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Mapping water and misorientations in experimentally deformed quartz

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The rheological profile through the earth's crust is usually modeled after the rheological behaviour of quartz because - in nature - quartz appears to be the weakest of the common rock forming minerals. In experiments, however, quartz proves to be extraordinarily strong. The difference between weak natural and strong experimental quartz is attributed to the presence or absence of water.

In this contribution we want to address a specific aspect of water weakening of quartz: What is the spatial relationship of water content and deformation microstructures at the microscopic scale of the crystal?

We conducted a series of deformation experiments at conditions where dislocation glide is active (T = 900°C and 1000°C, Pc = of 1 to 1.5 GPa, ė = 10-6 s-1). We used milky (i.e. fluid inclusion rich) quartz single crystals and deformed them in two different crystallographic orientations relative to the compression direction (sigma1): (1) normal to the prism plane (conducive to prism <a> glide) and (2) in O+ orientation where sigma1 is at 45° between [c] and <a> (conducive to basal <a> glide).

The water content of the samples was measured before and after deformation using FTIR and a spot size of 100 x 100 μm. Before deformation, the water resides in fluid inclusions; the crystal itself is essentially dry. After deformation, the water is distributed at a very fine scale throughout the crystals. Healed cracks - most of them vertical (parallel to the compression direction) - are decorated by very small new fluid inclusions (d < 10 μm).

At the scale of an entire sample, the crystals deform homogeneously by barreling - confirming prism a glide - or by bending - confirming basal a glide. At the resolution of FTIR measurements, strain and high water content are positively correlated.

At the smaller scale, strain is heterogeneous; using optical orientation imaging, cathodoluminescence and TEM observations, interesting details concerning spatial correlation and anti-correlation of water content and deformation induced misorientation structures emerge.

On O+ samples, two types of c-axis rotations take place - one associated with misorientation domains (deformation bands) and compatible with prism <a> slip (rotation about [m]), another one associated with deformation lamellae and compatible with prism [c] slip (rotation about <a>).

The misorientation domains are elongated regions parallel to the host [c] axis (up to several mm long and $\leq$1 mm wide) displaying undulatory extinction. They grow wider with increasing strain attaining [c] axis misorientations of 25° or more. In the previously reported 'internally kinked shear bands' (oriented subparallel to the basal plane), the misorientation domains are narrow ($\sim$20 μm) and closely spaced, appearing as the limbs of chevron folds with [c] axis rotations of $\sim$5°.

The deformation lamellae (width < 10 μm) are penetrative features occurring throughout the crystal. They show high contrast on orientation and orientation gradient images, on CL images and in TEM, indicating a high water content and dislocation density. The deformation lamellae are folded or kinked by the deformation bands.

On samples compressed normal to the prism plane, prism <a> glide is active and no [c] rotation should occur. Within approx. 100 μm of the vertical fluid inclusion trails, misorientations are indeed absent. With increasing distance from the trails, however, and particularly at mid distance between fluid inclusion trails, the [c] axes are rotated out of the slip plane with misorientations up to 25°.