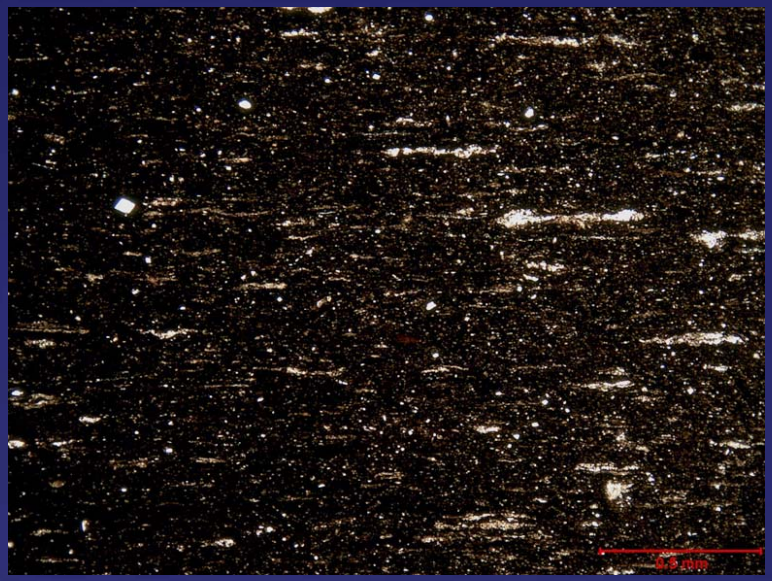


Evaluation of Shale Gas Reservoirs

Rick Lewis

Oklahoma City

Schlumberger

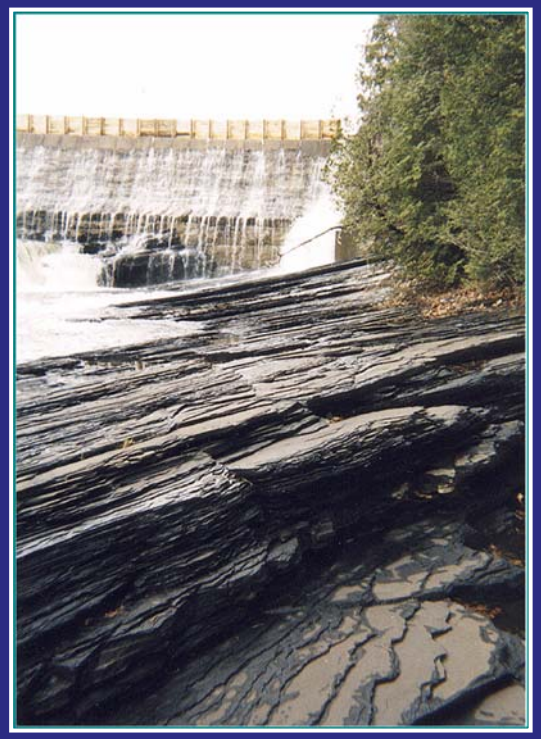
Gas Shales

What are they?

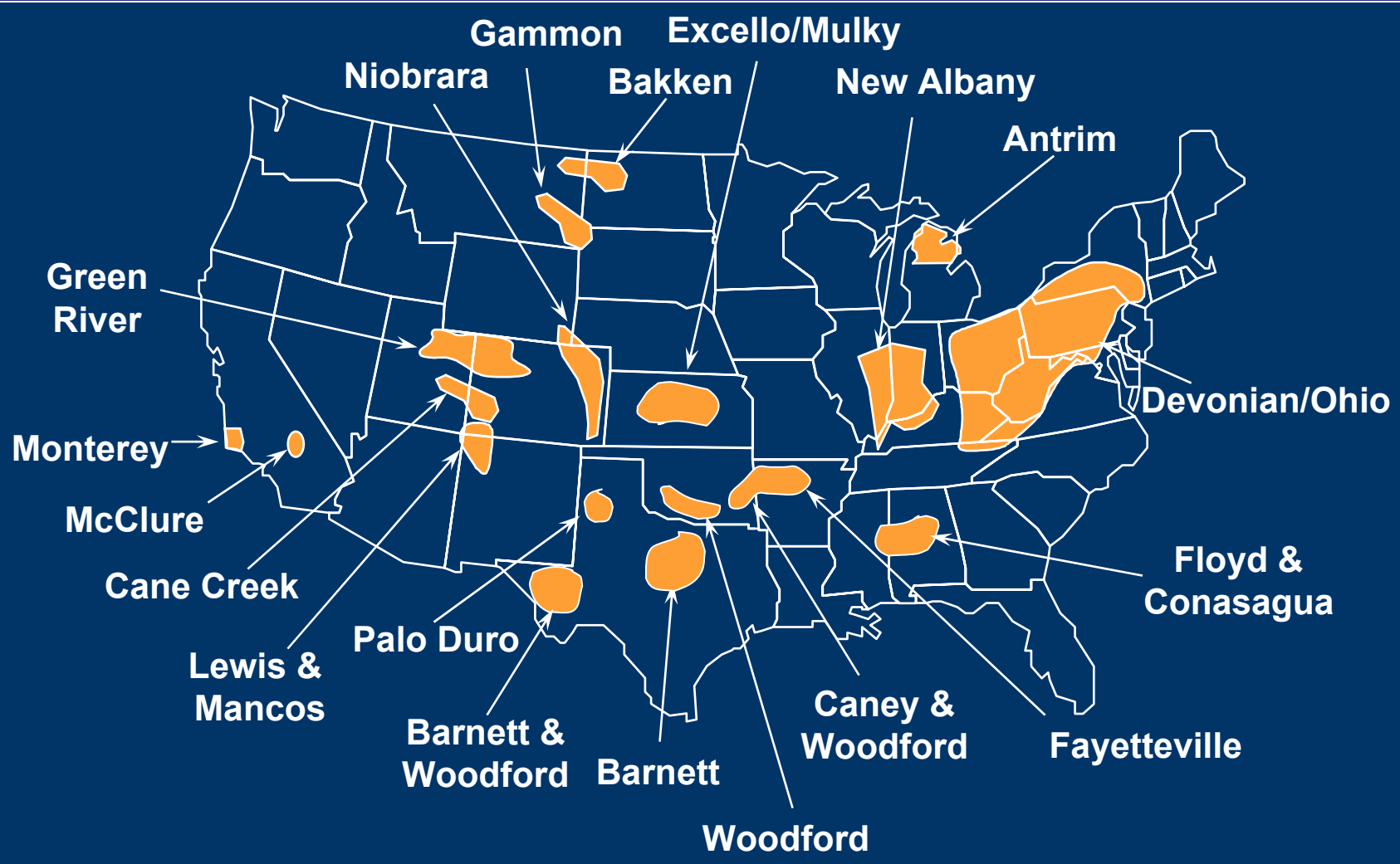
- Organic-rich shales
- Source rocks
- Adsorbed and free gas
- Very low permeability

Common traits of gas shale reservoirs

- Abundant gas (20 to 500 BCF/section)
- Low recovery efficiency (8 to 12%)
- Large developments (economies of scale)
- Fracture stimulation
- Long well life



Gas Shales of the United States



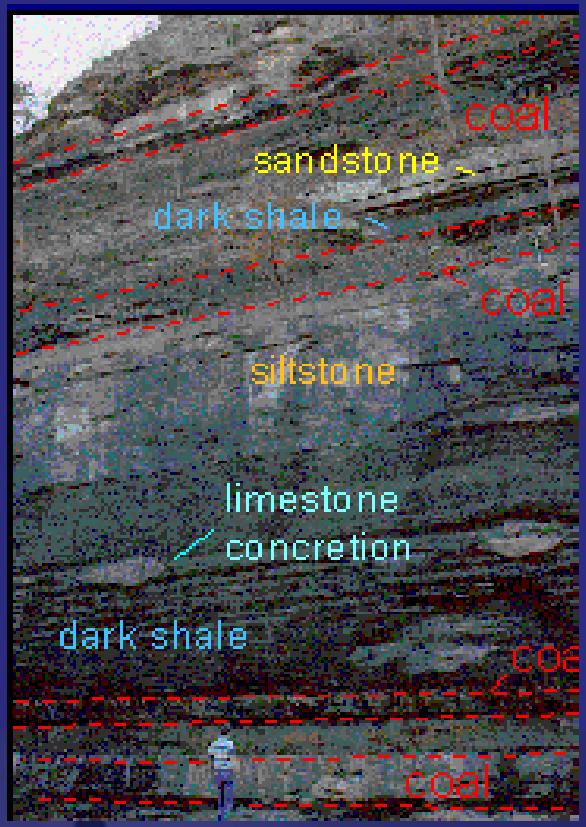
Shale Gas Evaluation Needs

Delineation of shale gas beds

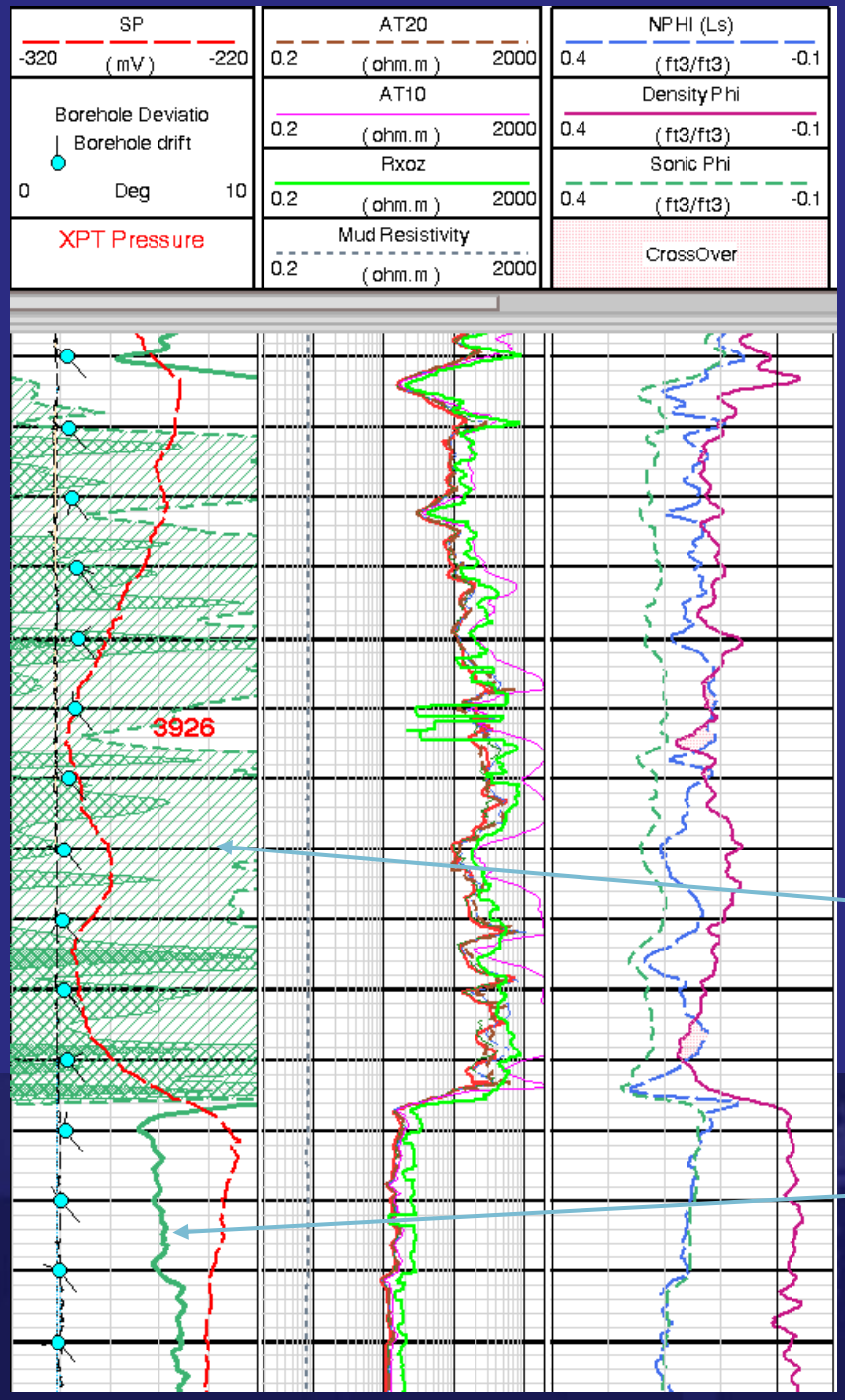
Quantify gas
- Adsorbed
- Free

Producibility
- Matrix permeability
- Amount and type of fractures
- System permeability
- Pressure

