Marcellus Shale - Geologic Considerations for an Evolving North American Liquids-Rich Play*

Bill Zagorski[1]

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*Adapted from presentation at the first AAPG DPA Playmaker Forum, "From Prospect to Discovery," January 24, 2013, Houston, Texas.
Editor's note: Please refer to related articles by the author and colleagues:
"Appalachian Basin Unconventional Reservoirs - A Discussion of Past, Present and Future Play Trends," Search and Discovery Article #80414 (2014).
"Marcellus Shale - Geologic Considerations for an Evolving North American Liquids-Rich Play," Search and Discovery Article #10166 (2013).
"An overview of Some Key Factors Controlling Well Productivity in Core Areas of the Appalachian Basin Marcellus Shale Play," Search and Discovery Article #110147 (2011).
"The Appalachian Marcellus Shale Play - Discovery Thinking, Timing and Technology," Search and Discovery Article #110138 (2010).

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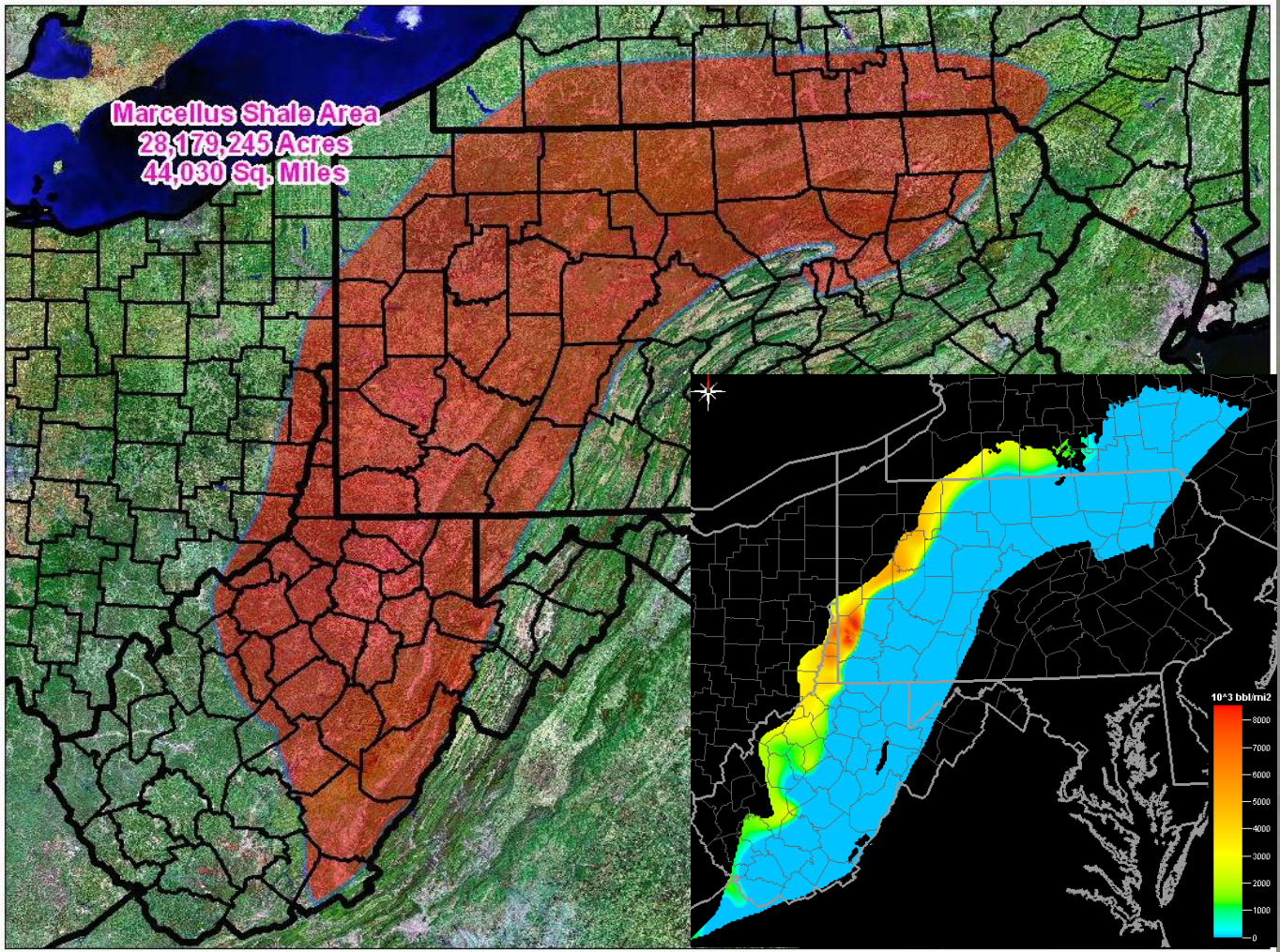
Abstract

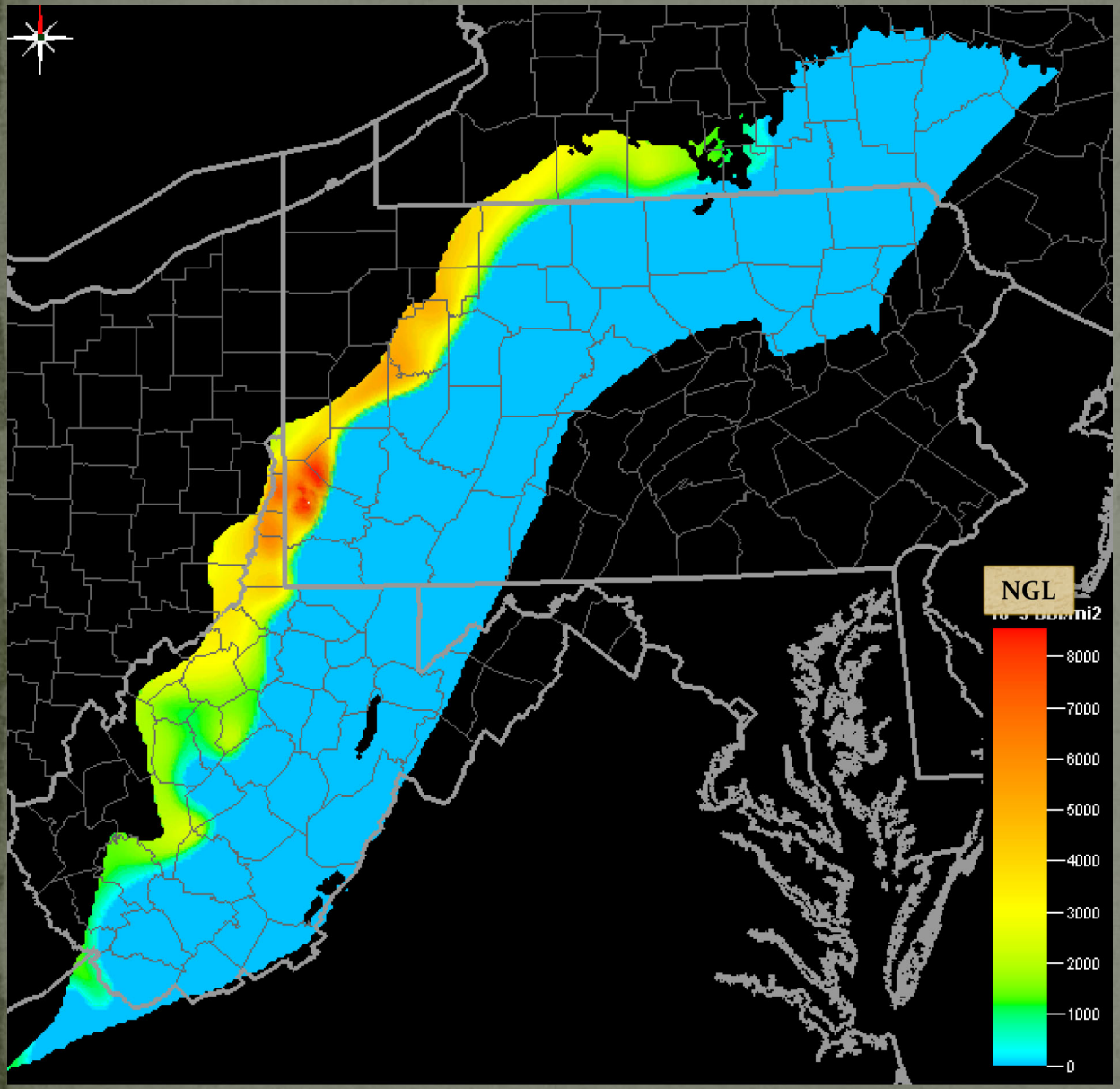
It is my intent in this presentation to cover the history and evolution of the Marcellus liquids rich play in SW PA, provide some regional perspectives on its unique geologic characteristics and compare it to other portions of the Marcellus play and other US liquids rich plays. I also will cover the importance of landing target selection and provide examples of various reservoir evaluation techniques and technologies used in the characterization and development of this play including 3D seismic, micro seismic, core data, and most recently FIB SEM analysis.

Marcellus Shale – Geologic Considerations for an Evolving North American Liquids –Rich Play



AAPG Playmakers Forum – January 24, 2013
William A. Zagorski – Vice President – Geology
Range Resources Corporation - SMSD

Regional Extent Marcellus Liquids Rich Play



Liquids-rich portion of play in SW PA discovered in 2006 and 2007. Play in full development now.

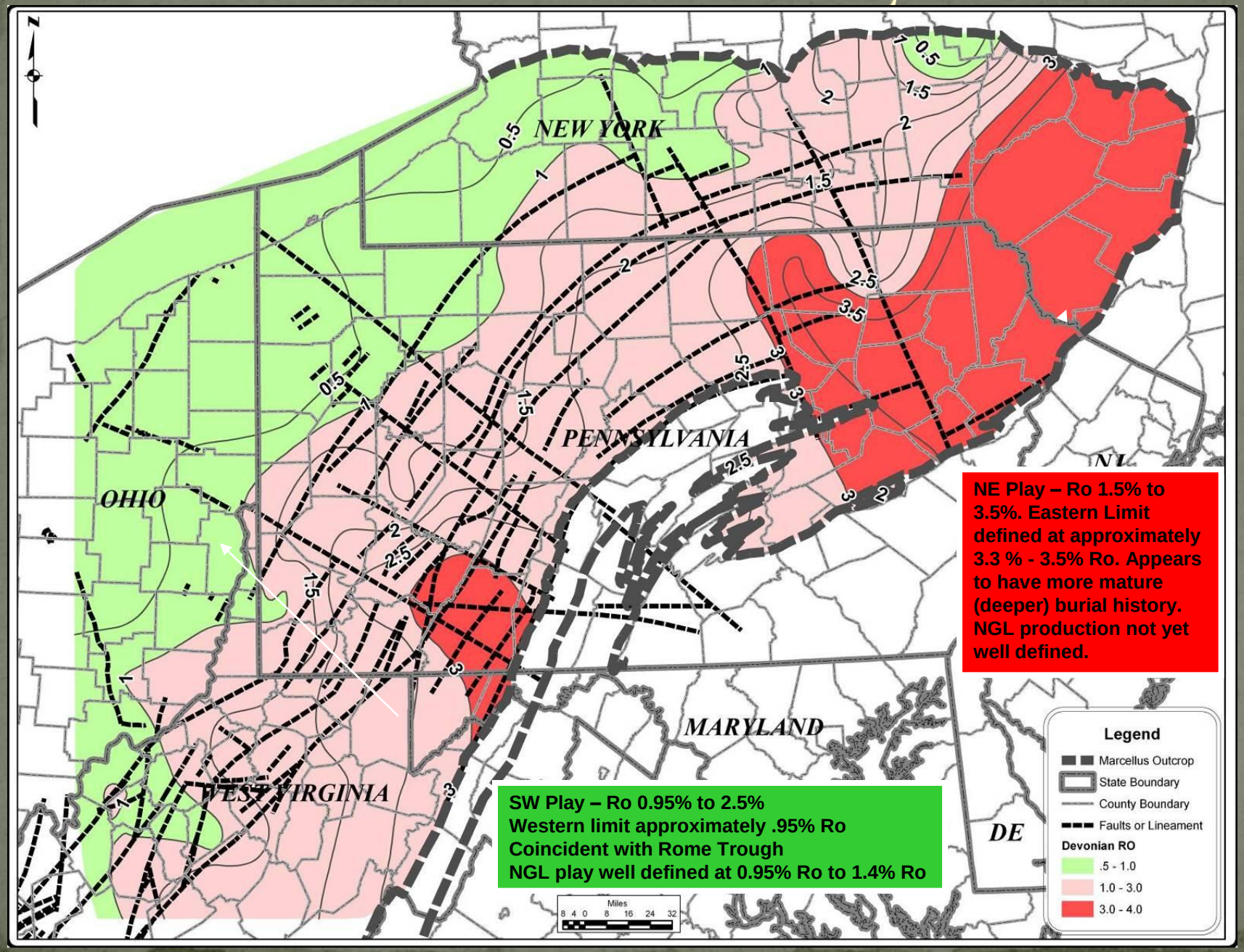
Initial results and potential not immediately evident.

Proved/de-risked portion of play under development in SW PA, northern WV and WV Panhandle.

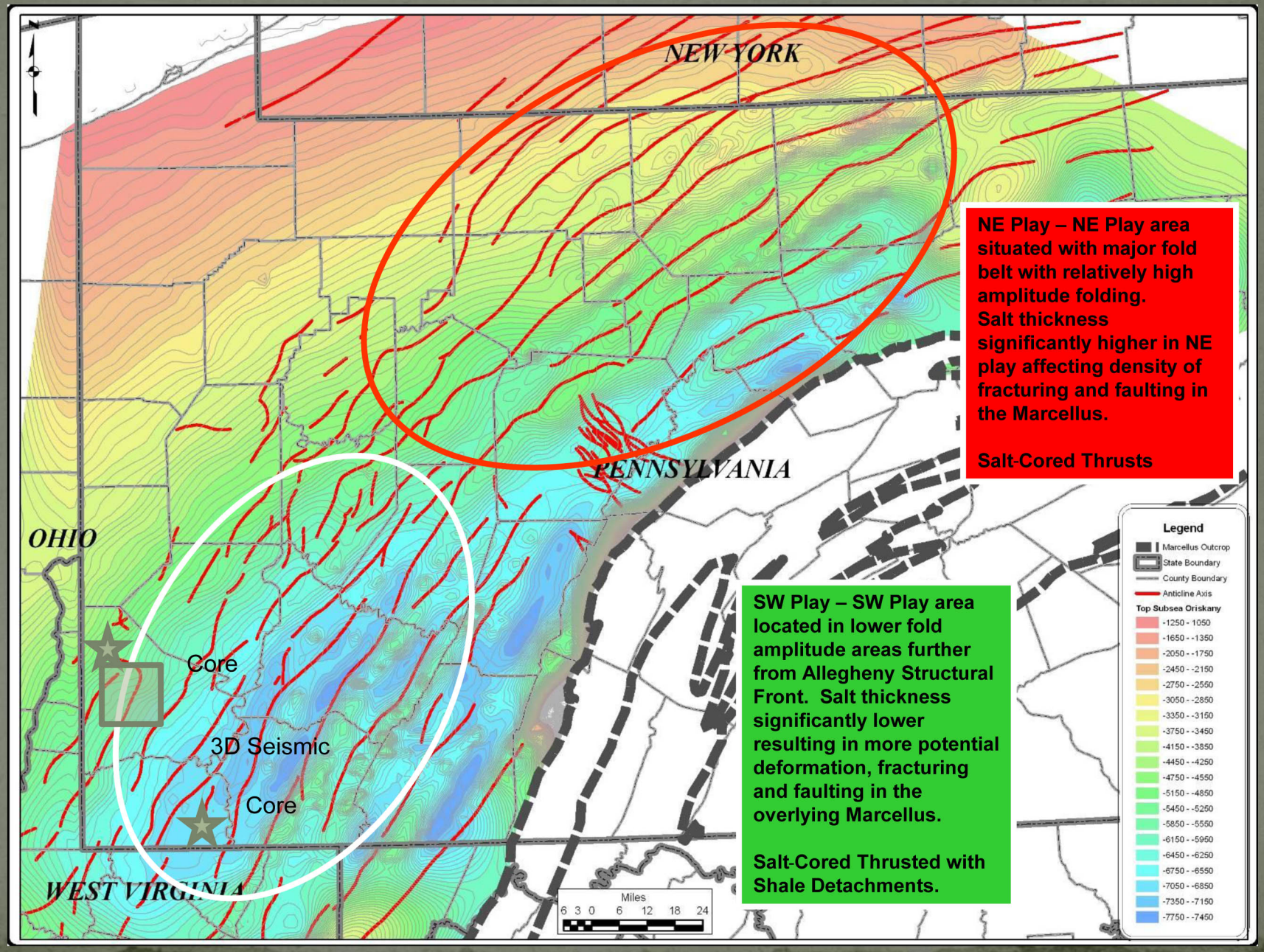
Northern PA still unexplored and problematic thus far.

