Grain Assemblages in Organic-Rich Mudstones Dominated by Extrabasinal Sediment Sources, Yanchang Formation (Triassic), Ordos Basin, China*

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Abstract

The primary composition of grain assemblages in mudrocks is a major control on post-depositional processes that affect the evolution of bulk rock properties such as porosity, sonic velocity, and mechanical moduli. Grain assemblages in a suite of mudstones from the lacustrine Yanchang Formation have been examined by field-emission scanning electron microscopy. Energy-dispersive X-ray mapping in combination with cathodoluminescence imaging reveals that the grain assemblages are dominated (>90 percent by volume) by grains derived from outside the basin of deposition, and hence, these mudstone are ‘tarls’ (terrigenous argillaceous rocks). Major extrabasinal grains include K-rich clay, quartz, plagioclase, K-feldspar, volcanic rock fragments, and micas. In terms of the quartz-feldspar-lithic grain compositions these samples are classified as arkoses. Intrabasinal grains include particulate organic matter and phosphatic debris. Organic matter content in particular is positively correlated with detrital clay content, denoting a reduction in the abundance of coarser extrabasinal detrital components in organic-rich samples. Authigenic components that can be observed using the imaging methodologies employed are restricted to localized cone-in-cone structures, grain replacements, pore-filling precipitates within anomalously large pores hosted by dissolved feldspars and other grains, and very minor quartz overgrowths associated with local packing flaws around detrital quartz grains. Matrix-dispersed cement crystals are not observed, suggesting that mechanical compaction and pore-filling by migrated hydrocarbon have been the dominant causes of porosity decline. Creation of brittle rock properties through early cementation related to alteration of abundant and unstable grains of intrabasinal derivation, analogous to other well known

organic-rich mudstones such at the Barnett Shale or the Eagle Ford Formation, is unlikely to have played a role in the diagenesis of these particular lacustrine mudstones.

Selected References

Milliken, K.L., 2013, Cementation in mudrocks: brief review with examples from cratonic basin mudrocks: AAPG Memoir 103, p. 133-150.

Milliken, K.L., 2014, Acompositional classification for grain assemblages in fine-grained sediments and sedimentary rocks: Journal of Sedimentary Research, v. 84, p. 1185-1199.

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1 Bureau of Economic Geology

2 Yanchang Petroleum

ETD Ca Na Mg

AAPG SEG International Conference & Exhibition 2015
13-16 September • Melbourne, Australia
PESA Incorporating PESA's Eastern Australasian Basins Symposium

Goals for Petrographic Study

Main tasks:

- Qualitative characterization of primary grain assemblage by EDS X-ray mapping
  - Extrabasinal
  - Intrabasinal
- Quantitative assessment of compositional variation:
  - Classification
- Assessment of textural variation

Secondary tasks

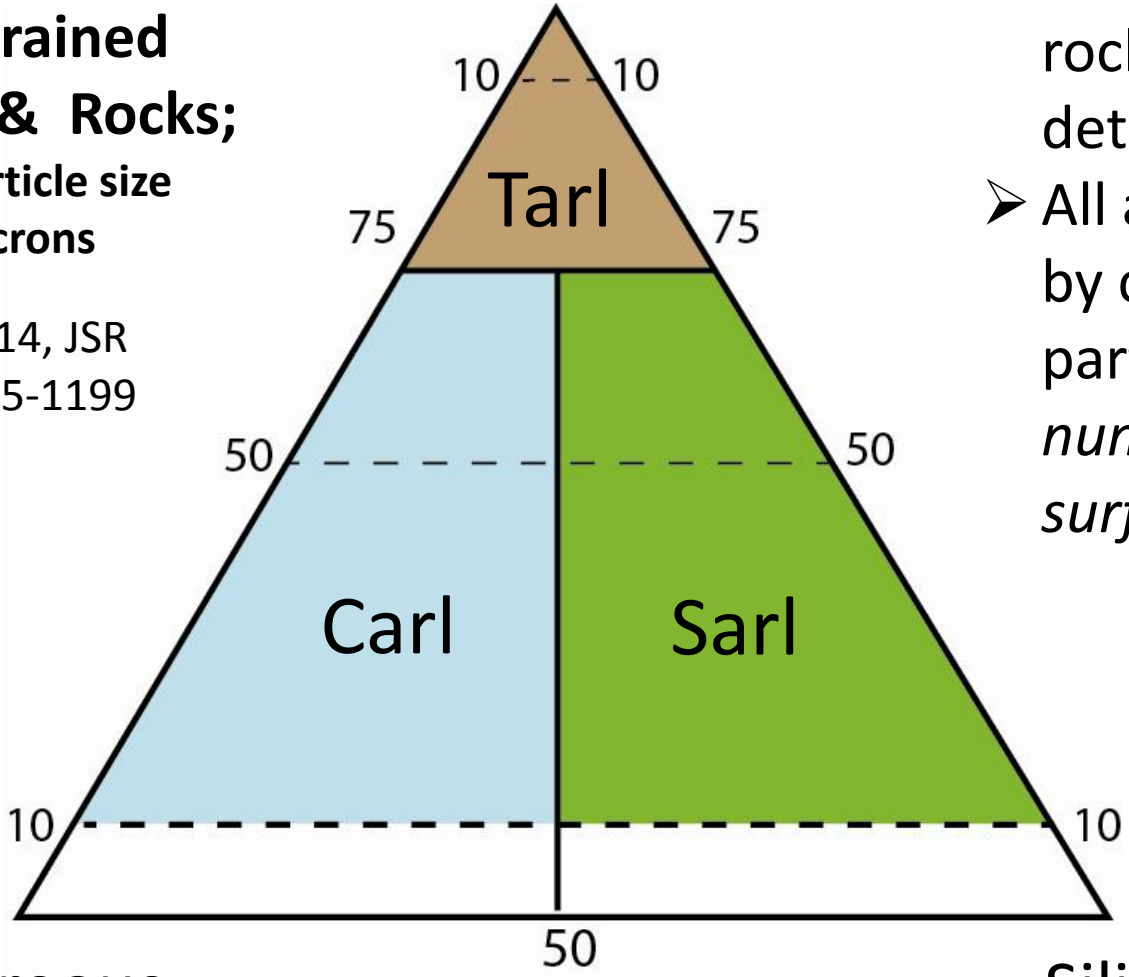
- Recognition of diagenetic features
  - Cements (including CL imaging)
  - Grain replacements
  - Compaction
  - Fractures
- Identification of biogenic components

Classification of Fine-grained Sediments & Rocks;

Average particle size < 62 microns

Milliken, 2014, JSR v. 84, p. 1185-1199

Terrigenous and Volcanic Grains

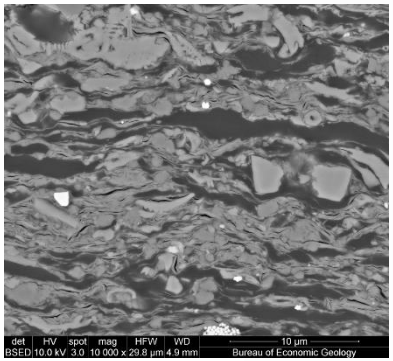


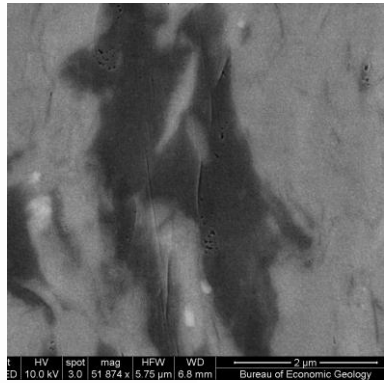
Calcareous Bio-grains

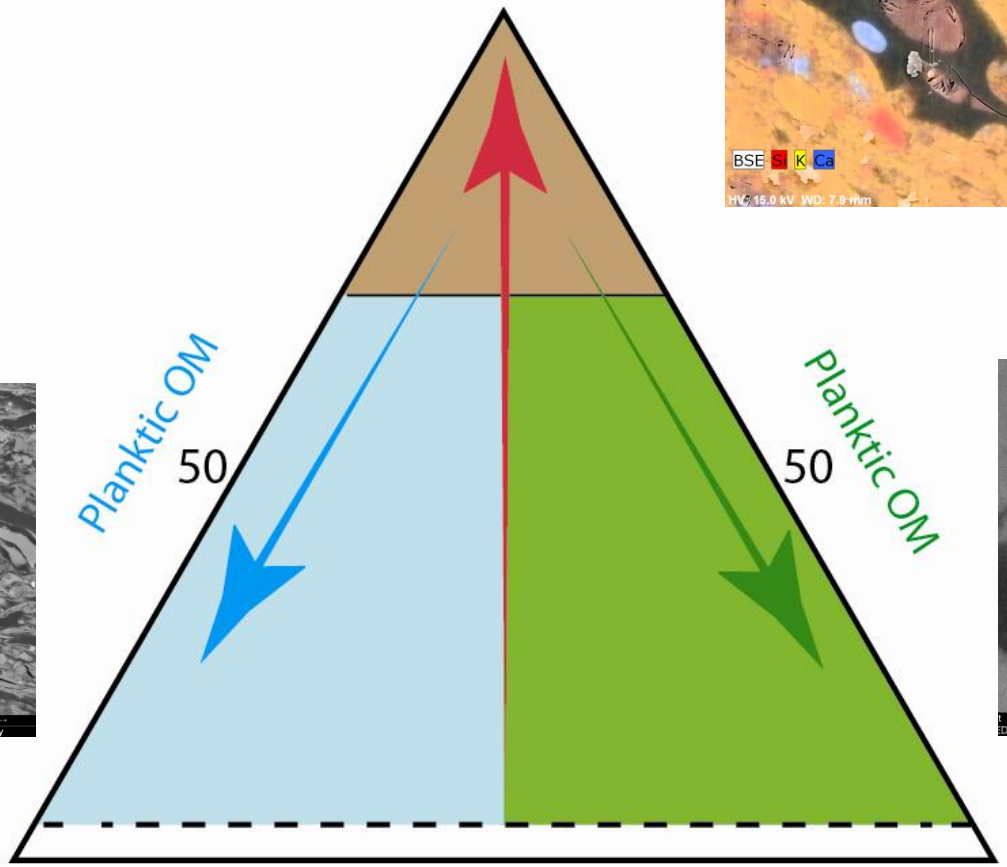
Siliceous Bio-grains

- All of these sediments and rocks contain detrital clay.
- All are dominated by clay mineral particles *by grain number and surface area*.

