Assessing the role of silica gel as a fault weakening mechanism in the Tuscarora Sandstone

BGSU

Krishna Borhara and Charles Onasch

Bowling Green State University

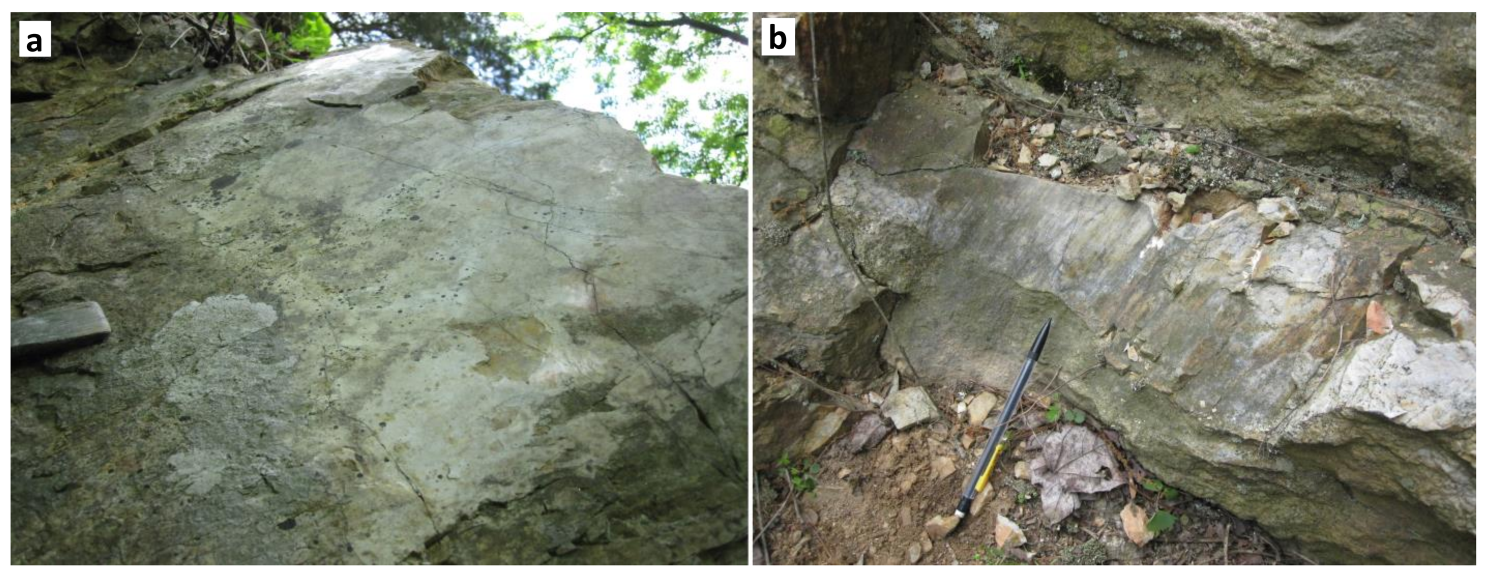
Introduction

- Previous work by Onasch et al. (2010) suggested that microcrystalline quartz bands and cement in cataclasites related to faults in quartz-rich rocks may have derived from a silica gel.
- Occurrences of microcrystalline quartz on fault surfaces of all scales in the Tuscarora Sandstone and other lithologies in the central Appalachian foreland raises the possibility that a silica gel may have been present during faulting and significantly reduced the frictional strength.
- We set out to find evidence for a gel origin for the material on these fault surfaces and to construct a model to explain the processes that occurred during faulting.

