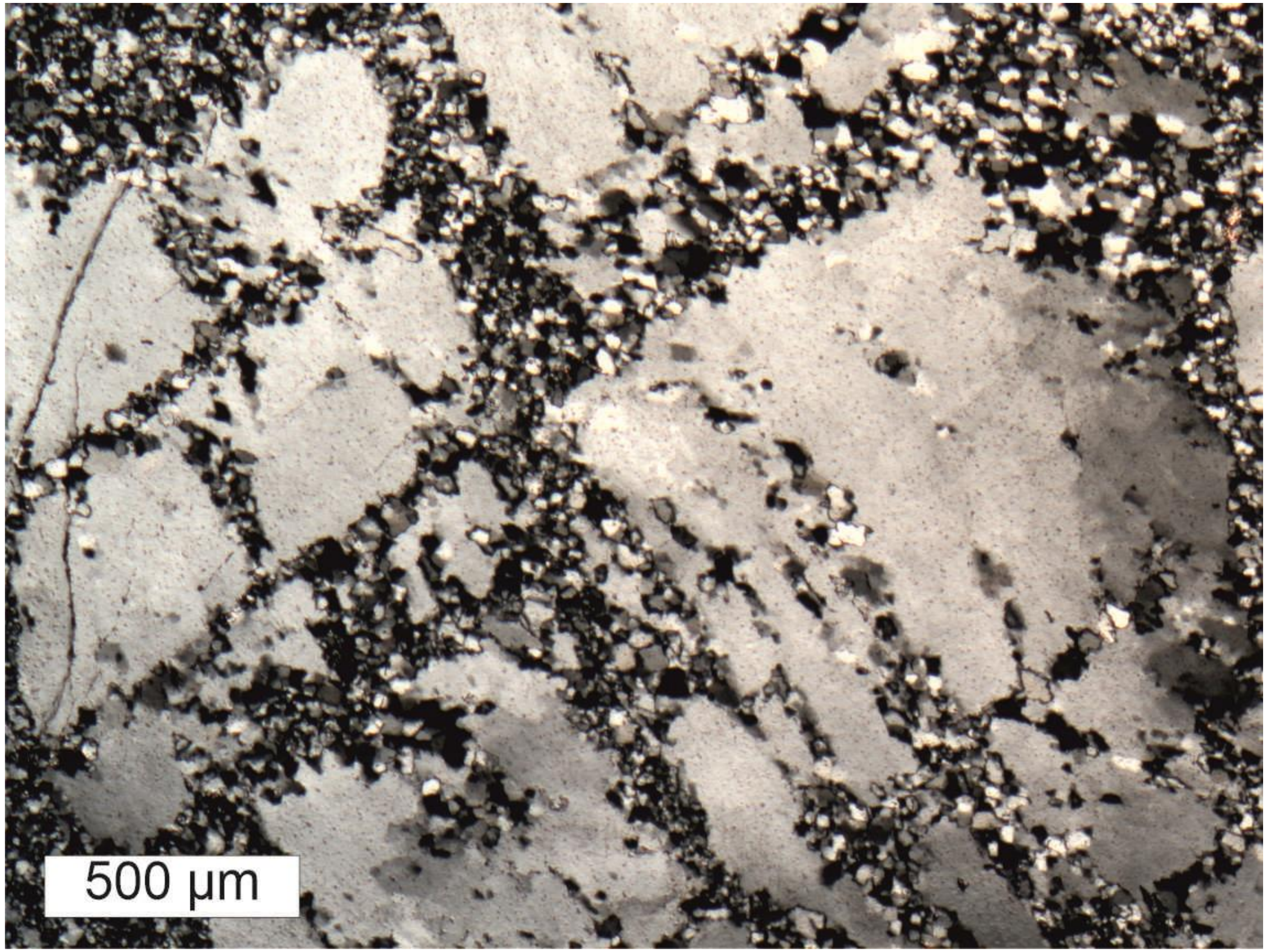
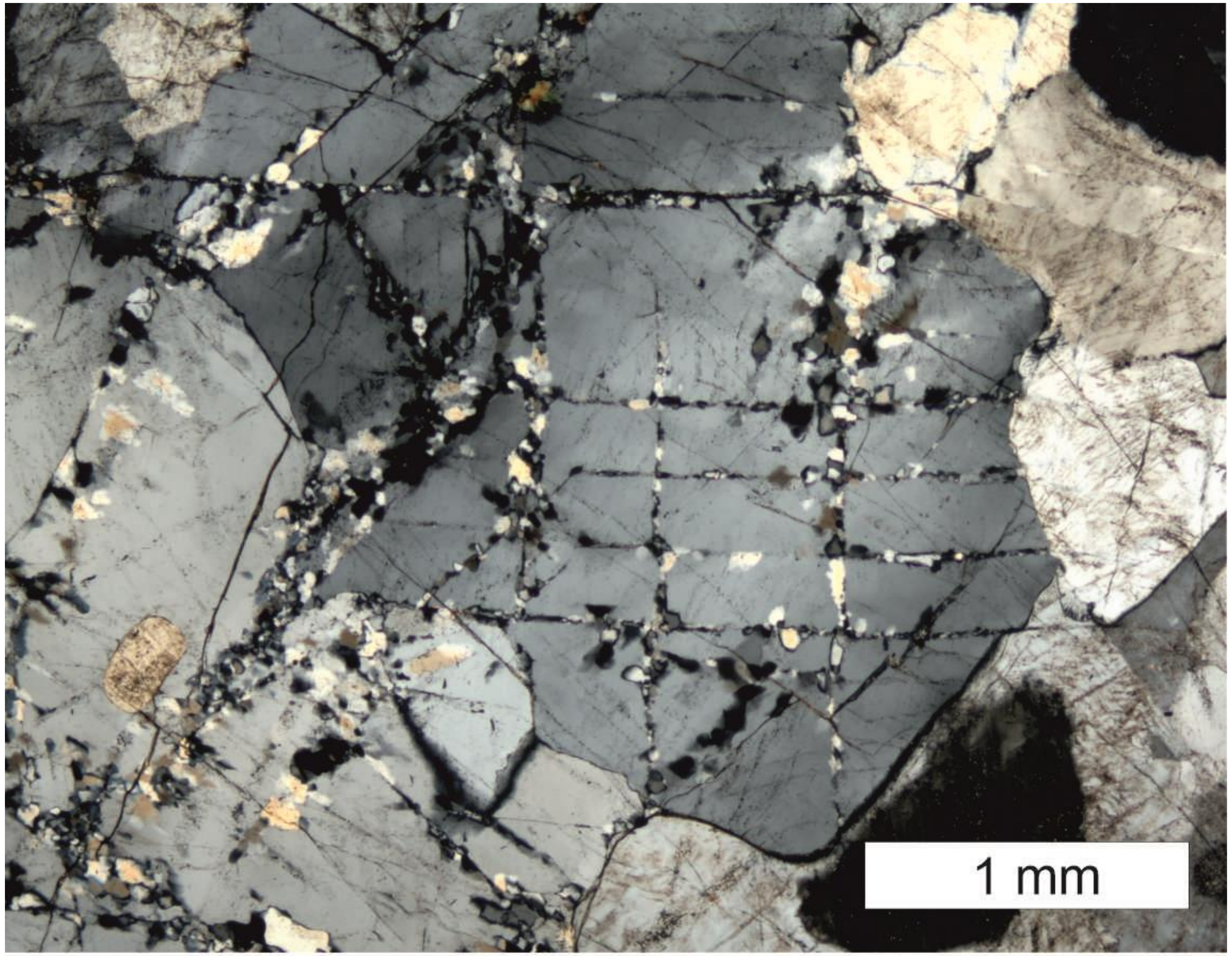
LUDWIG-
MAXIMILIANS-
UNIVERSITÄT
MÜNCHEN

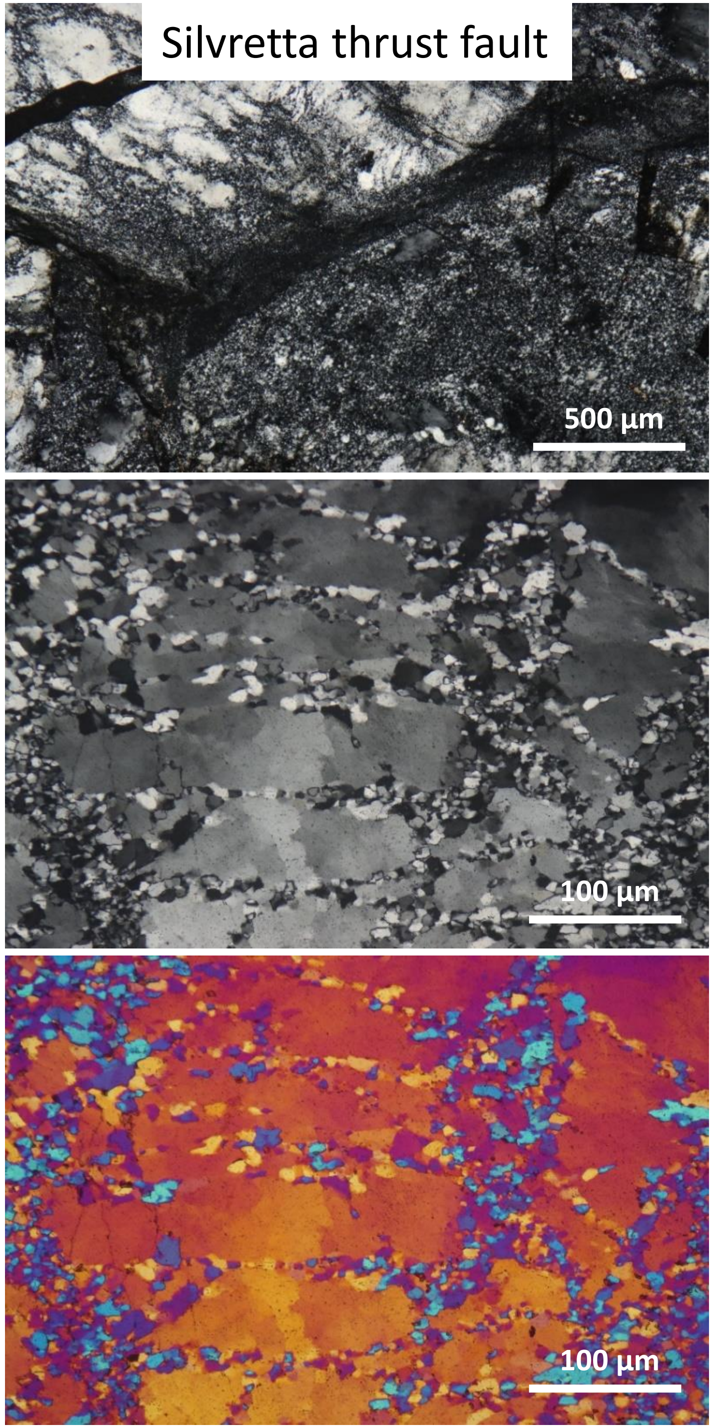
Fast stress-loading and -unloading during faulting and shock indicated by recrystallized grains along quartz cleavage cracks

