Ancient Fault-Fluid Interactions in Northern Oklahoma

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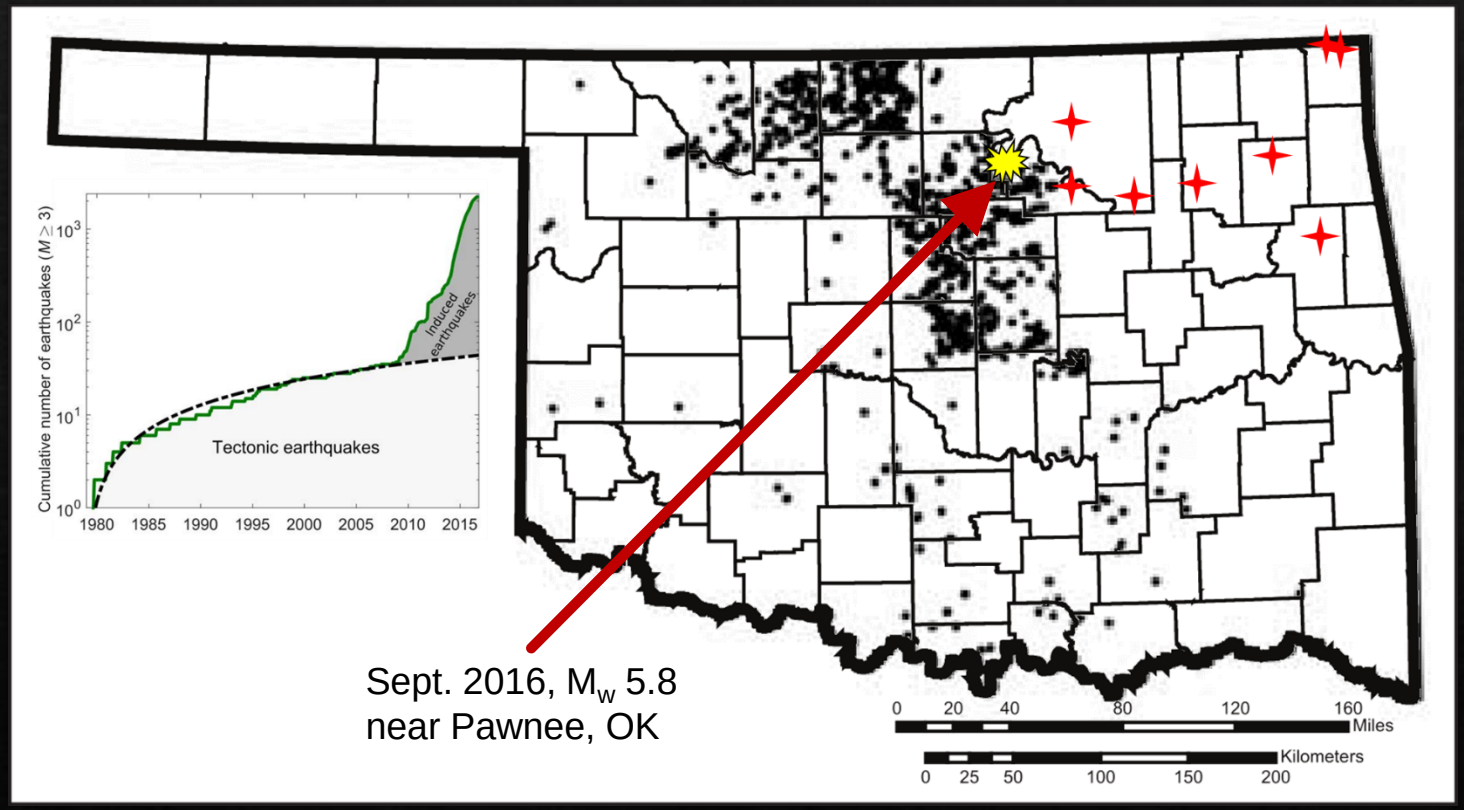
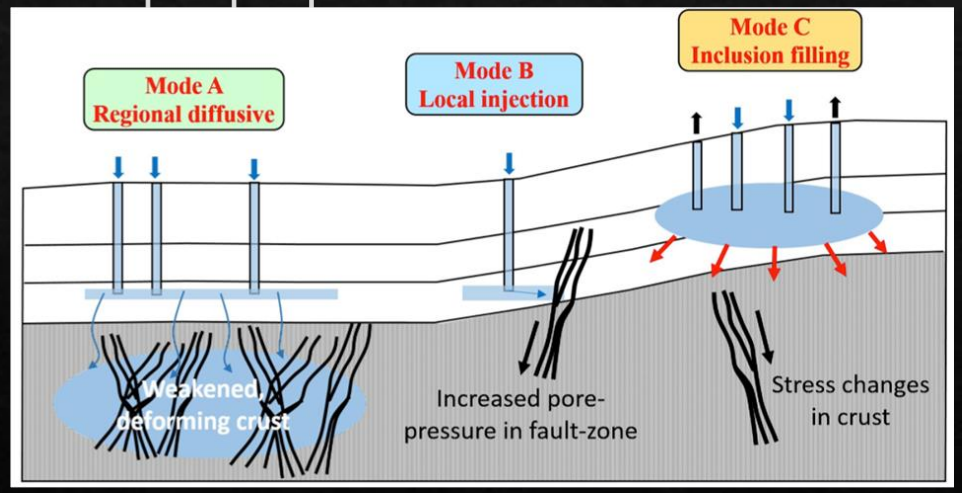
Induced/Triggered Earthquakes in an Intraplate Setting



Modified from Langenbruch & Zoback (2016)

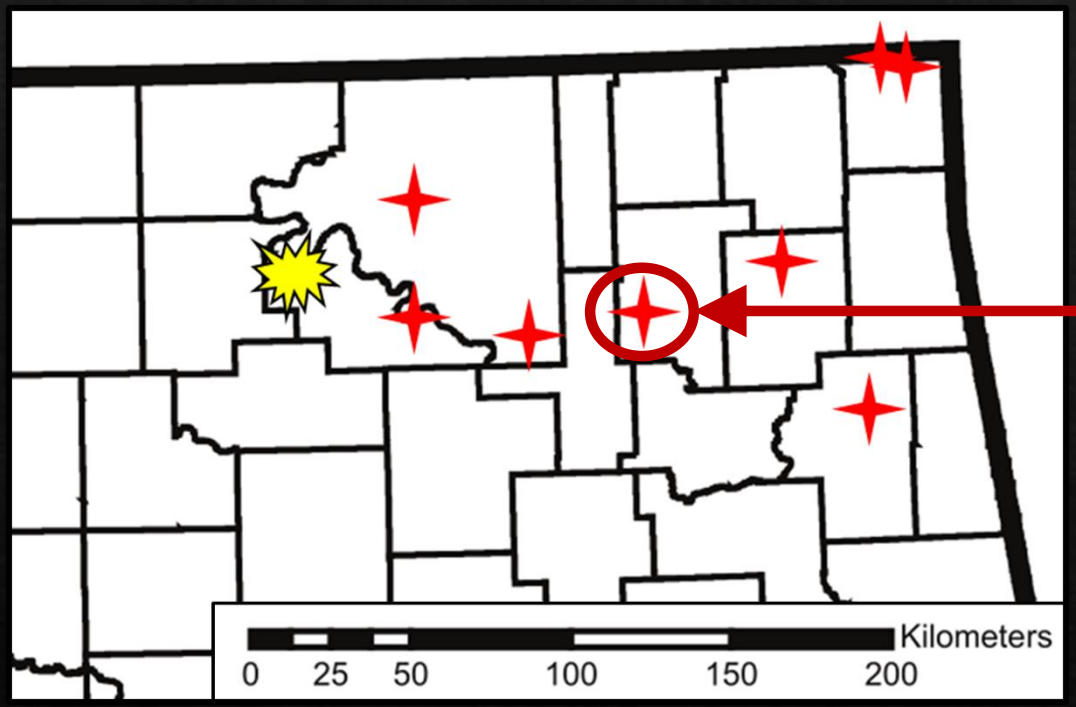
Relatively quiet until ca. 2009, then rapid increase in seismicity due to wastewater injection into overlying Arbuckle Group carbonates.

Multiple proposed mechanisms.



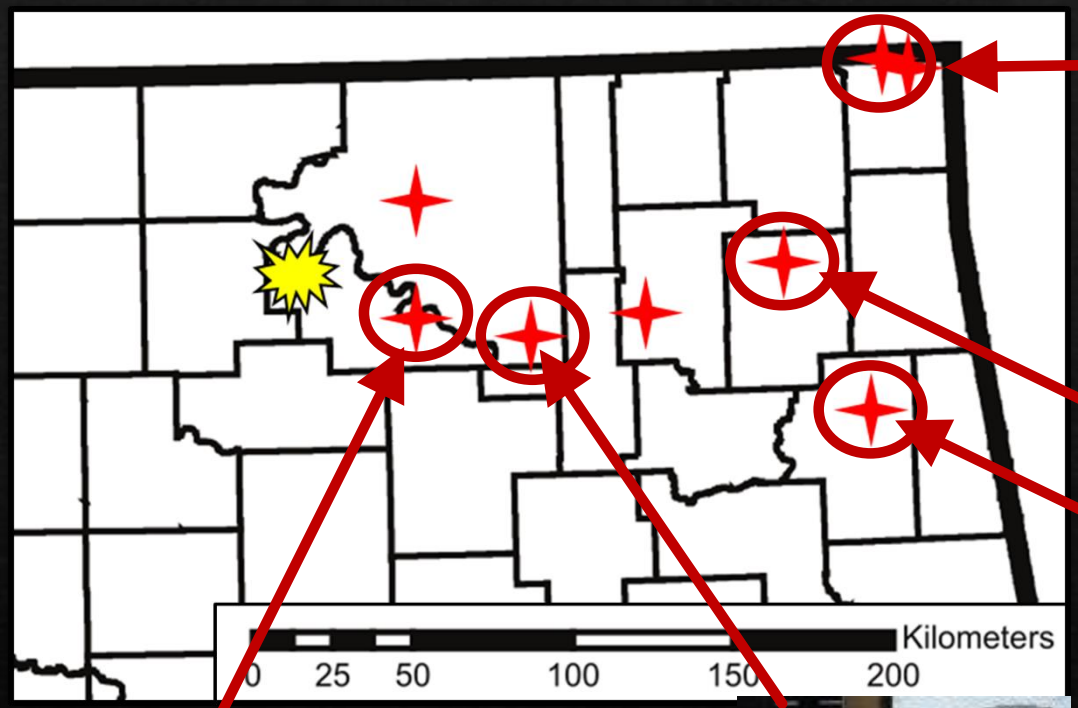
Courtesy of B. Carpenter

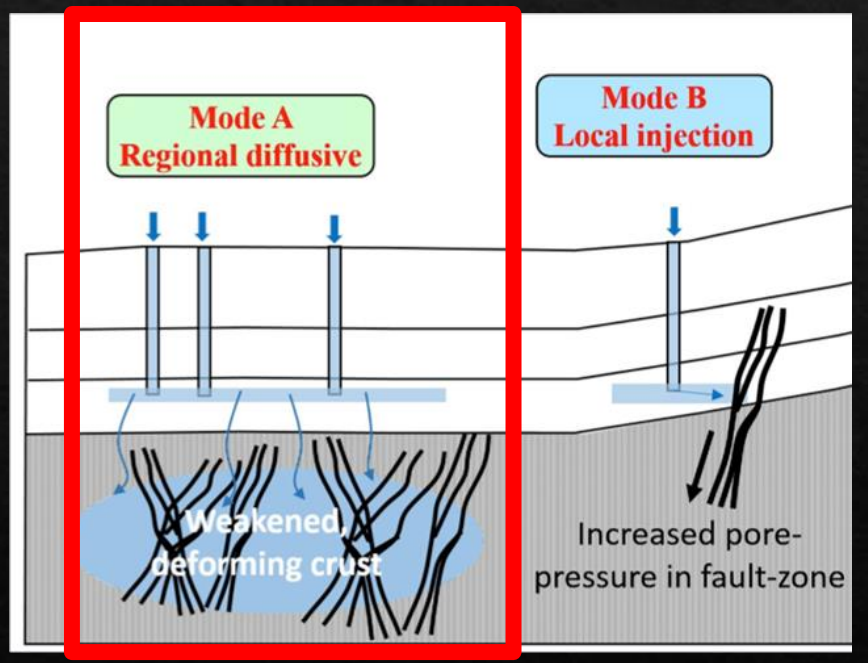
Fractured Basement, Fluid Pathways



Multiple sets of high-angle to subhorizontal mineralized fractures are ubiquitous in basement rocks investigated to date.