Production prediction



Gas Shale Log



Gamma ray activity > 150 gAPI

Resistivity > 15 ohm-m

Bulk density < 2. 58 g/cm^3

Density porosity > 8 pu (Ls matrix)

Neutron reflects clay content

Gas Shale

"Typical" Shale

Kerogen

Methane adsorbs to kerogen

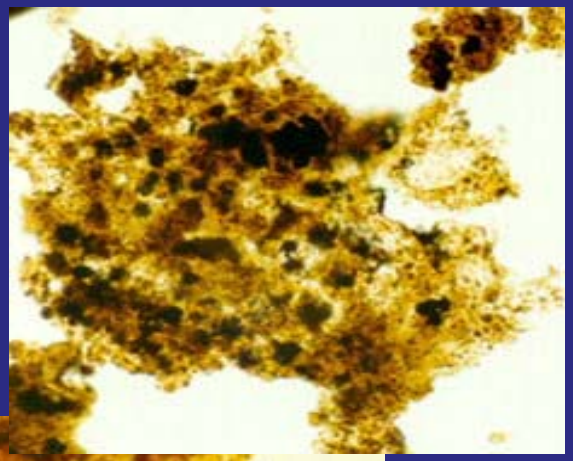
- Insoluble organic matter
- Equivalent to TOC

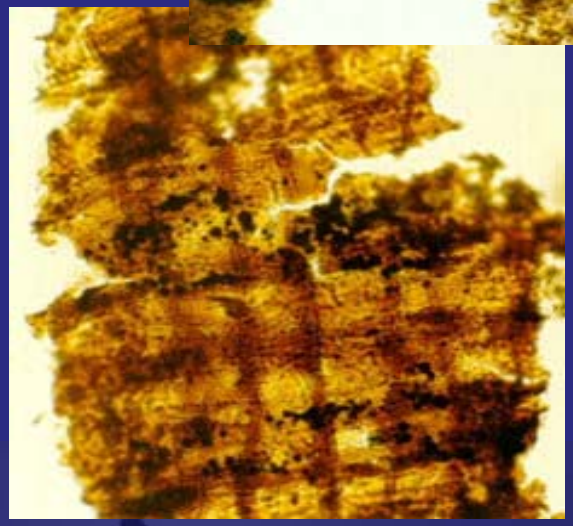
Kerogen

- Deposited in anoxic environments
- Mississippian and Devonian best
- Majority are mixed Type 2/3

Kerogen petrophysical properties

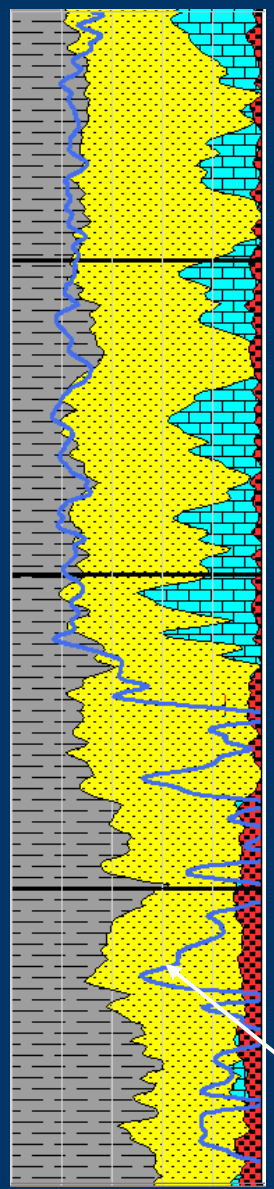
- Low density (1.3 g/cm^3)
- Very high GR activity (500 to 4000 gAPI)
- Low P_e (0.24)
- High neutron porosity (60 pu)

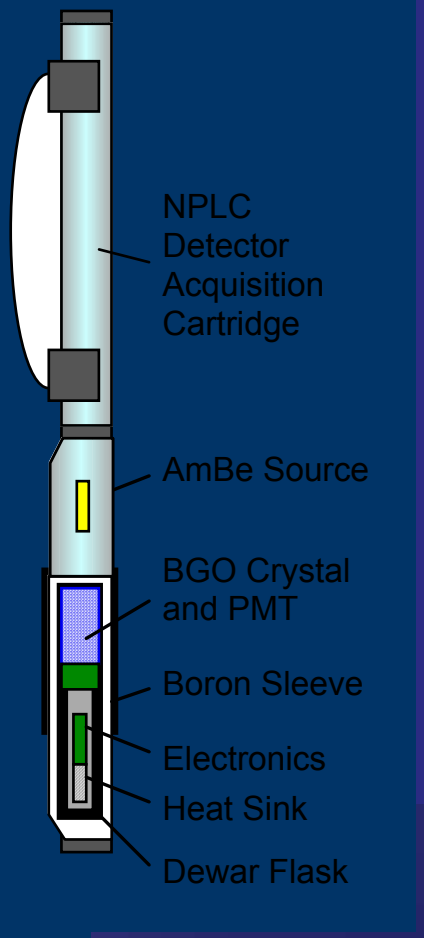




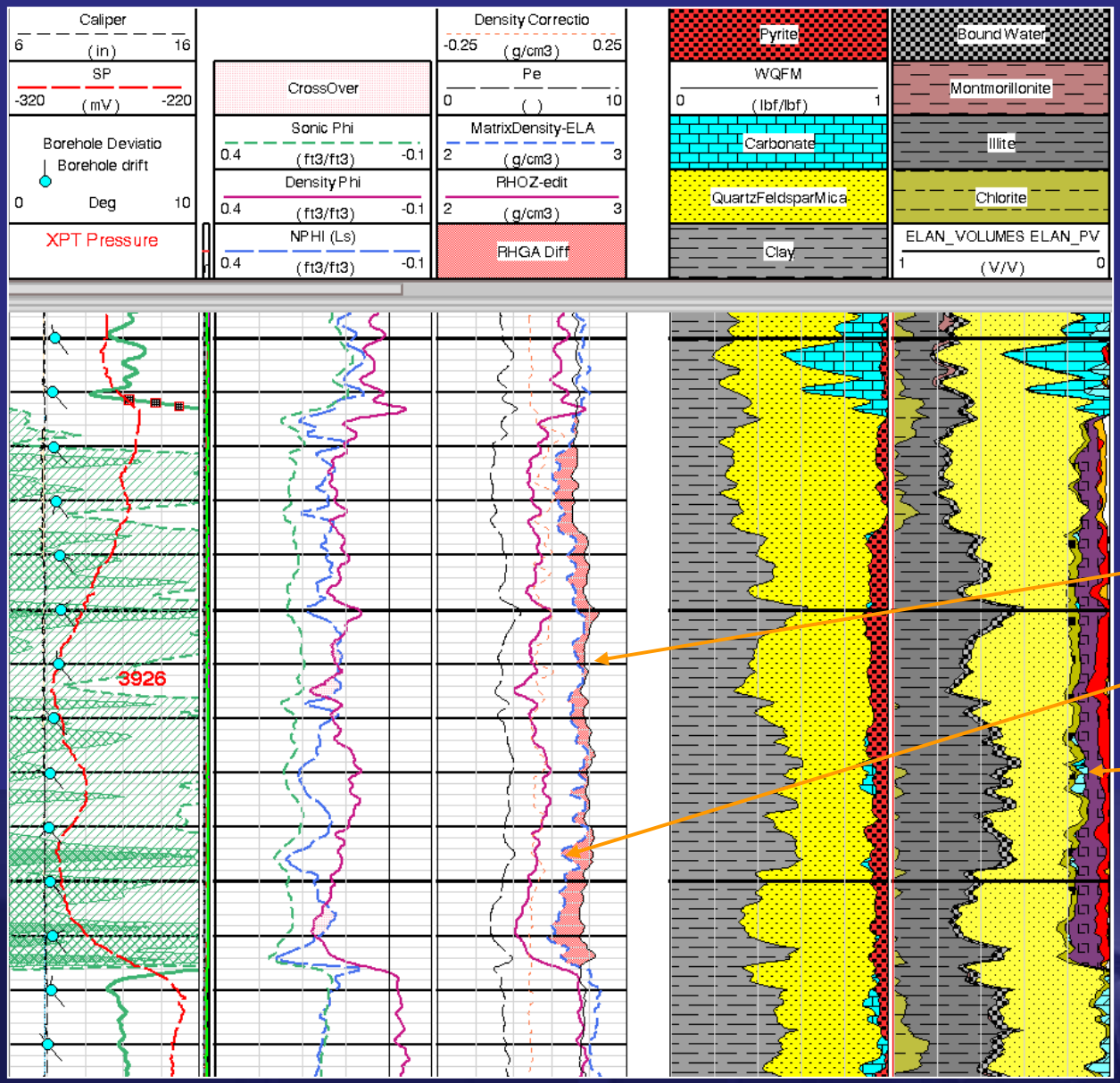
Clay Quantification

- Necessary for shale gas evaluation
  - Kerogen volume
  - S_w
- Geochemical log is key to evaluation
  - SpectroLith clay content independent of measurements affected by kerogen





