[AV]An overview of Some Key Factors Controlling Well Productivity in Core Areas of the Appalachian Basin Marcellus Shale Play*

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Abstract

The Middle Devonian Marcellus Shale is one of the premier gas shale plays of North America in terms of total gas resource, extent, production rates, and economic potential. The organic-rich shale of the Marcellus was deposited in a foreland basin setting that was sediment starved and allowed for accumulation and preservation of the organic material. The Marcellus Shale Formation is positioned in the lower portion of the Hamilton Group, which is bounded above by the Middle Devonian Tully Limestone and below by the Lower Devonian Onondaga Limestone. The Upper and Lower Marcellus Shale are divided by the Cherry Valley/Purcell Limestone.

Two major cores areas have developed in the 500-mi long, southwest-northeast trending Marcellus Shale play fairway. The two core areas display unique combinations of controlling geologic factors. Thickness, organic content, intra-organic matter porosity, overpressure, and maturity are some of the key Marcellus gas productivity factors. The Marcellus thickens from approximately 100 ft average gross thickness in southwestern Pennsylvania to over 300 ft average gross thickness in north-central Pennsylvania.
High organic content and the associated porosity and greater overpressure are key gas productivity factors for the Marcellus Shale. Organic content of the Marcellus can be inferred from GR- and density-log data calibrated with core measurements. The high organic content facies of the Marcellus is the key reservoir rock in terms of hydrocarbon storage. The organic content varies from approximately 2 to 15 wt% average in southwestern Pennsylvania to approximately 4 to 10 wt% average in north-central Pennsylvania and can be related to greater organic maturity to the north. The overpressure mechanism is conversion of liquid hydrocarbons to gas with increased organic maturity.

The key pore type in the Marcellus Shale is intra-organic porosity identified by FIB/SEM technology. The intra-organic porosity displays a degree of connectivity and is probably responsible for a significant portion of the Marcellus Shale productivity and gas in-place. Intra-organic pores range from <10 to 200+ nm. Other pore types include inter-particulate, inter-crystalline, and microcracks.

The major core areas of the Marcellus Shale play are examined and compared in terms of the regional thickness, structure, thermal maturity, overpressure trends. Within each core producing region we illustrate the various pore types within key reservoir units using various core, log, thin-section, standard SEM, and Ion Milled SEM work.

Reference

Cate, A.S., 1961, Subsurface structure of plateau region of north-central and western Pennsylvania on top of the Oriskany Formation: Pennsylvania Geological Survey, Map 9.

“An Overview of Some Key Factors Controlling Well Productivity in Core Areas of the Appalachian Basin Marcellus Shale Play”

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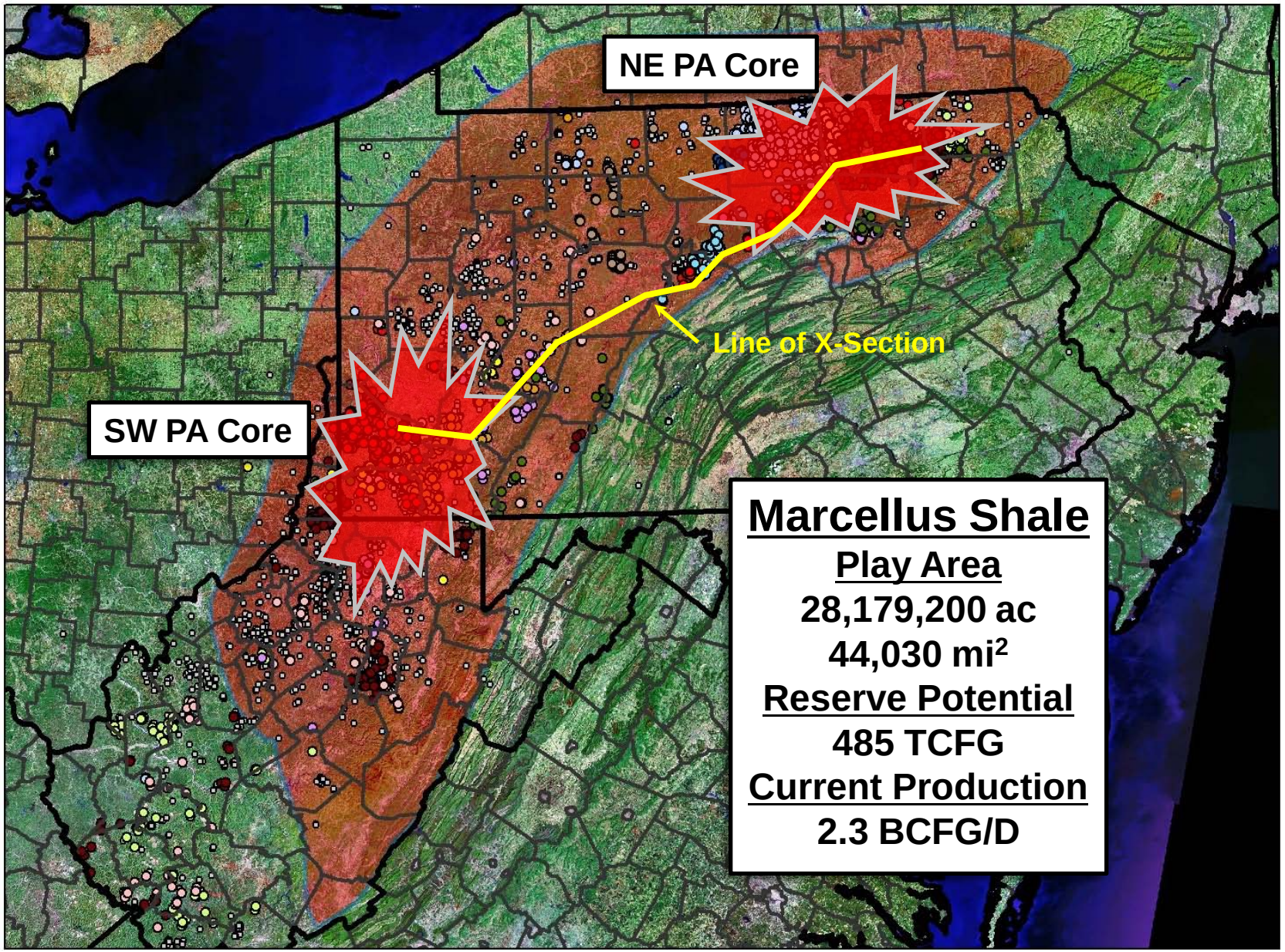
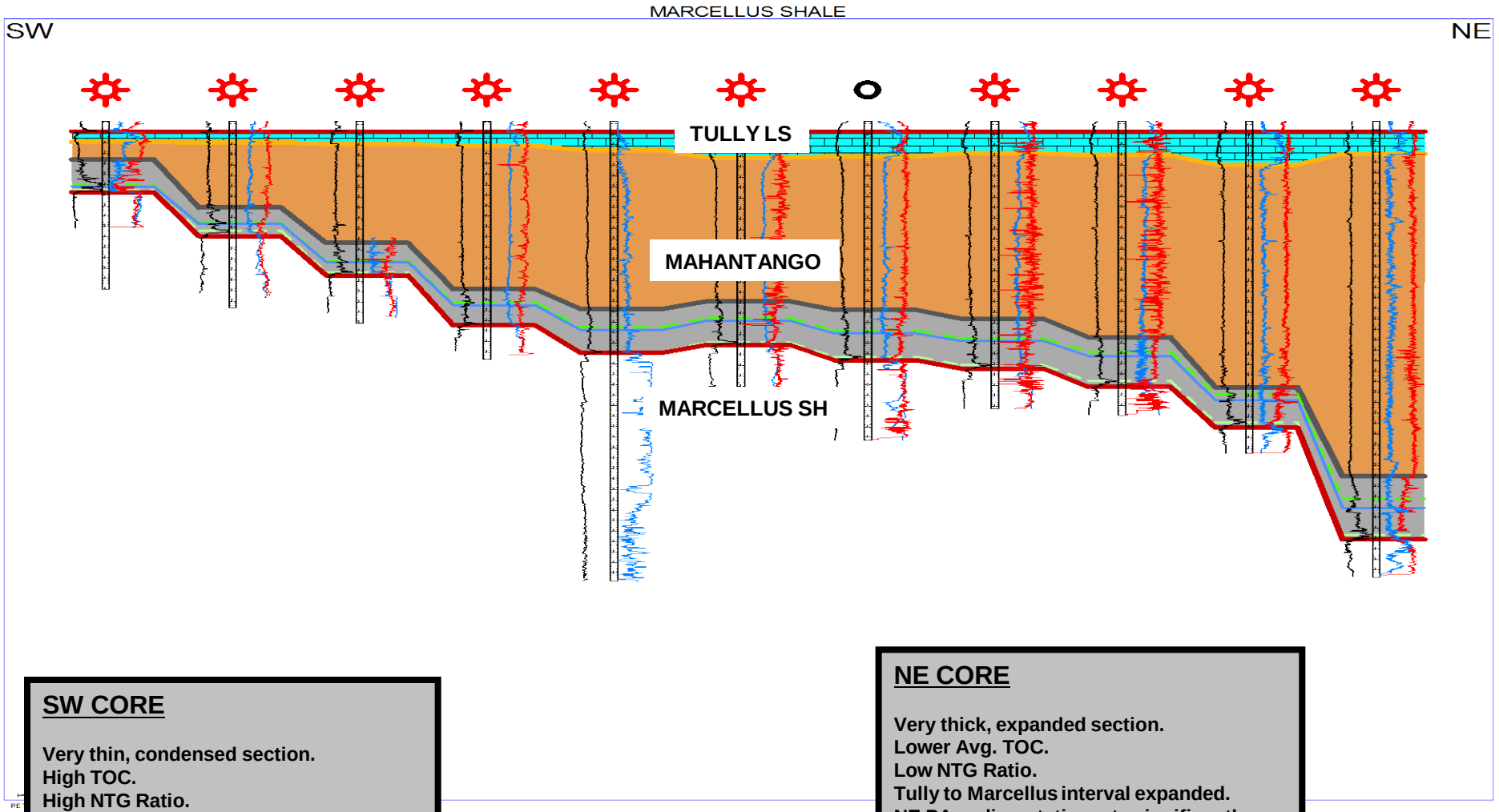
RANGE RESOURCES

