

Effects of H₂O-content, dynamic recrystallization, porosity, and grain boundary width in experimentally sheared quartz aggregates

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At depths of the middle to lower crust and in subduction zones pore pressure is expected to be lithostatic, and its mechanical effect is mainly a question of pore volume and its distribution. In nominally anhydrous minerals, such as quartz and olivine, small amounts of H₂O have large effects on viscous deformation properties. These effects are different from pore pressure and -volume effects. For quartz, it is established that increasing amounts of H₂O lead to weaker mechanical behavior. The purpose of this study is to determine the relative importance of these effects.

We have sheared powder of dry Brazil quartz (6-20 μm grain size) with 0.2wt% H₂O added at 800°C and 1.5 GPa at a shear strain rate of $\sim 5 \times 10^{-5} \text{ s}^{-1}$. Different types of quartz porphyroclasts ($\sim 150 \mu\text{m}$ diameter) were embedded in this matrix: (1) Dry Brazil quartz ($\sim 400 \text{ H}/106\text{Si}$) and (2) Wet Hyuga quartz ($\sim 22000 \text{ H}/106\text{Si}$).

The peak strength of samples containing 30 or 70vol% porphyroclasts decreases with increasing amount of wet porphyroclasts and increases with that of dry porphyroclasts. In addition, all experiments are characterized by pronounced strain weakening. The finite strength of assemblages with wet porphyroclasts converges after γ -values of 3-4 towards the one of pure matrix with 0.2wt% added water. A variable degree of recrystallization is visible in the experiments, and wet porphyroclasts are recrystallized more penetratively than dry ones.

After deformation H₂O contents, determined by FTIR, of dry porphyroclasts increase (H₂O intake from matrix), those of wet porphyroclasts decrease (H₂O expulsion to the matrix) as a consequence of recrystallization and microcracking.

In experiments with the largest water contents, we observe sets of shear bands containing faceted grains indicating that the latter have grown into open pore space filled with H₂O. H₂O contents in the pure matrix are $\sim 800 \text{ H}/106\text{Si}$ after deformation. Matrix H₂O contents of samples with dry porphyroclasts are on the same order of magnitude, those with wet porphyroclasts are much higher. It is concluded that there is a maximum water content which can be distributed along grain boundaries. Above this content, H₂O segregates into pores or shear bands.

Matrix grain sizes determined by EBSD are systematically smaller than those of recrystallized porphyroclasts (volume weighted modal value of diameter of 3D grains is $\sim 3 \mu\text{m}$ vs $\sim 5 \mu\text{m}$). From grain boundaries of EBSD maps, it is possible to calculate an order of magnitude of the grain boundary width, assuming that the H₂O-content measured by FTIR is primarily contained in the boundary region. Grain boundary widths decrease systematically with matrix H₂O content but do not correlate systematically with peak or final strengths of the samples.

Shear bands never form a connected network. As both, shear bands with high porosity and larger grain boundary widths, do not correlate with the lowest sample strengths, it can be concluded that pore pressure effects are not responsible for the weakening of the samples. Instead we propose that the effect of H₂O on the deformation is entirely through viscous deformation mechanisms such as grain boundary sliding and dislocation creep.