RUHR UNIVERSITÄT BOCHUM RUB

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Amorphization of Plagioclase at high-pressure, high-temperature conditions

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Motivation

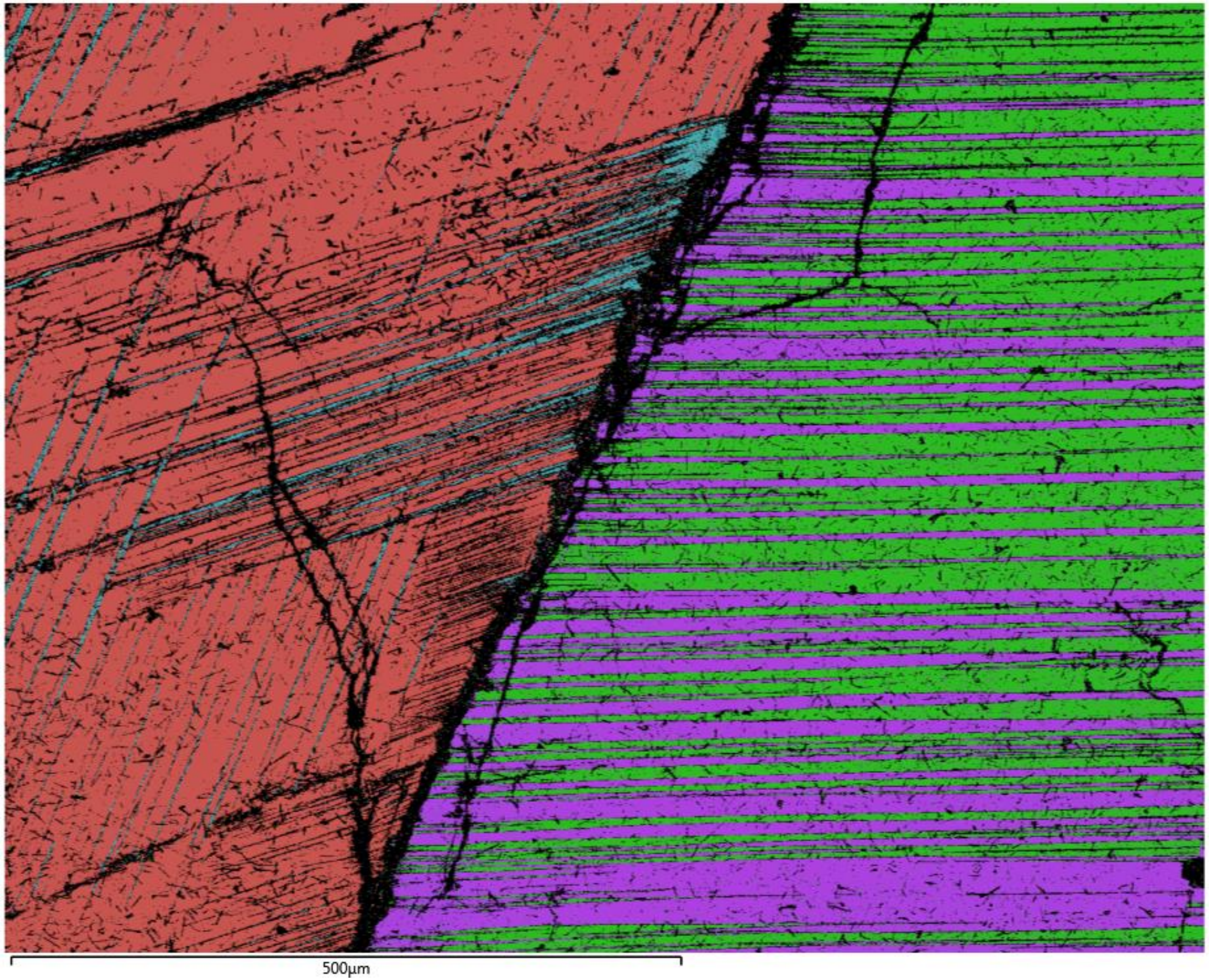
Deformation twinning is a common deformation mechanism in various materials that are exposed to stress and temperature.

Right hand side: Euler map of a natural granulite sample showing wedge-shaped deformation twins in two adjacent plagioclase grains found in a granulite from Holsnøy, SW Norway.

