Pore Types Across Thermal Maturity: Eagle-Ford Formation, South Texas*

Maxwell E. Pommer[1], Kitty L. Milliken[1], and Aysen Ozkan[2]

Search and Discovery Article #50987 (2014)**
Posted July 24, 2014

*Adapted from oral presentation given at 2014 AAPG Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014

[1]The Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas, USA (maxwell.pommer@gmail.com)
[2]Shell International Exploration and Production, Houston, Texas, USA

Abstract

Scanning electron microscopy of Ar-ion milled samples shows that character and evolution of porosity is strongly affected by type, abundance and distribution of organic matter (OM) within the Eagle Ford Formation, South Texas. Samples were collected, imaged and quantified to provide insight into pore types and distributions across a range of thermal maturities. Low maturity samples contain pore networks dominated by relatively large coccolith-hosted primary intergranular pores with a mean equivalent circular diameter of ~110 nm, ranging up to ~2 μm. Primary intragranular pores are observed within coccolith fragments, coccolith-bearing fecal pellets, foraminifers, phosphate clasts, and other skeletal debris. OM-associated pores at low maturity are dominantly large pores at boundaries between organic matter and mineral surfaces with a mean equivalent circular diameter of ~100 nm. Smaller pores within clay-associated OM are observed, with a mean equivalent circular diameter of ~30 nm. In contrast, high-maturity samples show porosity dominated by secondary pores within OM. OM consisting of smaller equant pores grading into larger pores with more complex and irregular shapes. Measured OM-hosted pores range in equivalent circular diameter from ~4 nm to ~400 nm with a mean of ~22 nm within high maturity samples. Mineral-hosted pores are also present at higher maturities, many associated with clay minerals or dolomite, but are much smaller, with a mean equivalent circular diameter of ~60 nm ranging up to ~850 nm. In addition, fecal pellets and skeletal grains are observed to contain OM that pervasively fills intra-particle pore space, which suggest that porosity is reduced through incursion of mobilized bitumen. Both detrital kerogen and diagenetic bitumen are present at both high and low maturity, and cause porosity loss both through deformation of ductile kerogen with compaction, as well as incursion of primary pore space with mobilized diagenetic bitumen. As thermal maturation increases, bitumen is mobilized filling intra-particle pore space, and secondary pores develop within OM.

Reference Cited

U.S. Energy Information Administration, 2014, Eagle Ford Shale Play, Western Gulf Basin, South Texas: Web Accessed July 4, 2014. http://www.eia.gov/oil_gas/rpd/shaleusa9.pdf.

Pore Types Across Thermal Maturity: Eagle-Ford Formation, South Texas

Maxwell E. Pommer[1], Kitty L. Milliken[1], Aysen Ozkan[2]

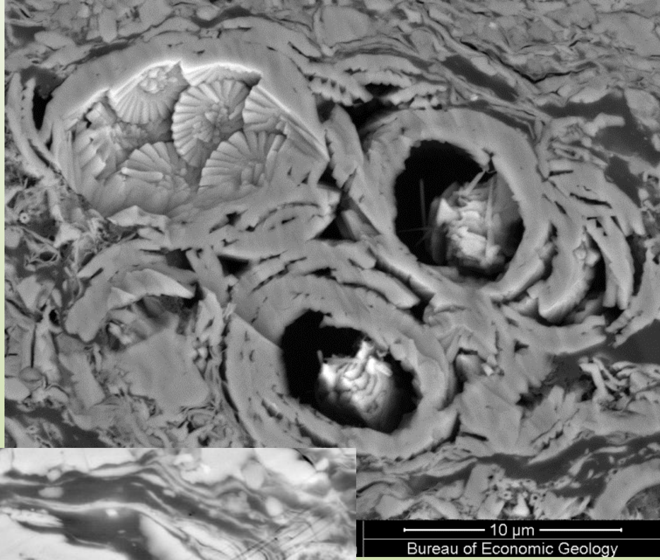
[1] *Bureau of Economic Geology*

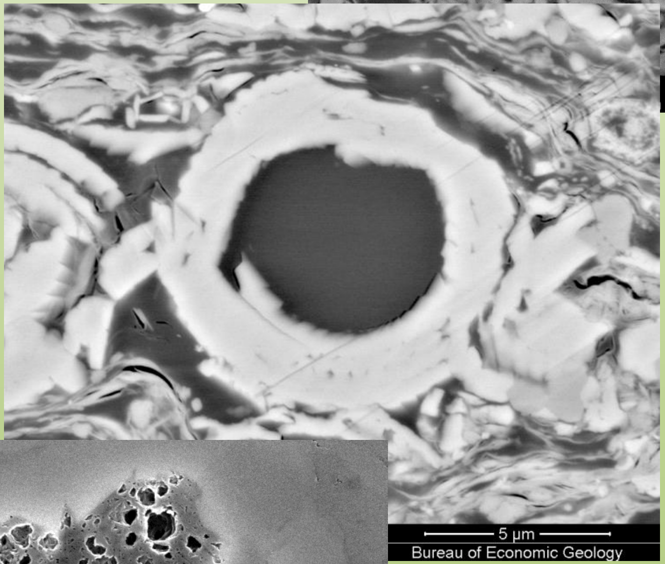
[2] *Shell International Exploration and Production*

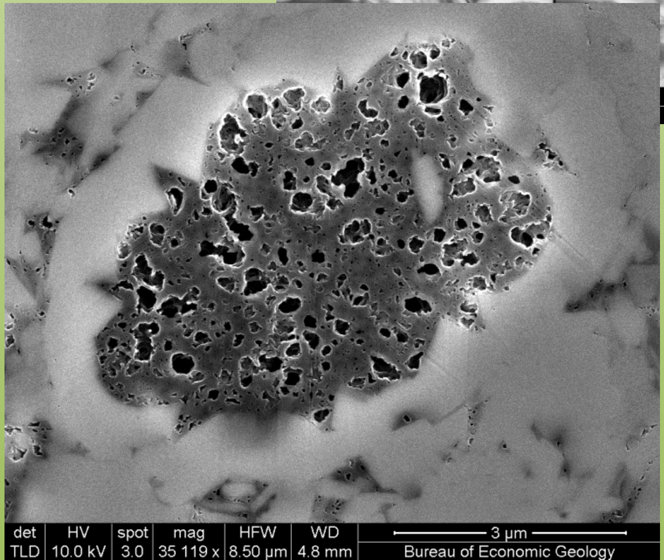
Supported by Shell/University of Texas Unconventional Research (SUTUR), Project 3, "Characterization of Mudrocks by Quantitative Analysis of High-resolution SEM Images"; K. Milliken, N. Hayman, Co-PIs

BUREAU OF ECONOMIC GEOLOGY

- **What controls porosity in mudrocks?**
  - Chemical processes
    - Cementation
    - Bitumen infill
    - OM-hosted pore generation
  - Physical processes
    - Compaction
    - Fracturing

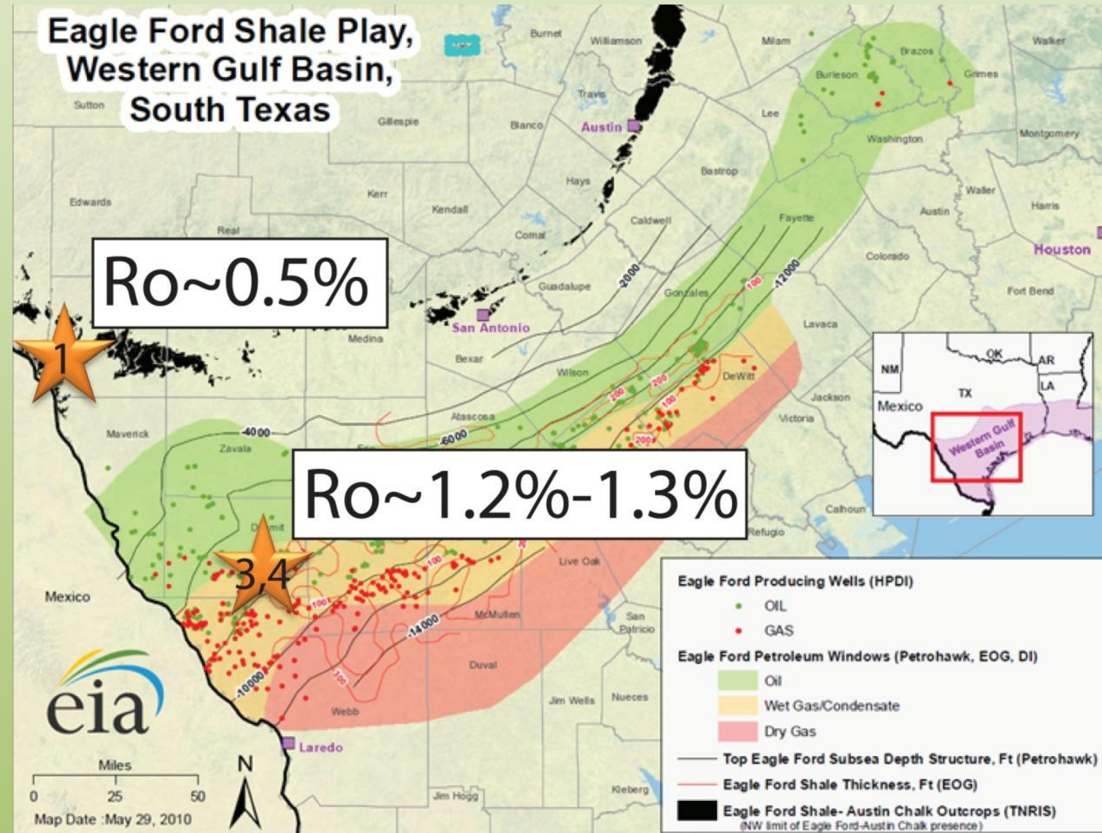






Samples

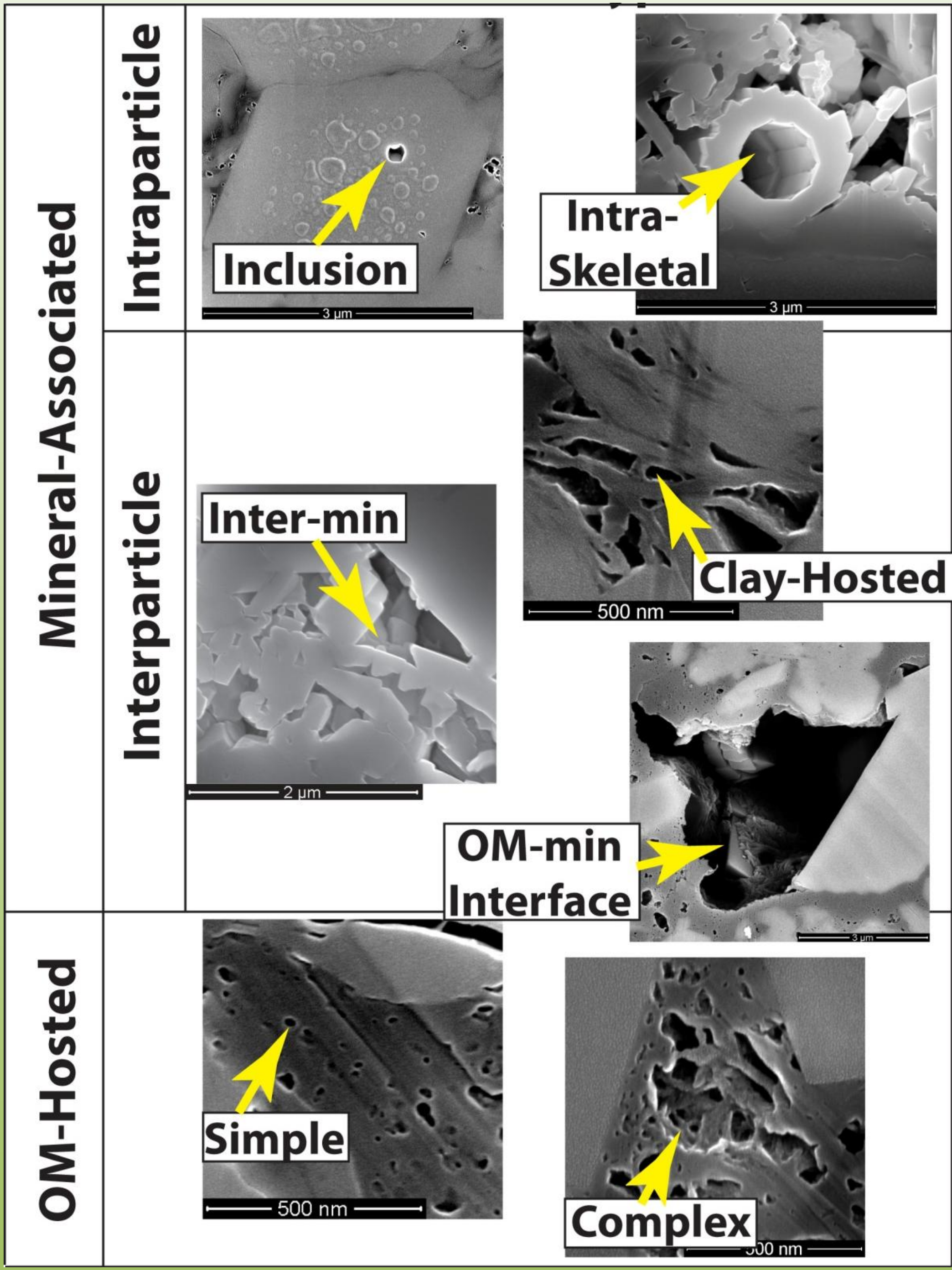
- 18 samples, 3 wells
  - Argon-ion cross-section polished
- Low-Maturity
  - Well #1: 7 samples
    - Early oil window (Ro~0.5%)
    - Outcrop core (~100m)
    - Mineral-associated pores
    - Non-porous OM
- High Maturity
  - Well #3: 4 samples
    - Wet gas window (Ro~1.2%)
    - Depth (~2,500 m)
    - OM-hosted and mineral-associated pores
  - Well #4: 7 samples
    - Wet gas window (Ro~1.3%)
    - Depth (~2,800 m)
    - OM-hosted pores



