Poseidon's Seismic Bread Crumbs: Ultracataclasite vein evolution within a granodiorite along the Naxos Detachment System

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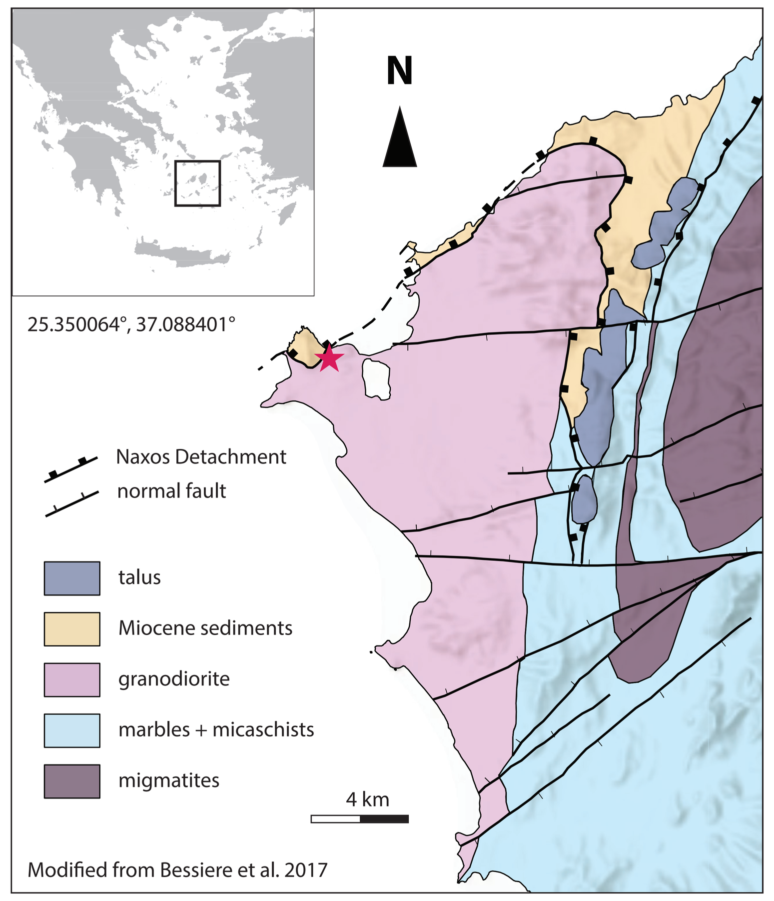
INTRODUCTION

Pseudotachylytes, quenched melts produced by frictional heating, and ultracataclasites, comminution of host rock, are direct indicators of coseismic slip and reflect localized deformation. However, the process of pulverization of crustal rock in fault zones into ultrafine-grained material, fluidization, and injection of that material into surrounding rocks remain equivocal as these earthquake-induced structures are rarely preserved in the rock record.

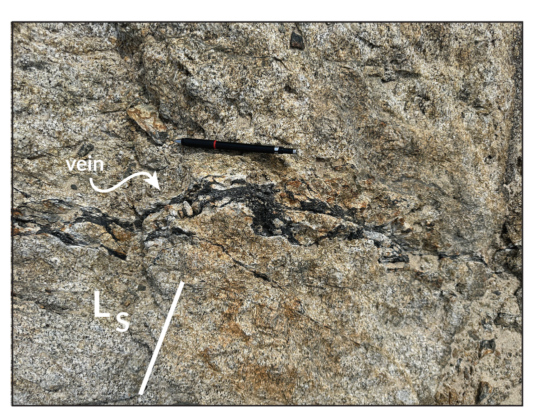
A set of ultracataclastic veins within the immediate footwall of the extensional Naxos Detachment in the Greek Cyclades provide the rare opportunity to examine the mechanisms of ultracataclasite nucleation and propagation. We employ microstructural analyses including electron backscatter diffraction (EBSD) mapping to evaluate the relationship between ductile creep and cataclasis of the host porphyroclasts.