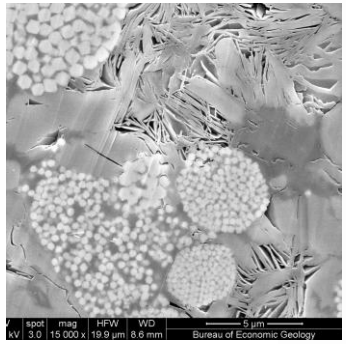
Prediction of Kerogen Content

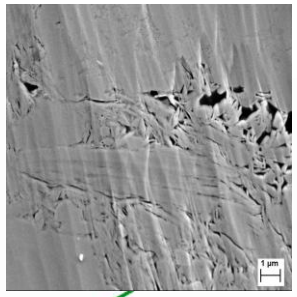


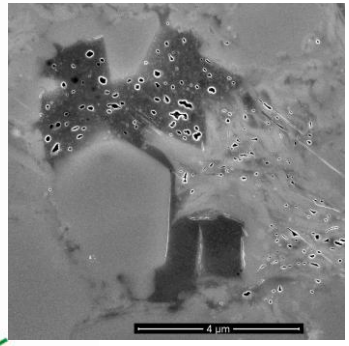


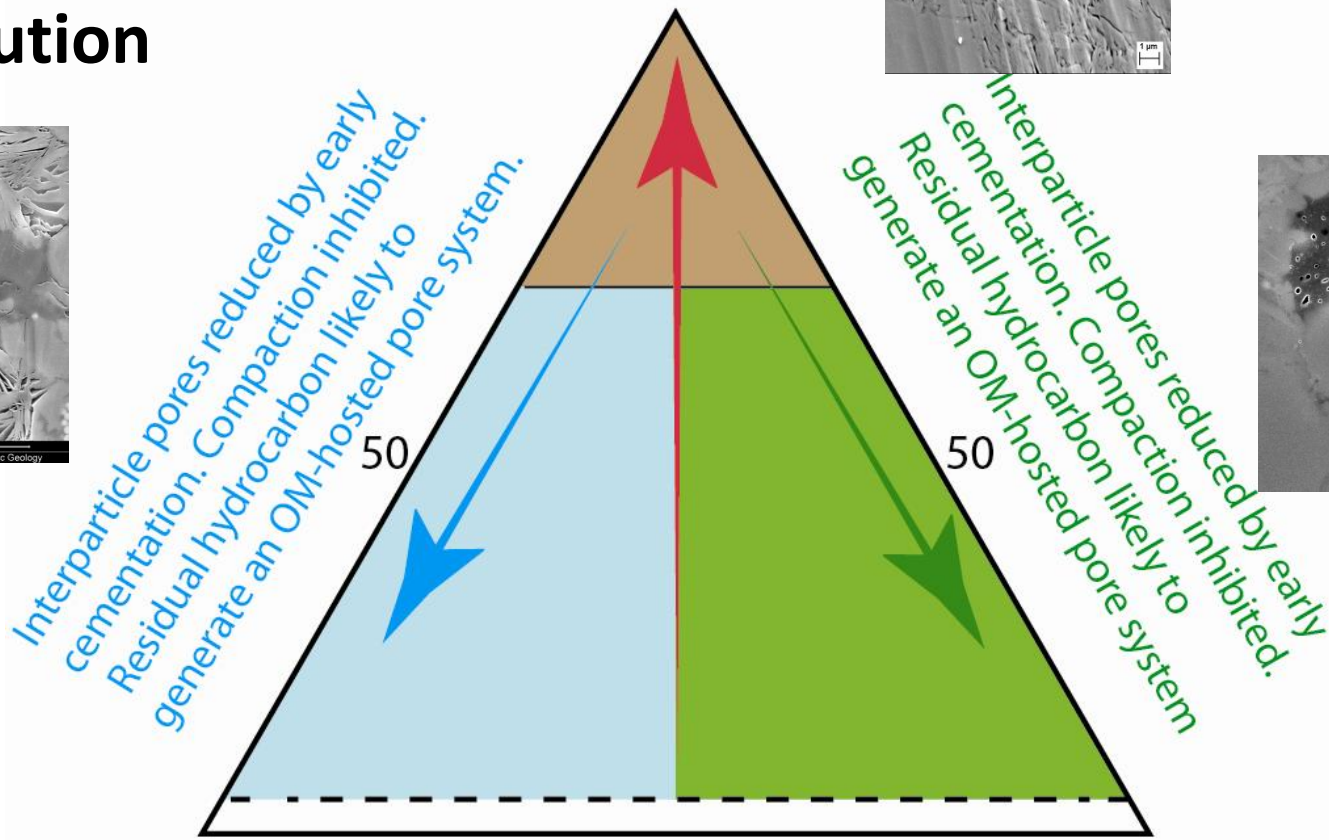


Prediction of Porosity Evolution

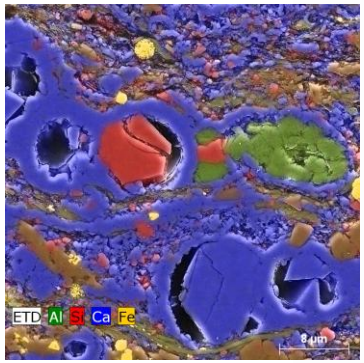


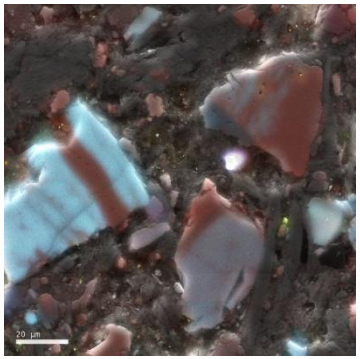


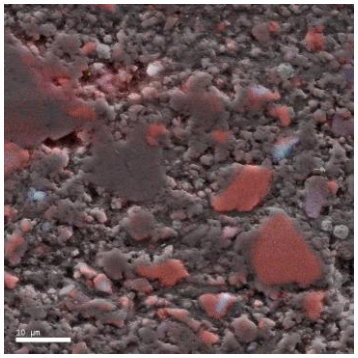


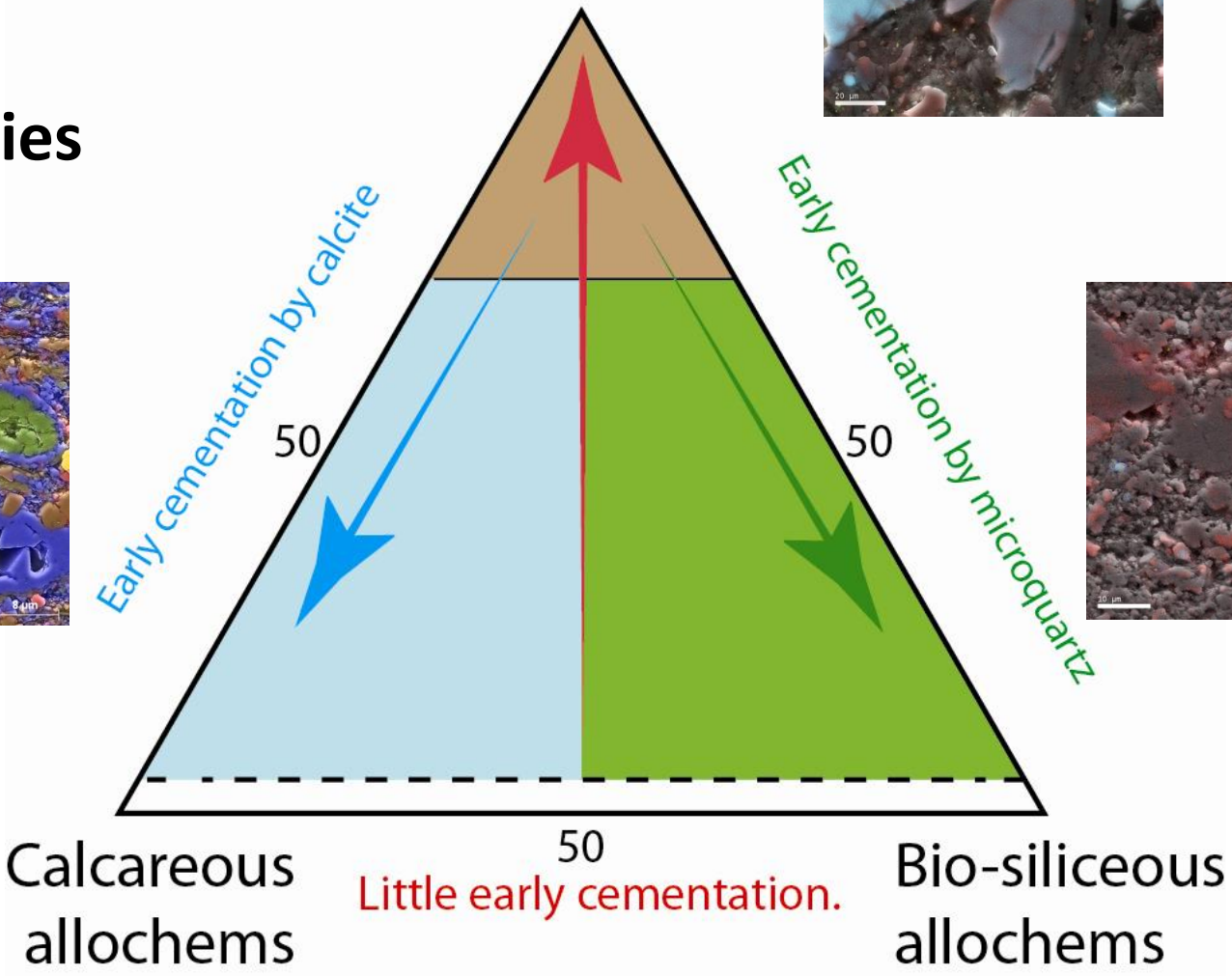


Prediction of Mechanical Rock Properties





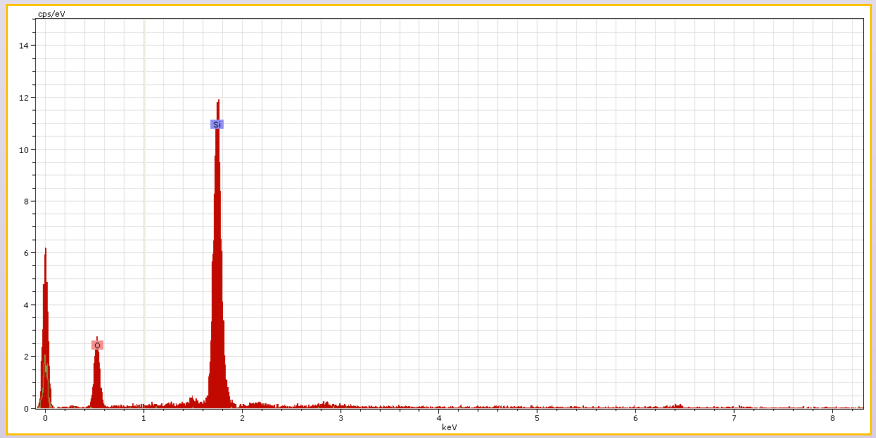




Petrographic Analysis Plan for 46 Samples

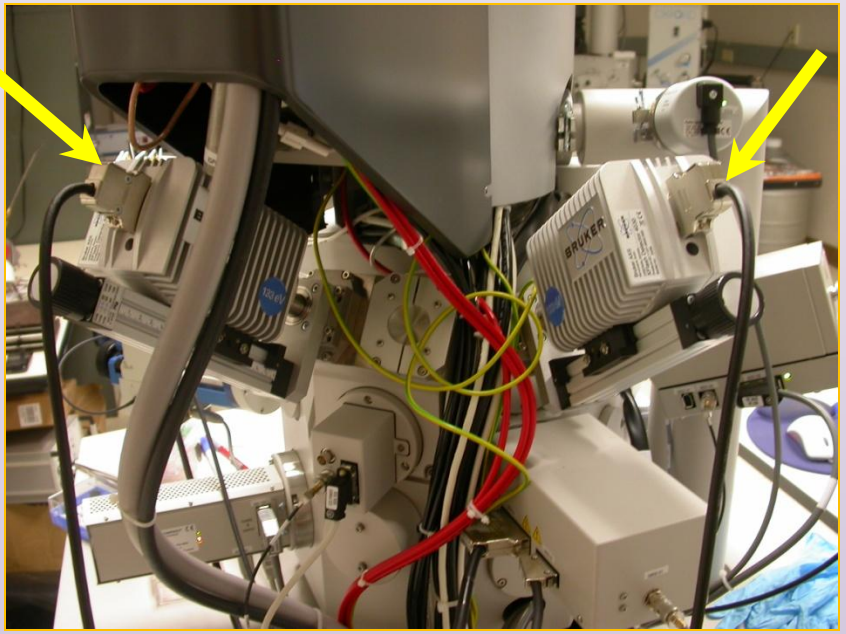
- High-resolution thin section scan
  - Fabric and general composition
- Transmitted light microscopy
  - Fabric, detrital grain assemblage, diagenetic features
- Reflected light microscopy
  - Assess silt content
- EDS X-ray mapping
  - Texture and fabric
  - Grain assemblage
    - Qualitative
    - Quantitative by point-count of images taken at uniform magnification
  - Authigenic components
- Scanned CL imaging
  - Authigenic versus detrital quartz
- High-resolution secondary electron imaging of Ar-ion milled surfaces
  - Pore characterization

X-ray mapping by Energy-Dispersive Spectroscopy (EDS)



Intensity (cps/eV)

Energy (keV)



Twin 30 mm^2 EDS detectors: sum the signals

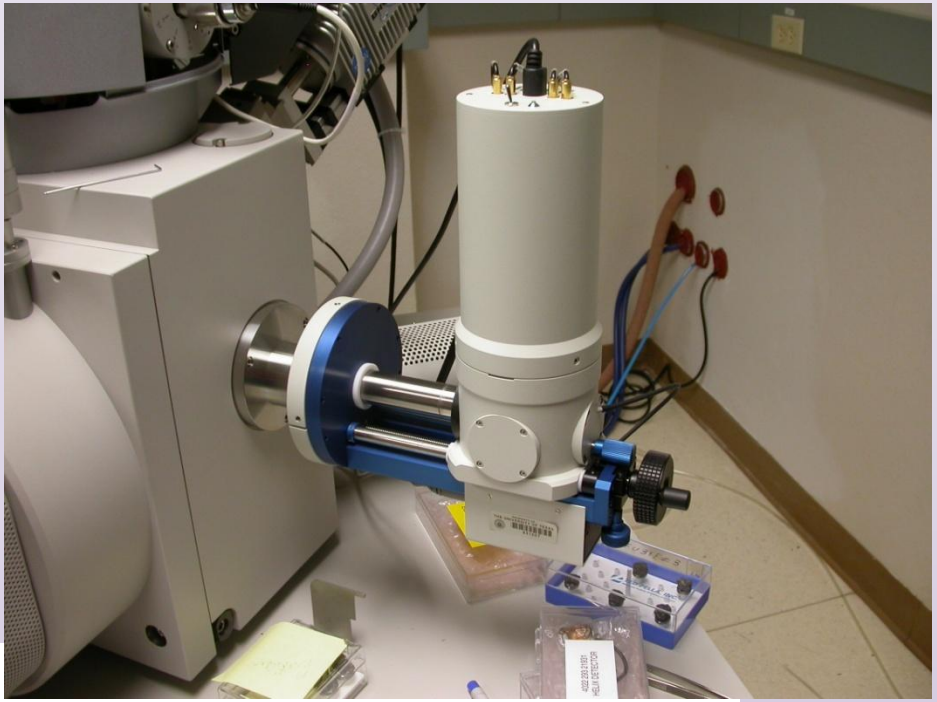
X-ray signal can be used qualitatively for element ID or mapping, or quantitatively for analysis.

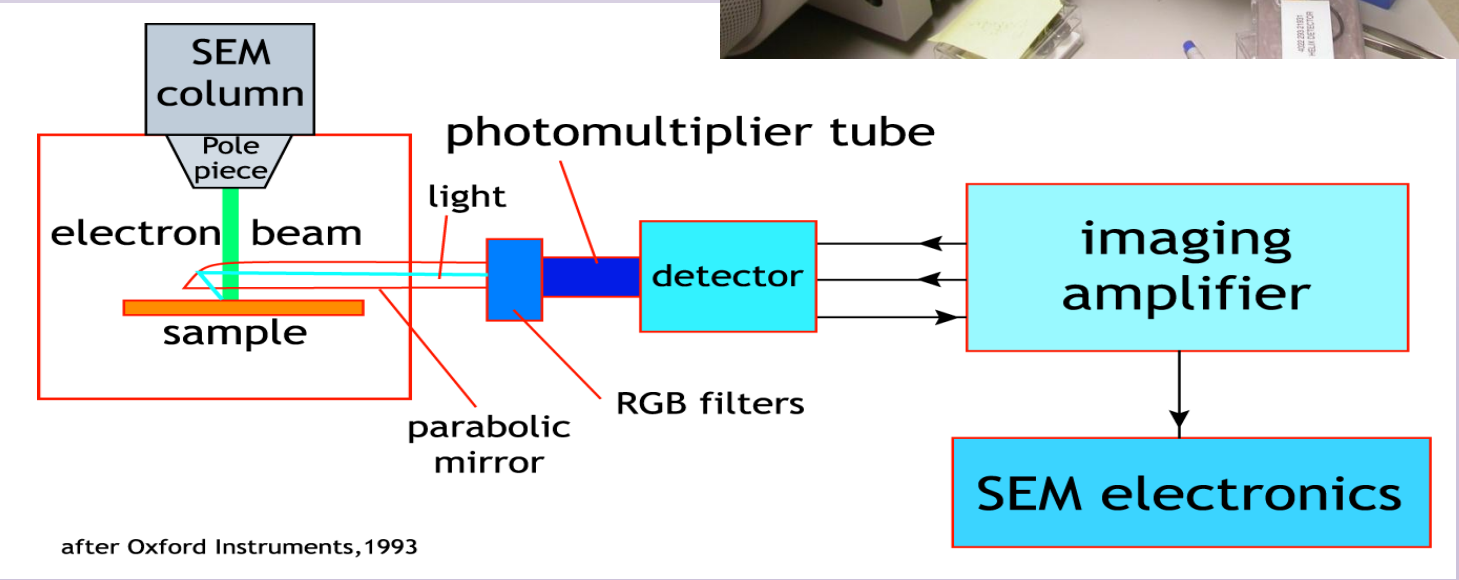
Scanned Cathodoluminescence Imaging

Visible light emitted in response to electron beam excitation.

