The Weak Textural and Compositional Control on Rock Properties in the Barnett Shale, Fort Worth Basin, Texas, USA*

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Editor's Note: Please refer to the companion article, "Petrology of High-Maturity Samples of the Barnett Shale," Search and Discovery Article #80243 (2012), authored by the first three authors listed above.

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Abstract

Porosity, permeability, and TOC in high-maturity samples (R_o 1.52 - 2.15) from the Barnett Shale in the eastern Fort Worth Basin display few correlations with parameters of primary rock texture, fabric, or inorganic composition. Compaction and cementation have largely destroyed primary intergranular porosity. Porosity (0.9 to 3.8 percent) and pore size are reduced to a degree such that pores are difficult to assess even by imaging Ar-ion milled surfaces with a field-emission SEM. Pores that can be imaged are mostly secondary and localized dominantly within organic particulate debris and pyrobitumen.

The ratio of extrabasinal to intrabasinal sources of siliciclastic debris has a weak correlation with bulk properties. Higher porosity, permeability, and TOC are observed in samples representing the extreme end-members of mixing between extrabasinal siliciclastic sediment and intrabasinal biosiliceous debris. Reservoir quality in these rocks is no longer strongly related to primary texture and composition because the conventional interrelationships between texture and composition and a primary pore system have been destroyed by the intense diagenetic overprint. Pore system properties and hence reservoir quality now have more affinity with the porous particulate organic matter and pyrobitumen occupying inter-mineral pore space within these samples. The correlation between organic matter and porosity is most evident in samples from the shallower of the two cores investigated in this study, where an R_o of 0.75 is observed.

Reference

Milliken, K.T., W.L. Esch, R.M. Reed, and T. Zhang, 2012, Grain assemblages and strong diagenetic overprinting in siliceous mudrocks, Barnett Shale (Mississippian), Fort Worth Basin, Texas: AAPG Bulletin, v. 96/8, p. 1553-1578.

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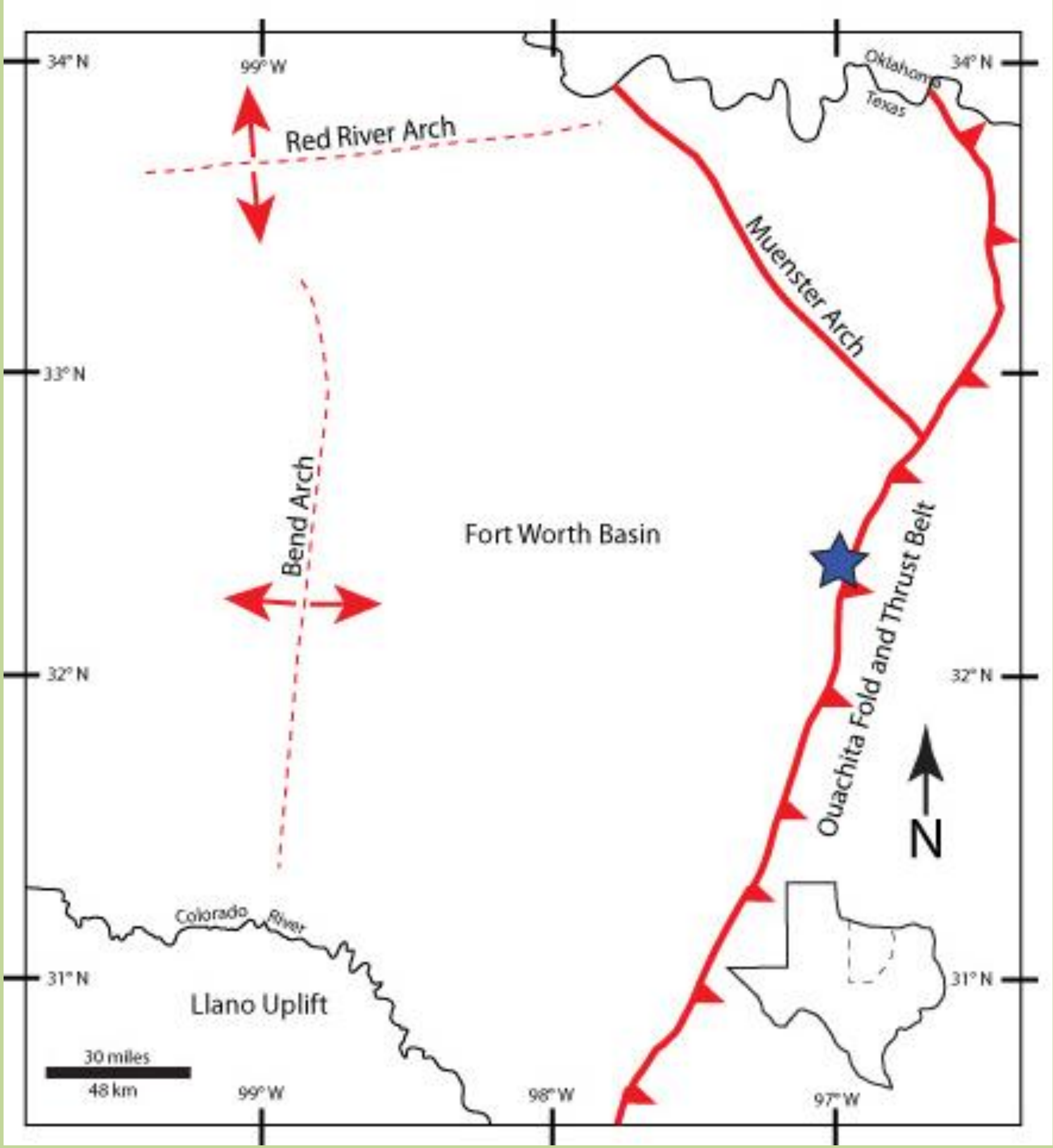


Goal: examine controls on bulk rock properties important to reservoir quality:

- Porosity
- Permeability
- Organic content (TOC)

Single well on far eastern side of the basin.

21 samples.

Depth: 8478 – 8810 ft.

Thermal maturity:

