PETROPHYSICS, STRATIGRAPHY, AND DEPOSITIONAL DYNAMICS OF THE MIDDLE DEVONIAN MARCELLUS INTERVAL IN WEST VIRGINIA AND SOUTHWESTERN PENNSYLVANIA

Matthew Boyce
Ph.D. Candidate
West Virginia University

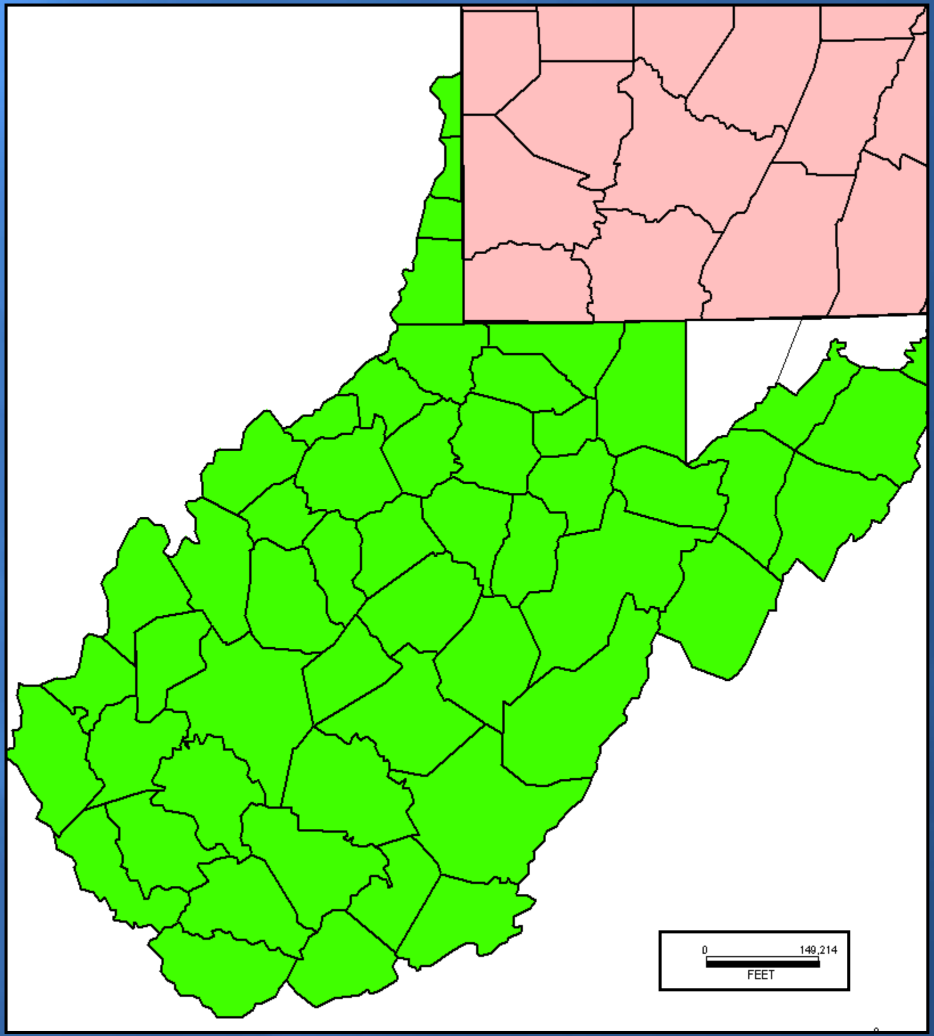
Outline

- Goals
- Study Area
- Regional Geology
- Lithostratigraphy and Depositional Environments
- Depositional Interpretations and Petrophysics
- Conclusions
- Future Work at WVU

Goals

- Improve subsurface stratigraphy of the Middle Devonian Marcellus interval
- Better define oxic and anoxic conditions
- Enhance the understanding of the well log relationship to lithology and organic richness
- Advance the understanding of depositional relationships and their economic potential

Study Area

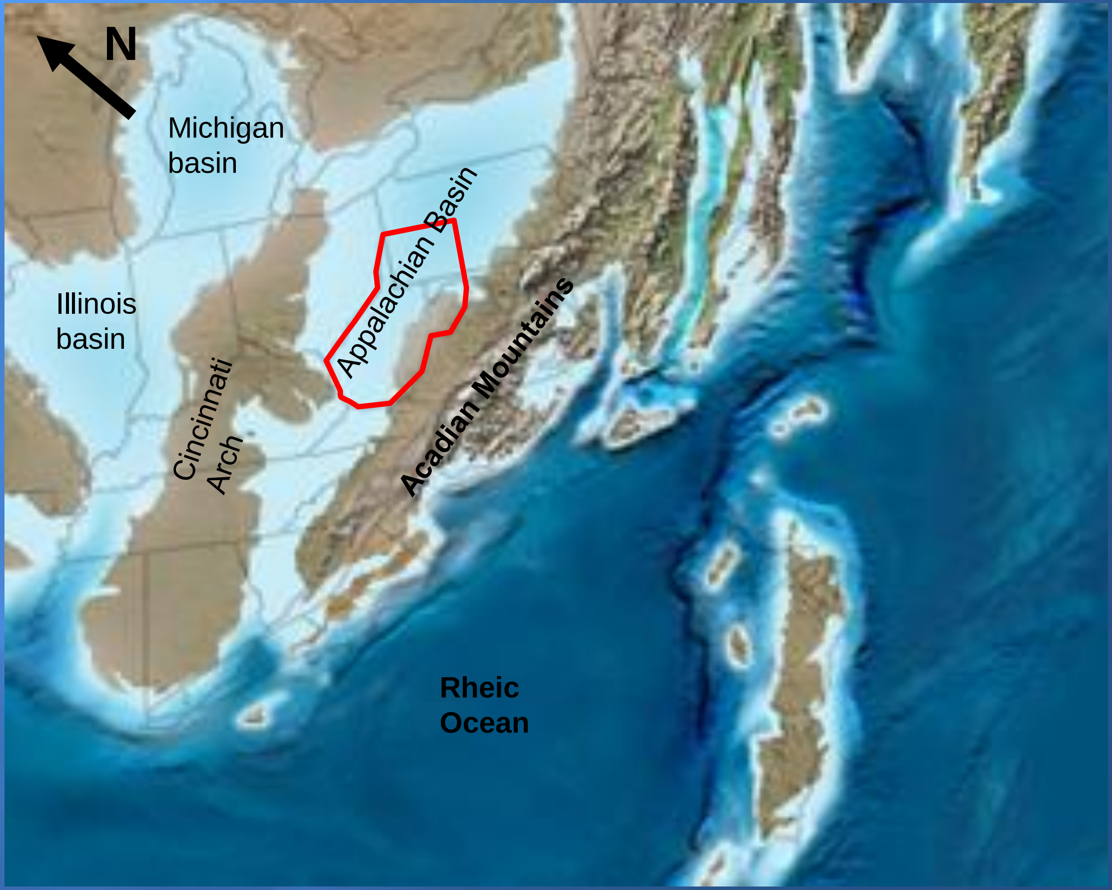


~23500 mi^2 (60865 km^2)

Regional Geology

Middle Devonian (385 Ma)
(Modified from Blakey, Ron: http://jan.ucc.nau.edu/~rcb7/namD385.jpg)