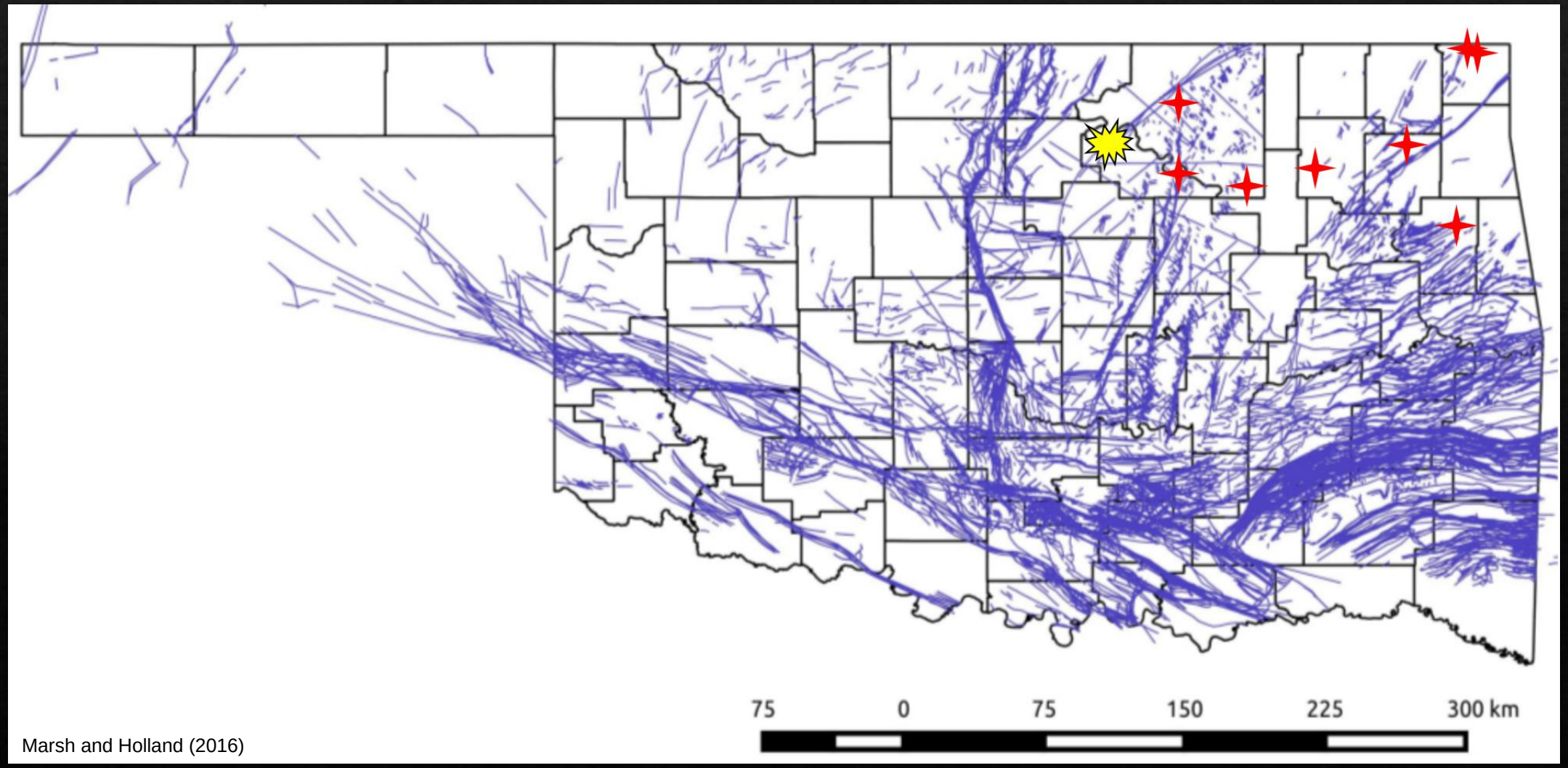
Fractured Basement, Fluid Pathways





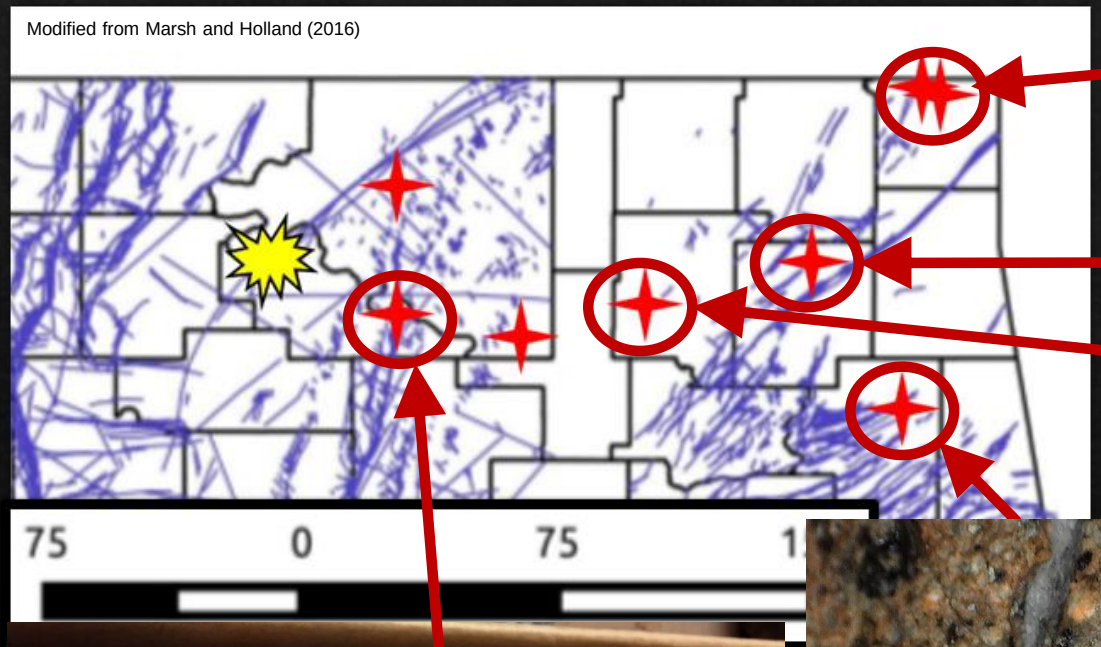
Ubiquitous fracturing may provide a pathway for diffusion through permeable basement rocks.

Earthquakes Require Faults

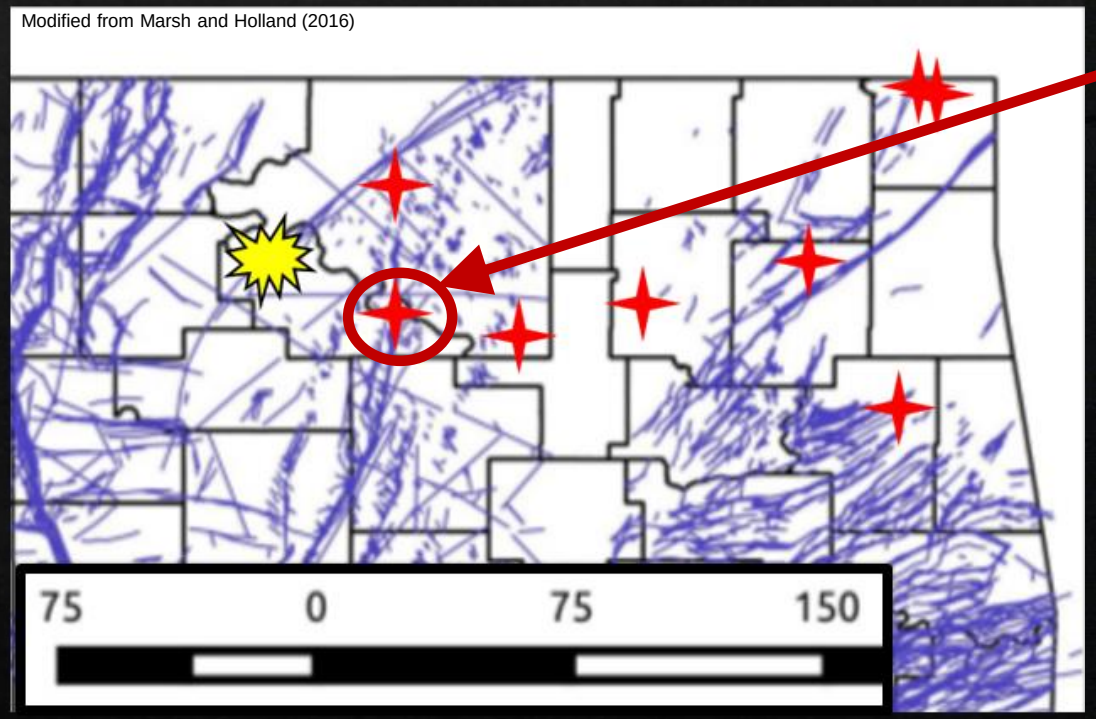


Marsh and Holland (2016)

Faulted Basement, Fluid Pathways



Sinclair Louisa M Jones 46 (Pawnee Co.)



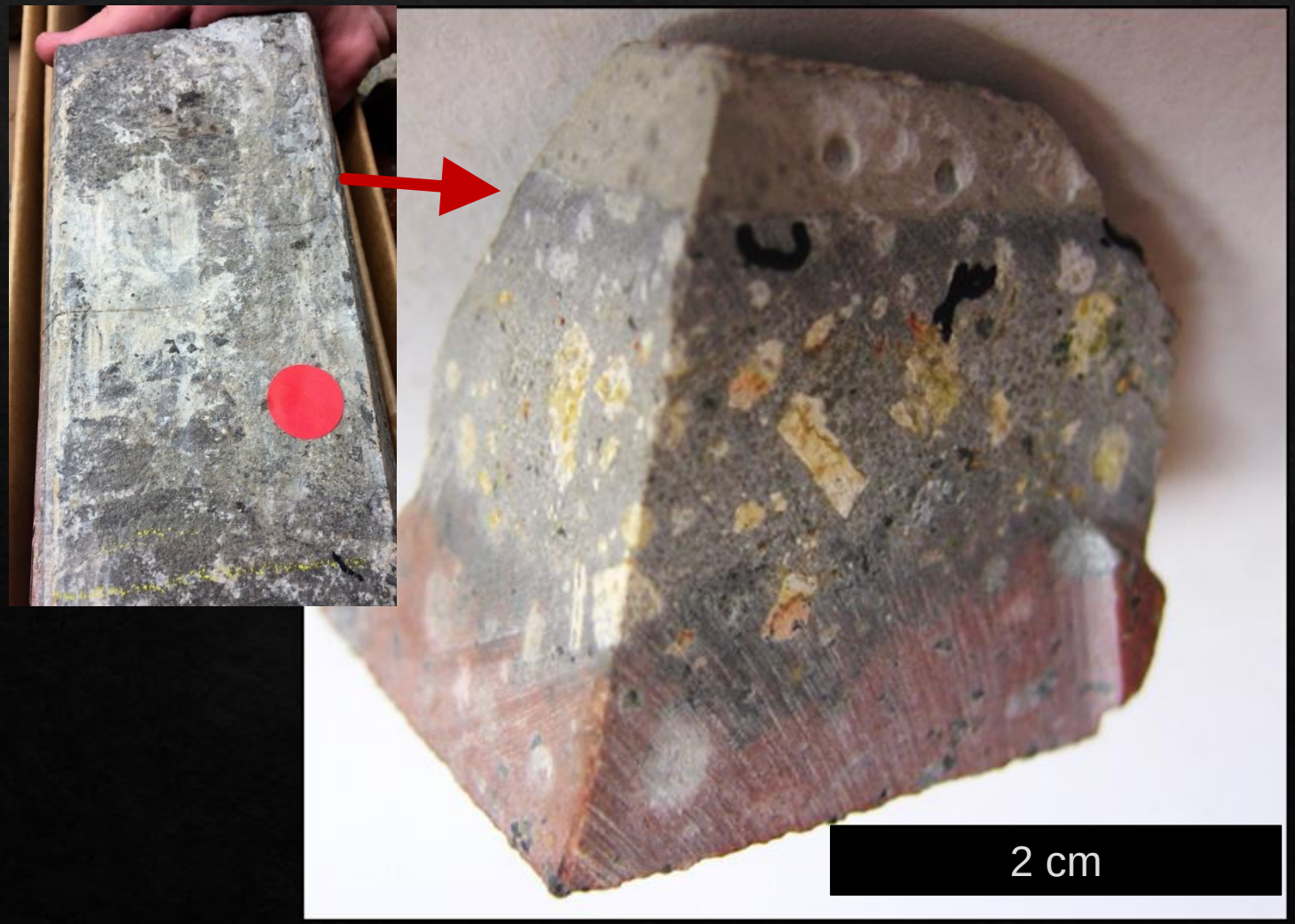
Mineralized fractures include a 2-5mm thick subvertical carbonate vein with basement clasts and slickensides.

