avalanching.

In this study, we performed a simple experiment of gravity-driven granular flow controlled by the outlet and obstacle. First, we insert a disk-like obstacle into a two-dimensional cell, and fill the cell with stainless balls in diameter of 6.35 mm. Then, a small outlet is opened at the center of the bottom in the cell to create the granular flow toward the outlet. Granular flow field and the flow rate as well as the drag force exerted on the obstacle are measured using a high-speed camera and load cells. In particular, we experimentally examine how the flow field and flow rate are influenced by the parameters such as the size of outlet and the position of obstacle.

From the images of the granular flow acquired by the high-speed camera, we observe that the alternate flow, i.e., non-uniform (asymmetric) flow field, is generated by inserting the obstacle. On the other hand, the net flow rate at the outlet is found to be approximately steady. We further analyze the granular flow movie by Particle Tracking Velocimetry (PTV) method. Using PTV method, tracks of flowing particles can be measured. We divide the cell into three parts: an area right above the outlet and two sides (left and right) around the obstacle. Then, we calculate the flow field and packing fraction for each area. Besides, we also compute Mean Square Displacement (MSD) from the paths of the individual particle, on the basis of PTV data.

We discuss the relation between these values and physical quantities such as granular flow rate and drag force exerted on the obstacle, and then, we clarify how obstacles influence the granular flow fields through these parameter dependency.

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Keywords: granular flow, clogging, obstacle, particle tracking velocimetry, mean square displacement

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Feasibility Study of Morphological Characterization to Comminuted Particles by A Particle Characterization Approach

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1.introduction

A faults zone contains fine rock powders called gouge that have been ground up by past fault motions. Particle size distribution and particle shape of gouge particles may affect the frictional properties of the fault and reflect the comminution process by the past fault motions. It is well known that particle size distribution (PSD) of fault gouge show power-law distributions. Exponent of this power law, called fractal dimension, is considered to reflect the style and amount of deformation. This report will be discussed for relationship between the particle morphology and a style and a degree of comminution of model particles by automated particle image analysis and laser diffraction as a particle characterization method.

2.Method

As an automated particle image analysis, Morphologi G3-SE (Malvern Instruments) was used for evaluation of particle size and shape. The observation mode was diascopic mode (Transmittance mode) and a magnification was choose to sufficient to cover 1 to 1,000um. The sample was dispersed with SDU (Sample Dispersion Unit) which attached Morphologi G3-SE. Number of measured particles was over than ten thousand and a parameter filter function on software was used based on shape and pixel number of particle image. As a laser diffraction instruments with dry dispersion methods , Mastersizer3000 with Aero unit (Malvern Instruments) was used for evaluation of particle size in less than 1um as fine particles.

Keywords: Fault gouge, Particle size, Particls Shape, Comminution, Fractal Distributions

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Shape, propagation style and velocity of a buoyancy-driven crack : a parameter study

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Introduction: Magma is considered to ascend in the form of a diapir by deforming the host rock in the asthenosphere whereas it ascends as a dyke by brittle fracturing in the lithosphere (Rubin, 1995). How does the magma ascend in the transitional regime? We have been studying the ascent mechanism in the transitional regime by model experiments using a viscoelastic agar and widely varying its stiffness (Sumita and Ota, 2011). Here we report the results of experiments which focus on the effect of fluid viscosity on the magma migration in a viscoelastic medium.

Experimental method: We conducted (1) rheology measurement of an agar and (2) fluid injection experiments. We inject magma (CsCl solution to which a thickener is added) using a syringe from the top of a cylindrical acrylic tank (height of 250 and 500 mm). The fluid has a volume of 1ml, a density difference with the agar of 0.580 and 0.770 g/ml, and is injected at a constant rate of 1 ml/s. We vary the agar concentration(C) in the range of C = 0.06-0.5 wt% and the fluid viscosity(η) in the range of η = 10ˆ-3 - 1300 Pas. As we increase the agar concentration in this range, the yield stress and the rigidity of the agar increases by 3 and 2 orders of magnitude, respectively. From creep test conducted under a constant shear stress, we find that the agar can be approximated by a Voigt model to which a spring is connected in series for C › 0.1wt%, and a Burgers model for C ‹ 0.1wt%. The experiments are recorded using video cameras from two sides and from the bottom of the tank.