NY political climate prohibited testing there.

Marcellus Thermal Maturity Patterns

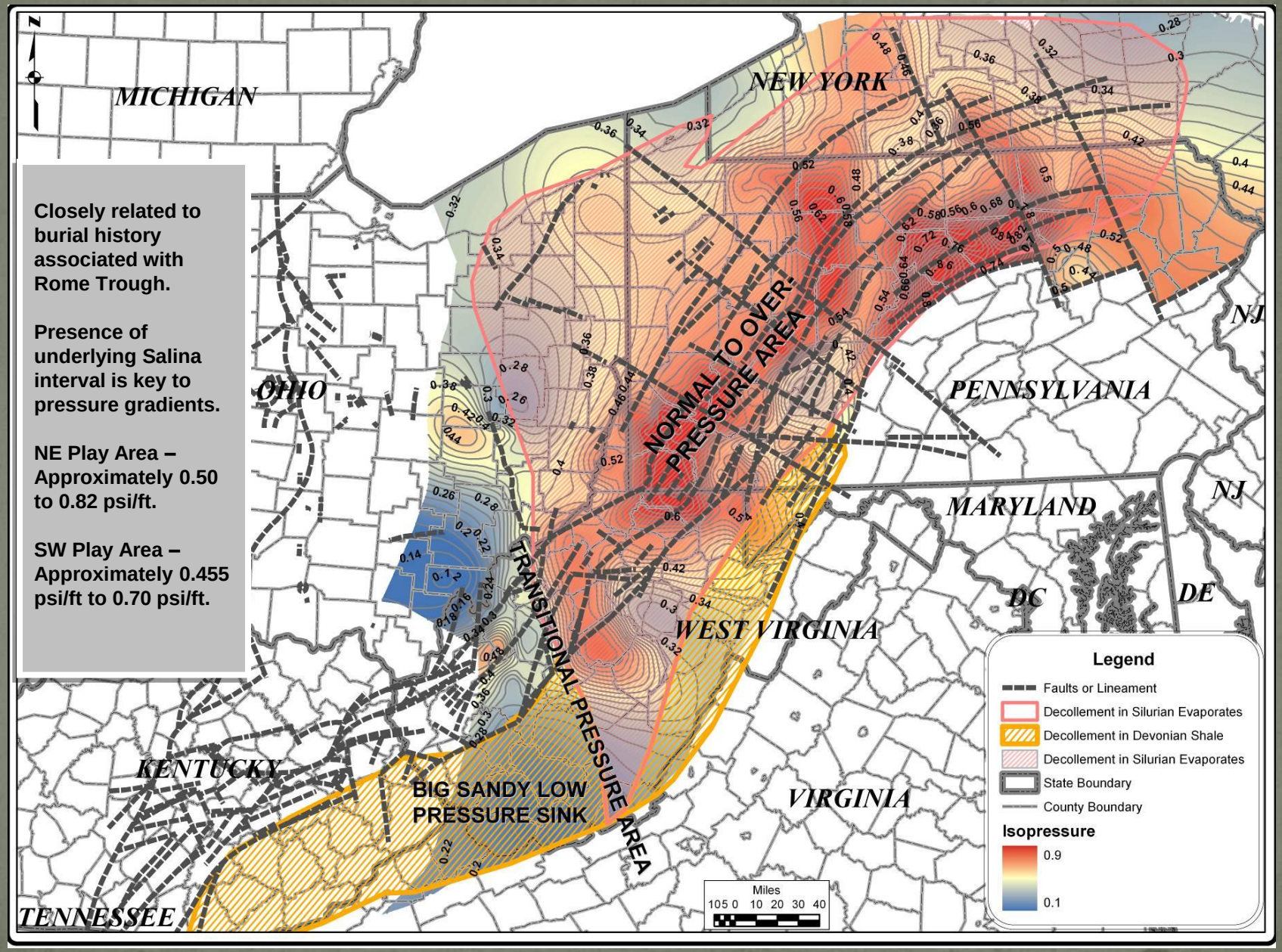


Regional Oriskany Structure * Major Fold Trends



Modified from Cate (1961)

Regional Pressure Trends – Marcellus Shale



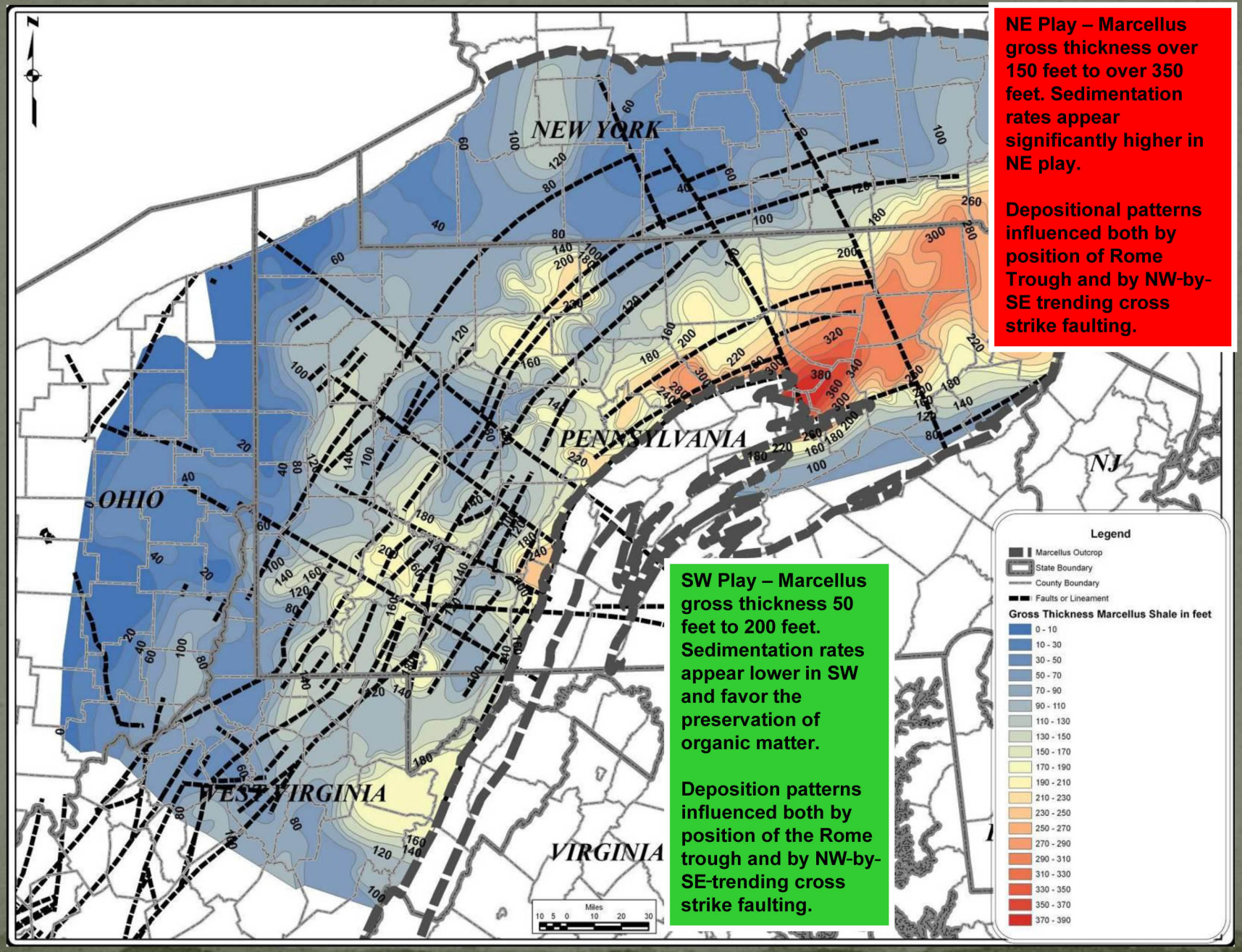
Closely related to burial history associated with Rome Trough.

Presence of underlying Salina interval is key to pressure gradients.

NE Play Area – Approximately 0.50 to 0.82 psi/ft.

SW Play Area – Approximately 0.455 psi/ft to 0.70 psi/ft.

Marcellus Shale Gross Thickness



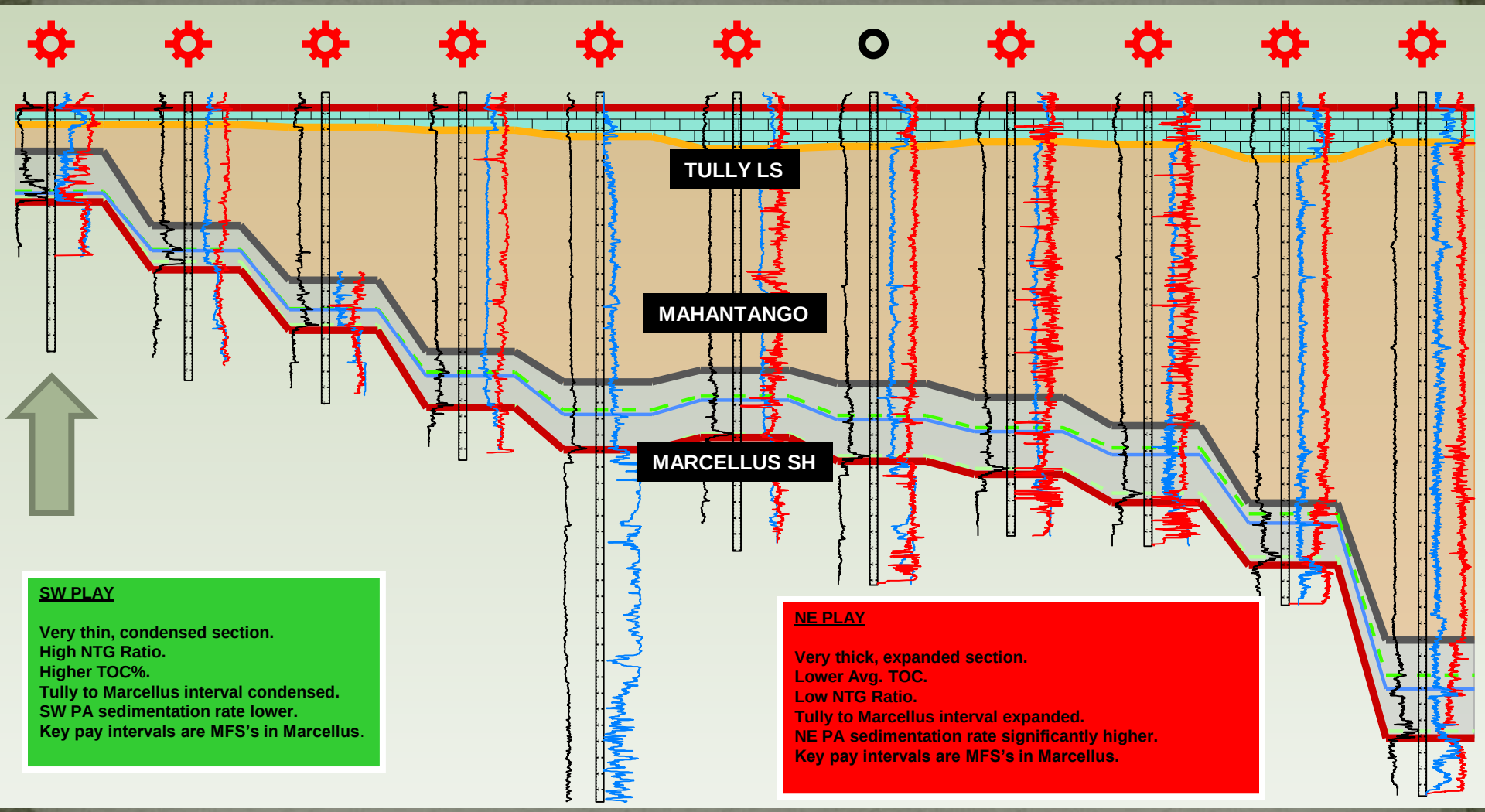
NE Play – Marcellus gross thickness over 150 feet to over 350 feet. Sedimentation rates appear significantly higher in NE play.

Depositional patterns influenced both by position of Rome Trough and by NW-by-SE trending cross strike faulting.

SW Play – Marcellus gross thickness 50 feet to 200 feet. Sedimentation rates appear lower in SW and favor the preservation of organic matter.

Deposition patterns influenced both by position of the Rome trough and by NW-by-SE-trending cross strike faulting.

Regional Stratigraphic Cross-Section



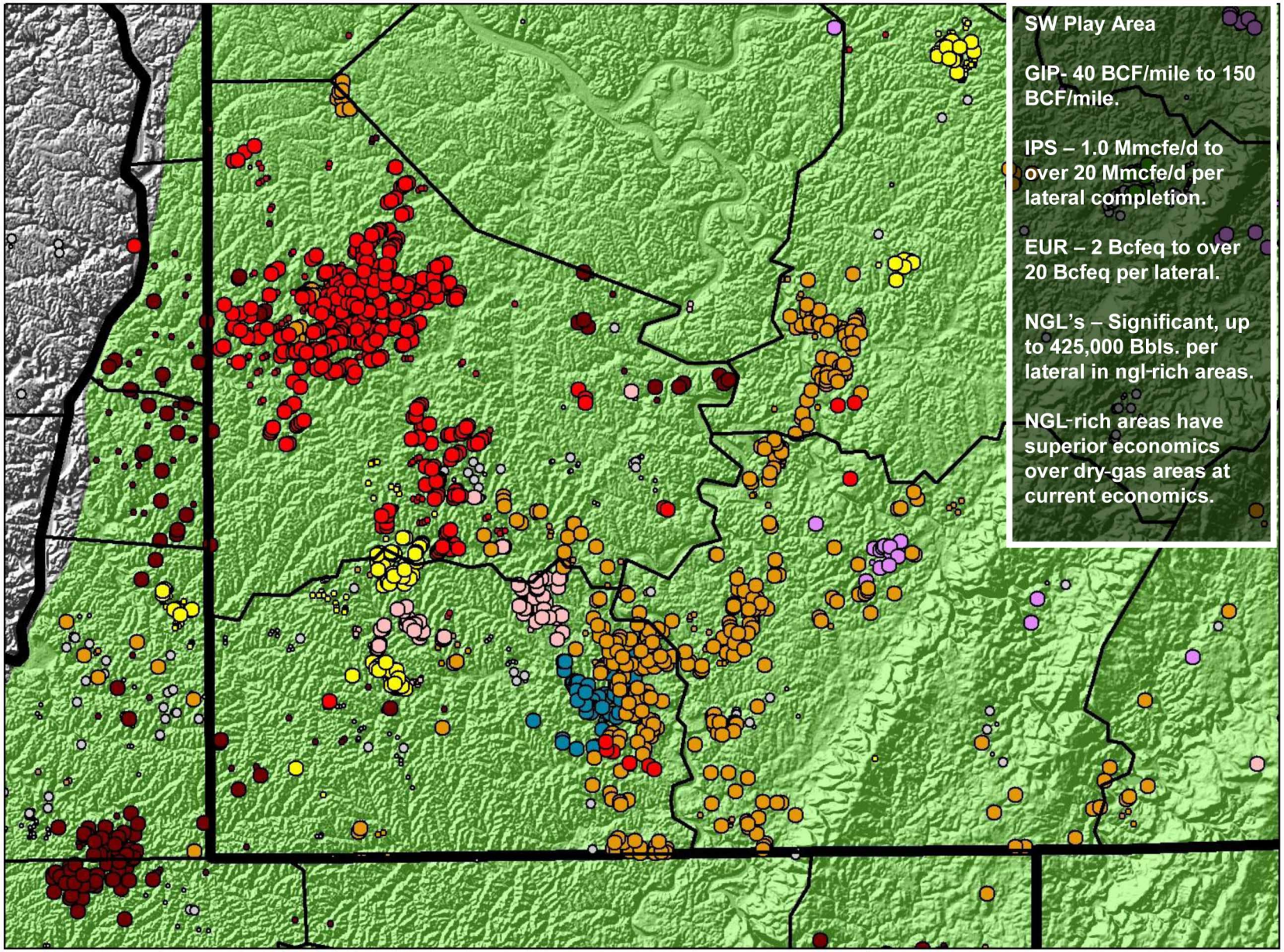
SW PLAY

Very thin, condensed section.
High NTG Ratio.
Higher TOC%.
Tully to Marcellus interval condensed.
SW PA sedimentation rate lower.
Key pay intervals are MFS's in Marcellus.

