

Grain-growth kinetics in wadsleyite: Effects of chemical environment

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It is widely understood that rheological property of material is highly dependent on its grain-size. Thus, knowledge of grain-growth kinetics of wadsleyite has substantial importance for understanding of rheology in the Earth's mantle transition zone. In this study, we have carried out the first systematic study on grain-growth of wadsleyite and have determined the effects of temperature, water content and oxygen fugacity.

Experiments were carried out using Kawai-type multi-anvil apparatus, KIWI, installed at Yale University. Average grain-size of samples were determined from images taken by optical microscope or SEM. Water content is calculated from FT-IR spectra using Paterson's (1982) calibration.

Starting materials for grain-growth annealing were synthesized from San Carlos olivine powder. The synthesis conditions are $P = 14\text{-}15$ GPa, $T = 1230\text{-}1573$ K and $t = 1\text{-}2$ h. When we synthesize very dry wadsleyite, sample was put in a welded AuPd capsule to prevent up-take of water which is presumably come from cement or ceramic parts surrounding sample capsule. By using this technique, very 'dry' wadsleyite, such as less than 100 ppm H/Si, is available.

In grain-growth annealing experiments, we used three different types of capsule assembly depending on target water content. The sintered wadsleyite samples were embedded in 1) a AuPd capsule for 'dry' experiments, 2) a metal foil capsule for 'nominally dry' experiments and 3) a AuPd capsule with surrounding talc + brucite mixture for 'wet' experiments. In order to address effect of oxygen fugacity, each sample was surrounded by Mo, Ni or Re foil. Oxygen fugacity during annealing experiments is considered to be kept at each metal-oxide buffer. The conditions of grain-growth annealing are $P = 15\text{-}16$ GPa, $T = 1450\text{-}2173$ K and $t = 0.25\text{-}48$ h. Water content of recovered samples ranges, as widely as, from below than detectable limit (less than 50 ppm H/Si) to 240,000 ppm H/Si.

As a result, grain-growth kinetics of wadsleyite was revealed to be enhanced not only by temperature but also by oxygen fugacity and particularly by water content. Quantitative analysis was carried out assuming that the grain-growth kinetics is controlled by two different mechanisms; one is dependent on water content and another is independent on water content, the former and the later are dominant at relatively wet and dry conditions, respectively. Parameters for this grain-growth law are determined as follows with assumed value of growth exponent $n = 2$; for 'dry' regime, activation enthalpy = 510(+290) kJ/mol and oxygen fugacity exponent = 0.12(0.11); for 'wet' regime, activation enthalpy = 140(50) kJ/mol, oxygen fugacity exponent = 0.23(0.05) and water content exponent = 2.1(0.3). Boundary between the two regimes is located at around 10^3 ppm H/Si when $T = 1773$ K and $f_{O_2} = 10$ Pa.

The large value of water fugacity dependence, 2.1, can not be explained only by a simple model in which the grain-growth kinetics is controlled by intrinsic diffusion of atoms (defects) across grain-boundary. The interaction of grain-boundaries with charged defects or the density of hydrated ledges may be a one of the important factor which controls the grain-growth kinetics of wadsleyite. When compared at similar thermo-chemical conditions, the grain-growth kinetics in wadsleyite is found to be more sluggish than that in olivine. The present results show that a small grain-size (less than 1 mm) of wadsleyite in the subducting slabs can be maintained for a significant geological time (1 My) under 'dry' (less than 200 ppm H/Si) conditions when the temperature is lower than 1500 K whereas when a large amount of water (more than 100,000 ppm H/Si) is present, small grain-size (less than 1 mm) can be maintained only at low temperature (less than 700 K).