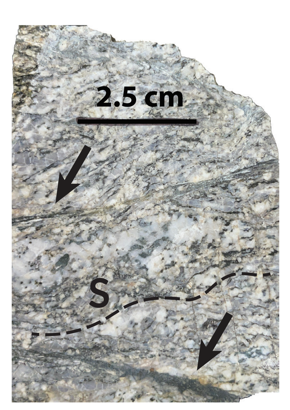
Modified from Bessiere et al. 2017

GEOLOGICAL SETTING

The ultracataclastic veins are hosted in a deformed Miocene granodiorite, along the island's Stelida peninsula. Naxos is a classical Cycladic metamorphic core complex, with migmatites and the granodiorite at its core. The granitoid was syn-tectonically intruded, cooling rapidly from crystallization (650-680°C) at c. 12 Ma to <60°C by c. 9 Ma. At the margins of the pluton, the low-angle Naxos Detachment System produces a strong N-S stretching lineation and SCC' fabric with top-to-N kinematics.



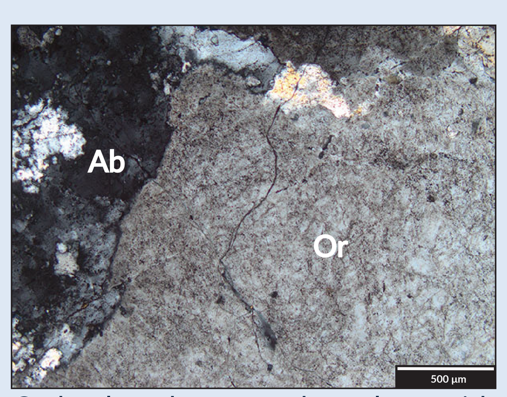
Representative field photo of an ultracataclastic vein in the granitoid. The veins are slightly anastomosing and oblique to the main foliation, ranging from 0.5-2 cm in width. Stretching lineation: Ls.



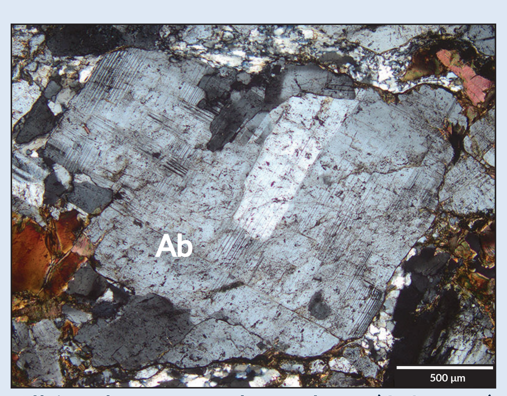
Cut face of sample, perpendicular to the foliation and parallel to the lineation, corresponding to EBSD Map 1. Black arrows point to ultracataclastic veins. Foliation: S.

PETROGRAPHIC ANALYSIS

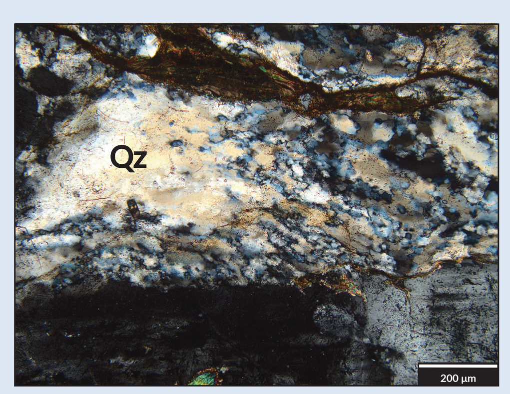
away from veins



Orthoclase host porphyroclast, with fluid inclusions, microfractures, patchy extinction and irregular grain boundaries with albite.

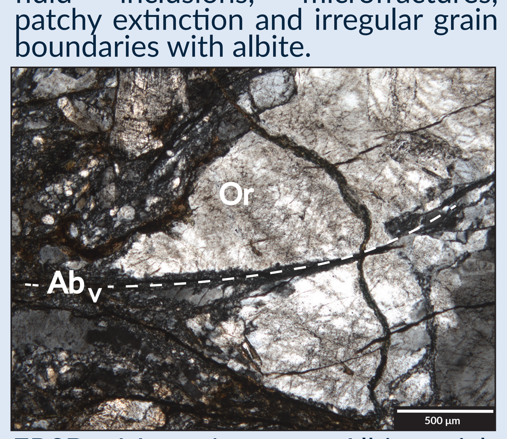


Albite host porphyroclast (2.0 mm) with microfractures, tapered twinning and patchy extinction.