It has been shown that extensive twinning can lead to local amorphization, e.g. during impact events (Stöffler 1967, Ostertag 1983, Stöffler et al. 1991).

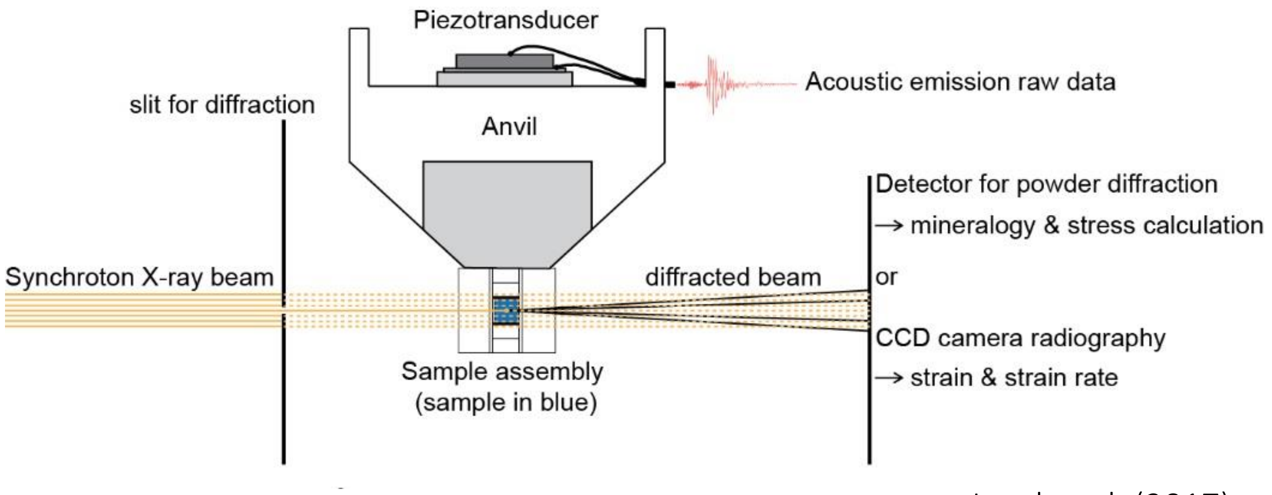
The occurrence of deformation twins and subsequent amorphization due to elevated temperatures could have an influence on the rheological behaviour of plagioclase-rich rocks at lower crustal conditions.

→ **Do we also observe twinning and amorphization of plagioclase in experimentally deformed granulite?**

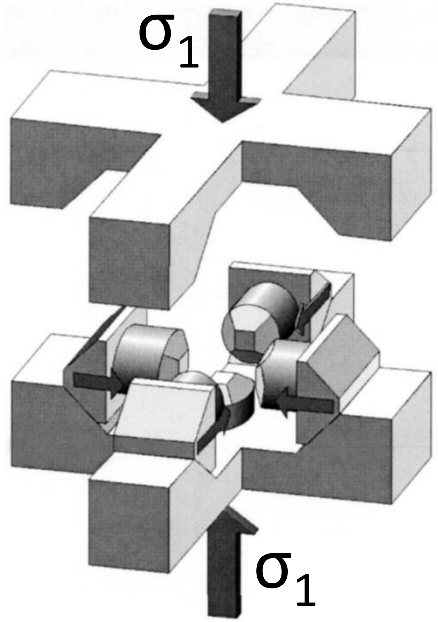


Material & Methods

We performed deformation experiments using the DDIA press mounted on the 13-BM-D beamline at the Advanced Photon Source, Argonne National Laboratory, IL USA. We used the synchrotron radiation to take (i) powder diffraction patterns and (ii) radiographs of the sample during deformation. The powder diffraction patterns were used to calculate the differential stress the sample experienced and the radiographs visualized the axial shortening in-situ. Both, diffraction patterns and radiographs were taken every 5 min. Additionally, the press is equipped with an acoustic emission setup enabling us to monitor the acoustic emission (AE) activity throughout the experimental runs (schematic drawing on the right hand side).