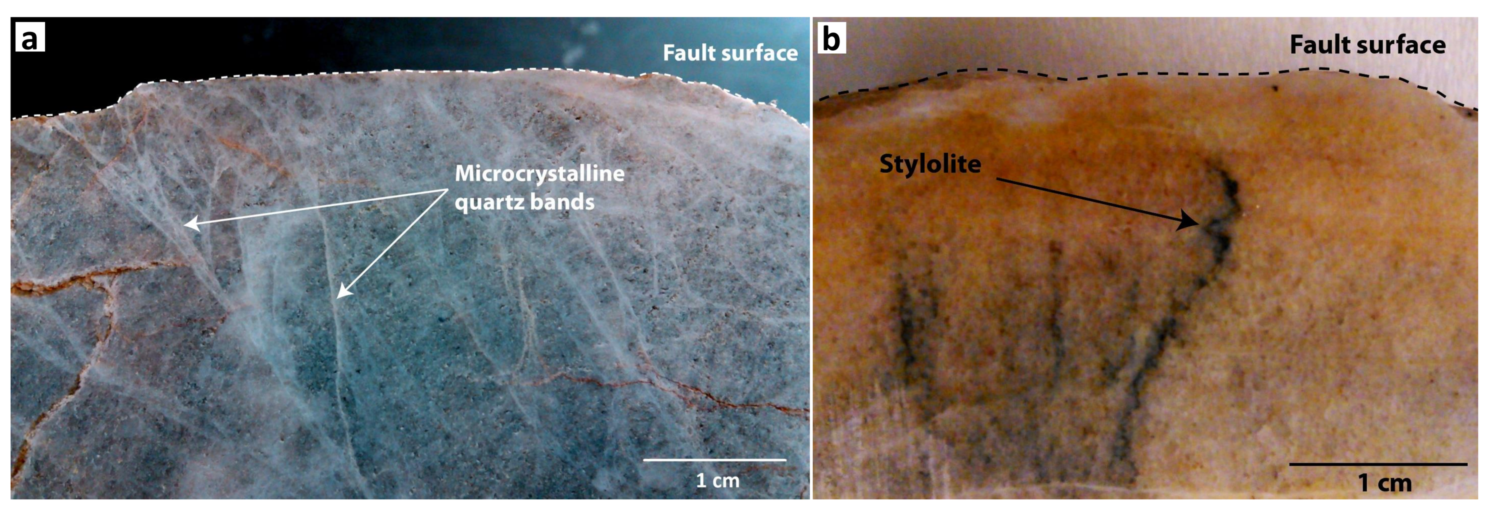
Key Findings

- Trapped silica nanospheres, flow features, amorphous silica, uniform grain size distribution and grains of low dislocation density within microcrystalline quartz on the fault surfaces are evidence of a silica gel that resulted from comminution and hydration of wallrock asperities along the fault surface.
- The presence of microcrystalline quartz on faults surfaces and in coeval Mode I fractures adjacent to faults suggests that the gel was mobile and capable of significant transport.
- Complex mutually crosscutting relations between microfractures and microcrystalline quartz along the faults, as well as presence of brecciated clasts within breccia, indicates that these processes were cyclic.
- Mutually overprinting textures between brittle and fault creep microstructures (stylolites) suggest alternating brittle and ductile episodes, possibly in response to varying stress levels.