Marcellus Shale Play – Core Areas



Regional Stratigraphic Cross-Section

SW NE



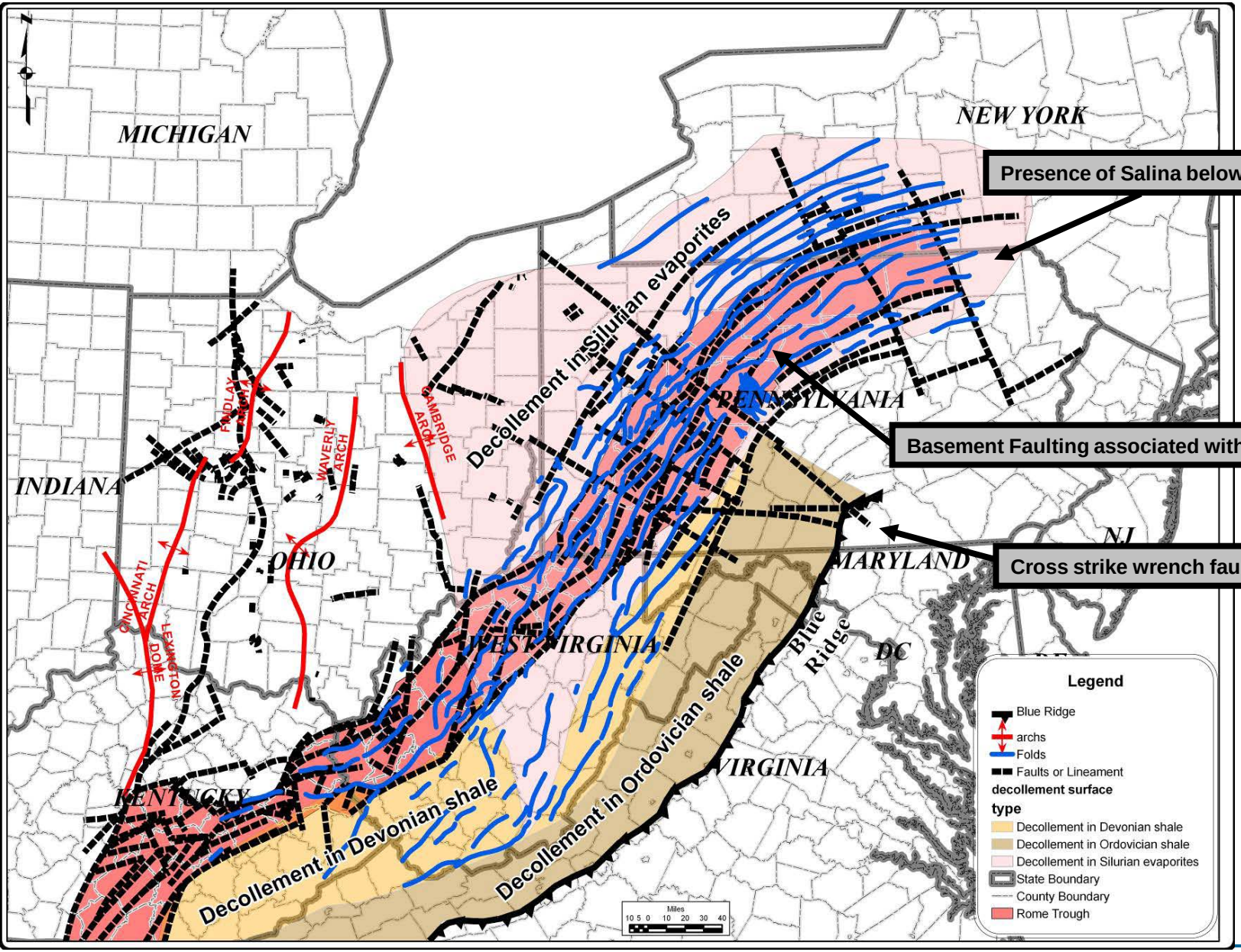
SW CORE

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

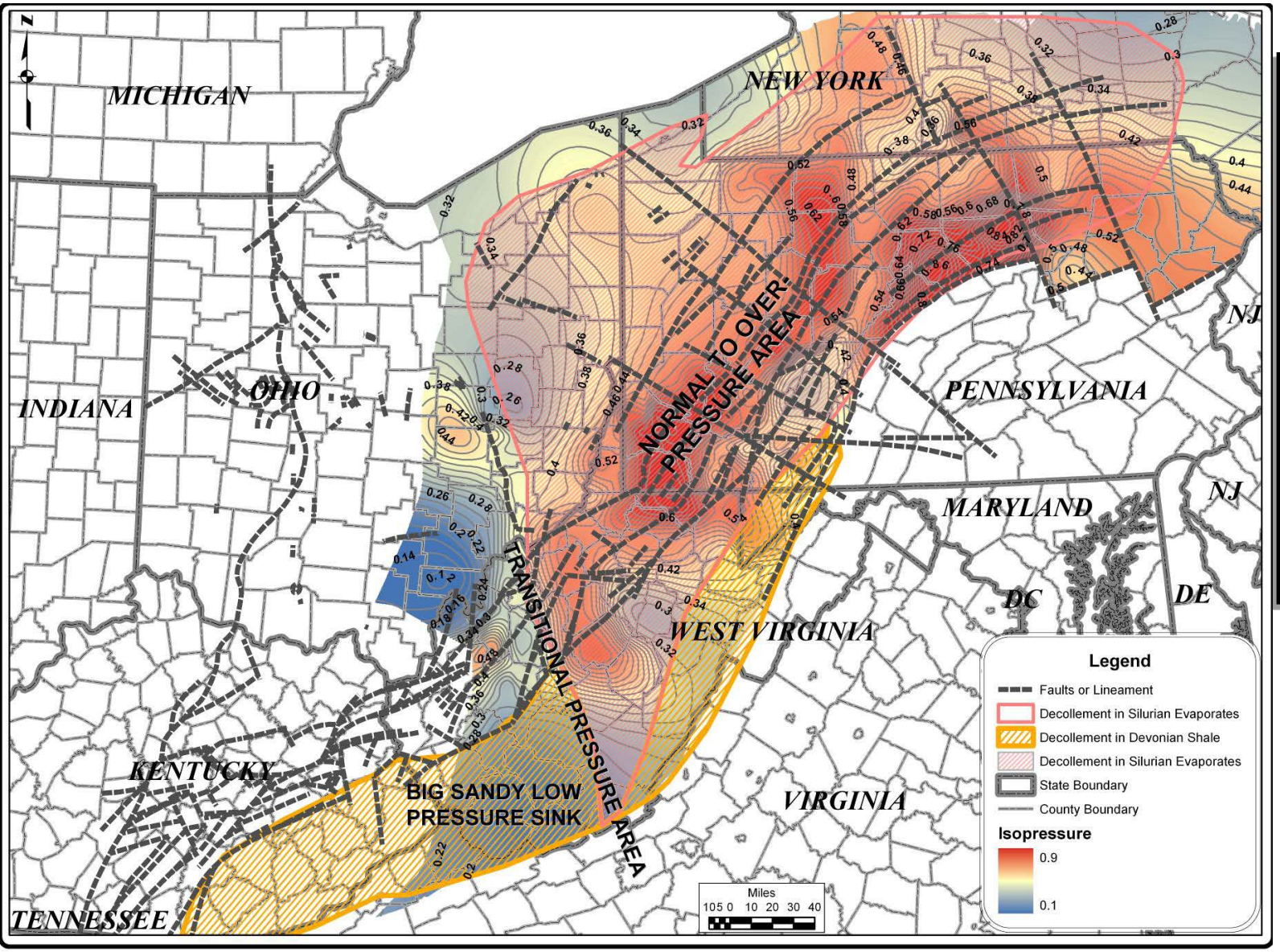
NE CORE

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.

Key Structural Features Affecting Marcellus Shale



Regional Pressure Trends – Marcellus Shale



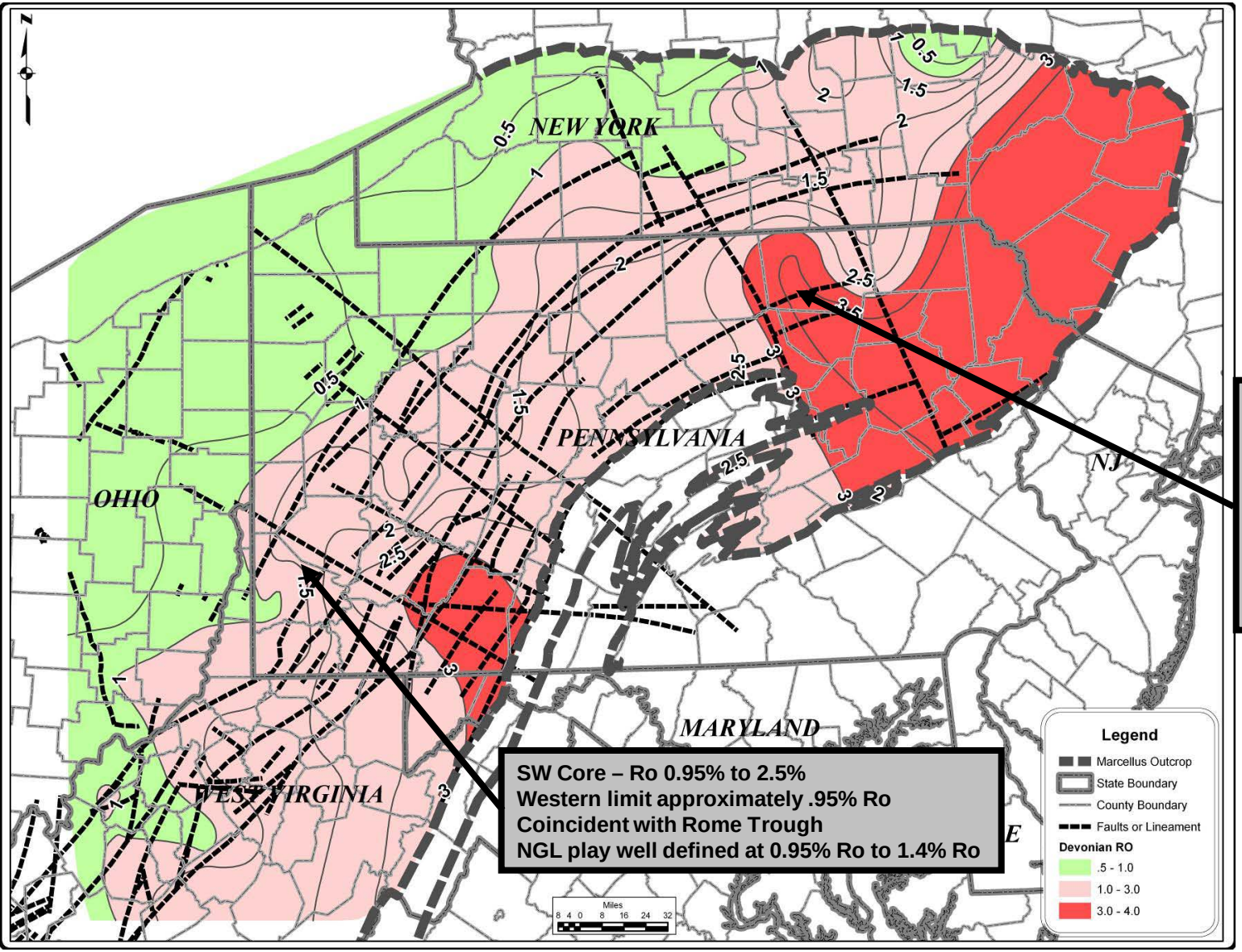
Closely related to burial history associated with Rome Trough.

Presence of underlying Salina interval is key to pressure gradients.