Incel et al. (2017)

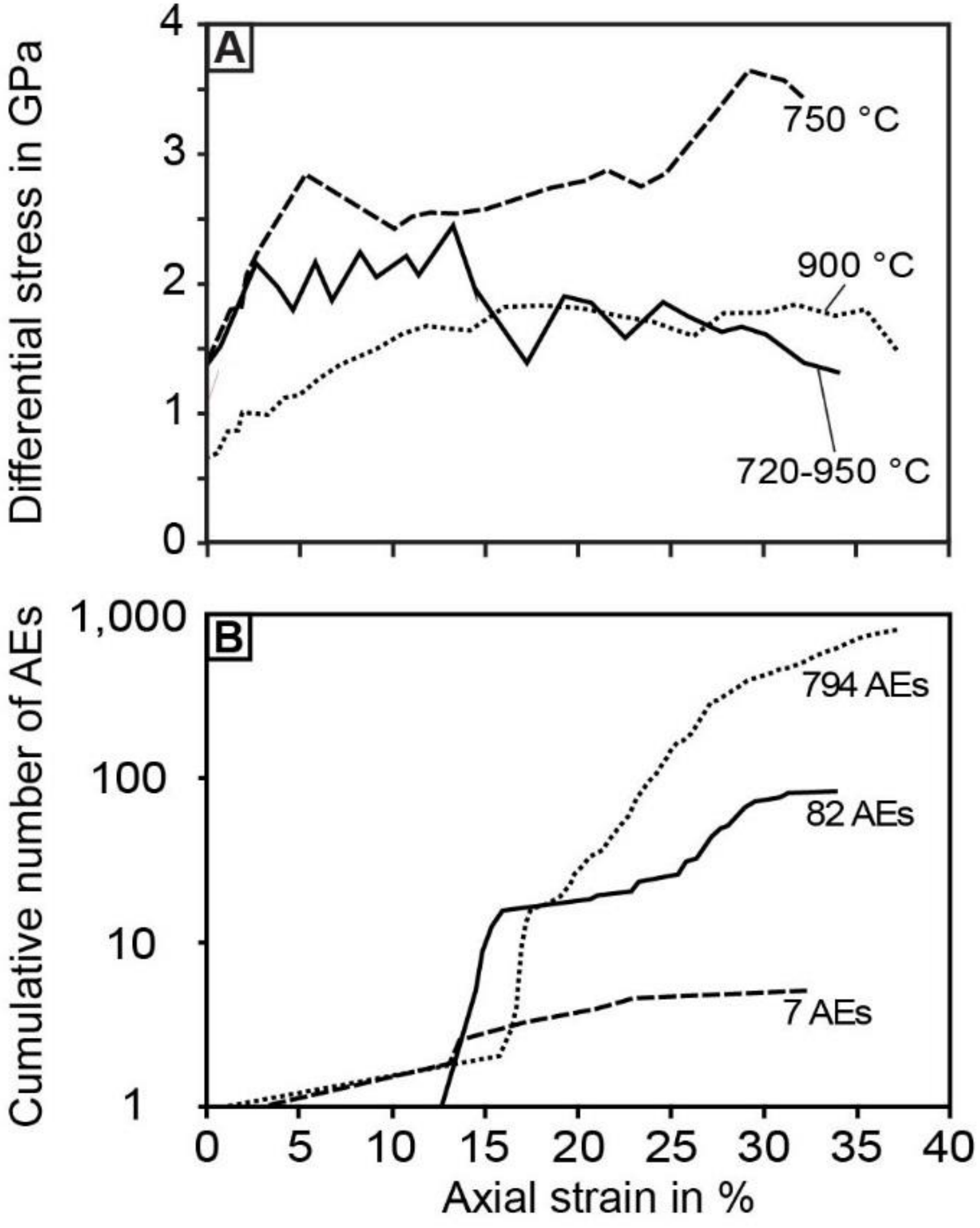


Wang et al. (2003)

The starting material was a natural granulite powder containing 95 vol.% plagioclase showing intermediate composition ($An_{50}Ab_{50}$) collected on Holsnøy in the Bergen Arcs, SW Norway.

The grain size of the starting material was <38 µm. Prior to deformation we hot-pressed the powders at 2.5 to 3 GPa confining pressure and around 720 °C for approx. 1 h. After hot-pressing, we initialized the deformation by advancing the upper und lower pistons (schematic drawing on the left hand side) with a constant displacement corresponding to a deformation rate on the sample of approx. 5×10^{-5} s^{-1}.