ELAN to Calculate Kerogen Volume

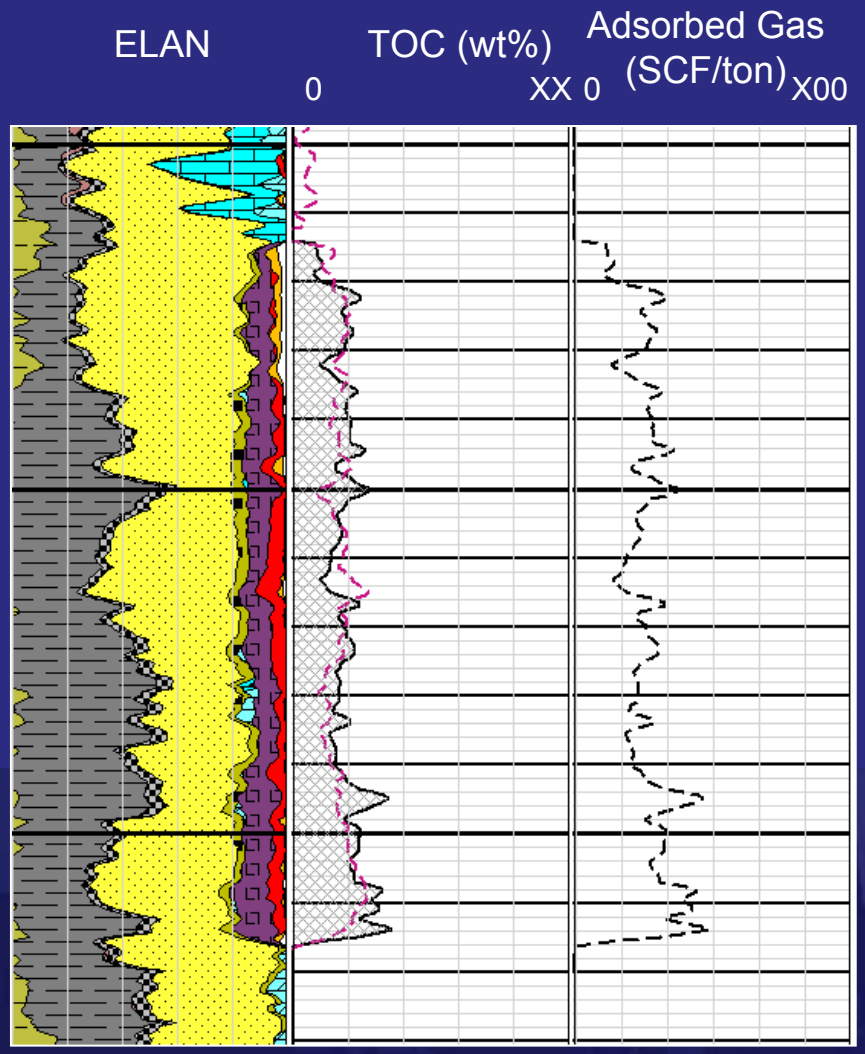


ECS RHOM

ELAN RHOM

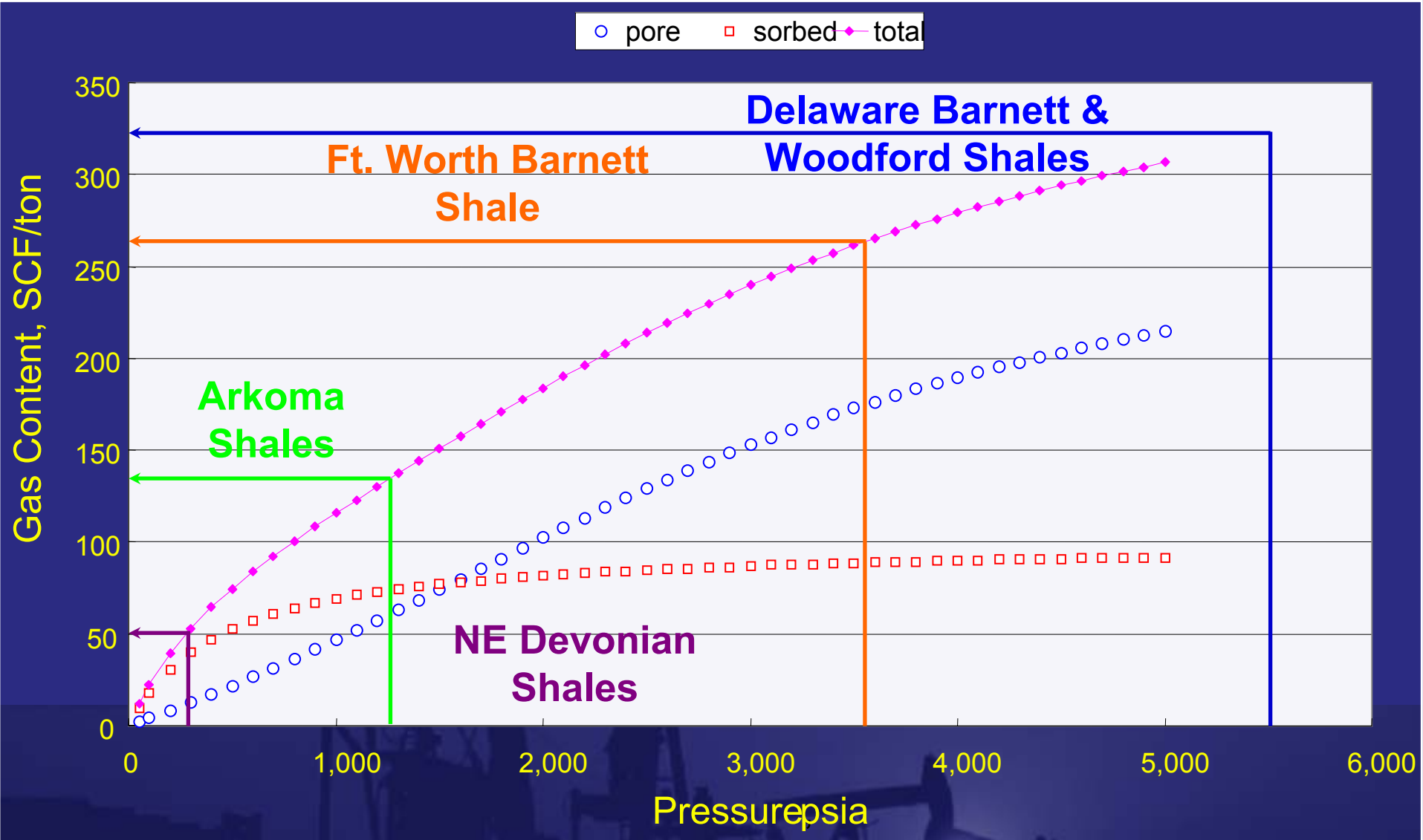
Kerogen

Adsorbed Gas Log



- Kerogen converted to TOC
  - Function of thermal maturity
- Isotherm used to calculate adsorbed gas
- Calculated in SCF/ton (industry standard)

GIP - Importance of Gas Location



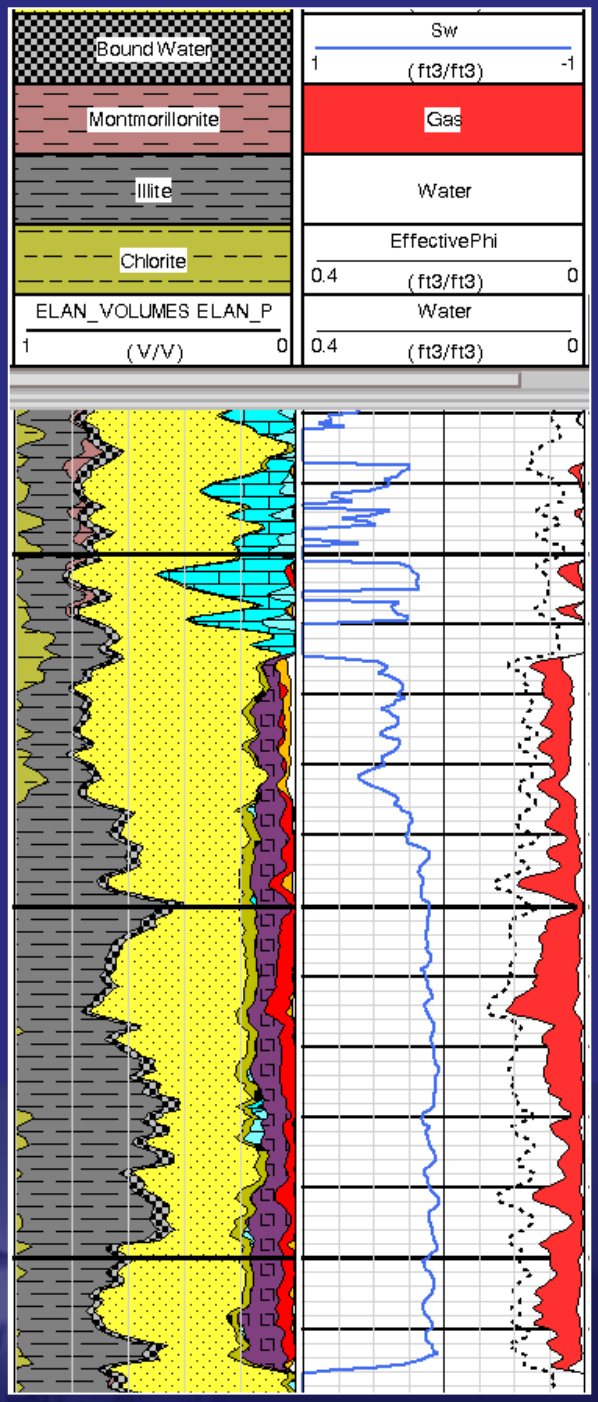
Free Gas Log

Accurate measure of gas within shale microporosity

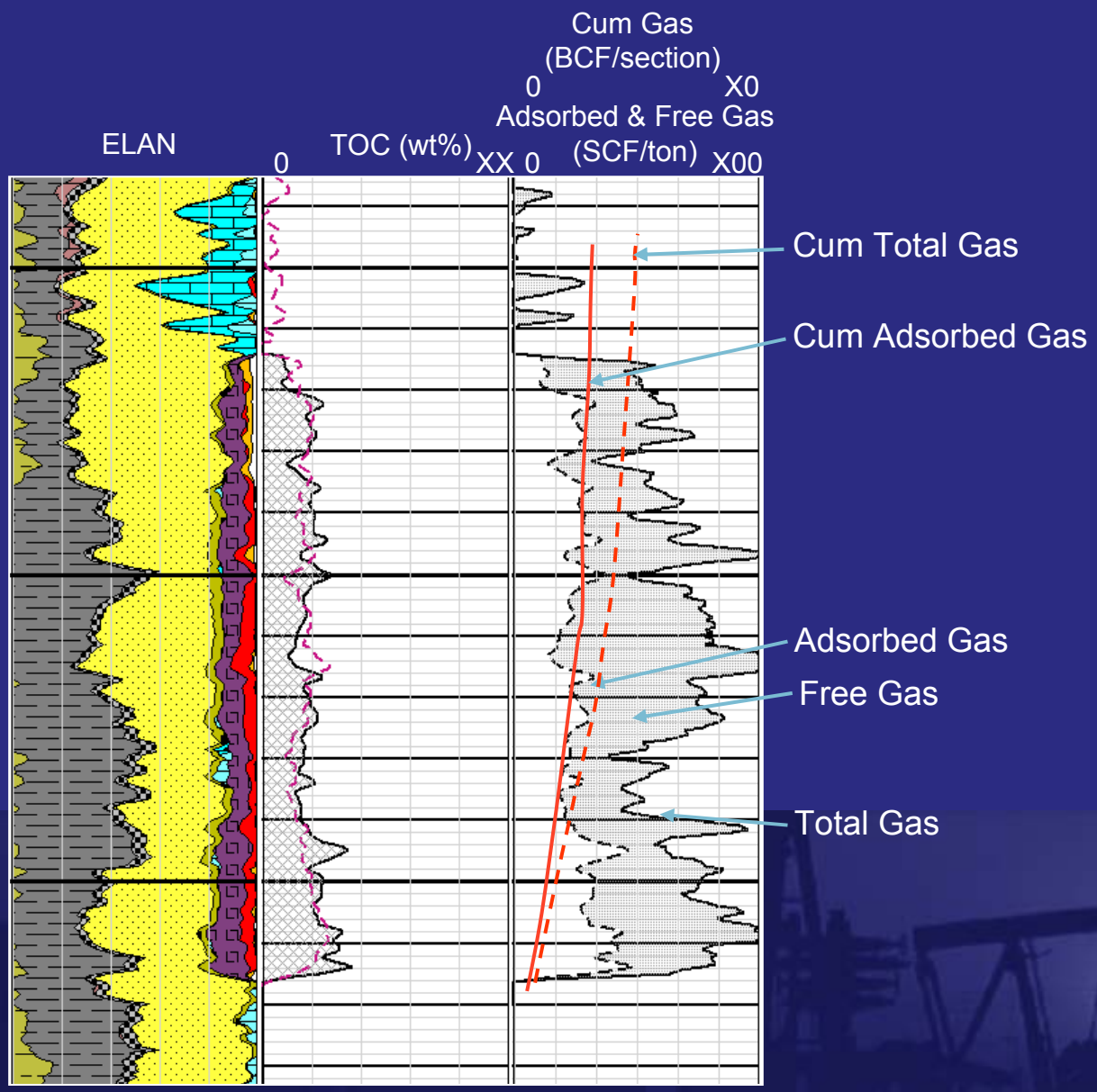
- Effective Phi
- S_w

Requires knowledge of

- Clay content
- Matrix density
- R_w, R_{bw}



Total Gas Log



All gas in SCF/ton

Solves for cumulative gas (BCF/section)

Identify and quantify resource not visible with conventional logs

Matrix Permeability

Range 0.001 mD to 0.0000001 mD

(1000 nD to 0.1 nD)

