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

SIT42-01 Room:105 Time:May 22 11:30-11:45

Pattern formation of fracture phase separation and its implications for structuring process of continents and oceans

KOYAMA, Takehito[1*]

[1] Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Phase separation [1-4] is one of phase transitions in mixtures. In this phenomenon homogeneous mixtures of multi components separate into different phases depending on physical conditions such as temperature, pressure, and composition. All matters are mixtures, so that this phenomenon occurs in any matters and is important in any fields of sciences. Recently, a new phase separation was found in polymer solution. It named fracture phase separation [5] because it was characterized by brittle fracture occurred in polymer-rich phase that indicate viscoelasticity. The polymer-rich phase is torn in some regions keeping slight connections with each other. The indentation of the periphery of these regions resembles the form of cracks in brittle materials like glasses, concretes and rocks. Around these regions are filled by solvent-rich phase. These characteristics of the pattern of fracture phase separation are similar to that of the pattern of continents and oceans of the earth.

On the other hand, continents and oceans of the earth is a peculiar feature different from the surface of other planets. These surface structures of the earth have three characteristics: (1) two characteristic matters of both continental rocks composed mainly of SiO2 and seawater composed mainly of H2O, (2) two regions of continents and oceans and the form of coastlines dividing the two and (3) two characteristic heights of both continents and ocean floors in solid surface of the earth. How do they occur? An interesting point is that all three characteristics are expressed by two factors. This seems to indicate that these three characteristics are three different sides of results of a phenomenon.

An idea that fracture phase separation concerned deeply with the formation of these surface structures of the earth will be presented. A possibility of occurrence of this phenomenon on the surface of the earth will also be discussed.

References

[1] J. D. Gunton, M. San Miguel, and P. Sahni, Phase Transitions and Critical Phenomena (Academic, London, 1983), Vol. 8.
[2] A. Onuki, Phase Transition Dynamics (Cambridge University Press, Cambridge, England, 2002).
[3] H. Tanaka, J. Phys. Condens. Matter, 12, R207 (2000).
[4] T. Kawasaki, Thermodynamics in rocks (Kyoritsu Shuppan, Tokyo, 2006) (in Japanese).
[5] T. Koyama, Phys. Rev. Lett.,102, 065701 (2009).

Keywords: continents, oceans, structuring process, phase separation, fracture, viscoelasticity

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

SIT42-02 Room:105 Time:May 22 11:45-12:00

Pressure transmission in a granular system

KATSURAGI, Hiroaki[1]*

[1]Dept. Earth & Environ., Nagoya Univ.

Usual fluids such as water obey a very simple pressure transmission law, so called the Pascal's principle. Then, how does pressure transmit in the earth? Since the structure of the earth is complex in terms of rheological properties, the answer for this question is not so easy. To understand the fundamental pressure transmission manner in the earth, we have experimentally studied the pressure transmission in a granular column. Although the actual constituents of the earth are much more complex than ideal granular matters, a small granular column has been used, as a first step. Moreover, we restrict ourselves within the pressure, i.e., we do not consider the shear stress components. Glass beads or sand are poured into a small cylindrical container. Then, an intruder is penetrated into it very slowly. The intruder is subjected to the drag force and induces pressure. We have simultaneously measured the drag force and the pressure at the wall. We found that they show nonlinear relations. It is known that the static wall pressure exhibits a saturation tendency in the deep region of the granular column. This tendency is called Janssen effect. The Janssen effect is based only on the static pressure balance. There has not been any pressure transmission law for pressed or plunged granular column, although it should be a fundamental principle to discuss the granular rheology. Only the penetration drag has been measured so far [1,2]. Our result reveals the simple but nontrivial scaling for the pressure transmission in a plunged granular column. More specifically, we obtained the empirical pressure transmission scaling, using the measured data. In the scaling, dimensionless thickness of the granular layer plays an important role. That is a source of nonlinearity of the drag force and pressure transmission. Moreover, we have checked the history dependence of the granular pressure transmission. Influences of various sample preparation methods and cyclic loading tests were experimentally evaluated. As a result, we found the universality and robustness of the nonlinear scaling.

References:

[1] M. B. Stone et al., Phys. Rev. E 70, 041301 (2004).
[2] G. Hill, S. Yeung, and S. A. Koehler, EPL 72, 137 (2005).

