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Mapping Water and Misorientations in Experimentally Deformed Quartz

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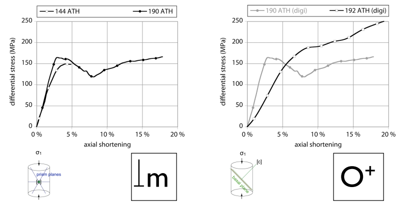
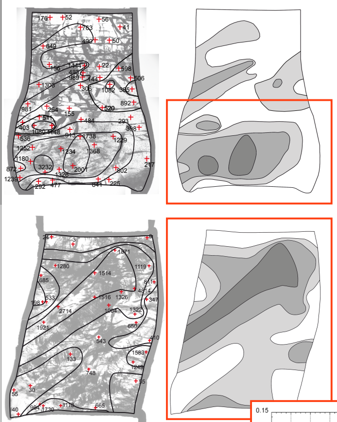
mechanical data



water content

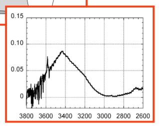


total shortening: 18 %

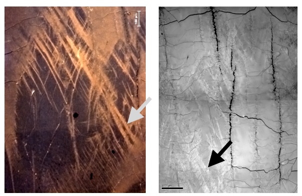
⊥m

total shortening: 20 %

O+



Whole samples (left) and maps of water content, FTIR measurements (right).
In ⊥m samples, the occurence of the peak at 3582 cm-1 is restricted to the barrel shaped bottom part, in O+ samples, they occur everywhere.



⊥m

Cathodoluminescence images: contrast is due to variations of trace element concentration = indication of water influx
left: cold optical right: SEM / CL

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, $\dot{e} = 10^{-6}\ s^{-1}$).

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.

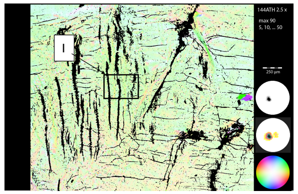
On O^+ samples, two types of c-axis rotations take place - one associated with misorientation domains (deformation bands) and compatible with prism <a> slip (rotation about [m]), another one associated with deformation lamellae and compatible with prism [c] slip (rotation about <a>).

The misorientation domains are elongated regions parallel to the host [c] axis (up to several mm long and ≤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 (~20 µm) and closely spaced, appearing as the limbs of chevron folds with [c] axis rotations of ~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°.

low strain sample (144ath)

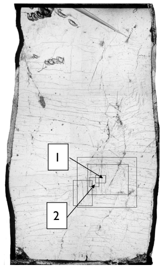


c-axis orientation image 144ath.COI

frame indicates site of image with higher magnification (below)

+ polefigures
+ colour look-up table

⊥m



deformed sample 144ath

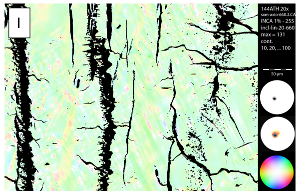
total strain = 5%

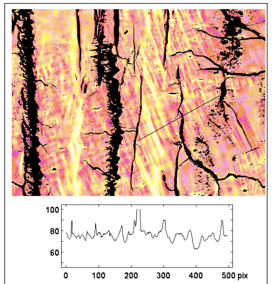
frames show sites of orientation images shown below

LOW DEFORMATION

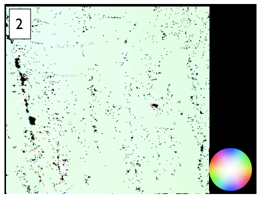
left:
high magnification
c-axis orientation image
144ath.COI
+ polefigures
+ colour look-up table