Lisa M. Brückner, Fabian Dellefant, Claudia A. Trepmann





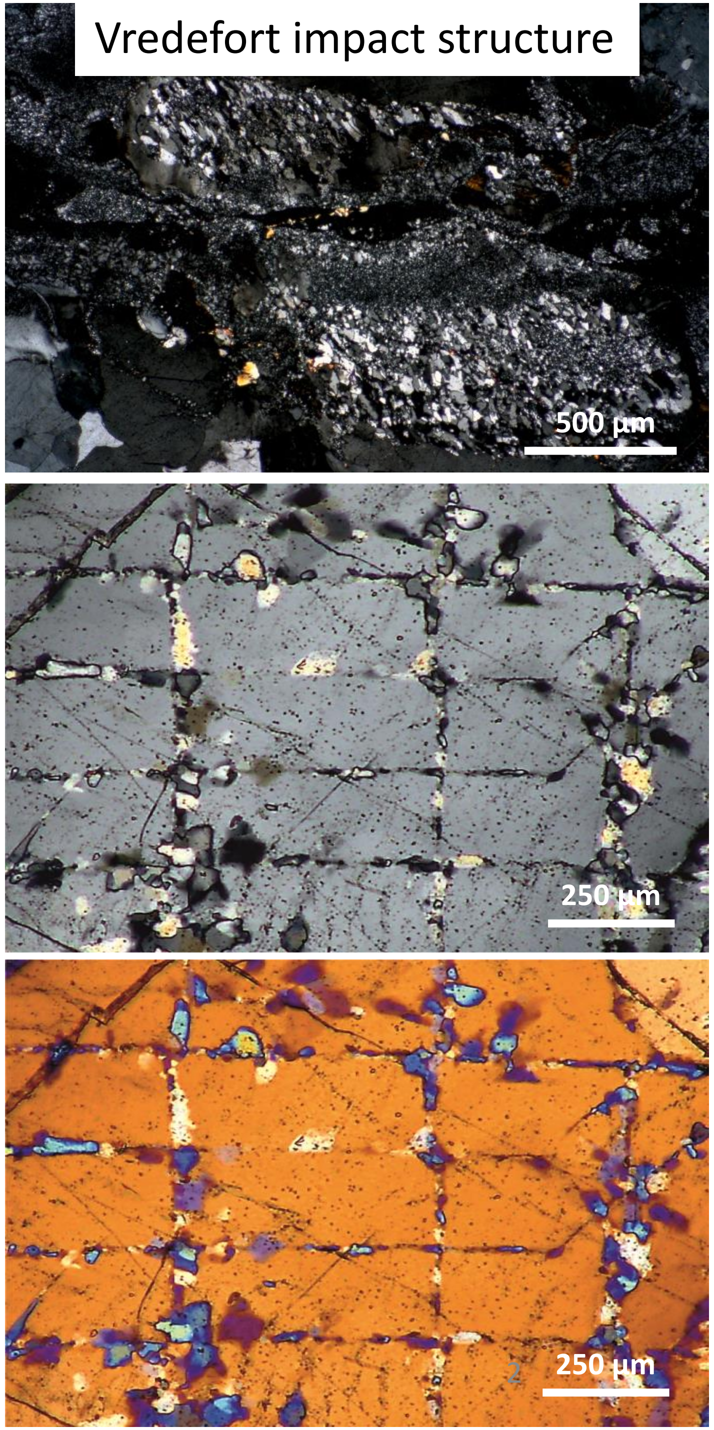
EGU 2022 - Vienna



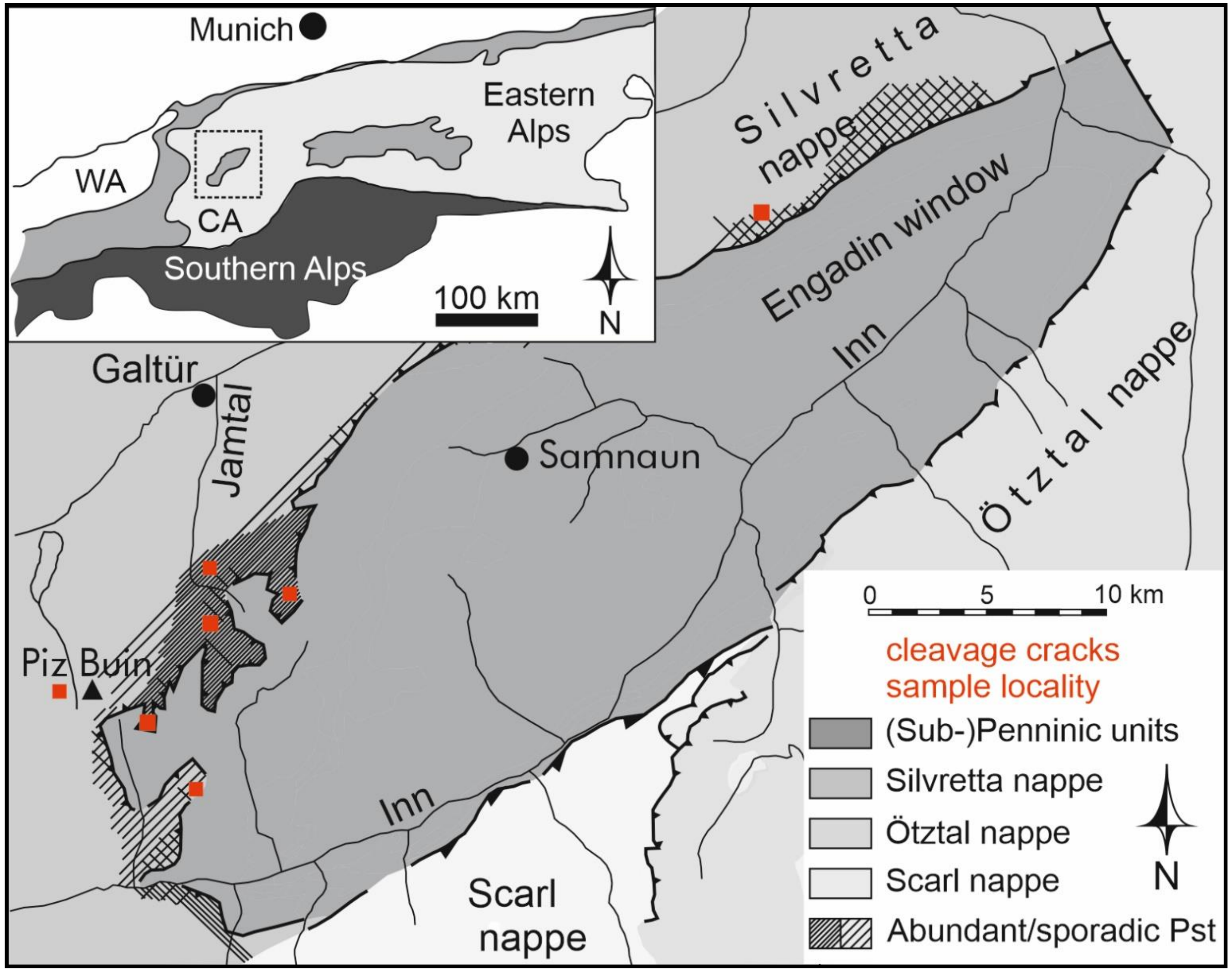
Cleavage cracks

- Cleavage cracks occur in minerals in sets parallel to specific crystallographic planes with low interfacial free energy controlled by the crystal structure
- Cleavage cracks are generally not associated with shear offsets
- Quartz usually does not show a good cleavage
- In high pressure compressional experiments they have been found to occur as tensile cracks during **unloading** (Kimberley et al., 2010)

We discuss their natural occurrence and formation in two different geologic settings (pseudotachylyte-bearing Silvretta basal thrust fault and shocked gneisses from the Vredefort impact structure) to obtain information on the deformation history.



1st locality - Silvretta thrust fault (Austria)



Modified after Koch and Masch, 1992

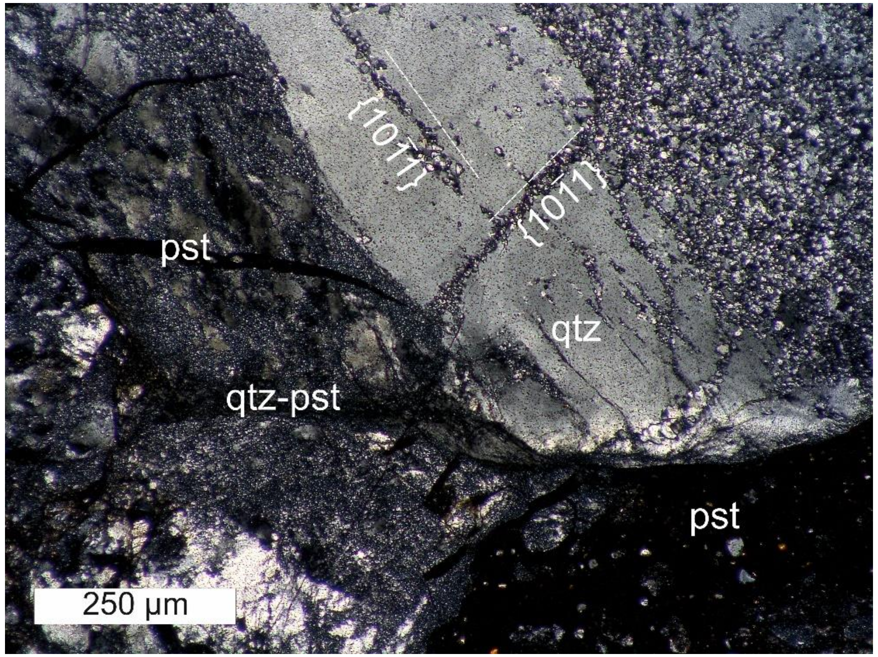
Quartz microstructures occur in spatial relation to pseudotachylytes

Quartz-rich gneisses and amphibolites

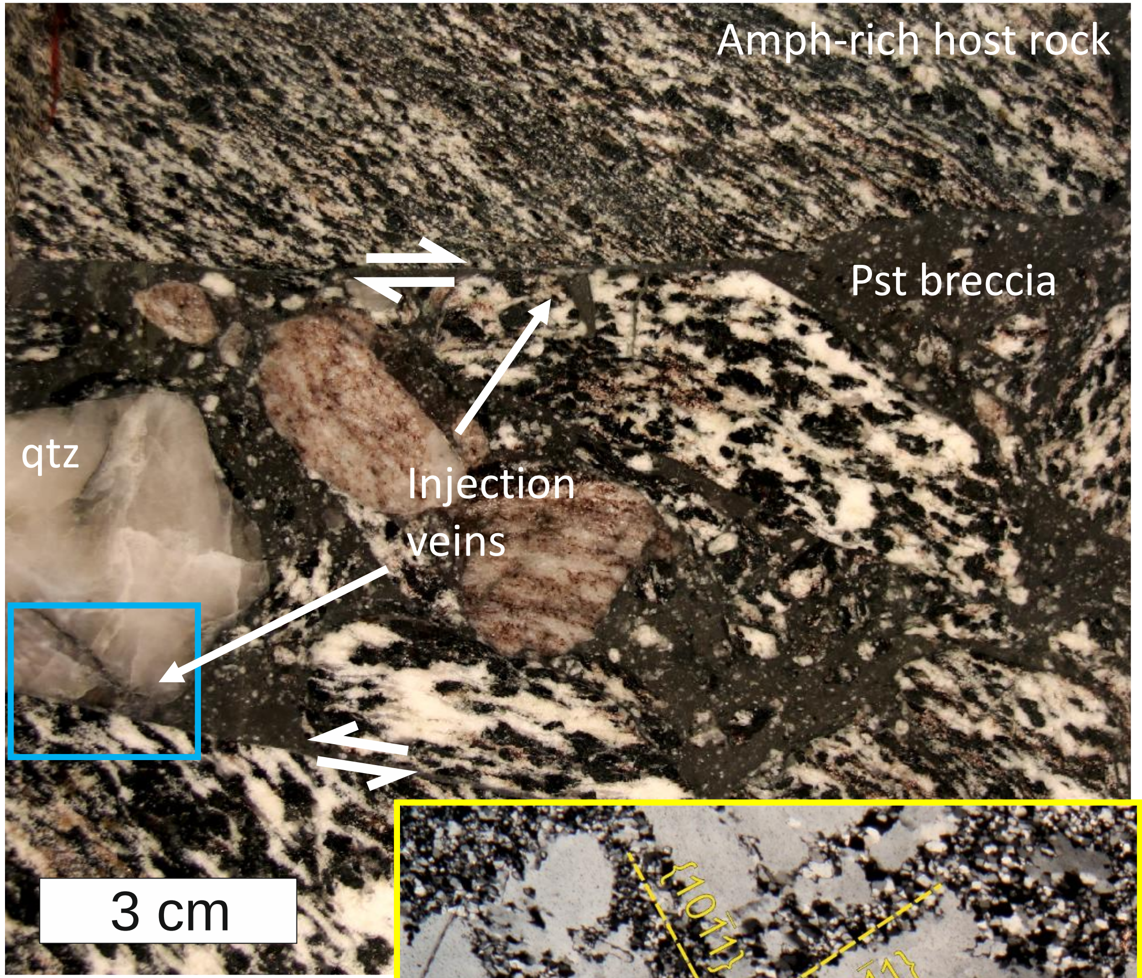
Common fault rocks: pseudotachylyte (-breccias) and mylonites
- developed under lower greenschist facies conditions
- formed at upper cretaceous times during the initial detachment of the nappe