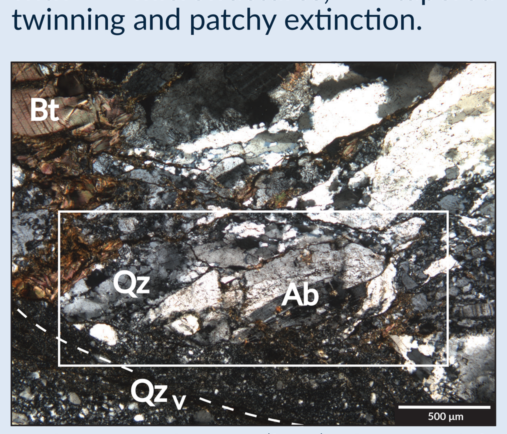


Dynamic recrystallization in quartz through grain boundary migration and subgrain rotation.

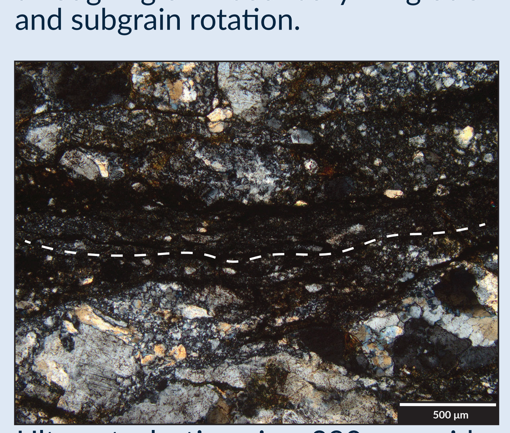
adjacent to veins



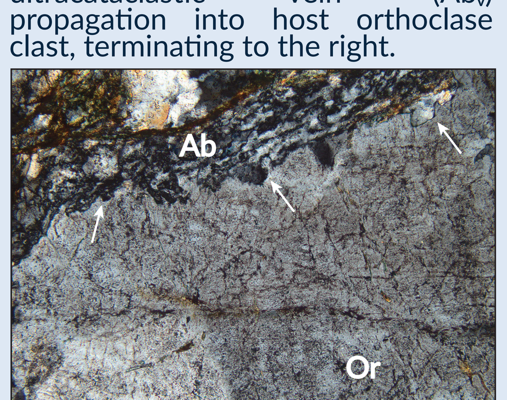
EBSD Map 1 area. Albite rich ultracataclastic vein (Ab$_v$) propagation into host orthoclase clast, terminating to the right.



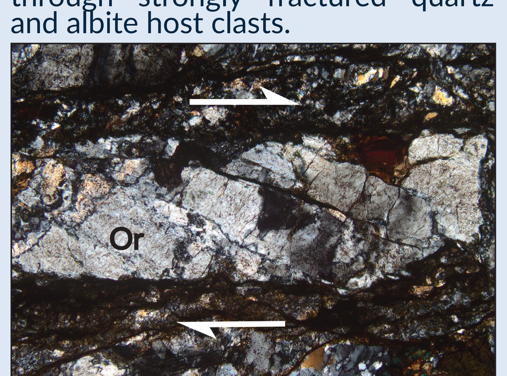
EBSD Map 2 area (box). Quartz-rich (Qz$_v$) ultracataclastic vein cutting through strongly fractured quartz and albite host clasts.



Ultracataclastic vein ~390 µm wide, with subrounded fragments up to 158 µm wide.



Cuspate phase boundaries between orthoclase clast and albite (5-30 µm).



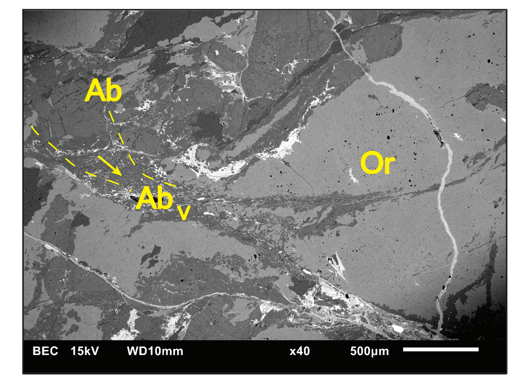
Bookshelf fracturing in orthoclase clast.

Bent twins in albite porphyroclasts.