Result: From the crack shape, propagation style and velocity, we classified the experiments into the following 3 regimes. Regime Ⅰ: The crack has a 2D(blade-like) shape, a straight trajectory and stops propagating in a short distance. We fit the distance(z) vs time(t) data to a power-law(z$\propto$tˆn) relation, and find that the power law exponent is n$\sim$1/5. The migration velocity depends on viscosity as $\sim$ 1/n. Regime Ⅱ: The crack shape transforms from 2D to 3D(i.e. , having a bulged head) and its trajectory is curved or meanders. The power-law exponent varies as n=1/3-1. We find that as the fluid viscosity increases, the amplitude of the meandering becomes smaller and transforms to a straight path. The same transformation was observed when the fluid density becomes smaller (Sumita and Ota, 2011). The migration velocity is intermediate from those of regimes Ⅰ and Ⅲ. Regime Ⅲ: The crack shape is 3D, the trajectory is straight and the propagation distance is long. The power-law exponent is n$\sim$1. The dependence of migration velocity on viscosity is small.

Discussion: The condition for the regime Ⅰ-Ⅱ transition can be approximately described using the dimensionless buoyancy B=△ρgVˆ1/3/G(△ρ: density difference, g: gravity, V: crack volume)as B$\sim$1. However in detail, we find that the B value becomes larger for a high viscosity fluid. This is because when the propagation velocity is small, a larger fraction of the fluid is left along the crack tail such that the crack head volume become smaller, which results in a smaller effective B value . The migration velocity was found to be comparable to or smaller than the channel flow velocity(n=1/3:Taisne et al. (2011)) in regime Ⅰ and comparable to the Stokes settling velocity(n=1) and shear wave velocity in regime Ⅲ. This suggests that the propagation velocity is also rate-limited by rupture velocity. We indeed confirmed that the propagation becomes faster when there is a preexisting crack. We find that the meandering of regime Ⅱ no longer occurs under a large viscosity. This suggests that in addition to B$\sim$1, there is a critical velocity, or a critical Reynolds number required for meandering to occur.

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Keywords: magma ascent, crack propagation, viscoelasticity, fluid viscosity, bouyancy

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Measurements of elastic wave velocity of Aji granite on triaxial compression fracture test

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Elastic wave velocity is one of the important physical properties to understand underground mechanics. Especially, in geothermal generation, it has an important part to play in estimating geothermal fluid reservoir. In addition, it is imperative in estimating artificial geothermal reservoir which is formed by hydraulic fracturing. Elastic wave velocity varies in different situations, for example, porosity, shape of crack, distribution of crack, with or without fluid and so on. Many experimental results have been reported until now, for example, velocity change against confining pressure (Nur and Simmons, 1969), velocity change in fracture process (Bonner, 1974). At laboratory, examining these change lead to interpreting underground mechanics which means that estimating geothermal reservoir or artificial one. This study is intended to examine the velocity change in fracture process existing pore pressure and lead to interpreting artificial reservoir in hydraulic fracturing. In this graduation work, we improved the system of measurement of elastic wave velocity using inter-vessel deformation fluid-flow apparatus at Hiroshima University and examined change of elastic wave velocity of dry rock in fracture process.

We used Aji granite which is formed into cylindrical shape as a specimen and tried three measurement systems. First method is pulse reflection method which place piezoelectric device on the top of specimen. Second method is transmission method (σ1 direction) which place piezoelectric device on the top and bottom of specimen. Third method is transmission method (σ3 direction) which place piezoelectric device on the lateral face of specimen directly. We measured elastic wave velocity under the confining pressure 10 to 200MPa using these methods. In all methods, we could find increase of elastic wave velocity due to compaction through increasing confining pressure. However, in pulse reflection method and transmission method (σ1 direction), we could'nt calculate the velocity under low confining pressure in which porosity is high and in long specimen because of attenuation of pulse. So these two methods are not well-suited on the purpose of measurement in fracturing process which use specimen of 40mm long. On the other hand, in transmission method (σ3 direction), although we cannot reuse piezoelectric device because it is attached directly, it is possible to minimalize the pulse attenuation.

From the results mentioned above, We used the transmission method (σ3 direction) and measured elastic wave velocity of Aji granite in fracture process. This experiment is conducted under confining pressure 20MPa and displacement rate 0.01mm/min using loading system by servo control of inter-vessel deformation fluid-flow apparatus. Specimen is Aji granite which is prepared into a cylindrical shape, which diameter and lengths is 20mm and 40mm, and also which is processed to attach the piezoelectric device.

Increasing of elastic wave velocity was observed until about one-fifth of fracture stress, and then over one-third of it increasing shifted to decreasing. Firstly, increasing of the velocity means closure of micro-cracks in existence. Then gradually, the changes of the velocity start to decrease due to formation of new cracks in the specimen. This effect of formation of crack is more strengthen and the velocity decreases rapidly. Therefore it is possible to explain this decreasing of the velocity by dilatancy effect. Increasing of Vs is affected strongly by closure of cracks extended to σ3 direction because direction of vibration of S-wave is normal to maximum compressional axis in this experiment.

