Rock Typing in Gas Shales

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Objective:

To identify, using petrophysical measurements, zones in gas shales that would be best for production.

Questions?

- Where should we land the laterals?
- Which zones are best for fracturing?
- How much vertical section are we producing from?

Rock Type

…units of rock deposited under similar conditions which experienced similar diagenetic process resulting in a unique porosity-permeability relationship, capillary pressure profile and water saturation …..

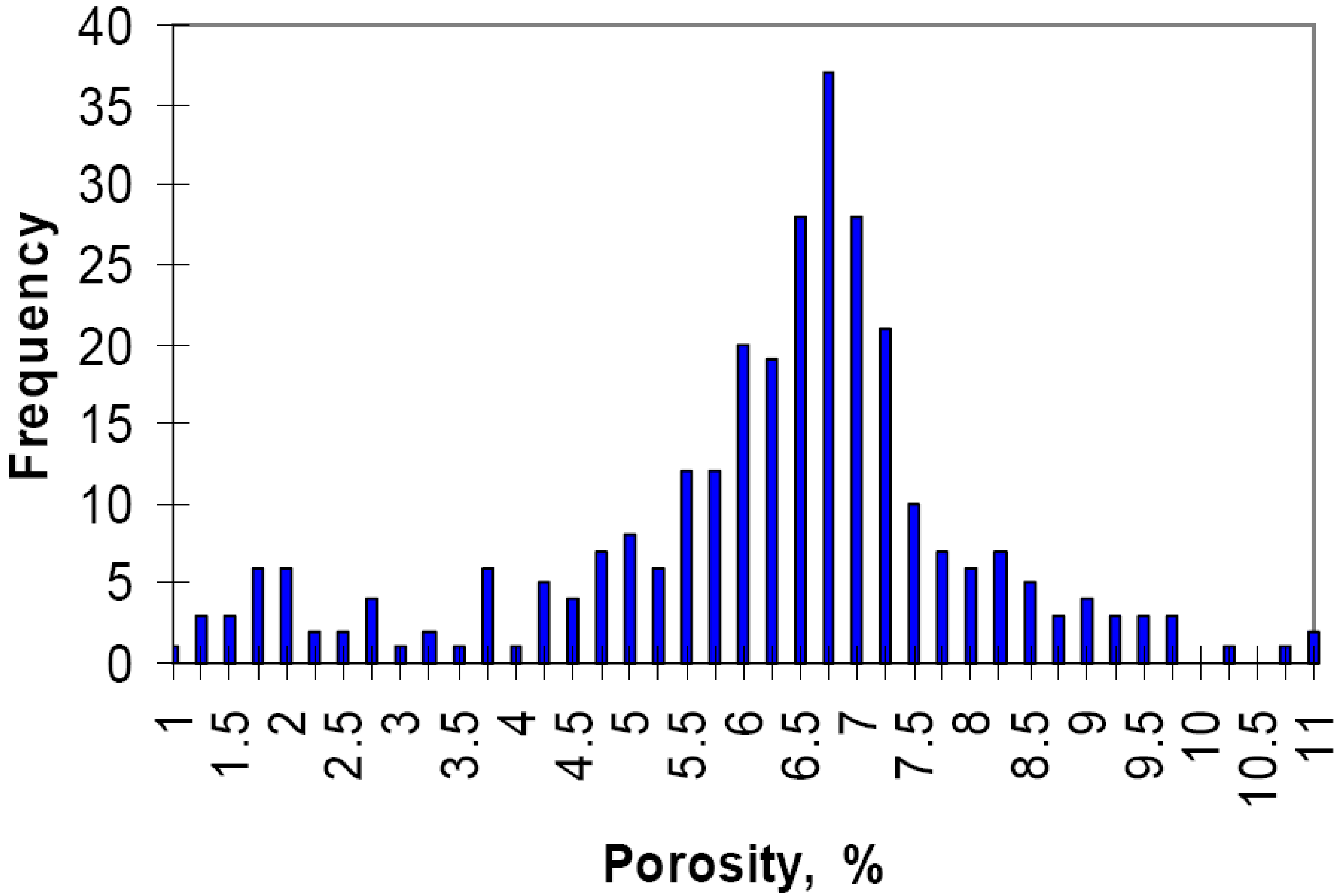
G. E. Archie, 1950

Measurements:

- Porosity
- Mineralogy
- Mercury Injection capillary pressure
- SEM studies
- Total organic carbon
- Permeability
- Nuclear Magnetic Resonance
- Compressional & Shear wave velocities
- Elastic Moduli
- Anisotropy
- Fracture Conductivity studies
- Micro-seismic studies

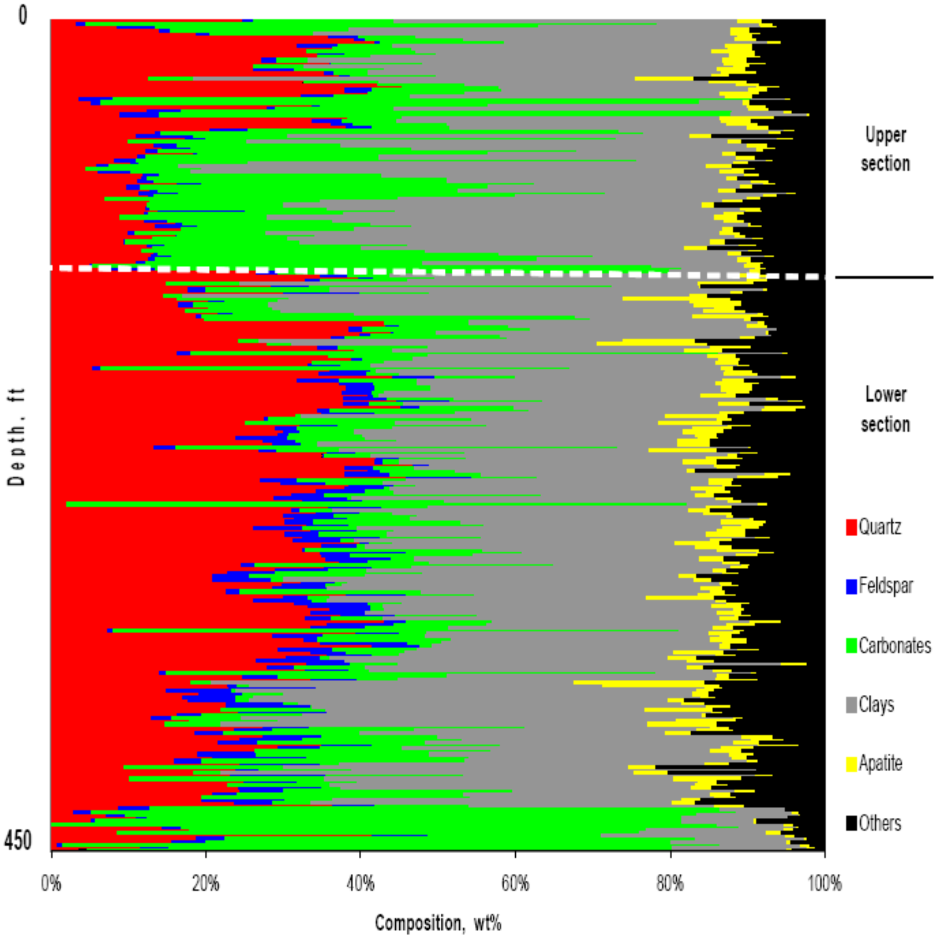
Measurements:

- ~1600 feet of core from four wells from Fort Worth Basin
- Porosity, Mineralogy and TOC on ~800 plugs
- Mercury Injection on ~ 150 plugs



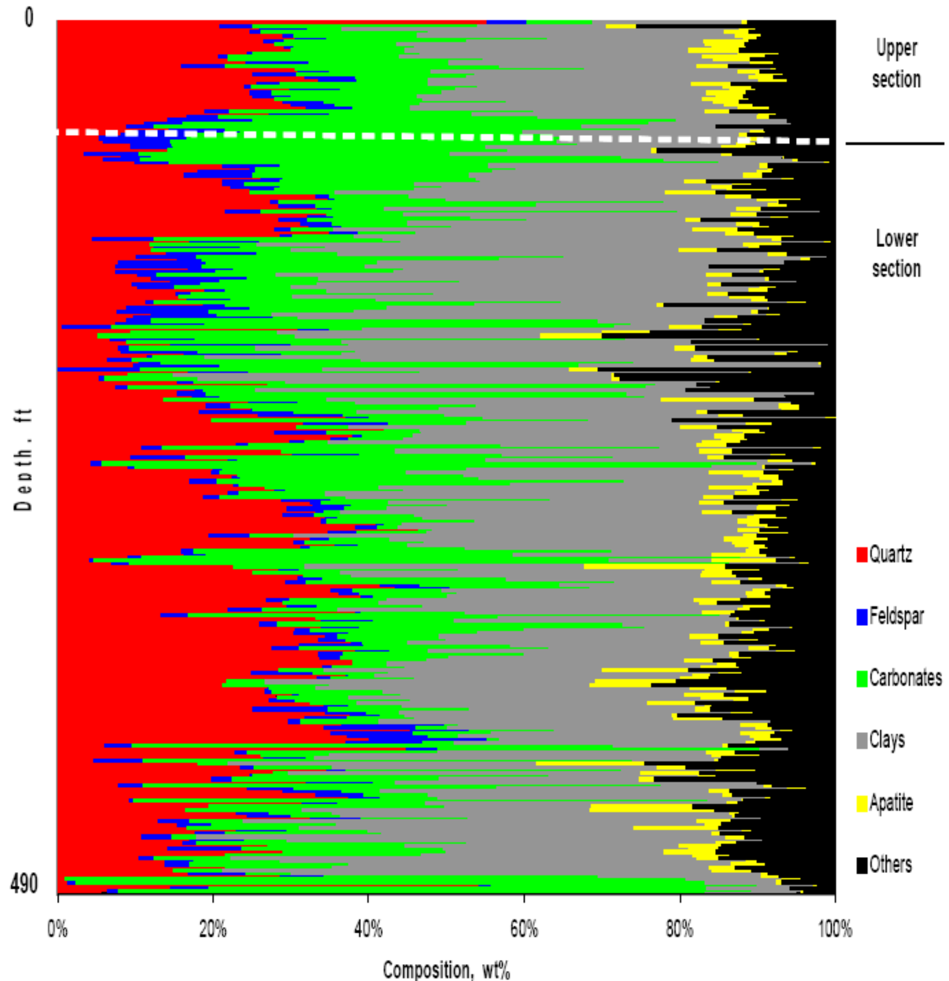
Porosity distribution in Well A, mean=6.1%

