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Deformation and microstructure of coarse- and fine-grained pure water ice

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In the outer solar system, water ice is abundant. It is the dominant constituent of icy moons and Kuiper belt objects. In order to better understand the dynamic processes on icy moons, good knowledge of the rheology of water ice is essential. We focus on the influence of grain growth on the deformation behavior of ice. By understanding grain growth in combination with deformation mechanisms, it is possible to reconstruct thermal evolutions and tectonic histories of icy moons. Grain growth is expected to influence the evolution of strength of ice by altering the relative contributions to strain rate by grain-size-sensitive (GSS) creep mechanisms, such as diffusion and grain-boundary sliding, and grain-size-insensitive (GSI) creep mechanisms, such as dislocation creep. We performed different types of experiments, including the preparation of fine-grained ice and the deformation of coarse- and fine-grained ice aggregates. To make fine-grained ice, we applied a pressure release technique resulting in phase changes. First, coarse-grained ice phase I was transferred to ice phase II by applying a confining pressure of around 245 MPa. The sample was exposed to this high confining pressure for approximately 15 minutes to assure full phase transformation. Then, the confining pressure was released as quickly as possible, resulting in nucleation of fine-grained ice phase I grains. These so called pressure-drop experiments can be performed in a special cryogenic Heard-type deformation apparatus. After repeating the pressure-drop procedure three times, the fine-grained ice powder material was cold-pressed, resulting in dense ice aggregates. The deformation experiments were performed at temperatures between 190 K and 240 K, at confining pressures between 30 MPa and 100 MPa, and at strain rates between 1E-08/s and 1E-04/s. We produced orientation maps of the undeformed fine-grained ice using electron backscatter diffraction in a scanning electron microscope. These show that during the back-transformation from ice II to ice I, the newly formed Ice I grains form clusters which share a c-axis orientation, pre-defined by their relationship to the previous rhombic ice II crystal lattice. Mechanical results of deformed coarse-grained samples show that dislocation creep is the dominant deformation mechanism resulting in grain size reduction caused by dynamic recrystallization. Fine-grained ice samples show grain-size-sensitive creep behaviour, which is affected by grain growth of grains at higher temperatures. For both coarse-grained and fine-grained samples, microstructures seen on SEM images support the interpretation of the mechanical results.