NTNU – Trondheim
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GEOLOGICAL SURVEY OF NORWAY
- NGU -

EARTH SCIENCES WITH PLYMOUTH UNIVERSITY

Brittle-viscous deformation of vein quartz under fluid-rich lower greenschist facies conditions

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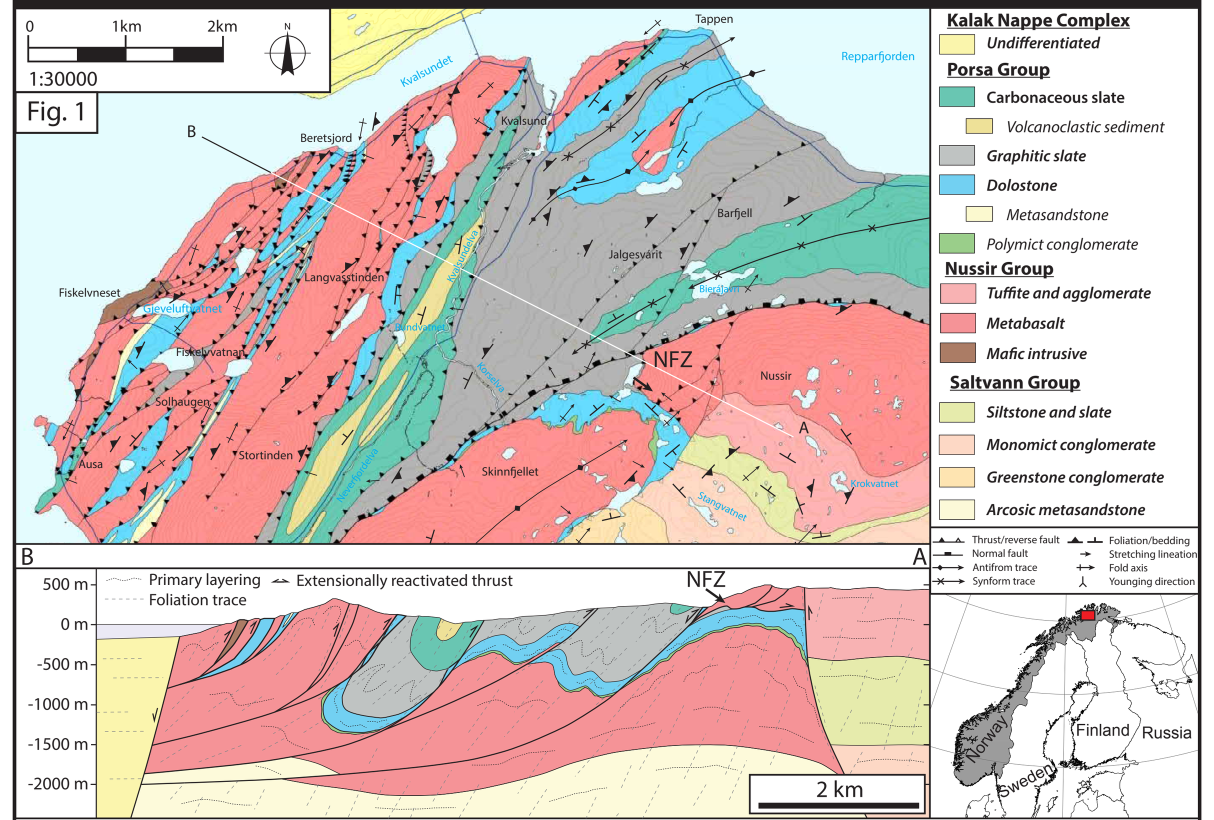
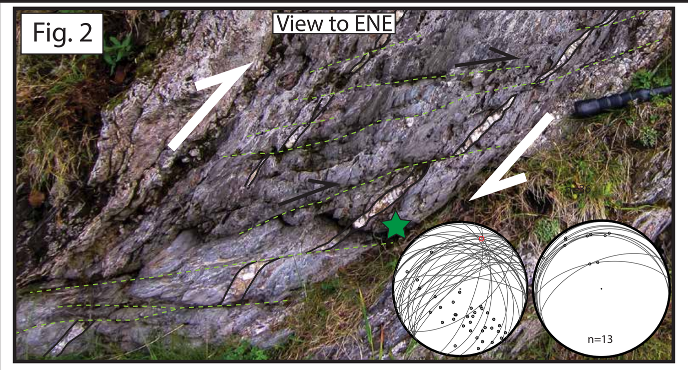
Geologic setting