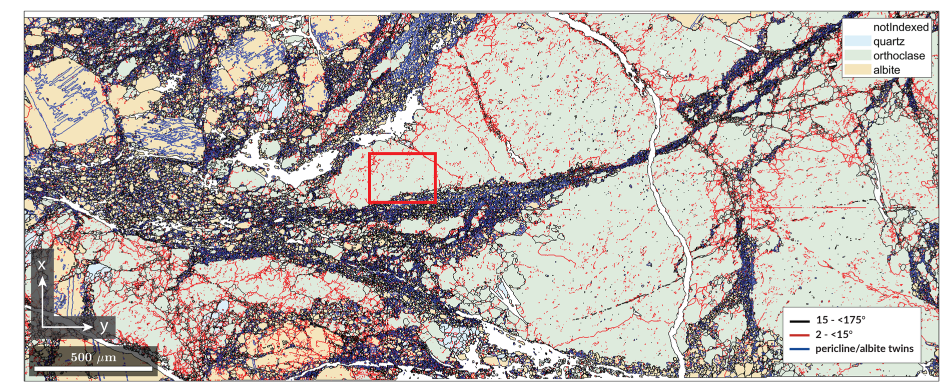
Quartz: Qz, albite: Ab, orthoclase: Or, biotite: Bt, hornblende: Hb.

MICROSTRUCTURAL ANALYSIS

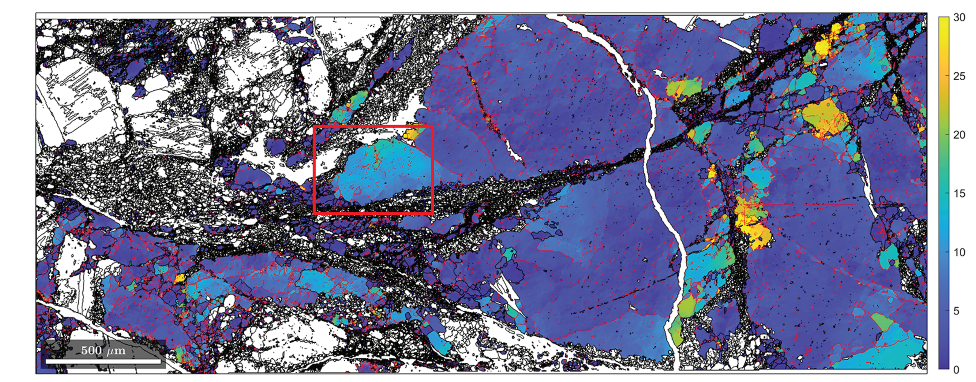
EBSD MAP 1 (parallel to lineation)



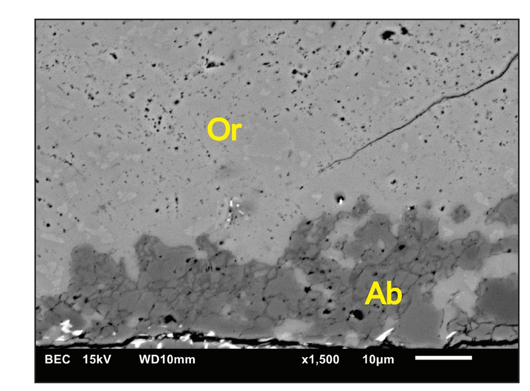
BSE image of EBSD Map 1 area. Ultracataclastic vein propagates through host orthoclase clasts. Fine grained (2-35 µm) albite material in the vein is likely from deformed albite clasts above.



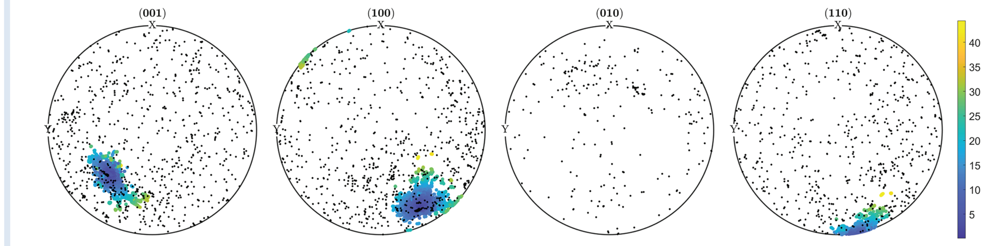
Phase and grain boundary map displaying ultracataclastic material propagating into a fractured orthoclase porphyroclast. The y (horizontal) axis is subparallel to foliation. Low-angle grain boundaries (LAGBs) in red increase towards outer rims and veins.