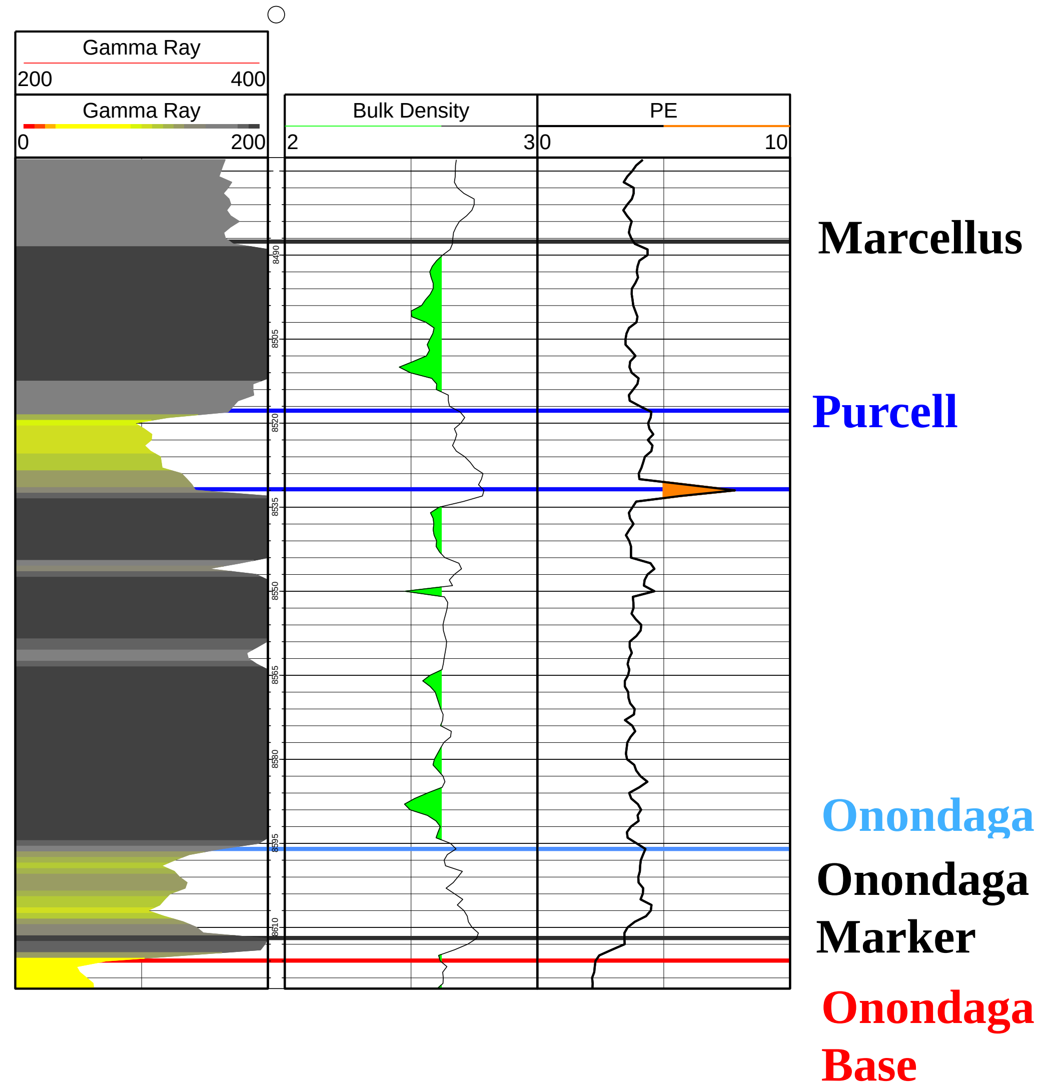
Regional Geology



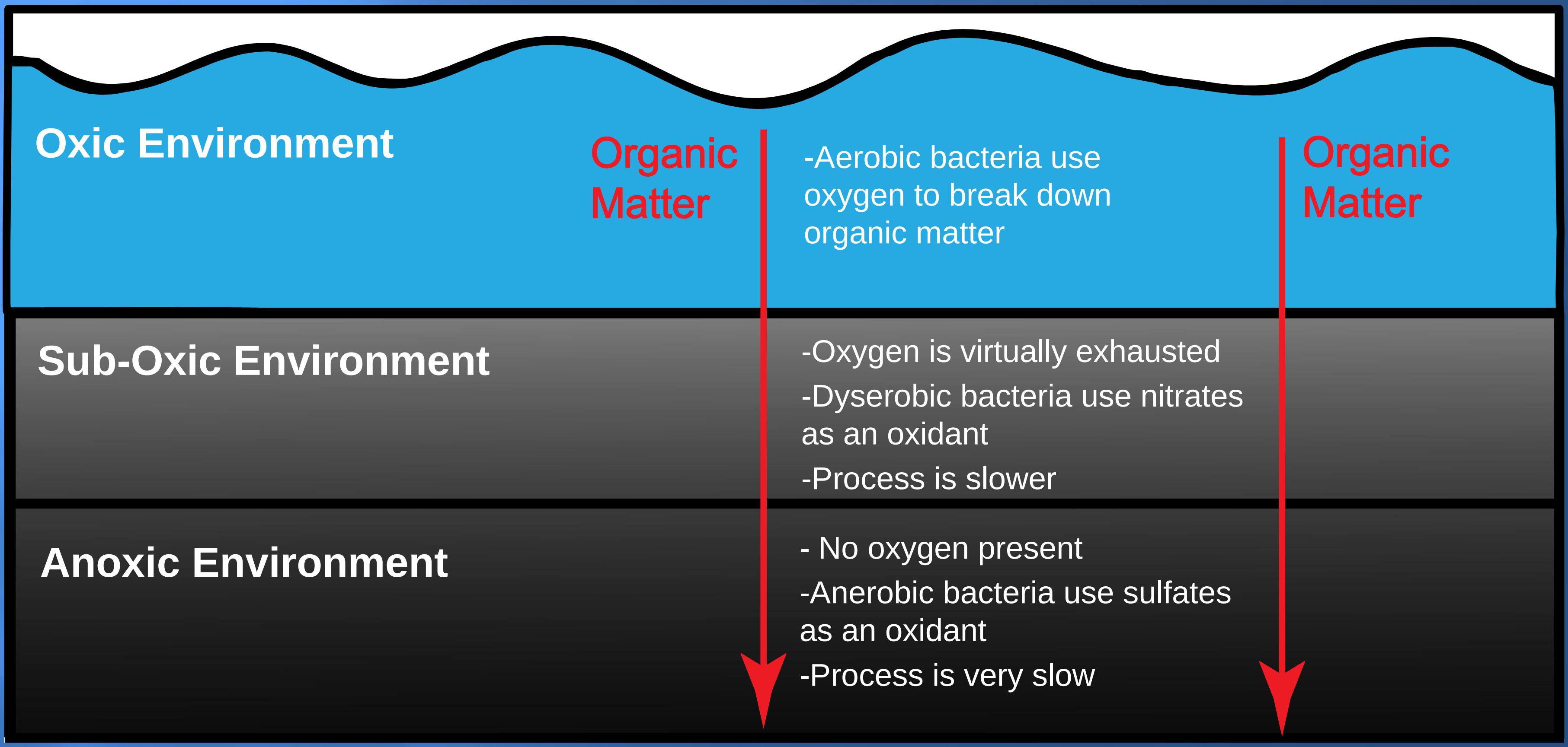
Middle Devonian (385 Ma)
(Modified from Blakey, Ron: http://jan.ucc.nau.edu/~rcb7/namD385.jpg)

Lithostratigraphy

Age	Formation	Member
Upper Devonian	Alexander	
	Huron	
	Rhinestreet Shale	
	Harrell Shale	
Middle Devonian	Tully Limestone	
	Mahantango Shale	
	Marcellus Shale	Purcell Limestone
	Onondaga Limestone	
	Huntersville Chert	
	Needmore Shale	
	Oriskany Sandstone	

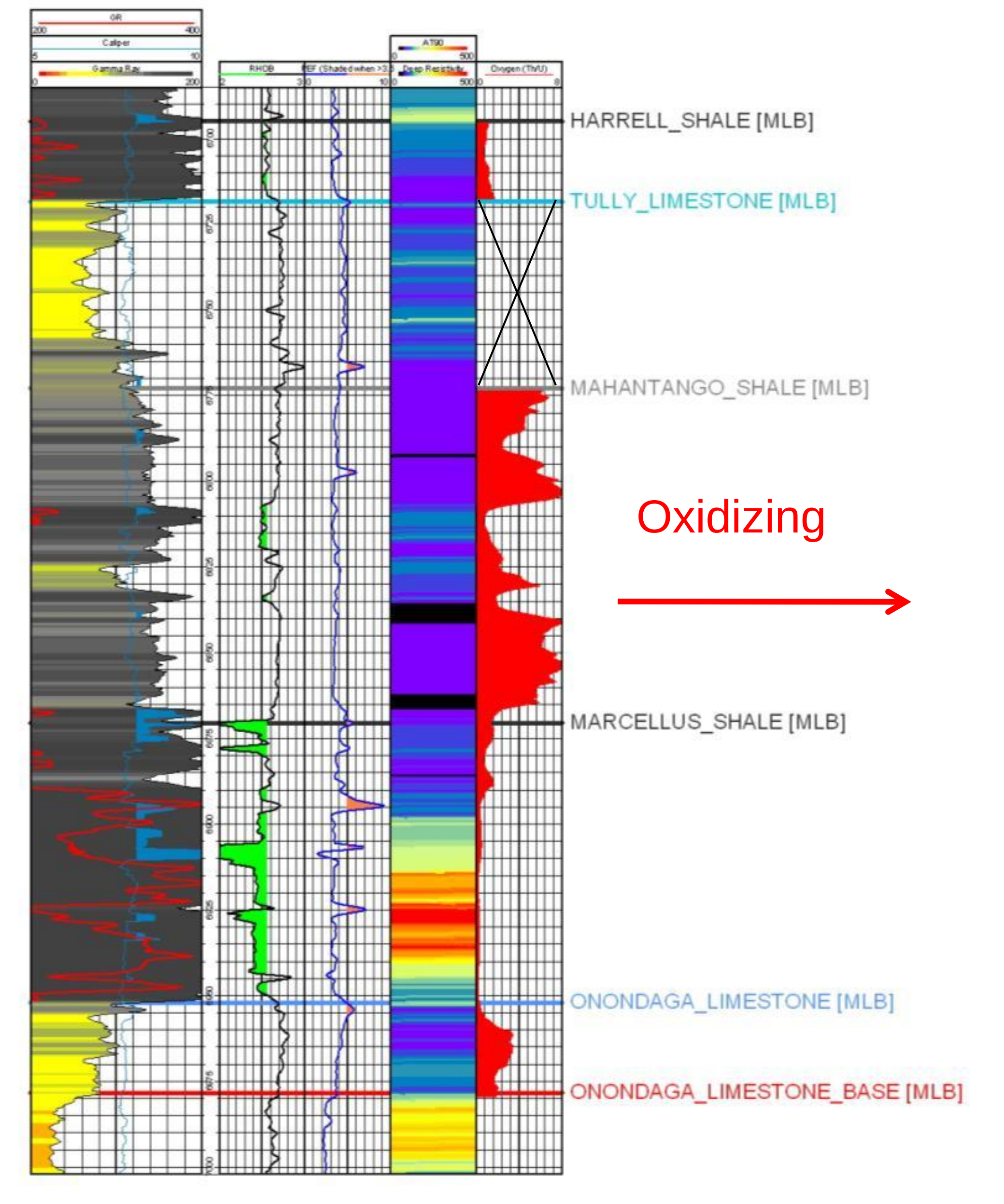


Depositional Environments



- Need low amount of sediment input, low circulation and high amount of organic input in order for a stratiphied water column to develop

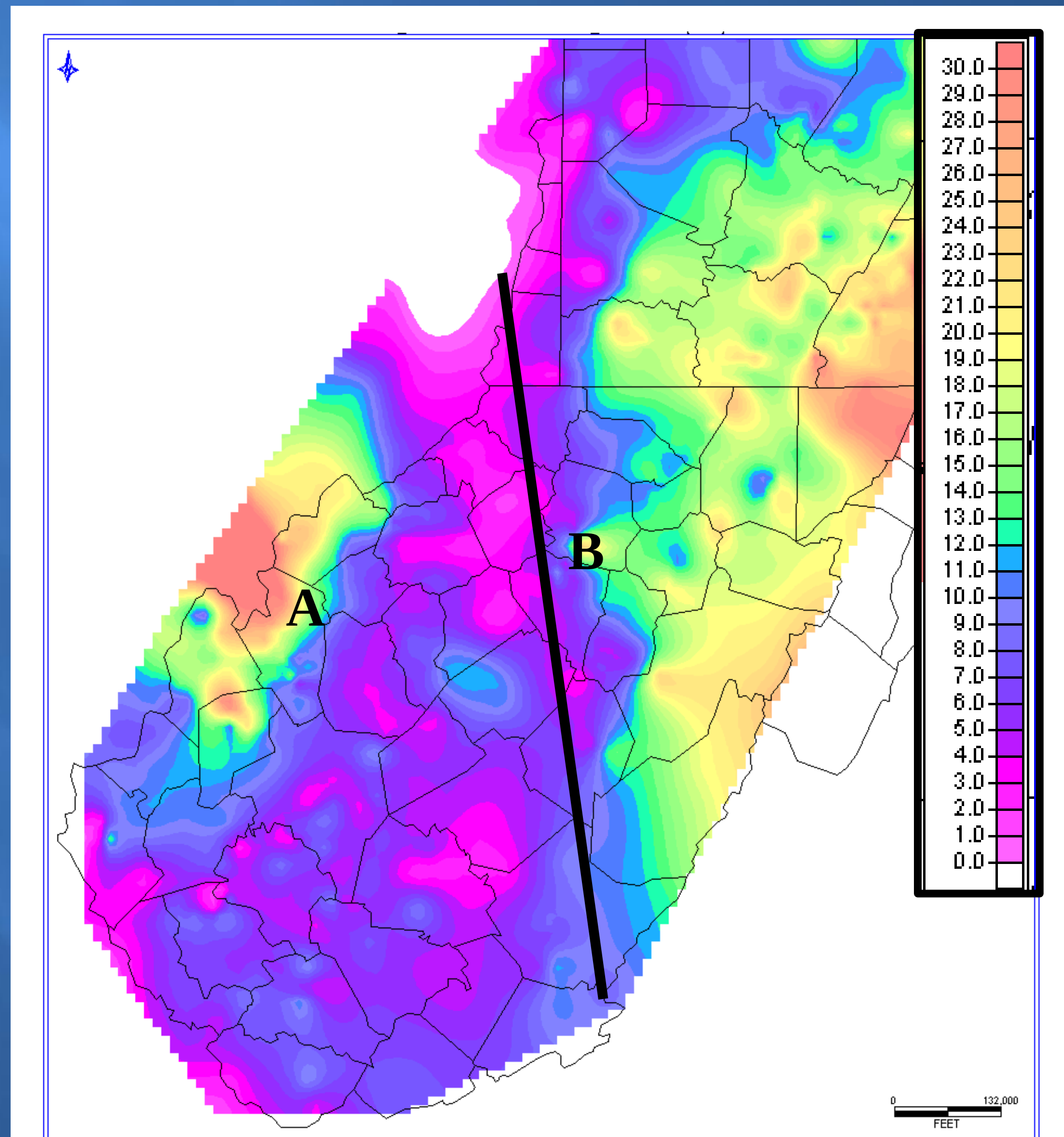
Petrophysical Analysis: Oxidizing and Reducing Conditions



