Compositional Classification for Fine-Grained Sediments and Sedimentary Rocks: Foundation for Bulk Rock Property Prediction*

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Abstract

In fine-grained sediments and rocks (>50 percent weight or volume of particles less than 62.5 μm) the primary grain assemblage reflects grain generation processes at deposition and is also an important control on the evolution of bulk rock properties in diagenesis. As in classifications for sandstones and limestones, the primary grain assemblage is a practical basis for classification of fine-grained materials. Tarl (terrigenous-argillaceous) refers to a grain assemblage with >75 percent of particles of extrabasinal derivation, including grains derived from continental weathering and also volcanogenic debris. Carl (calcareous-argillaceous) contains <75 percent of extrabasinal particles and among intrabasinal grains has a preponderance of biogenic carbonate particles including carbonate aggregates. Sarl (siliceous-argillaceous) contains <75 percent of extrabasinal particles and has a preponderance of biogenic siliceous particles over carbonate grains. These classes separate sediments of distinct depositional settings and contrasting organic matter content and minor grain types. Tarls dominate in thick mudrock successions characterized by high rates of sediment accumulation and typically contain little organic matter, much of it terrestrial. Carls and sarls are generally associated with thinner successions. The slower rates of accumulation for carls and sarls tend to favor generation of intrabasinal particles such as sediment aggregates (intraclasts, pellets, agglutinated allochems, etc.) and phosphatic debris. If organic-rich, carls and sarls tend to contain organic matter that originated in the water column. In the subsurface, tarls are relatively unreactive and only manifest significant reaction of the grain assemblage at elevated temperatures (>80° C). Under ordinary geothermal gradients tarls tend to remain unconsolidated until approximately 2 km of burial or more. In contrast carls and sarls contain chemically unstable grain assemblages (including labile organic matter) prone to react with pore fluids early in burial. Reactive grain assemblages in carls and sarls cause cementation and the generation of brittle rock properties relatively

early in the burial history. Classification based on the grain assemblage is only the beginning of a complete rock description, but constitutes a valuable foundation for placing samples into the larger stratigraphic context and for making predictions about the post-depositional evolution of bulk rock properties.

References Cited

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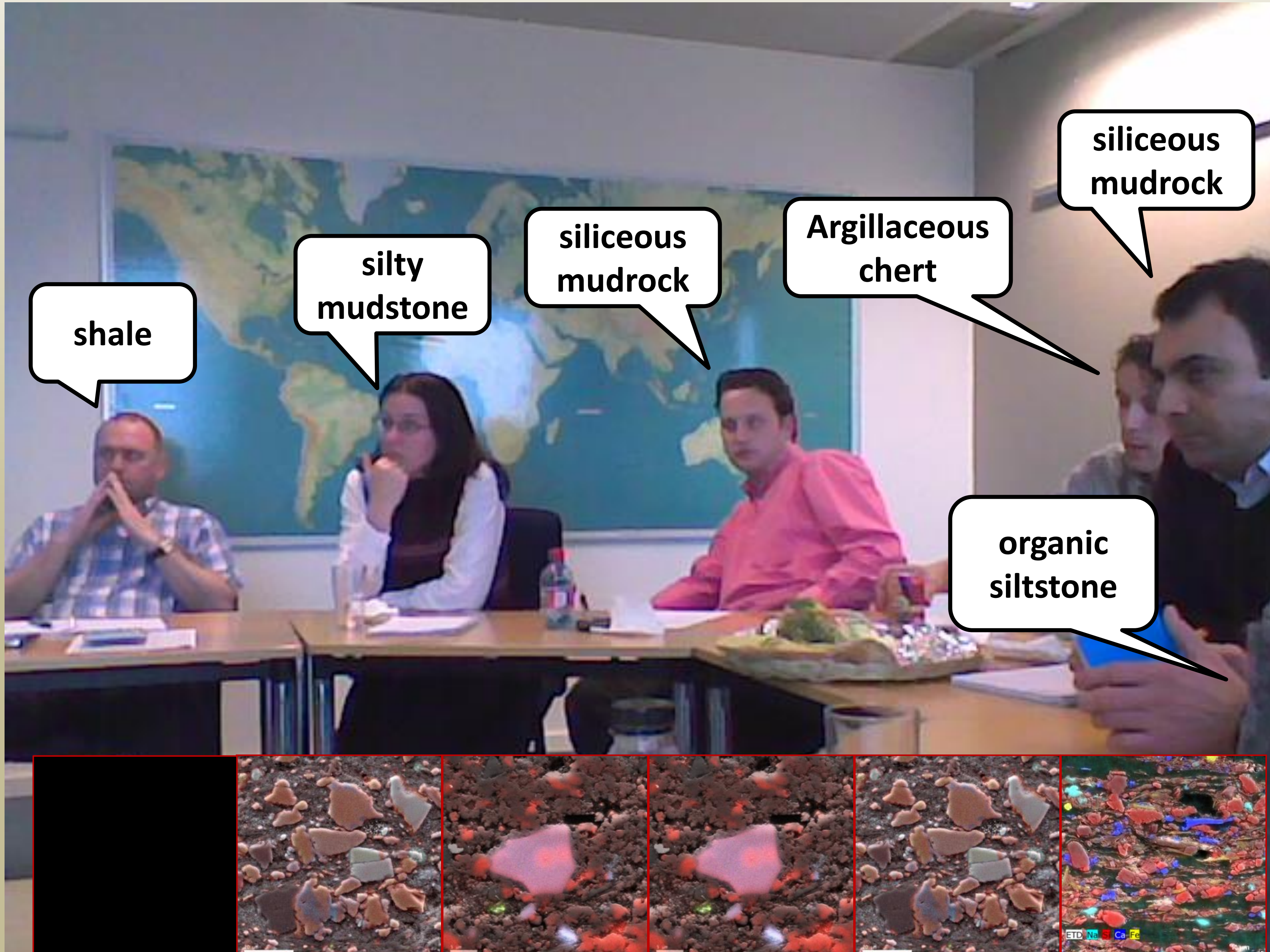
Bureau of Economic Geology


shale
silty mudstone
siliceous mudrock
Argillaceous chert
siliceous mudrock
organic siltstone

Classification of Sandstone and Limestone: More than a half-century of consensus

Folk Sandstone Classification

- Dominated by extrabasinal particles
- Classified based on the composition of the extrabasinal particles
- Grain types; QFL (quartz, feldspar, lithics)
- modifiers:
  - grain size
  - intrabasinal particles
  - post-depositional components

25%

Folk & Dunham
Limestone Classifications

- Dominated by intrabasinal particles
- Classified based on the make-up of the intrabasinal particles
- Grain types: skeletal, ooids, intraclasts, etc.
- modifiers:
  - grain size
  - extrabasinal particles
  - post-depositional components

10%

Description versus Classification

Data
Comparisons for:
- Trends
- Correlations

Communication

A part of description:
- Data
- Comparisons for:
  - Trends
  - Correlations
- Communication

➢ Underlying model
➢ Prediction

State of the Shale Classification Art:

Munsell color system.

"We prefer the straightforward use of mudrock color for classification."
Prothero & Schwab, 2003; p. 108.

Barnett Shale core.

Milliken et al., 2012

The most widely accepted and applied classification for fine-grained sediments is based on **grain size**, which in sandstone and limestone classification is *relegated to modifier status*.

In a sandstone this would be equivalent to identifying something as a "medium sand" and giving up on any further characterization!

Some of the terms applied to fine-grained sedimentary rocks:

shale, mudstone, mudrock, argillite,
pelite (from Latin), lutite (from Greek).

Extrabasinal				Mixed	Intrabasinal				
volcanic	texture	mineralogy	deposition		opal	phosphate	organic matter	iron-minerals	carbonate
tuff (fine ash) tuffaceous mud(st)	mud(st) clay(st) silt(st) many permutations…..	tonstein bentonite	loess glacial silt	marl(st) sarl(st) smarl(st)	siliceous ooze argillaceous chert novaculite radiolarite diatomite chert lydite jasper jasperoid	phosphorite	sapropel bituminous shale cannel shale torbanite oil shale	ironstone	calcareous ooze chalk micrite (Folk) mudstone (Dunham) calcilutite micarb micstone

There is no consensus on shale classification.

Most people begin with some variant of a textural description and then resort to a morass of terms variously directed to composition, grain source, depositional process, and diagenesis.

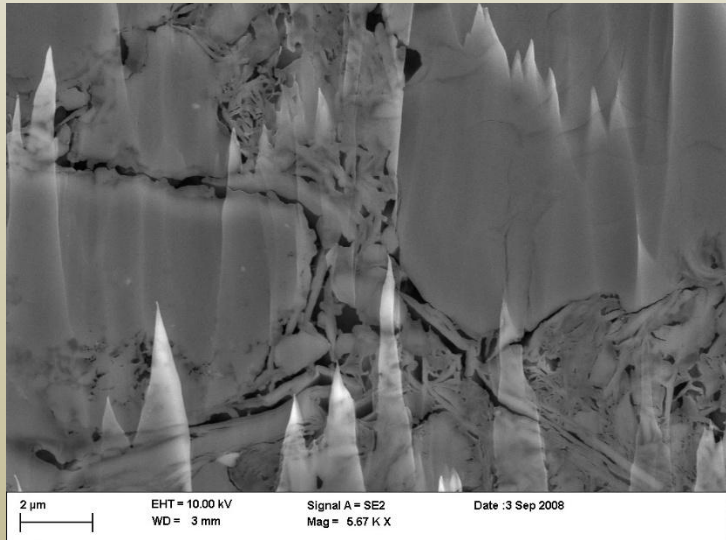
What would we like to predict in fine-grained rocks?

Bulk properties:

- Porosity
- Permeability
- Organic content
- Mechanical moduli

A mudrock classification should strive to serve such predictions, based on observations that are *independent* of bulk properties.

Mudrock Texture: Good for prediction?

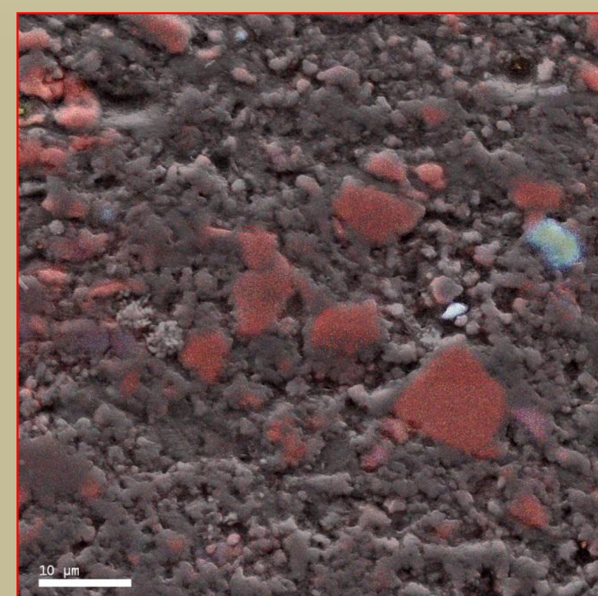


Nankai accretionary prism

In some cases………

Silt/clay mixtures have packing flaws and sheltered zones that enhance porosity and permeability. See Schneider et al. 2011.

