Gas Shale: Adsorbed component assessment

Jack Breig
Newfield Exploration

Outline

Geological Backdrop

Adsorption science

Measurement methodology

Key parameters for assessment

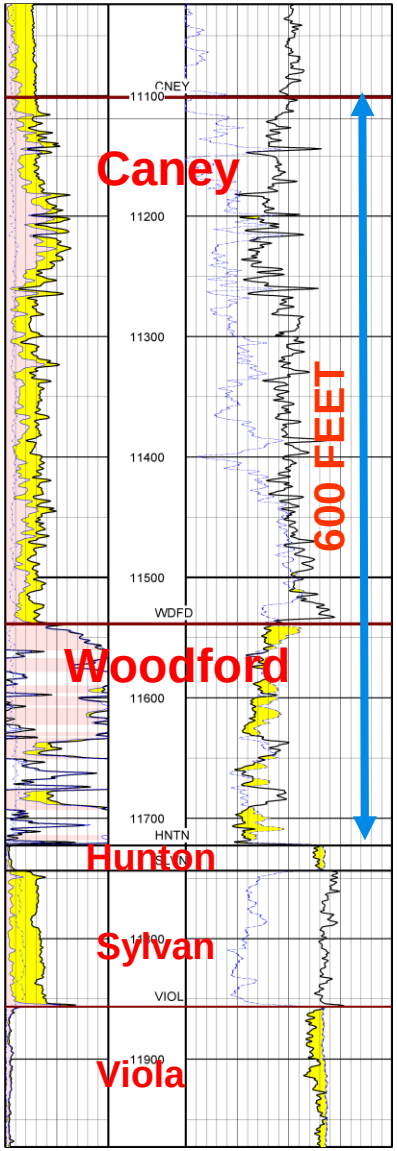
Petrophysical methods for TOC content

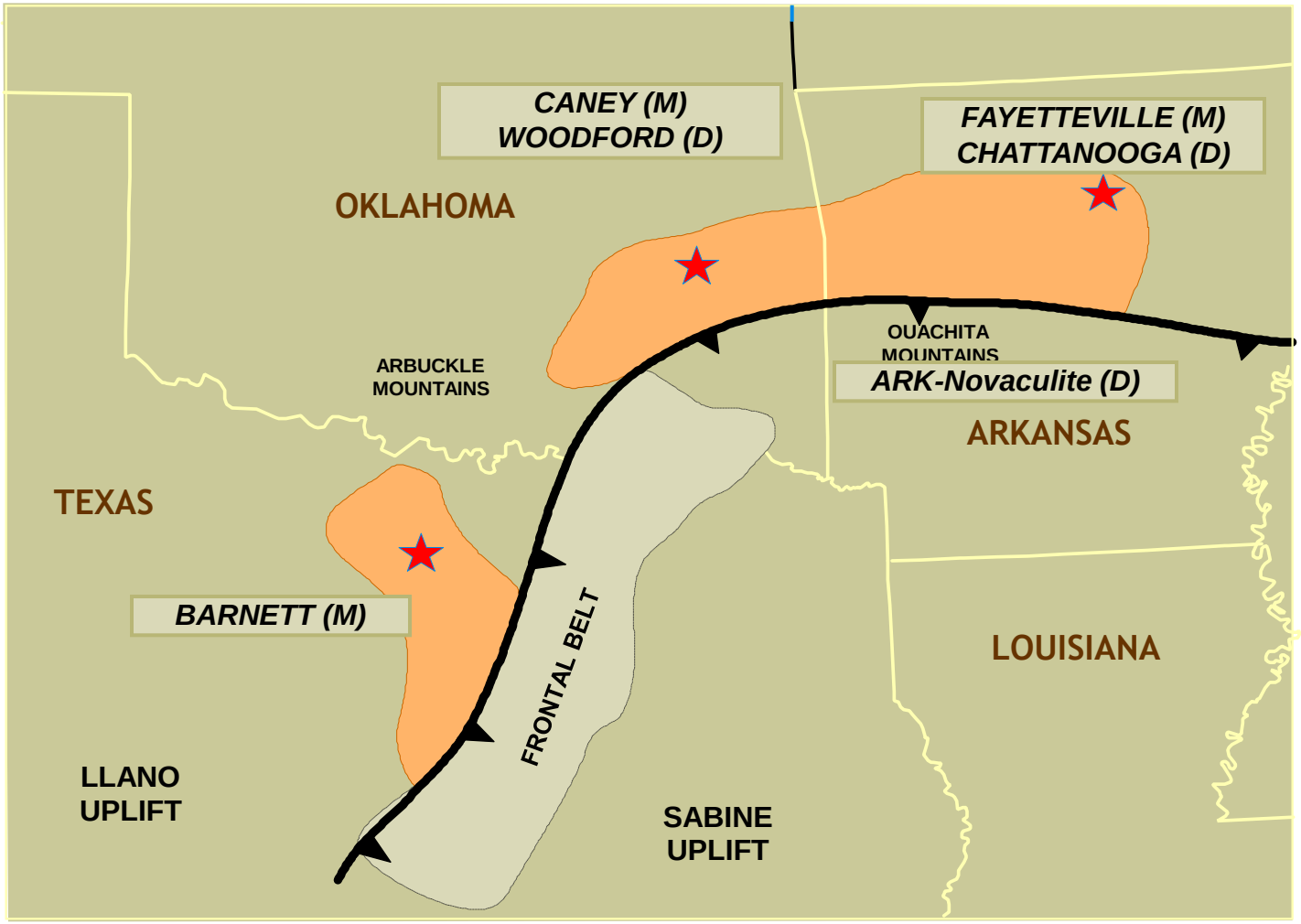
Source rock maturity & gas composition

Methodology to play analysis

Sorbed Gas in Place

Mississippian-Devonian Black shales





Woodford formation in outcrop

- Lightly colored facies caused by biodegradation of organic component of ‘shale’

Woodford formation in core

Black color caused by elevated organic carbon component

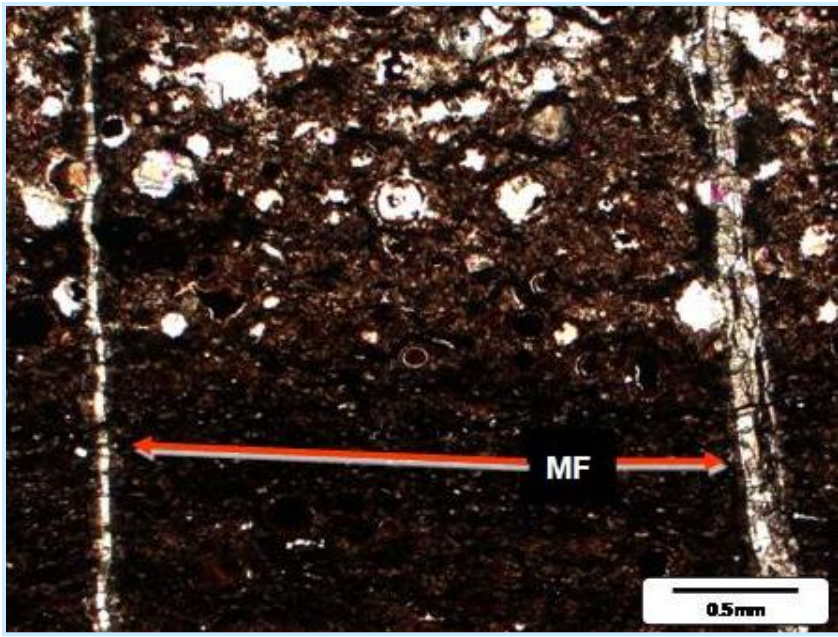
Woodford: Chert facies

ϕ = 2.49% k_e = 5.93E-06 md

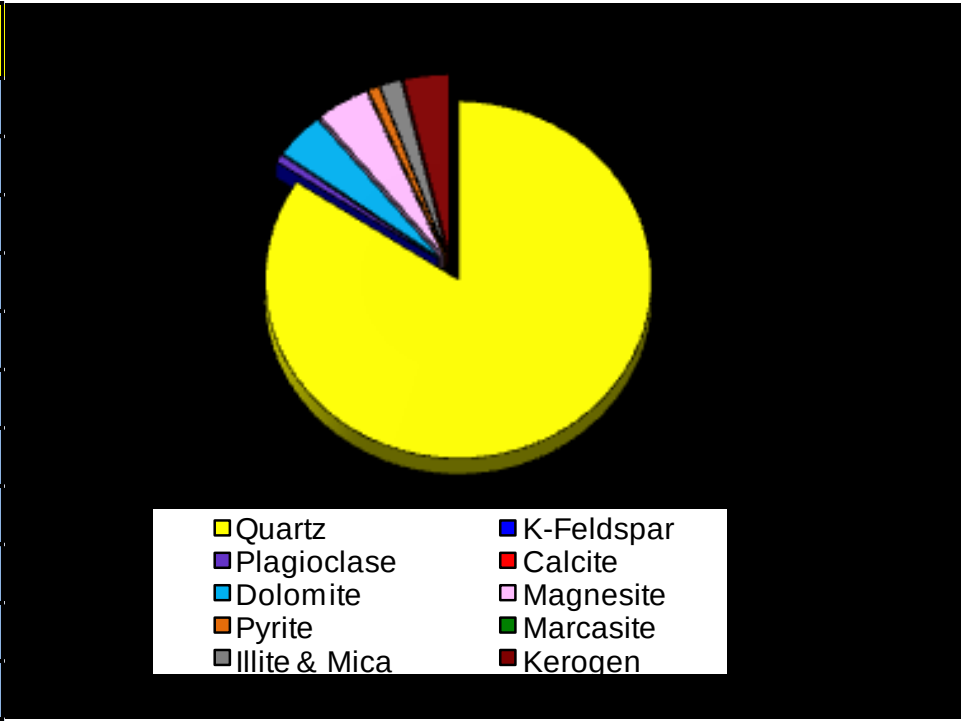
Sw = NA Sg = NA

So = NA GD = 2.61 g/cc

TOC = 1.70% Ro = 2.15



Chert Mineralogy (volume %)	Min	Max	Avg
Quartz	63.1	95.4	80.6
K-Feldspar	0.0	1.5	0.1
Plagioclase	0.0	11.6	1.6
Calcite	0.0	0.0	0.0
Dolomite & Fe-Dolomite	0.0	4.9	2.1
Magnesite	0.0	8.7	1.8
Pyrite	0.4	5.1	1.5
Marcasite	0.0	1.3	0.2
Illite & Mica	0.0	21.9	5.4
Kerogen	2.3	13.7	6.7
Vclay	0.0	21.9	5.4



