Critical Issues Forum

America's Increasing Reliance on Natural Gas: Benefits and Risks of a Methane Economy

Wifi network: FWC Wireless
Password: (no password needed)

AGI american geosciences institute
connecting earth, science, and people

Session 4:

Drivers of and barriers to natural gas development in North America

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Bureau of Economic Geology,
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Seeing Reservoir Quality at the Appropriate Scale: A Look at Tools for High-resolution Imaging and Our Evolving Understanding of Pore-Scale Processes in Fine-grained Systems

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JACKSON
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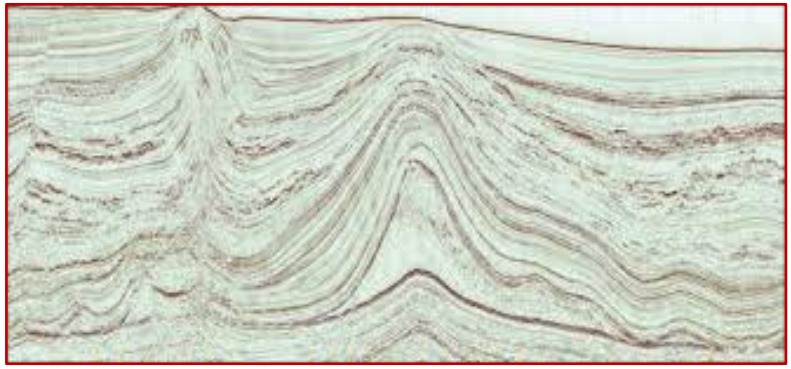
BUREAU OF ECONOMIC GEOLOGY

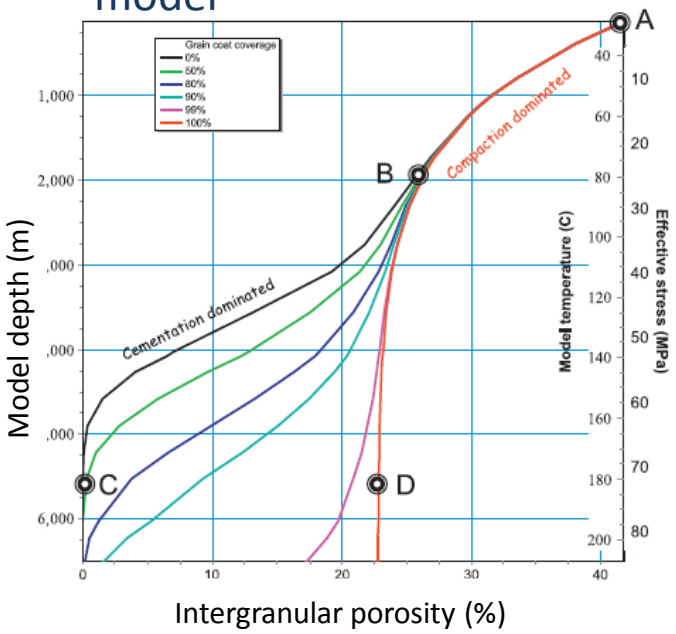
Exploration for conventional hydrocarbon reservoirs (sandstones and limestones) is a refined scientific endeavor that reduces economic risk.

Large-scale data

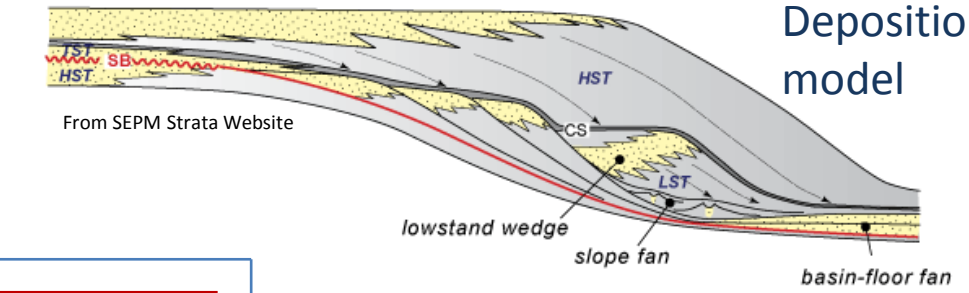


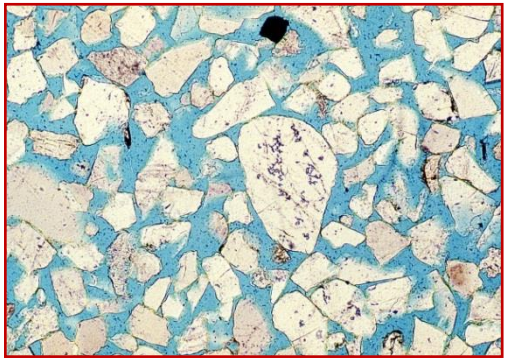
Porosity model

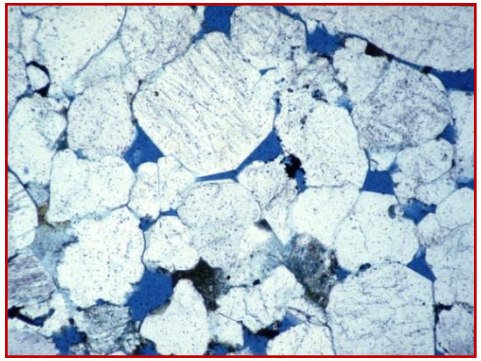
Ajdukiewicz & Lander, 2010



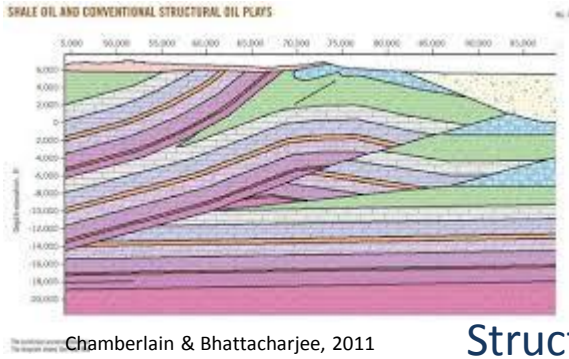
Depositional model







Small-scale data



Chamberlain & Bhattacharjee, 2011

Structural model

Barnett Shale core.

Shale – Mudrock – Mudstone: Fine-grained Sedimentary Rocks

- A major type of sedimentary rock
- The most abundant type of sedimentary rock: 2/3 of the sedimentary record on Earth.
- Fine-grained: “clay-rich”

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

Munsell color system.

Henry Clifton Sorby
"father of petrographic microscopy"

- Made first preparation of a rock for microscopic study.
- Published first paper on microscopic examination of rocks (1850s).

Possibly many may think that the deposition and consolidation of fine-grained mud must be a very simple matter, and the results of little interest. However, when carefully studied experimentally, it is soon found to be so complex a question, and the results dependent on so many variable conditions, that one might be inclined to abandon the enquiry, were it not that so much of the history of our rocks appears to be written in this language.

Sorby, 1908, Quarterly Jour. Geol. Soc. London, v. 64, p. 190-191.

EARLY 1960s

"In a way, shales are the last frontier of sedimentary petrology. . . ."
Folk, 1962, JSP, v. 32, p. 539-537.

EARLY 1970s

"….very little is known about the relative abundances of microcline, orthoclase, and plagioclase in sandstones. ***Nothing is known*** concerning these species in mudrocks." Blatt, Middleton, and Murray, 1972, *Origin of Sedimentary Rocks*: Prentice Hall, NJ, 634 p.

EARLY 1980s

"Although they form approximately two-thirds of the stratigraphic column, mudrocks are poorly understood and inadequately studied. Few sedimentary geologists have chosen to study mudrocks……"
Ehlers and Blatt, 1982, *Petrology, Igneous, Metamorphic, and Sedimentary*: Freeman & Co., NY, 732 p.

EARLY 1990s

"Although shales constitute the bulk of the Earth's clastic sedimentary rocks, relatively little is known about……." Issler, 1992, AAPG Bull., v. 76, p. 1170-1189

Late 1990s

"….fine-grained terrigenous clastics (mudstones, shales), the dominant sedimentary rock type, are still "*terra incognita*" for most geologists."
Schieber et al. (eds), 1998, *Shales and Mudstones I*: E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart

Why was the science of mudrocks less advanced than the science of coarser grained systems at the end of the 20th Century?

- Mudrocks are challenging to study because the fundamental components (grains, pores) are so small they cannot be readily observed.
- The occurrence of extractable resources within mudrocks was not expected.
- The more obvious economic importance of sandstones and limestones attracted most of the research interest and funding for study.
- Little funding was directed to mudrocks and few people chose to study mudrocks.

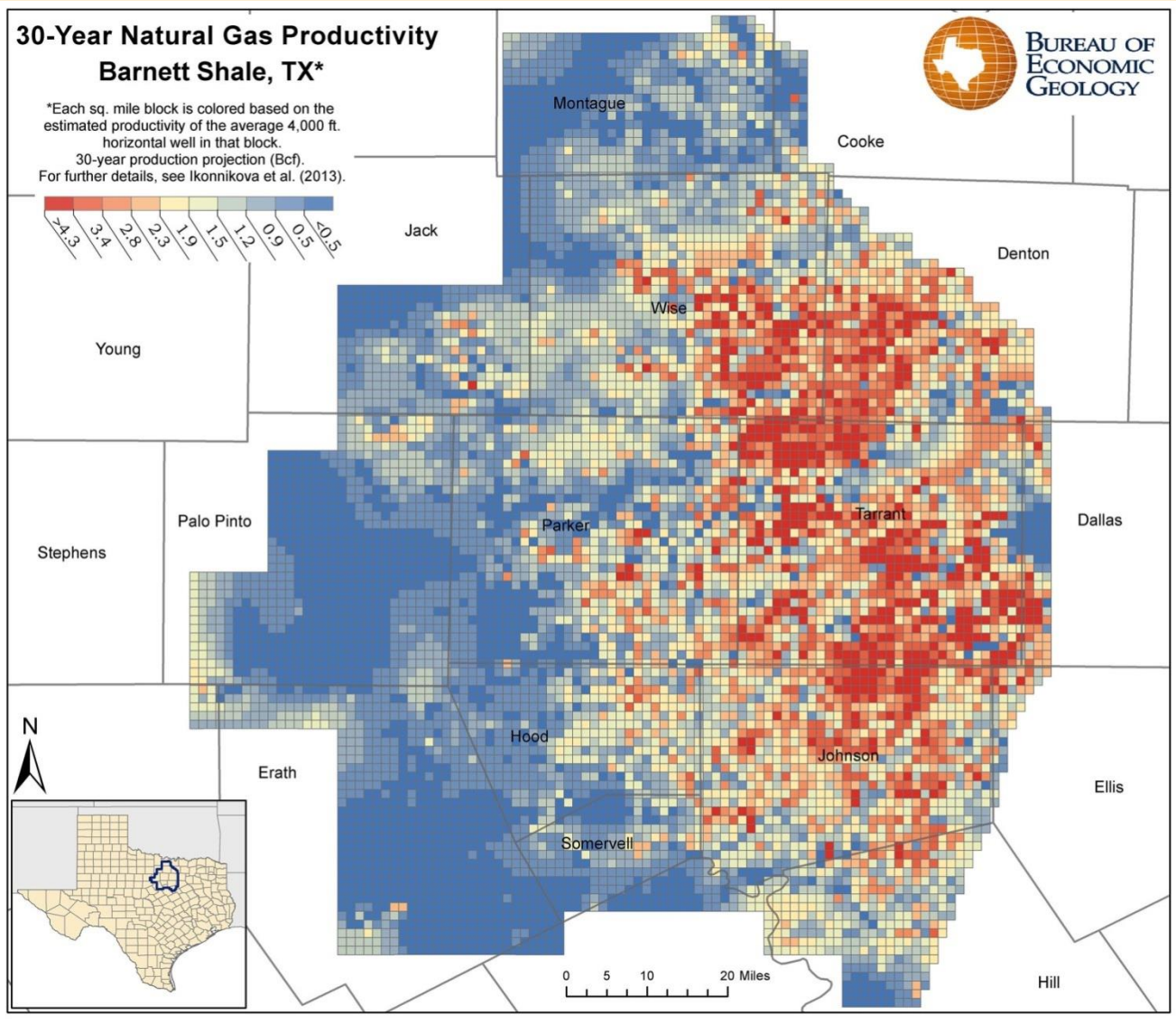
Mudrocks are no longer ignored!

And it's probably fair to say that we are in the *middle of a scientific revolution* in our understanding of the most common type of sedimentary rock.

We now know that mudrocks:

- Are a complex class of rocks that displays heterogeneity greater than that of sandstones and limestones.
- Contain abundant clay-size *crystals*, but are not necessarily dominated by clay *minerals* nor by clay-size *grains*.
- As "source, seal, and reservoir" for oil and gas, should be thought of as hosting *exploration targets,* because assessing mudrock heterogeneity is a solvable problem……

Productivity Tiers of the Barnett Shale; Browning 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.

http://www.beg.utexas.edu/info/sloan_barnett.php

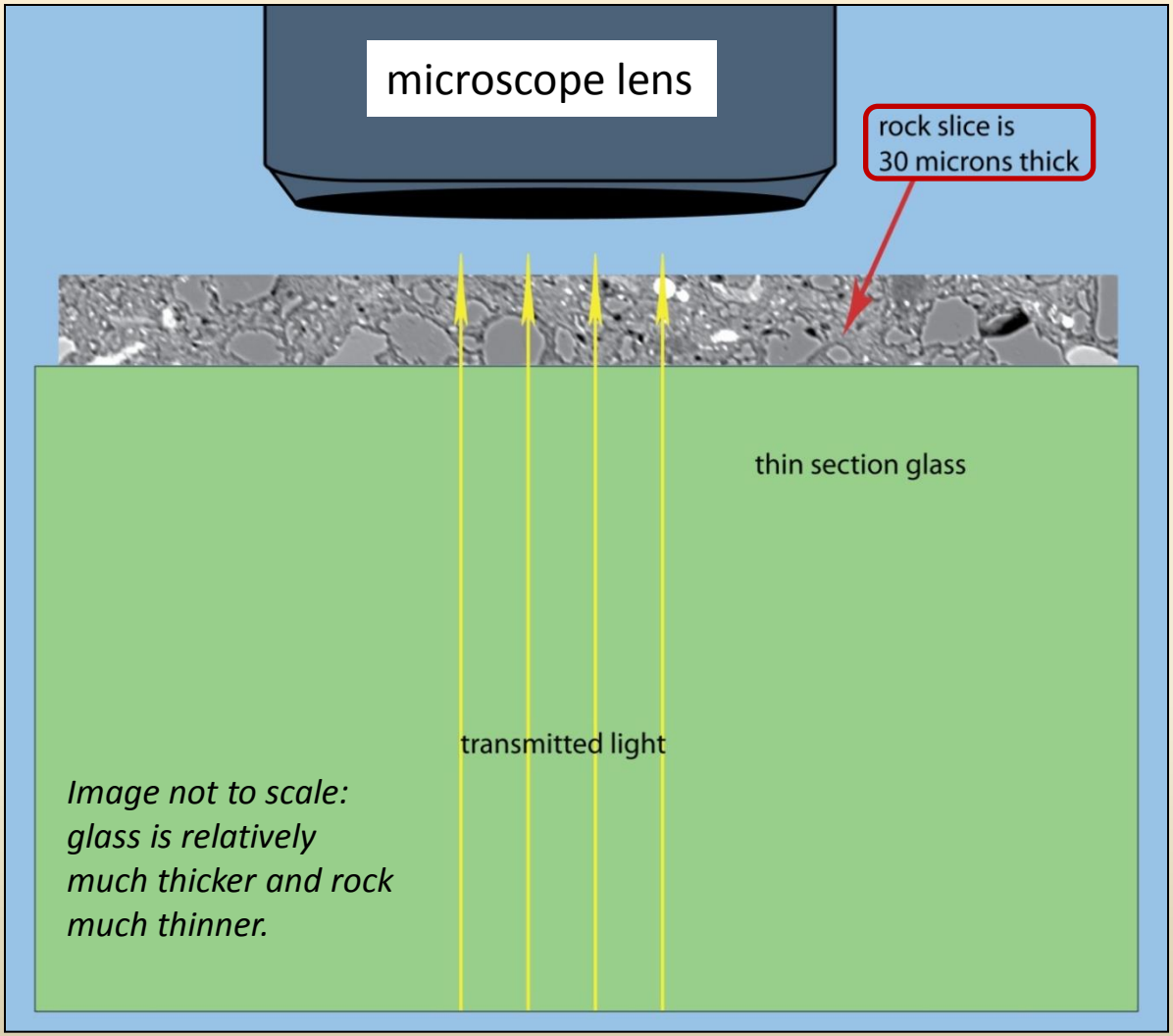
The Mudrock Problem in Light Microscopy:

Henry Clifton Sorby
"father of petrographic microscopy"

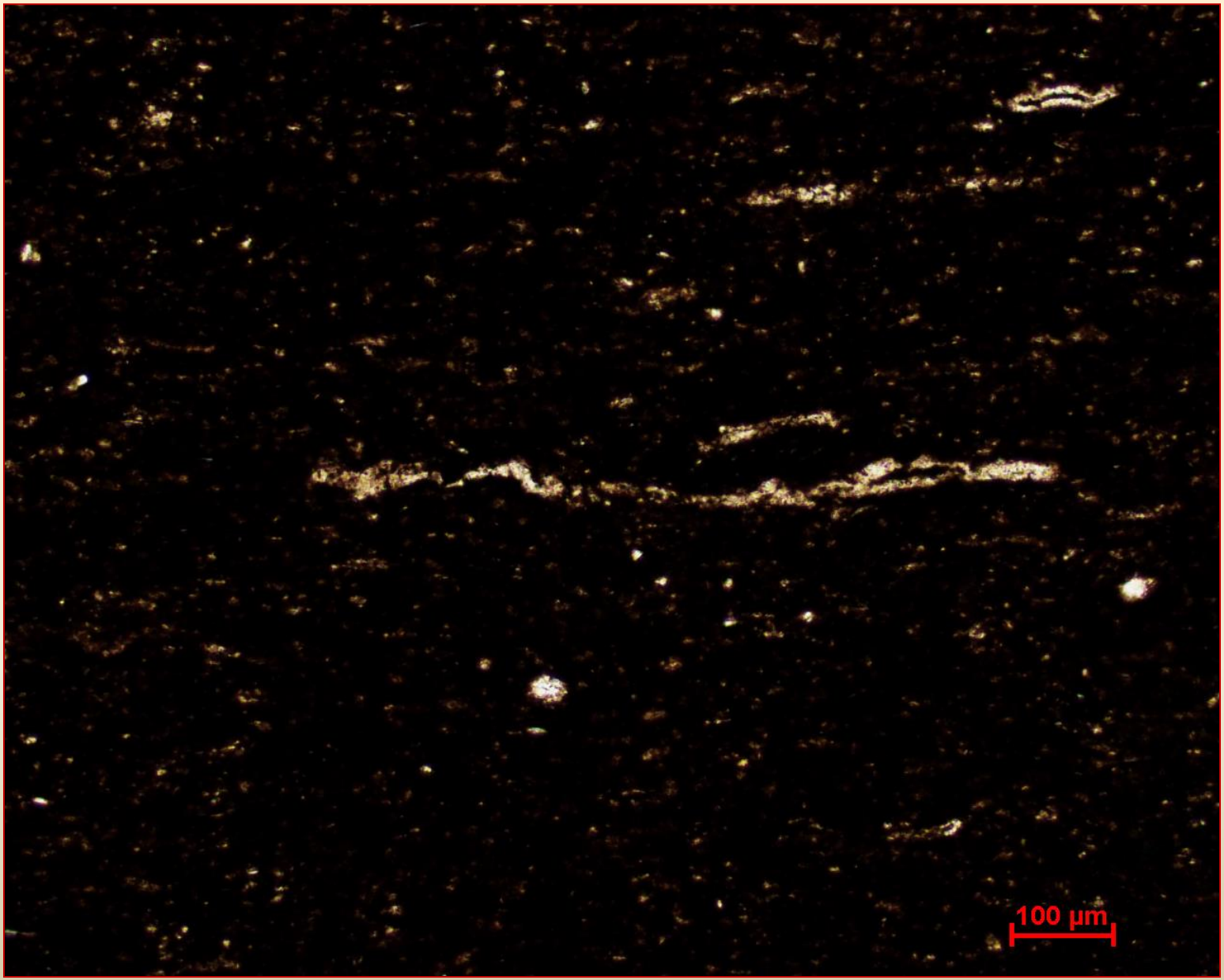
The challenge of mudrocks (shales) in the 19th century and today:

Components in mudrocks (grains, pores) are generally smaller than the thickness of the standard thin section (30 μm) used for light microscopy.

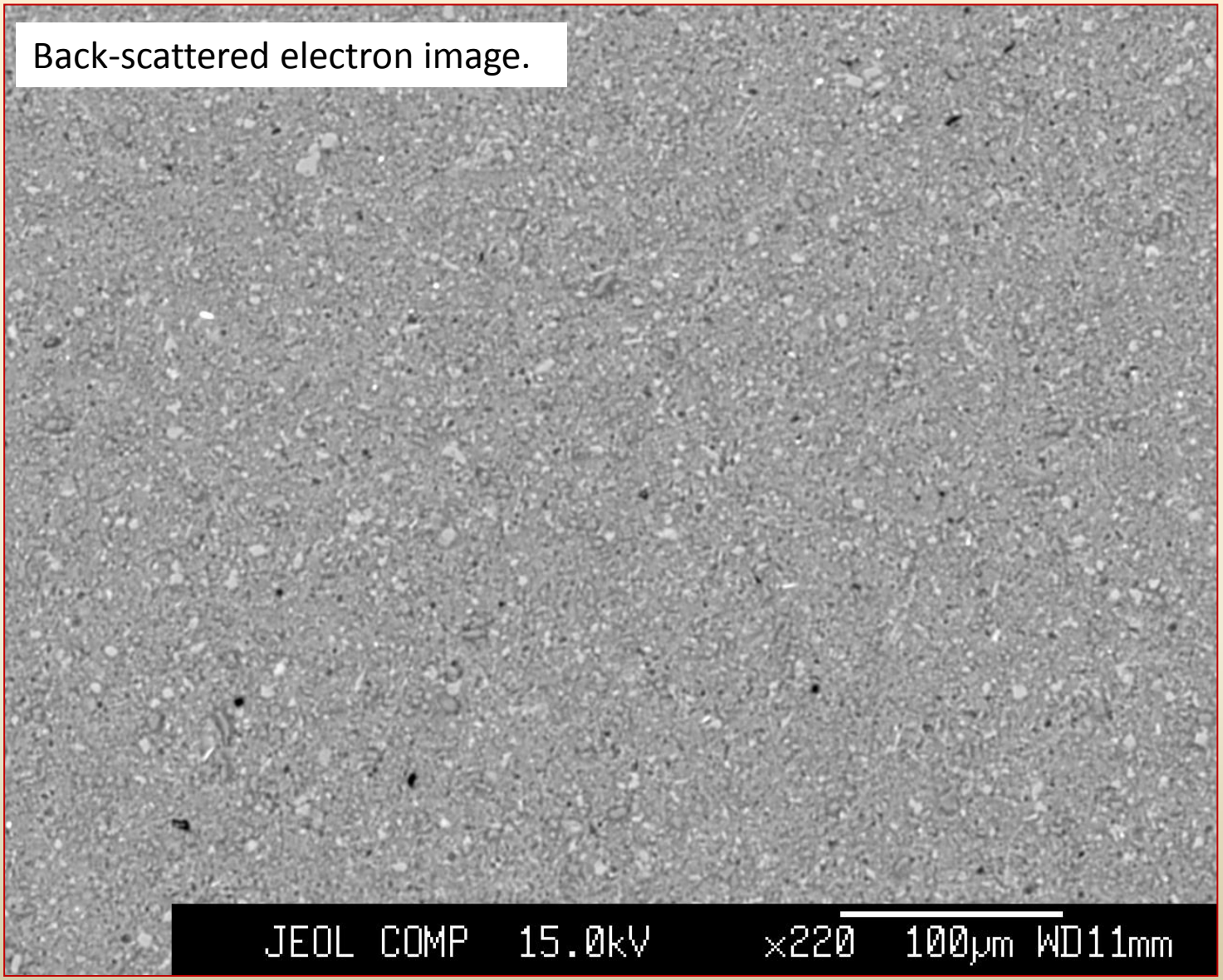
30 microns = 30,000 nm!