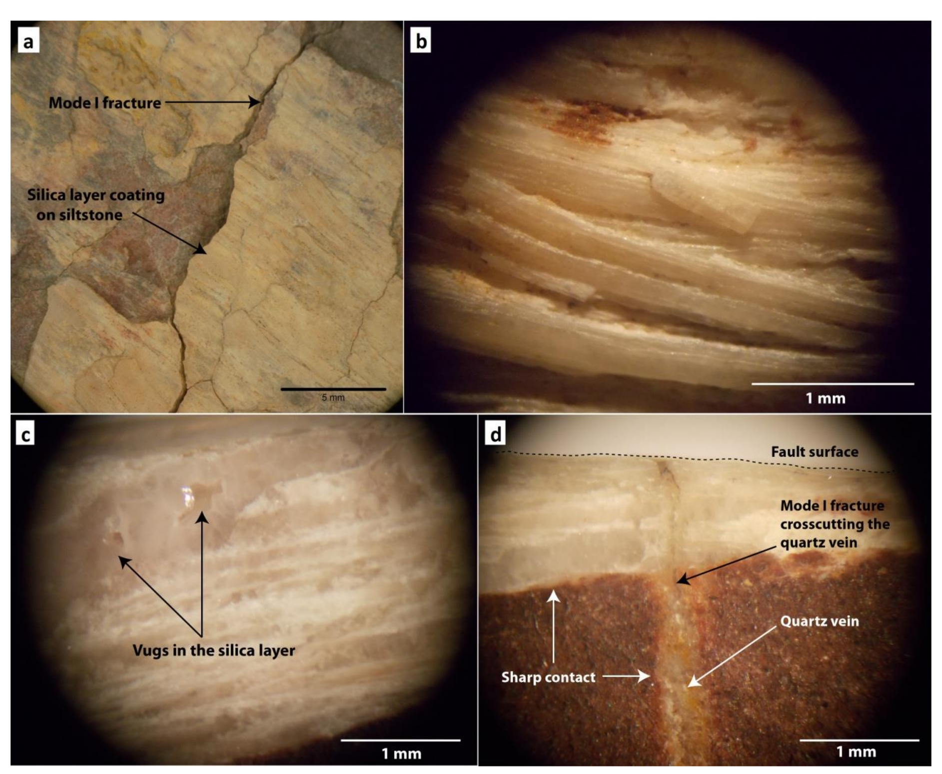
Fault features



Polished (a) and striated (b) fault surfaces in the Tuscarora Sandstone as seen in outcrop.

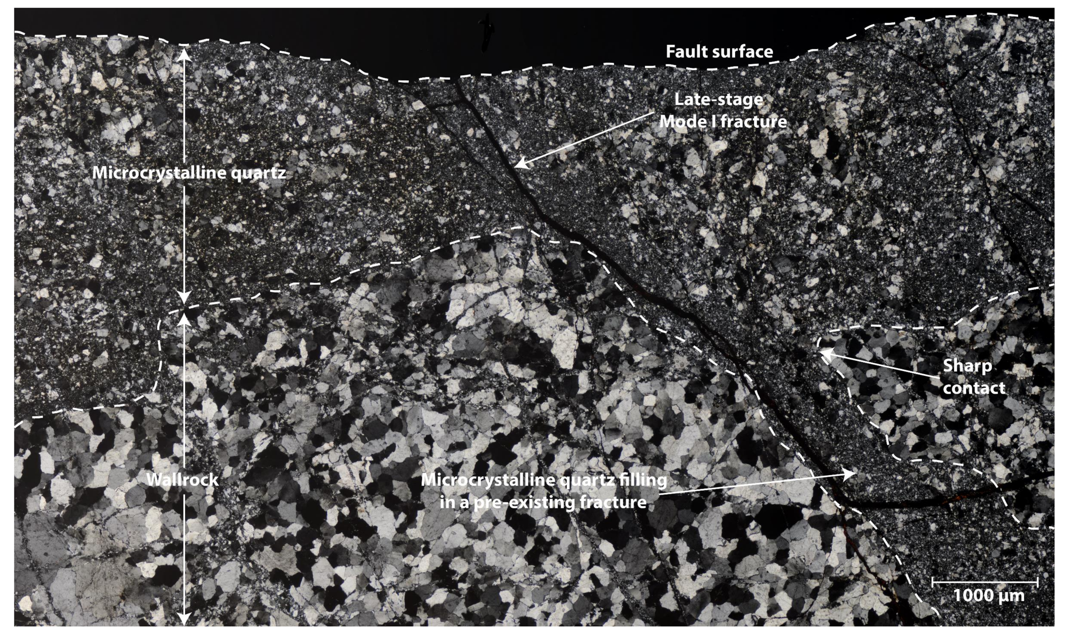


Fault surface features in the Tuscarora Sandstone as seen in outcrop. (a) Microcrystalline quartz bands: highest concentrations occur near the fault surface, which indicates that their formation is associated with faulting. (b) Truncation of stylolite by microcrystalline quartz at the fault surface.

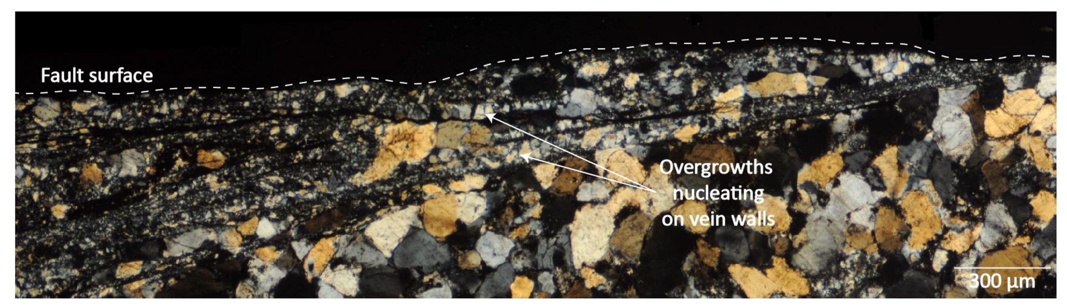


Fault surface features in the Bloomsburg Formation:

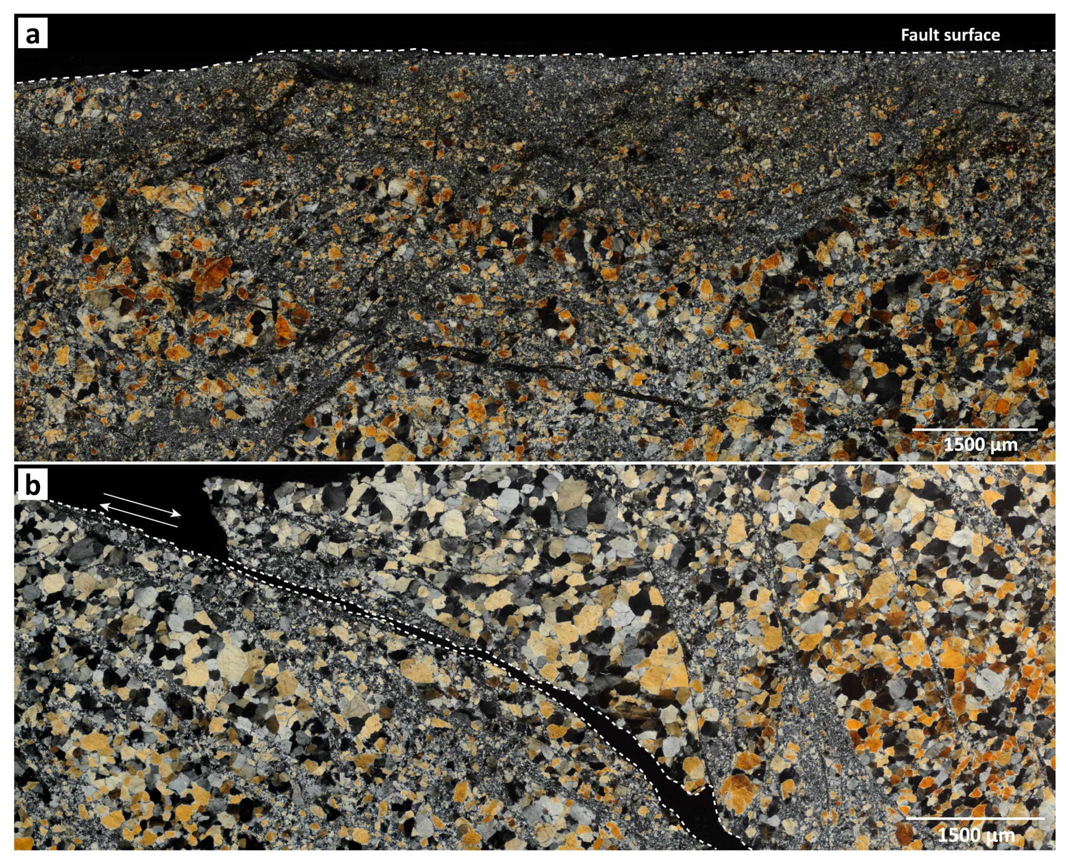
a) Silica layer on fault surface.
b) Striated microcrystalline quartz (white) interlayered with euhedral quartz (colorless).
c) Vugs in the micro-crystalline quartz layer with euhedral crystals.
d) Open Mode I fracture cutting older quartz vein, which cuts microcrystalline quartz on fault surface.