Keywords: granular matter

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

SIT42-03 Room:105 Time:May 22 12:00-12:15

Rate dependence of granular friction and its characteristic shear rate

KUWANO, Osamu[1*], ANDO, Ryosuke[2], HATANO, Takahiro[1]

[1]ERI, Univ. of Tokyo, [2]Geological Survey of Japan, AIST

In geoscience, the rate and state-dependent friction law is established, showing negative shear- rate dependence (Scholz, 1998, Nature). In statistical physics, another empirical law holds for much faster deformation than the former, showing positive shear-rate dependence (Jop et al., 2006, Nature). However, it remains unknown how these two distinct laws are connected. In this study, we experimentally show that the crossover from negative to positive shear-rate dependence of friction coefficient occurs at a characteristic shear rate, relating to competition between two different physical processes, namely frictional healing and anelasticity. We determine the expression of the characteristic rate.

Keywords: friction, granular matter, rheology

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

SIT42-04 Room:105 Time:May 22 13:45-14:00

Physical processes of quartz amorphization due to friction

MUTO, Jun[1*], NAKAMURA, Yu[1], NAGAHAMA, Hiroyuki[1], SHIMIZU, Ichiko[2], Takashi Miura[3], Ichiro Arakawa[3]

[1]Dept. Earth Sci., Tohoku Univ., [2]Dept. Earth Planet. Sci., Tokyo Univ., [3]Dept. Phys., Gakushuin Univ.

Solid state amorphization of minerals occurs in indentation and shock experiments, and has been observed in high pressure metamorphic rocks. A production of amorphous material is also reported in experimentally created silicate gouges (Yund et al., 1990), and in San Andreas Fault core samples (Janssen et al., 2010). Rotary-shear friction experiments of quartz rocks imply dynamic weakening at seismic rates (Di Toro et al., 2004). These experiments have suggested that weakening is caused by formation and thixotropic behavior of a silica gel layer which comprises of very fine particles of hydrated amorphous silica on fault gouges (Goldsby & Tullis, 2002; Hayashi & Tsutsumi, 2010). Therefore, physical processes of amorphization are essential to better understand the weakening mechanism of quartz bearing rocks. In this study, we conducted pin- and ball-on-disk friction experiments to investigate details of quartz amorphization (Muto et al, 2007). Disks were made of single crystals of synthetic and Brazilian quartz. The normal load F and sliding velocity V were ranged from 0.01 N to 1 N and from 0.01 m/s to 2.6 m/s, respectively. The friction was conducted using quartz and diamond pins (curvature radii of 0.2 ~ 3 mm) to large displacements (> 1000 m) under controlled atmosphere. We analyzed experimental samples by Raman spectroscopy and Fourier transform infrared spectroscopy FT-IR. Raman spectroscopy (excitation wavelength 532.1 nm) provides lattice vibration modes, and was used to investigate the degree of amorphization of samples. Raman spectra of friction tracks on disks show clear bands at wavenumbers of 126, 204, 356, 394, and 464 cm^{-1}, characteristics of intact a-quartz. Remarkably, in experiments using diamond pins (F = 0.8 N, normal stress calculated by contact area = 293 ~ 440 MPa, V = 0.12 ~ 0.23 m/s), the bands at 128, 204 and 464 cm^{-1} gradually broaden to reveal shoulders on the higher-wavenumber sides of these peaks. Especially, three distinguished peaks at 490, 500 and 515 cm^{-1} and a weak broad peak at 606 cm^{-1} appear sporadically on the track after the slip distance of $>$ 7 m. Moreover, in experiments using quartz pins (F = 1 N, normal stress calculated by contact area = 1 MPa, V = 0.01 ~ 2.6 m/s) after a large displacement ($>$ 78 m), the frequency shifts or appearance of new distinguished peaks similar to those in experiments using diamond pin are found. The bands at 490 and 606 cm^{-1} can be assigned to the symmetric stretching of four-membered SiO_4 ring (D1 band) and planar three-membered SiO_4 ring (D2 band) in amorphous silica, respectively. The peaks at 500 and 515 cm^{-1} correspond to the strongest moganite A1 mode and the strongest coesite A1 mode, which arise from four-membered SiO4 ring structure. These results indicate that quartz change intermediate range structure of SiO_4 network during friction, and four or three-membered SiO_4 rings gradually increase in six-membered quartz. The results of FT-IR analyses on friction tracks showed the presence of a broad peak at 3000 -3600 cm^{-1} only at frictional tracks, which indicates the ?OH symmetric stretching band of molecular H_2O. It shows that hydration of quartz occur only on friction tracks due to friction. The results of Raman spectroscopy and FT-IR as well as flow like structure of wear materials observed by SEM analyses imply that Si-O-Si bridging of strained rings preferentially react with water to form hydrated amorphous silica layer on friction surface. The formation of silica gel layer that occurs locally at real asperity contacts is likely to cause fault weakening observed by pin-on-disk friction experiment.

