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

SIT04-P01 Room:Convention Hall Time:May 27 18:15-19:30

Iron concentration around dislocation in naturally deformed olivine

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The concentration of specific atom on dislocation core can be caused by pipe diffusion and Cottrell atmosphere. Both the phenomena are important for the property of materials including rocks and minerals. As an example of the former, Fe concentration has been reported in the naturally deformed olivine (e.g. Plumper et al., 2011). Pipe diffusion is important for atomic migration during various reactions in the Earth, such as metasomatism and serpentinization. On the other hand, Kitamura et al. (1986) and Ando et al. (2001) have reported Fe concentration in the mantle-derived olivine caused by Cottrell atmosphere. The Cottrell atmosphere strongly influences plasticity of materials in the low strain rate regime. Therefore, the discovery of Cottrell atmosphere from the mantle-derived olivine indicates that the effect on the plasticity of olivine is important to understand mantle dynamics under very low strain rate condition. However, the possibility of pipe diffusion cannnot be neglected completely to explain the observations of Kitamura et al. (1986) and Ando et al. (2001). Here, we carried out more detailed chemical composition analysis of the mantle-derived olivine to assess whether the Fe concentration on dislocation core is a common phenomenon, and to clarify the exact mechanism of the Fe concentration, *i.e.* Cottrell atmosphere or not.

We studied two types of peridotites, which are xenolith-type in basalt (Takashima, Megata, Kurose and Salt Lake) and alpine-type (Uenzaru and Horoman) by using EPMA and ATEM techniques. EPMA and ATEM analyses show Fe concentration at dislocations in all the studied samples, which suggests that it is a common phenomenon in mantle peridotites. Fe-enrichment at the rim of olivine grains and other major element concentration on dislocations, which are general features of pipe diffusion, cannot be observed. Therefore, the mechanism of Fe concentration on dislocation core in olivine grains is possibly derived by Cottrell atmosphere, not pipe diffusion.

Ando et al. (2001) Nature, 414, 893; Kitamura et al. (1986) Proc. Japan Acad., 62, 149; Plumper et al. (2011), Contributions to Mineralogy and Petrology, 163, 701.

Keywords: Cottrell atmosphere, olivine, dislocation

SIT04-P02 Room:Convention Hall Time:May 27 18:15-19:30

Fabrication of textured Fe-free and Fe-bearing olivine aggregates using colloidal processing under high magnetic field

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Crystallographic preferred orientation (CPO) of minerals is considered to be widely produced in the Earth's interior. Due to the presence of anisotropic physical properties such as elasticity, plasticity, electron conductivity and etc... of single crystal minerals, their bulk rock properties can significantly be affected by the presence of CPO. To measure CPO effect on the bulk rock properties by room experiments, it is required to prepare polycrystalline materials with ideally controlled CPO.

Magnetic field was applied to fine-grained (~120 nm) equigranular Fe-free and Fe-bearing olivine particles, which were dispersed in ethanol (solvent) with dispersant (polyethyleneimin). We expected the particles to align with respect to magnetic direction due to their magnetic anisotropy. The aligned particles were gradually deposited on a solid-liquid separation filter during ethanol drainage. The directions of magnetic field and particle deposition were parallel. The dried particles were then densified isostatically at 200 MPa for 10 min and sintered using the alumina tube furnace with vacuum pump.

Highly dense (density of $\geqq$ 99%) and fine grained (~1 μm) samples with a-axis alignment for Fe-free and c-axis alignment for Fe-bearing olivine to the magnetic direction were obtained. Such synthesized aggregates will allow us to measure CPO effect on the physical properties of olivine aggregate.