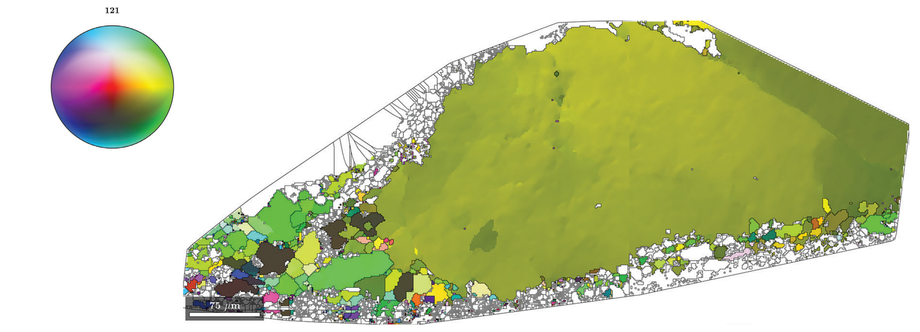
EBSD grain orientation deviation map of orthoclase evincing minor crystal-plasticity in the form of a continuous to heterogeneous misorientation pattern, with a maximum misorientation of ~52° relative to the mean in the vicinity of microfractures. Pole figure subset marked by the red box.



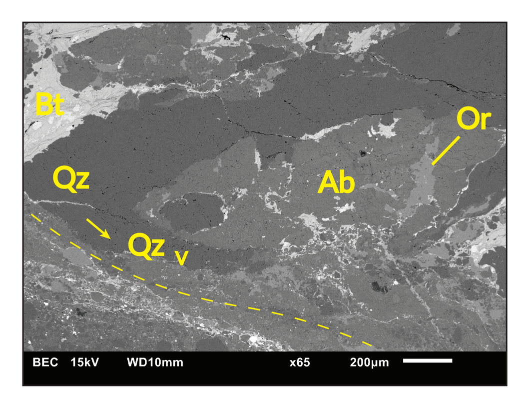
Margin of orthoclase porphyroclast in EBSD map 1 (red box in phase map). Phase boundary and albite fragments suggestive of a dissolution precipitation reaction front between the feldspars.



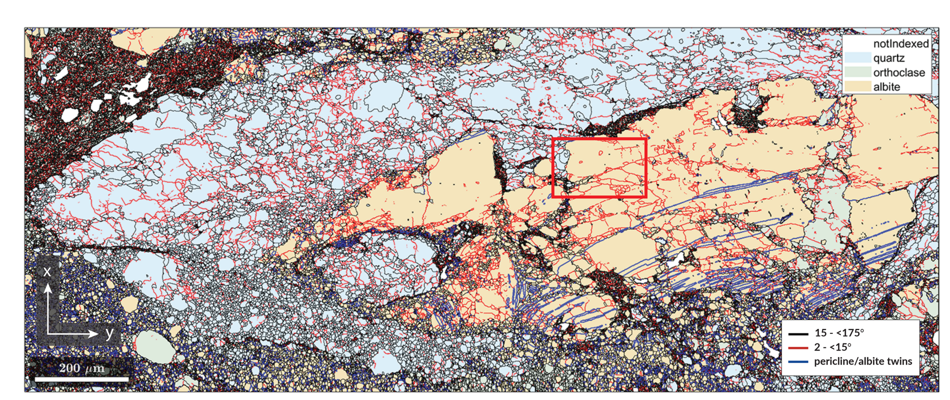
Lower hemisphere pole figure showing the misorientation spread of a larger orthoclase host clast (2.0 mm) shown relative to the mean orientation of the small orthoclase grains (<40 µm) surrounding the clast (black markers, one point per grain). The IPF colour map below shows the subset grain orientations relative to the z-axis.