Keywords: quartz amorphization, friction experiment, fault weakening, raman spectroscopy

SIT42-05 Room:105 Time:May 22 14:00-14:15

Formation process and mechanism of slickenside

ANDO, Jun-ichi[1*], NISHIWAKI, Takafumi[1], OHFUJI, Hiroaki[2], WATANABE, Katsuaki[2], HAYASAKA, Yasutaka[1]

[1]Hiroshima University, [2]Ehime University, [3]The University of Tokyo

Pseudotachylyte is well known rock to be produced by solidification of friction-induced melts during seismic fault slip. Therefore many researches of the pseudotachylyte are conducted to elucidate the microstructural process of seismic faulting. Slickenside is also known as a fault related rock (or structure), which shows smoothed surfaces developed on planes of movement. However the generation process and mechanism of slickenside has not been clarified so far, compared with pseudotachylyte. Now we study the microstructure of slickenside developed on chert block to get some information about generation process of slickenside.

The sample we studied is the chert block which occurs in the Jurassic accretionary complex in eastern Yamaguchi Prefecture, Japan. The complex, chaotic sediment, is composed of allochthonous blocks, mainly of chert, limestone, sandstone and mudstone in the argillaceous matrix, which has undergone very low grade metamorphism under conditions of Prehnite-Pumpellyite facies. The microstructural observations of quartz grains composed of the slickenside with an optical microscopy indicate that 1) they are not deformed by brittle manner even just vicinity of slickenside, 2) they show strong undulose extinction and bulging-recrystallization. TEM observation and EBSD measurement of these quartz grains reveal that 3) the dislocation tangling is typical, 4) they do not show LPO. The most important result is that 5) the amorphous layer having several ten nanometers thickness (~50nm) covers the top surface of slickenside, and 6) the composition of the amorphous layer is mainly Si, Fe and Al. These microstructural observations suggest that 1) the quartz grains were deformed plastically under high stress condition (but the plastic strain is small), 2) the amorphization of quartz grains occurred just near (~50nm) slip surface during faulting, and 3) the origin of Si, Fe and Al in the amorphous layer should be quartz grain itself and clay minerals (e.g. Biotite, Muscovite) contained in the chert. Because the quartz grains are not deformed by brittle manner, the fault slip probably occurred only within the amorphous layer.

We can not presently identify the mechanism of amorphization of quartz grains along slip surface. But we obtain the additional interesting microstructure which is the black veins and clusters in the vicinity of slickenside. These veins and clusters are mainly composed of apatite grains, whose size is ca. 5 to 10 um. Apatite is an important constituent mineral of chert, whose origin is microfossils such as fish scales, bones and so on. Therefore the generation of the black veins can be explained by the melting of the microfossils due to frictional heating of fault. We currently conclude that the slickenside was generated by frictional melting of quartz grains and clay mineral on the slip plane under high stress condition during faulting.

Keywords: slickenside, pseudotachylyte, fault, chert, microstructure

SIT42-06 Room:105 Time:May 22 14:15-14:30

Effect of pore pressure on frictional properties of talc under high normal stress

UEHARA, Shin-ichi[1*], SHIMIZU, Ichiko[2], OKAZAKI, Keishi[3]

[1]Faculty of Science, Toho University, [2]Faculty of Science, The University of Tokyo, [3]Graduate School of Science, Hiroshima University

Pore fluid pressure is a critical parameter governing the overall mechanical strength of plate boundary faults. Recent geophysical observations have suggested the importance of fluids in seismogenic processes. The role of pore fluid pressure at the brittle-plastic transition zone is especially important because this zone, located at the deepest part of the seismogenic zone, supports large shear stress during interseismic periods and therefore releases large energy at seismic events [1]. However, it is not well documented how pore fluid pressure influences frictional properties of faults at the depth, which is mainly due to the difficulty in conducting laboratory friction experiments at high pressures and temperatures that are comparable to the middle to lower crust and mantle. To overcome the limitation of experimental conditions, we used talc as an analogue material, which shows brittle-plastic transitional behaviors at relatively low pressures and temperatures.

Previous works on rock mechanics have suggested that the yield strength of rocks is governed by effective stresses $Se = S - C$ Pp, where S is total stress, Pp is pore fluid pressure, and C is a factor between 0 and 1. The observations in the brittle regime are well accounted for by $C = 1$ [2]. In the fully plastic deformation regime, however, yield stress is not significantly affected by pore pressure and the strength would not be lost even if Pp is equal to C [3]. This is quite different from the brittle deformation at shallow crustal levels. In the brittle-plastic transitional regime, intermediate behaviors between fully brittle and fully plastic deformation are expected. As a first step to quantify the fluid effects, we conducted friction experiments of talc at various Pp and C conditions.