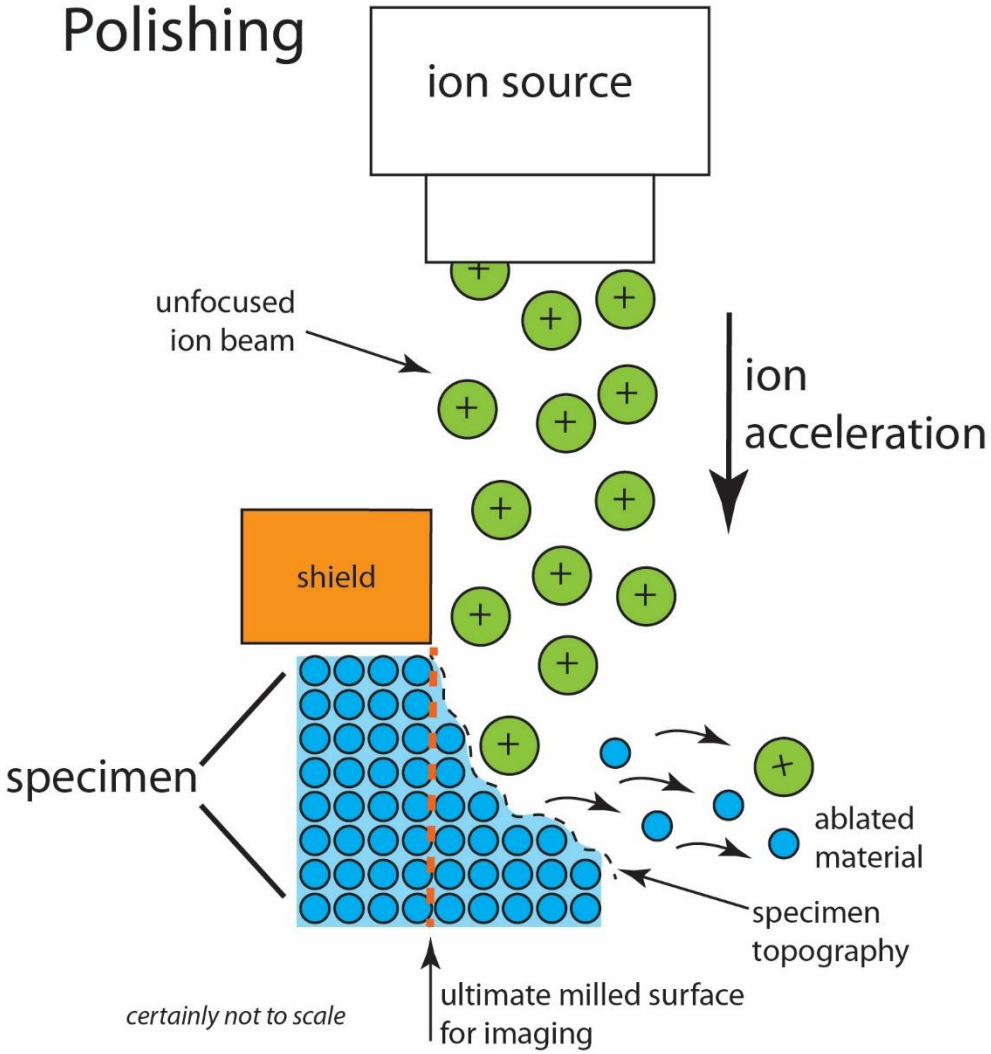
Sensitive to trace element and defect variations.

Images subtle chemical differences that are invisible in other techniques.

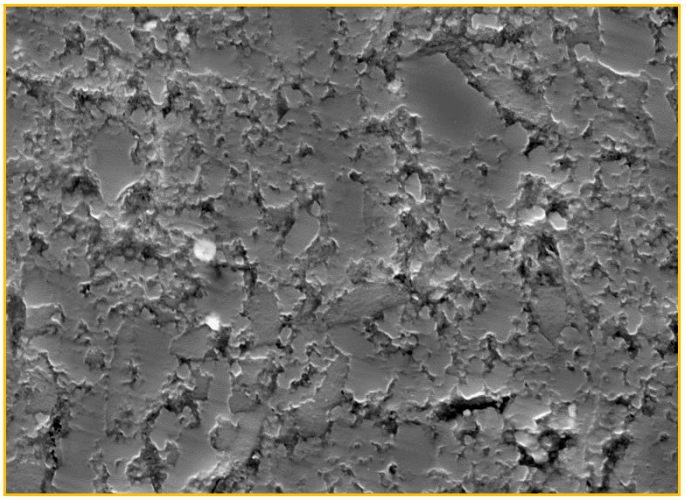




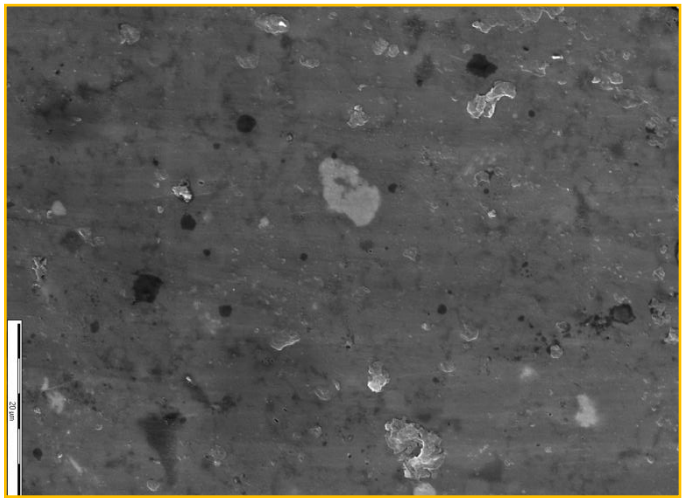
Ar-ion Cross-section Polishing



Barnett Shale sample:

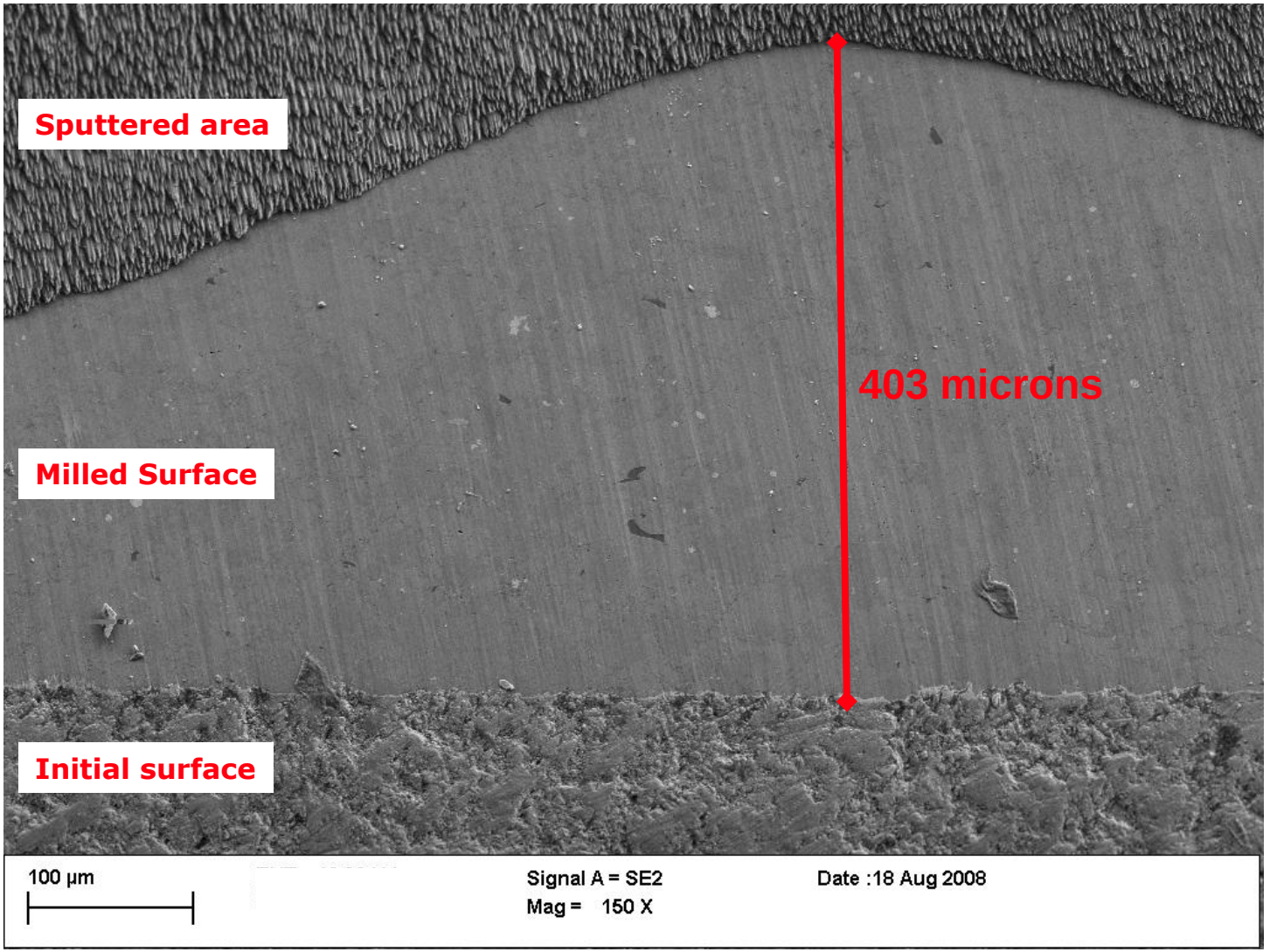


Polished thin section



Ion-milled surface.

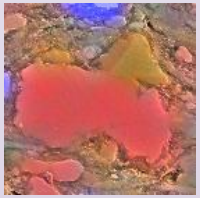
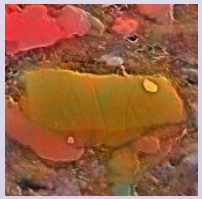
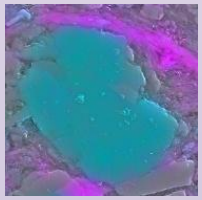
Imaging Mudrock Pore Systems: Ar-ion beam milling

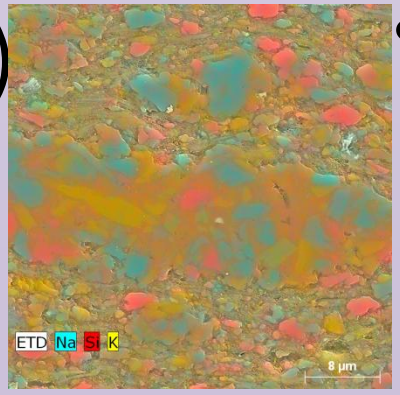


Blakely #1, 7138', Barnett Shale, Wise Co., Fort Worth Basin

Dominant Extrabasinal Components

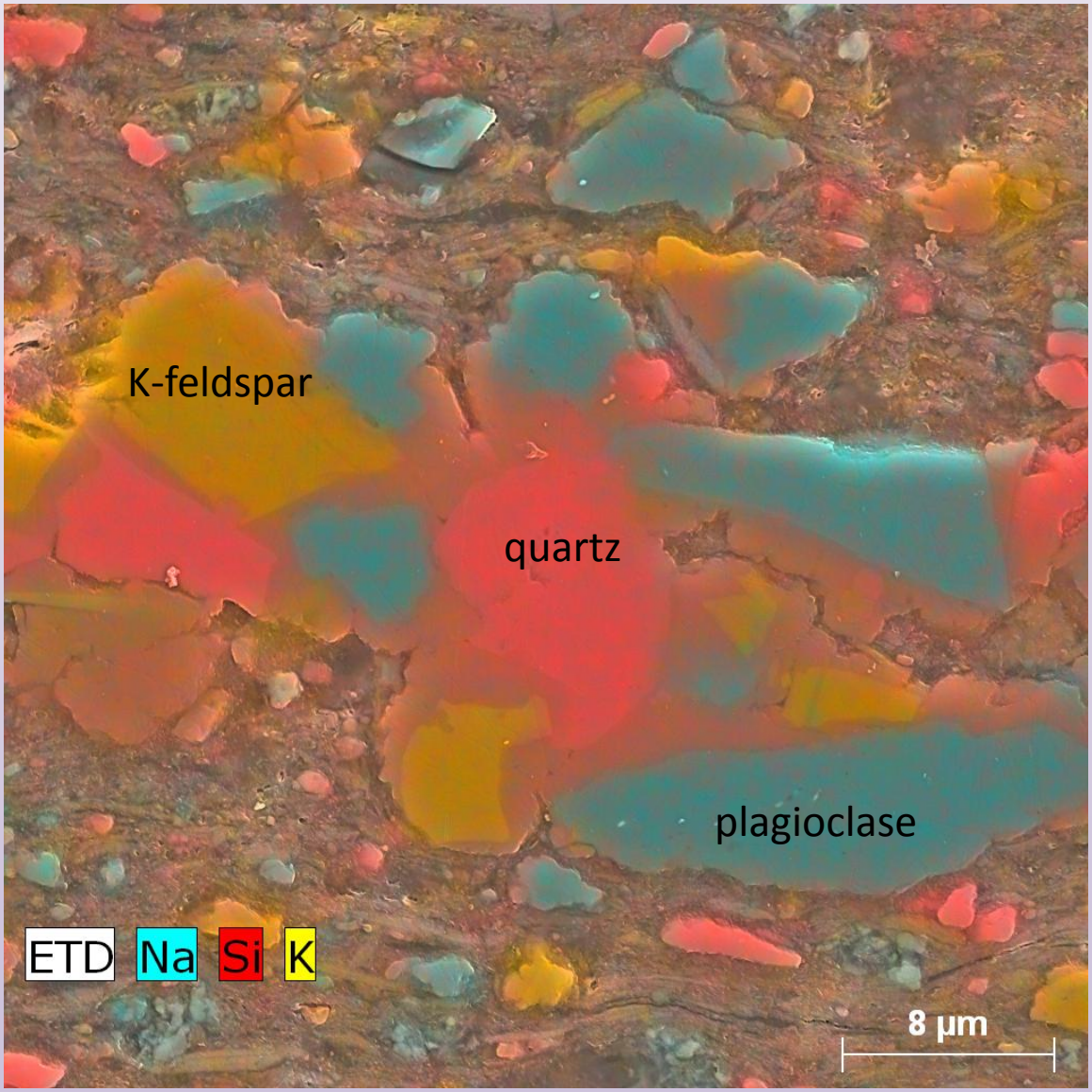
- Quartz
- K-feldspar
- Na-plagioclase
- Lithic grains (including possible volcanic glass)