Results & Discussion



Incel et al. in preparation

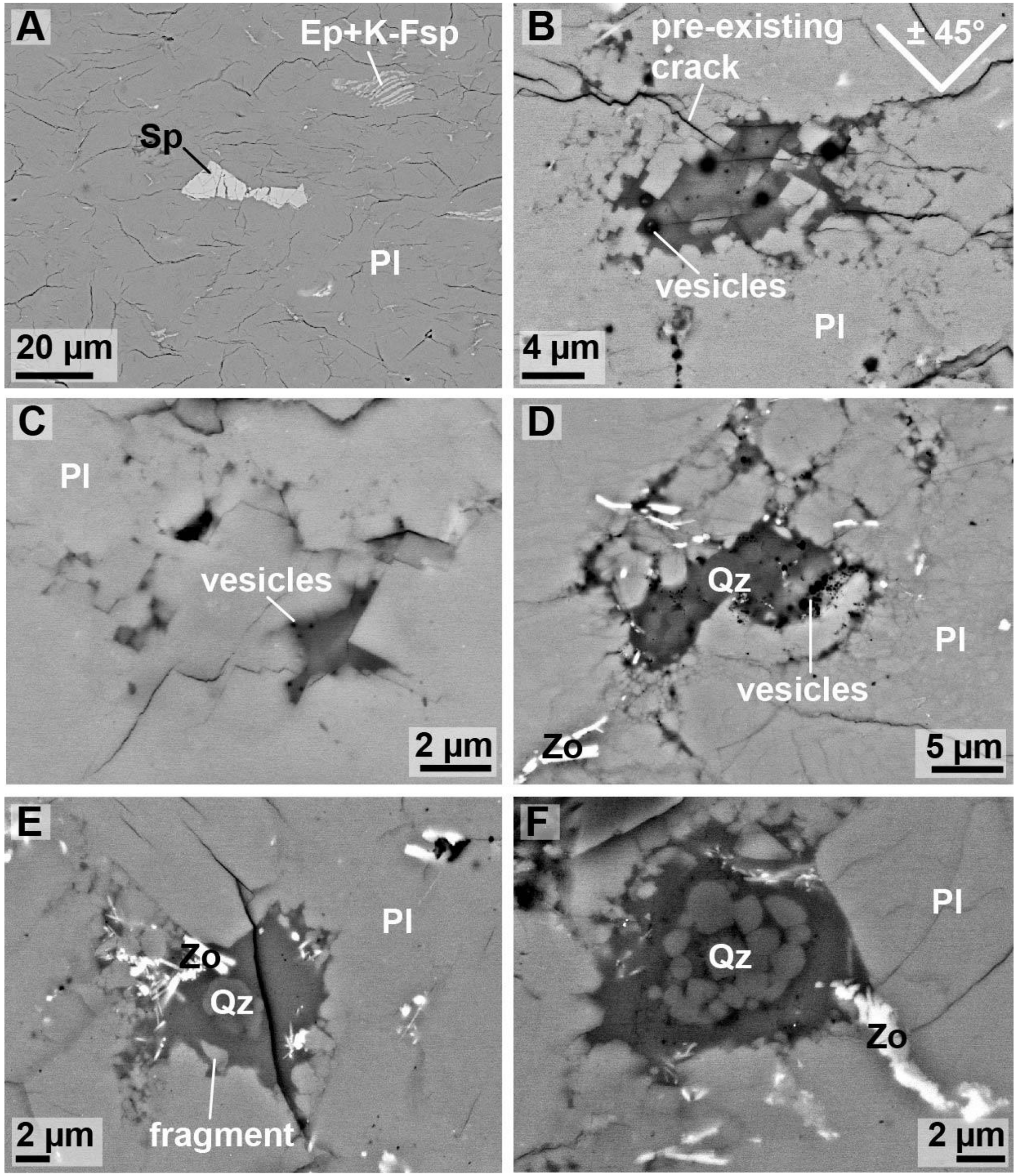
The stress-strain evolution (A) as well as the cumulative number of AEs versus axial strain (B) are shown for the tree experiments that were all performed at 2.5 GPa confining pressure and a strain rate of 5×10^{-5} s^{-1} but at different temperatures.

There seems to be a correlation between temperature and cumulative number of AEs with a much higher number of AEs recorded during deformation ≥ 900 °C.

→ counter-intuitive, because the number of AEs, as proxy for brittle deformation, was expected to be higher for the low-temperature experiment.