Barnett Shale

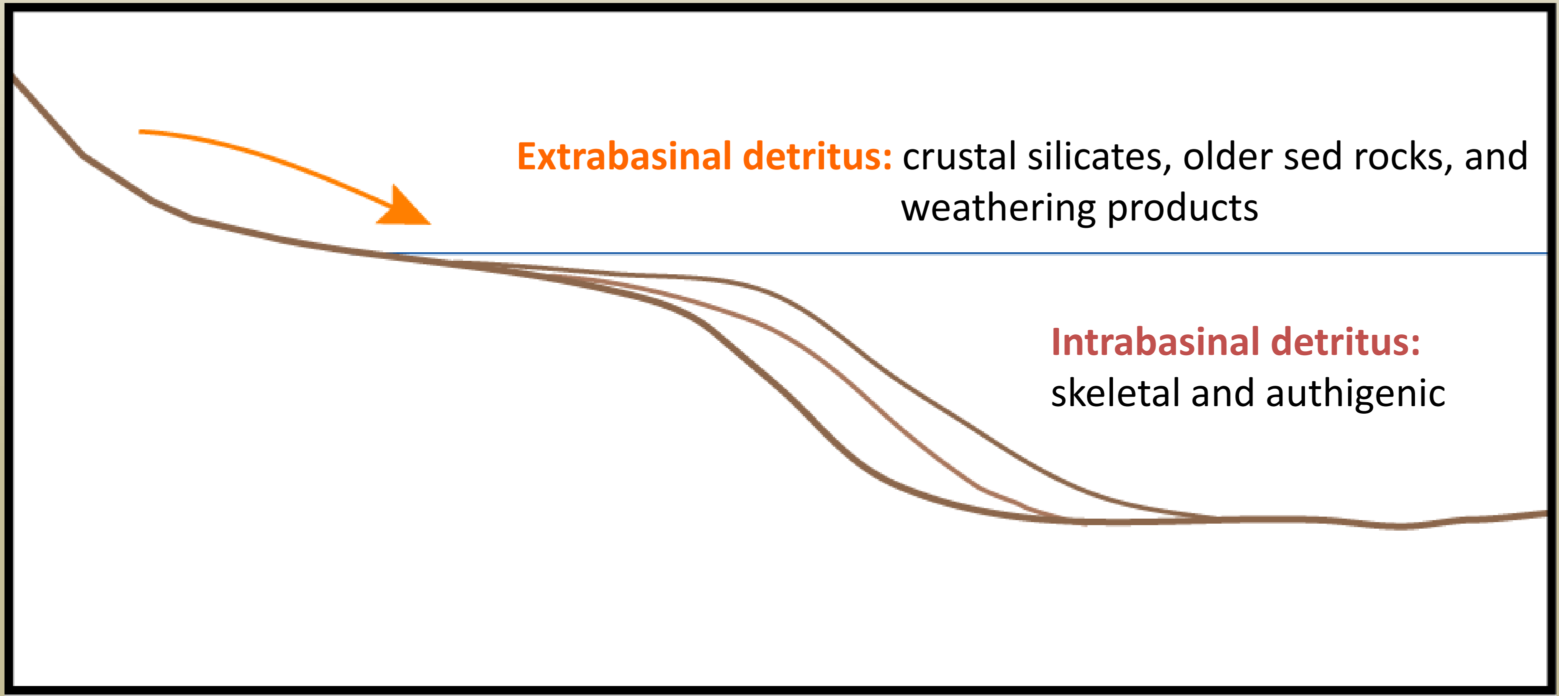


But not in others………

Diagenesis can erase the effects of primary texture. See Milliken et al., 2012.

Grain Assemblages in Mudrocks

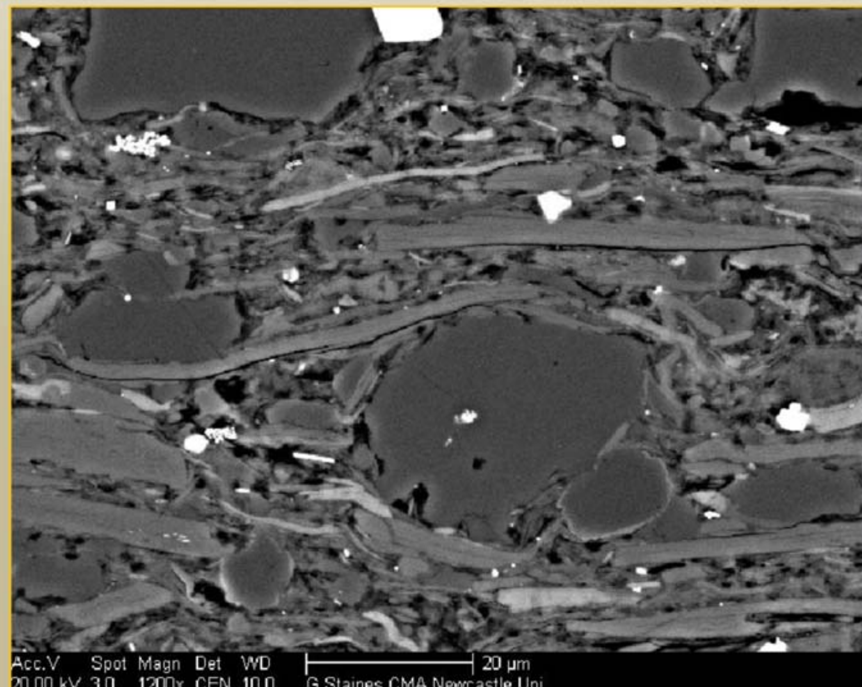
Like sandstones and limestones mudrocks are *particulate*. But mudrocks are not exclusively defined by extra- vs. intra-basinal particles.
Many mudrocks have both!



Identifying grain in sandstones and limestones is easy to do. It is NOT easy to do in mudrocks. Before you can classify the grains you have to SEE them. Two techniques, both performed on a ***field-emission SEM***, are useful for this:
EDS X-ray mapping and CL imaging.

Mudrock Particle Sources

Intrabasinal — Extrabasinal



Wilcox Gp
Paleocene

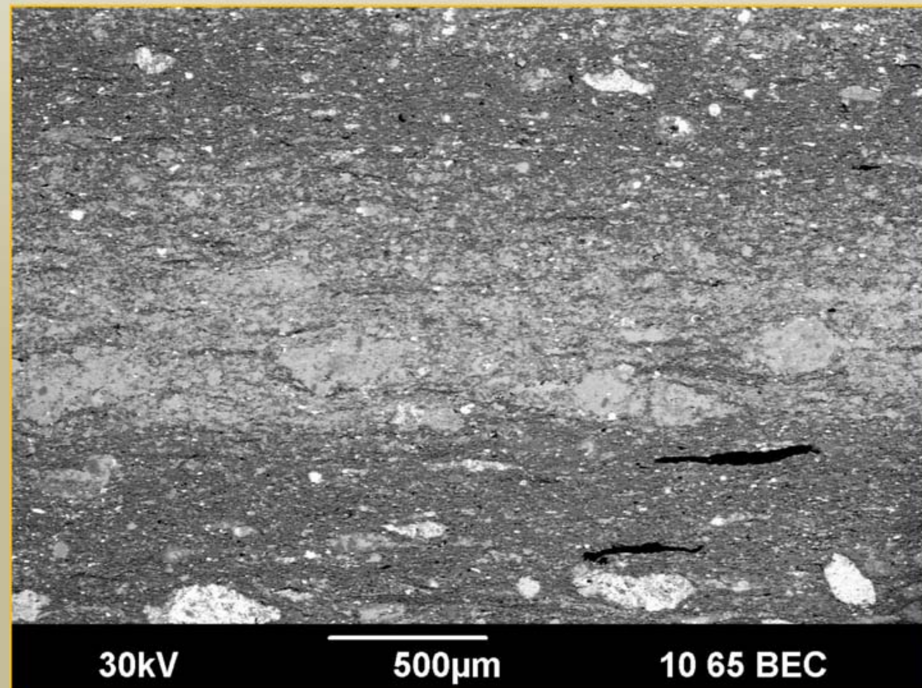
Presenter’s notes: Rich in detrital quartz and mica.