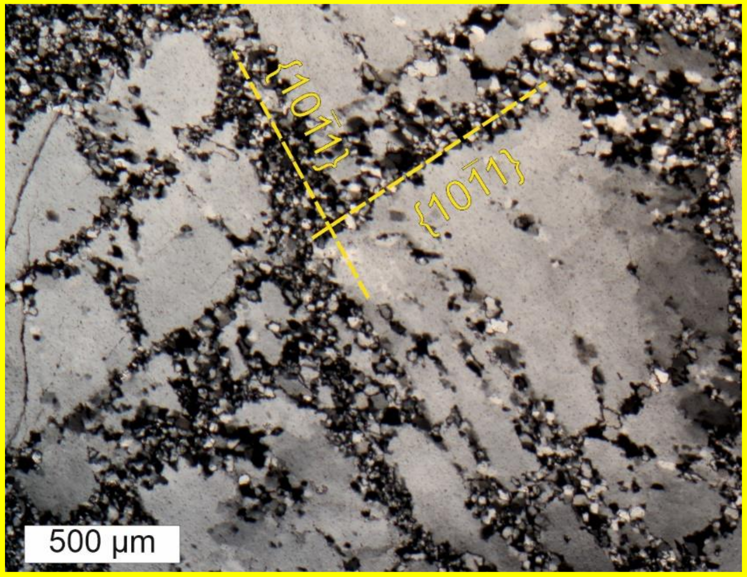
Pseudotachylytes are quenched friction-induced melts, associated with cataclasis

Stress cond.: σ_d > 400 MPa indicated by mechanical (-101)[101] twins in amphibole (Brückner and Trepmann, 2021)