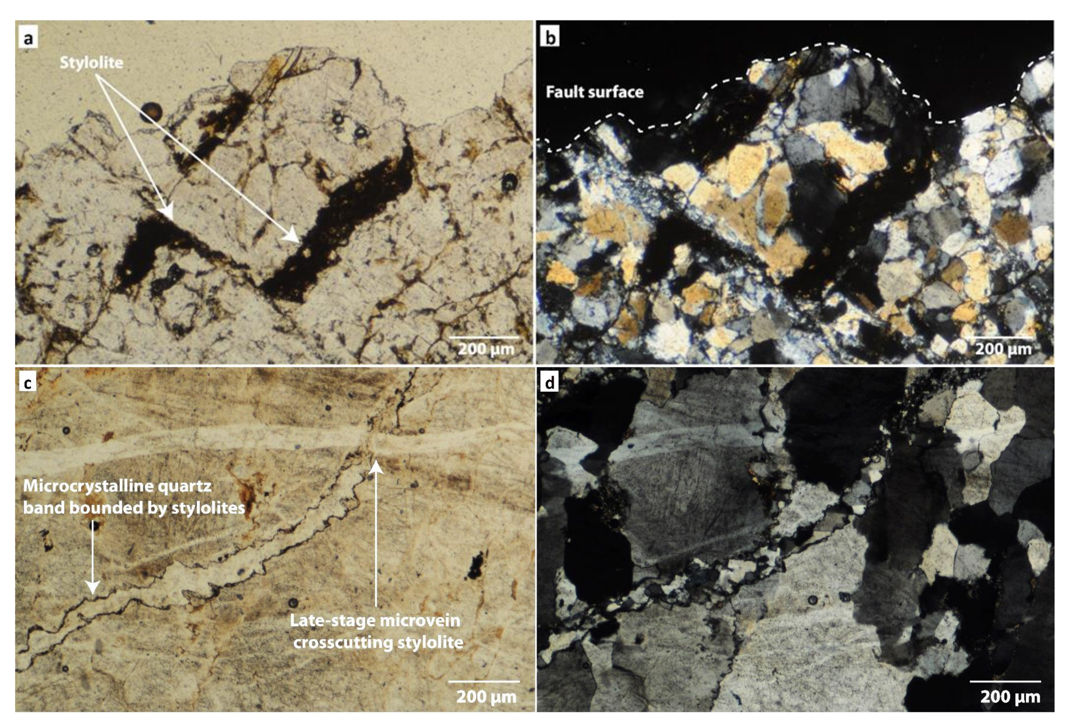
Complex network of microcrystalline quartz bands and microveins in the wallrock. Note the continuity of the bands in the wallrock with microcrystalline quartz along the fault surface.



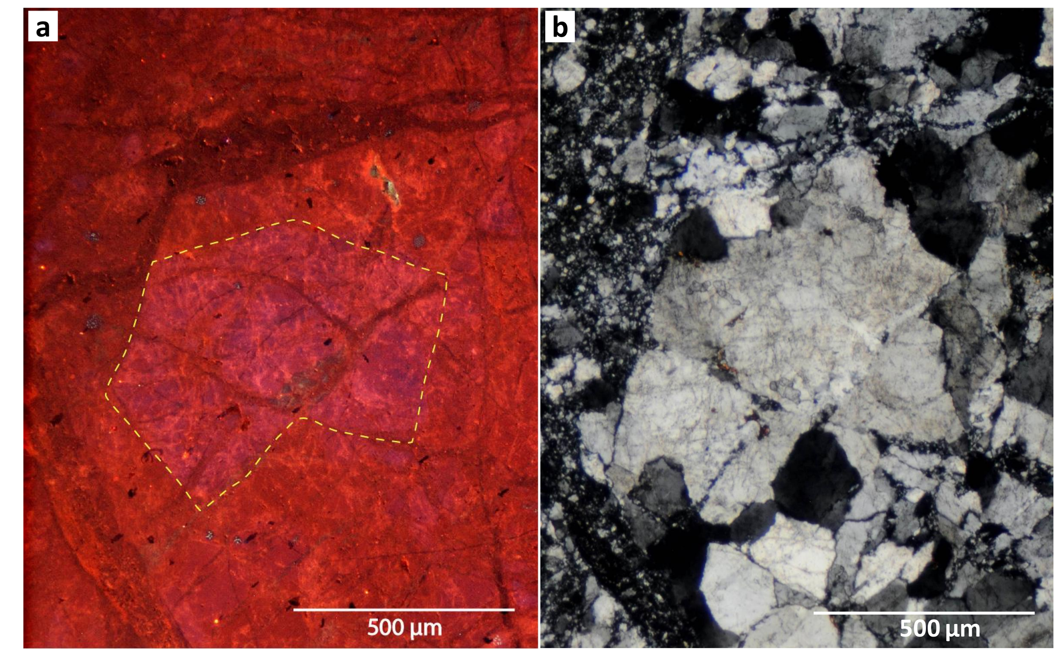
Sharp contact of the bands with the wall rock and microcrystalline overgrowths nucleating on the vein walls indicate that the bands are products of precipitation, not cataclasis.



