学位論文要旨

Mechanism of iron concentration around dislocation core in deformed olivine:
Implications for the dynamics of the upper mantle
（変形したカンラン石中の転位芯への鉄の濃集機構：
上部マントルのダイナミクスに与える影響）

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Olivine ((Mg, Fe)$_2$SiO$_4$) is one of the main constituent minerals in the upper mantle and indispensable to understand the dynamics of the upper mantle. The one of the most important effects on the plasticity of olivine is “ultra-low strain rate effect”, which is attributed by the slow deformation rate at the actual upper mantle condition. The Cottrell atmosphere is the phenomenon that the solute atoms concentrate around dislocation core. The Cottrell atmosphere inhibits the dislocation motion and cannot be formed at higher strain rate condition. The deformation at the different strain rate conditions, therefore, makes the difference of the material plasticity due to the presence or absence of the Cottrell atmosphere. In the present study, I conducted the following series of researches in order to investigate whether the Cottrell atmosphere can occur in the upper mantle or not: (1) to assess whether Fe concentration around dislocation core is a common phenomenon in naturally deformed olivine; (2) to clarify the deformation conditions of the mantle-derived deformed olivine showing the Fe concentration around the dislocation core, by characterization of microstructures; (3) to reproduce the Fe concentration around the dislocation core by annealing experiment; (4) to evaluate the effect of ultra-low strain rate on the plasticity of olivine. The present research is the first comprehensive study of the Cottrell atmosphere in olivine, based on the microstructural observation of naturally deformed olivine and experimental works. The major outcomes of this research are described below.

As a preparatory exercise, I acquired the basic and advanced knowledge on the scanning electron microscope, transmission and scanning transmission electron microscope techniques through the characterization of fracture-filling goethite vein along the Kerajang Fault Zone, eastern India. Microstructural observations and chemical composition analyses of the vein revealed that the vein microstructures were divided into domains A and B, mainly depending on the grain size and chemical composition. The formation of domain A can be explained by the incorporation of Al^{3+} instead of Fe^{3+} in the goethite crystal structure and geometrical selection. On the other hand, the microstructures of domain B are similar to those of the chalcedony and following formation processes can be proposed based on the analogy of chalcedony; precipitation of goethite colloidal particles with electrophoresis force, or heterogeneous nucleation from the Fe-rich supersaturated fluid and subsequent crystal growth.

The deformation conditions of naturally deformed olivine grains were identified from the microstructural observation, especially the determination of olivine slip systems based on three independent microstructures: lattice-preferred orientation, subgrain boundaries, and dislocations. The samples were the peridotite xenoliths collected from Megata, Takashima, Kurose, Salt Lake, and Pinatubo, and the alpine-type peridotites collected from Horoman and Uenzaru. The dominant slip system of the peridotite xenoliths was [100]$\{0kl\}$, which indicate that they originally deformed under medium to high temperature, and dry conditions in the upper mantle, except for the Takashima peridotite which is originated from the cumulus mantle. Only the Pinatubo peridotites among the studied peridotite xenoliths was strongly metasomatized and possibly affected by the CO_2-rich saline fluid trapped at the fore-arc mantle. The Horoman peridotite revealed the transition of slip systems, i.e., [100](001) to [100]$\{0kl\}$, which suggests that the deformation conditions changed from the high to low stress and/or low to high water content conditions during the exhumation process from the upper mantle. The Uenzaru peridotite was characterized by the mylonitized layer, and possibly deformed by the grain boundary sliding after the emplacement of the lower crust.

Chemical composition analyses by using electron probe microanalyzer revealed that the Fe enrichment along the cracks or grain boundaries in the alpine-type peridotites, which is the characteristic of the pipe diffusion. Analytical transmission electron microscope (ATEM) analyses revealed that the Fe enrichment around the subgrain boundaries in all studied peridotites, although the degree of the Fe enrichment or shape of the concentration profiles depend on the samples. The obtained concentration profiles in the Horoman and Megata peridotites, which showed relatively higher Fe concentration among the studied peridotites, were compared with diffusion profiles formed by the pipe diffusion, which is calculated from the finite differential methods. The results of the comparisons of the calculated diffusion profiles and concentration profiles suggest that the Fe enrichment around the dislocations in naturally deformed peridotites might be formed by the Fe pipe diffusion.

Annealing experiments of hot-pressed olivine aggregates were performed at 1200 and 1400 °C. ATEM analyses of annealed samples revealed that the fayalite number on dislocation was ca. 0.5 % higher than that of adjacent regions in both experiments. Lower Fe concentration on dislocations than naturally deformed olivine might be caused by the lower size misfit parameter, calculated from the change of the olivine lattice constant with increasing solute addition. The calculated critical strain rates of the Cottrell atmosphere formation in olivine are reproducible conditions by deformation experiments at the higher temperature (>1200 °C) and dislocation density (10^8 cm^{-2}). Nevertheless, the variation of the stress exponent around the critical strain rate condition or the Portevin-Le Chatelier effect, which is caused by the competition between the Cottrell atmosphere formation and dislocation breaking free during deformation experiments, has not been reported previously. Present study suggests that the effect of the Cottrell atmosphere formation on the plasticity of olivine is weak in the upper mantle conditions and demonstrates the validity of the olivine plasticity reproduced by the previous deformation experiments performed at relatively higher strain rate conditions.