Appalachian Basin Black Shale Exploitation: Past, Present , and Future

IOGA of PA Annual Meeting
May 16th and 17th, 2007

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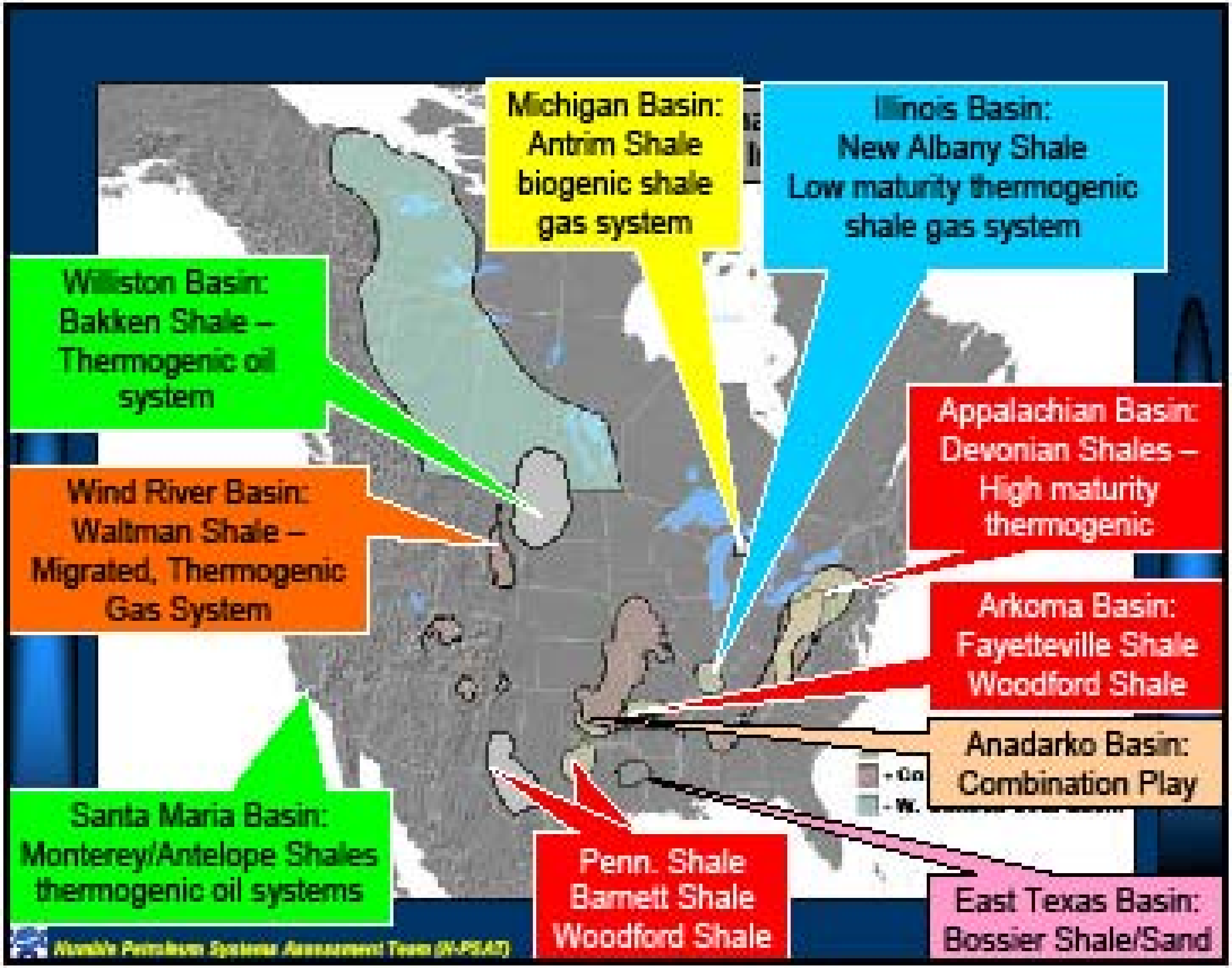
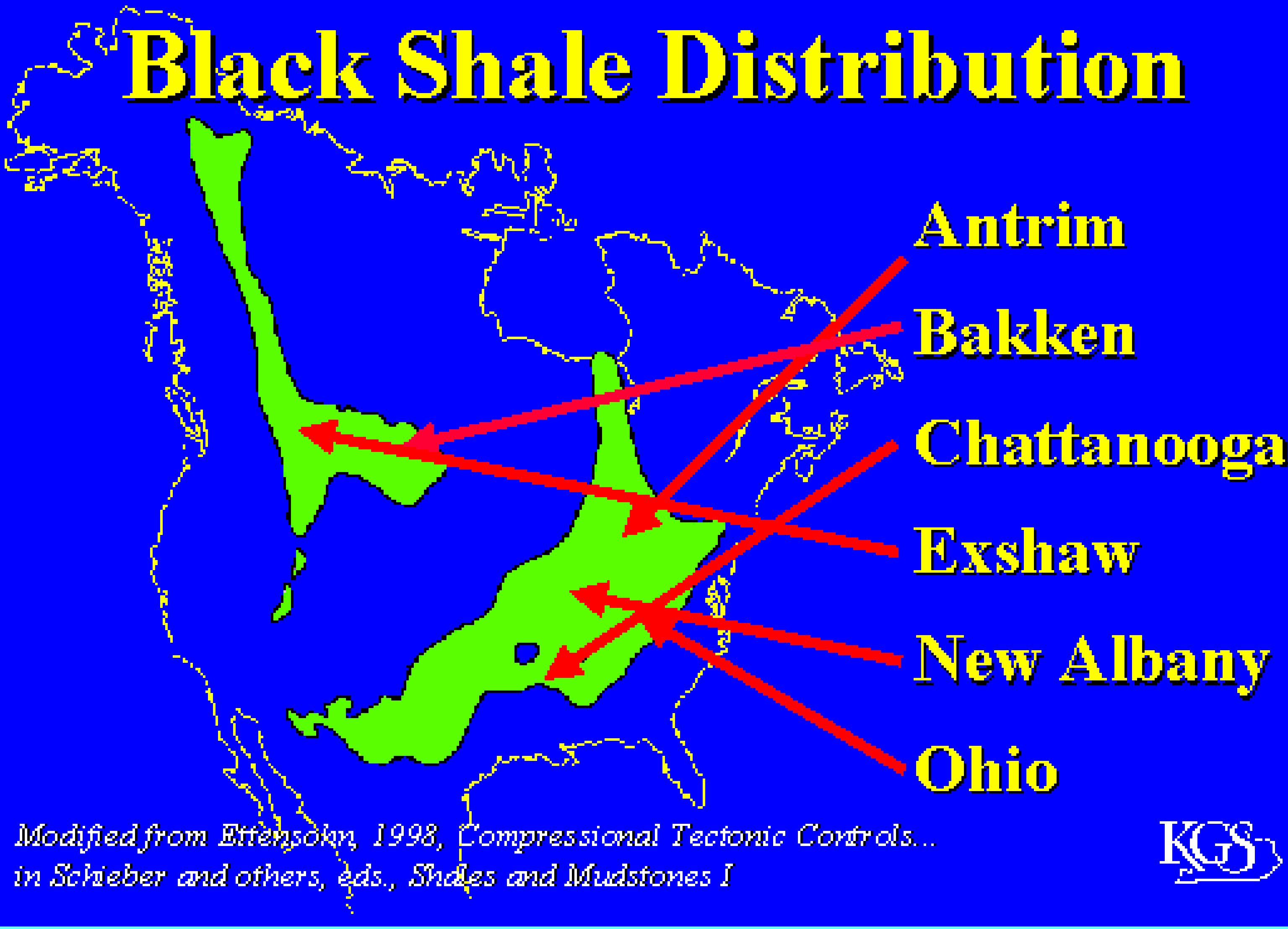
Region Tech Rep
BJ Services Company, U.S.A.

Agenda For Today

- Appalachian Basin Shale History
- Assessing Black Shale as Gas Pay
- The Current Focus on Marcellus Shale
- How Operators Frac the Marcellus Shale
- Future of the Marcellus Shale
- Questions


Michigan Basin: Antrim Shale biogenic shale gas system
Illinois Basin: New Albany Shale Low maturity thermogenic shale gas system
Williston Basin: Bakken Shale – Thermogenic oil system
Wind River Basin: Waltman Shale – Migrated, Thermogenic Gas System
Appalachian Basin: Devonian Shales – High maturity thermogenic
Arkoma Basin: Fayetteville Shale Woodford Shale
Anadarko Basin: Combination Play
Santa Maria Basin: Monterey/Antelope Shales thermogenic oil systems
Penn. Shale Barnett Shale Woodford Shale
East Texas Basin: Bossier Shale/Sand

Black Shale Distribution



Modified from Ettensohn, 1998, Compressional Tectonic Controls...
in Schieber and others, eds., Shales and Mudstones I

Historical Perspective of “Black Shale” in Northeast

- Chautauqua County, NY
  - Shallow shale gas south shore of Lake Erie in 1820s and 1830s
  - Some produced gas for 100 years
- Big Sandy Field, KY
  - Drilling began in 1920s
  - Wells produce 50 years or more
- Scarcity of natural gas in the 1970’s renewed interest in Appalachian Black Shales