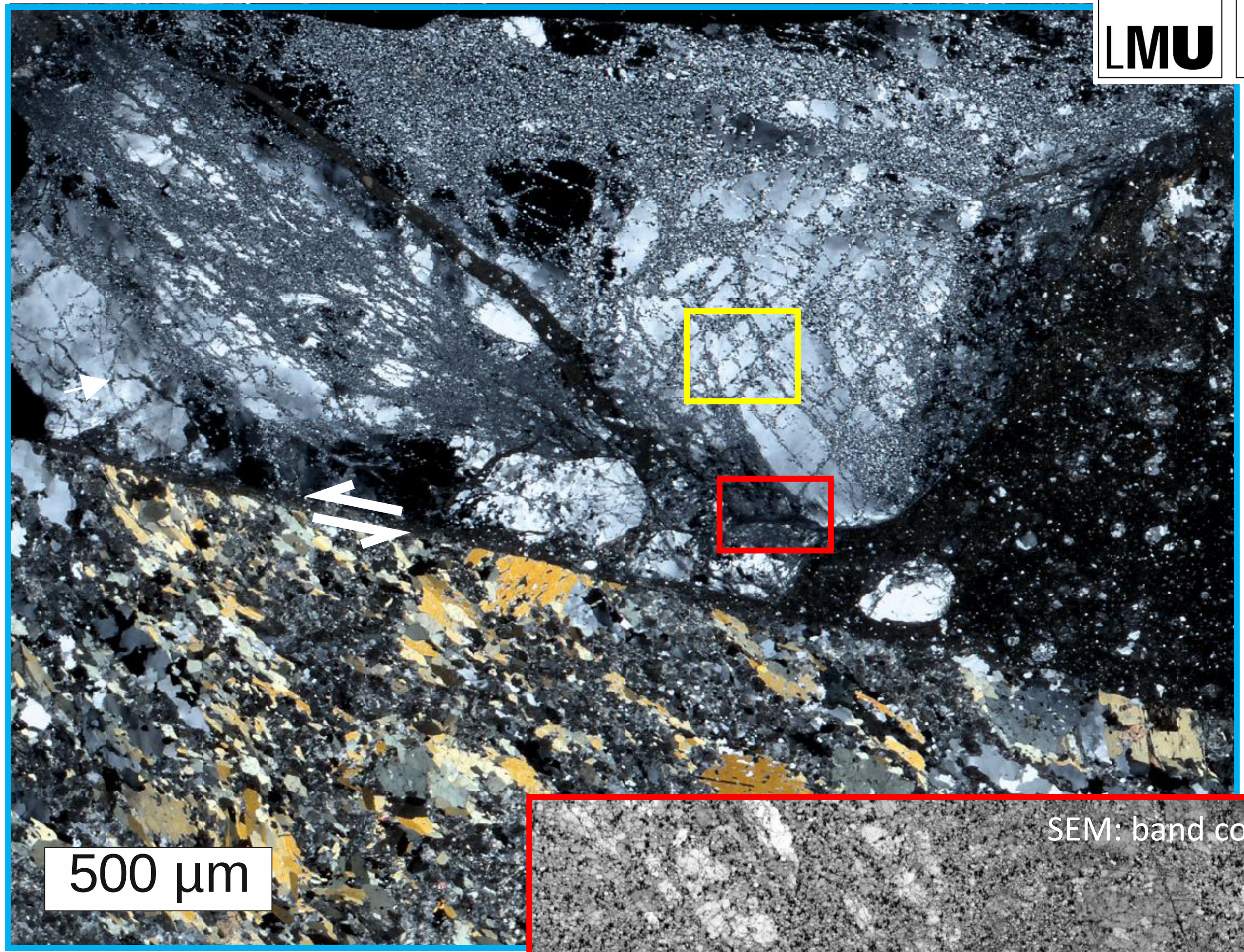


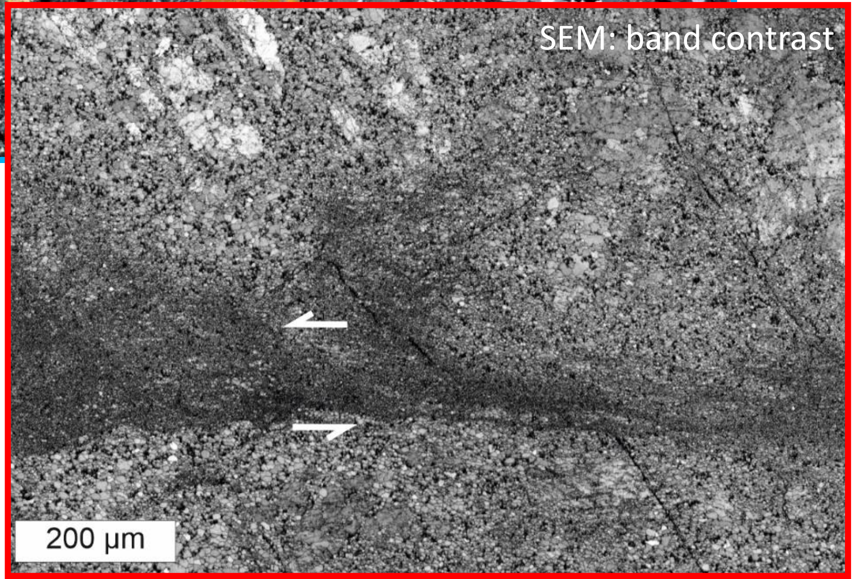
Silvretta fault rocks





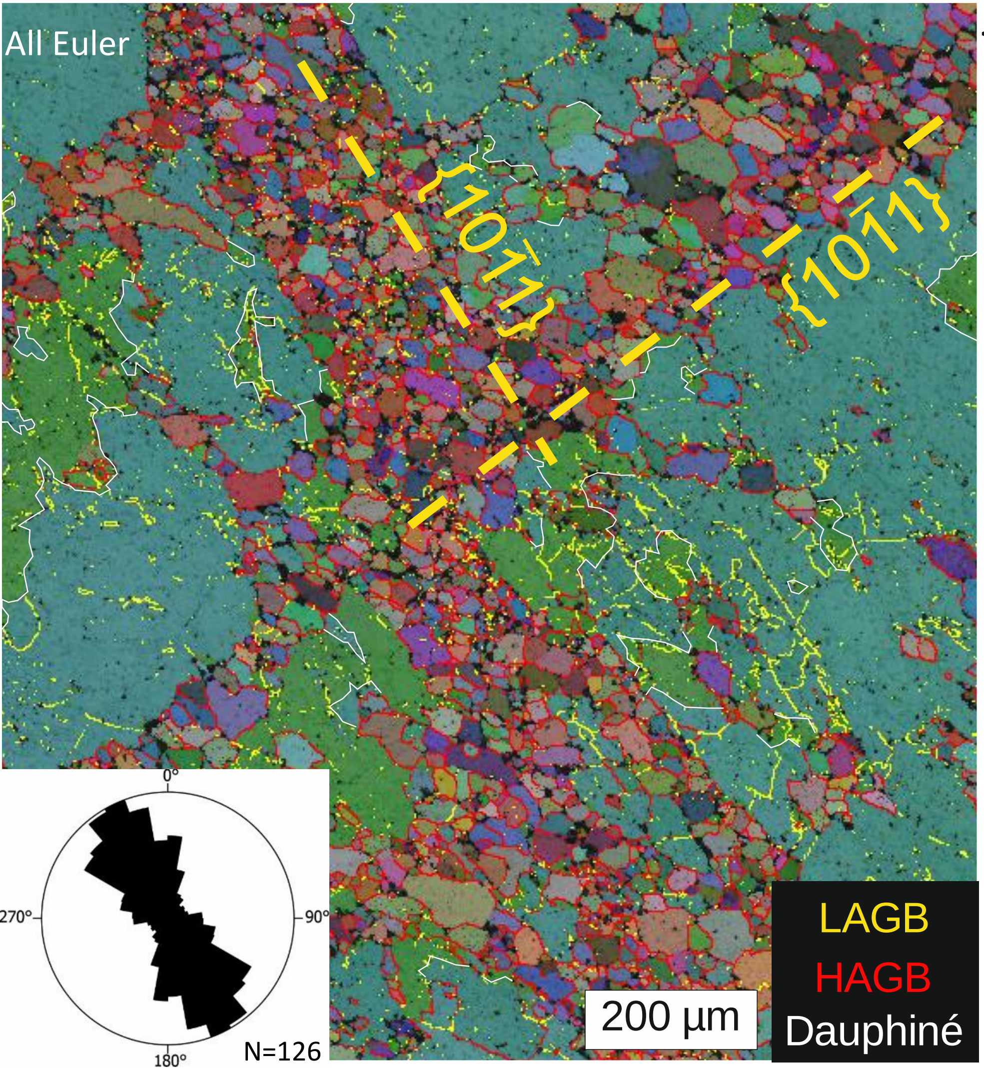
Cleavage cracks:
No shear offset





Pseudotachylytes:
Shear

Silvretta fault rocks

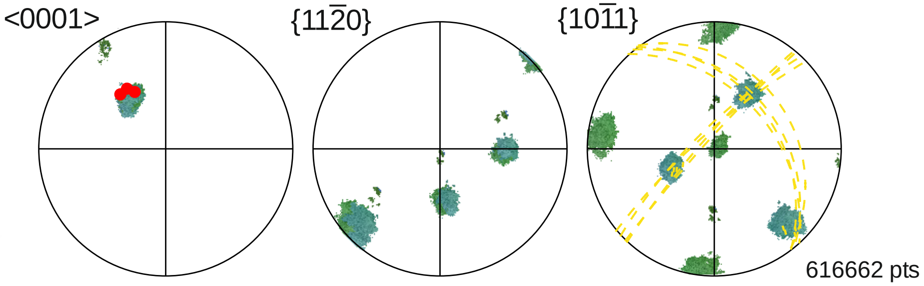


Aspect ratio:
1.7 ± 0.5 µm

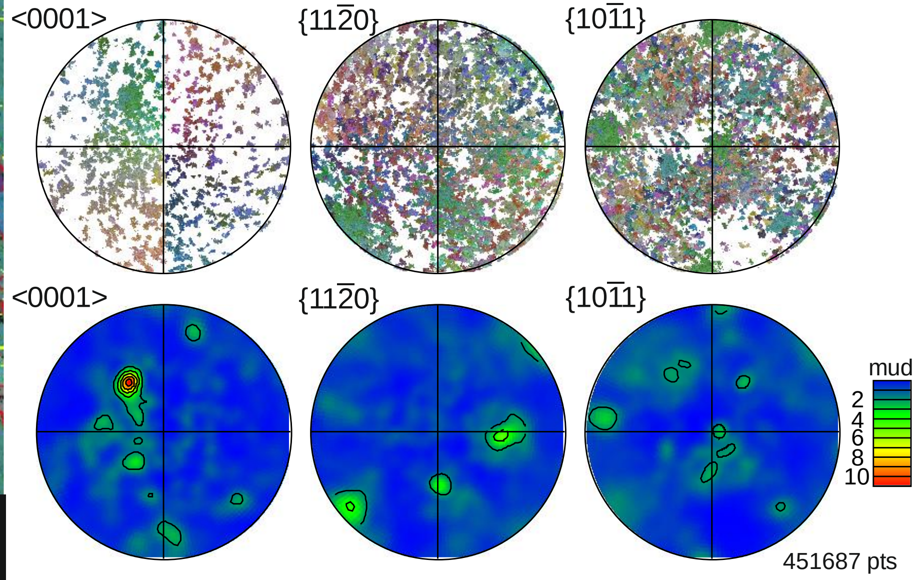
Spacing:
226 ± 100 µm

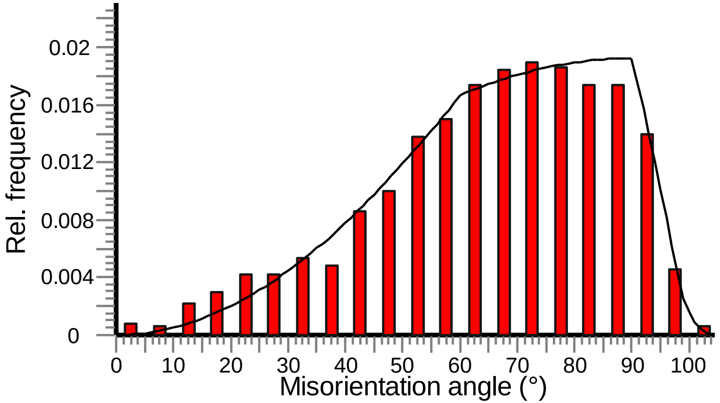
No evidences of shear offset

Host



New grains < 30 µm





U-stage measurements of:
{10-11} cleavage cracks
c-axis of host quartz

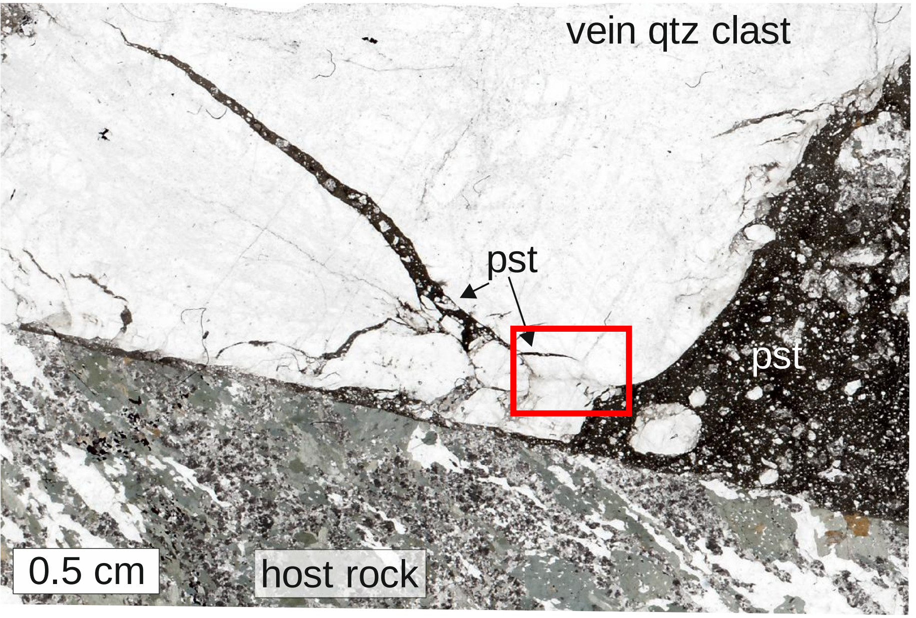
New grains:

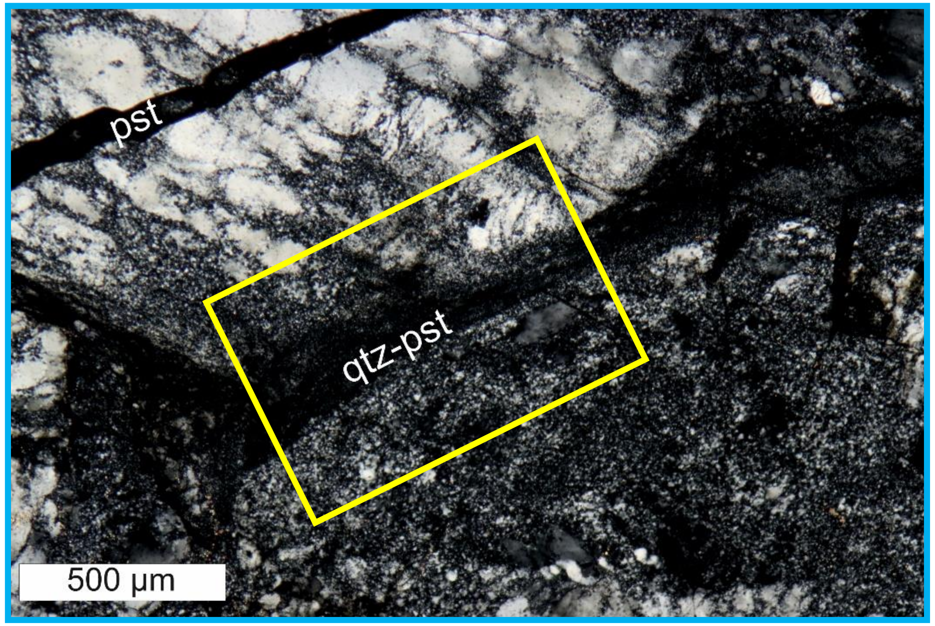
- Grain diameter: 10 ± 6 µm
- Slight host control
- Slightly elongated with long axis parallel to {10-11}
- No internal misorientation

⇩

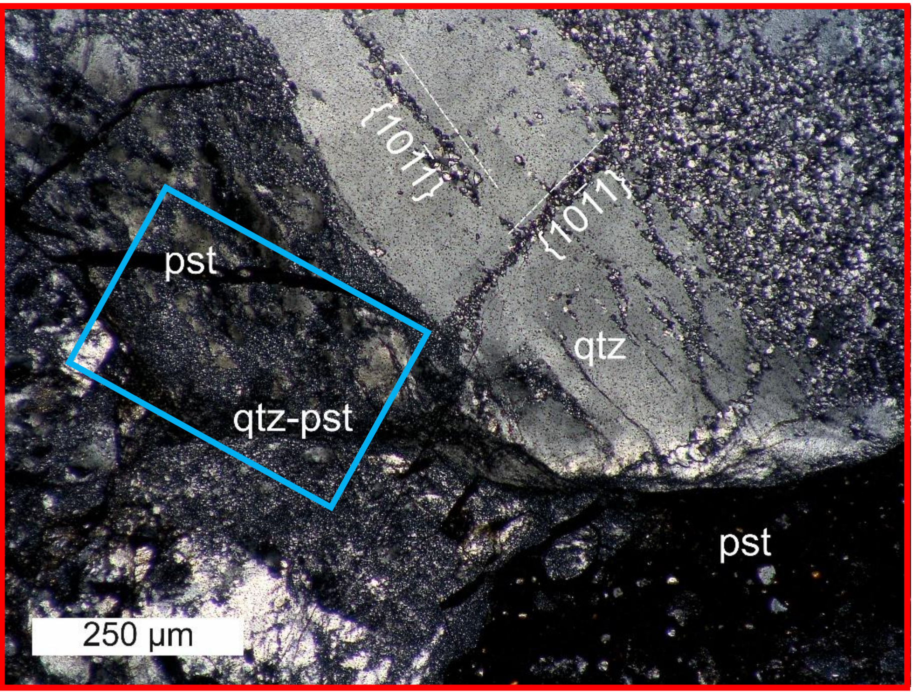
Secondary quartz grains formed during annealing after pseudotachylyte formation localized at the damage zone at quasi-isostatic conditions

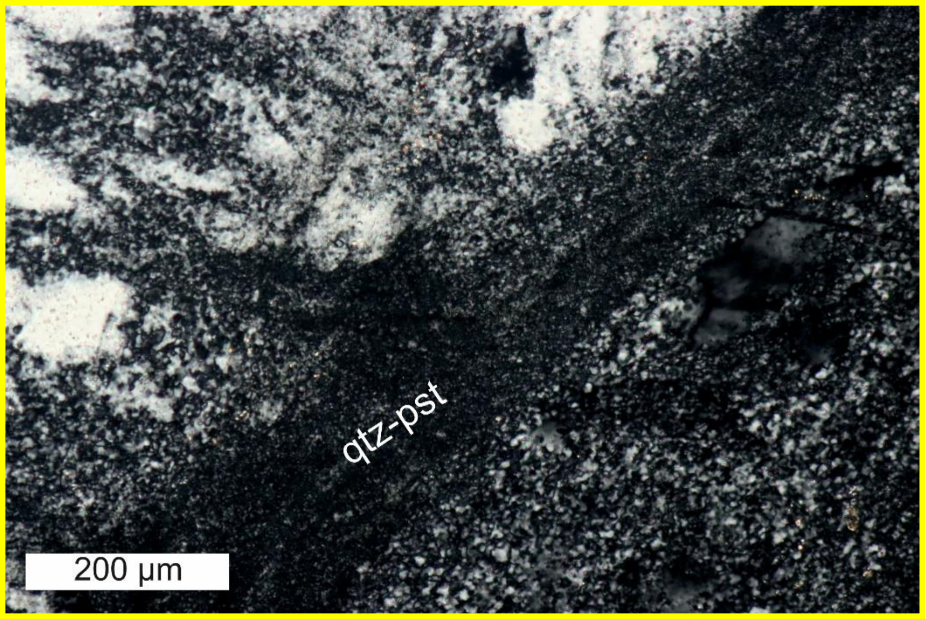
Silvretta fault rocks



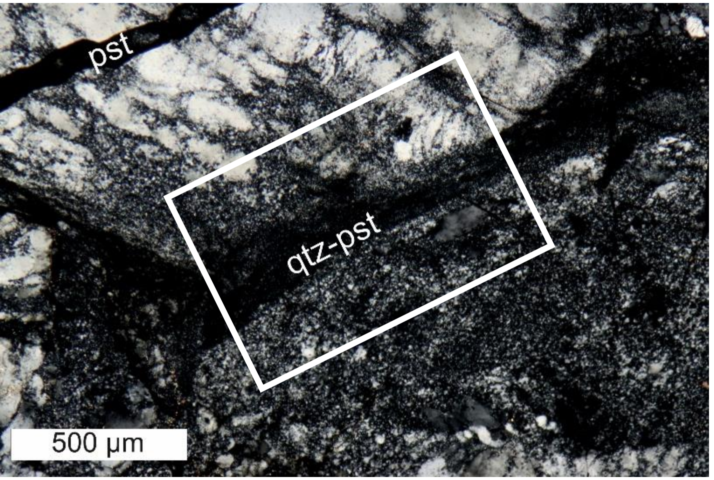


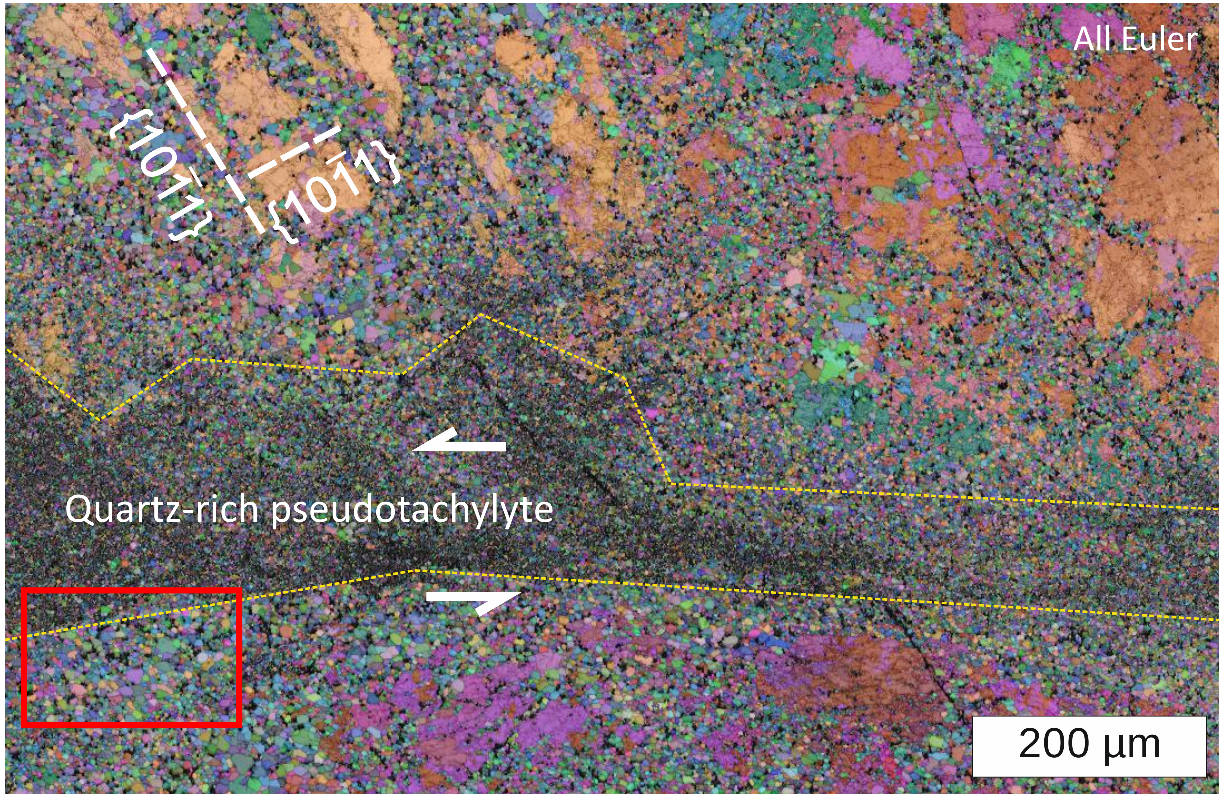
Fine-grained quartz-rich layers (qtz-pst) occur frequently in quartz clasts with cleavage cracks and associated with typically polymineralic pseudotachylytes