- Reducing Vs. Oxidizing conditions determined by Th/U
- Works in Shale

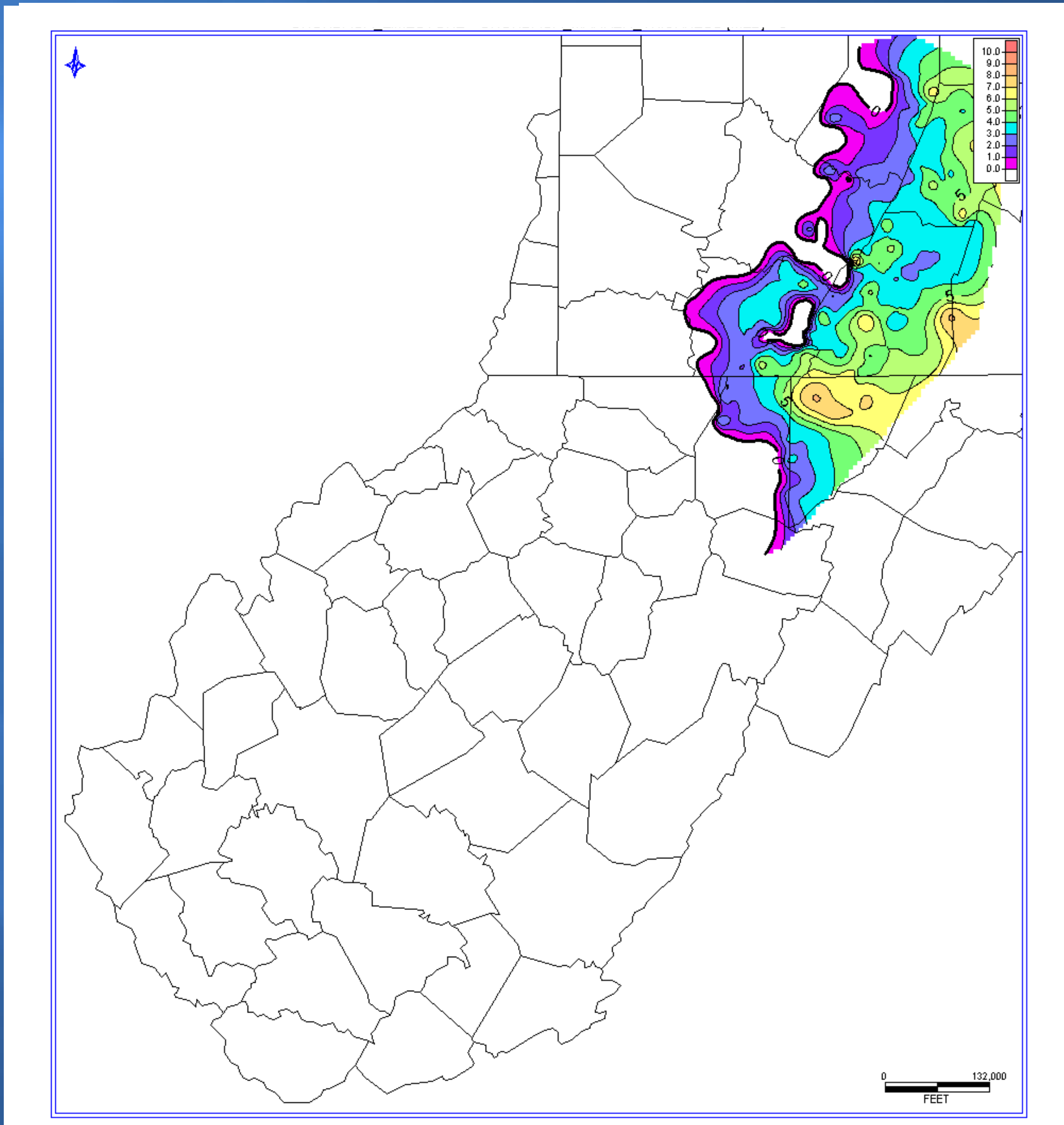
Regional Relationships: Onondaga Limestone Isopach

Age	Formation	Member
Upper Devonian	Alexander	
	Huron	
	Rhinestreet Shale	
	Harrell Shale	
Middle Devonian	Tully Limestone	
	Mahantango Shale	
	Marcellus Shale	Purcell Limestone
	Onondaga Limestone	
	Huntersville Chert	
	Needmore Shale	
	Oriskany Sandstone	

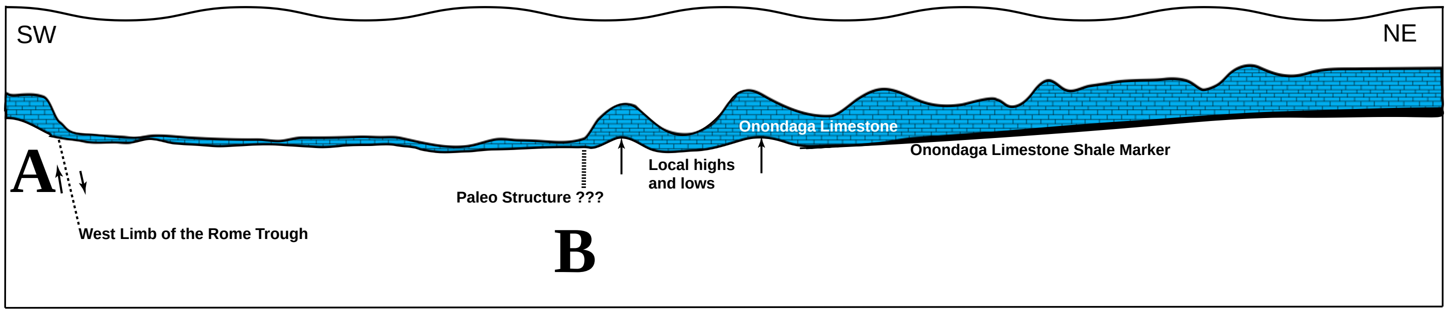


Regional Relationships: Onondaga Black Shale Marker Isopach

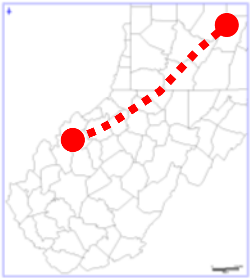
Age	Formation	Member
Upper Devonian	Alexander	
Upper Devonian	Huron	
Upper Devonian	Rhinestreet Shale	
Upper Devonian	Harrell Shale	
Middle Devonian	Tully Limestone	
Middle Devonian	Mahantango Shale	
Middle Devonian	Marcellus Shale	Purcell Limestone
Middle Devonian	Onondaga Limestone	
Middle Devonian	Huntersville Chert	
Middle Devonian	Needmore Shale	
Middle Devonian	Oriskany Sandstone	



Depositional Model: Onondaga Limestone

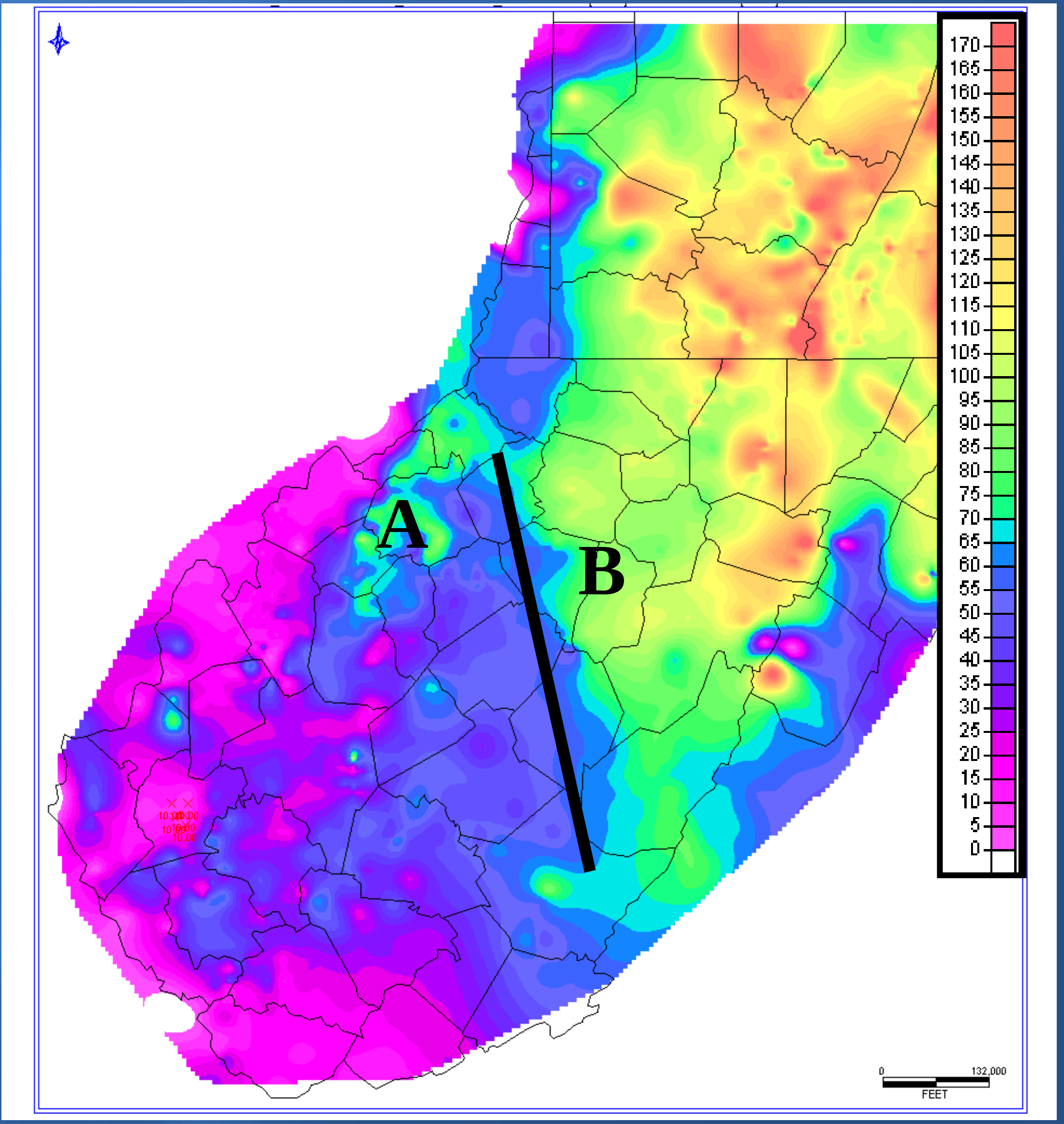


- ❑Offshore eperic sea
- ❑Limestone and black shale are facies in this environment
- ❑Limestone deposition across the study area
- ❑Structural highs and lows locally enhanced carbonate deposition
- ❑More limestone deposition to the northeast and across the west limb of the Rome Trough



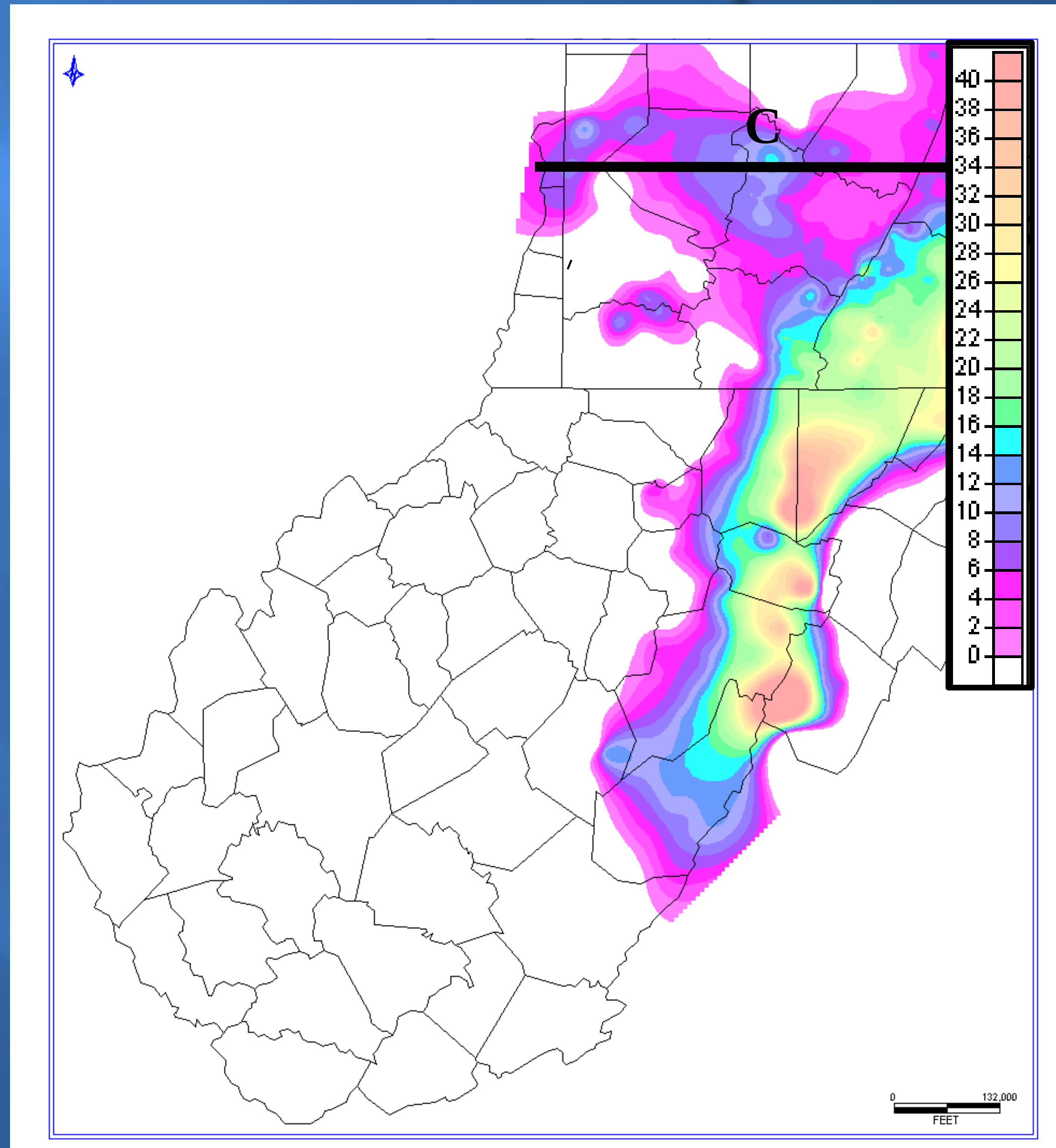
Regional Relationships: Gross Marcellus Shale Isopach