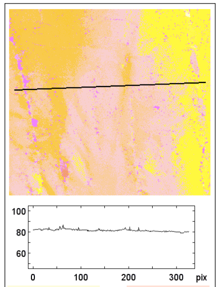
right:
c-axis misorientation image
reference direction:
North-East (45 / 90)
+ trace of profile: 61° from N
profile from upper right to lower left





yellow = 64° from NE red = 85° from NE





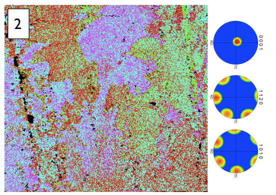
yellow < 80° from E red > 80° from E

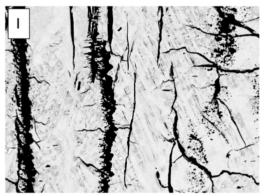
NO DEFORMATION

left:
EBSD derived c-axis orientation image

right:
c-axis misorientation image
reference direction:
East (90 / 90)
profile from left to right

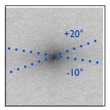
below:
EBSD orientation image (Euler angle colouring)
+ pole figures

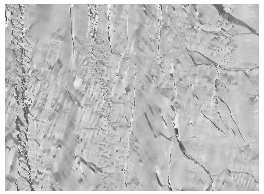




top: image of orientation gradients dark grey = 8°

azimuth image
+ FFT showing normals to orientation gradients

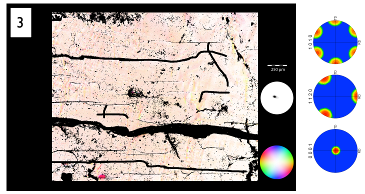


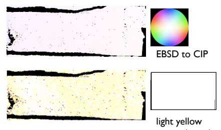


high strain sample (190ath)

below, for each sample:
top: c-axis orientation images from EBSD
bottom: orientation gradient image + histo

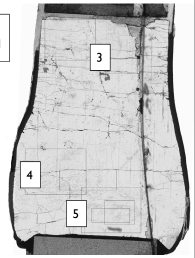
⊥m





EBSD to CIP

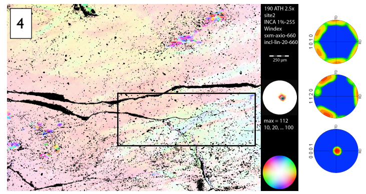
light yellow
max orientation gradient = 2°

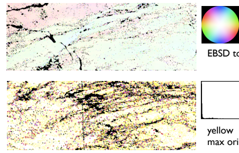


deformed sample 190ath

total strain = 18%

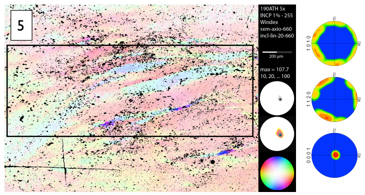
frames show sites of orientation images shown below

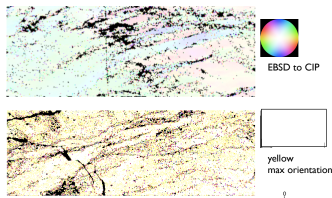




EBSD to CIP

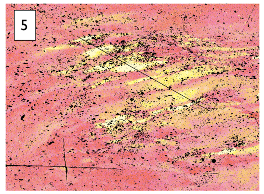
yellow
max orientation gradient = 5°

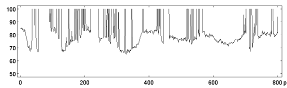




EBSD to CIP

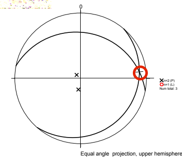
yellow
max orientation gradient = 3°





profile across misorientation image
reference direction = North (0 / 90)
trace of profile: 120° from North

yellow = 70° - red = 85° from North

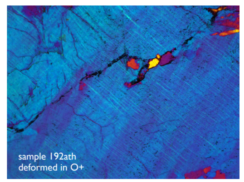


rotation of c-axis
rotation axis = <a>

conclusions:

- FTIR: high water content and 3582cm^{-1} peak → sample strain
- CL: high water content along prism planes
- site of high misorientations = away from fluid trails ≠ along prism plane
- prism plane = high orientation gradient → subgrain boundary
- c-axis rotation about <a> → prism [c] slip

what happens to biaxial quartz in EBSD ?



quartz used in this study is optically biaxial
2V ≈ 10-15°

CIP and EBSD produce consistent results...

... good!

... but why ?