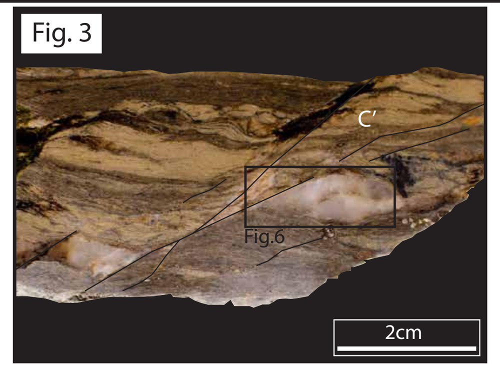


The Repparfjord tectonic window (RTW) is located in northern Norway. It is a window through the Caledonian fold and thrust belt and into a Paleoproterozoic metasedimentary and metavolcanic sequence. These Paleoproterozoic rocks were initially deformed during the Svecofennian orogeny under greenschist- to lower amphibolite facies conditions. Upright, gentle to open and km-scale, NE-SW trending folds accommodated most of the Svecofennian shortening.

Silurian-Devonian Caledonian compression resulted in NW-SE shortening and development of the Porsa Imbricate Stack, which form the study area. Individual imbricates exploited preexisting folds that became progressively tightened and finally overturned. Very steep to sub-vertical reverse brittle-ductile faults bound the imbricates and represents the focus of this project.