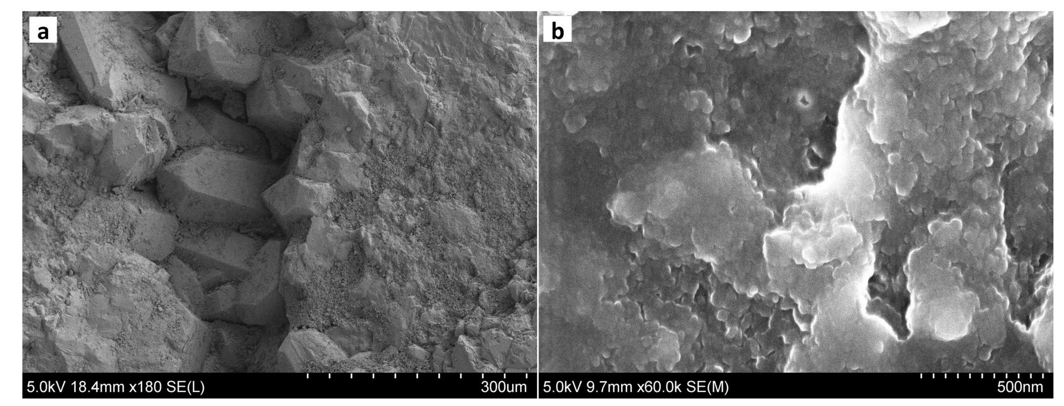
Highly polished faults (a) display greater extent of brecciation and abundance of microcrystalline quartz near the surface suggesting greater displacement and more rapid slip rates than unpolished fault surfaces (b).



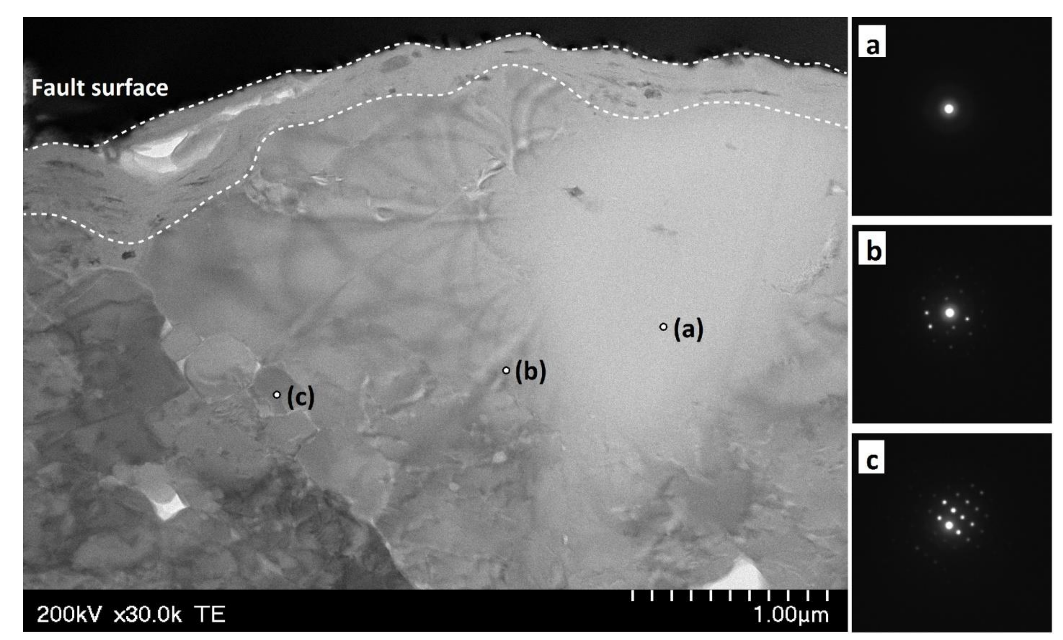
Mutually crosscutting relationships between different brittle and ductile microstructures near the fault surface. (a) and (b) Stylolite predates microcrystalline quartz bands. (c) and (d) Stylolite post-dates the bands but predates the microvein.