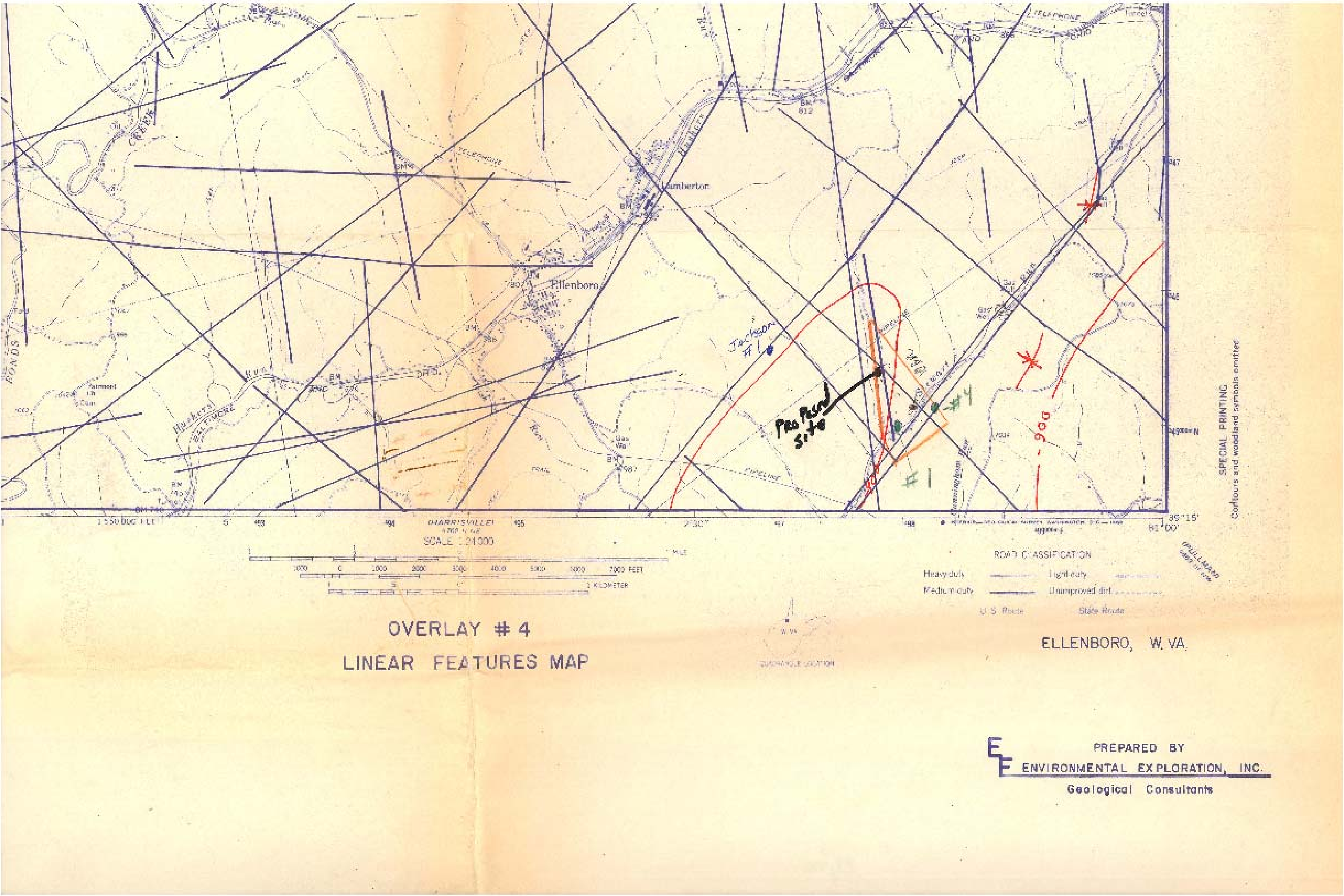
NYSERDA Report 85-17
December 1983

- 8 Marcellus Wells; 28-114 feet thickness
- 50-80 K sand foam fracs
- Emphasis on pressure/production analysis
- Results:
  – Wide range of reserves due to v.low K
  – Production controlled by natural fractures
  – Stimulation = marginal increase in some wells
  – Liquid loading prevention important

“Porosity and Permeability of Eastern Devonian Gas Shale”

- SPE Formation Evaluation, March 1988
- Conclusion
  – Gas productivity potential influenced by
    1. Organic content
    2. Thermal maturity
    3. Natural fracture spacing
    4. Stratigraphic relationships between black and grey shales
  – Marcellus K strongly stress dependent; doubling the stress = K decrease of 70%
  – Presence of liquid hydrocarbon lowers gas K

1980's Lineament Map



Nitrogen Gas and Sand: A New Technique for Stimulation of Devonian Shale

J.C. Gottschling, SPE, BJ-Titan Services
T.N. Royce, SPE, BJ-Titan Services
L.Z. Shuck, SPE, Technology Development Inc.

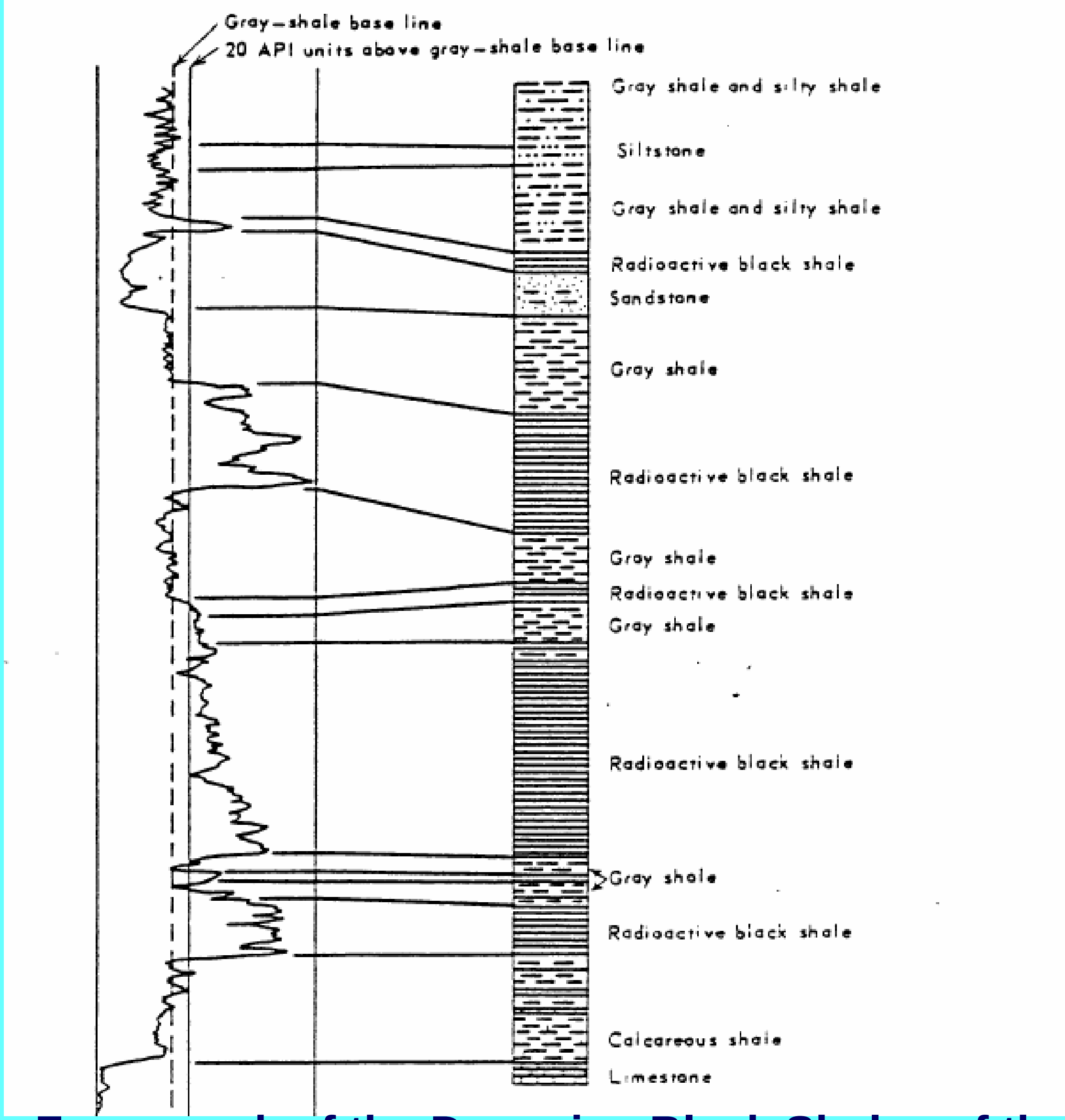
Summary

A process has been developed and demonstrated in 17 field tests in which sand proppant is added to a nitrogen gas stimulation treatment. Excepting minor problems with five treatments, all recent applications have been operationally successful. The early production results from two offset wells show decline curve improvement from the nitrogen-gas/sand treatment. Theories based on observed data from

The lack of any type proppant being used with a nitrogen gas stimulation treatment has provided the strongest argument against it. The contention that fracture conductivity cannot be maintained without proppant is well known. Production results showing rapid decline curves are given as corroboration to the lack of fracture conductivity after the nitrogen gas fracture. It has been demonstrated that some natural propping does occur under

SPE JOURNAL OF PETROLEUM TECHNOLOGY –May 1985

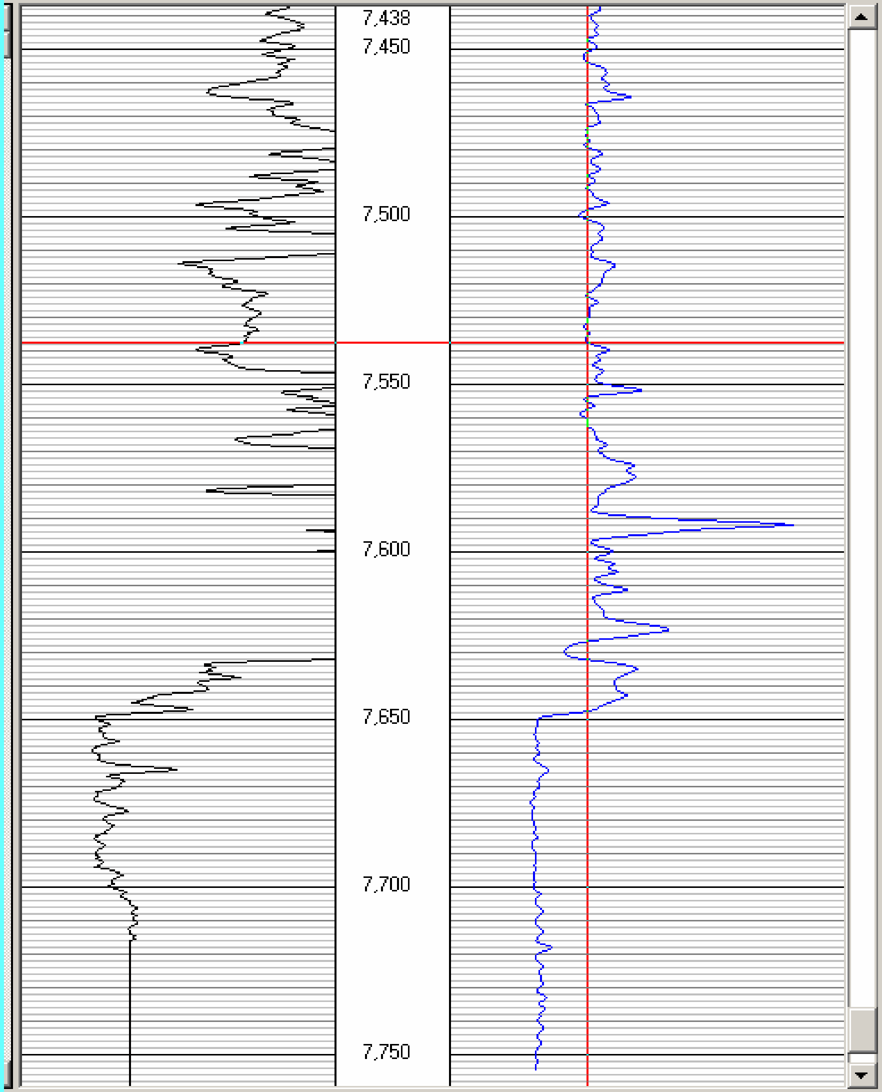
What's Black Shale?