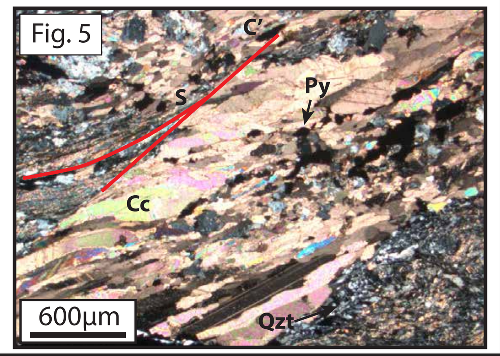
Field Observations



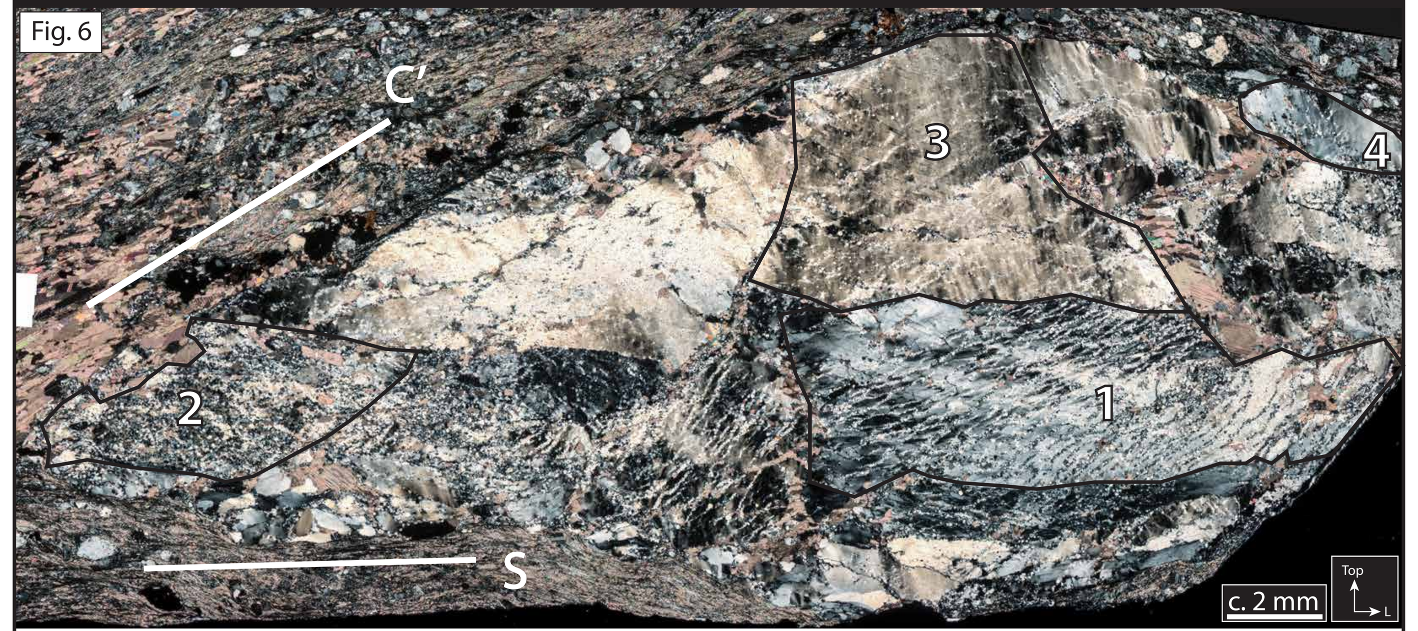


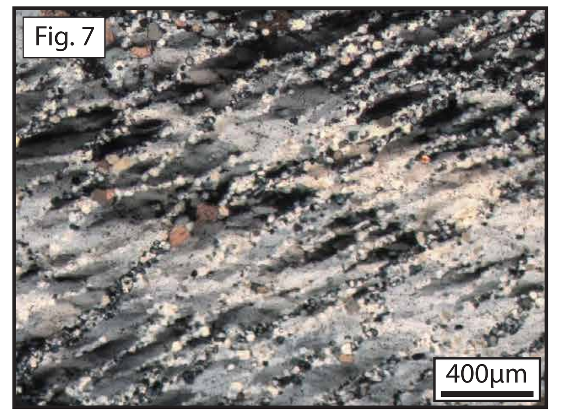
The Nussirjávri Fault Zone (NFZ; Fig. 1) is one of these reverse brittle-ductile faults. It is a phyllonitized thrust with a ramp-flat geometry containing pre to syn-kinematic veins offset by C′ shear bands (Fig. 2).
The hand specimen (Fig. 3) described here is a strongly foliated, phyllonitic rock containing a centimetric clast of a quartz vein, bound by- and offset along a C′ shear band. The vein is surrounded by a phyllonitic matrix composed of interconnected layers of fine grained phyllosilicates and quartz (Fig. 4), which leads to a significant competence contrast and strain partitioning in the sample. Locally, deformed feldspar porphyroclasts are observed (fig. 4). Veinlets, formed sub-parallel to the C′ shear band, accommodated several episodes of dilation and are found throughout the sample (Fig. 5), indicating that fluids were channeled along the shear bands into the deforming rock.

The studied quartz vein crystals display remarkably different microstructures. These microstructures were investigated in detail by optical microscopy and EBSD to understand how such characteristic microstructures can develop in quartz deformed at the frictional-viscous transition.



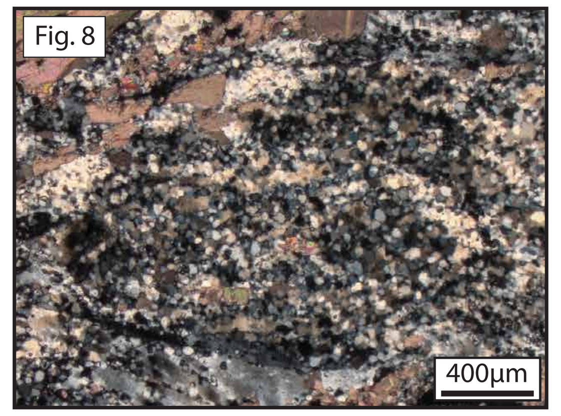
Microstructural Observations





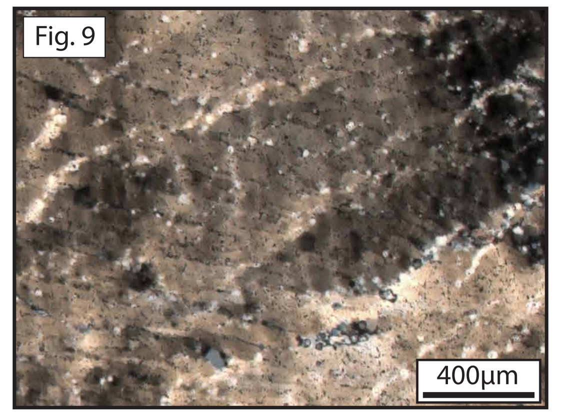
Domain 1

- "Striped-tiger" microstructure
- Tightly spaced set of sub-parallel and semi-straight bands of nucleated grains
- Some bands also contain small calcite and muscovite grains interspersed among the new grains (Fig. 7)
- The bands are sub-parallel to the C′ shear bands that offset the quartz vein (Fig. 6)



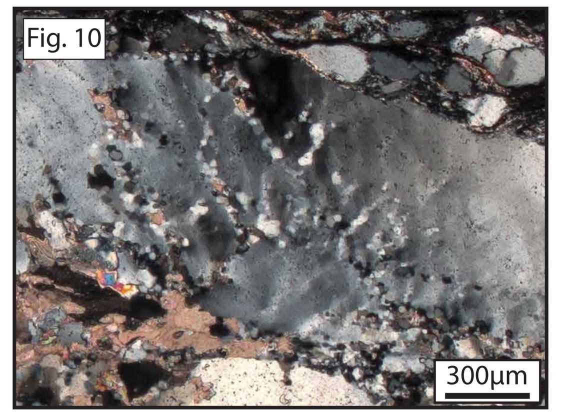
Domain 2

- > 90% of the domain area contains new grains (Fig. 8)
- Grain size distribution is unimodal, with relatively equigranular and equidimensional grains (Fig. 8)
- Located in a relatively high strain location between the C′ and the S (Fig. 6)



