Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

PPS025-P01 Room:Convention Hall Time:May 23 10:30-13:00

Strength contrast between plagioclase and olivine and rheological structure of the terrestrial planets

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It is thought that plate tectonics is a product of the localized brittle failure in the lithosphere and viscous flow in the asthenosphere, and strength profile is a key to understand tectonics of terrestrial planet (Burgmann and Dresen, 2008). Physical properties, such as temperature and pressure and stress, and the chemical compositional layering between crust and mantle result in a strong rheological layering in the planet interior. It has been estimated by previous experiments that the brittle-ductile transition occurs in the planet interior and deformation mechanisms can be changed with increasing depth. In the present study, we evaluate rheological variation in the crust-mantle transition based on new series of deformation experiments, and discuss why plate tectonics doesn't exist in the other terrestrial planets except the Earth.

In case of the earth, two different models on the strength profile in the continental crust have been proposed. The first is the "jelly sandwich" model that had been embraced for the past two decades. This model is that a weak middle and lower crust are sandwiched between strong upper crust and strong mantle lithosphere just like a jelly sandwich (e.g., Chen and Molnar, 1983). The second one is the "creme brullee" model, in which the upper mantle is significantly weak, and consequently region for viscous deformation continues into the mantle depth (Jackson, 2002). These two models of strength profile are given by extrapolating frictional strength and viscous flow law of each material to temperature and pressure corresponding to interior of the Earth.

In this study, we performed experiment to directly determine the relative strength between plagioclase and olivine without any extrapolating of flow law; the crustal materials consist predominantly of plagioclase that largely control deformation of the crust, whereas deformation of the upper mantle is largely controlled by olivine. These samples are together sandwiched between alumina pistons in simple shear geometry and we used the hot-pressed samples and performed deformation experiments using solid-medium deformation apparatus. The experimental conditions were ranging 1GPa and 400- 800 degrees, corresponding conditions to Moho of the Earth under water-rich conditions. The experimental results show that plagioclase and olivine are expected to show almost no difference in strength at temperatures of the continental Moho of the Earth, ca. 500- 600 degrees. Moreover, we found the change of relative strength contrast between plagioclase and olivine at low temperature; plagioclase becomes stronger than olivine at 400 degrees. Plagioclase is generally believed to be weaker than olivine (Brace and Kohlstedt, 1980). However, our experimental results indicate that olivine can be weaker than plagioclase (Azuma et al., 2010). In materials with a relatively strong chemical bonding such as silicates, Peierls mechanism becomes dominant at low temperatures (Tsenn and Carter, 1987). Based on deformation mechanism map, deformation of olivine could be controlled by this type of flow mechanism under our low temperature experiments. Thereby, the strength contrast between plagioclase and olivine are reversed. Consequently, our result of this experiments supported "creme brullee" model (e.g., Jackson, 2002), as continental strength profile and showed us that flow law can not be applied for low temperature conditions.

In the future, we are going to conduct experiments under dry condition to evaluate strength profile of terrestrial planets like dry Venus. Venus has been thought as a similar planet to the Earth because of closet to the Earth in mass, density, size (Taylor and McLennan, 2008). However, Venus has extraordinary crustal features and plate tectonics does not seem to work. This can be a result of different rheological property on the Venus. We are going to report our new result of deformation experiments under dry conditions, and their tectonic difference.

Keywords: strength profile, terrestrial planet, rheology, olivine, plagioclase

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PPS025-P02 Room:Convention Hall Time:May 23 10:30-13:00

Petrographic observations of hibonite-bearing inclusions from Murchison using SEM-EDS.

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Hibonite is one of the minerals which condense from the solar nebula at the highest temperature ranges. Therefore, hibonite-bearing refractory inclusions may have important information in the earliest history of the solar system formation. Hibonite-bearing inclusions found in Murchison (CM2) meteorite are morphologically classified into several groups such as SHIBs (Spinel-HIBonite inclusions), PLACs (PLAty Crystals), BAGs (Blue AGgregates) (Ireland, 1988), and each group has its own significant isotopic characteristics (Ireland, 1988; Liu et al., 2009). PLACs and BAGs show large isotopic anomalies in Ca and Ti, and to less extent in Mg (delta-25Mg), but their inferred initial 26Al/27Al ratios are low or even negative. On the contrary, SHIBs show almost canonical 26Al/27Al ratios (˜4.5x10E-5) but almost no anomalies in Ca and Ti. These characteristics may reflect the presence of distinct isotopic reservoirs and their mixing processes in the early solar system.

