Exploration / Appraisal of Shales

Rick Lewis

Petrophysics Technical Manager
Unconventional Resources

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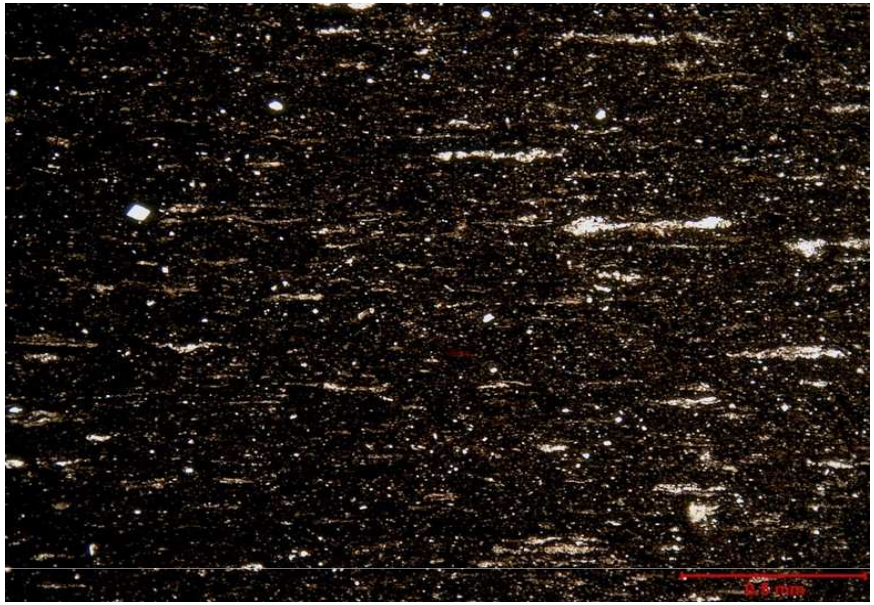
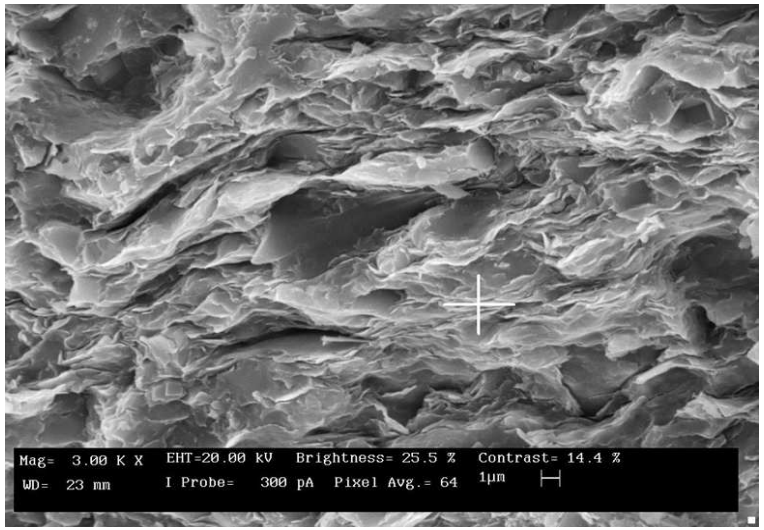
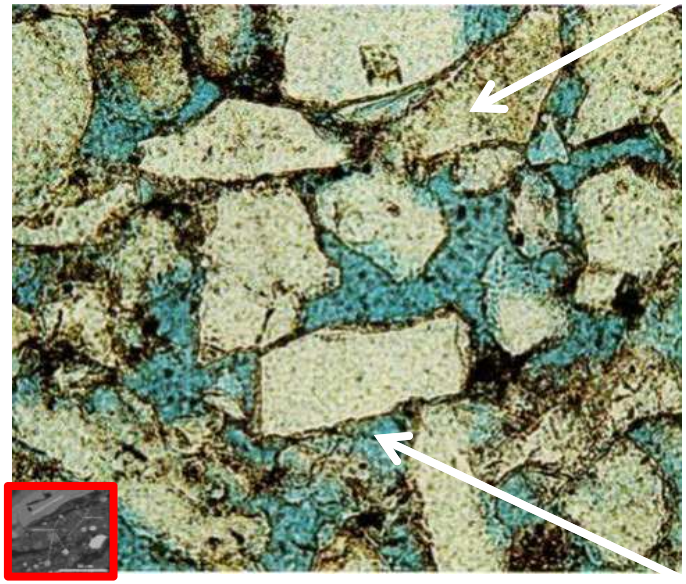
Organic Shale





Factors Controlling Gas Reservoir Quality

Conventional sandstone



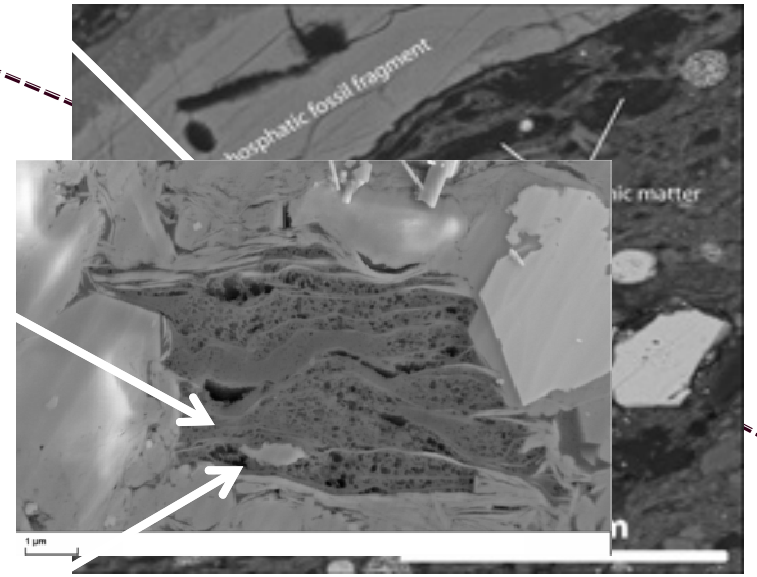
700 µm
Free gas in pore space

Mineral framework

Kerogen

Pore system

Gas shale



100 µm
Free gas in pore space
Adsorbed gas on kerogen

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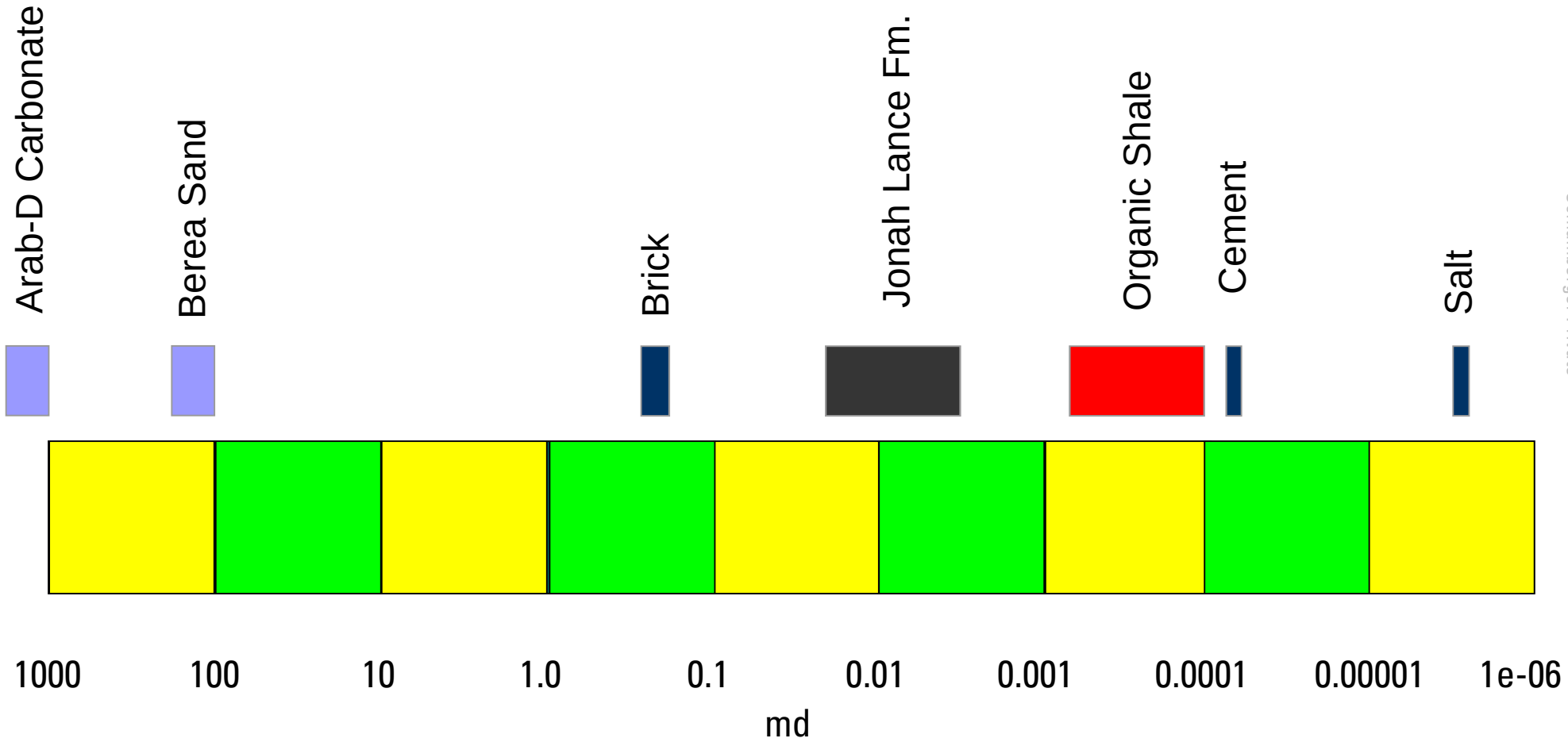
Shale in Perspective: Permeability