(U.S. Energy Information Administration, 2014)

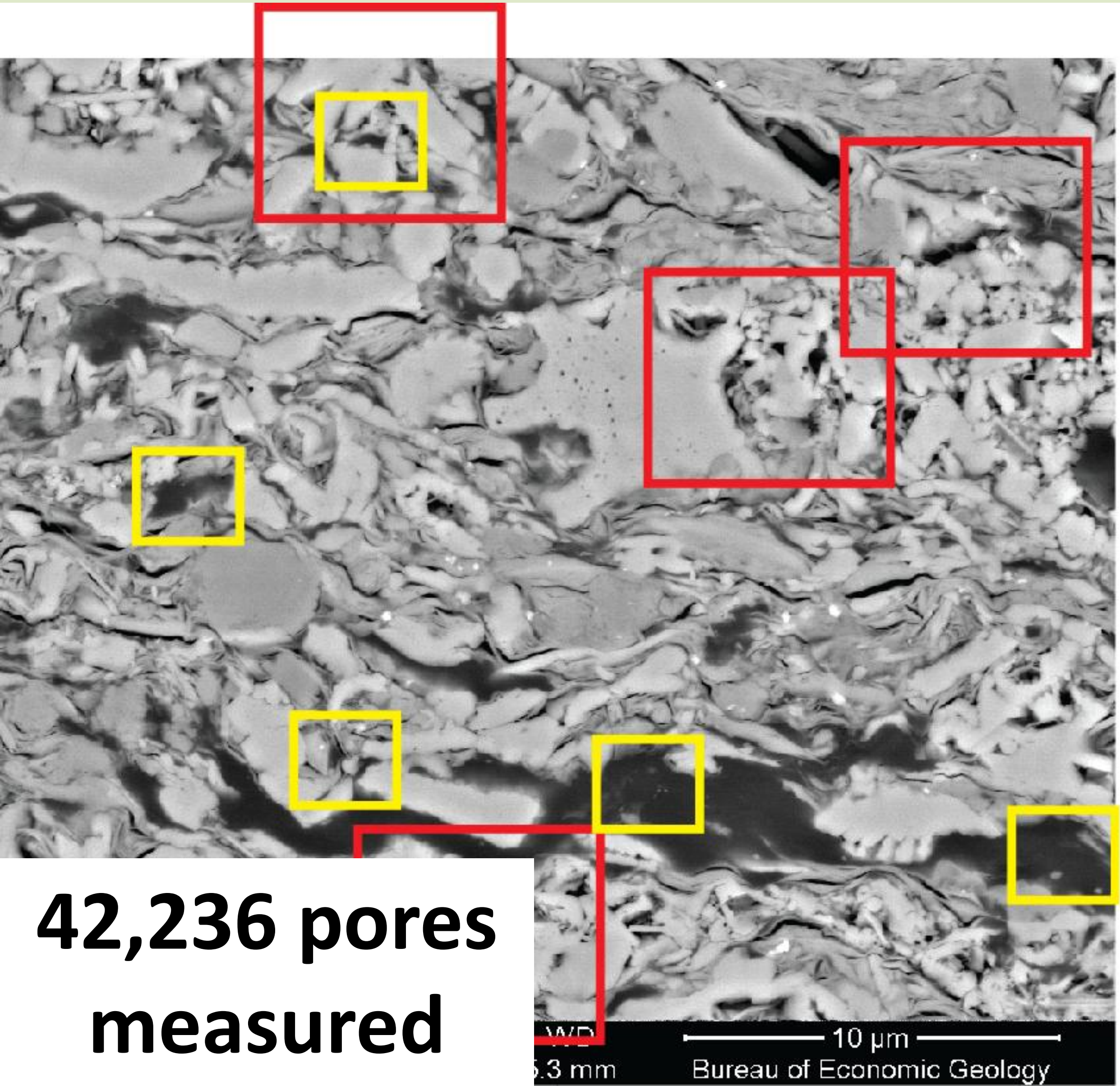
Common Pore Types

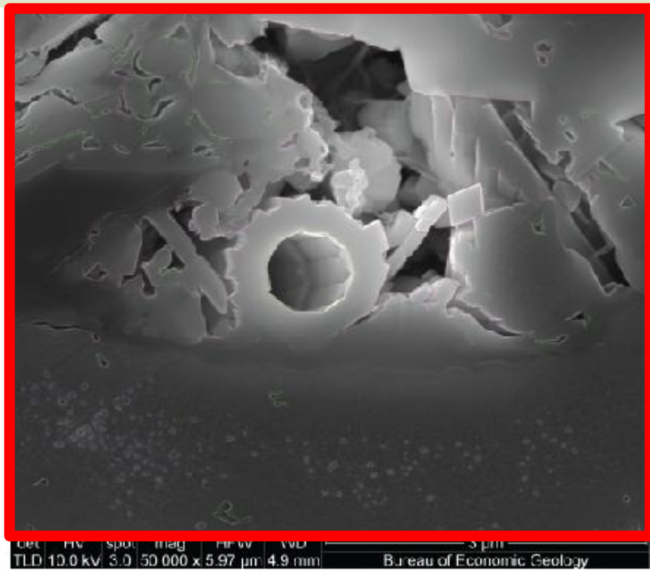
- Mineral-associated
  - Inter-particle
    - Inter-mineral*
    - OM-mineral interface*
  - Clay-hosted
  - Intra-particle
    - Intra-skeletal*
    - Intra-inclusion
- OM-hosted
  - Simple
  - Complex

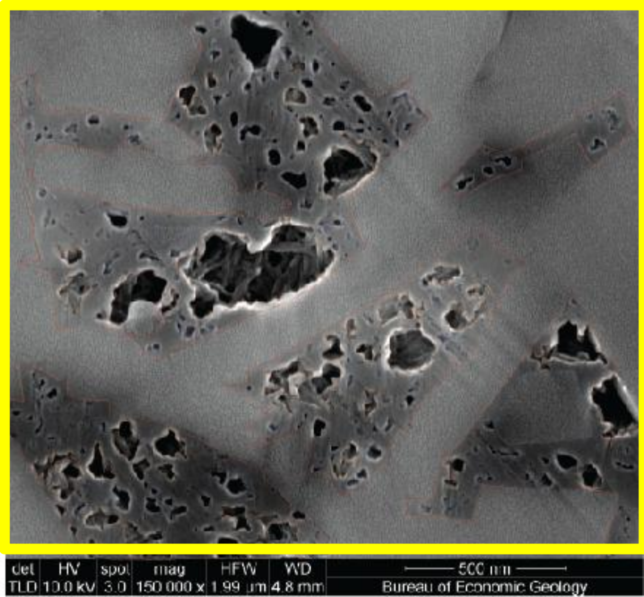


Quantification

- 2 images at 10,000x for pt ct
- 8 images at 50,000x for MIN pores
- 10 images at 150,000x for OM pores