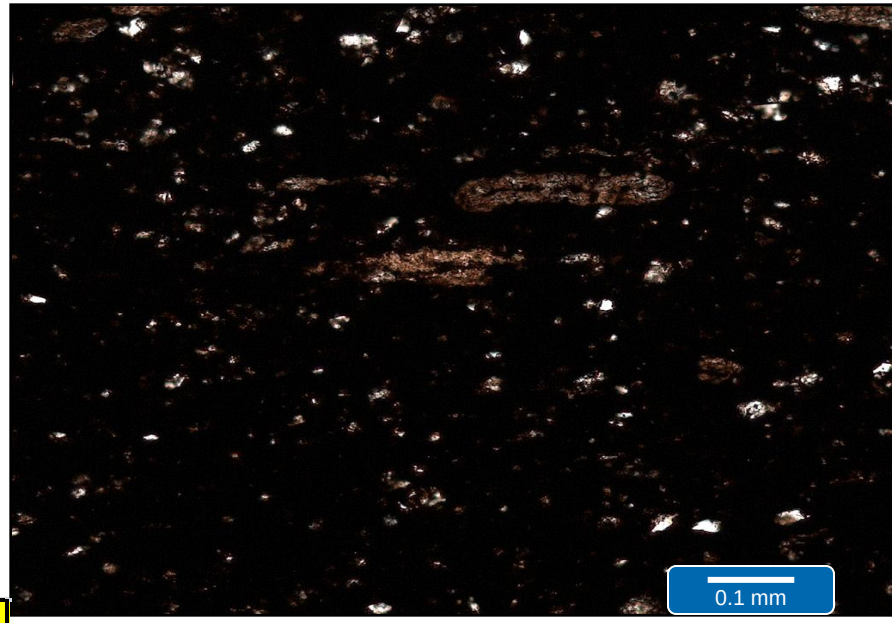
Woodford: Siliceous mudstone facies

ϕ = 4.75% k_e = 8.16E-06 md

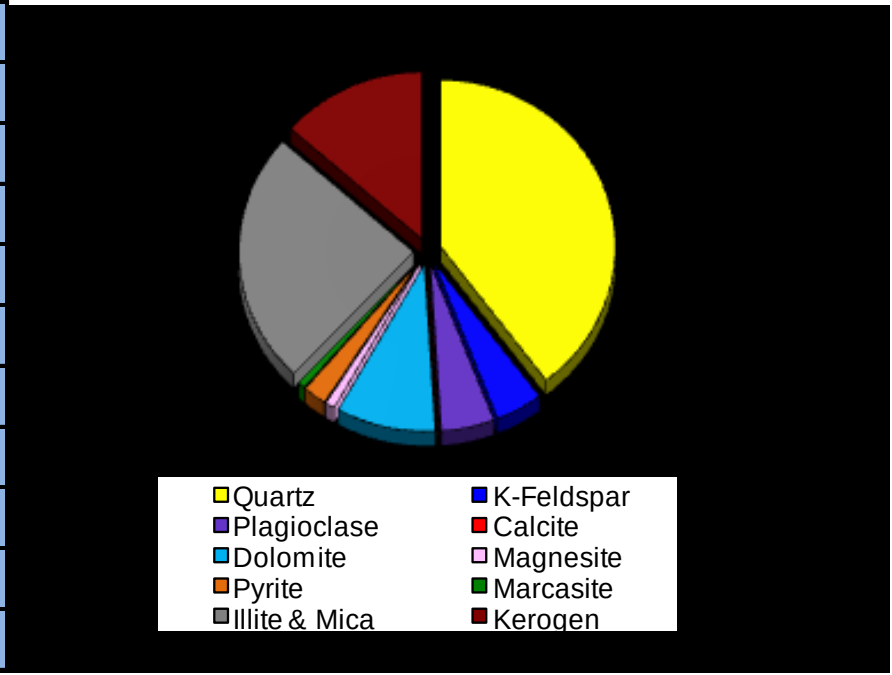
Sw = NA Sg = NA

So = NA GD = 2.56 g/cc

TOC = 4.16 wt% **Ro = 2.3**



Shale Mineralogy (volume %)	Min	Max	Avg
Quartz	25.5	68.5	50.0
K-Feldspar	0.0	5.7	2.3
Plagioclase	1.5	9.9	5.0
Calcite	0.0	14.0	0.7
Dolomite & Fe-Dolomite	0.0	31.8	5.3
Magnesite	0.0	2.6	0.2
Pyrite	1.2	11.4	4.5
Marcasite	0.0	4.9	1.2
Illite & Mica	9.2	35.8	18.7
Kerogen	2.0	18.3	11.9
Vclay	9.2	35.8	18.7



Gas swollen Woodford cuttings bags—doubled plastic bags inside cloth bags

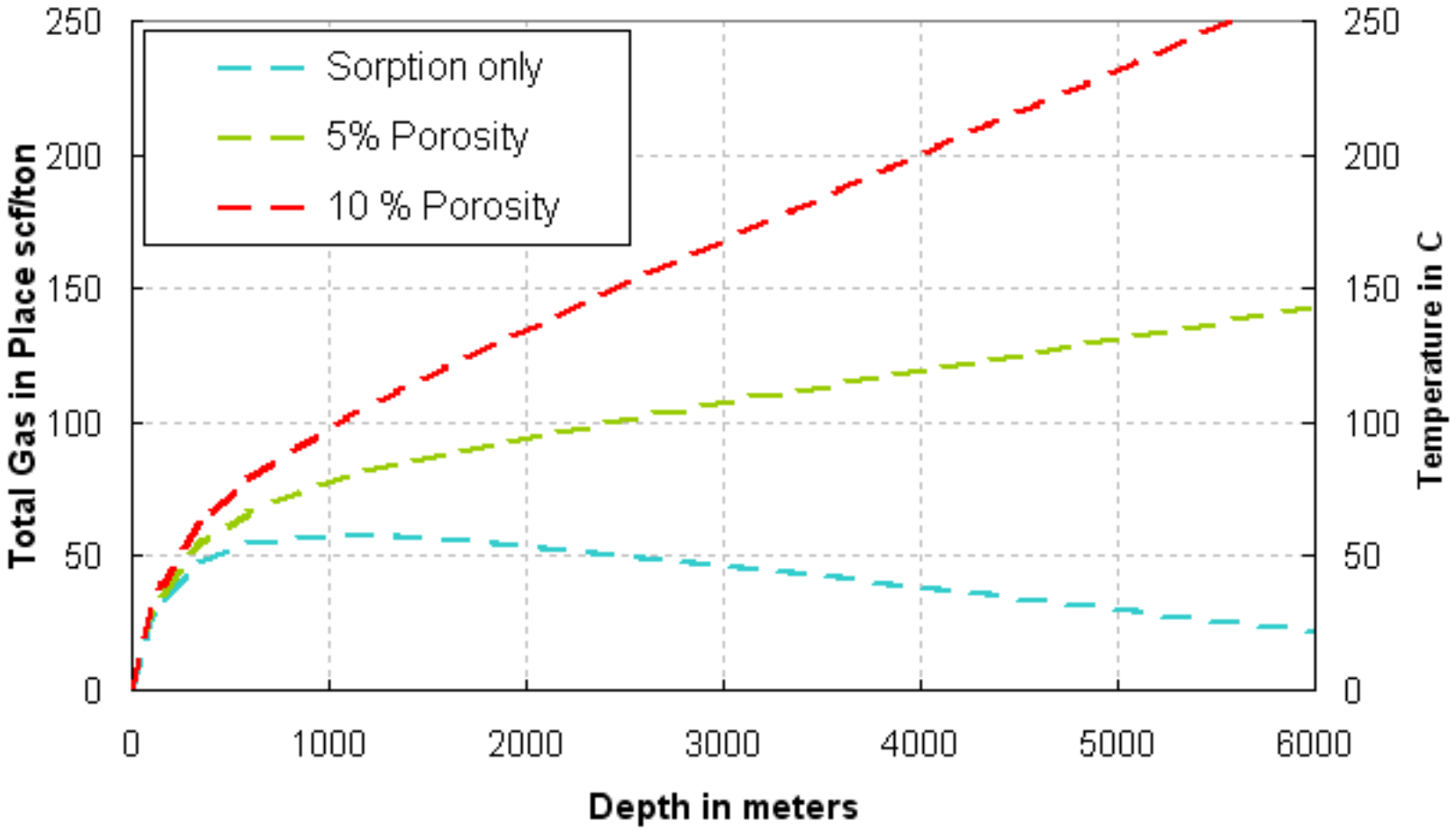
Cannister desorption test

Gas Composition Data (Continued)

Sample Number	Collection Point	As-Received Gas Content	Incremental Gas Content[2]	Gas Analysis (O_2, N_2 and H_2 Mole Fractions Omitted)[1]						
				C_1	C_2	C_3-C_{10}	CO_2	Total	Dry	Saturated
	hours	scf/ton	scf/ton	mole %	mole %	mole %	mole %	mole %	Btu/ft^3	Btu/ft^3
Average Depth (ft): 8,132.5				**Lost Gas Content: 38.12%**			**Woodford Shale**			
638-23-1	5.9	59.1	59.1	95.29	4.24	0.38	0.09	100.00	1,052.3	1,034.0
638-23-2	11.7	76.9	17.8	94.34	4.93	0.45	0.28	100.00	1,056.8	1,038.4
638-23-3	22.5	96.6	19.6	91.42	6.91	0.72	0.95	100.00	1,069.6	1,051.0
638-23-4	24.7	98.4	1.8	92.13	7.05	0.74	0.08	100.00	1,080.0	1,061.2
638-23-5	140.2	111.7	13.4	79.78	16.55	2.08	1.59	100.00	1,160.3	1,140.1
638-23-6	400.6	115.4	3.7	67.59	28.33	3.83	0.24	100.00	1,293.8	1,271.3
~~638-23-7~~	~~635.2~~	~~116.0~~	~~0.6~~	~~63.02~~	~~0.00~~	~~0.00~~	~~36.98~~	~~100.00~~	~~639.4~~	~~628.3~~
638-23-C[4]	635.2	133.9	17.9	23.63	43.17	22.53	10.66	100.00	1,628.3	1,600.0
Apparent Gas Composition[3]				**82.60**	**11.89**	**3.69**	**1.82**	**100.00**	**1,150.7**	**1,130.7**
Average Depth (ft): 8,163.5				**Lost Gas Content: 11.25%**			**Woodford Shale**			
~~638-26-1~~	~~6.1~~	~~15.4~~	~~15.4~~	~~90.66~~	~~6.45~~	~~0.38~~	~~2.51~~	~~100.00~~	~~1,043.8~~	~~1,025.6~~
638-26-2	12.0	21.7	6.3	95.70	3.82	0.28	0.20	100.00	1,046.1	1,027.9
638-26-3	22.8	52.6	30.9	91.90	4.85	0.37	2.88	100.00	1,028.4	1,010.5
638-26-4	25.1	54.9	2.3	94.28	4.99	0.38	0.35	100.00	1,055.4	1,037.0
638-26-5	156.9	81.7	26.8	88.53	8.55	0.59	2.33	100.00	1,065.9	1,047.3
~~638-26-6~~	~~401.0~~	~~88.9~~	~~7.2~~	~~82.50~~	~~13.68~~	~~0.99~~	~~2.83~~	~~100.00~~	~~1,106.5~~	~~1,087.2~~
638-26-7	635.4	91.6	2.7	79.59	16.65	1.27	2.50	100.00	1,137.5	1,117.7
638-26-C[4]	635.4	114.2	22.5	42.63	45.11	7.13	5.12	100.00	1,425.4	1,400.6
Apparent Gas Composition[3]				**78.73**	**16.14**	**2.12**	**3.01**	**100.00**	**1,142.3**	**1,122.4**

Note increasing contribution of C2 and C3-C10 as sample desorption proceeds from high to low pressure (collection point time)

Sorbed gas capacity in relationship to free gas



Measurement methodology

- Determine the chemical composition of produced gas
- Derive storage capacity relationships for each chemical species for appropriate ranges of:
  - Temperature
  - Pressure
  - TOC content
  - Source rock maturity

Gas composition examples from western Arkoma Basin (Wet to dry gas transition)

THURMOND-McGLOTHLIN, INC.

THE NATURAL GAS MEASUREMENT COMPANY
501 East Main Street
Wilburton, OK 74578
Phone 918-465-2336 Fax 918-465-0013
E-mail joeyw@tm-ems.com
Website www.tm-ems.com

FRACTIONAL ANALYSIS *

COMPONENTS		MOL %	GPM
Carbon Dioxide	CO2	0.745	
Nitrogen	N2	1.820	
Methane	C1	78.181	
Ethane	C2	12.608	3.352
Propane	C3	4.523	1.239
iso-Butane	IC4	0.382	0.124
n-Butane	NC4	1.044	0.327
neo-Pentane	neo C5	0.000	0.000
iso-Pentane	IC5	0.223	0.081
n-Pentane	NC5	0.017	0.006
Hexane +	C6+	0.458	0.199
		100.000	

DATE RUN:	September 21, 2006
COMPANY:	NEWFIELD
PURCHASER:	
LEASE:	CATTLE 1 H-21
STATION:	
PRESSURE:	33
TEMPERATURE:	
CYLINDER:	6033
ANALYSIS BY:	JW
SECURED BY:	DS
DATE SAMPLED:	9/21/2006
LEGAL:	

GASOLINE CONTENT @ 14.65 PSIA & 60 F

	GPM
PROPANE & HEAVIER	1.777
BUTANE & HEAVIER	0.539
PENTANE & HEAVIER	0.087

Gross Heating Value
BTU @ 14.65 PSIA & 60 F-REAL

Dry	1206.3
Wet	1185.3

SPECIFIC GRAVITY- REAL Z= 0.9966691
0.7134
MOL WEIGHT
24.56

REMARKS:

RESULTS TO:
NEWFIELD

Western margin of gas play

THURMOND-McGLOTHLIN, INC.