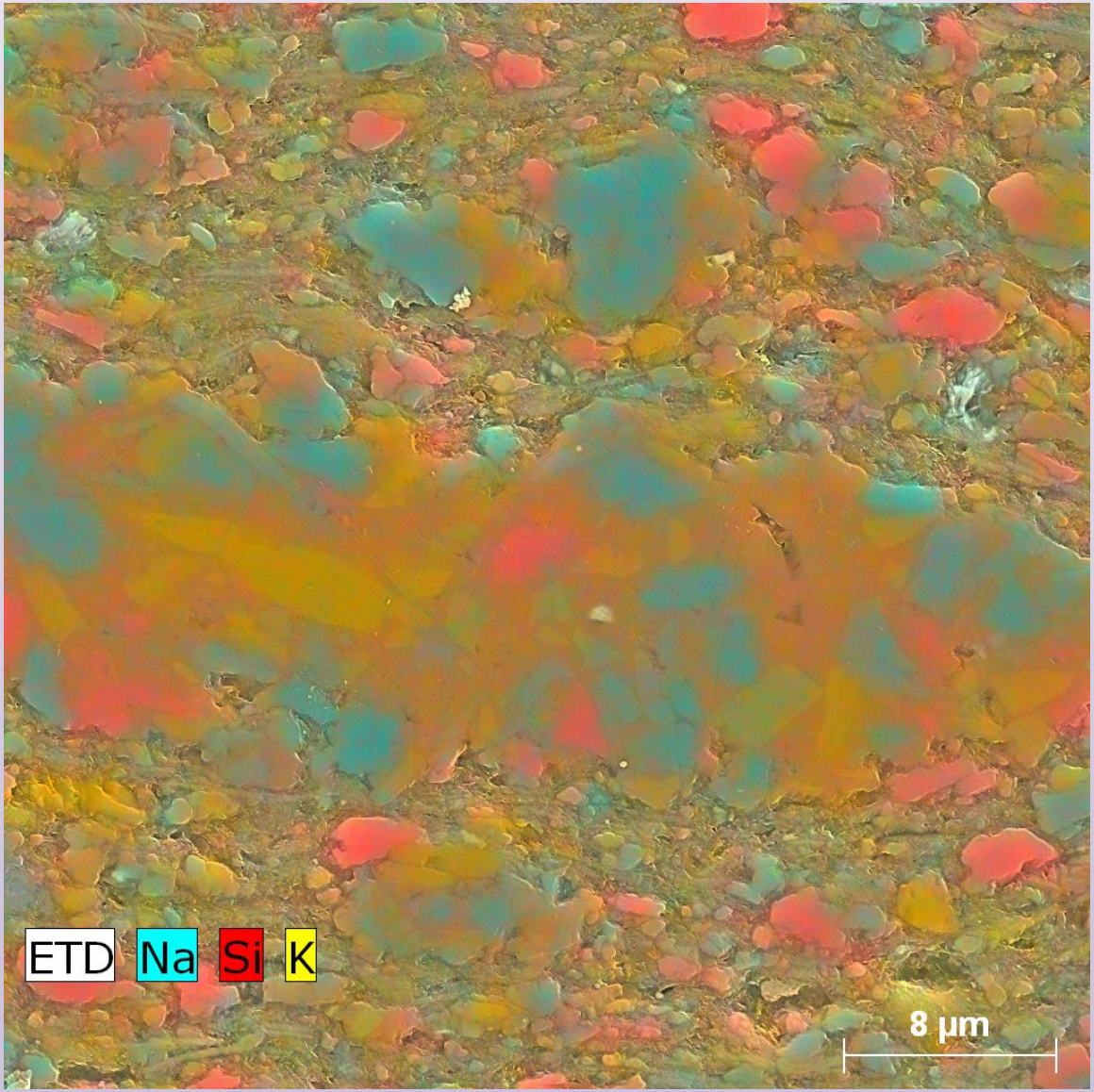



- K-mica (sericite/musc.)
- K-Fe mica (biotite)
- Mg-Fe mica (chlorite)
- K-clay (illite and mixed-layer)

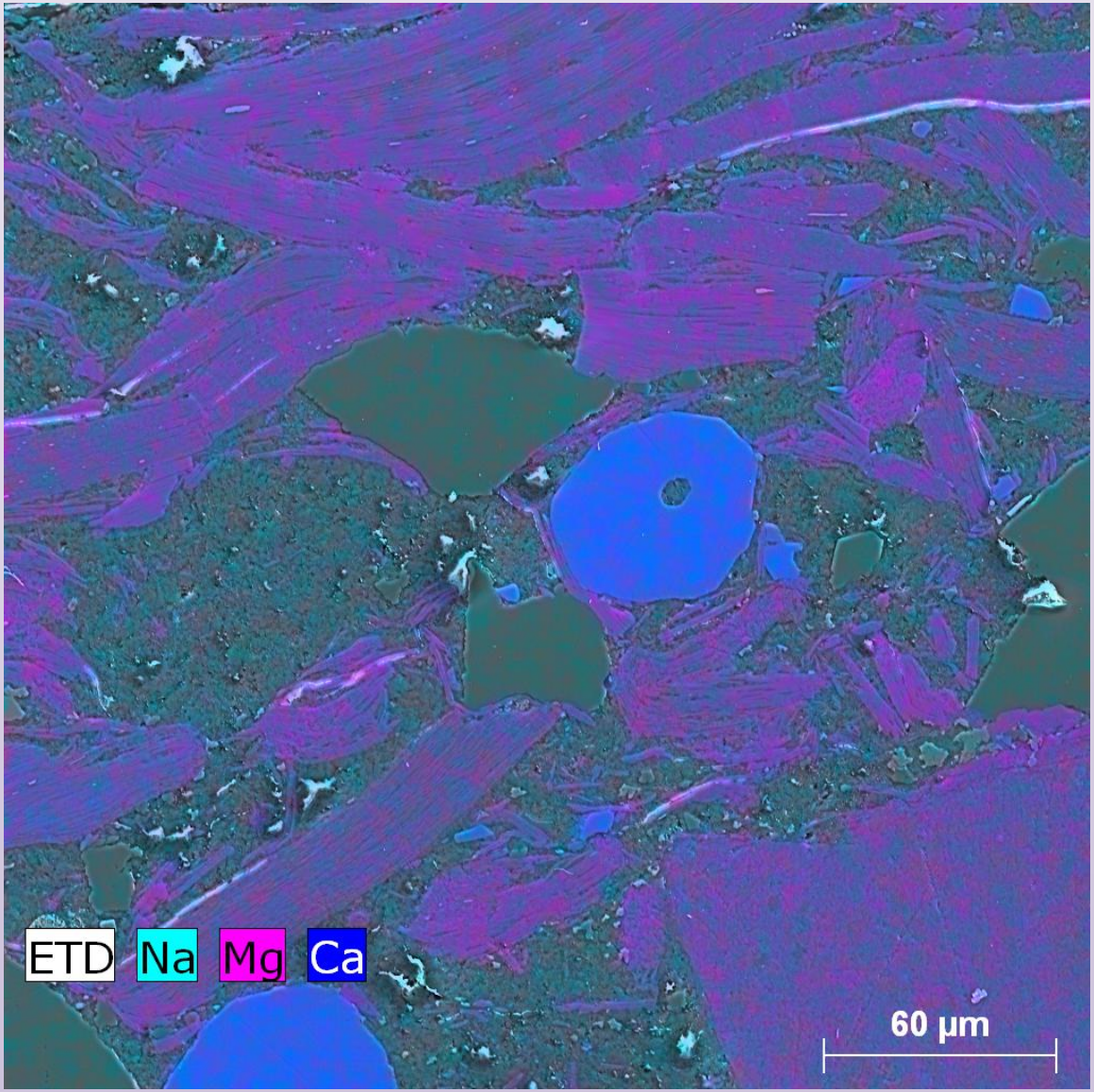


Volcanic rock fragment with glassy groundmass.

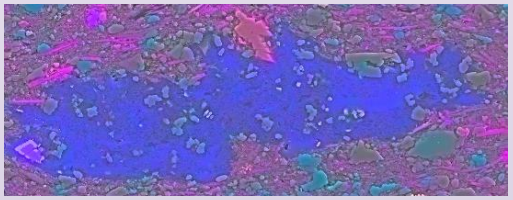
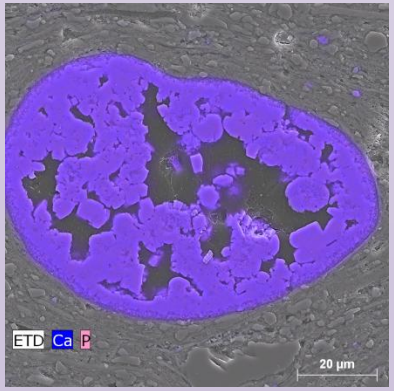


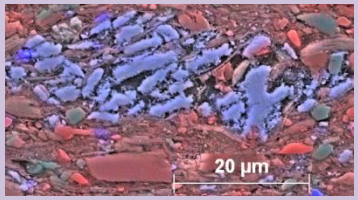
Volcanic rock fragment with glassy groundmass.



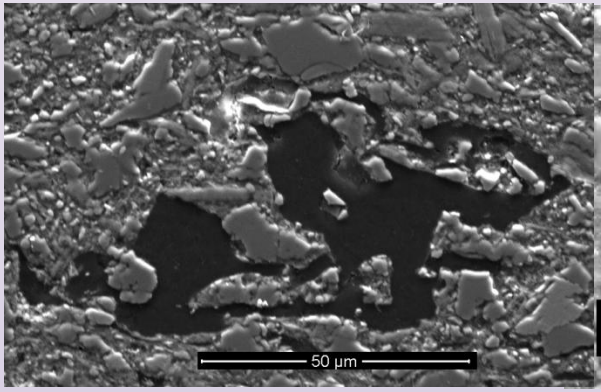
Sandy mudstone with large biotite grains.

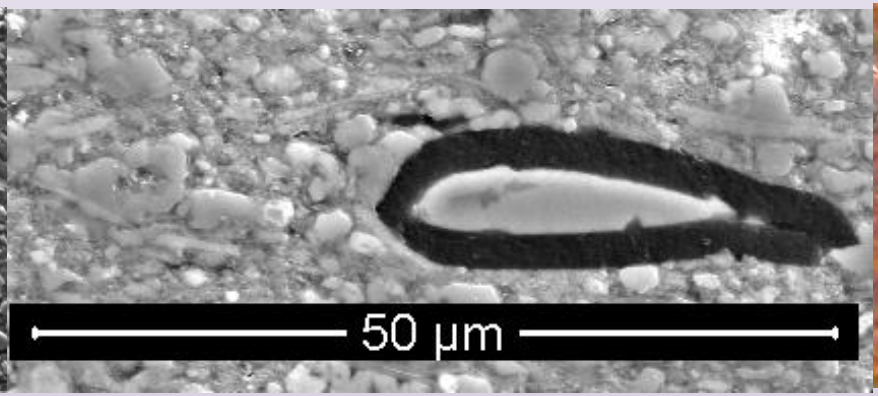
Dominant Intrabasinal Components

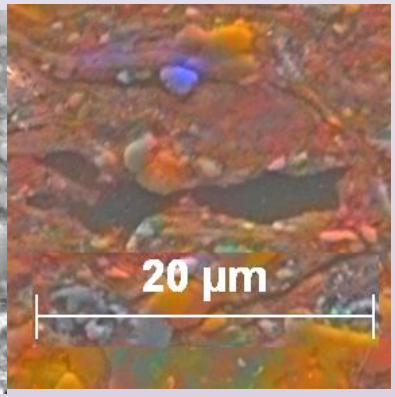
- Calcite grains 
- Ca-phosphate grains 
- Organic matter (kerogen) 
- Skeletal grains 

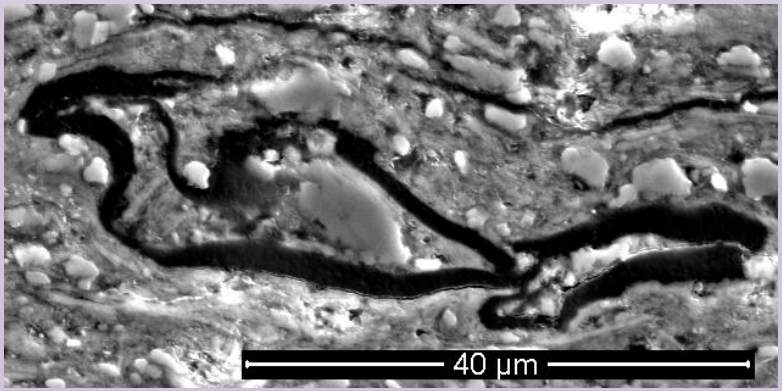
- Aggregates (pellets, and OMA) 

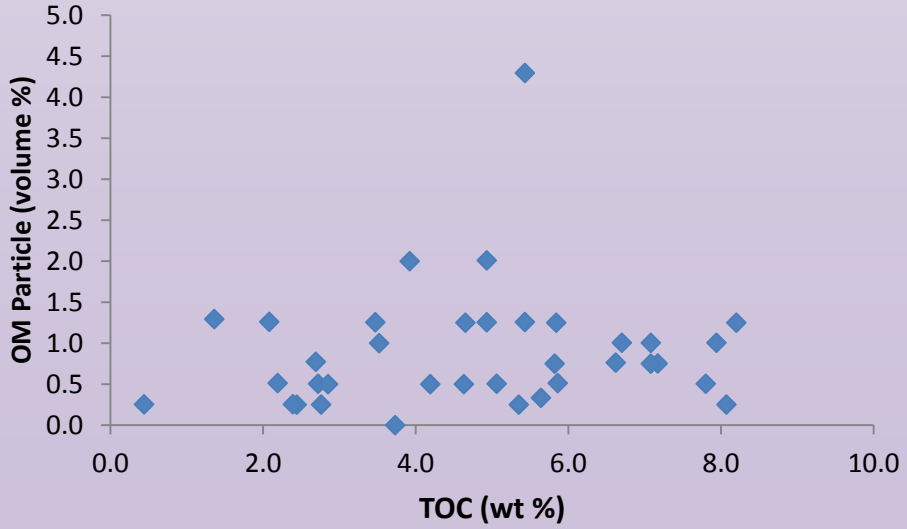
Particulate organic matter visible at the scale of X-ray mapping is a relatively small portion of the total organic matter.