No general algorithm

Basin specific

Function of

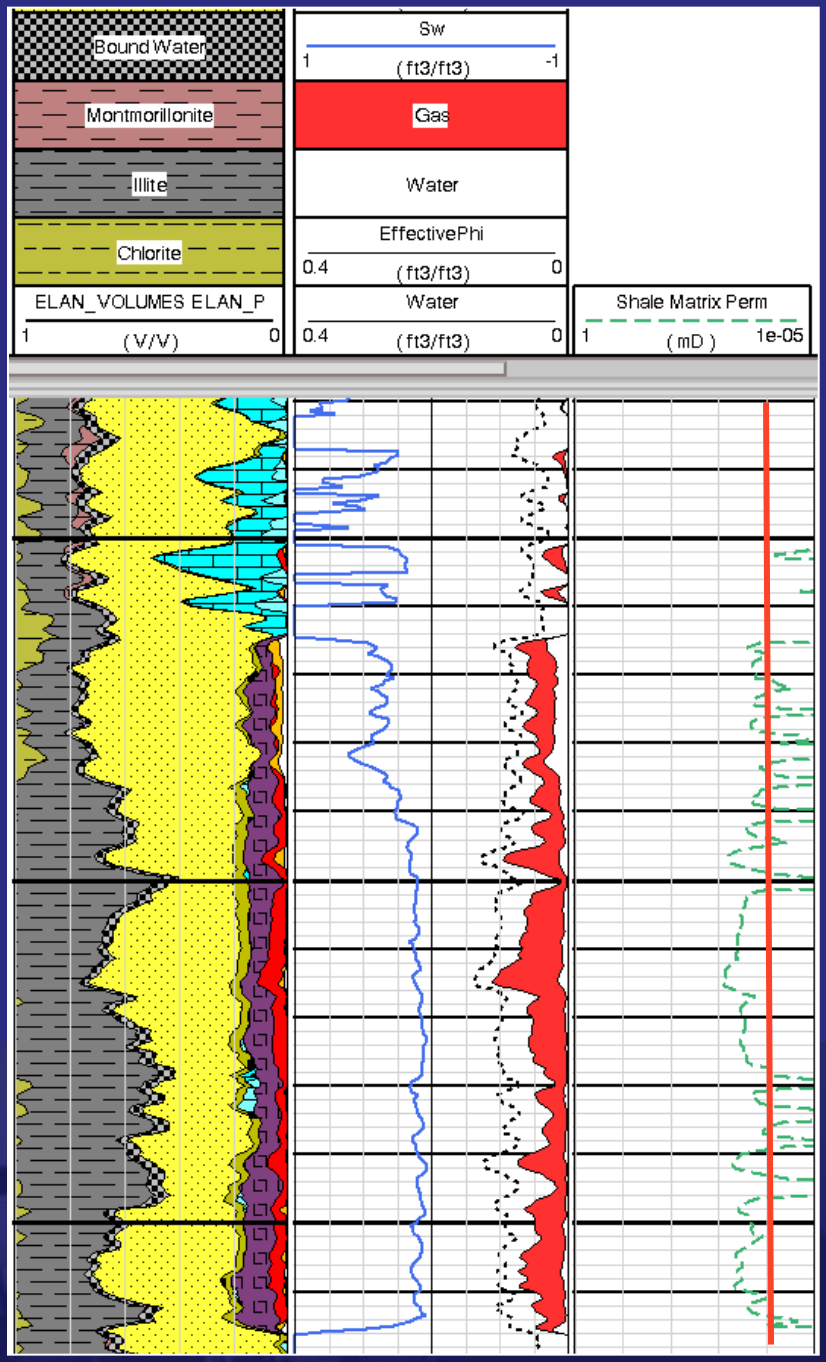
Porosity

Gas saturation

Oil saturation

Mineralogy

Specialized core analysis



Critical Reservoir 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 12 pu

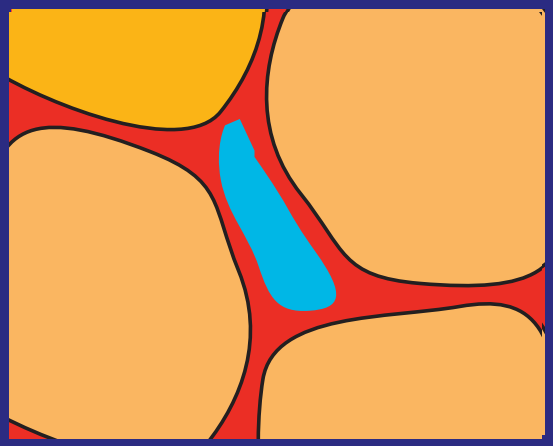
Saturations: S_w < 45%, S_o < 5%

Permeability: >100 nd

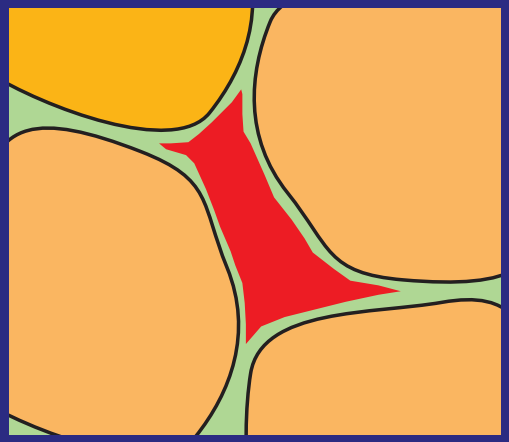
TOC: >2 wt%

Saturation vs. Wettability

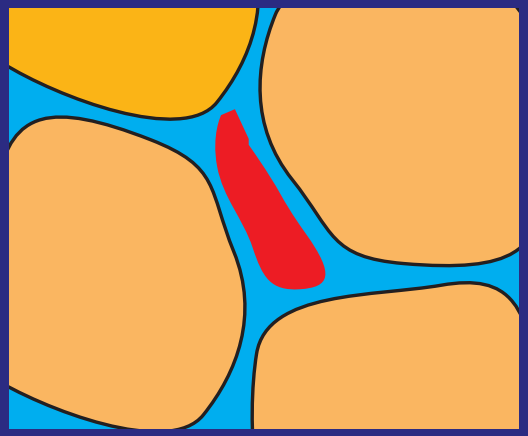
Hydrocarbon (Gas)



Hydrocarbon (Oil)



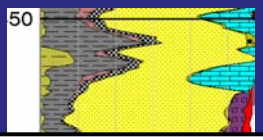
Water Wet



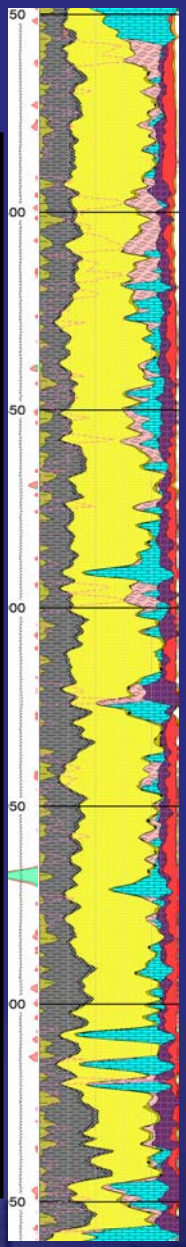
Shale Mineralogy

Typical

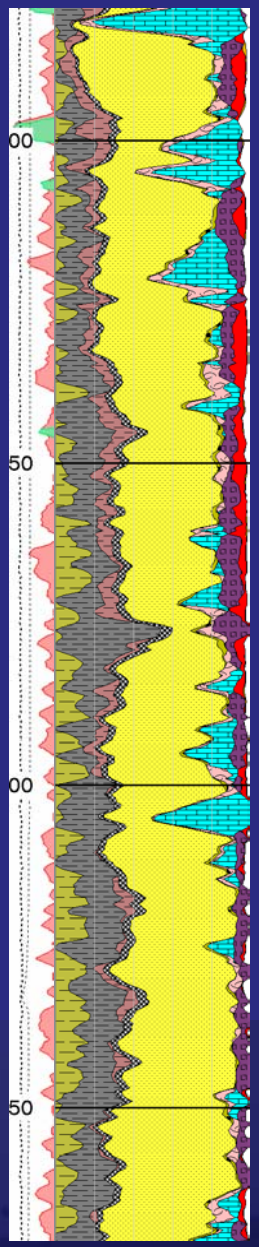
Woodford



Barnett



Caney



WHOLE ROCK MINERALOGY					
Sample	**#1**	**#2**	**#3**	**#4**	**#5**
Sample Depth (ft)					
QUARTZ	31.8	38.2	37.6	35.5	37.3
POTASSIUM FELDSPAR	1.3	0.7	0.9	1.0	0.9
PLAGIOCLASE	1.3	6.6	5.9	7.2	7.4
CALCITE	0.2	0.3	5.6	0.4	0.8
DOLOMITE/Fe-DOLOMITE	0.0	0.4	2.0	2.8	1.0
SIDERITE	0.7	0.2	0.5	0.9	0.4
PYRITE	1.2	4.0	2.2	3.7	3.5
TOTAL NON-CLAY	**36.3**	**50.6**	**54.7**	**51.6**	**51.2**
ILLITE/SMECTITE (I/S)	4.5	2.5	4.0	3.6	3.0
ILLITE	18.6	27.3	25.7	29.0	28.8
KAOLINITE	24.2	6.5	4.4	4.0	3.9
CHLORITE	16.4	13.1	11.1	11.8	13.1
TOTAL CLAY	**63.7**	**49.4**	**45.3**	**48.4**	**48.8**
GRAND TOTAL	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
RELATIVE CLAY ABUNDANCE					
% I/S Expandable	*20-25*	*20-25*	*20-25*	*20-25*	*20-25*
ILLITE/SMECTITE (I/S)	7	5	9	7	6
ILLITE	29	55	57	60	59
KAOLINITE	38	13	10	8	8
CHLORITE	26	26	25	24	27
TOTAL	**100**	**100**	**100**	**100**	**100**