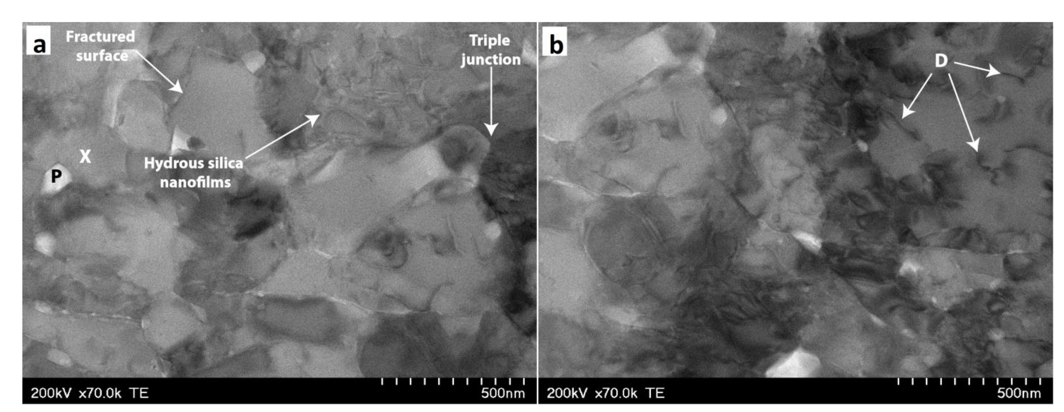
Features in cataclasites along faults. (a) Yellow dashed polygon in CL image delineates a breccia fragment consisting of smaller breccia fragments. Note the different luminescence and abrupt terminations of the microveins in the breccia indicating multiple generations of brecciation and cementation near the fault surface. (b) Cross polarized light view of same area.



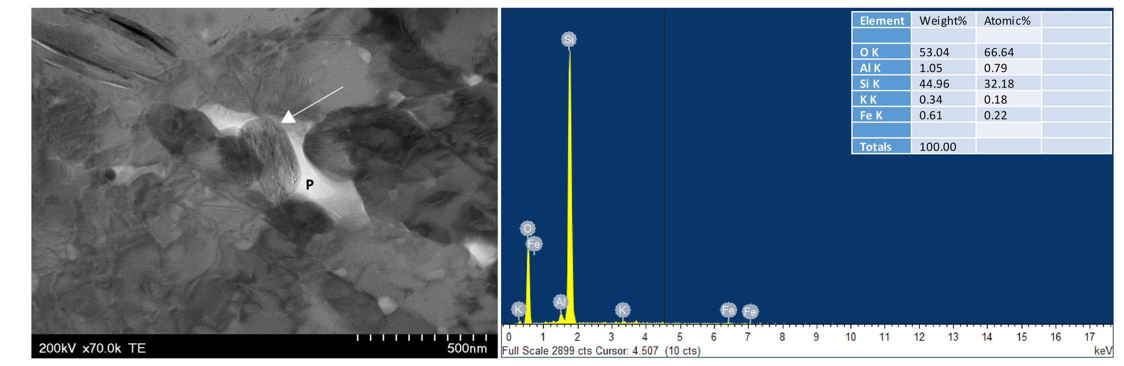
SEM micrographs of microcrystalline quartz: (a) Vug on a fault surface containing euhedral quartz crystals surrounded by microcrystalline quartz. Note progressive increase in grain size towards the center of the vug. (b) Fine- grained phases on polished fault surface consisting of opaline spheres with uniform grain size distribution.



TEM micrograph showing flow features (between dashed lines) on the fault surface indicating that the fault surface was once fluid. Inset: diffraction patterns of amorphous (a) and crystalline (b) and (c) regions. Presence of amorphous silica is indicative of a precursor silica gel.