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FRACTIONAL ANALYSIS *

COMPONENTS		MOL %	GPM
Carbon Dioxide	CO2	1.012	
Nitrogen	N2	0.751	
Methane	C1	94.288	
Ethane	C2	3.135	0.833
Propane	C3	0.592	0.162
iso-Butane	IC4	0.064	0.021
n-Butane	NC4	0.082	0.026
neo-Pentane	neo C5	0.000	0.000
iso-Pentane	IC5	0.022	0.008
n-Pentane	NC5	0.015	0.005
Hexane +	C6+	0.037	0.016
		100.000	

DATE RUN:	July 25, 2005
COMPANY:	NEW FIELD
PURCHASER:	
LEASE:	REYNOLDS 1-11
STATION:	
PRESSURE:	241
TEMPERATURE:	114
CYLINDER:	1224
ANALYSIS BY:	BB
SECURED BY:	LB
DATE SAMPLED:	7/22/2005
LEGAL:	

GASOLINE CONTENT @ 14.65 PSIA & 60 F

	GPM
PROPANE & HEAVIER	0.222
BUTANE & HEAVIER	0.060
PENTANE & HEAVIER	0.014

Gross Heating Value
BTU @ 14.65 PSIA & 60 F

Dry	1027.6
Wet	1009.7

SPECIFIC GRAVITY
0.5917

REMARKS:

RESULTS TO:
NEW FIELD

Core area of gas play

Gas composition examples from eastern Arkoma Basin (elevated CO_2)

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Website www.tm-ems.com

FRACTIONAL ANALYSIS *					
COMPONENTS		MOL %	GPM		
Carbon Dioxide	CO2	0.745		DATE RUN:	September 21, 2006
Nitrogen	N2	1.820		COMPANY:	NEWFIELD
Methane	C1	78.181		PURCHASER:	
Ethane	C2	12.608	3.352	LEASE:	CATTLE 1 H-21
Propane	C3	4.523	1.239	STATION:	
iso-Butane	IC4	0.382	0.124	PRESSURE:	33
n-Butane	NC4	1.044	0.327	TEMPERATURE:	
neo-Pentane	neo C5	0.000	0.000	CYLINDER:	6033
iso-Pentane	IC5	0.223	0.081	ANALYSIS BY:	JW
n-Pentane	NC5	0.017	0.006	SECURED BY:	DS
Hexane +	C6+	0.458	0.199	DATE SAMPLED:	9/21/2006
		100.000		LEGAL:	

GASOLINE CONTENT @ 14.65 PSIA & 60 F	GPM
PROPANE & HEAVIER	1.777
BUTANE & HEAVIER	0.539
PENTANE & HEAVIER	0.087

REMARKS:

RESULTS TO:
NEWFIELD

Gross Heating Value BTU @ 14.65 PSIA & 60 F-REAL	
Dry	1206.3
Wet	1185.3

SPECIFIC GRAVITY- REAL Z= 0.9966691
0.7134
MOL WEIGHT
24.56

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Website www.tm-ems.com

FRACTIONAL ANALYSIS *					
COMPONENTS		MOL %	GPM		
Carbon Dioxide	CO2	5.642		DATE RUN:	October 23, 2006
Nitrogen	N2	0.558		COMPANY:	NEW FIELD
Methane	C1	93.342		PURCHASER:	
Ethane	C2	0.432	0.115	LEASE:	JOHNSTON 3-24
Propane	C3	0.026	0.007	STATION:	
iso-Butane	IC4	0.000	0.000	PRESSURE:	683
n-Butane	NC4	0.000	0.000	TEMPERATURE:	102.9
neo-Pentane	neo C5	0.000	0.000	CYLINDER:	5376
iso-Pentane	IC5	0.000	0.000	ANALYSIS BY:	JW
n-Pentane	NC5	0.000	0.000	SECURED BY:	DS
Hexane +	C6+	0.000	0.000	DATE SAMPLED:	10/23/2006
		100.000		LEGAL:	

GASOLINE CONTENT @ 14.65 PSIA & 60 F	GPM
PROPANE & HEAVIER	0.007
BUTANE & HEAVIER	0.000
PENTANE & HEAVIER	0.000

REMARKS:

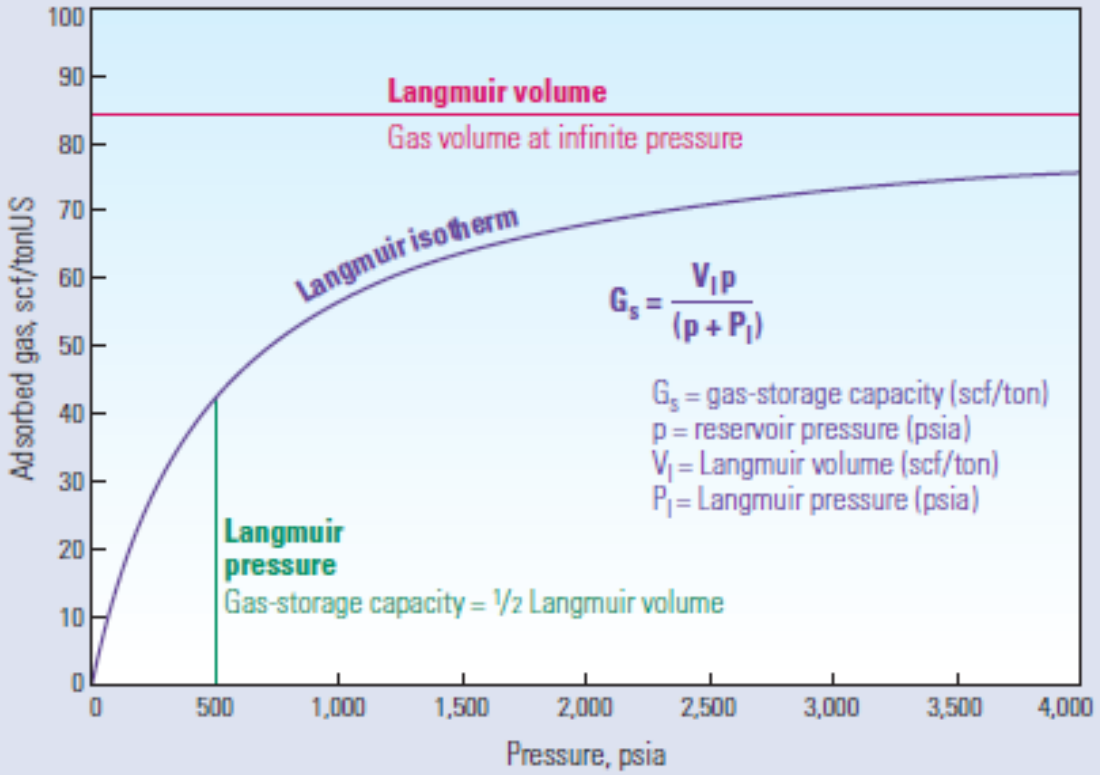
RESULTS TO:
NEW FIELD

Gross Heating Value BTU @ 14.65 PSIA & 60 F-REAL	
Dry	950.1
Wet	933.6

SPECIFIC GRAVITY- REAL Z= 0.9978636
0.6144
MOL WEIGHT
20.43

Little CO2 in western areas of gas play. This increases to > 10% in the deeper central parts of the basin. CO2 can reach 75% in the south side of Red Oak field, where VRo reaches 5.0.