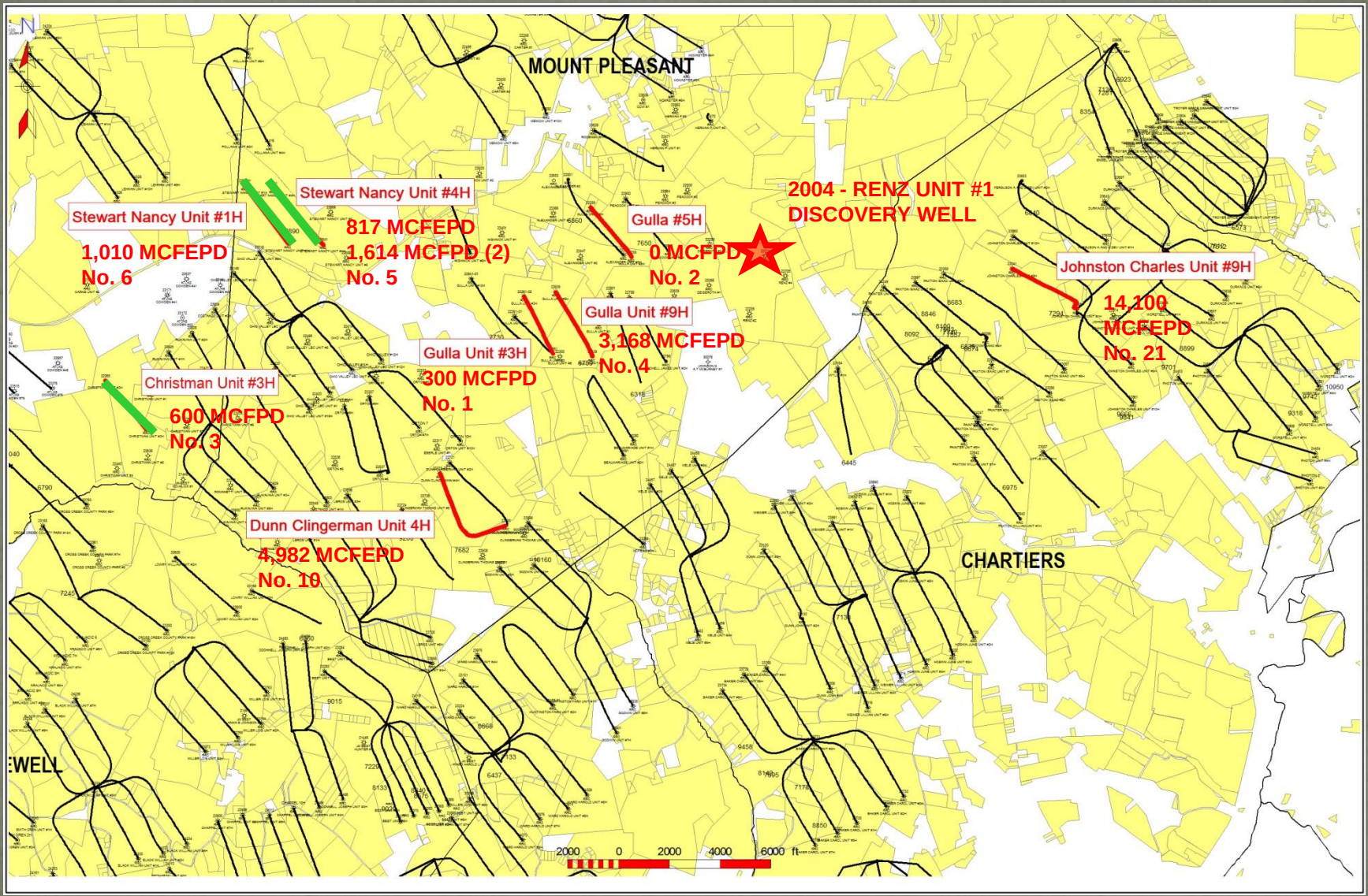
NE PLAY

Very thick, expanded section.
Lower Avg. TOC.
Low NTG Ratio.
Tully to Marcellus interval expanded.
NE PA sedimentation rate significantly higher.
Key pay intervals are MFS's in Marcellus.

SW PA Marcellus Core Area – 2004 to Present

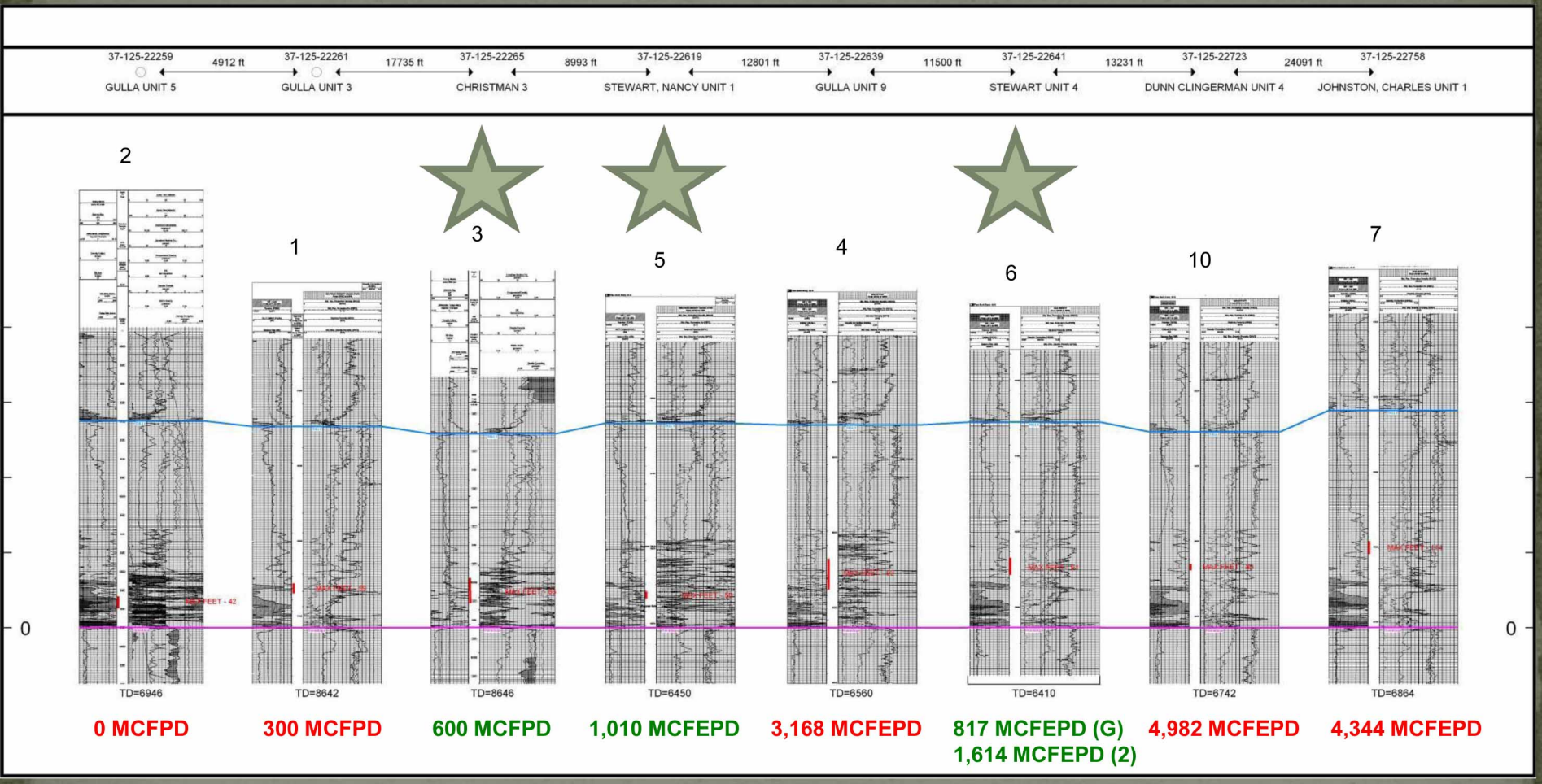


Initial Discovery Well and Key Horizontal Tests to 2008



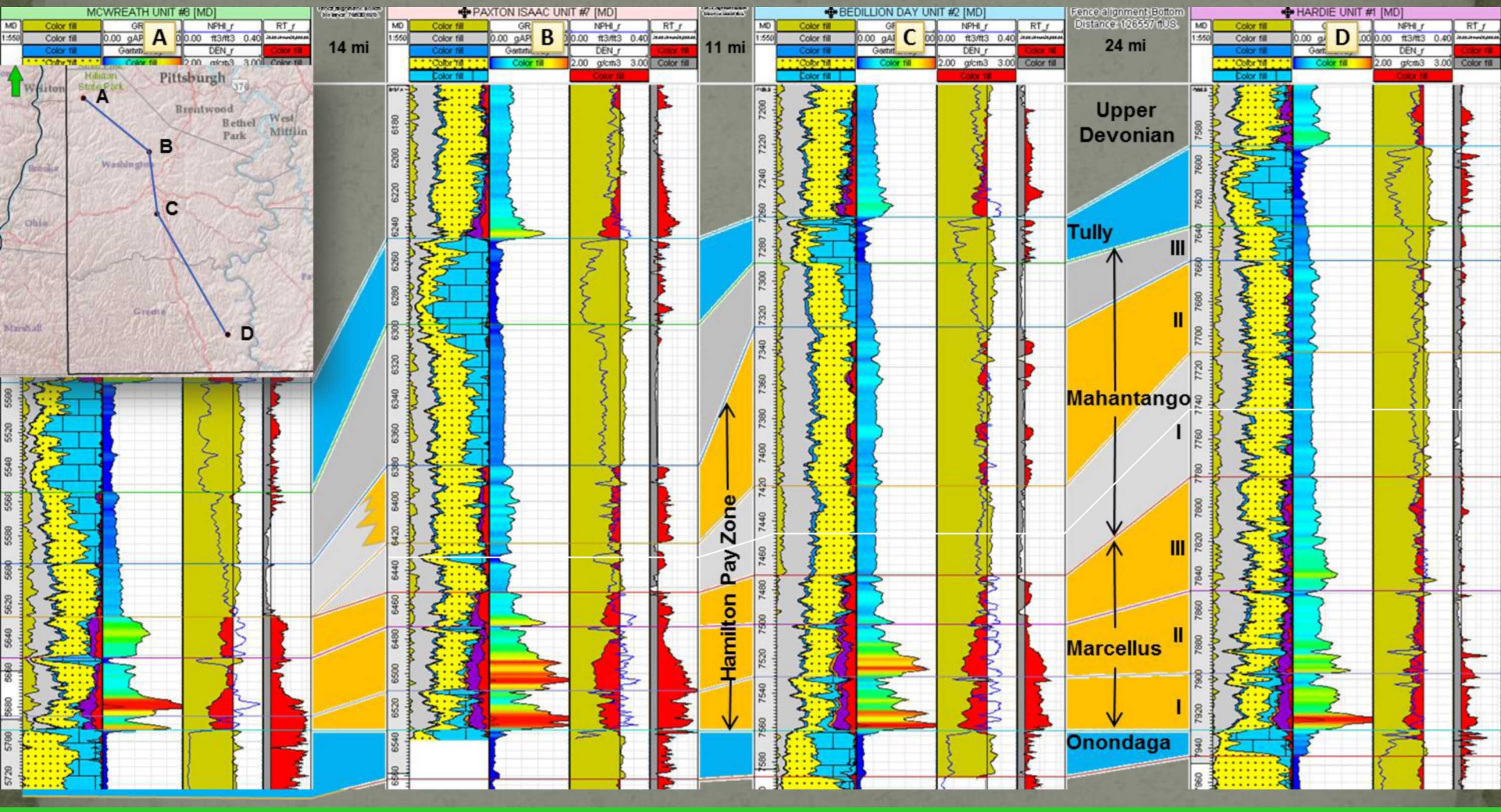
First three lateral wells tested 0 MCFPD to 600 MCFPD. Fourth and afterwards tested 1,614 MCFEPD to 14,100 MCFEPD…What was the driver? All have similar azimuths and length. Initial laterals in liquids rich portion of play highlighted in green and were among the first laterals in the play.

2006 – 2008 Early Horizontal Well Target Intervals



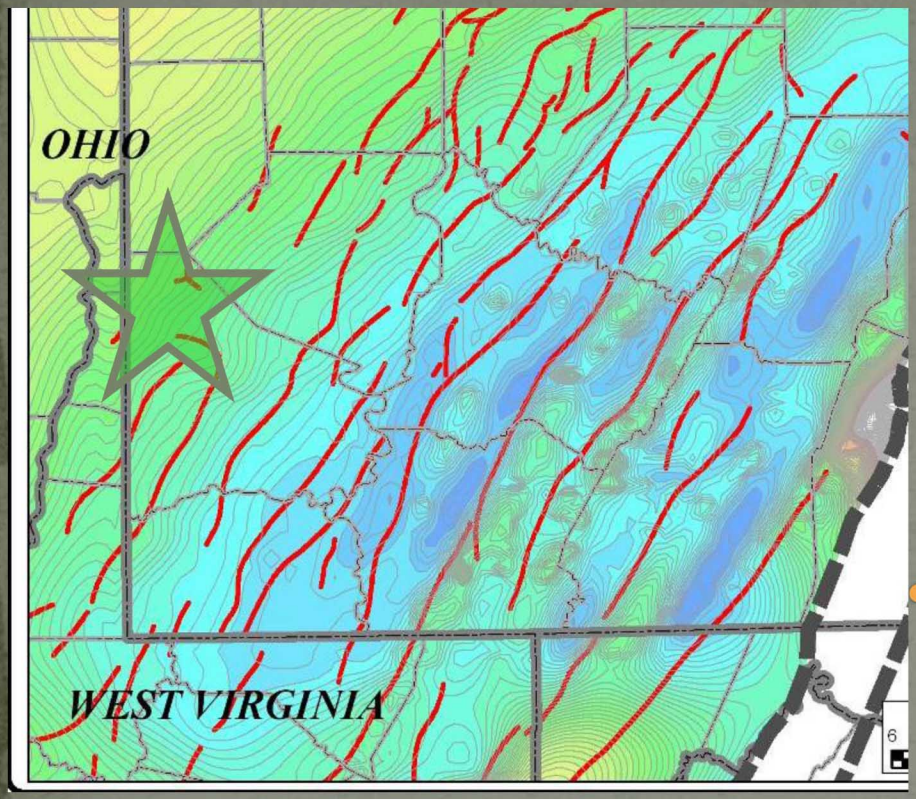
Initial four wells on left landed lower in Marcellus section all low IP's. Four laterals on the right landed higher in section with major changes in results. <u>Landing point/target = Major driver!</u> <u>Note the sequence and IP's of the liquids-rich laterals. IP test rate strong driver in focus of field development but not the entire story.</u>

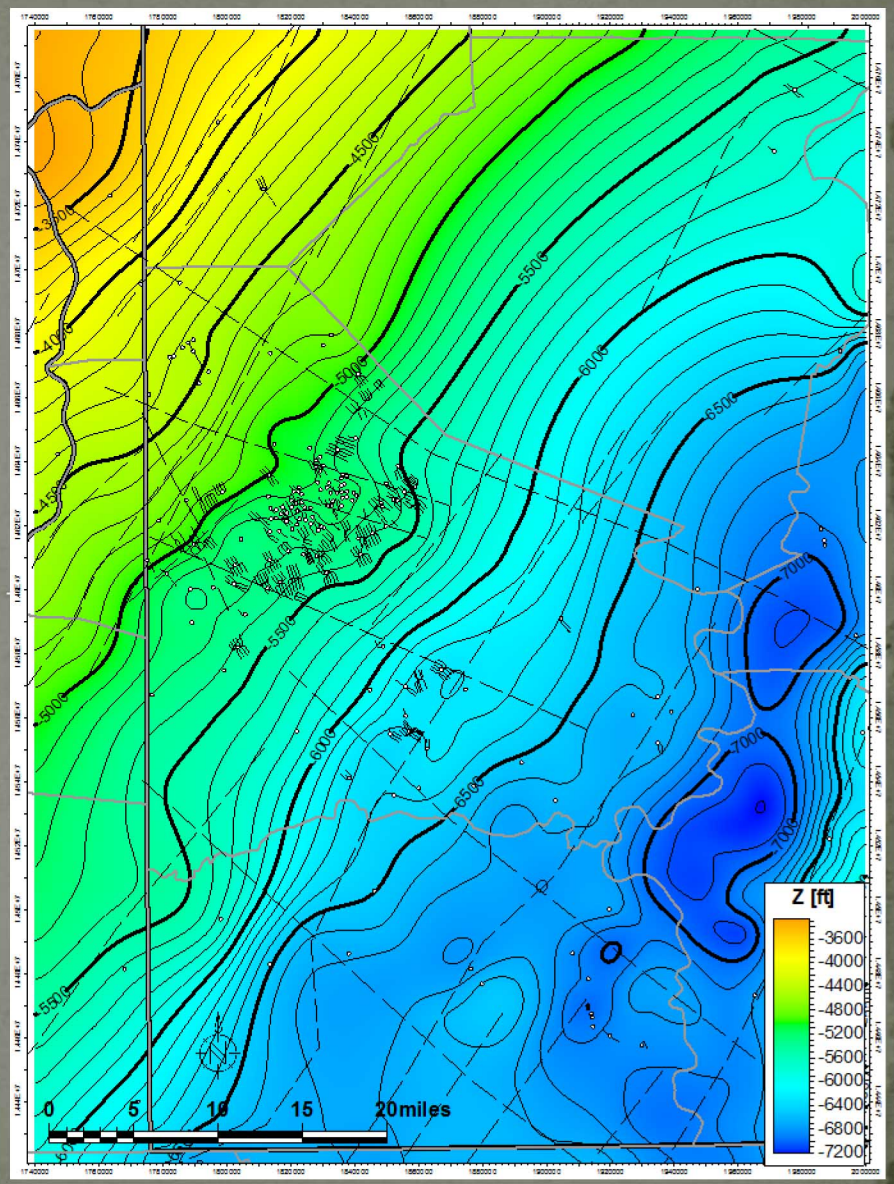
Marcellus Stratigraphic Packages SW PA



Cross section shows significant differences between western liquids-rich area and eastern dry-gas trends. Note the rapid thinning from east to west but see hints of increasing porosity and permeability.