Age	Formation	Member
Upper Devonian	Alexander	
	Huron	
	Rhinestreet Shale	
	Harrell Shale	
Middle Devonian	Tully Limestone	
	Mahantango Shale	
	Marcellus Shale	Purcell Limestone
	Onondaga Limestone	
	Huntersville Chert	
	Needmore Shale	
	Oriskany Sandstone	



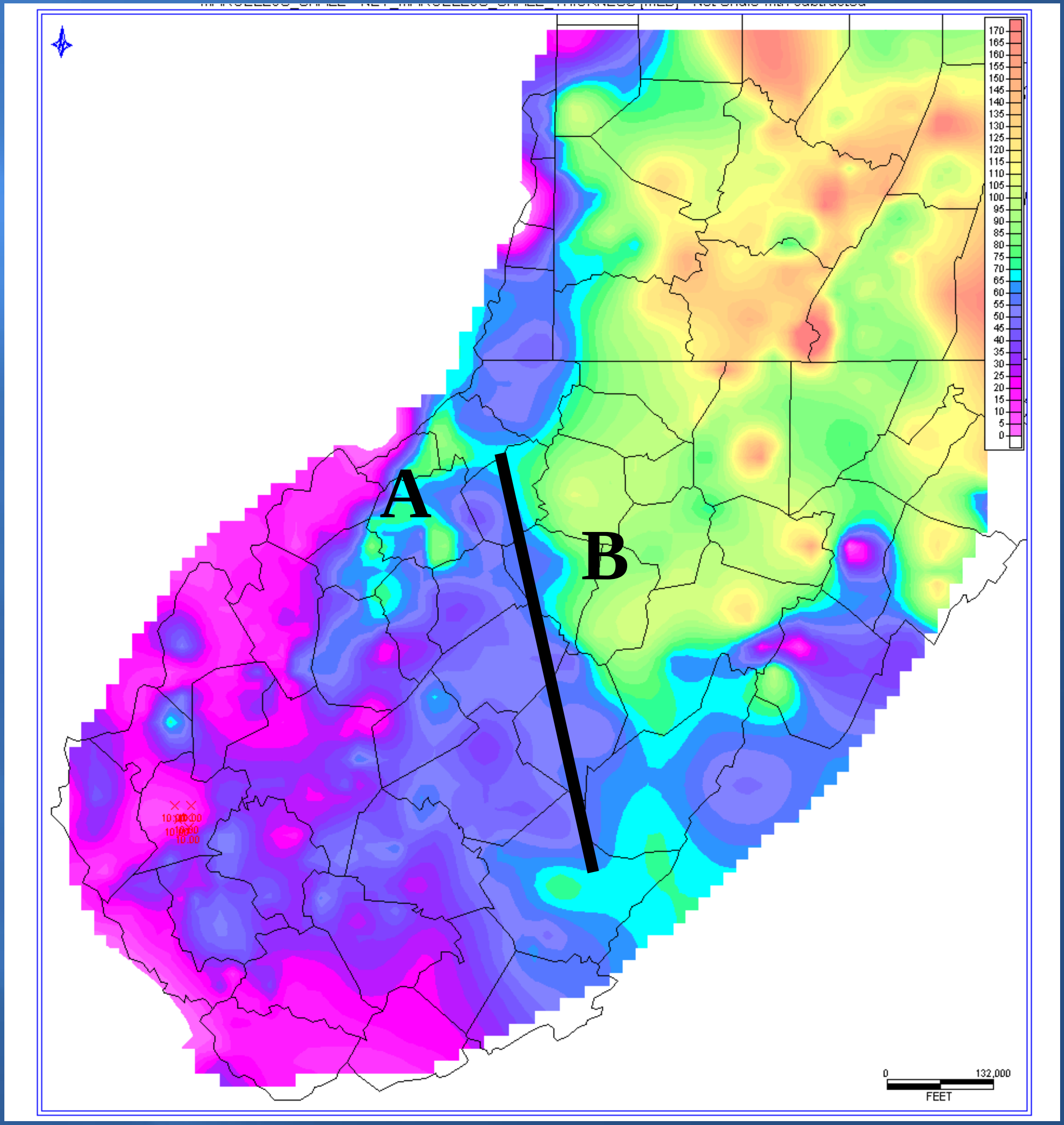
Regional Relationships: Purcell Limestone Isopach

Age	Formation	Member
Upper Devonian	Alexander	
	Huron	
	Rhinestreet Shale	
	Harrell Shale	
Middle Devonian	Tully Limestone	
	Mahantango Shale	
	Marcellus Shale	Purcell Limestone
	Onondaga Limestone	
	Huntersville Chert	
	Needmore Shale	
	Oriskany Sandstone	

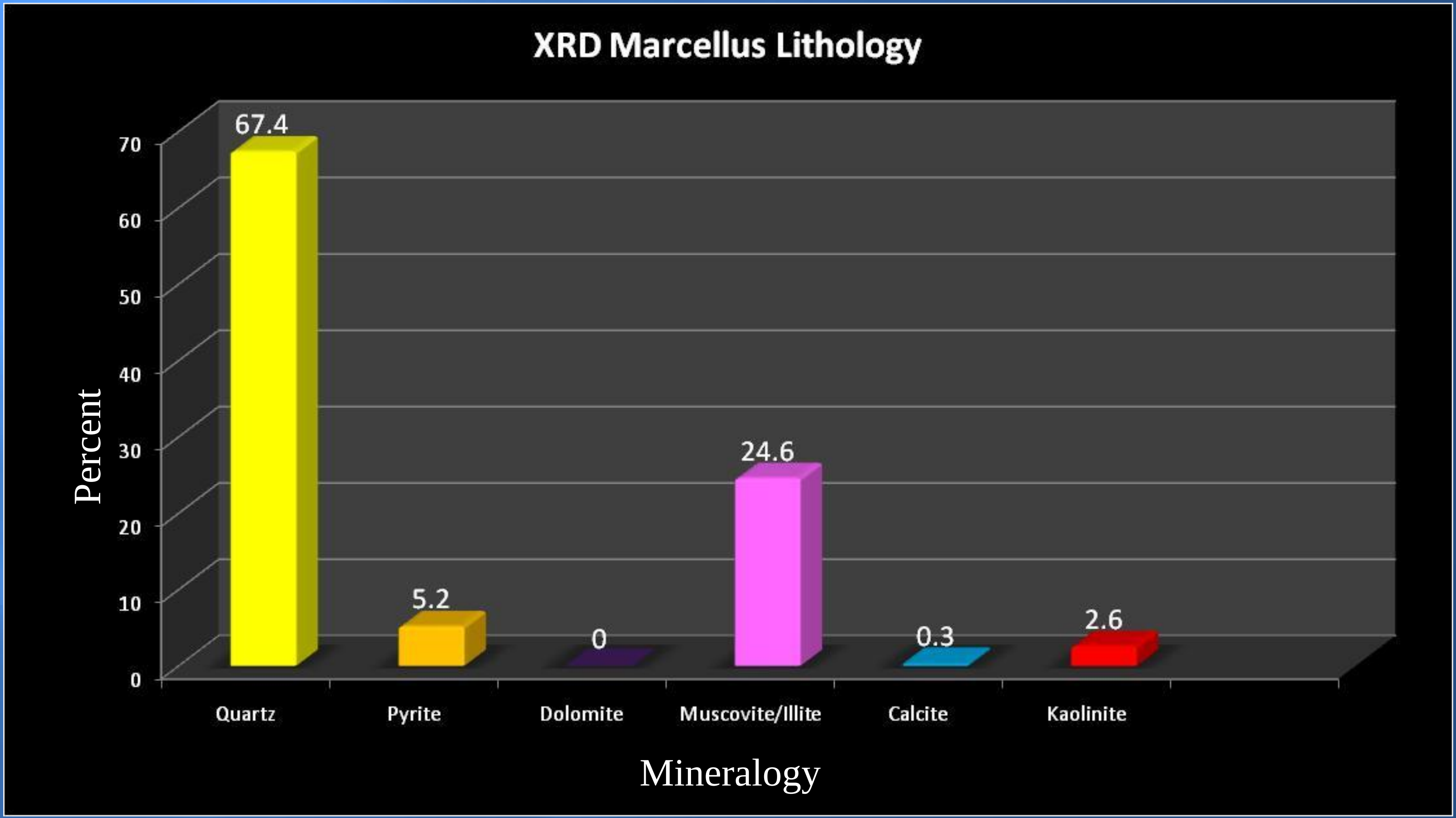


Regional Relationships: Marcellus Net Shale Isopach

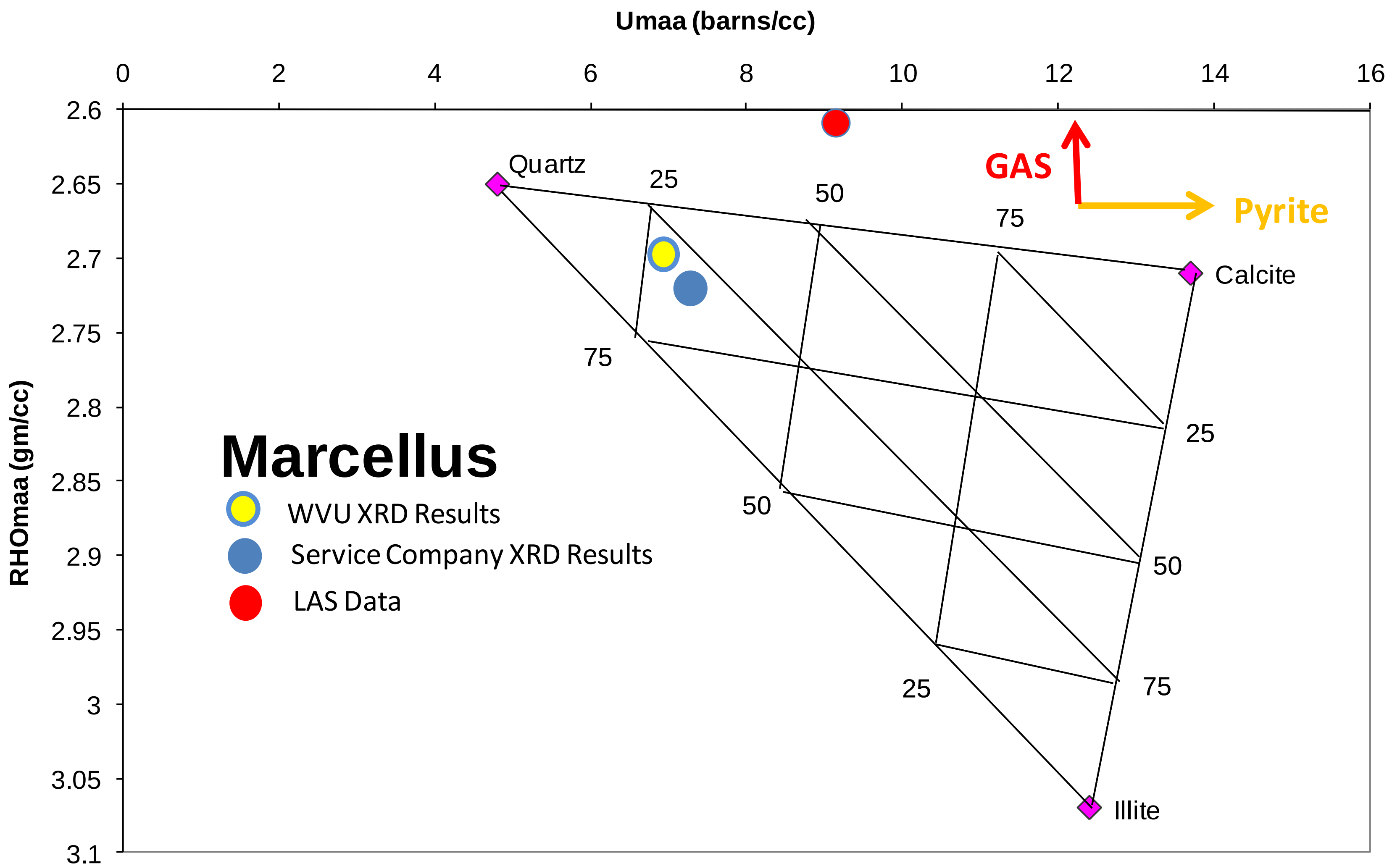
Age	Formation	Member
Upper Devonian	Alexander	
	Huron	
	Rhinestreet Shale	
	Harrell Shale	
Middle Devonian	Tully Limestone	
	Mahantango Shale	
	Marcellus Shale	Purcell Limestone
	Onondaga Limestone	
	Huntersville Chert	
	Needmore Shale	
	Oriskany Sandstone	