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Shale Evaluation Needs

Delineate organic shale beds

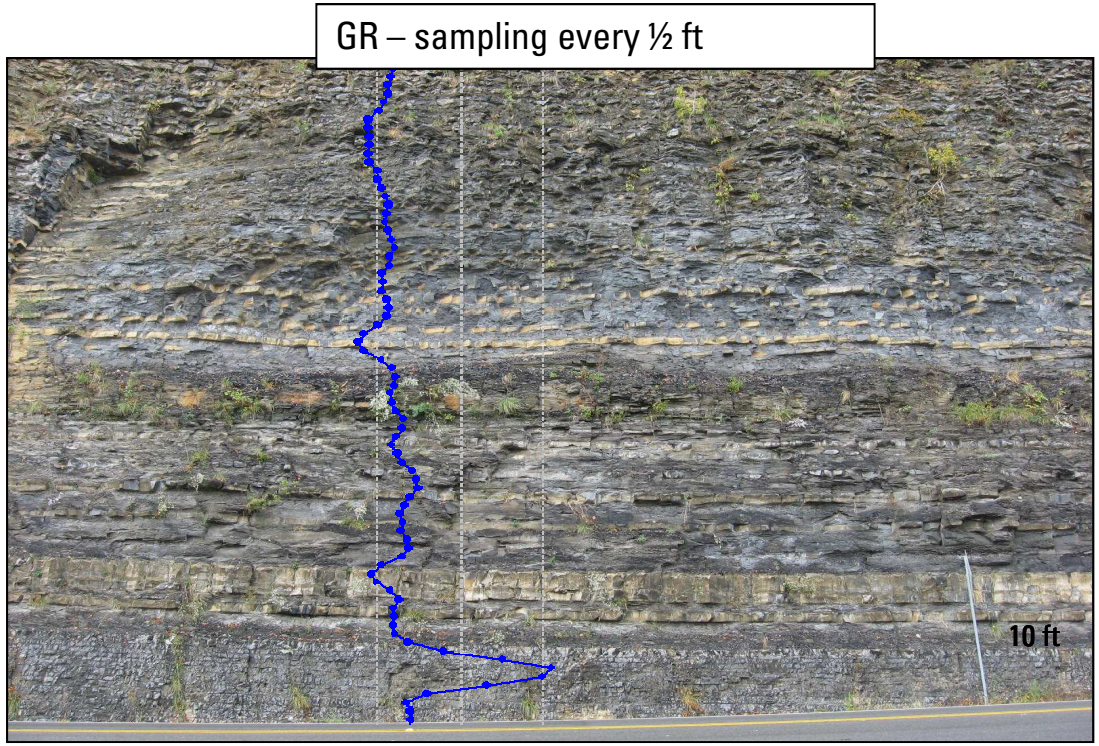
Quantify mineralogy (clays)
- Accurate log evaluation
- Completion design

Quantify hydrocarbon in place

Predict producibility
- Permeability
- Pressure
- Amount and type of fractures

Determine lateral landing point
- Near and far-field stress profile
- Rock quality

Optimize frac design
- Near and far-field stress
- Rock quality
- Fluid compatibility
- Fines production



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Key Factors for Economic Shale

Gas in Place

Matrix Permeability

Hydraulic Fracture Surface Area

Hydraulic Fracture Conductivity

Hydraulic Fracture Containment

Reservoir Quality

Completion Quality

Evaluation Process Must Address These Factors!

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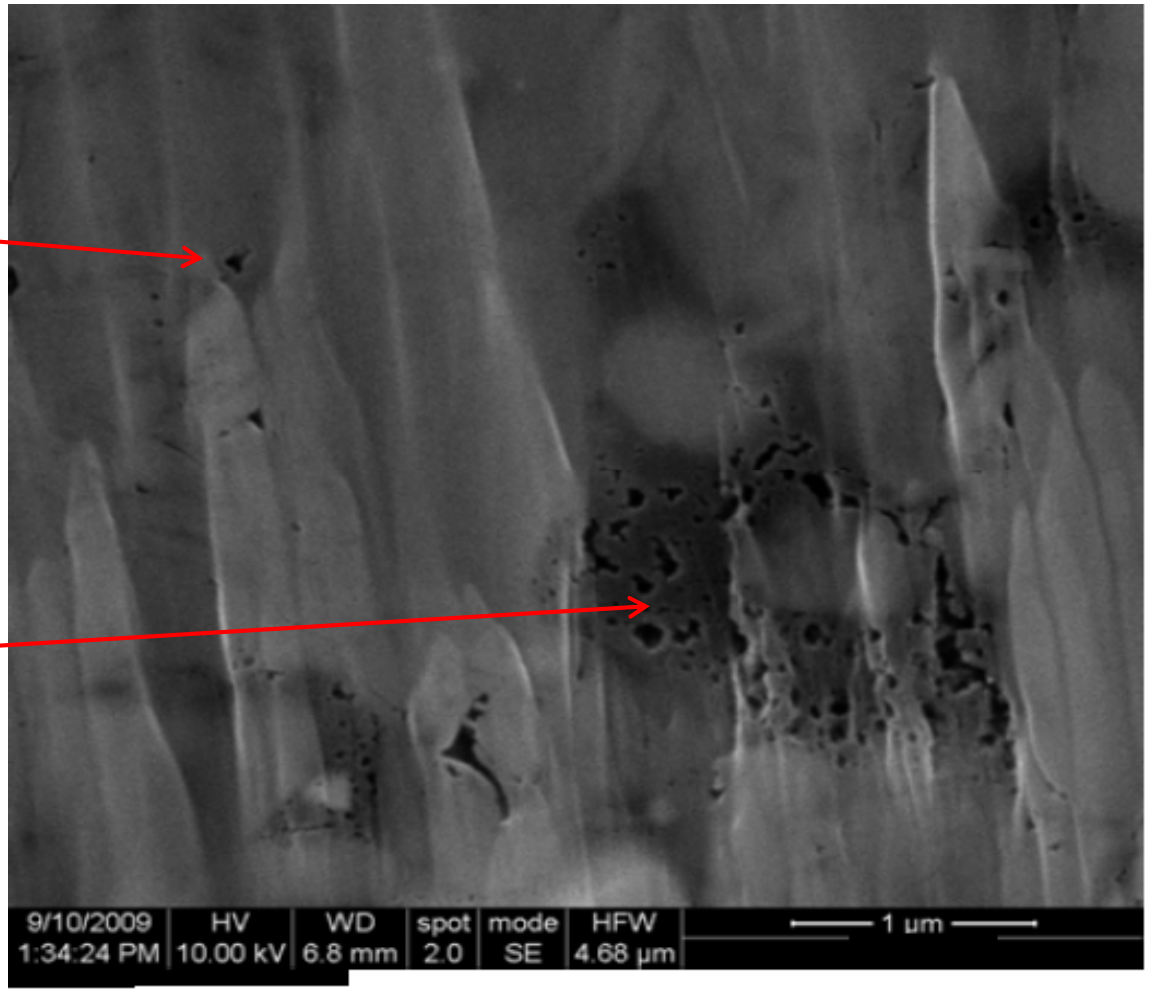
Reservoir Quality

Phyllosilicate Pores

Organic Pores



Moncrieff 2009

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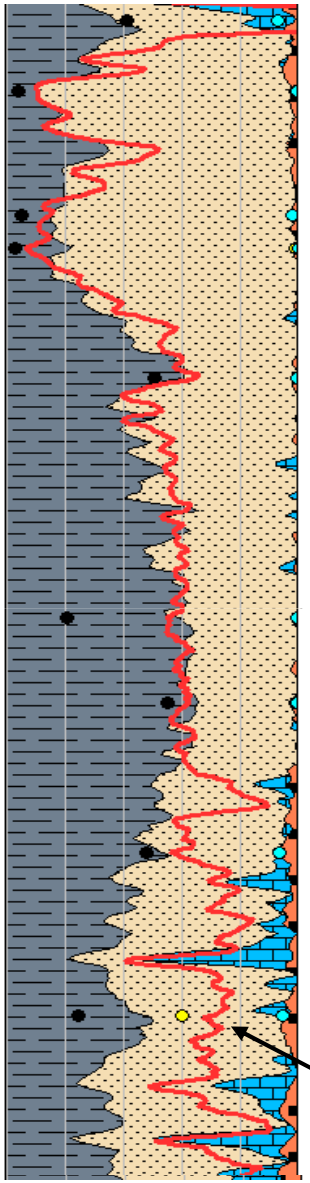
Clay Quantification

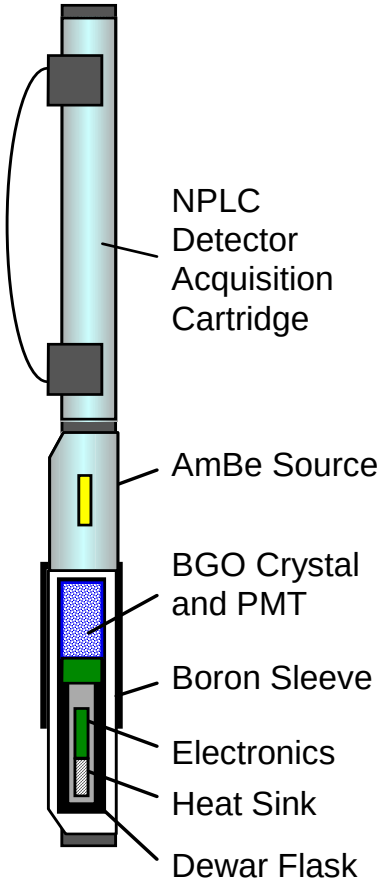
Necessary for shale gas evaluation

- Kerogen volume
- S_w

Geochemical log is key to evaluation

- Si, Ca, Fe, S, K
- SpectroLith lithology
- Independent of measurements affected by kerogen