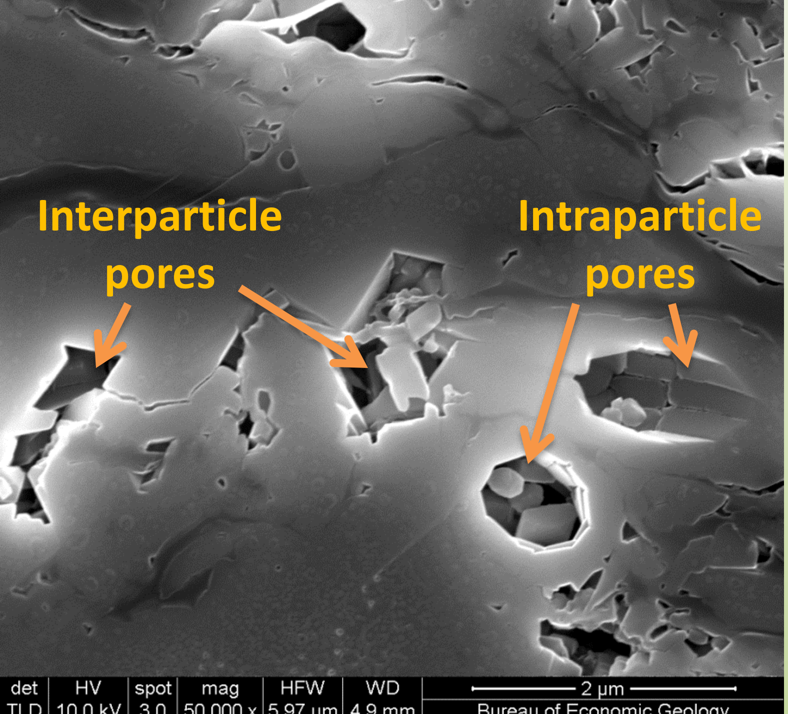


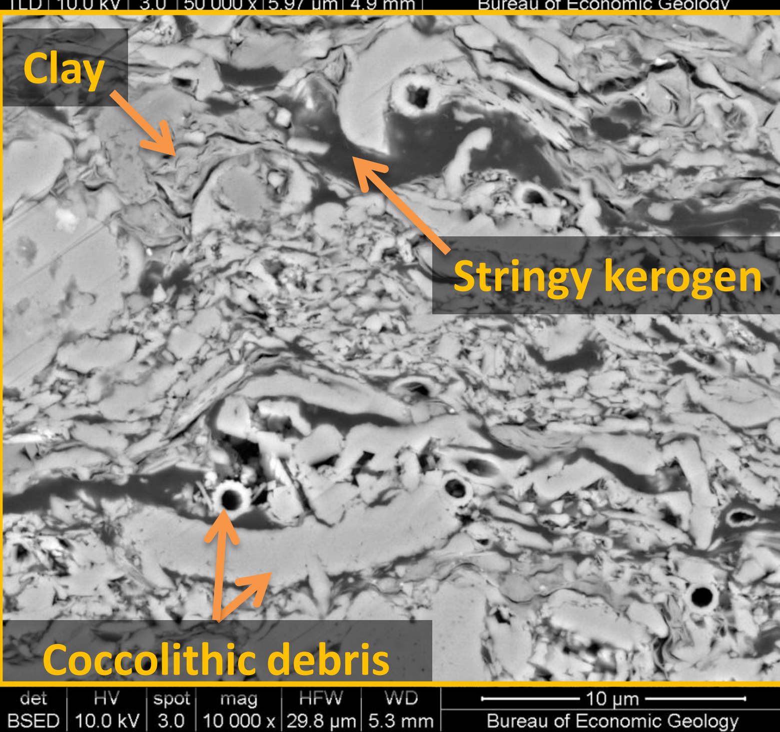


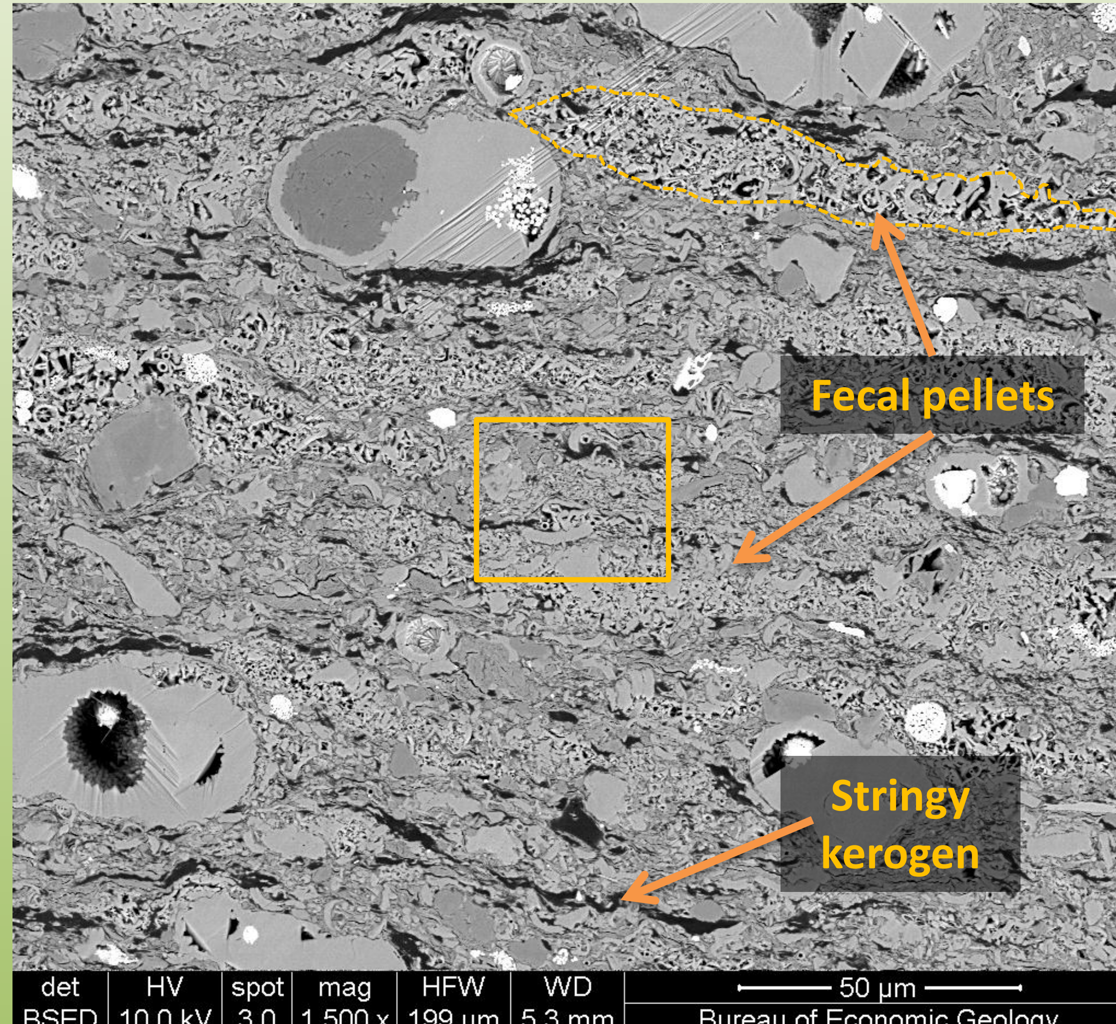


42,236 pores measured

Well #1: Ro~0.5%: Sample 16

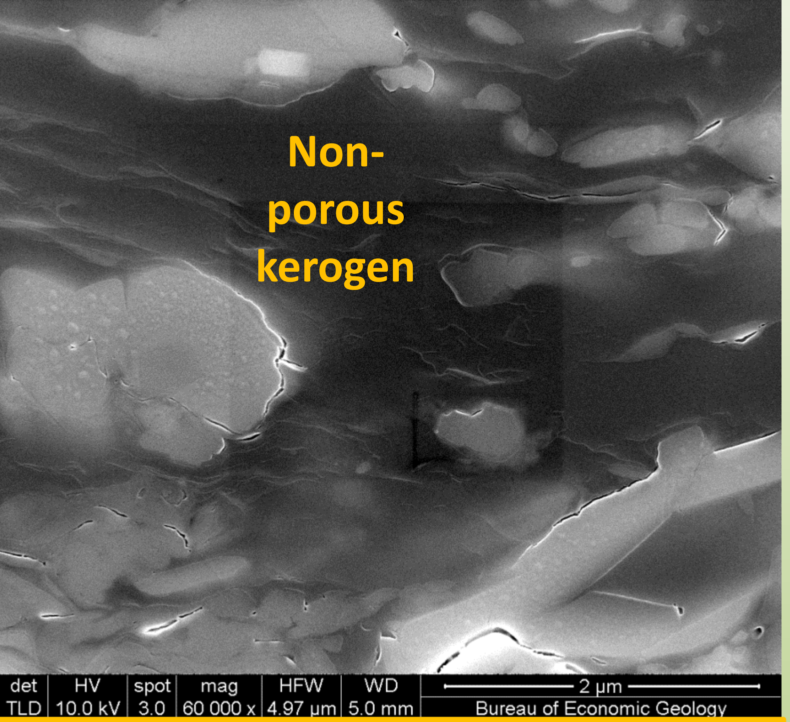


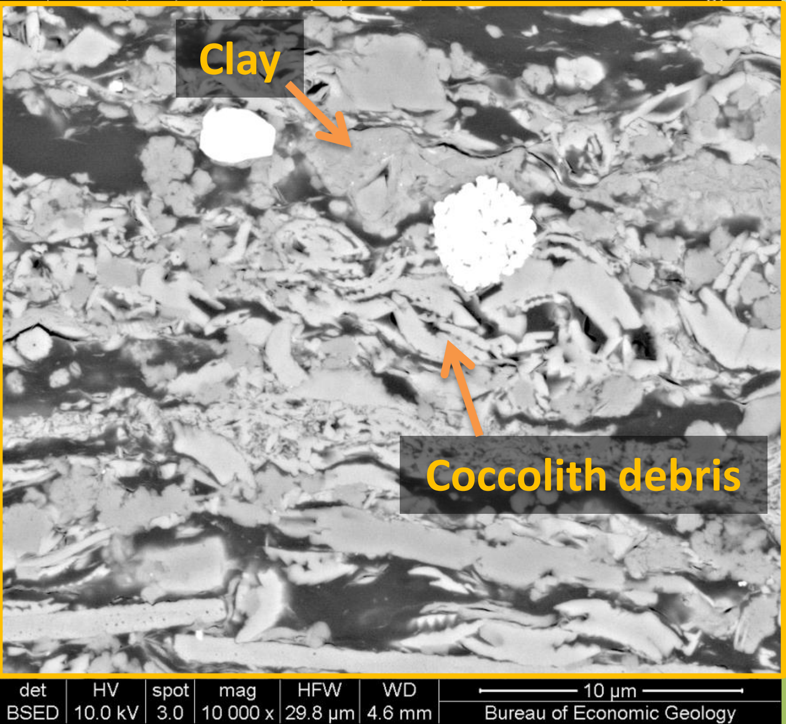


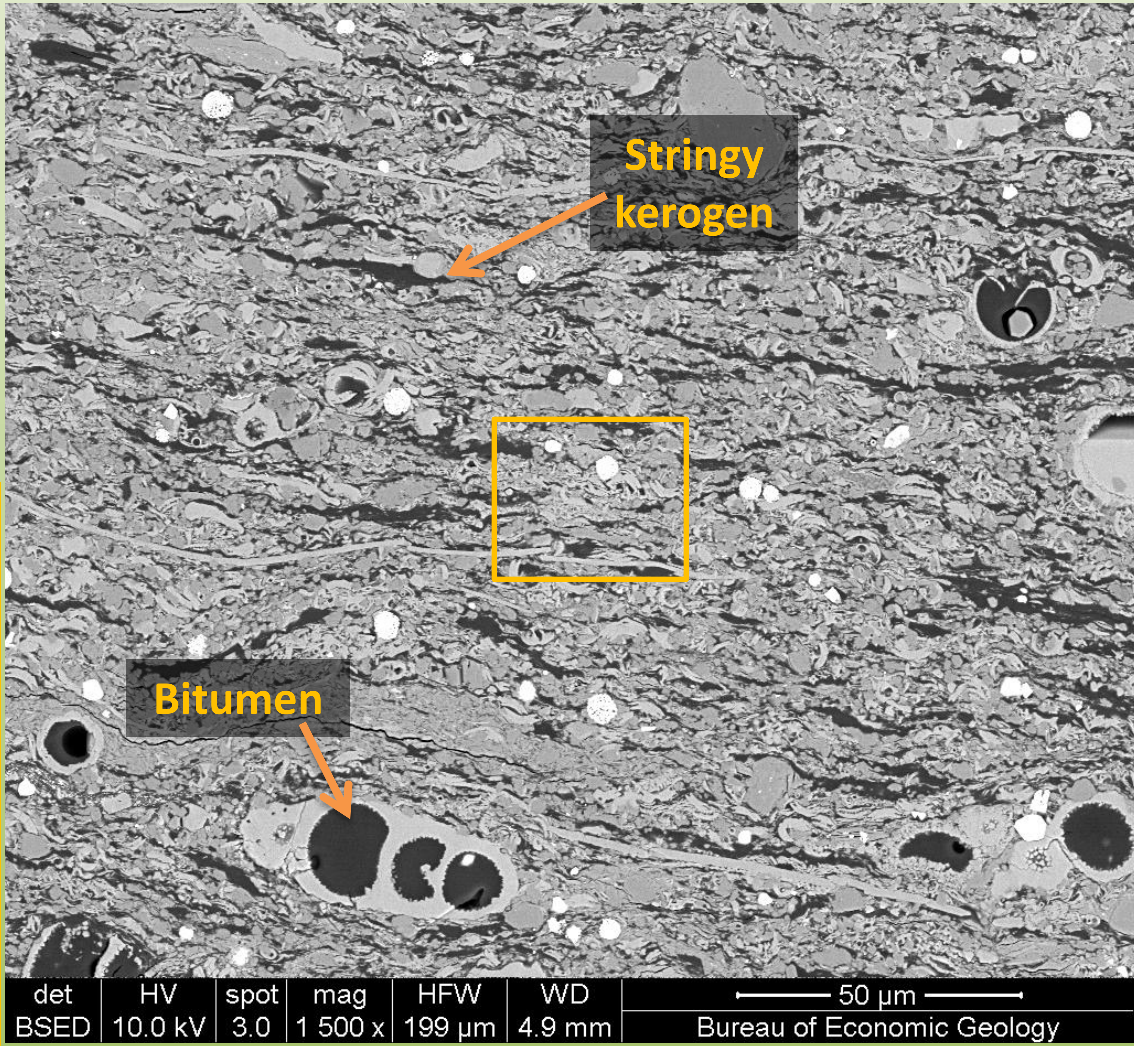


TOC=14.6 (BV%-ϕOM)
Total ϕ=5.9%

Well #1: Ro~0.5%