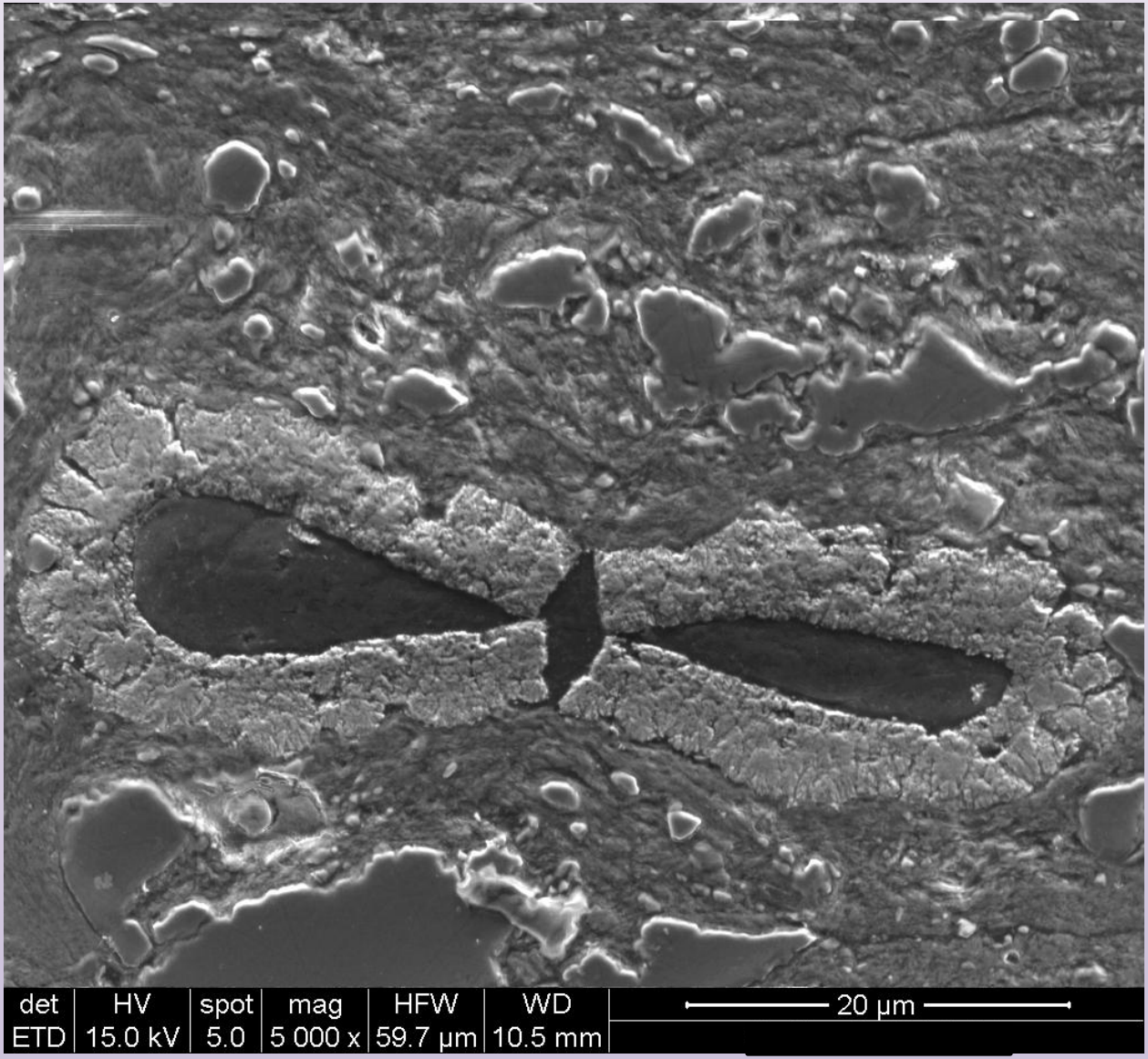




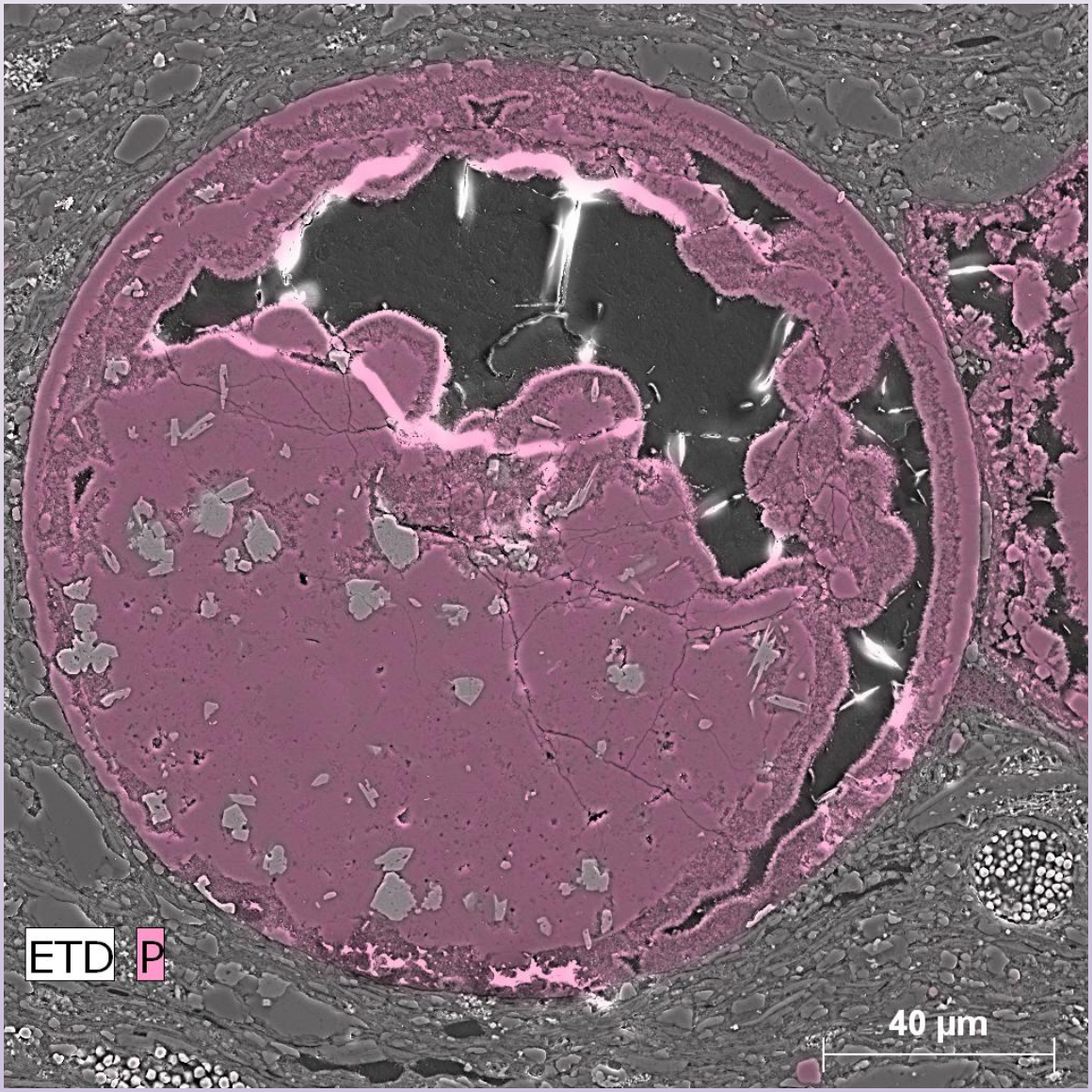




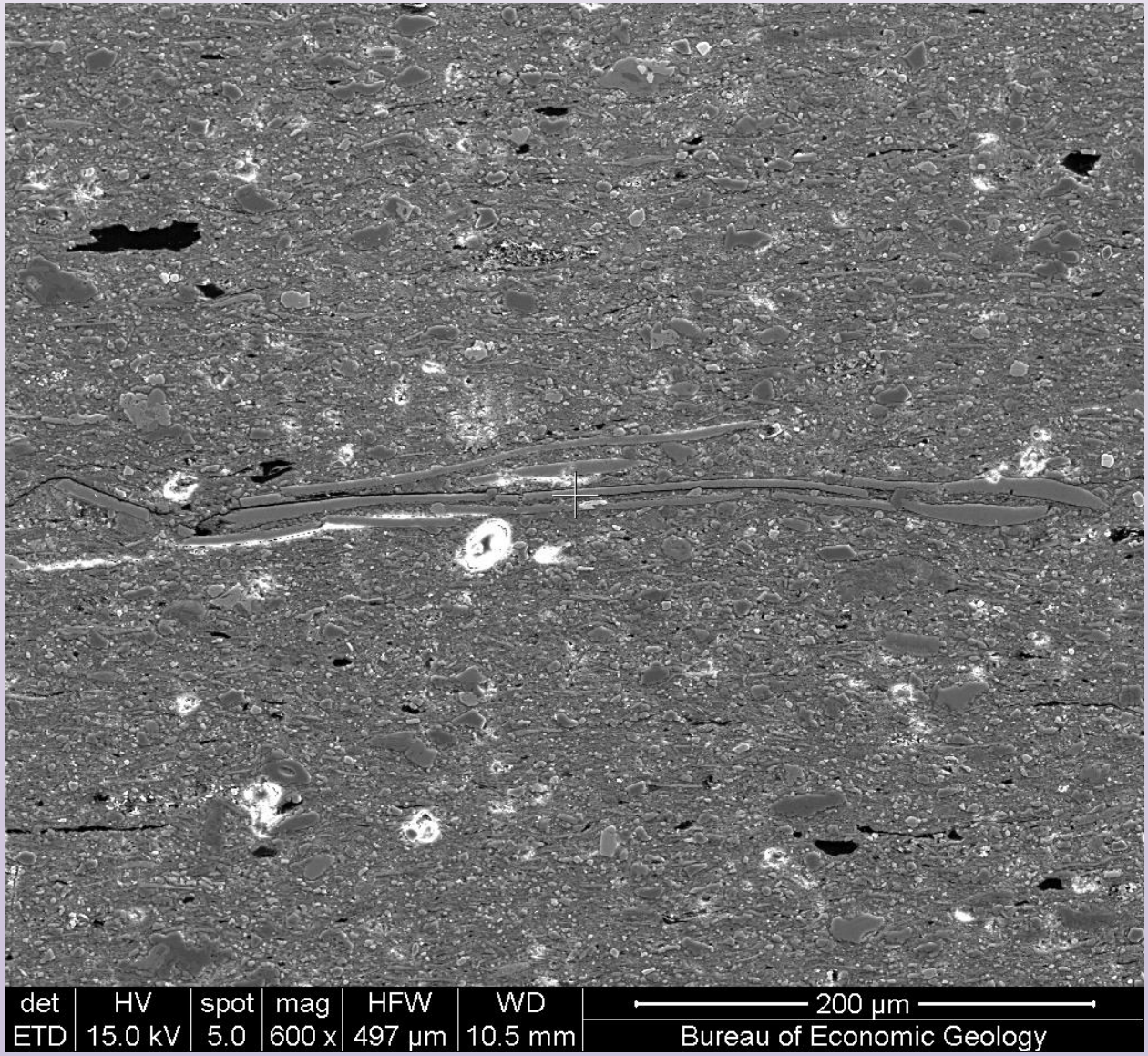




Compacted spore(?)

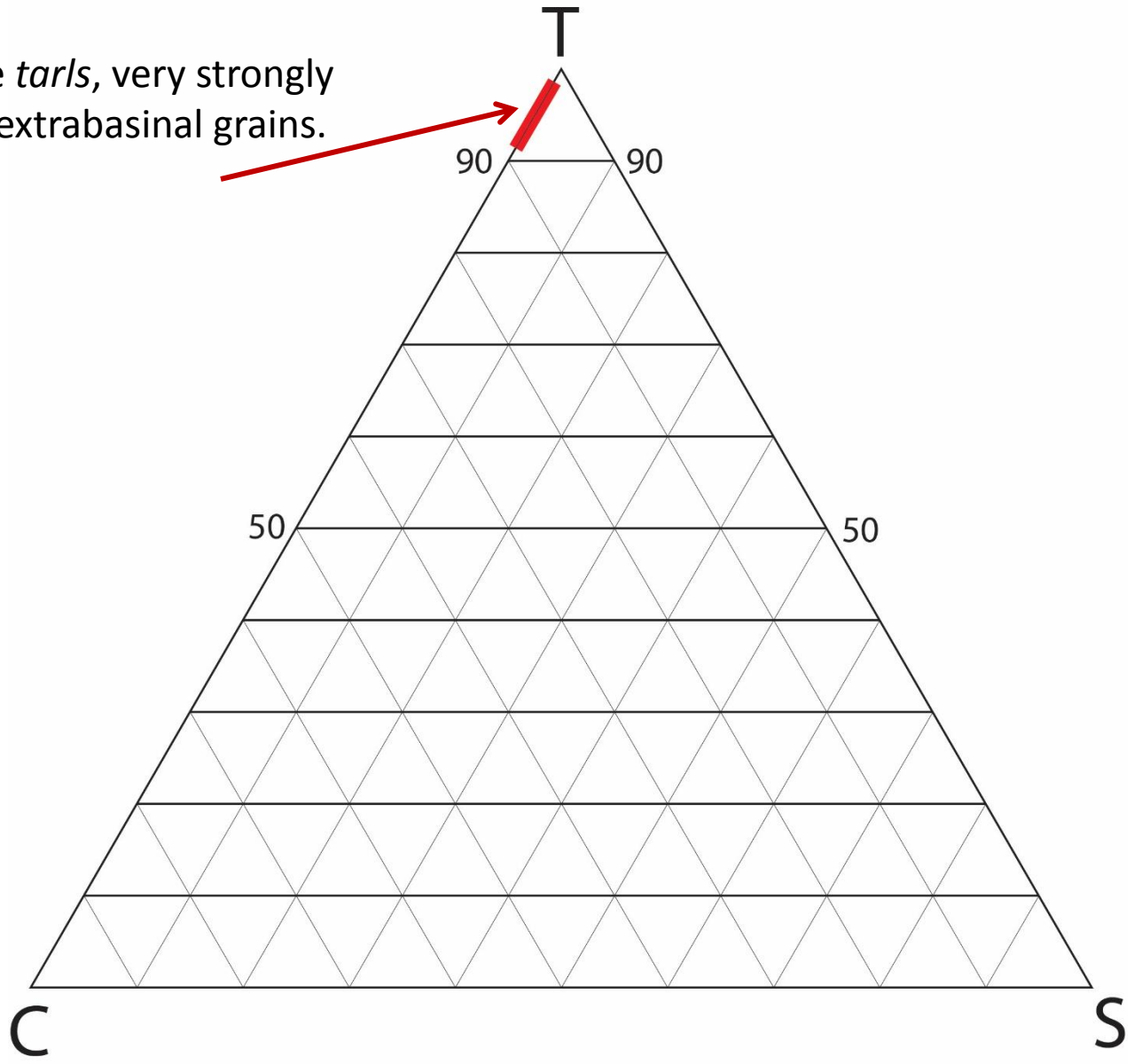


Fossil with phosphatic infilling


det
ETD
HV
15.0 kV
spot
5.0
mag
600 x
HFW
497 µm
WD
10.5 mm
200 µm
Bureau of Economic Geology

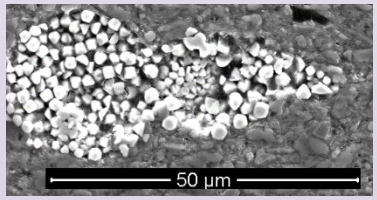
Fish bones

All samples are *tarls*, very strongly dominated by extrabasinal grains.