Structure: Onondaga Top





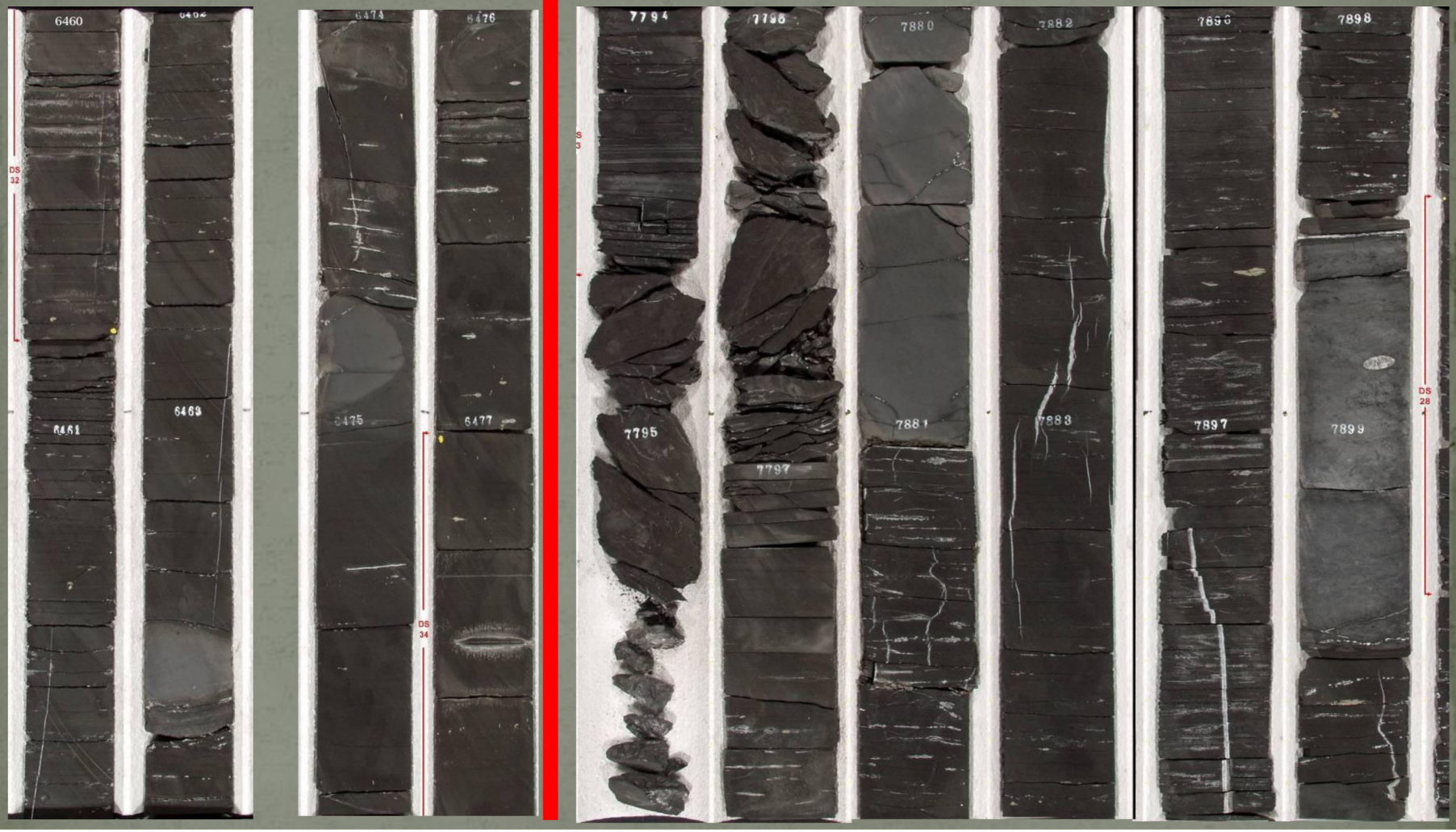
Play area is significantly west of major Appalachian Fold Belt. Key structural features affecting area are basement-faults systems related to Rome Trough rift system and later-day recurrent strike-slip movement.

SW PA Core Studies – Natural Fractures Increase to East

Western Washington County Well

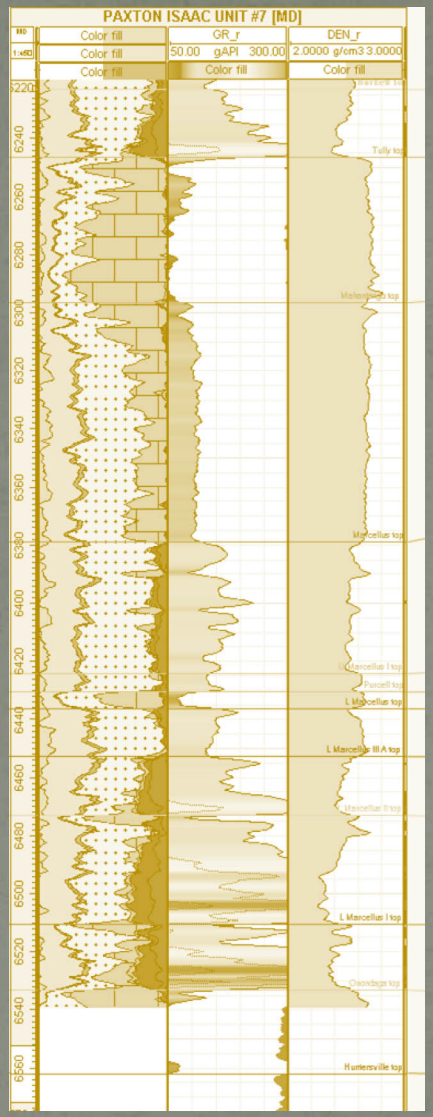
Eastern Greene County Well

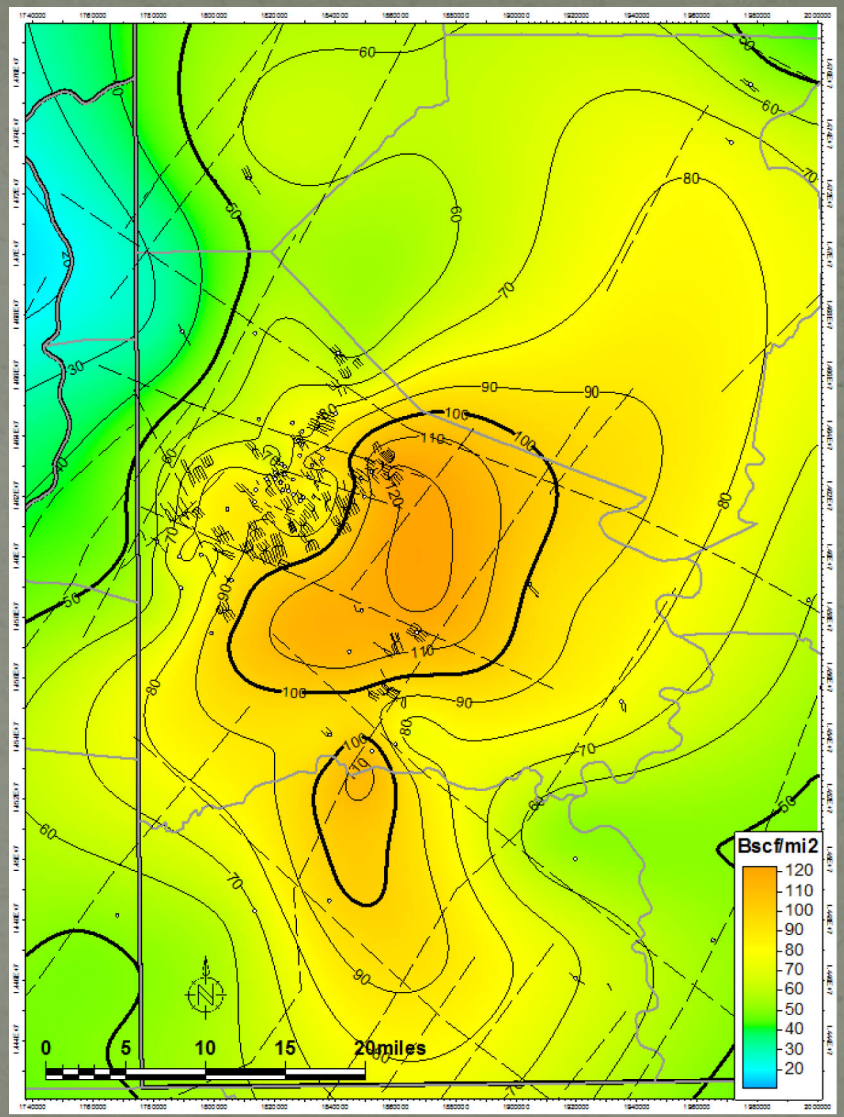
Eastern Greene County Well



The number and width of vertical calcite-filled fractures increases significantly from the Western Washington County cores to the eastern Greene County cores.

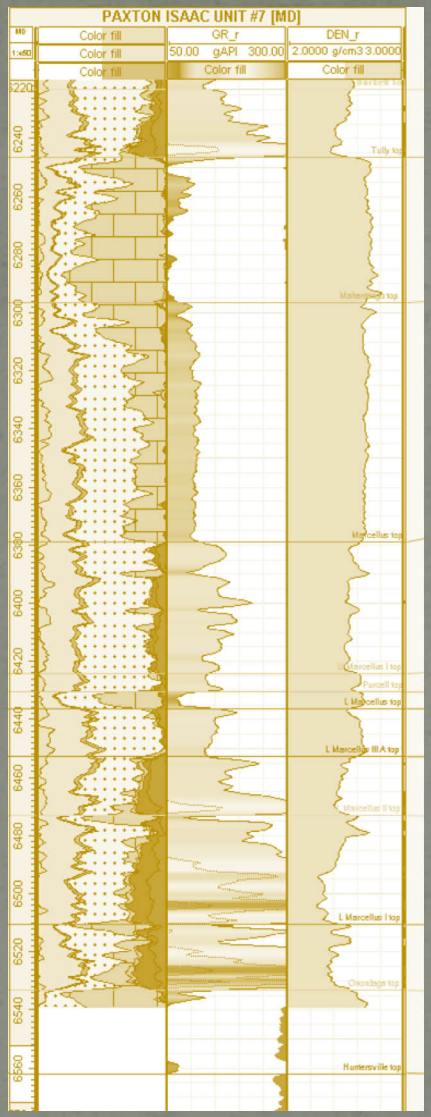
Net GIP: Marcellus Interval

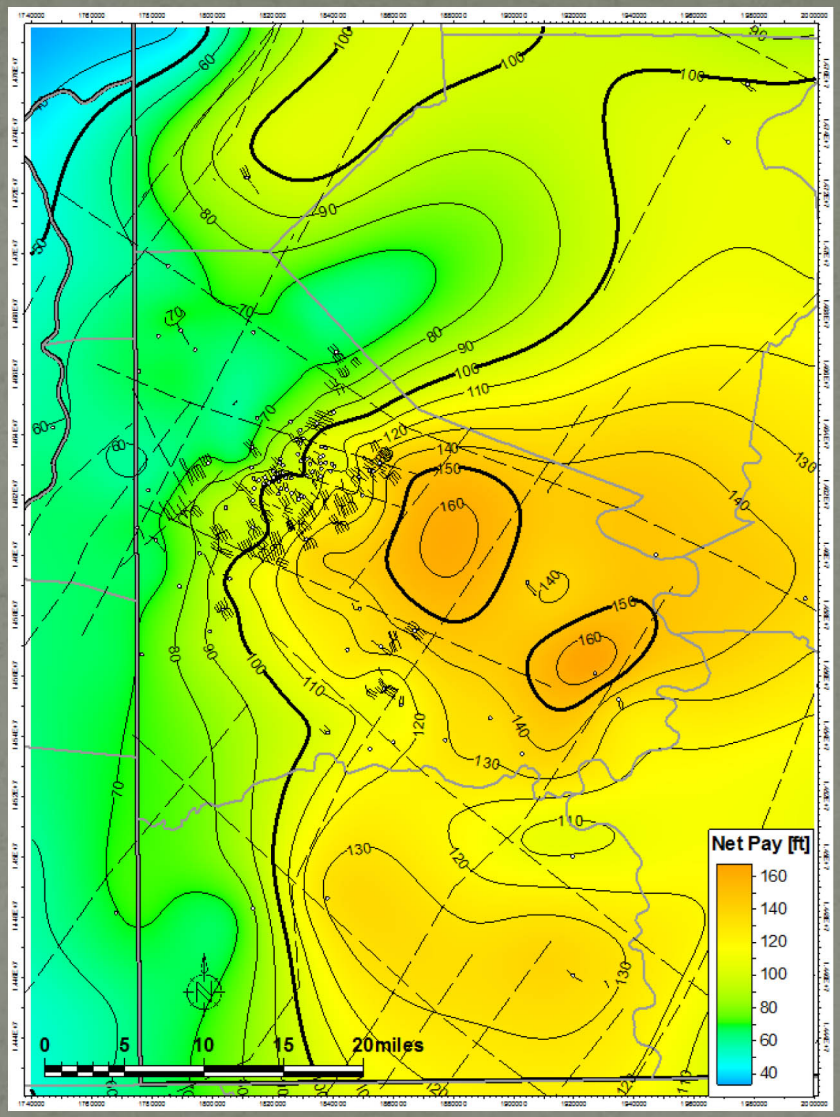




GIP ranges from 50 BCF/mi2 to over 140 BCF/mi2 with lower values in liquids-rich portion of play. Note strong control by basement faults.