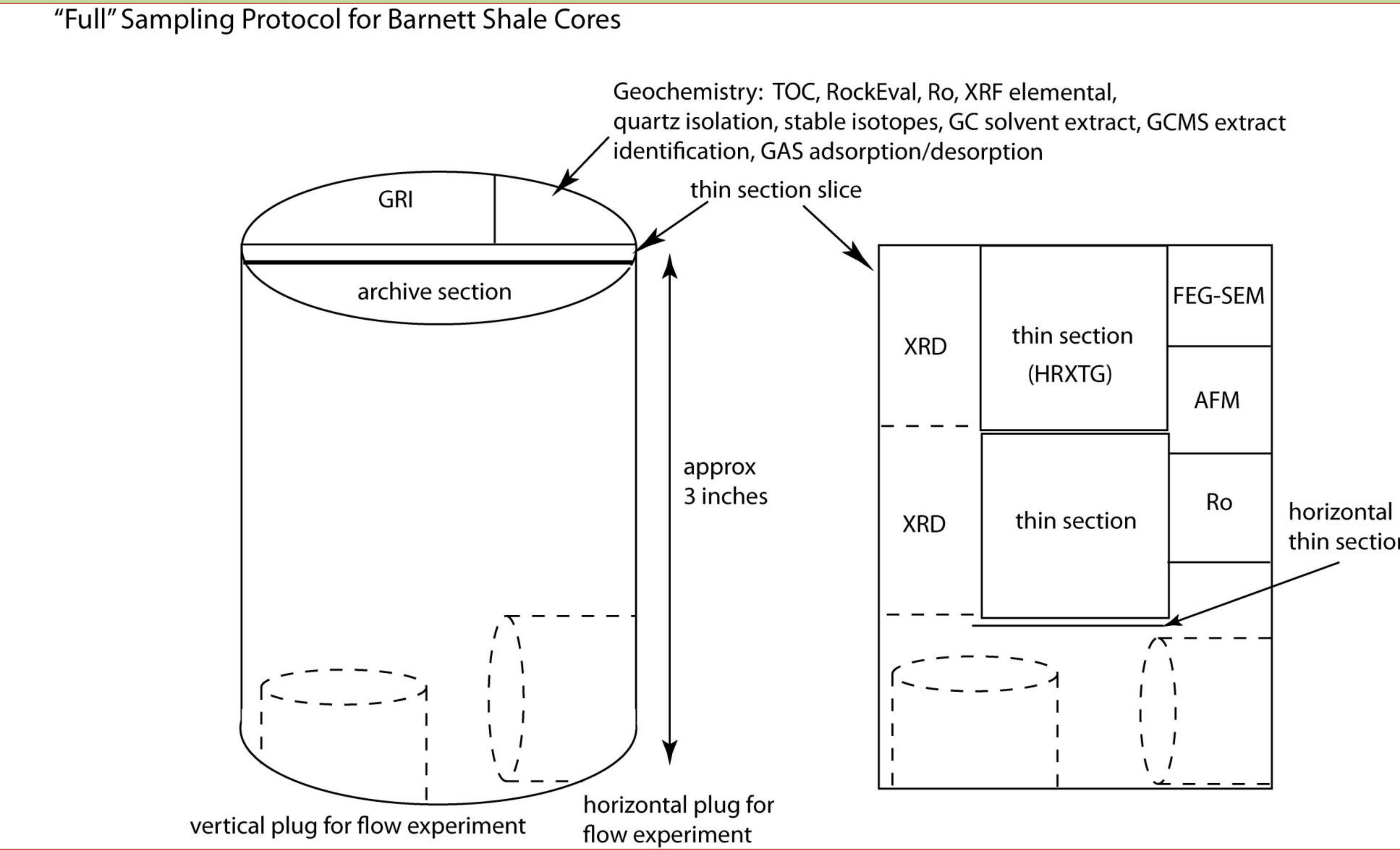
R_o % = 1.5 – 2.2

Sampling Strategy

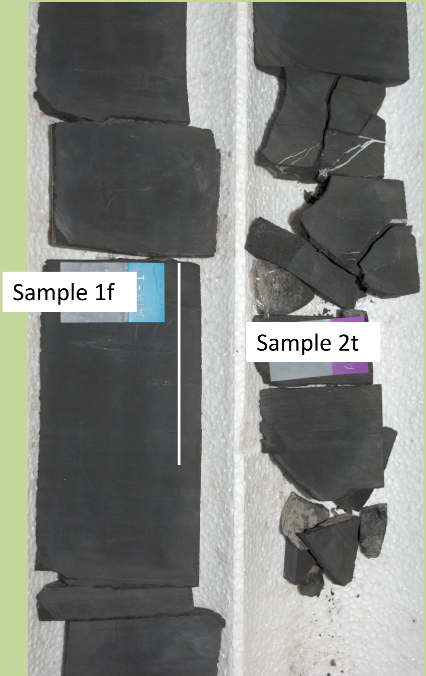
- Comprehensive analysis of petrophysical, geochemical, and petrologic properties of <u>volumetrically significant</u> materials
  - Necessary to seek zones of *relative* uniformity in order to obtain sufficient volume
  - 21 samples from 4 lithologies
- Minor lithologies sampled to provide a fuller understanding of depositional environment and chemical and mechanical history
  - 32 additional thin sections

The major lithologies sampled in core:

- “silty clay” or “clayey silt”
  - Type 1: relatively homogeneous with color banding on the scale of 1-4 cm
  - Type 2: pronounced sandy laminations
  - Type 3: rich in fine-grained calcite; strong parallel laminations
  - Type 4: color banded with notable layers of skeletal debris
  - Concretion



Sampled 4 volumetrically significant lithologies & a concretion.



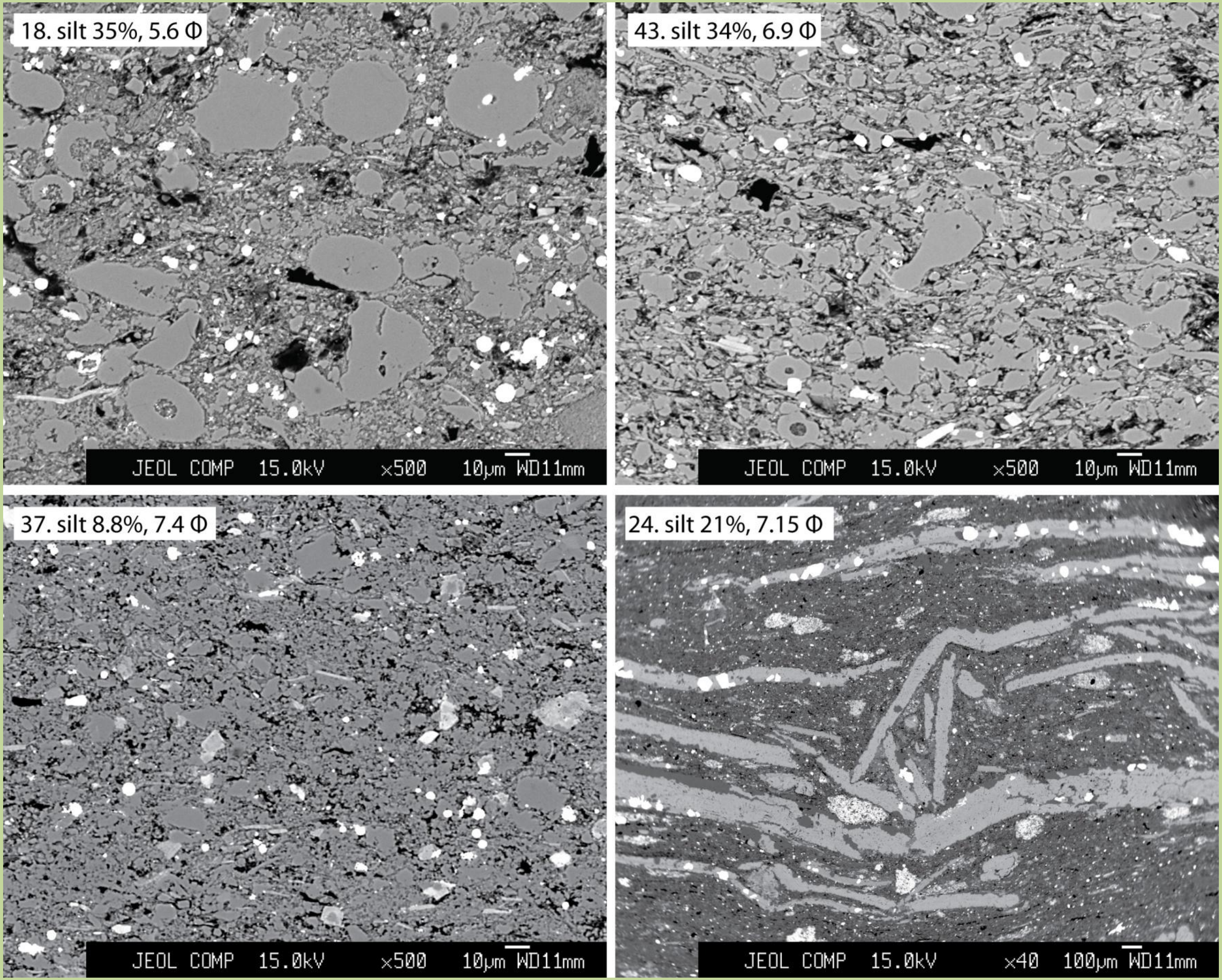
Examples of sampling choices:

Sample 1f: Faintly color-banded silty clay: most abundant lithology (Type 1)

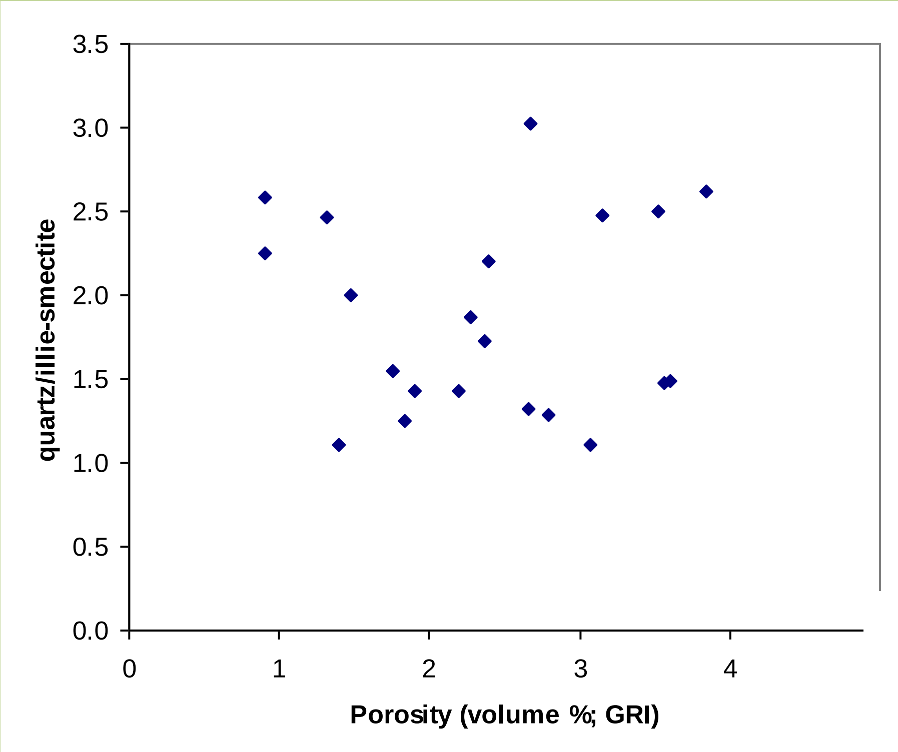
Sample 2t: Faintly color-banded silty clay with prominent sponge spicules:

Presenter's note: Bedding-plane image in the lower right.

Back-scattered electron images.



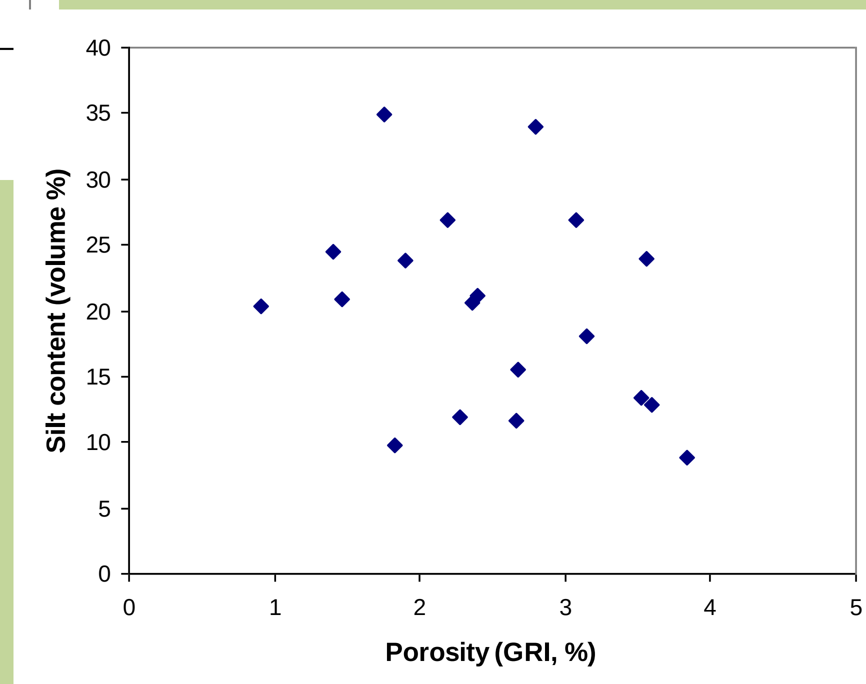
Textural heterogeneity: silt content, silt size