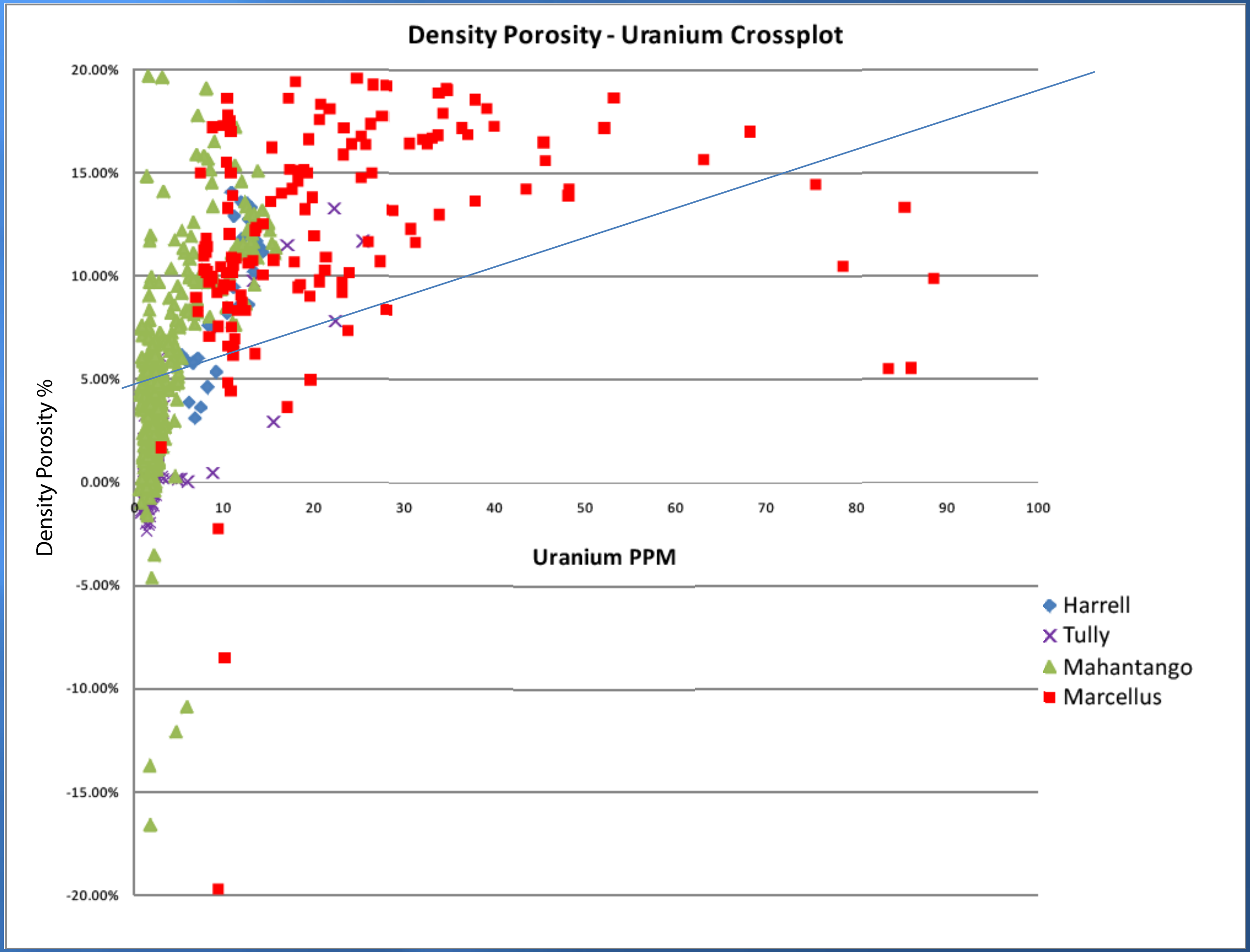
XRD Analysis



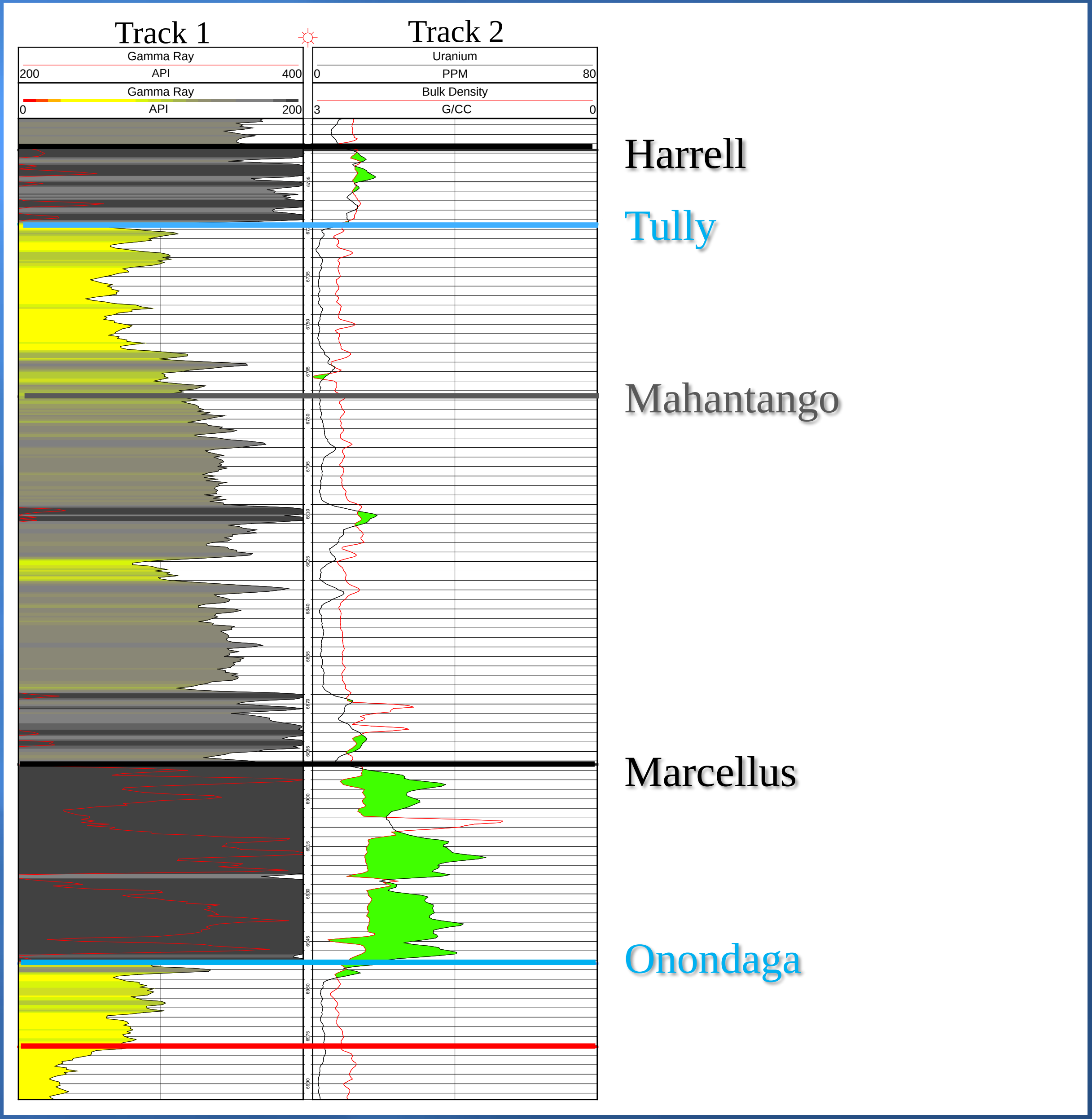
Lithological Analysis



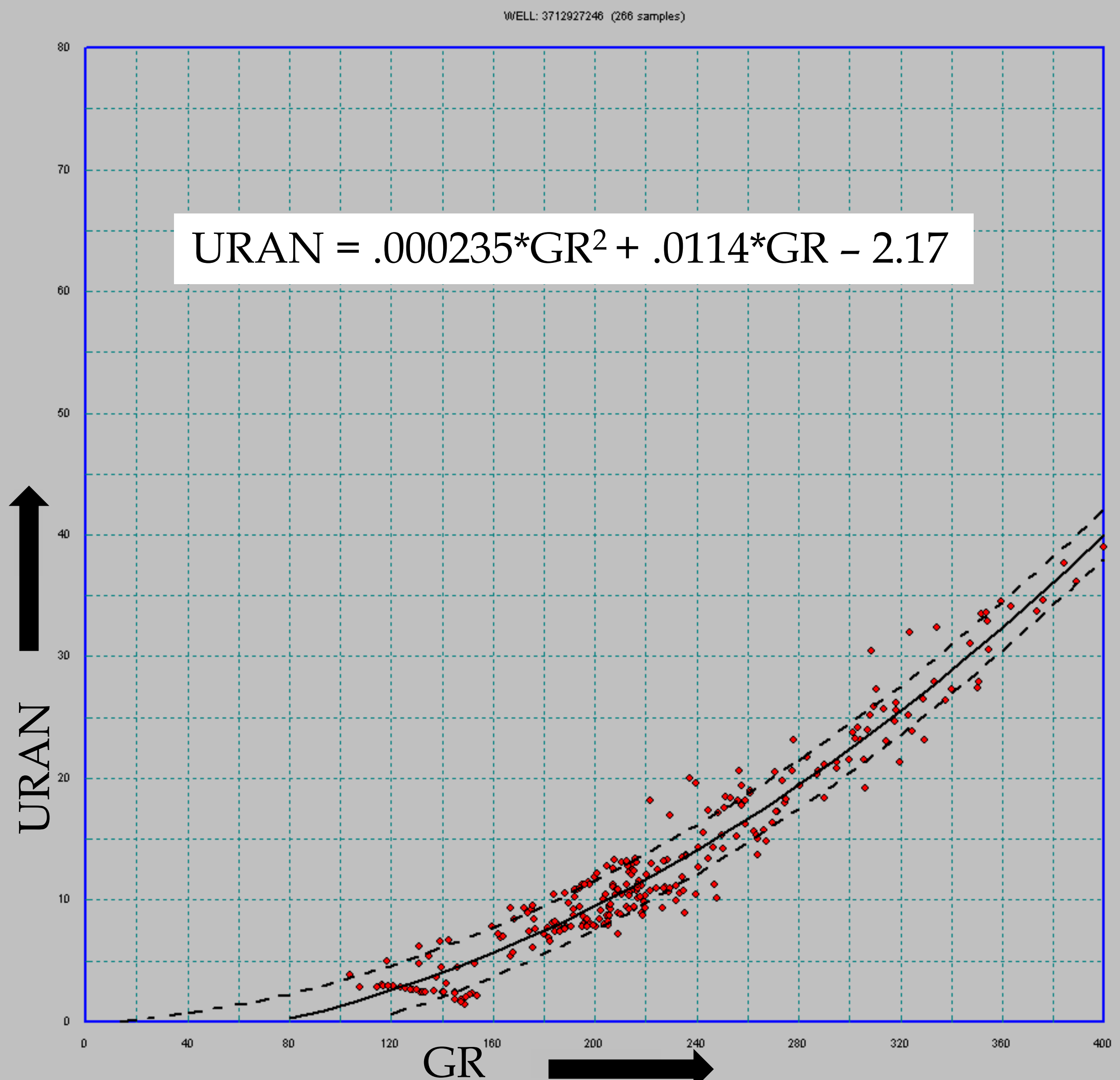
Petrophysical Analysis: Gas Identification