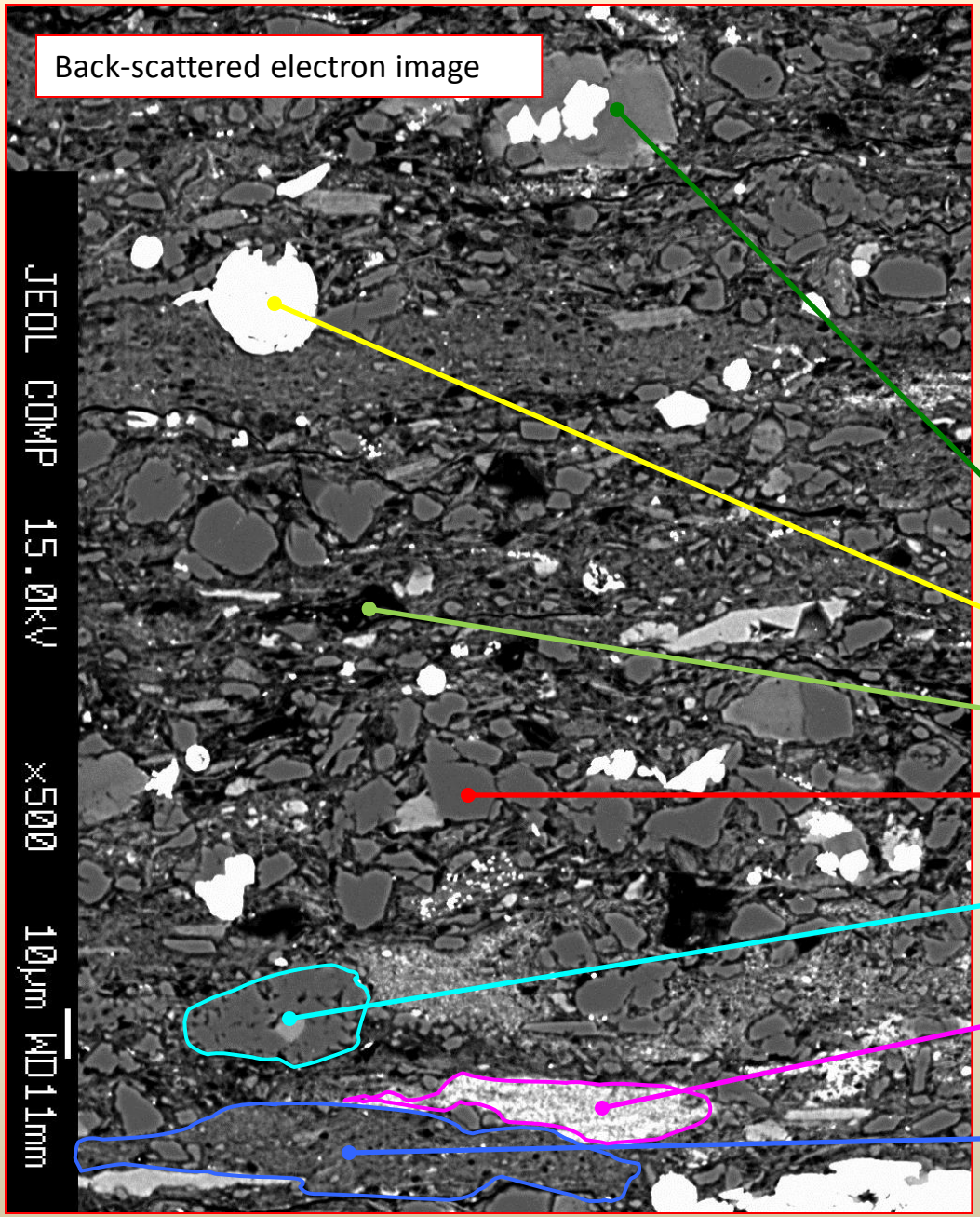
Barnett Shale seen in transmitted polarized light microscopy.



Claystones exist but are NOT the most common type of mudrock.



Oligocene Frio Formation, South Texas, USA.



Mudstones (mudrocks, shales) contain abundant:

- silt-size and sand-size grains
- non-clay minerals
- detrital and authigenic components
- fossils

Dolomite (authigenic?)

Pyrite (authigenic)

Organic matter

Quartz or feldspar (detrital)

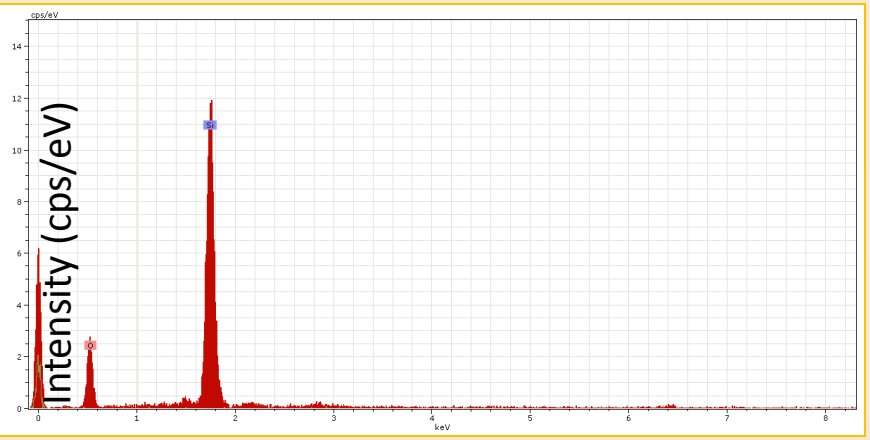
Agglutinated foraminifer

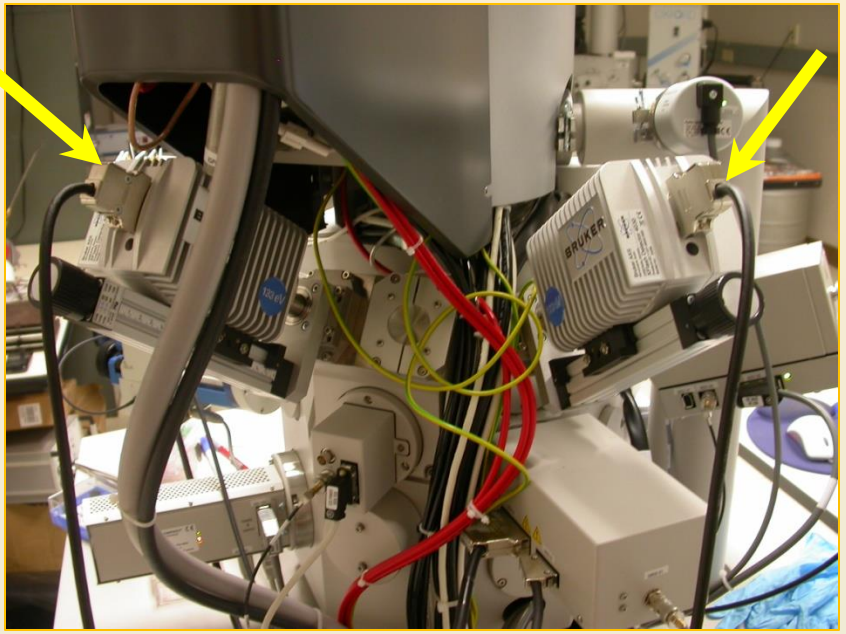
Phosphate clast

Clay aggregate

Barnett Shale, Wise County, Texas, USA

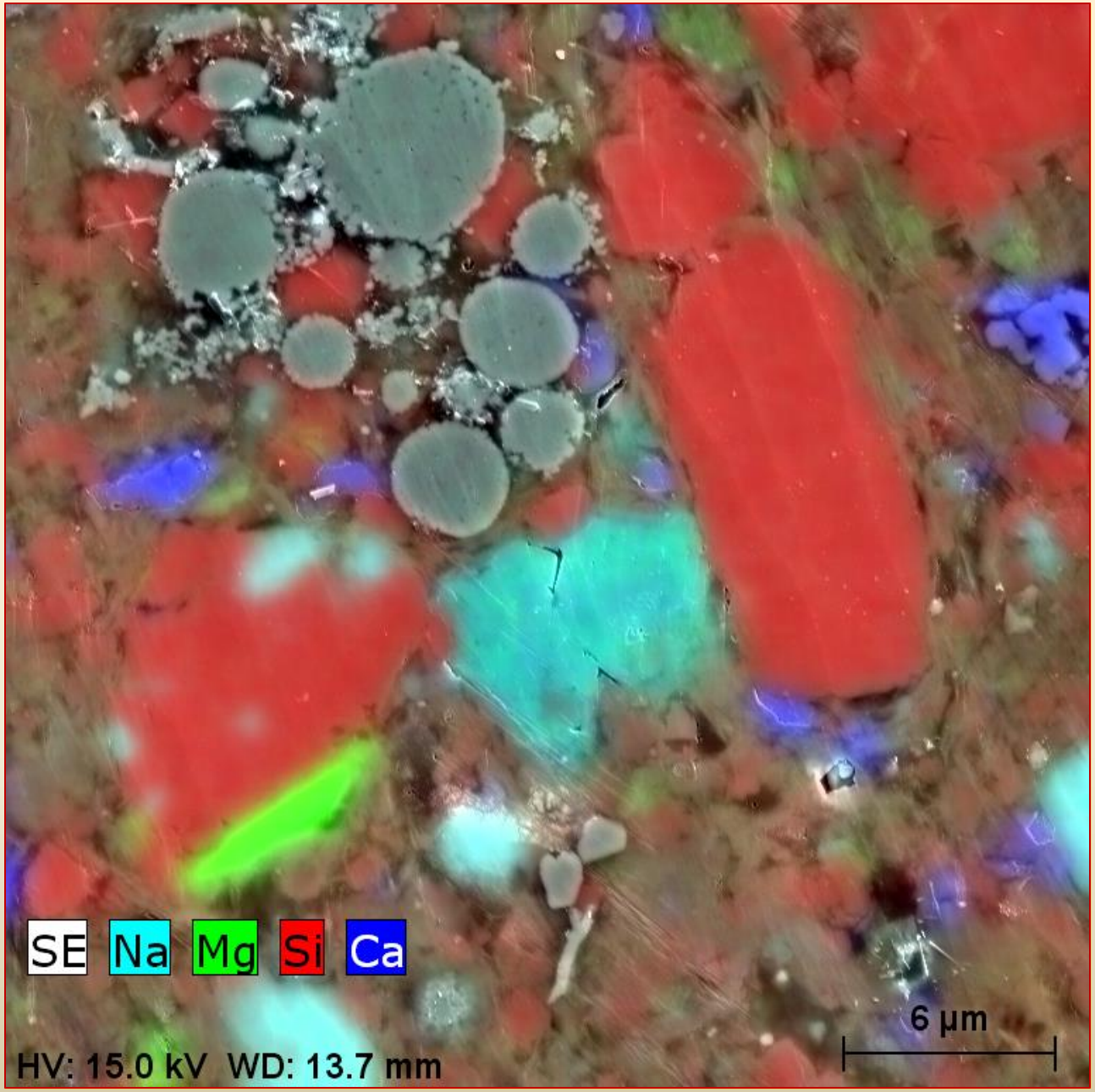
X-ray mapping by Energy-Dispersive Spectroscopy (EDS)





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.



Marcellus Formation, Pennsylvania

Multi-element map:

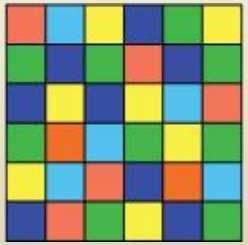
Nova NanoSEM 430

<5 nA

15 KV

10 minutes

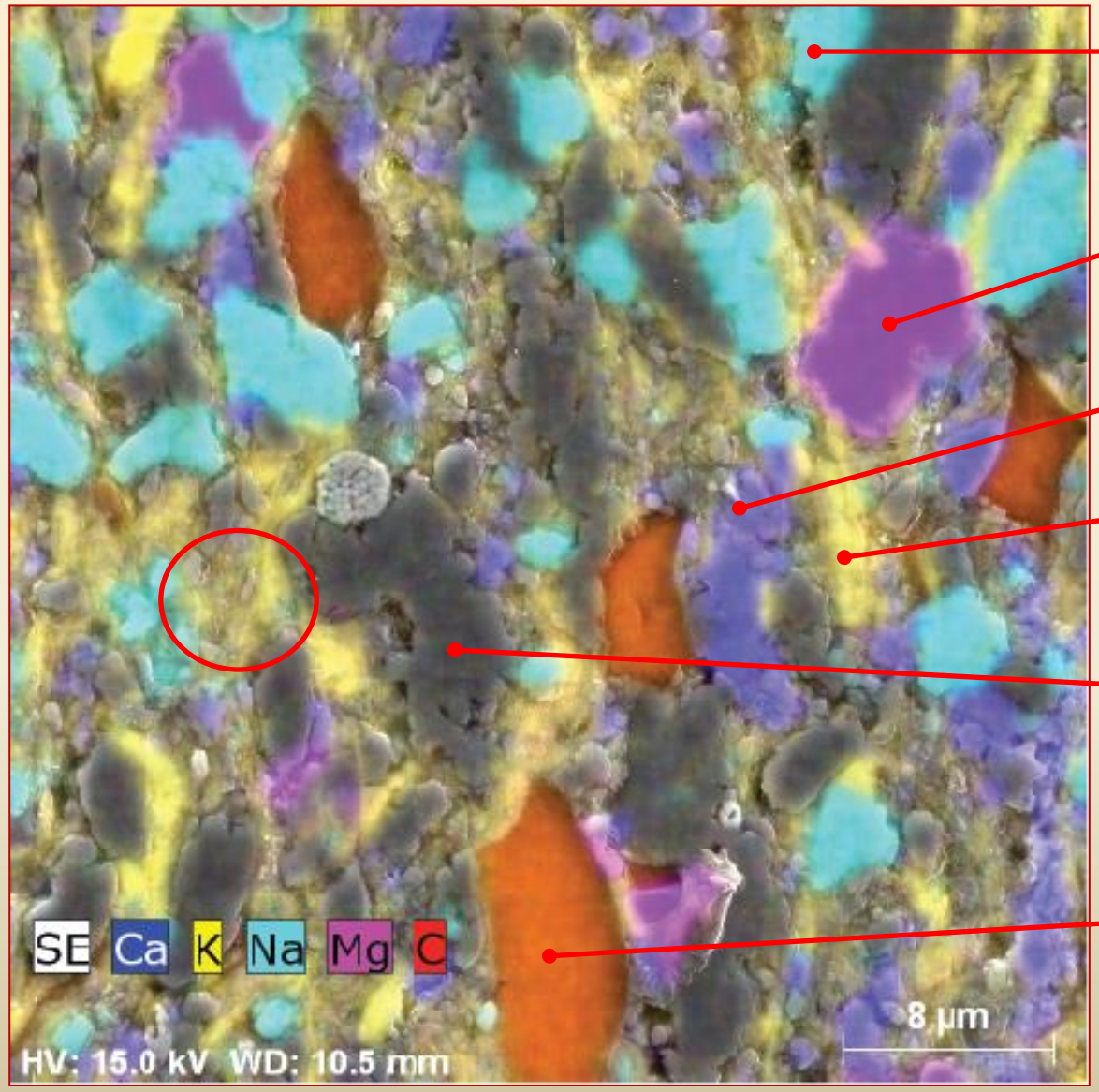
0.05 micron/pixel (approx)



1-micron pixel resolution

Mudrocks contain complex grain assemblages.

DETRITAL, mostly extrabasinal grains:



Barnett Shale, Ellis County, Texas, USA

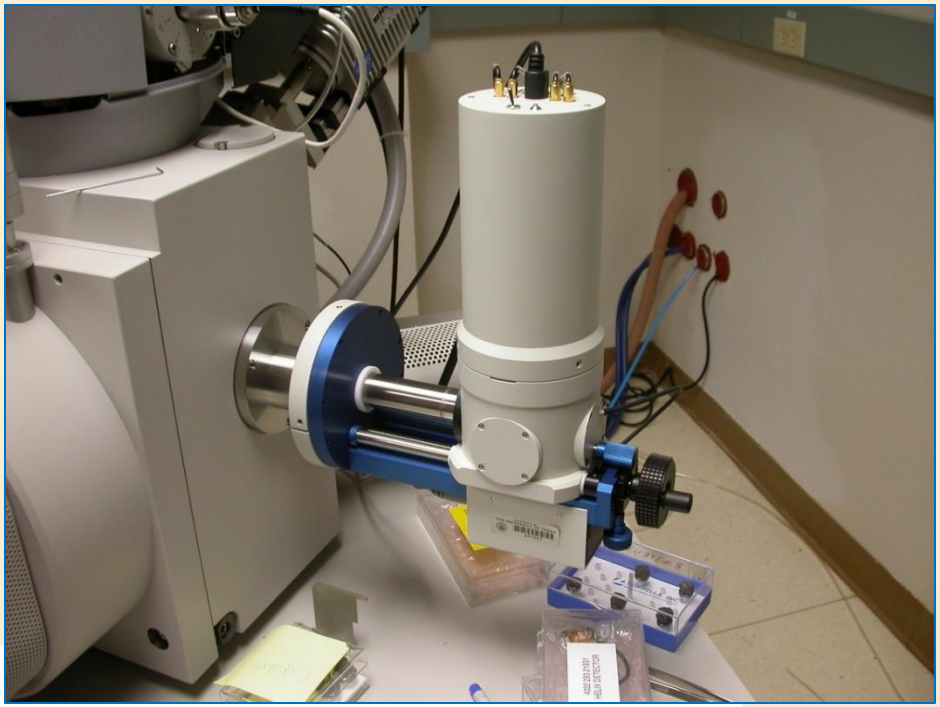
X-ray map

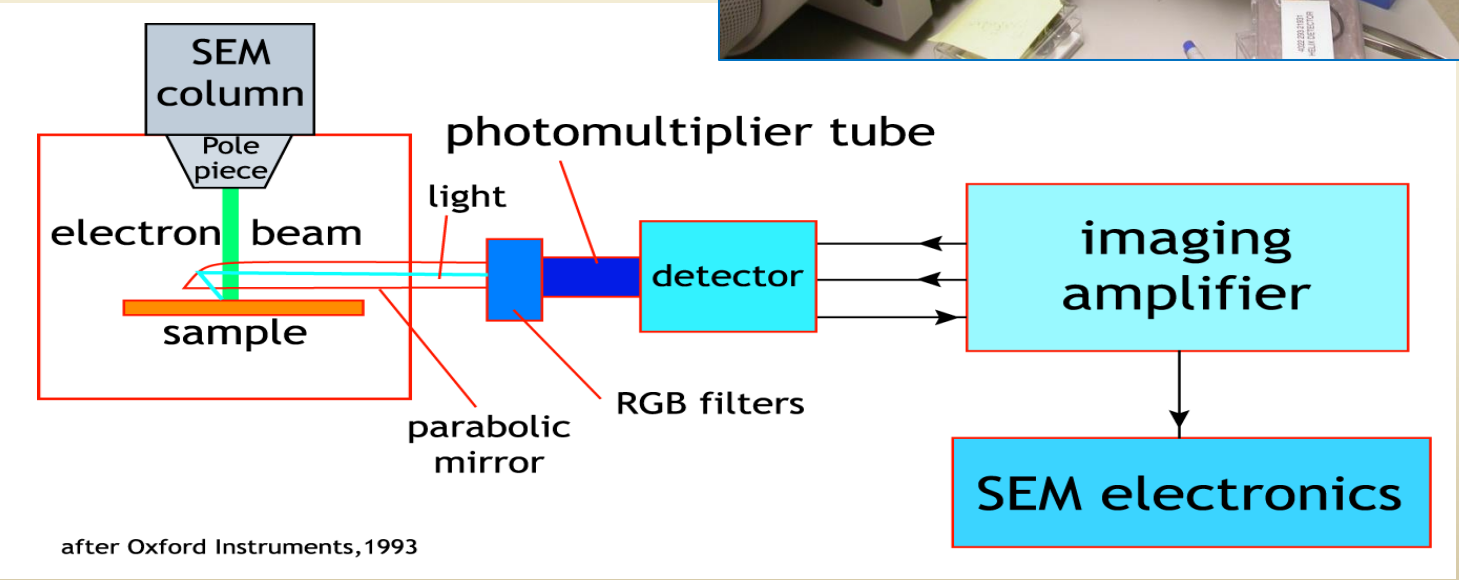
Scanned Cathodoluminescence Imaging

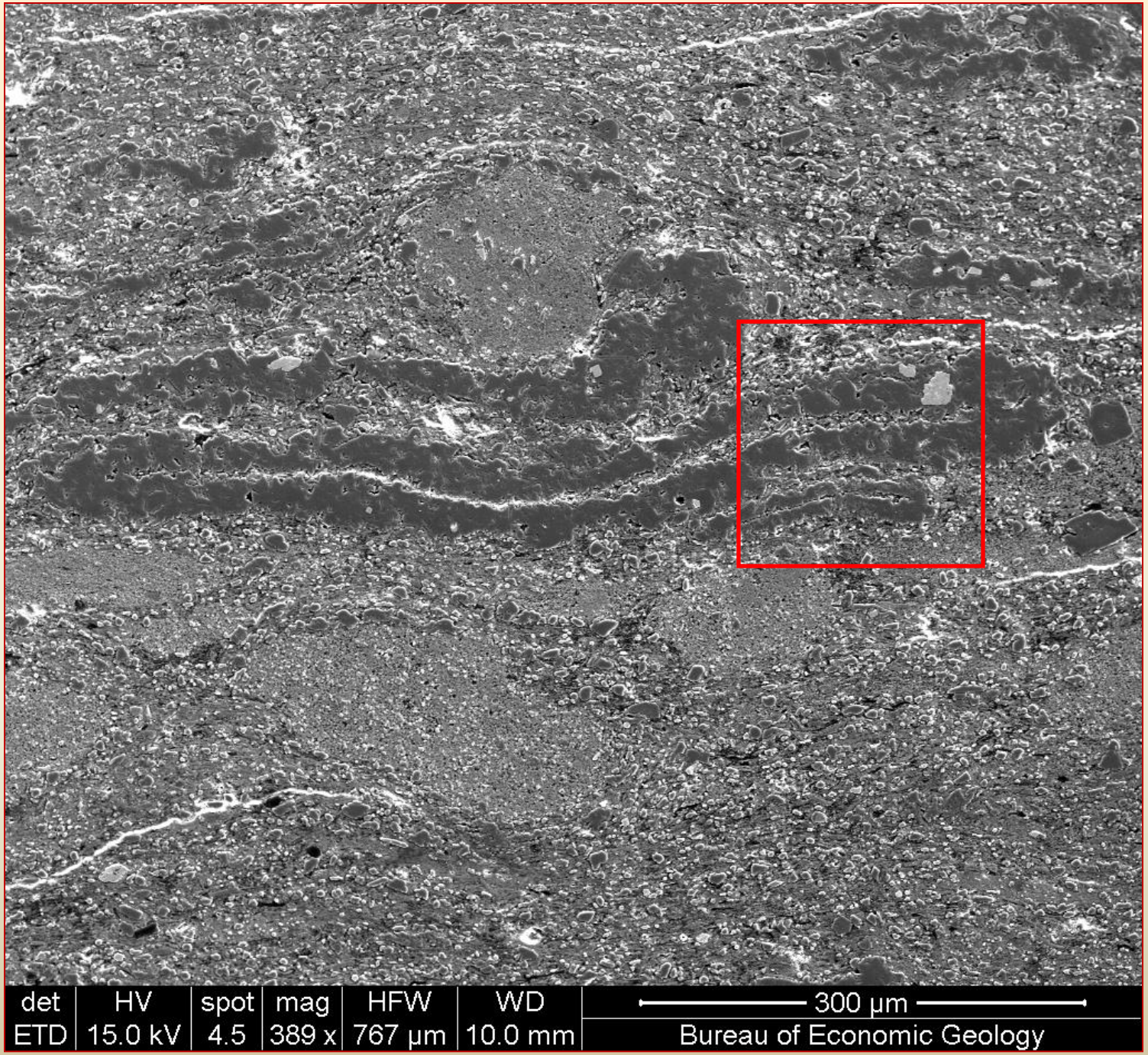
Visible light emitted in response to electron beam excitation.