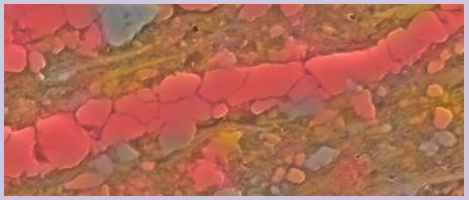
Diagenetic Features

- Pyrite framboids



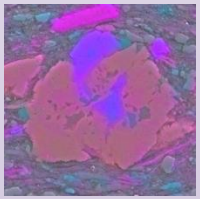
- Grain replacements and cements
  - Pyrite

  - Quartz (rare)

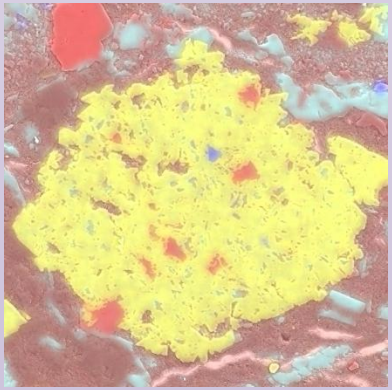


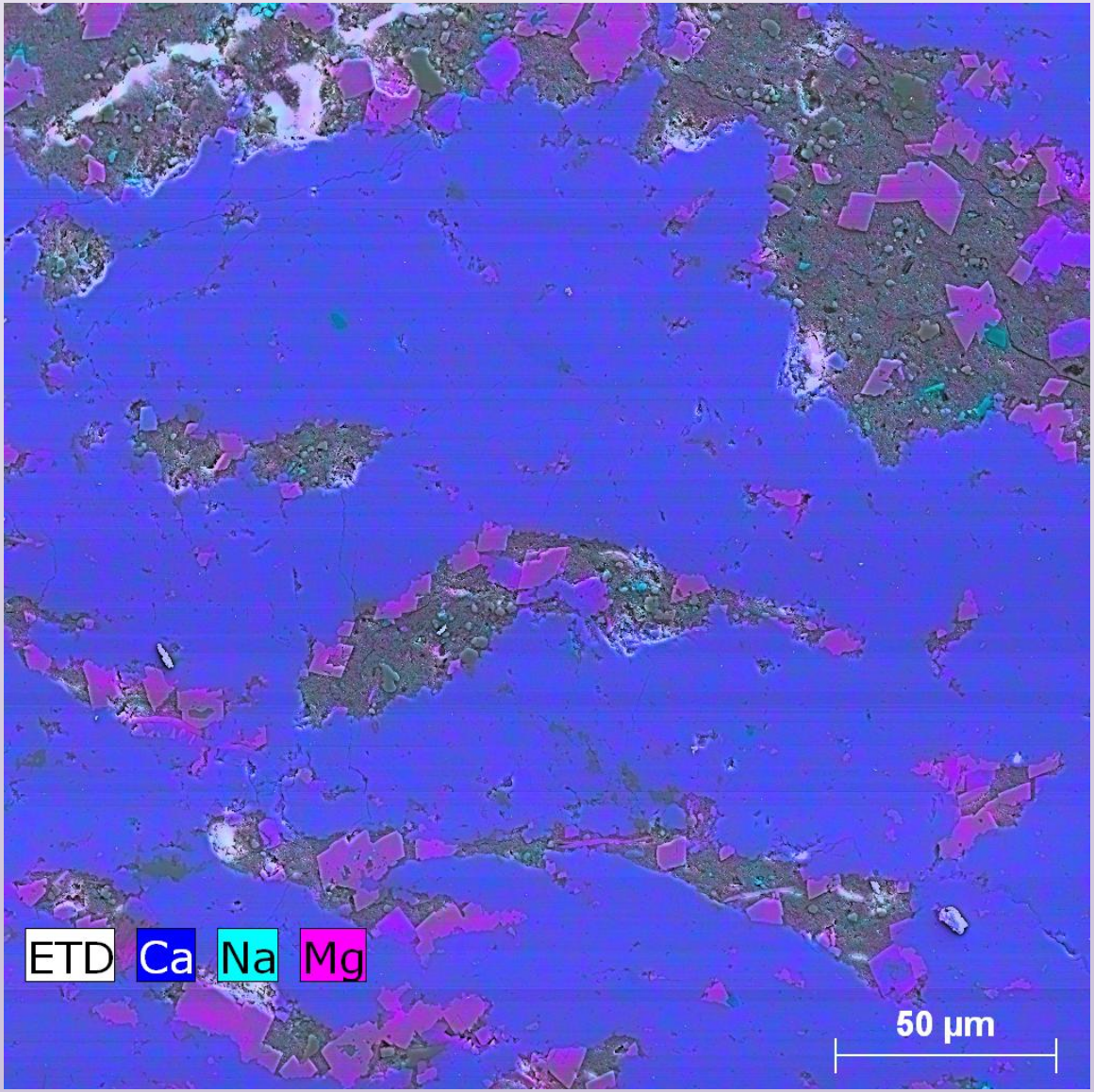
- Grain replacements and cements
  - Dolomite