Sample 4



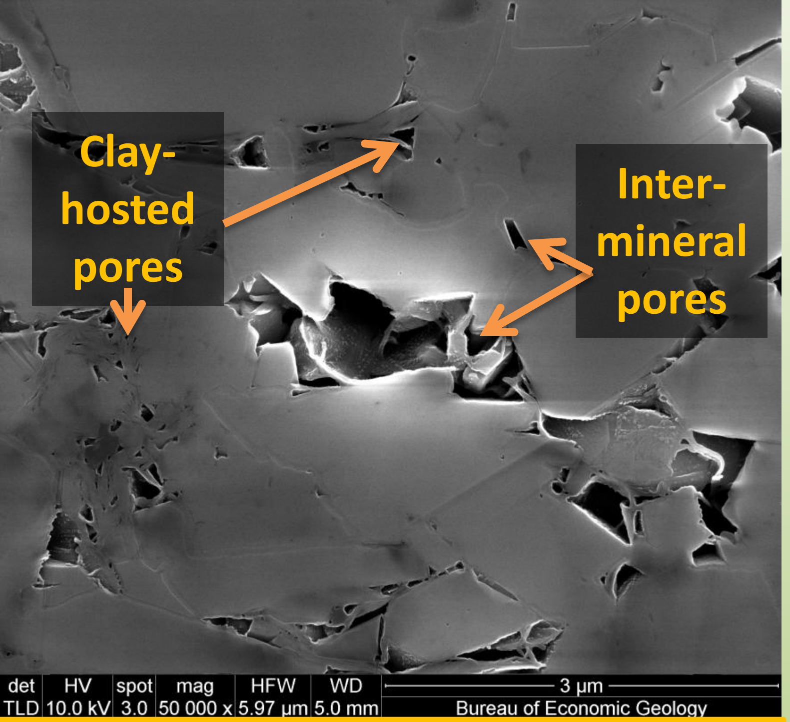


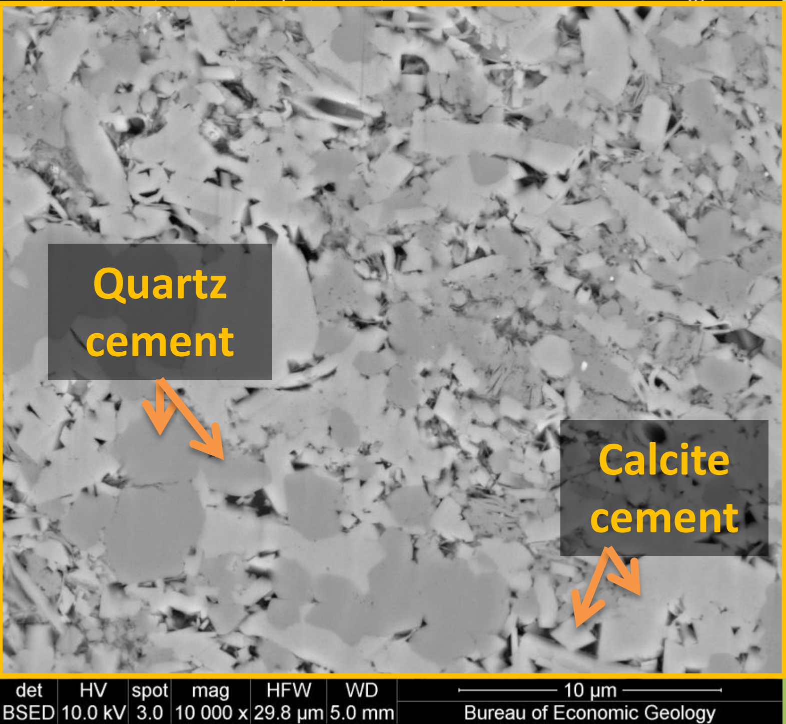


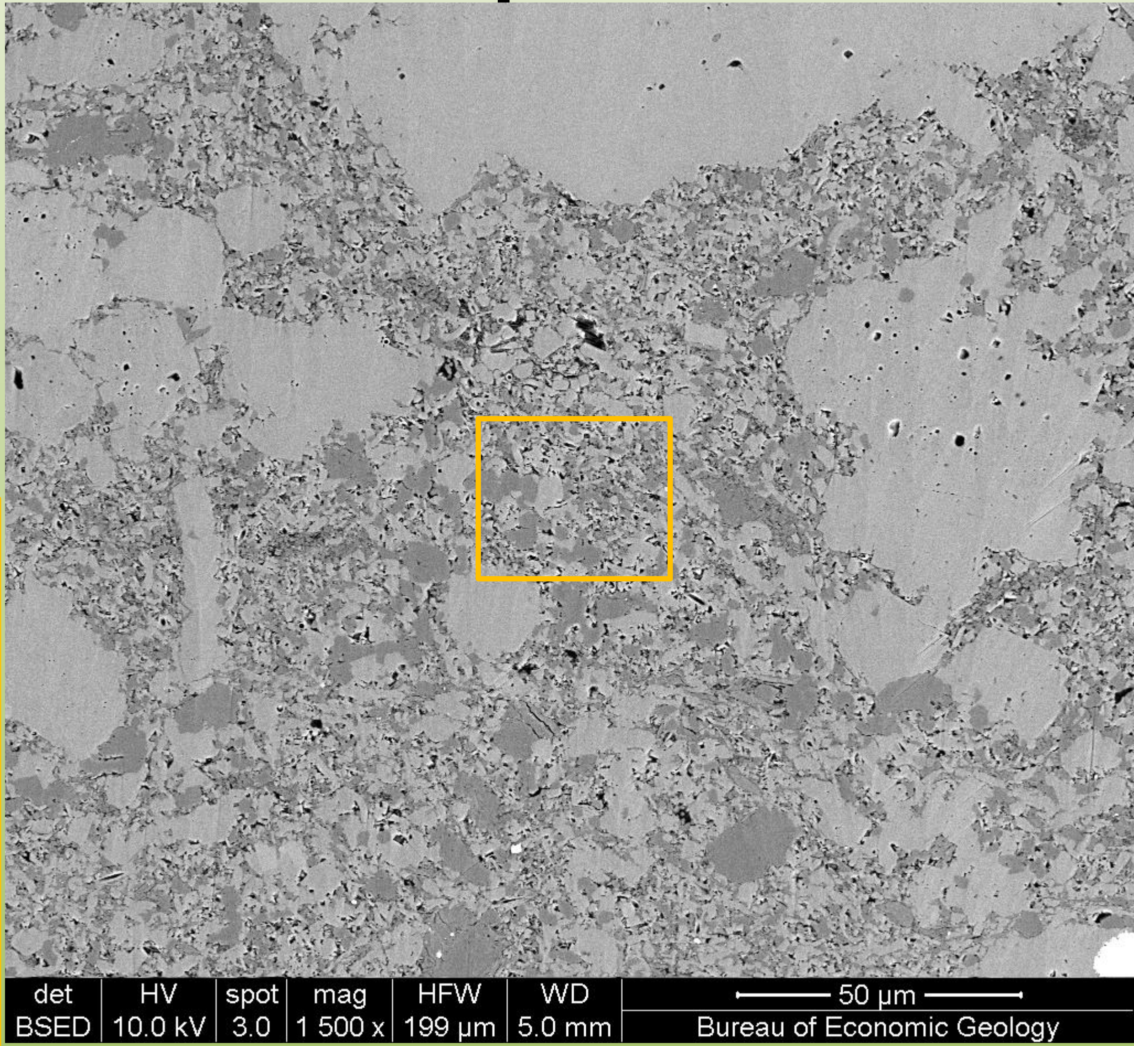
TOC=31.0 (BV%-ϕOM)

Total ϕ=0.1%

Well #3: Ro~1.2% Sample 1-66



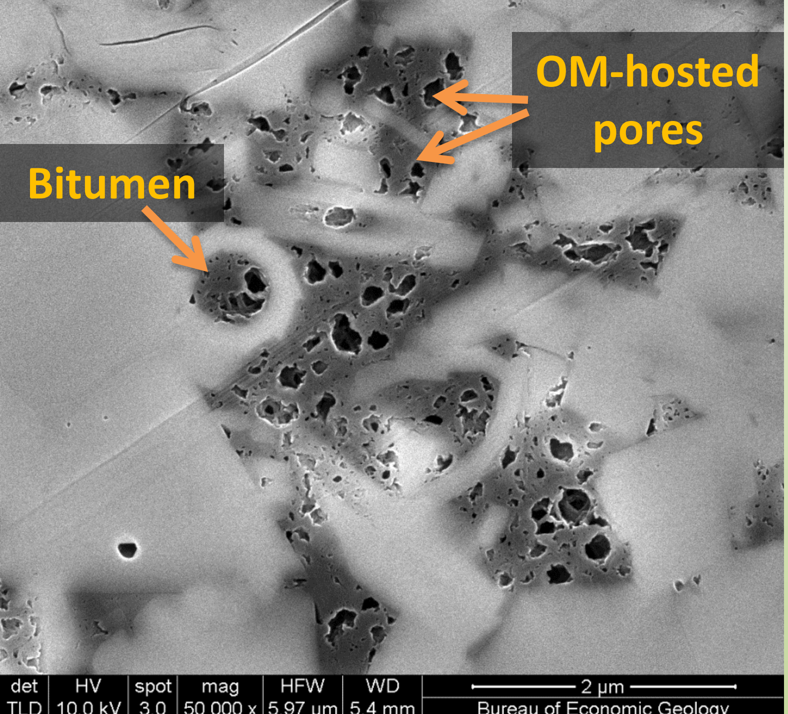


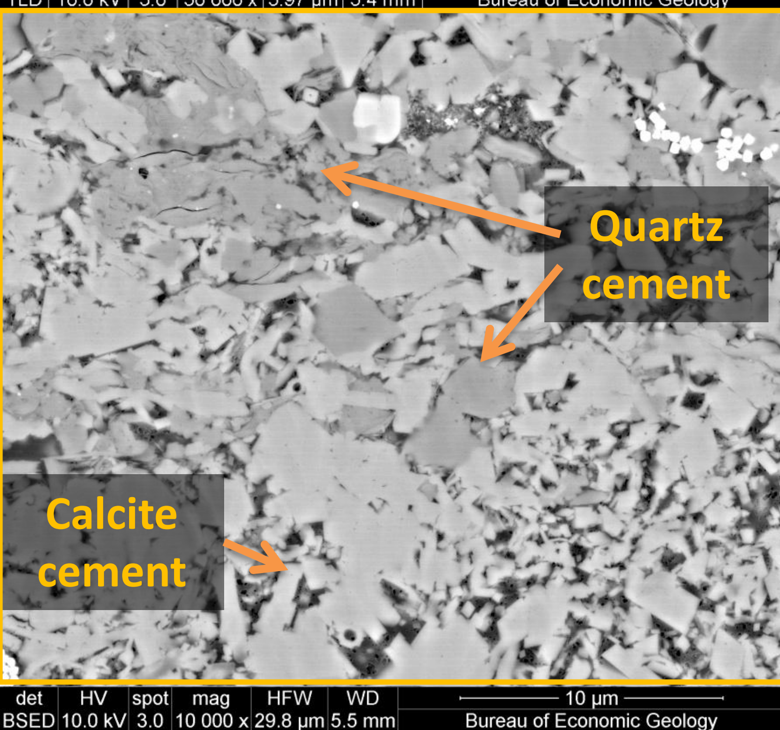


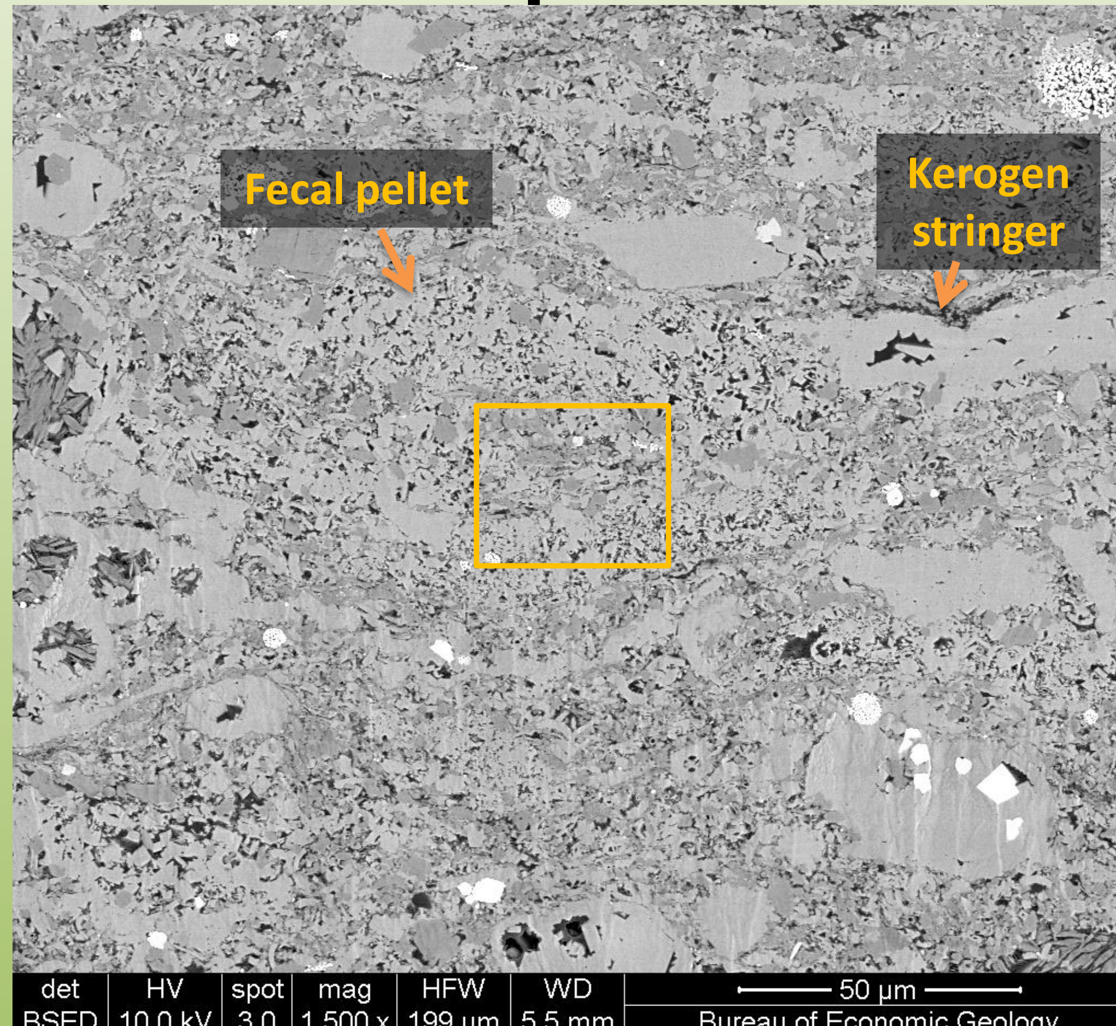
TOC=1.0 (BV%-ϕOM)