Sensitive to trace element and defect variations.

Images subtle chemical differences that are invisible in other techniques.

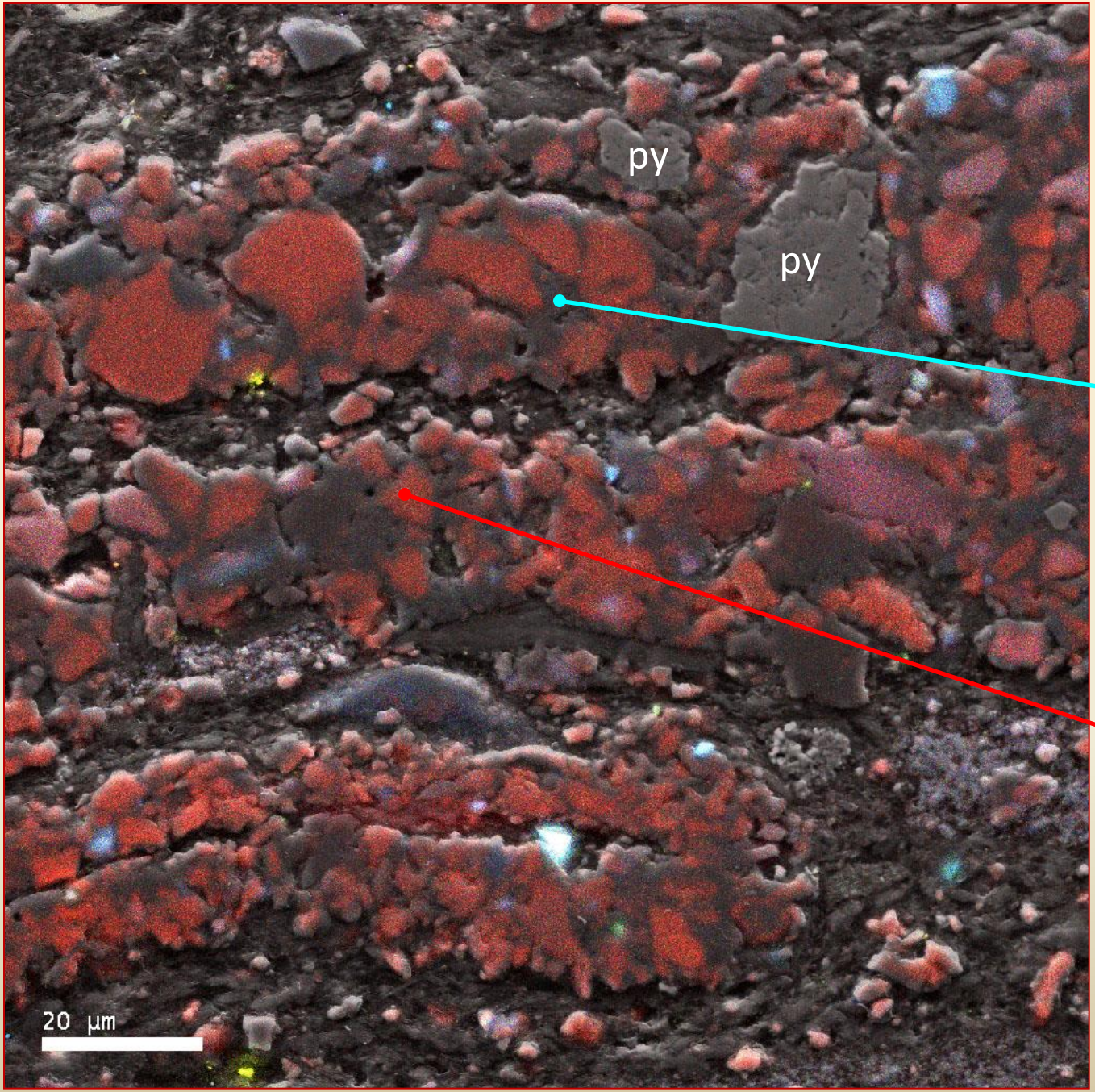






SE/BSE image

Barnett Shale, Wise County, Texas



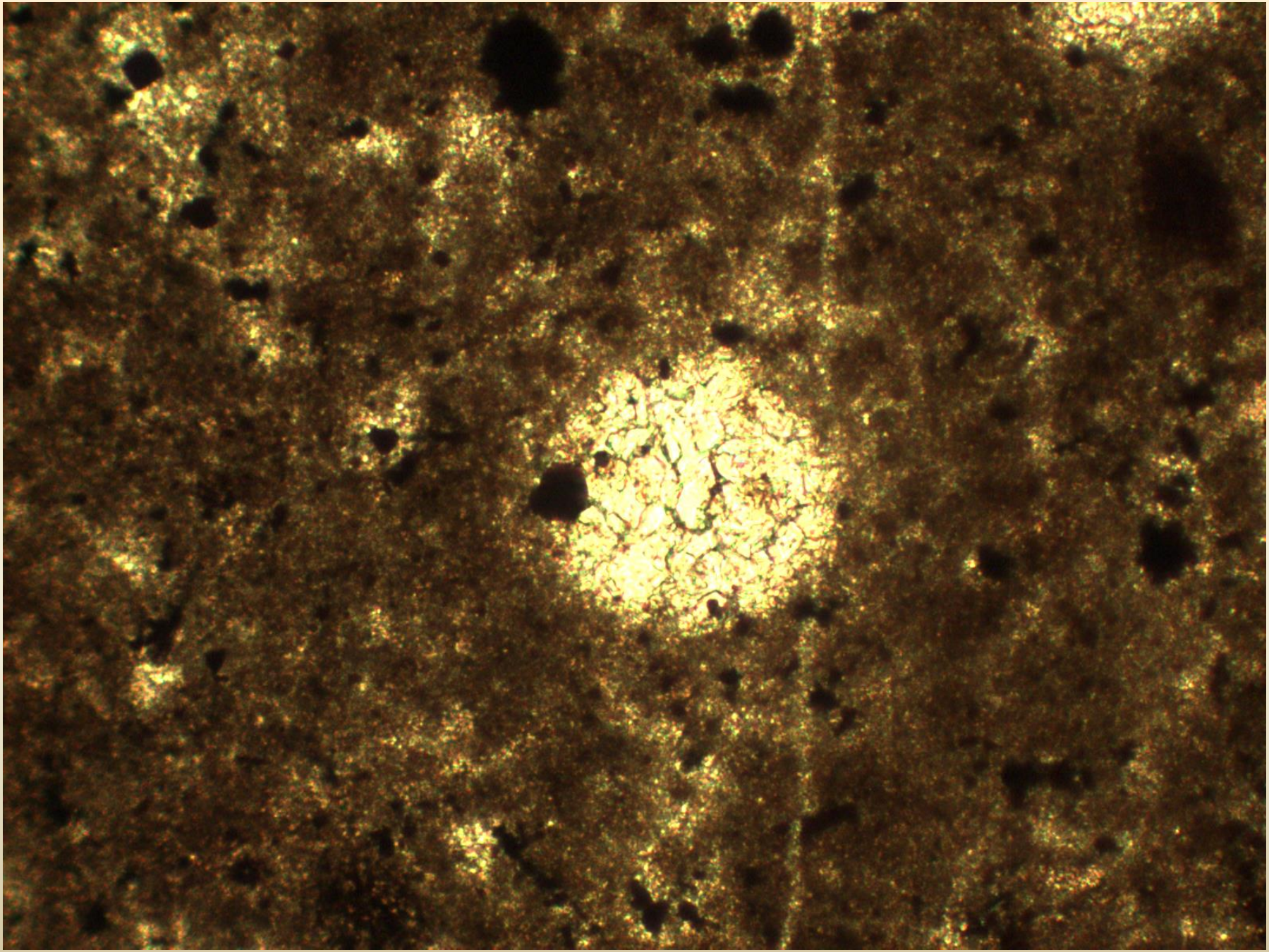
“matrix” quartz with dark CL:

- former opal?
- former organic matter?

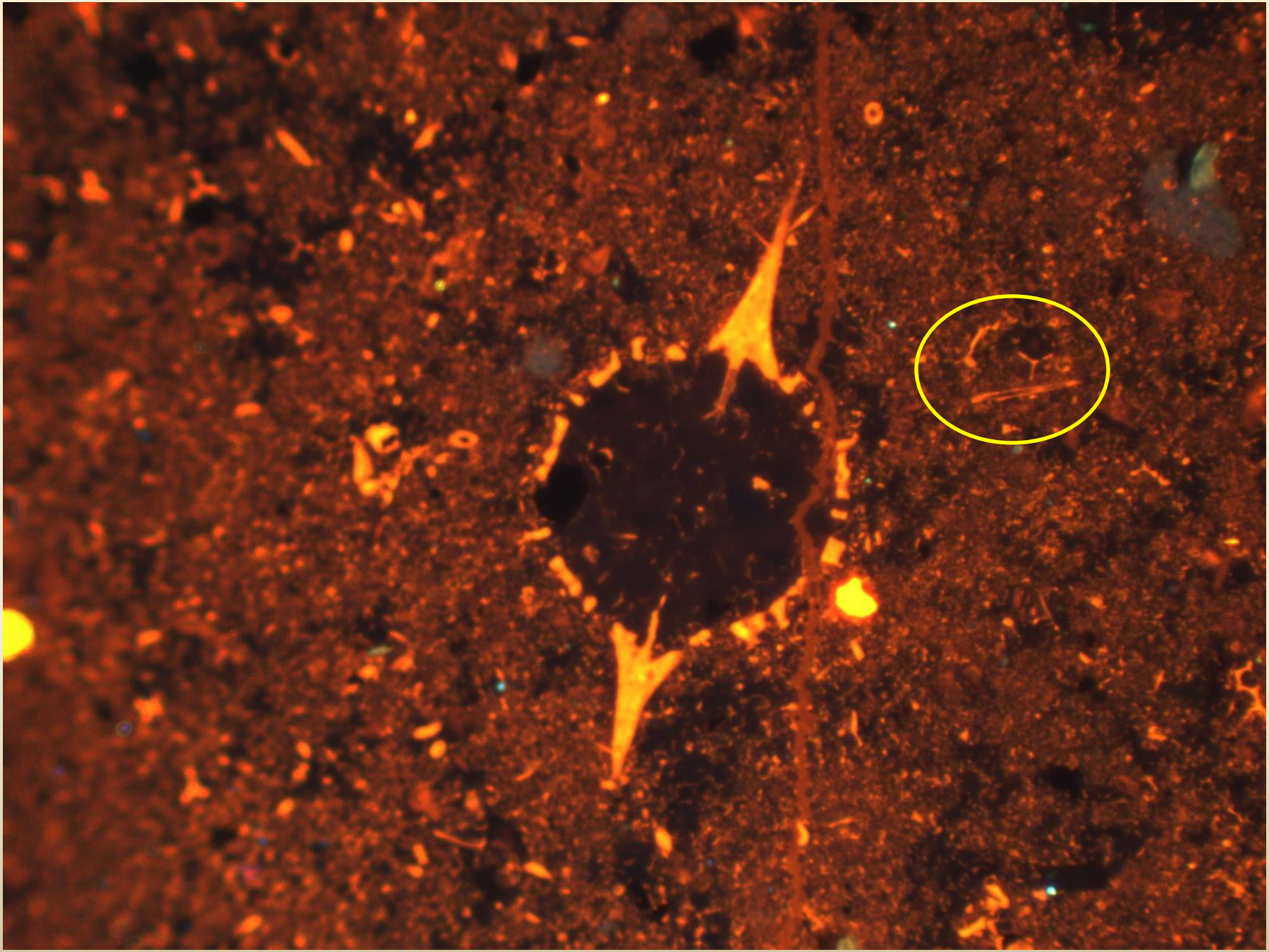
Angular silt with variable CL color & brightness

SE/BSE image

Barnett Shale, Wise County, Texas

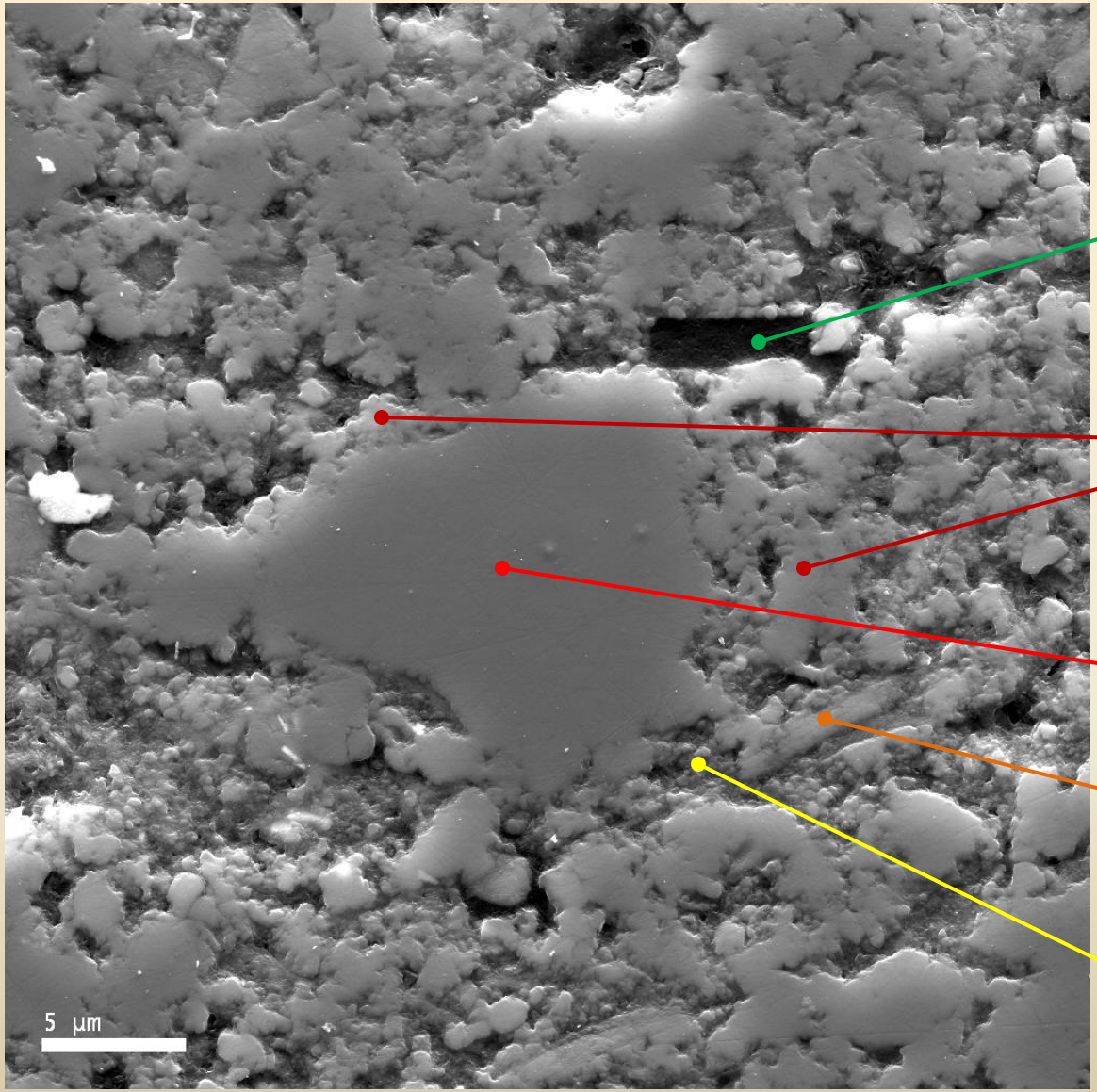


Barnett Shale, Wise County, Texas



Barnett Shale, Wise County, Texas

Barnett Shale: siliceous lithology



organic matter

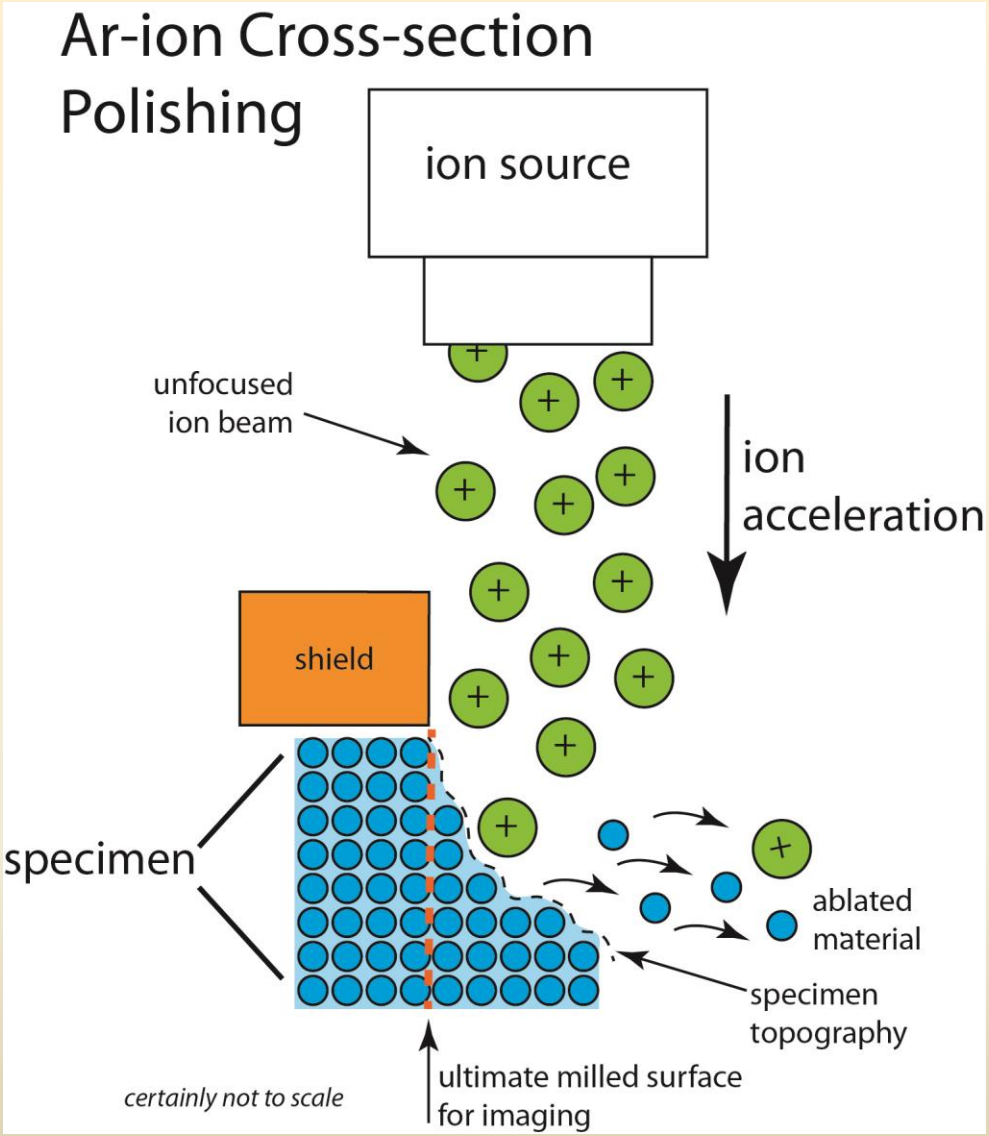
microquartz cement

extrabasinal quartz grain

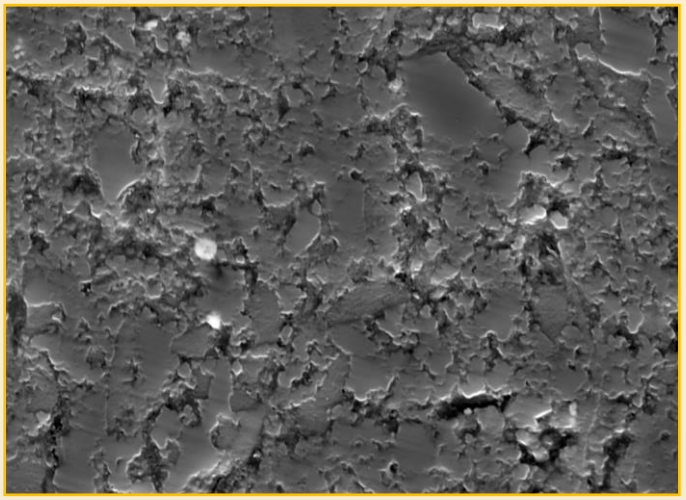
mica

clay mineral matrix

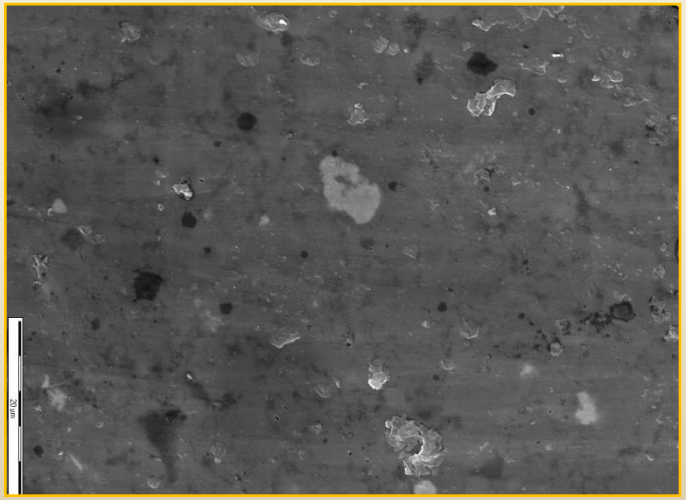
Barnett Shale, Ellis County, Texas



Barnett Shale sample:

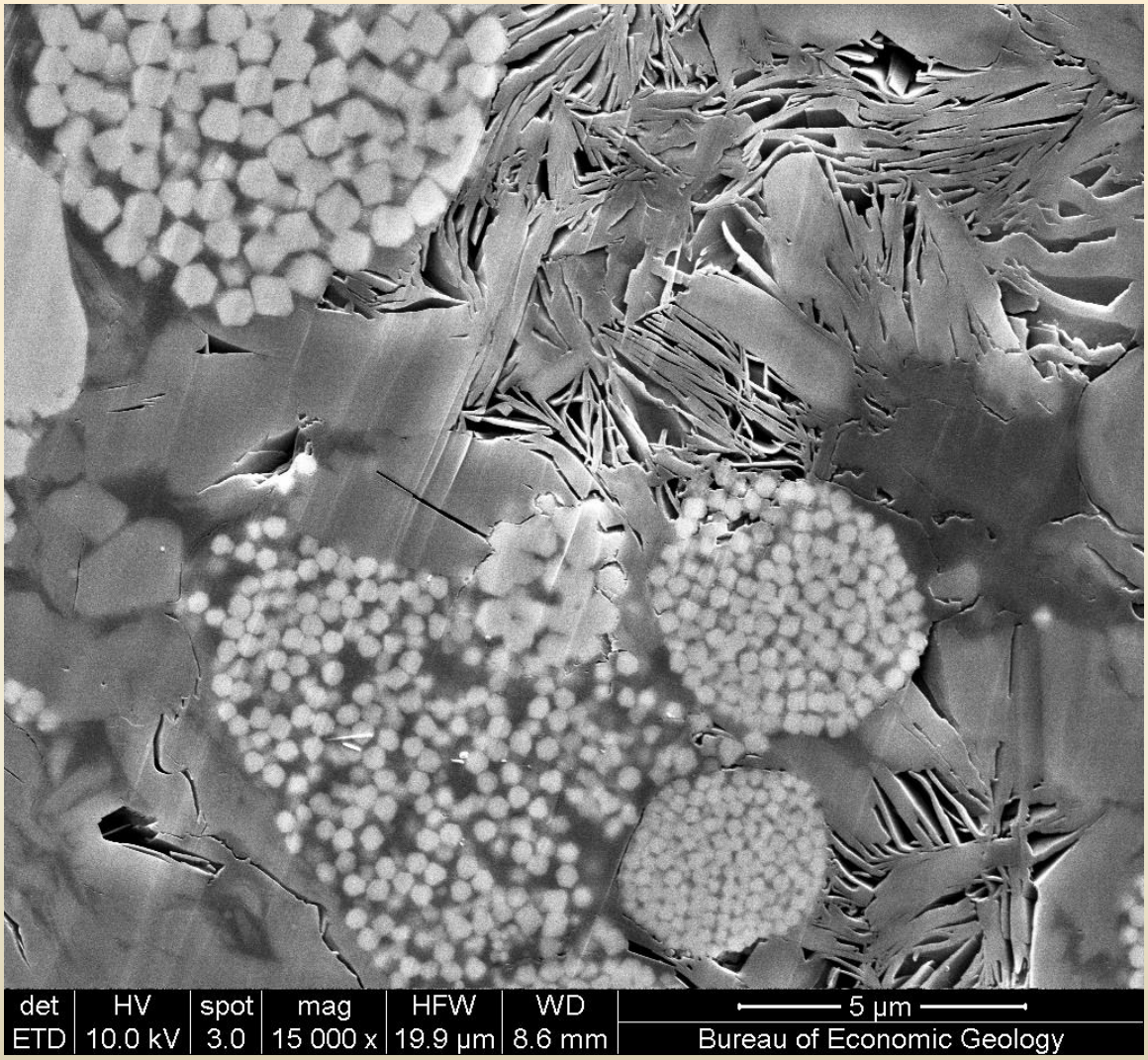


Polished thin section



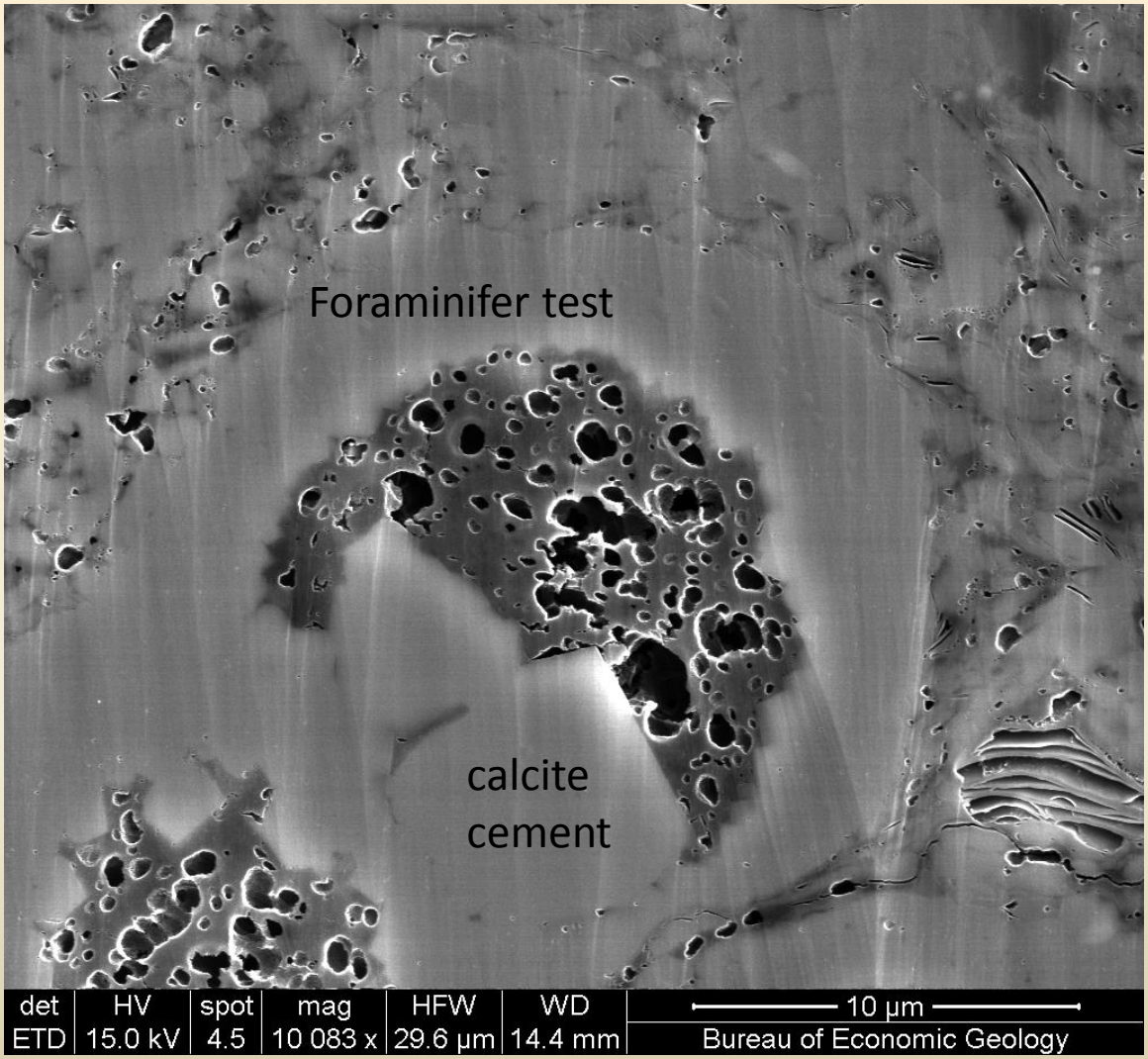
Ion-milled surface.

Mineral-hosted pores



Eagle Ford Formation, South Texas.

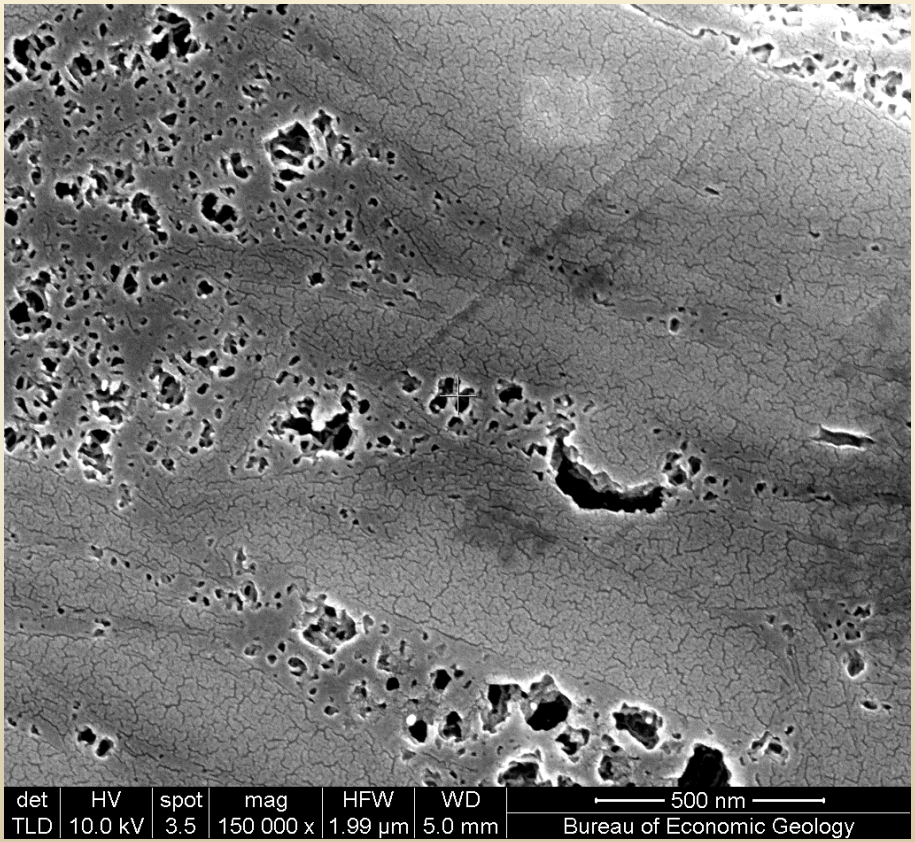
Secondary pores within pore-filling residual hydrocarbon.

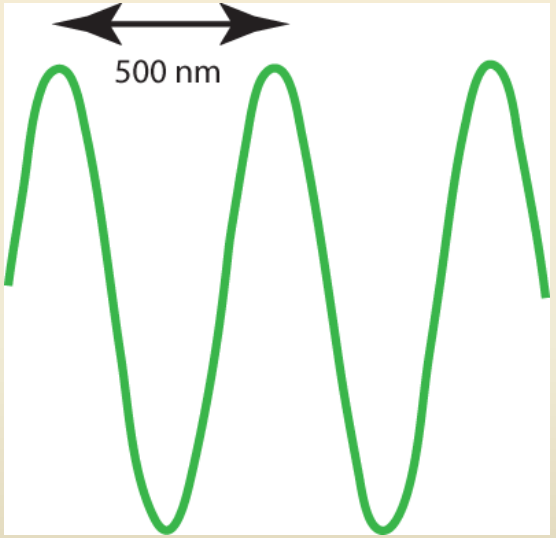


Eagle Ford Formation, South Texas

Something to think about:

Pores in mudrocks are generally smaller than the wavelength of light. Mudrocks are *natural nanomaterials*.





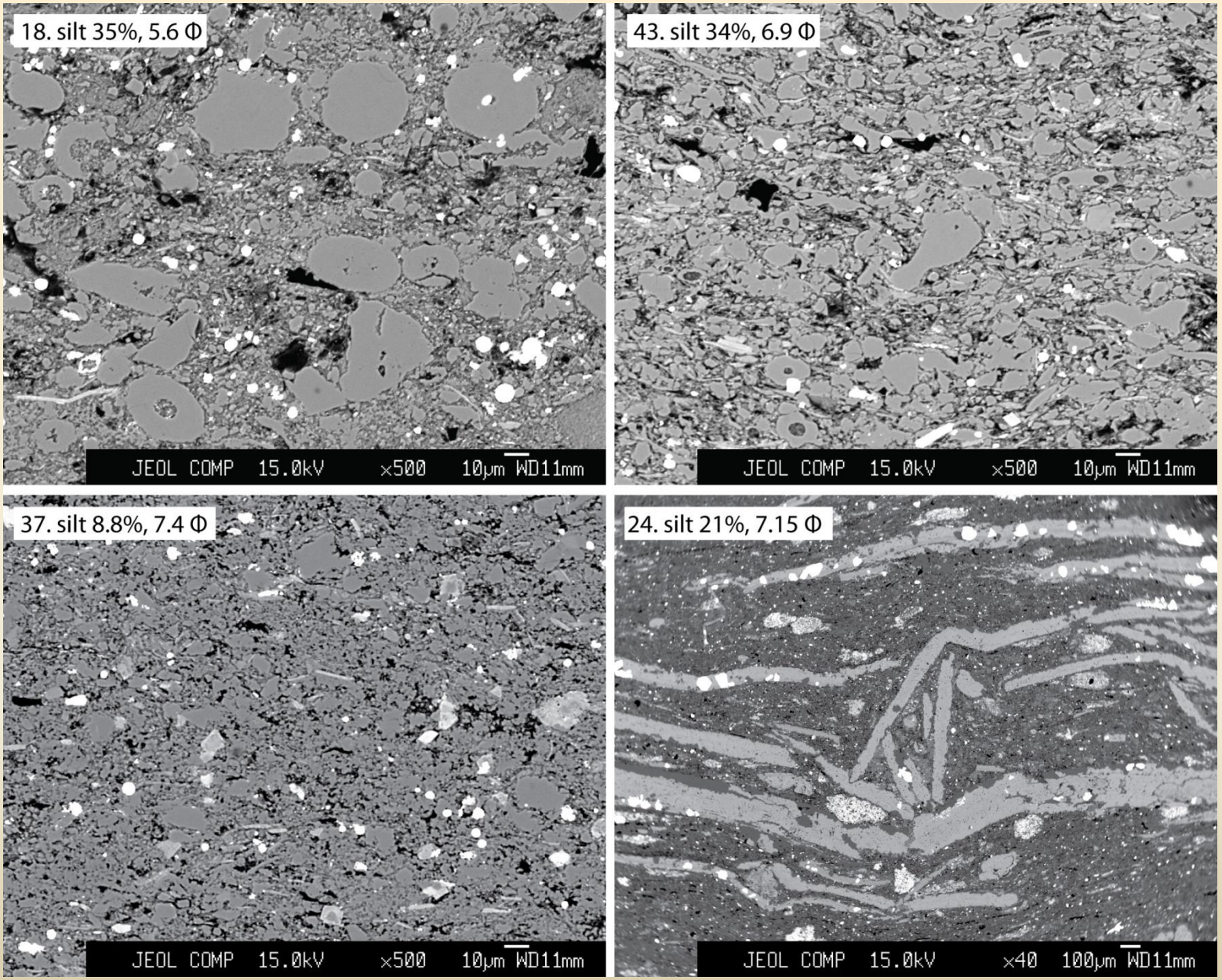
green light

If we had exploration models for fine-grained systems what would we want them to predict ?

Bulk properties:

- Porosity (storage)
- Permeability (flow)
- Organic content (source)
- Mechanical moduli (“frackability”)

Back-scattered electron images.

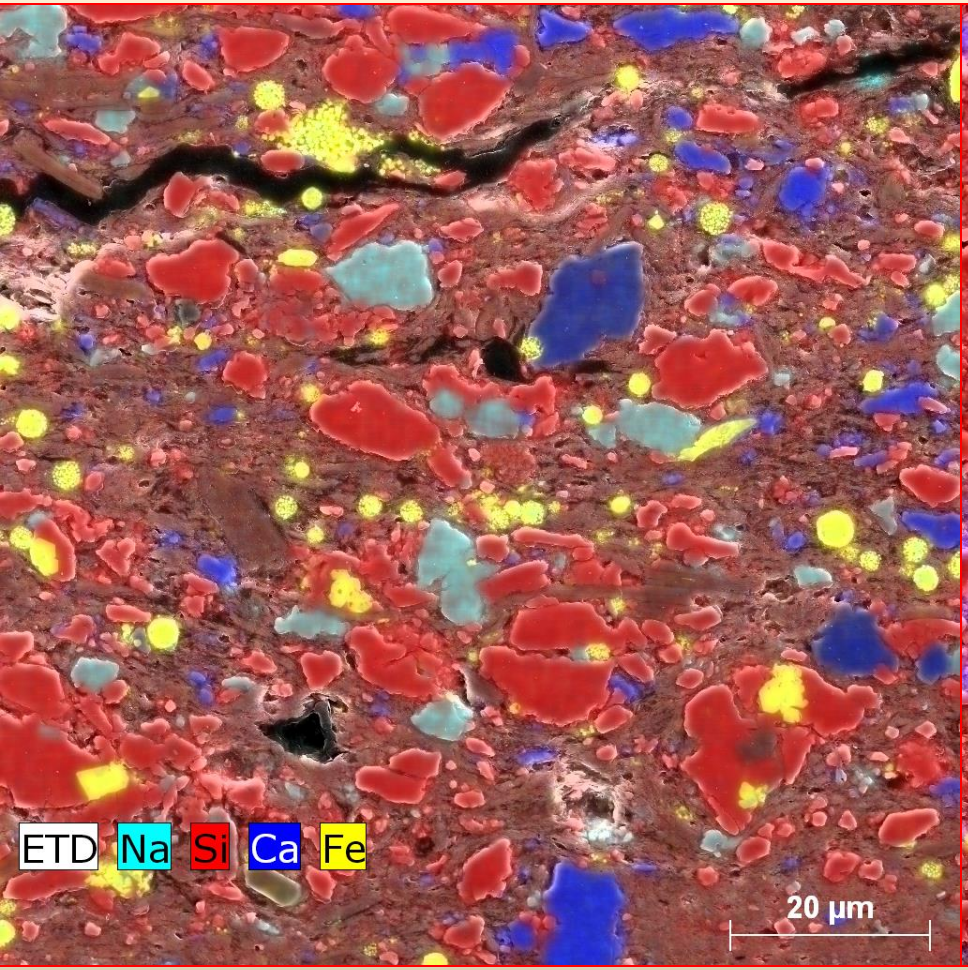


Textural heterogeneity: silt content, silt size

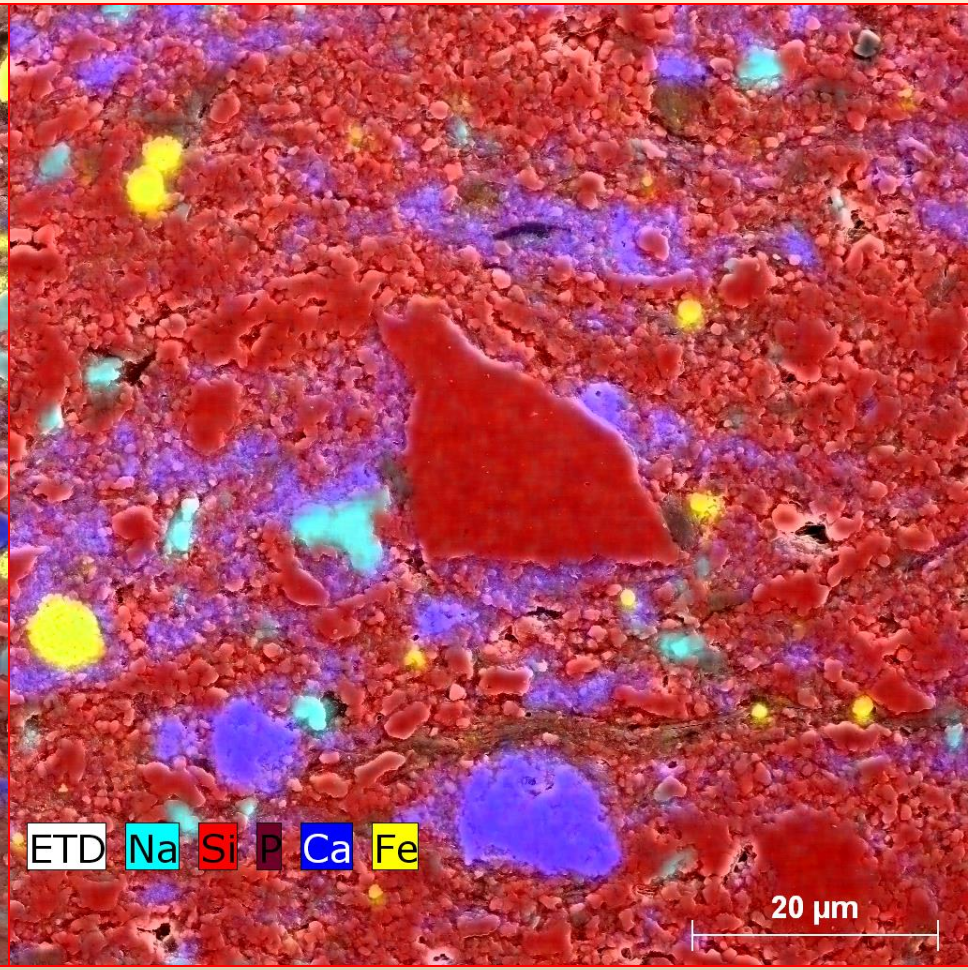
Barnett Shale, Ellis County, Texas, USA

Variations in grain assemblages can be assessed by CL and X-ray mapping.