Drilled in 1962

Lithology: Coarse-grained Rhyolite

44 km SE of the 2016 M_w 5.8 Pawnee Earthquake

Jones 46 – Sheared Vein

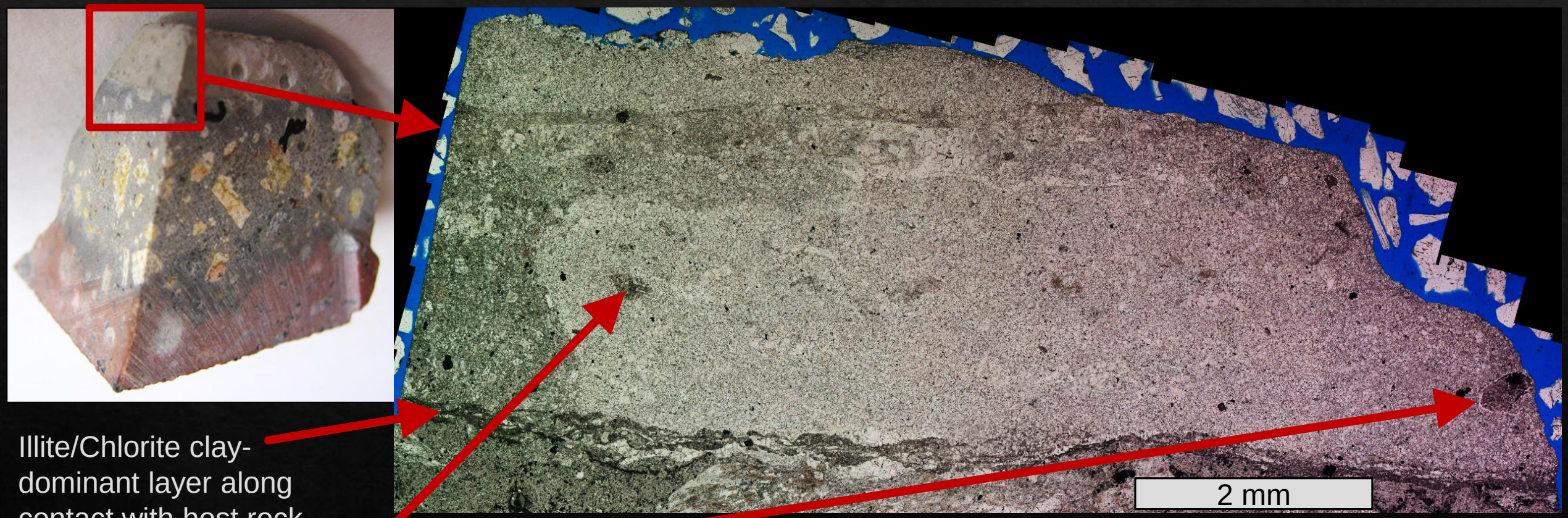


Carbonate “vein” with slickensides.

Mineralogy: ~90% Calcite, 10% Dolomite, minor pyrite and clay. Some spots contain host rock clasts.

Adjacent host rock chemically altered – Fe largely oxidized, Na mostly removed, enriched in As, depleted LREE, primary plagioclase replaced by calcite and/or clay minerals, precipitation of pyrite and sulfate.

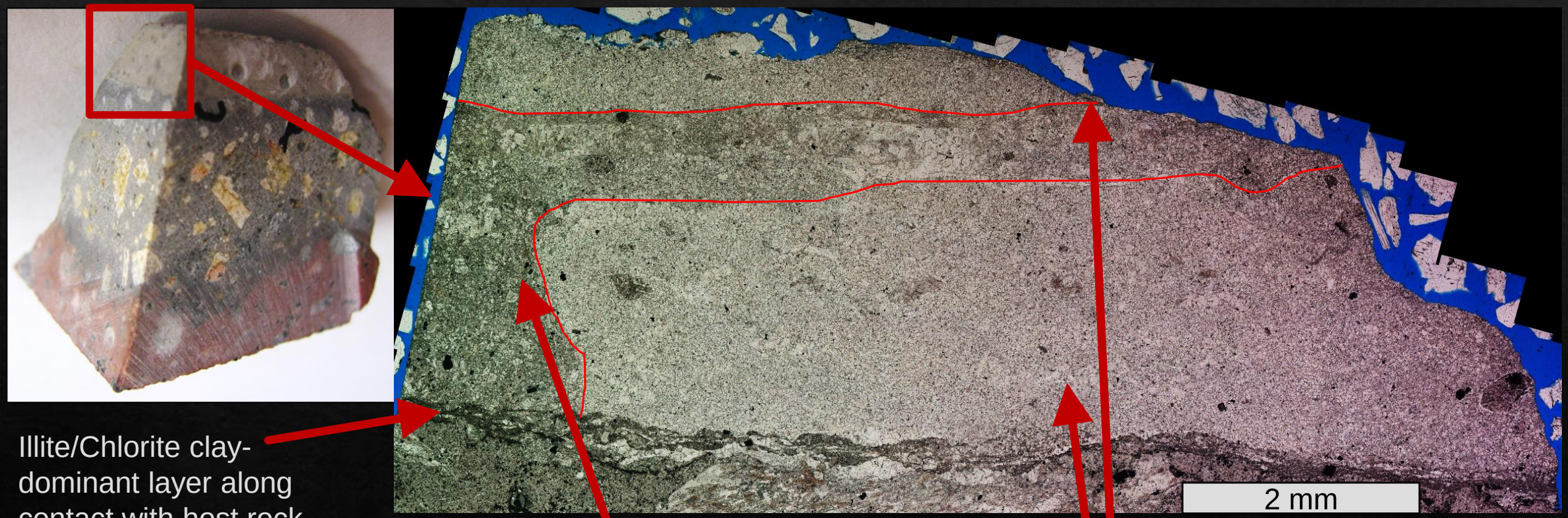
Jones 46 – Sheared Vein



Illite/Chlorite clay-dominant layer along contact with host rock, shows sheared fabric

Rhyolite clasts

Jones 46 – Sheared Vein

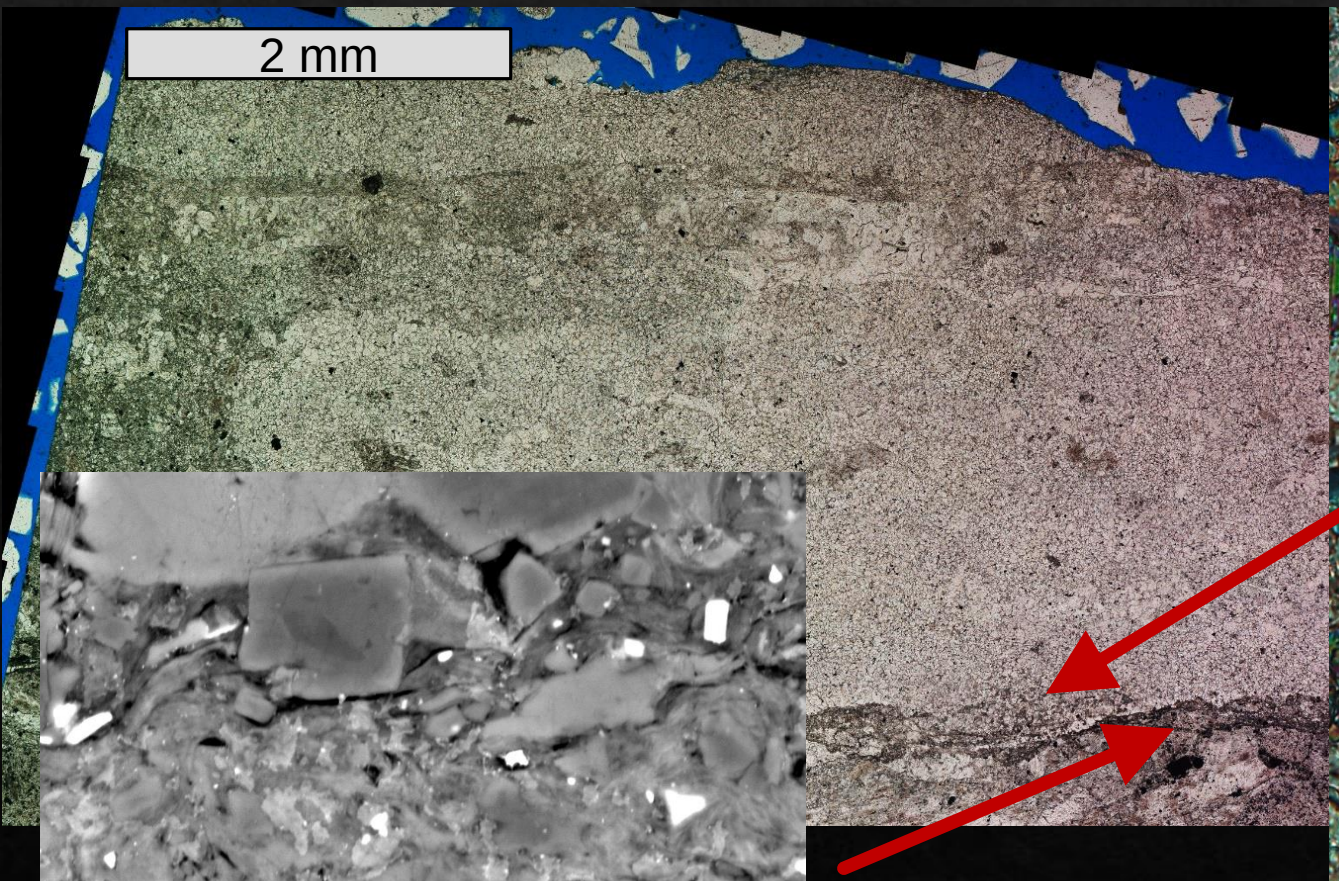


Illite/Chlorite clay-dominant layer along contact with host rock, shows sheared fabric, cross-cuts other vein textures

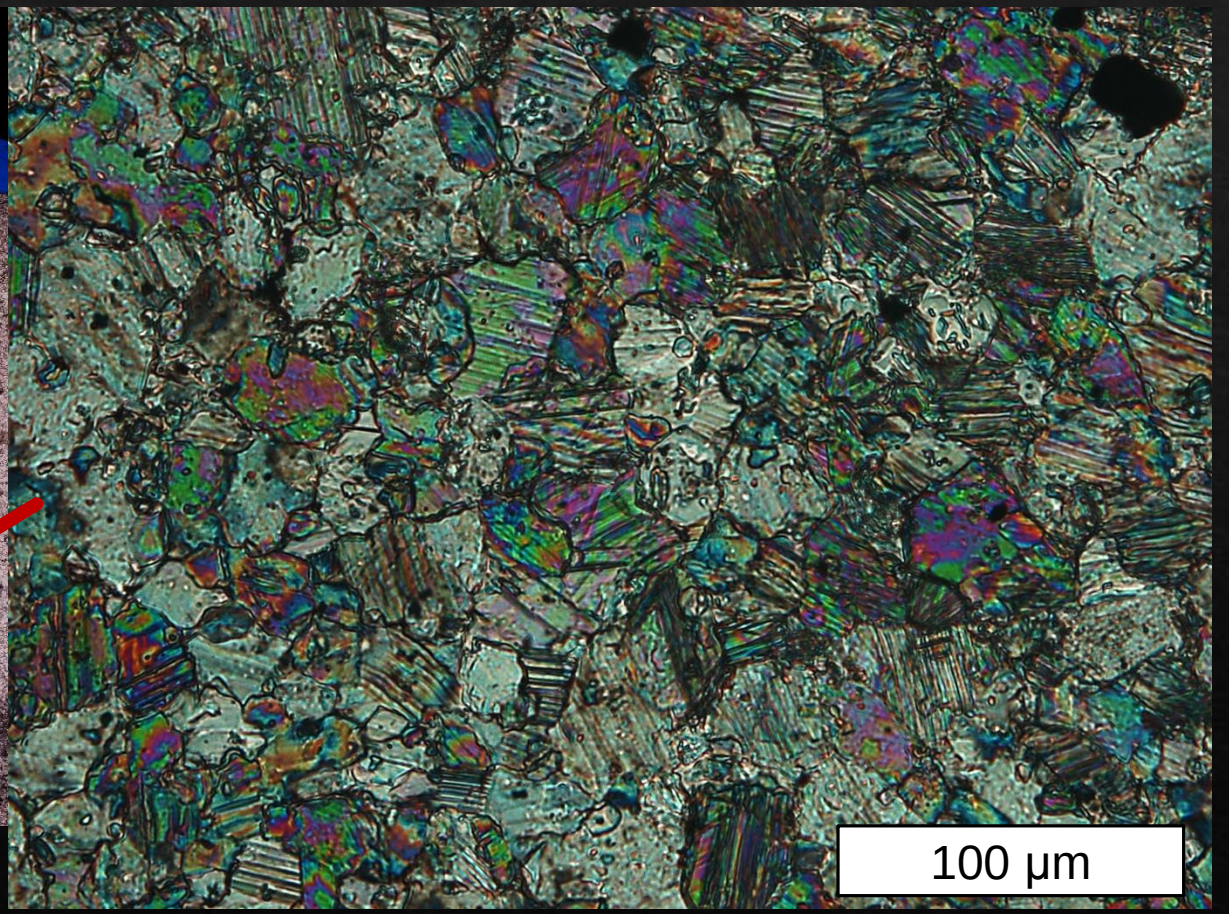
Heterogeneous calcite with illite and dolomite, porosity, incoherent structure. Interpreted as fluidized injection.