Mudrock Particle Sources

Intrabasinal

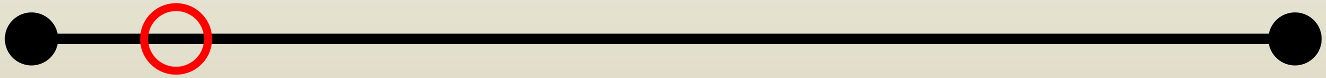
Extrabasinal

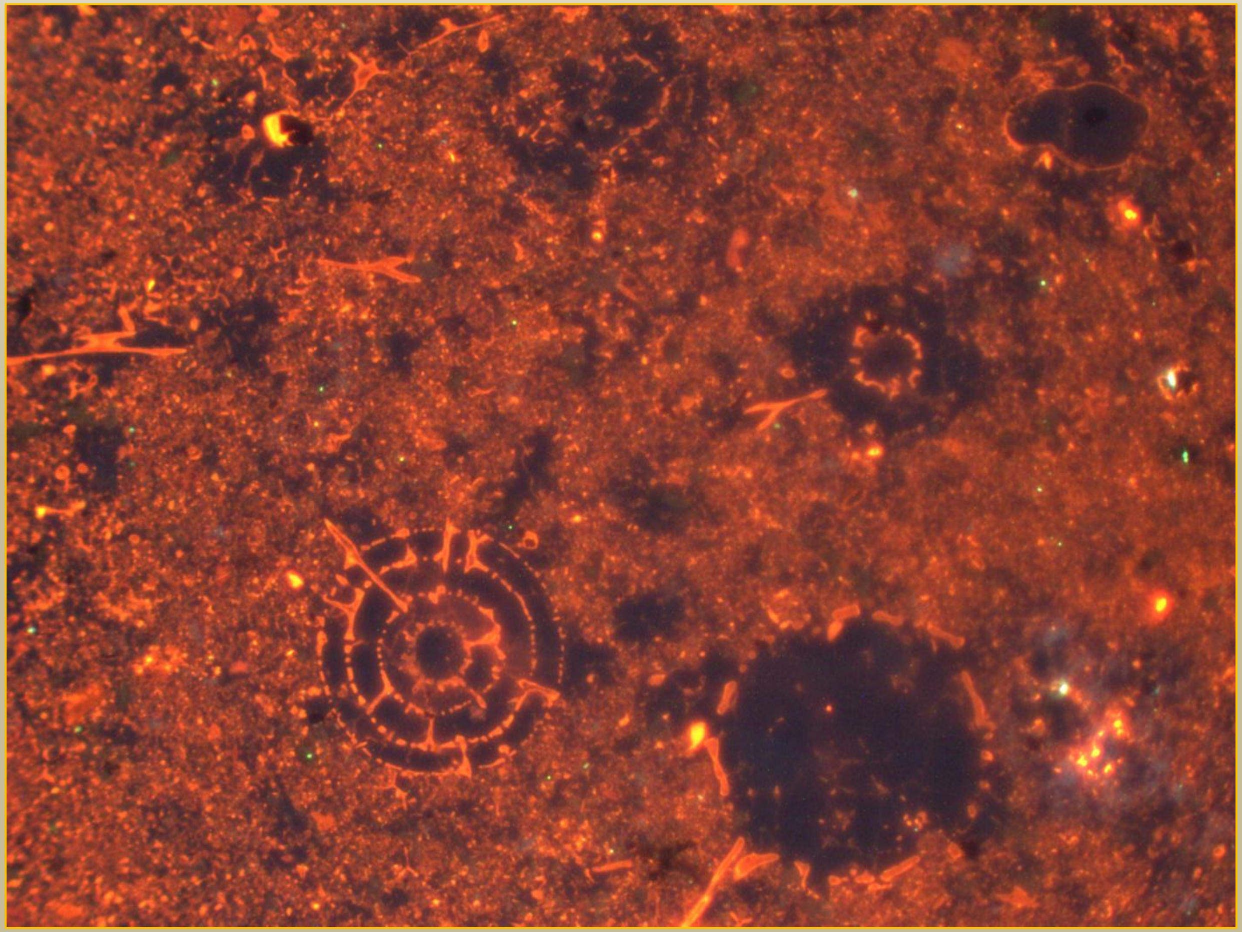
Barnett Sh., U. Miss.



Presenter’s notes:Particles of phosphorous (bright) medium gray is calcite.

Mudrock Particle Sources





Barnett Sh.,
U. Miss.

A possible way forward for classification of fine-grained sediment and rock:

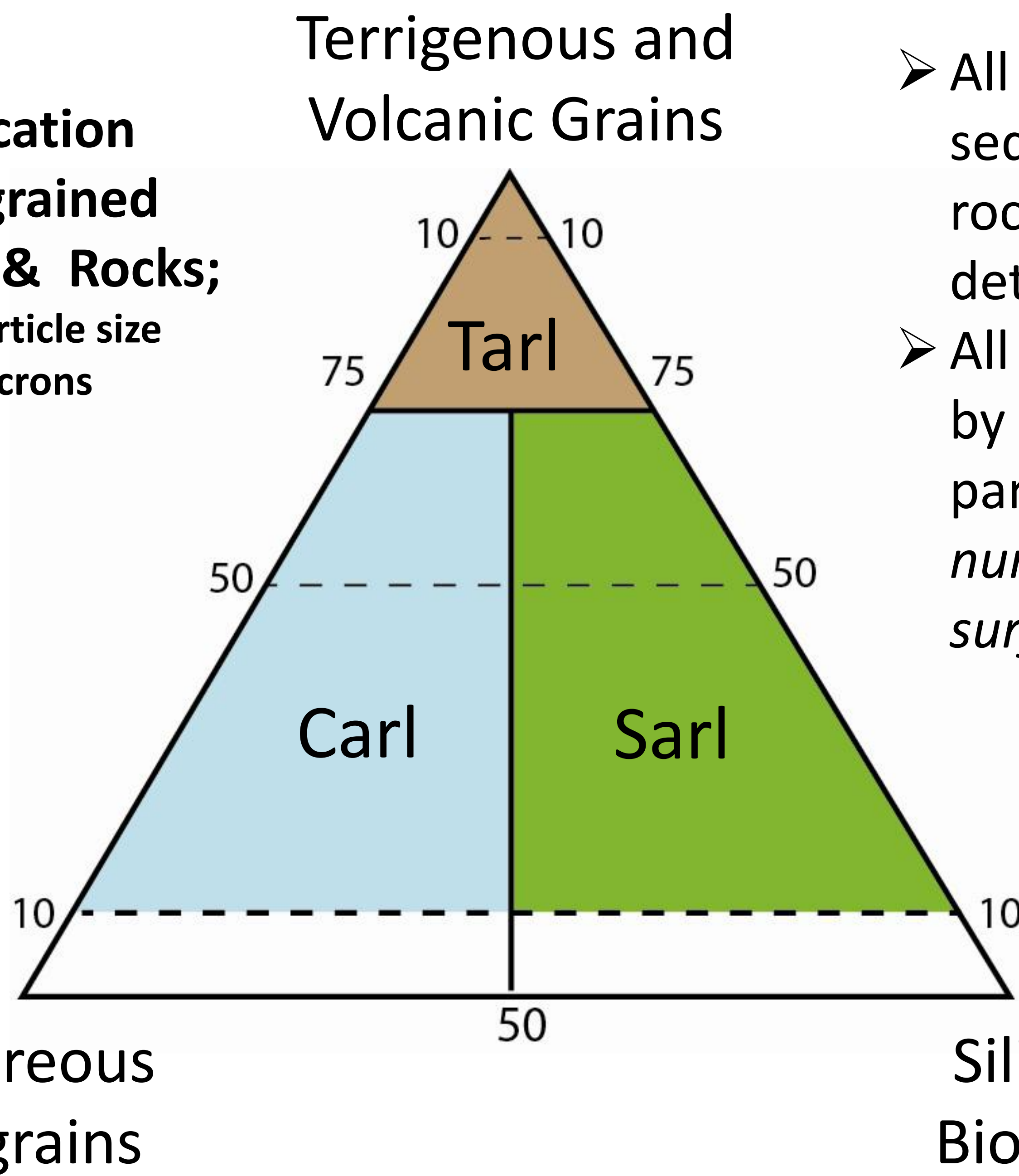
- Copy some aspects of sandstone and limestone classification:
  - Classify based ONLY on the grain assemblage
  - Use texture, minor grains, and diagenetic features as descriptive modifiers.

- Draw a fundamental division between sediments dominated by extrabasinal versus intrabasinal components.

- Divide intrabasinal compositions into calcareous and siliceous classes. Other intrabasinal grain types (e.g., glauconite and phosphate) affect the ratio of extra- to intra-basinal grains but do not contribute to the major name.

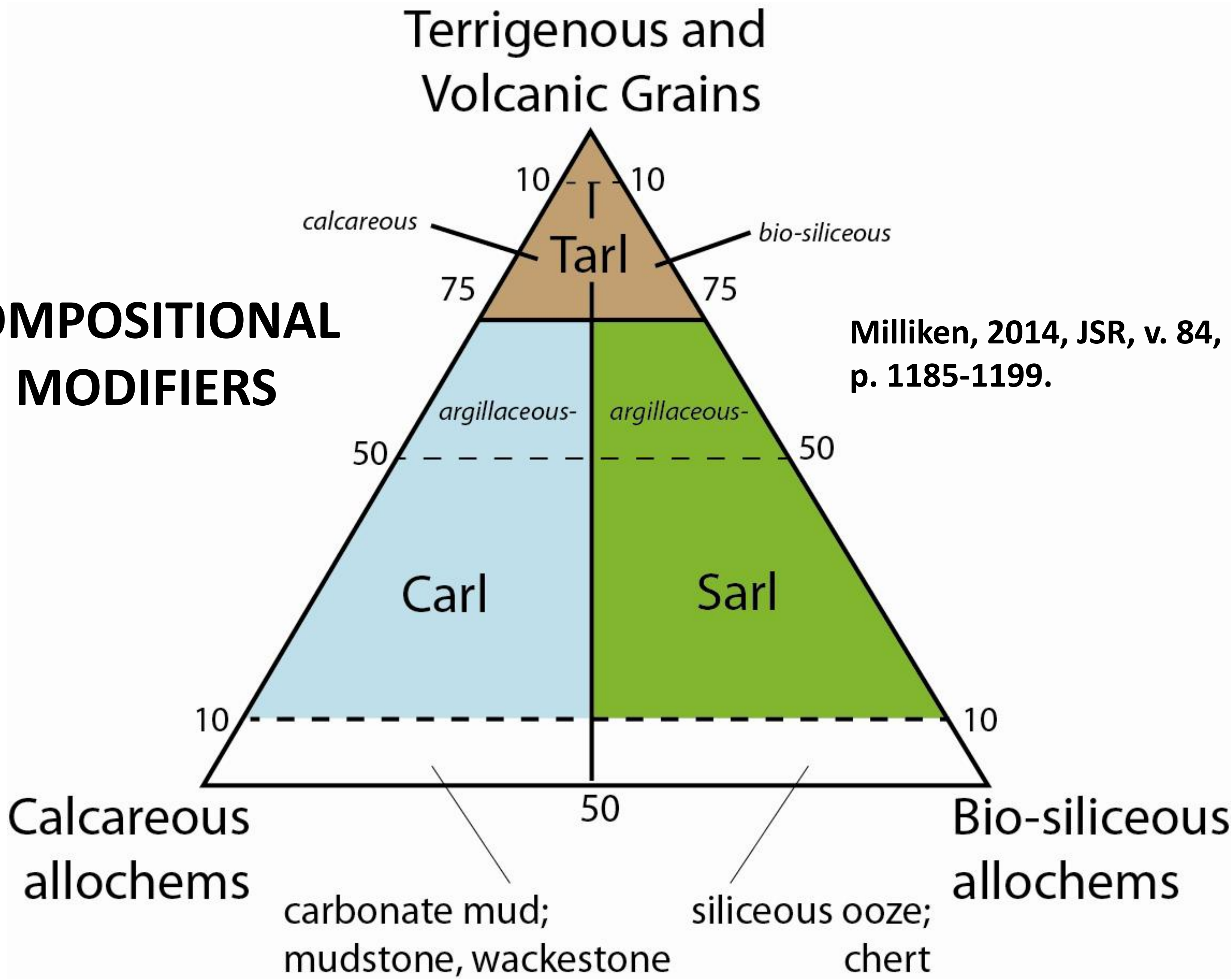
Classification of Fine-grained Sediments & Rocks;

