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Preliminary experiments on grain growth kinetics of planetary ices

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Rheology of planetary ices has an important key role on evolution, internal structure, internal convection, and tectonics of icy moons and planets of the outer solar system. Recent plastic deformation experiments on water ices have suggested that the grain-size sensitive creep is a dominant deformation mechanism under low stress conditions of planetary interiors. Therefore, it is important to constrain the grain size of ice that possibly controls viscosities of outer ice shell and icy mantle. The grain-size evolution in convective mantle depends on several processes such as dynamic recrystallization, grain-size reduction due to phase transitions, and grain growth. In the present study, we focus on the grain growth process of planetary ices. We have performed preliminary grain growth experiments using two kinds of starting materials. One is two-phase mixture of ice I and sodium sulfate hydrate, and another is high-pressure ice VI.

It is suggested that some kinds of sulfate hydrates are present in Europa's outer ice shell. Grain growth kinetics of pure water ice is possibly rather different from that of two-phase mixture of ice and sulfate hydrate, which is important for the viscosity of Europa's outer ice shell. We have synthesized two-phase mixture of ice and sodium sulfate hydrate (mirabilite, Na_2SO_4 $10H_2O$, hereafter NS10) by solidification of the liquid solution of eutectic composition at 243-268 K. We have observed various eutectic textures of ice and NS10 depending on the freezing temperatures. The lamellar spacing in the eutectic texture tends to decrease with the freezing temperatures (about 100 microns at 243K). The two-phase mixture with having the eutectic texture obtained at 243 K was annealed at 268 K for 6 days, however any changes in textures and grain sizes were not observed. On the other hand, pure water ice with the grain size of about 200 microns showed grain growth to about 1-3 mm after annealing at 268 K for 17 days. These results may indicate different grain growth kinetics between pure water ice and the eutectic mixture, although further quantitative experiments are needed.

High-pressure phases of water ice are major constituents of the interiors of low-density icy moons with radius larger than 700 km. Ice VI is stable at the base of the icy mantle (if differentiated) of large icy moons of Ganymede, Callisto, and Titan. Grain growth experiments of ice VI were carried out by in-situ X-ray diffraction method using diamond anvil cell at Photon Factory, KEK Tsukuba. We used monochromatic X-ray (29 keV, collimated to 100 microns in diameter) and obtained time-resolved 2D diffraction patterns every 10-20 minutes using imaging plate. Thickness of sample is about 400 microns. We have observed grain growth processes of polycrystalline ice VI from changes of the number of diffraction spots in the 2D diffraction patterns. Fine grained ice VI was synthesized at about 2 GPa and 246K, and subsequently annealed at 273 K, 320 K, and 350 K. The numbers of diffraction spots did not change at 273 K for 20 hours, and slightly decreased at 320 K for 3 hours. At 350 K, the number of diffraction spots rapidly decreased and the intensity of each spot increased. Based on optical microscopic observation, grain size of ice VI synthesized at 246 K was too fine to be observed, whereas after the annealing at 350 K for 75 min, the grain size of ice VI was increased to be about 60-70 microns. By counting the number of diffraction spots as a function of time, the evolution of the number of ice VI grains in reflection is obtained. The observed number of grains that fulfill the Bragg condition is proportional to the grain density, and the intensity of each spot is proportional to the volume of the grain. We expect to obtain grain growth kinetics of ice VI from quantitative analysis of time-resolved 2D diffraction data obtained.