Cemented calcite, some variance but mostly equant

Jones 46 – Sheared Vein

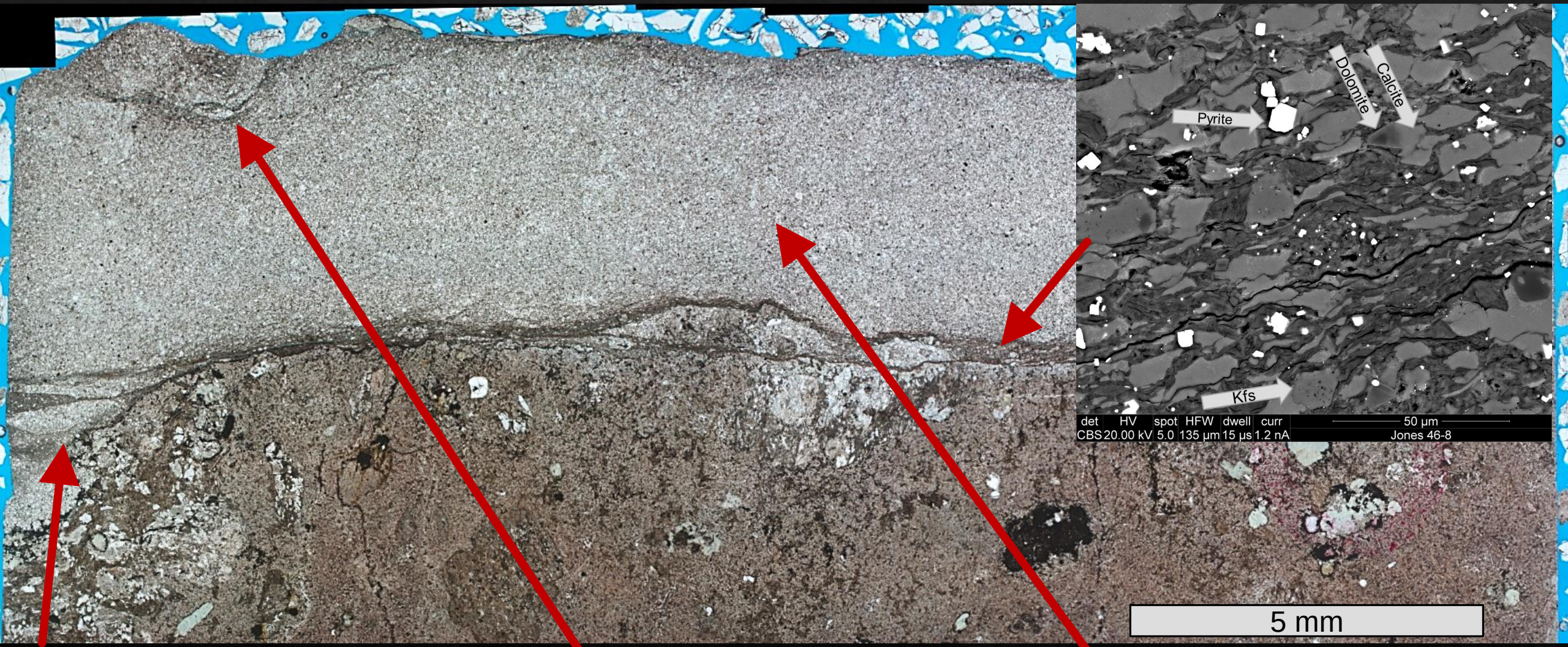


Grainsize reduction and dolomite authigenesis along boundary



Twinning and recrystallization textures in calcite consistent with high strain at temperatures below 170° C

Jones 46 – Sheared Vein

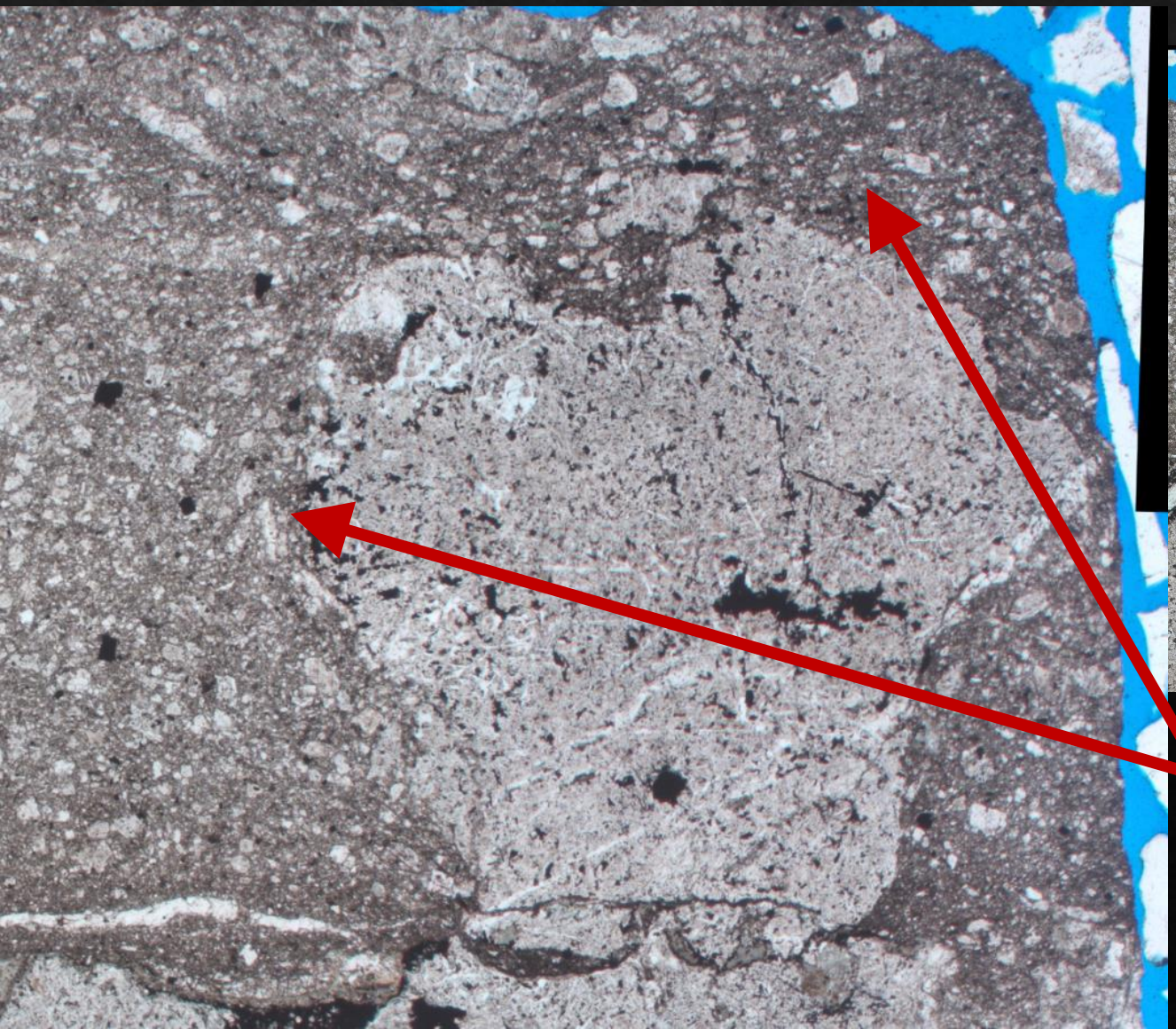


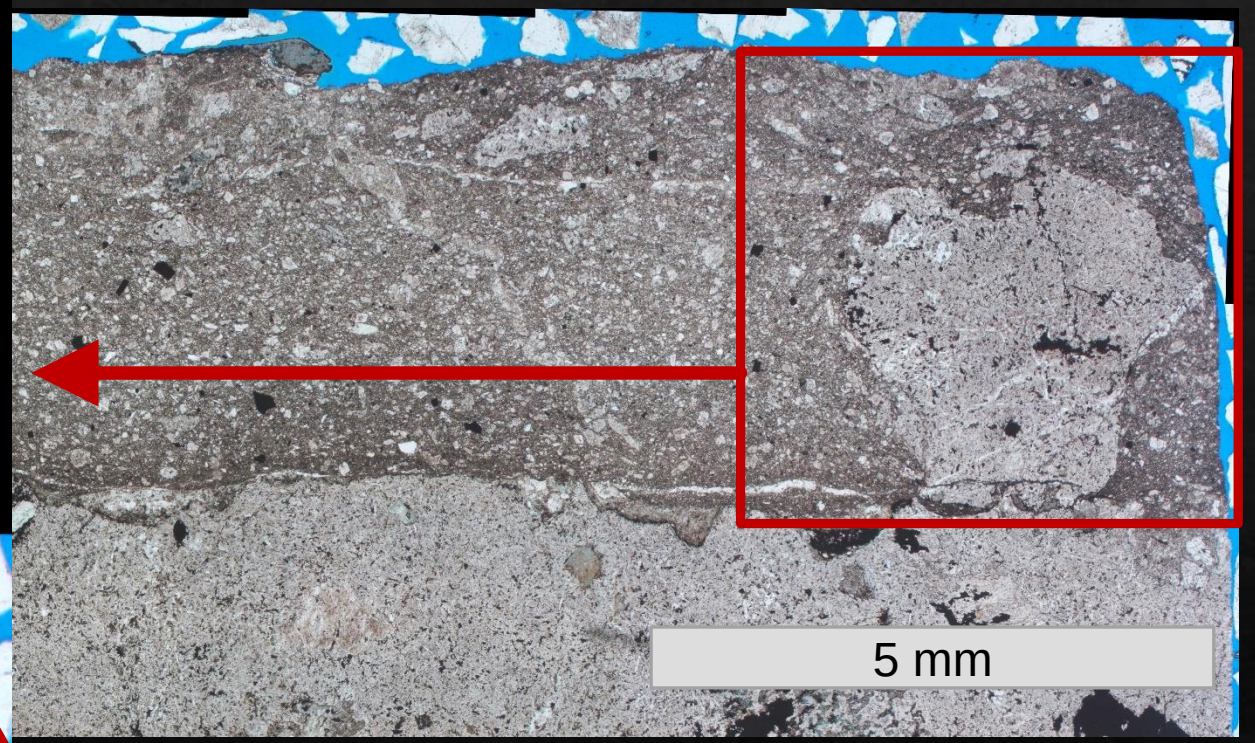
Embayment and development of lenses in pre-existing clay-rich alteration zone

Formation of carbonate clasts containing host fragments

“Massive” fine-grained, homogeneous texture

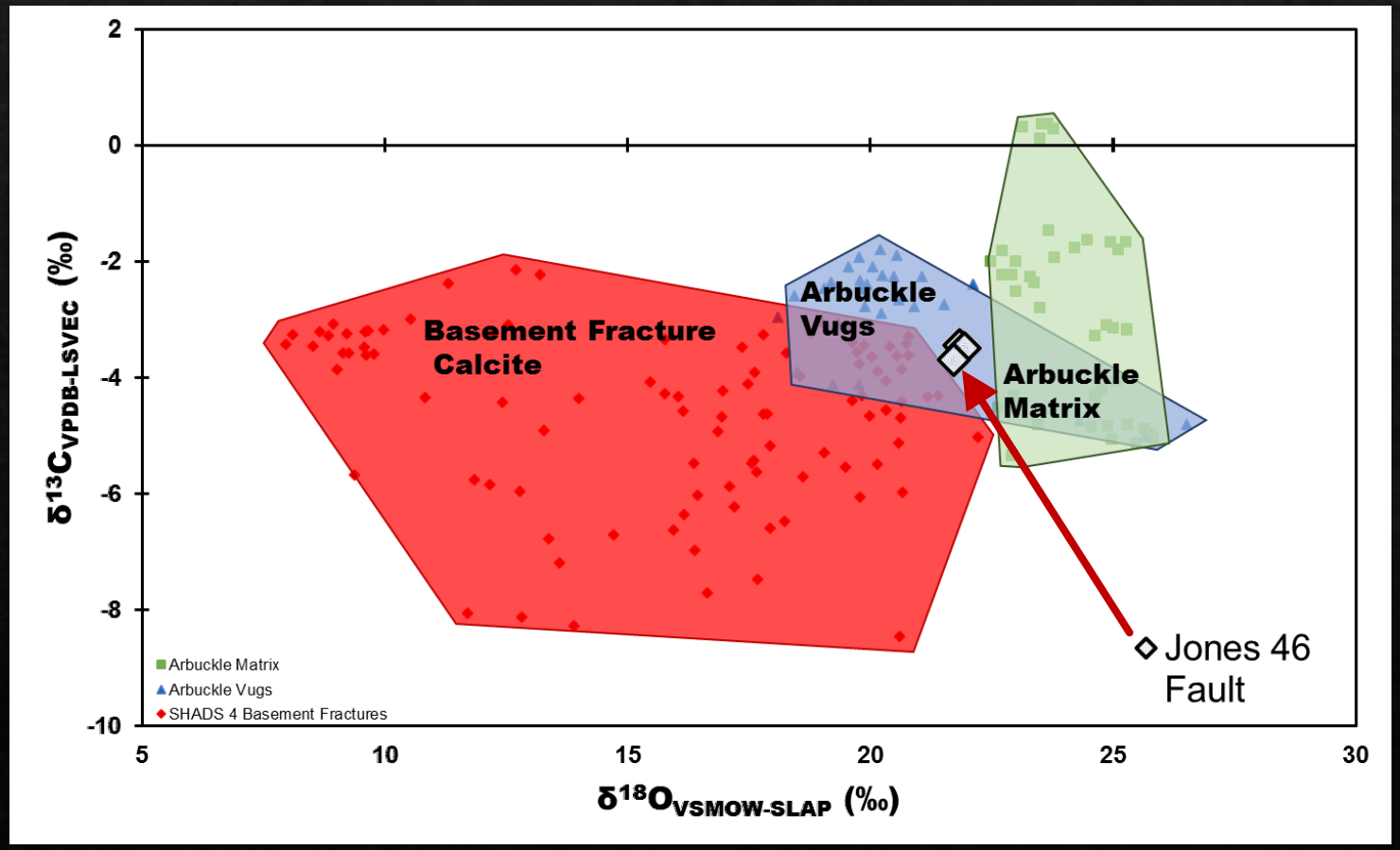
Jones 46 – Sheared Vein





Overall chaotic fabric, but weak alignment of clays and carbonate fragments developing around host rock clast.