TEM micrographs showing different textures along the fault surface. (P = pore spaces, X = crystalline silica, D = dislocations). (a) Hydrous silica phases cementing fractured clasts (that resulted from comminution). Presence of triple junctions and low dislocation density of several grains are interpreted as evidence for crystal growth, rather than comminution. (b) Dislocations in comminuted fragments.



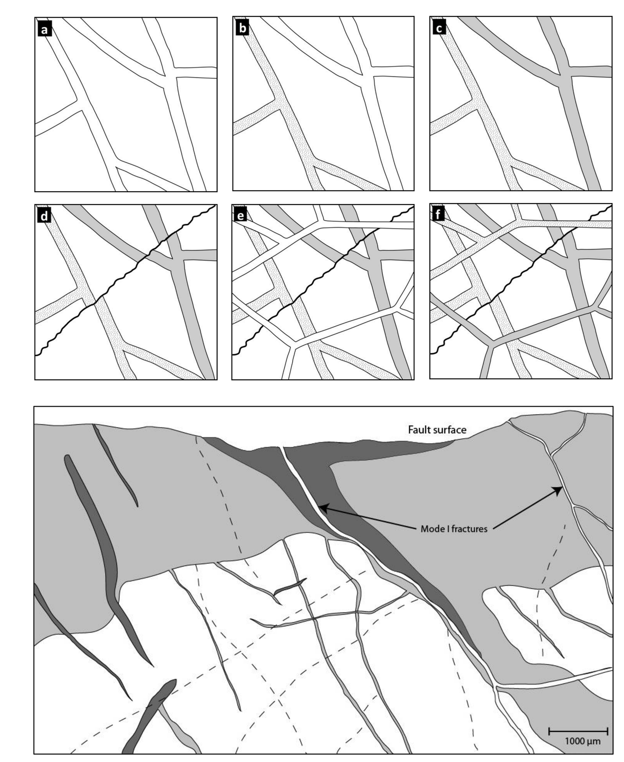
Left: TEM photomicrograph showing trapped ellipsoidal inclusion in a pore space (P). Right: Energy dispersive spectroscopy (EDS) shows that the spherical/ellipsoidal particles have high Si and O content.

Evidence for a silica gel precursor

- Opaline phases
- Polygonal network of grains with uniform grain size distribution and low dislocation density
- Vugs with euhedral crystals
- Flow features
- Amorphous silica
- Hydrous silica nanofilms surrounding clasts

Evidence suggests that an amorphous, viscous, supersaturated silica gel precipitated rapidly into opal nanospheres or hydrous silica nanofilms around clasts. Upon silica-depletion, the remaining fluid was expelled from the precipitating phases. Dehydration of these phases resulted in shrinkage cracks into which the remaining fluid migrated and precipitated euhedral quartz, leaving behind vugs.

Model for gel formation



1. Open Mode I fractures are generated along the fault surface and accompanied by formation of Riedel shears resulting in brecciation and an increase in porosity **(a)**.

2. Silica gel is frictionally generated along the fault surface via comminution of quartz at asperities and subsequent hydration.

3. The viscous gel lowers strength of fault zone thereby facilitating slip.

4. Formation of additional fractures results in pressure drop, which decreases quartz solubility further increasing the degree of saturation/supersaturation.

5. With fault displacement, the gel flows from the fault surface into open fractures and Riedel shears and precipitates rapidly as opaline phases to form microcrystalline quartz bands and cement between breccia fragments **(b)**.

6. With silica-depletion of the gel, quartz precipitates in open fractures to form microveins and cement between remaining breccia fragments **(c)**.

7. Crosscutting relations between brittle microstructures and stylolites indicate that periods of brittle faulting alternated with ductile deformation by pressure solution. These temporal changes are believed to form from alternations of slip followed by periods of fault creep indicating a wide range of strain rates within the fault zone **(d-f)**.

8. Presence of a silica gel during faulting may have provided a fault weakening mechanism that allowed slip under low shear stresses.

References:

Onasch, C.M., Farver, J.R., Dunne, W.M., 2010. The role of dilation and cementation in the formation of cataclasite in low temperature deformation of well cemented quartz-rich rocks. Journal of Structural Geology 32, 1912-1922.