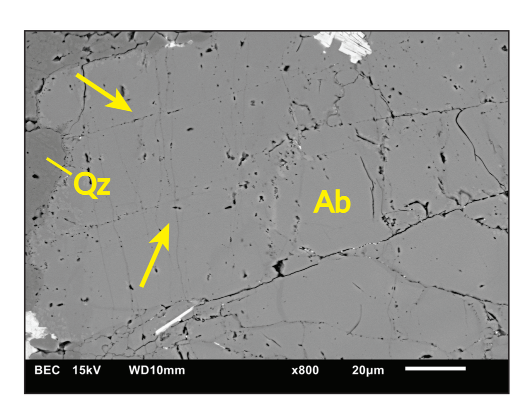
EBSD MAP 2 (perpendicular to lineation)



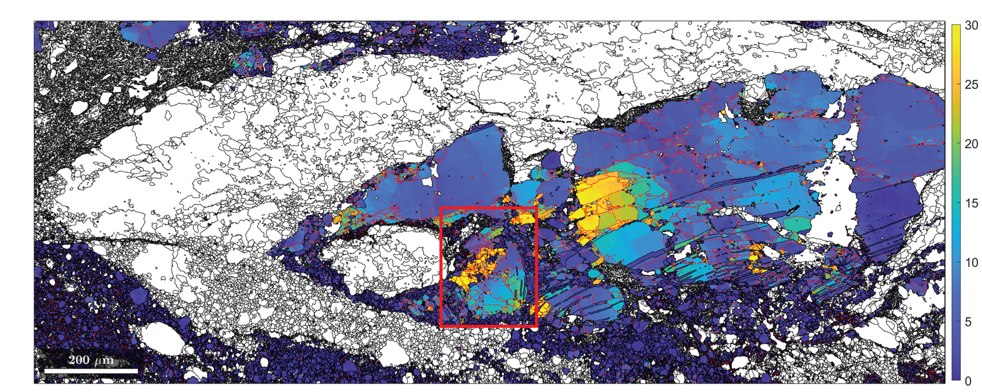
BSE image of EBSD Map 2 area. Ultracataclastic vein cuts through strongly fractured orthoclase, quartz and albite fragments (5-75µm). Clasts within the veins are subrounded.



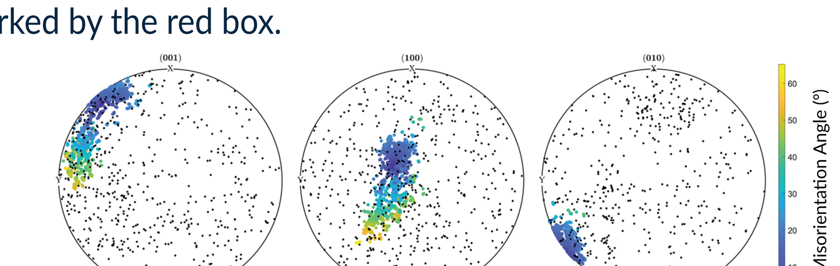
Phase map with the y (horizontal) axis subparallel to foliation. Twins (blue) in the albite porphyroclast are parallel to the c-axis, but bend towards the ultracataclastic vein (bottom left). Albite and quartz LAGBS are concentrated proximal to the vein.



Margin of albite porphyroclast in EBSD map 2 (red box above). Structures in image suggest boundaries identified as LAGBs in EBSD map are instead healed micro-fractures (yellow arrows).