Keywords: elastic wave velocity, geothermal fluid reservoir, hydraulic fracturing, dilatancy

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Rheological weakening due to phase mixing of olivine + orthopyroxene

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The formation of well-mixed, fine-grained, poly-phase rocks may lead to strain localization and play a key role in the development of the lithosphere asthenosphere boundary (LAB). To understand the mixing process in the olivine + orthopyroxene rocks, we have conducted torsion experiments on samples of iron-rich olivine + orthopyroxene aggregates at a temperature of 1200 ℃ and a pressure of 300MPa. We fabricated the samples with grain sizes significantly larger than the steady state grain size. The samples were deformed to total shear strains up to γ = 17. We conducted two series of torsion experiments, the first at fixed strain rate to different strains and the second at different strain rates to the same strain.

The stress exponent of $n \approx 3$ and grain size exponent of $p \approx 1$ were determined from a least-squares fit to the strain rate, stress and grain size data using a power-law creep equation; these values of n and p indicate that our samples deformed by dislocation-accommodated grain boundary sliding. Dynamic recrystallization occurred with significant grain size reduction of both phases in deformed samples. Well-mixed microstructures develop in samples deformed to higher strains at faster strain rates, whereas elongated olivine and pyroxene grains without a mixed texture are observed at lower strain and strain rate. Mixing of the olivine and orthopyroxene phases occurs due to a contribution of interface-reaction-limited diffusion (IRLD) creep [Sundberg and Cooper, 2008]. This IRDL creep process involves diffusion of metal oxides along phase boundaries oriented perpendicular to σ_1 to boundaries parallel to σ_1 resulting in the formation of new pyroxene grains along boundaries perpendicular to σ_1 and olivine grains along boundaries parallel to σ_1. Grain size reduction due to dynamic recrystallization of olivine and orthopyroxene enhance the rate of this process.

Keywords: olivine, opx, deformation, mixing process

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Technical developments on acoustic emissions monitoring at high pressures

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The subduction zone produces a major fraction of the Earth's seismic activity. Intermediate-depth earthquakes within the subducting slab form a double seismic zone. The cause of intraslab seismicity have been attributed to dehydration of hydrous minerals (e.g., Peacock, 2001). Brittle fracture associating dilatancy is difficult at high pressures (i.e., depths at which intermediate-depth and deep-focus earthquakes occur), although dilatancy prior to failure usually occurs in the case of shallow-depth earthquakes.

At deeper depths, dehydration embrittlement (i.e., hydrofracturing) is expected to play an important role in failure of rocks because the overall volume change of the dehydration reaction is positive and thus pore pressure can be increased (e.g., Raleigh and Paterson, 1965). However, experimental results on dehydration embrittlement of antigorite are controversial. Dobson et al. (2002) conducted a series of experiments on dehydration of antigorite, and they reported that dehydration of antigorite associates acoustic emission (AE) when the dehydration reaction is positive. Even though the volume change becomes strongly negative above 2 GPa, Jung et al. (2004) reported that brittle failure of antigorite occurs at pressures up to 6 GPa. Recently, Gasc et al. (2011) reported that no detectable AEs through dehydration of antigorite-rich serpentinite. Therefore, the cause of intermediate-depth earthquakes is still unclear.

In some of subduction zones, a significant activity of deep-focus earthquakes has been reported (e.g., Kirby et al., 1996). It has been proposed that deep-focus earthquakes are triggered by an instability faulting caused by olivine phase transformations (Kirby et al., 1991; Green et al., 1992). Schubnel et al. (2013) conducted deformation experiments on germanium olivine (Mg_2GeO_4) at 2-5 GPa and 1000-1250 K, and they observed many AEs generated in the sample. Schubnel et al. (2013) discussed that fractures nucleated at the onset of the olivine-to-spinel transition.

To investigate the brittle properties of rocks, determination of AE source is critical. In the community of high-pressure rock physics, Green et al. (1992) conducted AE monitoring by using a Griggs apparatus combined with an AE sensor. Dobson et al. (2002, 2004) and Jung et al. (2006) adopted 2 or 4 AE sensors to a multianvil apparatus. However, the position of AE source has not been determined in the experiments because of not enough number of sensors used in the experiments. De Ronde et al. (2007) adopted 8 AE sensors to a multianvil apparatus and they succeeded to determine the position of AE sources. Recently, Gasc et al. (2011) succeeded to develop an experimental setup that allows determining the position of AE source by using DIA-type multianvil apparatus combined with 6 AE sensors. Schubnel et al. (2013) adopted the experimental setup reported by Gasc et al. (2011) to a D-DIA apparatus installed at a synchrotron facility, and they succeeded to measure strain and stress of the sample and AE signals. We have developed an experimental setup that is optimized for the determination of the position of AE source in a synchrotron D-DIA apparatus. We will report some preliminary experimental results on AE monitoring under the upper mantle conditions.