FTIR Mineralogy for Samples from Two Wells

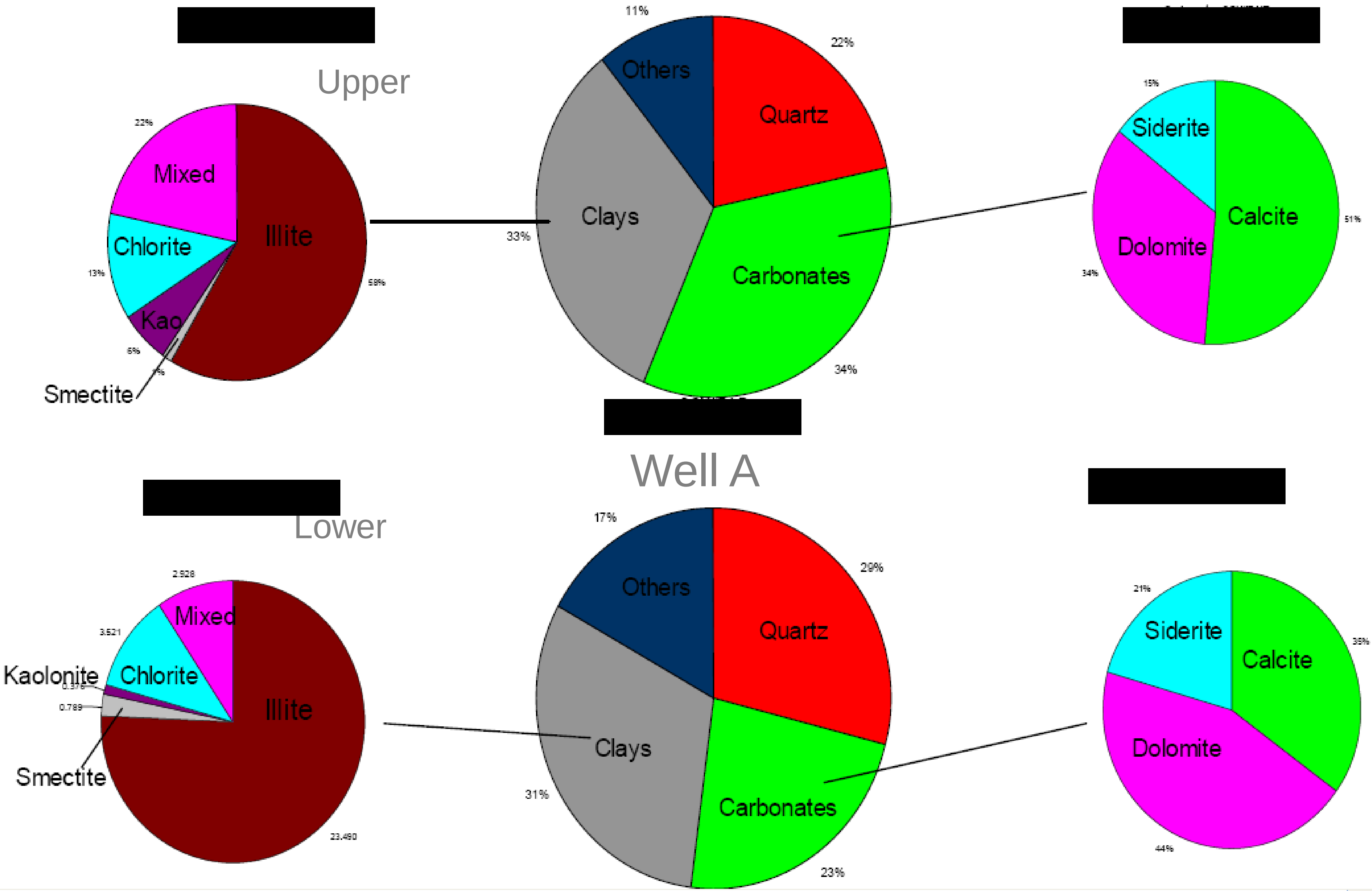


Well A

Well B



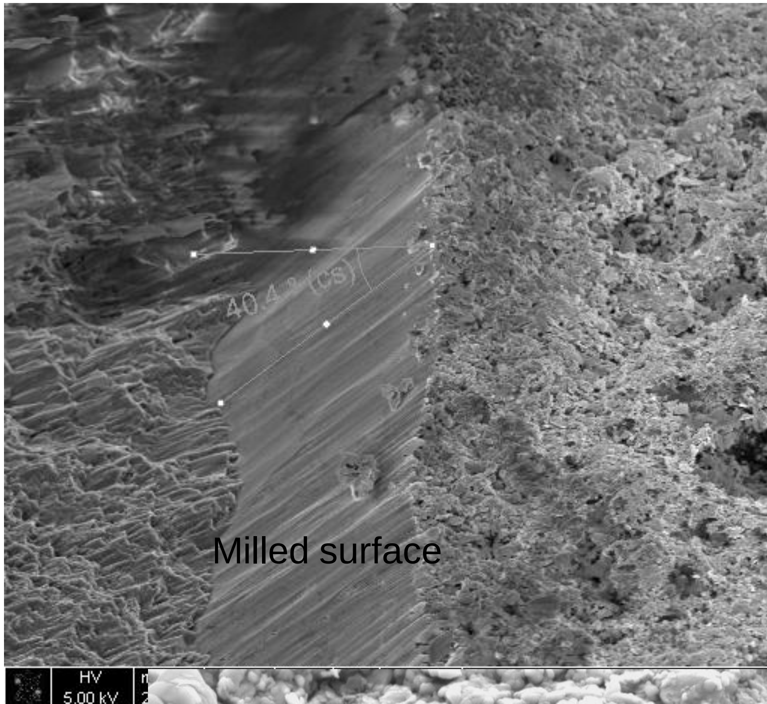
Comparison of Upper & Lower Barnett Mineralogy in Well A