  - Fe-dolomite

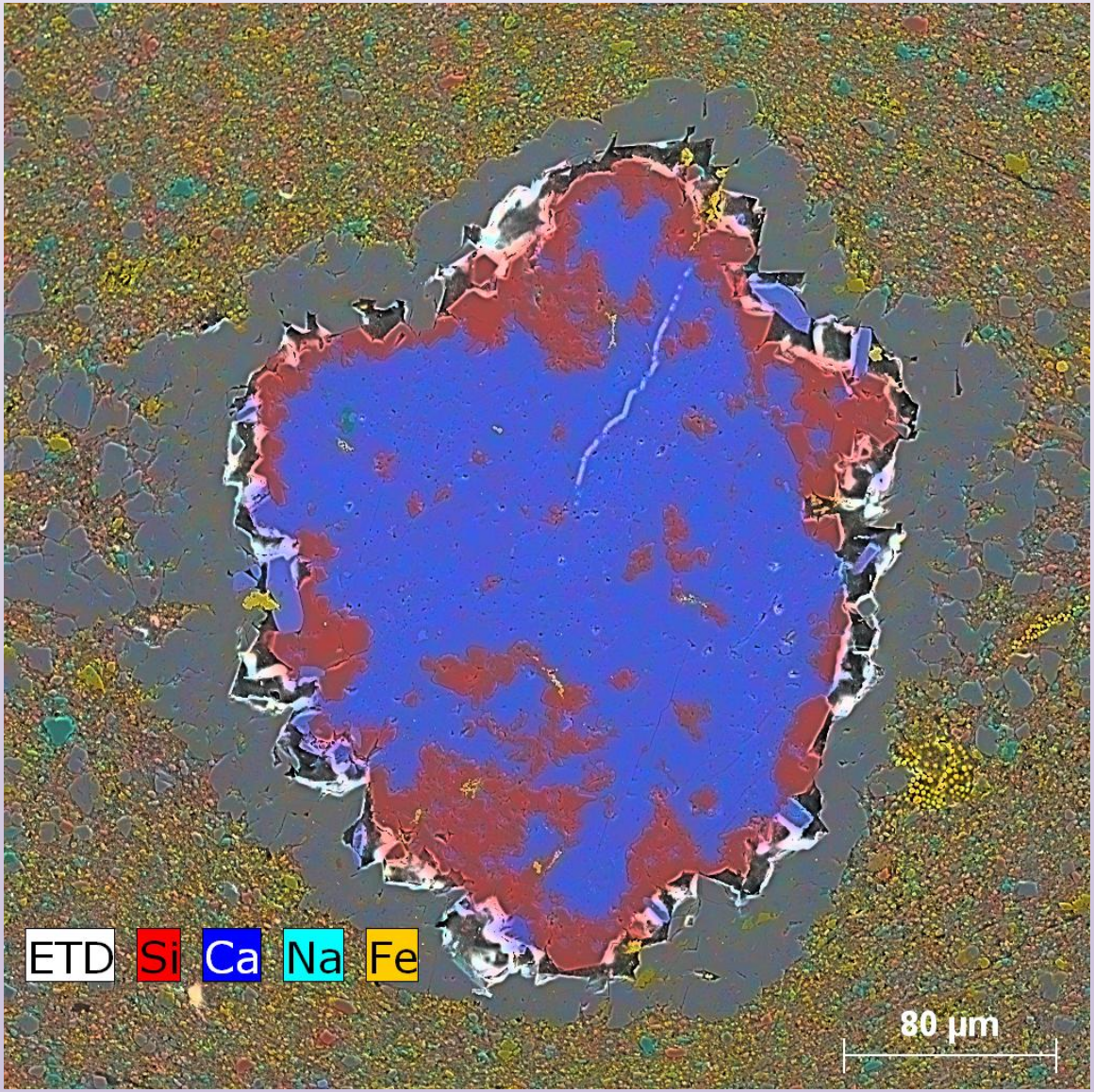


  - Siderite

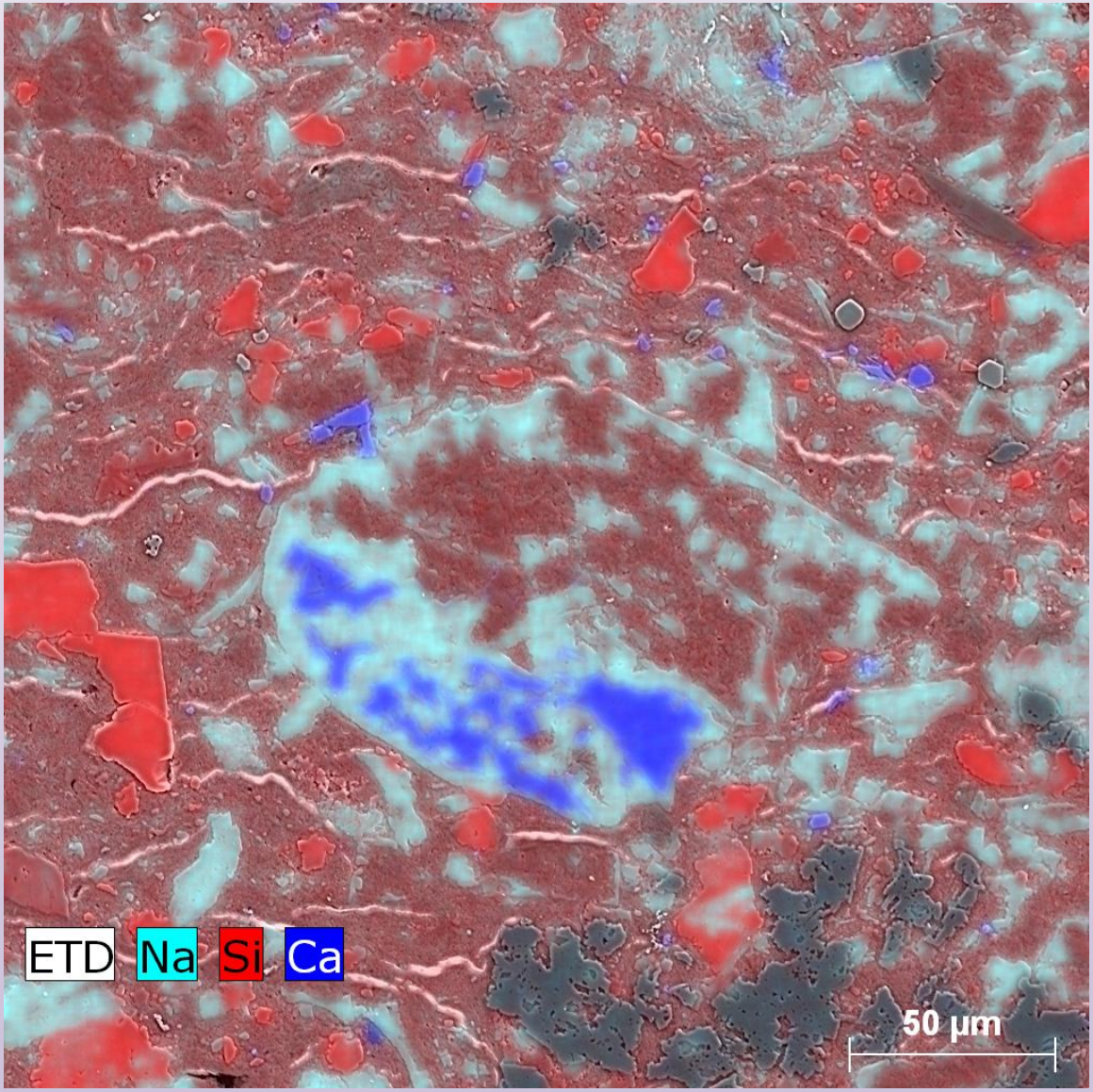




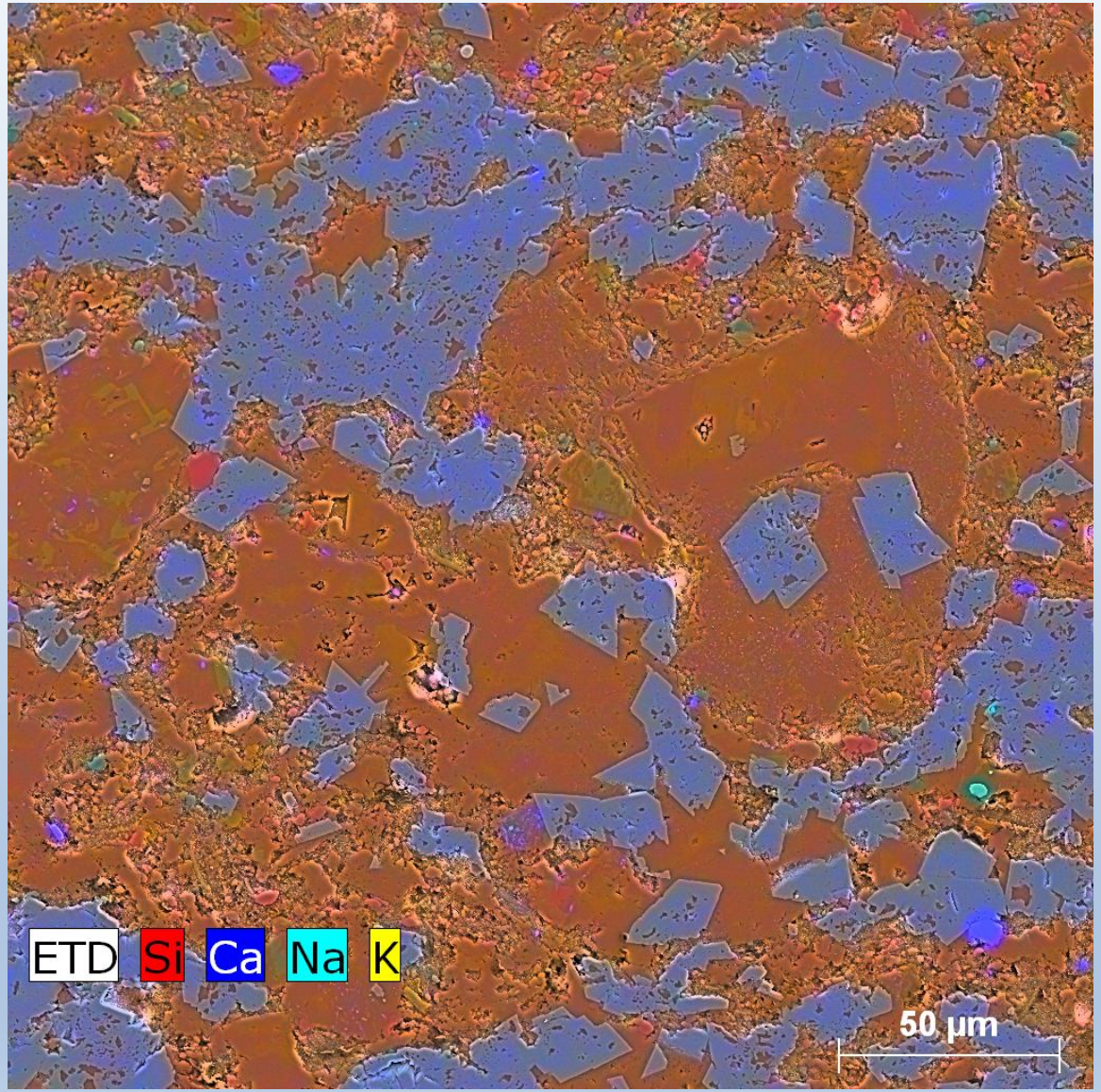
Cone-in-cone calcite



Massively dolomitized fossil filled with quartz (red) and calcite (blue).



Calcite replacing plagioclase.



Dolomite replacing K-rich lithic fragments.

Background on Quartz Cementation in Triassic YanChang Lacustrine Sediments

In other mudrock units (e.g., Barnett Shale), authigenic quartz has proven to be a key factor in generation of brittle mechanical rock properties.

- No known opaline planktic organisms in Triassic freshwater.
- Abundant volcanogenic material provides a potentially significant source of mobilized Si in diagenesis.

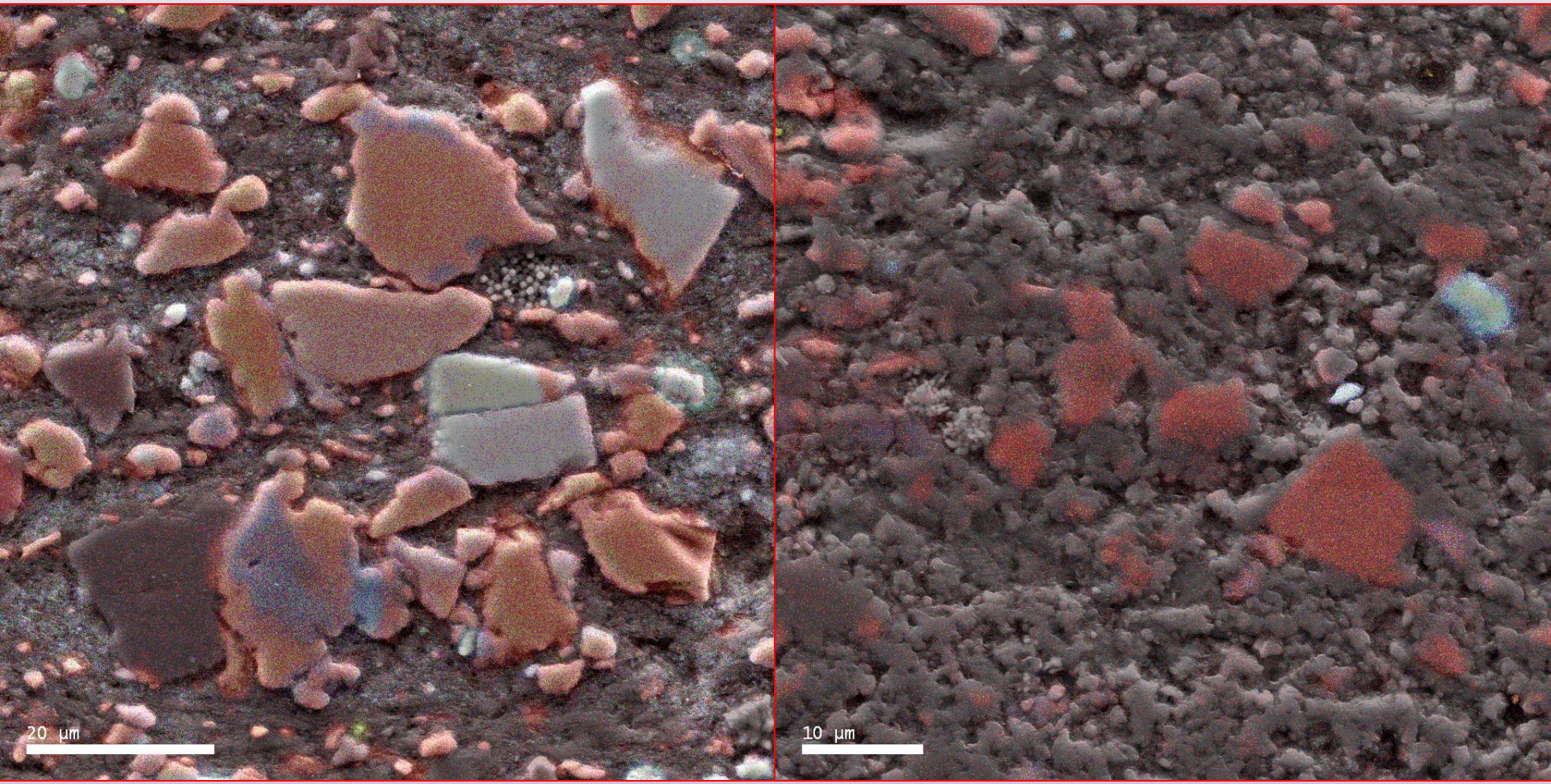
- It is reasonable to inspect the samples for evidence of authigenic quartz and other authigenic silicates.

Mudrock Cementation:

Milliken, 2013

NO

YES



tarl

sarl

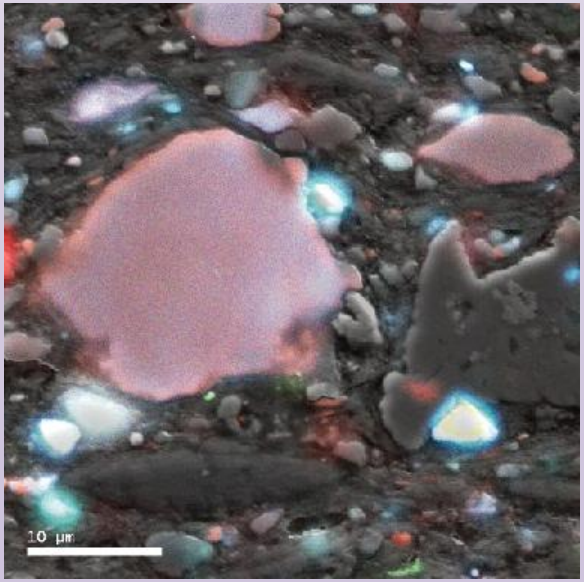
Barnett Shale

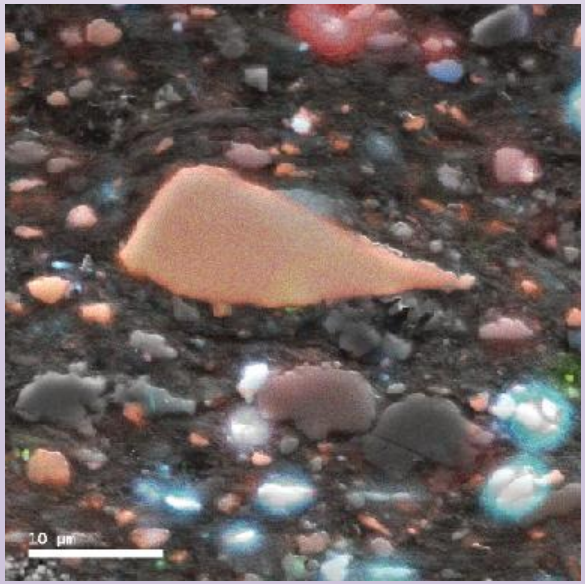
Cathodoluminescence images

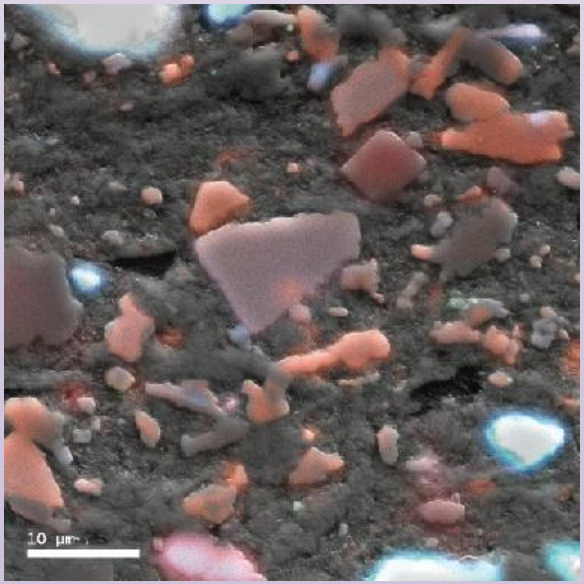
“matrix-dispersed authigenic microquartz”

Cathodoluminescence reveals little to no authigenic quartz.

Most quartz grains are fully in contact with adjacent matrix clay minerals and show no evidence of overgrowths.

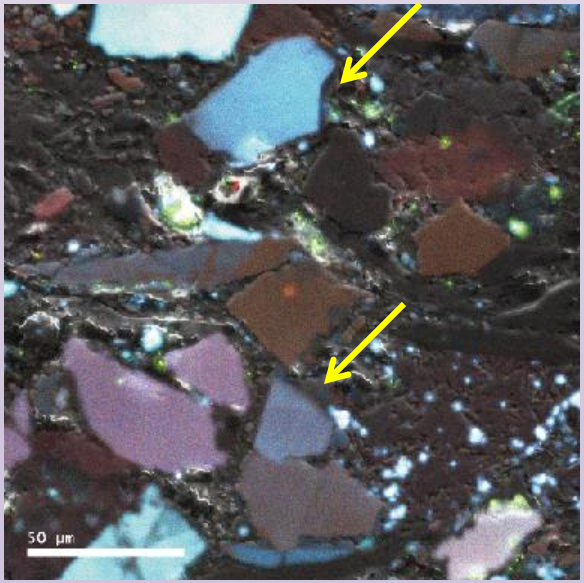






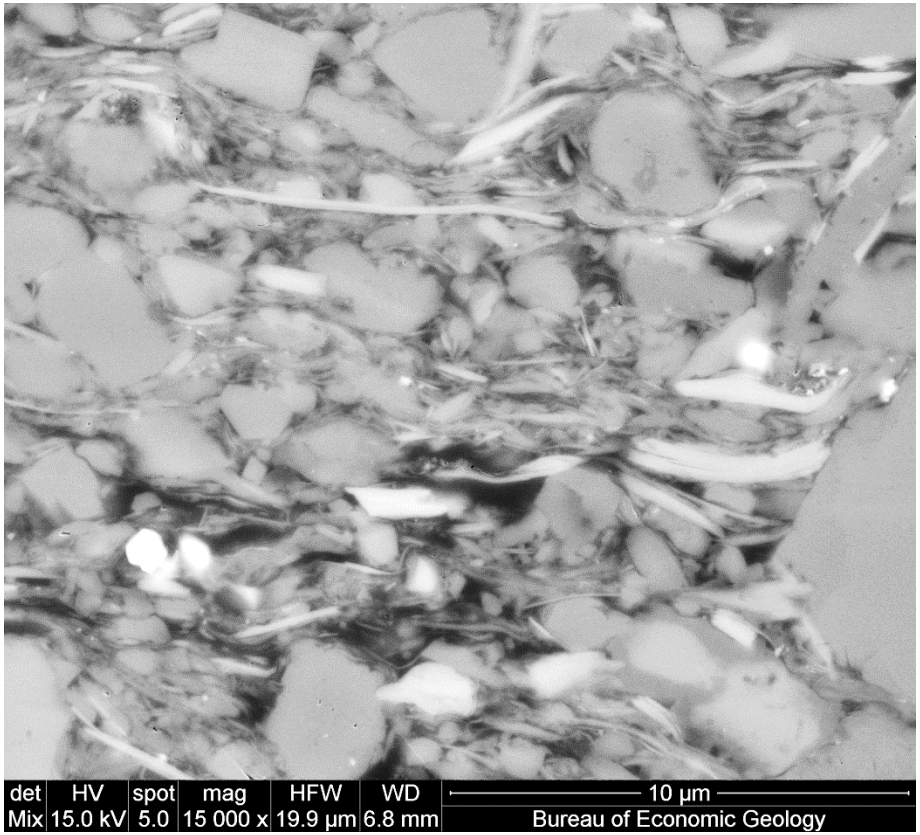
CL images.

