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Strength of dry and wet quartz in the low–temperature plasticity regime: insights from nanoindentation

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The strength of experimentally deformed natural and synthetic quartz is strongly affected by the intracrystalline water content. Water–related defects weaken quartz by either decreasing the resistance to dislocation motion (Peierls stress) or by enhancing the nucleation of dislocations, during what is commonly referred to as hydrolytic weakening. However, hydrolytic weakening has been observed predominantly in synthetic quartz grains, with water contents higher than 20–30 wt ppm H_2O and at high-homologous temperatures, for which the activation of dislocation climb and recovery processes is enhanced.

In the low-temperature plasticity (LTP) regime, at low-homologous temperatures and high stress conditions, quartz plasticity is mainly controlled by dislocation glide. At these conditions, the possible effect of intracrystalline water on quartz strength is still a matter of debate.

In order to analyse the effects of intracrystalline water content on the plastic yield and hardness of quartz in the LTP regime, natural samples from recrystallized quartz domains of a granulite-facies migmatitic gneiss, presenting different water contents and microstructures, have been investigated through a series of spherical and Berkovich nanoindentation tests at room conditions. Nanoindentation tests have been integrated with measurements of intracrystalline water contents of the indented grains with secondary ion-mass spectrometry (SIMS), and with electron backscatter diffraction (EBSD) measurements of the crystallographic orientation of the indented grains.

Water content of indented quartz grains ranges between 2 and 104 wt ppm H_2O. Samples and related nanoindentation tests were thus classified as either “dry” (DQ, for water contents < 20 wt ppm H_2O) or “wet” (WQ, for water content > 20 wt ppm H_2O). Spherical nanoindentation tests revealed comparable yield stresses (ranging between 3.5 and 8.8 GPa, depending on the crystal orientation) for DQ and WQ grains. In addition, significant strain hardening was observed in both DQ and WQ grains. Berkovich nanoindentation tests also resulted in comparable hardness (ranging from 8.0 to 13.5 GPa) in both DQ and WQ grains. The hardness also increases with indentation depth, which is consistent with the “size-effect” on mineral strength during LTP.

These results suggest that, for the investigated range of water contents, the yield strength and

flow stress of quartz in the LTP regime is not affected by the intracrystalline water content of the indented grain. Both the dry and wet quartz experienced significant crystal plastic deformation prior to the nanoindentation tests, as evidenced by the occurrence of undulatory extinction, misorientation bands, subgrains, and recrystallized grains. This pre-indentation strain history may have had a major role in generating the dislocation density, which then controlled the yield stresses during low-temperature plasticity in our experiments. Hence, inherited strain history, crystallographic orientation, and grain size may play a more important role than water in controlling the strength of the continental crust at the brittle–ductile transition, where LTP is dominant and quartz is the most abundant phase.