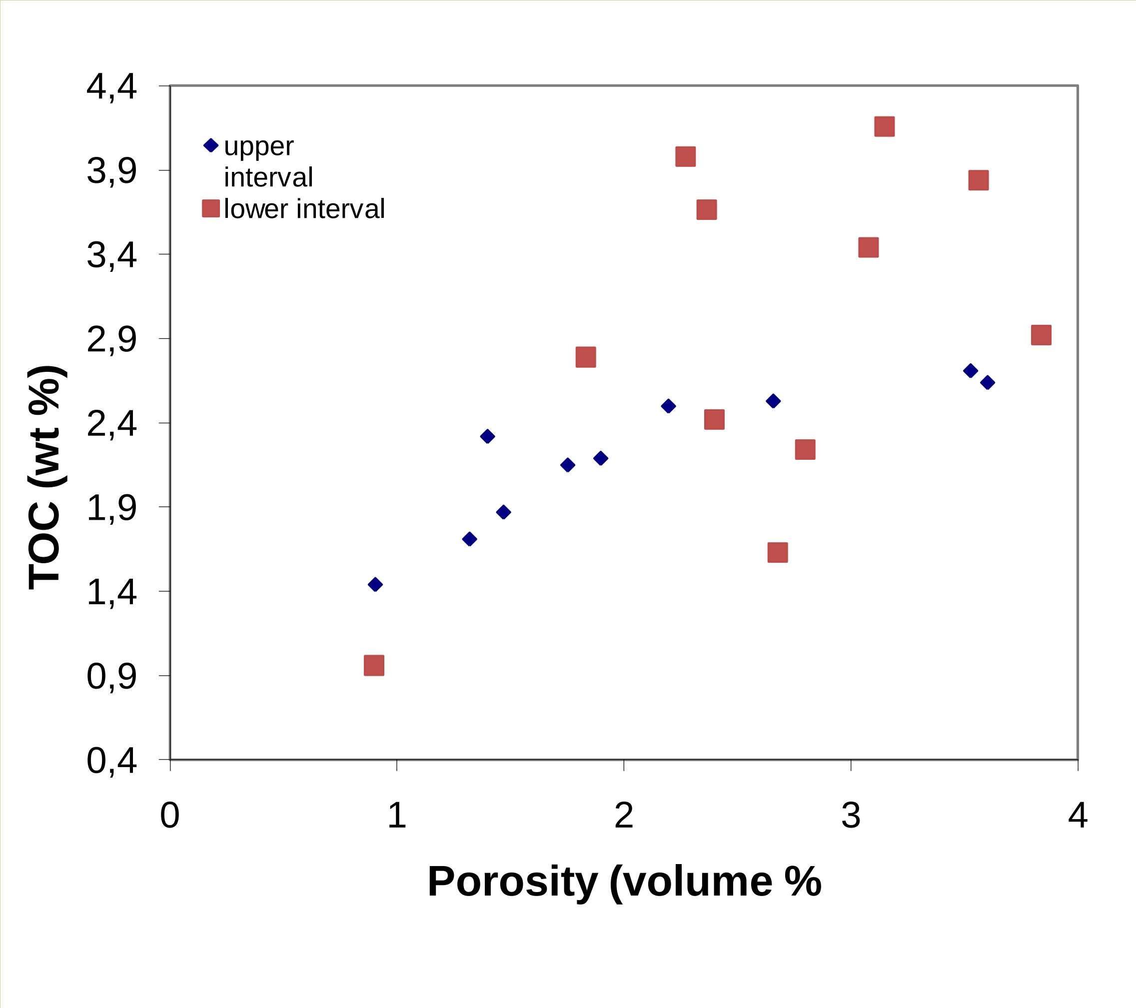


	DEPTH (ft)	% silt	ORG_C	Φ_{50}	Mean	std dev	median pore diam	modal pore diam	gas-filled	md	dry	mrd
DEPTH (ft)		0.08	0.38	0.19	-0.18	-0.15	-0.58	-0.86	0.32	0.04	-0.39	0.30
% silt			-0.19	-0.27	0.51	0.49	0.29	0.14	-0.30	-0.12	0.03	**0.74**
ORG_C				0.50	-0.03	-0.54	-0.28	-0.50	0.63	0.49	0.32	0.63
Φ_{50}					0.32	-0.91	0.08	-0.04	0.57	0.30	0.27	0.36
Mean						0.00	0.50	0.40	-0.21	0.05	0.23	0.54
std dev							0.09	0.13	**-0.71**	-0.44	-0.34	-0.11
median pore diam								0.82	-0.25	-0.07	0.43	-0.42
modal pore diam									-0.33	-0.03	0.48	-0.48
gas-filled										0.61	0.62	0.55
md											0.50	0.44
dry												0.47

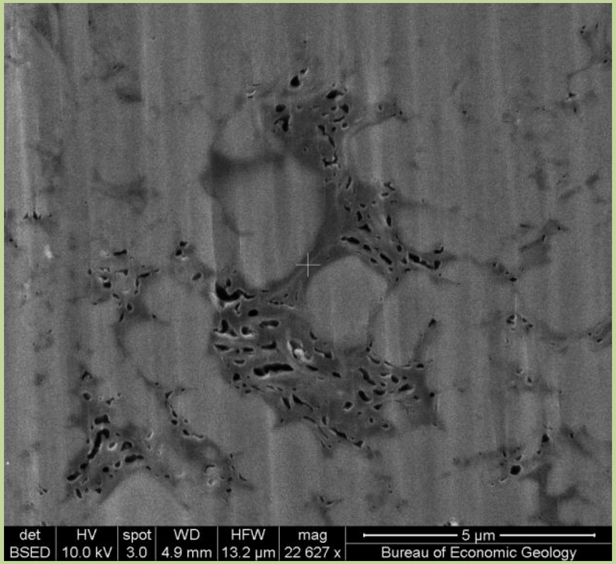
A complete correlation matrix revealed no clues….

Porosity, permeability, and TOC do not yield significant correlations with mineralogical parameters, nor with texture.



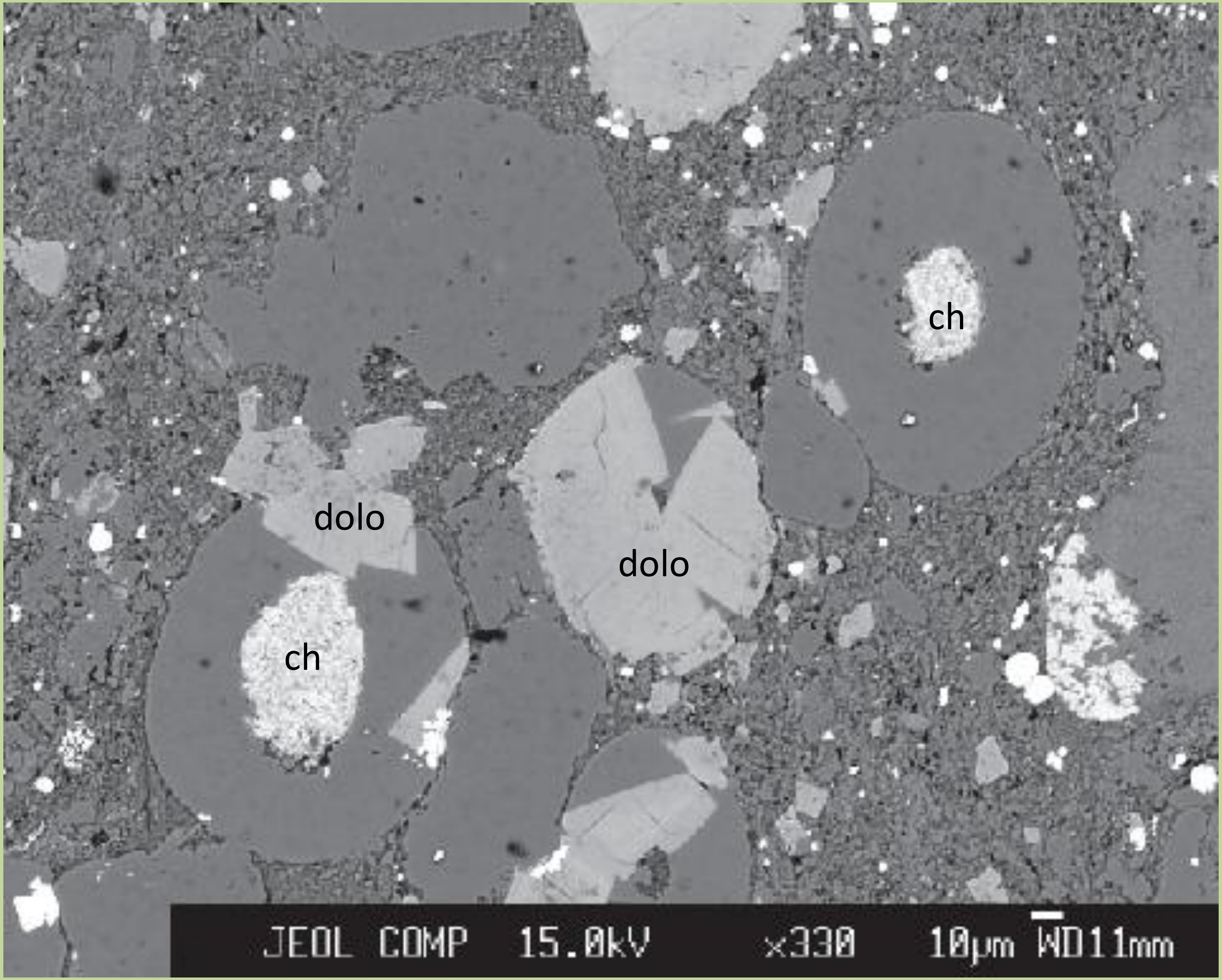


4,4
3,9
3,4
2,9
2,4
1,9
1,4
0,9
0,4
0
1
2
3
4
TOC (wt %)
Porosity (volume %
upper interval
lower interval



det BSED
HV 10.0 kV
spot 3.0
WD 4.9 mm
HFW 13.2 µm
mag 22 627 x
5 µm
Bureau of Economic Geology

Back-scattered electron image.