Cylindrical samples of talc, from Gvangjsih, China, 20mm in diameter, were cut at an angle of 30˜{o} to the sample axis. The surfaces were ground with carborundum (#400). A small hole (3mm in diameter) through the center of each talk piece ensured adequate communication of the water between the precut surfaces with the rest of the pore pressure system. The specimen was loaded by a gas-medium triaxial apparatus and sheared under an axial displacement rate of 1 um/s. We used water as a pore fluid. All measurements were performed under conditions of room temperature. Experiments were conducted under the following four types of stress paths: (a) pore pressure was held constant at 0 MPa, and confining pressure was increased from 10 MPa to 110 MPa, and then decreased 10 MPa. (b) Confining pressure was held constant at 110 MPa, and pore pressure was decreased from 100 MPa to 0 MPa, then increased up to 100 MPa. (c) Confining pressure was held constant at 110 MPa, and pore pressure was increased from 0 MPa to 100 MPa. (d) Confining pressure was held constant at 110 MPa, and pore pressure was held at 100 MPa for a hour before axial loading, and then was decreased to 0 MPa and the specimen was sheared.

When we compared the results of shear stress measurements on the stress path (a) with others and derived the constant C in the effective stress law, C was almost equal to 1 through whole stress path in the case of (b). On the other hand, in the case of (c), the results could not be explained when $C = 1$. C of (d) was almost 1, but the peak shear stress were approx. 1.5 times larger than that of (a). These results indicate that C depends on the stress path and that the effective stress law cannot be directly applied to talc under these conditions.

This research is supported by Grant-in-Aid for Scientific Research on Innovative Areas, KAKENHI (21109005), JSPS.

References: [1] C.H. Scholtz, The mechanics of earthquakes and faulting, 2nd ed., 2002. [2] M.S. Paterson and T.-F. Wong, Experimental rock deformation - the brittle field, 2nd ed., 2005. [3] I. Shimizu, Chikyu Monthly, 32, 3 (2010).

Keywords: fault mechanics, brittle-plastic transition, effective stress law, talc, friction experiment

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

SIT42-07 Room:105 Time:May 22 14:30-14:45

Brittle-ductile transitional zone in the Tohoku-oki interplate thrust fault

SHIMIZU, Ichiko[1*]

[1]Department of Science, University of Tokyo

BBefore the 2011 Tohoku earthquake (M9), the interplate coupling in NE Japan, where a cold slab of the Pacific plate is subducting, had been believed to be weak.

A strength envelope is proposed for the plate boundary megathrust that generated the 2011 Tohoku earthquake. It is assumed that the frictional properties of the plate interface is governed by subducting oceanic crust materials and sediments in the accretionary prism. For siliceous oceanic sediments, a dislocation creep flow law wet quartz (Paterson and Luan, 1990) was applied. The hypocenter of the M9 event is located at a depth the deepest part of the island arc crust or the uppermost part of the wedge mantle. The pressure and temperature conditions at this depth corresponds to to the upper limit of the brittle-ductile transitional zone of wet quartz. The rupture of this high-strength zone at mainshock of the 3.11 event is possibly triggered by the collapse of the subducted seamount. The M7-class asperity of the Miyagi-oki earthquake in 1978 is considered as a seamount, which has subducted to the depth of the mantle wedge. The conditionally stable nature of their matrix is understood by the velocity-dependence of viscous/frictional properties in the brittle-ductile transitional zone.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, asperity, rheology, subduction zone, brittle-ductile transition, quartz

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

SIT42-08 Room:105 Time:May 22 14:45-15:00

Rheology of quartz at high-temperature: an example from Rundvagshetta, Antarctica

WALLIS, Simon[1*], INOUE, Yusaku[1]

[1]Department of Earth and Environmental Sciences, Faculty of Environmental Studies, Nagoya University