Domain 3

- < 10% of the domain area contains new grains (Fig. 9)
- Sweeping and patchy undulose extinction with upright WEBs and two sets of bands of new grains (Fig. 9)
- Large fluid inclusions and some tiny muscovite grains encircle the new grains (Fig. 9, 15, 16 and 17)
- The bands are sub-parallel to the C′ shear bands that offset the quartz vein (Fig. 6)

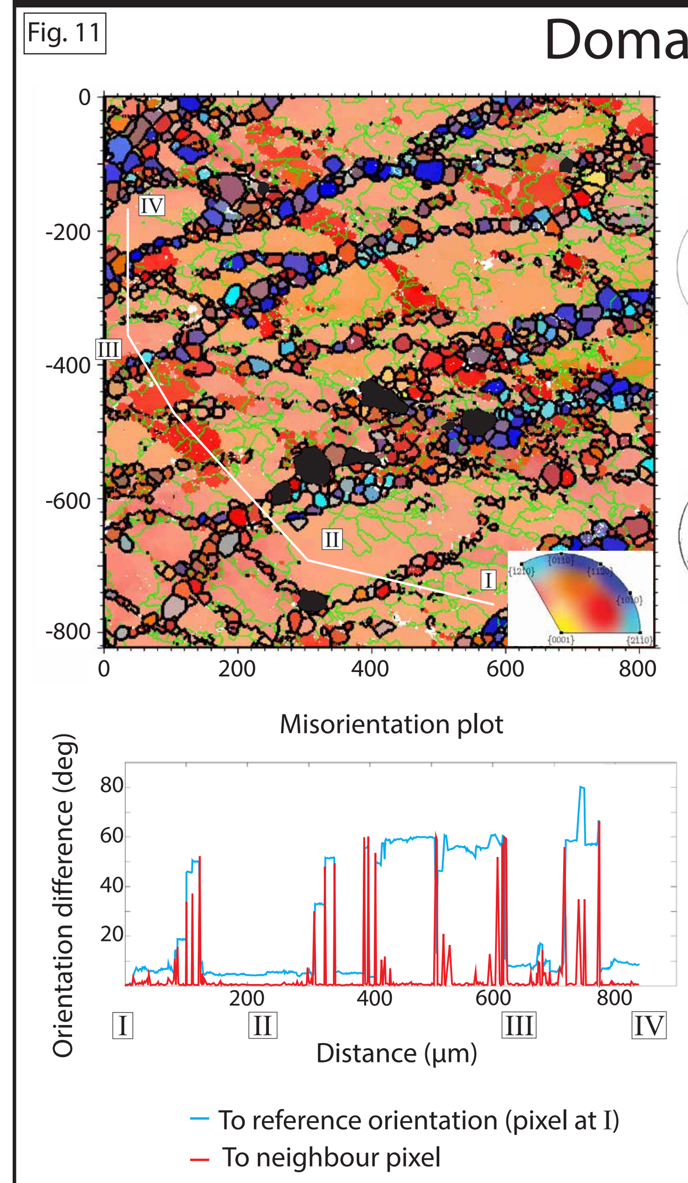


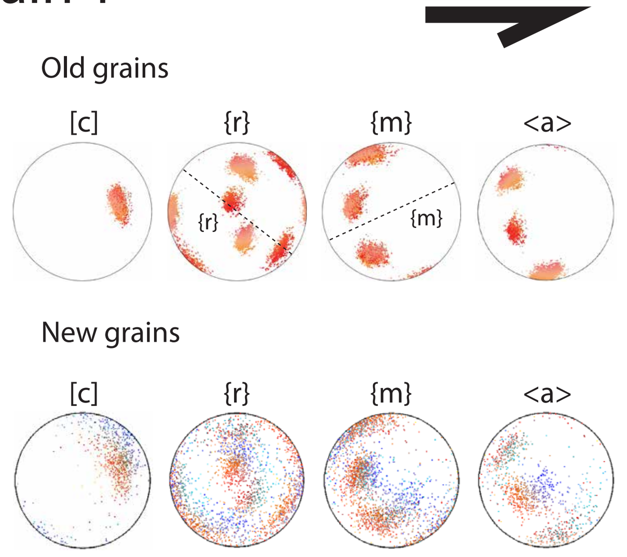
Domain 4

- "Striped-tiger" microstructure (Fig. 10)
- Two sets of bands, forming an angle of c. 70° to each other (Fig. 10 and 14)
- Domain is located close to the phyllonitic matrix, which contains shear bands with opposite shear sense (Fig. 10).
- Resembles domain 1 (Fig. 10)