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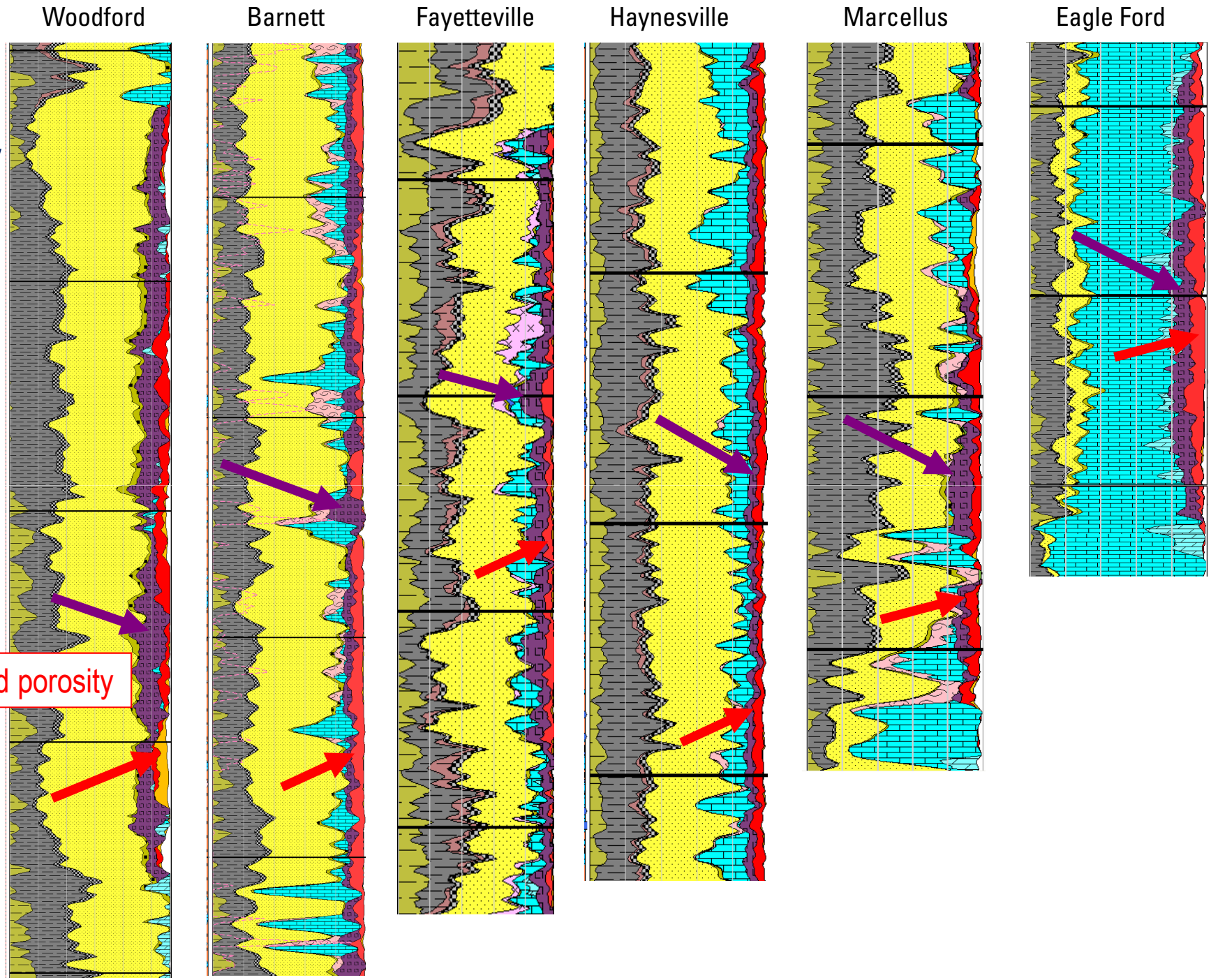
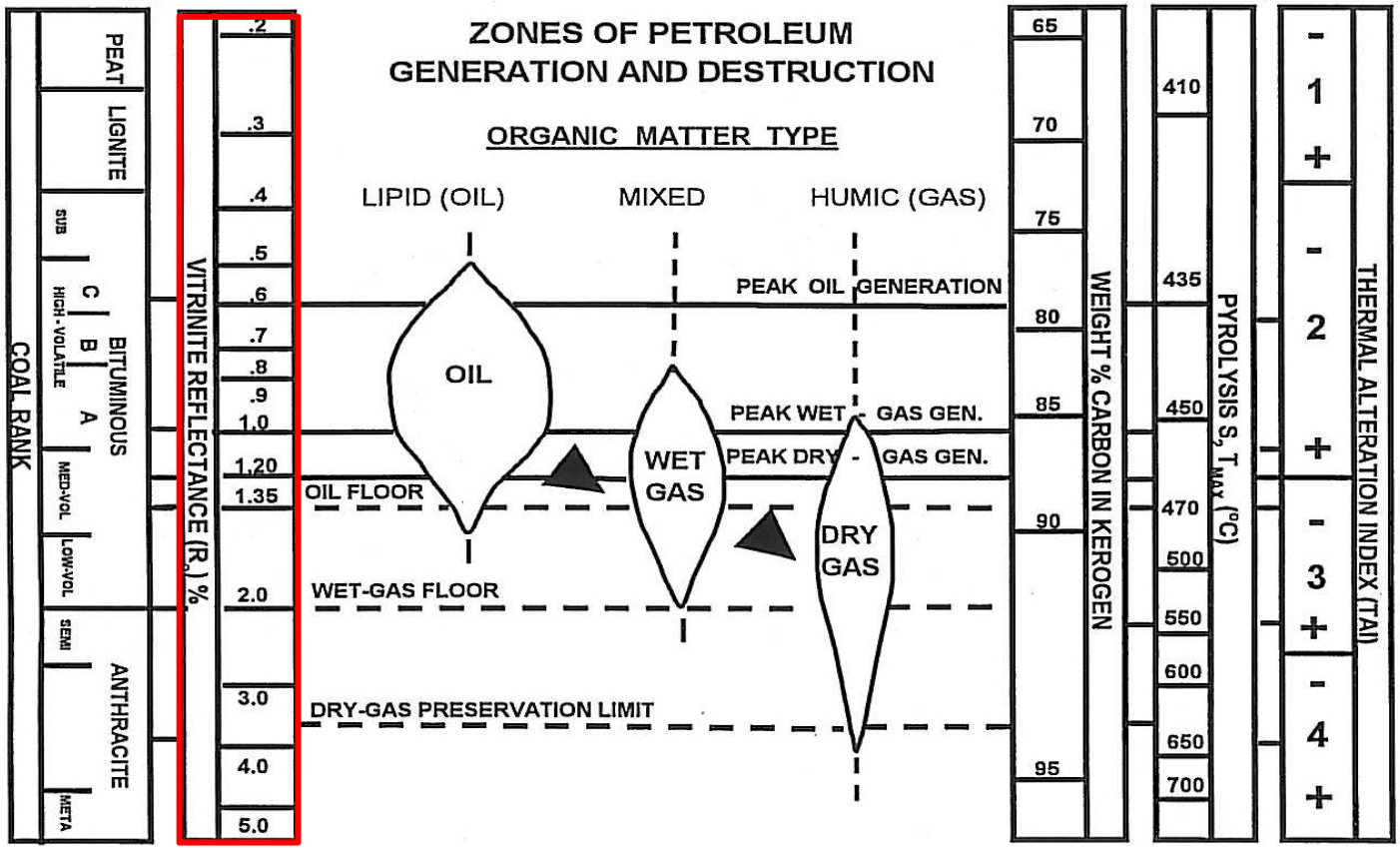
Shale Lithology