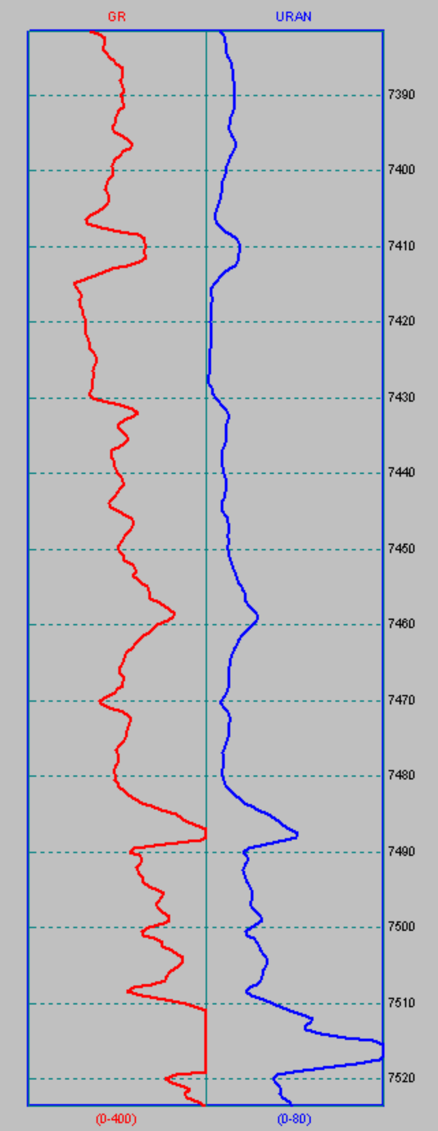
Gas Identification



Derived Uranium Curves

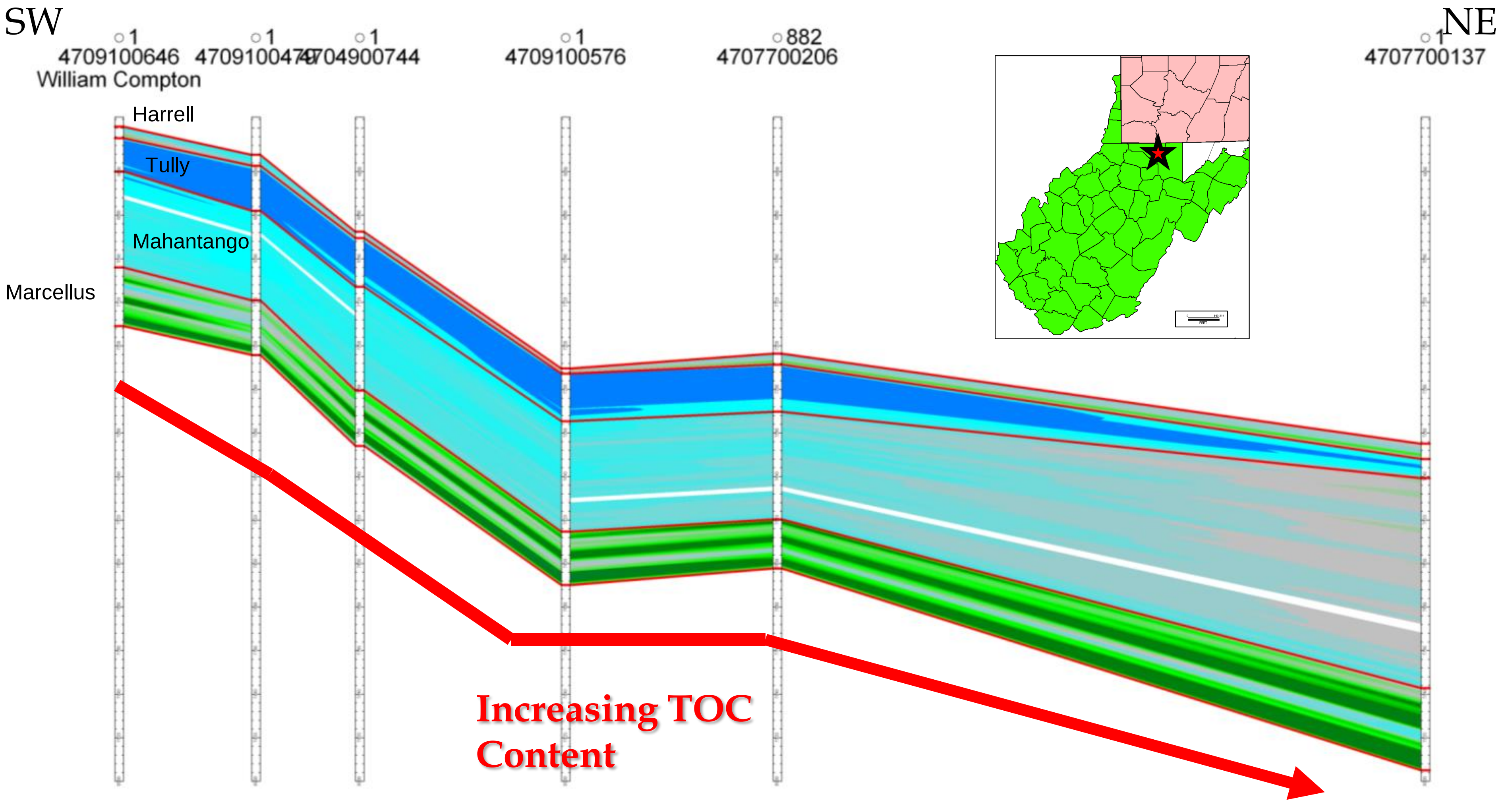


$$URAN = .000235*GR^2 + .0114*GR - 2.17$$

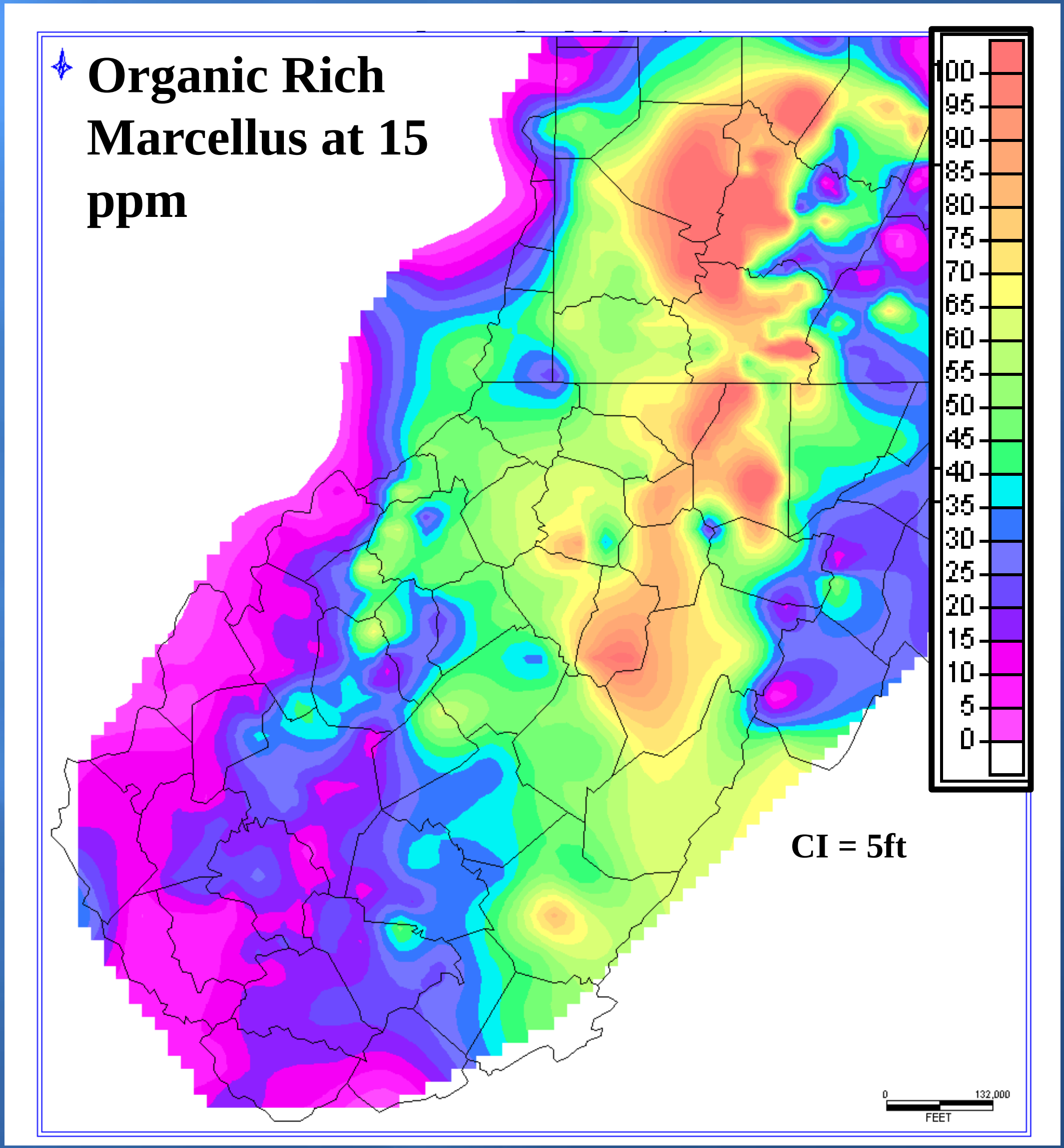


Regional Relationships

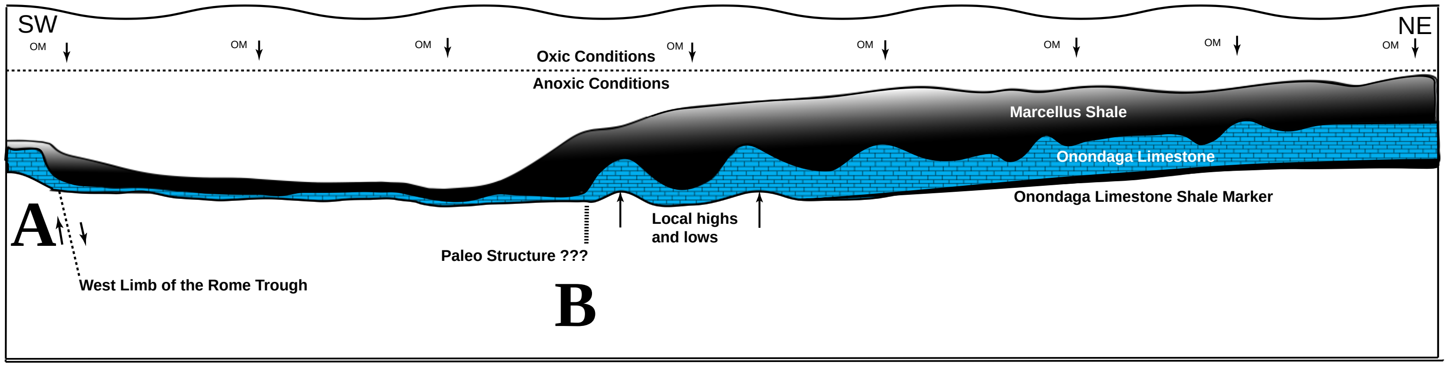
Structural X-Section Near Chestnut Ridge Anticline (NW West Virginia)