Average particle size < 62 microns

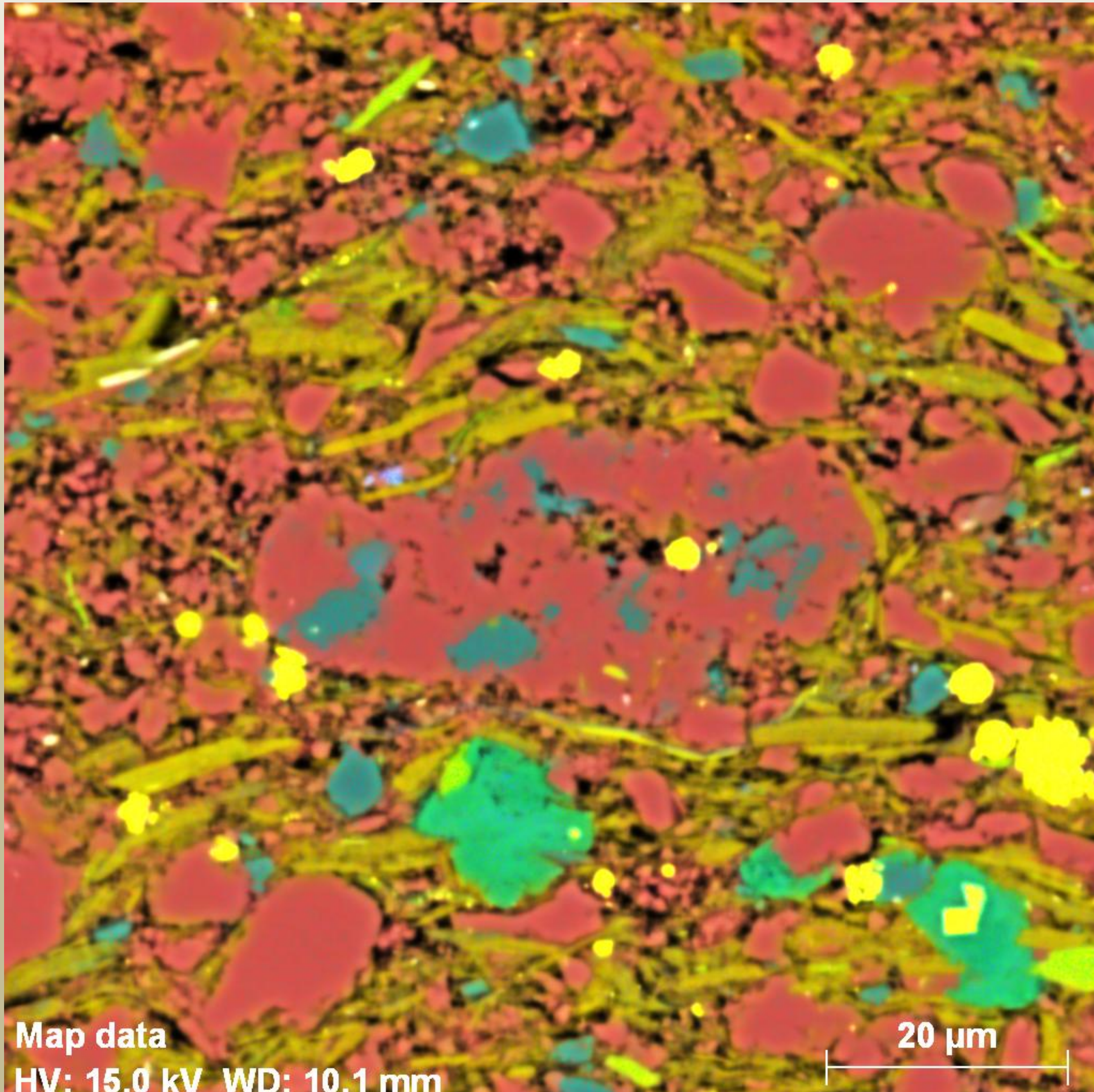


- All of these sediments and rocks contain detrital clay.
- All are dominated by clay mineral particles *by grain number and surface area*.

COMPOSITIONAL MODIFIERS



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



X-ray map at sufficiently high magnification for use in classification.

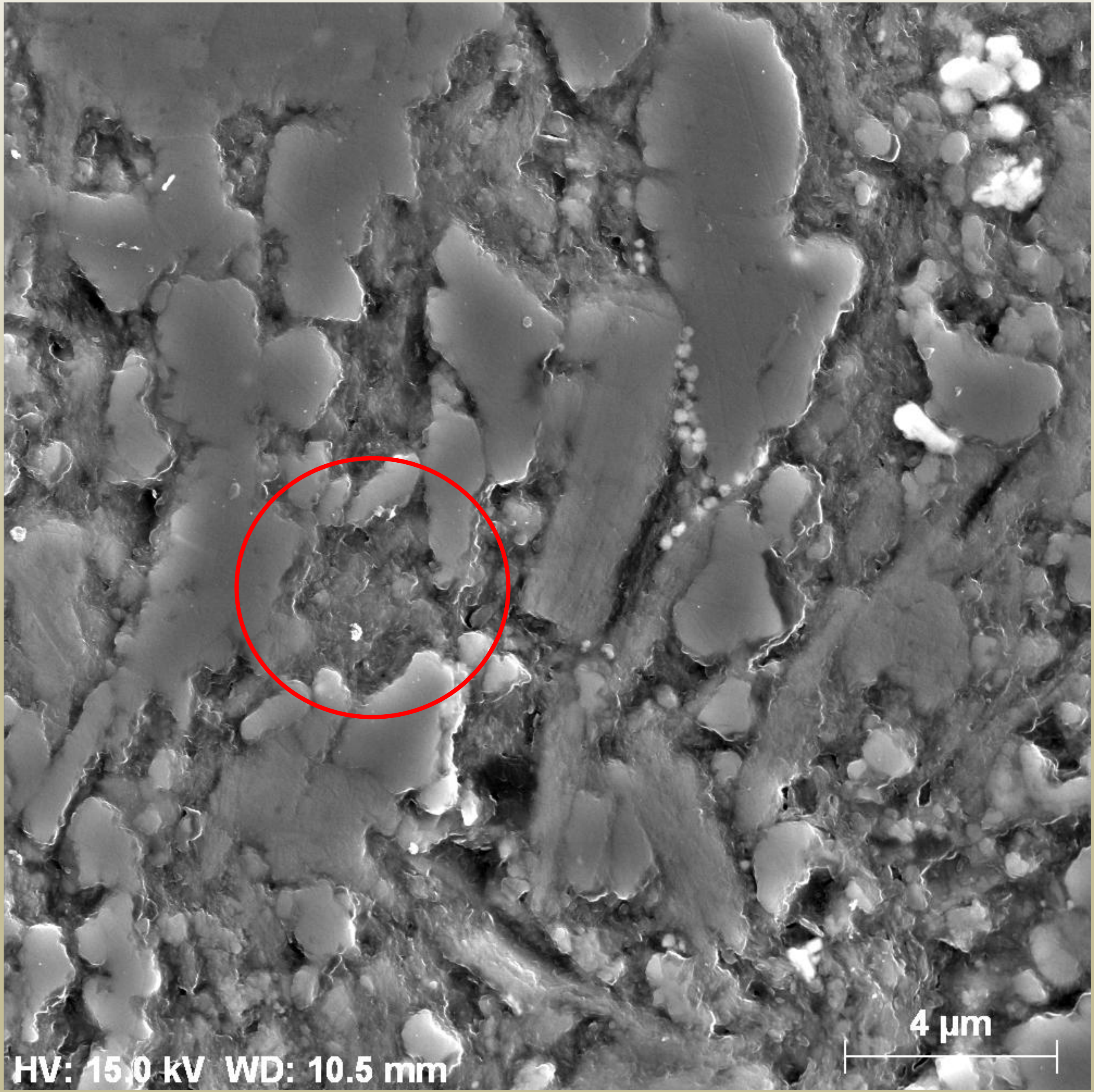
Red: quartz

Blue: Na-feldspar

Dark yellow: clay & mica

Bright yellow: pyrite

Green: dolomite



A Challenge for Classification (and a research opportunity):

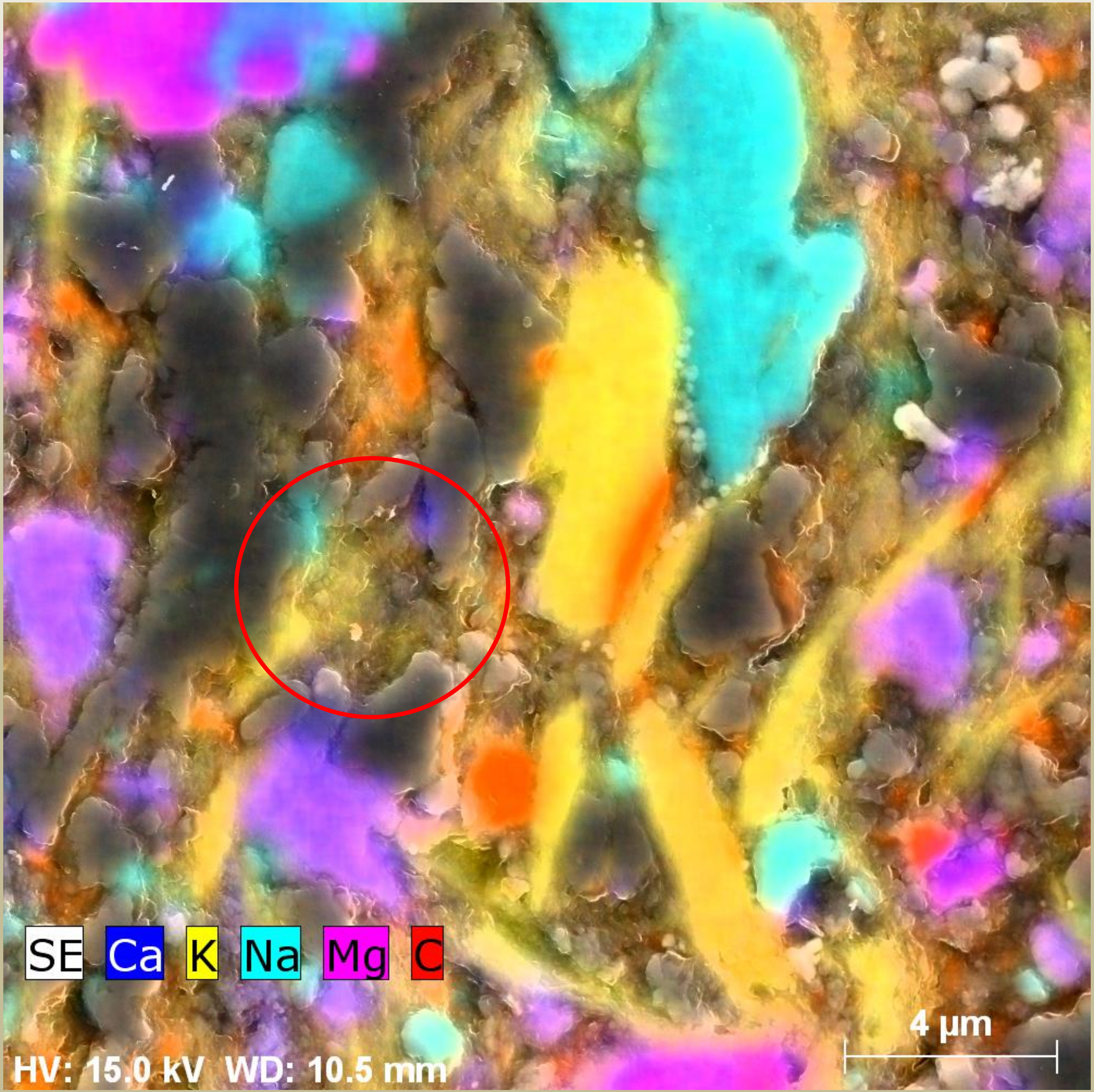
What is in the <1 micron fraction?