Kerogen

Hydrocarbon-filled porosity

Organic Geothermal Diagenetic Criteria



CORRELATION OF VARIOUS MATURATION INDICES AND
ZONES OF PETROLEUM GENERATION AND DESTRUCTION

Only measure with core

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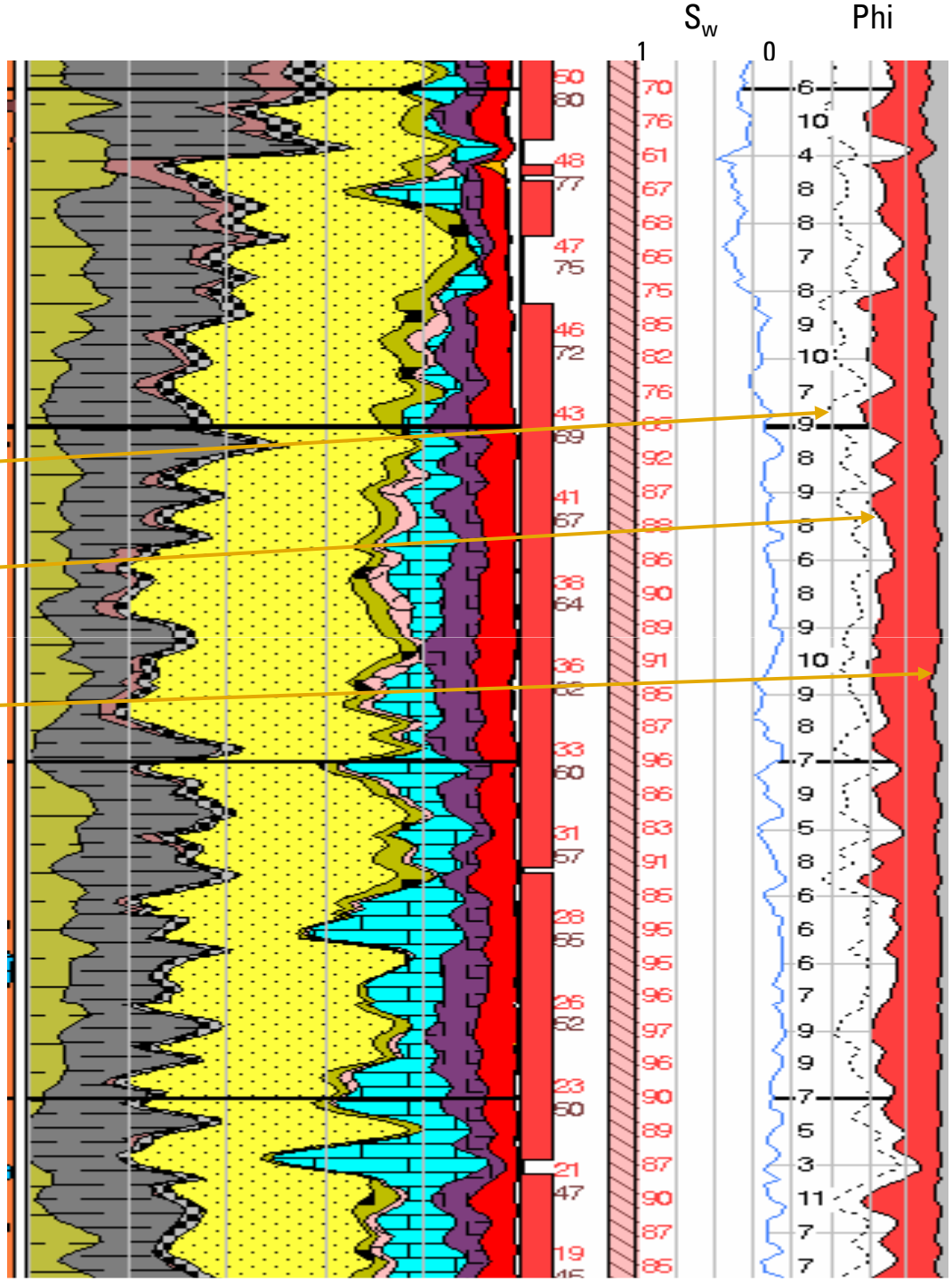
Porosity / Saturation

Total Phi

Eff Phi

Pore Water



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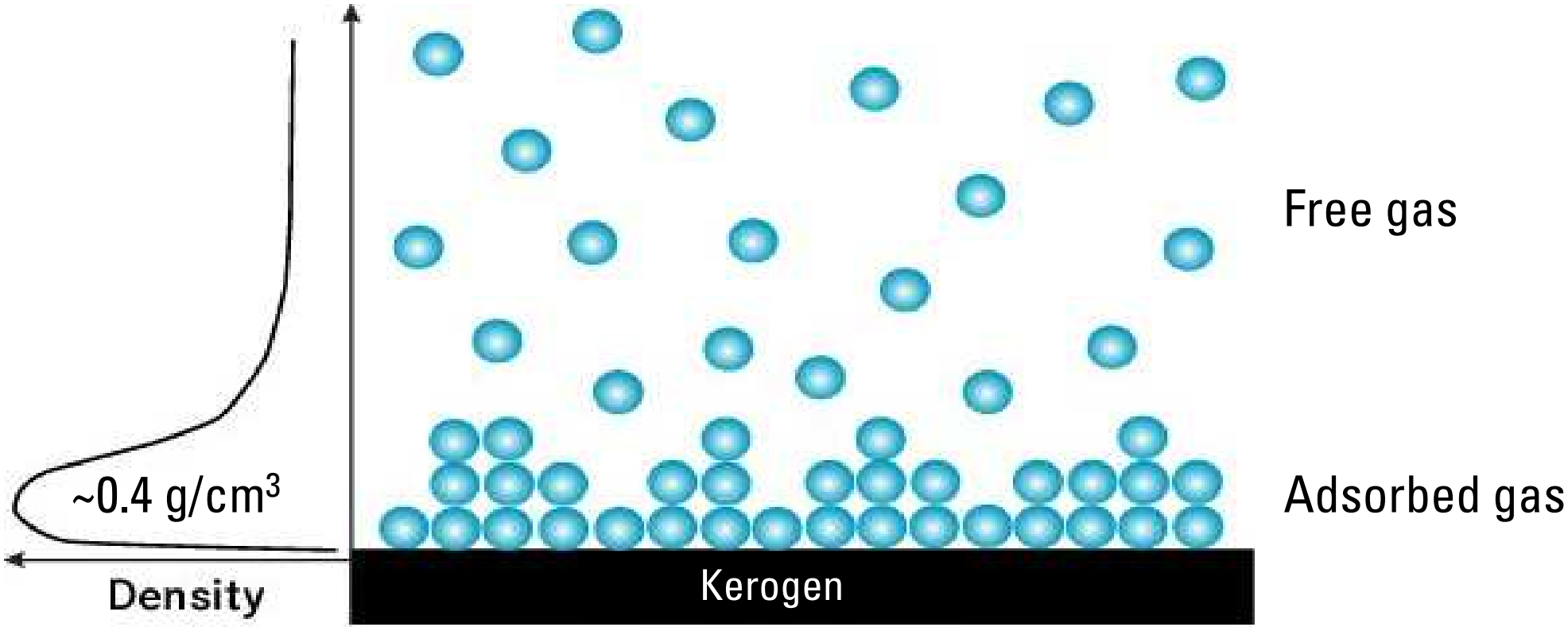
Gas Adsorption



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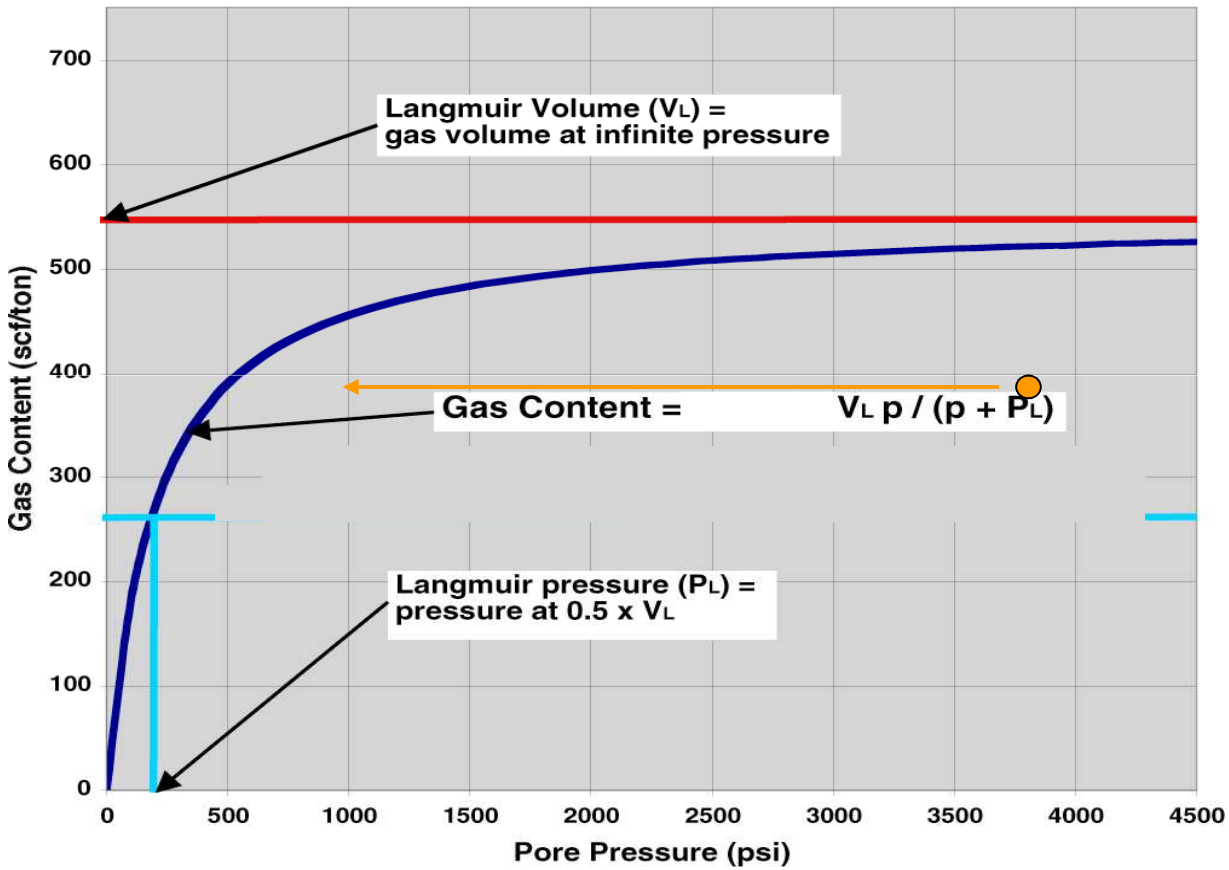
Shale Gas Adsorption / Desorption Isotherm