In order to better understand these isotopically distinct reservoirs and their mixing processes, we recovered about ˜30 of hibonite-bearing inclusions from the Murchison (CM2) meteorite. About 10 grams of the Murchison chips were disaggregated using the freeze-thaw method. Then we applied size separations, magnetic separations, and density separations (using methylene iodide: ˜3.3 g/cm3). Candidates of hibonite-bearing inclusions (containing blue or light blue minerals) were hand-picked under an optical microscope from non-magnetic, dense fractions of the separated grains. After preliminary examinations of these grains with SEM-EDS, they were fixed on a glass slide with epoxy and were examined using an optical microscope. Finally the glass slide was polished so that surfaces of most of the grains were exposed together. They were petrographycally analyzed with SEM-EDS. In the present study, we have recovered 21 SHIBs, 3 PLACs, 2 BAGs, 3 grains either SHIBs or BAGs, and 2 unidentified ones. In addition, some hibonite-free inclusions, especially spinel-rich ones, and a few large spinel grains were also recovered. In the present report, we will show petrographic characteristics of these hibonite-bearing grains in detail and compare them with those of previously reported grains. We will make isotopic analyses (e.g., Al-Mg isotope analysis) on these grains in near future.

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Keywords: hibonite, refractory inclusion, isotopic anomaly, Al-Mg chronology, Murchison meteorite

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PPS025-P03 Room:Convention Hall Time:May 23 10:30-13:00

Evolution of infrared spectra in crystallization by heating of amorphous magnesium silicates

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Comparison between infrared spectra of astronomical observations and laboratory measurements revealed that circumstellar and interstellar dust has been investigated, crystalline silicates (e.g., olivine ($(Mg;Fe)_2SiO_4$), and pyroxene ($(Mg;Fe)_2SiO_3$) exist in circumstellar environments around oxygen rich young and evolved stars(e.g., Waelkens et al. 1996; Waters et al. 1996). It is possible that the crystalline silicates are formed by crystallization by heating from amorphous silicate in the circumstellar environments. For example, a precursor material for the crystalline silicates in circumstellar regions around young stars is considered to be interstellar amorphous silicate dust, which is believed almost completely amorphous (Kemper et al. 2004). And, in circumstellar regions around evolved stars, it is considered that amorphous silicates condense from out flow gas and are partially crystallized by heating. In order to reveal the conditions of circumstellar environments, it is important to understand crystallization process of the silicates. In recent years, distributions of minerals and crystallinity in protoplanetary disks around the T Tauri stars are estimated by comparison between the 10 um infrared emission arising from inner warm regions in the protoplanetary disks and the 20 um emission arising from more distant regions (e.g. Olofsson et al., 2010). In order to discuss the properties of the circumstellar dust, it is necessary to investigate evolution of infrared spectra at each wavelength region particularly.

As starting materials of heating experiments, amorphous silicates with the enstatite composition (Mg/Si =1) and the forsterite composition (Mg/Si=2) were synthesized using the radio frequency thermal plasma processing at Nisshin Engineering Co. Ltd. The amorphous samples were heated at various temperatures for various durations, and clinoenstatite ($MgSiO_3$) and forsterite (Mg_2SiO_4) were crystallized from the starting amorphous materials in the Mg/Si ratio of 1 and 2, respectively. By analyses of infrared absorption spectroscopy and x-ray powder diffraction of the heated samples, the degrees of crystallization were estimated. Then, we investigated the relation between the degree of crystallization and change of the infrared spectral features at each wavelength regions. At results, the infrared spectral features of the samples with forsterite component at around 20um change at a more rapid rate than those at around 10um in the crystallization process. On the other hands, the infrared spectra of the samples with enstatite composition have no such trend. By comparing between the results and astronomical observation of T Tauri stars, we discuss crystallization from amorphous silicate in circumstellar environments.