Shale is the common name applied to fine-grained varieties of sedimentary rock formed by the consolidation of beds of clay or mud

Stratigraphic Framework of the Devonian Black Shales of the Appalachian Basin, Roen and de Witt, Jr., USGS Open File 84-111

Marcellus Shale Log - 2006



PE Curve Values

Quartz – 1.81

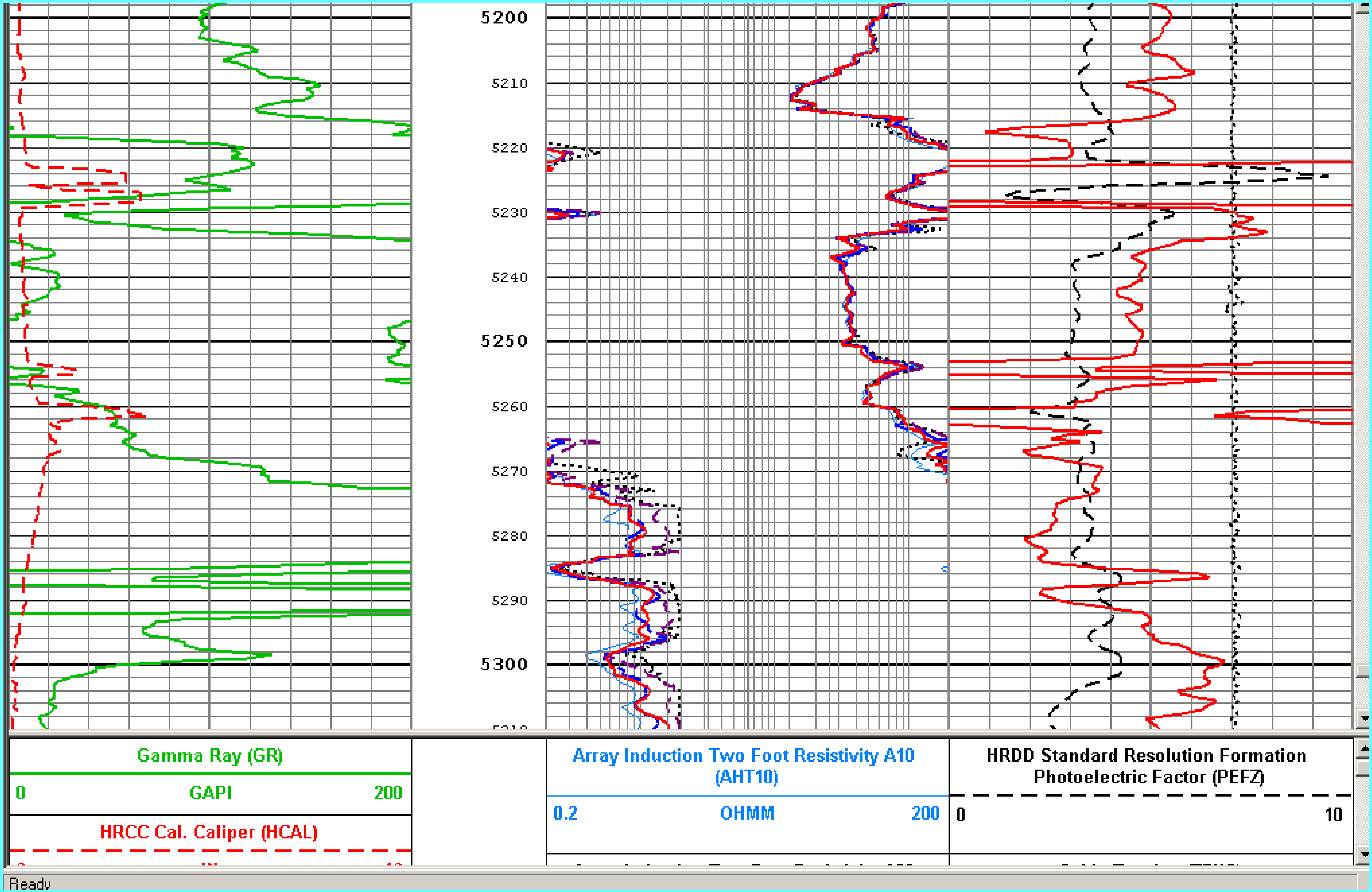
Calcite – 5.08

Dolomite – 3.14

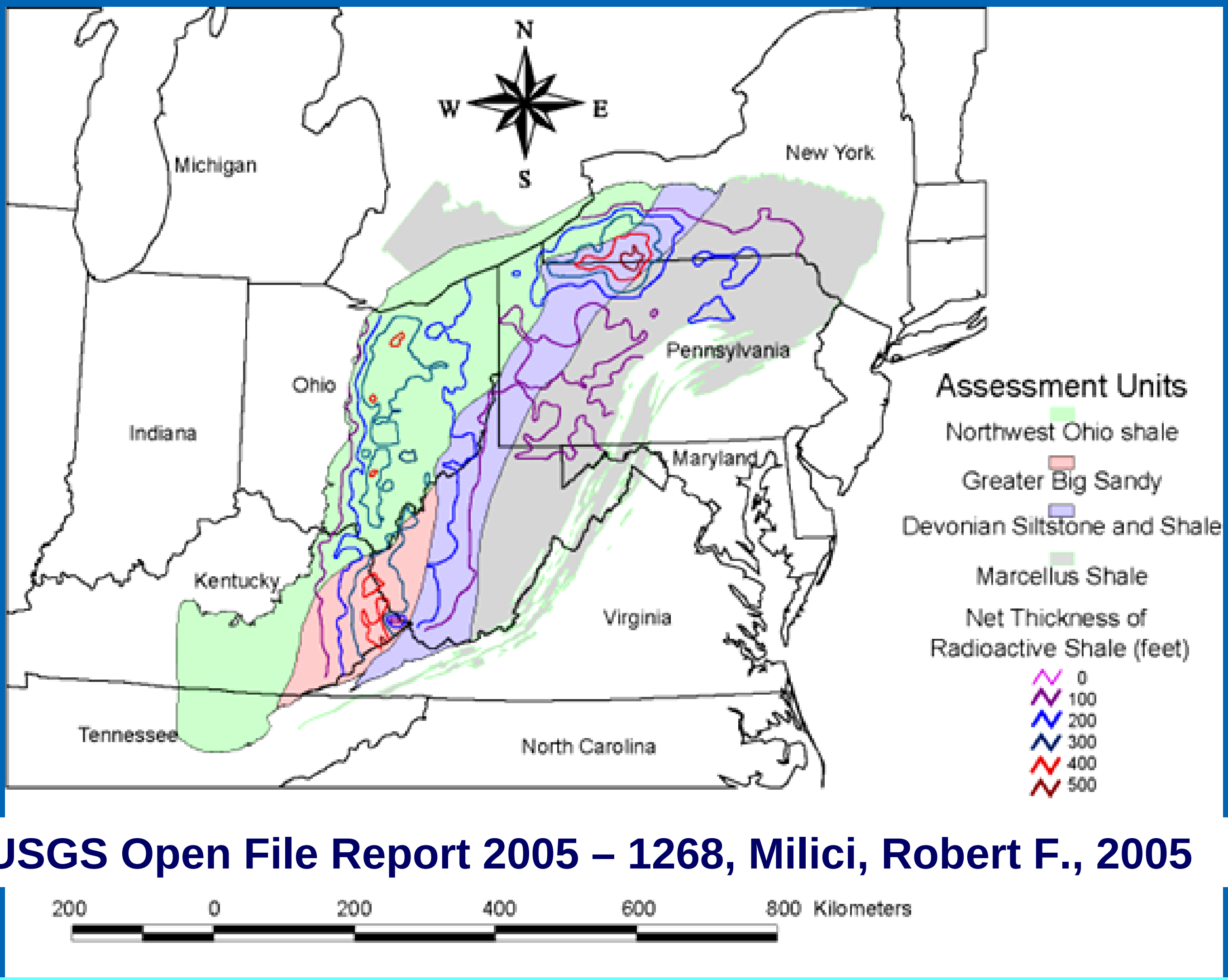
Illite – 2.52

Pyrite – 16.97

Marcellus Interval

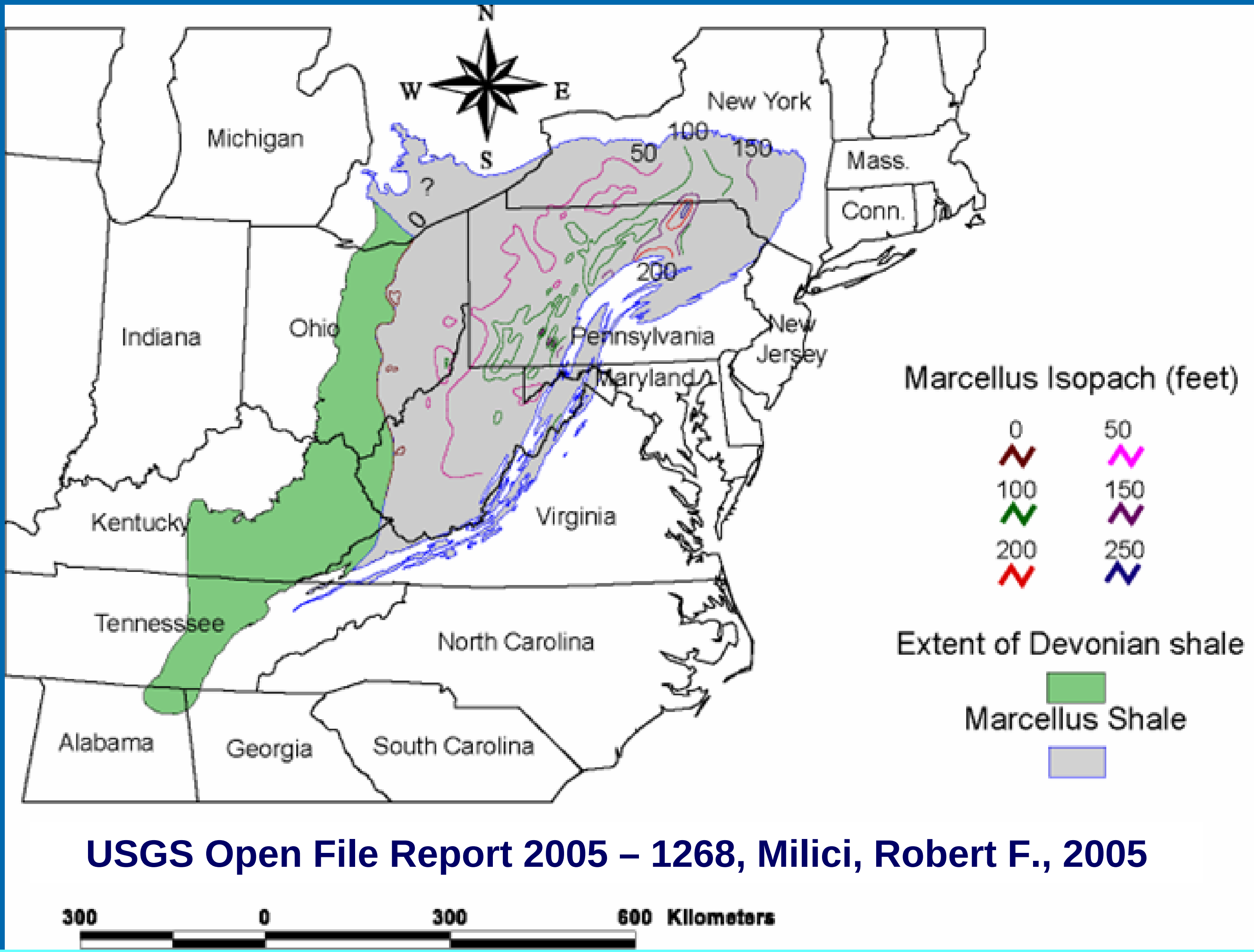


Devonian shale assessment units, showing net thickness of radioactive shale



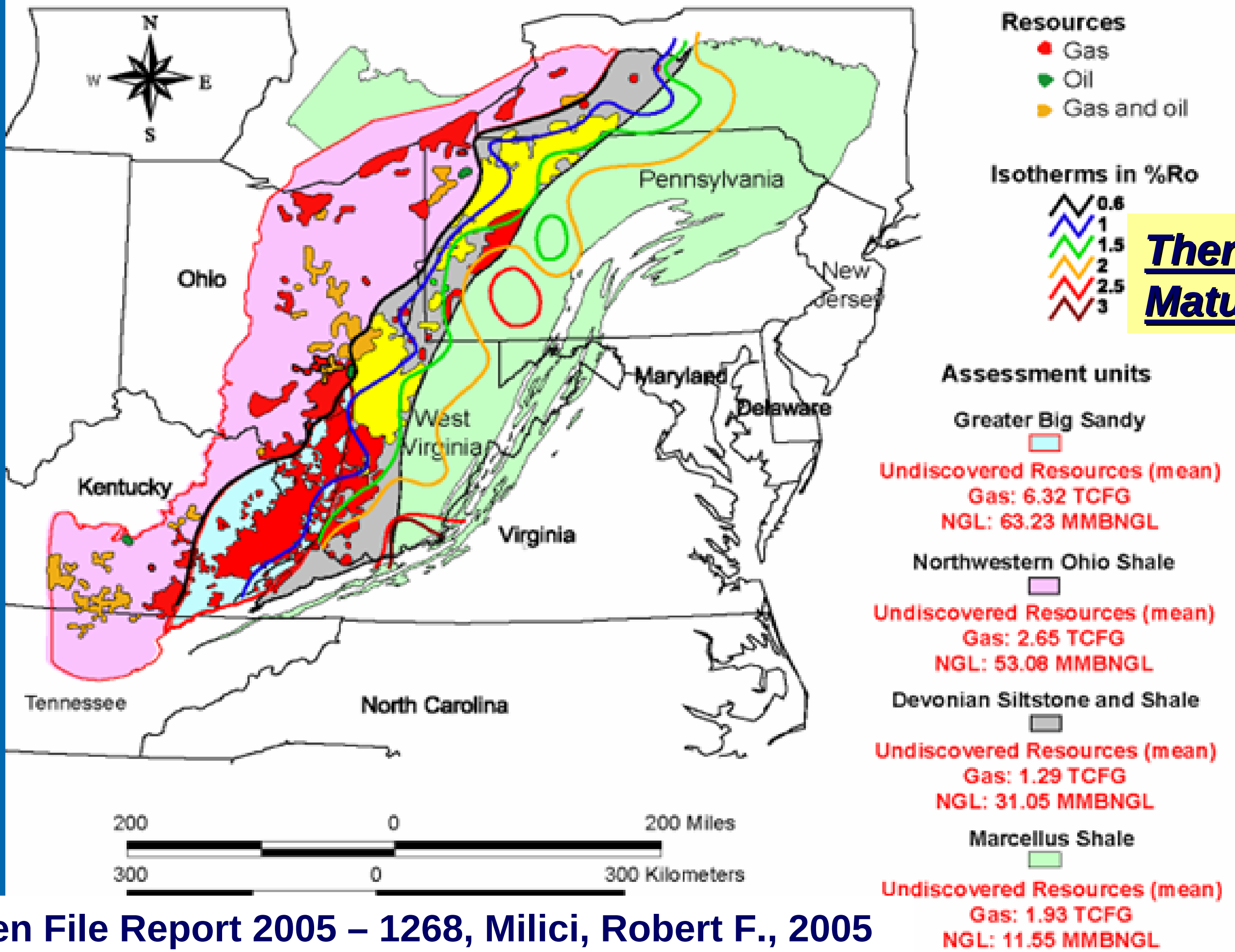
USGS Open File Report 2005 – 1268, Milici, Robert F., 2005

Marcellus Shale



USGS Open File Report 2005 – 1268, Milici, Robert F., 2005

Undiscovered Resources



Thermal Maturity

USGS Open File Report 2005 – 1268, Milici, Robert F., 2005

US Geological Survey Open File Report 82-474

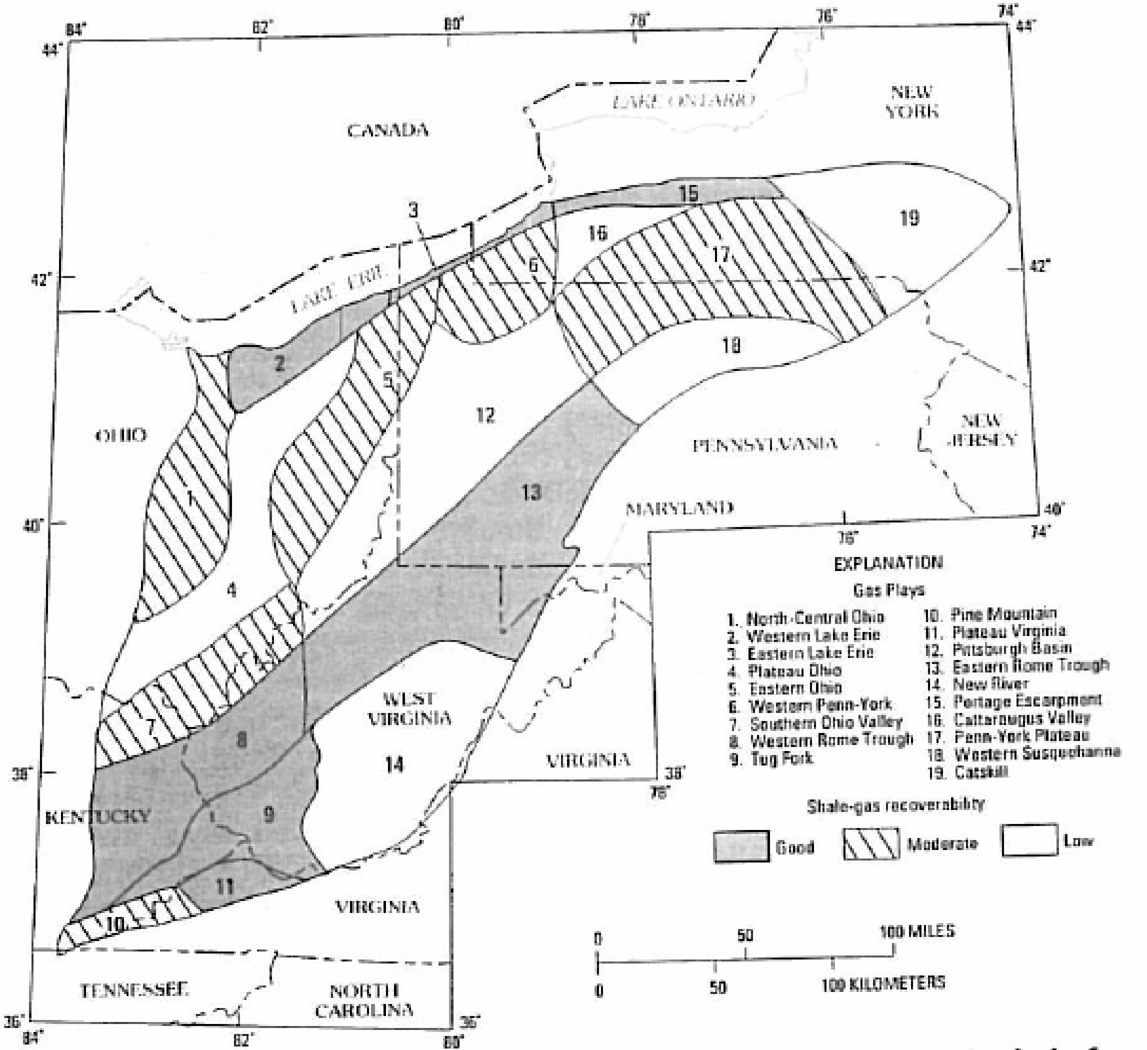