Langmuir Equation



"Gold Standard" for adsorption

Outputs

- V_L
- P_L
- TOC content
- Temperature

Typically only methane

Assume complete saturation

Assume no input from clay

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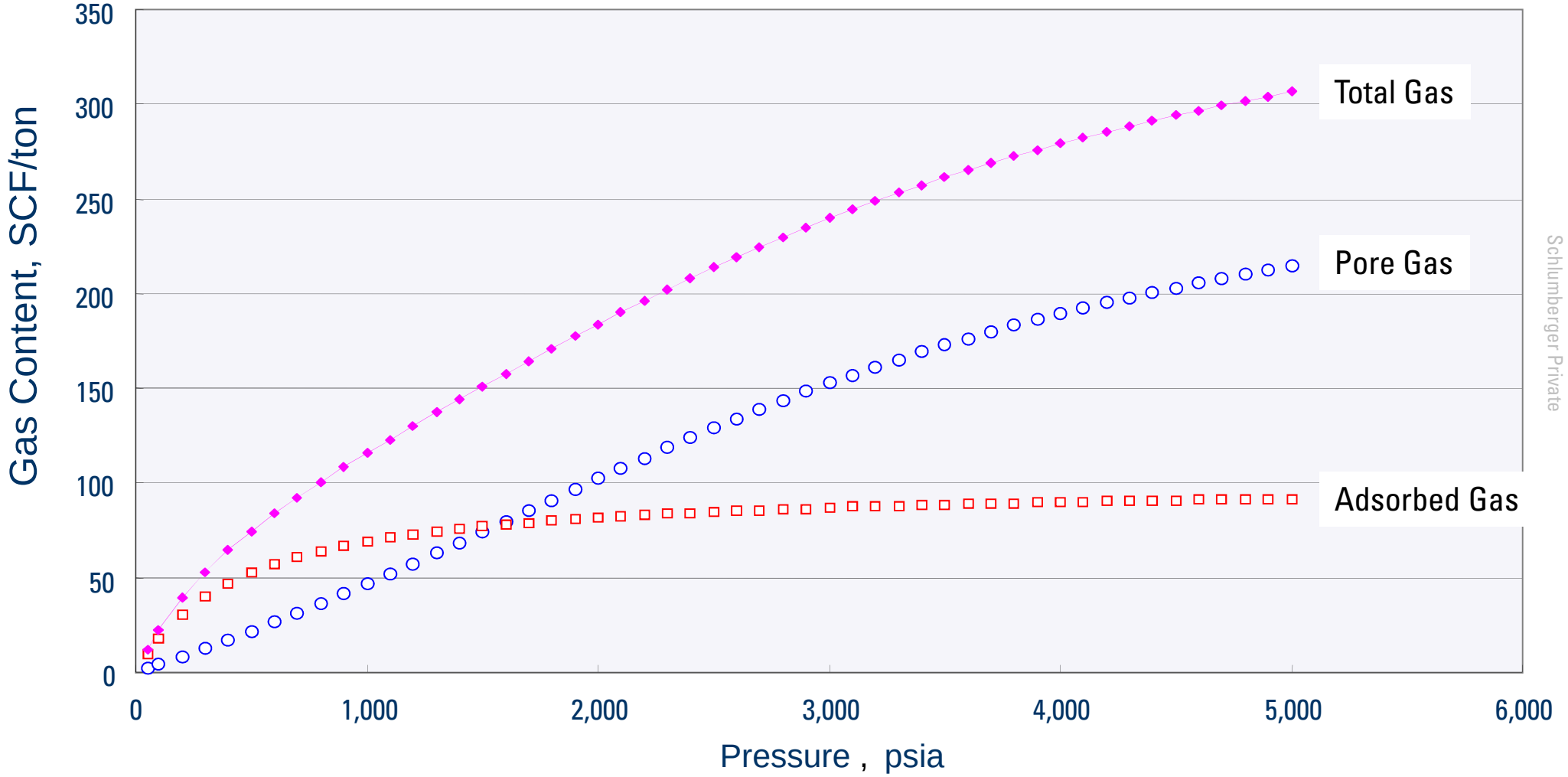
GIP - Importance of Pore Pressure



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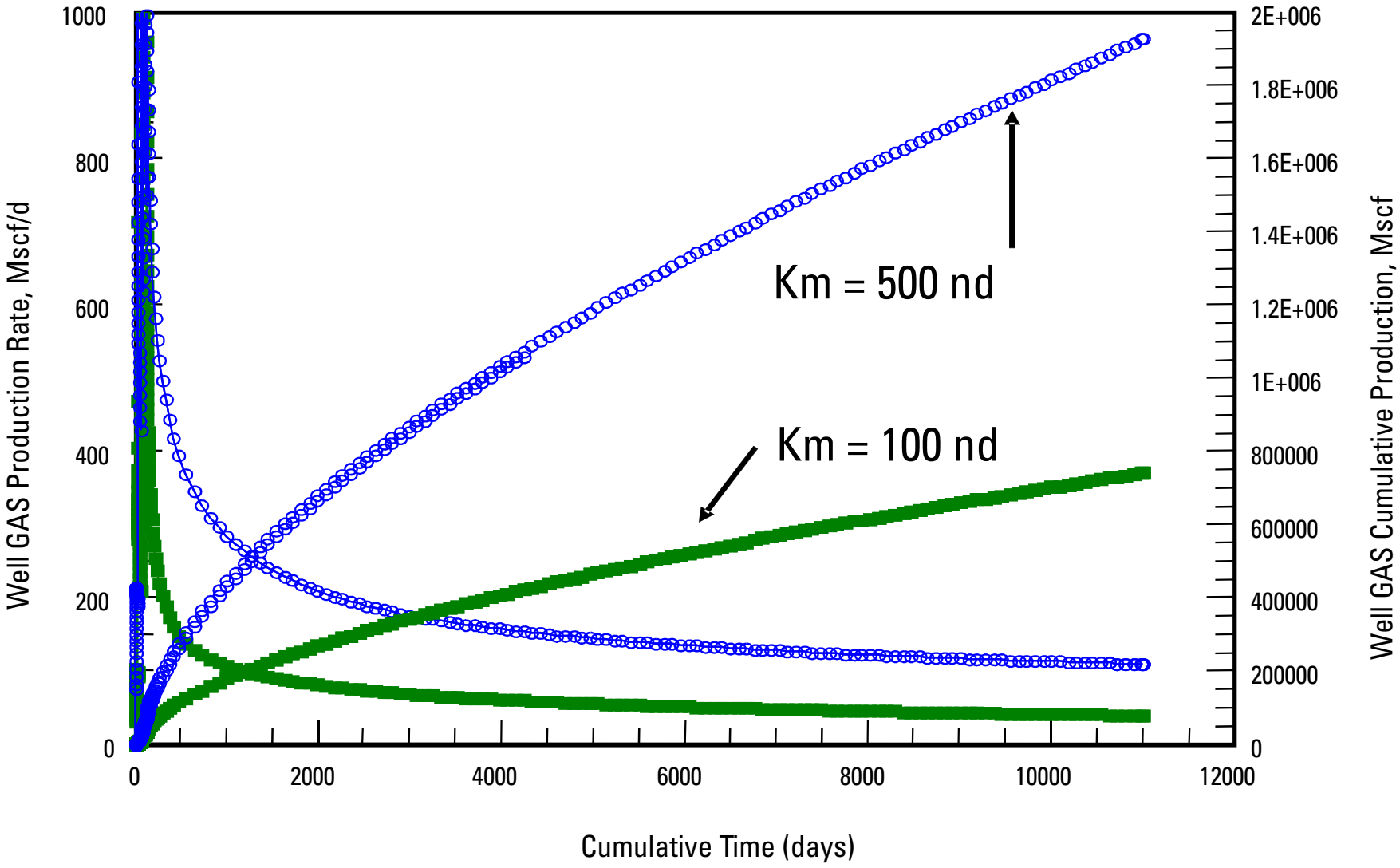
Matrix Perm vs. Production
Barnett Vertical Wells



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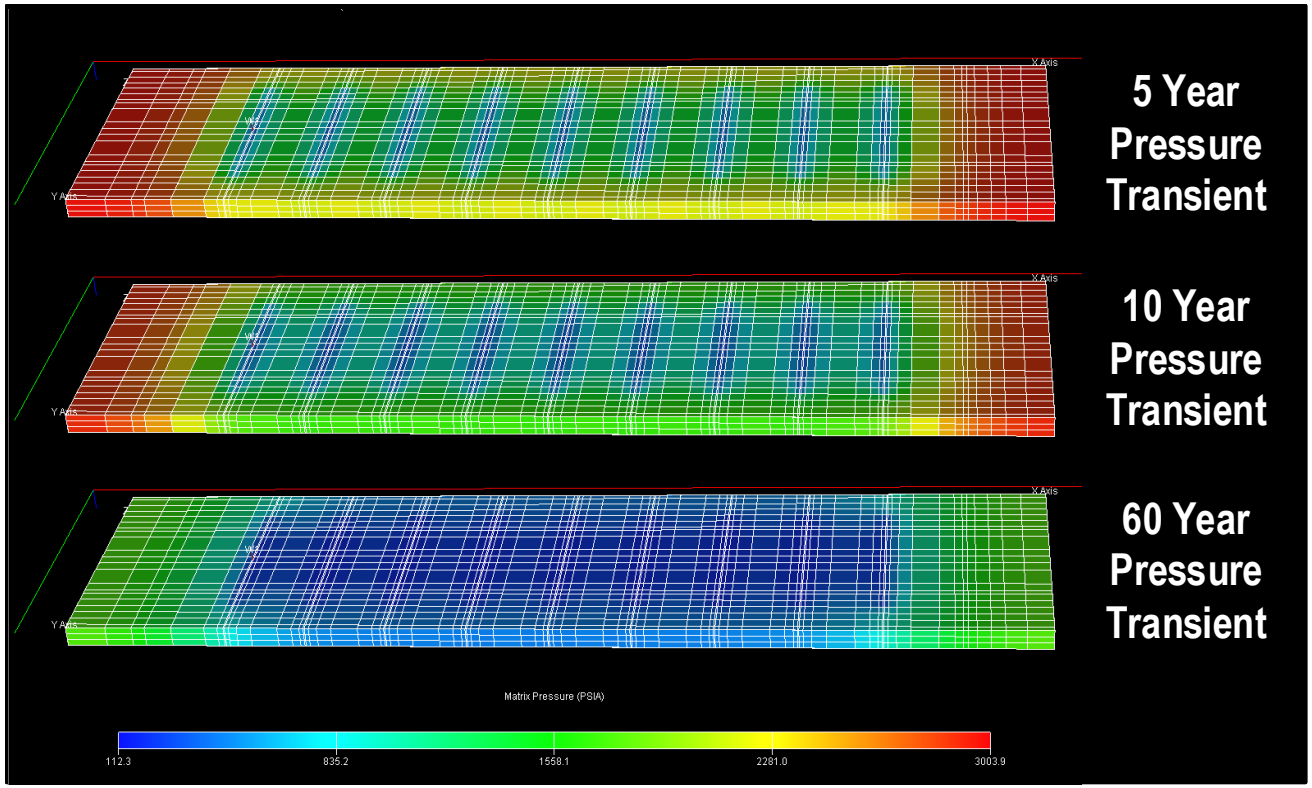
Shale Permeability