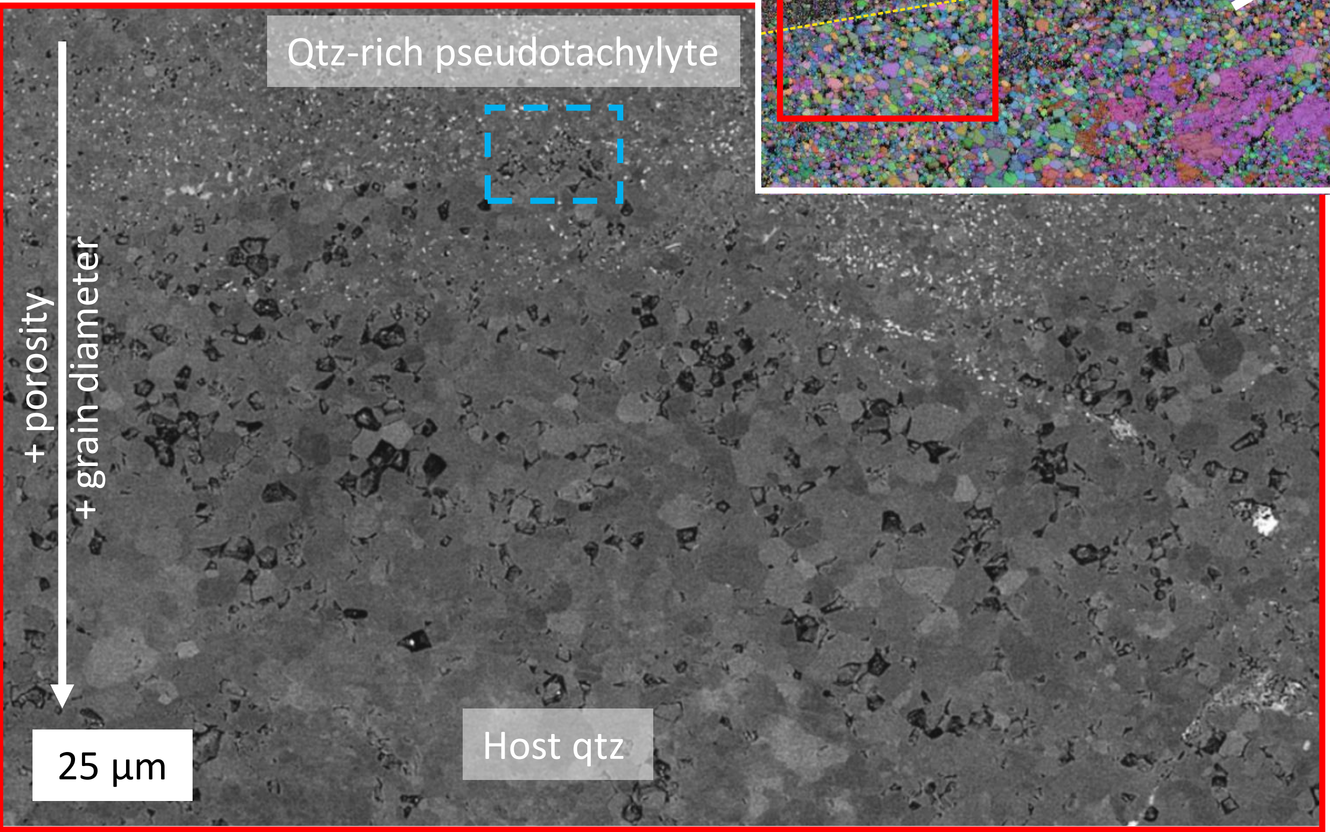
Silvretta fault rocks

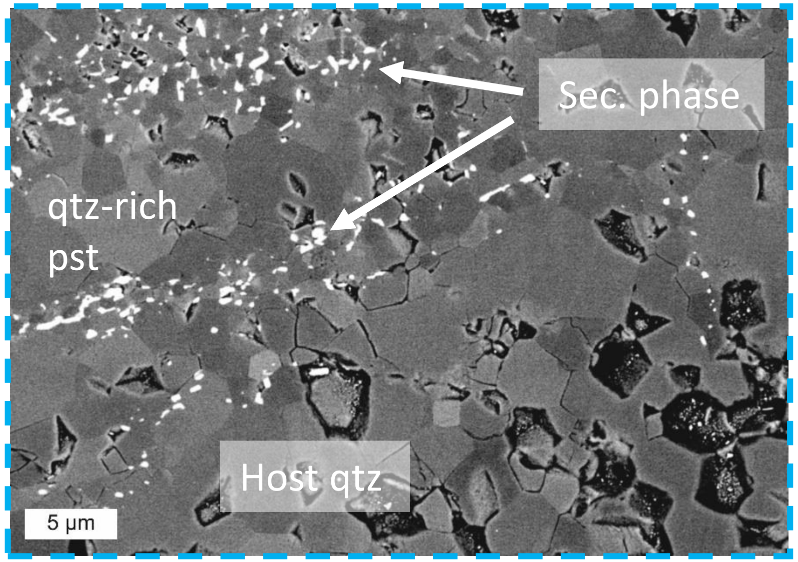




"Quartz-rich pseudotachylyte":

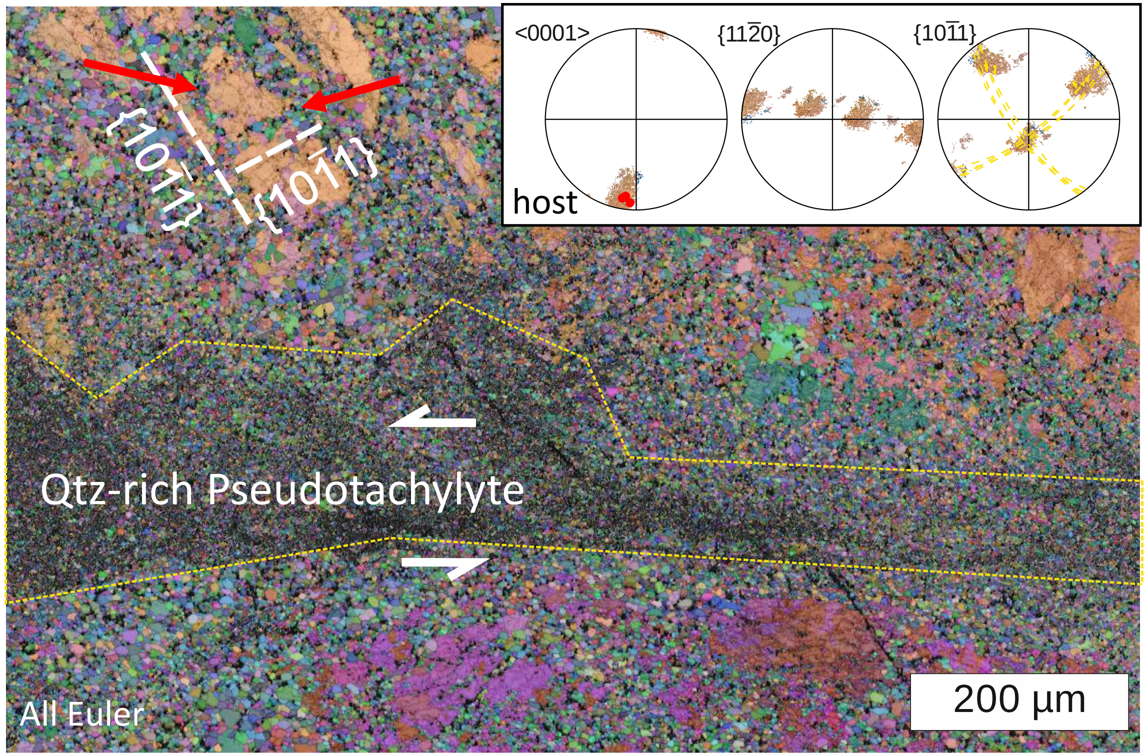
- Marked shear offset
- mostly pure ultra-fine-grained quartz
- Secondary phases (alkali-feldspar and amphibole) and lower porosity compared to the host indicating melting played a role



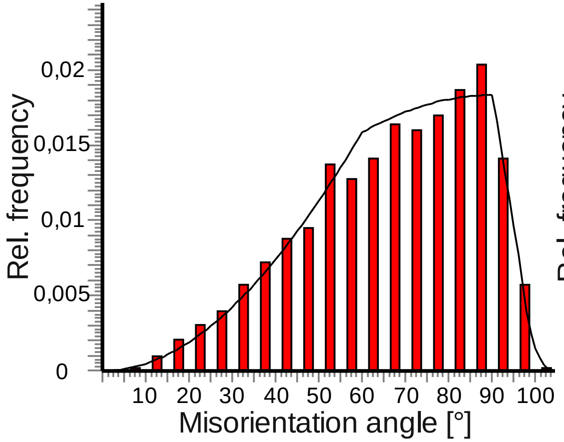


Melting temp. of quartz undergoing rapid friction: 1300-1500 °C (Lee et al., 2017)