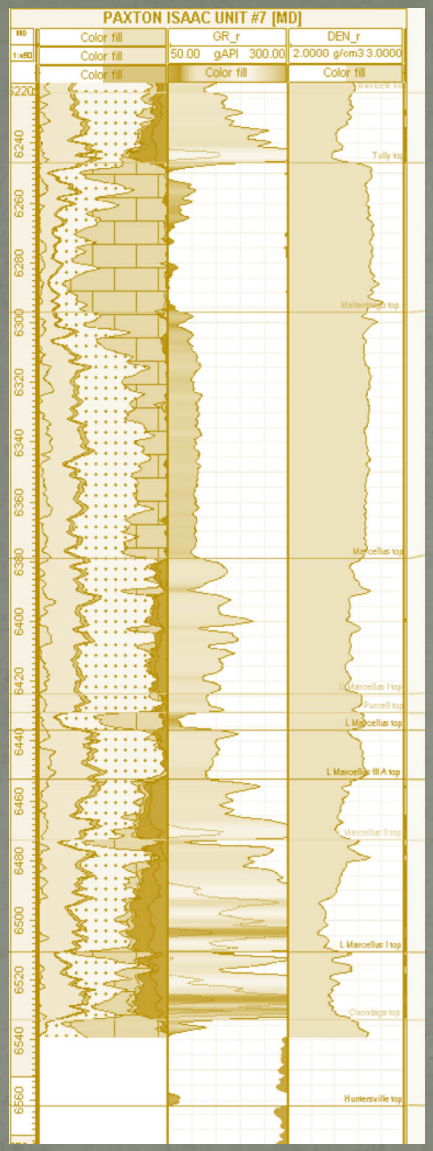
Net Thickness: Marcellus Pay

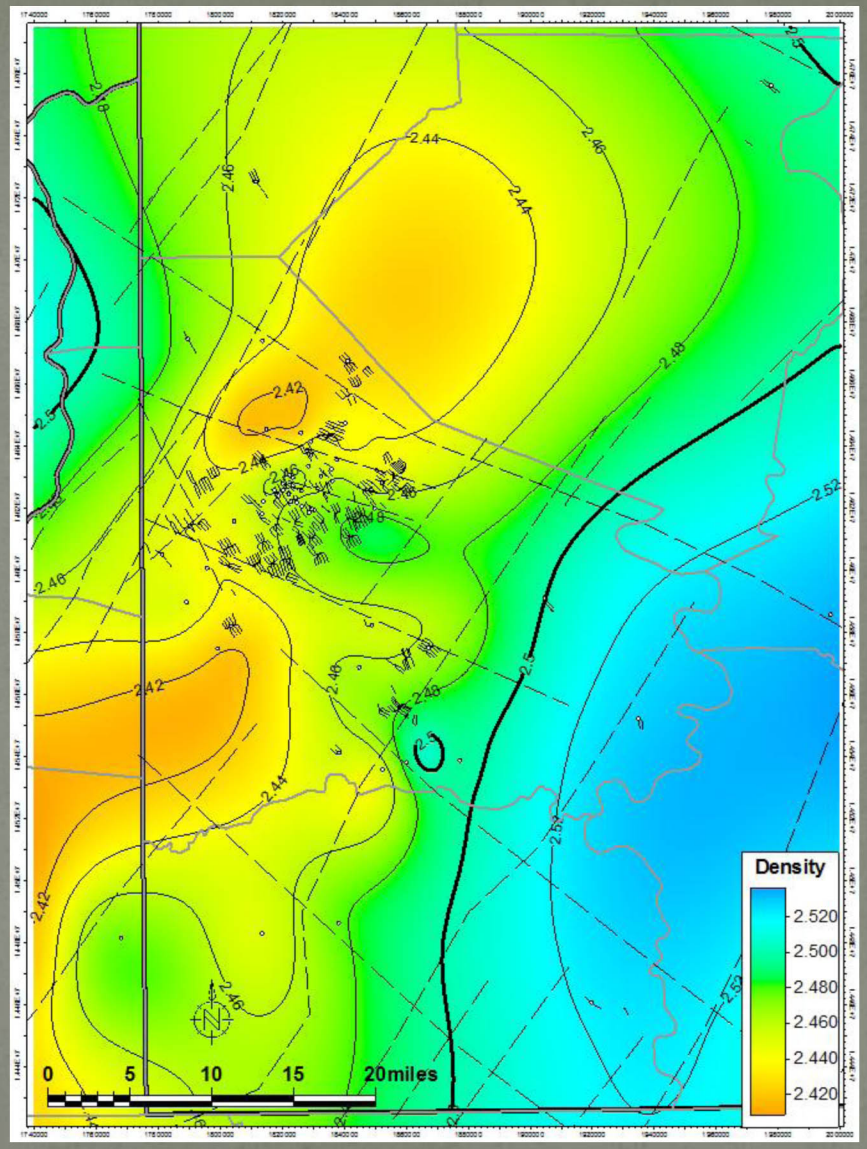




Net pay thickness ranges from 40 to 150 feet with rapid thinning associated with the western liquids-rich portion of the play.

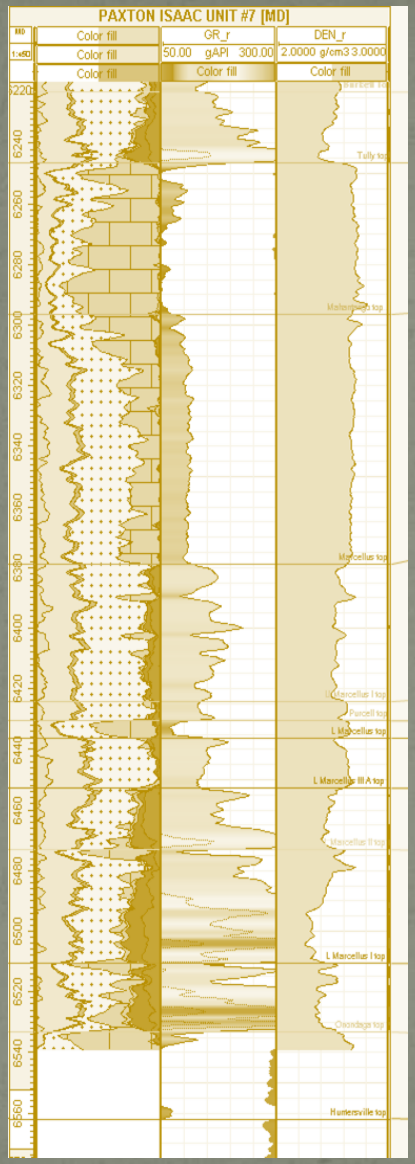
Net Bulk Density Average: Marcellus Pay

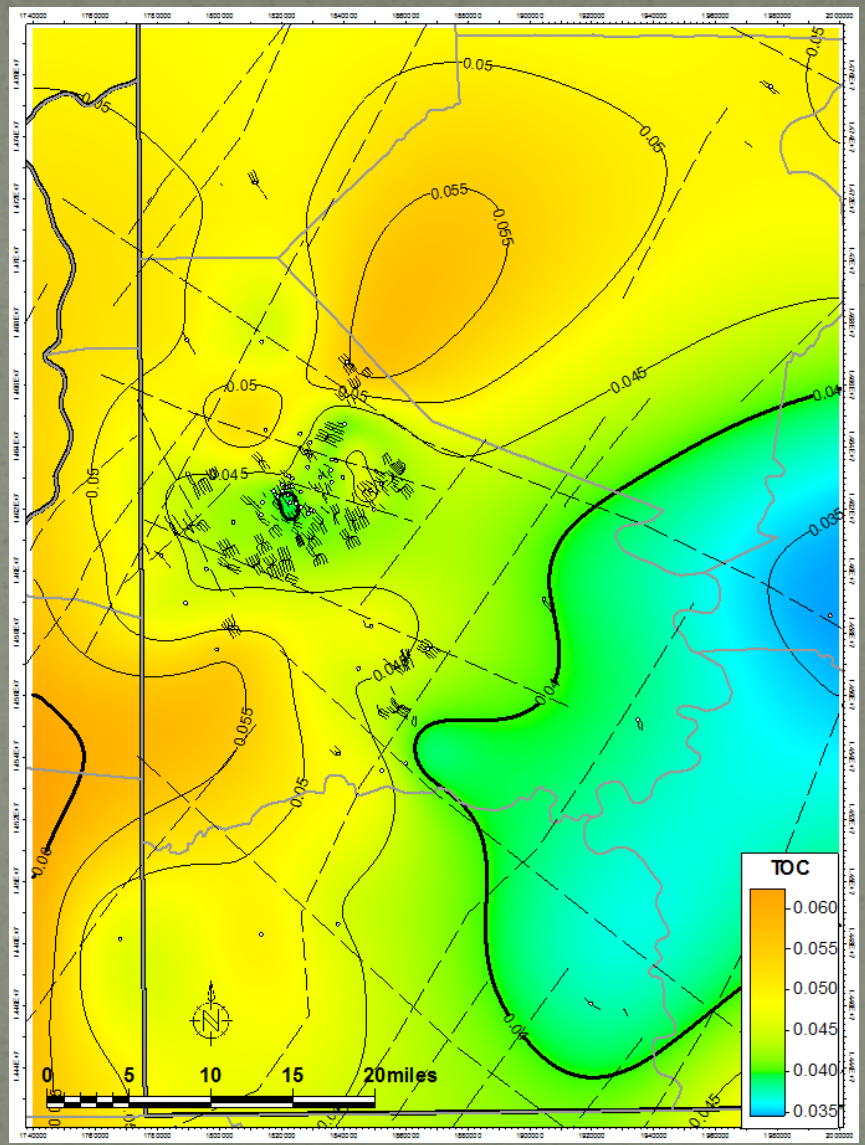




Note the decrease in bulk density to the west suggesting increased porosity and permeability on a unit of pay basis. Note control of basement-fault blocks.

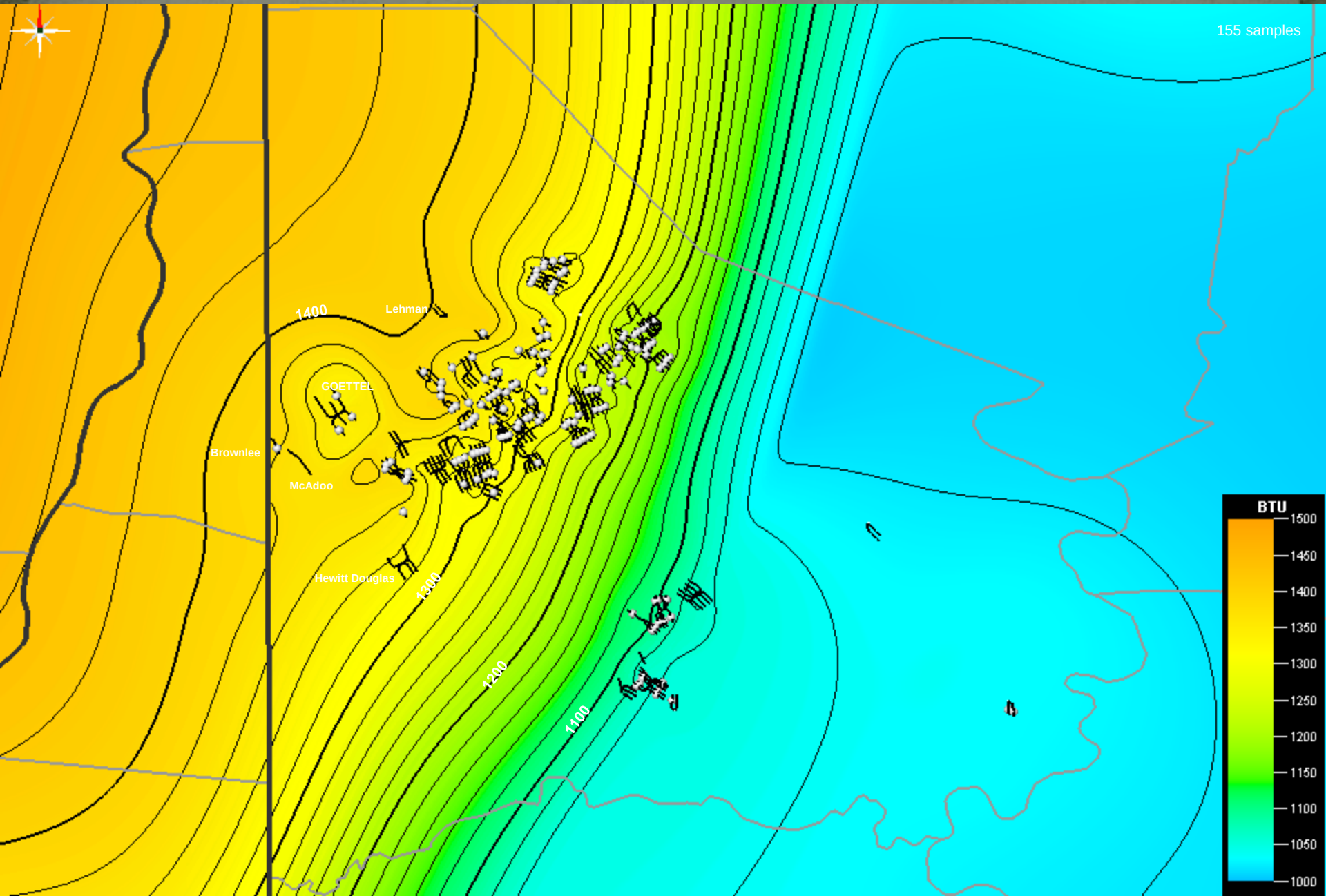
Net TOC Average: Marcellus Pay



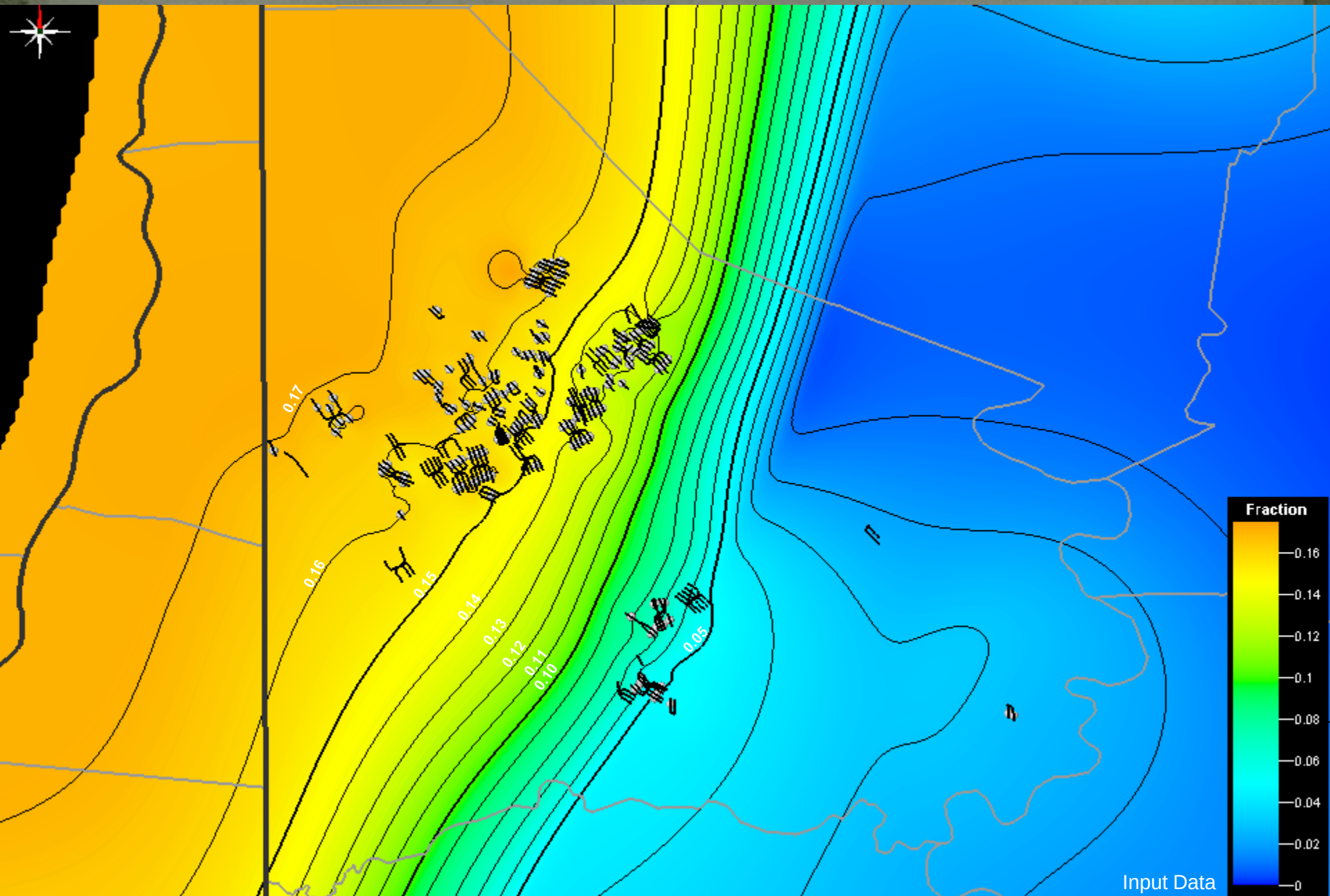


Note the increase in average TOC content to the west and strong influence of basement faults.