Grains?

Cements?

Grain replacements?

Pores?
  Primary?
  Secondary?



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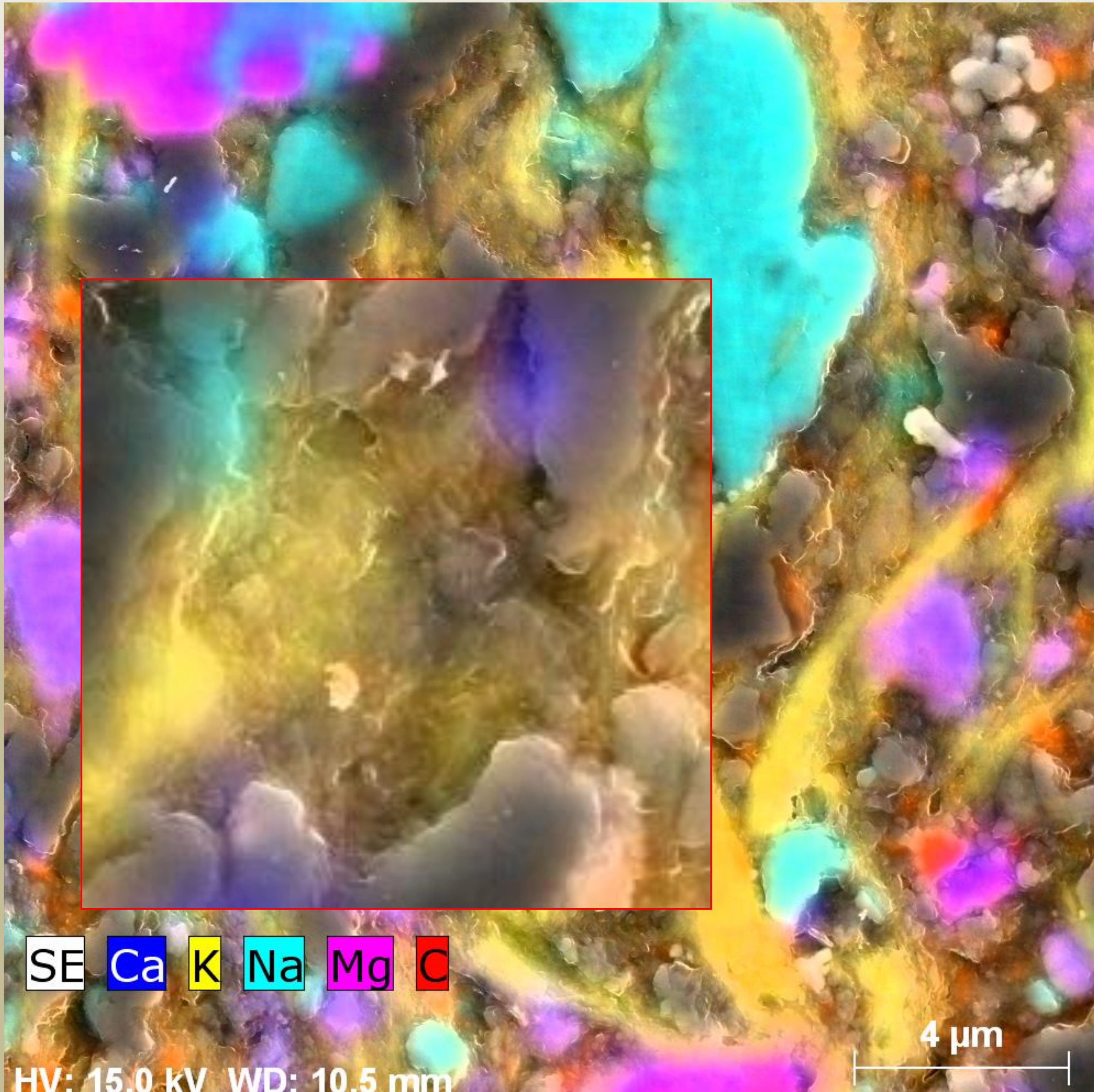

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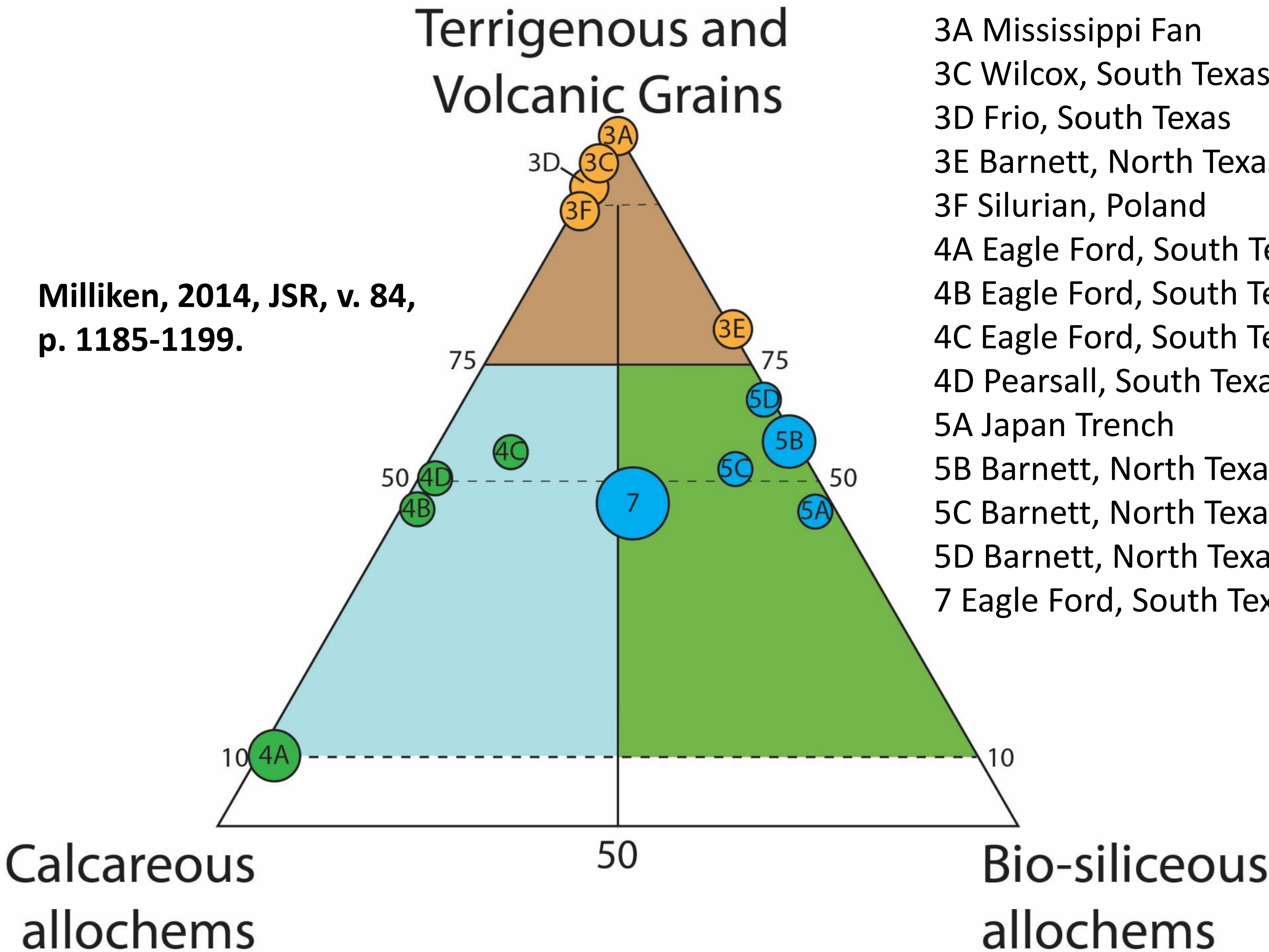
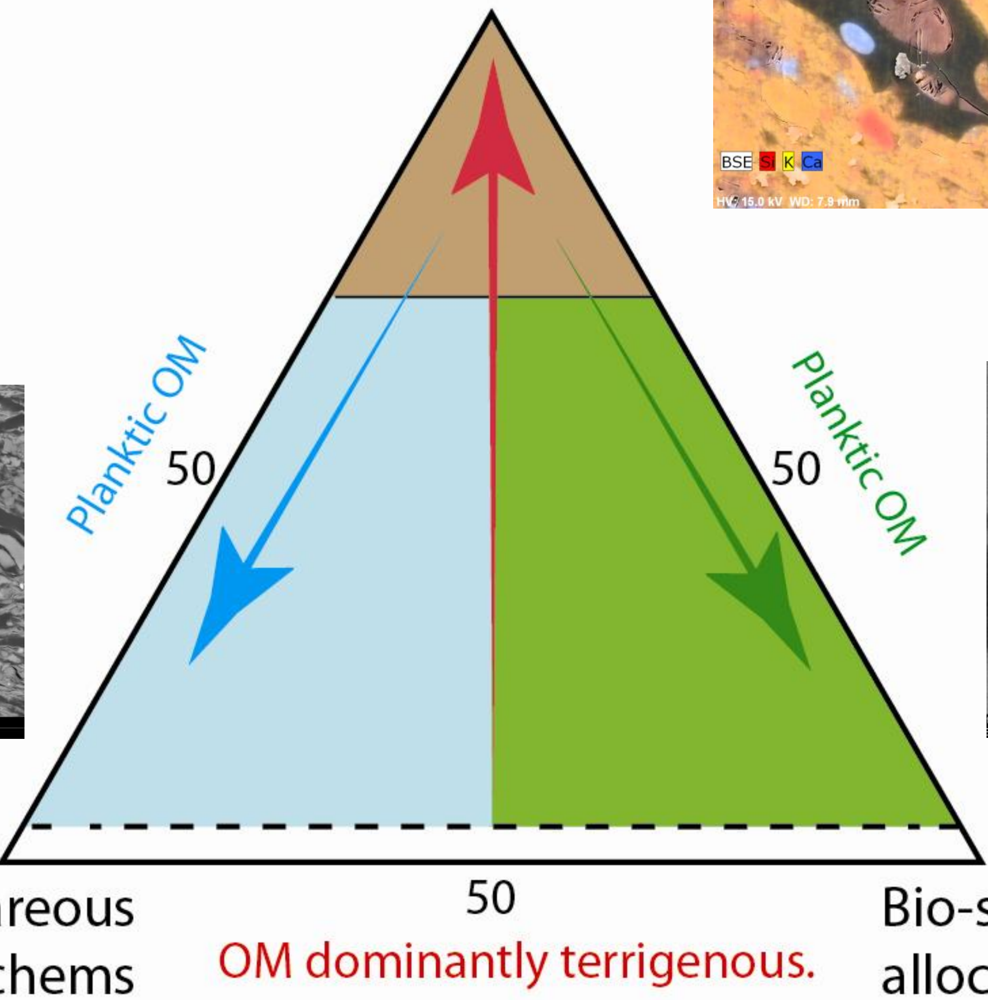
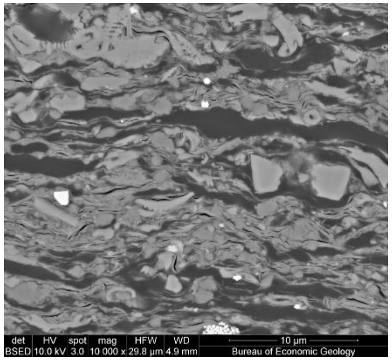
Milliken, 2014, JSR, v. 84, p. 1185-1199.