Figure UDs-33. Location of sub-plays within the Devonian black shale for which resource estimates were provided by Charpentier and others (1993).

Estimates of Unconventional Natural Gas Resources of the Devonian Shale of the Appalachian Basin - USGS 82-474

- Pittsburgh Basin
  - – Rhinestreet, Geneseo, and Marcellus present
  - – Gas shales from 5,000 – 7,500 feet
  - – Total thickness from 300 – 500 feet
  - – TOC ranging from 4 – 6 % by weight of shale
  - – CAI – moderate to moderately high at 2.0
  - – Fracturing not wide scale
  - – USGS said this basin had <u>poor potential</u>

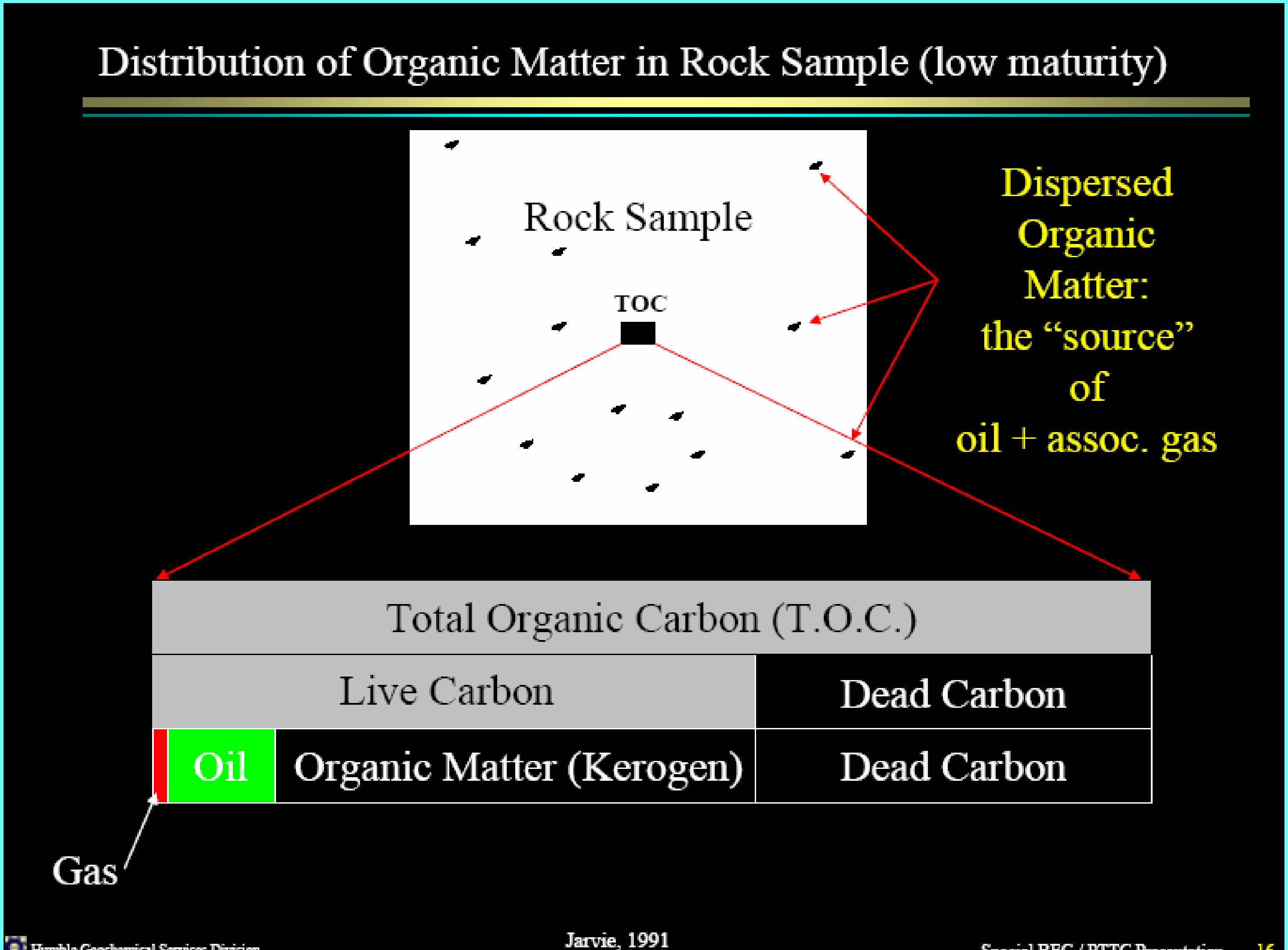

M O N O N G A H E L A C O

Filled Vertical Fracture in Monongahela County, WV core @ 7,460 feet

Ingredients for Commercial Shale Gas Play

- ✓ Organic content cooked to temperature
- ✓ Permeability in the form of nature fractures
- ✓ Thick net pay
- ✓ Pressure is always a plus
- ✓ Sealed off above and below
- ✓ Widespread distribution of shale

T.O.C. – What is it?



