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Rheology of water ice VII

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1 Introduction

Flow laws of high-pressure ices are crucial to understand the convecting interiors of large icy moons and planets. Rheology of high-pressure ices has been studied by using a gas-medium deformation apparatus, however it cannot reach the VI-VII transformation of water ice because the pressure range is limited. We conducted deformation experiments of ice VII by using multi-anvil type deformation apparatus to construct the flow law. Based on results obtained, the viscosity contrast between ice VI and VII is discussed.

2 Experimental method

Plastic deformation experiments of ice VII were carried out by using a deformation-DIA (D-DIA) apparatus installed at NE7A of Photon Factory, Japan (Shiraishi et al., HPR2011). We used monochromatic X-ray (50 keV, collimated to 100-500 microns) to obtain two-dimensional X-ray diffraction (2D-XRD) patterns every 3-5 minutes using imaging plate (IP). Differential stress of the sample in uniaxial compression can be measured from distortions of Debye ring on IP. X-ray radiography image is used to determine the sample strain during plastic deformation. We first compressed water enclosed in teflon capsule at 300K to synthesize ice VII. Then, the polycrystalline ice VII was uniaxially deformed at 3.0-14.8 GPa, 300-650K, and constant strain rates of around 1.5-14 x 10^{-5}/s. We measured stress-strain curves at various pressure, temperature, and strain rate conditions to construct flow law of ice VII.

3 Results and discussion

The flow stress at room temperature was obtained at a total of 10 different strain rate and pressure conditions, which was used to constrain the stress exponent (n) and activation volume (V*) in the flow law as shown in Figure 1. Comparison with the flow law of ice VI (Durham et al., JGR1996) and VII (this study) suggests that both ices deform by dislocation creep with similar n values, however the pressure dependence in ice VII is much weaker than that in ice VI. Figure 2 shows viscosity contrast between ice VI and ice VI as a function of pressure. Viscosity of ice VI rapidly increases with pressure. It discontinuously jumps by about two orders of magnitude at the VI-VII boundary, and gradually increases with pressure in the ice VII field. On the other hand, the flow stress was measured at 8 different temperature conditions. The temperature dependence in the flow law of ice VII was roughly estimated to be ~31 kJ/mol at P of 10 GPa, which is rather small compared to other high-pressure ices.

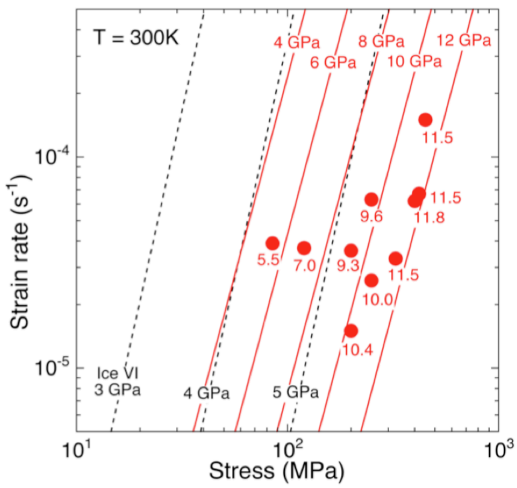

Figure 1 Comparison of flow laws between ice VI (black, Durham et al., JGR1996, n=4.5, V*=11 cm^3/mol) and VII (red, this study, n=3.8, V*=2.1 cm^3/mol) at 300K.

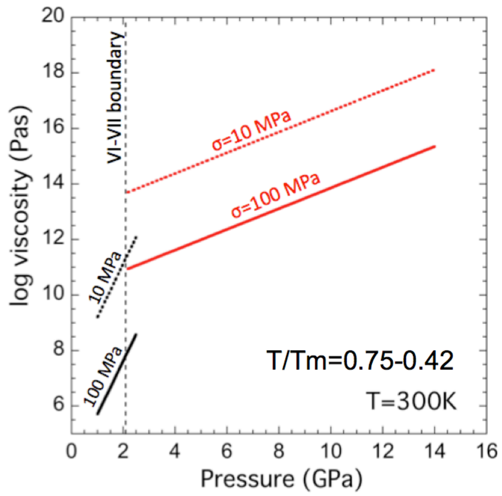

Figure 2 Plots of dislocation creep viscosity in ice VI (black) and VII as a function of pressure at 300K. The stress values are shown.

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