Keywords: acoustic emission, high pressure, earthquake

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Study of rock deformation mechanism using neutron diffraction technique and AE signal measurement

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Acoustic emission (AE) is defined as a transient elastic wave generated by the rapid release of energy within a material. Crack initiation and slipping generated inside rock materials are all detectable with the measurement of AE signals, and therefore such measurement helps to research the underlying mechanism of macroscopic deformation. On the other hand, strain gauge is commonly used to measure strain in rock. In recent years, diffraction techniques for investigating strain in engineering materials have been developed. Strain measurements using diffraction technique are based on Bragg's law. Strain value can be estimated from the changes of lattice parameter.

Accumulation of macro strain in rock samples is generally caused by lattice strain as well as grain boundary shearing and pore collapse generated inside the rock, which would be detectable as AE events. Therefore, simultaneous using of neutron diffraction technique and AE signal measurements should provide us with new insight into rock deformation and fracturing mechanism. In order to study deformation mechanism of geological materials under uni-axial compression, neutron diffraction patterns and AE signal have been measured simultaneously.

Berea sandstone and calcarenite are used as a specimen. Main composed mineral of Berea sandstone is quartz (SiO2), and that of calcarenite is calcite (CaCO3) with minor apatite. Berea sandstone was compressed uniaxially up to 35.6 MPa with two-cycle compression. Calcite was compressed until the specimen fractured at 16.4 MPa. Lattice strain measurements using neutron diffraction technique were performed at the Engineering Materials Diffractometer "TAKUMI" in J-PARC/MLF. The diffractometer have been designed to investigate the stress-strain state of engineering materials (e.g. steel) using a pulsed neutron beam. Macroscopic strain was recorded using a strain gauge attached to the rock specimen surface. AE signal measurements were conducted using USB AE NODE (PHYSICAL ACOUSTIC CORP.) with a miniature AE sensor (Micro30) attached to a compression jig.

Macroscopic strain of both rock materials was greater than lattice strain. Inside rock specimens, mineral grain slip and pore collapse might be generated under compression. These changes would induce macroscopic deformation of the rock specimens. In addition, AE signals which might be derived from these changes in the internal structure of the rock specimens were detected. Parameters of AE signals might be a function of the amount of grain-boundary shear and/or the degree of resistance to deformation. And the frequency characteristics of AE signals depend on rock type. This difference between rock types might be related to the deformation mechanism of the rock specimens.

Keywords: neutron diffraction, lattice strain, AE, uxi-axial compression, rock deformation

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High-pressure deformation experiments on olivine-orthopyroxene aggregates under hydrothermal conditions

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For plate tectonics to operate on a terrestrial planet, the strength of faults within the oceanic lithosphere must be low, with the coefficient of friction below 0.05. However, standard strength profile using olivine flow law far exceeds this threshold value, particularly at depths of 20 to 40 km, where fluids passed through the faults may interact with peridotites to form hydrous minerals (e.g., serpentine). Here, we conducted deformation experiments on harzburgitic olivine-orthopyroxene aggregates under hydrothermal conditions, at a temperature of 500 ℃, a confining pressure of 1.0 GPa, and shear strain rates of 5.9 x 10^{-5} to 4.3 x 10^{-6} s^{-1}. All experiments showed a peak shear strength (about 400 MPa) at shear strains of 0.7, followed by a large stress drop (up to 150 MPa), after which steady-state sliding was observed until significant strain weakening started to occur at shear strains of 1.5. The drop in shear stress was initially caused by unstable slip, which resulted from the development of localized shear planes (Riedel or boundary shears) after yielding. The strain weakening after shear strains of 1.5 is related to shearing of newly formed talc along the shear planes. Talc may form from preferential dissolution of orthopyroxene rather than olivine. The final shear strength (down to 30 MPa) decreased with decreasing shear strain rates, reflecting widening of the talc layer along the shear planes. These results suggest that hydrothermal alteration of peridotites along the deep faults play an important role in forming the extremely weak zone for subduction initiation.

Keywords: olivine, orthopyroxene, talc, hydration reaction, strength weakening, subduction initiation