Gas Shale Evaluation Log

Mineralogy

Phi, Effective Phi

S_w

TOC

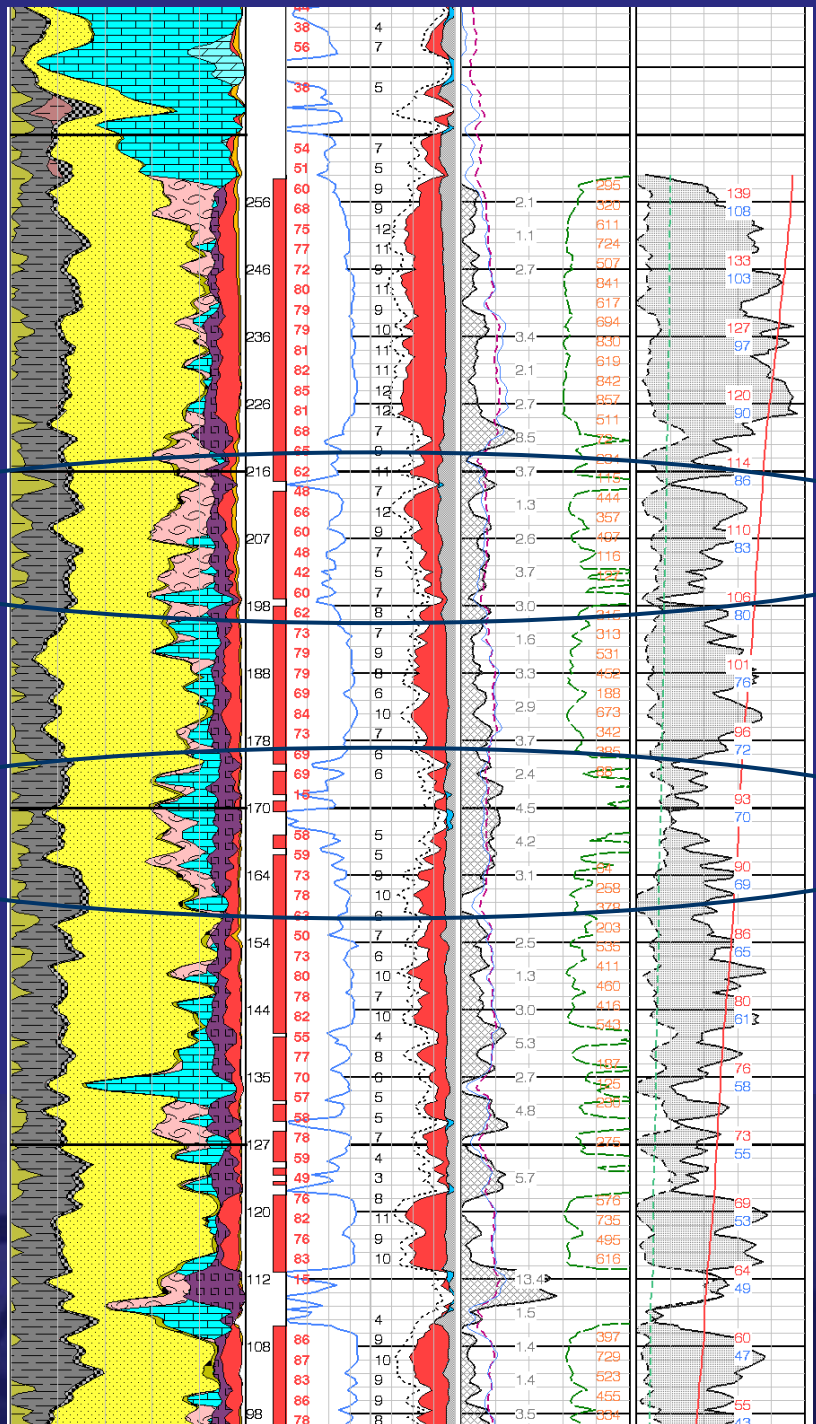
K_{int}

GIP and Cum GAS

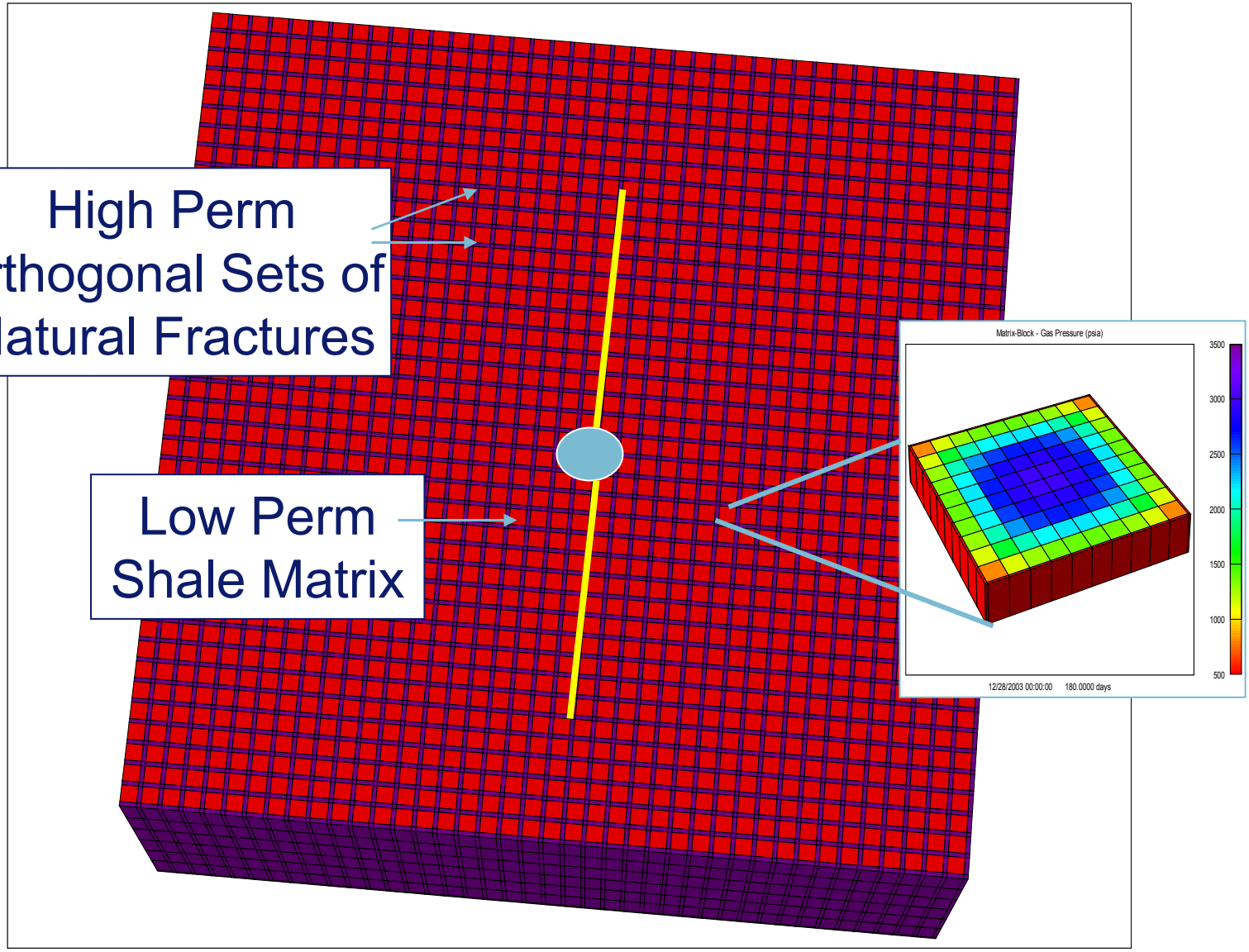
- SCF and BCF/mi^2

Inputs for

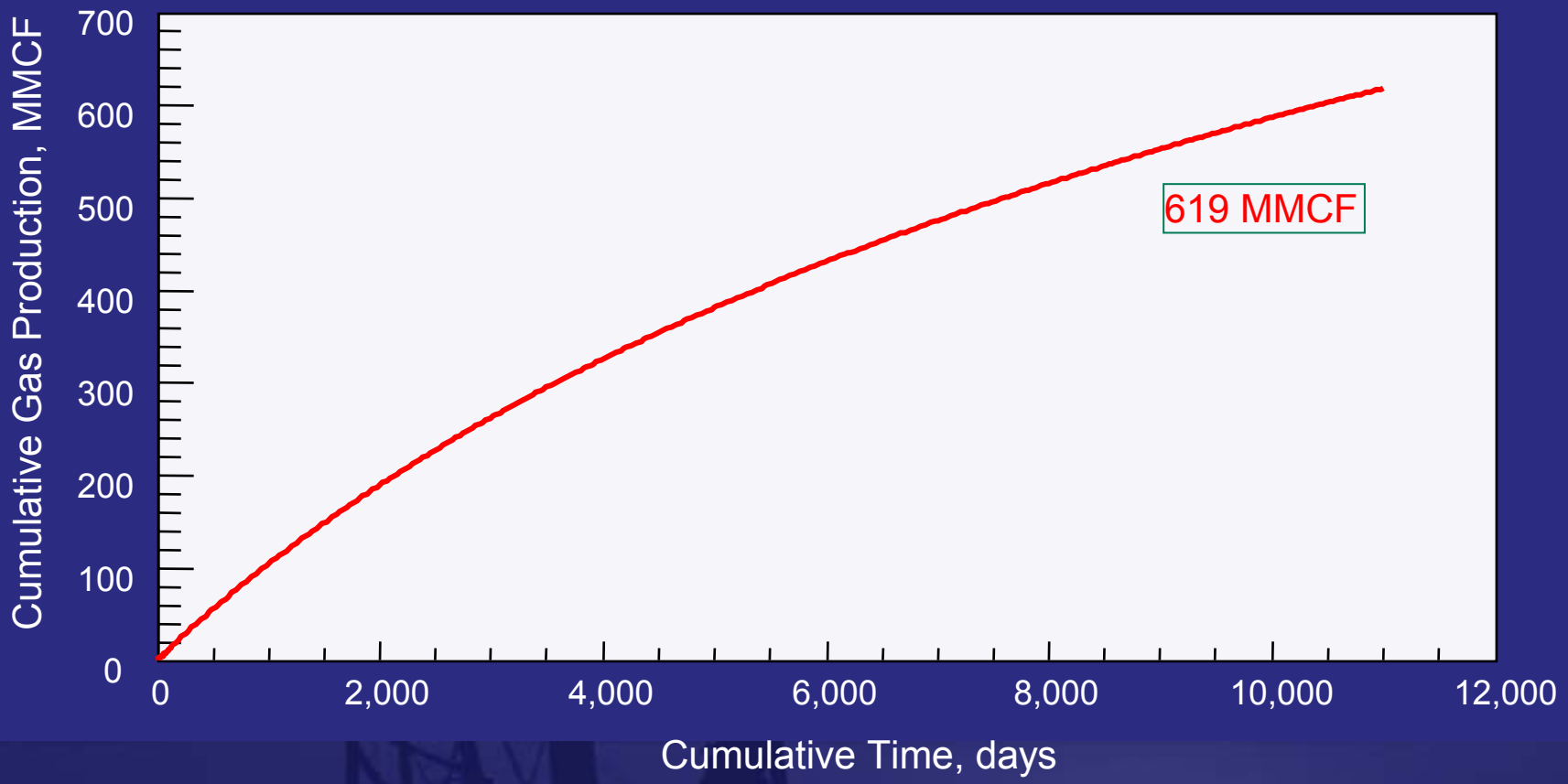
- Frac design
- Production simulator



ShaleGAS – Model Naturally Fractured Shale Reservoirs



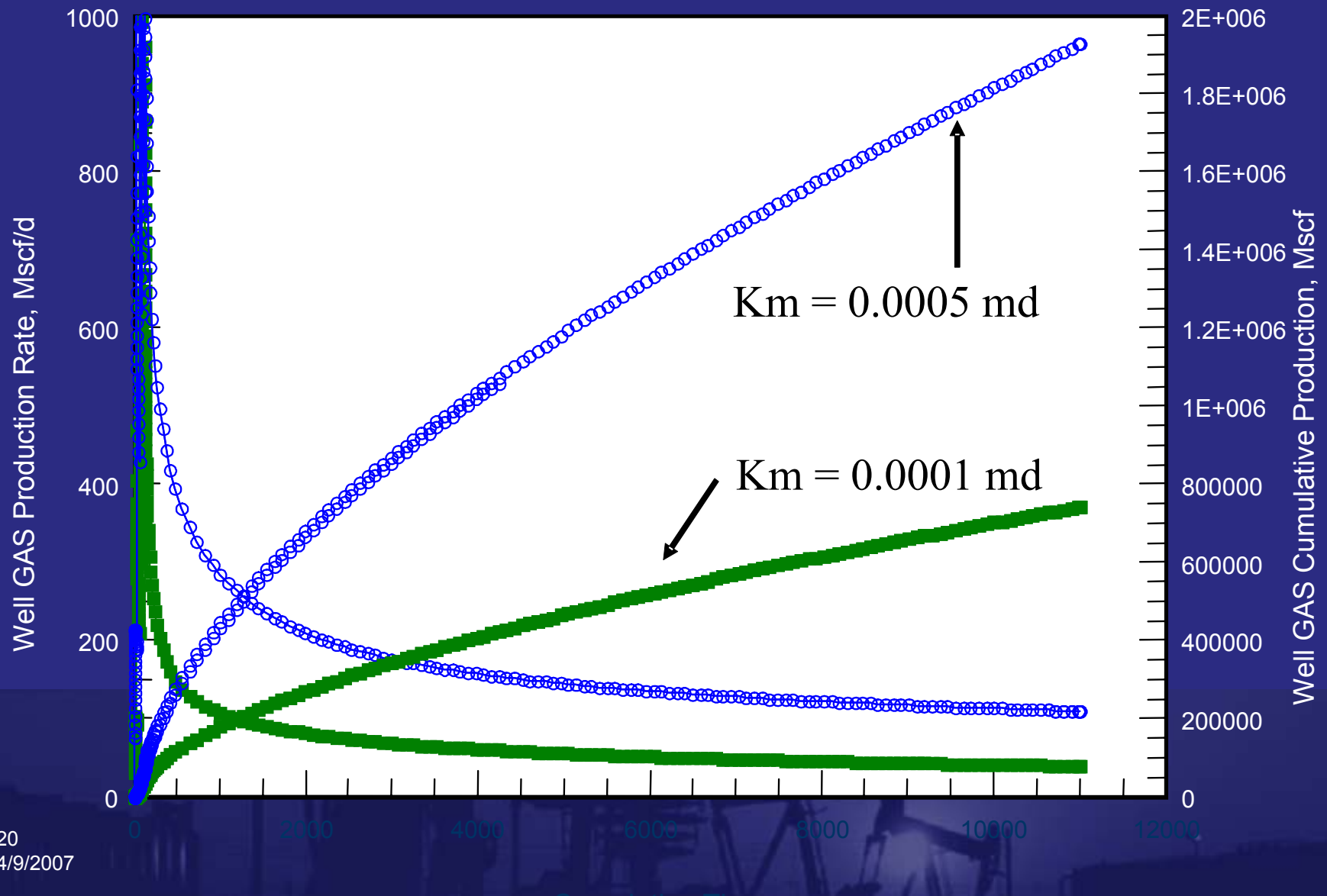
Production Prediction



ShaleGAS

Simulator for naturally fractured shales

Matrix Permeability is Important in Barnett



Recommended Coring Program

Capillary Suction Test
- Fluid sensitivities

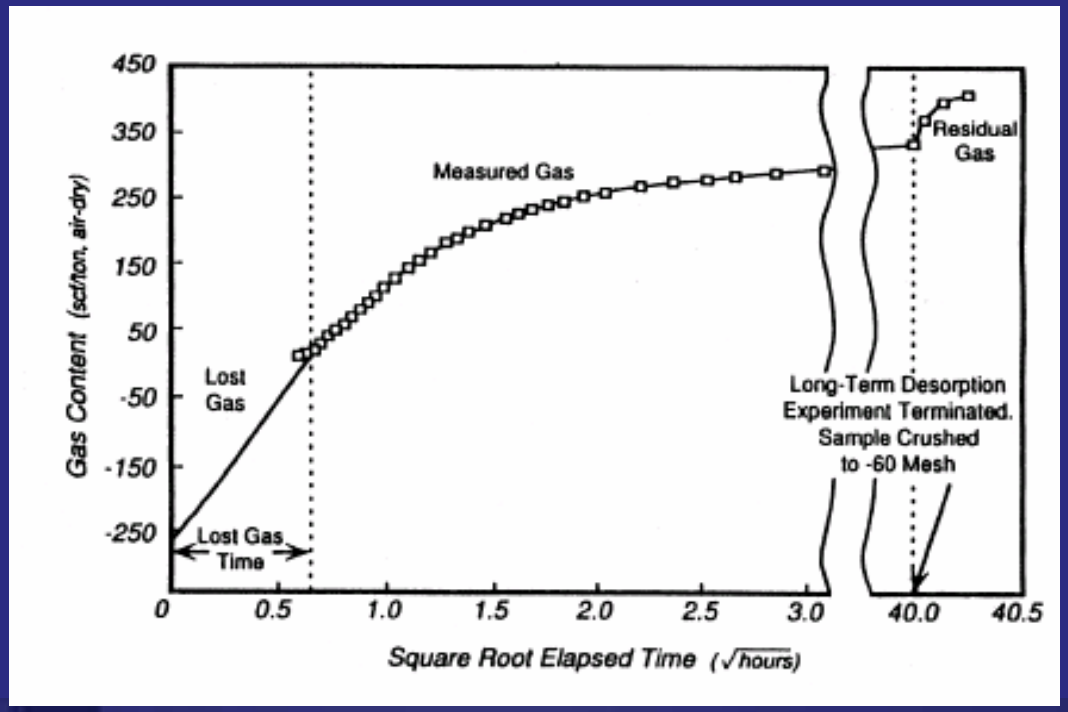
P&P
- Tight-Rock Analysis (TRA)