Thermal Maturation

TAI = Thermal Alteration Index

Various TAI Standards

Amoco

TAI	HC
1	Immature
2	Immature
3	Immature
3+	Immature
4	Oil
4+	Oil
5	Oil
5+	Cond.
6	Gas
6+	Gas
7	Over Mature

Core Lab

TAI	HC
<1+	Immature
1+/2	Immature
2	Immature
2/2+	Oil
2+	Oil
2+/3	Oil
3	Oil
3/3+	Oil
3+	Oil
3+/4	Oil
4	Cond.
5	Over Mature

NPL

TAI	HC
1	Immature
2	Oil
3	Oil
4	Gas
5	Over Mature

Robertson

TAI	HC
1	Immature
2	Immature
3	Immature
4	Oil
5	Oil
6	Oil
7	Gas
8	Gas
9	Over Mature
10	

Humble

TAI	HC
1	Immature
1+	Immature
2	Immature
2+	Oil
3	Oil
3+	Oil
4	Oil
4+	Gas
5	Gas
5+	Over Mature

Note the variability in the hydrocarbon window detail
and the numbering system (i.e. Amoco 5 = Oil; Core Lab 5 = Over Mature).

Relationship of TOC and Porosity to Formation Density

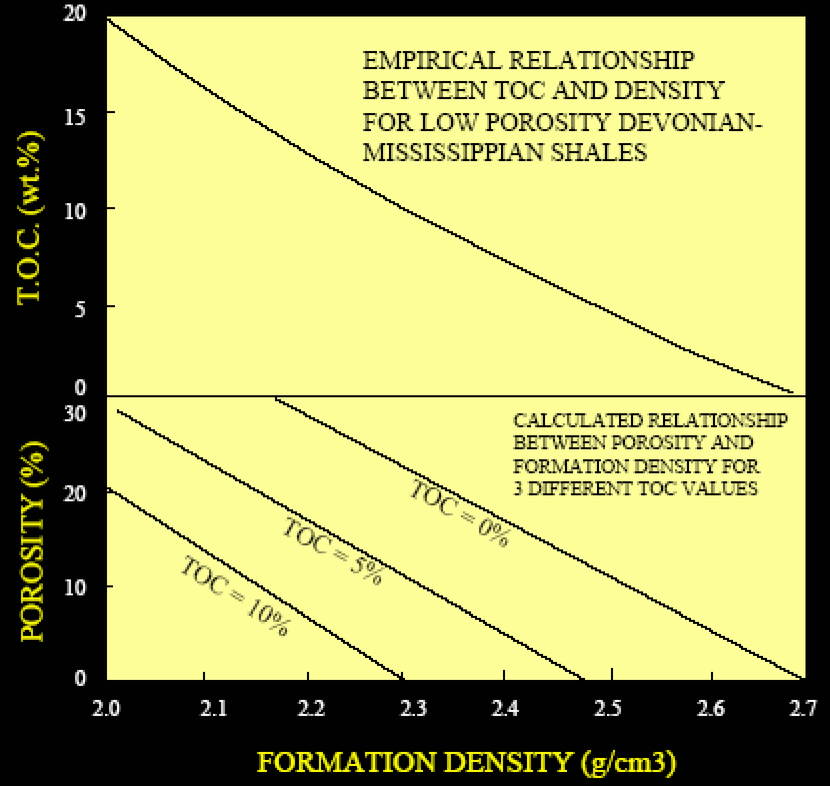


TABLE 1
RELATIVE SOURCE ROCK RATING OF DEVONIAN SHALES

Organic Carbon Content (percent)	THERMAL ALTERATION INDEX 1+ to 2	2 to 3	3 – 4	4 – 5
0–1	0	0	0	0
1–2	1	1	2	0
2–3	1	2	4	0
3–4	2	4	7	0
4+	2	6	10	0

0 - Little Potential

1 - Good Gas Potential only if organic matter is Tasmanites or Marine

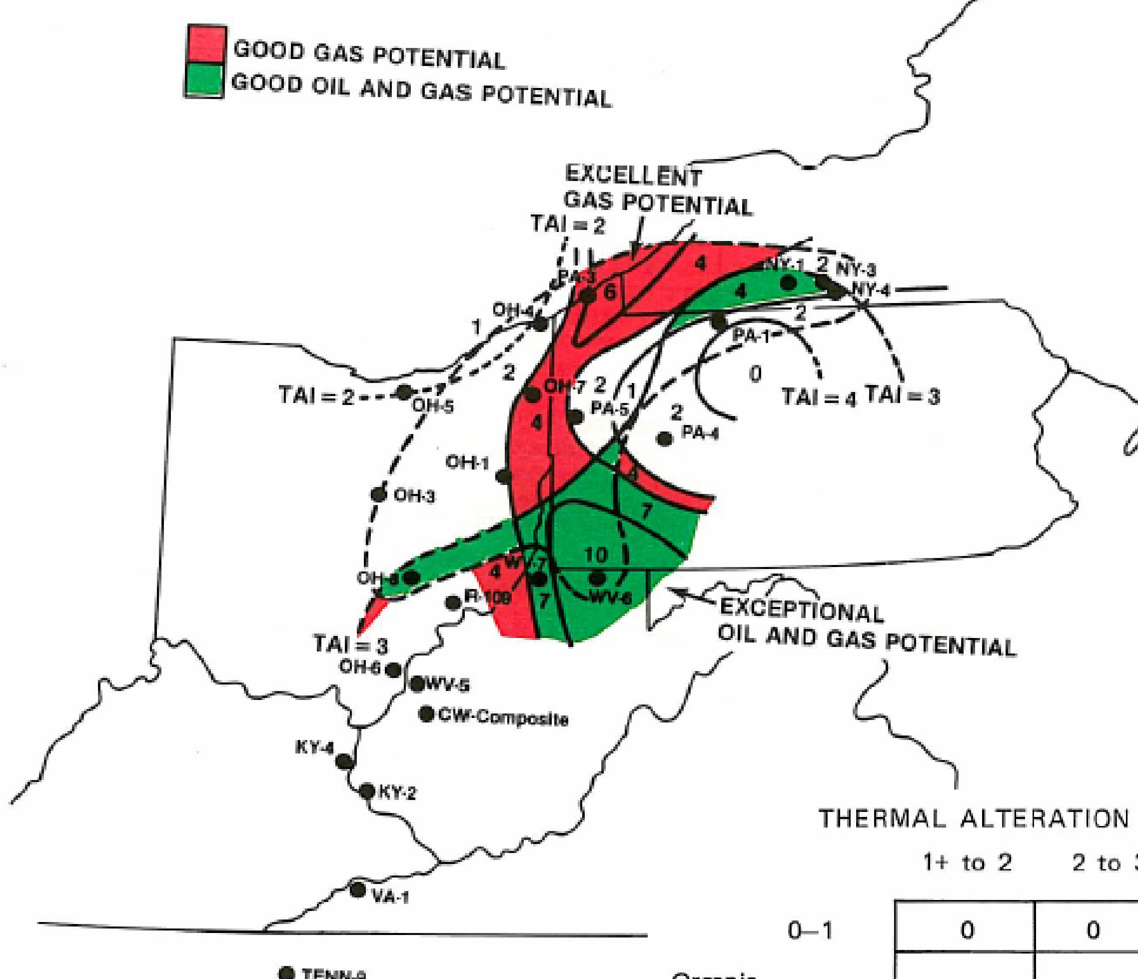
2 - Excellent Gas Potential if OM is Tasmanites or Marine; Good Gas Potential if OM is Terrestrial

4 - Good Oil and Gas Potential if OM is Tasmanites or Marine; Good Gas Potential if OM is Terrestrial

6-7 - Excellent Oil and Gas Potential if OM is Tasmanites or Marine; Good Oil and Gas Potential if OM is Terrestrial

10 - Exceptional Oil and Gas Potential

Resource and Exploration Assessment of the Oil and Gas Potential in The Devonian Gas Shales of the Appalachian Basin, DOE/DP/0053-1125



THERMAL ALTERATION INDEX

Organic Carbon Content (percent)	1+ to 2	2 to 3	3 – 4	4 – 5
0–1	0	0	0	0
1–2	1	1	2	0
2–3	1	2	4	0
3–4	2	4	7	0
4+	2	6	10	0

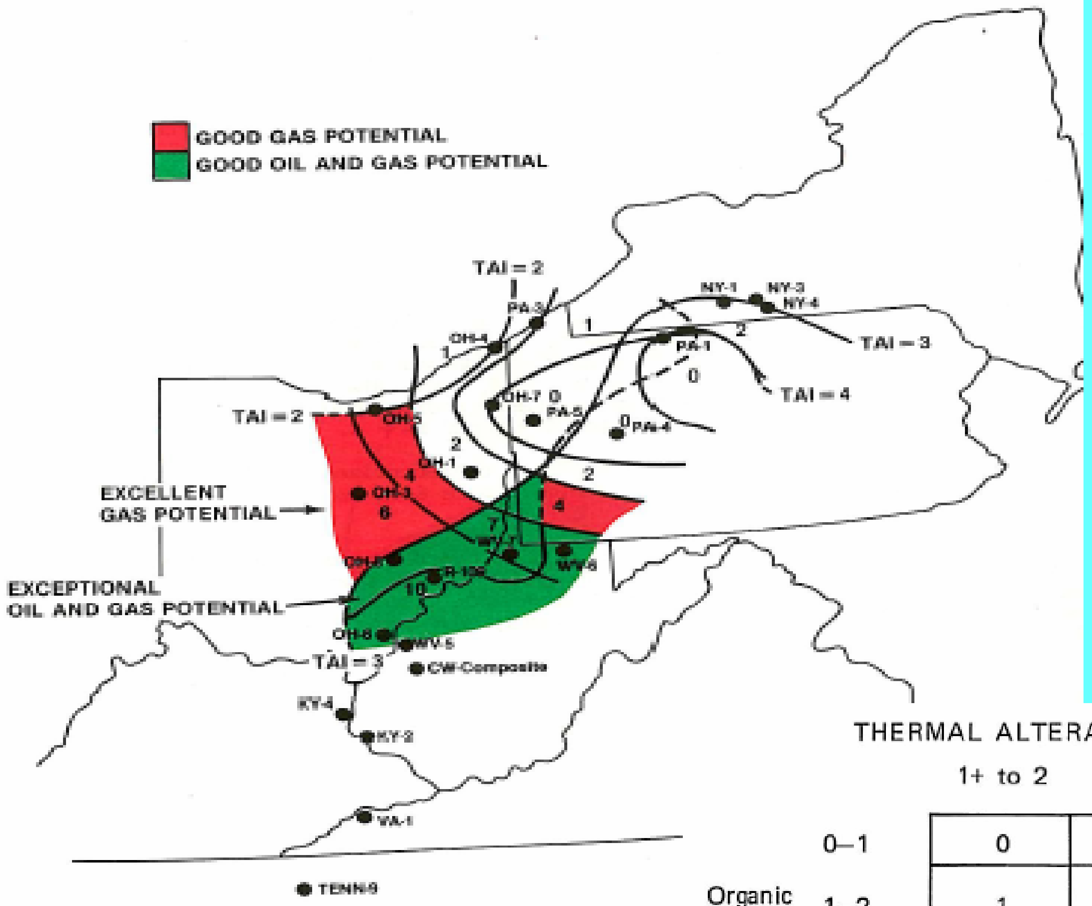
FIGURE 56

EARLY MARCELLUS TIME

MAP UNIT 1

Resource and Exploration Assessment of the Oil and Gas Potential in The Devonian Gas Shales of the Appalachian Basin, DOE/DP/0053-1125