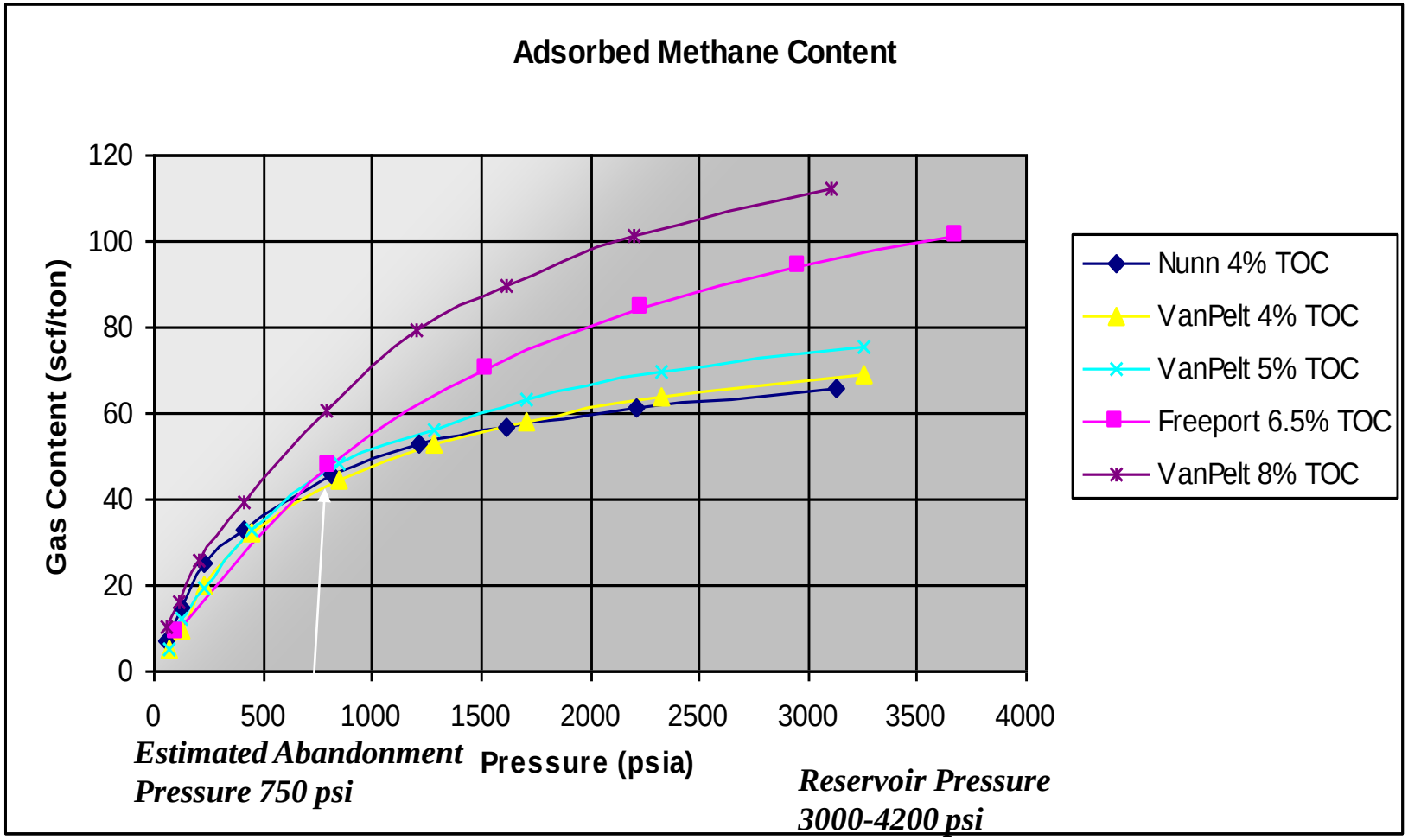
The Langmuir Isotherm



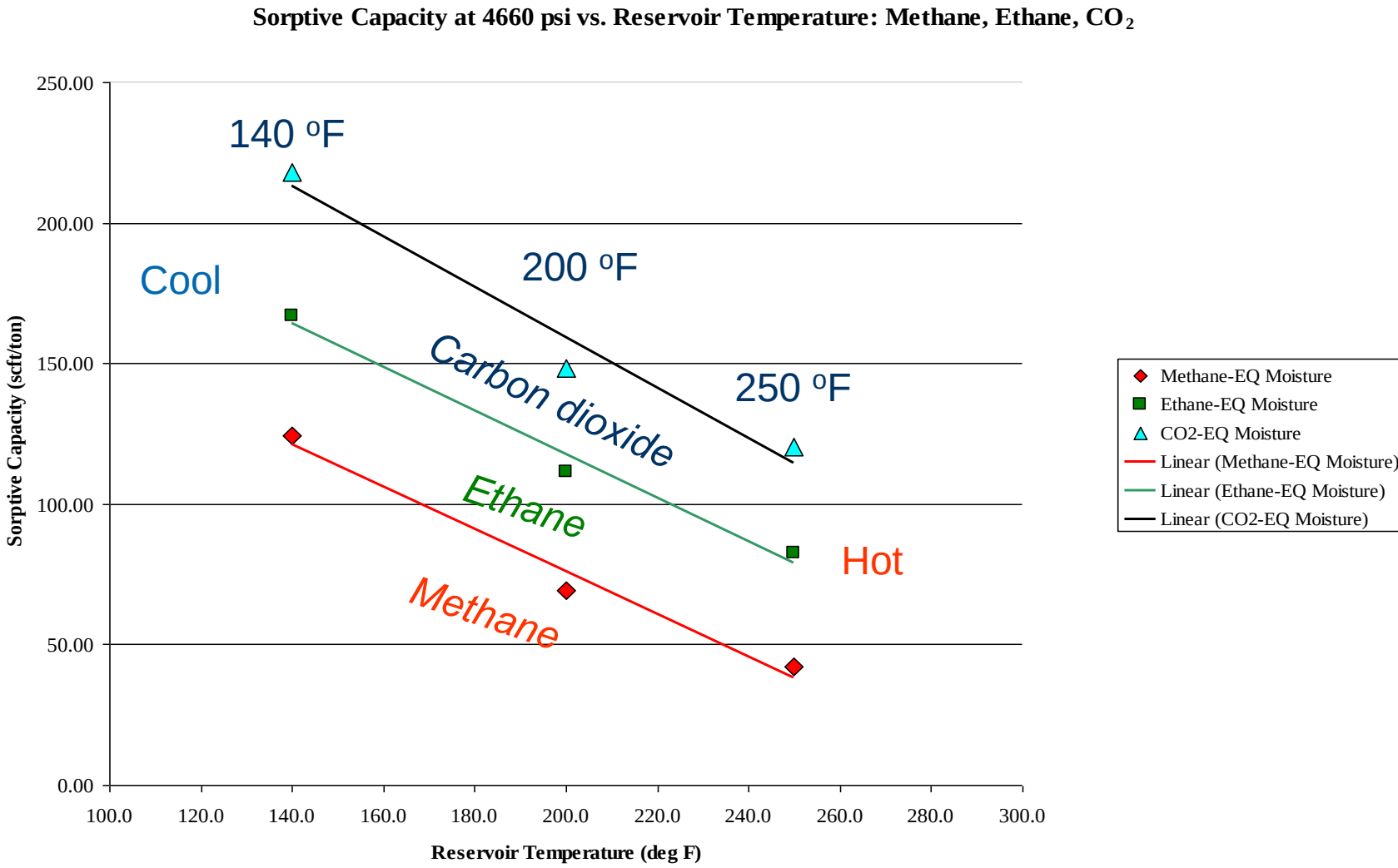
^ Adsorbed gas storage. The Langmuir isotherm (blue) shows the quantity of adsorbed gas that a saturated sample will contain at a given pressure. Decreasing pressure will cause the methane to desorb in accordance with behavior prescribed by the blue line. Gas desorption increases in a nonlinear manner as the pressure declines. Thus, in this example, a sample at 3,500-psi [24.2-MPa] pressure will have about 74 scf/ton adsorbed methane. As pressure first decreases from this point, the amount of gas desorbed is relatively small. Once the pressure has declined to 500 psi [3.4 MPa], one-half of the total gas that this shale could adsorb will have been desorbed. The remaining volume will desorb over the final 500 psi.

Adsorbed Gas Content

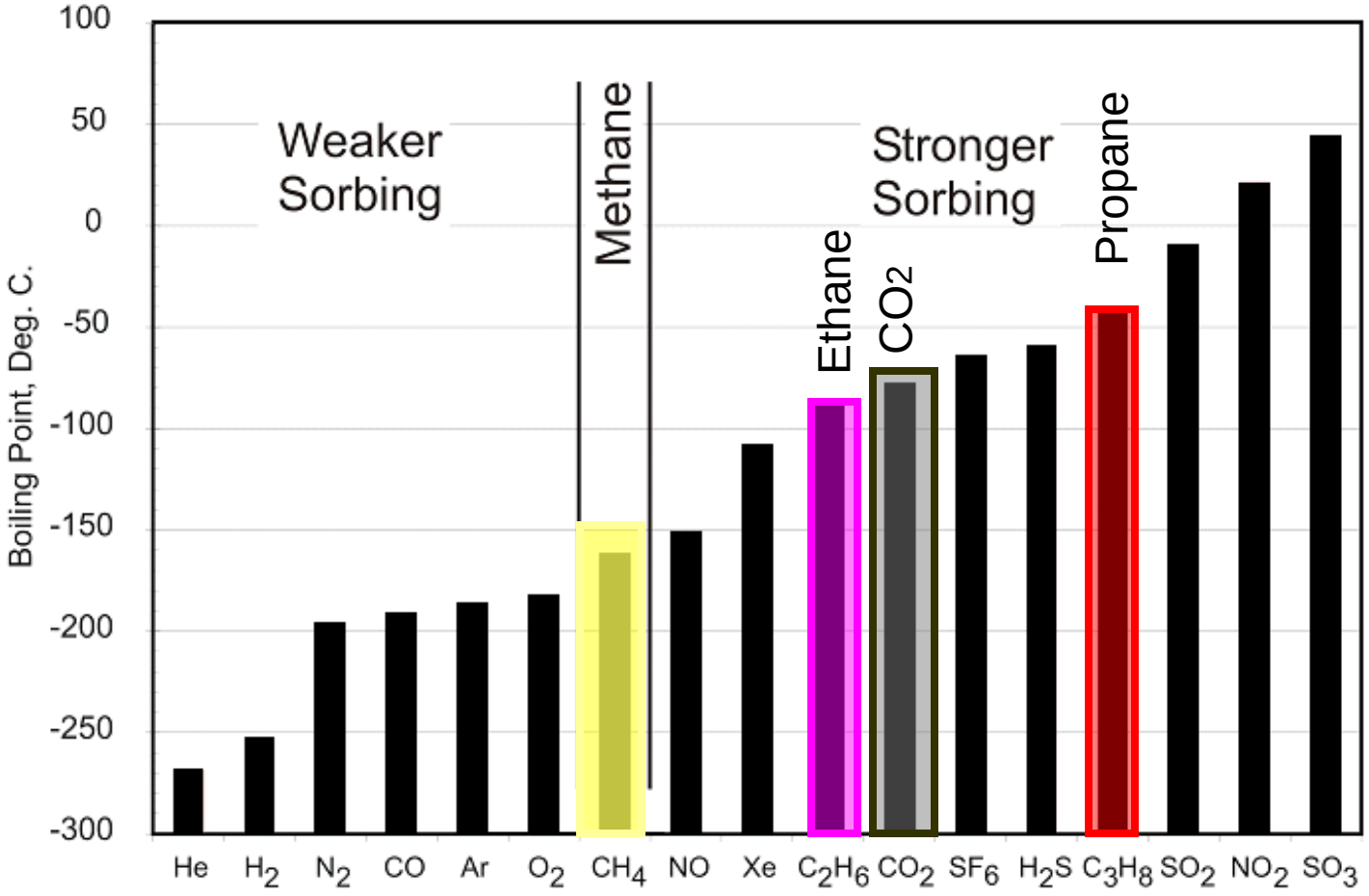
experimentally determined from core samples



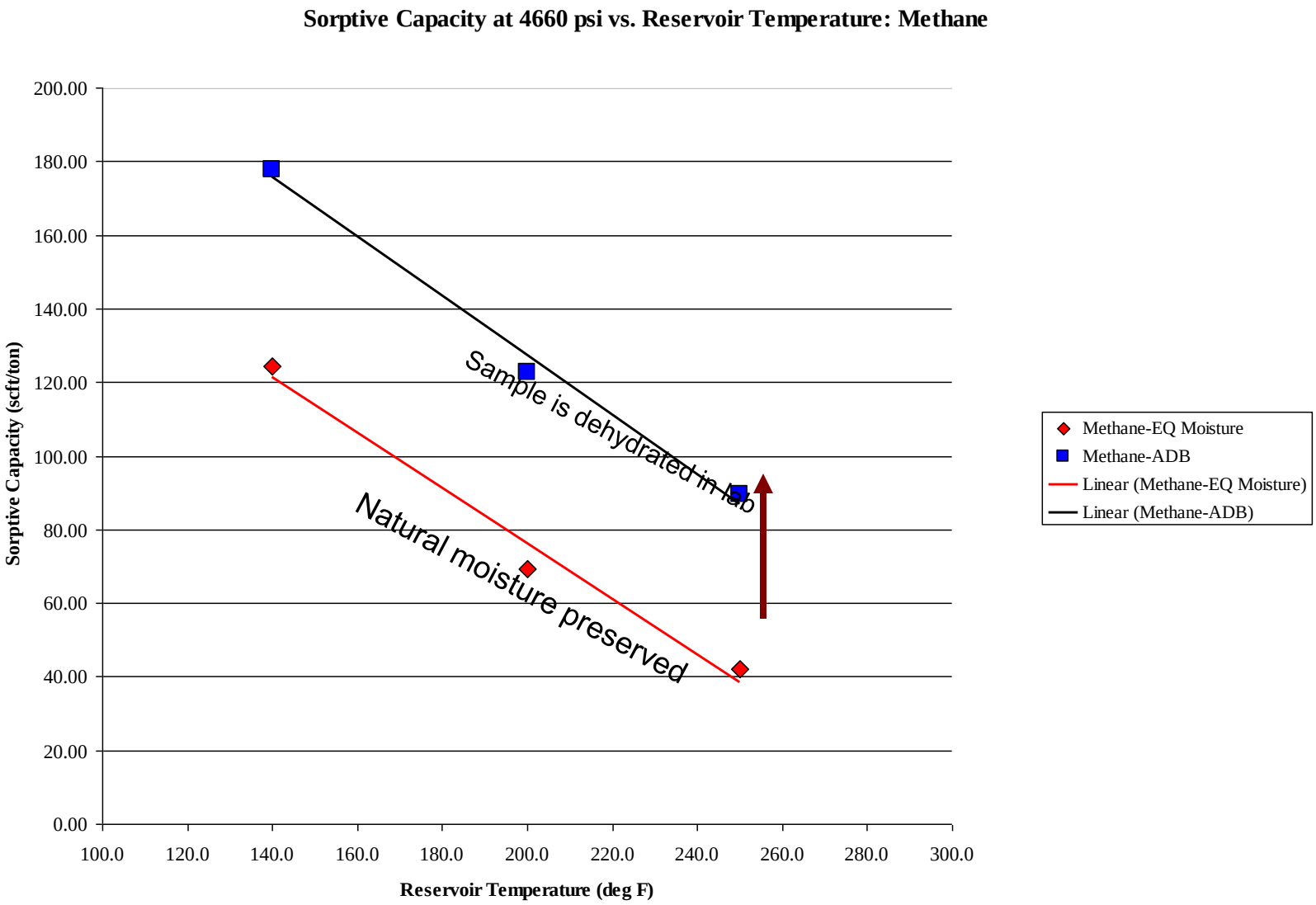
Sorptive capacity of methane, ethane, and CO2 at 3 temperatures