- Porosity, saturations, matrix perm
- R_w, K_{int}, S_{oil}

XRD
- Mineralogy
- Clays

TOC
- Maturation

Langmuir Isotherm
- Adsorbed gas content
- V_l, P_l

Thermal Maturity



Key Parameters for Gas Shale Plays

Geology

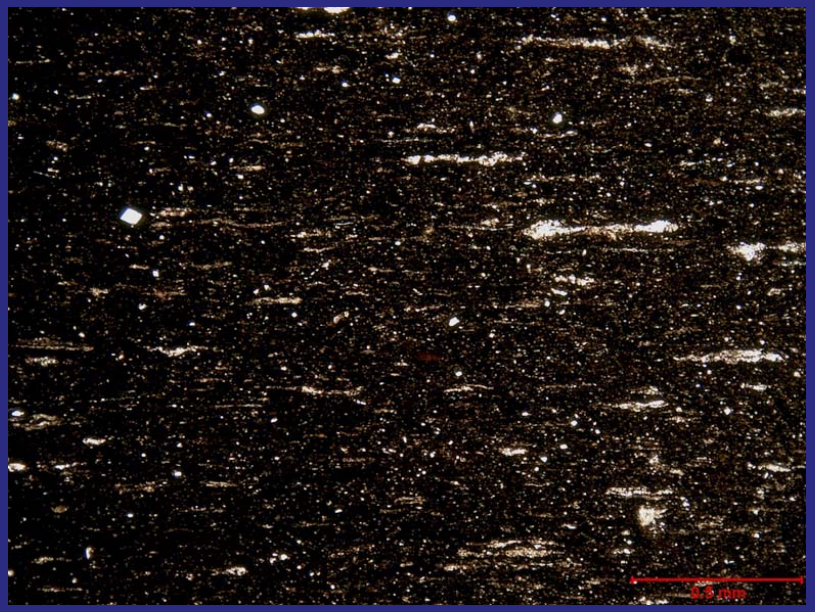
- Thermal Maturity
- Adjacent water bearing formations
- Mineralogy
- Faults and fractures
- Organic richness
- Matrix Permeability

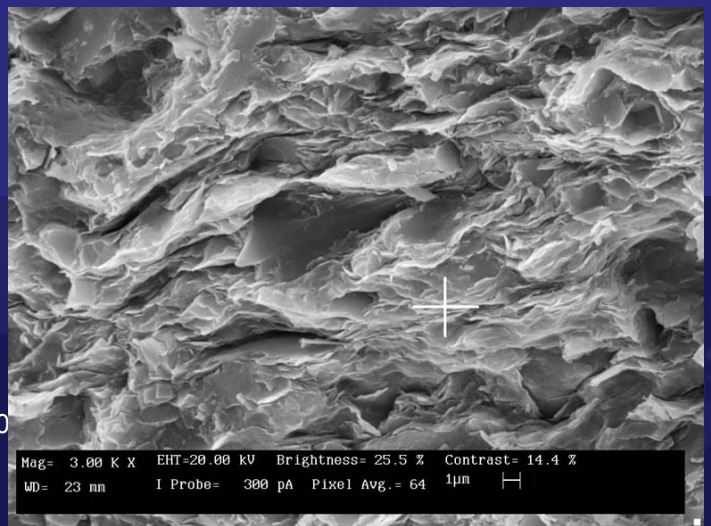
Engineering

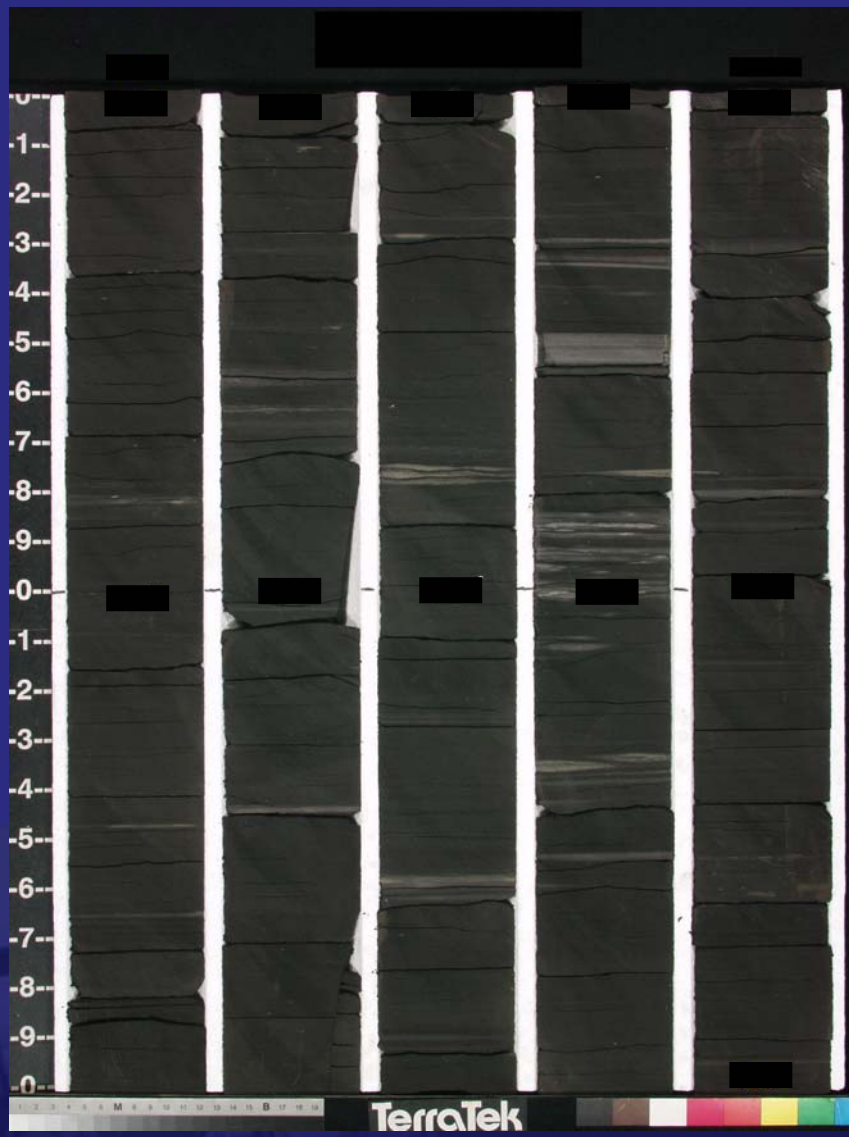
- Penetration rate
- Fluid compatibility
- Frac containment
- Frac orientation
  - Hydraulic vs. natural
- Frac complexity
- Frac conductivity

Questions?