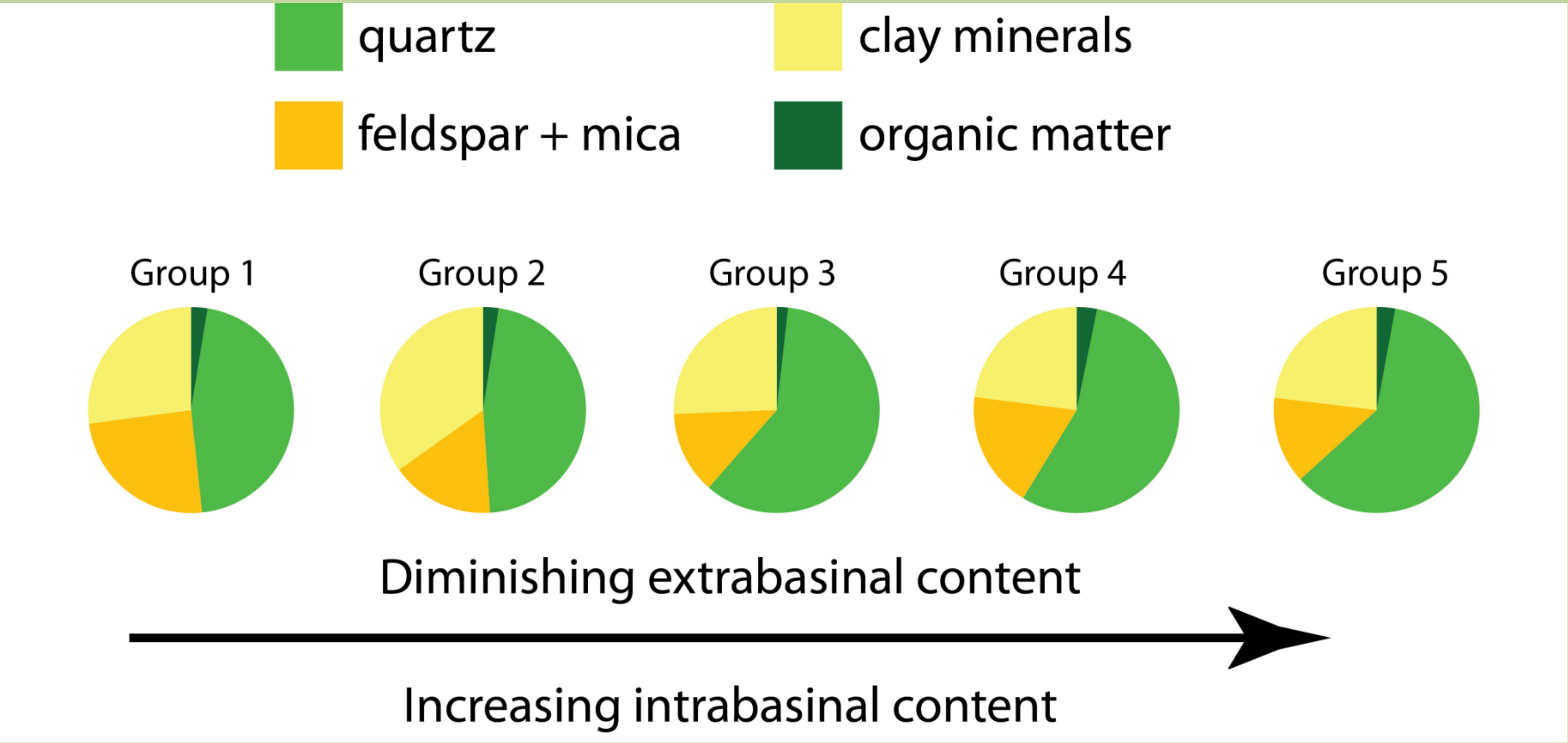
Authigenic minerals are dominantly grain replacements.

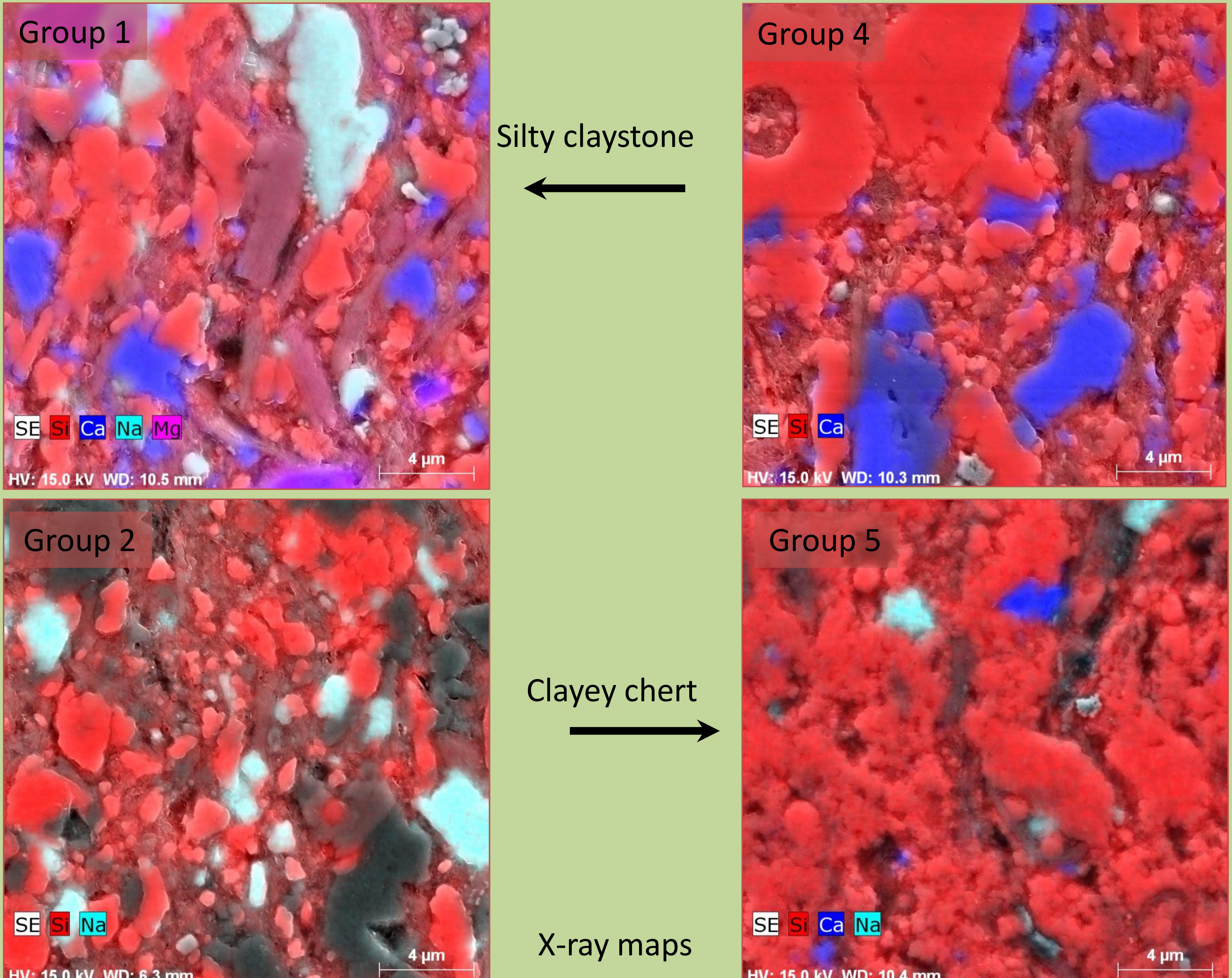
Has diagenesis erased primary controls on rock properties?