Adsorption tendency in relationship to Fluid boiling point



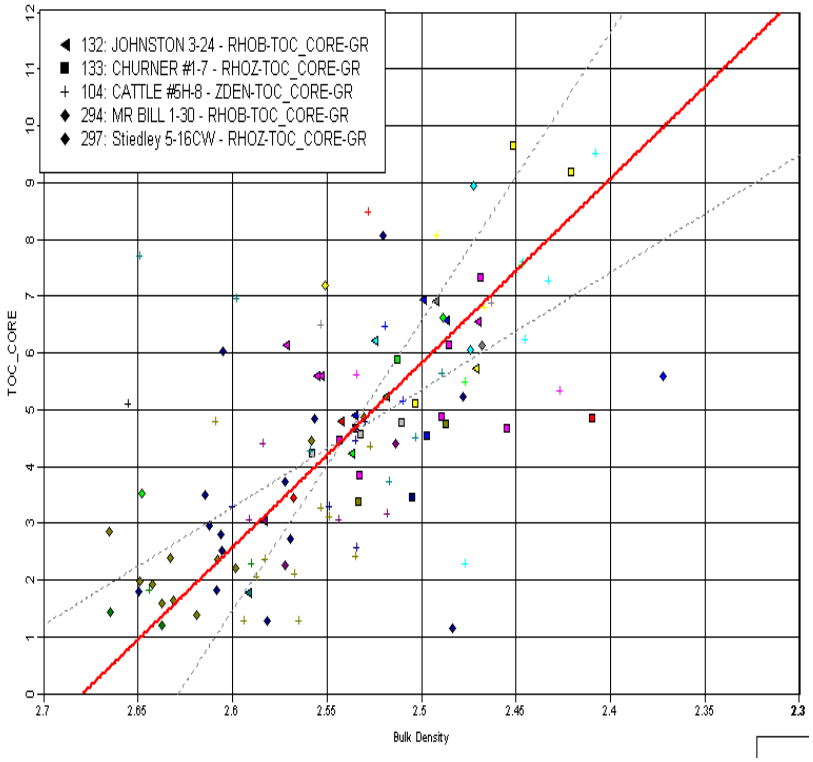
Sorptive capacity of methane in moisture equilibrated and dried samples

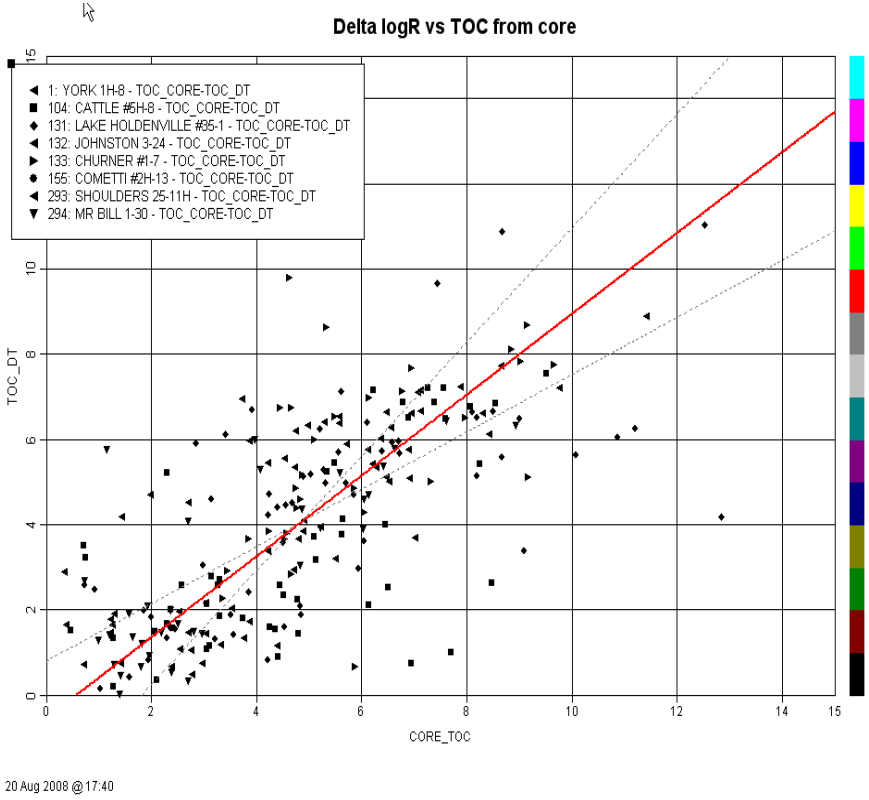


Key Parameters for assessment

- Map of Organic matter content
- Maps of reservoir temperature and pressure
- Map(s) of free gas composition
- Component storage capacity relationship, as specified in extended Langmuir isotherm relationships

TOC estimation from RHOB and DeltaT- log(Rt)
Caney & Woodford shales





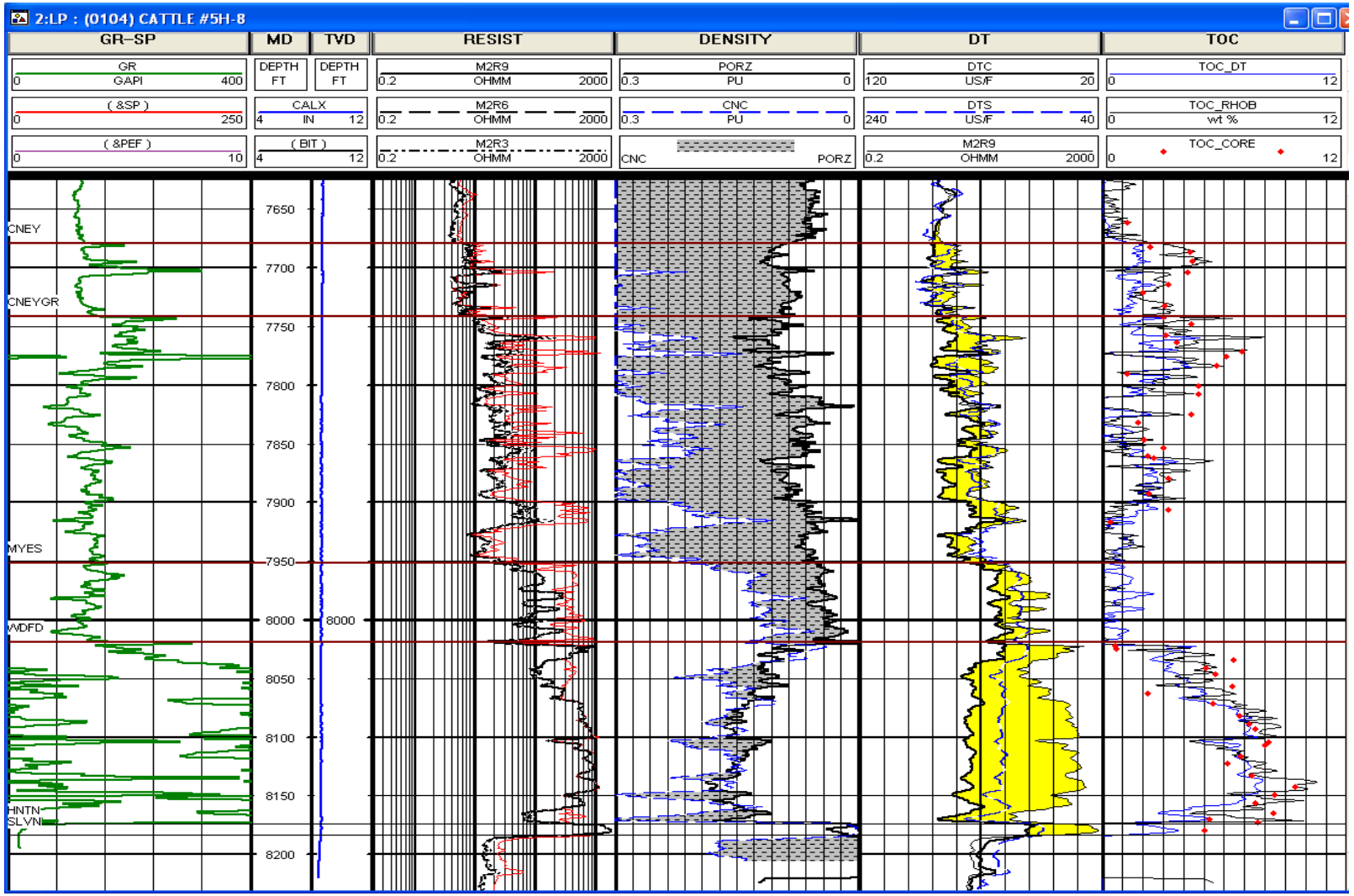
TOC = 87. - 34.5 * RHOB
Correlation Coefficient: r-square = 0.40

Regression : TOC = .82 * X - .57
Correlation Coefficients: r-square = 0.50

Newfield 5H-8 Cattle
TOC is approximated by petrophysical techniques

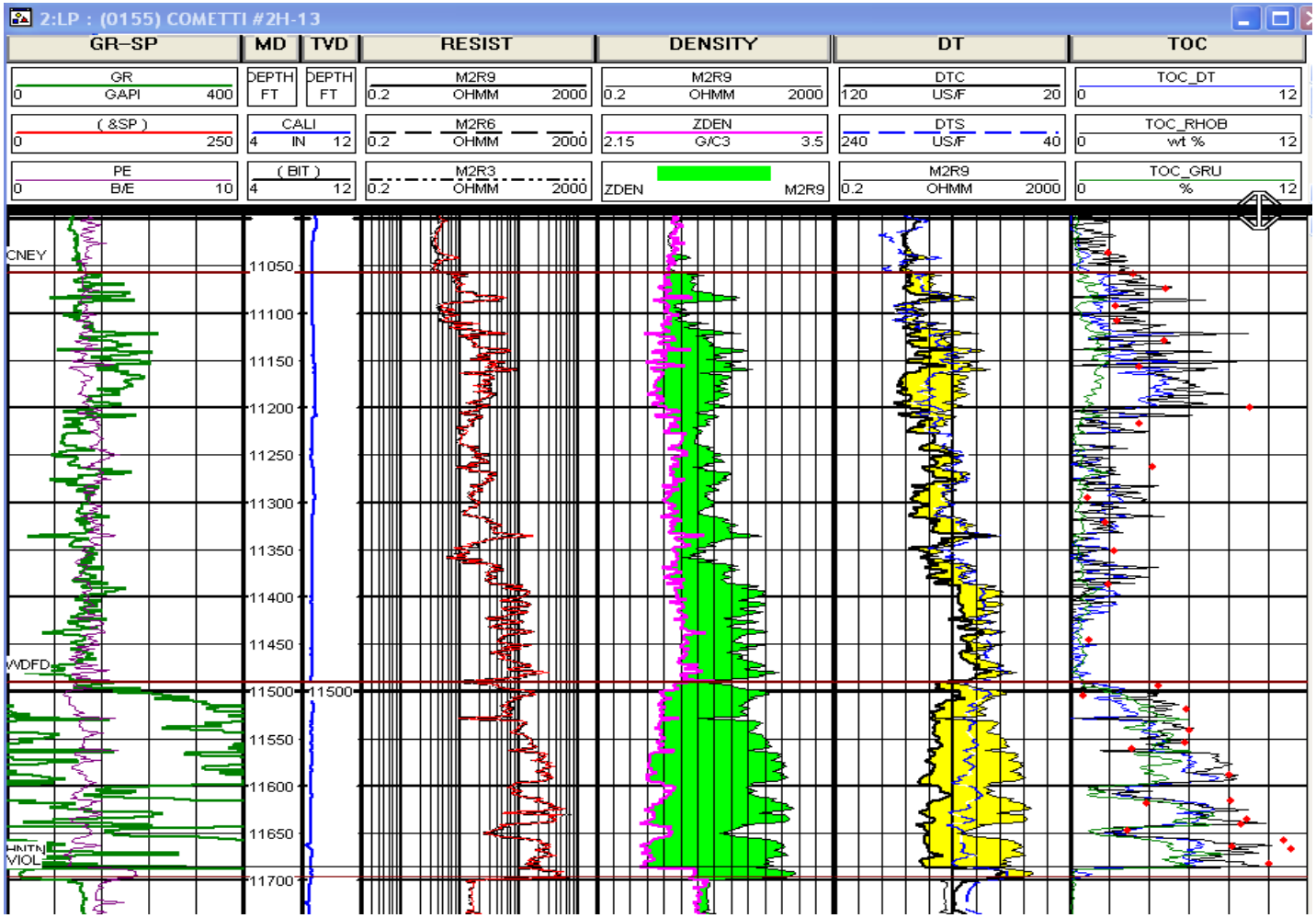
CANEY

Woodford



Calculated TOC curves from Density (black) and DTlogR (blue) are calibrated to core TOC measurements (red points);