Jones 46 – Stable Isotopes

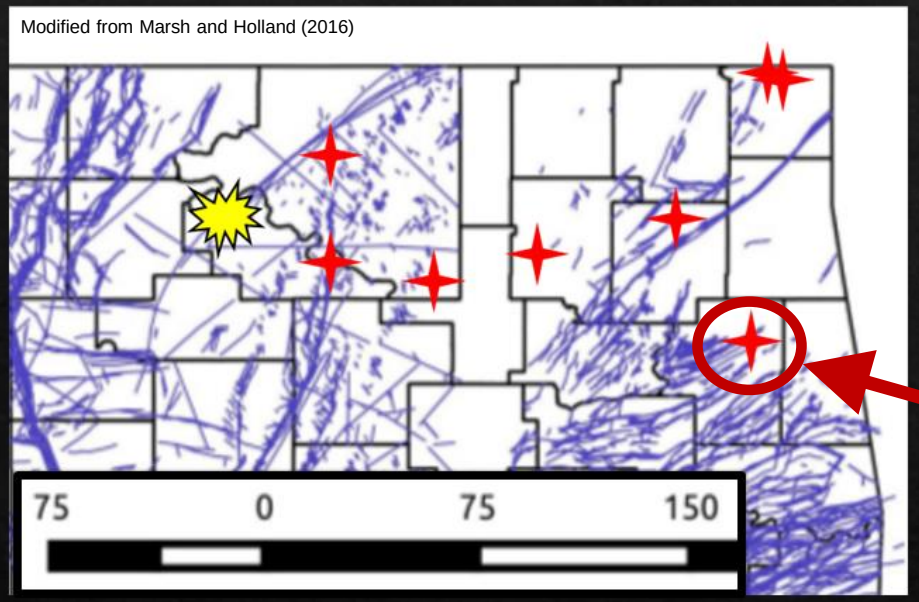


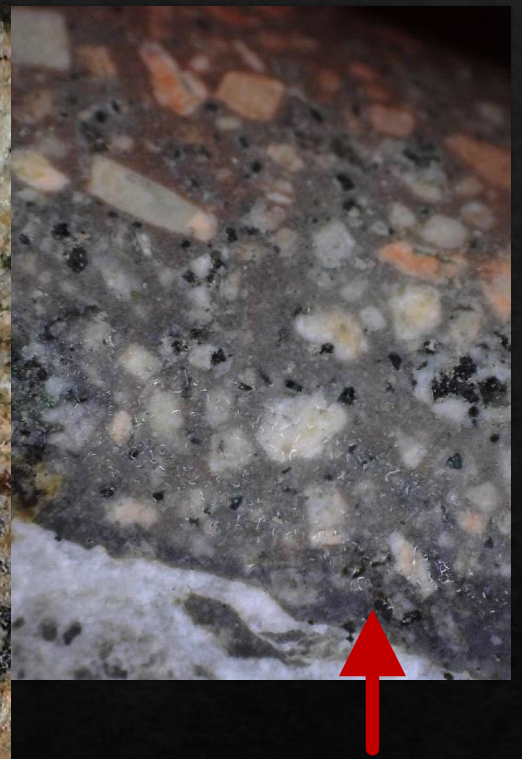
Comparison of ^{13}C and ^{18}O values shows overlap with those of secondary vug-filling carbonates from the overlying Arbuckle group.

May be an averaged value from multiple generations of calcite – early fracture fill + later authigenesis.

Not definitive, but suggestive of fluid communication with Arbuckle carbonates.

AMAX T-1 (Cherokee Co.)



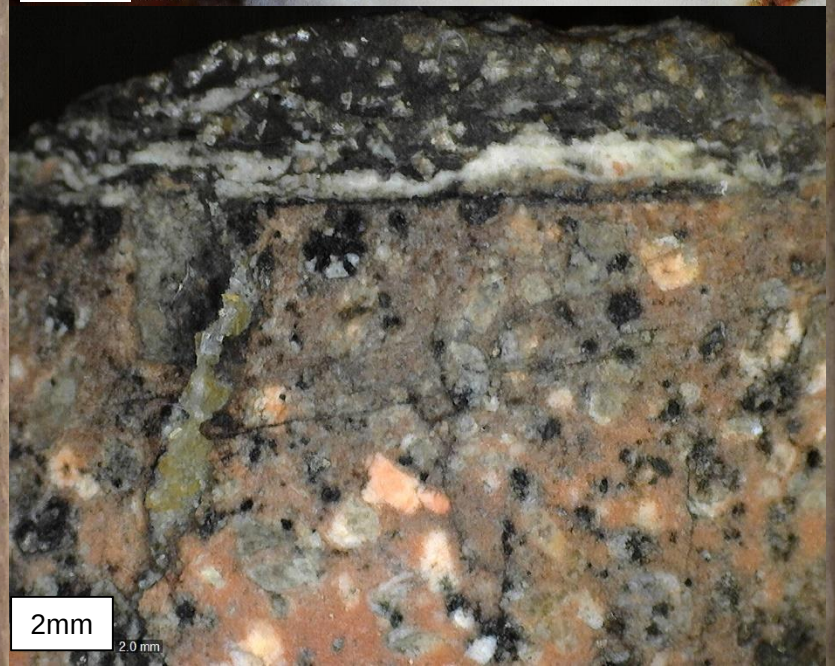


Lithology: Trachydacite

Probably welded ignimbrite (lithic clasts, weak rheomorphism)

Leaching, visually similar to the Jones 46

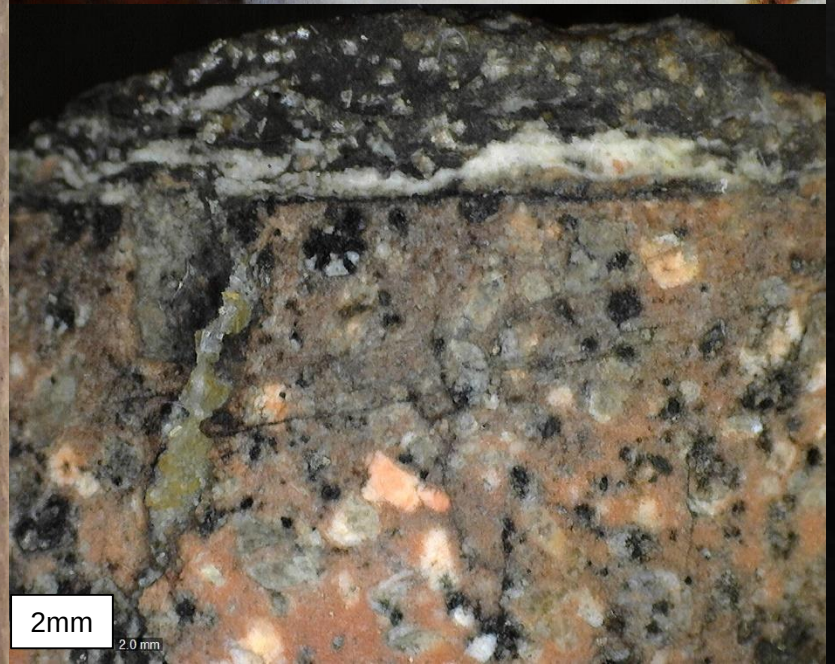
T-1 Faulting & Brecciation

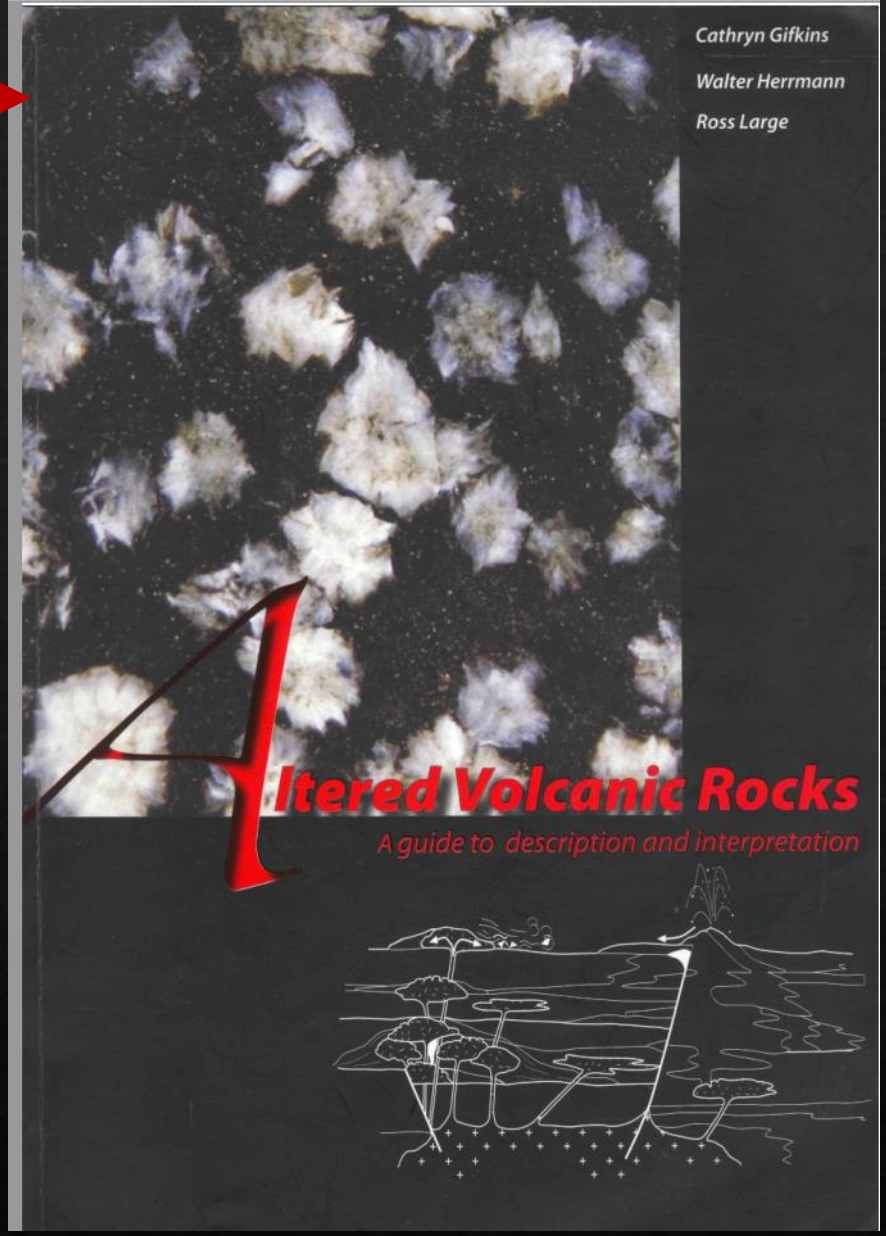


Unusual material present in several spots, always localized to fractures.

Variably alters to carbonate or clay with minor carbonate.