Total ϕ=7.7%

Well #4: Ro~1.3%
Sample 1-75



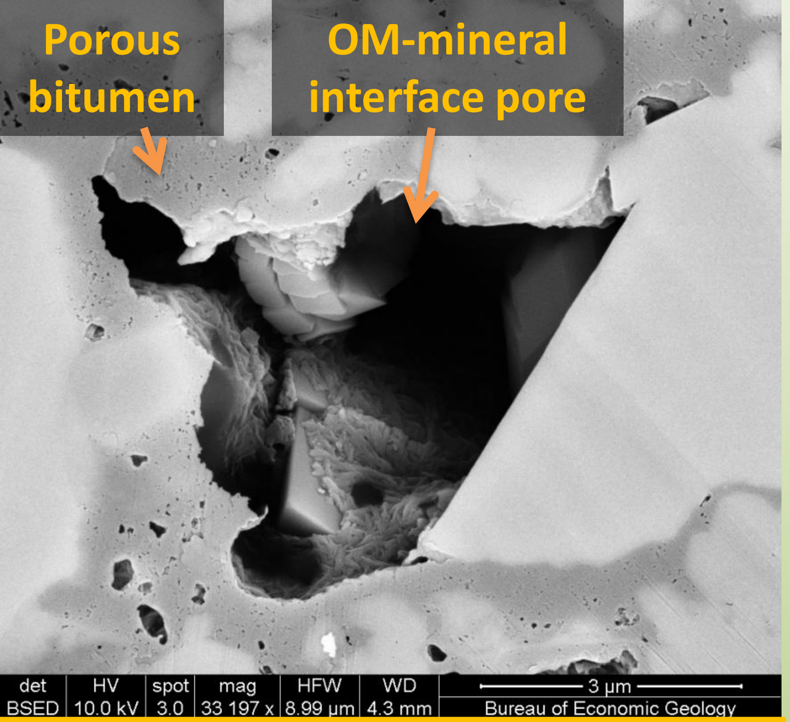


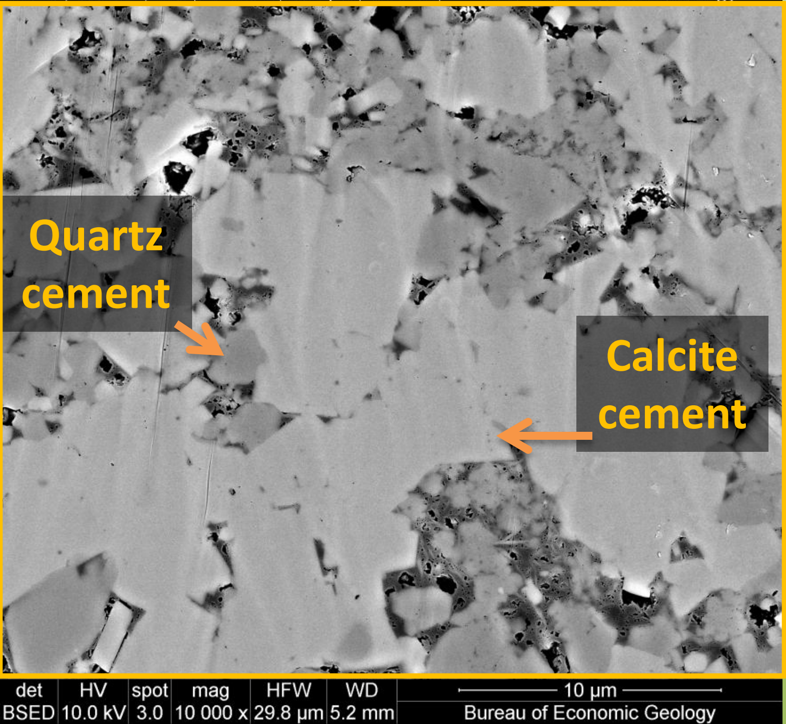


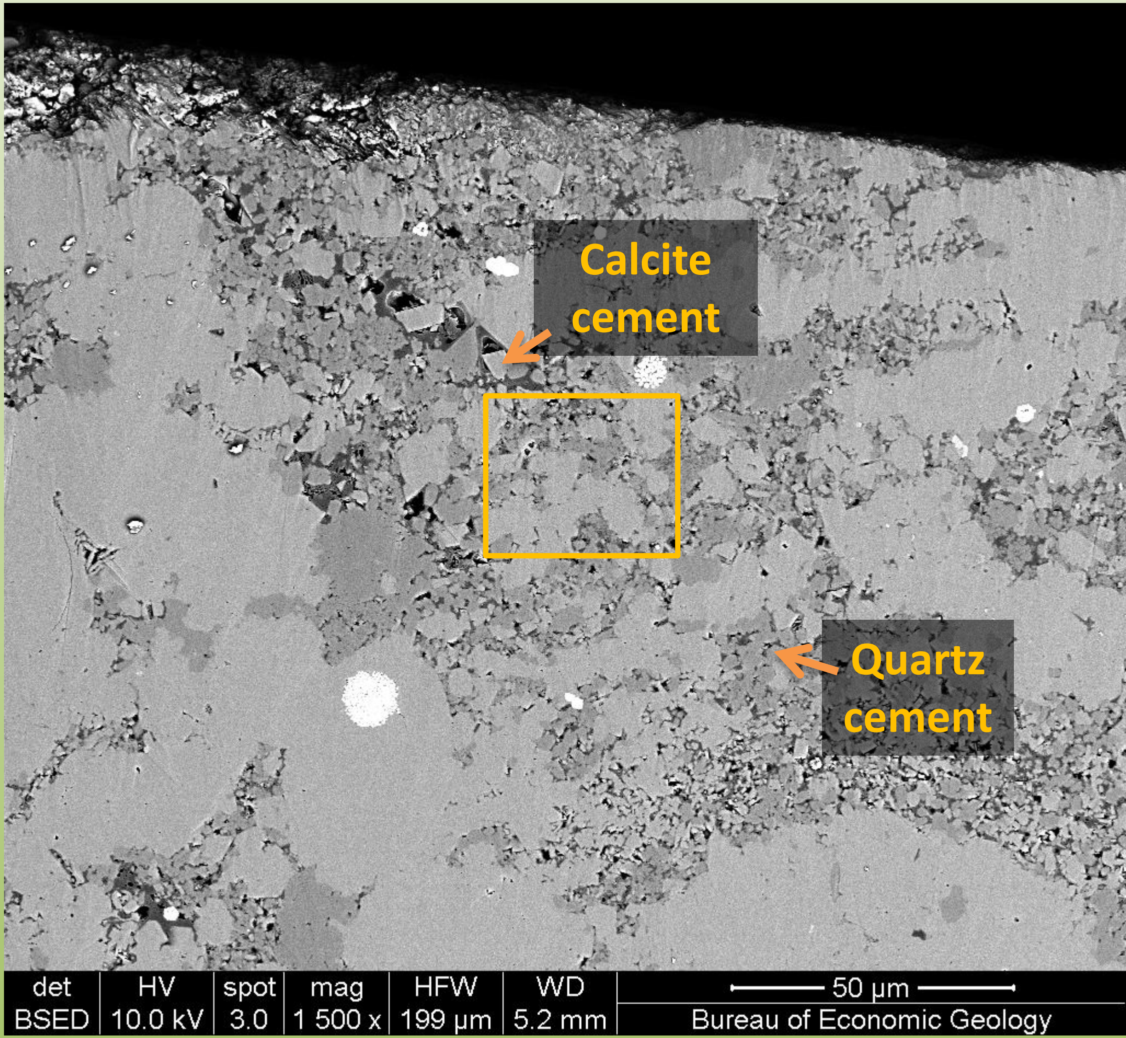
TOC=9.31 (BV%-ϕOM)

Total ϕ=3.0%

Well #4: Ro~1.3%
Sample 1-80

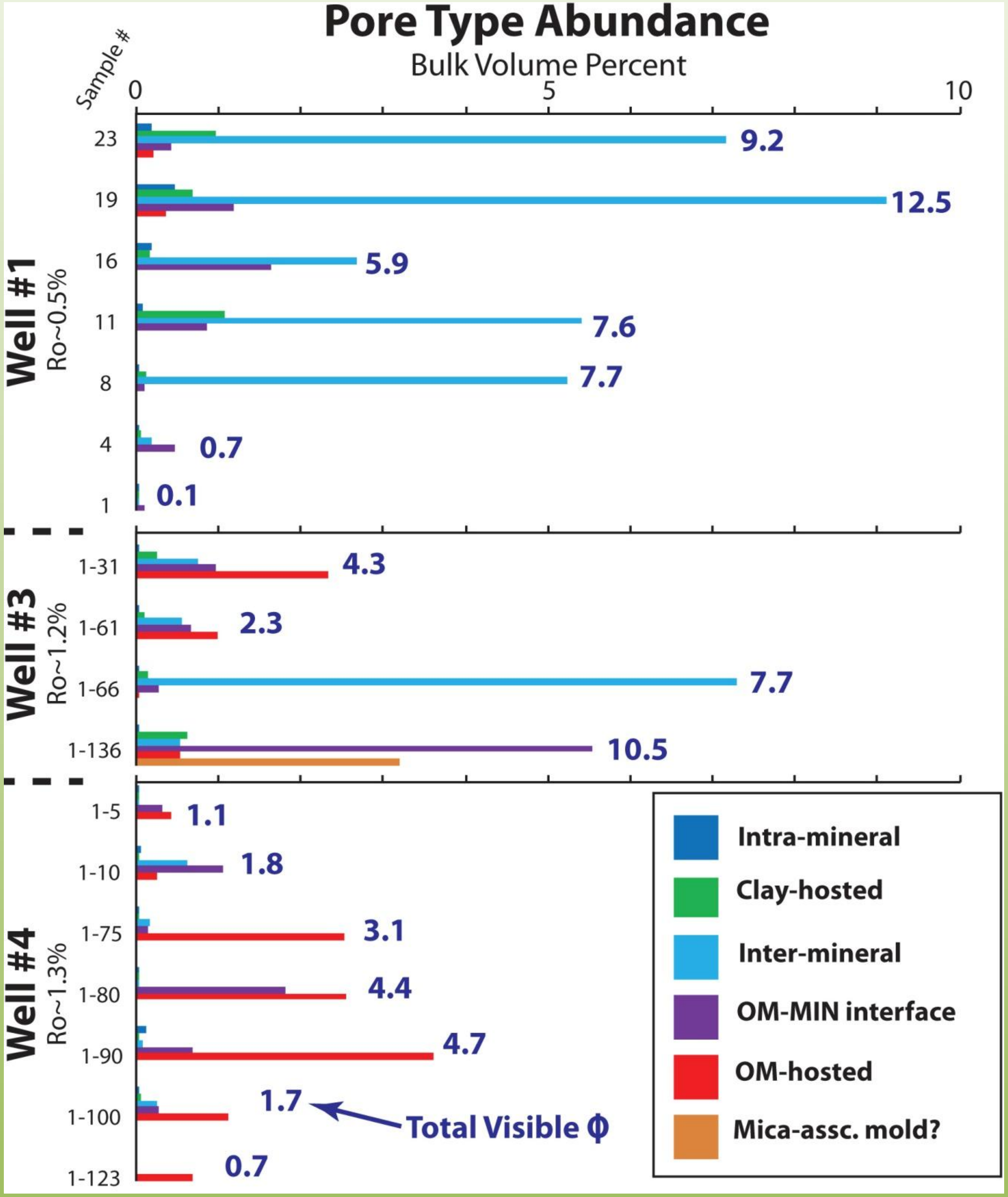




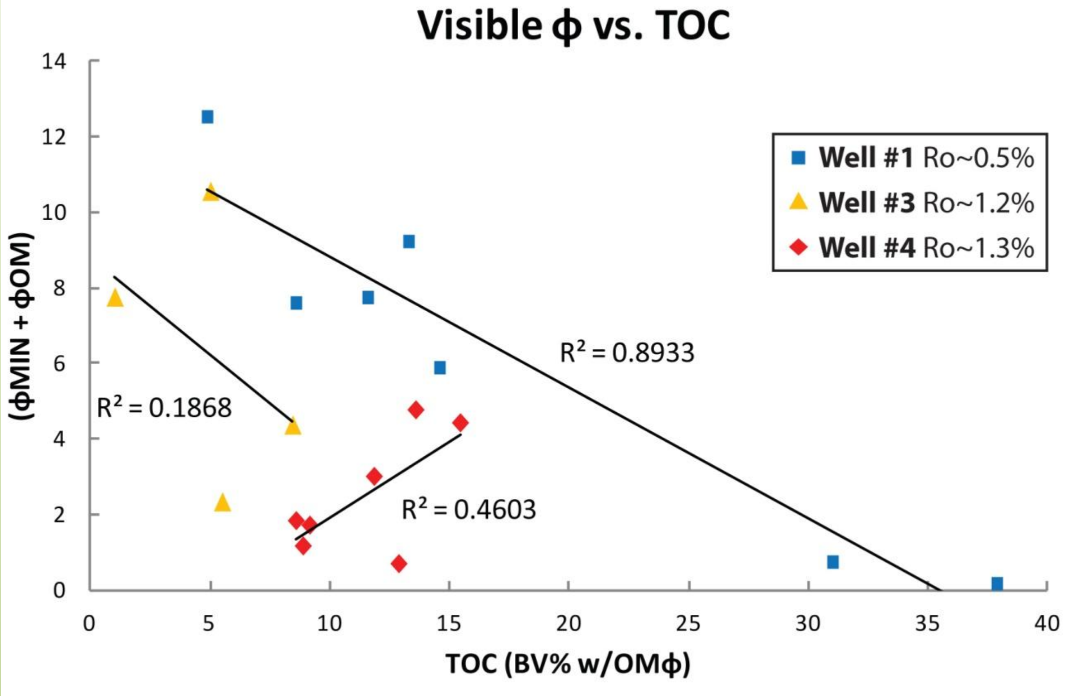


TOC=12.9 (BV%-ϕOM)

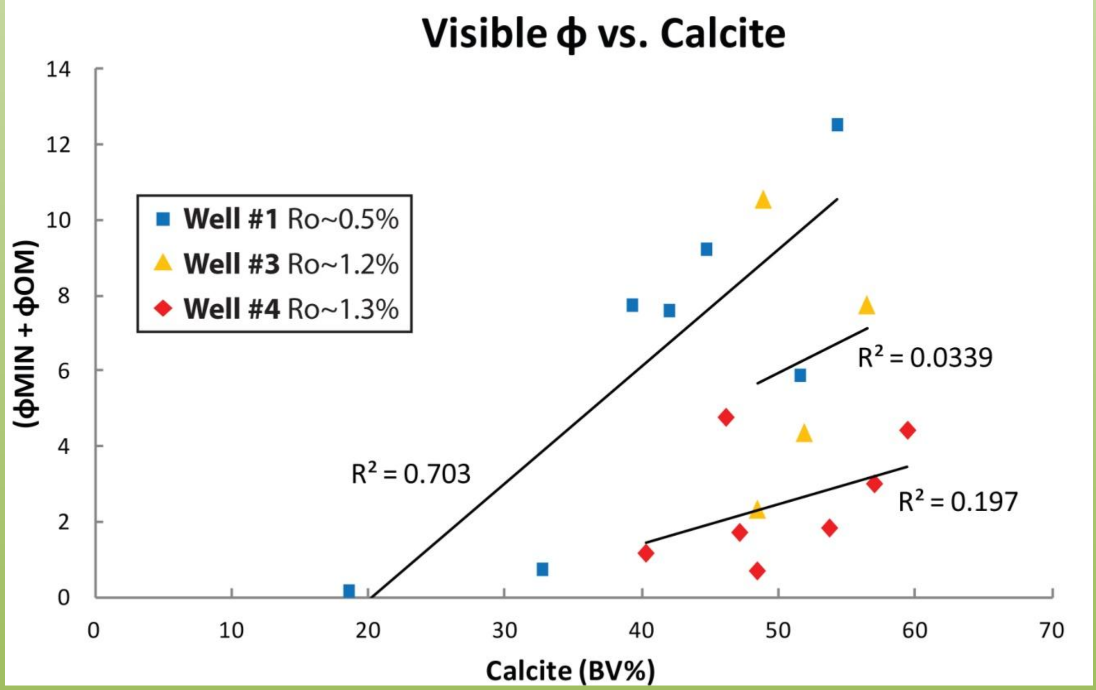
Total ϕ=4.4%



Pore Type Abundance
Bulk Volume Percent
Sample #
0
5
10
Well #1
Ro~0.5%
23
9.2
19
12.5
16
5.9
11
7.6
8
7.7
4
0.7
1
0.1
Well #3
Ro~1.2%
1-31
4.3
1-61
2.3
1-66
7.7
1-136
10.5
Well #4
Ro~1.3%
1-5
1.1
1-10
1.8
1-75
3.1
1-80
4.4
1-90
4.7
1-100
1.7
Total Visible ϕ
1-123
0.7
Intra-mineral
Clay-hosted
Inter-mineral
OM-MIN interface
OM-hosted
Mica-assc. mold?