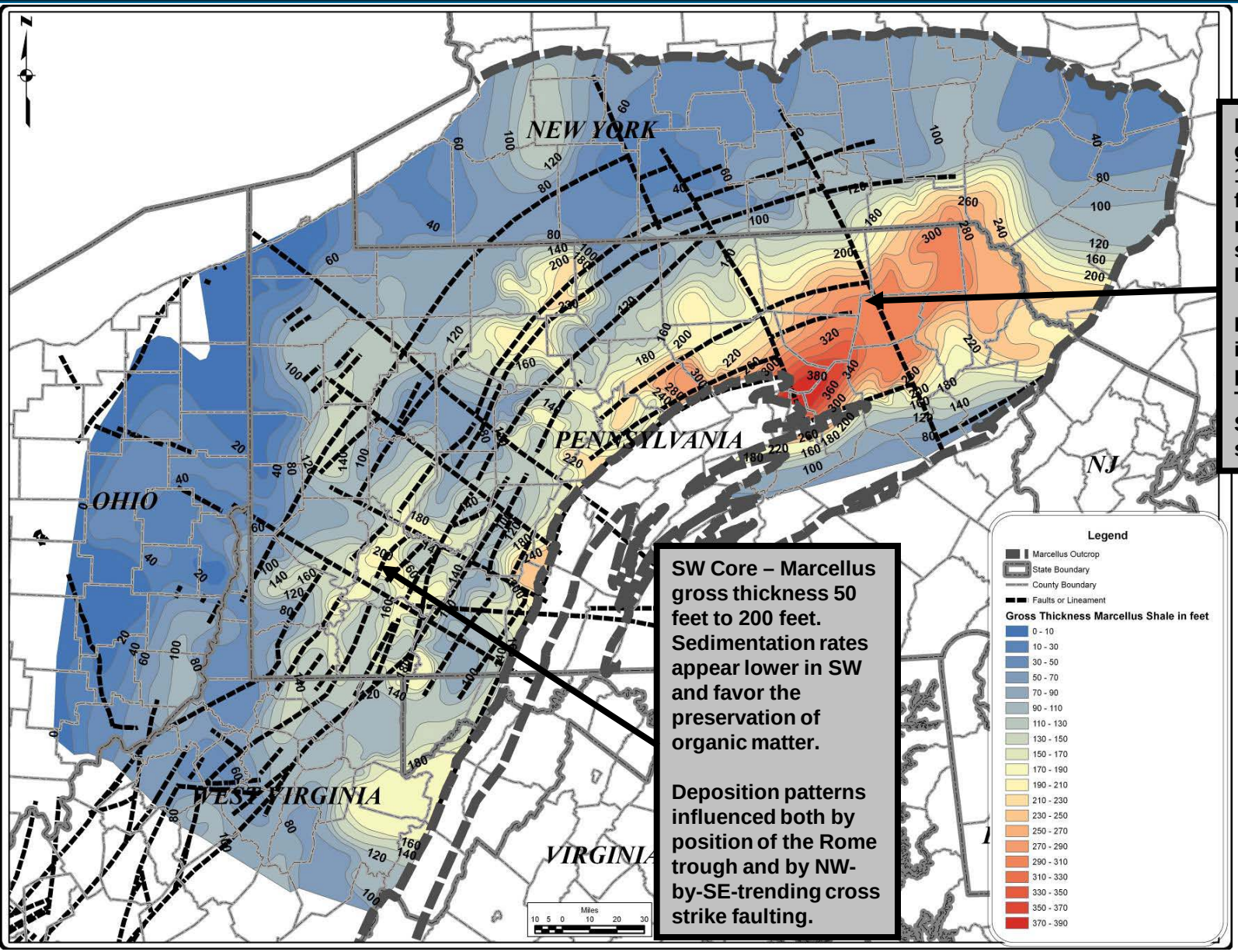
NE Core Area – Approximately 0.50 to 0.82 psi/ft.

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

Marcellus Thermal Maturity Patterns



Marcellus Shale Gross Thickness



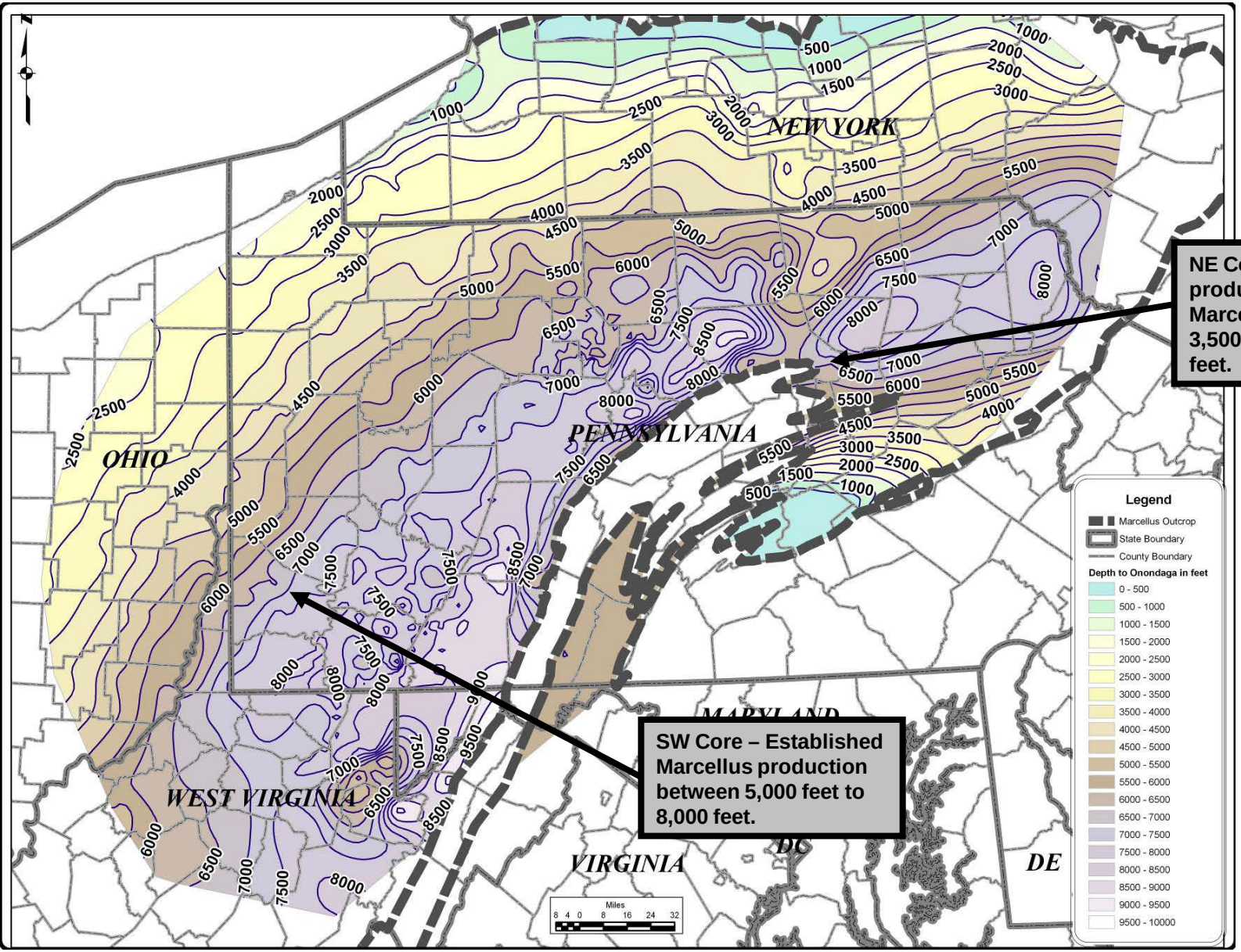
NE Core – Marcellus gross thickness over 150 feet to over 350 feet. Sedimentation rates appear significantly higher in NE play.

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

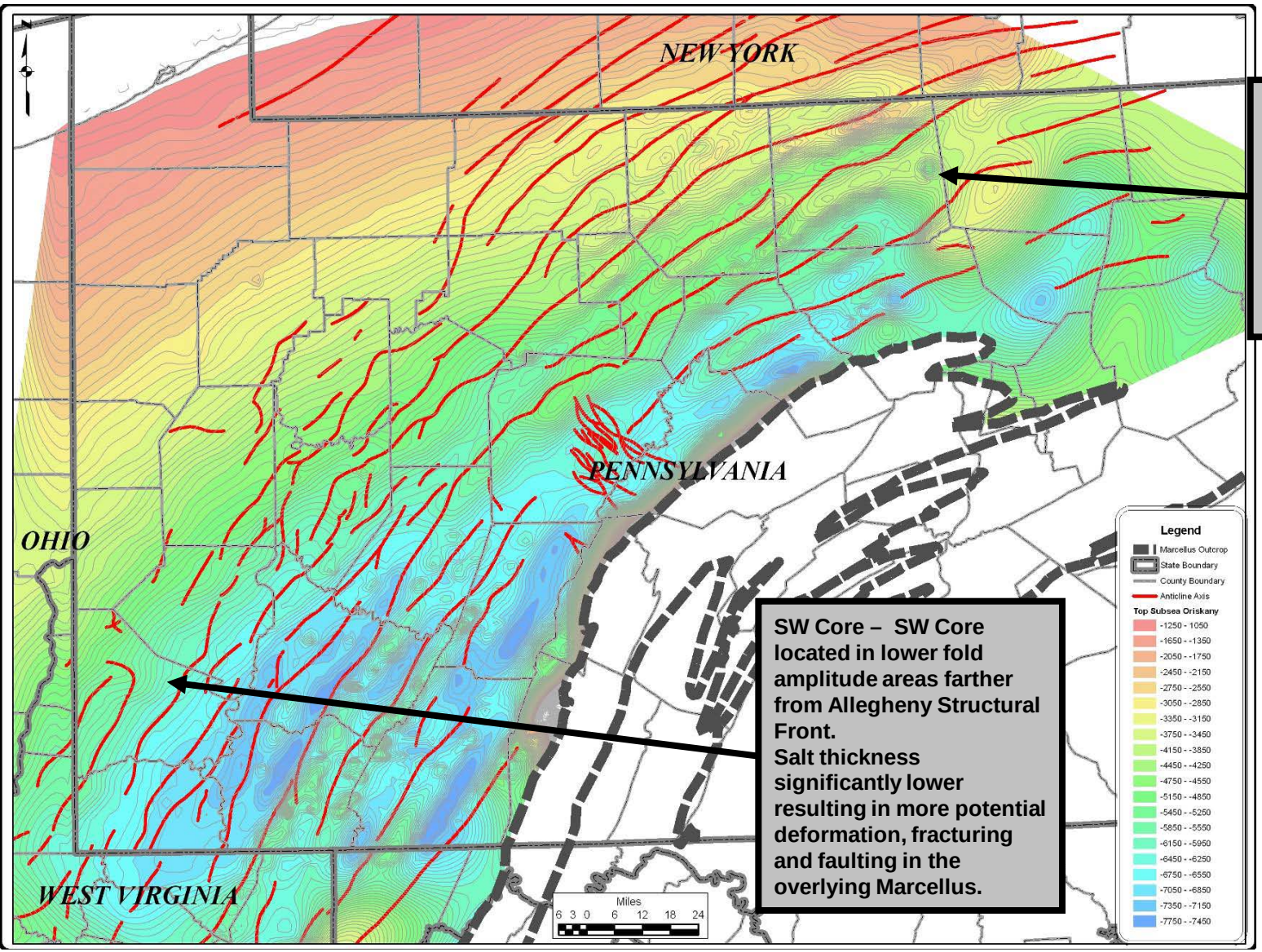
SW Core – Marcellus gross thickness 50 feet to 200 feet. Sedimentation rates appear lower in SW and favor the preservation of organic matter.