Quartz is one of the most common minerals in the continental crust and has a relatively low yield strength. The rheological behaviour of this mineral therefore has an important influence on the mechanical behaviour of the crust as a whole. High-temperature crystal plastic deformation is dominantly achieved by dislocation creep and diffusion creep. Dislocation creep is due to the movement and climb of line dislocations within crystals and shows power law stress-strain relationship with the stress exponent usually between 3 and 6. This represents non-Newtonian behaviour where the apparent viscosity depends on the differential stress:high stress domains have a low apparent viscosity. In contrast, diffusion creep is caused by the movement of point defects including vacancies and interstitial atoms and is characterized by a linear relationship between stress and strain representing a Newtonian rheology. The strain rate and temperature also affect the dominant deformation mechanism. To assess the bulk rheology to be used in tectonic studies it is important to assess the affects of these different parameters and to decide the dominant deformation mechanism. Laboratory experiments on quartz shows that that diffusion creep is dominant at relatively high T and small grain sizes (>900K, <1micro m). Plastic deformation at lower T and for larger grain sizes is expected to take place by dislocation creep. However, natural examples of diffusion creep taking place at temperatures of around <500^{o}C in quartz-rich metacherts with a grain size of about 10-20micro m have recently been reported. Such examples suggest that diffusion creep may occur more commonly in natural examples than generally thought. To investigate this possibility, it is important to examine natural examples of deformation at higher temperatures. Two quartz-rich deformed samples collected from the ultra high temperature metamorphic region of Rundvagshetta (RH-112-20A, RH-112-20B) were studied to examine evidence for the dominant deformation mechanism. Both samples show a strong foliation and stretching lineation that are assumed to reflect the X-Y plane and X directions of the finite strain (X>Y>Z).

RH-112-20A has a grain size of 2.9+/-1.2mm, and a strong quartz c-axis preferred orientation with concentrations in three separate directions. The presence of a strong CPO is strong evidence for deformation by dislocation creep. The orientations of the c-axis concentrations are similar to those reported in other high temperature tectonites. RH-112-20B has a grain size of 0.93+/-0.03mm and the c-axes show no clear preferred orientation. The lack of a CPO is not compatible with dislocation creep, but can be readily explained if the deformation is by diffusion creep. Measurements of the Ti content of quartz can be used as an indication of the P-T conditions of deformation. A combination of these results with microstructural observations and the P-T path of this area allows the temperature of deformation to be estimated at around 600~700^{o}C, 4~6kbar. The two samples come from the same outcrop and hence have undergone very similar physical conditions of deformation. However, they show contrasting deformation mechanisms. This can be used to investigate the applicability of published rheological models for quartz. A construction of deformation maps using flow laws derived from mainly from experimental work and those derived mainly from theoretical considerations shows that the results of this study are not compatible with extrapolation of experimental work. In theoretically focused flow laws can explain the observed change of dominant deformation mechanism at strain rates of around 10^{-15} s^{-1}.

This study implies deformation in the Rundvagshetta region was as geologically normal strain rates despite the very high temperatures. This study also implies that diffusion creep may be more widespread than generally thought by extrapolation of deformation experimental work.

Keywords: Quartz, Deformation mechanism, Crystal Preferred Orientation, Diffusion creep, Dislocation creep

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

SIT42-09 Room:105 Time:May 22 15:00-15:15

Phenomenological constitutive law for transient rheological behavior of rocks and minerals

KAWADA, Yusuke[1*], NAGAHAMA, Hiroyuki[2]

[1]Earthquake Research Institute, University of Tokyo, [2]Department of Geoenvironmental Sciences, Graduate School of Science, Tohoku University

Phenomenological constitutive law for transient rheological behavior of rocks and minerals involving the work hardening effect is investigated in terms of viscoelastic theory and fractional rheology. Viscoelastic behavior is often defined in term of the linear response function, and output of stress is the convolution integral of viscoelastic response and strain-input. The response function is called relaxation modulus (a time-dependent modulus of stress to strain) and regarded as a constitutive equation. The convolution integral is identical to a definition function of fractional-order derivative, and stress is then equal to the noninteger-order derivative of strain, which expresses the behavior between Hookean elasticity and Newtonian viscosity. Using the constitutive law, we analyze the experimental data of high-temperature deformation of rocks and minerals such as marble, halite and orthopyroxene. The relaxation modulus of rocks and minerals shows a temporal power-law scaling, and the exponents of the power-law corresponds to the reciprocal of exponent of stress in the flow law. The constitutive equation then represents both transient and steady-state behaviors in the same mathematical structure. The exponents span the range from 0.04 to 0.13 (the stress exponent, from 7.5 to 25.0) for the transient behaviors and from 0.14 to 0.25 (the stress exponent, from 4.1 to 7.1) for the steady-state behaviors. The exponent of stress in the flow law is dependent on the deformation mechanisms such as diffusion and dislocation creeps. For orthopyroxene, the response function involves the strain nonlinear function, a power-law of strain, expressing the effect of work hardening, and can be transformed into the empirical evolution equation of work hardening, stress equals to the power-law of strain and strain-rate.