→ a thermally-activated process enables brittle deformation in the granulite samples?

Results & Discussion



Backscattered-electron images of the recovered deformation samples. The direction of maximum compression (σ_1) is oriented normal to the long edges of the images.

A) Microstructure of the sample deformed at 750 °C shows numerous microcracks, but no significant change in mineralogy relative to the starting material.

B, C) Amorphous patches are only found in samples deformed at temperatures ≥900 °C. The patches reveal vesicles that increase in number and size after interaction with the electron beam in the SEM. The patch edges are often very sharp and are oriented at approx. 45° relative to σ_1.

D-F) Patches filled with amorphous material showing the growth of subhedral quartz grains. The edges are rather sharp and oriented at approx. 45° relative to σ_1 as well.

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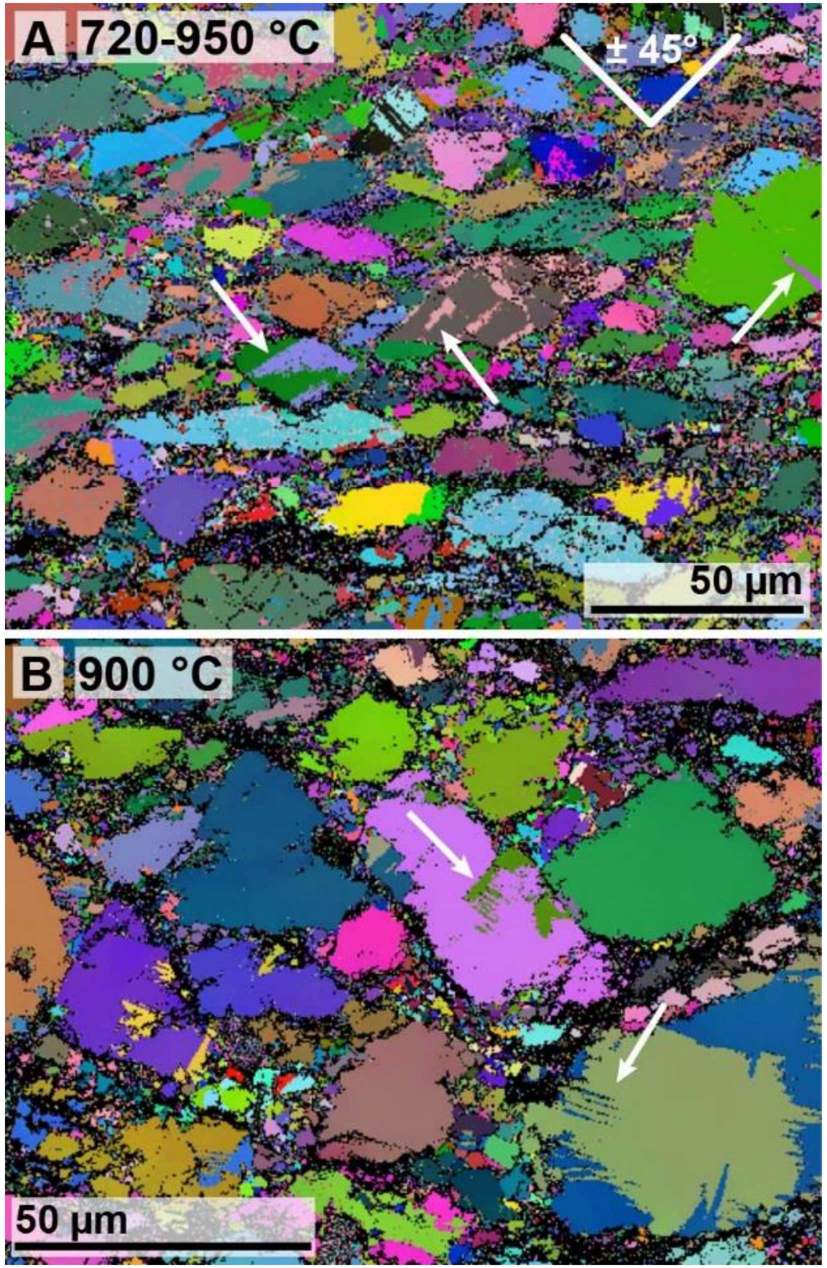
Results & Discussion