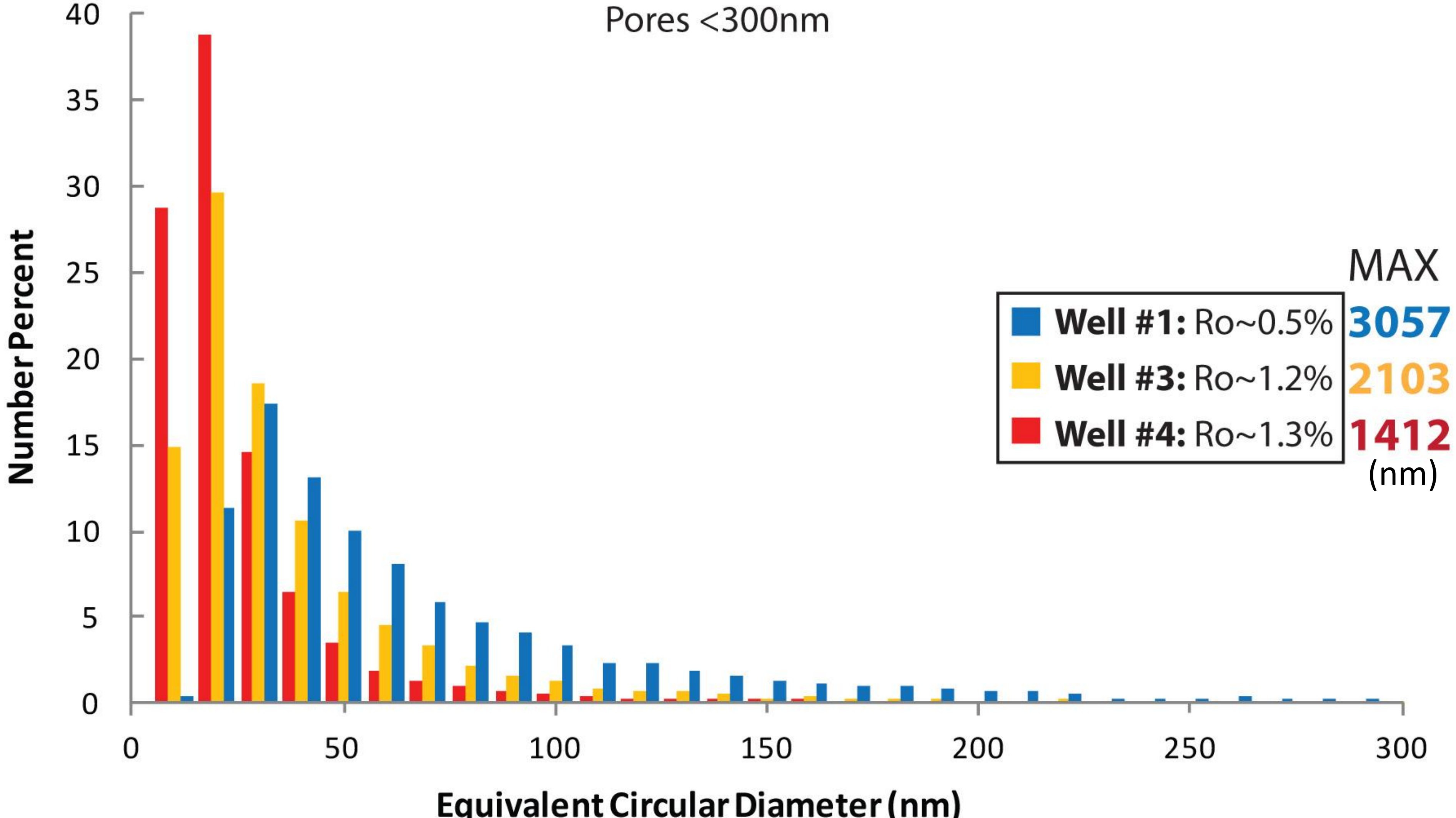


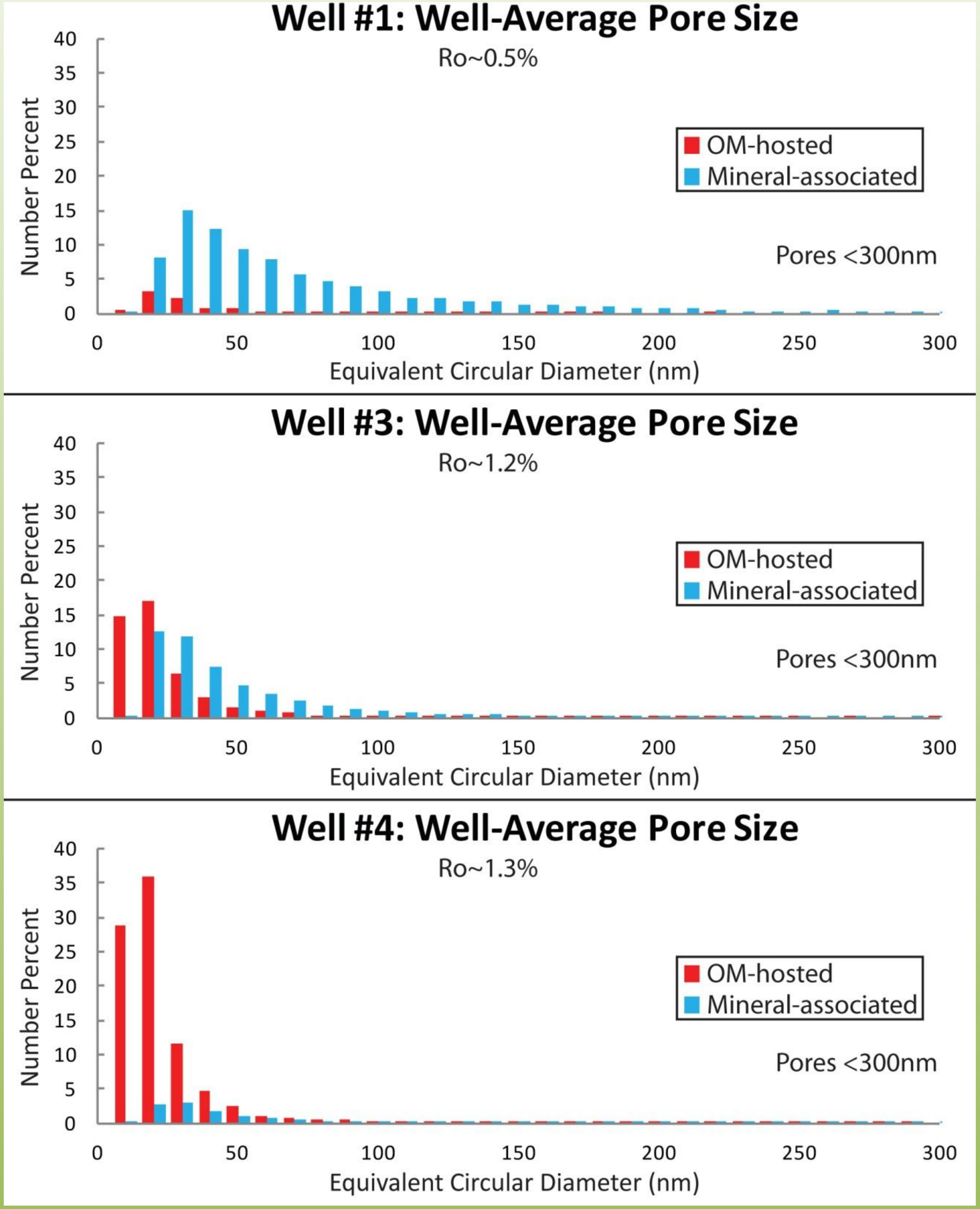
Visible ϕ vs. TOC
(ϕMIN + ϕOM)
TOC (BV% w/OMϕ)
Well #1 Ro~0.5%
Well #3 Ro~1.2%
Well #4 Ro~1.3%
R² = 0.8933
R² = 0.1868
R² = 0.4603
0
2
4
6
8
10
12
14
0
5
10
15
20
25
30
35
40

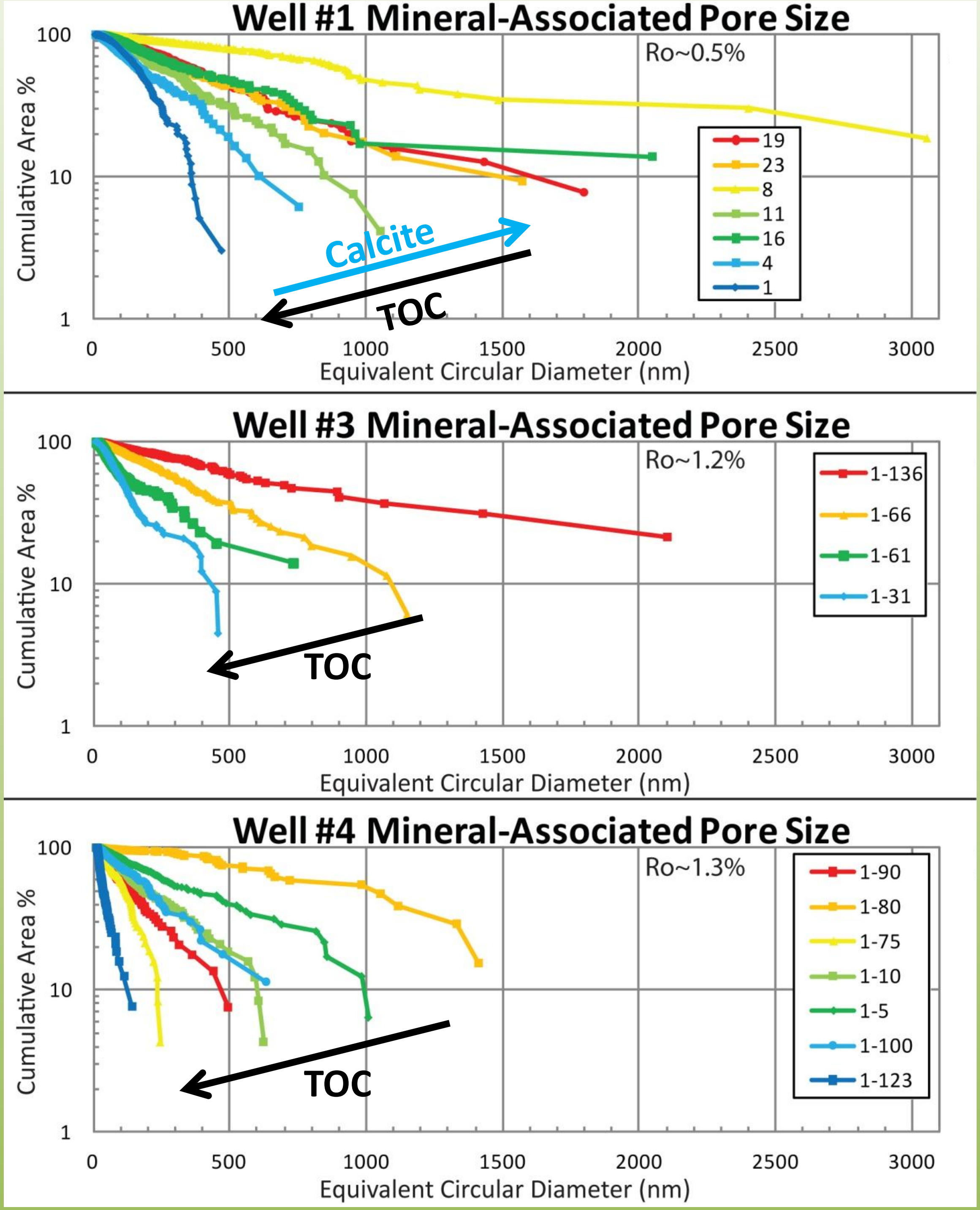


Visible ϕ vs. Calcite
(ϕMIN + ϕOM)
Calcite (BV%)
Well #1 Ro~0.5%
Well #3 Ro~1.2%
Well #4 Ro~1.3%
R² = 0.0339
R² = 0.703
R² = 0.197
0
2
4
6
8
10
12
14
0
10
20
30
40
50
60
70