Keywords: viscoelasticity, fractional calculus, transient behavior, rheology, work hardening

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

SIT42-10 Room:105 Time:May 22 15:30-15:45

Olivine fabric transition during ductile shearing in the uppermost mantle: an example from Oman ophiolite

MICHIBAYASHI, Katsuyoshi[1*]

[1]Institute of Geosciences, Shizuoka Univeristy

A ductile shear zone across the crust-mantle boundary occurs in the Fizh massif, Oman ophiolite. The dunites in the ductile shear zone were classified into coarse granular texture, medium-grained texture, protomylonite, mylonite and ultramylonite. The average grain sizes of olivine decreased toward the shear zone, by which a high strain zone was estimated approximately 15 m. Amount of hydrous minerals (amphibole and chlorite) and spinel Cr# in the mylonites increased toward the gabbro boundary, suggesting that water infiltration into the ductile shear zone could occur from the gabbro boundary. The amphibole porphyroclasts show deformation structures, indicating that the water infiltration and subsequent water-induced metamorphic reactions occurred before or during shearing. P-T estimate and equilibrium temperatures show that the shear zone may be thought to preserve higher deformation temperature (around 900 degree C) for outside of the high strain zone and lower deformation temperatures (around 750 degree C) for inside of the high strain zone. Olivine CPO pattern evolutions indicate the following continuous deformation scenario. First, the deformation by dislocation creep at high temperature condition have formed A-type CPO or E-type CPO (more close to high strain zone). Next, the deformation by dislocation creep at low temperature and wet conditions have formed C-type CPO. Finally, superplastic deformation by grain boundary sliding at low temperature and wet conditions have occurred and formed random CPO.

Keywords: olivine, fabric analysis, ductile deformation, uppermost mantle

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

SIT42-11 Room:105 Time:May 22 15:45-16:00

The uppermost mantle evolution during back-arc spreading: Microstructural and petrological characteristics of Ichinomega

SATSUKAWA, Takako[1*], MICHIBAYASHI, Katsuyoshi[1], GODARD, Marguerite[2], DEMOUCHY, Sylvie[2]

[1]Institute of Geosciences, Shizuoka University, [2]Geosciences Montpellier, Universite Montpellier II

This study deals with the microstructural development in the uppermost mantle associated with melt/fluid rock interactions in peridotites induced by the back-arc spreading. We have studied spinel peridotite xenoliths from Ichinomegata volcano, back-arc region of Japan Islands. The mineral chemistry shows a typical residual trend, depleted in LREE. Their strong Th-U positive anomaly indicates a possible metasomatic origin associated to the subduction of the Pacific plate. Water contents in olivine and pyroxenes were low, which values are in the same range of spinel peridotite xenoliths sampling the continental lithosphere. Olivine CPO are consistent with slip on (010)[100] and {0kl}[100]. Moreover, the peridotite xenoliths have distinct foliations defined by the compositional layers between olivine-rich and pyroxene rich layers as well as lineations defined by mineral shapes of olivine and pyroxene. The angles between the foliations and the olivine slip planes decrease with increasing J-index values (i.e. CPOs strength). Such composite planar relationships could result from shearing in the uppermost mantle, so that shear strains may be estimated by the angles between the foliation and the olivine slip plane in terms of simple shear strain. As a consequence, we argue that a suit of the peridotite xenoliths recorded a rare snapshot of the uppermost mantle flow related to back-arc spreading during the opening of Japan Sea. Moreover, the peridotites xenoliths with higher J-index values (higher shear strain) tend to have lower minimum temperature, indicating that a vertical strain gradient could take place from upper to lower in the uppermost mantle section.

Keywords: olivine, peridotite, fabric, back-arc spreading, upper mantle, mantle dynamics

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

SIT42-12 Room:105 Time:May 22 16:00-16:15

Influence of anisotropic grain growth on development of lattice preferred orientation of forsterite

MIYAZAKI, Tomonori[1*], HIRAGA, Takehiko[1], YOSHIDA, Hidehiro[2]

[1]ERI, [2]NIMS

It is believed that LPO (lattice preferred orientation) of main mineral of mantle is caused by the flow of the Earth's interior, which introduces seismic anisotropy. Generally, it is considered that LPO (and seismic anisotropy) is generated by rock deformation via dislocation creep. In this study, we deformed mineral aggregates of forsterite + diopside by uniaxial compression and tension tests at atmospheric pressure, temperature of 1200 to 1350 degree, and strain rate of 1x10^{-6}- 1x10^{-4} s^{-1}. The stress exponent (n) of 1 was obtained from the analysis of stress-strain relationship showing the aggregates deformation via diffusion creep mechanism. Crystallographic orientation analysis of forsterite grains in the deformed aggregates was conducted using electron backscatter diffractometry. The results show b-axis alignment parallel to the compression axis in the compressed samples and a-axis alignment in the tensiled samples. Long axis of grains in statically annealed samples is often parallel to a-axis of forsterite. We consider that the LPO development under diffusion creep is attributed to the alignment of anisotropic shaped of forsterite to the tensile direction after its anisotropic grain growth.