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

Marcellus Drilling Depth Map



Regional Oriskany Structure * Major Fold Trends

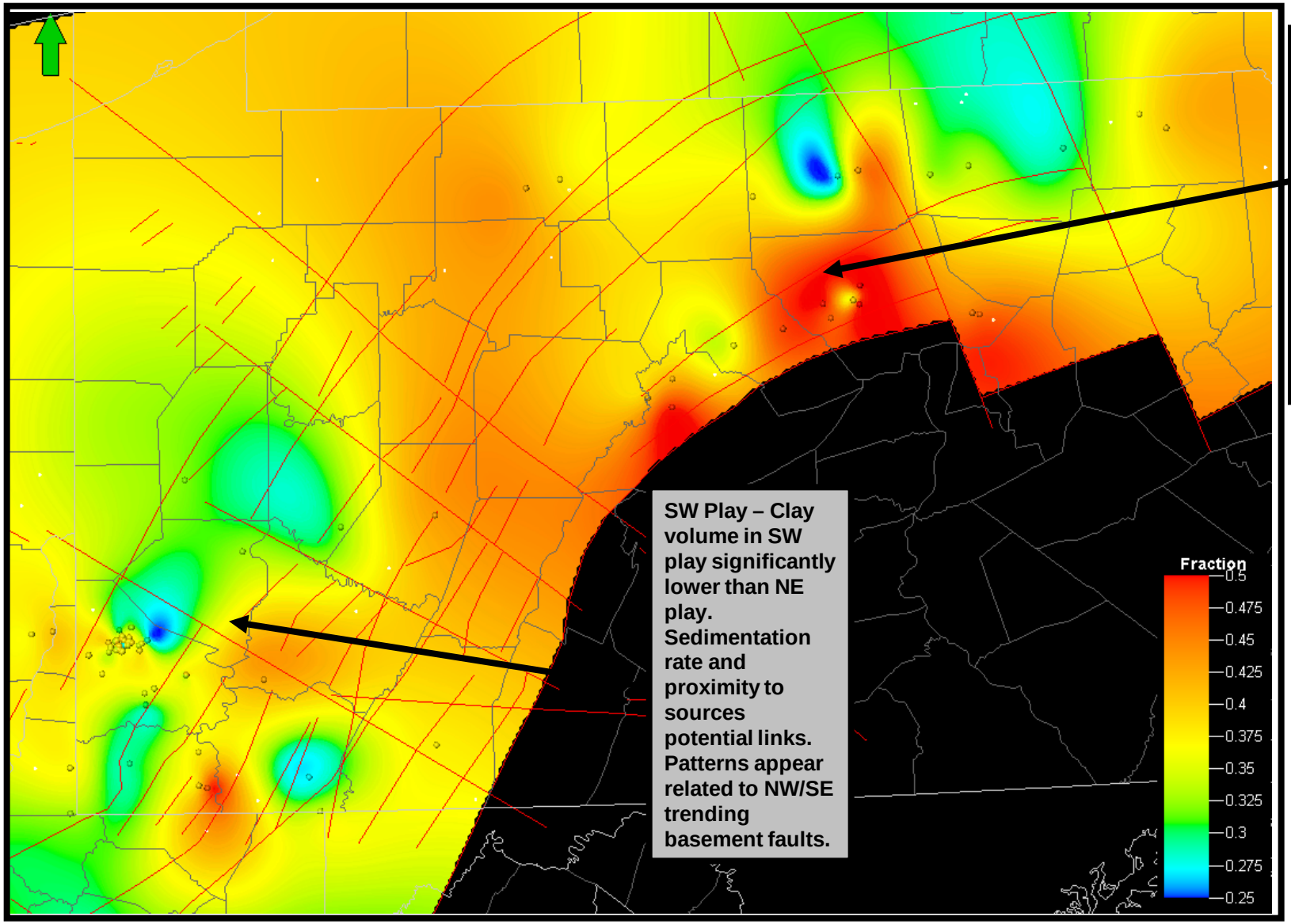


NE Core – NE Core situated with major fold belt with relatively high amplitude folding. Salt thickness significantly higher in NE play affecting density of fracturing and faulting in the Marcellus.

SW Core – SW Core located in lower fold amplitude areas farther from Allegheny Structural Front. Salt thickness significantly lower resulting in more potential deformation, fracturing and faulting in the overlying Marcellus.

Modified from Cate (1961)

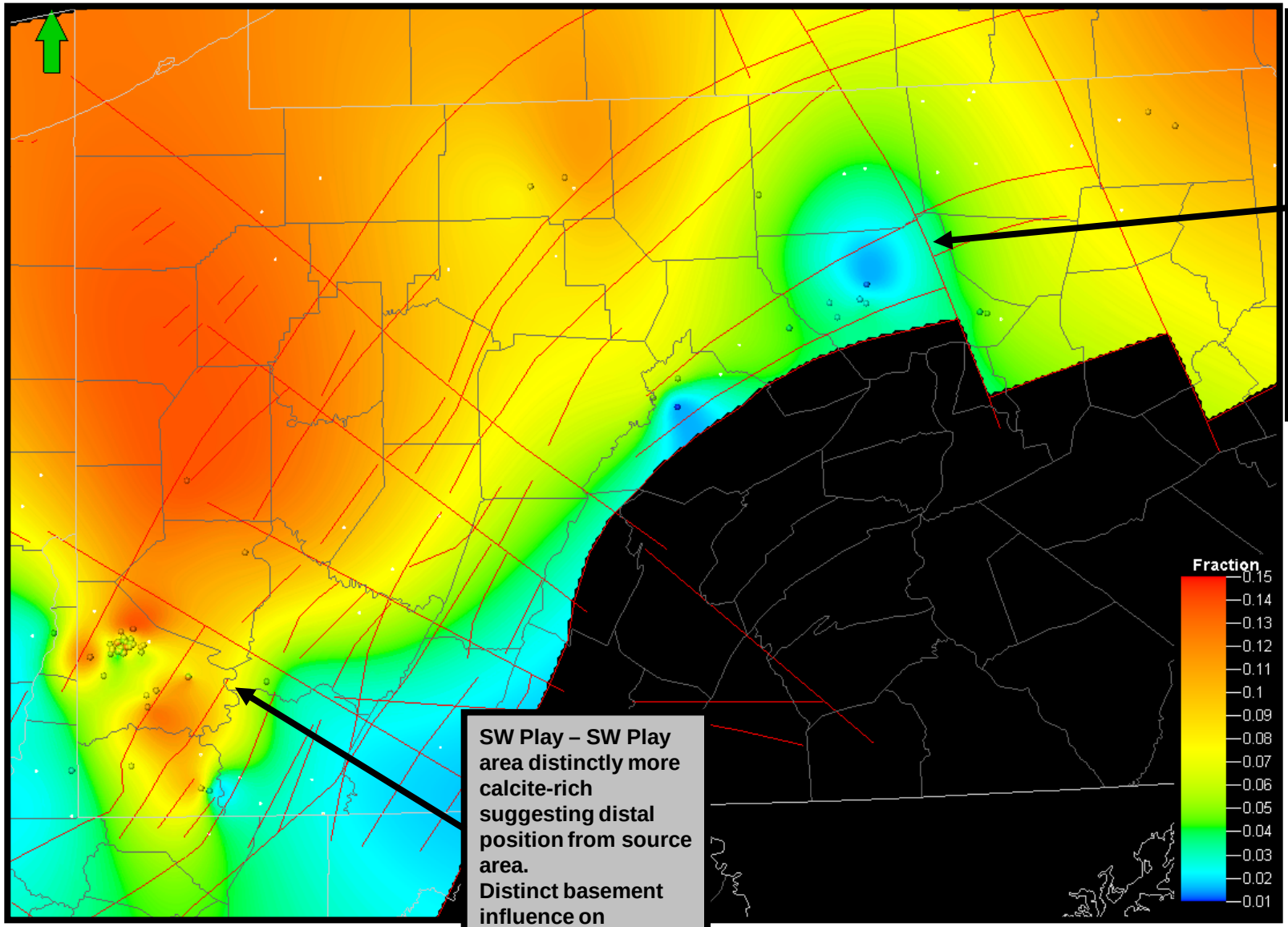
Vclay Comparison between SW & NE PA



NE Play – Clay volume of Marcellus interval significant elevated and related to sedimentation rate and proximity to source. Patterns appear affected by NW/SE basement fault trends.

SW Play – Clay volume in SW play significantly lower than NE play. Sedimentation rate and proximity to sources potential links. Patterns appear related to NW/SE trending basement faults.

Vcalcite Comparison between SW & NE PA



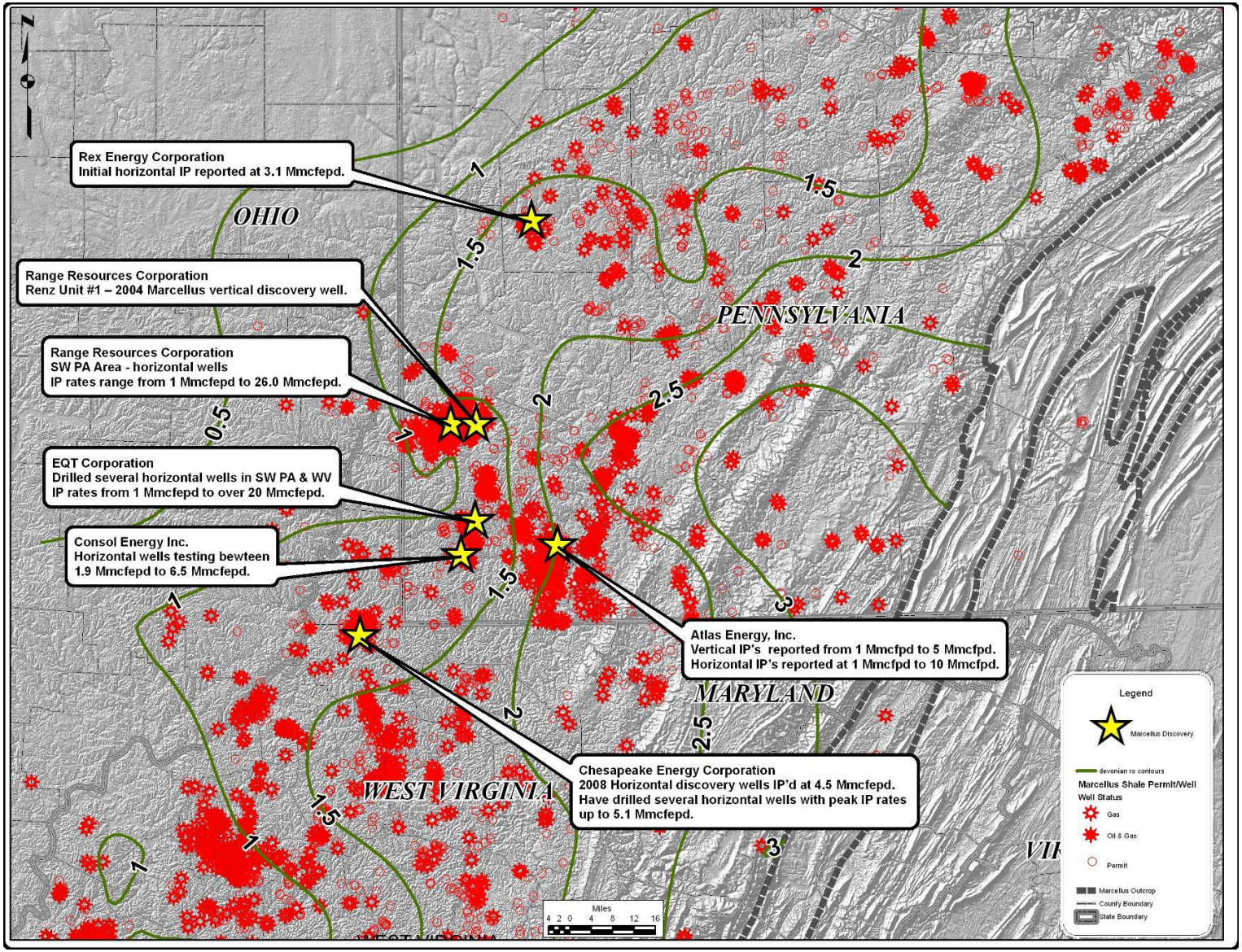
NE Play – NE Play shows overall lower calcite content and increased clay content suggesting closer proximity to source.