Hydraulic Fractures at 250 ft Spacing (400 nd)



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Matrix Permeability

Range 0.001 mD to 0.0000001 mD

(1000 nD to 0.1 nD)

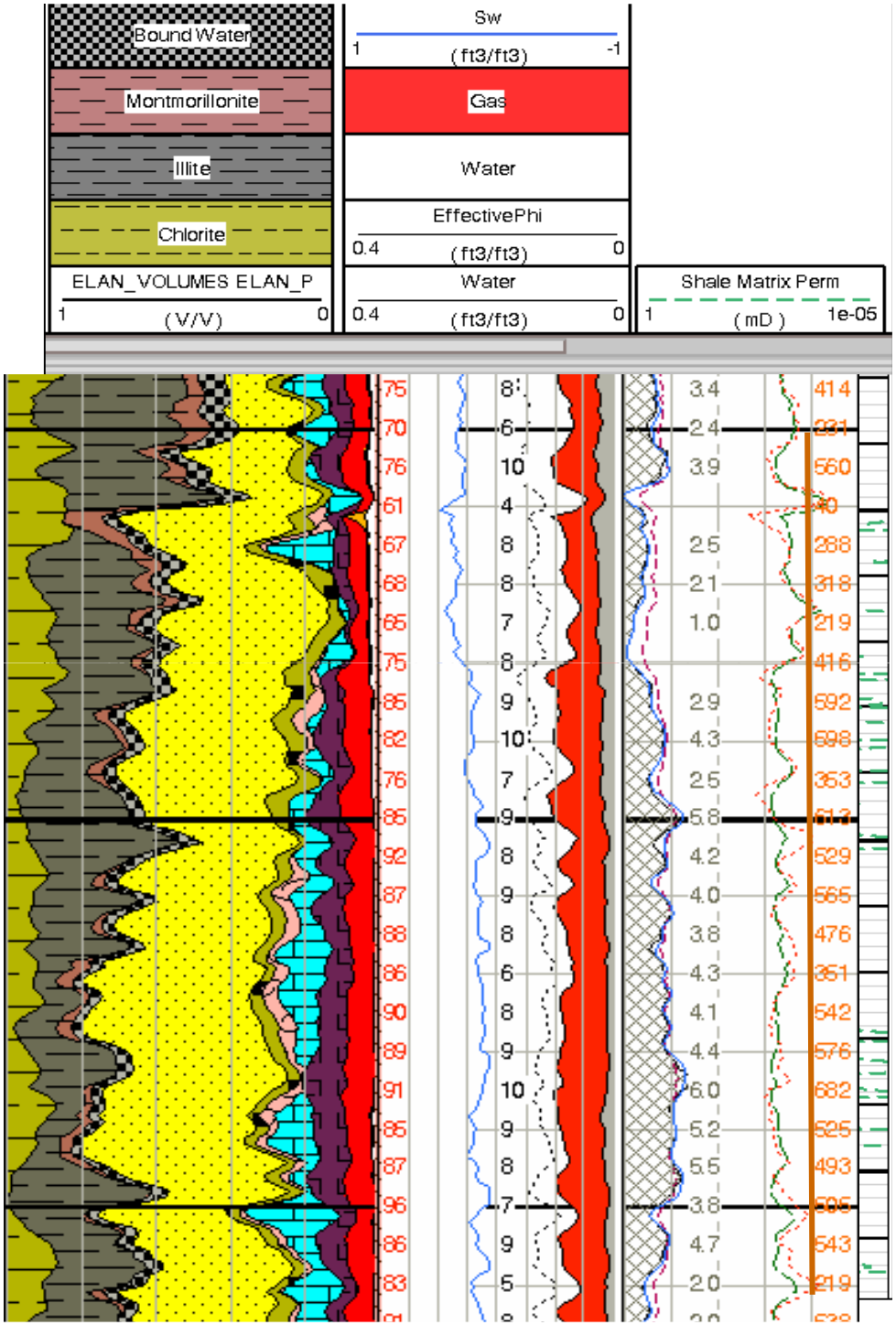
General algorithm exists

- Tuned algorithms for basins
- Calibrated to TerraTek data

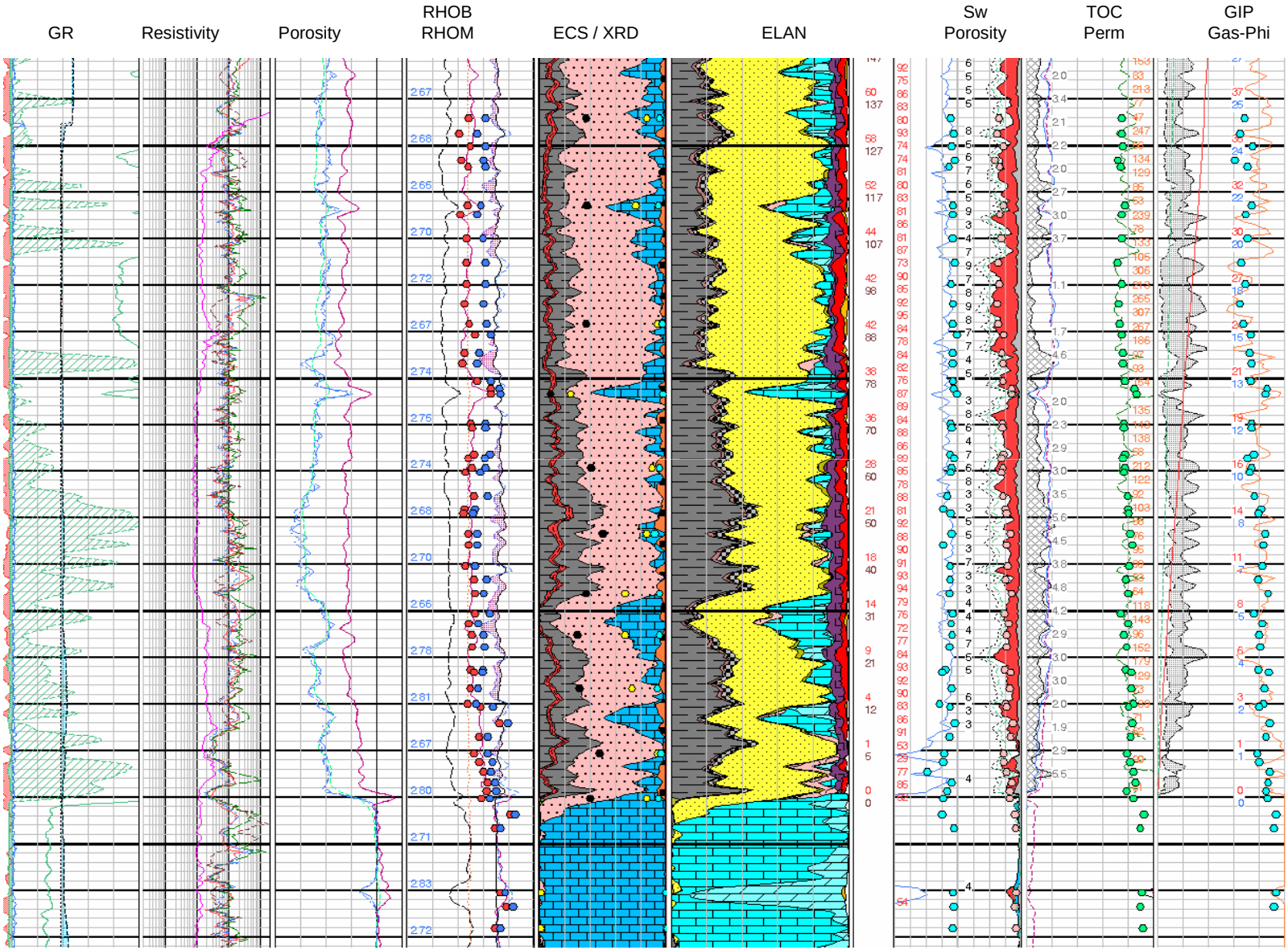
Function of

- Porosity
- Water saturation

Specialized core analysis



Barnett Shale - Log vs. Core Comparison



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Gas Shale Pay Parameters

Sample No	A-R Bulk Density	A-R Grain Density	Dry Grain Density	Porosity	Water Saturation	Gas Saturation	Mobile Oil Saturation	Gas-Filled Porosity	Bound Hydrocarbon Saturation	Bound Clay Water	Pressure Decay Perm	TOC
	(g/cm^3)	(g/cm^3)	(g/cm^3)	(% of BV)	(% of PV)	(% of PV)	(% of PV)	(% of BV)	(% of BV)	(% of BV)	(md)	(wt %)
1	2.48	2.622	2.645	6.65	15.16	81.4	3.43	5.42	0.5	6.21	0.00027	3.77
2	2.436	2.559	2.584	6.26	18.5	76.44	5.05	4.79	1.29	7.03	0.00023	6.75
3	2.48	2.633	2.652	6.87	15.43	83.9	0.66	5.77	0.5	6.8	0.00027	3.36
4	2.327	2.487	2.509	7.74	13.09	83.02	3.87	6.43	0.73	6.67	0.000347	7.41
5	2.373	2.539	2.558	7.58	11.17	85.92	2.9	6.52	0.34	2.63	0.000359	5.95
6	2.461	2.605	2.63	6.87	16.26	80.42	3.32	5.53	0.99	7.19	0.000298	5.04
7	2.75	2.812	2.818	2.48	7.41	88.89	3.69	2.21	0.29	1.87	0.000044	0.98
8	2.341	2.511	2.527	7.66	7.67	88.39	3.93	6.77	0.82	4.9	0.000463	7.84
9	2.428	2.573	2.599	7.11	17.77	79.06	3.16	5.62	0.75	7.01	0.000292	4.12