NFX 2H-13 Cometti
TOC is approximated by multiple techniques



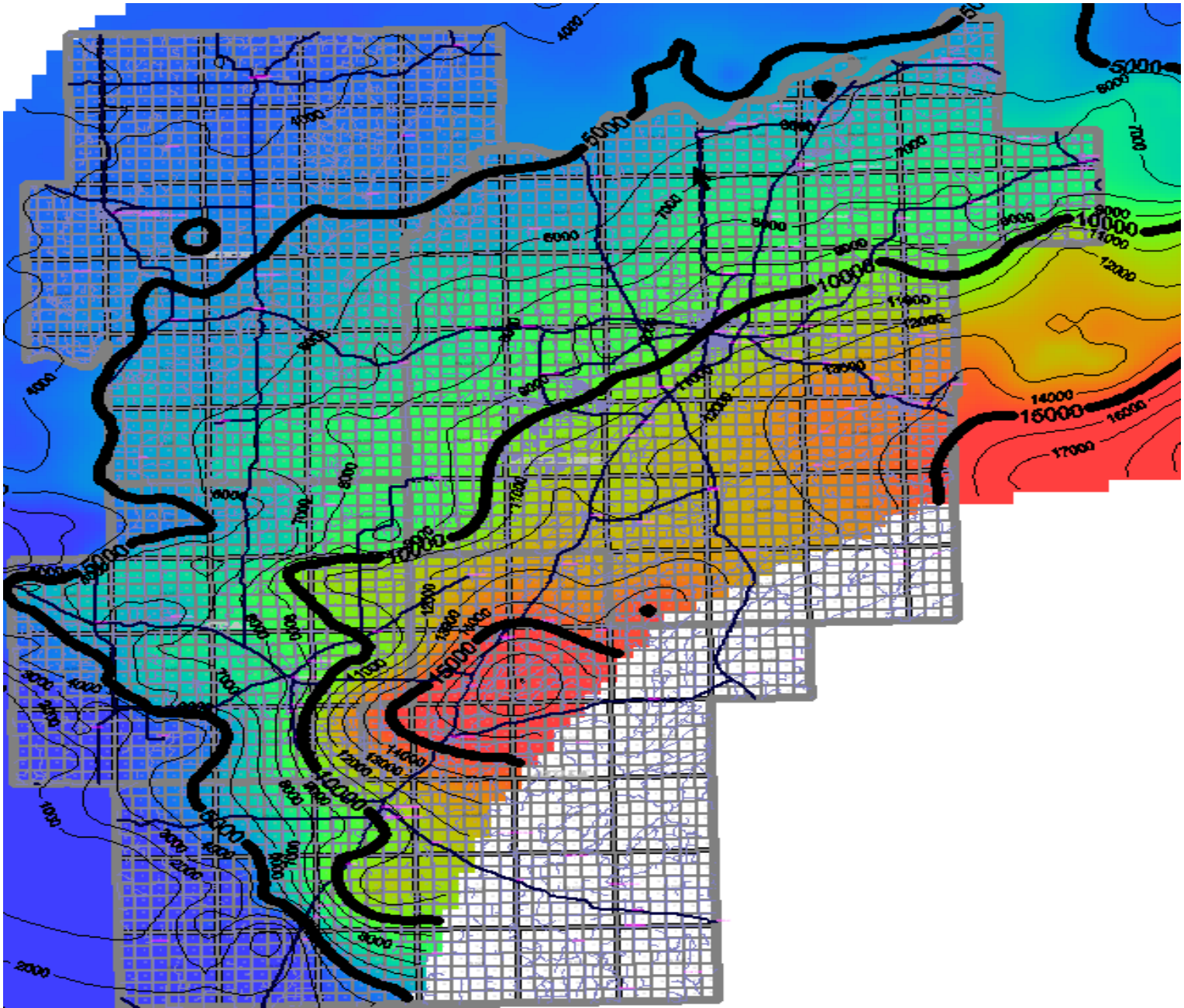
CANEY

Woodford

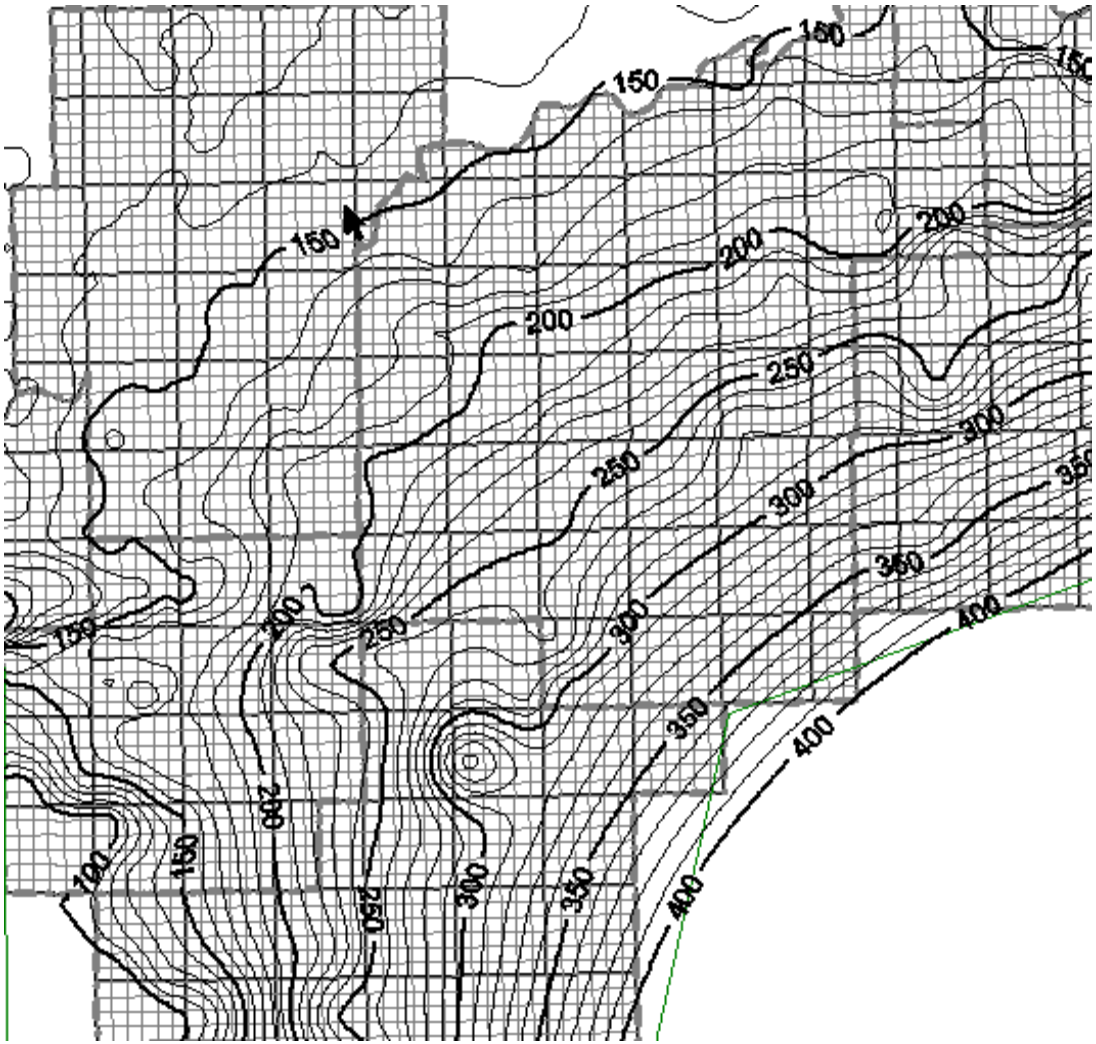
Calibration: Goddard shale (top of picture) (TOC = 0%). Limestone & sandstone units excluded from evaluation.

Calculated TOC curves are calibrated to core TOC measurements (red points);

Woodford structure



Woodford Temperature map



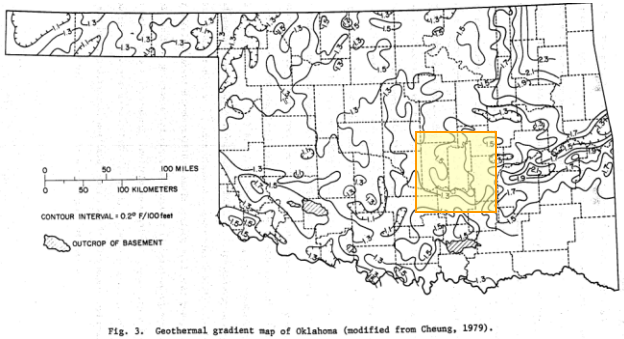
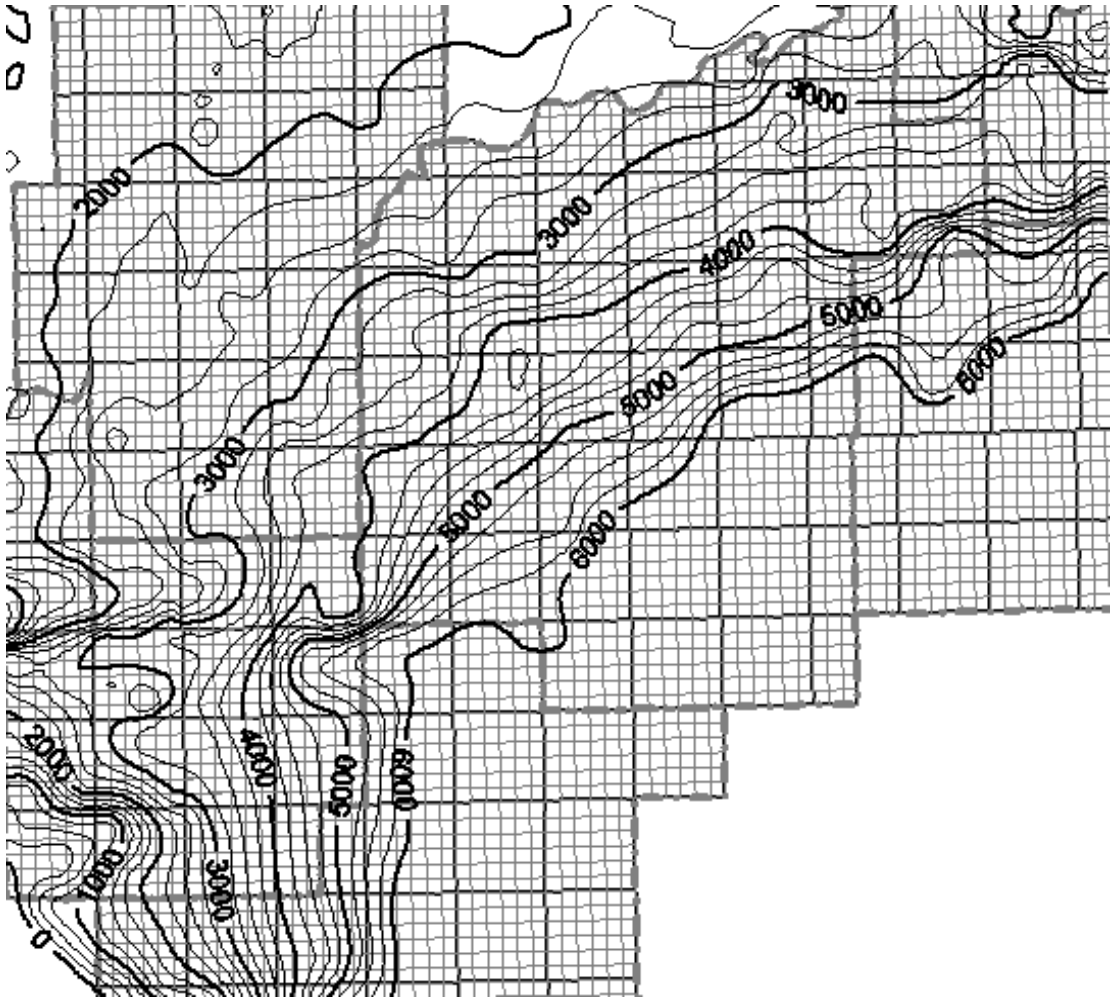


Fig. 3. Geothermal gradient map of Oklahoma (modified from Cheung, 1979).