Keywords: crystallographic orientation, olivine

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SIT04-P03 Room:Convention Hall Time:May 27 18:15-19:30

High pressure and high temperature deformation on lawsonite: Implication for low velocity layers in subduction zones

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Low-velocity layers (LVLs) located in the upper portions of subducting slabs, are regions of lower seismic wave velocities than those in the surrounding mantles. LVLs apparently persist to depths of 100-250 km [1,2]. Hydrated mafic rocks provide a plausible explanation for the origin of LVLs and trench-parallel/normal S-wave fast polarization. Lawsonite ($CaAl_2Si_2O_7(OH)_2 \cdot H_2O$), which is stable at depths greater than serpentine minerals, is considered to be one of the prime candidate hydrous minerals that can be present deep in the cold subduction zones [3,4]. Single crystals of lawsonite have a high elastic anisotropy, suggesting that the development of the crystallographic preferred orientations (CPOs) when it deformed might strongly affect the seismic properties [5].

This study reports deformation experiments on lawsonite aggregates that were conducted at high pressure and high temperature corresponding to 150 km depth in the subduction zone, to investigate the development of CPOs and the seismic properties of lawsonite. Experiments were performed using a multi-anvil apparatus with six independently acting rams installed at Bayerisches Geoinstitut, Bayreuth University. The starting material consisted of fine-grained (<25 μm) natural lawsonite powder, which was loaded in a Pt capsule and annealed for >20 h at 5 GPa, between 500 and 800 ℃. The samples were then deformed using pure or simple shear geometry at strain rates of 10^{-4}-10^{-6} s^{-1} and a finite strain of 0.3-1.0. Recovered samples were analyzed using a scanning electron microscope (SEM) coupled with an electron backscatter diffraction (EBSD) detector and a transmission electron microscope (TEM).

The deformed lawsonite aggregates display a porphyroclastic texture characterized by a bimodal grain size distribution. The microstructures with dynamically recrystallized grains imply the evidence for the deformation through grain-boundary sliding accommodated by diffusion creep due to the grain size reduction, whereas the porphyroclasts (20-50 μm in size) have undulose extinction, deformation lamellae, irregular grain boundaries, and many sub-grain boundaries. The porphyroclasts also display a CPO characterized by a girdle distribution of the [100] axes in the shear plane with a maximum concentration close to the shear direction. The [010] axes form a maximum subnormal to the shear plane. The microstructures and the occurrence of a CPO show that the dominant deformation mechanism for the porphyroclasts is dislocation creep. These results of CPOs diverge from those of previous studies of natural lawsonite rocks [e.g., 6], which might result from differences in experimental or natural conditions. TEM images show a variety of dislocations with a high density of {110} wedge-shaped mechanical twins. Lawsonite seems to have numerous potential slip systems with [100](010) appearing to be the most dominant. The calculated anisotropies of the seismic wave velocities (AVp = 2% and AVs = 6%, respectively) are characterized by the fast propagation of P-wave is oriented subnormal to [010] maxima of the deformed lawsonite aggregates and the polarization of the fastest S-wave is perpendicular to the foliation. This indicates that lawsonite can contribute to the LVL observations and trench-normal S-wave splitting observed at depth of >150 km in the cold subducting slab of northeastern Japan [7].

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Keywords: lawsonite, deformation, crystallographic preferred orientation, high pressure, subduction zone, low velocity layer

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SIT04-P04 Room:Convention Hall Time:May 27 18:15-19:30

Calibration for stress measurement of Griggs-type high temperature and high pressure deformation apparatus

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1. Introduction

It is necessary to perform deformation experiments in appropriate temperature and pressure conditions equivalent to the inside of the earth to characterize rheological properties of rocks. There are several types of deformation apparatus using different confining media such as gases, liquids or weak solids (e.g., Tullis and Tullis, 1986). Liquid medium apparatus has a disadvantage that it cannot be used for temperatures above 500 ℃ because of prevention from alteration of oil. Gas medium apparatus has the most accurate stress measurements because of using internal force gauge. However, experiments are typically restricted to confining pressures less than 300 MPa. Solid medium apparatus can provide us high pressure (~2.0 GPa) easily and safely. However, its stress measurements accuracy is low mainly because of frictions between the confining media and samples or loading piston (e.g., Tullis and Tullis, 1986).