Susquehanna core area distinctly calcite-rich.

Distinct basement influence on mineralogy.

SW Play – SW Play area distinctly more calcite-rich suggesting distal position from source area.
Distinct basement influence on mineralogy.

SW PA Marcellus Core Area



SW Core Area

GIP- 40 BCF/mile to 150 BCF/mile.

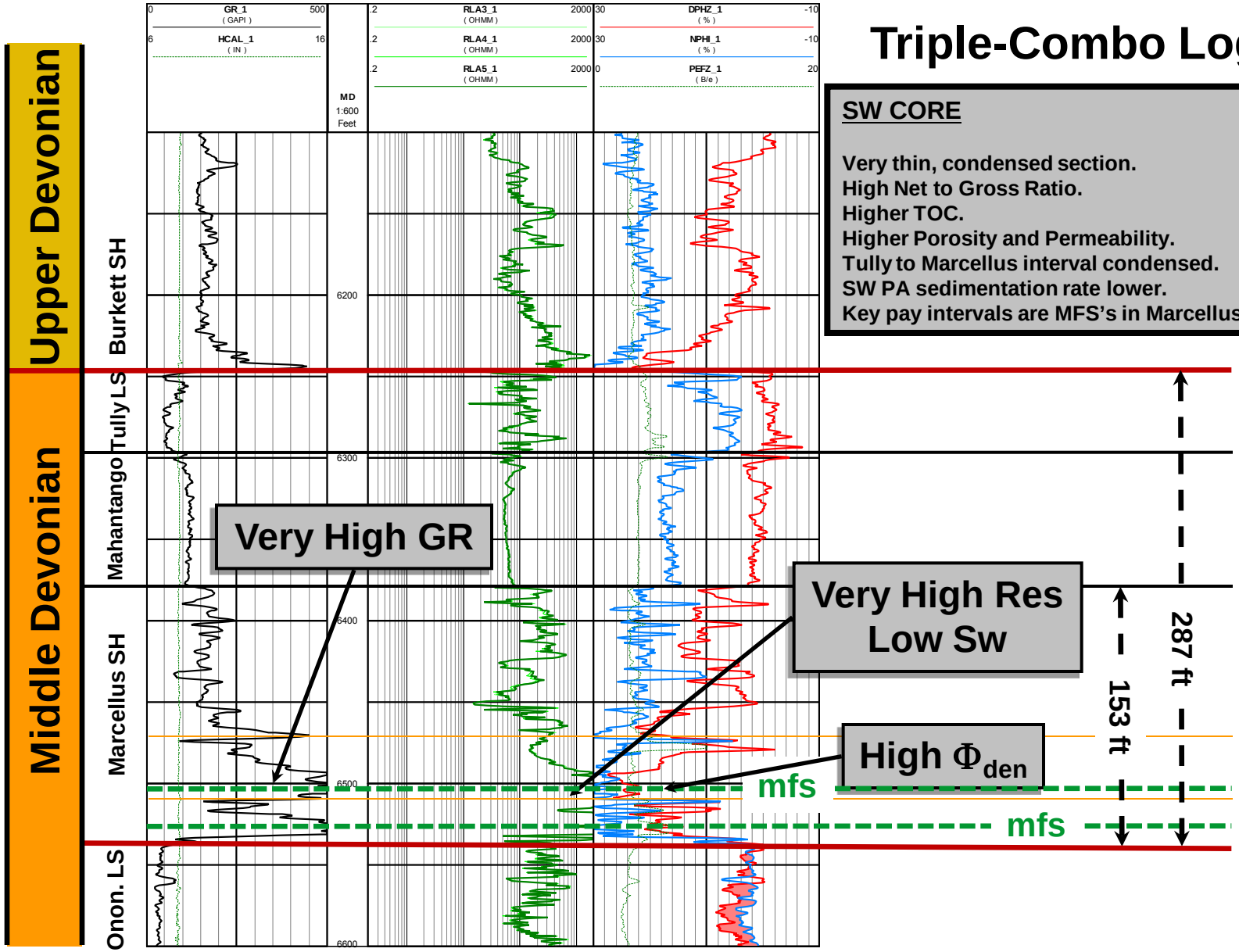
IPS – 1.0 Mmcfe/d to over 20 Mmcfe/d per lateral completion.

EUR – 2 Bcfeq to over 12 Bcfeq per lateral.

NGL's – Significant, up to 250,000 Bbls. per lateral in wet areas.

NGL-rich areas have superior economics over dry gas areas.

SW PA Marcellus Type Log

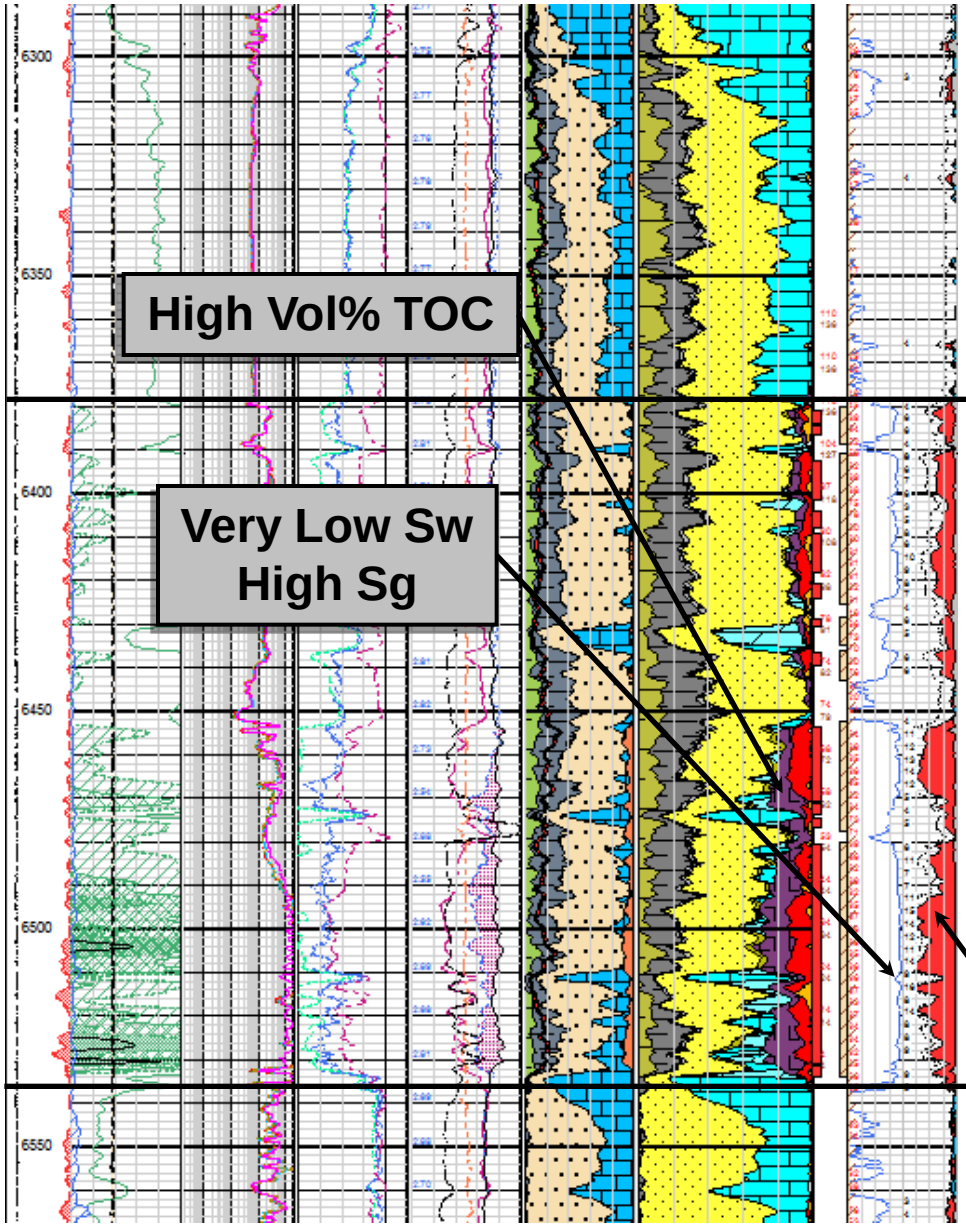


Triple-Combo Log

SW CORE

Very thin, condensed section.
High Net to Gross Ratio.
Higher TOC.
Higher Porosity and Permeability.
Tully to Marcellus interval condensed.
SW PA sedimentation rate lower.
Key pay intervals are MFS's in Marcellus.

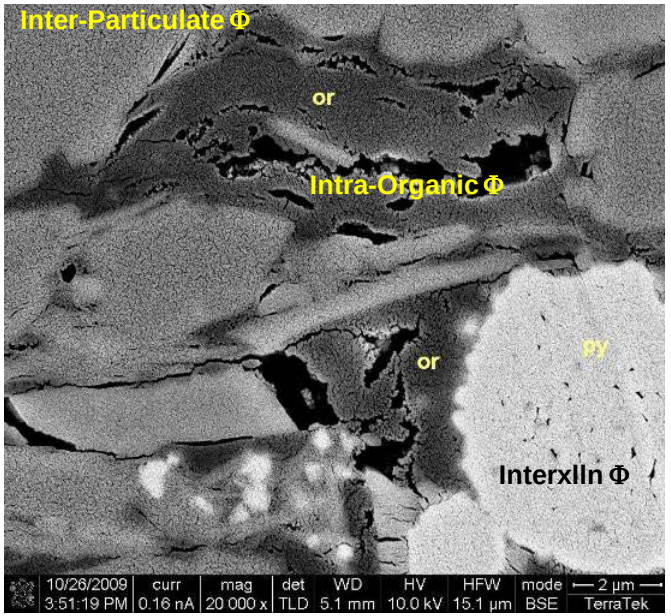
SW PA Marcellus Shale Analysis Log



Key Pore Types – SW PA Organic Rich Shales

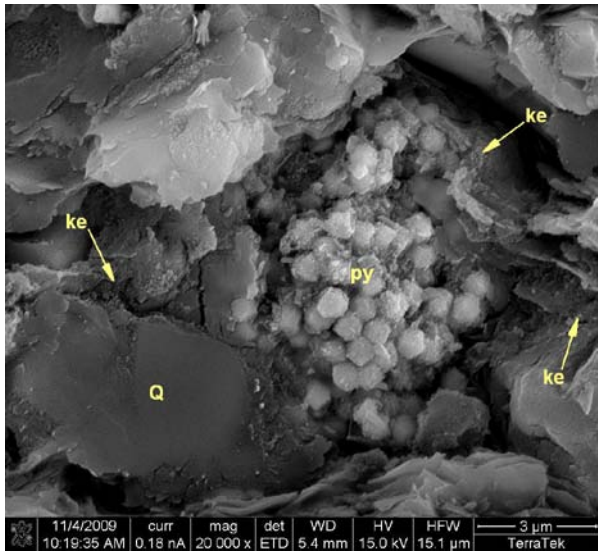
Intra-organic
- Present in all successful gas shales
- HC don't migrate far; organic C sorbent for HC
- Very low Sw
- Key pore type