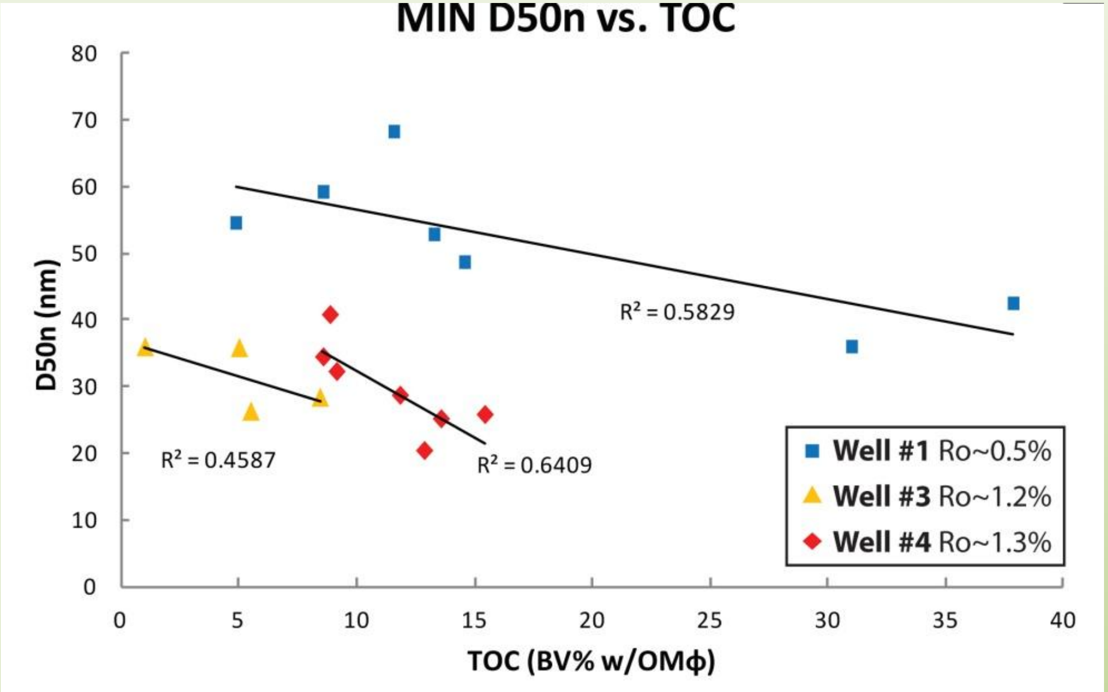
Well-Average Pore Size



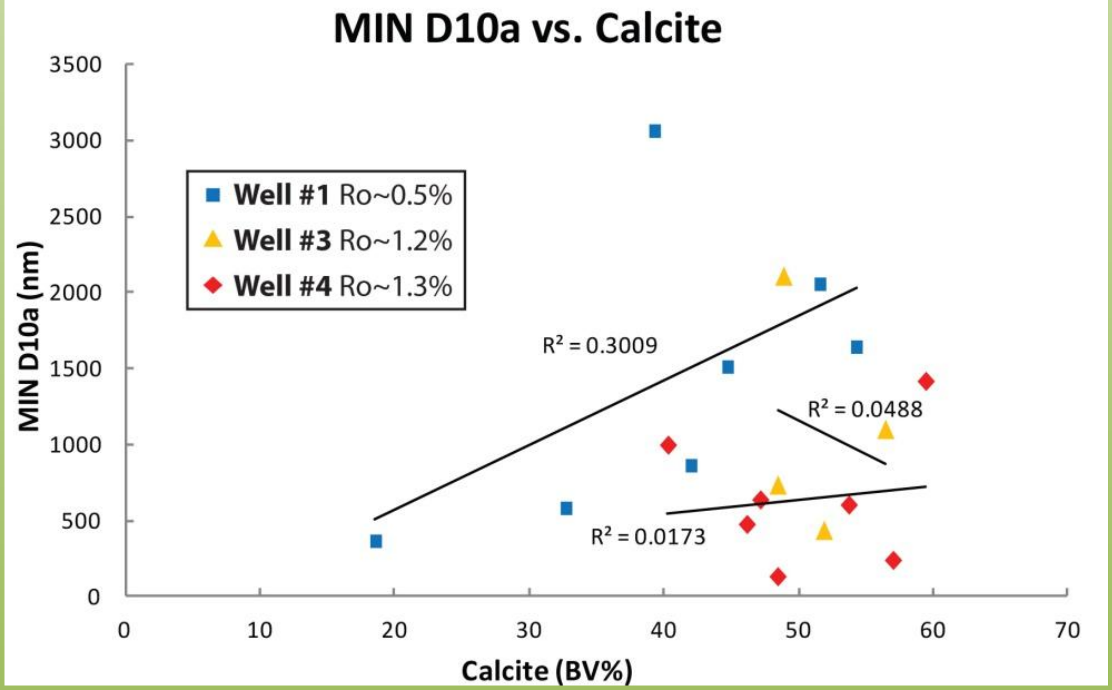

Well #1: Well-Average Pore Size
Ro~0.5%
OM-hosted
Mineral-associated
Pores <300nm
Number Percent
Equivalent Circular Diameter (nm)
Well #3: Well-Average Pore Size
Ro~1.2%
OM-hosted
Mineral-associated
Pores <300nm
Number Percent
Equivalent Circular Diameter (nm)
Well #4: Well-Average Pore Size
Ro~1.3%
OM-hosted
Mineral-associated
Pores <300nm
Number Percent
Equivalent Circular Diameter (nm)



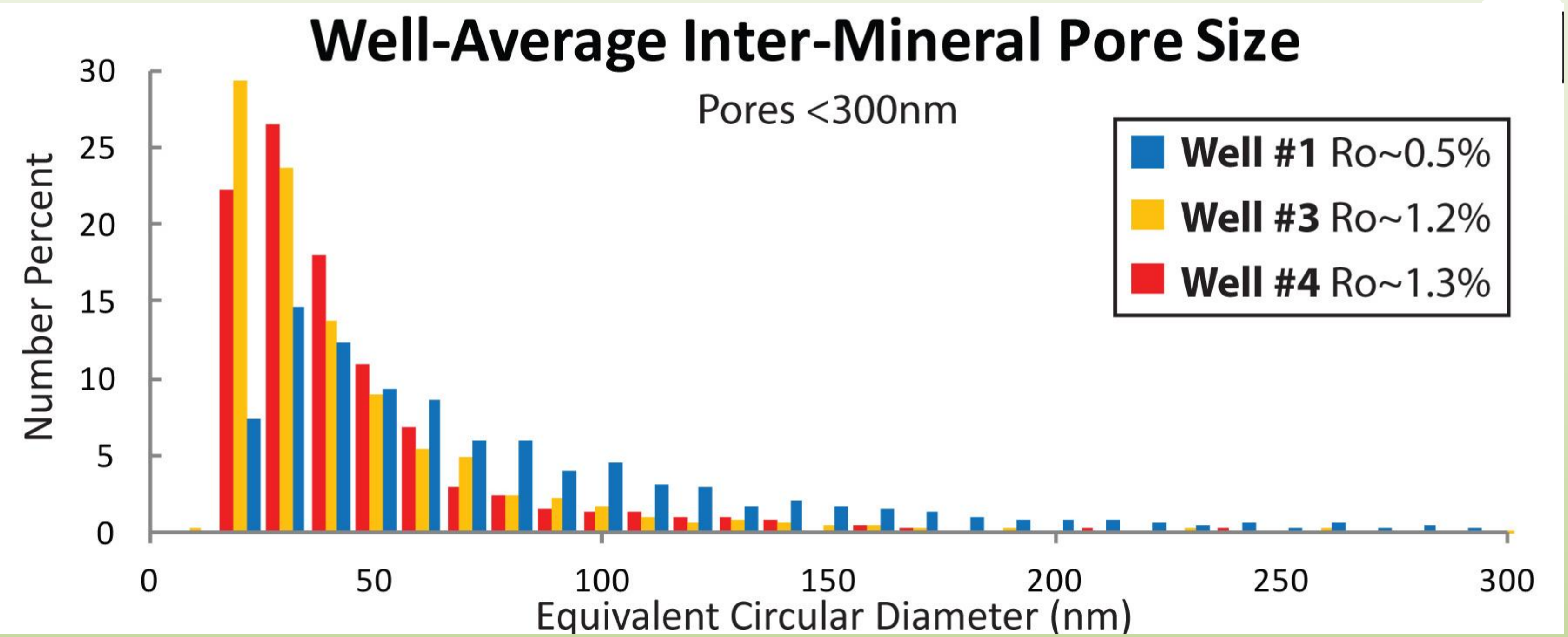
Well #1 Mineral-Associated Pore Size
Ro~0.5%
19
23
8
11
16
4
1
Calcite
TOC
Cumulative Area %
Equivalent Circular Diameter (nm)
Well #3 Mineral-Associated Pore Size
Ro~1.2%
1-136
1-66
1-61
1-31
TOC
Cumulative Area %
Equivalent Circular Diameter (nm)
Well #4 Mineral-Associated Pore Size
Ro~1.3%
1-90
1-80
1-75
1-10
1-5
1-100
1-123
TOC
Cumulative Area %
Equivalent Circular Diameter (nm)



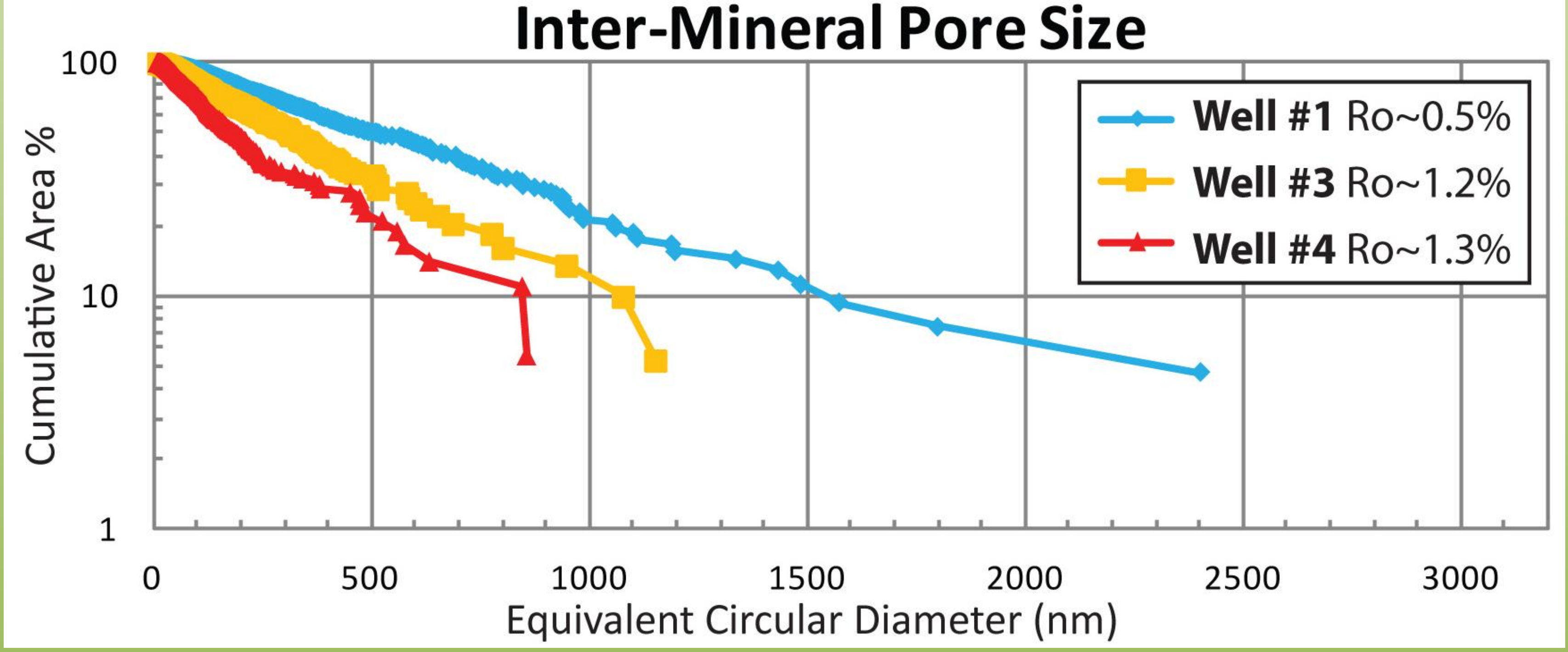
MIN D50n vs. TOC
D50n (nm)
TOC (BV% w/OMϕ)
R² = 0.5829
R² = 0.4587
R² = 0.6409
Well #1 Ro~0.5%
Well #3 Ro~1.2%
Well #4 Ro~1.3%