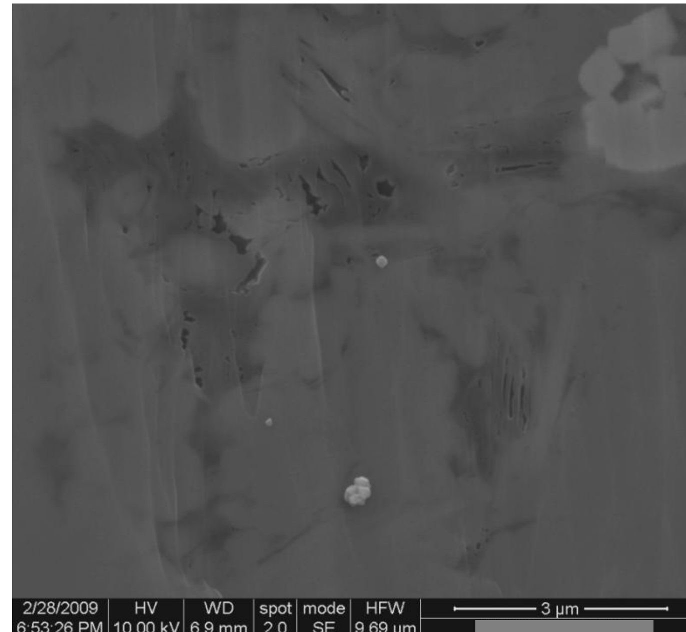


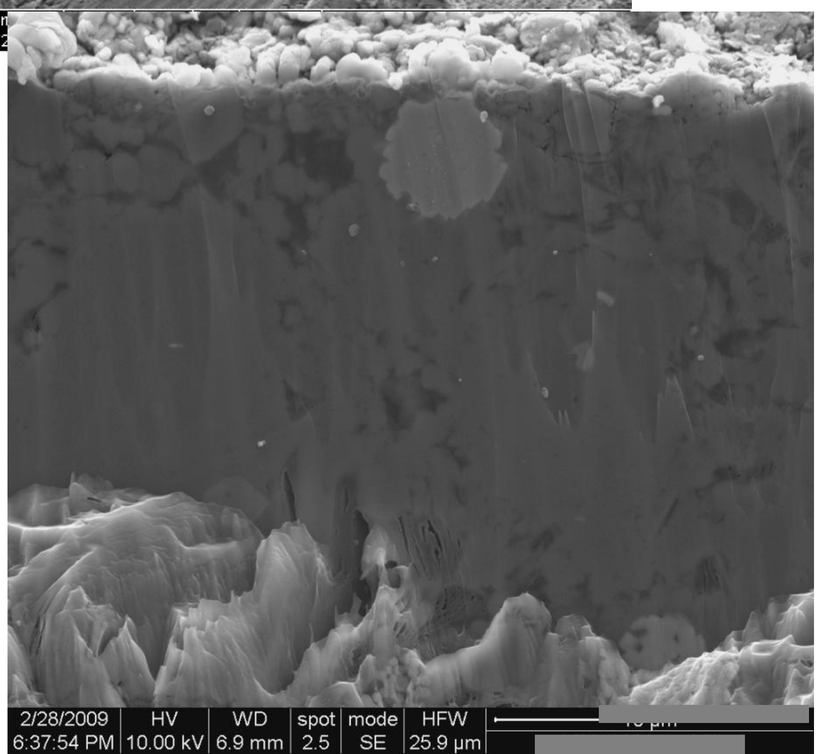
Microstructural Studies -SEM

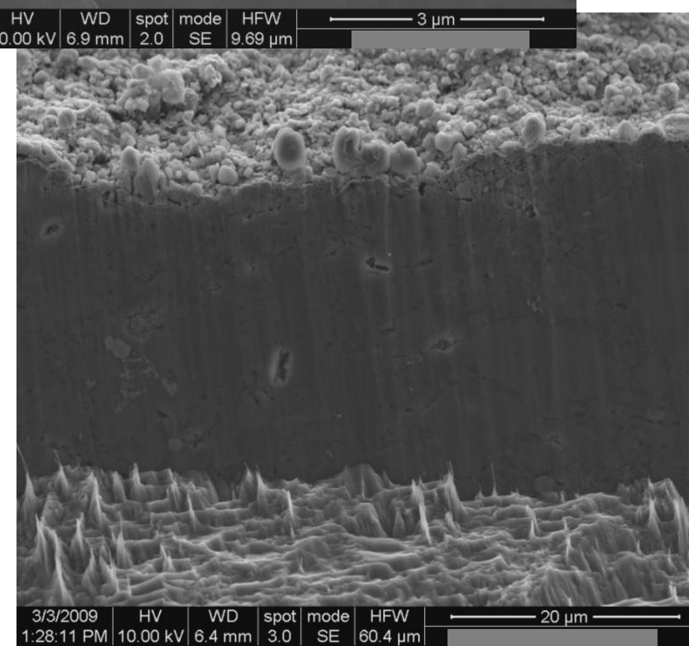
- Fractured surfaces show properties such as bedding planes and crystal habits
- However, fractured surfaces hide the nature of pores
- Polished surfaces show pore morphology
- Ion milling removes polishing artifacts and gives a very low-relief surfaces