SIT42-13 Room:105 Time:May 22 16:15-16:30

Deformation experiments of (Mg,Fe)SiO3-Perovskite at the lower mantle conditions

TSUJINO, Noriyoshi[1*], NISHIHARA, Yu[2], SETO, Yusuke[3]

[1]Tokyo Institute of Technology, [2]GRC, Ehime University, [3]Kobe University

The Earth's lower mantle is thought to be consisting of ~77 vol% (Mg,Fe)SiO_3-perovskite (Pv), ~16 vol% ferropericlase and ~8 vol% $CaSiO_3$-perovskite in pyrolite model. In the uppermost and lowermost lower mantle, presence of seismic anisotropy has been reported. The anisotropy may be produced by lattice preferred orientation of the majority phase Pv. Thus, knowledge of slip system of Pv is important for understanding of rheology in the lower mantle.

Shear deformation experiments at the lower mantle conditions were conducted using Kawai-type apparatus triaxtial deformation (KATD) at Tokyo Institute of Technology. Dense aggregates of synthetic (Mg,Fe)SiO_3- orthopyroxene (Mg# = 0.97) was prepared as starting material using Kawai-type multi anvil apparatus at 2 GPa and 1273 K. The shear deformation assembly consists of a Cr_2O_3-doped MgO pressure medium with 7 mm edge length and a cylindrical $LaCrO_3$ furnace. Temperature was estimated from power-temperature relationship in a similar cell assembly. Pt foil is placed at the back of Al_2O_3 piston to assist sideslip of the piston, and Ni foil placed at the center of sample is used as strain marker. Undeformed runs, which were not deliberately deformed by the differential rams, were quenched after phase transitions and relaxation of stress at 25 GPa and 1873 K. In deformation runs, samples were deformed by moving differential rams in the guide blocks each 75 um (total 150 um) during 1 h after the annealing process (for 30 min or 1 h).

Lattice preferred orientation (LPO) of sample was determined using 2D-Xray diffraction patterns of sample. The 2D-Xray diffraction patterns were measured using Imaging plate in the SPring-8 (BL04B1). Analysis of LPO was conducted by the software "ReciPro".

Strains of undeformed and deformed recovered samples measured from rotation of strain marker were ~0.4 +- 1 and ~1.3 +- 1, respectively. Then total stains of samples during deformation process in deformation runs are calculated to be ~0.9 +- 1. Average strain rates of sample are $3 * 10^{-4}$ s^{-1}. LPO of perovskite in shear deformation experiments developed greatly in comparison with that at undeformed experiment. The results suggest that main slip system of Pv at 25 GPa and 1873 K is [100](001).

Keywords: Lower mantle, Deformation experiments, (Mg,Fe)SiO3-Perovskite

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

SIT42-14 Room:105 Time:May 22 16:30-16:45

Si and Mg diffusion in aluminous perovskite at 25 GPa

SHIMOJUKU, Akira[1*], KUBO, Tomoaki[2], KATO, Takumi[2], YOSHINO, Takashi[1], YAMAZAKI, Daisuke[1], NAKAMURA, Tomoki[3], OKAZAKI, Ryuji[2], CHAKRABORTY Sumit[4]

[1]Okayama Univ., [2]Kyushu Univ., [3]Tohoku Univ., [4]Ruhr Univ. Bochum

Silicate perovskite is thought to be a major constituent mineral in the lower mantle. In order to understand rheological properties of the lower mantle, it is essential to determine the diffusion rates of the slowest diffusing species which control high-temperature creep processes involving diffusion creep and climb-controlled dislocation creep. It has been reported that Si diffusion rates in $MgSiO_3$ perovskite and Mg-Fe interdiffusion rates in $(Mg,Fe)SiO_3$ perovskite are almost comparable (Yamazaki et al., 2000; Holzapfel et al. 2005). In addition, O diffusion rates in $MgSiO_3$ perovskite are faster than Si diffusion and Mg-Fe interdiffusion rates (Dobson et al. 2005). Thus, Si or Mg is a candidate for the rate-controlling species in perovskite. In this study, we determined Si and Mg diffusion rates simultaneously in $(Mg,Fe)(Si,Al)O_3$ perovskite by utilizing ^{25}Mg and ^{29}Si enriched $(Mg,Fe)(Si,Al)O_3$ thin film as diffusion source. Based on the result, we discuss the rate-controlling species in $(Mg,Fe)(Si,Al)O_3$ perovskite and rheological properties in the lower mantle.