Keywords: infrared, dust, crystallization, amorphous silicate

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PPS025-P04 Room:Convention Hall Time:May 23 10:30-13:00

Density Estimation from Impact Track Morphology in Silica Aerogel: Application to Dusts of Comet 81P/Wild 2

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Cometary dust particles of Wild2 have been successfully collected and returned in Stardust Mission [Brownlee et al. (2006) Science 314, 1711-1726]. Hypervelocity capture (6.1 km/s) of those particles mandated various degrees of heating, fragmentation and evaporation of the projectiles during their capture process in silica aerogel [Zolensky et al. (2006) Science 314, 1735-1739]. Nevertheless, an impact track formed by each particle can be an indicator of its original properties [Horz et al. (2006) Science 314, 1716-1719]. Particle size dependence of track properties has been studied in several papers [Burchell et al. (2009) Planet. Space. Sci. 57, 58-70; Horz et al. (2009) Meteo. Planet. Sci.44, 1243-1264] and impact tracks in Stardust aerogel formed by several sized soda lime glass beads of different sizes were used for calibration of Wild2 dust size distribution [Burchell et al. (2008) Meteo. Planet. Sci. 43, 23-40]. In the work of Iida et al. [(2010) Meteo. Planet. Sci. 45, 1302-1319], three-dimensional structures of Stardust impact tracks were analyzed and Wild2 dust density was estimated based on their track formation model. However, density dependence of track properties has not been investigated precisely yet. Therefore, we carried out impact experiments into silica aerogel (20 mg/cc) using projectiles of several densities in order to clarify the relation between projectile properties (size and density) and track morphology.The experiments were carried out with a two-stage light-gas gun at ISAS, JAXA. The projectiles we used were bubble glass (0.5 g/cc) polystyrene (1.06 g/cc), sintered silica (˜1.3 g/cc), soda lime glass (2.5 g/cc), alumina (3.9 g/cc), and copper (8.9 g/cc). All the projectiles except for sintered silica were spherical in shape. Size of these impactors ranged from ˜0.03 to ˜0.1 mm in diameter and they were fired into 20 mg/cc silica aerogel at ˜6 km/s to simulate the capture of Wild2 dust. All the individual impact tracks were observed with an optical microscope. The results show that track length (Lt) depends on projectile size and density while maximum track width (Dm) mainly depends only on projectile size. Therefore, aspect ratio (Lt/Dm) does not change with projectile size, but only with projectile density. This means that when we estimate projectile properties from a track shape, Lt/Dm is a good indicator of projectile density.This can be applicable for Stardust impact tracks; densities of Wild2 dust particles are estimated by examining the relation between projectile density and aspect ratio of a track in Stardust aerogels.

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PPS025-P05 Room:Convention Hall Time:May 23 10:30-13:00

Planetesimal Bow Shocks: A Heating Mechanism for Chondrule Formation II

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We simulated the bow shock excited around the planetesimal moving with supersonic velocity relative to the nebula gas, and examined whether dust grains are heated enough to melt and become chondrules.

Chondrules are millimeter sized spherical silicate particles that constitute up to 80% of chondrite in volume. Although they must have experienced heating and then melting to account for their spherical shapes and their textures, the heating source remains to be solved. Some kind of heating events must have happened in their formation age, about 4.56 billion years ago, because the temperature of the nebula gas was a few hundred kelvins at that time, which is too low to melt dust grains.

The shock wave heating model is the one of the ideas for the heating mechanism, which explains the observational constraints for chondrule formation properly. However, no reliable sources of shocks are still confirmed.

In this study, we focused on the planetesimal bow shock as the source of the shock. The idea of the bow shock excited by the supersonic planetesimal with respect to the nebula gas is offered by Hood (1998) and Weidenschilling et al. (1998) and the only numerical study so far for the planetesimal bow shock is conducted by Ciesla et al. (2004). They simulated the bow shocks in two-dimensional Cartesian coordinate system, regarding the planetesimal as a cylinder, and calculated the thermal history of a dust grain in one dimensional shock model by using the shock properties given by their simulation.