Recently, comparison of stress measurements of Griggs-type apparatus with solid salt assemblies (SSA) and gas apparatus provide a calibration law for Griggs apparatus with SSA (Holyoke and Kronenberg, 2010). This calibration law allowed steady-state stresses to be measured accurately to within $\pm$30 MPa. However, it was not able to reproduce elastic, transient and post-yield behaviors because the calibration law was obtained from the comparison of stresses measured only at 5% strain. Moreover, since the calibration was carried out in low confining pressure, influence of confining pressure to stress measurements of Griggs apparatus is not clear. Calibration law for Griggs apparatus in various deformation conditions are required for revealing detailed rheological properties of the lower crust and upper most mantle rocks. In this study, we derived a calibration law for stress measurements of Griggs apparatus by the master curve method.

2. Axial compression experiments and construction of master curves

Axial compression experiments were performed on high-purity metals (nickels and molybdenums) using a Griggs apparatus with SSA. Experiments were performed in several conditions (confining pressures: ~300 MPa, ~1200 MPa, ~1500 MPa, temperatures: 600 ℃, 700 ℃, 800 ℃, strain rates: 2×10^{-4} /s, 2×10^{-5} /s, 2×10^{-6} /s). Measured stresses were consistent with results of the former study (Holyoke and Kronenberg, 2010) within $\pm$30 MPa under the identical confining pressure of ~300 MPa. Measured stresses tended to become higher with confining pressures. Logarithms of steady-state stresses almost linearly increase with confining pressures in the range of this study. Obtained mechanical data were analyzed based on high temperature viscoelastic constitutive law proposed by Shimamoto (1987). Then, a master curve which normalized temperatures strains and confining pressures was constructed. A master curve from mechanical data (Holyoke and Kronenberg, 2010) using gas apparatus was also constructed.

3. Derivation and application of a calibration law

Master curves were constructed from identical materials between Griggs and gas apparatuses under normalized temperatures, strains, and confining pressures. Therefore, it is considered that differences between both master curves are derived from distinction of various rheology components of two apparatuses. A calibration law for Griggs apparatus was derived from differences in both master curves. Applying the calibration law to stress measurements of metals using Griggs apparatus with SSA, it became possible to reproduce gas apparatus's stresses not only at steady-state but also at elastic, transient and post-yield behaviors within an error of $\pm$30 MPa. Moreover, calibration can be extended to higher confining pressure up to 1500 MPa. When the calibration law was also applied to the stresses of carbonate rock, although an error was at most ~70 MPa, elastic to post-yield behaviors could be reproduced.

Keywords: rheology, rock deformation experiment, solid medium deformation apparatus

SIT04-P05 Room:Convention Hall Time:May 27 18:15-19:30

Weak-beam dark-field TEM characterization of dislocations in wadsleyite deformed in simple shear at 18 GPa and 1800 K

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Characterization of dislocations in textured wadsleyite is important in understanding crystallographic preferred orientation (CPO) of wadsleyite and in turn seismic anisotropy at the mantle transition zone. A [001](010)-textured wadsleyite was recently obtained by deformation experiments on wadsleyite in simple shear at 15-18 GPa and 1770-1870 K with a deformation-DIA apparatus (Kawazoe et al., 2013; Ohuchi et al., 2014). However, [001] dislocations have been rarely reported in wadsleyite in the literature (cf. Cordier, 2002). To reconcile the wadsleyite CPO pattern with its slip systems, dislocation microstructures of the [001](010)-textured wadsleyite have been investigated in weak-beam dark-field imaging in a transmission electron microscope. 1/2<101>partial dislocations on the (010) plane are characterized with [100] dislocations on the (001) plane and 1/2<111>dislocations forming {011} slip bands. The former partial dislocations are extended on the (010) stacking fault as a glide configuration (i.e. Shockley-type stacking faults with 1/2<101>displacement vector). The [001] slip on the (010) plane occurs by glide of the dissociated dislocations on a sub-oxygen close packing plane, which can play an important role to generate the crystallographic preferred orientation patterns reported in water-poor deformation conditions (e.g., Kawazoe et al. 2013, Ohuchi et al. 2014).

Keywords: wadsleyite, crystallographic preferred orientation, dislocation, seismic anisotropy, transmission electron microscopy, deformation-DIA apparatus