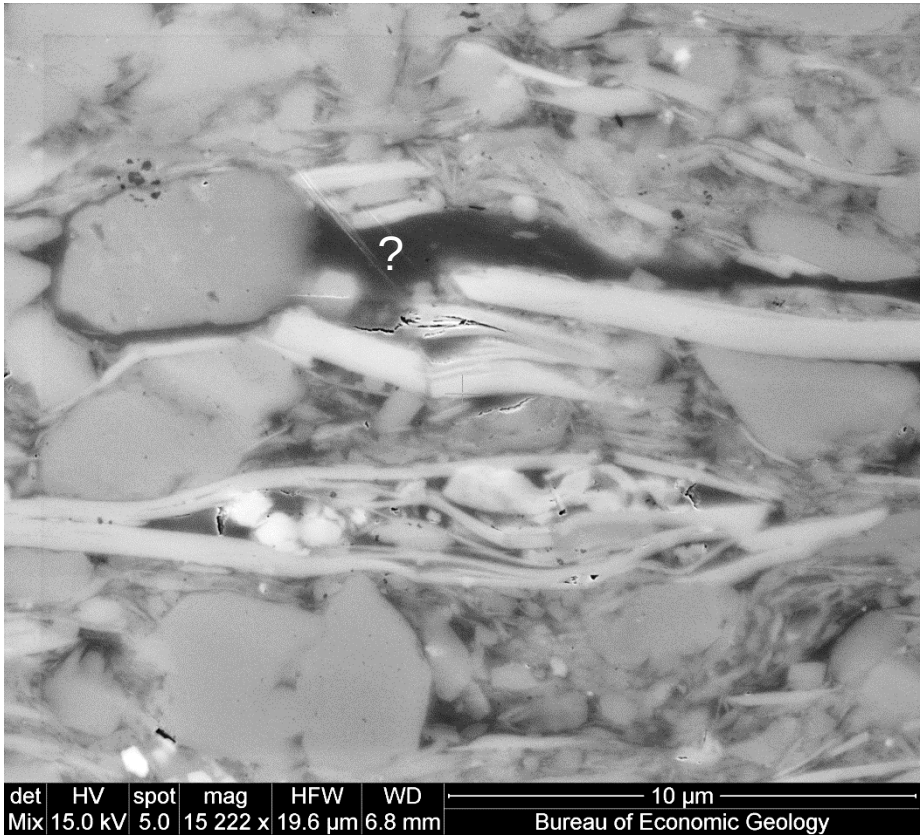
Locally, tiny overgrowths are observed associated with pores sheltered between touching silt particles. This minor cement is of a type analogous to ordinary quartz cement in sandstones. There is no evidence of matrix-dispersed authigenic microquartz that would lead to prominent enhancement of brittle rock properties.



CL images.

Kerogen vs Bitumen

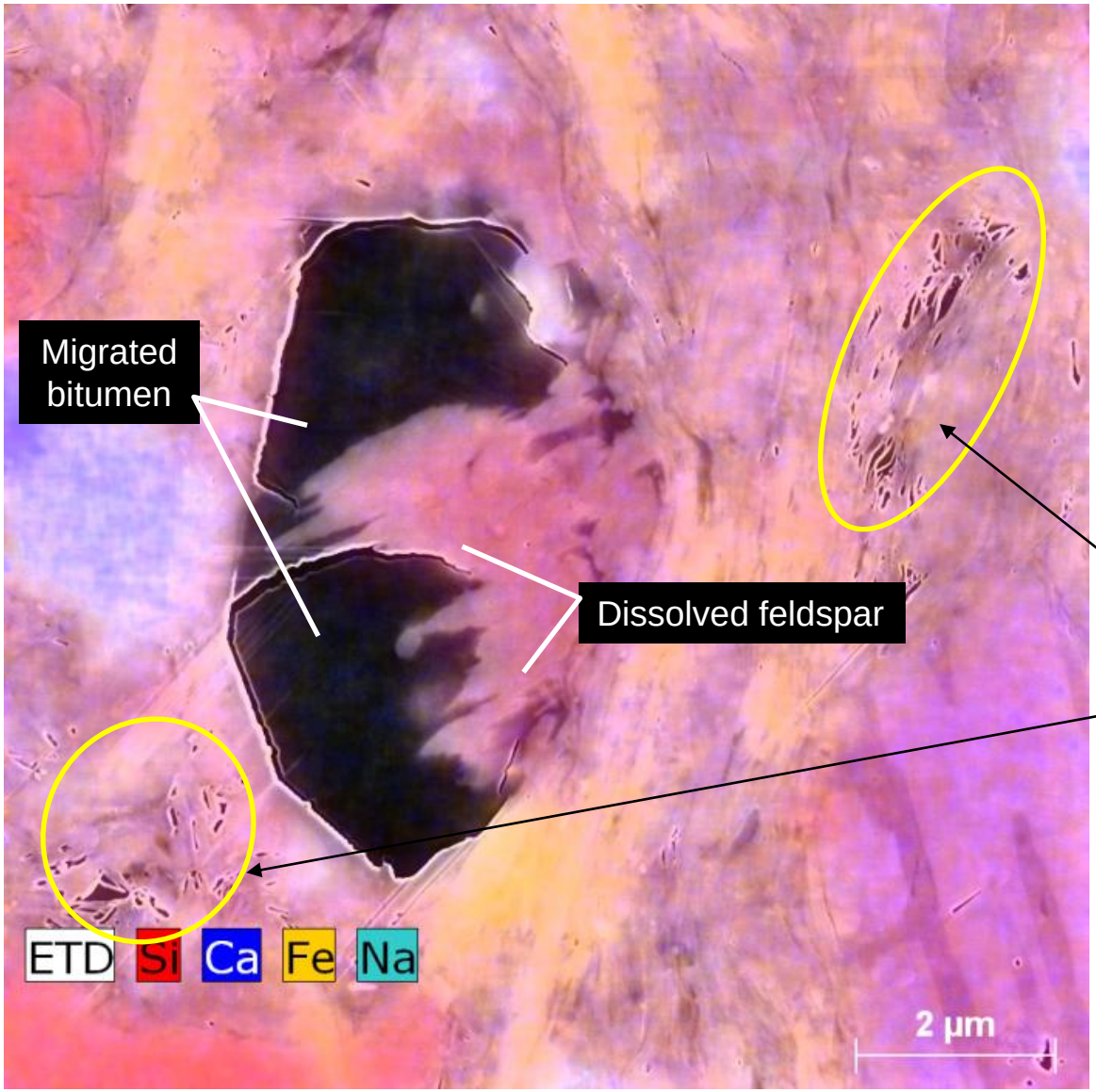




Mixed SE/BSE images. Bob Loucks.

OM is a pervasive intergranular filling.

Pore Types

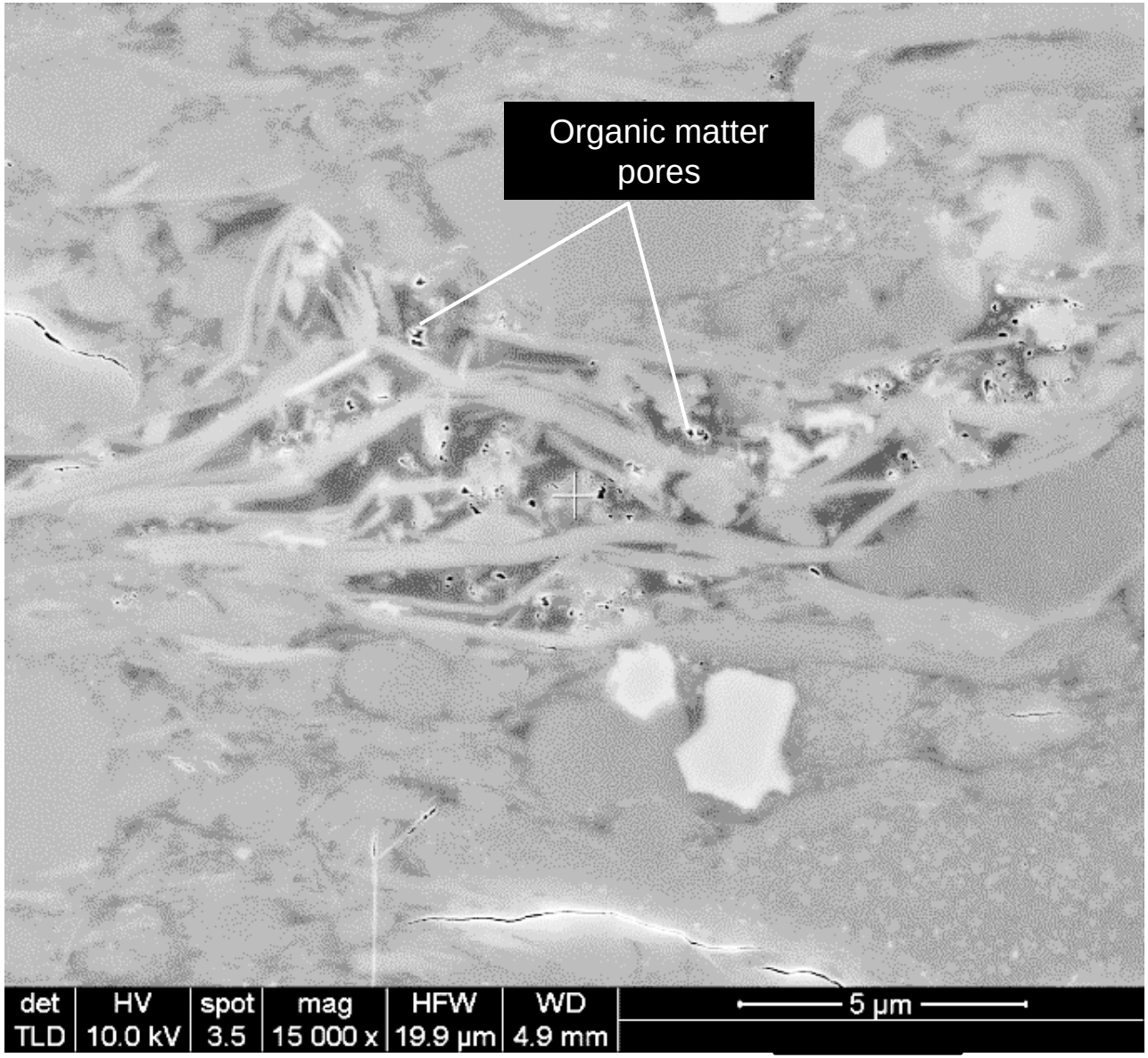


Mixed SE/X-ray image. Bob Loucks.

Large intraparticle pore filled with migrated bitumen

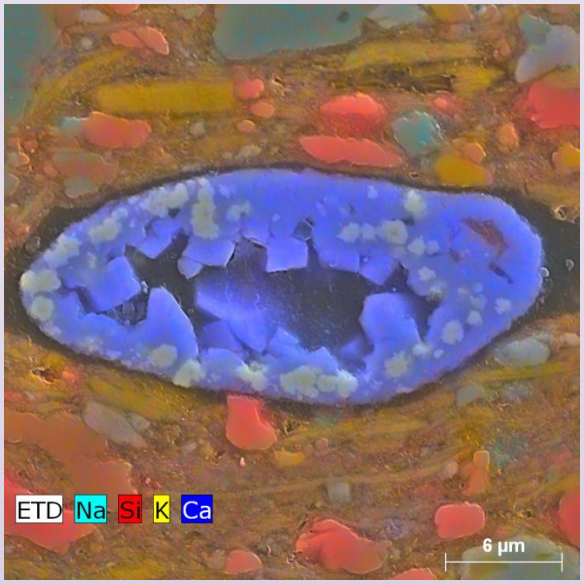
Intergranular pores between clay particles constitute a major portion of the porosity.

Migrated Organic Matter



Organic matter-hosted pores in migrated OM within a mica aggregate.

Mixed SE image. Bob Loucks.



The dominant diagenetic effect is compaction.

Chemical diagenesis is highly localized and is dominated by:

- Early diagenetic dolomite (possibly reworked as grains.
- Localized development of cone-in-cone structures.
- Carbonate (calcite, dolomite, and siderite) replacement of feldspar and lithic grains. Minor cementation relates to growth of this carbonate into adjacent intergranular pore space.
- Cementation in large, primary intragranular pores (algal spores?).
- Quartz cement is very minor and is developed locally as overgrowths at contacts between silt particles. There is no evidence of matrix-dispersed authigenic microquartz.
- Migrated, diagenetic OM (bitumen) and an unknown amount of authigenic clay may be the only significant intergranular pore fills.

CONCLUSIONS

Mudrocks of the Triassic lacustrine Yanchang Formation:

- Tarl having only minute quantities of intrabasinal grains
- Volcanogenic with abundant feldspars and lithic fragments
- Contain little cement, mostly within anomalously large pores
- Diagenesis dominated by mechanical compaction
- Organic-matter-hosted porosity is minor and OM-hosted pores are small.

FUTURE WORK

- Best reservoir quality may occur where higher silt content preserves inter-connected primary intergranular porosity.

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