X-ray maps



Silt-bearing mudstone



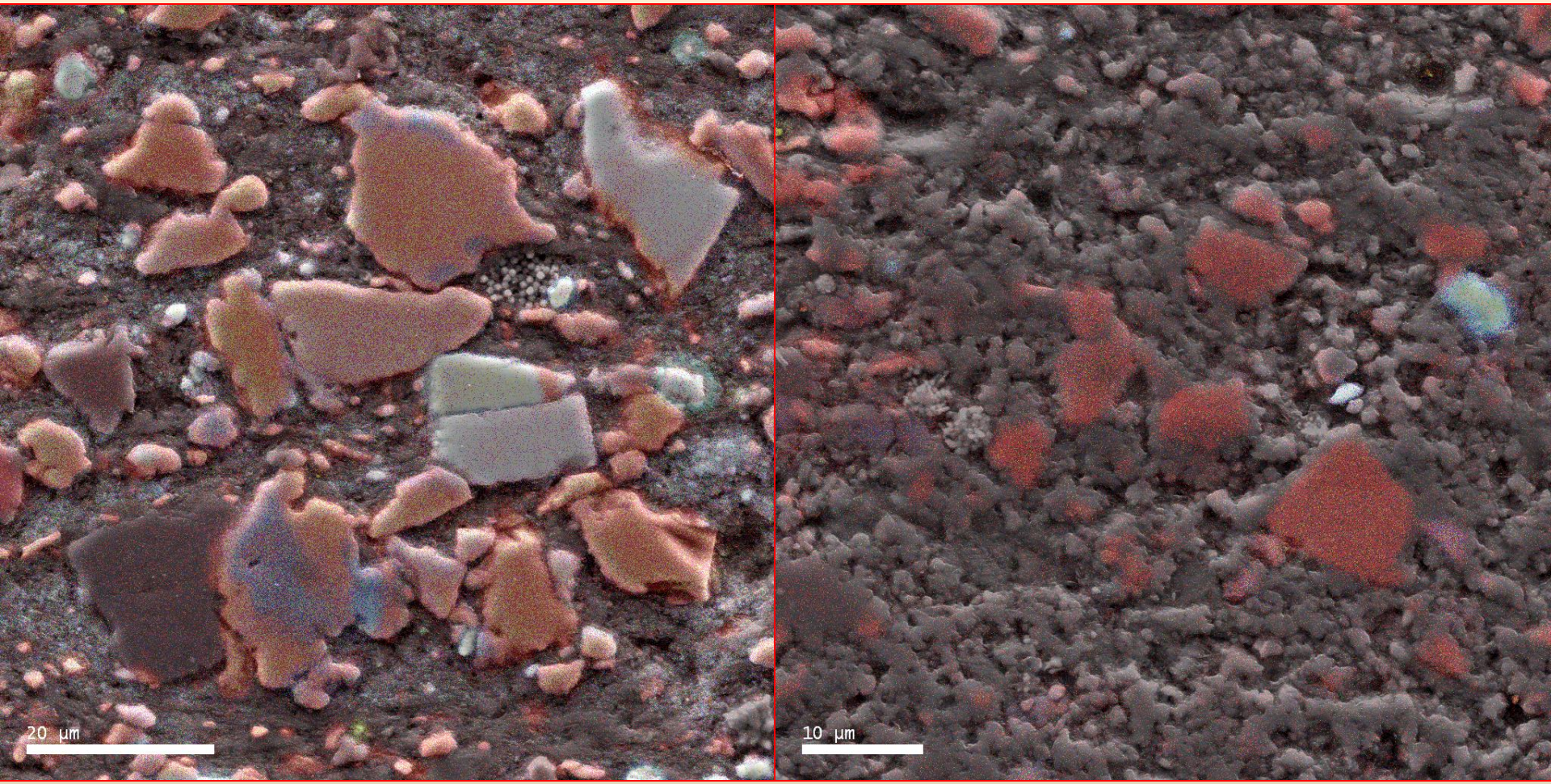
Chert-cemented mudstone

Barnett Shale

Milliken, 2013

Variations in grain assemblages can be assessed by CL and X-ray mapping.

CL maps



Silt-bearing mudstone

Barnett Shale

Cathodoluminescence images

Chert-cemented mudstone

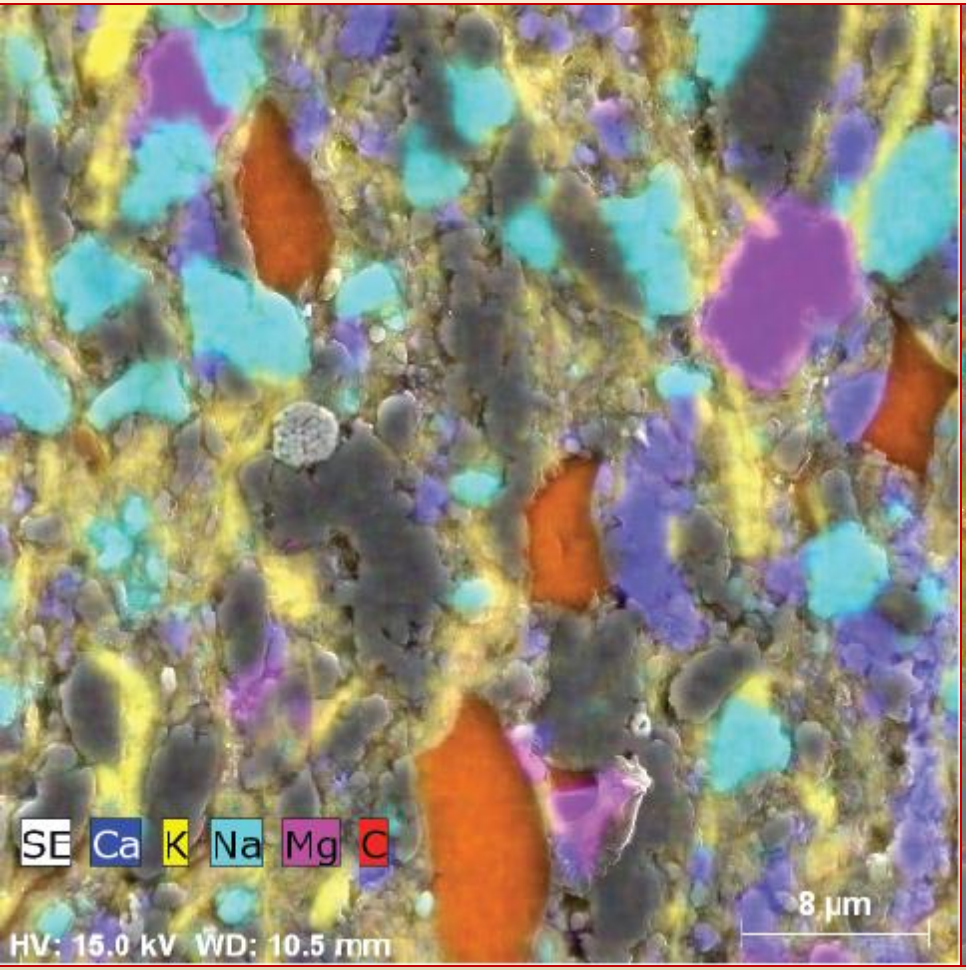
“matrix-dispersed authigenic microquartz”

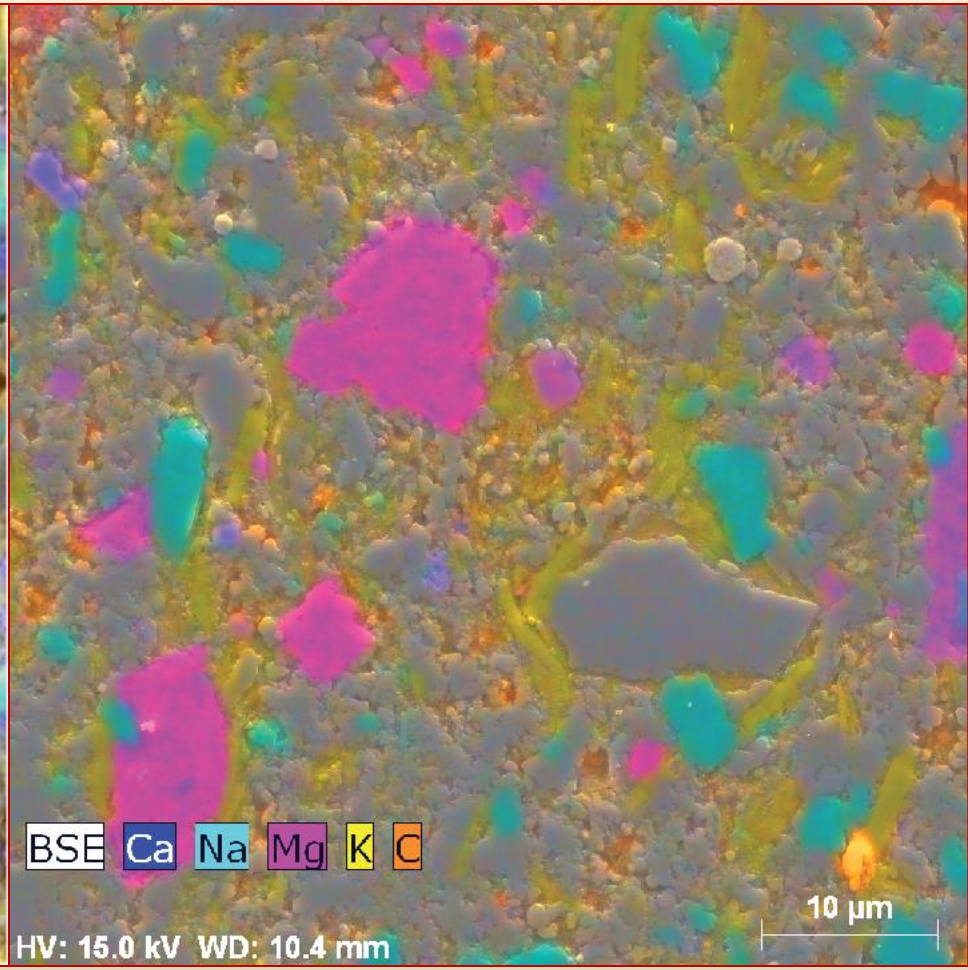
Milliken, 2013

Variations in grain assemblages can be assessed by CL and X-ray mapping.

X-ray maps

Organic matter: terrigenous vs marine vs residual hydrocarbon.



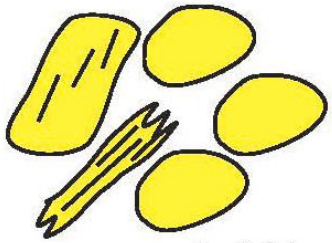
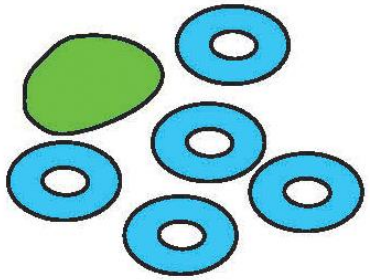
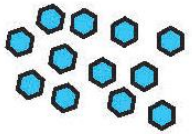


Silt-bearing mudstone

Chert-cemented mudstone

Milliken et al., 2012

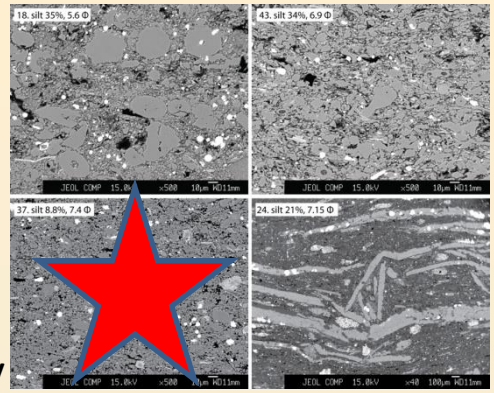
Four-component mixing system for sediments in the Barnett Shale

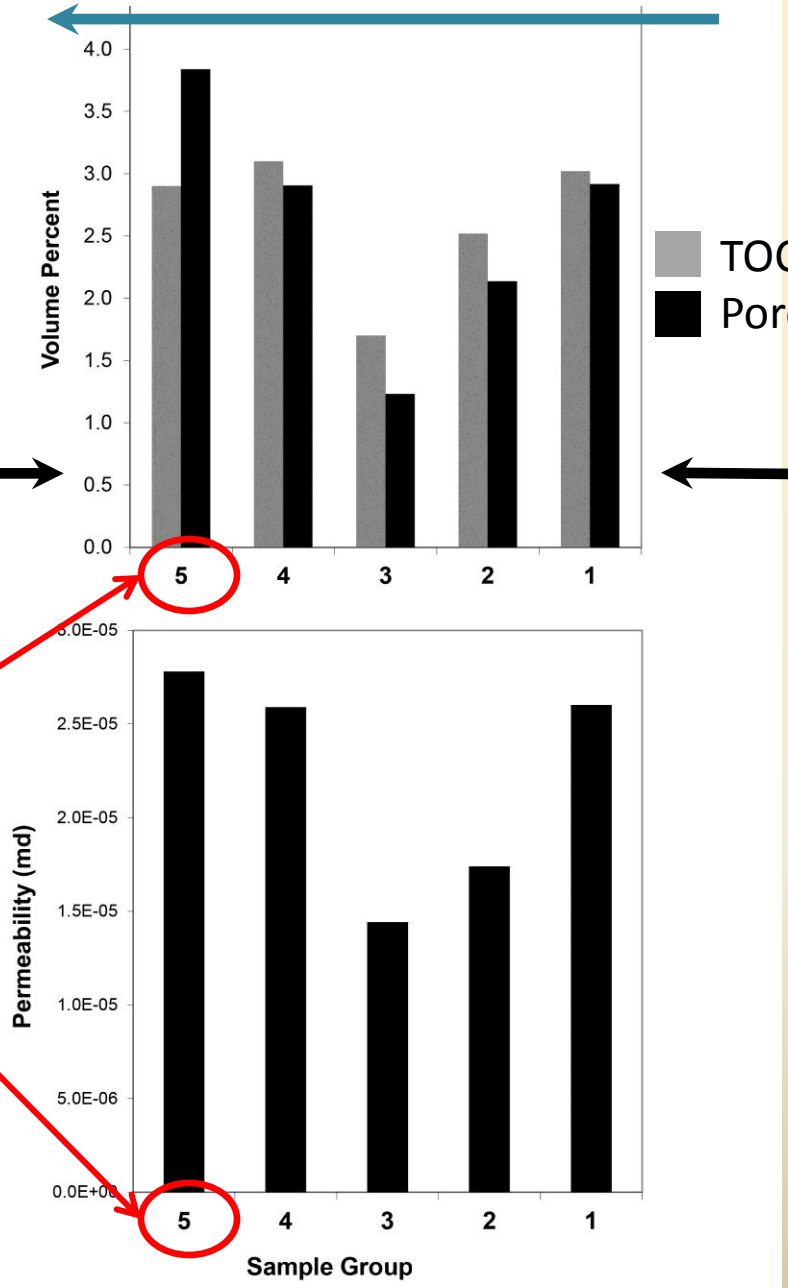
	Silt-size components	Clay-size components
Extrabasinal debris	 quartz, feldpar, mica	 clay, quartz, feldspar
Intrabasinal particles	 bio-siliceous allochems, glauconite	 bio-siliceous allochems

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

Milliken et al., 2012

Declining extrabasinal content





Chert-cemented mudstone →

← Silt-bearing mudstone

Porous
Permeable
Brittle
Oil-prone

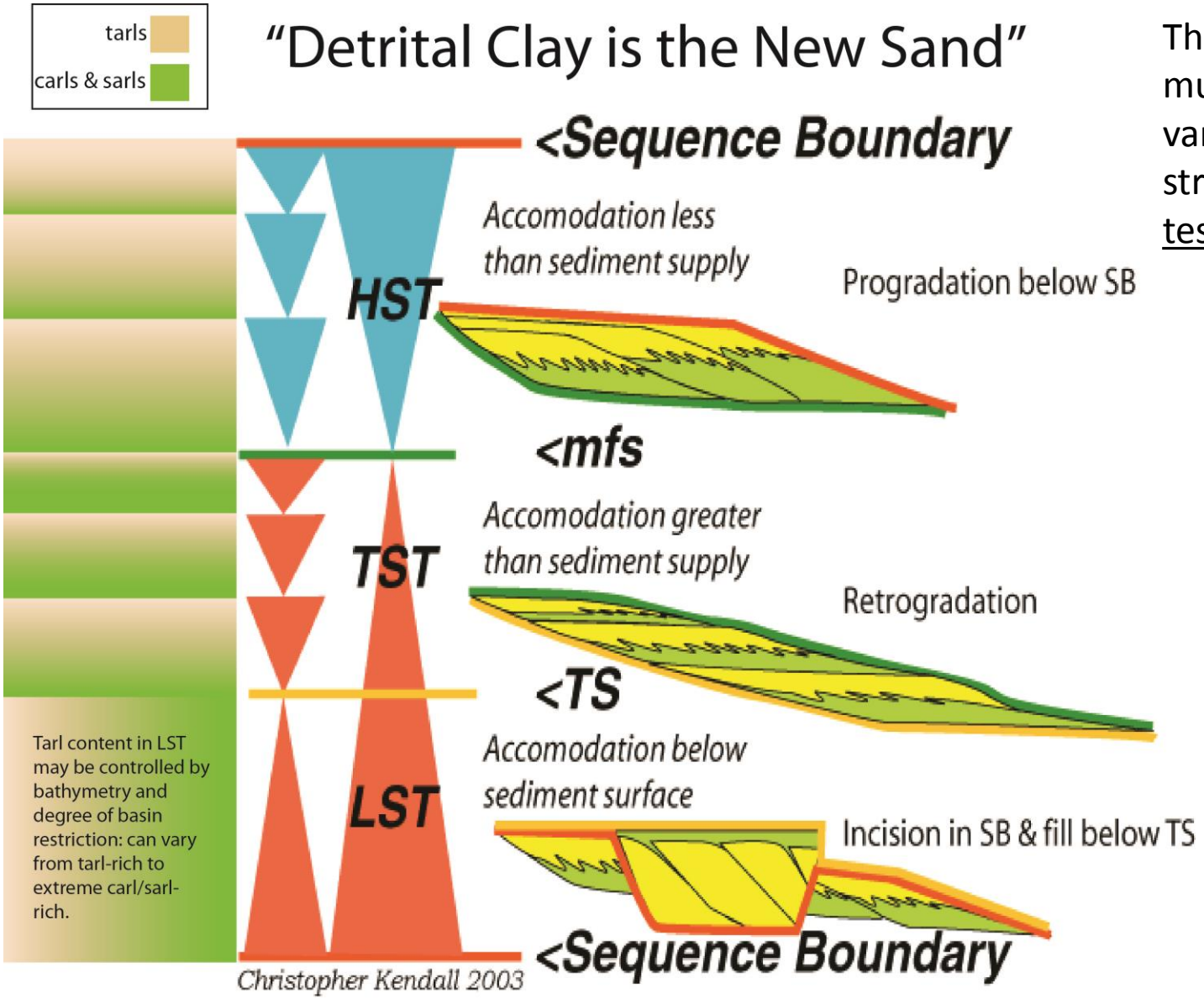
MODEL

best reservoir quality where:

- extrabasinal influx is minimal
- marine OM is highest
- siliceous fossils react to form brittle mudstones.

Milliken et al., 2012

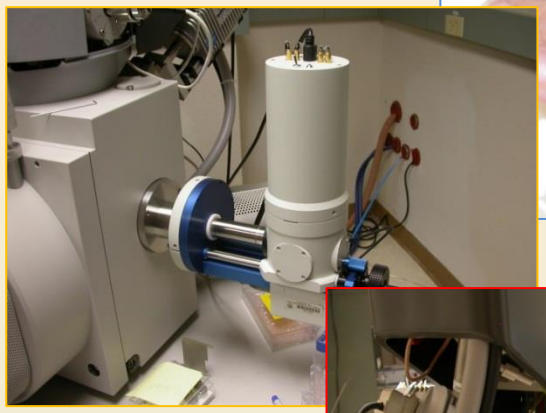
Future Exploration Model?

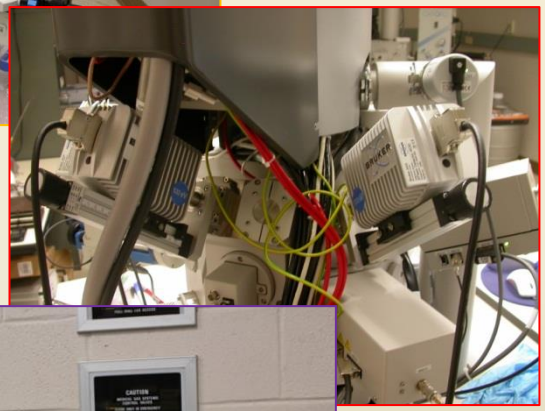


Theoretical idea for mudrock compositional variation across stratigraphy needs to be tested.