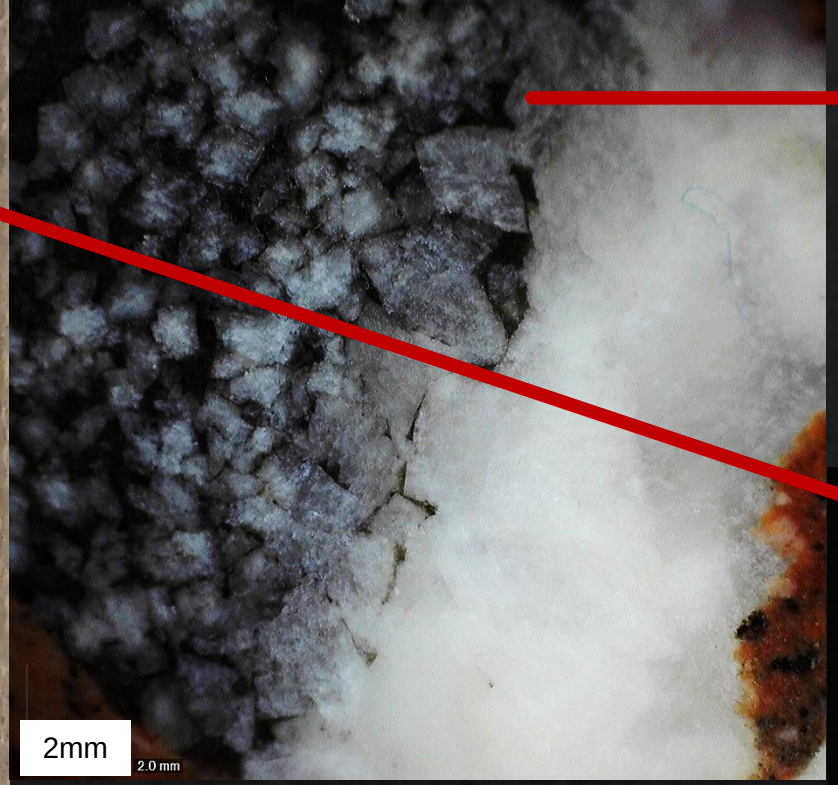
Commonly contains breccia fragments and evidence of shear, contact with host rock has slickensides.

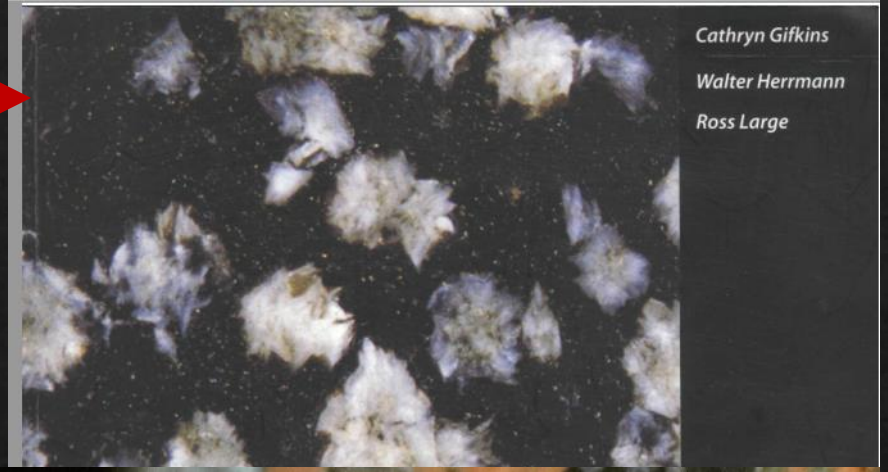


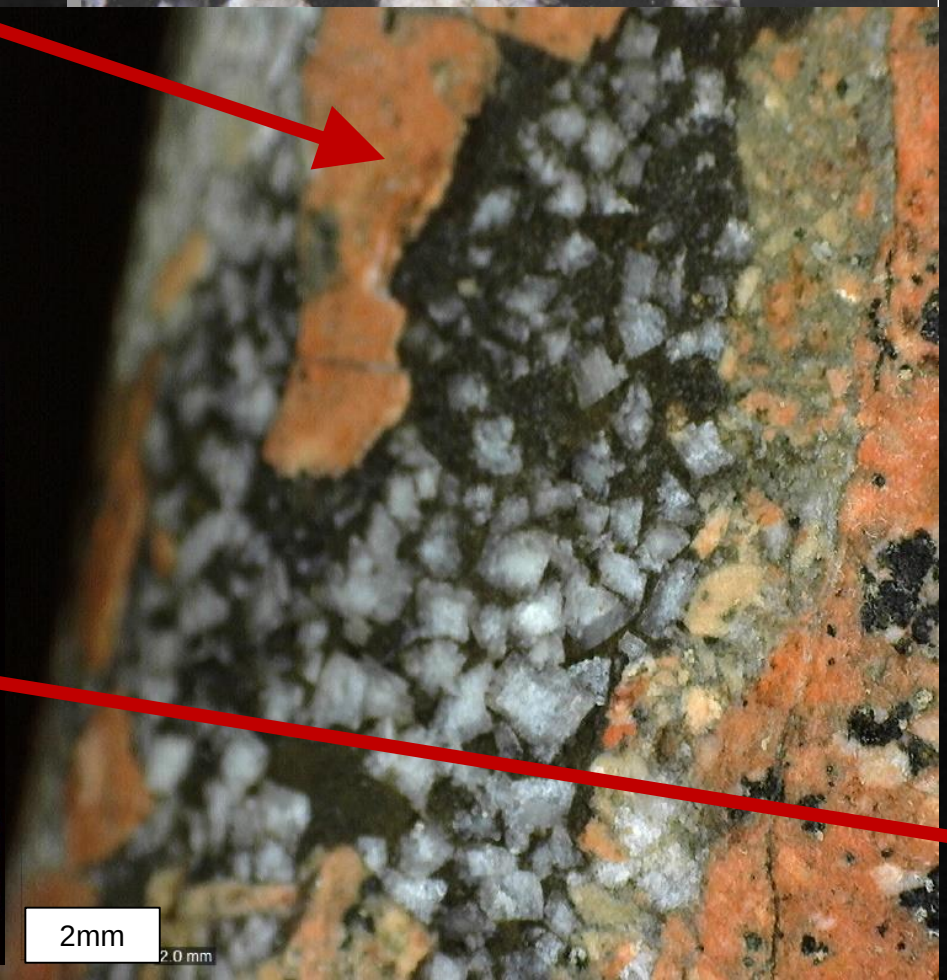


Gifkins et al., 2005

Textural resemblance to hydrothermally-altered vesicular dacite glass, led to hypothesis of altered pseudotachylyte







Textural resemblance to hydrothermally-altered vesicular dacite glass, led to hypothesis of altered pseudotachylyte

Textural evidence for multiple events of damage and/or fluid alteration

Continued slip after formation and mineralization

T-1 “Fracture” Fill

Possible dilational breccias.

Secondary carbonate and quartz almost completely overprints original texture, dark material is hematite-dusted chlorite with some “Illite”.

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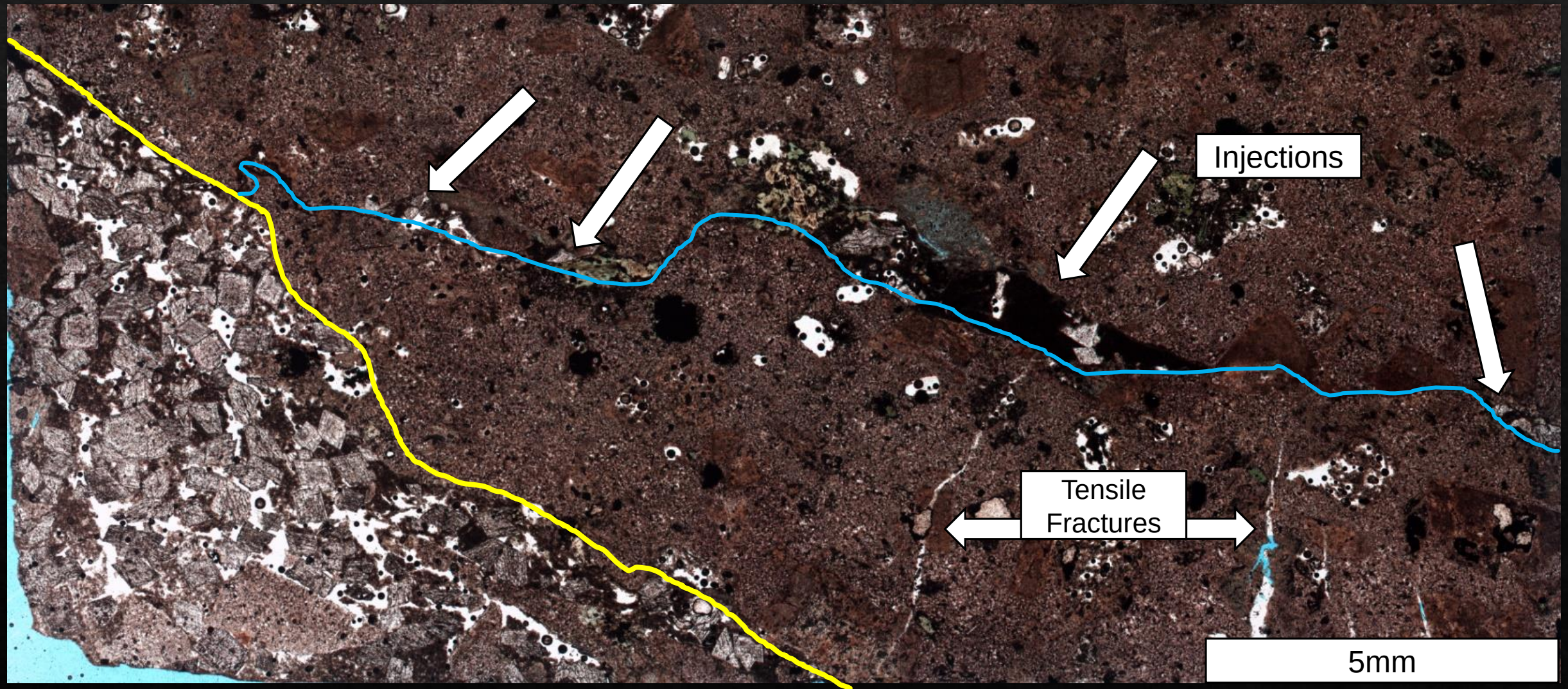
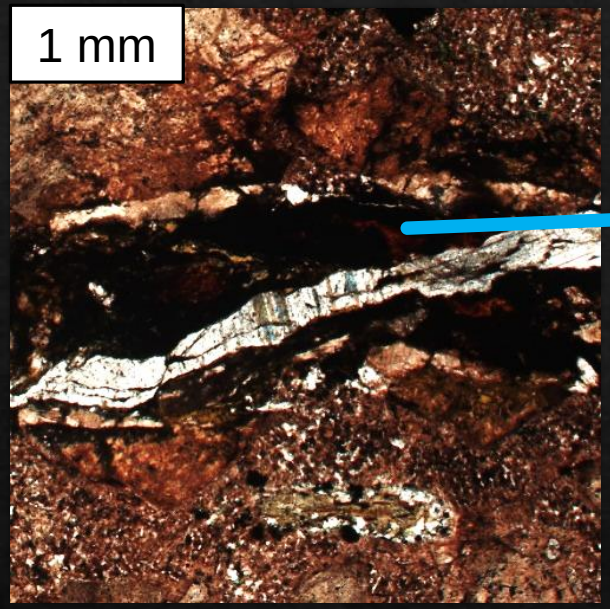
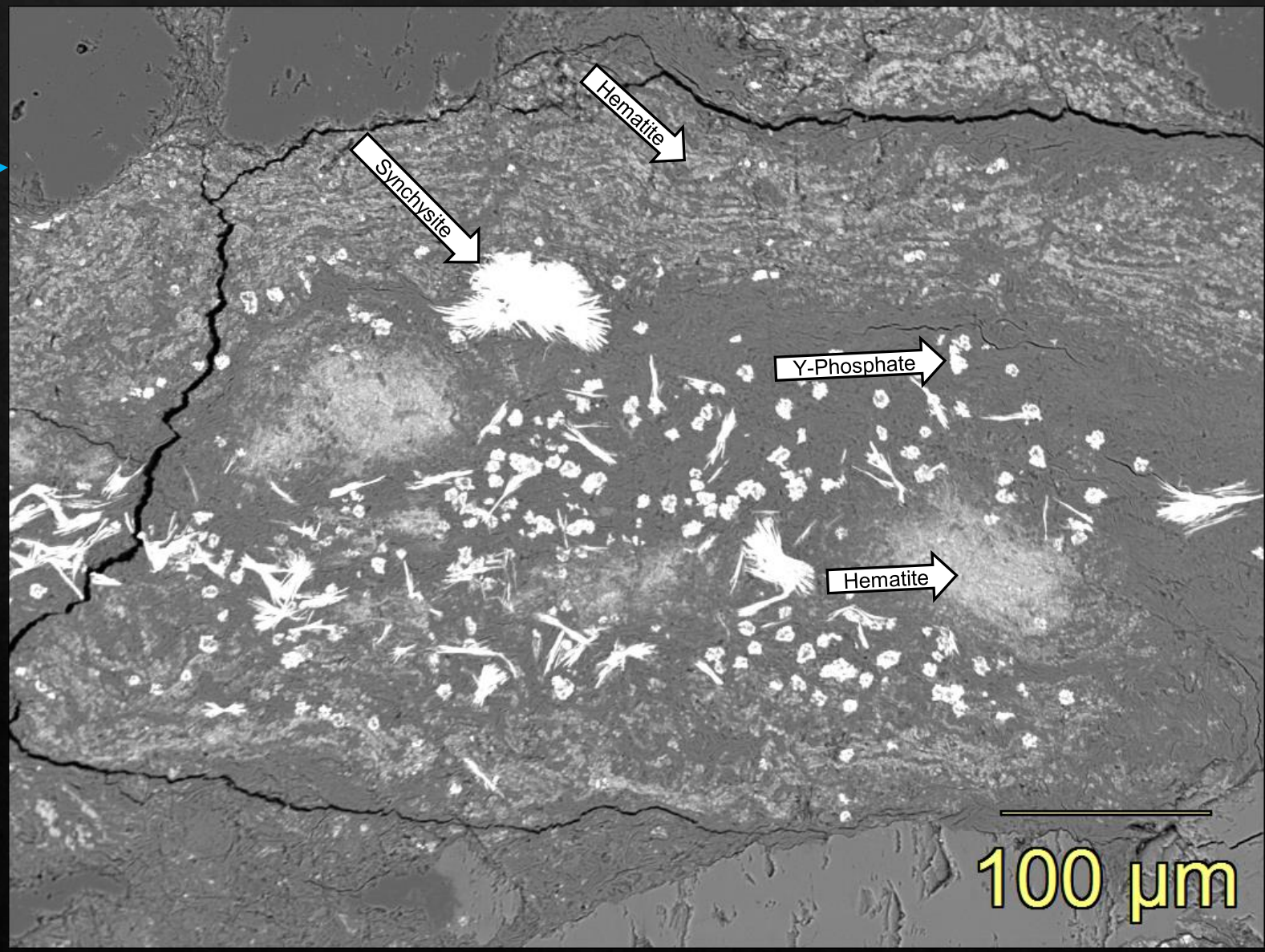