Ion-milled Surfaces

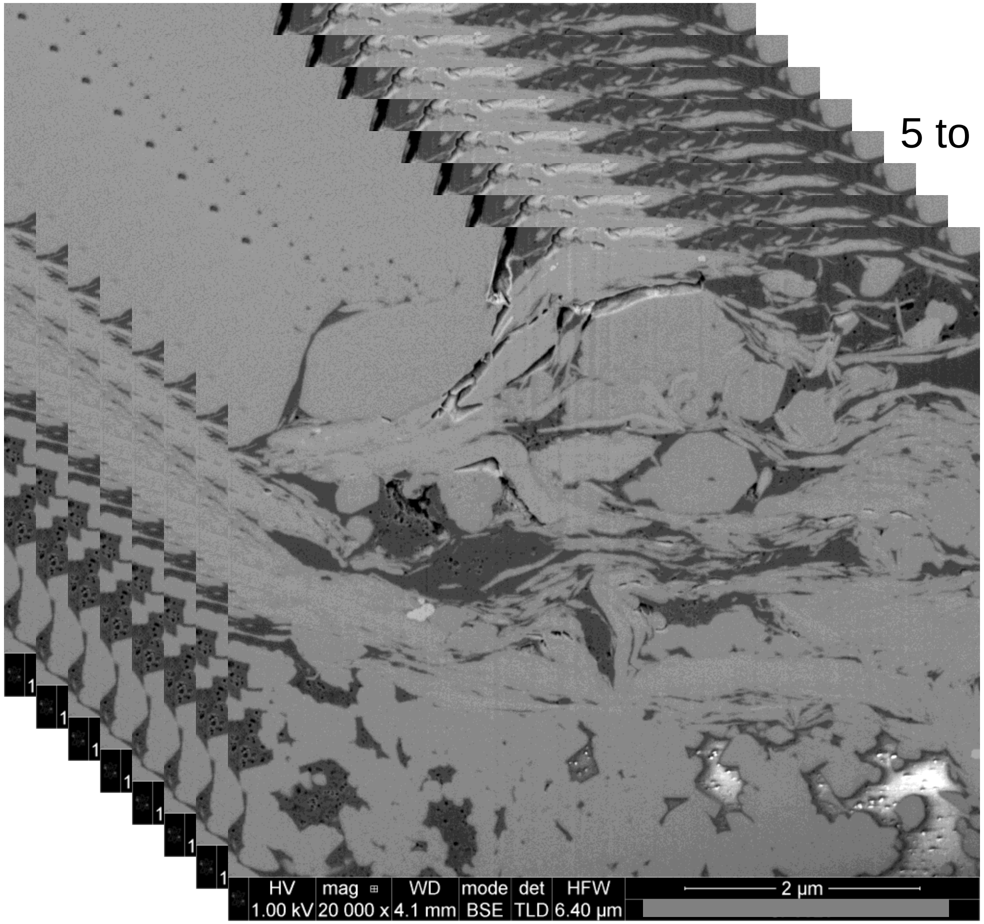






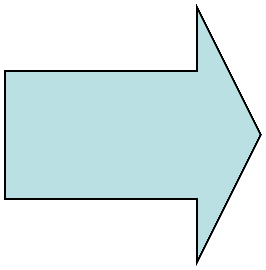


FIB Technology for 3-D mapping of the microstructure

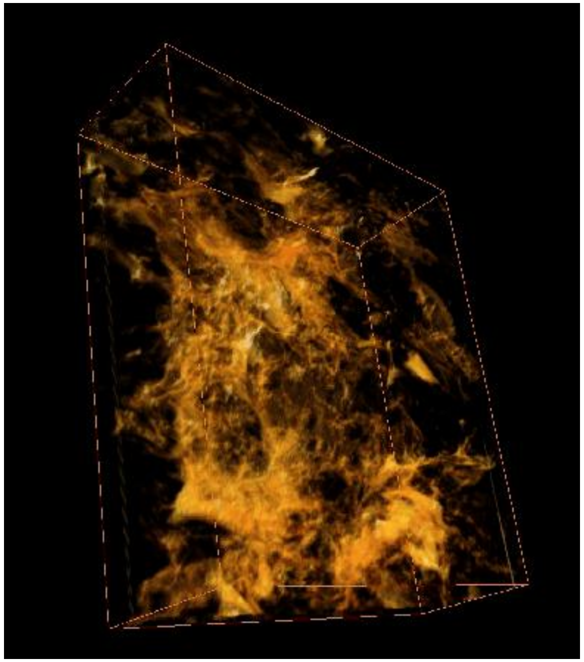


5 to 6 hundred slices at 10 nanometer intervals

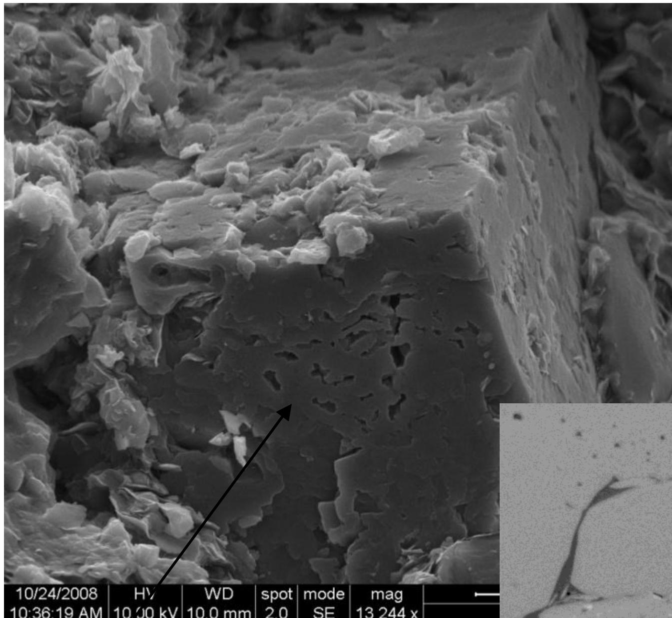
2-D slices



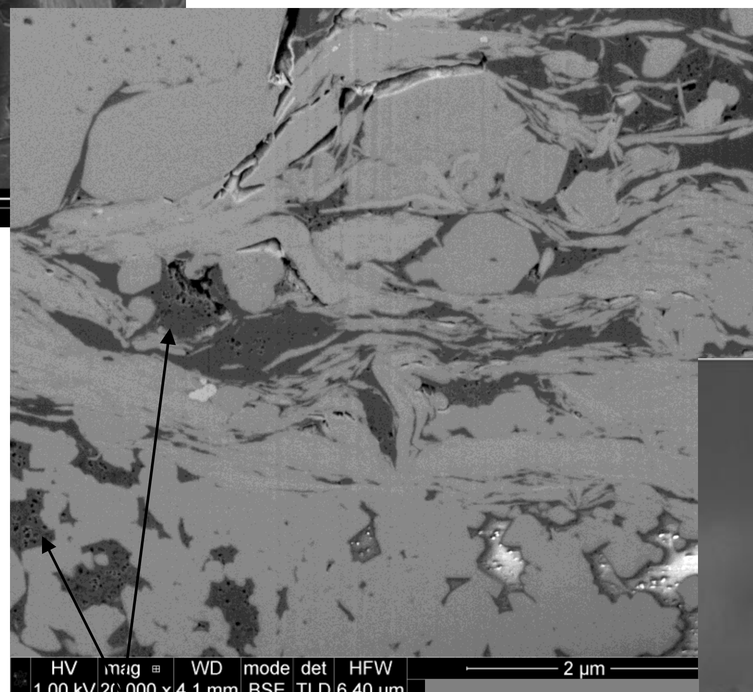
3-D Microstructure



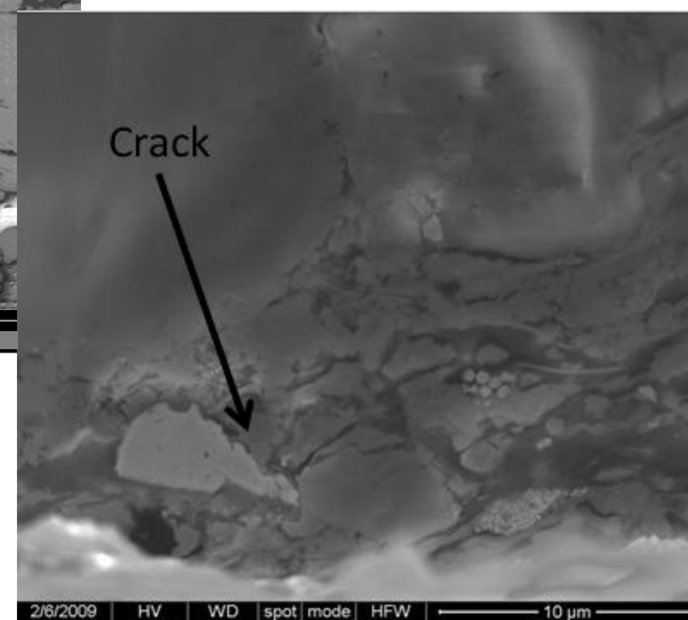
Where is the Porosity?