Characteristics of Gas Shales

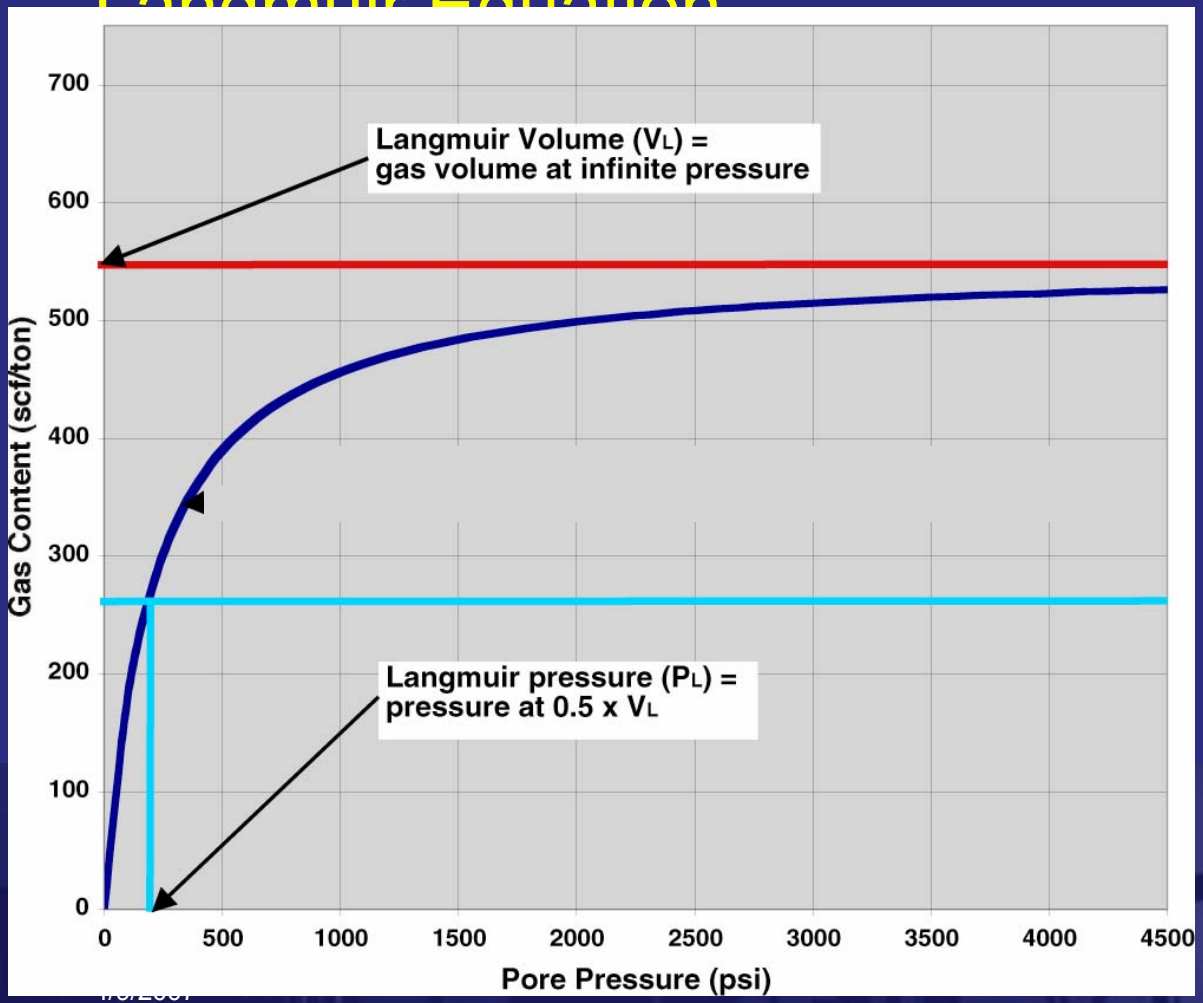






Shale Gas Adsorption / Desorption Isotherm

Langmuir Equation

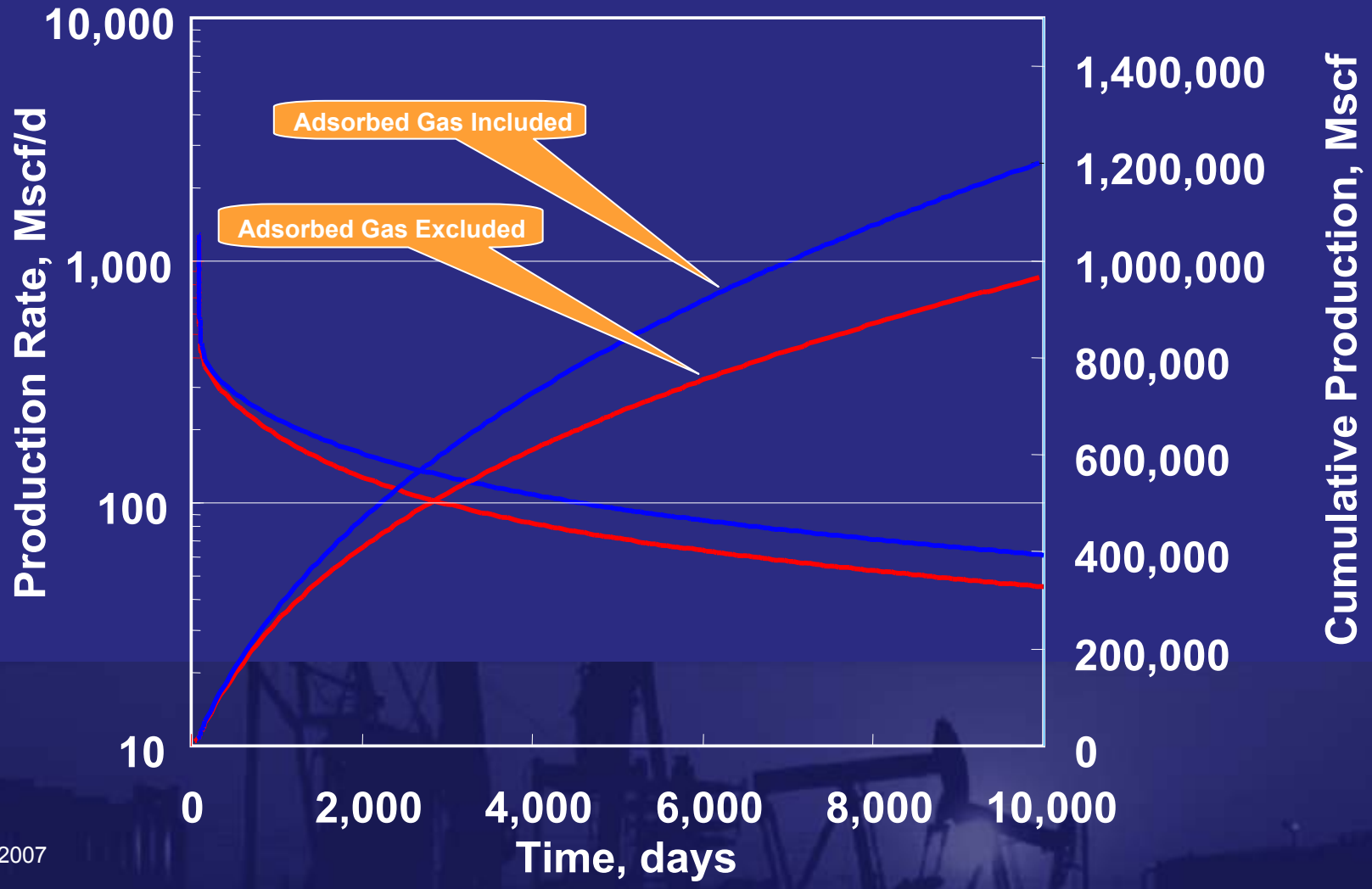


"Gold Standard" for adsorption

Outputs

- V_L
- P_L
- TOC content
- Temperature

Adsorbed Gas Impacts
Late -Term Production in Lewis Shale



Conclusions

Shale gas log evaluation

- Lithology / mineralogy
- TOC
- Porosity and matrix perm
- GIP (adsorbed and free)

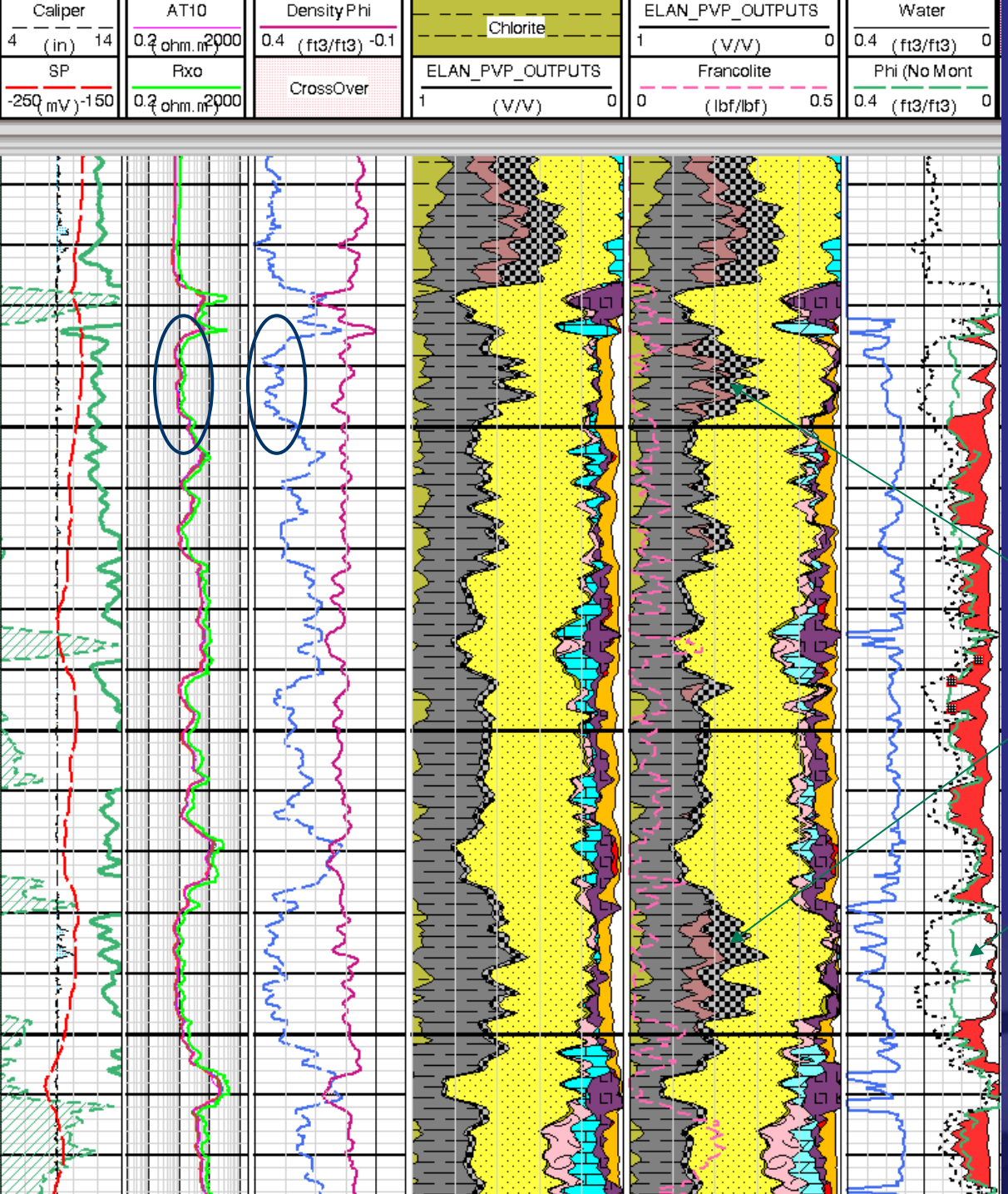
Geochemical log critical to evaluation

- Robust clay quantification independent of kerogen
- Matrix density
- Cased hole option