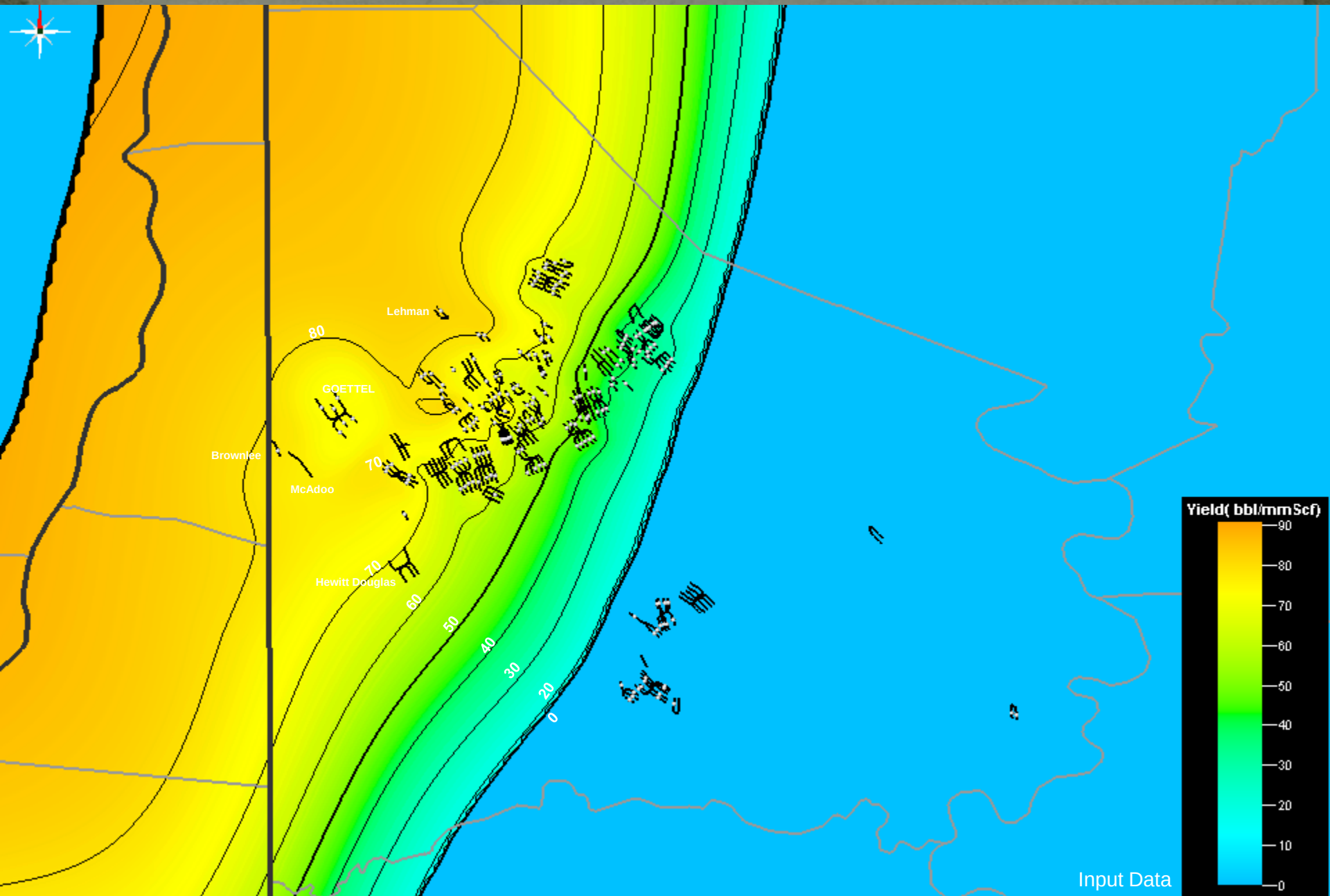
Marcellus BTU



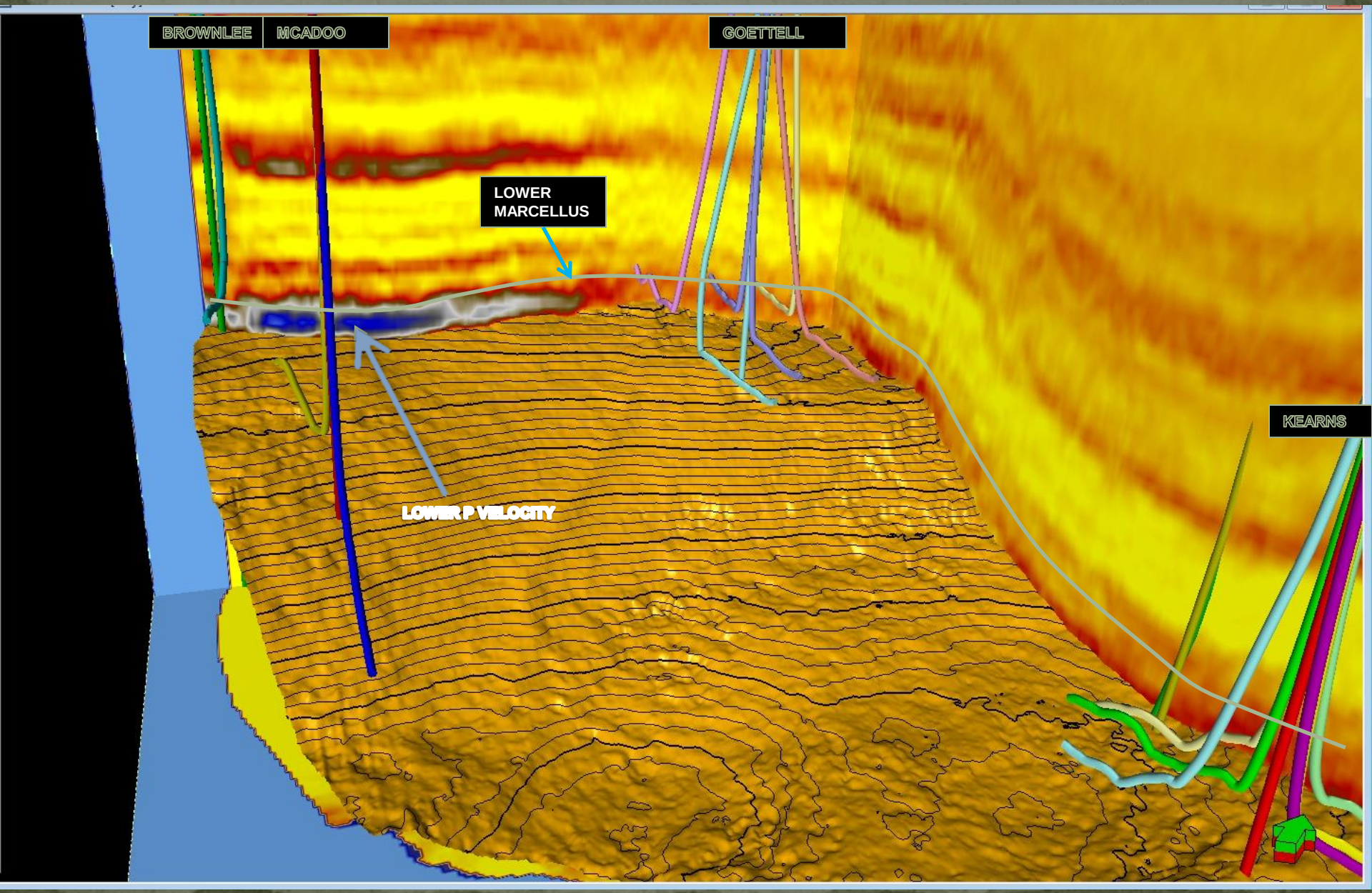
Estimated Ethane Distribution



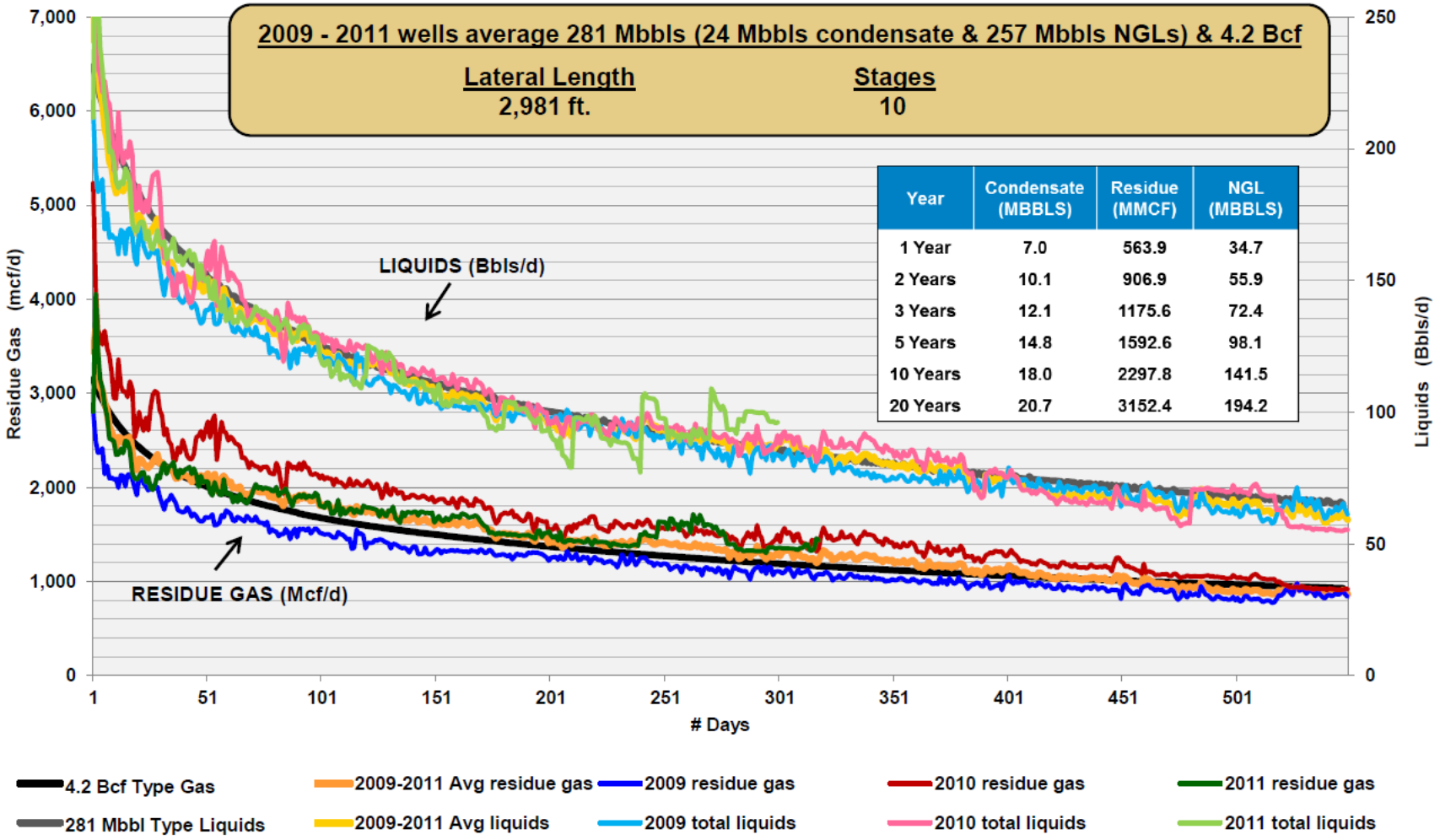
Marcellus NGL Yield



SEISMIC EVIDENCE OF LIQUIDS IN MARCELLUS

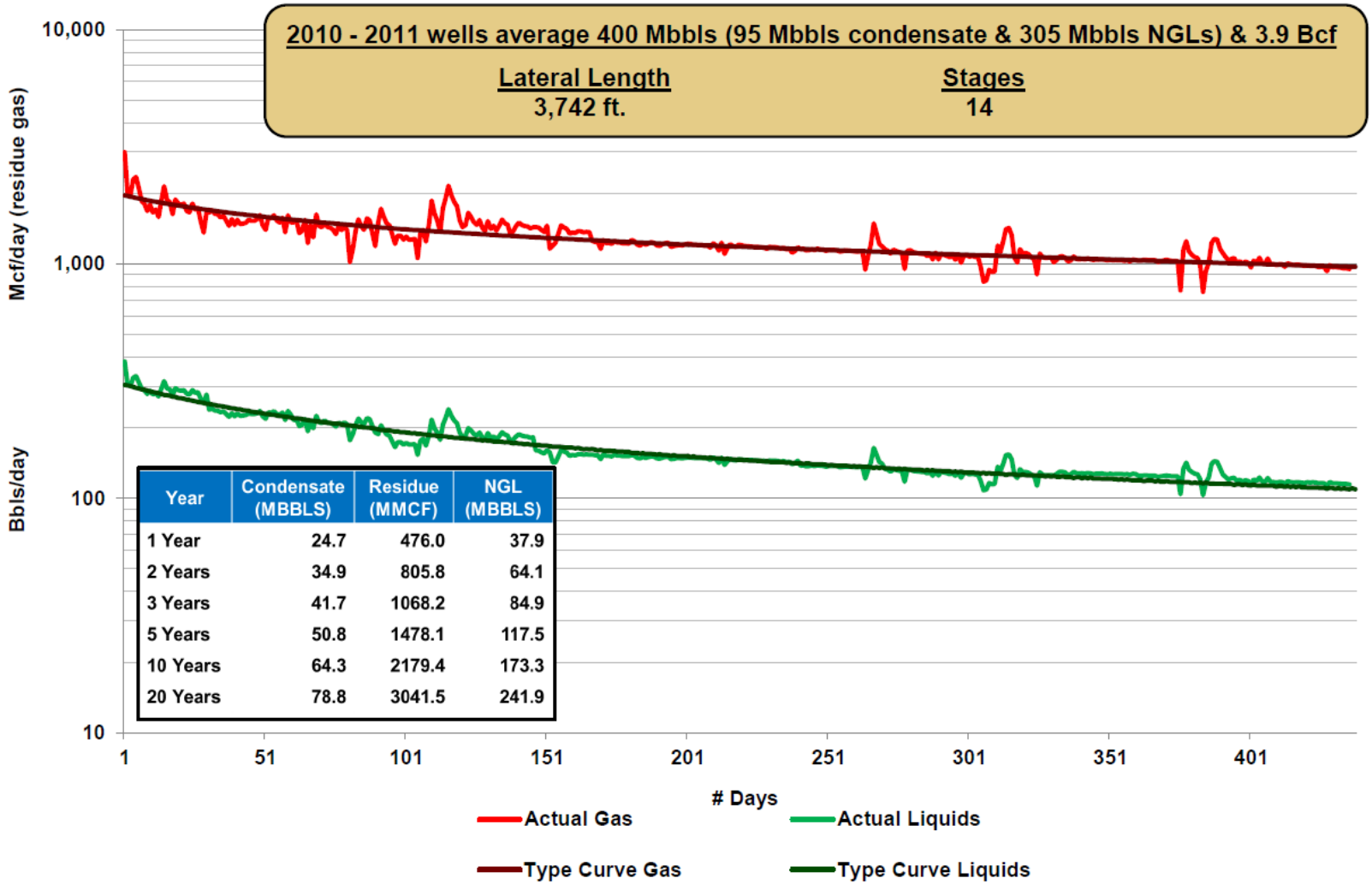


SW PA Wet Area Marcellus Type Curve



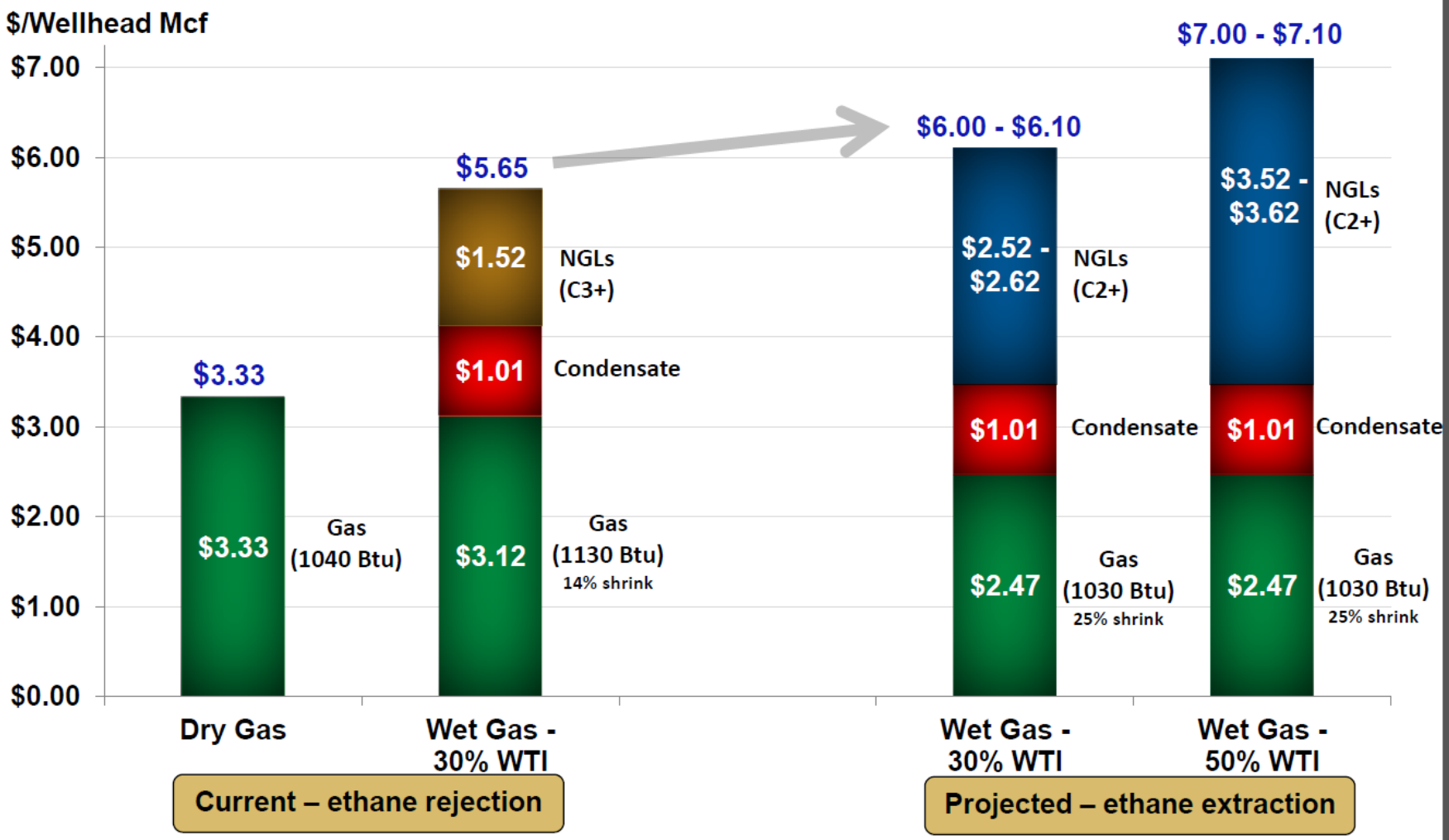
Year	Condensate (MBBLS)	Residue (MMCF)	NGL (MBBLS)
1 Year	7.0	563.9	34.7
2 Years	10.1	906.9	55.9
3 Years	12.1	1175.6	72.4
5 Years	14.8	1592.6	98.1
10 Years	18.0	2297.8	141.5
20 Years	20.7	3152.4	194.2