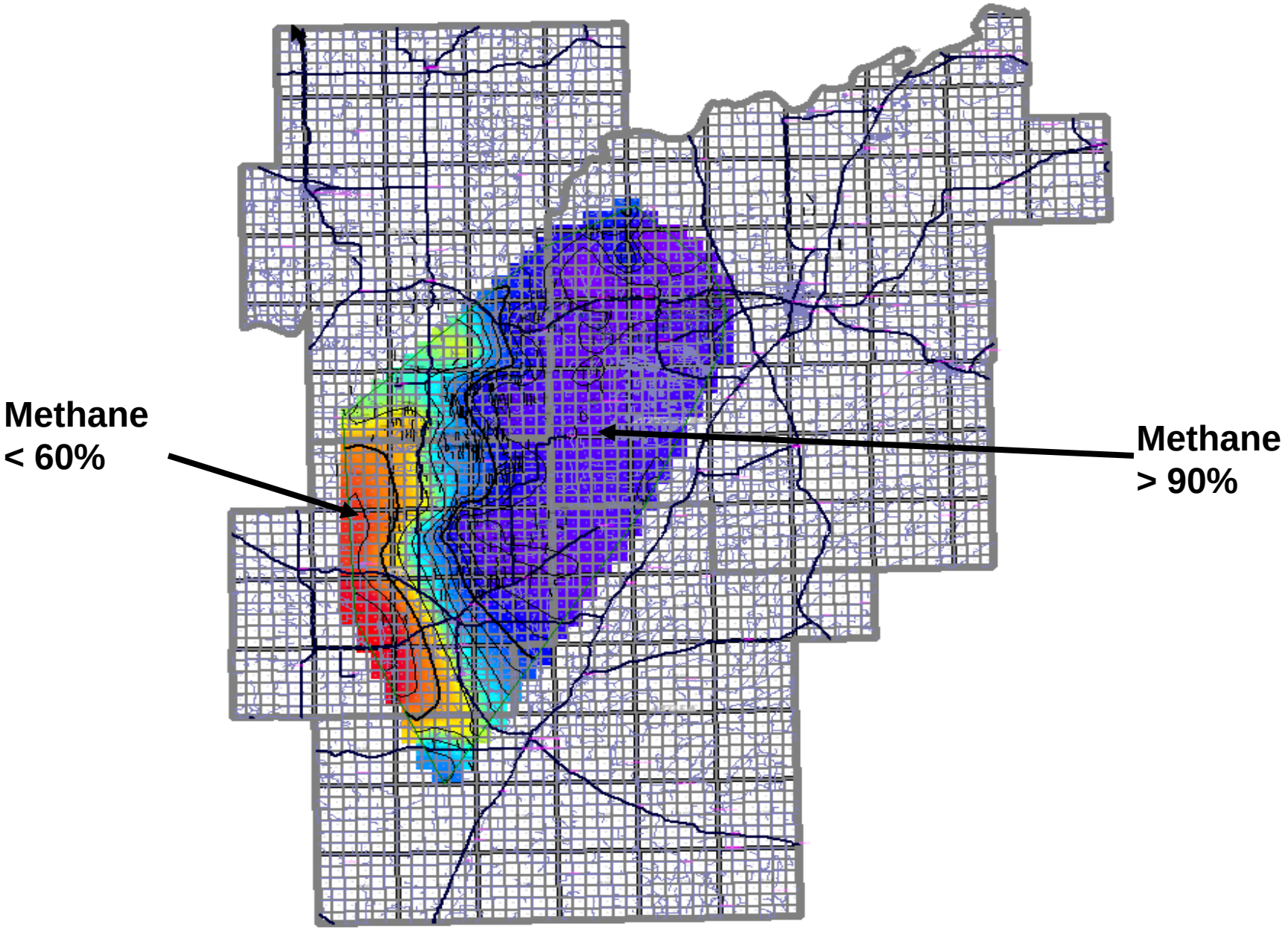
Geothermal gradient of 1.3 – 1.5 deg F / 100 ft. Mean surface temperature is 72 deg F across study area.

Woodford Pressure map

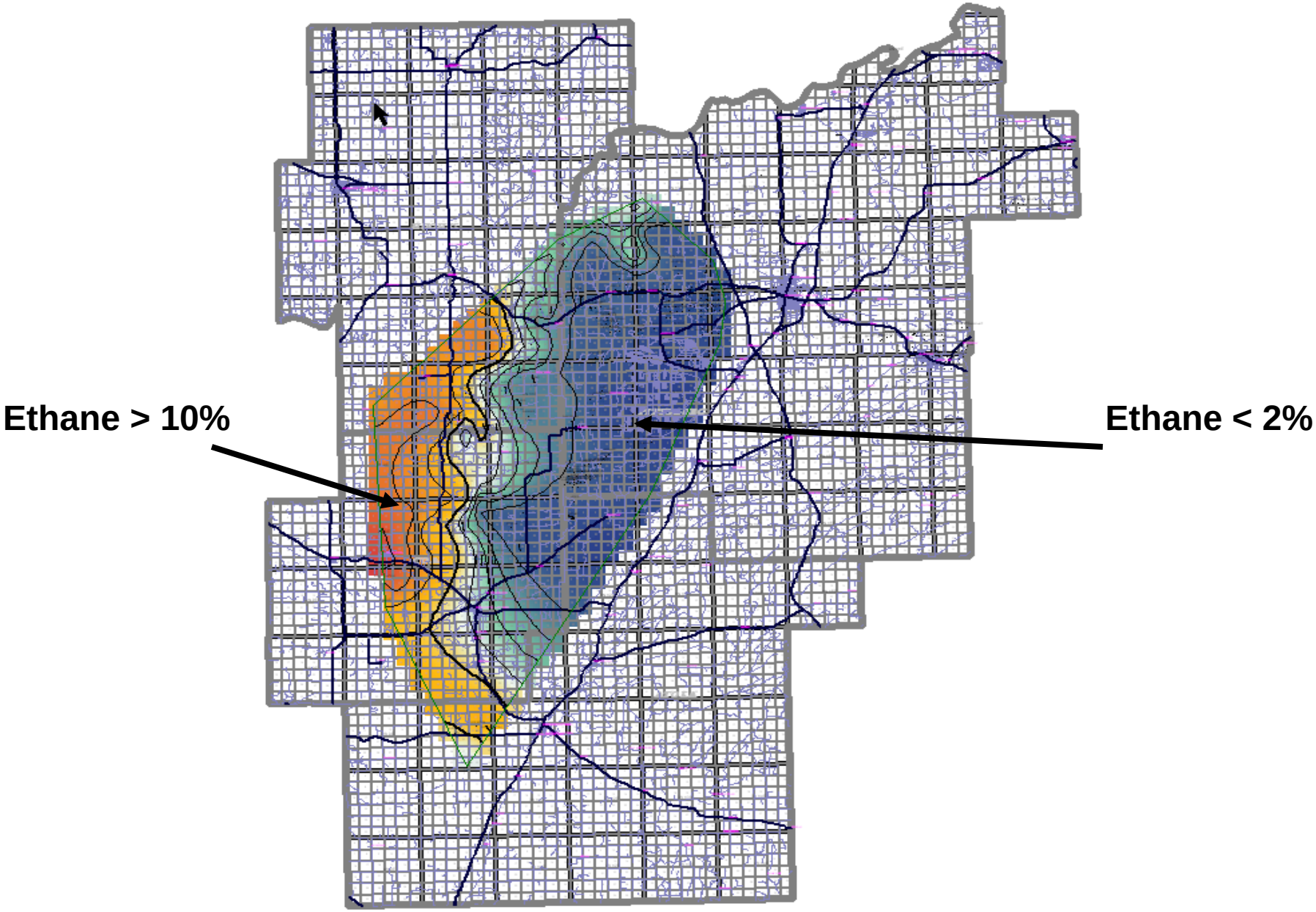


Geopressure Gradient:
.47 psi / ft (TVD)