In order to analyze quantitatively the possibility of the planetesimal bow shock for chondrule formation, we conducted hydrodynamic simulations in axisymmetric spherical coordinate system, regarding a planetesimal as a sphere, and calculated the thermal history of a dust grain along its trajectory with various impact parameters. The flow around the supersonic planetesimal was simulated by using the ZEUS-2D code (Stones & Norman 1992) with various velocities, densities and planetesimal sizes.

As a result, we restricted the possible chondrule formation region in the gas density - gas relative velocity parameter space. In addition, we found the possible impact parameter range in which dust grains could melt. By using these results, we estimated the total amount of chondrules that could be made by planetesimal bow shocks. About one earth mass of dust grains could be heated to melting point by bow shocks under the scenario that supersonic planetesimals with high eccentricity was excited by Jovian resonances (Marzari & Weidenschilling 2002). We concluded that the planetesimal bow shocks are still possible chondrule formation site.

Keywords: planetesimal, shock wave, chondrule

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PPS025-P06 Room:Convention Hall Time:May 23 10:30-13:00

UV-CPL irradiation experiment of lactic acid: photostability, racemization, and asymmetric decomposition

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Introduction: Since L-amino acid enantiomeric excesses (e.e. = 0.4 - 9.1%) were found in carbonaceous chondrites (Cronin and Pizzarello, 1997), the study on the origin of homochilarity in space has been developing. In particular, detection of circular polarized light (CPL) in the star forming regions (Bailey, 1998; Fukue, 2010) has provided an opportunity for a number of the UV-CPL irradiation of amino acids or its precursors to detect e.e. experimentally (e.g., Takano et al. 2007; Takahashi et al. 2009). However, the production mechanism of molecular homochilarity and a possibility of homochirality production of the other extraterrestrial organic molecules than amino acids have been infrequently investigated. Recently, e.e. of L-lactic acid (3 - 12%) from carbonaceous chondrites have been newly reported (Pizzarello, 2010). We have conducted the UV-CPL irradiation experiment of lactic acid in aqueous solution, as a starting study to understand the homochilarity of lactic acid in space.

Experimental: 0.02 mM DL lactic acid (D:L = 1:1) in aqueous solution, 0.01 mM L-lactic acid in aqueous solution and 0.01 mM D-lactic acid in aqueous solution were prepared. Four ml of in quartz cell was irradiated with UV-CPL. Left and right UV-CPL at 215nm from a free electron laser produced at BL5U, UVSOR. Power of irradiation was 10-200mWh. After irradiation, 100 micro L of the sample solution was analyzed by High Performance Liquid Chromatography (HPLC) with UV detector (254 nm). For the optical resolution of D- and L- lactic acids, ligand exchange chiral HPLC column (D-penicillamine ODS silica, SUMICHIRAL, OA-5000) was used. 1 mM copper sulfate aqueous solution was used for the mobile phase. Identification and quantification of compounds were made by comparison of peak retention times on HPLC chromatograms and peak areas, respectively, with those of standard compounds.

Results and discussion: For every sample, the concentrations of lactic acid exponentially decreased with increasing irradiation power, indicating the progress of photodecomposition of lactic acid. After 100 mW irradiation, the concentration of lactic acid decreased to less than 1% of the initial concentration. There was no difference in the concentration change between left and right CPL. Irradiation of D-lactic acid yielded L-lactic acid, and the ratio of D to L came close to 1:1 with increasing irradiation power. The opposite result was obtained by irradiation of L-lactic acid. There was no difference in the ratio change between left and right CPL. These results are probably reflected by deprotonation and racemization of a lactic acid molecule. A small e.e. was detected after irradiation of DL-lactic acid in this study. However, at this stage, it is difficult to determine whether the value is a true e.e. or analytical error. To be summarized, photodecomposition, racemization, and asymmetric decomposition of lactic acid occur simultaneously during UV-CPL irradization, which gives a final e.e., if any. If the obtained e.e. in this study is a true value, CPL would have likely played a role of inducing the initial small asymmetry of lactic acid, which can be consistent with the past studies about amino acids (e.g., Flores et al. 1977).

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Keywords: homochilarity, circular polarized light, lactic acid, photostability, racemization, asymmetric decomposition