EBSD Analysis of the domains

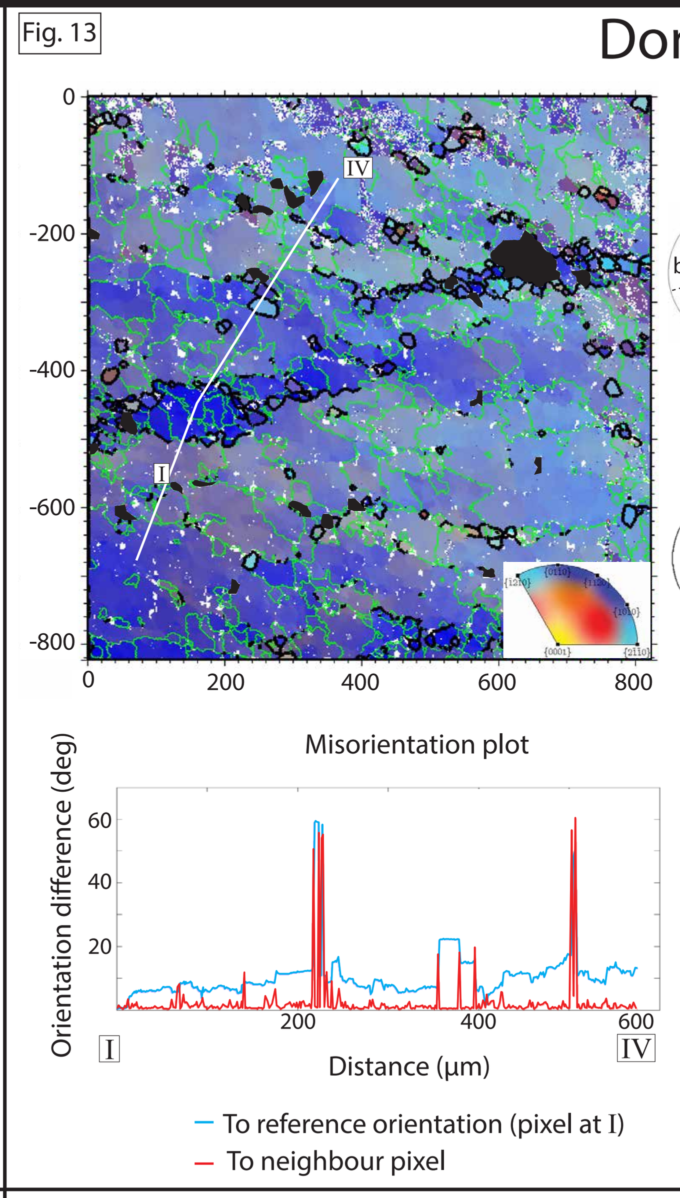
Domain 1

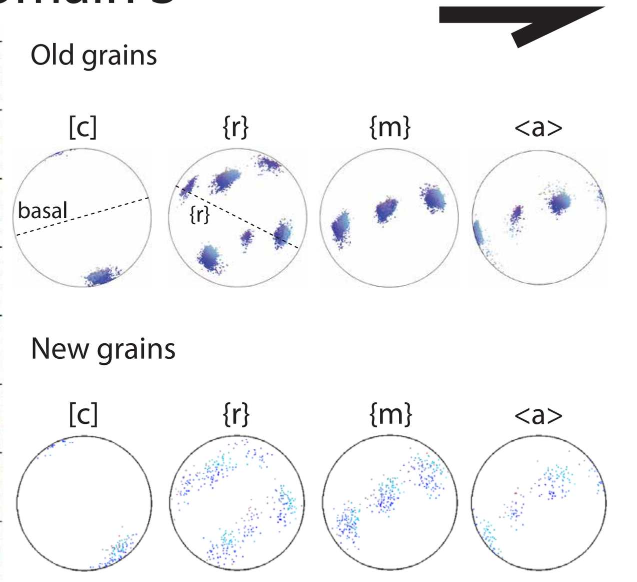




- New grains range in size from c. 5 - 40 µm
- C-axis of the old grains in domain 1 is in the foliation plane at c. 20° from the lineation
- Most developed bands are || to {m}, which is sub-parallel to C′. Subordinate band are || to {r}
- New grains have a scattered c-axis distribution with a counterclockwise rotation around the Y-axis
- No progressive lattice rotation towards the bands of new grains as shown from misorientation plot