Silvretta fault rocks

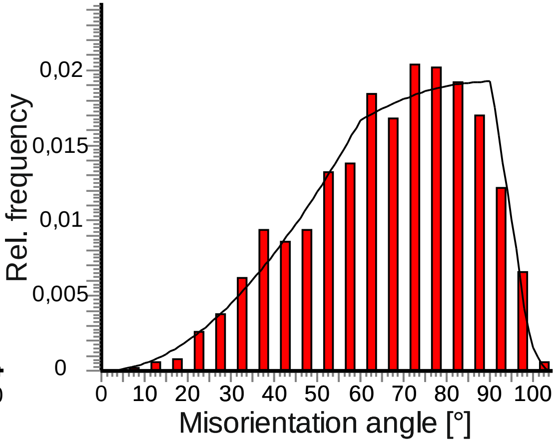


Quartz-rich Pseudotachylyte

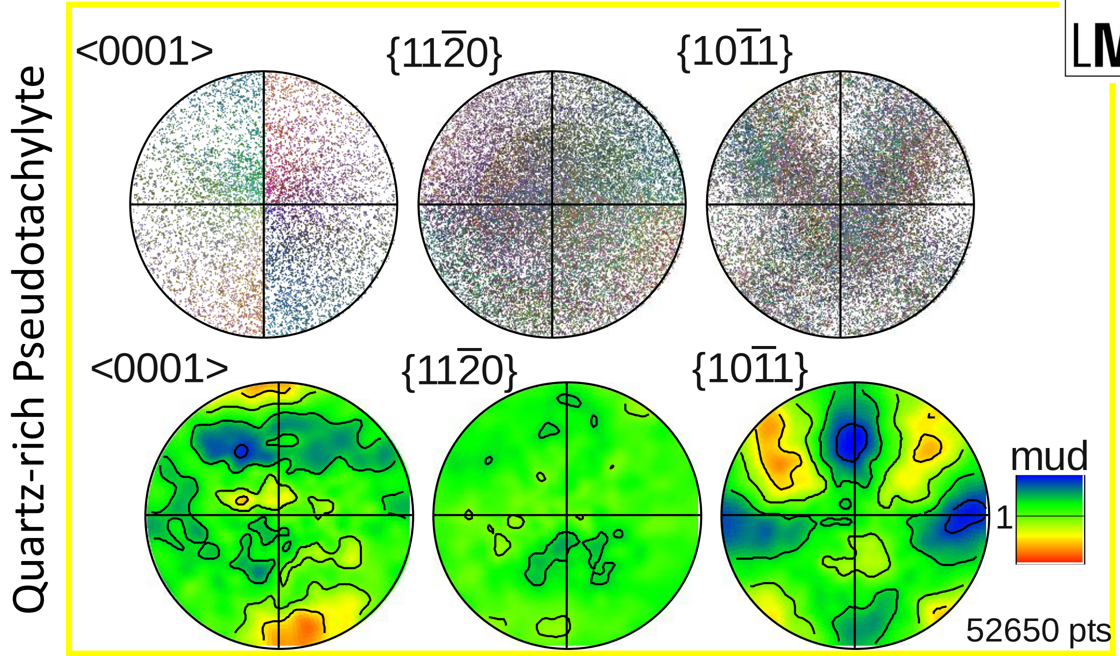


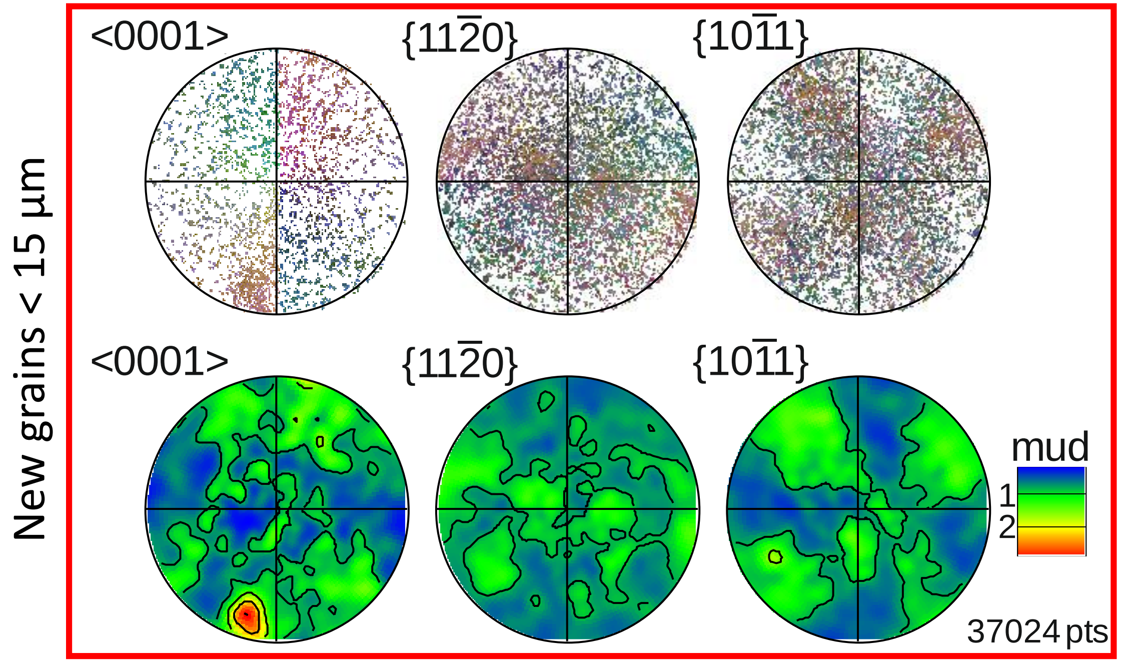
Grain diameter: 2.9 ± 0.7 µm

New grains < 15 µm



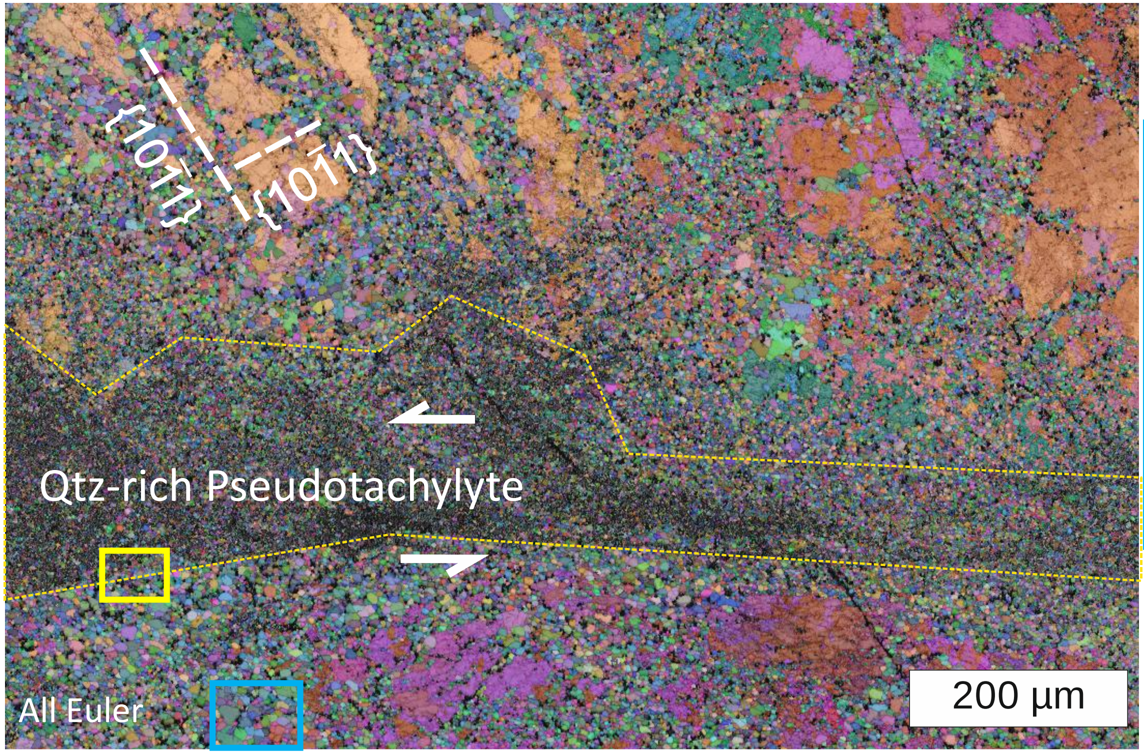
Grain diameter: 4 ± 2 µm

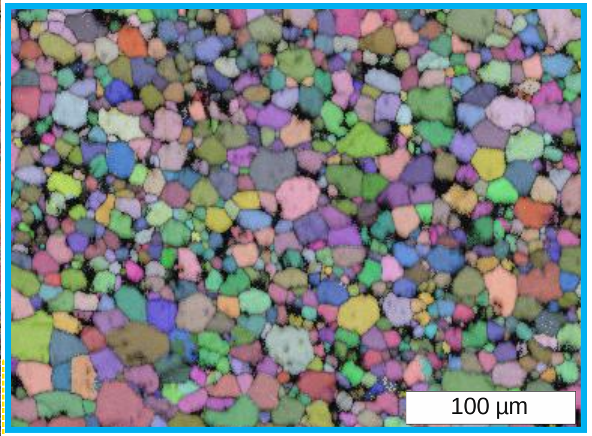


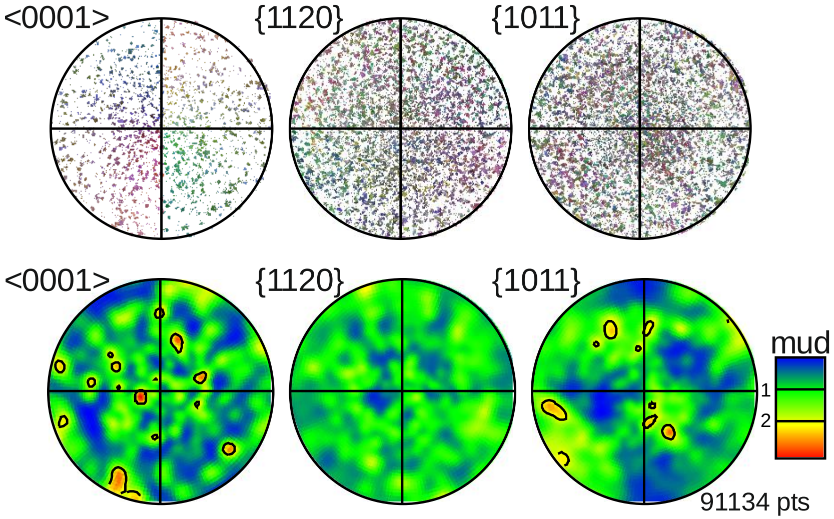


LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

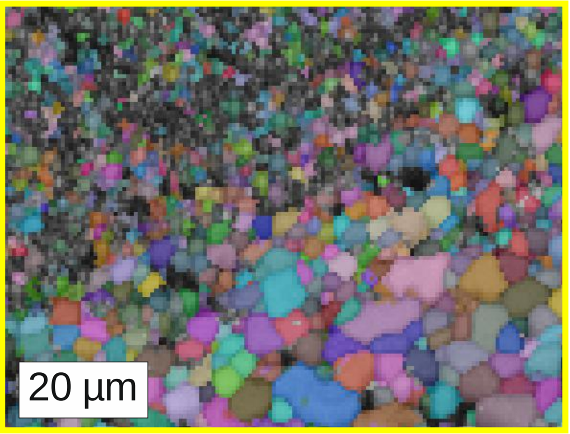
Silvretta fault rocks

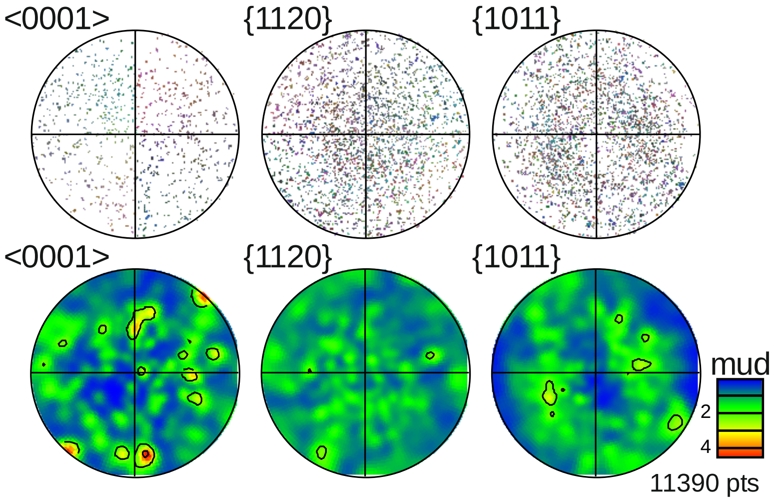






Grain diameter: 4.0 ± 1.5 µm





Grain diameter: 2.4 ± 1.1 µm

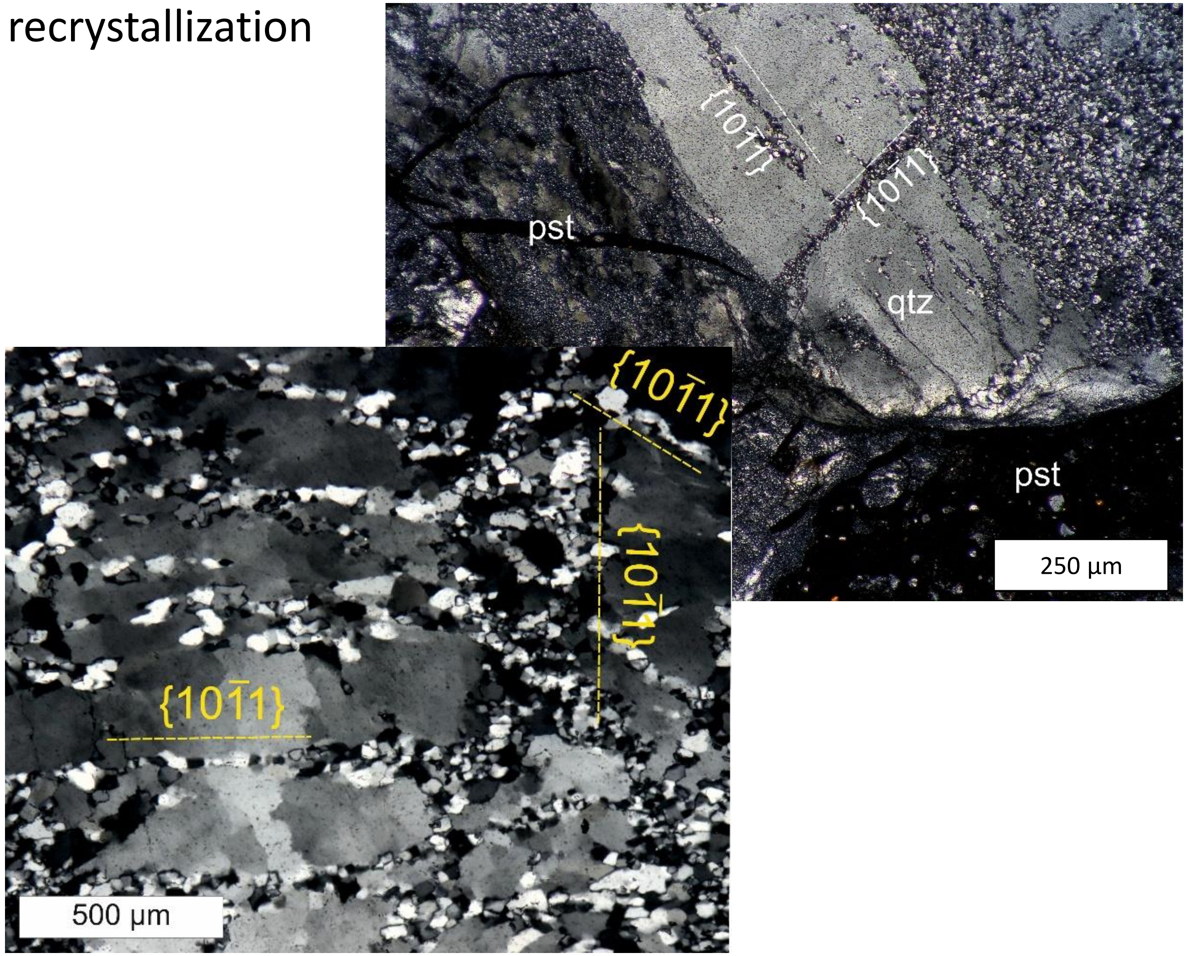
New grains:

- Small grains show a large spread of crystallographic orientations
- New grains become larger with decreasing distance to the qtz-rich pseudotachylyte
- No deformation of small new grains

New grains within deformed host

Cleavages crack formation as tensile cracks without shear

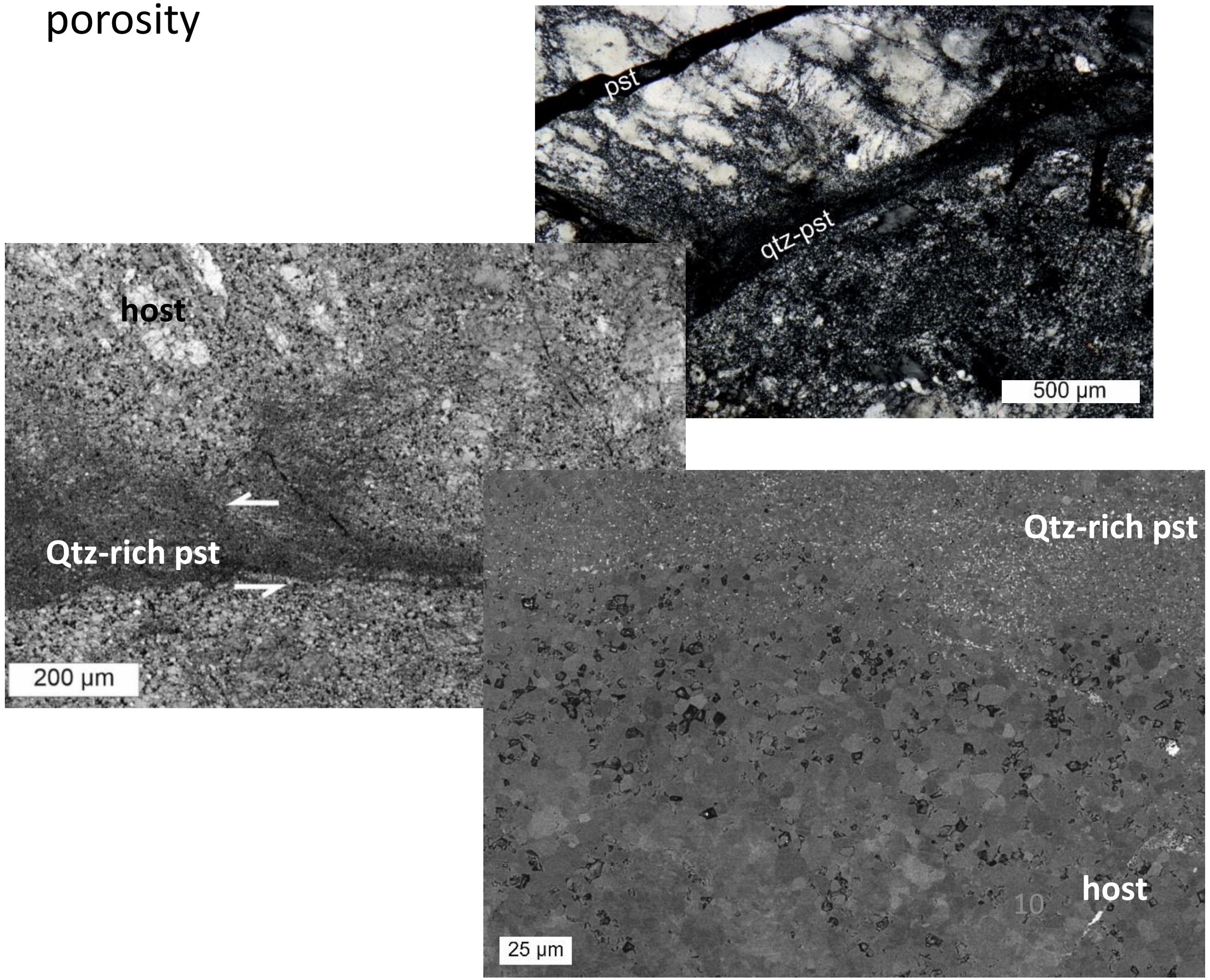
New grains replacing deformed host along damage zone of cleavage cracks driven by reduction of strain energy, i.e. recrystallization



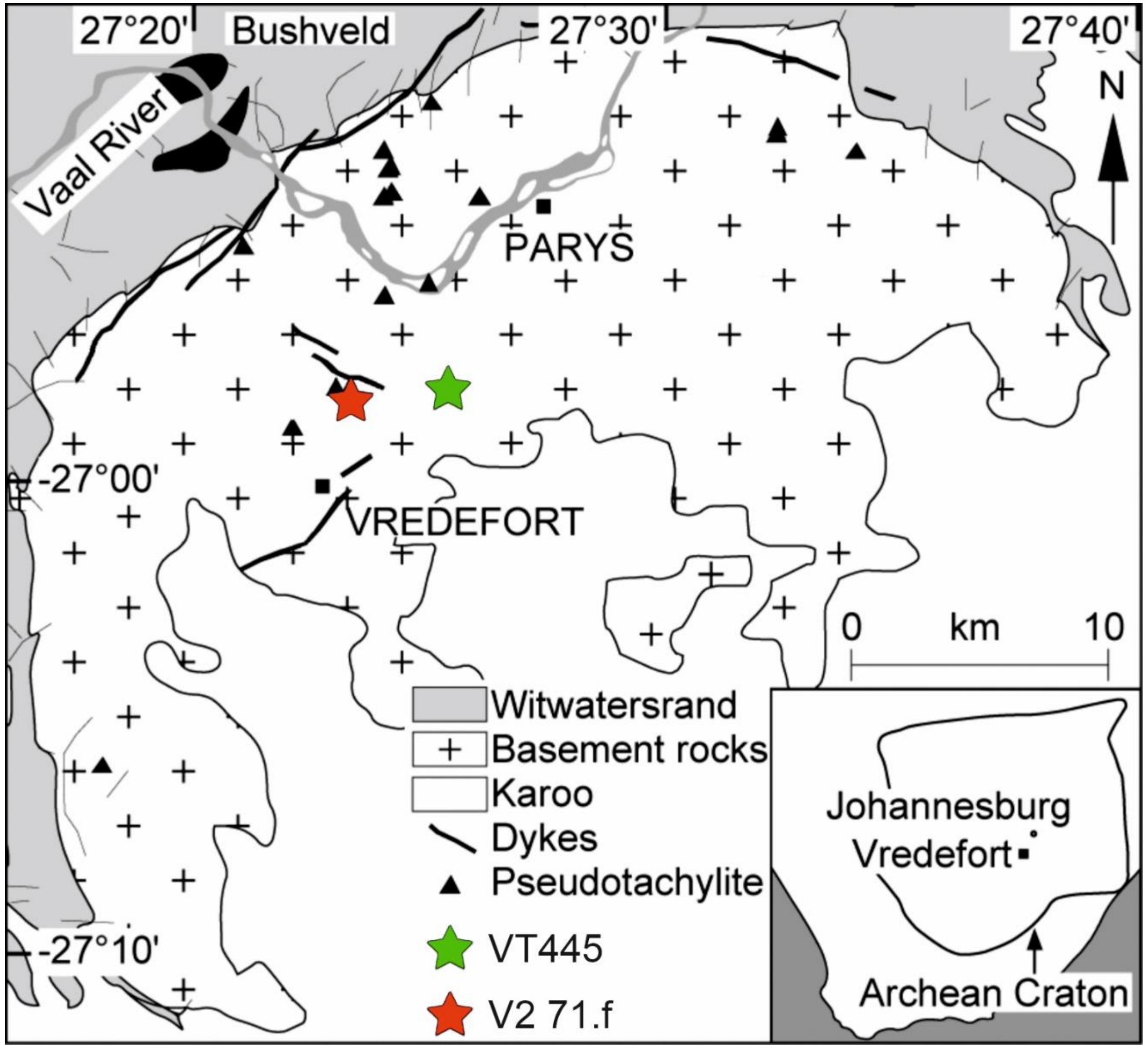
Fine-grained aggregates in qtz-rich pseudotachylyte

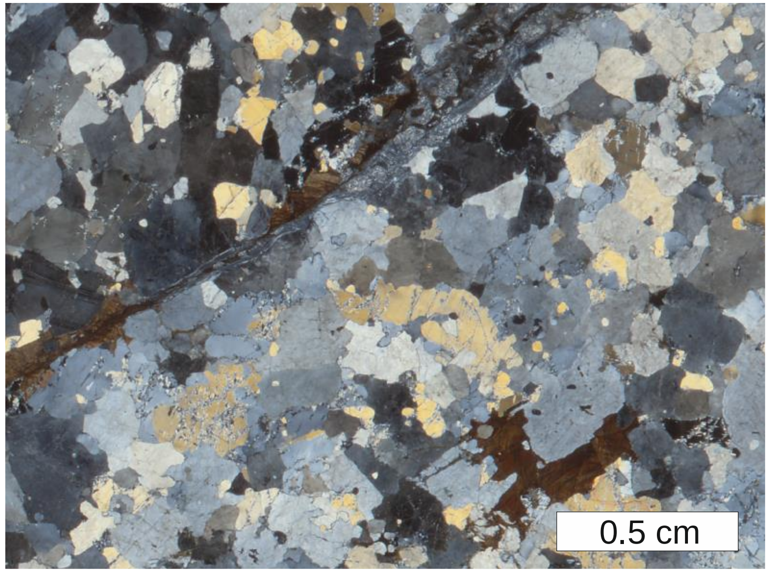
Quartz-rich Pseudotachylytes are generated by shear that causes a higher strain in the damage zone

Microcrystalline quartz layers suggesting cataclasis together with melting indicated by multiphase aggregates and lower porosity



2nd locality - Vredefort impact structure (South Africa)

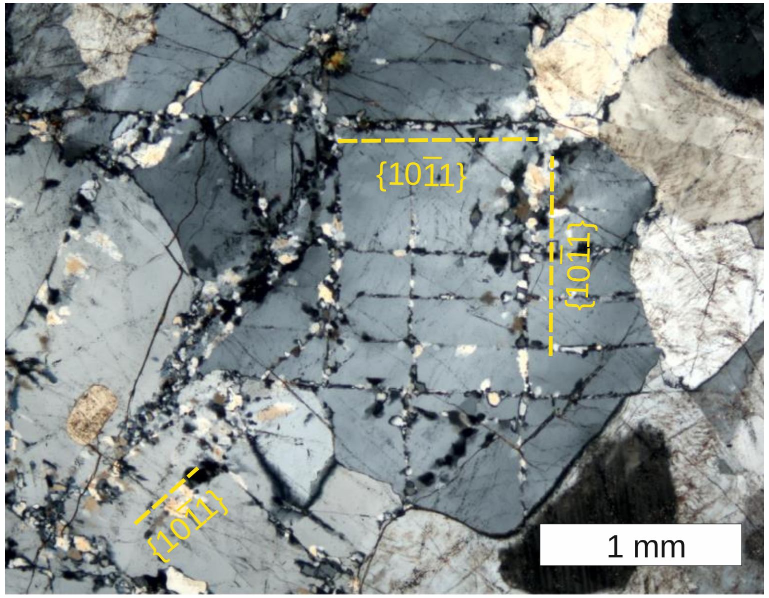




Archean amphibolite- to granulite-facies migmatitic gneisses with planar features