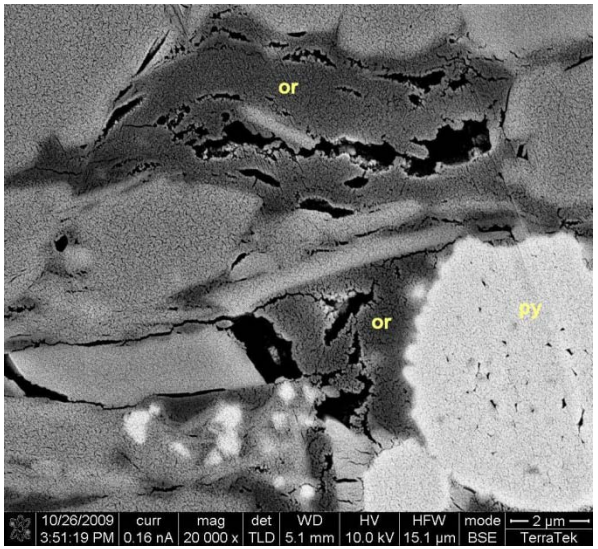
Inter-crystalline/particulate
- Between pyrite crystals in framboidal pyrite
- Between platy clay crystals or detrital clay grains/plates
- Higher Sw

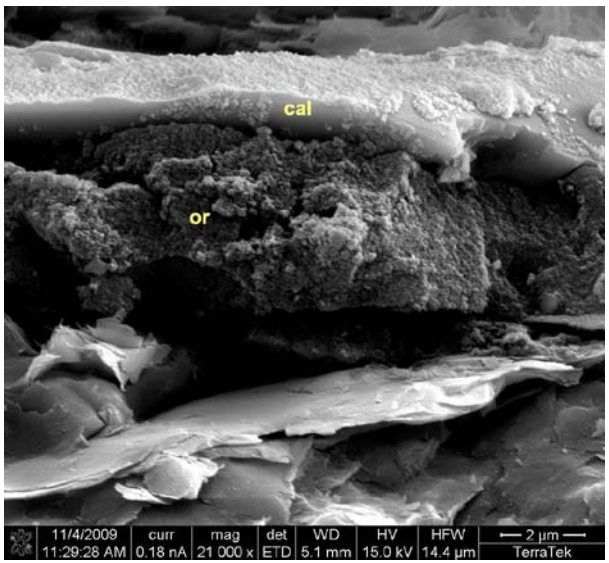


Porosity: 7.3-12.3% BV
GF Porosity: 5.6-10.5% BV
Permeability: 373-1379 nD
TOC: 4.5-12.9 wt%
Ro: 0.85-1.86%

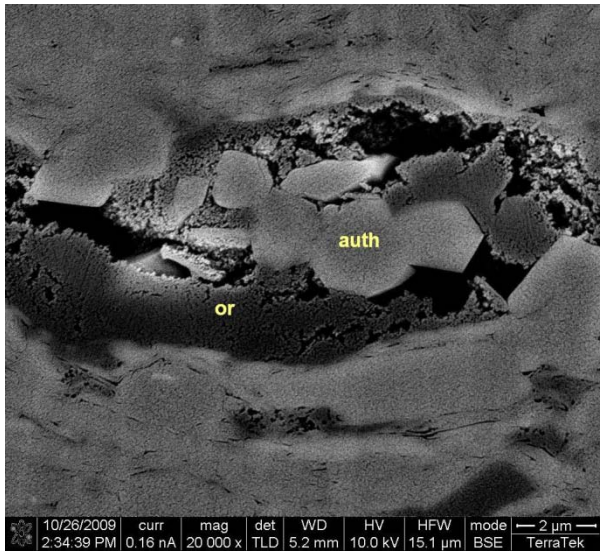
SW PA Marcellus Type Log Pore Types/SEM







Traditional SEM Method



Ar-Ion Beam Milling Method

Pore Types – SW PA Organic Rich/Calcite-Rich Marcellus Shale

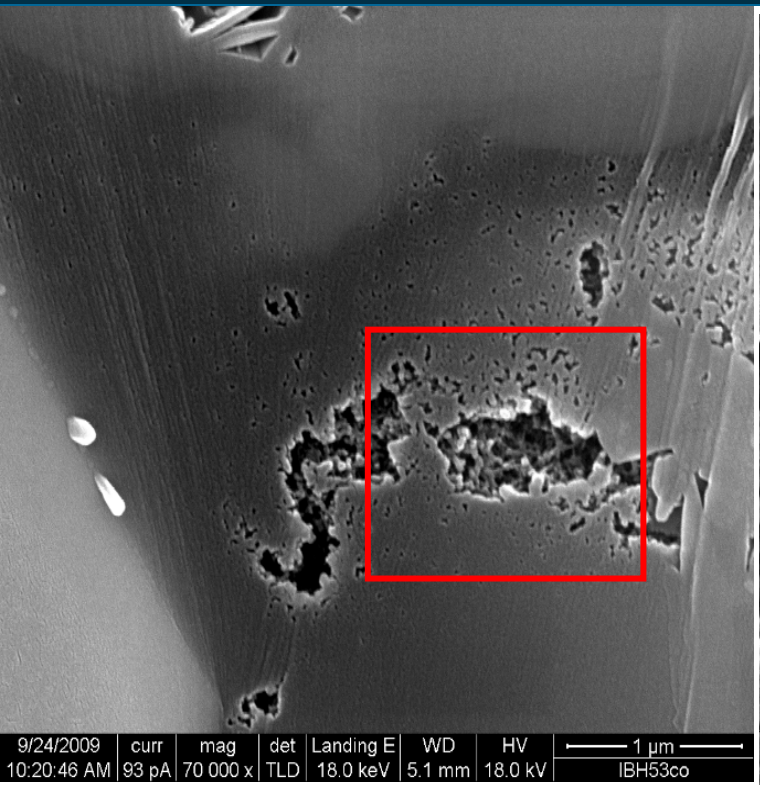
<u>Intra-organic</u>

- **Present in all successful gas shales**
- **HC don't migrate far; organic C sorbent for HC**
- **Very low Sw**
- **Key pore type**

<u>Inter-crystalline/particulate</u>

- **Between pyrite crystals in framboidal pyrite**
- **Between platy clay crystals or detrital clay grains/plates**
- **Higher Sw**