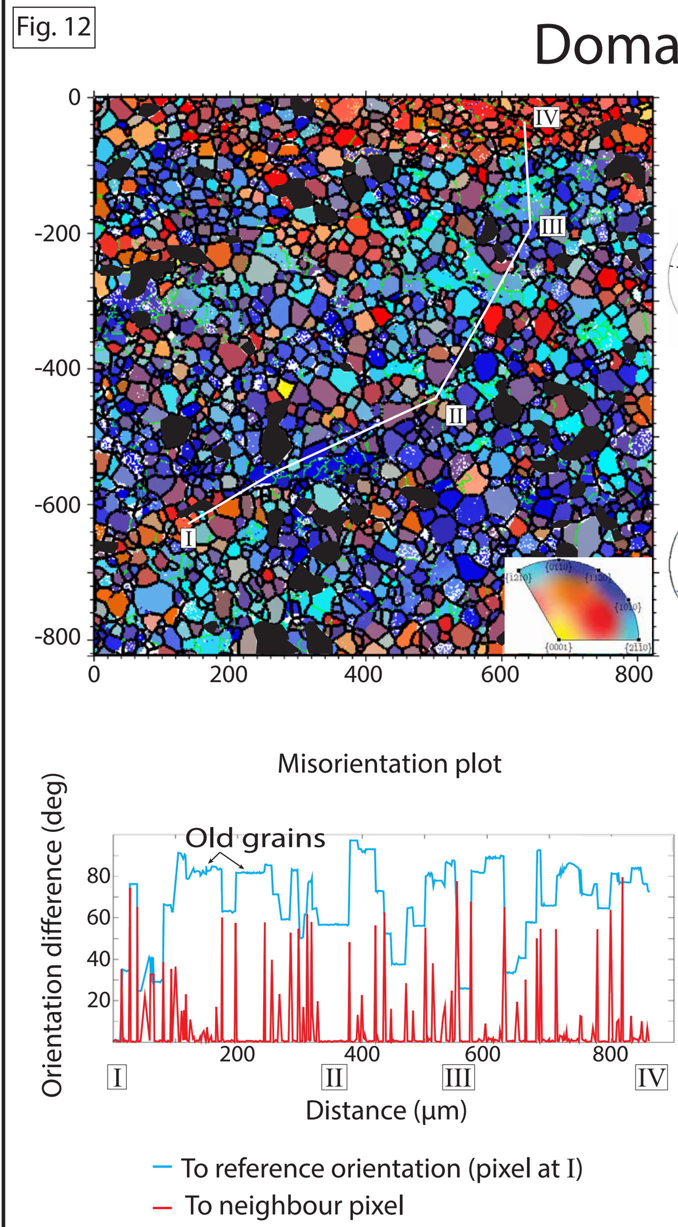
Domain 3

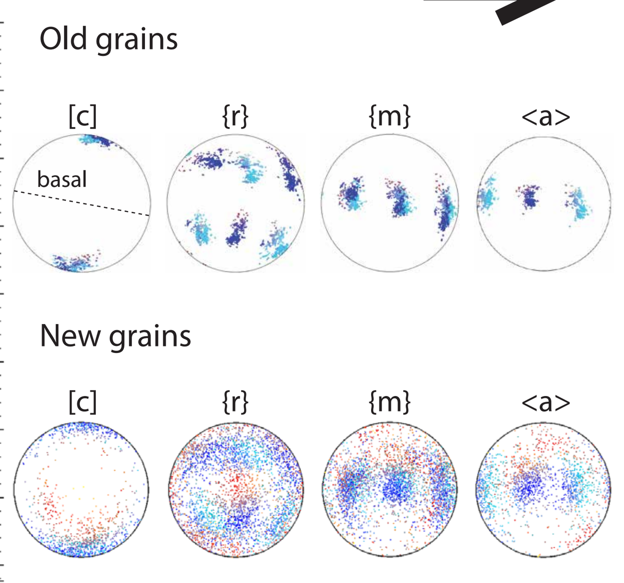




- New grains range in size from c. 10 - 35 µm
- C-axis of the old grain is subparallel to the Z-direction of finite strain, and slightly inclined with the bulk sinistral sense of shear
- Most developed bands of new grains are || to the basal plane, which is sub-parallel to C′. Subordinate bands are || to {r}
- New grains have a slightly scattered c-axis distribution.
- No progressive lattice rotation towards the bands of new grains as shown from misorientation plot