High-temperature and high-pressure experiments were performed using a Kawai-type high-pressure apparatus. Starting material of polycrystalline $(Mg,Fe)(Si,Al)O_3$ perovskite was synthesized from San Carols orthopyroxene powder at 25 GPa and 1973K. Surface of the polycrystalline perovskite was polished and then coated with ^{25}Mg and ^{29}Si enriched $(Mg,Fe)(Si,Al)O_3$ thin film using pulsed laser deposition (Dohmen et al. 2002). Diffusion experiments were conducted at 25 GPa and 1773-2073K. After the diffusion experiments, concentration profiles of ^{25}Mg and ^{29}Si were obtained by the depth-profiling mode using secondary ion mass spectrometry.

It was found that Si and Mg diffusion rates in $(Mg,Fe)(Si,Al)O_3$ perovskite are almost comparable under our experimental conditions. Thus, Si and Mg are likely to be rate-controlling species in $(Mg,Fe)(Si,Al)O_3$ perovskite. Si and Mg diffusion rates in $(Mg,Fe)(Si,Al)O_3$ perovskite could be slightly slower than previously reported Si diffusion rates in $MgSiO_3$ perovskite.

Keywords: perovskite, lower mantle, diffusion, rheology

SIT42-15 Room:105 Time:May 22 16:45-17:00

Predictions of the shear response of Fe-bearing MgSiO3 post-perovskite at lowermost mantle pressures

METSUE, Arnaud[1*], TSUCHIYA, Taku[1]

[1]Geodynamics Research Center Ehime University

Observation of seismic data put in forth evidence of a spatial anisotropy in the seismic wave velocities in the D"layer, the lowermost part of the mantle. (Mg,Fe)SiO_3 post-perovskite (PPv) is thought to be the most abundant phase in this part of the mantle.This mineral exhibits a strong elastic anisotropy and may contribute significantly to the seismic anisotropy in the D" layer. However, the seismic anisotropy cannot be expressed at the rock scale if the orientations of the grains are distributed randomly. Consequently, the formation of lattice preferred orientations with an anisotropic mechanism of plasticity, such as dislocation creep, can cause the seismic anisotropy in the D" layer. Some experiments have been done on the plasticity of pure and Fe-bearing $MgSiO_3$ post-perovskite and lead to textures of deformation dominated by the (100) and (110) slip planes (Merkel et al., 2007) or by the (001) slip plane (Miyagi et al., 2010). On the other hand, theoretical calculations on the dislocations mobility on pure $MgSiO_3$ (Carrez et al., 2007; Metsue et al., 2009) suggested a texture dominated by the (010) slip plane. A first step to understanding the mechanisms of plasticity and, therefore, the shear wave splitting occurring in the deep Earth is to test the response of the PPv phase to a plastic shear in a geophysical relevant composition.

In this study, we present new results from first-principles calculations on the shear response of pure and ferrous Fe-bearing $MgSiO_3$ PPv. The originality of this work is the use of internally consistent LSDA+U formalism to accurately describe the local interactions between the d-states of Fe. About 8% of Fe^{2+} is incorporated in the high spin and low spin states, as a Mg substitution defect, to test if a spin transition could be induced by shearing mechanisms, even several studies report that Fe^{2+} is in the high spin in the D" layer pressure range (Stackhouse et al., 2006; Metsue and Tsuchiya, 2011). The response of the PPv to a plastic shear is investigated at 120 GPa through the calculations of the Generalized Stacking Faults (GSF) energy in pure and Fe-bearing systems for 10 potential $<$uvw$>$$\{hkl\}$ slip systems, since these latter are not well constrained for the PPv phase. The GSF energies are obtained by shearing homogeneously half of an infinite crystal over the other half for every slip system and give the value of the ideal shear stress (ISS), which can be defined as the theoretical elastic limit of the crystal. The [100](001) slip system in pure and Fe-bearing phases exhibits the lowest ISS and may play an important role in the plastic deformation of the PPv phase. The activation of this slip system is compatible with the observed shear wave splitting $V_{SH}>V_{SV}$. We show that incorporation of Fe decreases the GSF energy and the ISS of all slip systems. In particular, the decreasing of the energy of stable stacking faults indicates that Fe tends to be adsorbed in the stacking faults, which increases the width of the defect and could have some implications on deformation mechanisms. Finally, we discuss the plastic anisotropy of pure and Fe-bearing phases from the values of the ISS and the orientation of applied tensile stress. Our results suggest that the incorporation of ferrous Fe in the PPv phase has a limited effect on its plastic anisotropy, and, therefore, on the deformation texture.

Keywords: MgSiO3 post-perovskite, stacking faults, deformation mechanisms