OIL AND GAS SOURCE ROCK POTENTIAL



THERMAL ALTERATION INDEX

Organic Carbon Content (percent)		1+ to 2	2 to 3	3 – 4	4 – 5
	0–1	0	0	0	0
	1–2	1	1	2	0
	2–3	1	2	4	0
	3–4	2	4	7	0
	4+	2	6	10	0

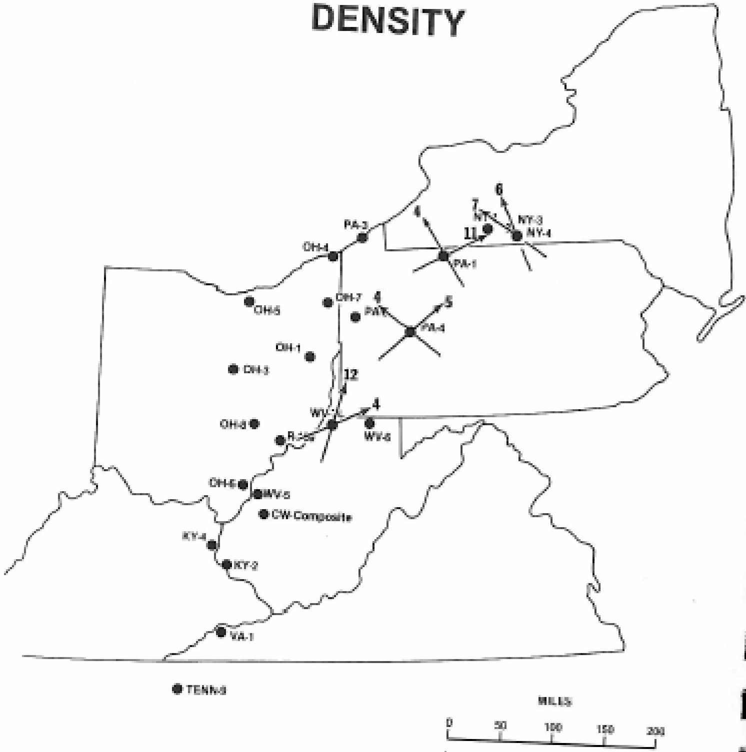
FIGURE 57

LATE MARCELLU

MAP UNIT 2

Resource and Exploration Assessment of the Oil and Gas Potential in The Devonian Gas Shales of the Appalachian Basin, DOE/DP/0053-1125

FRACTURE ORIENTATION AND DENSITY



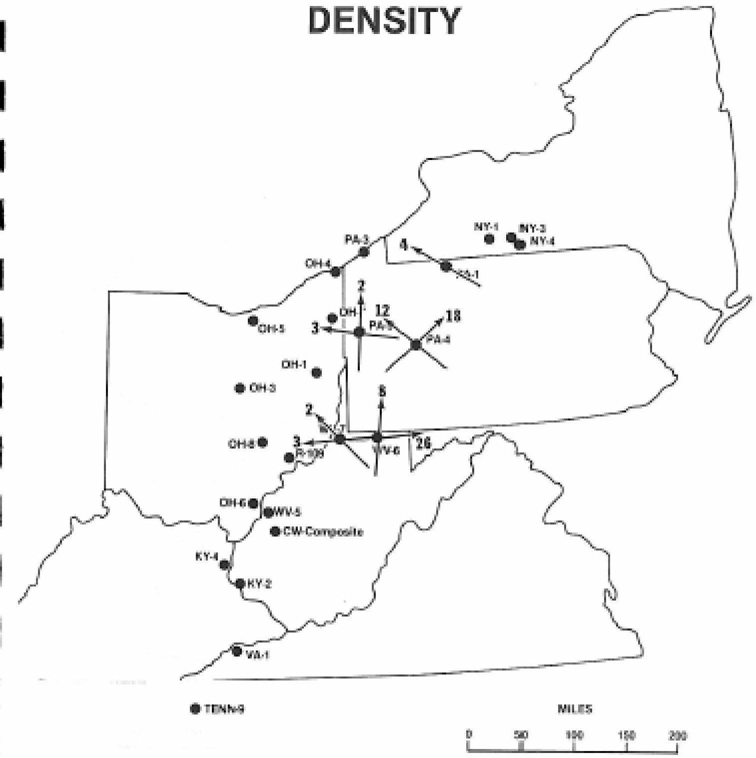
MARCELLUS TIME

Map Units 1 & 2

FIGURE 192

Prepared by Mound Facility

FRACTURE ORIENTATION AND DENSITY



HAMILTON GROUP/POST MARCELLUS TIME

Map Unit 3

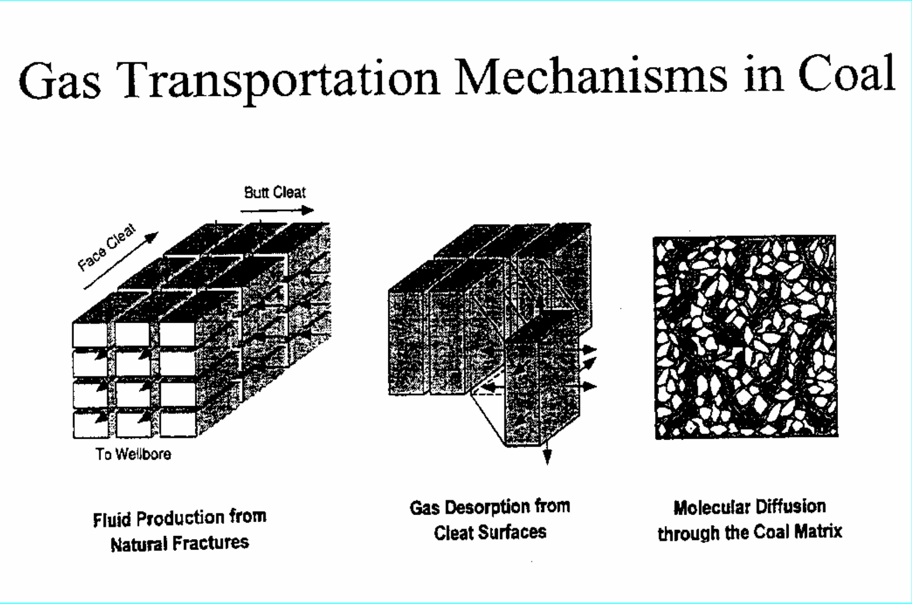
FIGURE 193

Prepared by Mound Facility

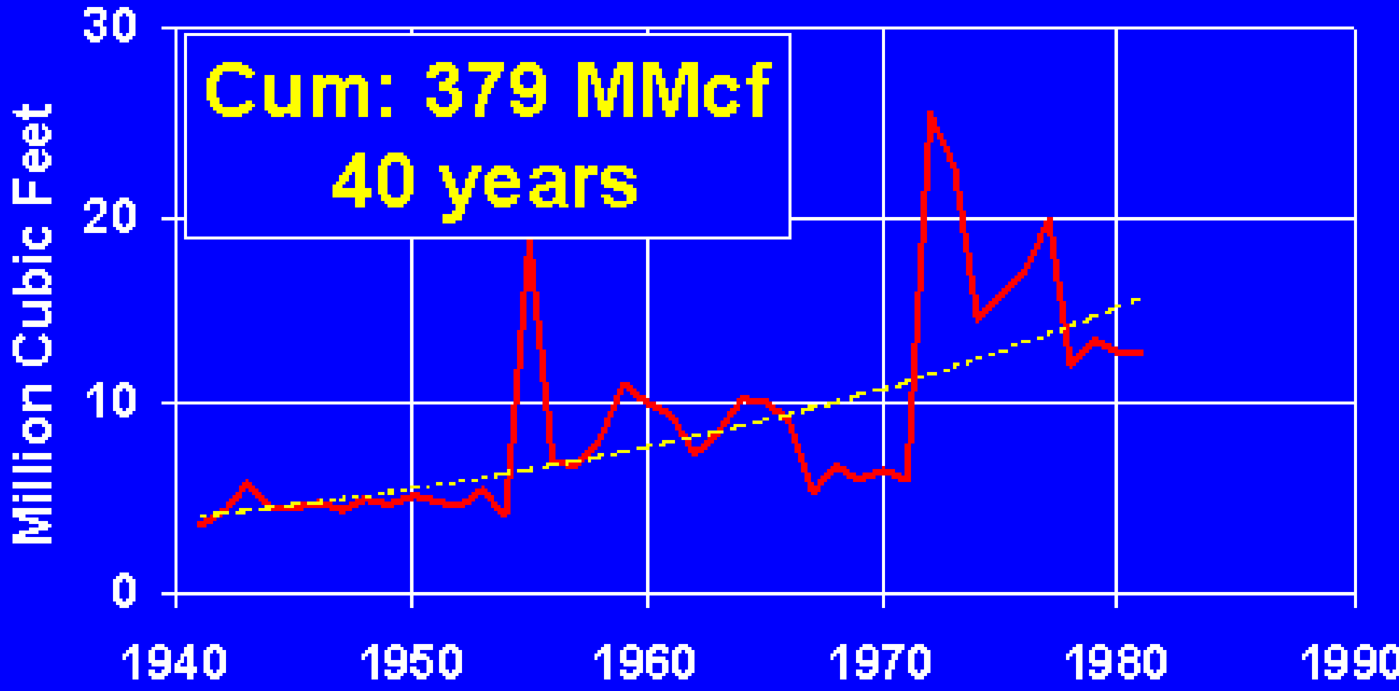
Resource and Exploration Assessment of the Oil and Gas Potential in The Devonian Gas Shales of the Appalachian Basin, DOE/DP/0053-1125

Black Shale (CBM) Production Mechanisms

- Production occurs via pressure depletion, free gas in natural fractures first (easiest)
- Primary flow through fracture system
- Matrix supplies fracture