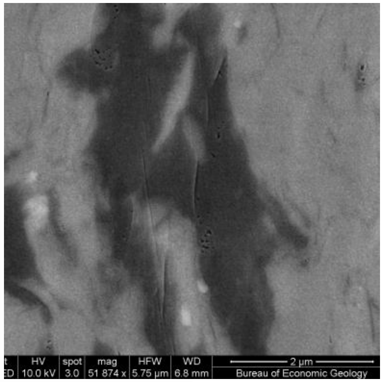


3A Mississippi Fan
3C Wilcox, South Texas
3D Frio, South Texas
3E Barnett, North Texas
3F Silurian, Poland
4A Eagle Ford, South Texas
4B Eagle Ford, South Texas
4C Eagle Ford, South Texas
4D Pearsall, South Texas
5A Japan Trench
5B Barnett, North Texas
5C Barnett, North Texas
5D Barnett, North Texas
7 Eagle Ford, South Texas

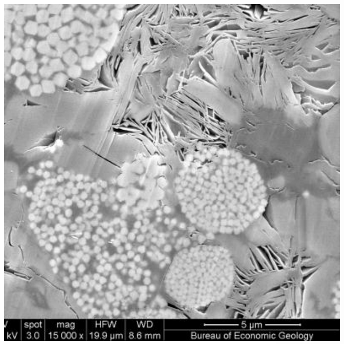
Prediction of Kerogen Content

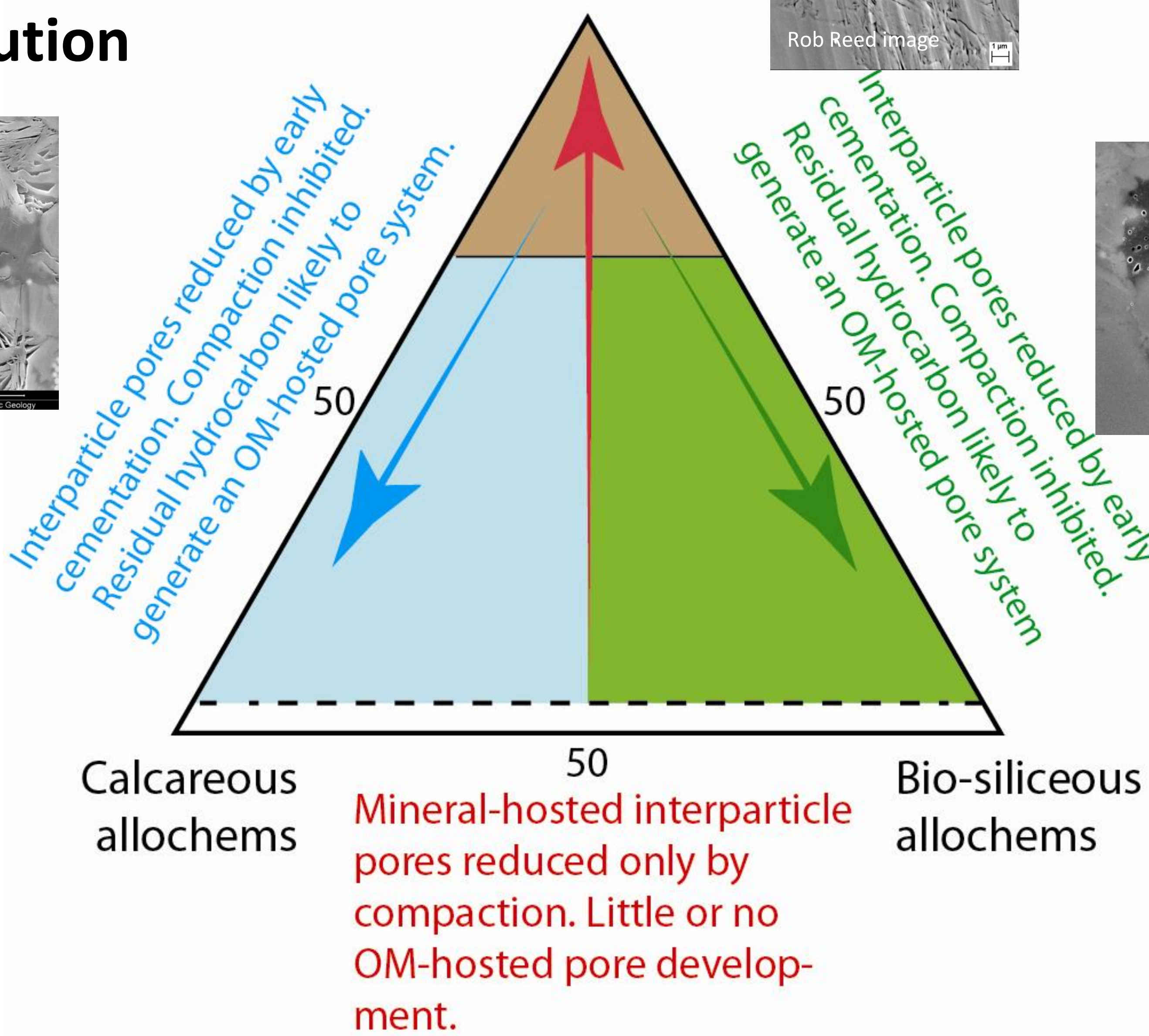


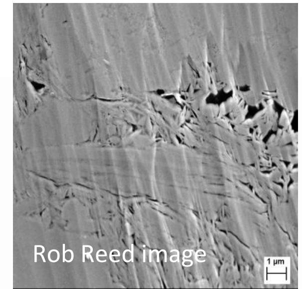


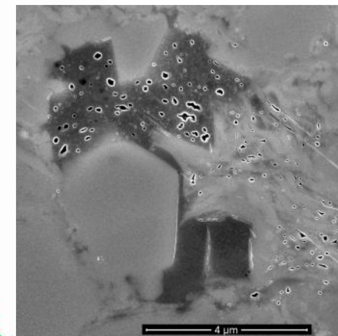


Prediction of Porosity Evolution

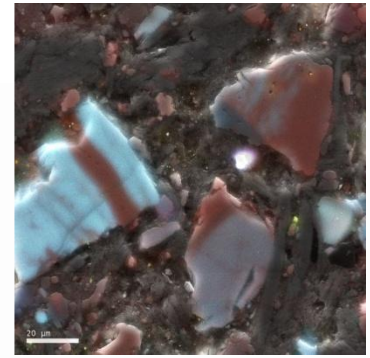


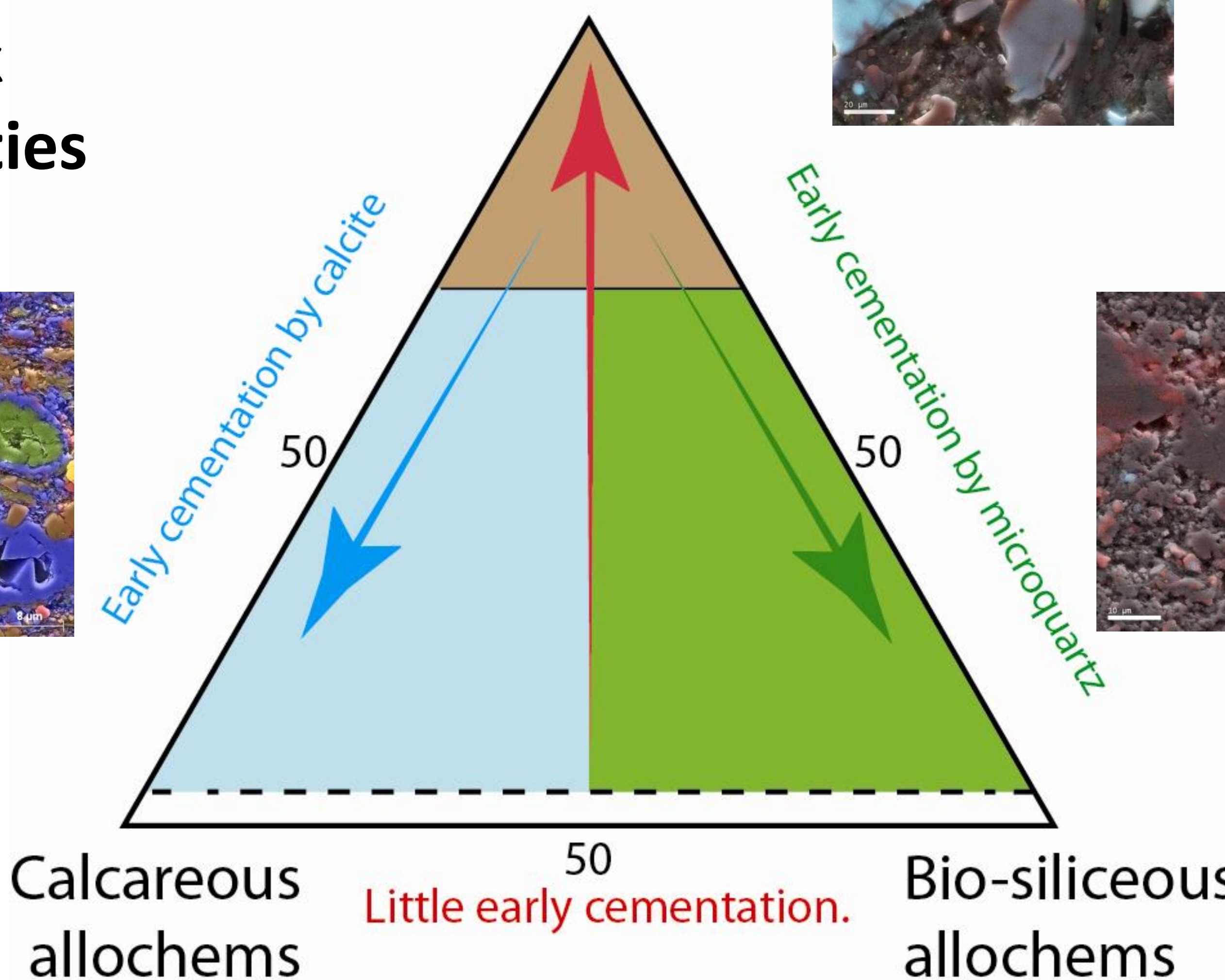


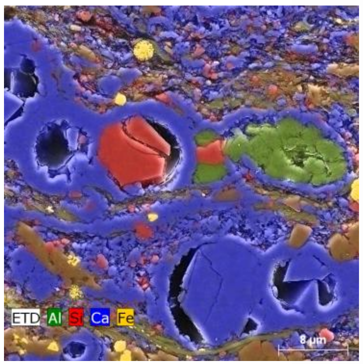


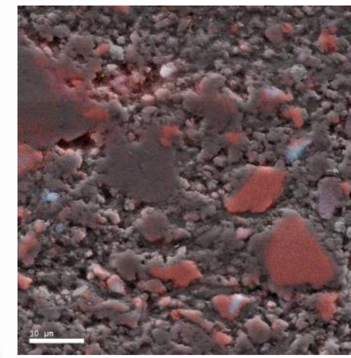