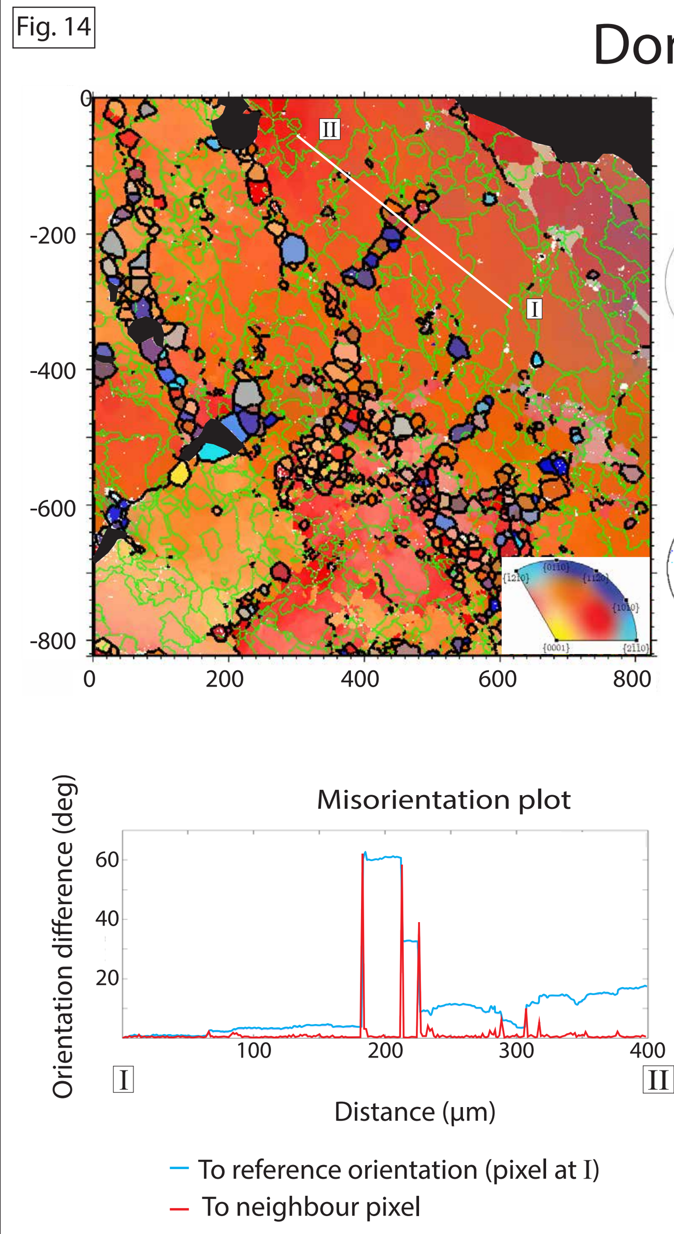
Domain 2

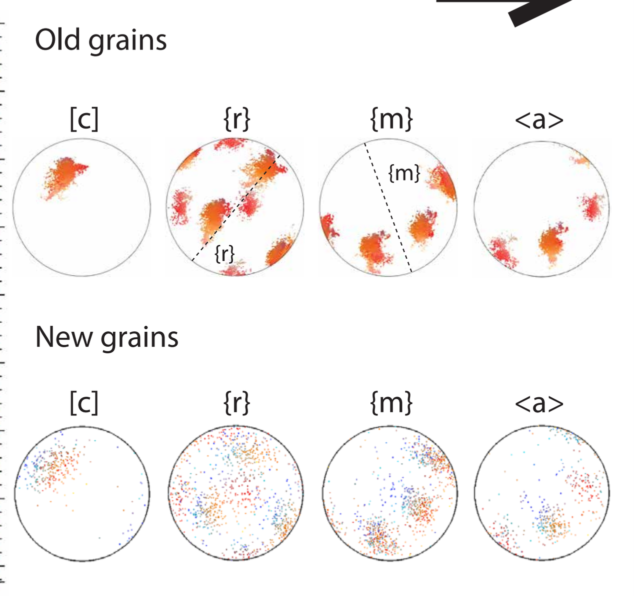




- New grains range in size from c. 5 - 45 µm
- Old grains form a c-axis maximum close to the N and S poles of the pole figure, with only a weak clockwise deflection
- Old grain show a high density of sub grain boundaries
- New grains have a scattered c-axis distribution, rotated around the Y-axis
- No progressive lattice rotation towards the bands of new grains as shown from misorientation plot