T-1 – Fabric and Secondary Minerals



Hematite dusting in chlorite under backscattered electron imaging appears to contain a flow fabric.

Unusual mineralogy including Synchysite-(Ce) and Yttrium phosphate (Xenotime, Churchite or Rhabdophane-Y)



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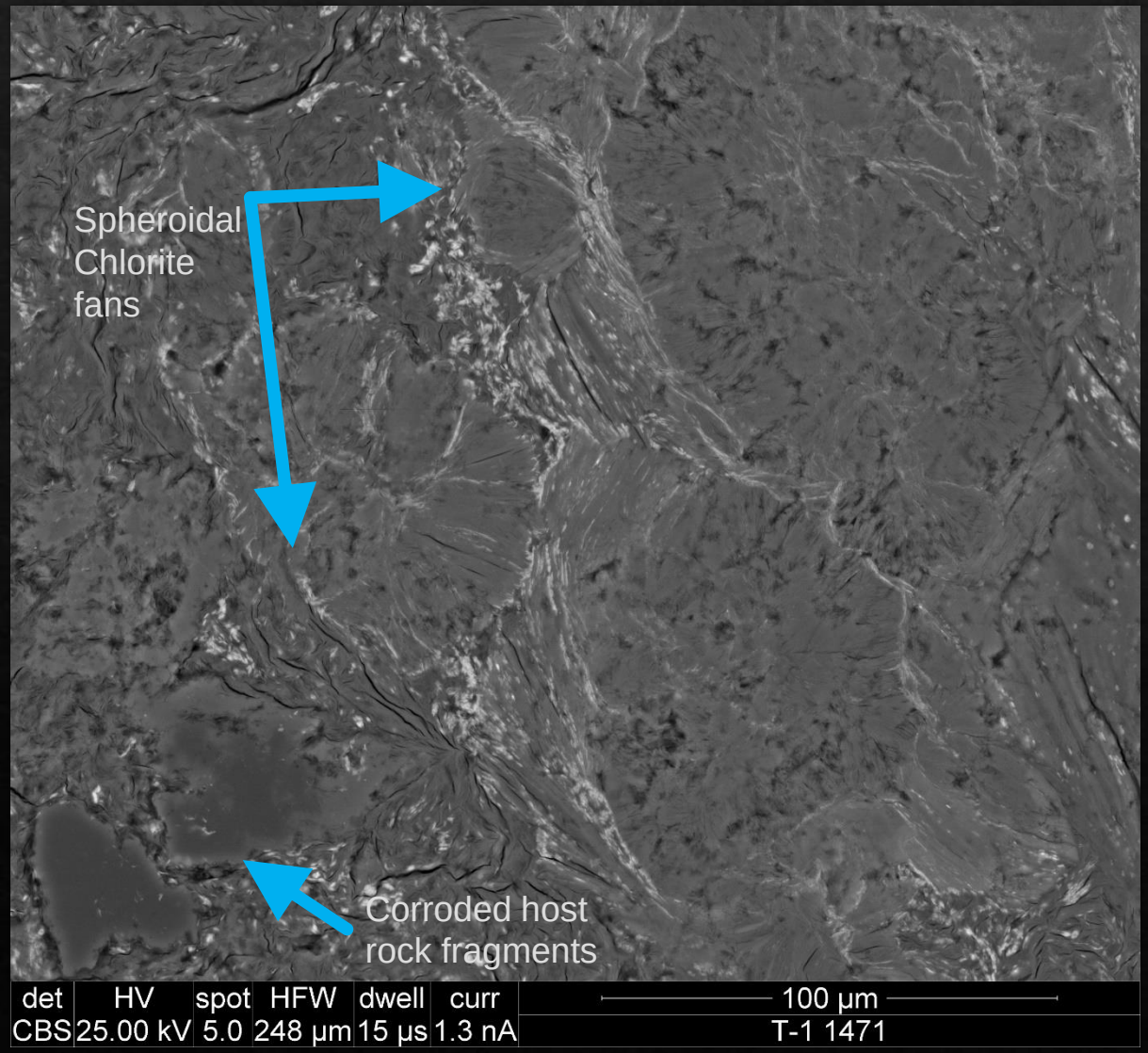
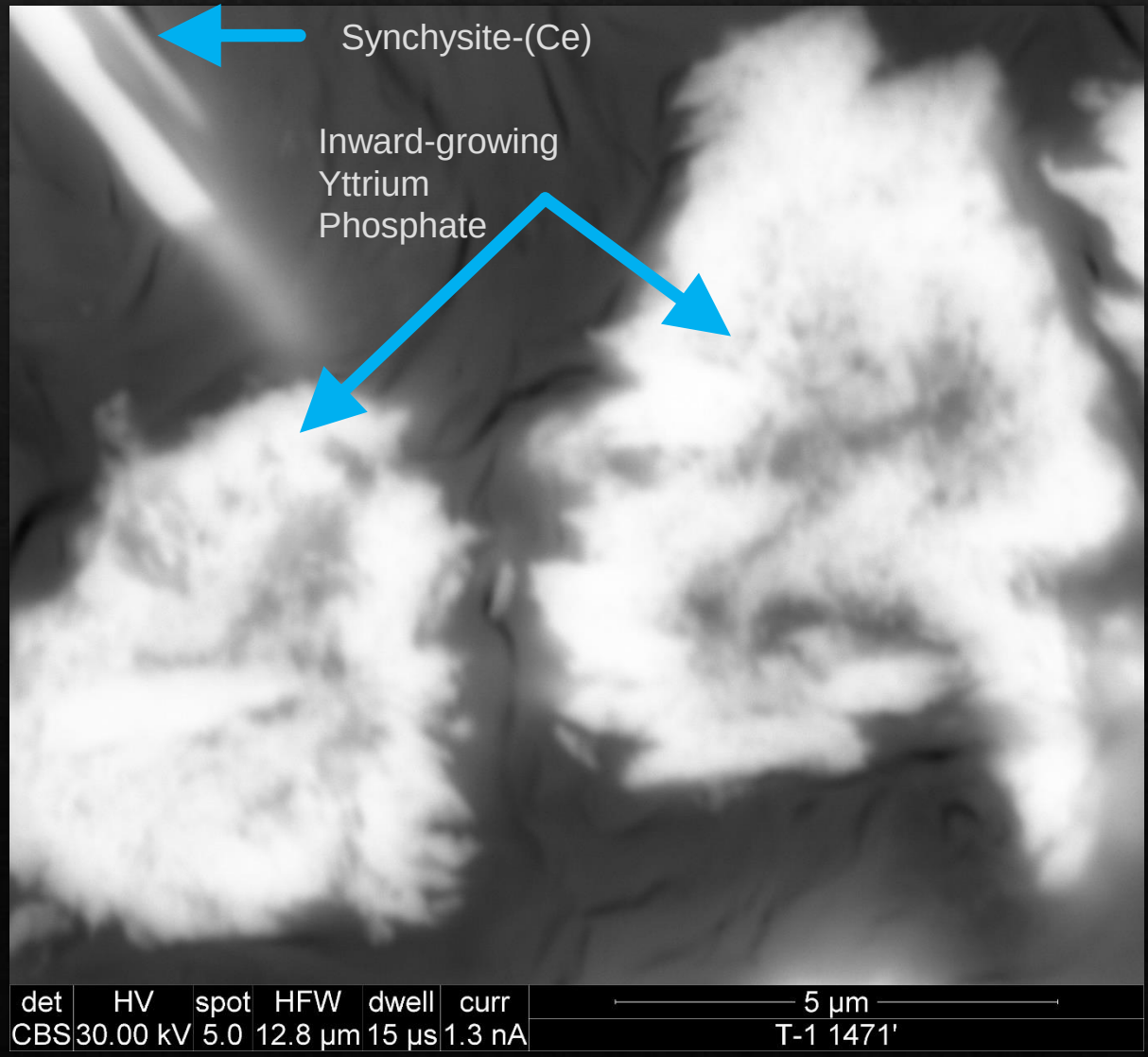




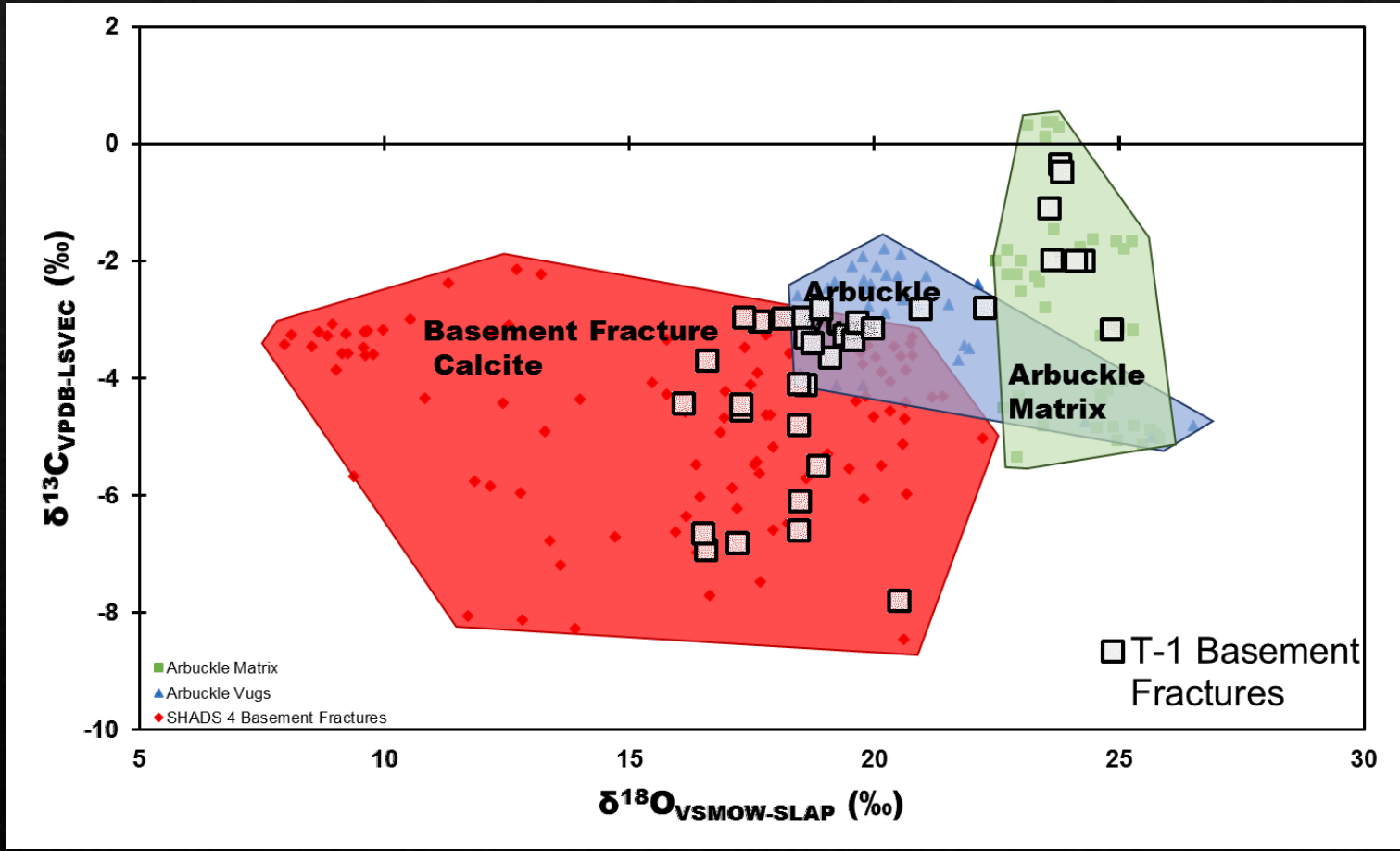
Verdict?