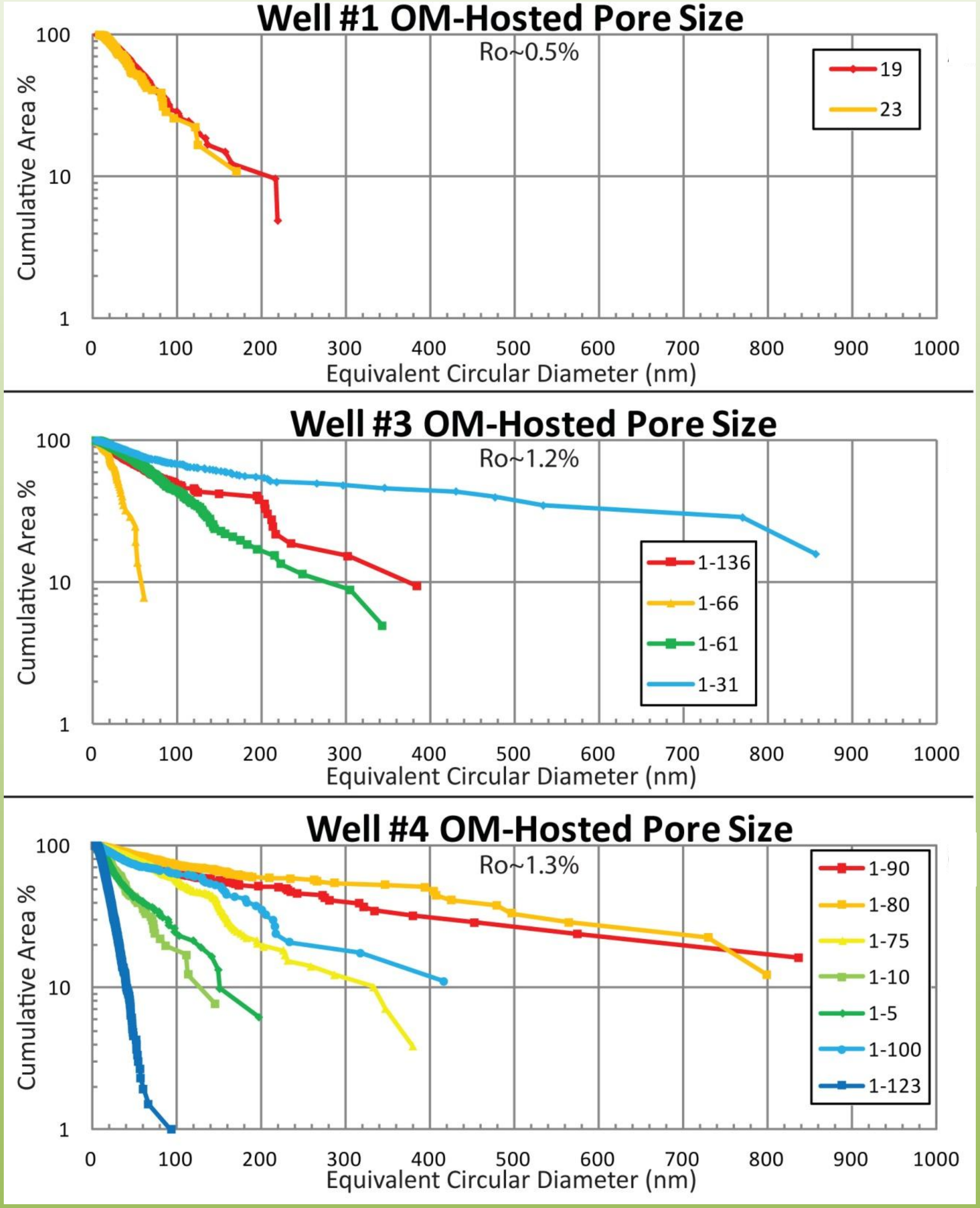
MIN D10a vs. Calcite
MIN D10a (nm)
Calcite (BV%)
R² = 0.3009
R² = 0.0488
R² = 0.0173
Well #1 Ro~0.5%
Well #3 Ro~1.2%
Well #4 Ro~1.3%



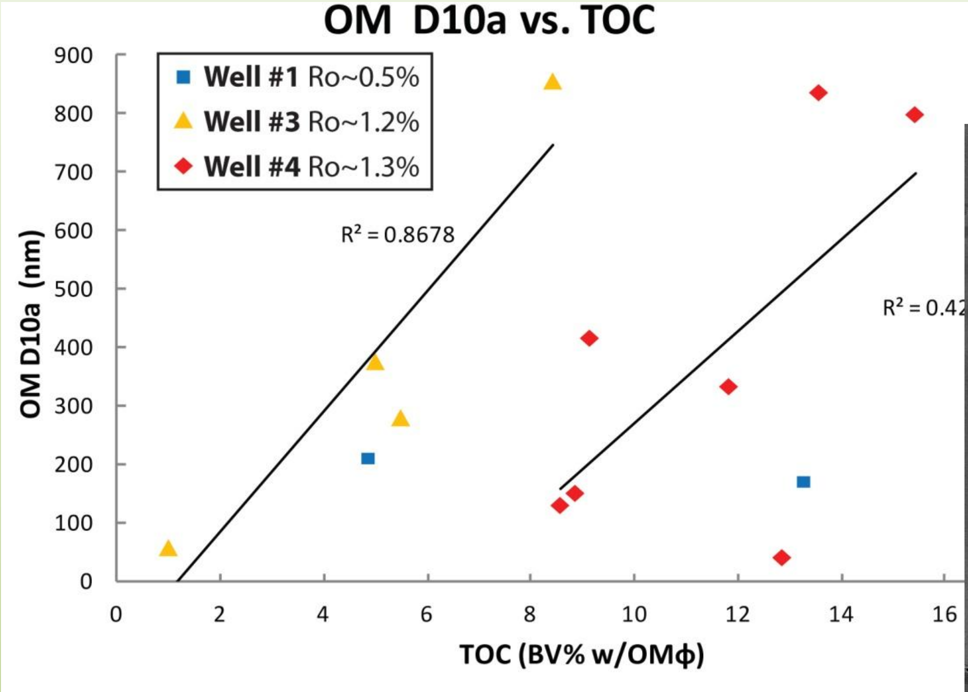
Well-Average Inter-Mineral Pore Size
Pores <300nm
Well #1 Ro~0.5%
Well #3 Ro~1.2%
Well #4 Ro~1.3%
Number Percent
0
5
10
15
20
25
30
0
50
100
150
200
250
300
Equivalent Circular Diameter (nm)

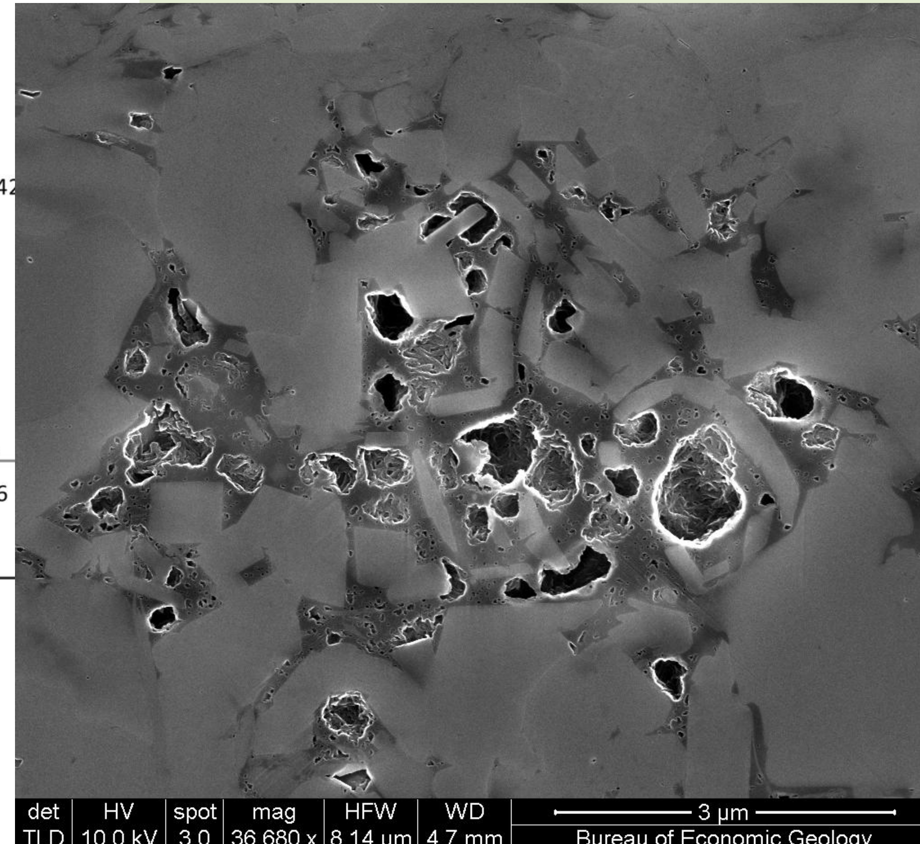


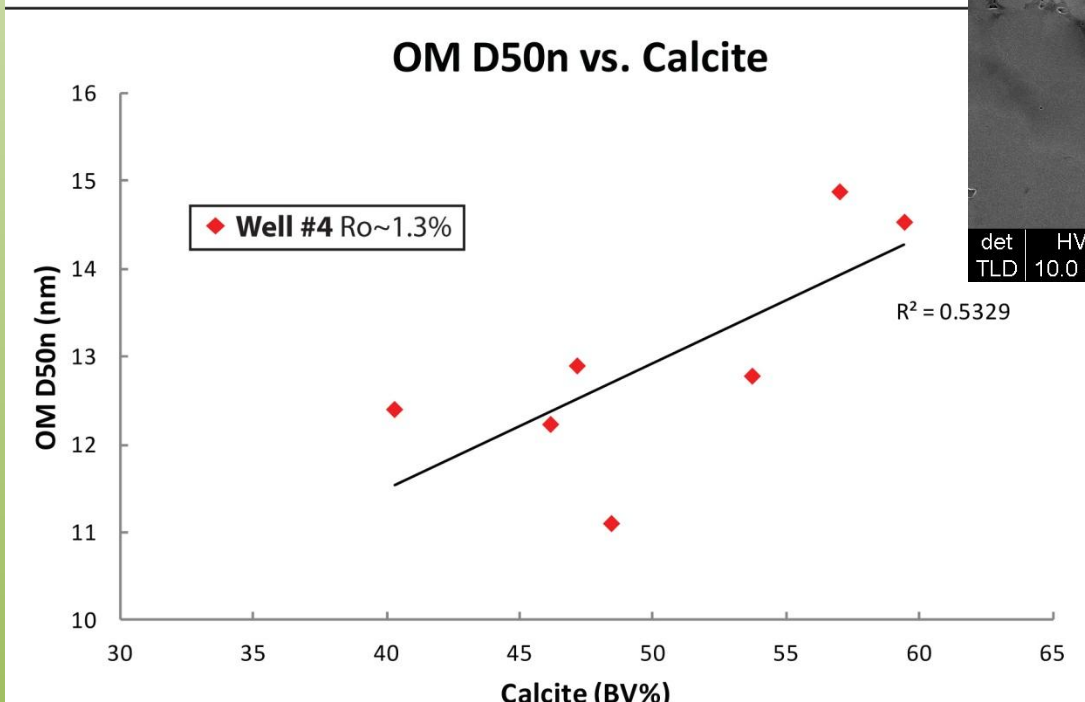
Inter-Mineral Pore Size
Well #1 Ro~0.5%
Well #3 Ro~1.2%
Well #4 Ro~1.3%
Cumulative Area %
1
10
100
0
500
1000
1500
2000
2500
3000
Equivalent Circular Diameter (nm)



Well #1 OM-Hosted Pore Size
Ro~0.5%
19
23
Cumulative Area %
100
10
1
0
100
200
300
400
500
600
700
800
900
1000
Equivalent Circular Diameter (nm)
Well #3 OM-Hosted Pore Size
Ro~1.2%
1-136
1-66
1-61
1-31
Cumulative Area %
Equivalent Circular Diameter (nm)
Well #4 OM-Hosted Pore Size
Ro~1.3%
1-90
1-80
1-75
1-10
1-5
1-100
1-123
Cumulative Area %
Equivalent Circular Diameter (nm)







Large OM-hosted pores where bubbles have room to grow?

Conclusions

- Porosity in the Eagle Ford is controlled by chemical and mechanical processes: compaction, cementation, and pore generation during OM maturation.
- The detrital grain assemblage (texture and composition) controls the diagenetic response.
- Abundant detrital OM is subject to compaction.
- Rigid bioclastic debris is more resistant to compaction.
- Secondary OM (bitumen) destroys porosity and is prone to later secondary pore generation.

BUREAU OF ECONOMIC GEOLOGY

Supported by Shell/University of Texas Unconventional Research (SUTUR), Project 3, "Investigation of Oil Storage and Migration in the Eagle Ford Formation by Integrated Geochemistry and Petrography"; K. Milliken, T. Zhang, Co-PIs

Other SUTUR projects at AAPG 2014

- Hayman et al., Marcellus microtextures/Tues posters
- Milliken et al., Marine Sapropels/ Wed 10:50
- Zhang et al., Eagle Ford N-adsorption/Wed 2:00
- Ozkan et al., Eagle Ford pore system evolution/Wed 2:20
- Lunsford et al., Marcellus microtextures/Wed morning posters
- Sun et al., Eagle Ford OM geochemistry/Wed morning posters