- One last look at composition:
  - Normalize XRD and elemental chemistry on a carbonate-free basis (removes heterogeneity related to carbonate allochems and diagenetic carbonate)
  - Sort sample set on basis of Ti-content (a proxy for extrabasinal detritus, both silt- and clay-size)
  - Separate samples based on feldspar content (reveals rel. importance of silt vs. clay in the extrabasinal component).
  - Separate further based on clay content and quartz content. Pay attention to clay type: micas vs. ‘real’ clays.
  - Look again at porosity, permeability, and TOC
  - Does it make sense petrographically?

Five groups based on carbonate-normalized compositions:

1. Prominent silt-size siliciclastic component (quartz, feldspar, mica)
2. Prominent siliciclastic component, but less coarse; more clay minerals
3. Lesser siliciclastic component; bio-siliceous component is coarse (silt and sand)
4. Lesser siliciclastic component; bio-siliceous component is finer.
5. Extremely fine bio-siliceous component; very little terrigenous debris.

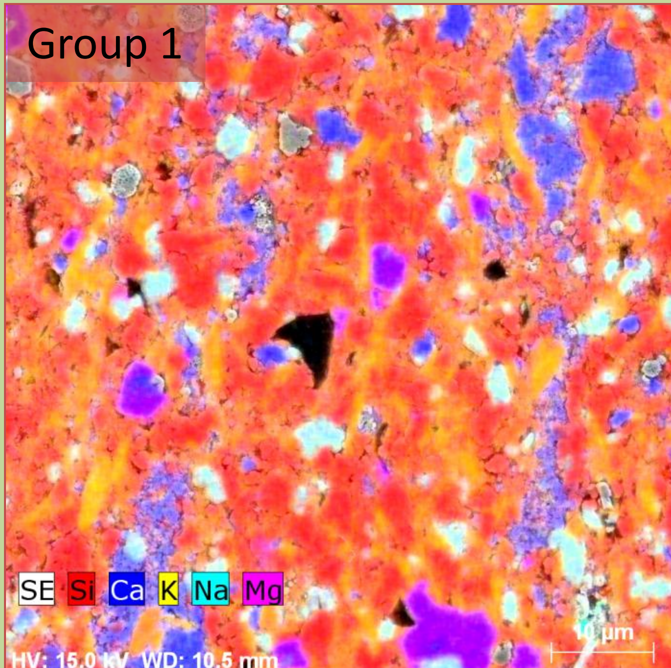

quartz
clay minerals
feldspar + mica
organic matter
Group 1
Group 2
Group 3
Group 4
Group 5
Diminishing extrabasinal content
Increasing intrabasinal content



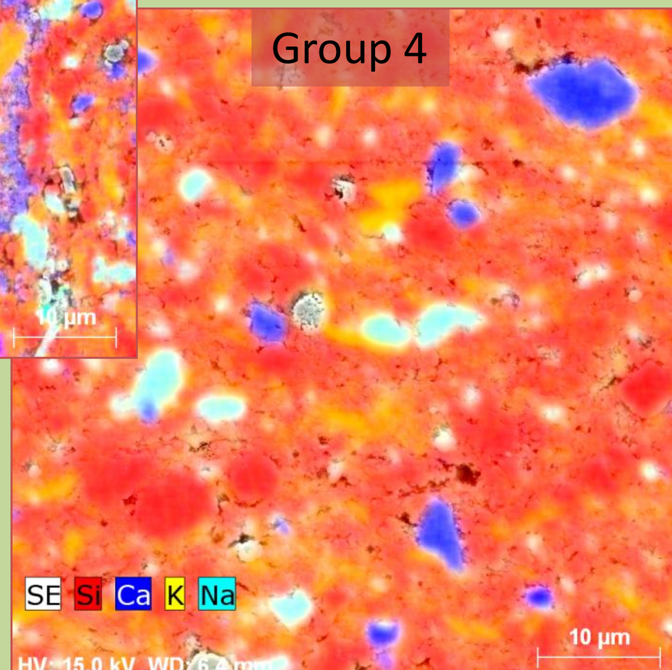
Group 1
SE Si Ca Na Mg
4 µm
HV: 15.0 kV WD: 10.5 mm
Group 4
SE Si Ca
4 µm
HV: 15.0 kV WD: 10.3 mm
Silty claystone
Group 2
SE Si Na
4 µm
HV: 15.0 kV WD: 6.3 mm
Group 5
SE Si Ca Na
4 µm
HV: 15.0 kV WD: 10.4 mm
Clayey chert
X-ray maps

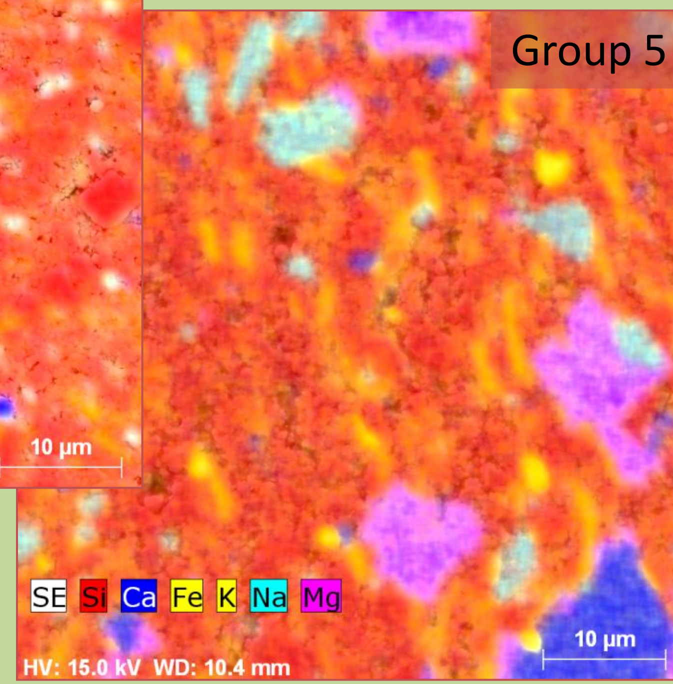
Quartz surrounded by clay:

X-ray maps



Silty claystone

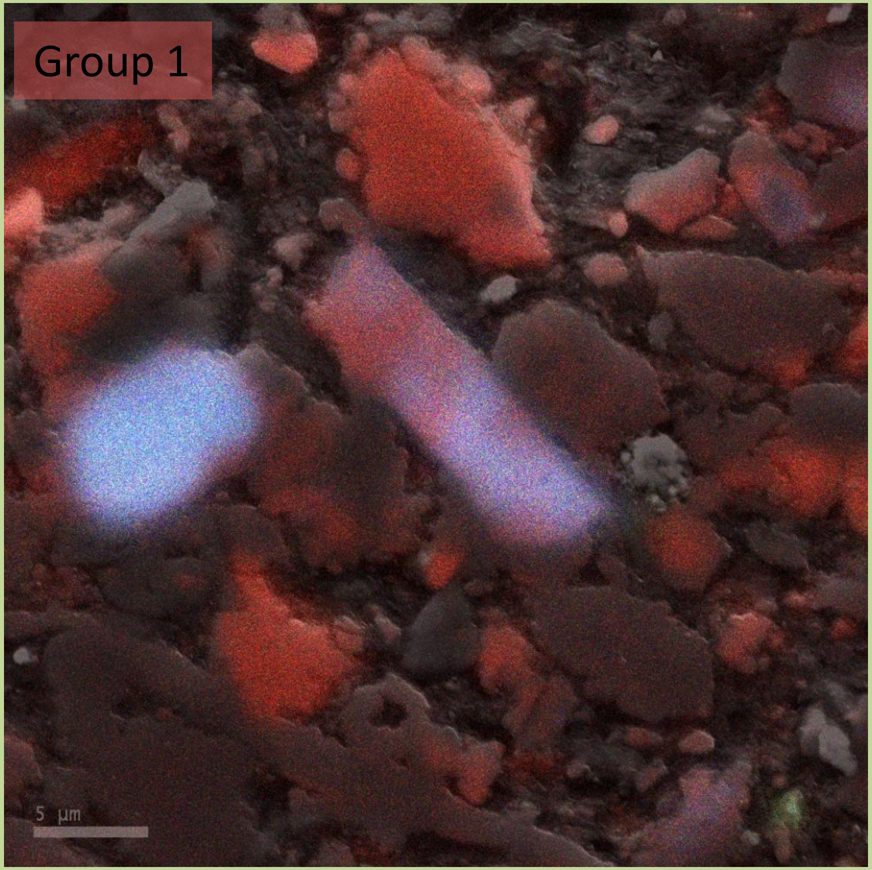




Clayey chert

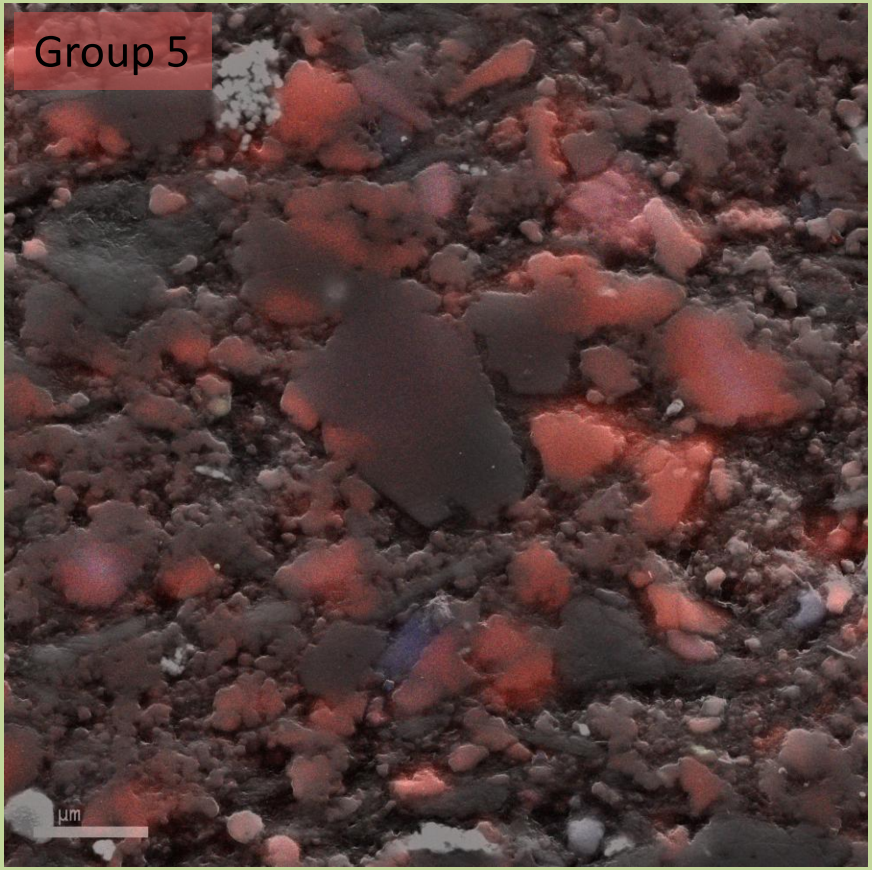
Clay surrounded by quartz:

Cathodoluminescence images

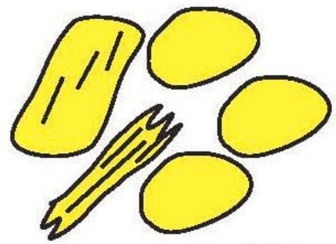
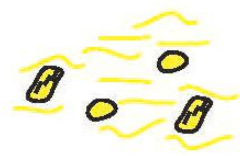
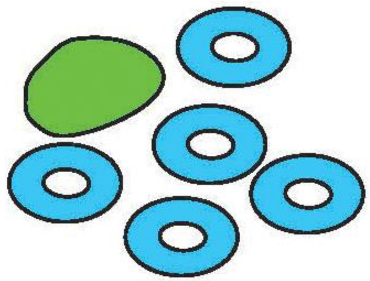
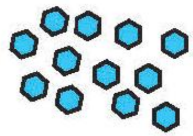