Meteorite impact at about 2 G years

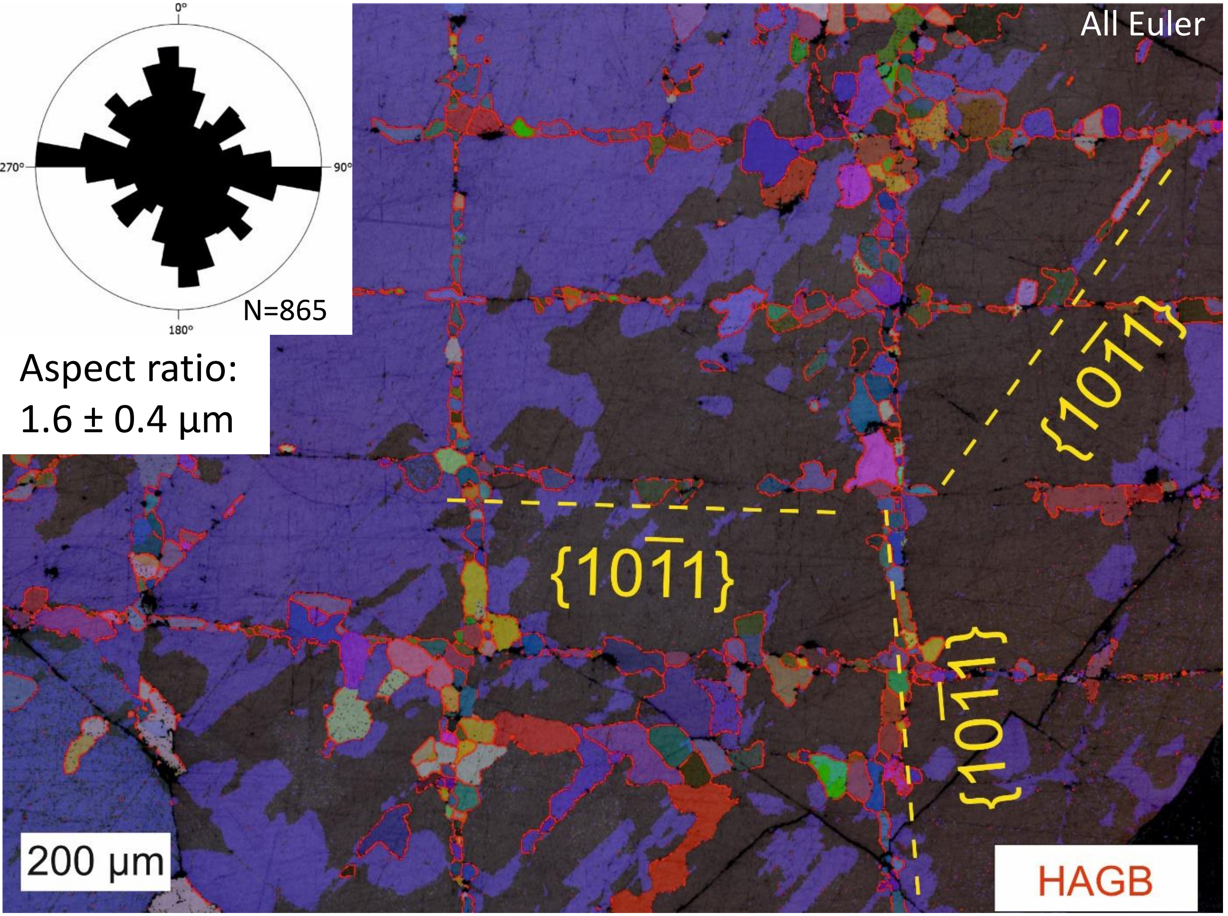
Shock pressures indicated by shock effects: <20 GPa

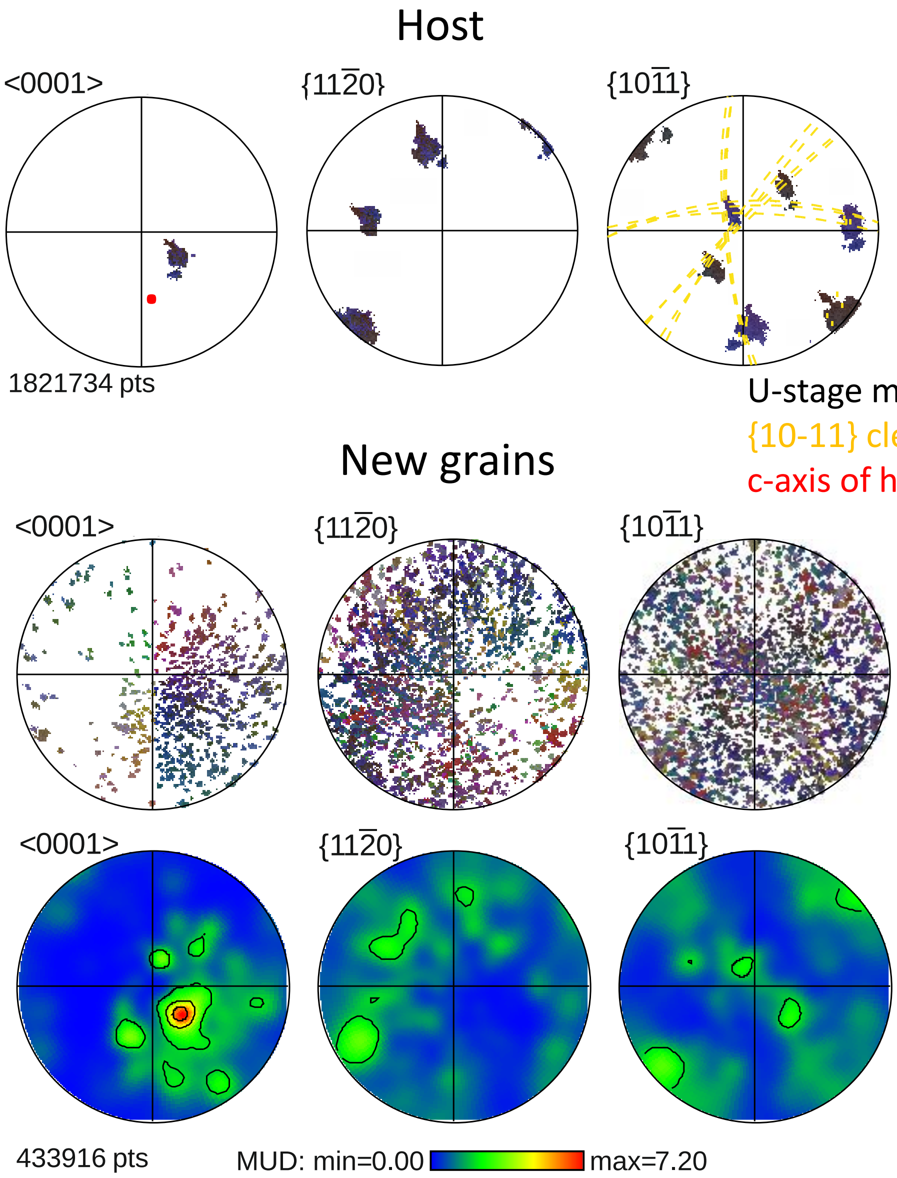


Similar quartz microstructures compared to the Silvretta thrust fault

Spacing: 136 ± 107 µm

Shocked Vredefort Archean gneisses





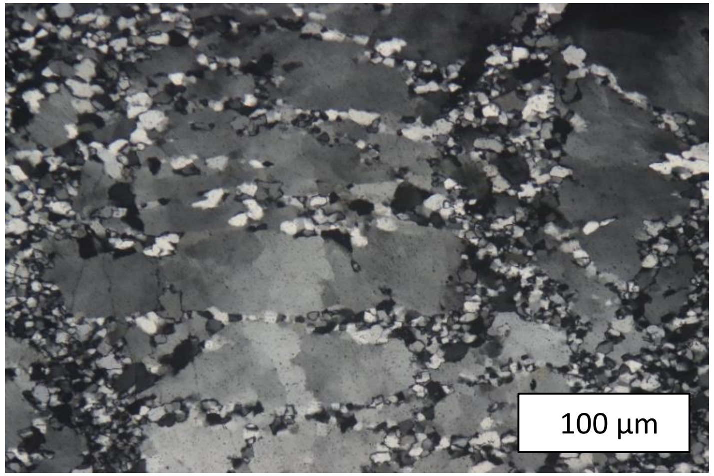
U-stage measurements of:
{10-11} cleavage cracks
c-axis of host quartz

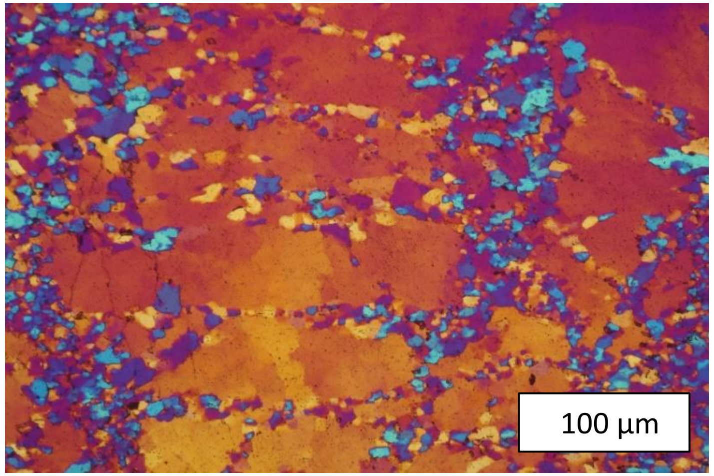
New grains:

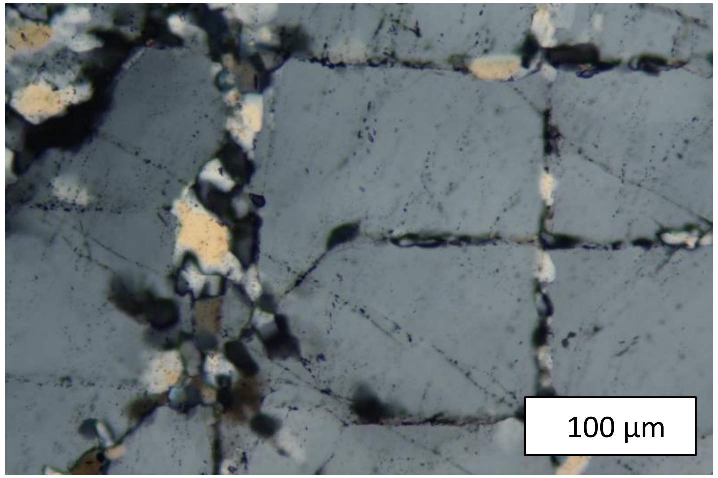
- Grain diameter: 15 ± 1 µm
- Slight host control
- Slightly elongated with long axis parallel to {10-11}
- No internal Misorientation or CPO → No evidence of deformation after growth

⇨ Analogous to Silvretta: growth of new quartz grains occurs restricted to the damage zone of cleavage cracks at quasi-isostatic stresses during post-shock annealing

No evidences of shear offset







Conclusions

- {10-11} quartz cleavage cracks develop as
  - **tensile cracks** in fault rocks from the Silvretta basal thrust **associated to brecciation and pseudotachylyte formation**
  - **tensile cracks upon unloading from shock conditions** in the shocked quartz in the Vredefort gneisses
- New grains in the host crystals form by **strain-induced grain boundary migration** along the **damage zone around the cleavage cracks** at quasi-isostatic conditions
- In contrast, **microcrystalline quartz** along planes of **high shear strain** (i.e. pseudotachylytes) are interpreted to be related due to cataclasis, probably with shear heating and melting

The new grains along the damage zone surrounding cleavage cracks represent quasi-instantaneous loading to high stresses and fast unloading to quasi-isostatic stress conditions.

References

Brückner, L. M., & Trepmann, C. A. (2021). Stresses during pseudotachylyte formation - Evidence from deformed amphibole and quartz in fault rocks from the Silvretta basal thrust (Austria). *Tectonophysics*, *817*(June), 229046. https://doi.org/10.1016/j.tecto.2021.229046

Kimberley, J., Ramesh, K. T., & Barnouin, O. S. (2010). Visualization of the failure of quartz under quasi-static and dynamic compression. *Journal of Geophysical Research: Solid Earth*, *115*(8). https://doi.org/10.1029/2009JB007006

Koch, N., & Masch, L. (1992). Formation of Alpine mylonites and pseudotachylytes at the base of the Silvretta nappe, Eastern Alps. *Tectonophysics*, *204*(3–4), 289–306. https://doi.org/10.1016/0040-1951(92)90313-U

Lee, S. K., Han, R., Kim, E. J., Jeong, G. Y., Khim, H., & Hirose, T. (2017). Quasi-equilibrium melting of quartzite upon extreme friction. *Nature Geoscience*, *10*(6), 436–441. https://doi.org/10.1038/ngeo2951