Prediction of Mechanical Rock Properties

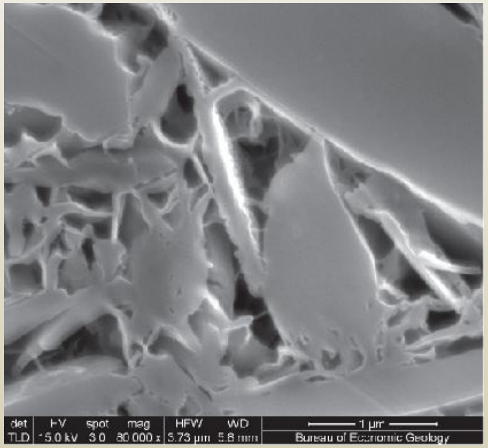


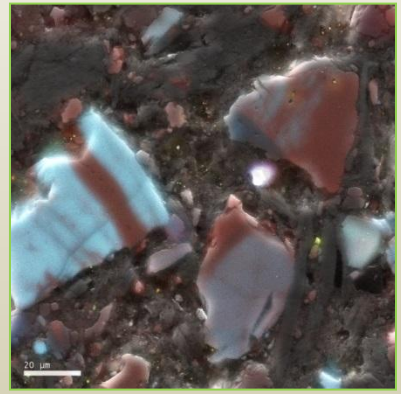


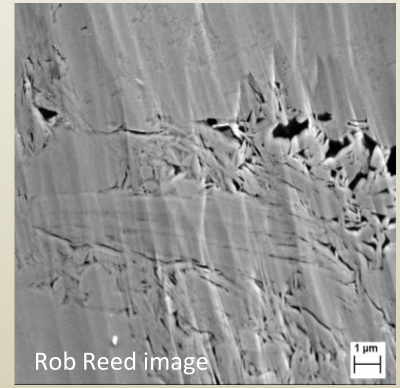




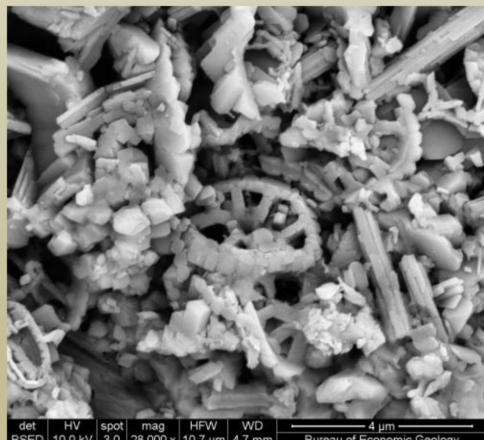
TARL

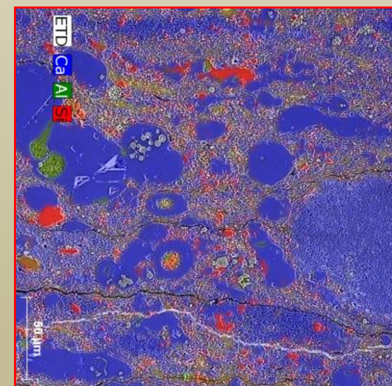


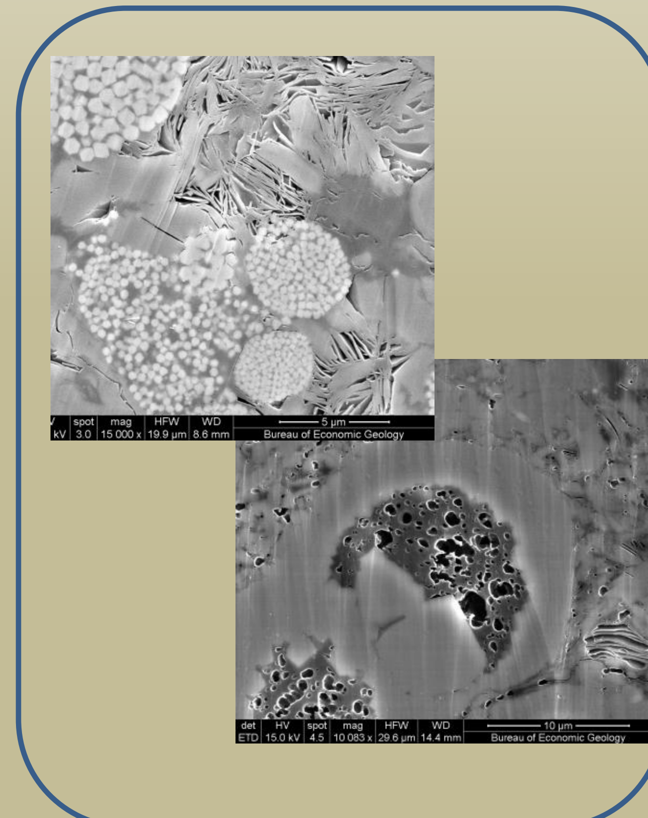




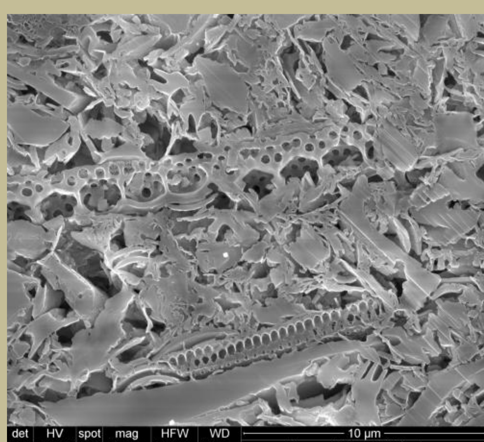
CARL

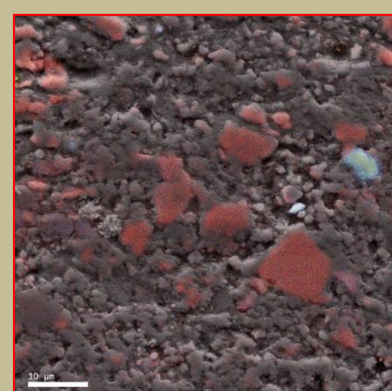


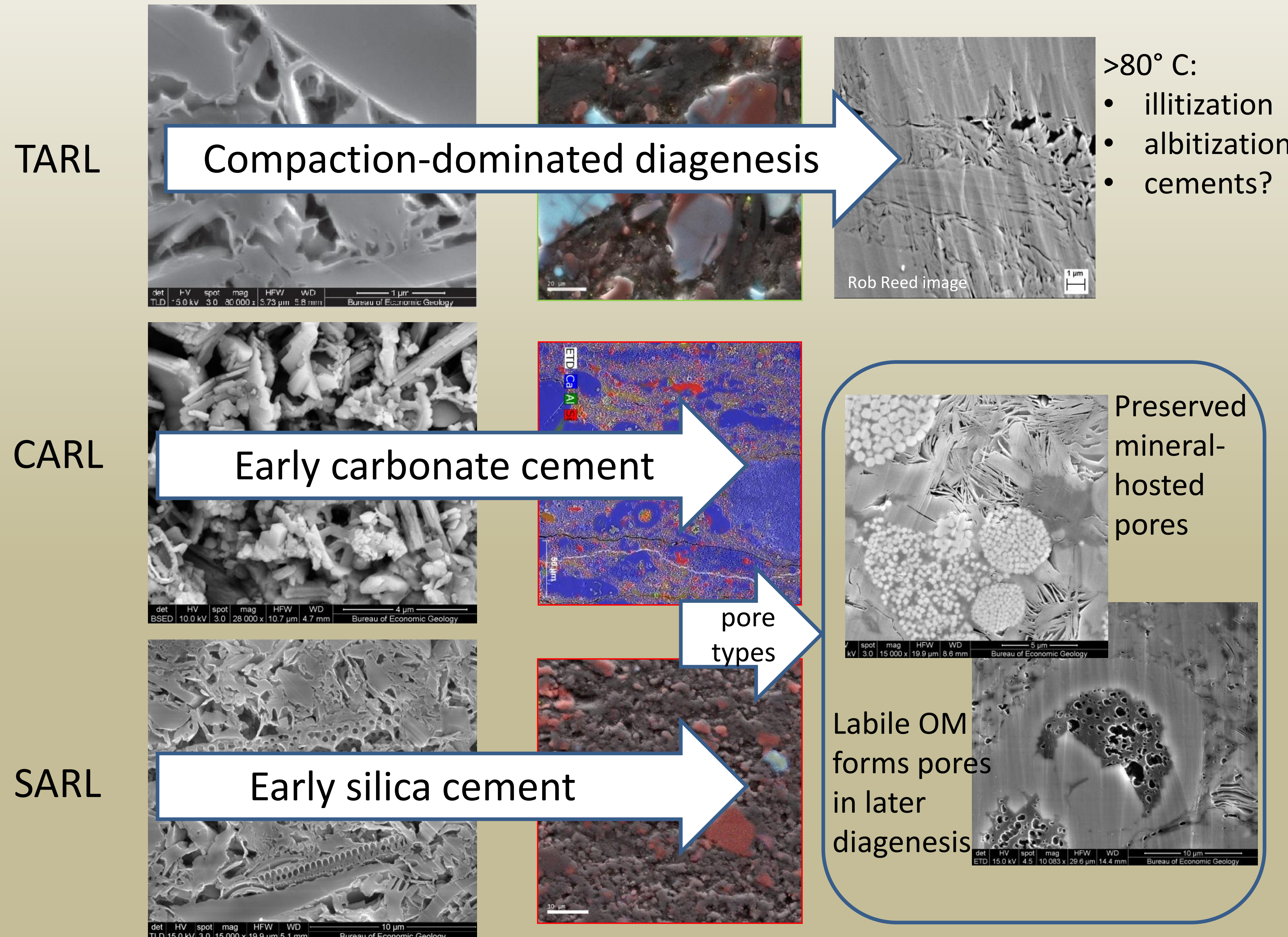




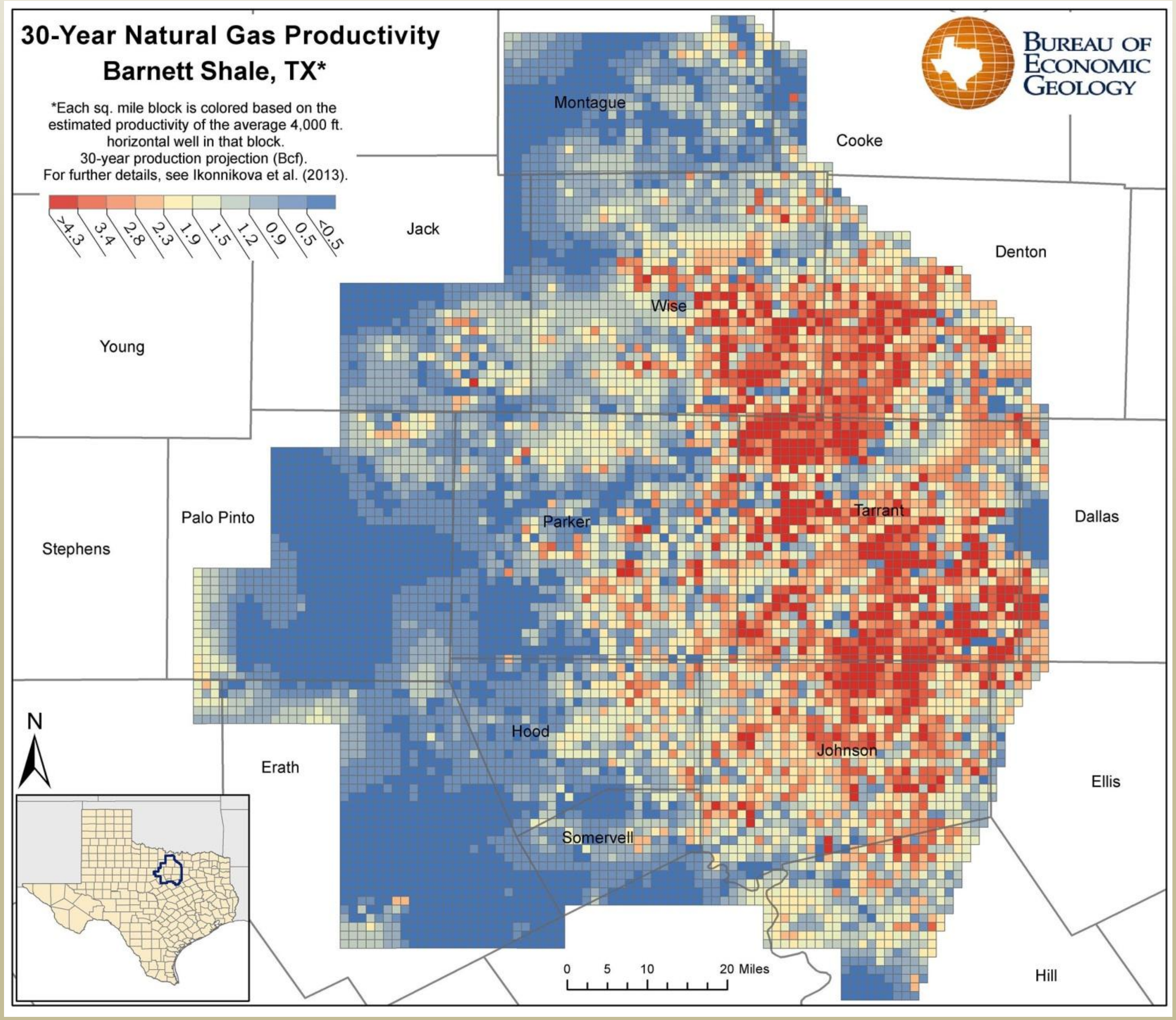
SARL





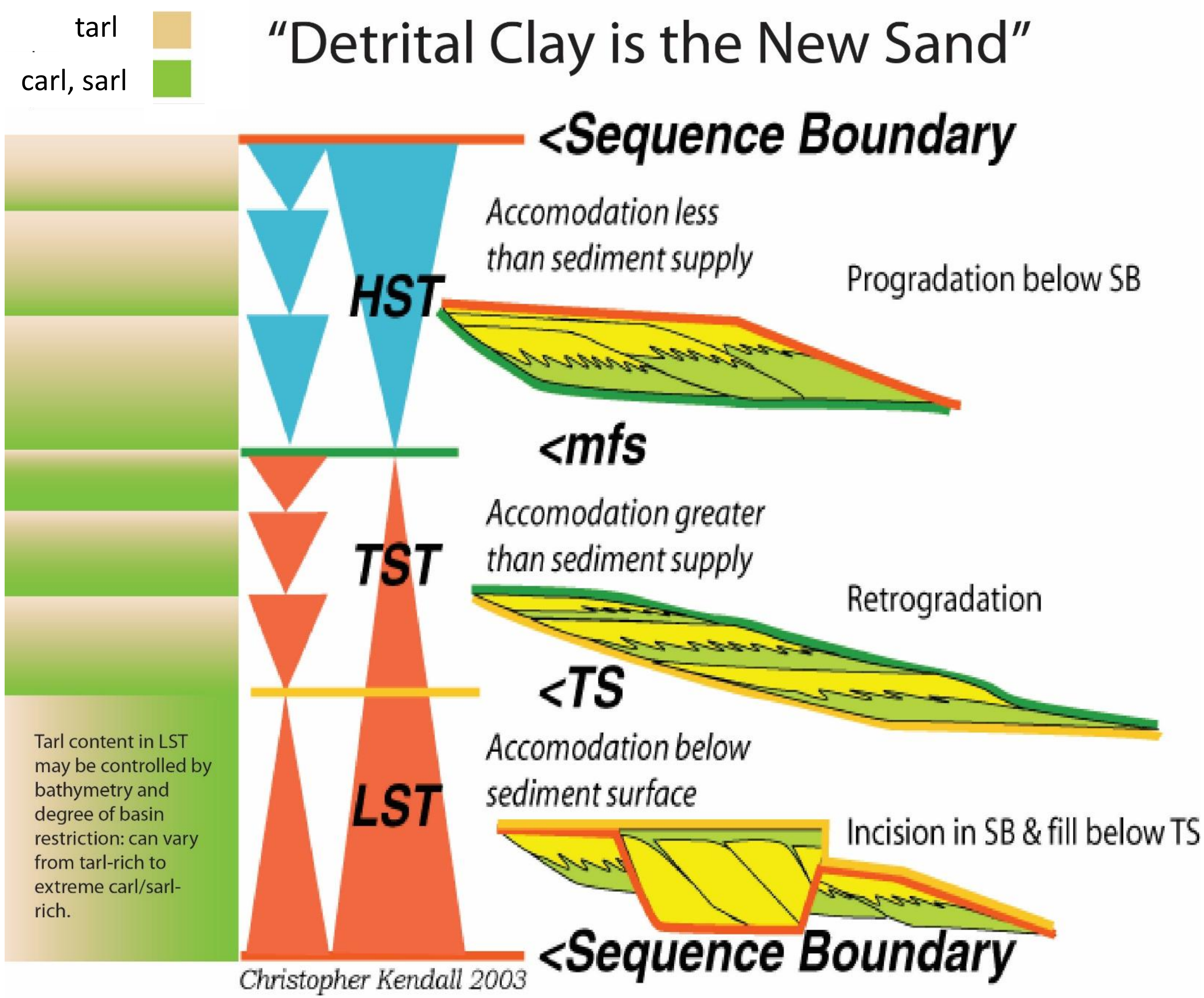

TARL
Compaction-dominated diagenesis
>80° C:
• illitization
• albitization
• cements?
Rob Reed image
CARL
Early carbonate cement
SARL
Early silica cement
pore types
Preserved mineral-hosted pores
Labile OM forms pores in later diagenesis
Bureau of Economic Geology

Productivity Tiers of the Barnett Shale (Ikonnikova et al., 2013)



"Sweet spots" : suggest potential for significant gains in efficiency by application of exploration models that address depositional environments, grain source mixing, and other basic causes of shale heterogeneity.

Future Exploration Model?



Hypothesis for mudrock compositional variation across stratigraphy: <u>needs to be tested</u>.

A Compositional Classification for Fine-grained Particulate Sedimentary Rocks:

Tarl Carl Sarl
?

Do these terms make sense?
Do they communicate something important?
Do they aid prediction?
Can you give these a try?

You can help consensus to develop!

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

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