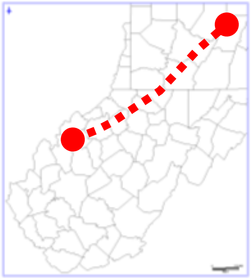
Organic Richness of the Marcellus



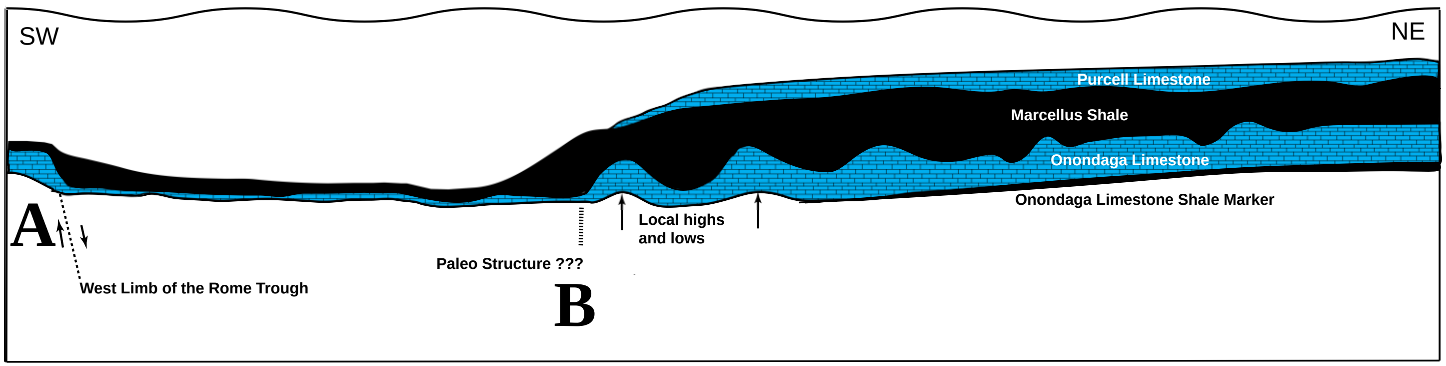
Depositional Model: Marcellus Shale



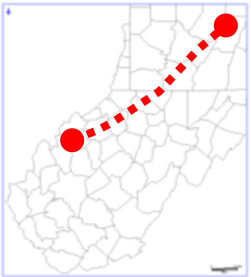
- ❑Black shale is deposited across the study area
- ❑Shale appears to be source primarily from the NE
- ❑Thicker Marcellus deposits exist in Onondaga lows and to the NE
- ❑Organic matter extends across the study area, however more organic matter accumulates in the paleo-topographic lows
- ❑Shelf break at A and B



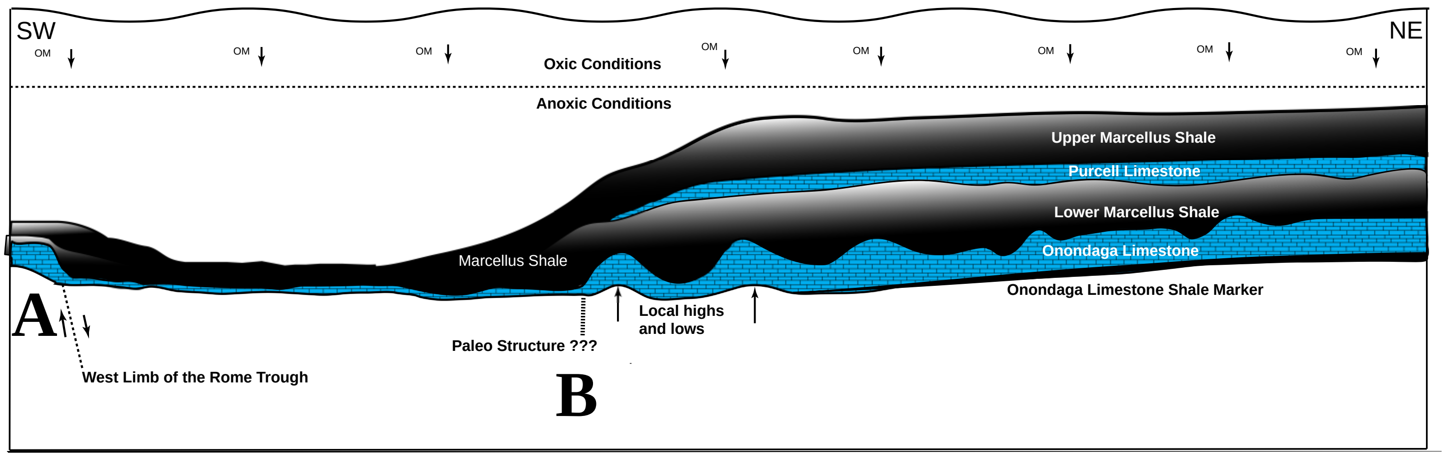
Depositional Model: Purcell Limestone



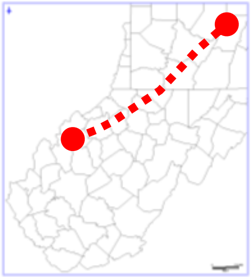
- ❑Limestone is deposited on the underlying Marcellus highs to the NE and E
- ❑The Purcell is not present to the SW
- ❑Water was deep enough (approximately 200ft) and anoxic to the SW



Depositional Model: Marcellus Shale

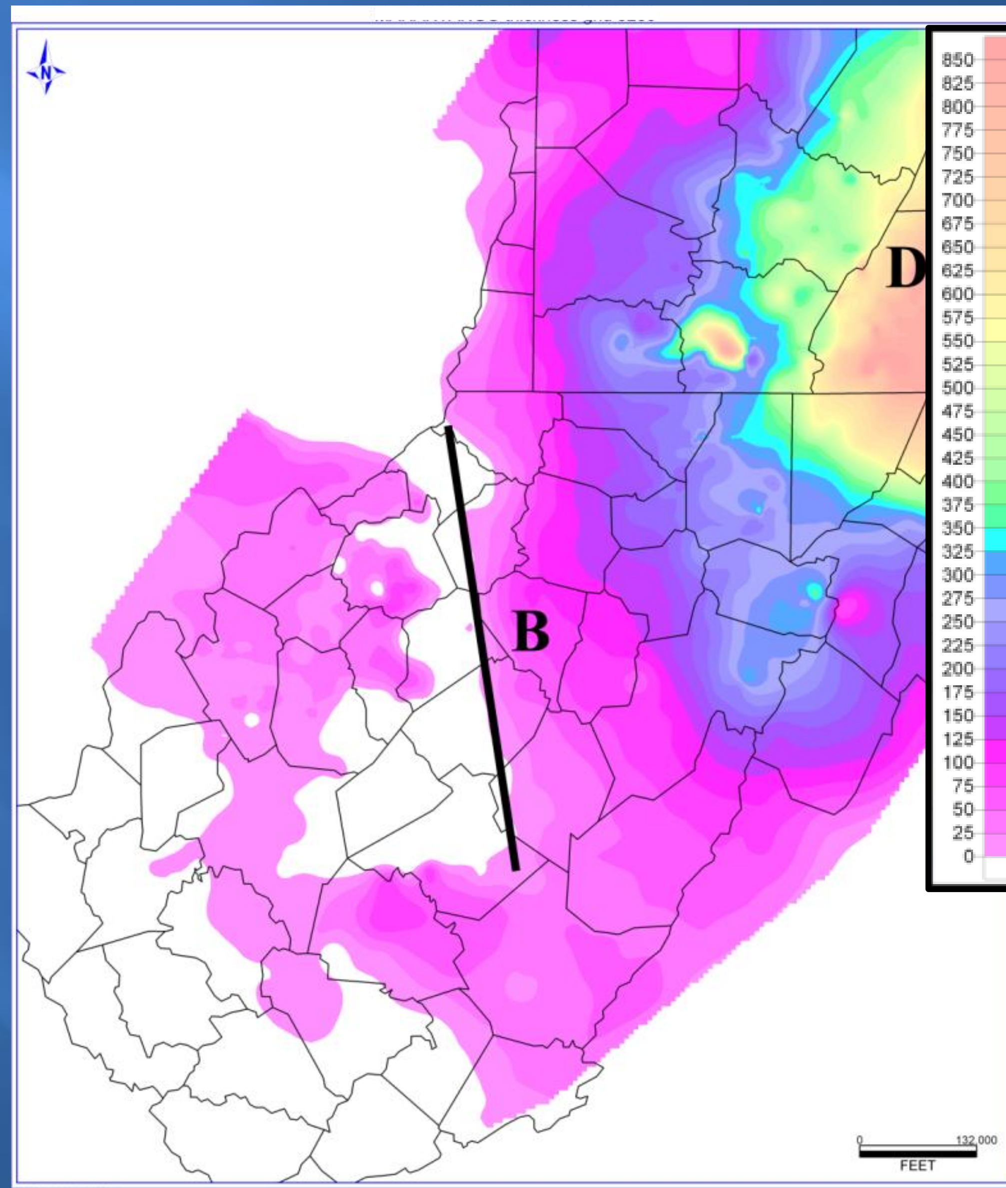


- ❑Sediment supply is turned-on again inhibiting limestone deposition and sea level would have risen approximately 100 ft
- ❑More accumulation of black shale in the SW especially near the central paleo-structure and the low created by the west limb of the Rome Trough
- ❑Marcellus black shale deposition resumes
- ❑Increase accumulation of organic rich shale along breaks in paleo-slopes



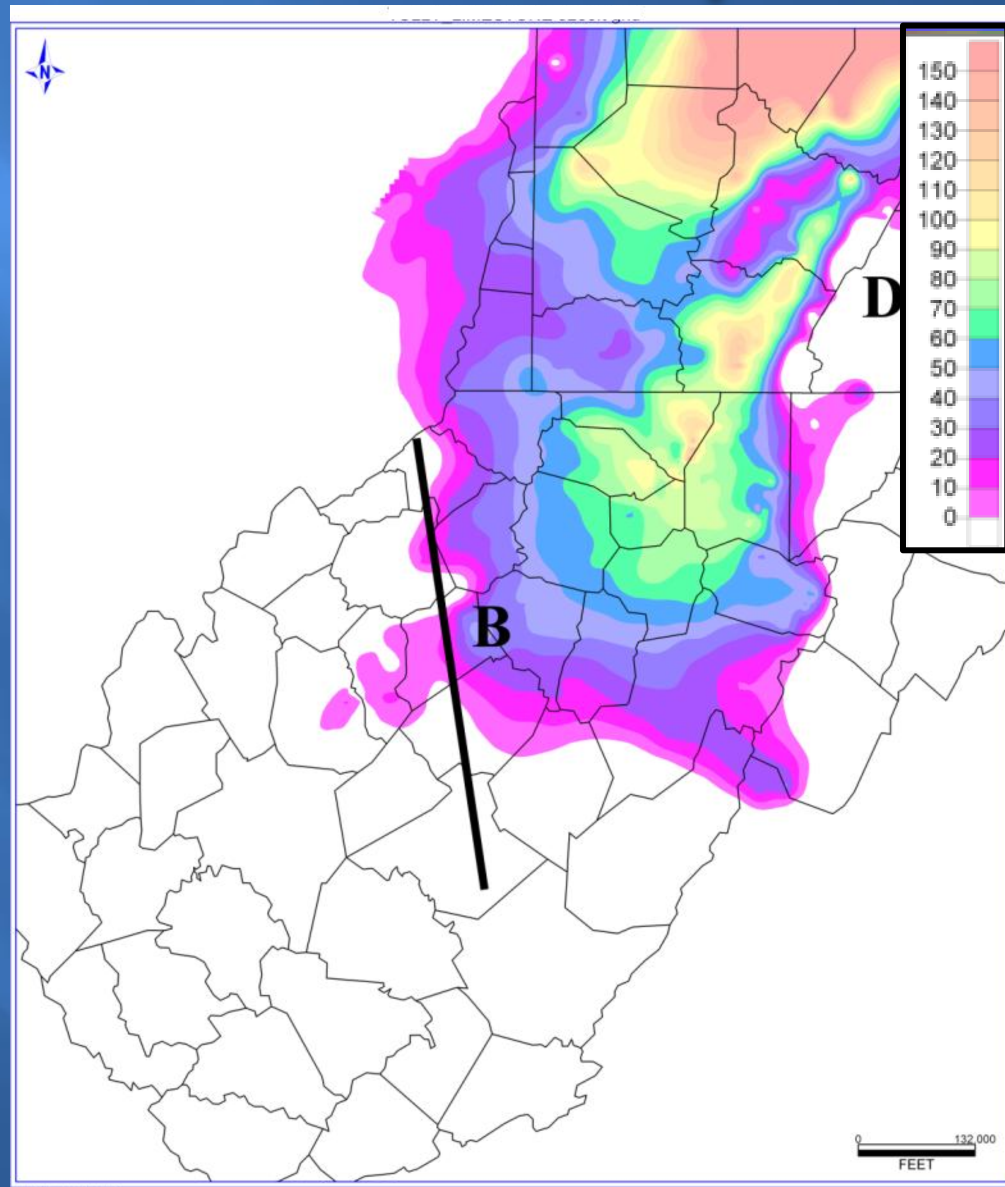
Regional Relationships: Mahantango Isopach

Age	Formation	Member
Upper Devonian	Alexander	
	Huron	
	Rhinestreet Shale	
	Harrell Shale	
Middle Devonian	Tully Limestone	
	Mahantango Shale	
	Marcellus Shale	Purcell Limestone
	Onondaga Limestone	
	Huntersville Chert	
	Needmore Shale	
	Oriskany Sandstone	