SW PA Super-Rich Area Marcellus Type Curve



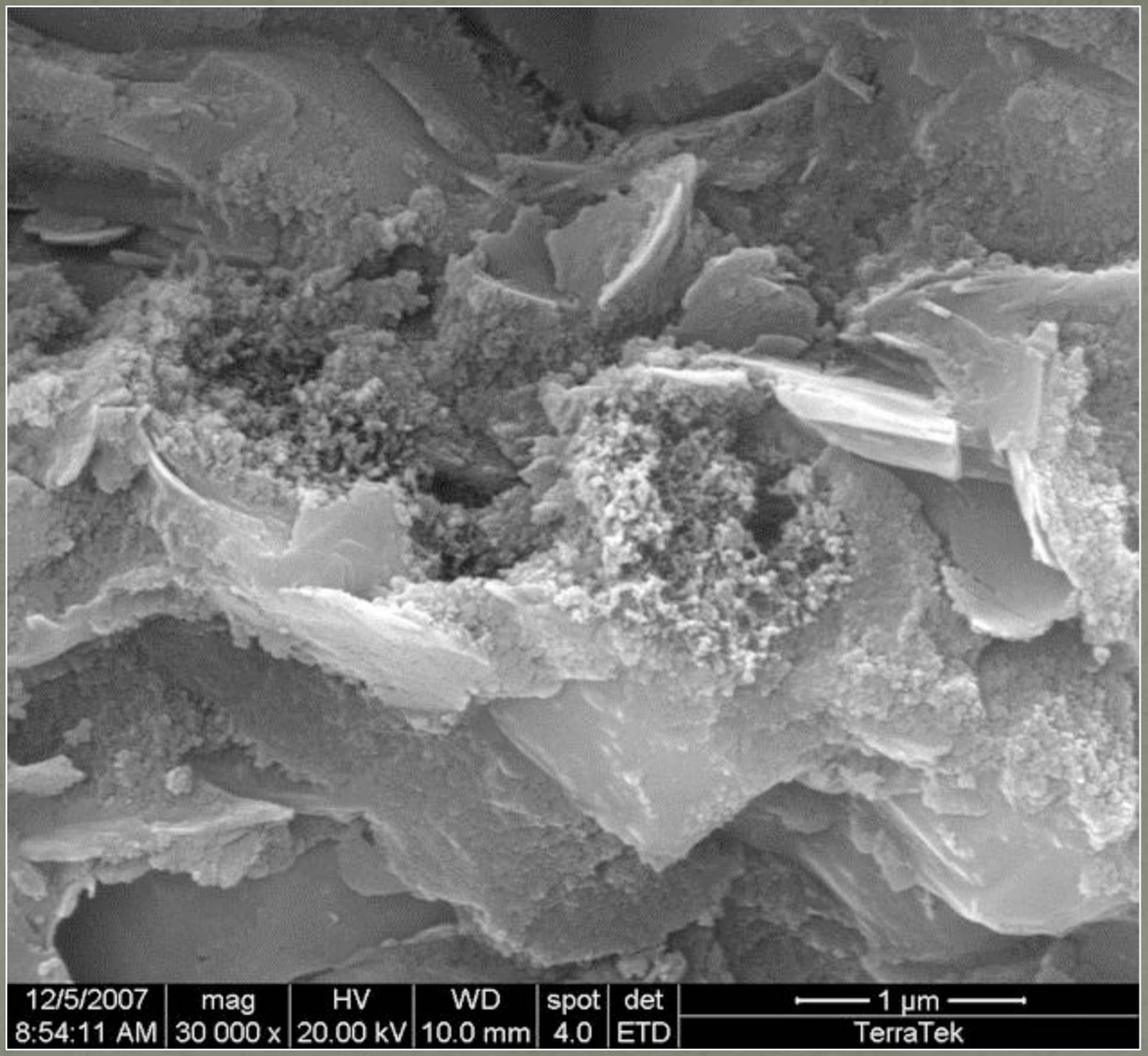
Year	Condensate (MBBLS)	Residue (MMCF)	NGL (MBBLS)
1 Year	24.7	476.0	37.9
2 Years	34.9	805.8	64.1
3 Years	41.7	1068.2	84.9
5 Years	50.8	1478.1	117.5
10 Years	64.3	2179.4	173.3
20 Years	78.8	3041.5	241.9

Marcellus Wet Gas Provides Significant Uplift



Assumptions: $3.20 HH, $95.00 WTI, 30% WTI, 2.255 GPM (ethane rejection), 5.255 GPM (ethane extraction), all processing costs, shrink and fuel included. Based on SW PA wet gas quality (1266 processing plant inlet BTU). Wet Gas (Future) based on full utilization of current ethane / propane agreements.

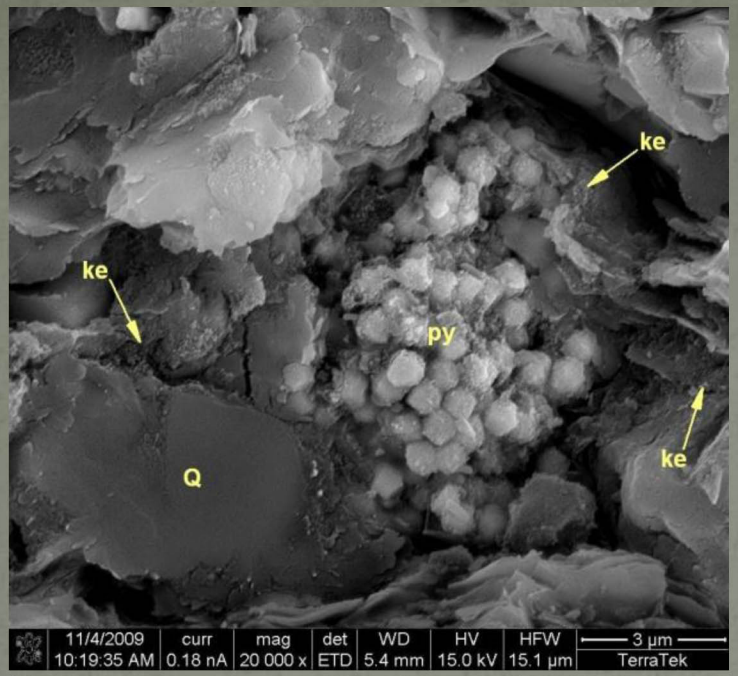
2D /SEM Images – Marcellus Shale SW PA

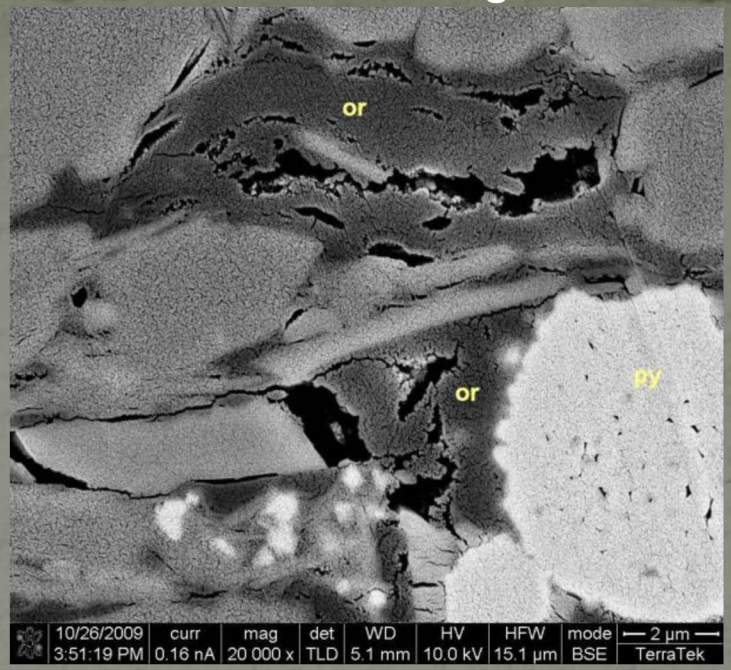


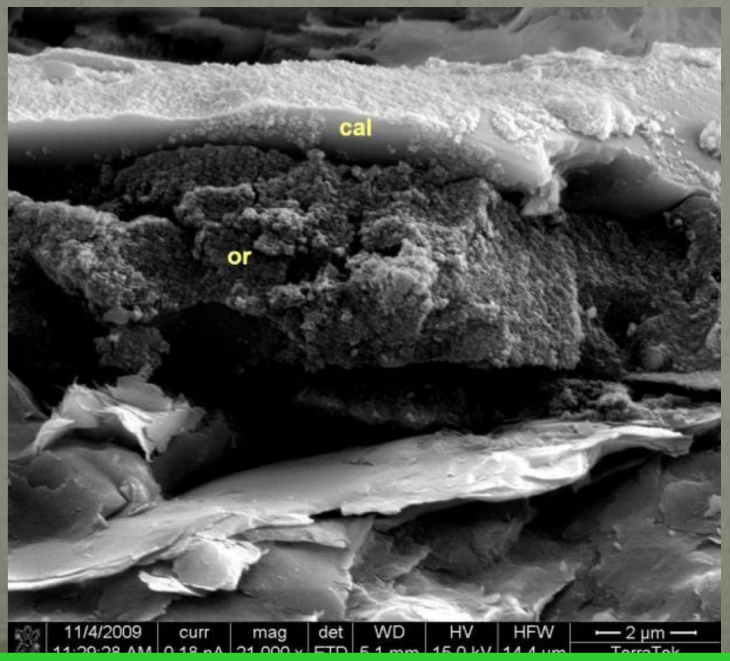
Example standard SEM images are from NGL-rich portion of SW Core area. Note large degraded organics and suggestions of larger pore sizes and high concentration of organics. Large pore sizes and degree of interconnectivity not effectively imaged by standard SEM