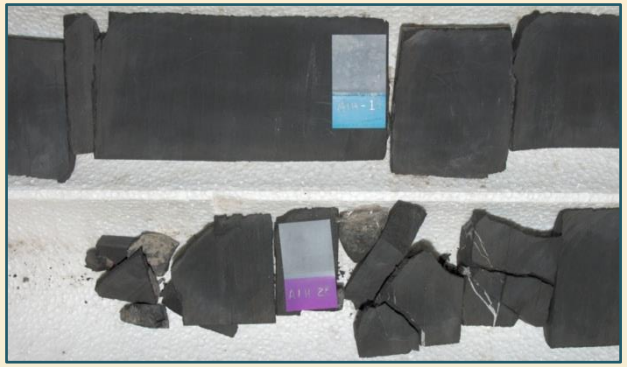
Transformative Technologies for Micro-Imaging:

- Light microscopy
- X-ray mapping & CL imaging
  - Grain assemblages in mudrocks
- CL-imaging
  - Integrated chemical-mechanical history
- FE-SEM
  - *Ar-ion cross-section polishing*
  - Pore systems in mudrocks: correlating pore evolution to thermal maturity

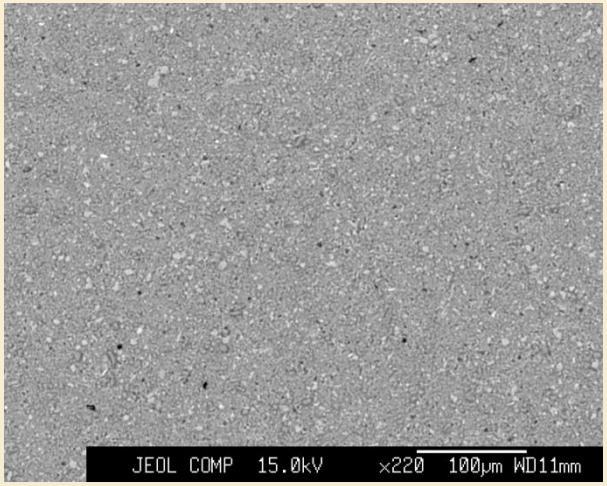




Apparent homogeneity of shales as seen by visual inspection is misleading……

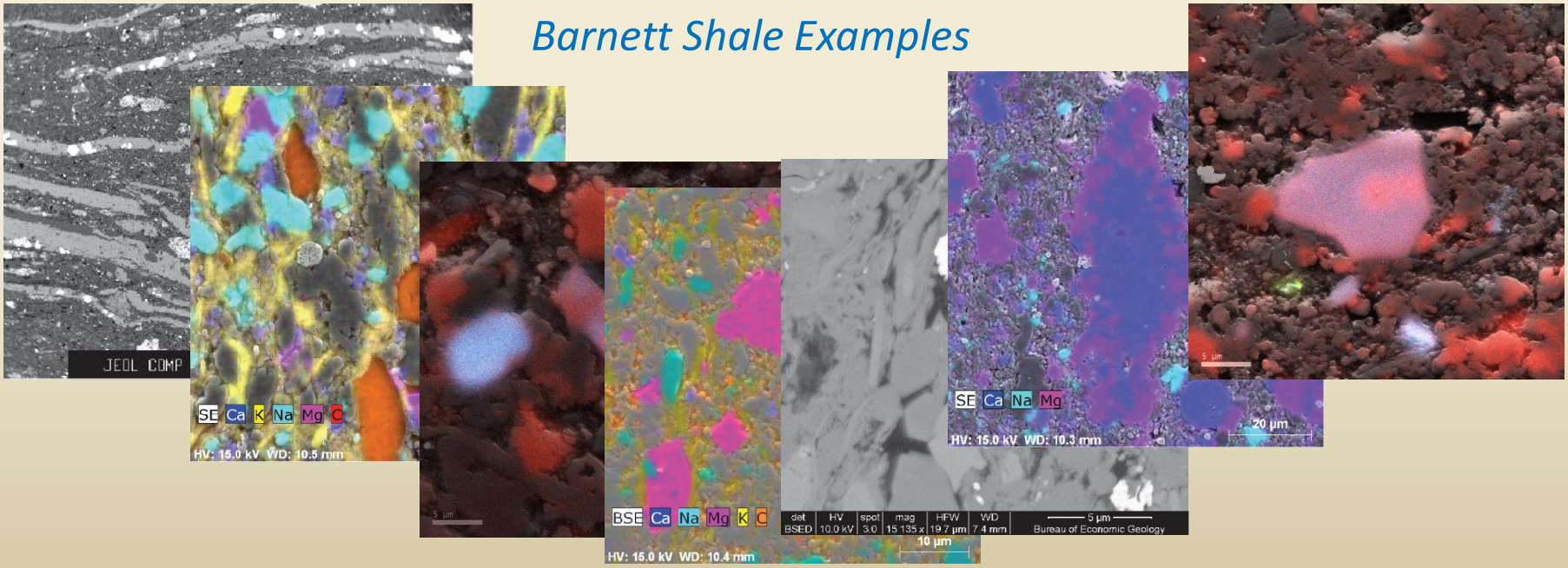


At high magnifications, we learn that most shales don't look like this:



But rather, like:

Barnett Shale Examples



Building exploration models for fine-grained depositional systems: What does it take?

integration

- Training (undergraduate and graduate levels)
  - Basic chemistry, physics, biology, mathematics
  - Basic geoscience
  - Sedimentology and stratigraphy
  - Mineralogy and geochemistry
  - Petrology
  - Paleontology

integration

- Working environment
  - Interdisciplinary
  - Multi-scale: basinal to nanometer

integration

- Tools
  - High-quality log suites
  - Core descriptions
  - Micro-imaging
    - Light microscope
    - X-ray mapping
    - CL imaging
    - High-resolution pore imaging
    - Many affiliated techniques

http://www.fei.com/natural-resources/oil-gas/

Drivers:

- Economic motivations
- Technologies
- Scientific understanding

Needs:

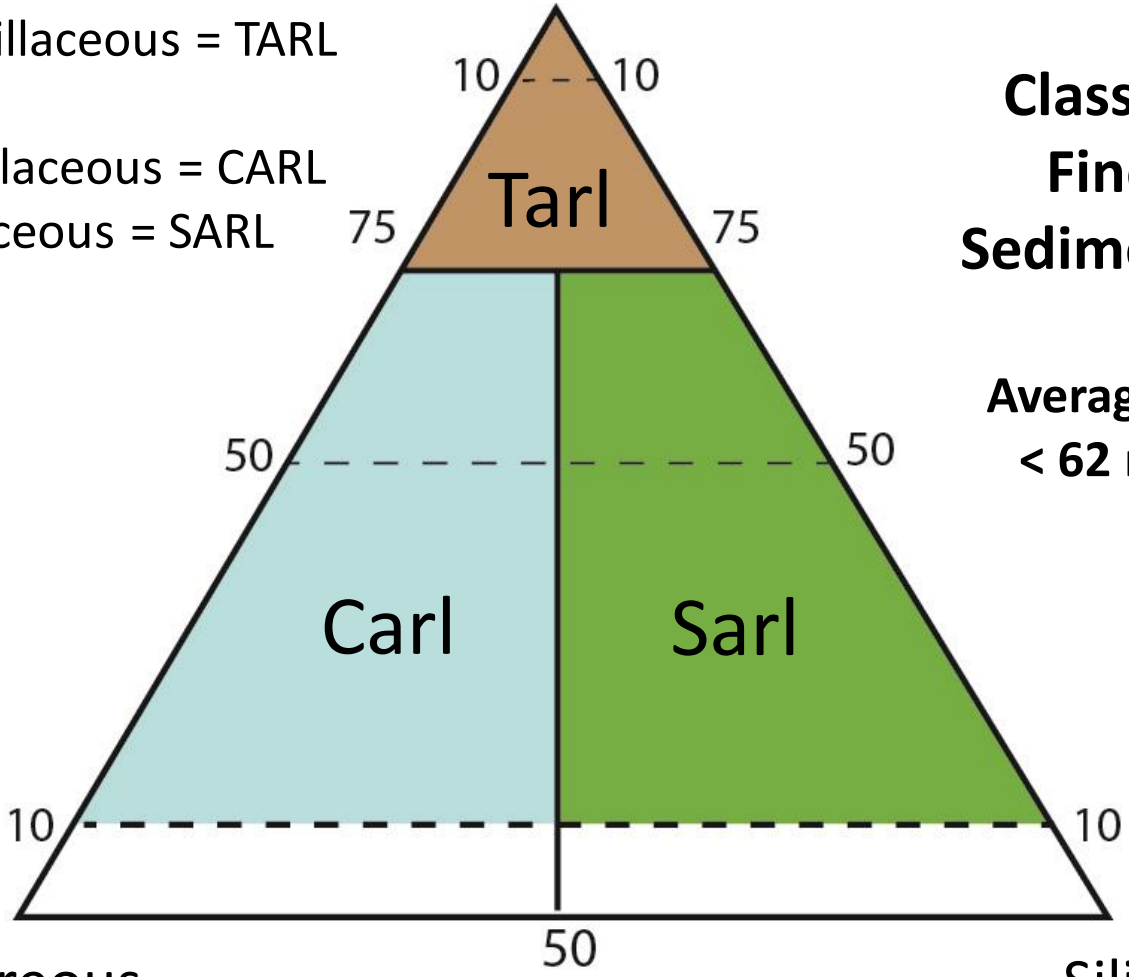
- Education in rock-based studies
- Integration across disciplines and scales
- Cores (please share!)
- Time (Research takes time…..)

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

BUREAU OF ECONOMIC GEOLOGY

Terrigenous and
Volcanic Grains

EXTRABASINAL:
Terrigenous-argillaceous = TARL
INTRABASINAL:
Calcareous-argillaceous = CARL
Siliceous-argillaceous = SARL



Classification of Fine-grained Sedimentary Rocks

Average particle size < 62 micrometers

Calcareous
Bio-grains

Siliceous
Bio-grains

From Milliken, in press, JSR.

Randy Randolph

Southern Gas Association

AGI Critical Issues Forum

America's Increasing Reliance on Natural Gas: Benefits and Risk of a Methane Economy

"Politics & Public Opinion"

The Natural Gas Conundrum

L. C. (Randy) Randolph Jr.

Southern Gas Association
Who We Are…

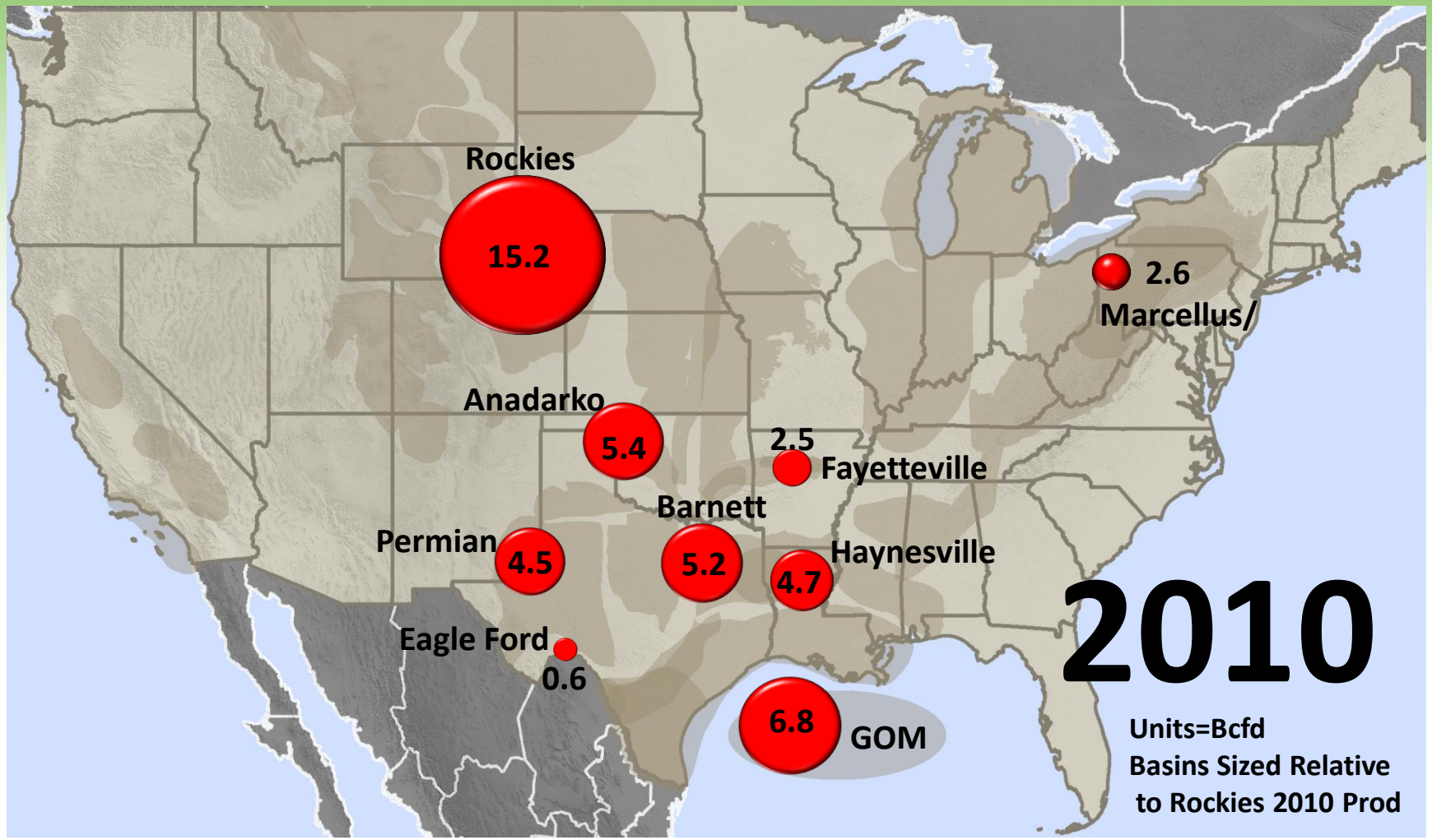
- **106 year old natural gas trade association**
- **160 natural gas company members**
- **300 associate members**
- **500+ member volunteers**
- **60 live & 50 virtual events per year**

SGA Member Service Areas

Outline

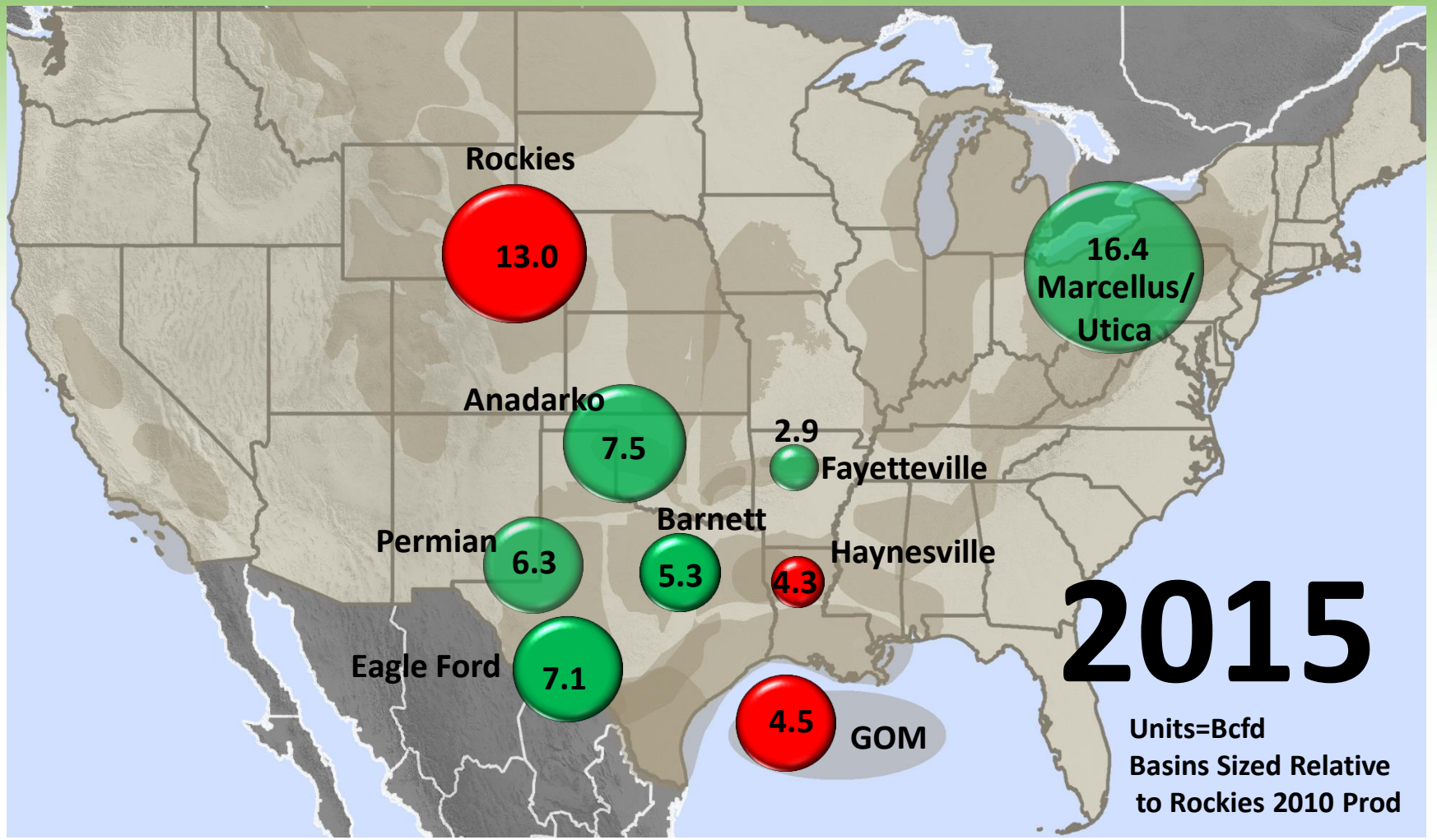
- Geographic Changes in Nat Gas Supply
- Nat Gas & Liquid Hydrocarbon Connection
- US Refining Capacity
- Economic Contributions
- Regional Responses
- Technology

Natural Gas Production Geography Keeps Evolving



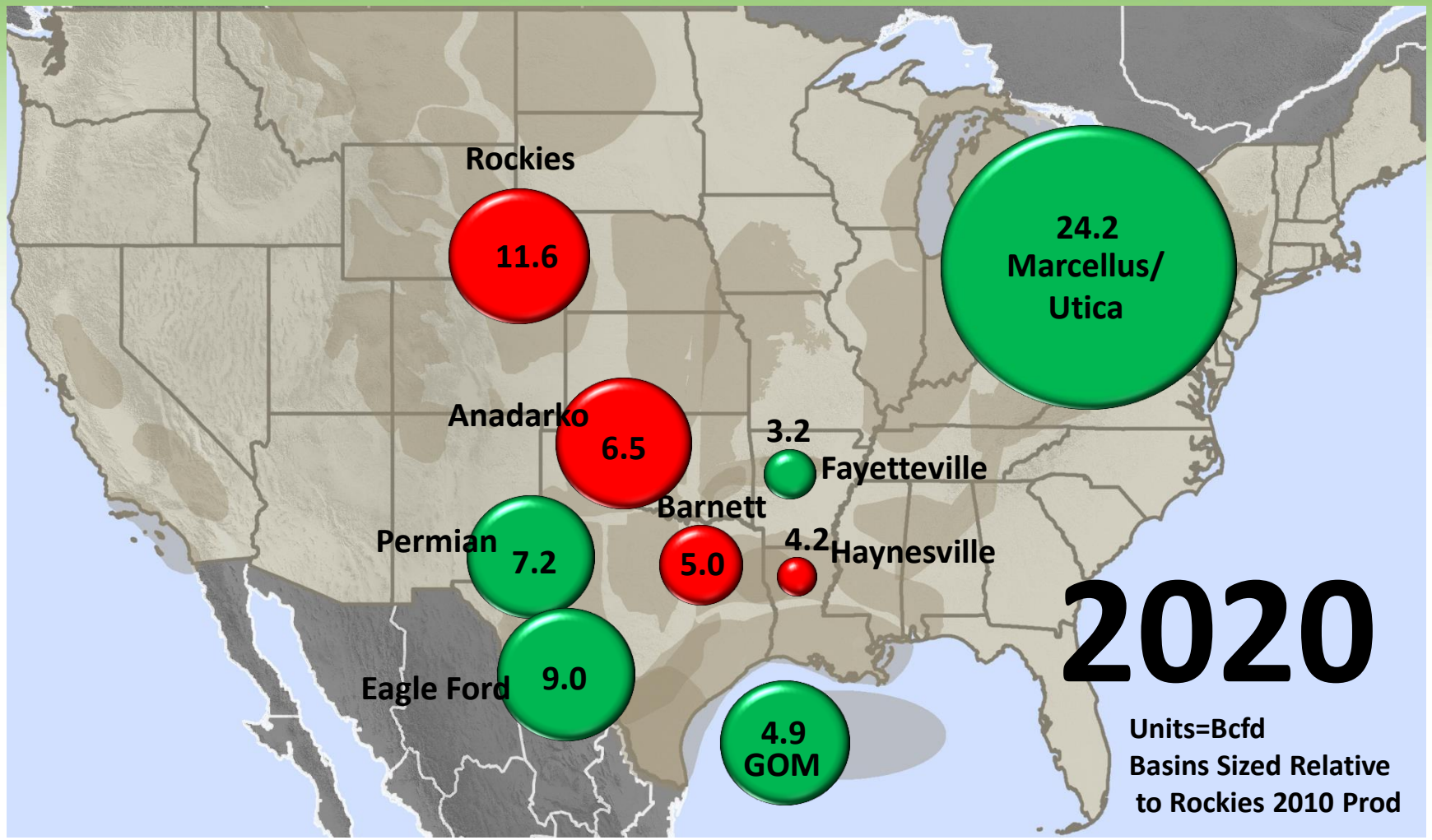
Source: Ponderosa Advisors & HPDI

Marcellus/Utica Transforming The Natural Gas Market



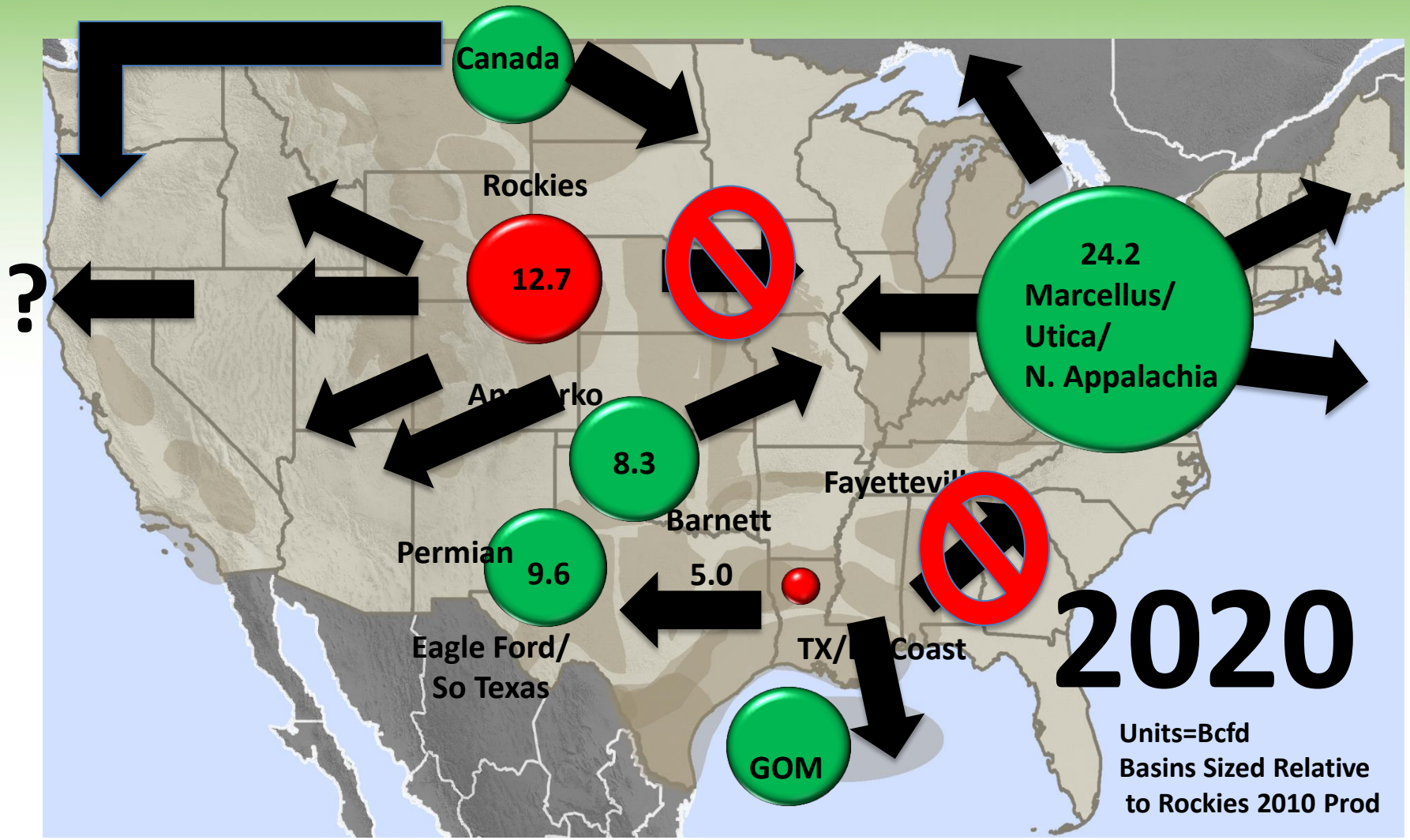
Source: Ponderosa Advisors HPDI

Marcellus/Utica Will Transform The Natural Gas Market



Source: Ponderosa Advisors & HPDI

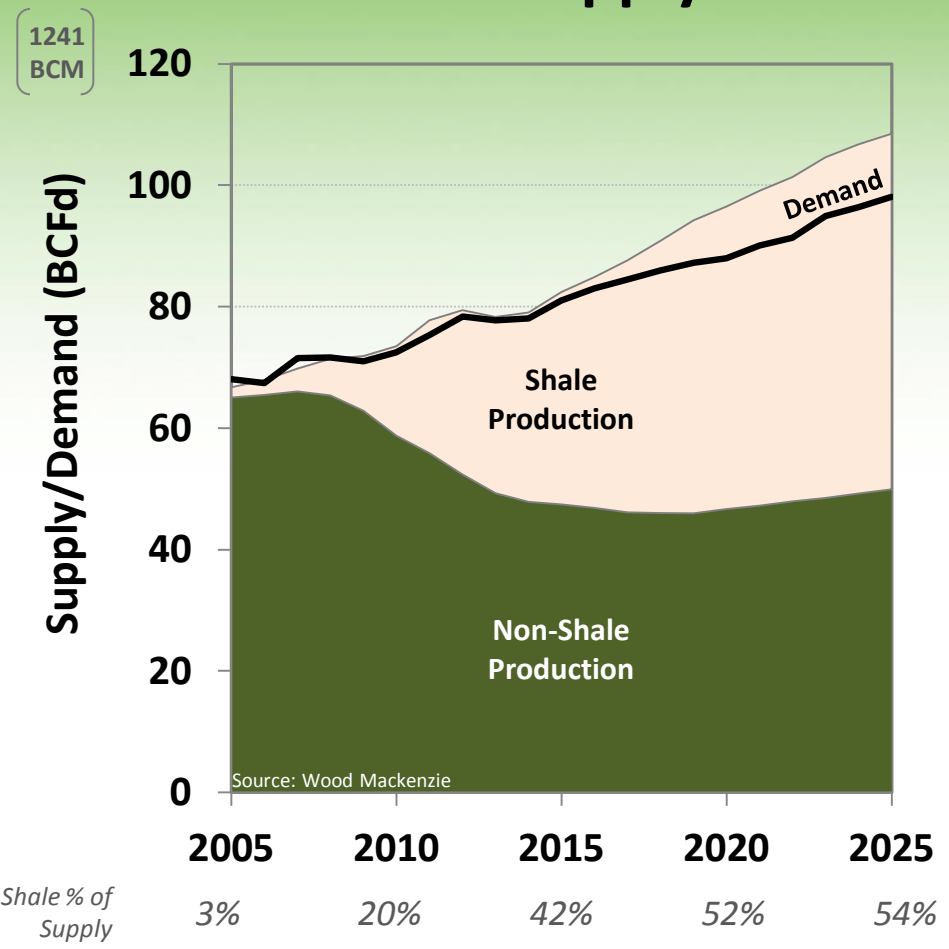
Marcellus/Utica Production Dominates NA Flow Patterns Straining Pipeline Assets