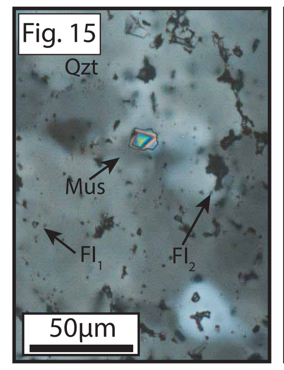
Domain 4

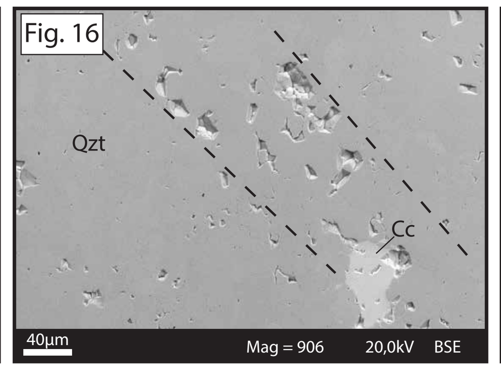


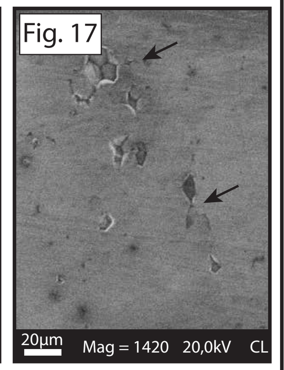


- New grains range in size from c. 5 - 40 µm
- Old grain c-axis orientation plots in an intermediate position between the Z- and Y-axis of strain and slightly inclined with the bulk sinistral sense of shear
- Bands of new grains are || to the {r}, which is sub-parallel to C′. Subordinate bands are || to {m}
- New grains define a more scattered c-axis distribution, with no clear directional trend
- No progressive lattice rotation towards the bands of new grains as shown from misorientation plot

Evidence for ingress of fluids



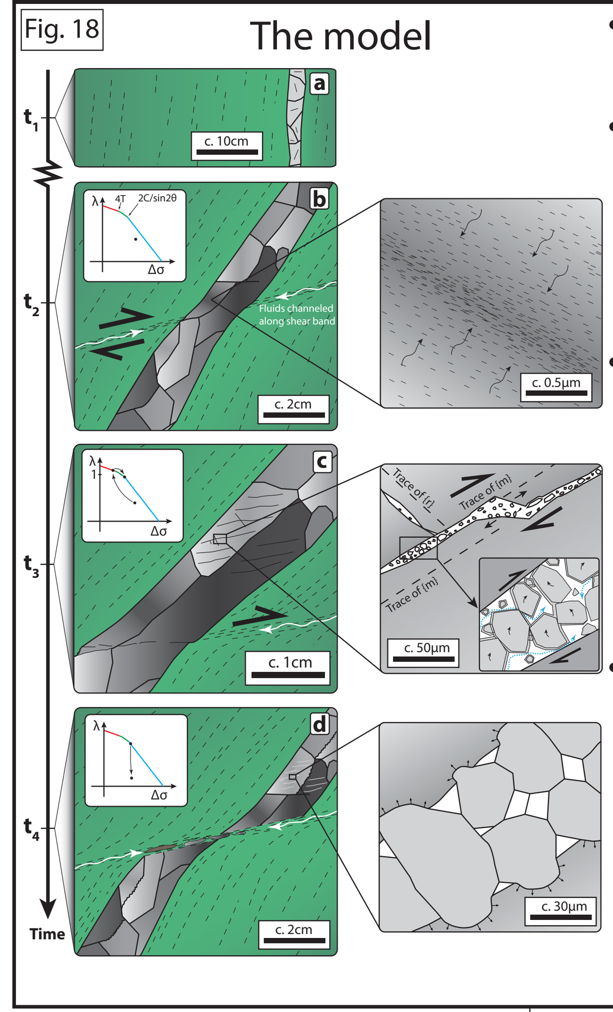




- Optical photomicrographs reveal secondary phases, such as muscovite (Fig. 15) and calcite (Fig. 16) within the large, single crystals of quartz. In addition, relatively large fluid inclusions (FI; Fig. 15,16 and 17) are found surrounding the newly formed grains. There is a significant size difference between what is interpreted as primary FI (FI_1) and secondary FI, (FI_2; Fig. 15).
- BSE images show large fluid inclusions surrounding the new grains within a confined band (Fig. 16). Secondary phases (calcite) are also present within the band.
- Due to very low temperature during formation, quartz is not particularly luminescent and there is very little contrast in CL signature from the bands to the host, although a small contrast in gray-scale may be inferred locally (Fig. 17; see arrows).

Conclusions

The model



- Initial fracturing and vein crystallization occurred under quasi-static conditions.
- During development of the NFZ, quartz deformed by dislocation creep, which is not effective at the constrained environmental conditions. This led to strain hardening of the crystals oriented poorly for basal <a> slip.
- Hardening, in combination with transiently high fluid pressure and strain rates, induced fracturing of the crystal along suitably oriented crystallographic planes, such as the {m} in domain 1. This caused enhanced fluid permeability and subsequent nucleation and growth of new grains.
- Slow grain boundary migration took over when the new grains were in contact with the fracture wall. Further growth happened at the expense of the more deformed old grains. As the fractures sealed, viscous deformation could prevail again, possibly promoting dislocation creep due to hydrolytic weakening effects.

Acknowledgements

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