SW PA Marcellus Intra-Organic Porosity

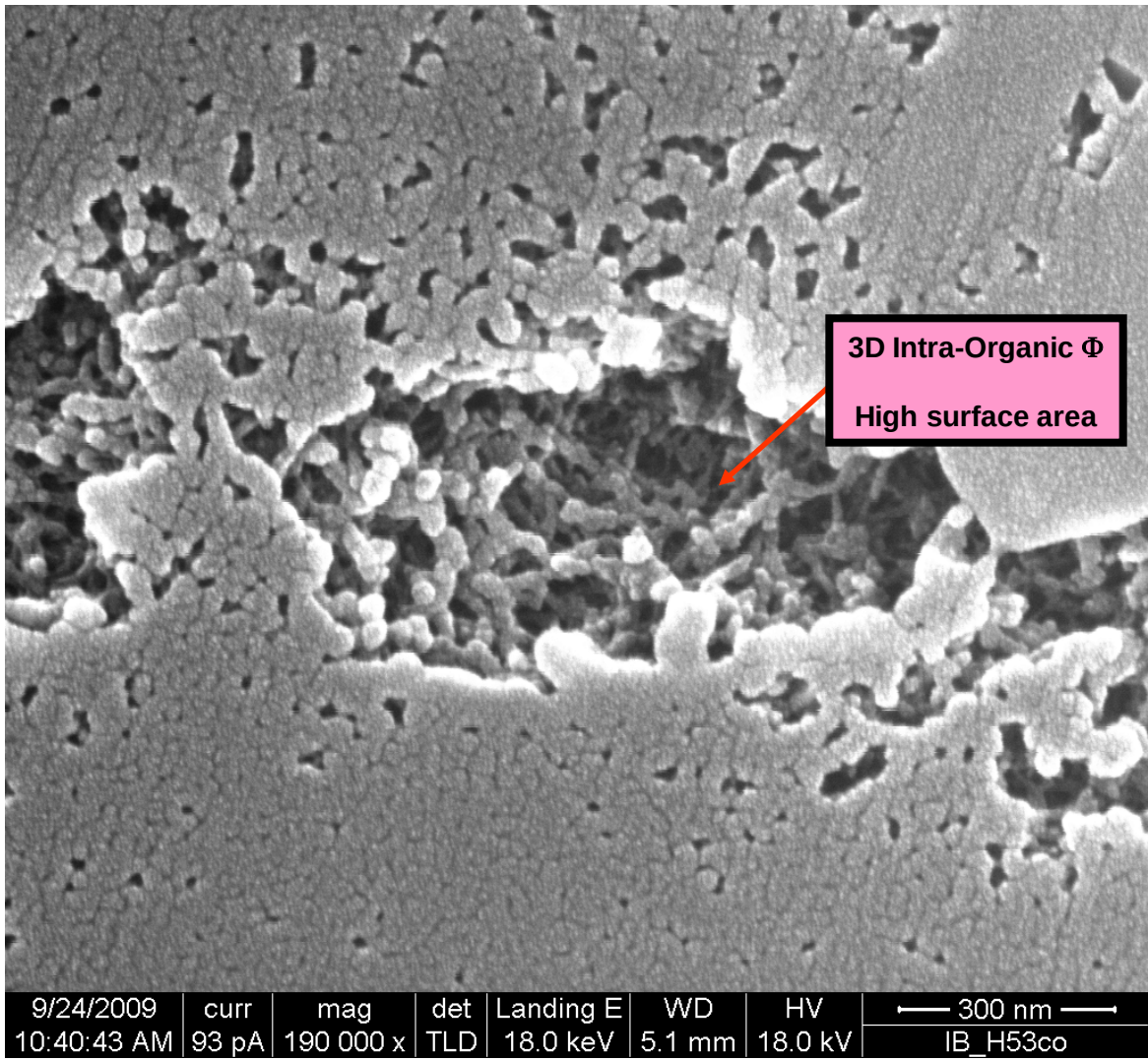


Ion-Milled Sample

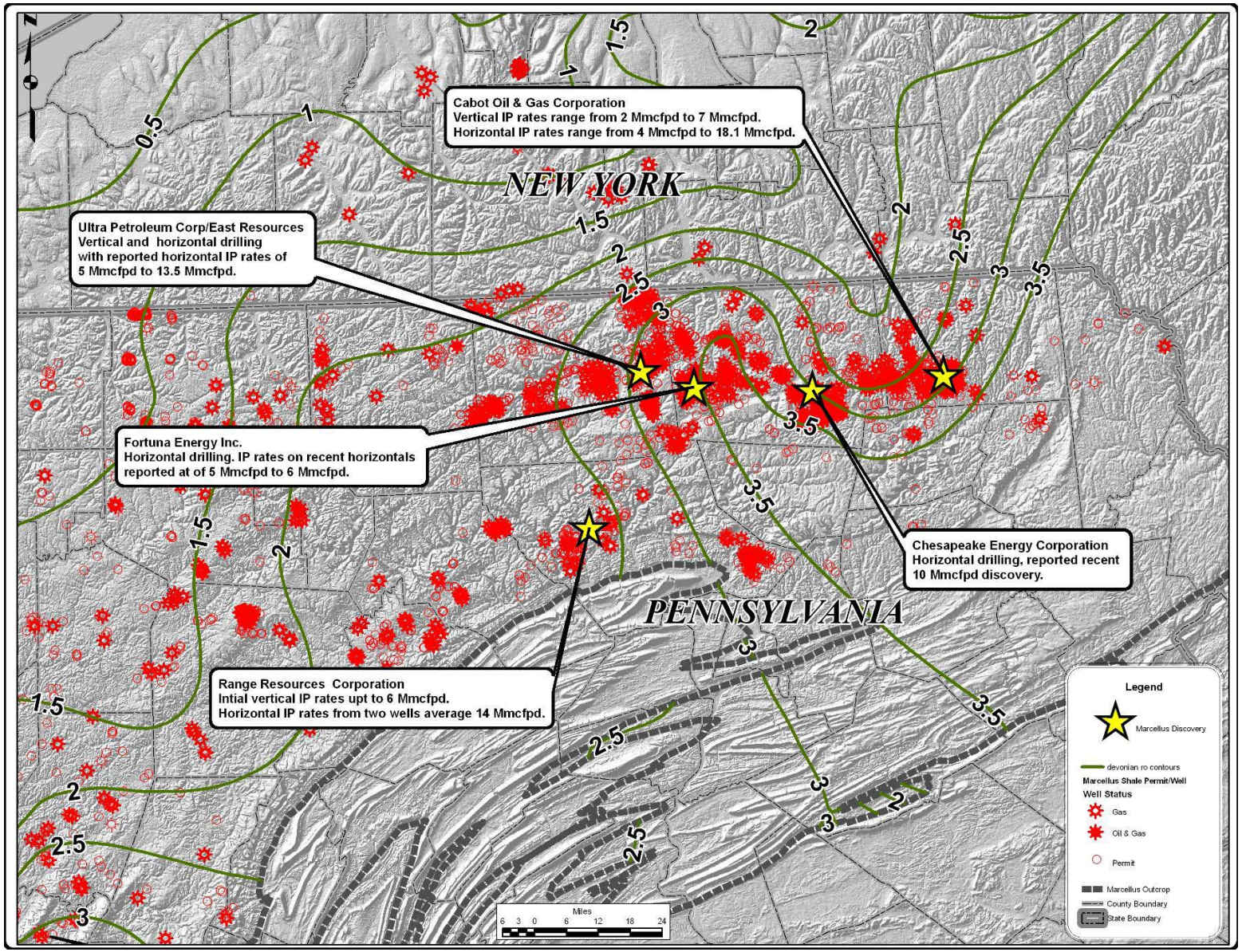
Intra-organic porosity key storage component of shales.

Contains both free and adsorbed gas.

Low or no Sw



NE PA Marcellus Core Area



NE Core Area

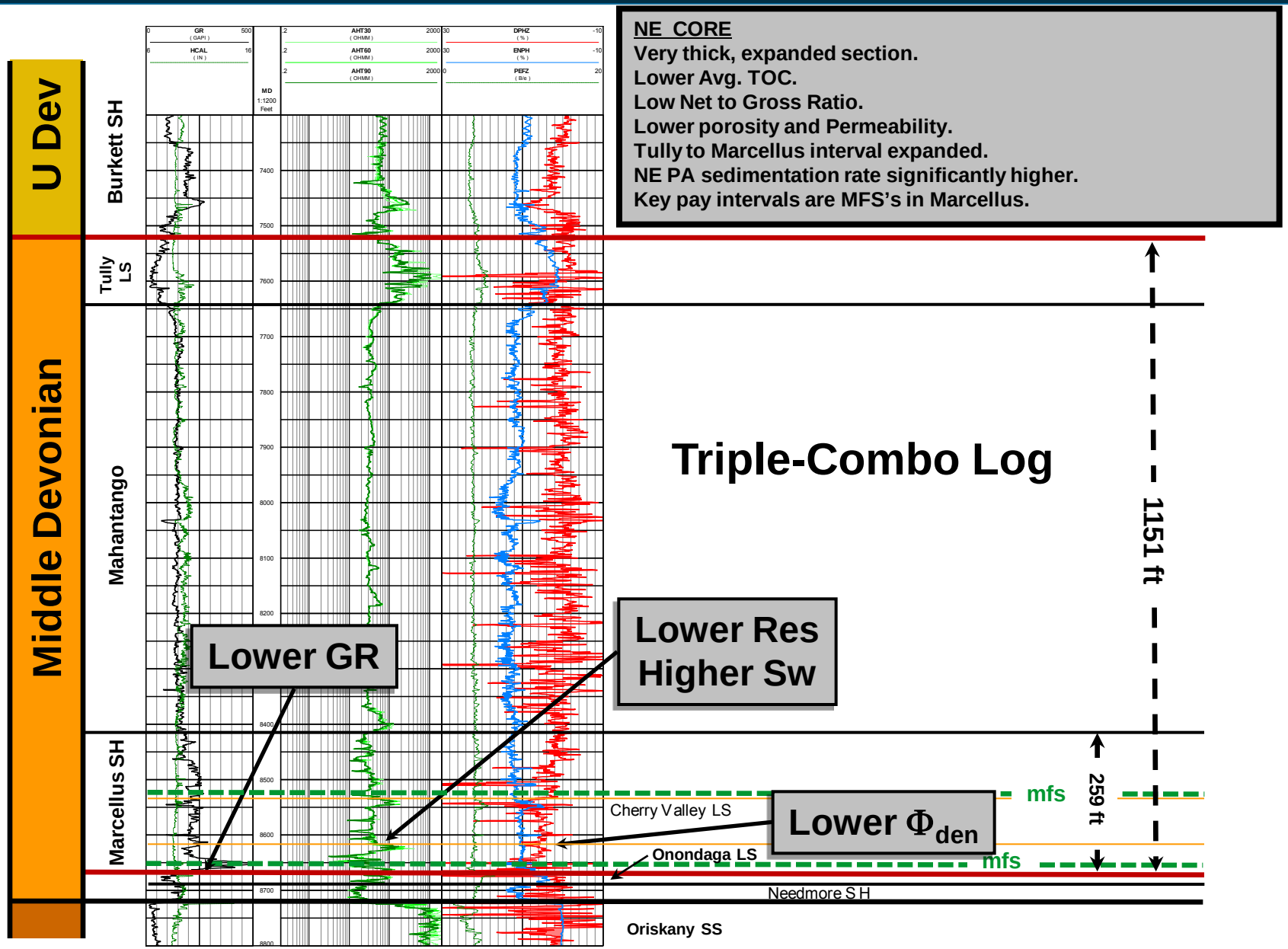
GIP – 40 BCF/mile to 180 BCF/mile

IPS – 1.0 Mmcfe/d to over 21 Mmcfpd.

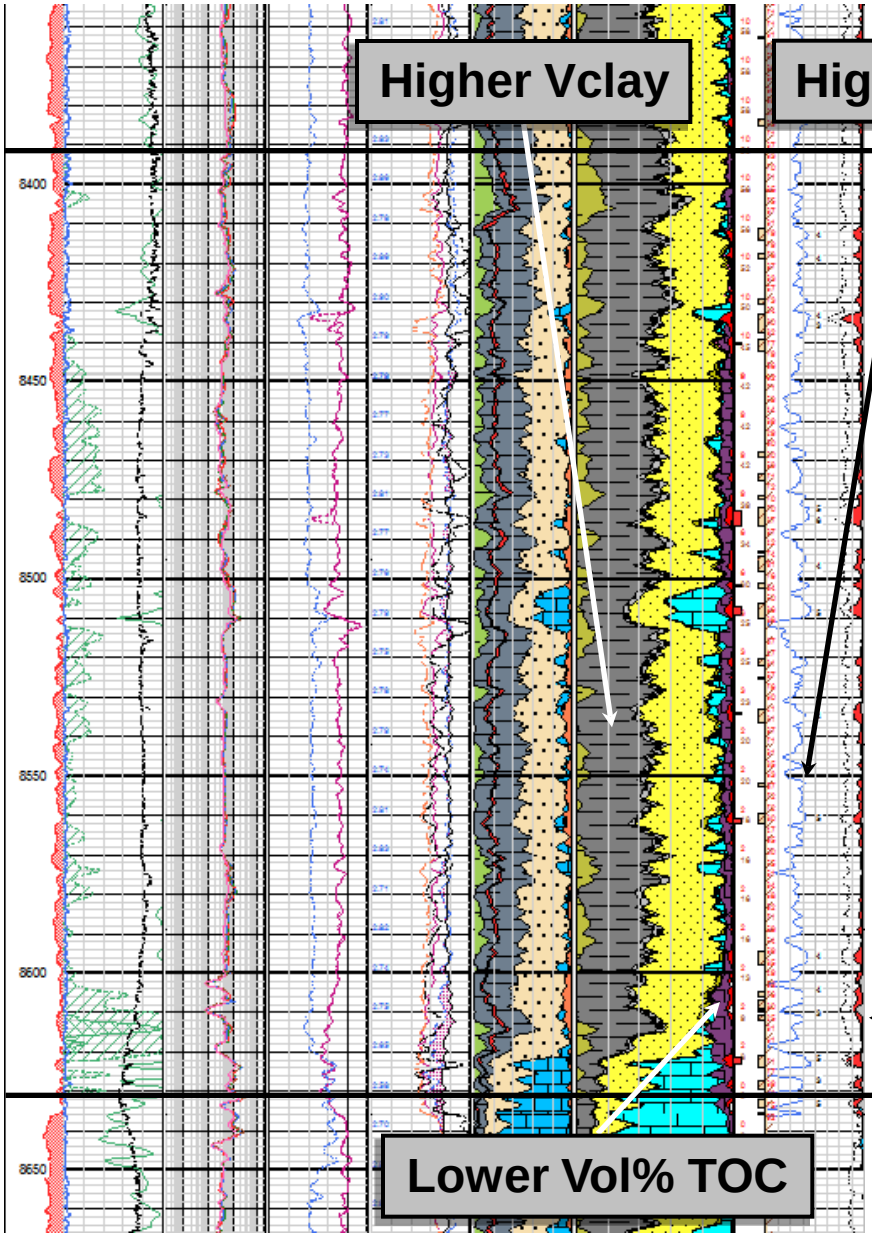
EUR's – 2 Bcf to 20 Bcf per lateral.

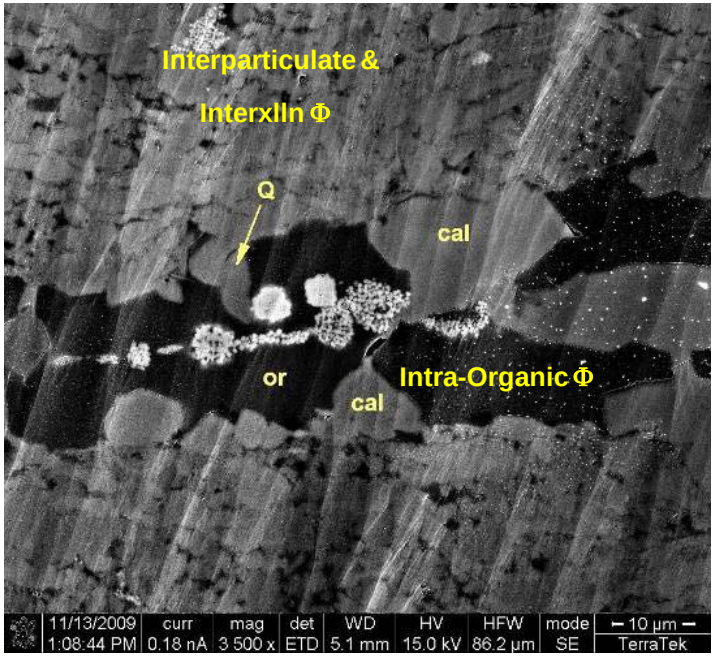
NGL – Not as significant to date as SW PA core area.