Production Incline Suggests Adsorbed Gas



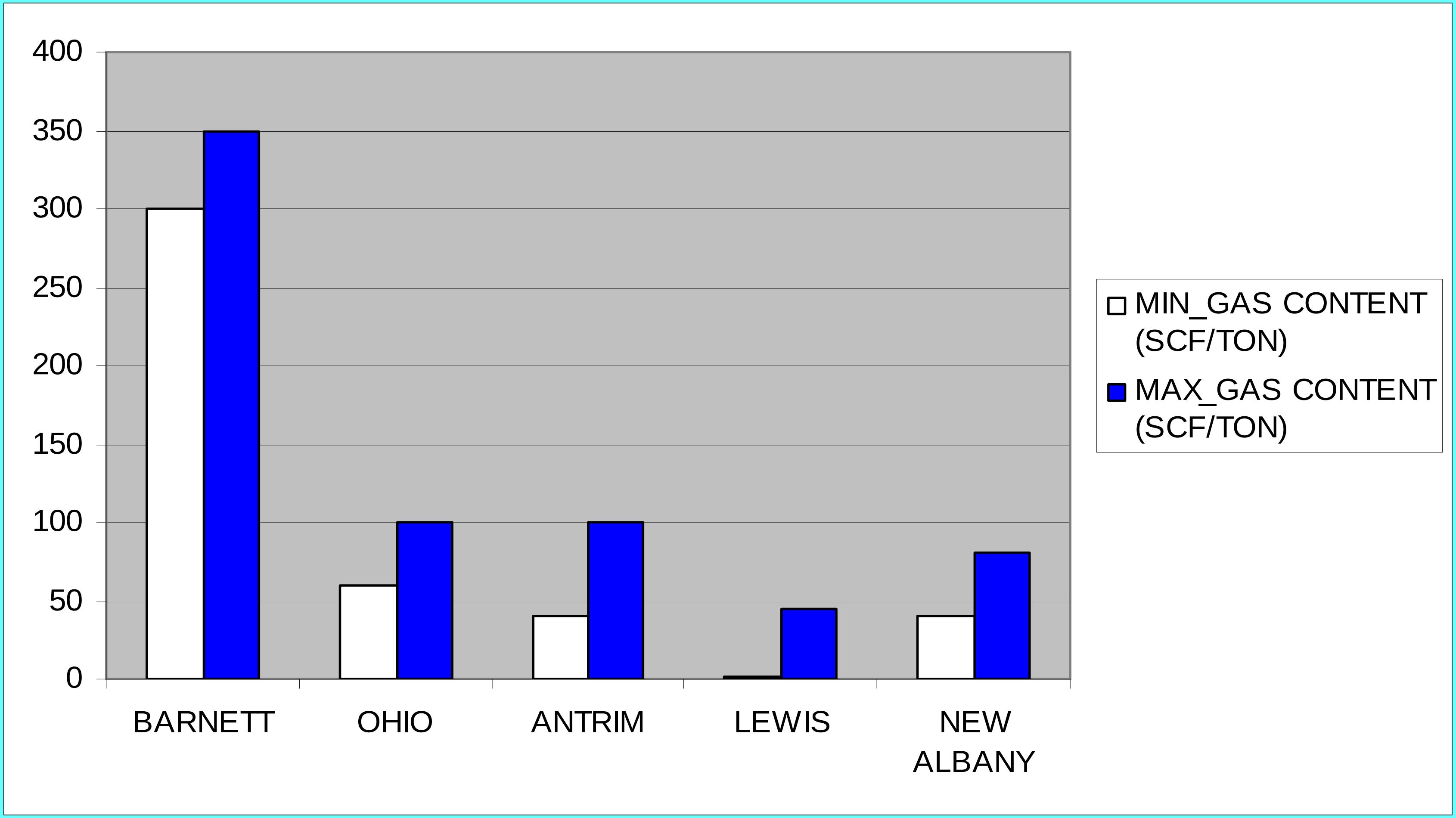
Eastern Kentucky Devonian Shale Gas Production

KGS

SPE 106070
"Stimulation of Gas Shales: They're All the Same – Right?"

- Shale reservoirs are a classic example of one size does not fit all.
- Optimum fluid type and volume, pump rate, proppant type and amount can vary by field in the same basin

Variability: Gas Content
*p*V = *n*RT



In Appalachia We Have More Than Marcellus

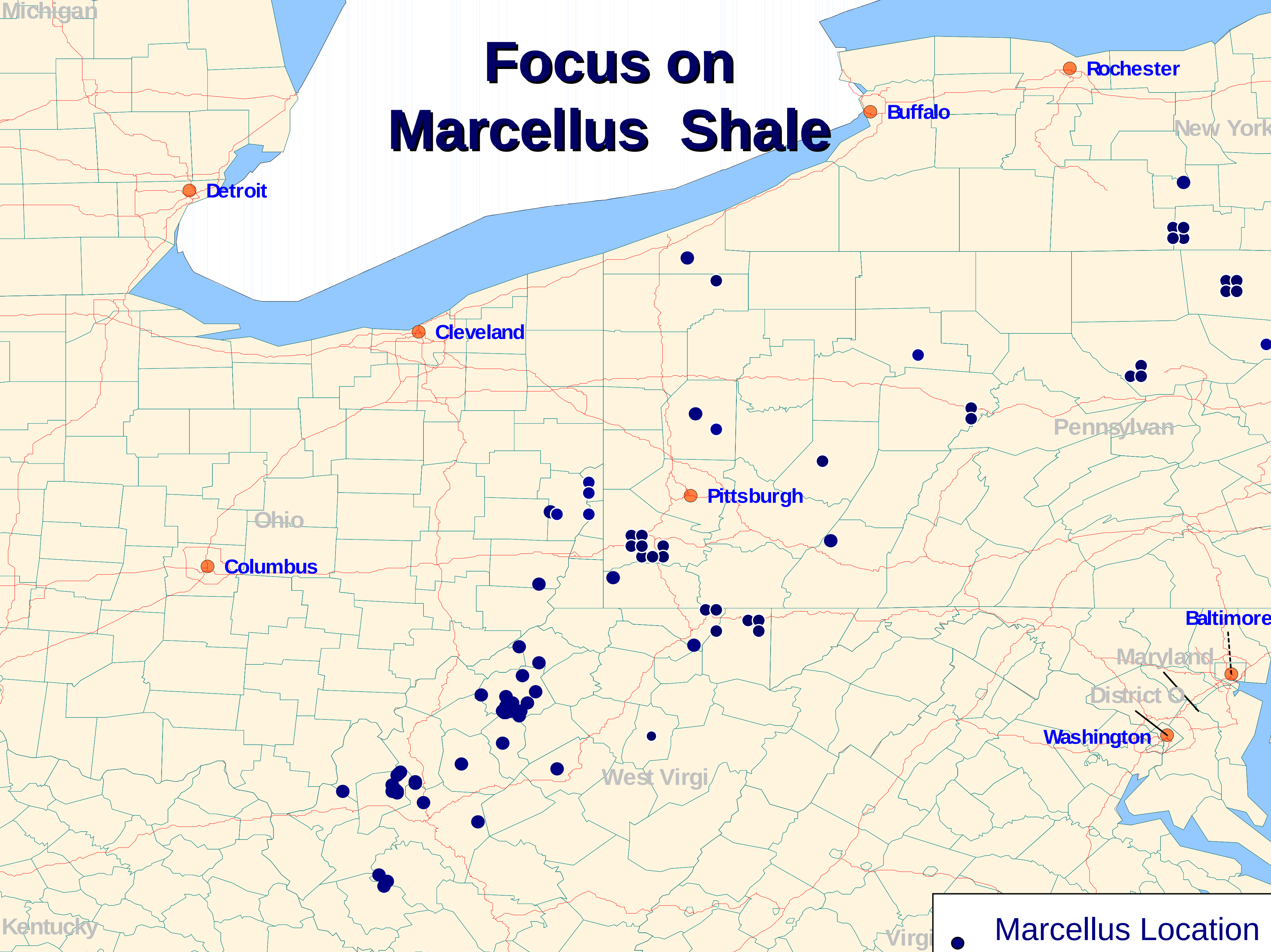
- Late Rhinestreet
- Early Rhinestreet
- Sonyea/Middlesex
- Genesee
- Hamilton Group/Post-Marcellus
- Late Marcellus
- Early Marcellus

Current Focus on Marcellus Shale

- Range Resources 2007 Press Release:
  – "Our Appalachian shale project is progressing with 410,000 net acres currently under lease. In 2006, the Company drilled 12 vertical wells and three horizontal wells to test commerciality of the play. In 2007, drilling continues with 60 vertical and eight horizontal wells planned. To support our shale expansion effort, Range has opened an office in Pittsburgh, Pennsylvania."

FORT WORTH, TEXAS, FEBRUARY 26, 2007…RANGE RESOURCES CORPORATION (NYSE: RRC)

Focus on Marcellus Shale



Current Frac Operations

- Two very different main design schemes
  - Large to massive slickwater jobs with large volumes of sand
  - Normal to moderately larger straight nitrogen (circa. 1980) or nitrogen foam jobs with moderate amounts of sand

Current Frac Concerns

- Equipment requirements/logistics
  - Toward large slickwater jobs
    - Rates: 30 – 100 bpm
    - Sand: 2,000 – 5,000 sks
    - HHP: 8,000 – 15,000
  - Large foam jobs horizontal wells
    - Nitrogen: 5 – 10 MMSCF
    - Sand: 2,000 – 5,000 sks

Current Frac Concerns: Containment or Frac Height Control

Barnett Shale

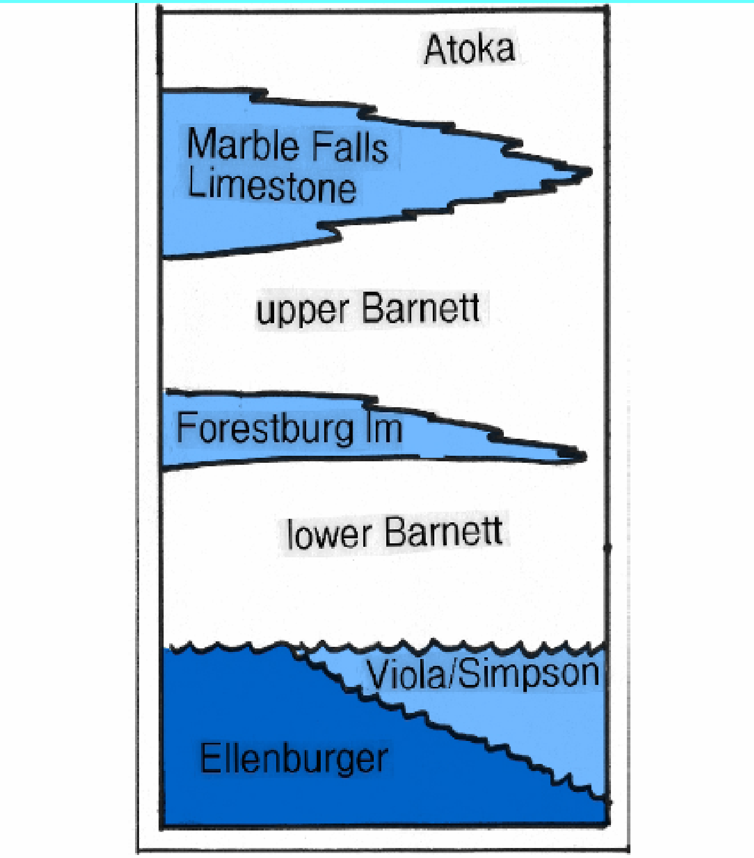
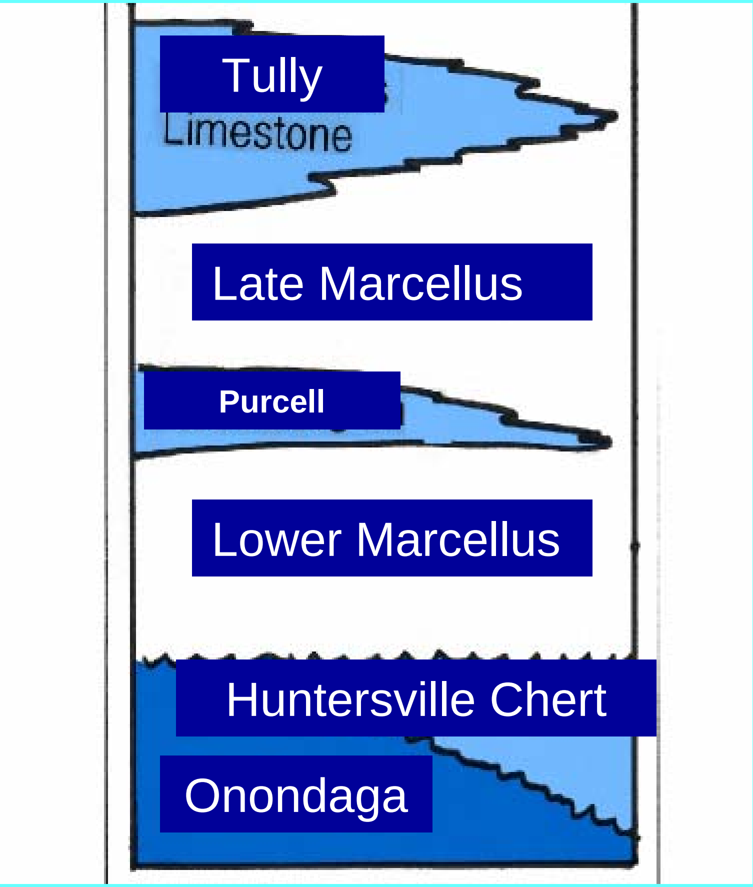


Figure 5. A section of the stratigraphic column in the northern portion of the Fort Worth basin.