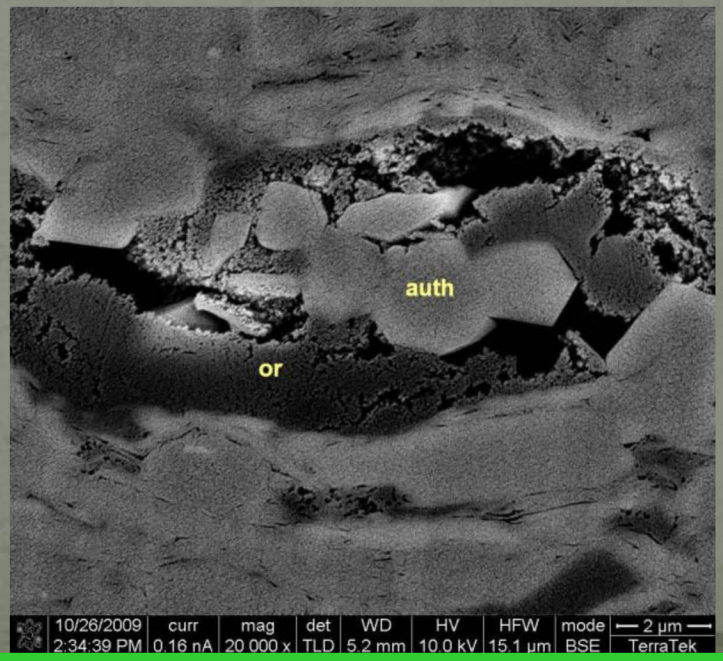
Traditional SEM Method

Ar-Ion Beam Milling Method



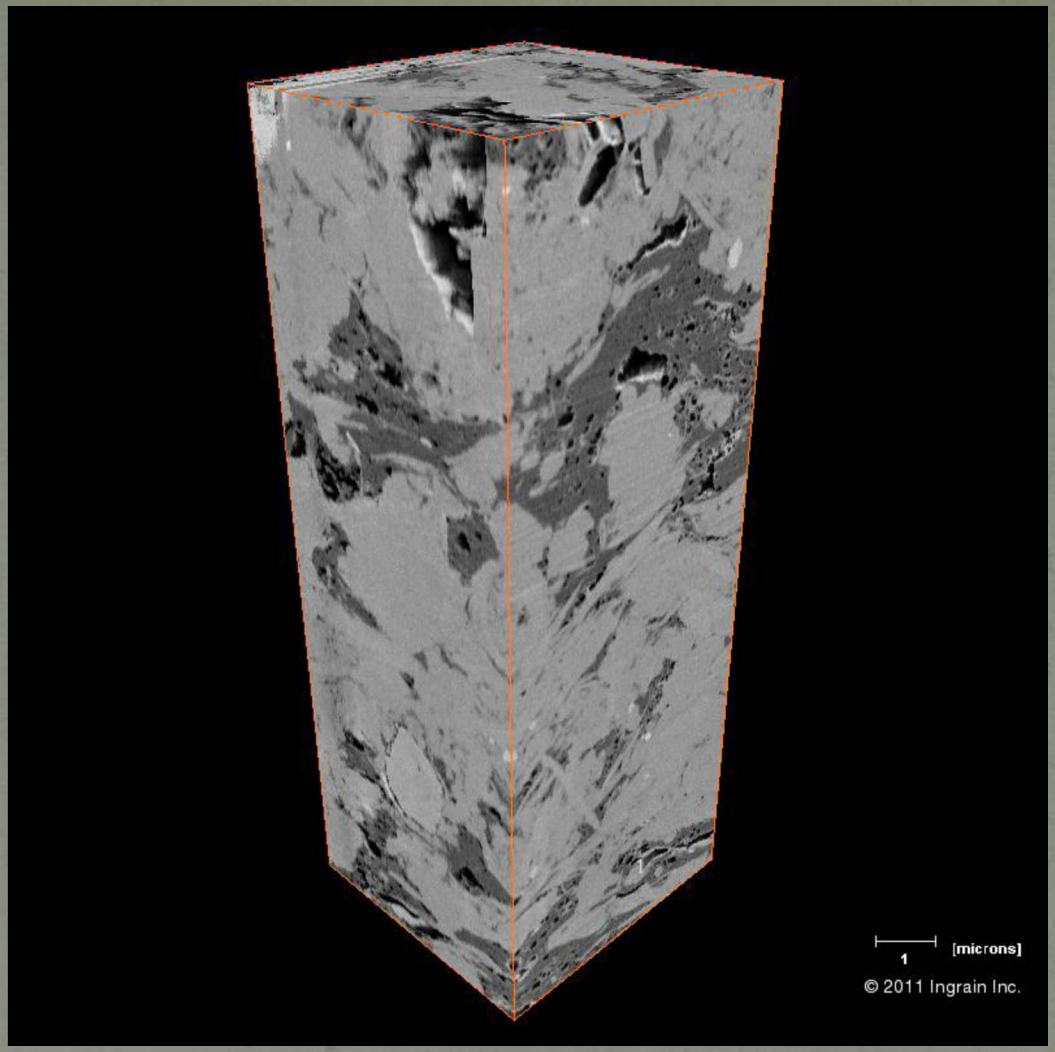






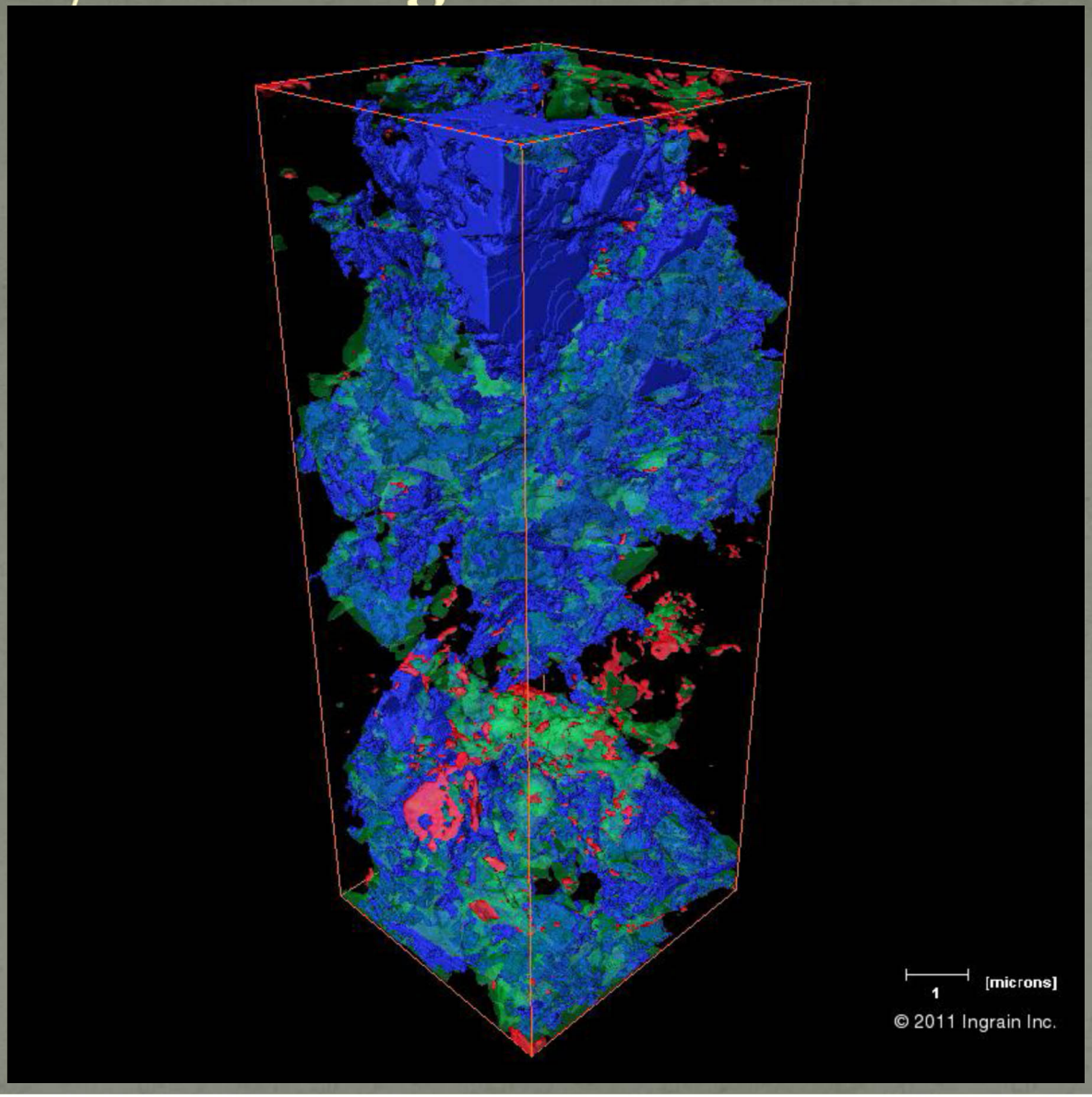
Use of Ar-Ion Beam milling techniques greatly aiding in showing role of organic porosity over standard 2D SEM

3D FIB/SEM Images – Marcellus Shale SW PA



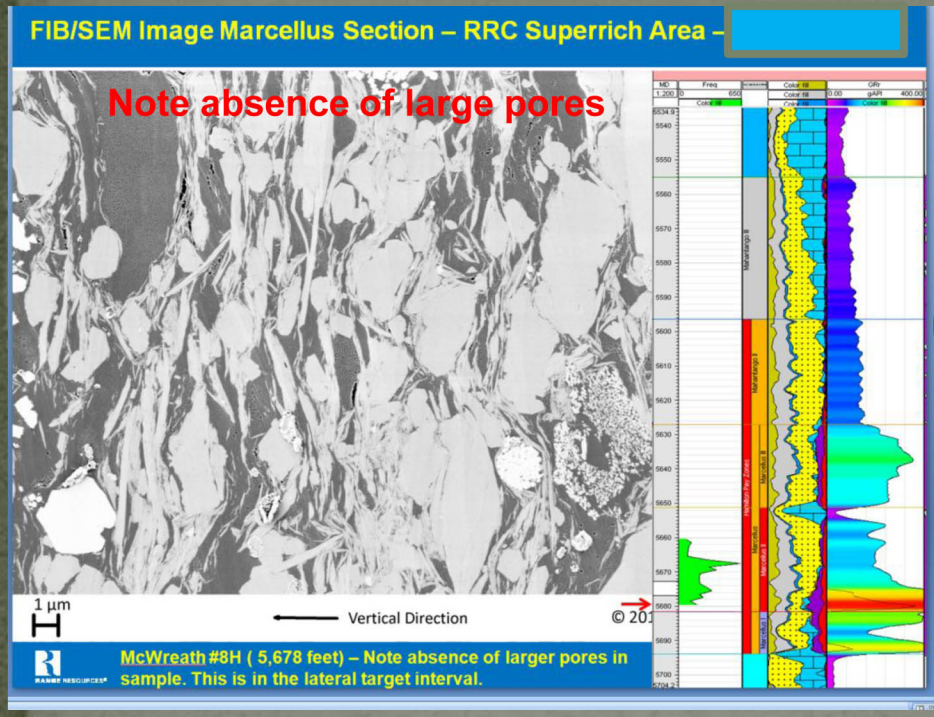
Example FIB/SEM images are from NGL-rich portion of SW Core area. Note large pore sizes and high concentration of organics. Large pore sizes and degree of interconnectivity only imaged by FIB SEM

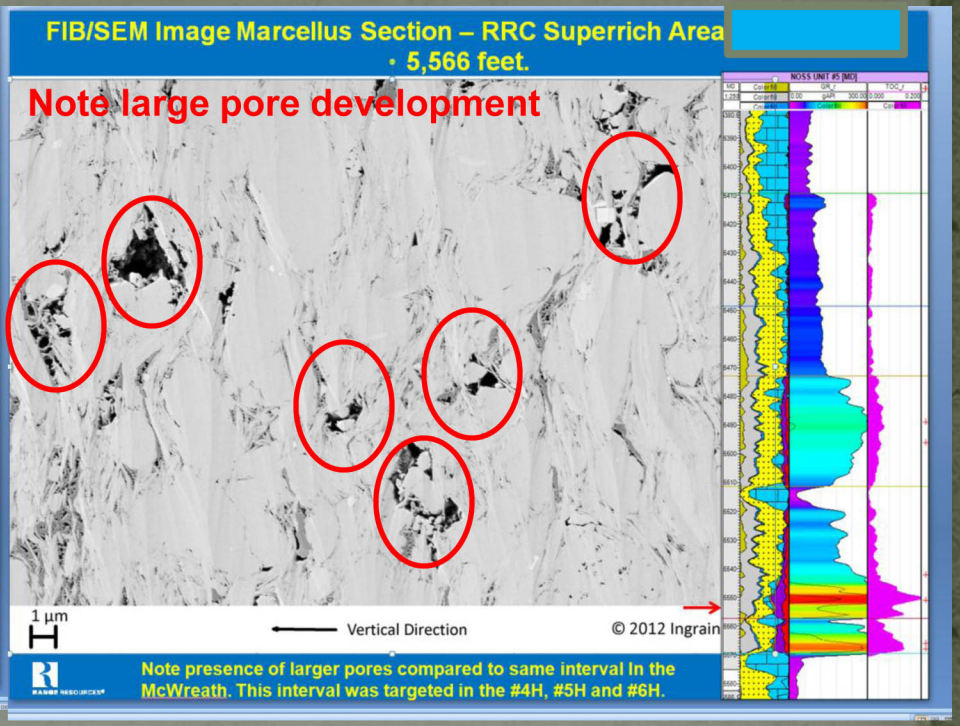
3D FIB/SEM Images – Marcellus Shale SW PA



Example 3D FIB/SEM images are from NGL-rich portion of SW Core area. Note large interconnected pore sizes and volume related to high concentration of organics combined with large pore sizes and surprising degree of interconnectivity

Comparison of Landing Targets and FIB/SEM

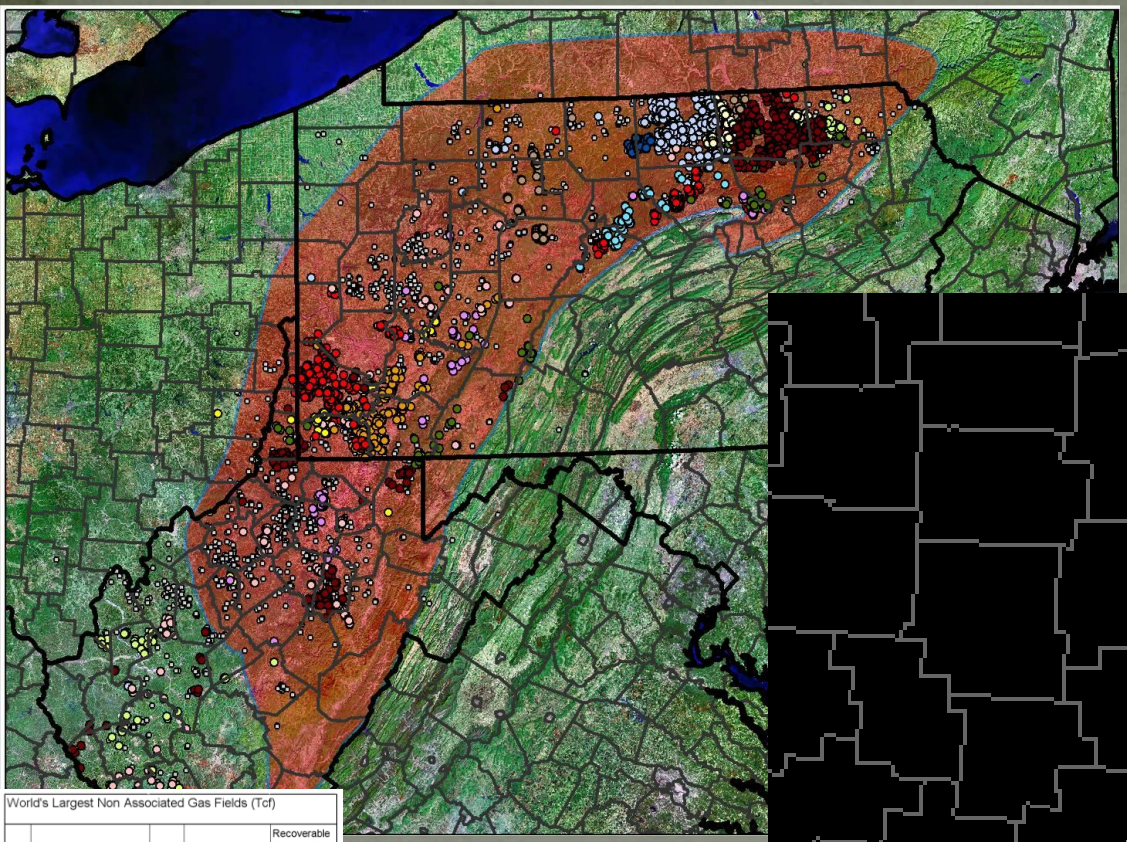


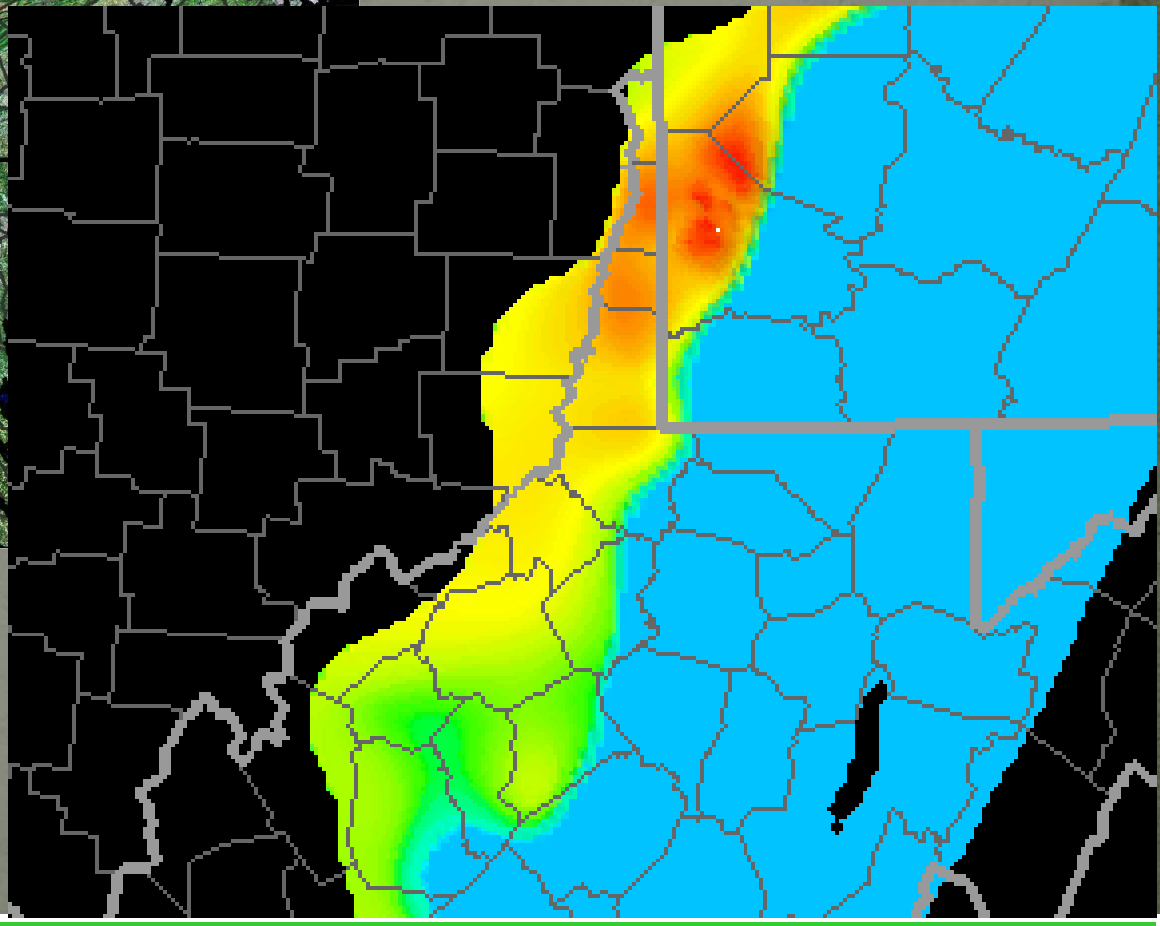


Note SEM image shows high concentration of organics but no large pores. Well results disappointing.

Note SEM image shows moderate concentration of organics and the presence of much larger pores. Landing target specifically chosen based on presence of larger pores. Well results were excellent,opening a significant new development area.

Marcellus Shale Play – Giant Status!!!!! Future!!!!





World's Largest Non Associated Gas Fields (Tcf)

No.	Field Name	Country	Recoverable Reserve Tcf
1	South Pars/North Dome	Iran & Qatar	1235
2	Urengoy	Russia	222
3	Yamburg	Russia	138
4	Hassi R'Mel	Algeria	123
5	Shtokman	Russia	110
6	South Iolotan-Osman	Turkmenistan	98
7	Zapolyarnoye	Russia	95
8	Hugoton	USA (TX-OK-KS)	81
9	Groningen	Netherlands	73
10	Bonavenko	Russia	70
11	Medvezhye	Russia	68
12	North Pars	Iran	48
13	Dauletabad-Donmez	Turkmenistan	47
14	Karachaganak	Kazakhstan	46
15	Kish	Iran	45

Table Sources: Global Natural Gas Reserves - A Heuristic Viewpoint
Raphael Sandrea, 2006

Size refers to ultimate recoverable reserves expressed in trillion cubic feet

Marcellus Play Potential – 84 TCF/3.5 Billion Bbls liquids (USGS 2011) to 489 TCF (Engelder PSU 2009)!!!
What about the resource potential of the Genesee Group and Utica/Point Pleasant intervals?!?!?!!