10	2.468	2.633	2.645	6.87	5.5	91.15	3.34	6.26	0.91	4.58	0.000305	4.02
11	2.525	2.593	2.661	6.53	54.54	40.42	5.03	2.64	0.1	5.19	0.000112	2.29
12	2.637	2.73	2.765	5.27	34.63	64.44	0.92	3.4	0.05	5.04	0.000149	6
13	2.451	2.543	2.599	6.97	47.77	51.58	0.64	3.6	0.28	9.45	0.000161	5.3
14	2.432	2.574	2.605	7.29	24.19	75.19	0.61	5.48	0.28	7.48	0.000333	5.73
15	2.436	2.56	2.579	5.96	18.23	81.01	0.75	4.83	0.28	5.05	0.000346	6.59
16	2.445	2.548	2.573	5.38	9.65	75.13	15.21	4.05	0.4	3.12	0.000243	5.19
17	2.523	2.619	2.687	7.02	9.07	51.88	39.04	3.65	0.67	3.22	0.000176	5.68
18	2.472	2.606	2.621	5.99	13.06	85.56	1.37	5.13	0.25	4.76	0.000325	6.26

- Effective phi: 4 to 14 pu
- Saturations: S_w < 45%, S_o < 5 to 15%
- Permeability: >100 nD
- TOC: >2 wt%
- Ro: >1.0

Completion Quality

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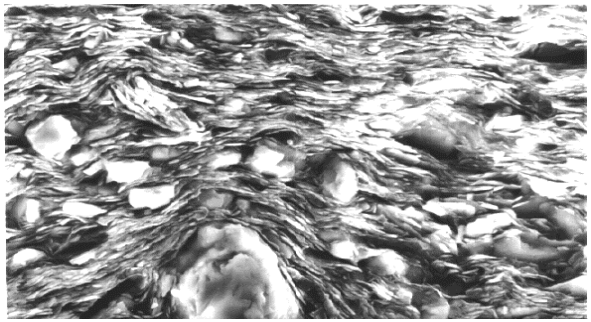
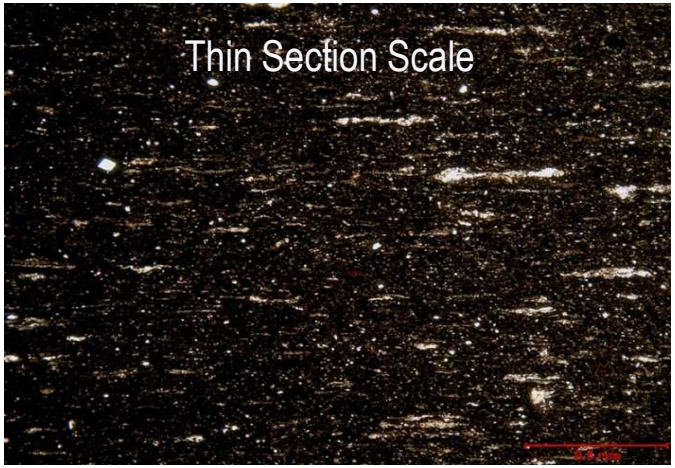
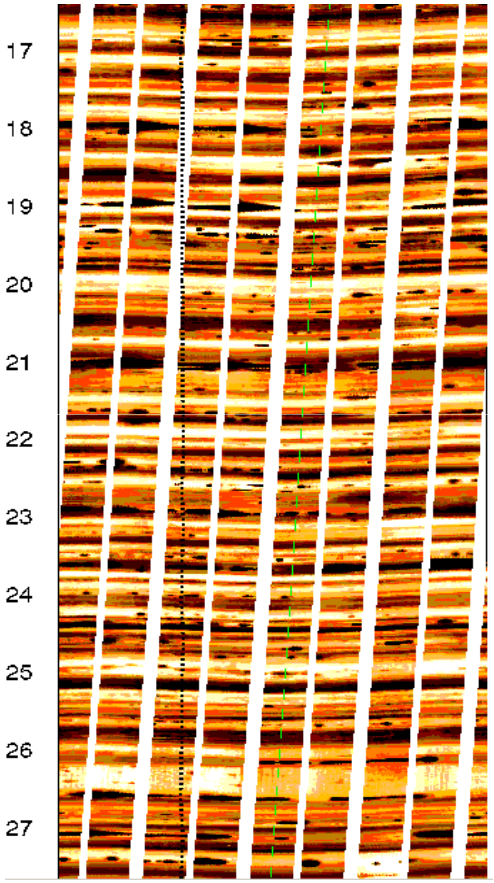
Unique Geomechanical Properties of Organic Shales

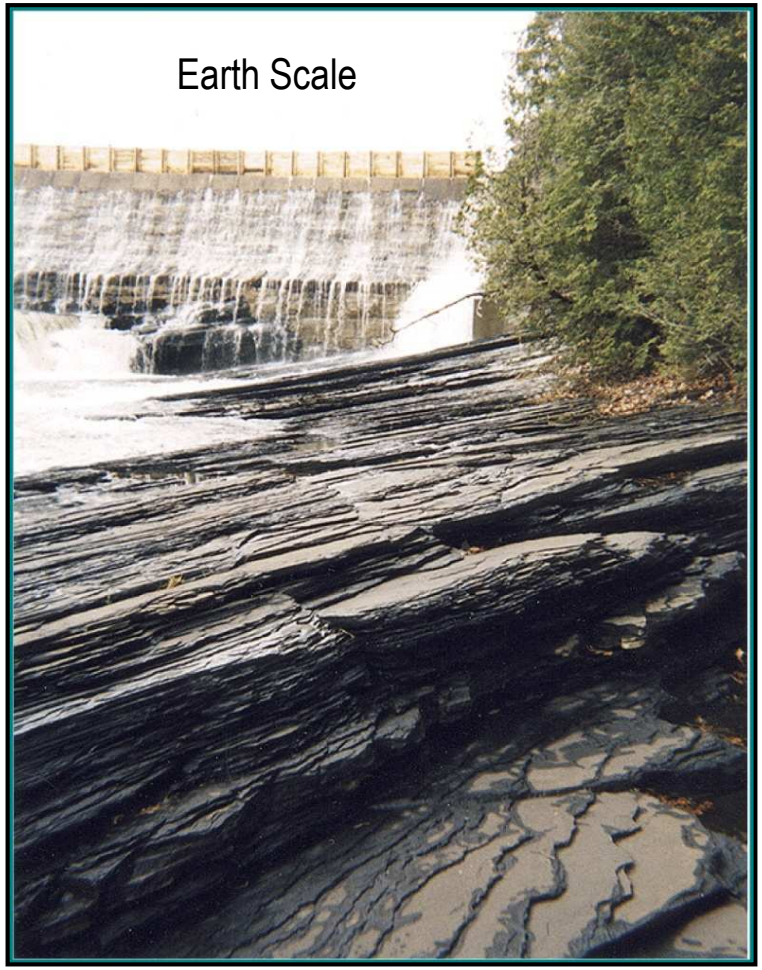


SEM Scale





Log Scale



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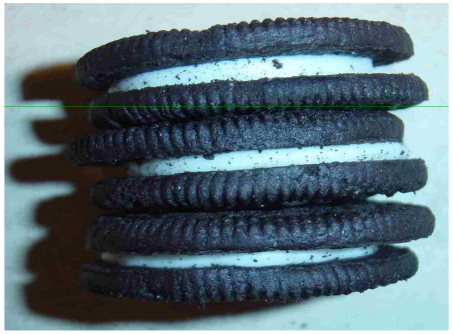
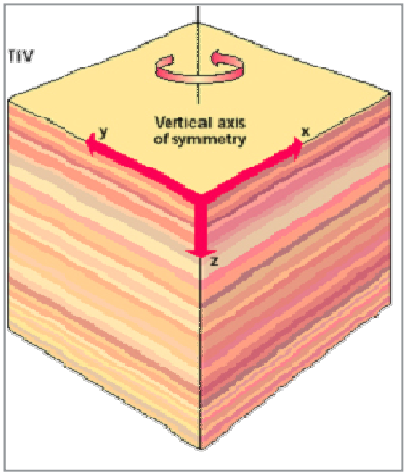
Impact of Shale Laminations on Stress

Laminations lead to significant differences between horizontal and vertical properties

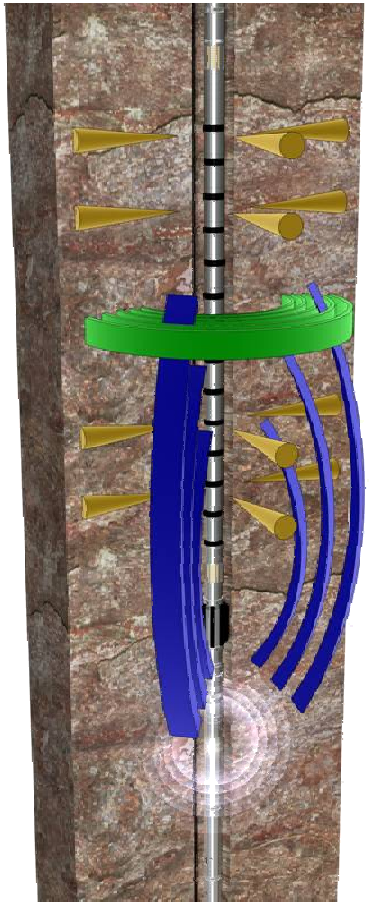
- Shear velocity
- Young's Modulus
- Poisson's Ratio