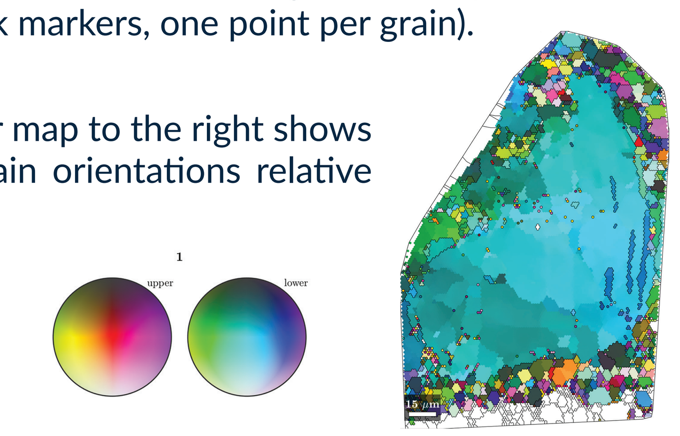


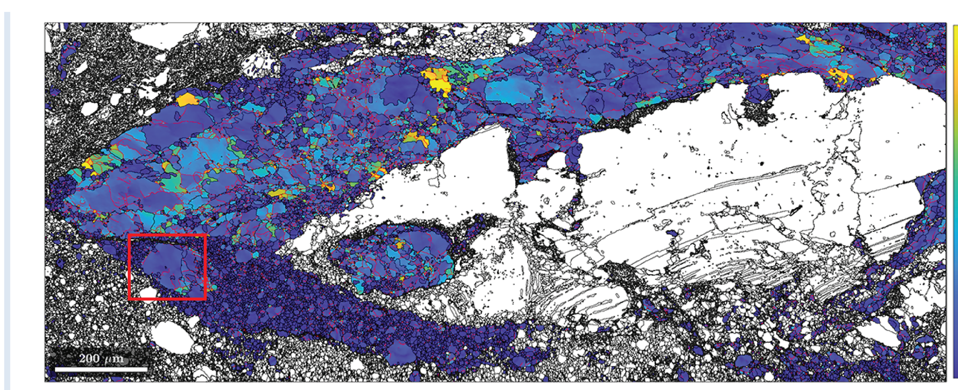
Albite displays a continuous to heterogeneous misorientation pattern in the host rock, with a maximum misorientation angle of ~73°. Fine grains of albite (<50 µm) occur at the clast rims and vein tip, with maximum misorientations of ~10°. Pole figure subset marked by the red box.



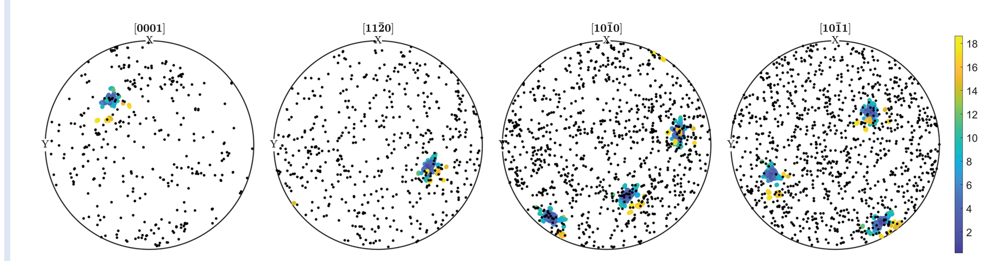
Lower hemisphere pole figure showing the misorientation spread of a larger albite (120 µm) clast shown relative to the mean orientation of small albite grains (<30 µm) surrounding the clast (black markers, one point per grain).

The IPF colour map to the right shows the subset grain orientations relative to the z-axis.

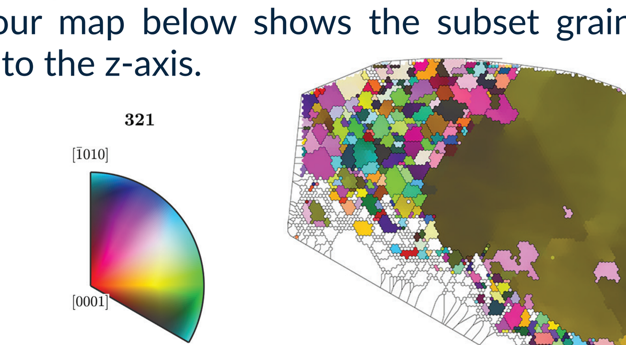




Quartz displays a continuous misorientation pattern in the host rock with a maximum misorientation angle of ~46.04°. Misorientation increases towards the vein, in which fine grains have low (~0-8°) misorientations. Pole figure subset marked by the red box.



Lower hemisphere pole figure showing the misorientation spread of a larger quartz clast (86 µm) shown relative to the mean orientation of the small quartz grains (<40 µm) surrounding the clast (black markers, one point per grain). The IPF colour map below shows the subset grain orientations relative to the z-axis.



IMPLICATIONS

- Microstructures present in the host porphyroclasts away from the vein tips indicate that deformation occurred prior to cataclasis at temperatures of ~ 450–600°C.
- EBSD analysis and resulting pole figures with scattered orientations of the small grain populations suggest that cataclasis is the primary deformation mechanism in areas surrounding the ultracataclastic veins.
- Cuspate boundaries of albite along orthoclase host clasts fracture margins suggest fluids potentially play a role in weakening the host rock and facilitating vein propagation.

NEXT STEPS

- Further field mapping and sampling of the ultracataclastic veins on Naxos.
- Electron microprobe chemical analyses and element mapping of quartz, orthoclase, and albite, targeting vein tips and possible reaction fronts.
- Cathodoluminescence imaging to observe subgrain boundaries.
- Follow up microstructural and textural analysis.