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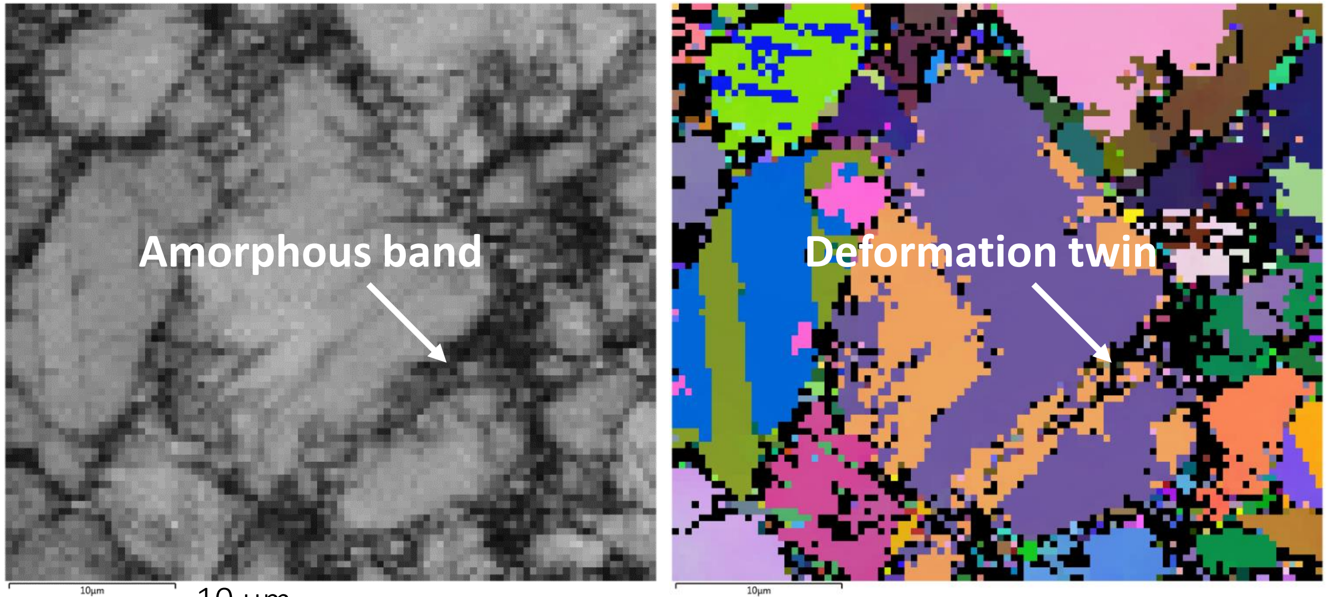
Euler maps of the two samples that experienced temperatures ≥ 900 °C (images on the left hand side).

Both sample microstructures demonstrate that favourably oriented plagioclase deformed by twinning (white arrows in A and B). Those twins are oriented at around 45° relative to σ_1 (normal to the long edges of the images).

In granulite samples deformed in a Griggs press by Marie Baïsset we observe amorphization along deformation twins in plagioclase as well (images below). Furthermore, twinned plagioclase crystals also show amorphization along pre-existing deformation twins when hot-pressed in the piston-cylinder press.