Marcellus Shale

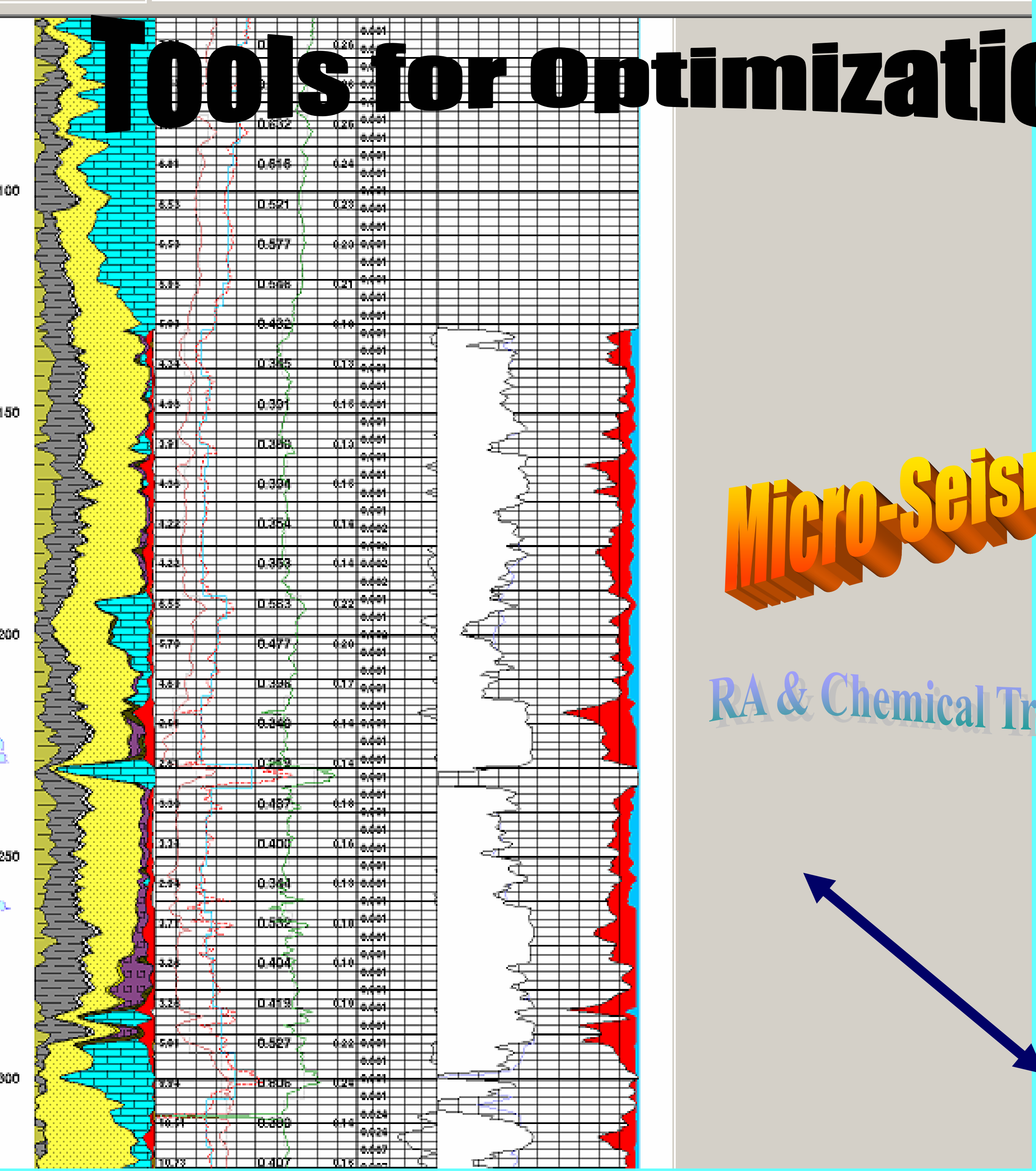


Development of the Barnett Shale Play, Ft. Worth Basin, Bowker, Kent A., Search and Discovery Article #10126, 2007

Current Frac Concerns

- True in-situ stresses in Marcellus, Onondaga, and Tully
  - Controls fracture height growth
  - Determines horsepower requirements
- Rock properties, E and μ
  - Determine fracture width
  - Dictates maximum sand concentration and average sand size
- Maximize Stimulated Reservoir Volume
  - Hydraulic fracture fairway $ optimized

Tools for Optimization



Lithologies

Mechanical Properties

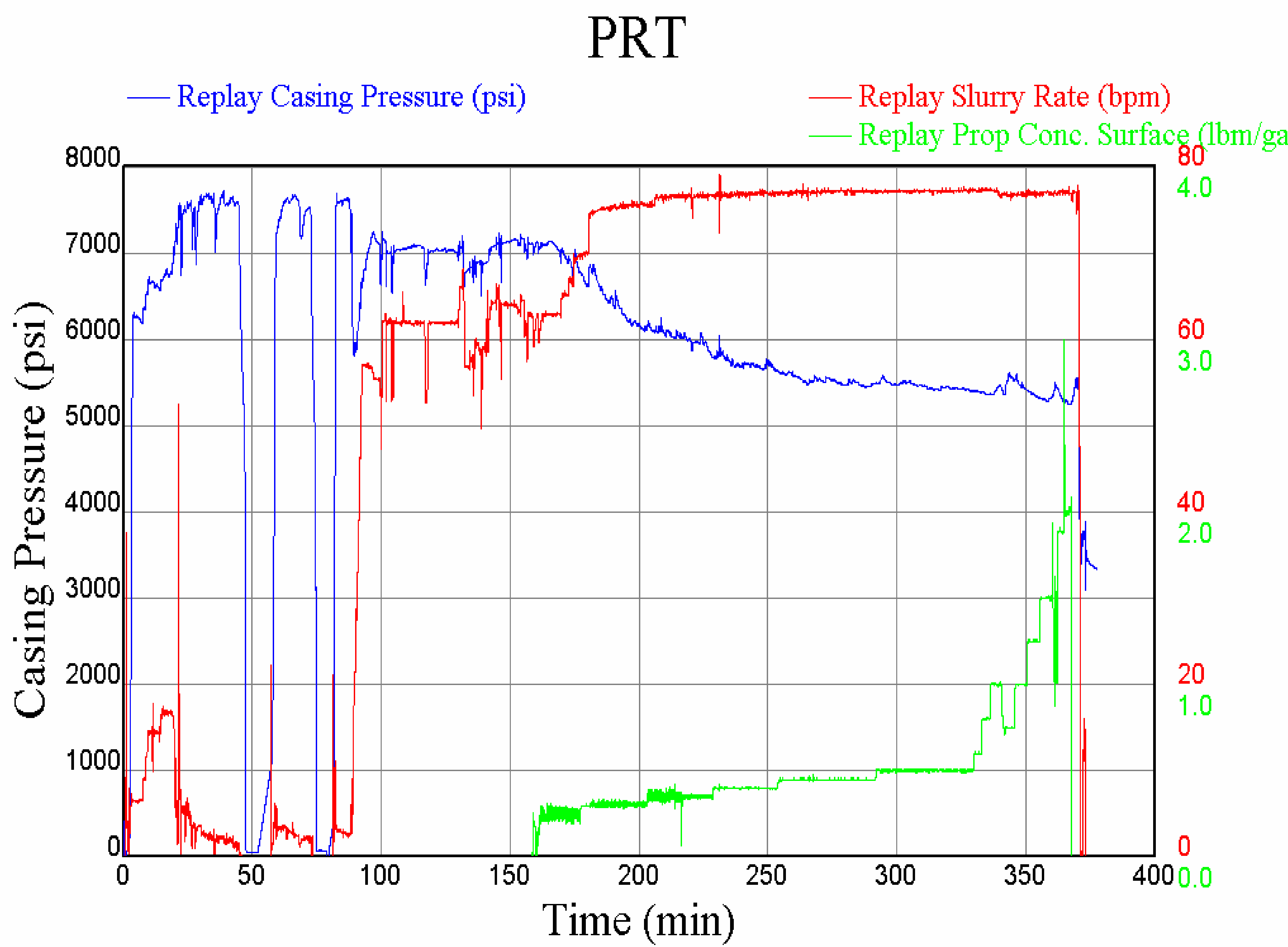
Micro-Seismic

Realtime Analyses

3D Modeling

RA & Chemical Tracers

"? ?"


PRT
Replay Casing Pressure (psi)
Replay Slurry Rate (bpm)
Replay Prop Conc. Surface (lbm/ga
Casing Pressure (psi)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
350
400
80
60
40
20
0
4.0
3.0
2.0
1.0
0.0
Time (min)

Current Frac Concerns

- Horizontal wells
  - Open hole completions
    - Number of stages
    - How to mechanically separate stages
  - Cemented hole completions
    - Acid soluble cement
    - How to mechanically separate stages
    - Overcoming fracture initiation problems

Current Frac Concerns

- Overcoming fracture initiation problems in cemented horizontal wellbores
  - Why problems in the first place
    - Stress anisotropy common to layered shales
  - Strategies to minimize fracture initiation psi
    - 0º/180º or 60º phasing (SPE 103232)
    - Sand notching
    - HCl acid
    - Viscous plugs
    - Plugs with sand slugs
    - Reperforate and try again

Future of Marcellus Shale

- More horizontal wells (2x $, 3x Q)
- Explore new areas WV, OH, PA, & NY
- Accelerated growth will stress current infrastructure for services (short term)
- Real deal or big hype?
  - Production data unavailable
  - Some claiming 0.6 – 1.0 BCF per well

CO2: The Other Gas

- Soluble in water, stays with flowback water longer, enabling higher % recovery, if you have low BHP
- Demonstrated better IP in refrac test following straight N2 frac in Wayne County, WV
- CO_2 showing good results in Conasauga shale in Alabama
- Infrastructure exists in NE where in past 20+ years it has not

Paired Simultaneous Fracturing "Simo-Frac"

- Two HZ wells fraced simultaneously
  - 2 wells 30' apart on a pad
  - Roughly parallel HZ trajectories +/- 1000' apart @ toe
  - Simultaneous fracs (4 stgs in one and 5 in the other to prevent communication between fairways
  - Significantly higher MCFD than individually fraced offsets – record MCF for Barnett HZ
  - To date, 5 well pairs treated in this manner

Thank You – Questions?