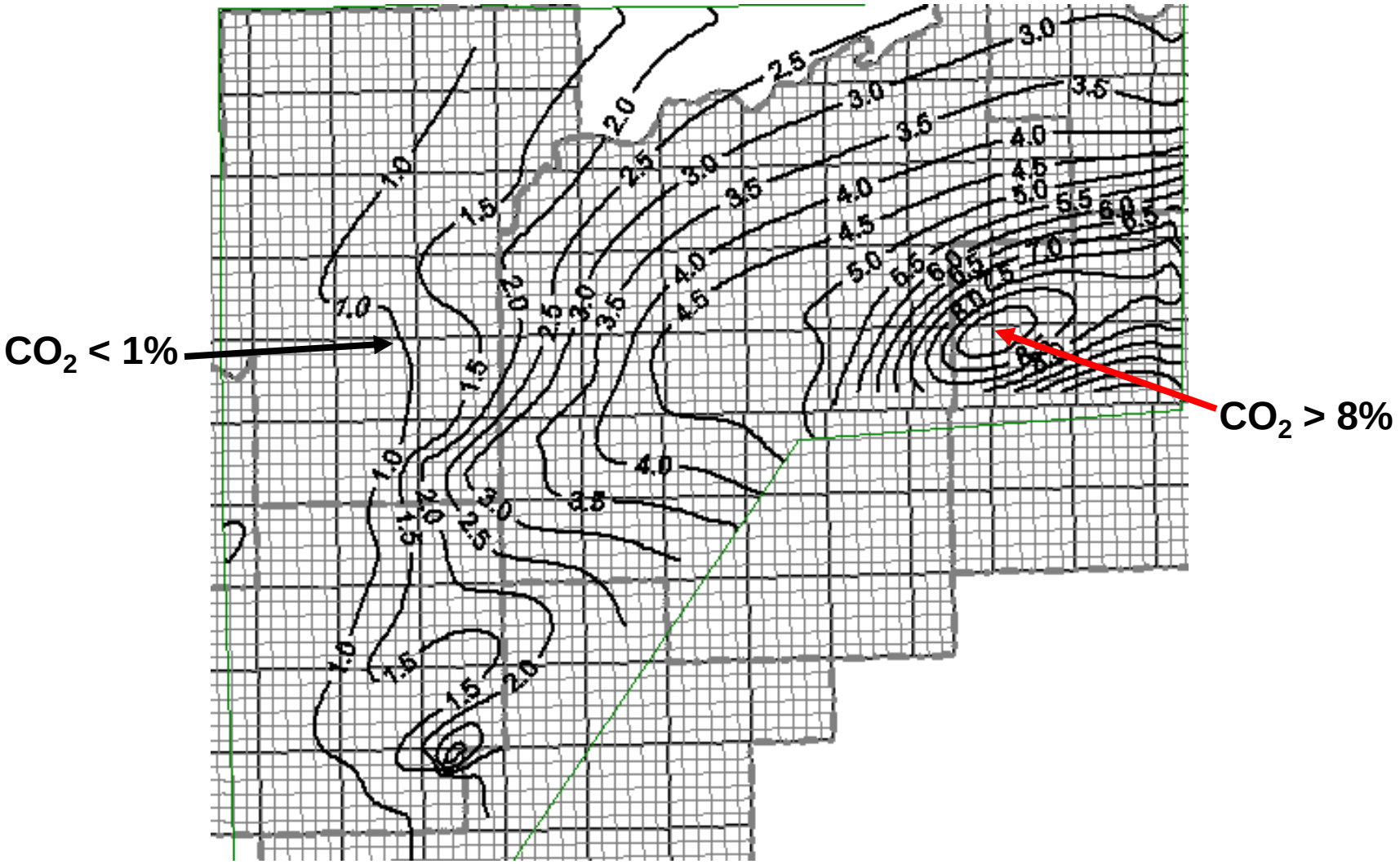
Map of initial Methane



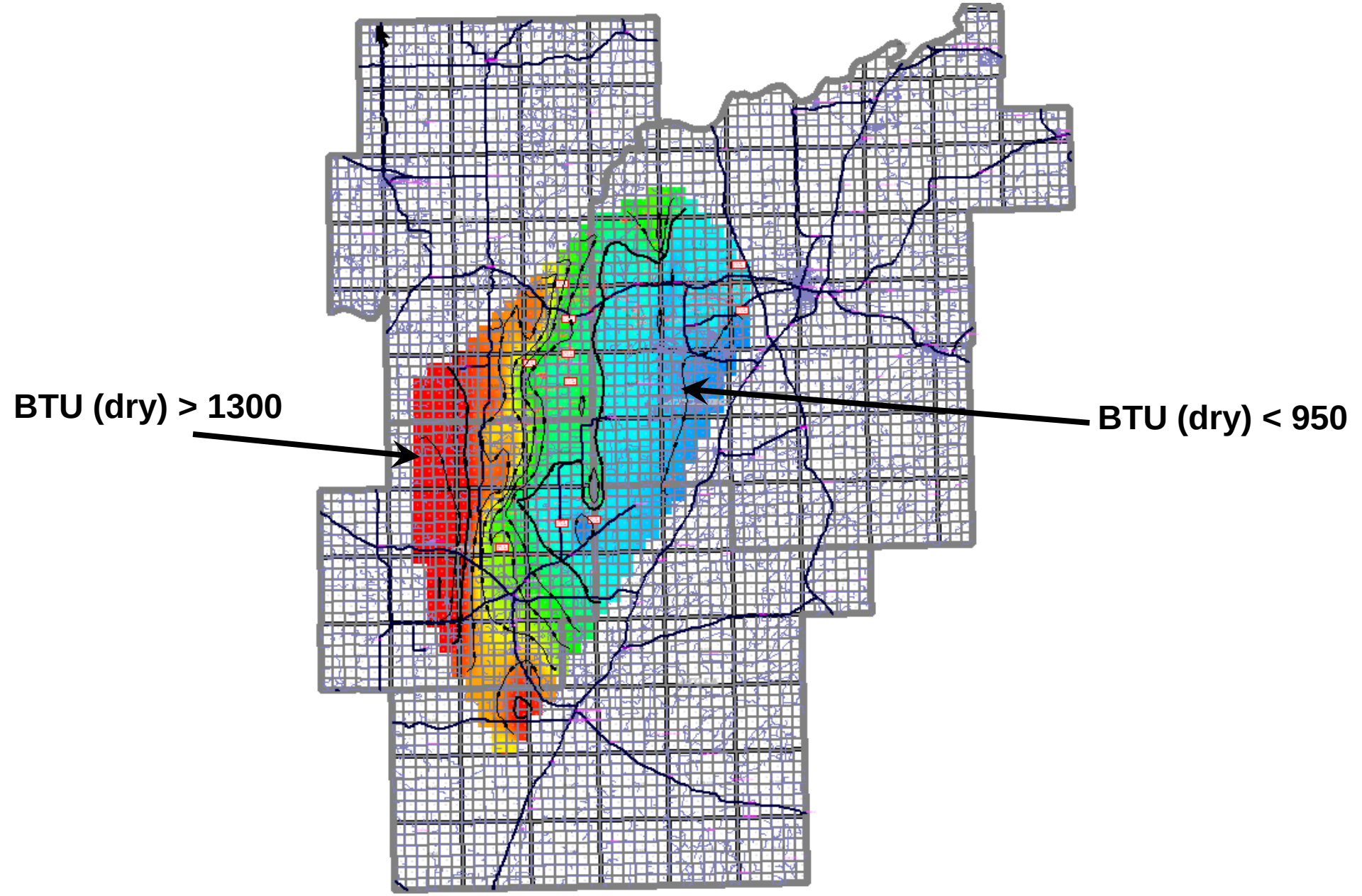
Map of initial Ethane



Map of initial CO2



Produced gas (BTU content)



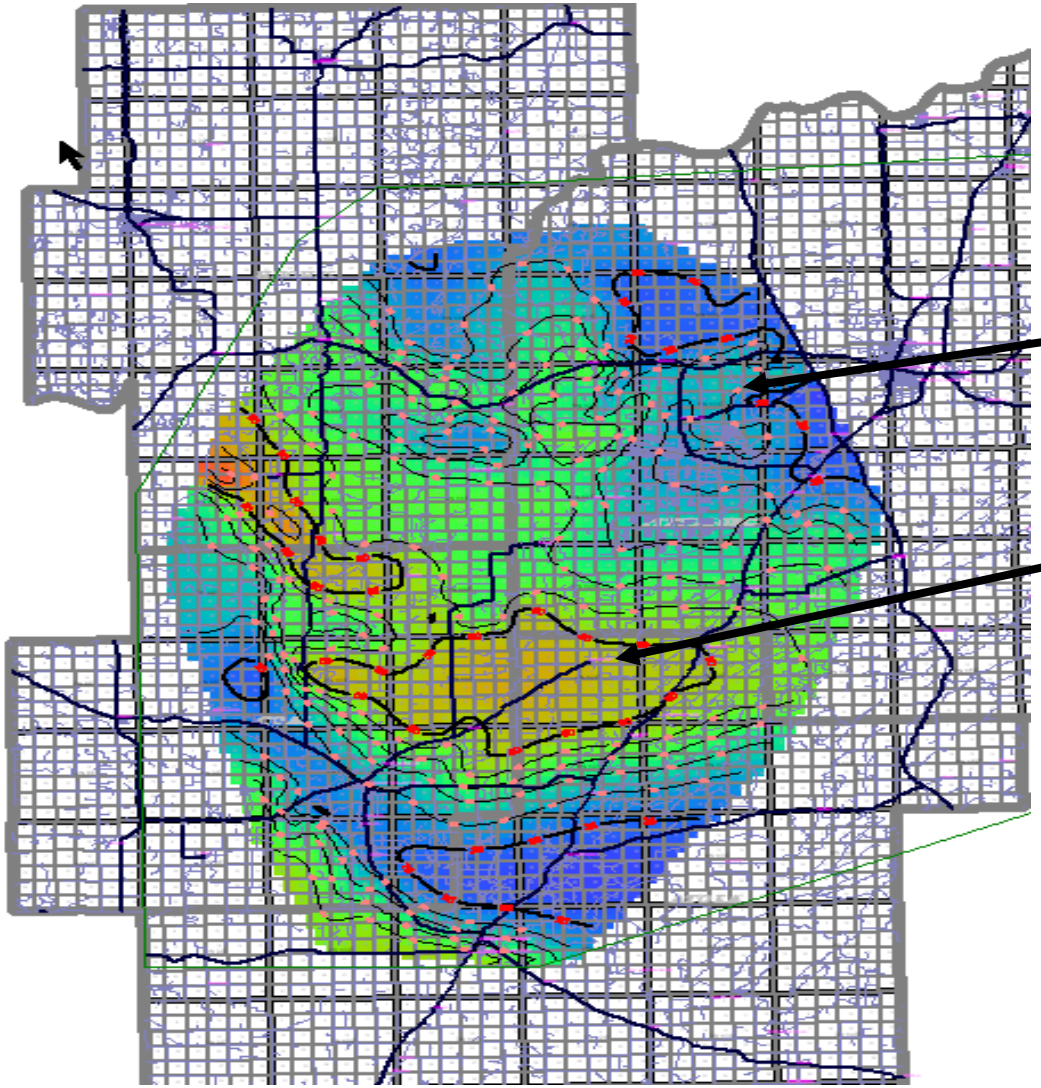
Extended Langmuir relationship

Multi-component isotherm relationships can be computed from single component data by use of extended Langmuir theory.

$$G_{si} = G_{sLi} \frac{\frac{py_i}{p_{Li}}}{1 + p\sum_{j=1}^{nc} \frac{y_j}{p_{Lj}}}$$

where:
Gsi *multi-component storage capacity of component i, scf/ton*
GsLi *single component Langmuir storage capacity of component i, scf/ton*
pLi, pLj *single component Langmuir pressure of component i or j, psia*
yi *or* ***yj*** *mole fraction of component i or j in the free gas (vapor) phase, dimensionless*
nc *number of components*
p *pressure of the free gas phase, psia*

Adsorbed Gas in Place
Woodford



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- Randy Miller (Core Laboratories)
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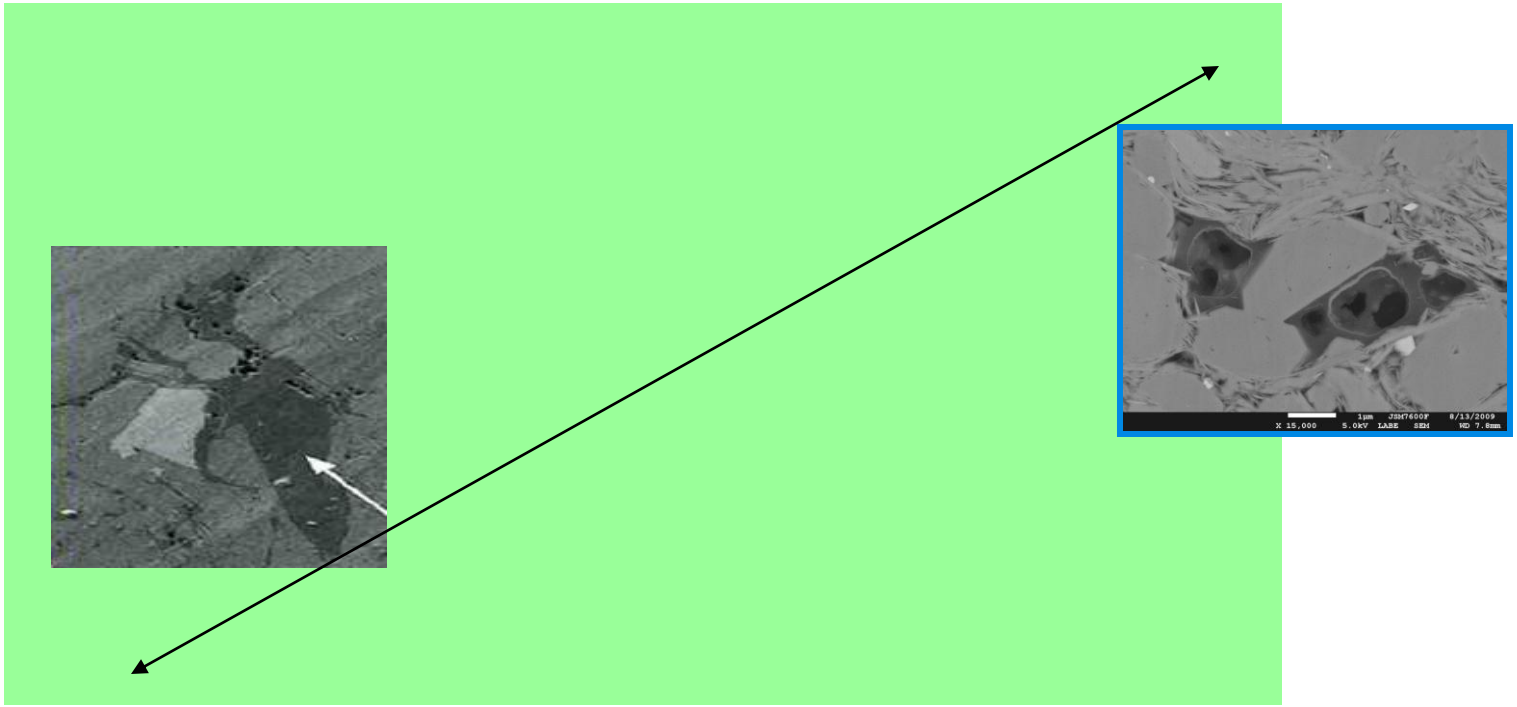
- Marc Bustin

Kerogen adsorptive capacity related to thermal maturation



Effective surface area of Kerogen, based on observed nanoporosity level, using Field Emission SEM on Argon milled samples)

THIS IS STILL IN RESEARCH

Thermal maturity of Woodford Fm. organic matter (VRo) – western Arkoma Basin