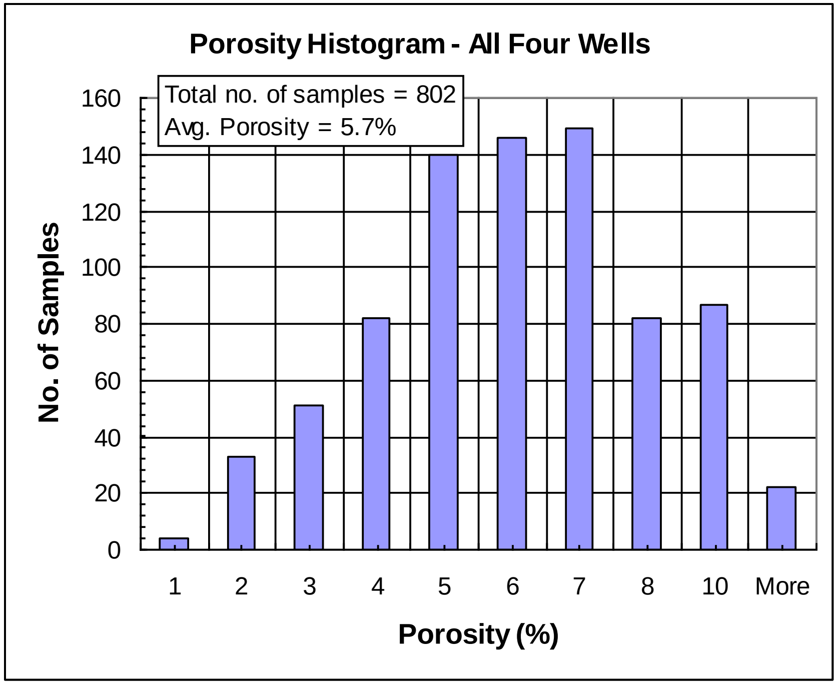


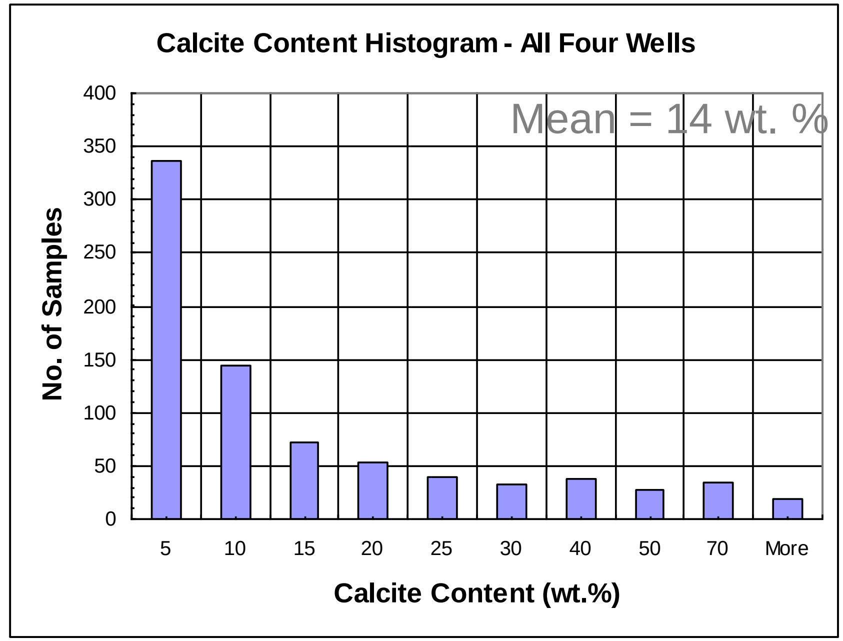
Mineral grains

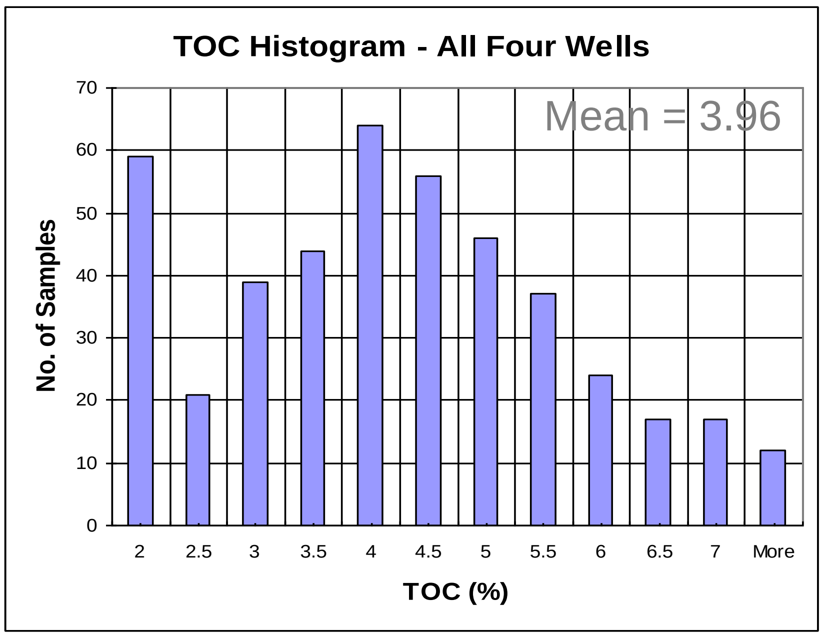


Organic matter

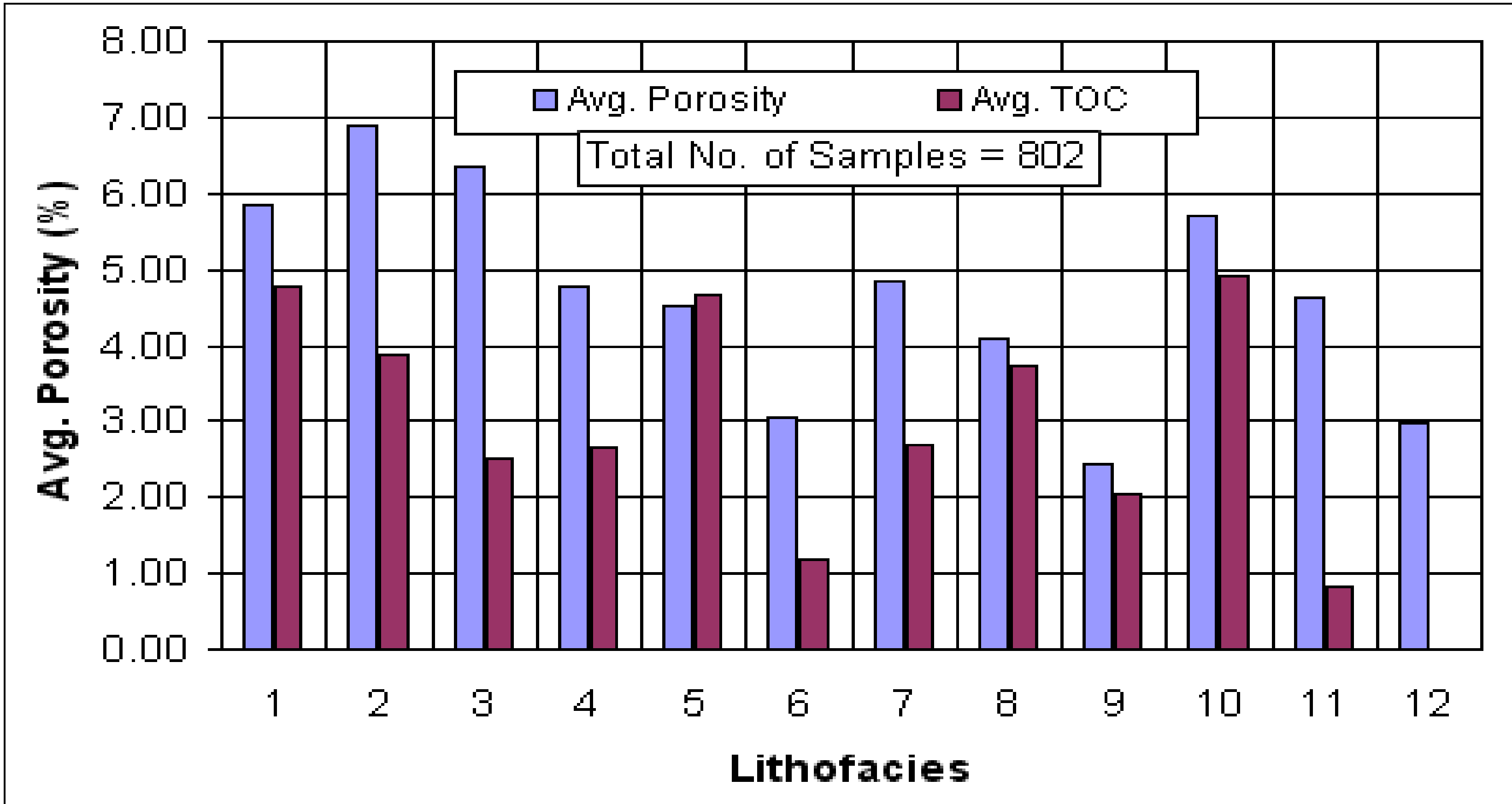



Porosity Histogram - All Four Wells
Total no. of samples = 802
Avg. Porosity = 5.7%
No. of Samples
0
20
40
60
80
100
120
140
160
1
2
3
4
5
6
7
8
10
More
Porosity (%)


Calcite Content Histogram - All Four Wells
Mean = 14 wt. %
No. of Samples
0
50
100
150
200
250
300
350
400
5
10
15
20
25
30
40
50
70
More
Calcite Content (wt.%)


TOC Histogram - All Four Wells
Mean = 3.96
No. of Samples
0
10
20
30
40
50
60
70
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
More
TOC (%)

Average Porosity & TOC of Lithofacies



1. Siliceous non-calcareous mudstone, 2. Siliceous calcareous mudstone, low calcite, 3. Siliceous calcareous mudstone, high calcite, 4. Silty-Shaly deposits, 5. Phosphatic deposits, 6. Limy mudstone 7. Dolomitic mudstone, 8. Calcareous laminae, 9. Concretions, 10. Fossiliferous deposits, 11. Spicule rich deposits, 12. Debris flow deposits (Singh,2008)

Petrotype 1:

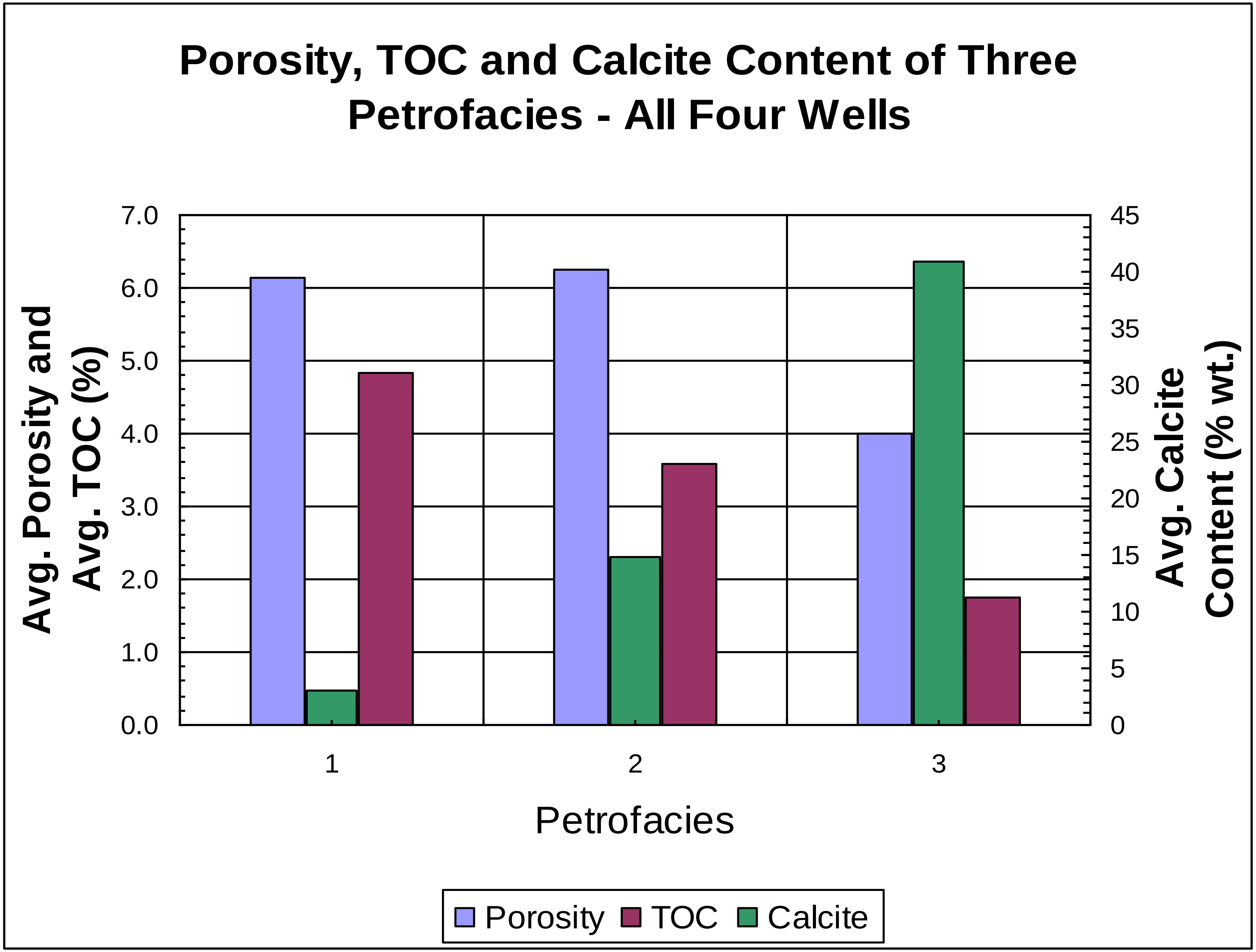
Lithofacies: 1, 5, 2 (calcite < 10%)

Petrotype 2:

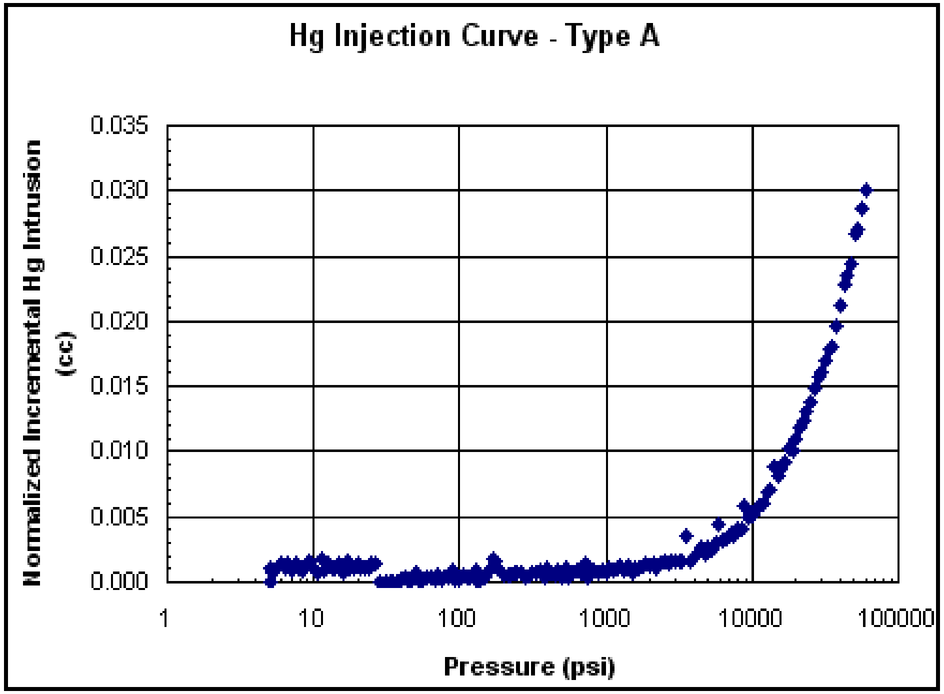
Lithofacies: 3,7,8, 10 and 2 (calcite > 10%)

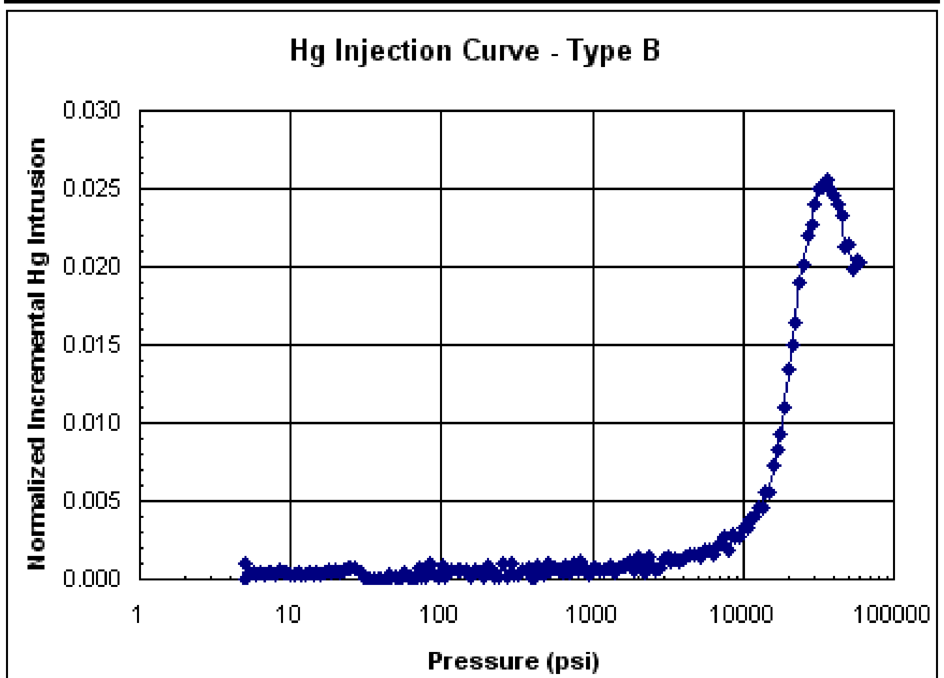
Petrotype 3:

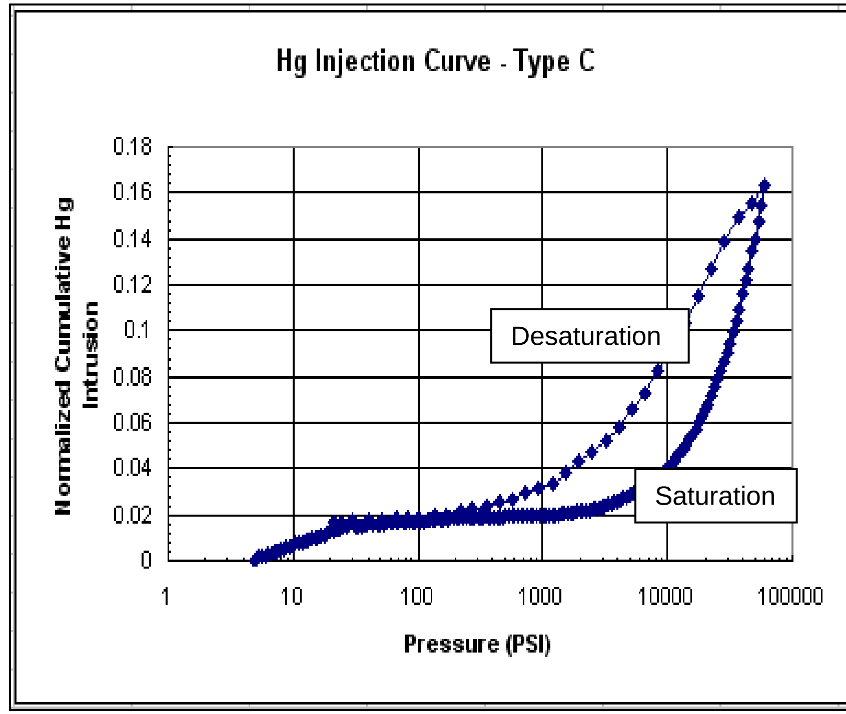
Lithofacies 6,9,4,11, and 12



Porosity, TOC and Calcite Content of Three Petrofacies - All Four Wells
Avg. Porosity and Avg. TOC (%)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
45
40
35
30
25
20
15
10
5
0
Avg. Calcite Content (% wt.)
1
2
3
Petrofacies
Porosity
TOC
Calcite


Hg Injection Curve - Type A
Normalized Incremental Hg Intrusion (cc)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1
10
100
1000
10000
100000
Pressure (psi)


Hg Injection Curve - Type B
Normalized Incremental Hg Intrusion
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1
10
100
1000
10000
100000
Pressure (psi)


Hg Injection Curve - Type C
Normalized Cumulative Hg Intrusion
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
10
100
1000
10000
100000
Pressure (PSI)
Desaturation
Saturation

Petrofacies	Lithofacies	Porosity	TOC	Calcite	Quartz	Hg Rock Type
1	1, 2, 5	High (6.0 - 6.3%)	High (4.7 - 5.0%)	Low (0 - 10%)	High (28-32%)	A
2	2, 3, 7, 8, 10	High (6.0 - 6.6%)	Moderate (3.4 - 3.8%)	Moderate (10 - 25%)	Medium (18-22%)	B
3	4, 6, 9, 11, 12	Low (2.7 - 3.4%)	Low (1.5 - 2.2%)	High (>25%)	Low (12-16%)	C