Presence of injections, possible flow textures, possible collapsed vesicles, Fe-oxide specks, lack of extremely granular material consistent with melt injection.

Lack of cataclastic damage zone and high degree of alteration makes textural clues equivocal at best.

Clearly a dynamic injection feature, though we cannot prove melting – remobilization of earlier fine-grained fracture fill could yield similar textures.

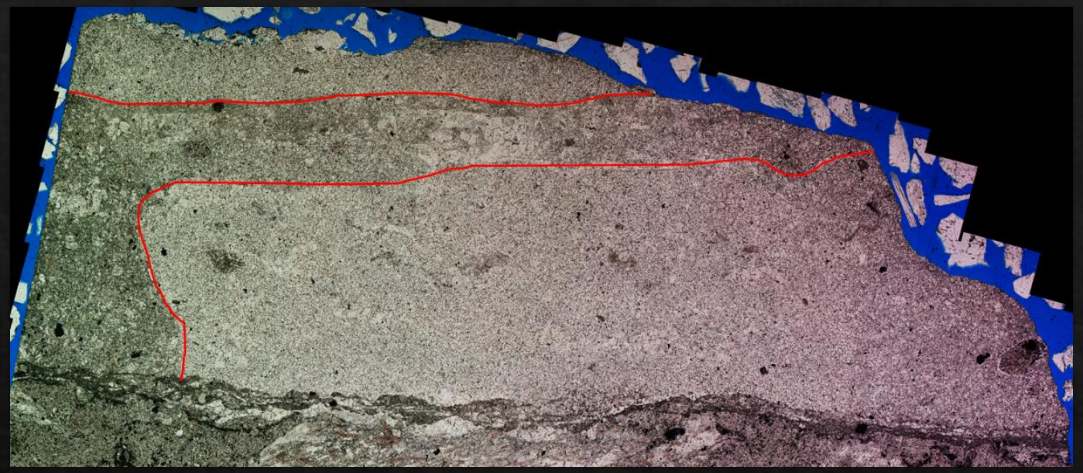
T-1 Stable Isotopes

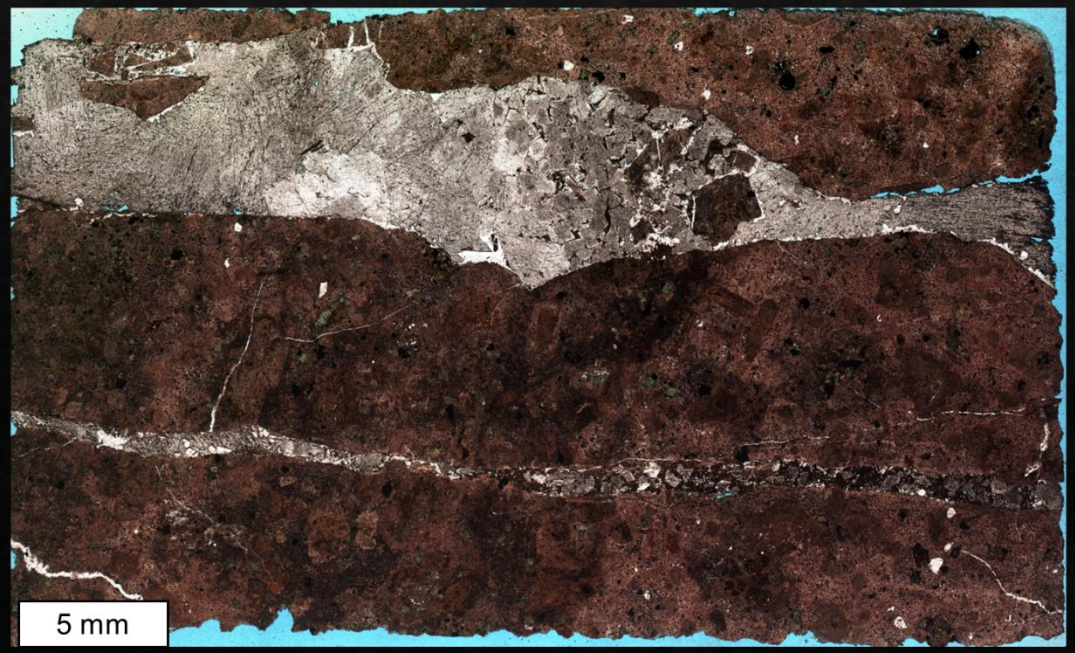


Stable isotopic values overlap with SHADS basement, Arbuckle vugs as well as Arbuckle Matrix – consistent with fluid communication during Arbuckle deposition or early diagenesis.

Overlap with vugs may be real or due to mixing of multiple generations.

Synthesis





Most cores of northern Oklahoma basement rock show evidence of shear deformation and faulting.

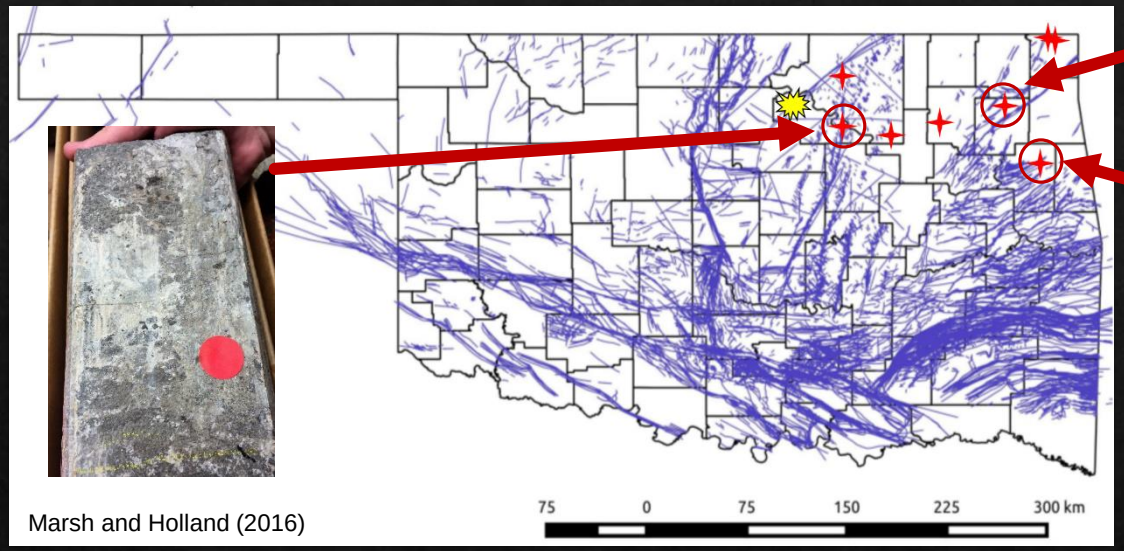
The Jones 46 and the T-1 both show evidence of dynamic deformation, possibly multiple times. These features also show evidence of continued, low strain rate slip.

Probably not major slip zones themselves, but affected by nearby ones.

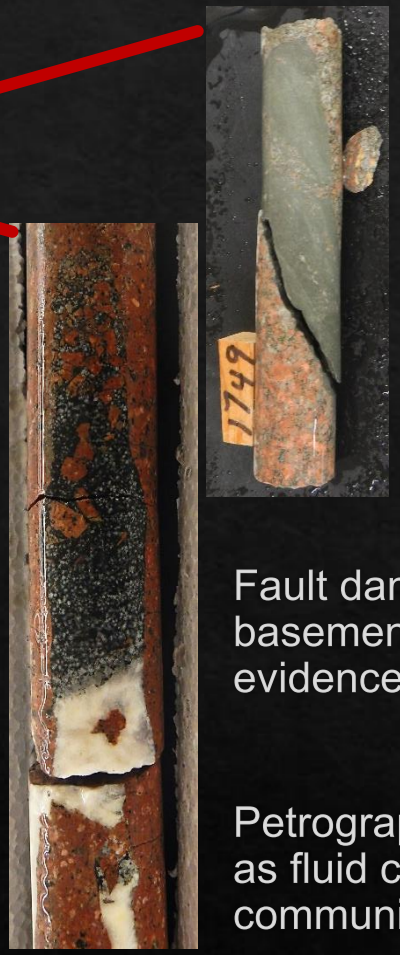
Deformation zones are heavily influenced by fluid activity, probably multiple episodes.

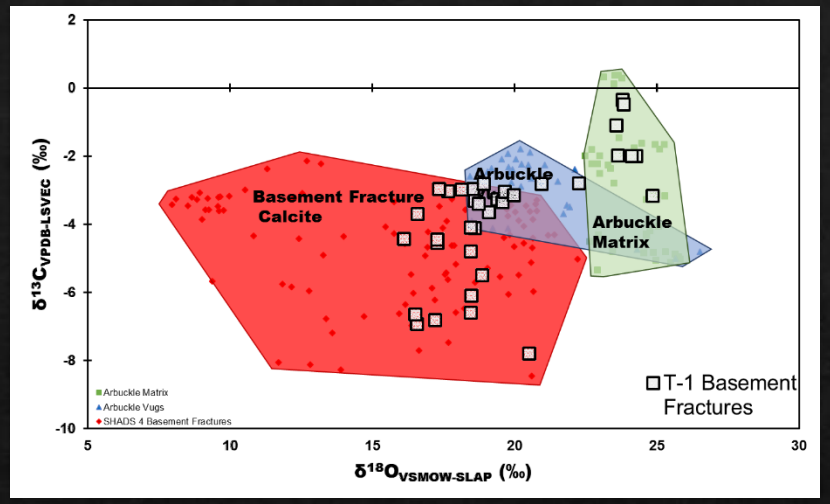
Isotopic analysis of carbonate from both cores shows possible fluid communication between faulted basement & Arbuckle group in the geologic past. May be analogous to the present.

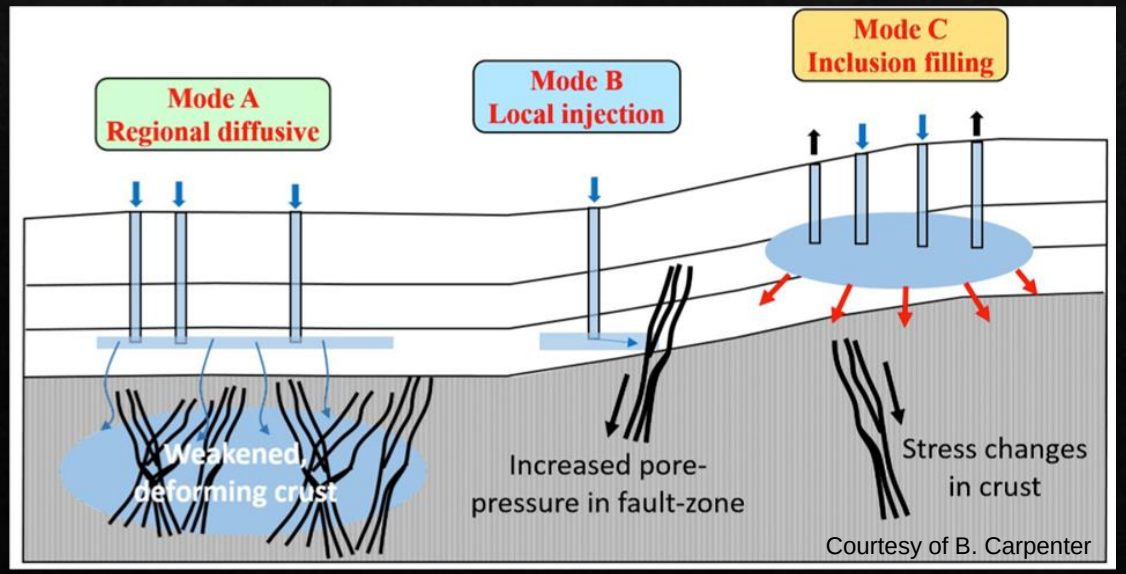
Synthesis



Marsh and Holland (2016)







Courtesy of B. Carpenter

Fault damage zones are ubiquitous in the upper basement of northeastern Oklahoma. Some contain evidence of ancient seismicity.

Petrography and isotopic data show they have acted as fluid conduits in the past and were likely in fluid communication with the overlying Arbuckle.

Petrography also shows evidence for continued Phanerozoic slip and modern porosity/permeability.