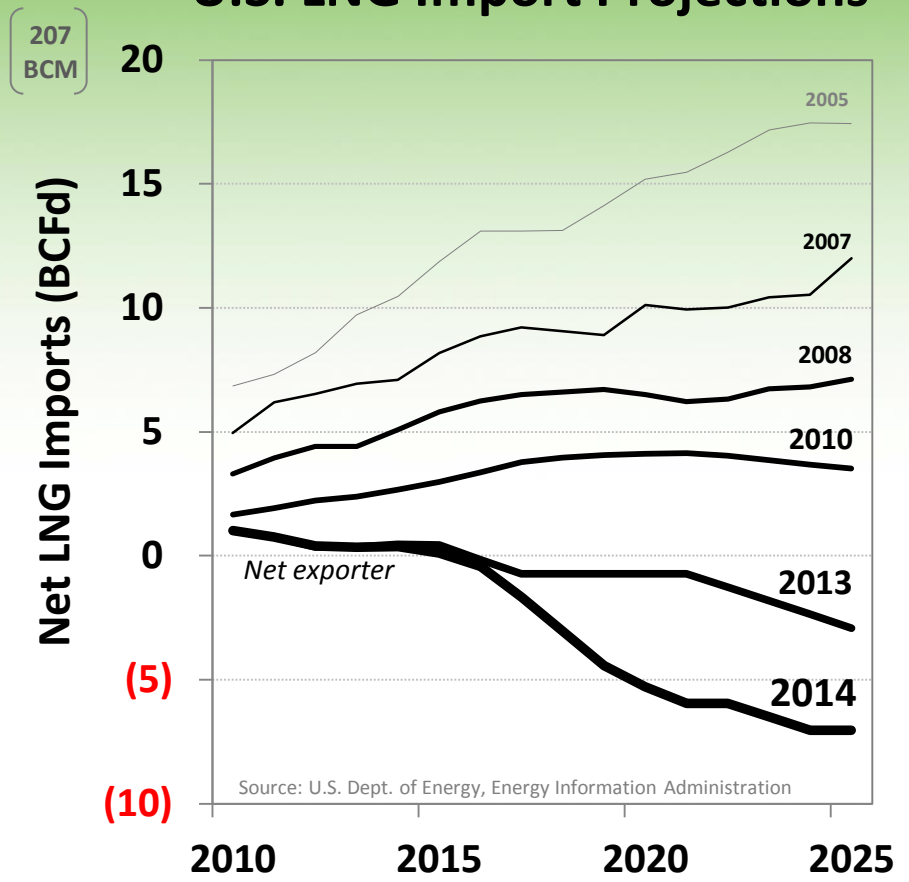
Source: Ponderosa Advisors & HPDI

North America Natural Gas Supply and Demand

N. America Supply vs. Demand



U.S. LNG Import Projections

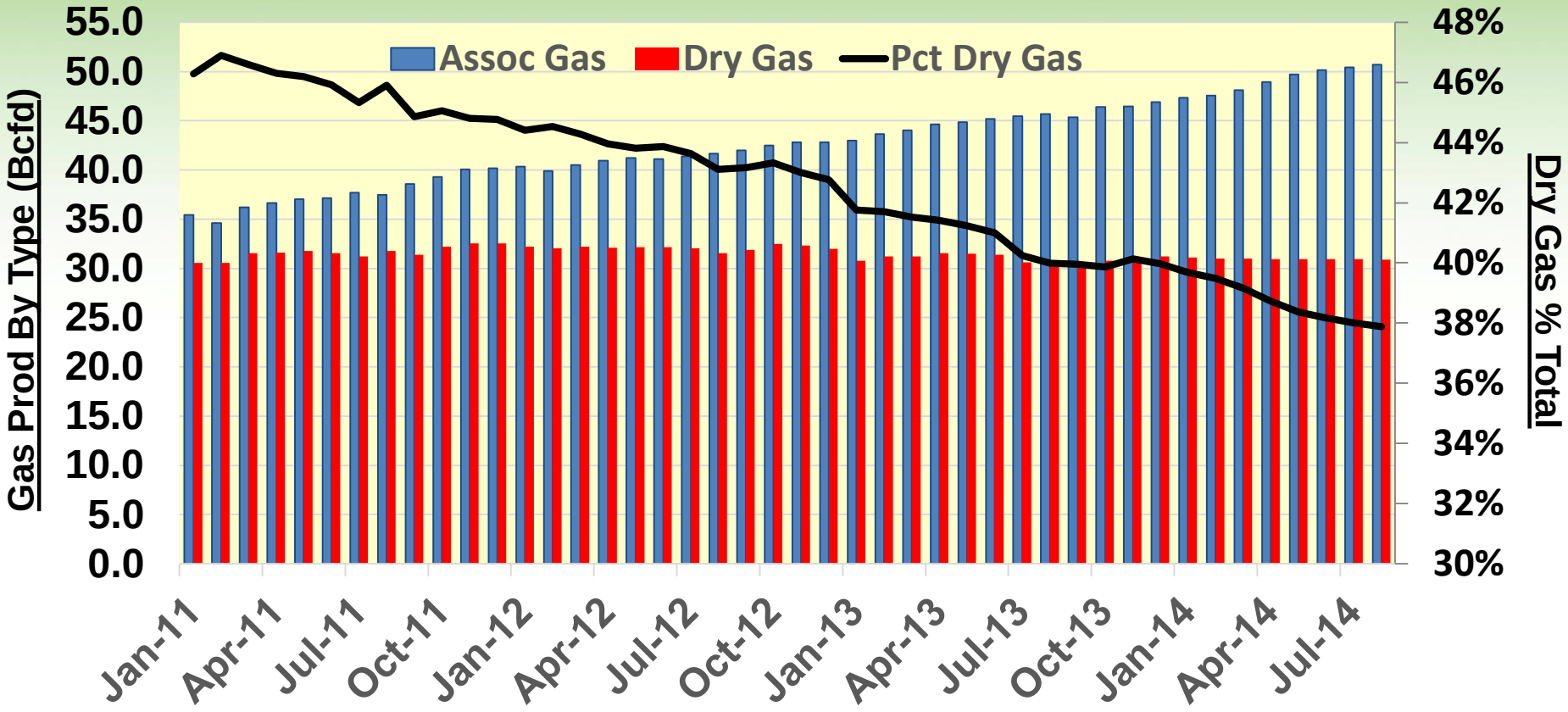


North America is poised to become a net LNG exporter

*N. America: U.S. and Canada only

Dry Gas Declines Have Been Offset By Associated Gas Production

Gross Gas Production By GPM



Assoc Gas Definition: Onshore Production Areas With GPM>1.15, Data through 8/2014

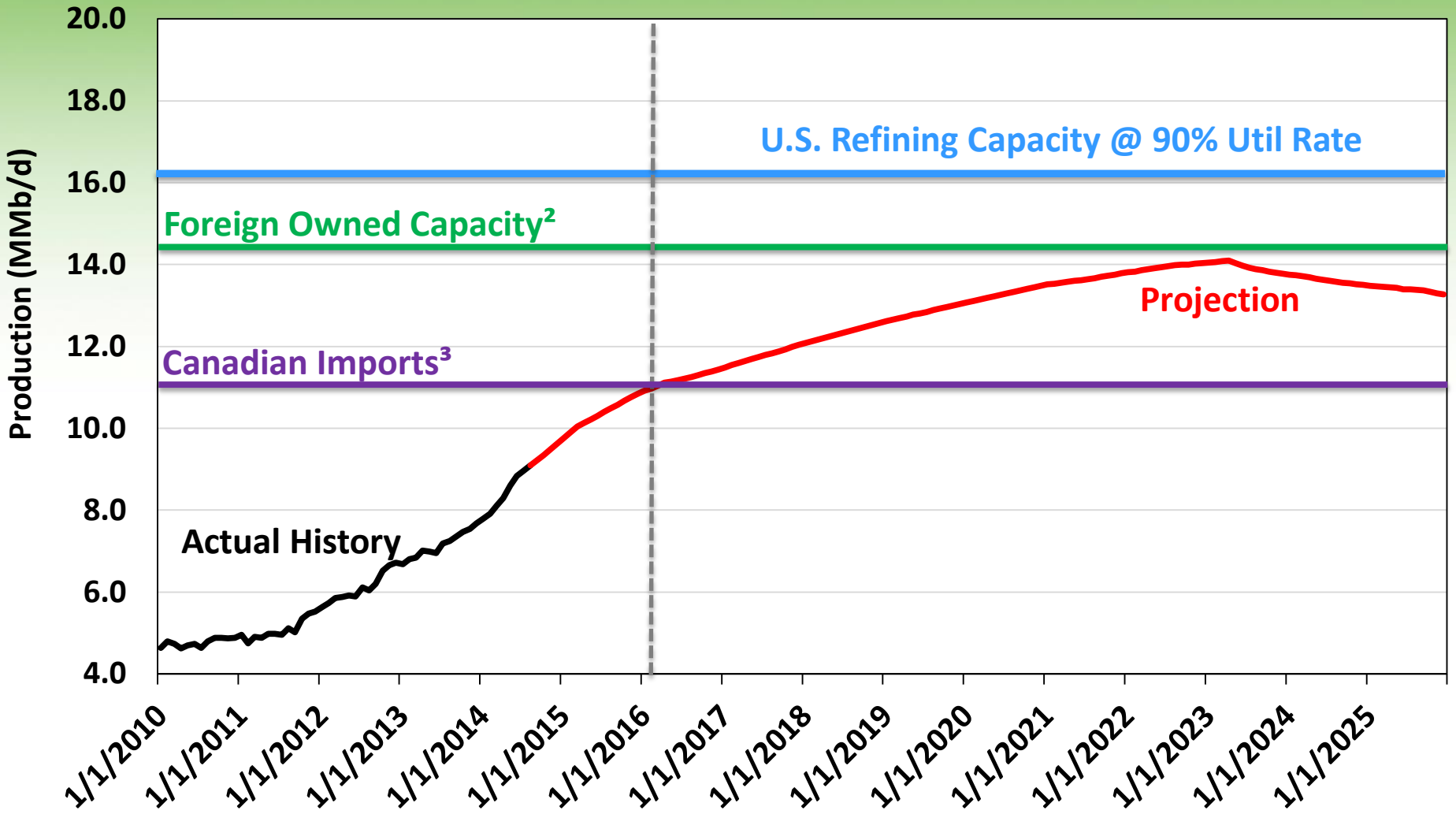
Source: *Ponderosa Advisors, HPDI, FERC*

[1]Utilization Rate: 90%

[2]Foreign Owned Capacity: 1.4 MMb/d

[3]Canadian Imports: 3.1 MMb/d

US Refining Capacity Will Slow Production Growth



Source: *Ponderosa Advisors, HPDI, FERC*

[1]Utilization Rate: 90%

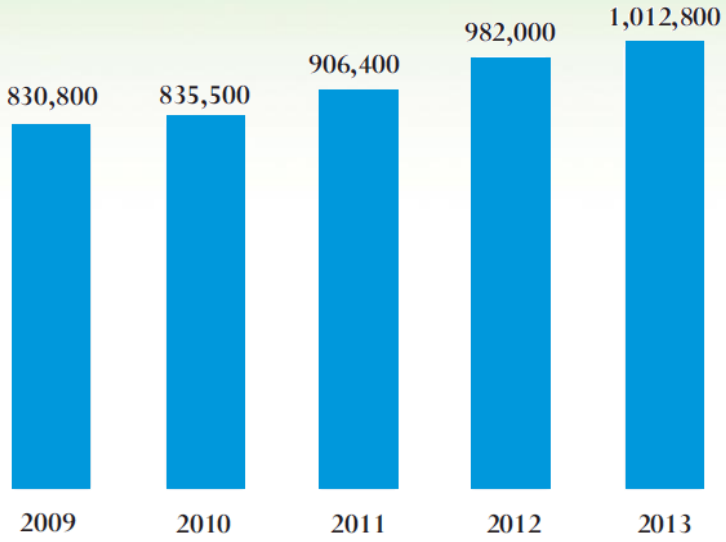
[2]Foreign Owned Capacity: 1.4 MMb/d

[3]Canadian Imports: 3.1 MMb/d

United States Oil & Gas Key Industry Statistics

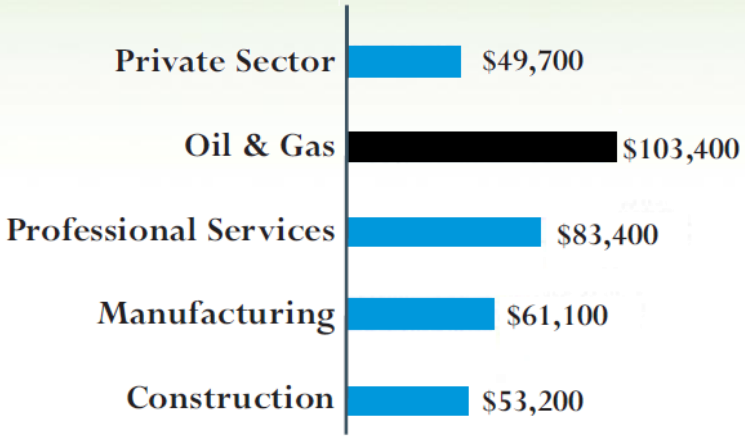
EMPLOYMENT

2009-2013



WAGE COMPARISON

Annual Average in 2013

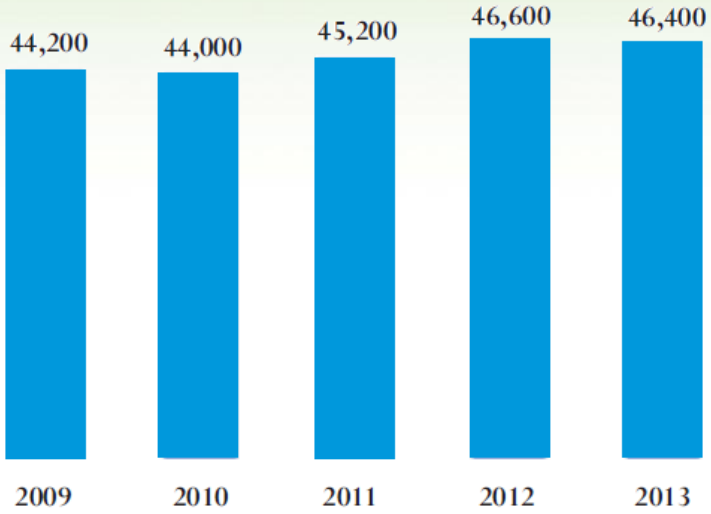


Source: U.S. Bureau of Labor Statistics
All data is for 2013 except where noted.

California Oil & Gas Key Industry Statistics

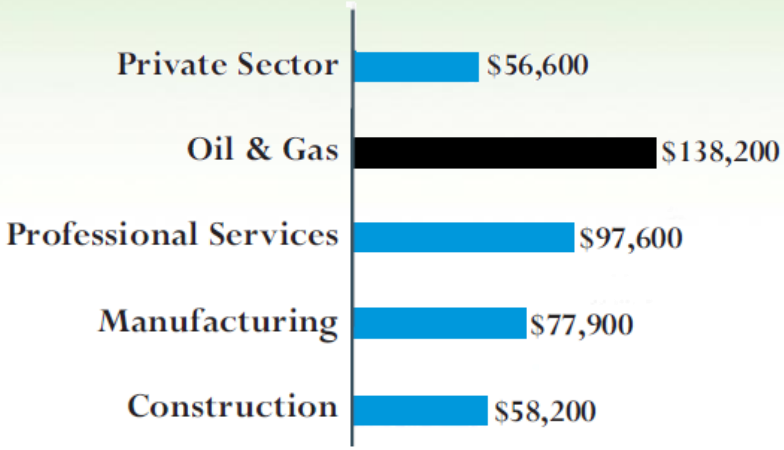
EMPLOYMENT

2009-2013



WAGE COMPARISON

Annual Average in 2013



Source: U.S. Bureau of Labor Statistics
All data is for 2013 except where noted.

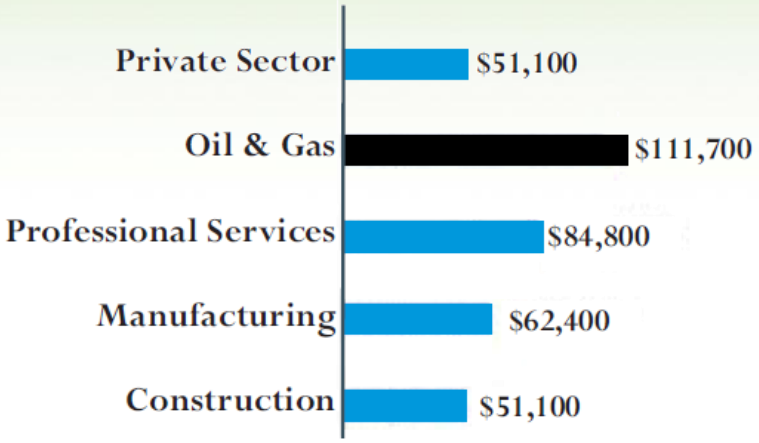
Colorado Oil & Gas Key Industry Statistics

EMPLOYMENT

2009-2013

WAGE COMPARISON

Annual Average in 2013



Source: U.S. Bureau of Labor Statistics
All data is for 2013 except where noted.

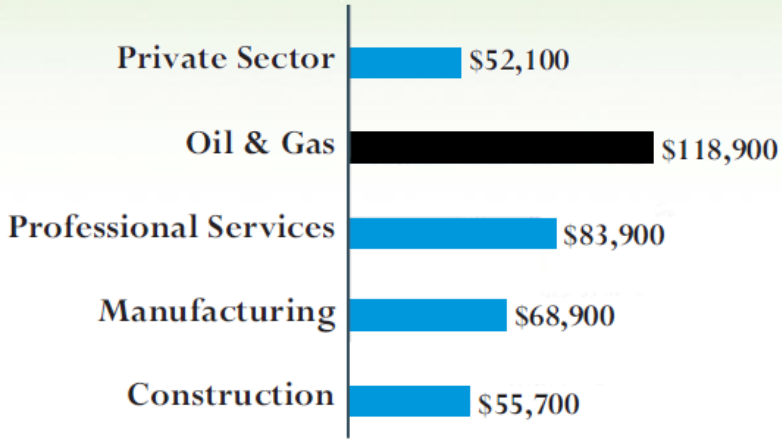
Texas Oil & Gas Key Industry Statistics

EMPLOYMENT

2009-2013

WAGE COMPARISON

Annual Average in 2013



Source: U.S. Bureau of Labor Statistics
All data is for 2013 except where noted.

