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Effects of water on grain growth and deformation of fine-grained quartz.

Quartz plays key roles in the crystal dynamics because of its abundant existence. The brittle–plastic transition of quartz as the load-bearing framework can be linked with occurrence of earthquakes. Plastic deformation of materials can be widely categorized into two main types; grain-size-insensitive (GSI) creep and grain-size sensitive (GSS) creep. GSI creep caused by dislocation motion in a crystal and referred to as dislocation creep dominates when the grain size of the load-bearing framework is enough large (>a few tens of micrometers in nature). When the grain size is initially or becomes small by grain size reduction process, GSS creep becomes the dominant process as grain boundary diffusion creep and/or grain boundary sliding. The main grain size reduction process in the GSI creep regime is dynamic recrystallization to relax the imposed strain and the deformation resultantly shifts to the GSS creep regime. Grain growth occurs at the same time and after the deformation event. Then, the deformation regime could shift back to the GSI creep regime. All of the above processes are promoted by water: Water assists dislocation motion in a crystal and grain boundary motion both for GSS creep and grain growth.

The effect of water is parameterized as water fugacity. There are numerous experimental works on GSI creep, which have determined parameter relationships called flow law which includes temperature, stress, strain rate, water fugacity, etc. However, the experimental results were obtained under wide ranges of temperature (e.g. 700–1200°C) and pressure (200–1500 MPa), which give a wide range of water fugacity (200–5000 MPa). Another factor in these experimental temperature and pressure ranges is the difference between α-quartz and β-quartz. However, most experiential data have been obtained in the β-quartz conditions, meaning high temperature to facilitate plastic deformation.

In this study therefore, we derive a theory for dislocation creep including the above parameters differently for α- and β-quartz and compare it with experimental deformation data. Previous flow laws determined by experiments were modified as the same form, meaning the same parameter expressions. Diffusions in different crystallographic orientations were taken into account. The result shows that previous experimental flow laws for β-quartz very interestingly match with the theoretical lines (Figure 1). In contrast, theoretical lines for α-quartz show different strength profiles. This means that the crustal strength, where α-quartz is the dominant phase, needs to be reconsidered and this theory needs to be verified by extensive experiments. This result is now under revision.

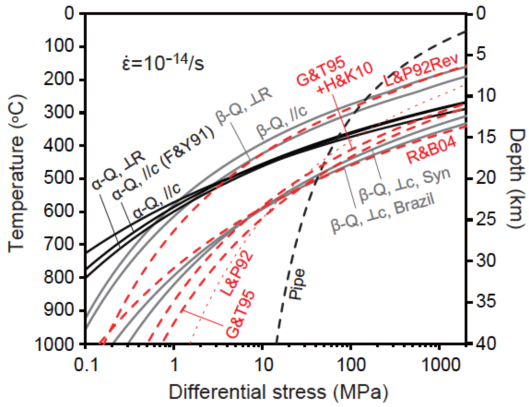

Figure 1. Comparison between the theoretical low laws and experimental flow laws. Modified from Figure 2 of Fukuda and Shimizu [2017, JGR].

Another topic of this study is to evaluate effects of water by experiments. First, we try to understand grain growth behavior of quartz with different amounts of water. We use fine-grained natural quartz powder (Min-U-Sil5) whose grain size is 0.1–5 μm and 1.7 μm on average. We also use novaculite which is a fine-grained quartz aggregate (2 μm on average) (Figure 2). The samples were dried at 900 °C and set together in a gold or platinum capsule with 0.2 wt% added water. We also use the non-treated original powder sample with adsorbed water of 0.2 wt% and novaculite with 0.03 wt% of trapped water. We use a piston cylinder (solid pressure medium) for pressure up to 3 GPa and an internally-heated vessel (gas pressure medium) for pressure up to 0.3 GPa. Temperature in both experiments is up to 1000 °C and duration is up to 10 days. I have learned how to prepare the sample assemblies and how to operate the apparatuses. We will measure water contents in the samples by infrared spectroscopy. Following the results from the grain growth experiments, we are planning deformation experiments by using a solid pressure medium (new Griggs-type) deformation apparatus and gas deformation (Paterson-type) apparatus, where the pressures are up to 3.0 GPa and 0.3 GPa, respectively.

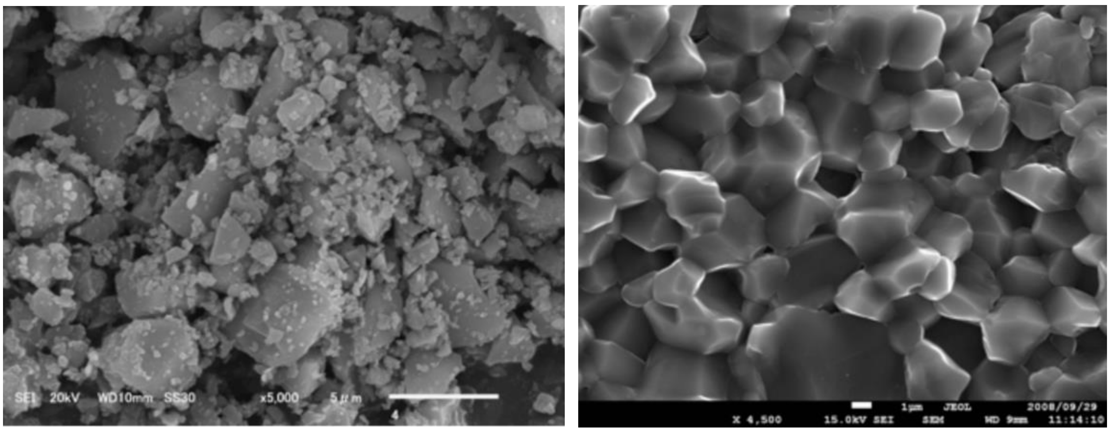

Figure 2. SEM images of the starting samples. Natural quartz powder; Min-U-Sil5 (left) and quartz aggregate; novaculite (right).