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Experimental study on grain growth of quartz and effect of water

Dynamic and static processes of quartz are important to understand the crustal behavior. Since quartz itself is composed of the simple chemical composition, the most important dynamic and static processes for quartz are deformation and grain growth which do not involve decomposition by phase transition. During plastic deformation, grain size of quartz is reduced by dynamic recrystallization. Recrystallized small grains, which can be down to a few micrometers, could experience subsequent deformation and grain growth. Many previous studies have been dedicated to understand deformation of quartz. However, knowledge about grain growth of quartz is limited. Therefore, this study focuses on grain growth of quartz by experiments in the presence of water, which is well known to enhance grain boundary motion as a carrier for silicon in quartz.

We performed grain growth experiments using a piston cylinder. We used two quartz samples; one is a natural quartz aggregate (quartzite) and the other is natural quartz powder (Min-U-Sil5). Both of the samples are composed of ~2 µm quartz grains. Almost the same amounts of the two samples of 40–160 mg in total were put together in a platinum capsule of 2.5 or 5.0 mm diameter with 2.0 wt% water, which is an enough amount to form completely wet grain boundaries based on our calculation. The powder becomes an aggregate under high pressure and temperature conditions. We assembled other pieces such as a talc sleeve, graphite heater, MgO pressure confining medium and set the assembly in a pressure vessel (19.1 mm assembly space for pressure of up to 1.5 GPa and 12.7 mm assembly size for pressure of up to 2.5 GPa). Pressure and temperature conditions ranged 1.0–2.5 GPa and 900–1100°C. The annealing time was 6–240 hours. No grain growth was observed without water at any experimental conditions. We made sample thin sections after experiments and analyzed grain sizes from optical photomicrographs. We used the following grain growth law to deal with our data.

$$L^p - L_0^p = k_0 {f_{\mathrm{H_2O}}}^r \exp(-\frac{Q}{RT_\mathrm{k}})t,$$

where L is the grain size after annealing time t, p is a constant and set to be a simple value of 2, L_0 is the initial grain size, k_0 is a constant factor, $f_{\mathrm{H_2O}}$ is the water fugacity term with the exponent of r, Q is the activation energy, R is the gas constant, and T_k is absolute temperature in Kelvin. The water fugacity represents the effect of water.

The most interesting finding we obtained this fiscal year is the effect of water fugacity. We performed experiments under various pressure and temperature conditions which are converted into water fugacity values assuming water saturated conditions (Figure 1, left). The relationships between water fugacities and grain sizes are clear for the two quartz samples and we determined water fugacity exponents. The relationships between temperatures and grain sizes may not be clear especially for quartzite (Figure 1, right). The grain size of quartzite is always larger than that of the powder starting material. This may be because of pores filled with water that entirely distribute around the powder and may prevent grain growth although water would also be a silicon carrier to enhance grain growth.

The obtained grain growth laws from the two quartz samples were applied to natural conditions (Figure 2). We assumed two temperature conditions of 400 and 600 °C as representative middle and lower crustal conditions. Water fugacity was calculated by 25°C/km and 27 MPa/km. As starting grain sizes in the natural conditions, we set 20, 100, 300 μm, which could be formed by dynamic recrystallization. At 400°C, the grain growth law obtained from the powder sample does not give significant grain growth with time evolution. The grain growth law by quartzite shows significant grain growth especially at 600°C. Even in 1000 years, the grain sizes increase to ~500 μm from the three starting grain sizes. In terms of plastic deformation, 1000 years correspond to strain of ~0.05% at strain rate of 10^{-14}/sec and ~3% at 10^{-12}/sec. This indicates that the effect of grain growth during plastic deformation may not be negligible and careful consideration is needed for quartz samples deformed especially under lower crustal conditions.

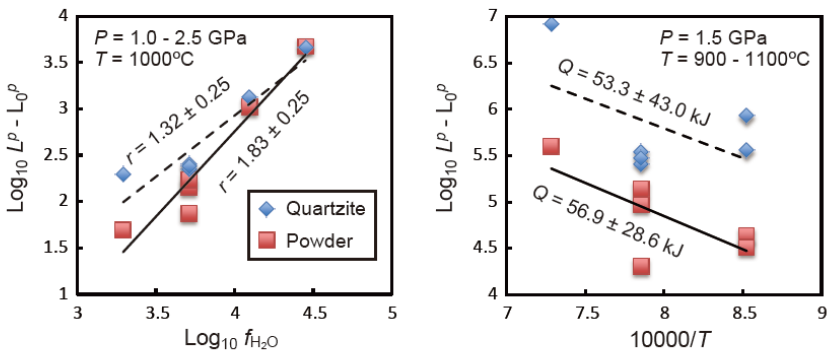

Figure 1. Dependences of grain growth on water fugacity (left) and temperature (right). The grain size exponent of p=2 was used.

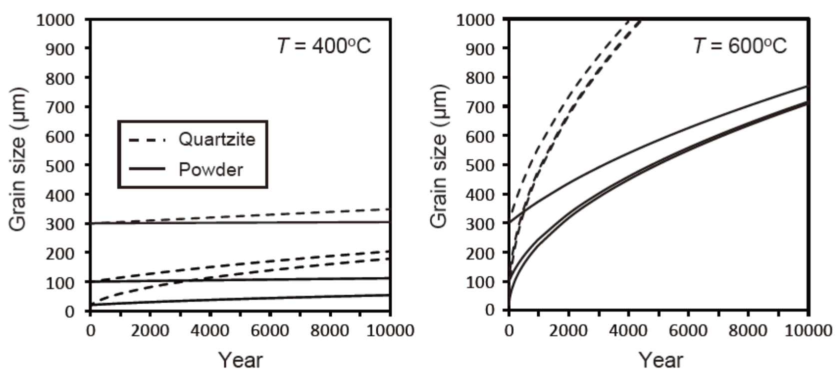

Figure 2. Extrapolations of our grain growth laws to two natural conditions.