NE PA Marcellus Type Log



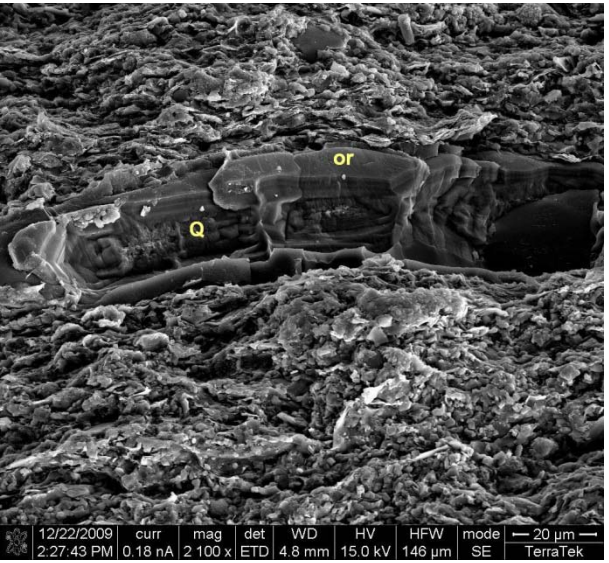
NE PA Marcellus Shale Analysis Log

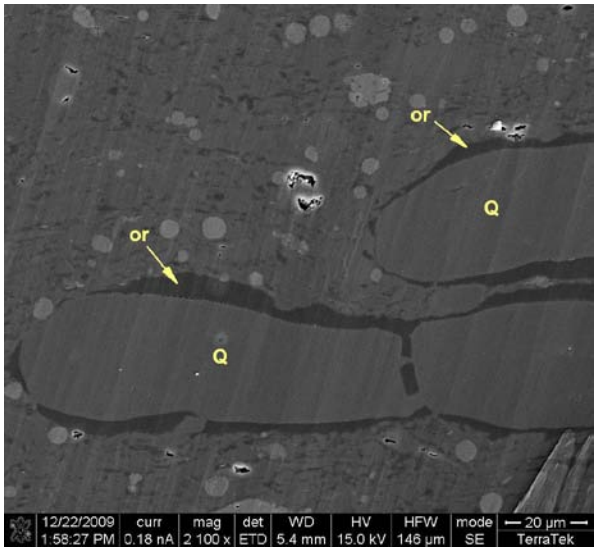


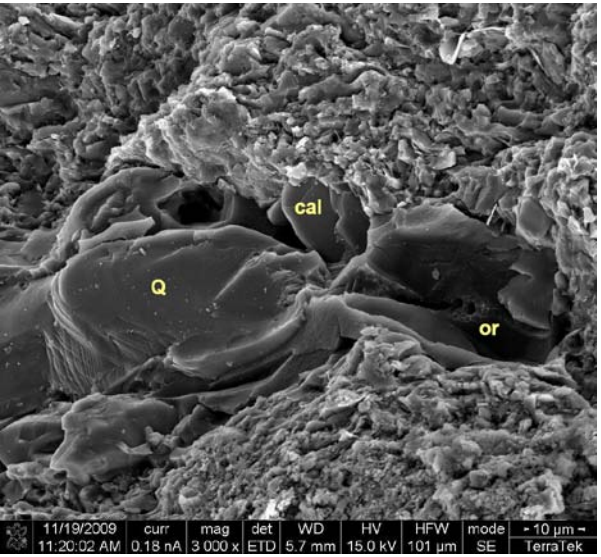


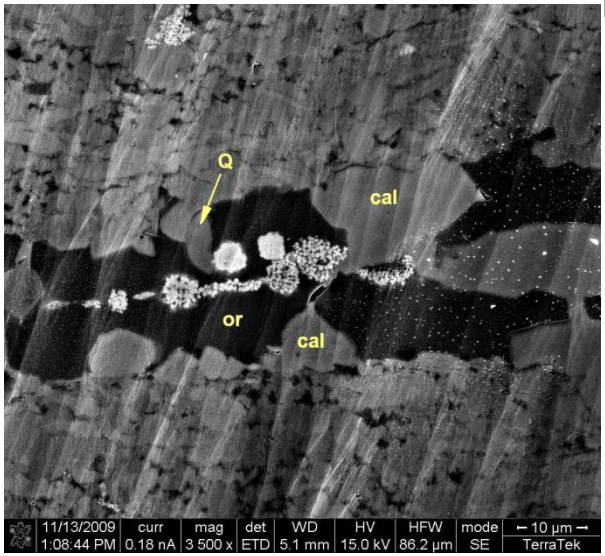
Porosity: 4.6-11.1% BV
GF Porosity: 3.9-10.0% BV
Permeability: 50-200 nD
TOC: 4.4-9.7 wt%
Ro: 1.23-2.56

NE PA Marcellus Type Log Pore Types/SEM









Traditional SEM Method

Ar-Ion Beam Milling Method

Pore Types – NE PA Clay –Rich Marcellus Shale

Intra-organic

- **Present in all successful gas shales**
- **HC don't migrate far; organic C sorbent for HC**
- **Very low Sw**
- **Key pore type**

Inter-crystalline/particulate

- **Between pyrite crystals in framboidal pyrite**
- **Between platy clay crystals or detrital clay grains/plates**
- **Higher Sw**

NE PA Marcellus Intra-Organic Porosity

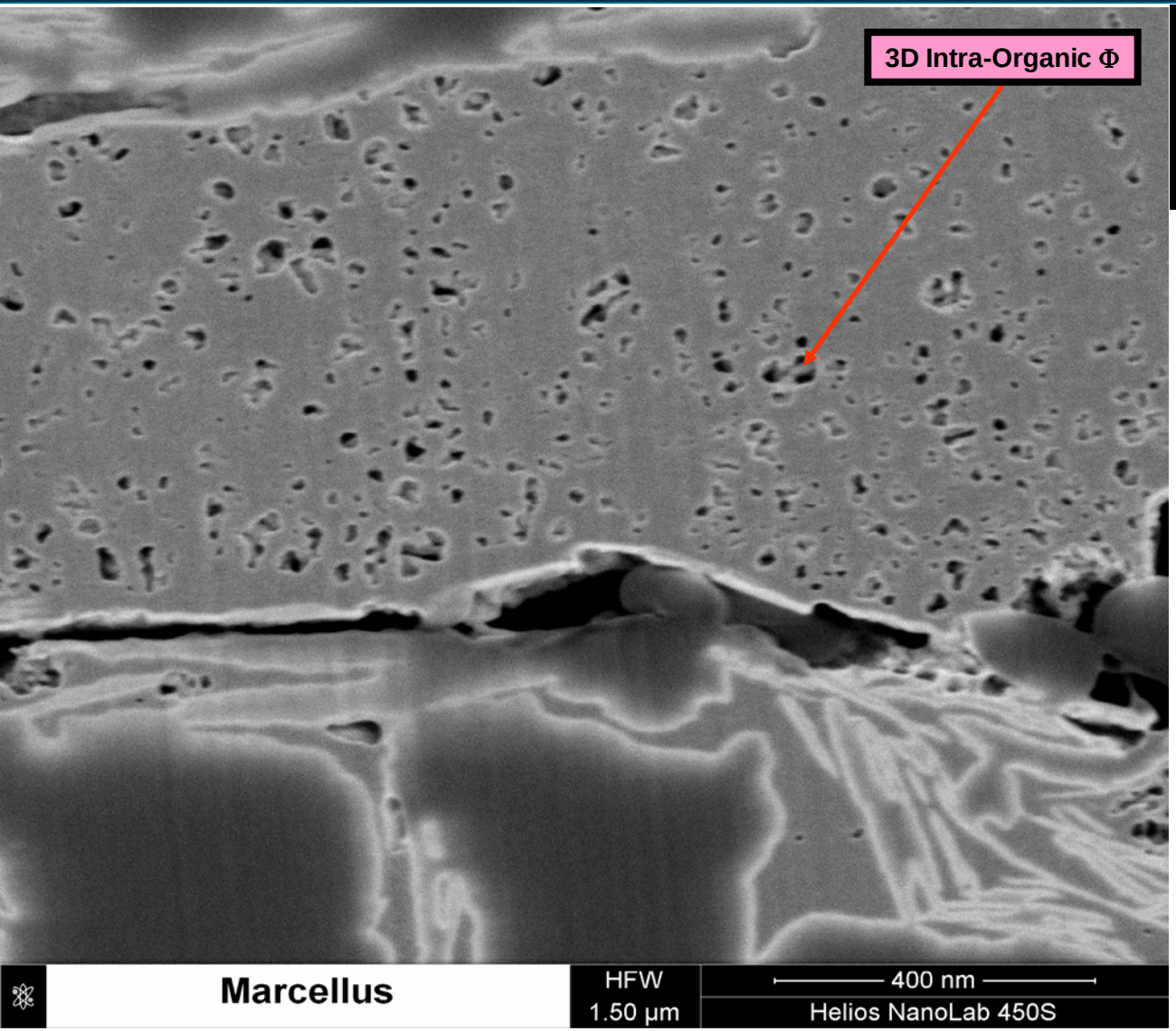
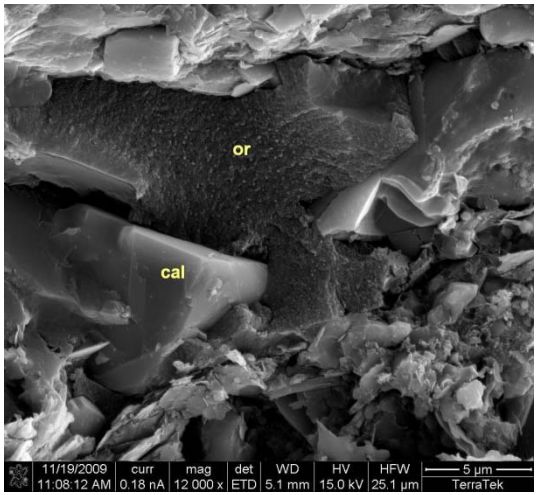


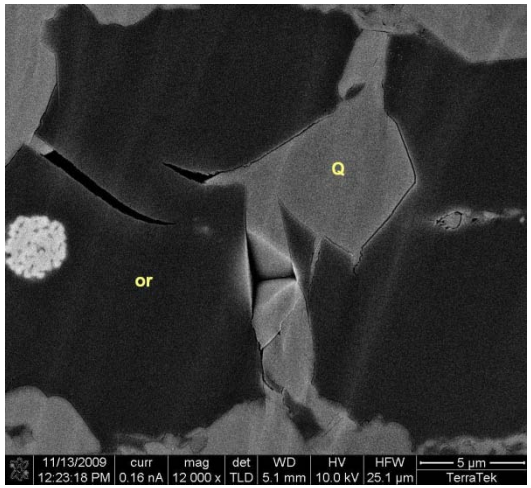
Photo Courtesy of Chris Laughrey

Ion-Milled Sample

Intra-organic porosity key storage component of shales.

Contains both free and adsorbed gas. Low or no Sw.





Comments & Summary

- **Organic content/concentration and associated intra-organic porosity at higher LOM are key factors for Marcellus Shale GIP and productivity**
  - **Less organic content and increased Vclay towards the NE Core area**
- **Higher intra-organic porosity and overpressure are related to maturity**
  - **Increased conversion of kerogen to HC and reduction of liquid HC to gas result in greater intra-organic porosity**
  - **Liquid HC converted to gas, in a relatively fixed pore space, is the overpressure mechanism**
- **SW Core and NE Core areas have similar Marcellus productivity (especially when liquids are included) despite the NE Core area having thicker gross Marcellus**