ShaleGAS simulation software

- Predict production
- What-ifs

Complex Clay Assemblages



Low resistivity /high neutron clays

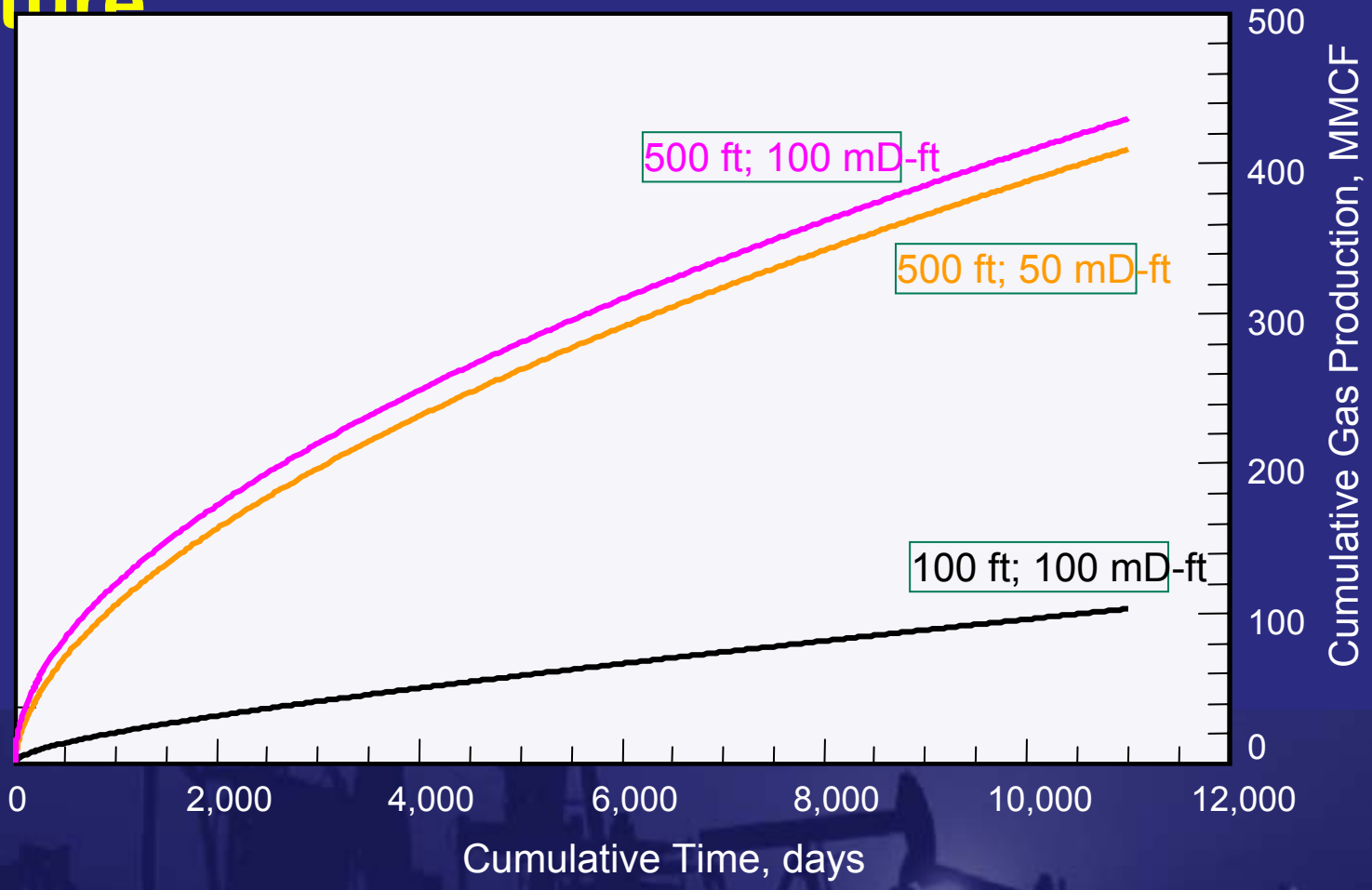
Completion design

Montmorillonite

Porosity Reduction

ShaleGAS Simulator

Cumulative Production vs. Hydraulic Fracture

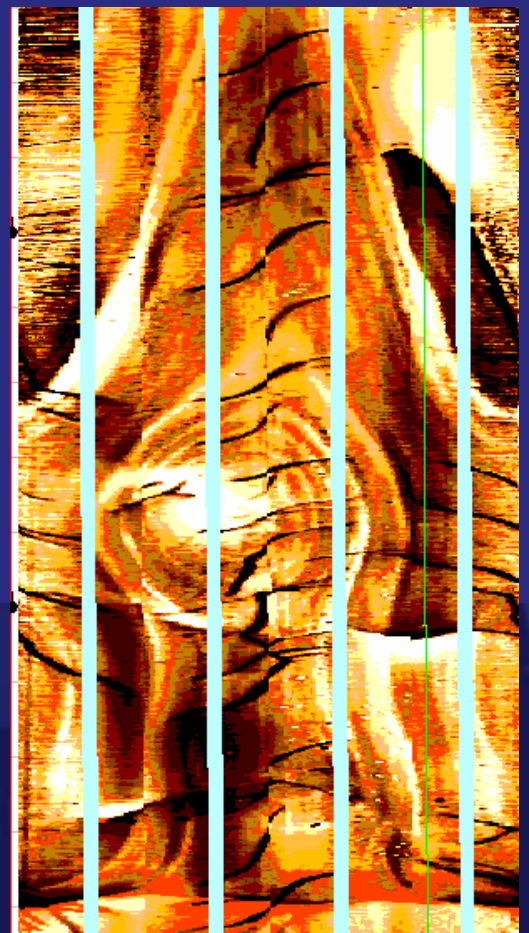


Fracture Geometry Information from Horizontal Image Logs

Variable Induced Fractures Infers Variable Stress

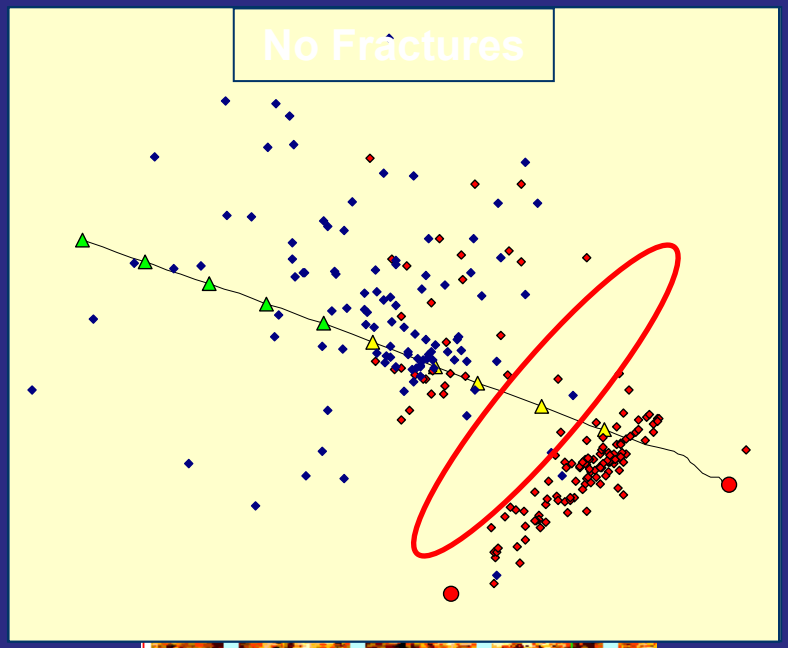
Transverse Fractures Only:

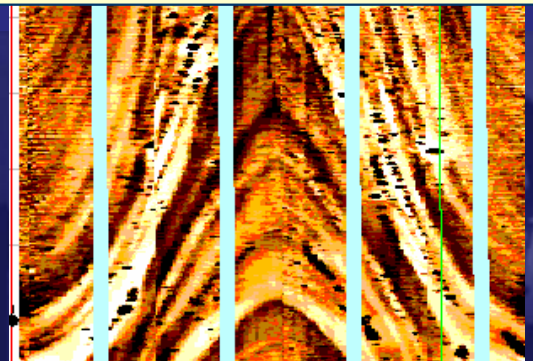
$\sigma_H >> \sigma_h$



No Fractures:

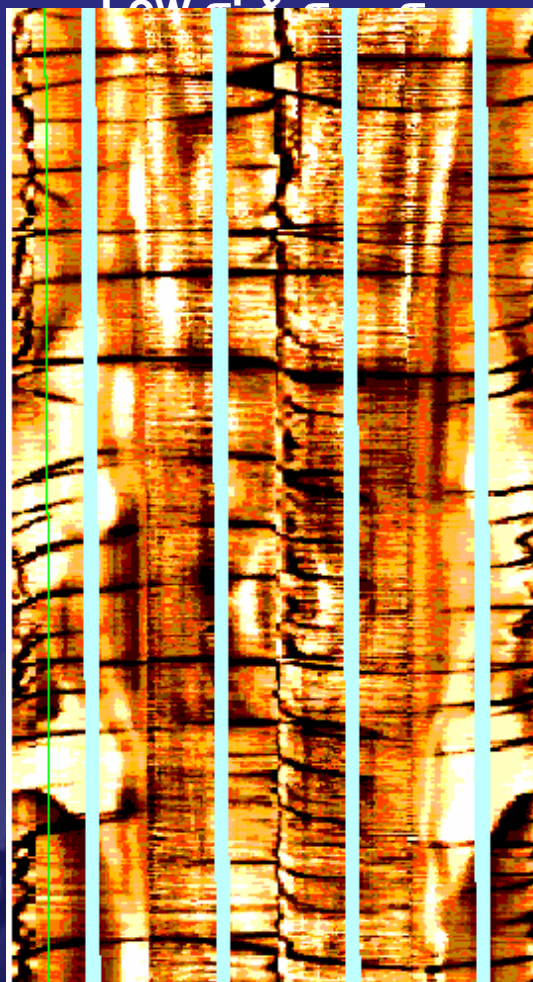
High σ'





Long & Trans Fractures:

Low σ' & σ



Sonic Log

Mechanical properties

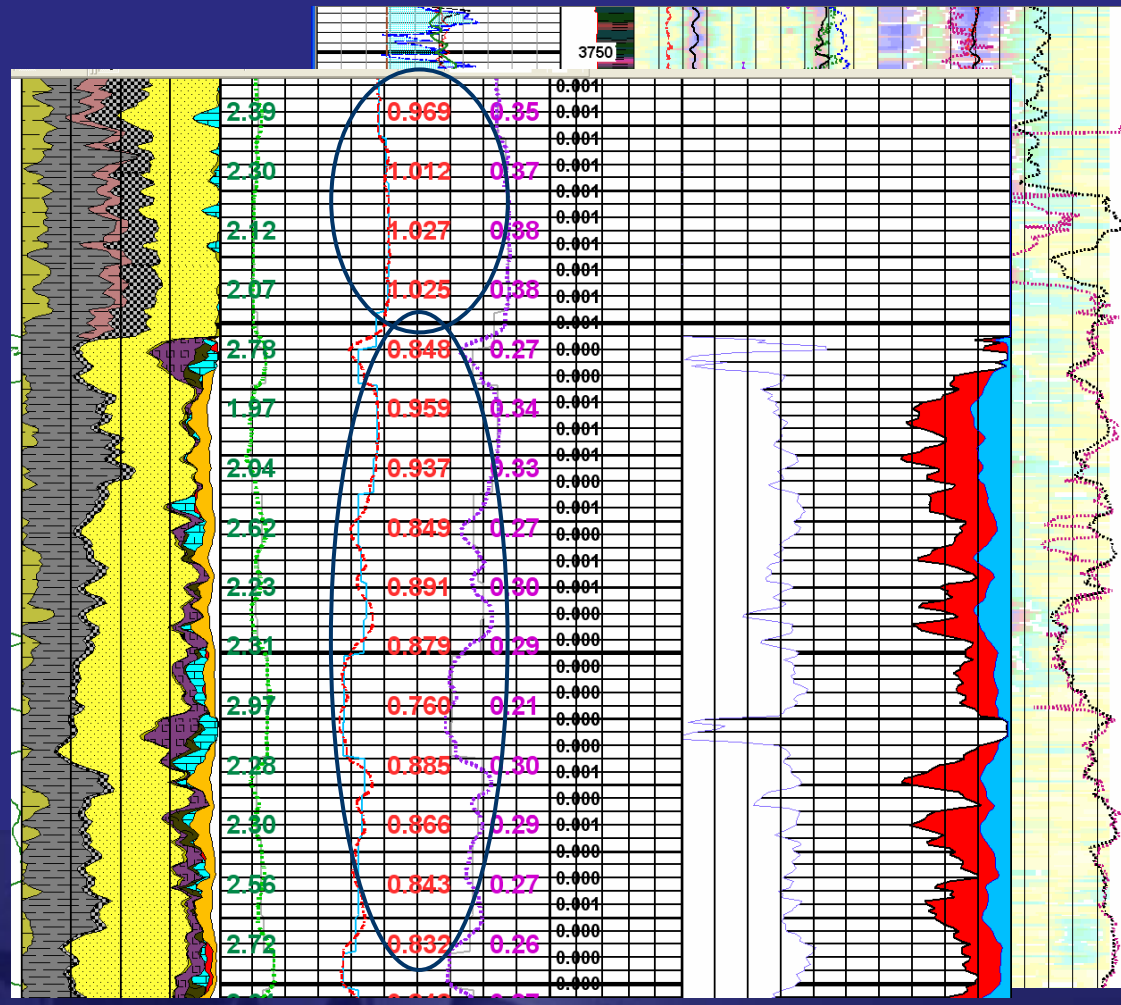
Seismic tie

Anisotropy

Fracture ID

Oil saturation

Liquid-filled borehole

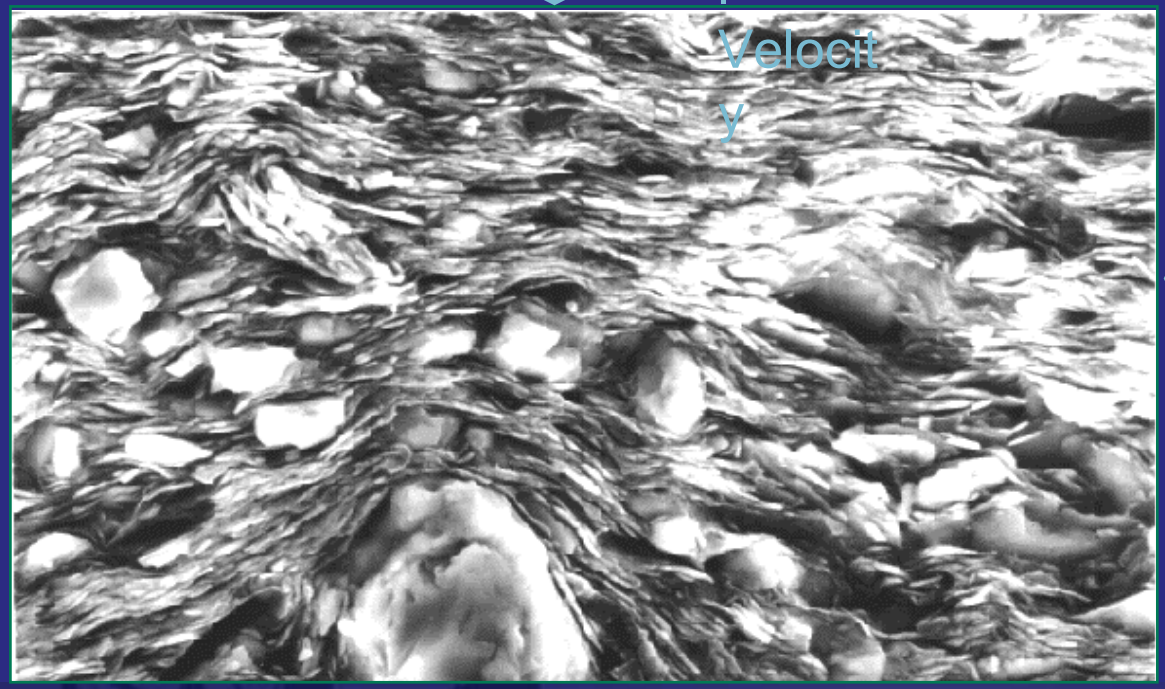


Anisotropic Formation

Sound speed changes with direction of propagation

Comp. Vertical Velocity

Not the Same!!



Comp. Horizontal Velocity

Kimmeridge Clay