10 µm

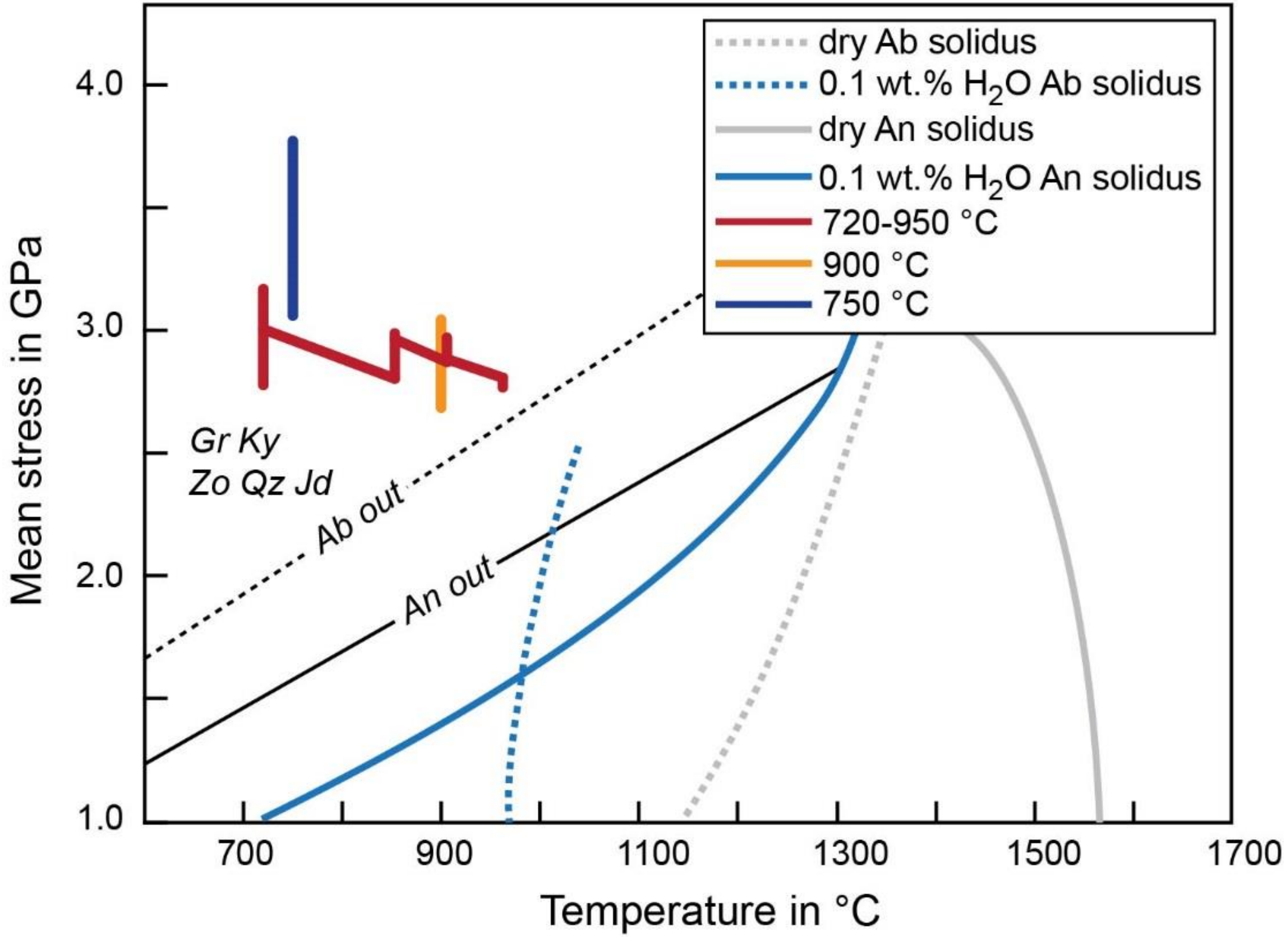
Granulite sample deformed at 2.5 GPa, 850 °C and 10^{-6} s^{-1} in the Griggs apparatus at ENS Paris. Experiment performed by Marie Baïsset

Results & Discussion

Could the presence of amorphous material be explained by partial melting of plagioclase?

Thermodynamic modelling demonstrates that the temperatures during deformation were too low for partial melting to occur (see figure on the right hand side).

→ partial melting cannot explain the presence of amorphous patches.



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Conclusion

We observe in the DDIA experiments and in the Griggs-deformation experiments that, like various other materials, plagioclase undergoes deformation twinning when exposed to stress.

Deformation twins then act as amorphization sites, if the temperature is high enough

→ From our results it appears that plagioclase starts to amorphize at temperatures >700 °C.

We observe a relation between AE-activity and the occurrence of amorphous patches indicating that amorphization either enables or enhances brittle deformation at high-pressure, high-temperature conditions.

Link to nature:

Deformation twinning in plagioclase is common in naturally deformed plagioclase-rich samples from the lower continental crust. Temperatures >700 °C are also expected to prevail at depths of the lower continental crust.

→ We therefore suggest that local amorphization along deformation twins in plagioclase could act as mechanical instabilities eventually leading to brittle failure at high-pressure, high-temperature conditions.

The absence of fluids in the lower continental crust makes it difficult to explain brittle failure by transformational faulting due to metamorphic reactions, because in order to effectively weaken the rock a significant amount of rock must react.

→ However, local amorphization along twins does not require the presence of fluids.

Acknowledgements

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