Micro-structure

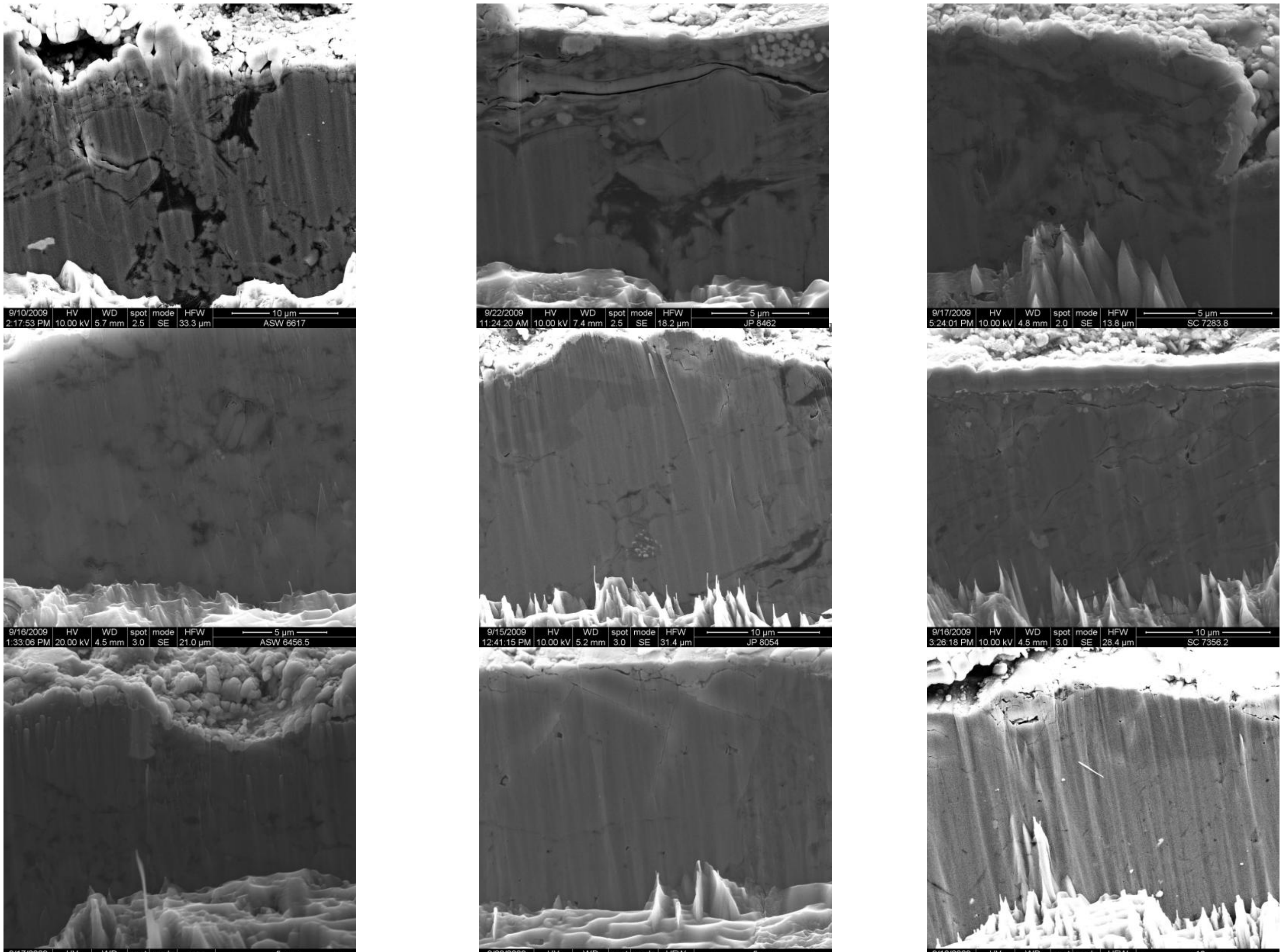
WELL/ TYPE

ASW **JP** **SC**

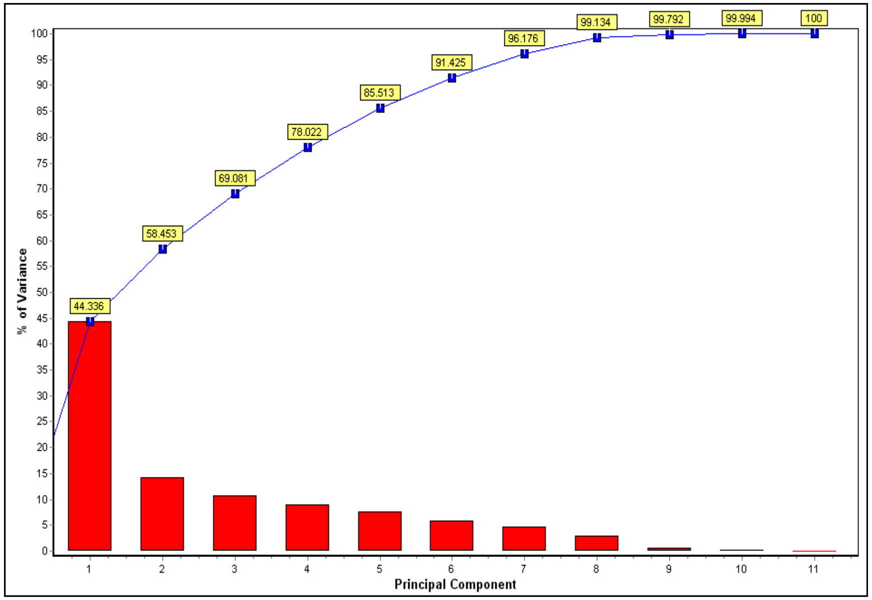
 # 1

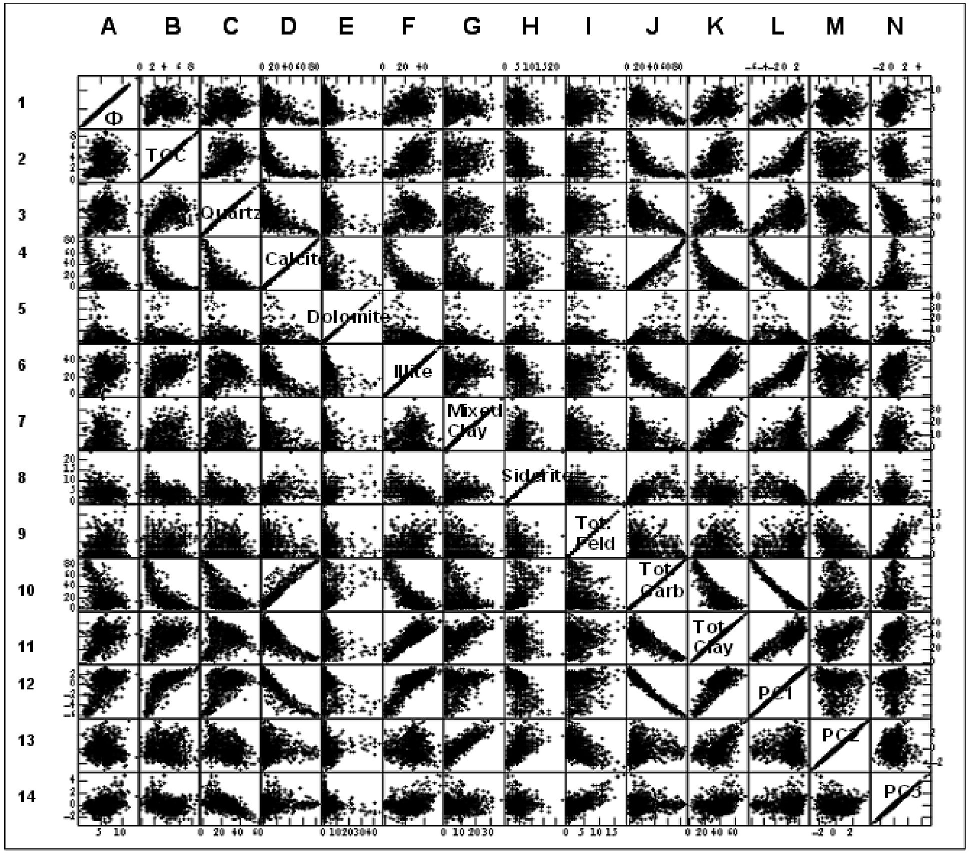
 # 2

 # 3

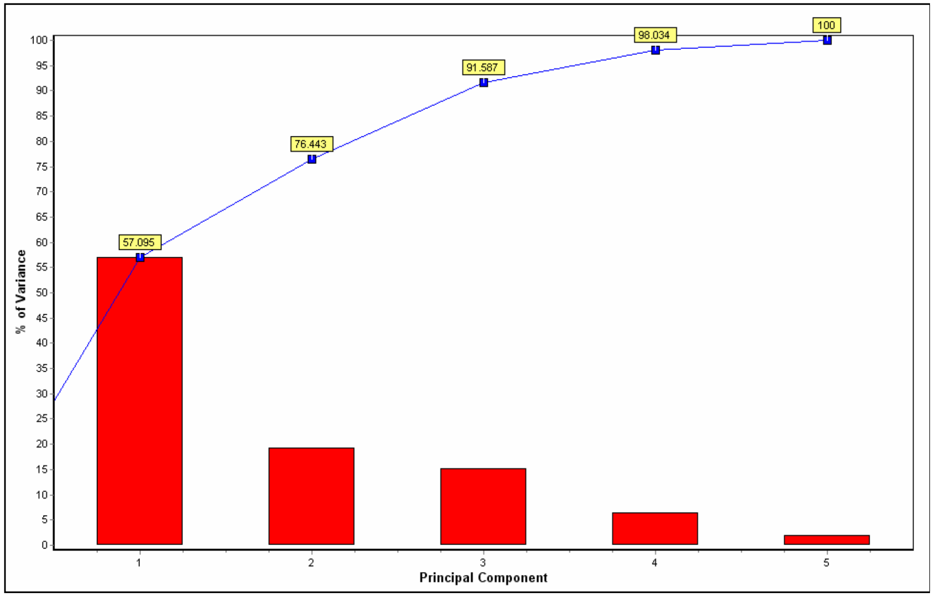


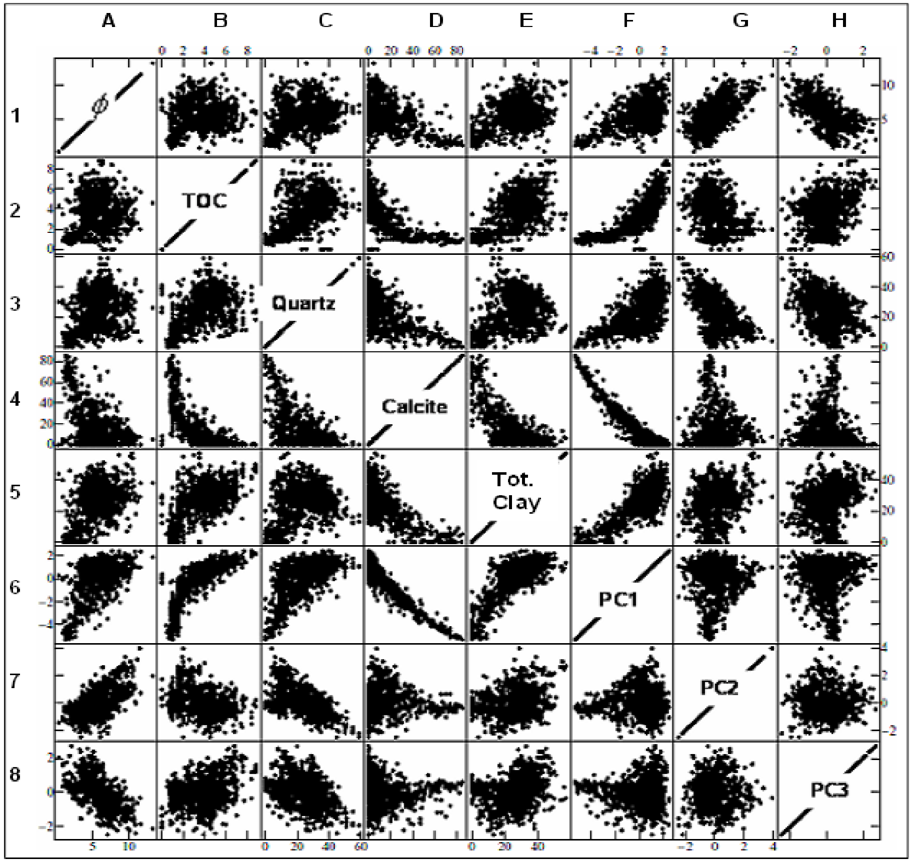
Principal Component and Cluster Analysis:

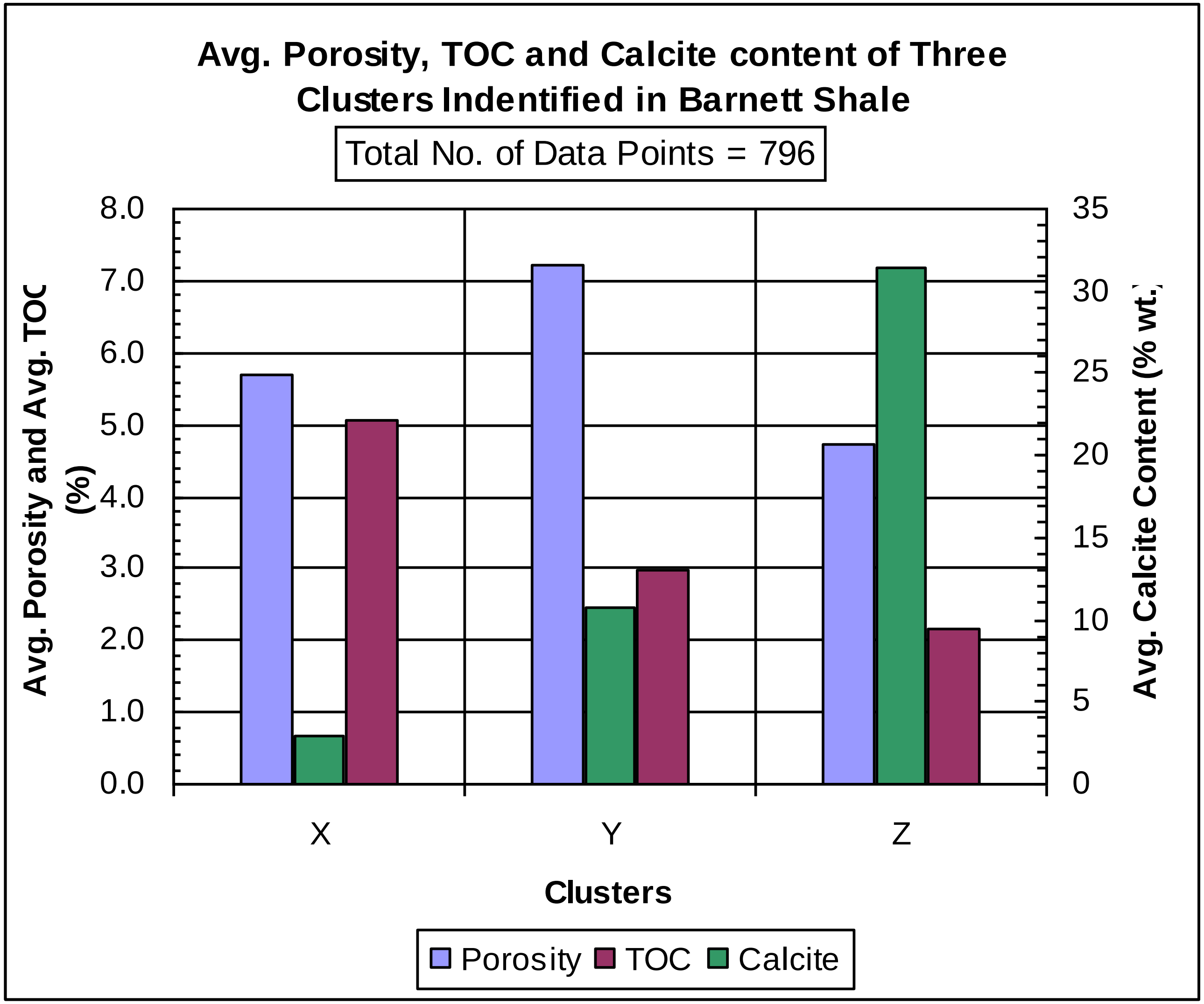




Principal Component and Cluster Analysis:

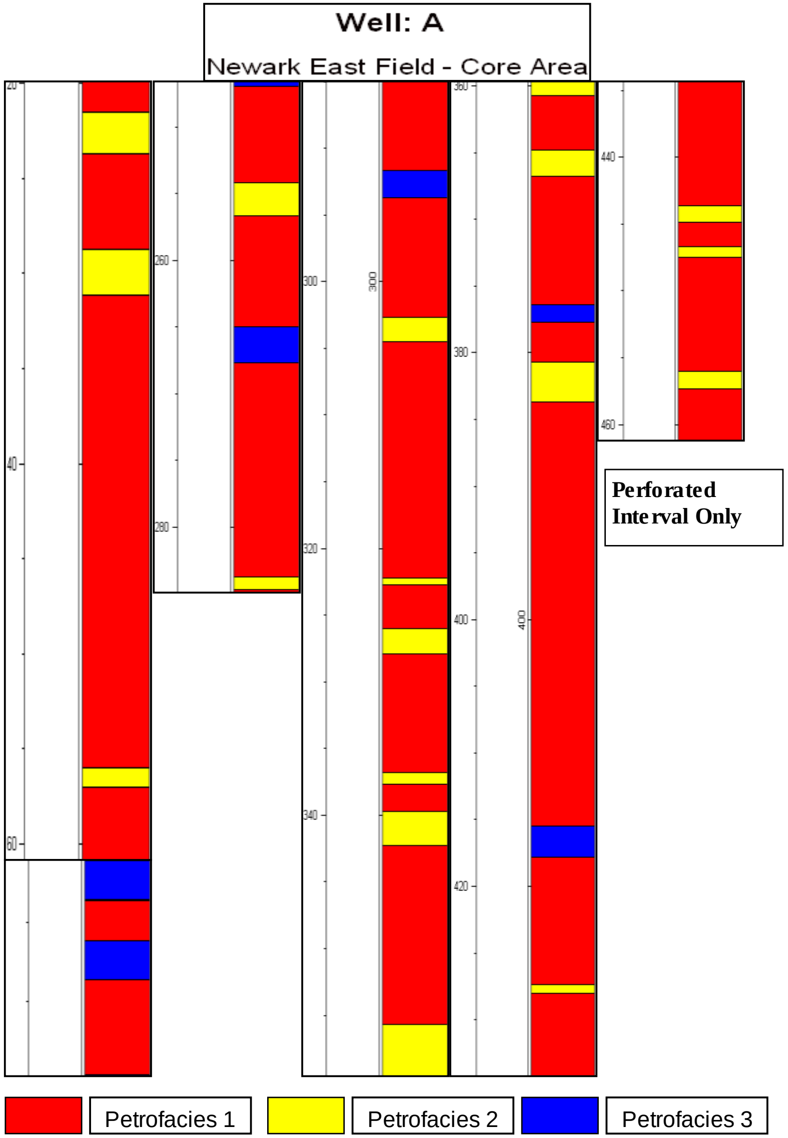




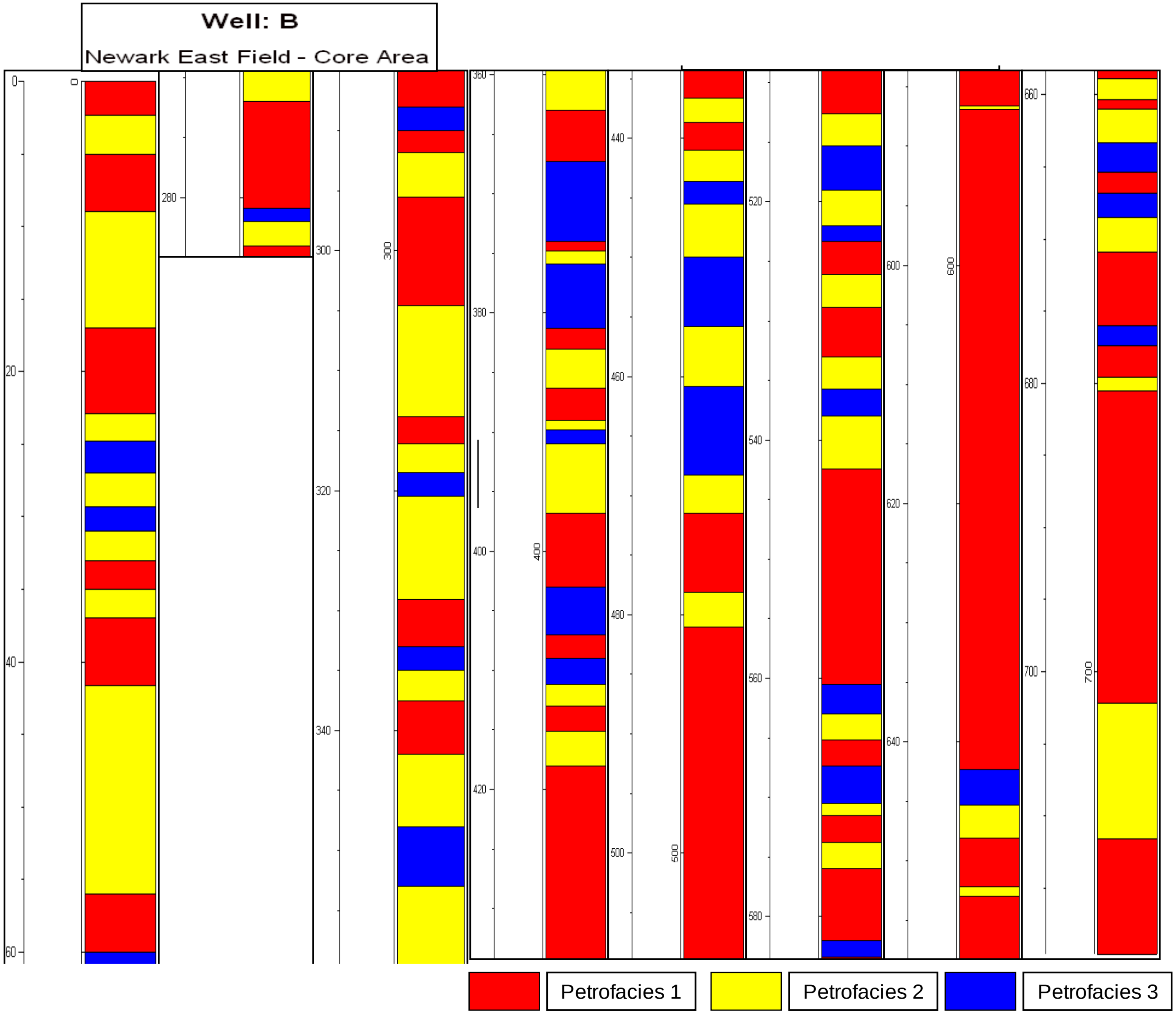


Avg. Porosity, TOC and Calcite content of Three Clusters Indentified in Barnett Shale
Total No. of Data Points = 796
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
35
30
25
20
15
10
5
0
Avg. Porosity and Avg. TOC (%)
Avg. Calcite Content (% wt.)
X
Y
Z
Clusters
Porosity
TOC
Calcite

Distribution of Petrotypes in Well A:



Distribution of Petrotypes in Well B:



Production data from Wells A & B:

Well Name	Perforated zone thickness, ft	% Net to Gross-pertotype 1	Cumulative prodution-70 months, MCF
A	217	84	628,000
B	542	52	441,000

Conclusions:

- Barnett shale can be classified into three ‘petro types”.
- Petrotype 1, which is quartz, clay and TOC rich with least amount of calcite likely represents the best reservoir rock.
- Even though the dynamic range of porosity and TOC associated with different petro types is narrow, they differ considerably in terms of calcite content.
- Ion milling reveals the microstructure of shale.
- Porosity is associated within organic matter, mineral grains and grain boundaries.

Acknowledgement:

We thank Devon Energy for funding this project.