Silty claystone

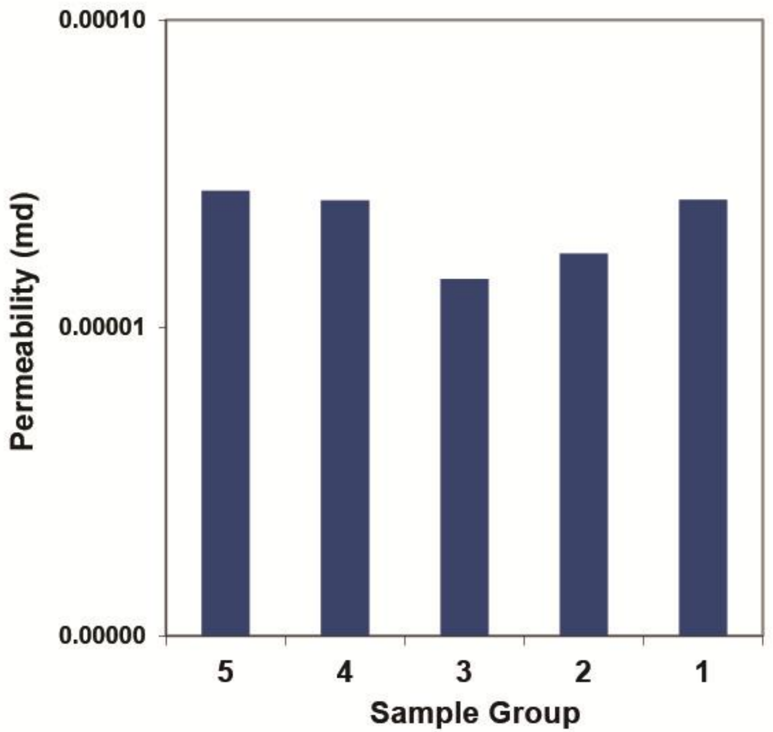
Clayey chert

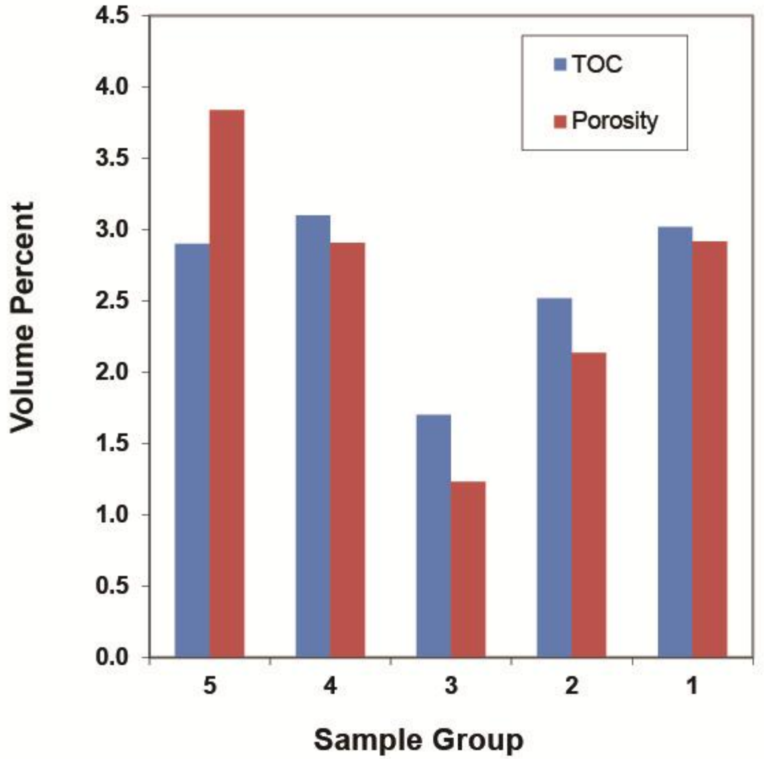


Four-component mixing system for sediments in the Barnett Shale

	Silt-size components	Clay-size components
Extrabasinal debris	 quartz, feldpar, mica	 clay, quartz, feldspar
Intrabasinal particles	 bio-siliceous allochems, glauconite	 bio-siliceous allochems

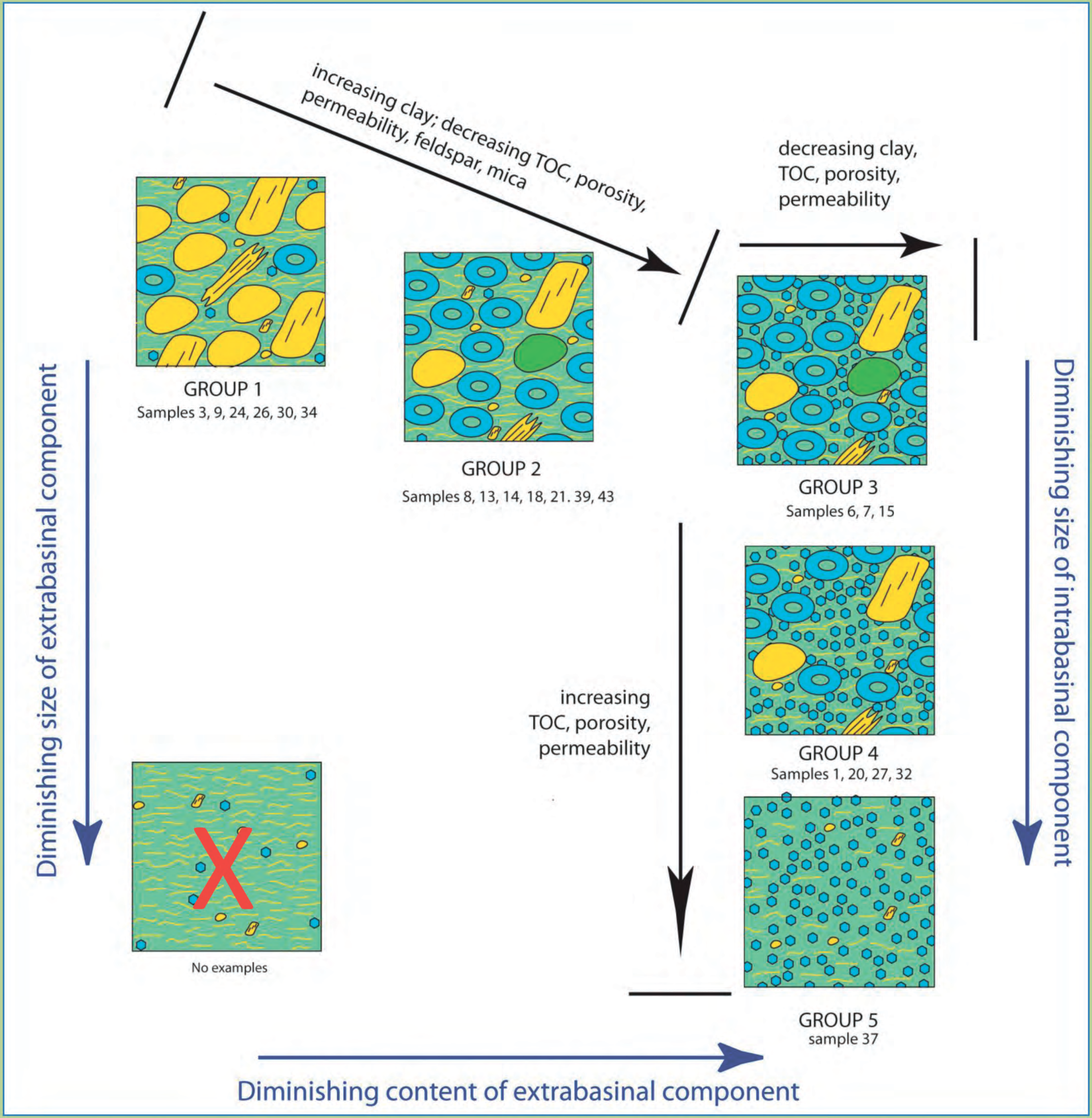
Quartz may dominate in 3 of these, even in a single sample.





Increasing siliciclastic content

Increasing siliciclastic content



Conceptual Model for lithologic variation through sediment mixing in the Barnett Shale.

Rest of the Story, Told in Photomicrographs:

"Petrology of High-Maturity Samples of the Barnett Shale"

Authors: Milliken, Esch, and Reed

Search and Discovery Article #80243 (2012)

CONCLUSIONS

- Perceived lithologic heterogeneity depends on the observation method: more variation seen with microscopy + compositional analysis.
- Ratio of extrabasinal and intrabasinal grains of clay-size and silt-size varies tremendously across the 21-sample set.
- Post-depositional reactivity of detrital components has caused a major re-organization of the rock. Textural and compositional controls on rock properties are manifested primarily by their effects on diagenesis.
- Dark-luminescing clay-size quartz (chert) is interpreted as the product of recrystallization of biogenic opal
- Secondary pores within organic matter, both kerogen and solid bitumen, dominate the pore system.

Study funded by the ExxonMobil/Bureau of Economic Geology Collaborative Project for Unconventional Resources.

Bureau of Economic Geology

ExxonMobil Upstream Research

Unconventional Resources