Bedded Shales
Transverse Isotropic Vertical

Sonic Scanner



	Horizontal Young's Modulus	Horizontal Poisson's Ratio	Vertical Poisson's Ratio	Vertical Young's Modulus
Sample 1	8.890E+06	0.158	0.227	4.598E+06
Sample 2	6.133E+06	0.150	0.155	4.091E+06

Core Measurement

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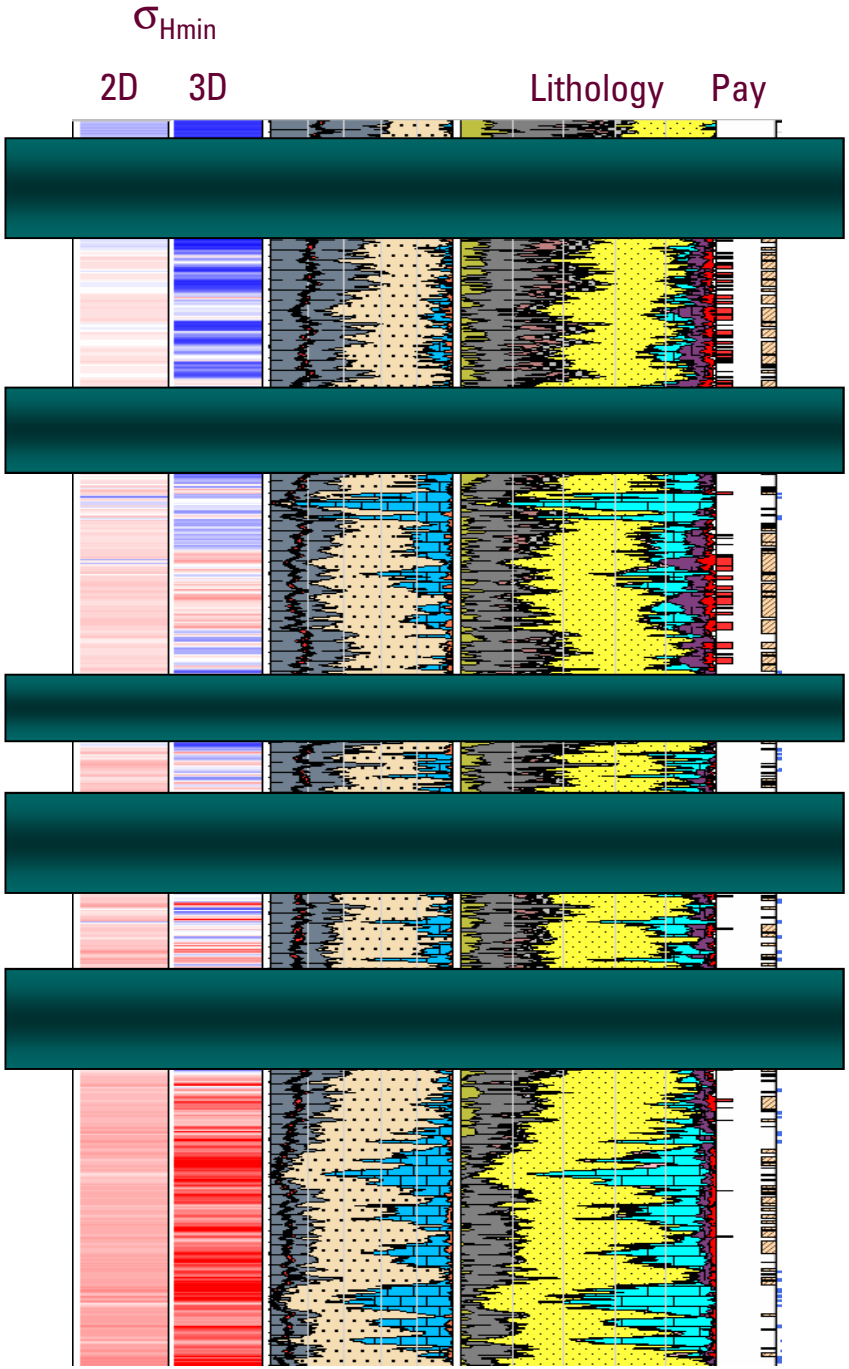
Expandable Clay Stress Concentration



Red – low stress
Blue – high stress

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Importance of Lateral Landing Point Location

Well #1

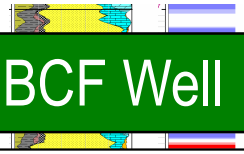
325 MMCF/ft

< 1BCF Well

Well #2

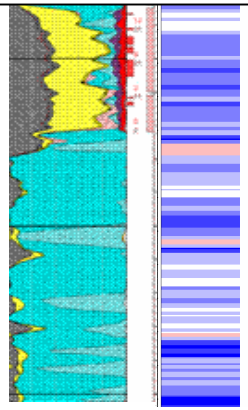
332 MMCF/ft

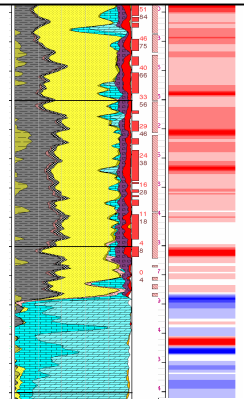
3 BCF Well



3 new wells drilled with lateral placed in low stress interval
Original well IP 1.2 MM/day

New wells IP from 2 to 4 MM/day
After Tax Rate of Return doubled
EUR increased by 20%
Profit to Investment Ratio double





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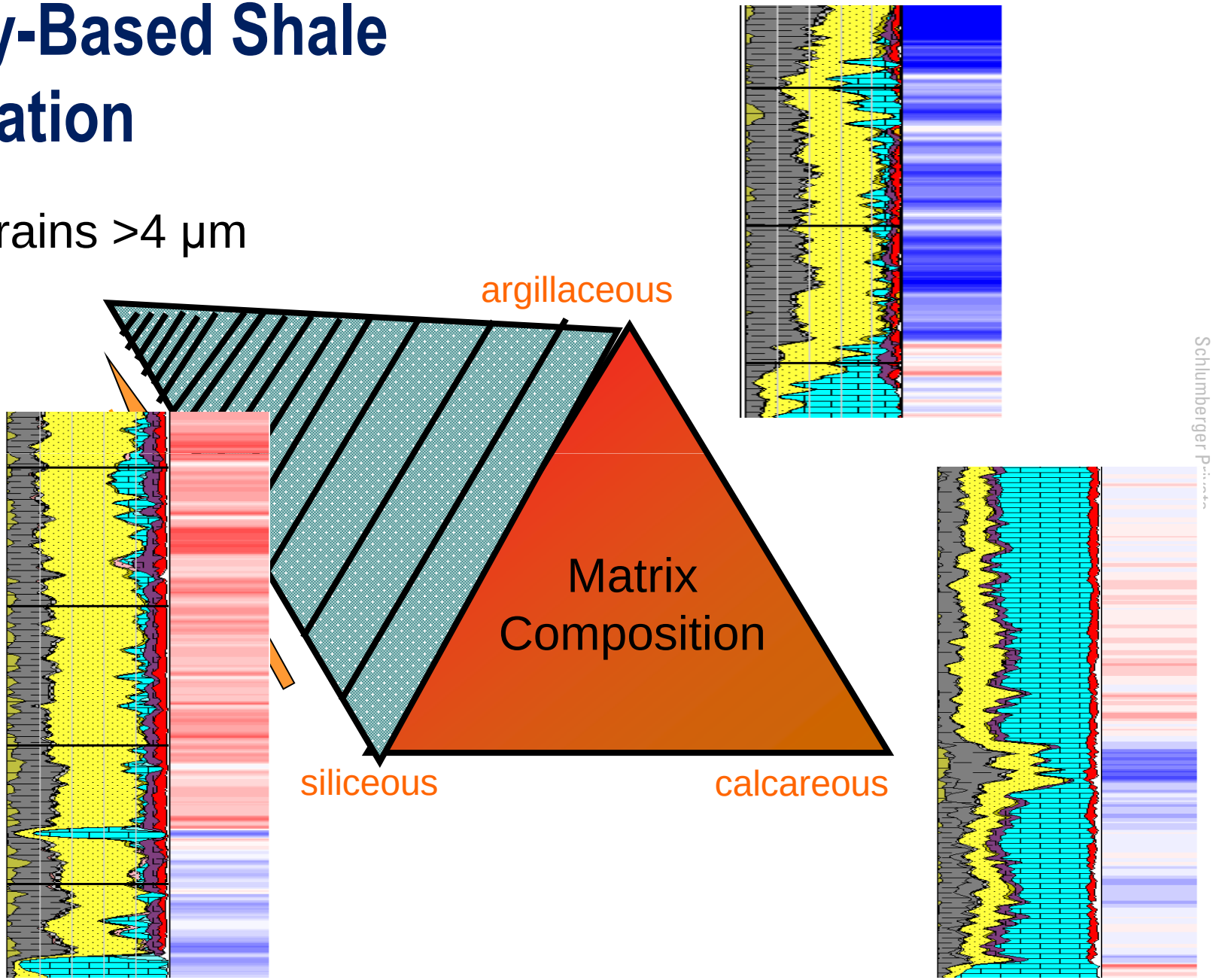
Lithology-Based Shale Classification

Grains >4 µm



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