UT Austin Energy Survey

35 years old and younger

- 68% would likely vote for candidates that support carbon emission reductions
- 56% are willing to pay much higher prices to protect the environment
- 72% strongly support subsidies for renewable energy
- 39% are familiar with hydraulic fracturing for hydrocarbon fuel extraction
- 37% support the use of hydraulic fracturing

65 years old and older

- 50% would likely vote for candidates that support carbon emission reductions
- 20% are willing to pay much higher prices to protect the environment
- 58% strongly support subsidies for renewable energy
- 52% are familiar with hydraulic fracturing for hydrocarbon fuel extraction
- 52% support the use of hydraulic fracturing

Building Creditability & Relationships

- Education – Public, Customers & Employees
- Advocacy Training
- Local Community Engagement
- Workforce Training & Development
- Public Forum Participation
- Safety - Public, Customer and Employee
- Communications

Contact

L. C. (Randy) Randolph Jr.

Vice President

rrandolph@southerngas.org

713-299-9414

Find Us Online

www.southerngas.org

www.gmrc.org

http://twitter.com/SouthernGas

www.facebook.com/Southern.Gas.Association

www.linkedin.com/company/Southern-Gas-Association

Lawrence Bengal

Arkansas Oil and Gas Commission



American Geosciences Institute Critical Issues Forum

Forth Worth, Texas
November 19-20, 2014

America's Increasing Reliance on Natural Gas: Benefits and Risks of a Methane Economy

Session 4 – Drivers of and Barriers to Natural Gas Development in North America

StatesFirst
An Initiative of the IOGCC & GWPC

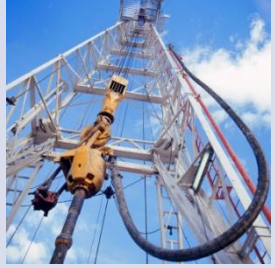
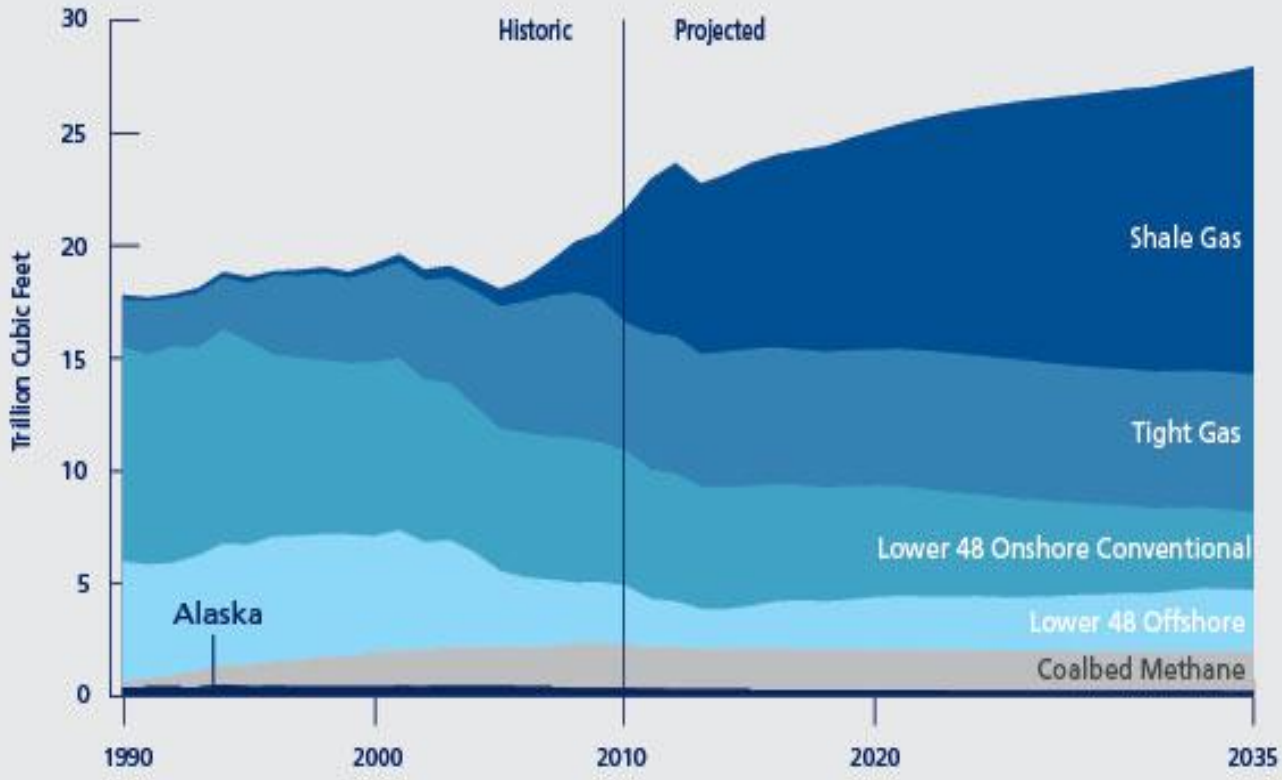




Figure 1. **U.S. Natural Gas Production by Source (Historic and Projected)**



Source: U.S. Energy Information Administration, *2012 Annual Energy Outlook*, http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf

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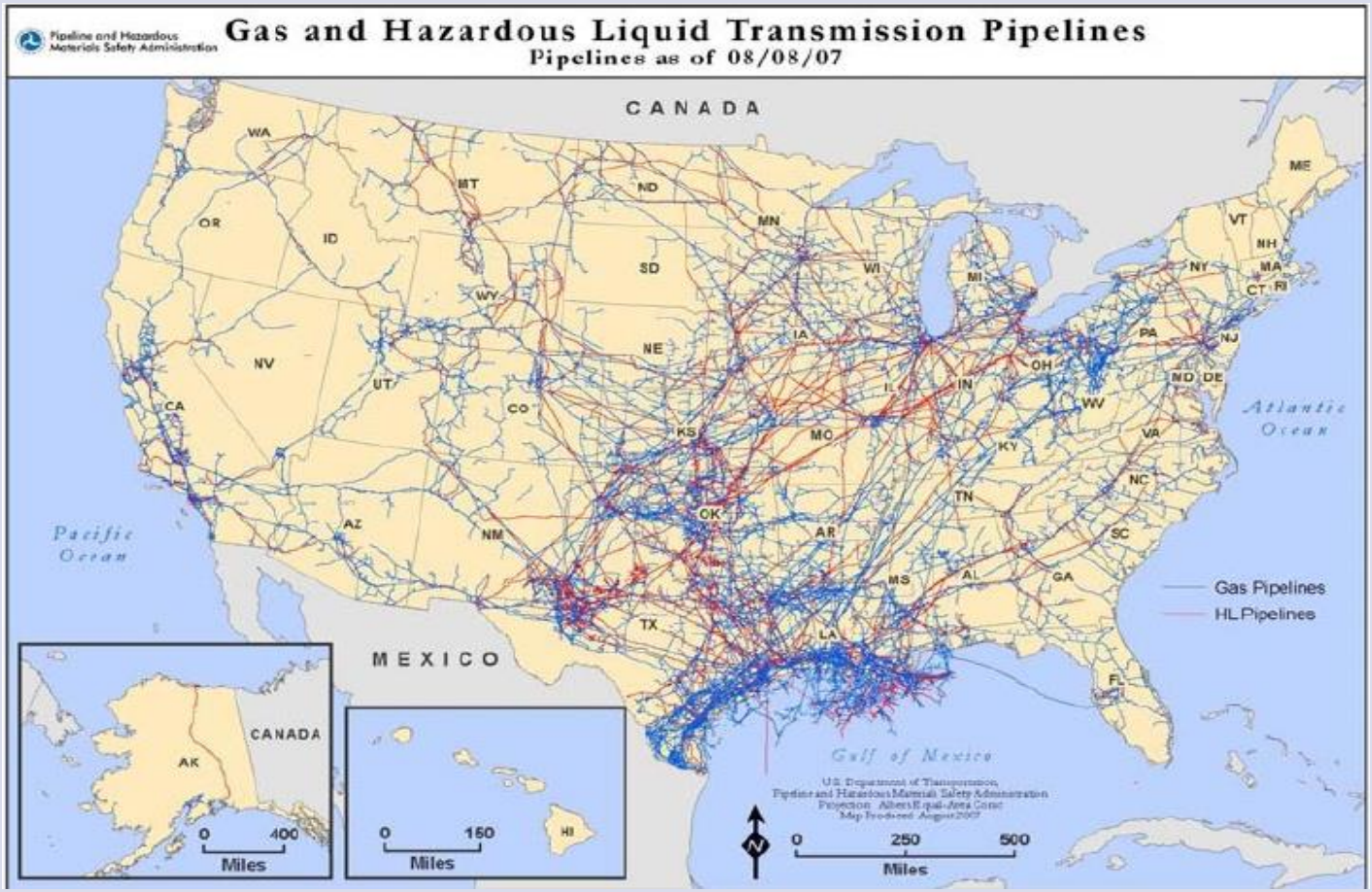
480,000 Miles of Existing Natural Gas and HL Pipelines In-Place Facilitating Shale Production



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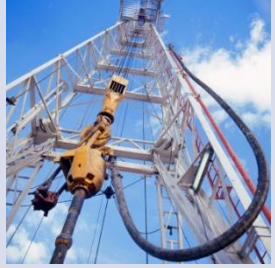
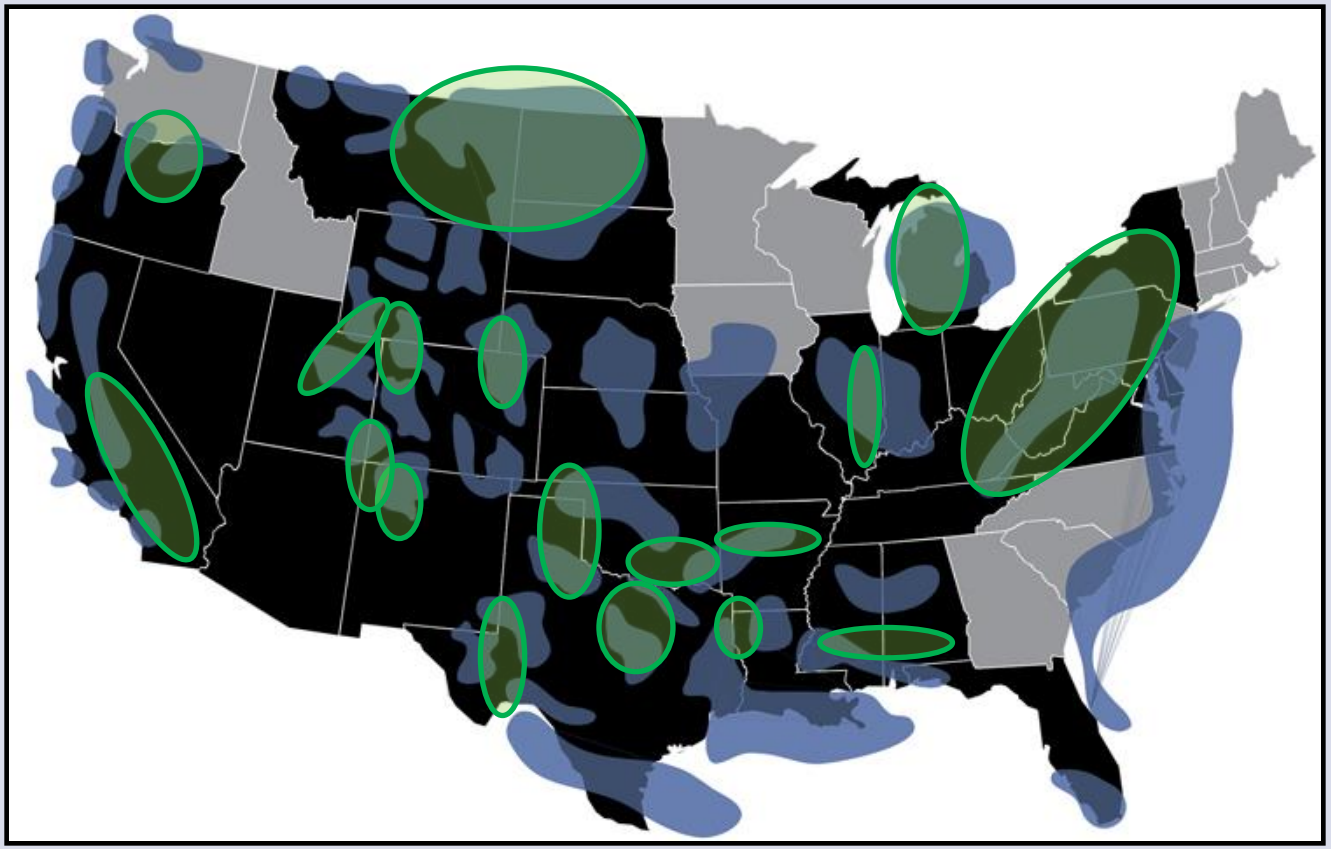



Most U.S. Unconventional Shale Resources Occured in States With Existing Conventional Oil and Gas Regulatory Frameworks In-Place



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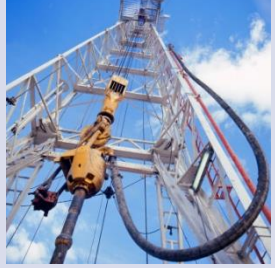


Key Points : State Oil and Gas Regulation

- **Diversity of geology, topography, work force, culture make states logical oil and gas regulators**
- **States have historically been the primary regulators of oil and gas development**
- **States are innovative, flexible, can rapidly respond to changes in technology**
- **States work collaboratively as oil and gas resources cross state boundaries**

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Primary Barriers to and Drivers of Natural Gas Development Challenge States

Public Policy

Regulatory

Technology

Environment

Economic

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States are rising to these challenges as laboratories for creative solutions and regulatory innovation .....
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STATES FIRST INITIATIVE

Governors' letter of support

Robert Bentley
Governor of Alabama
2013 IOGCC Chairman

Gary R. Herbert
Governor of Utah

Sean Parnell
Governor of Alaska

Mary Fallin
Governor of Oklahoma

Tom Corbett
Governor of Pennsylvania

Phil Bryant
Governor of Mississippi

John Hickenlooper
Governor of Colorado

Jack Dalrymple
Governor of North Dakota

Steve Bullock
Governor of Montana

Partnership between IOGCC and GWPC

States First Initiative

Shaping the STATE of our energy future together.

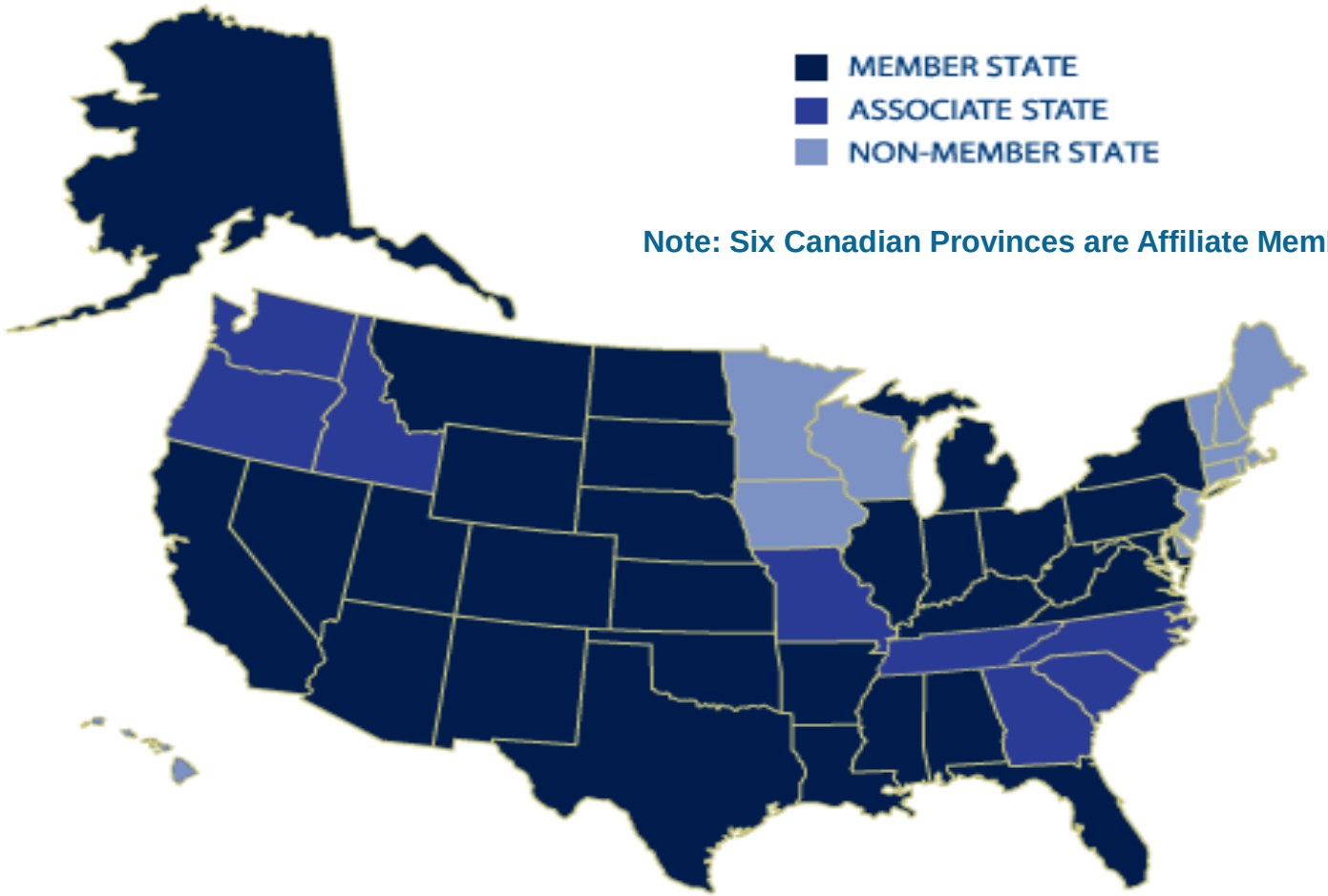
Collaboration, Solutions, Regulatory Leadership

Interstate Oil and Gas Compact

- **Established by Congress in 1935**
- **Governors of oil and gas producing states**
- **Collectively representing the States**
- **State led, Chaired by governors**
  - **Governor Robert Bentley (Alabama) 2013**
  - **Governor Phil Bryant (Mississippi) 2014**
  - **Governor Gary Herbert (Utah) 2015**
- **Promote conservation and efficient recovery of oil & gas while protecting health, safety and the environment**

IOGCC 38 Member States

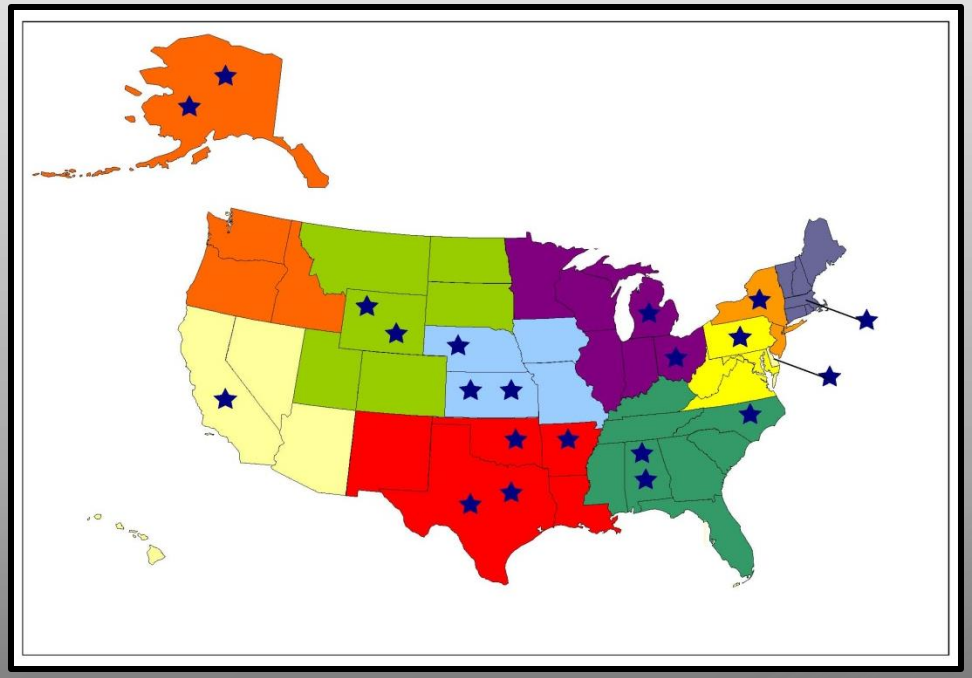
INTERSTATE Oil & Gas COMPACT COMMISSION



Note: Six Canadian Provinces are Affiliate Members

GROUNDWATER PROTECTION COUNCIL

The national association of state groundwater protection programs



What is States First?

- *Partnership between IOGCC and GWPC*
- *Platform demonstrating states continuing regulatory improvements*
- *Initiated by 14 IOGCC member Governors*
- *Announced by 2013 IOGCC Chairman Alabama Governor Bentley*
- *Approved by IOGCC and GWPC governing bodies*

STATES FIRST INITIATIVE

PURPOSES OF THE INITIATIVE

1. ***Recognition of the state's continuing regulatory improvements.***
2. ***Provide a platform for open communication and sharing between state's.***
3. ***Develop best practices.***
4. ***Assist states efficiently develop and implement regulatory solutions.***
5. ***Contribute to Nation's economic growth, national security and energy independence.***

STATES FIRST INITIATIVE

Promoting and Documenting Continuous Regulatory Improvement

- Underground Injection Control
- Hydraulic Fracturing
- Inspector Training & Certification
- Effective Regulation through SOGRE
- Science, Technology and Information Transfer

STATES FIRST INITIATIVE

UNDERGROUND INJECTION CONTROL

- ***Peer Reviews of State Class II Regulatory Programs***
- ***Consultation with States on Regulatory Improvements***

EFFECTIVE REGULATION THROUGH SOGRE

- ***Peer Reviews and Consultations of Oil and Gas Regulatory Programs***
- ***State to State Issue Focused Workshops and Forums – Utah Horizontal Well Spacing Workshop***
- ***Stakeholder Forums***

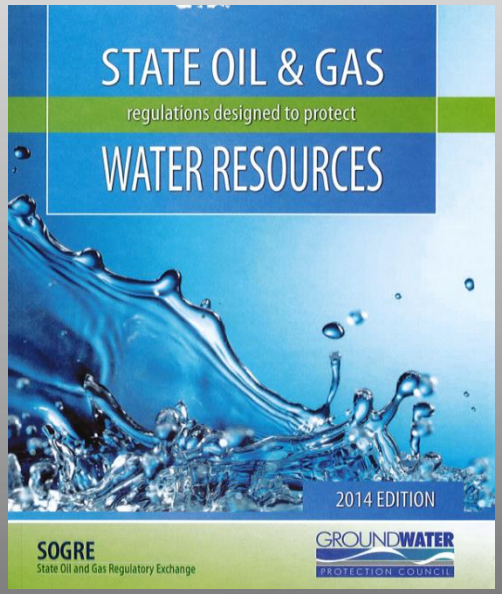
STATES FIRST INITIATIVE

INSPECTOR TRAINING AND CERTIFICATION

- ***State Oil and Gas Inspector Training Program (Affiliated With Universities')***
- ***State Oil and Gas Inspector Certification Program***

INFORMATION, TECHNOLOGY AND SCIENCE TRANSFER

- ***Recently created Seismicity Task Force***
- ***New report on state regulations to protect groundwater.***



STATES FIRST INITIATIVE

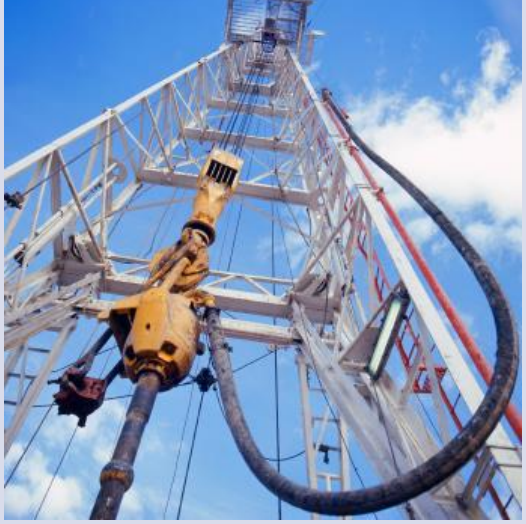
HYDRAULIC FRACTURING

- ***Chemical Disclosure through Frac Focus***

STATES FIRST INITIATIVE

GOALS

- Continuous Improvement
- Build Public Confidence
- Open Communications For States and Federal Agencies
- Empower states
- Educate Congress
- Inform Industry


STATES FIRST INITIATIVE

A Partnership of IOGCC and GWPC

Questions ?

StatesFirst

An Initiative of the IOGCC & GWPC

Critical Issues Forum

America's Increasing Reliance on Natural Gas: Benefits and Risks of a Methane Economy

Wifi network: FWC Wireless
Password: (no password needed)

AGI american geosciences institute
connecting earth, science, and people