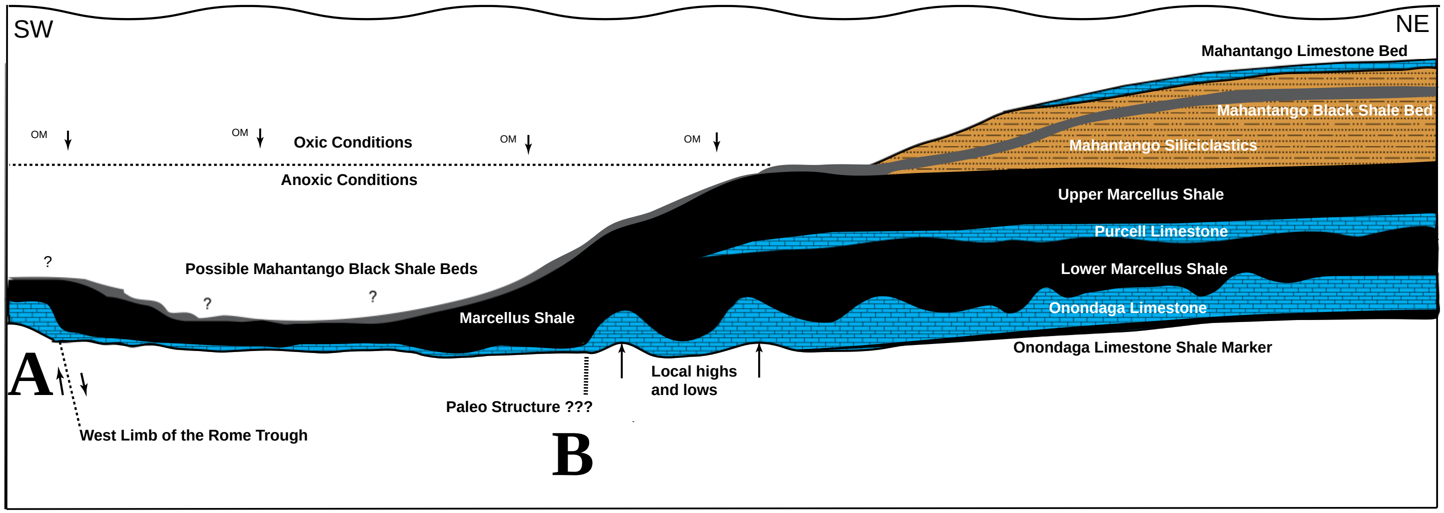


Regional Relationships: Tully Limestone Isopach

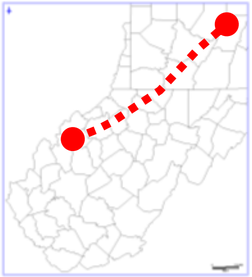
Age	Formation	Member
Upper Devonian	Alexander	
Upper Devonian	Huron	
Upper Devonian	Rhinestreet Shale	
Upper Devonian	Harrell Shale	
Middle Devonian	Tully Limestone	
Middle Devonian	Mahantango Shale	
Middle Devonian	Marcellus Shale	Purcell Limestone
Middle Devonian	Onondaga Limestone	
Middle Devonian	Huntersville Chert	
Middle Devonian	Needmore Shale	
Middle Devonian	Oriskany Sandstone	



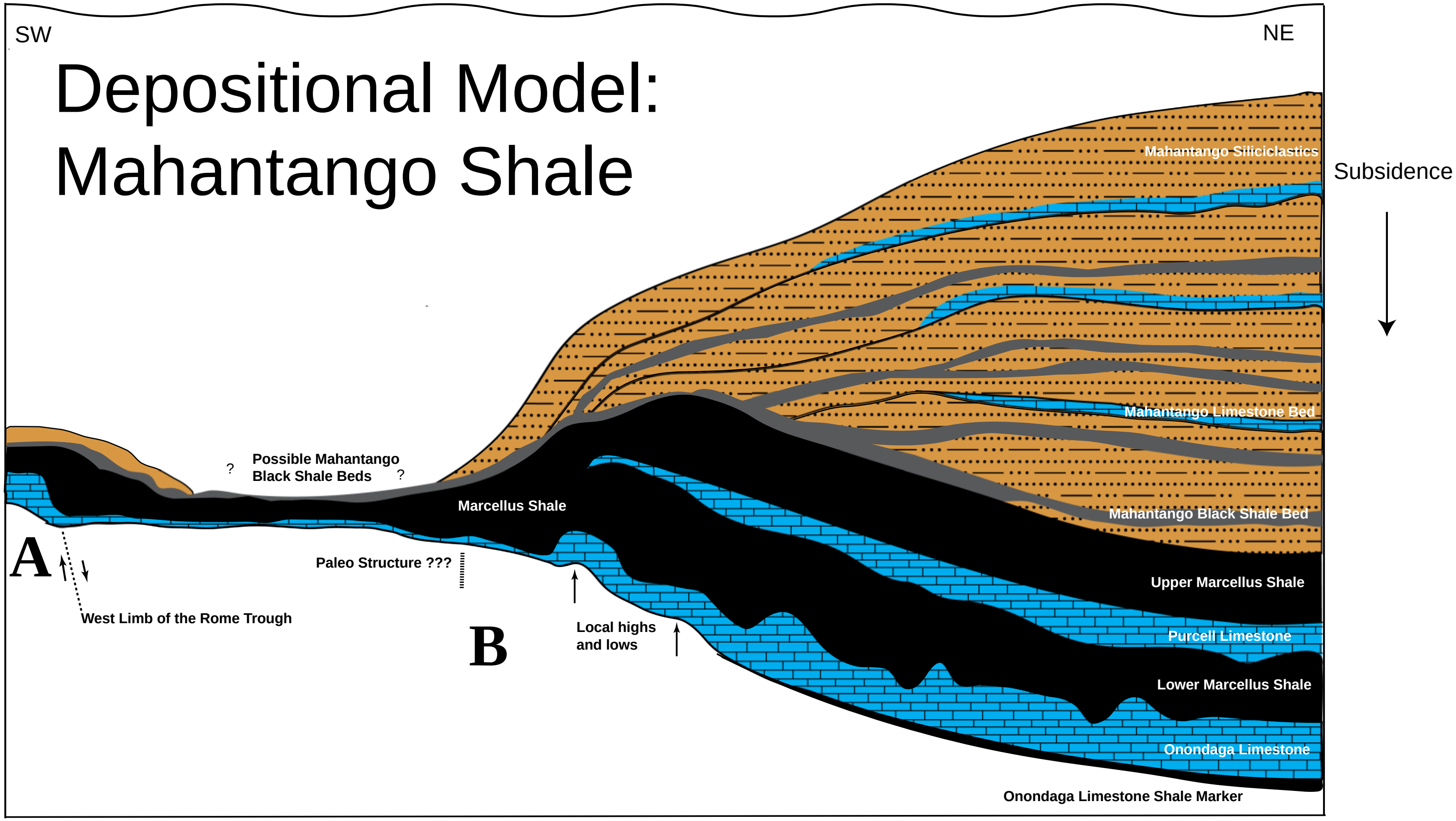
Depositional Model: Mahantango Shale



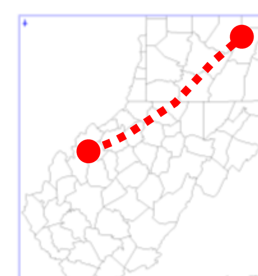
- ❑Mahantango coarser grained terriginous clastics began to prograde from the NE
- ❑Occasional organic –rich black shale deposits exist in the Mahantango
- ❑There is possible equivalent deposition of Mahantango black shale beds to the SW
- ❑Occasional limestone beds form on the paleo-topographic highs to the NE



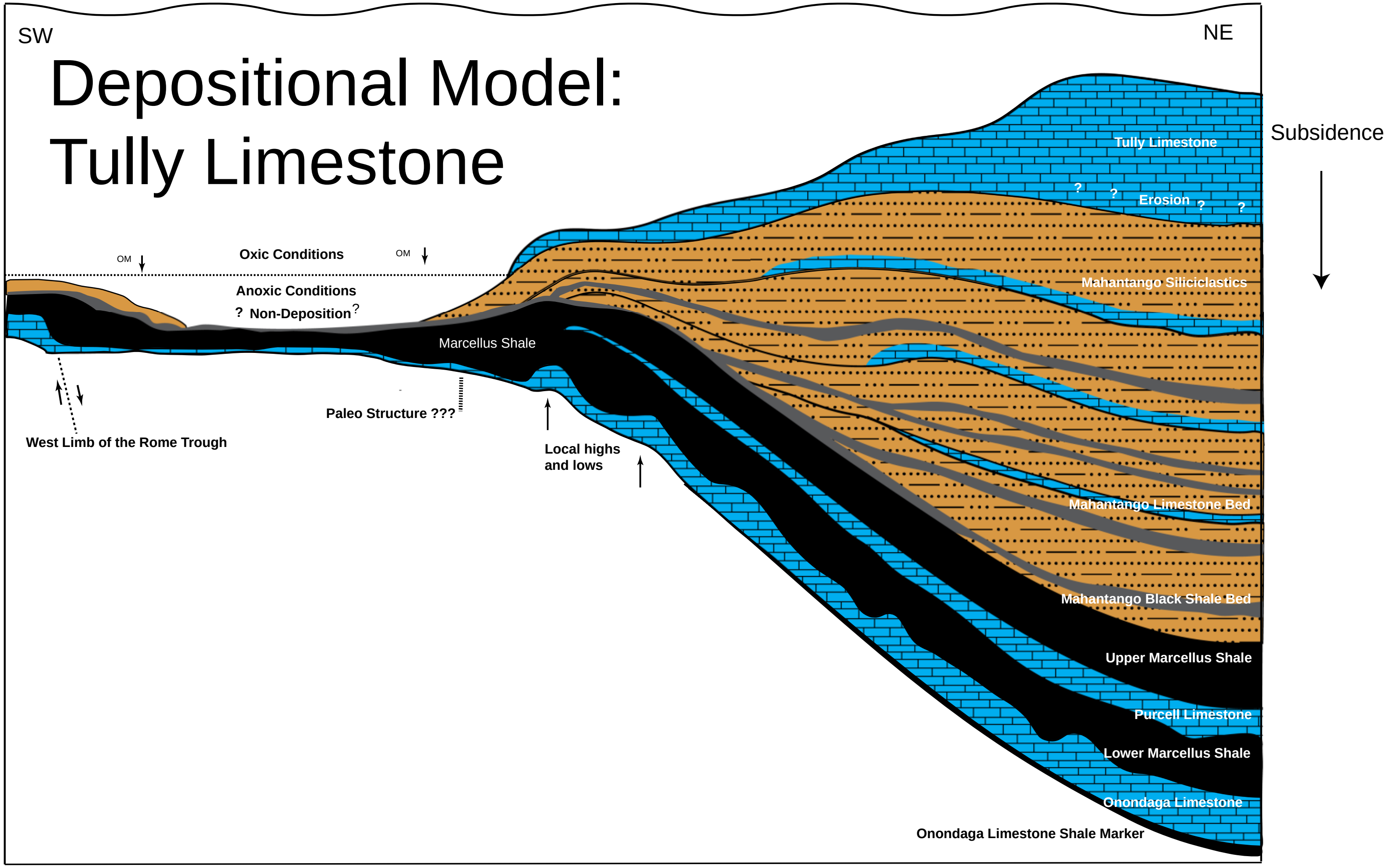
Depositional Model: Mahantango Shale



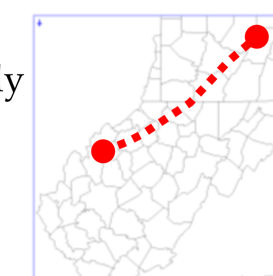
- ❑Large sediment load (+800ft) and to the NE
- ❑Continued cycles of coarser grained siliciclastics, limestone beds, and black shale beds created clinoforms in the Mahantango that downlap onto the pre-existing Marcellus
- ❑The water depth to the SW is interpreted as approximately +600ft
- ❑The conditions to the SW would have bordered on anoxic environments.
- ❑However to SW a thin Mahantango deposit suggests source to the N or W



Depositional Model: Tully Limestone

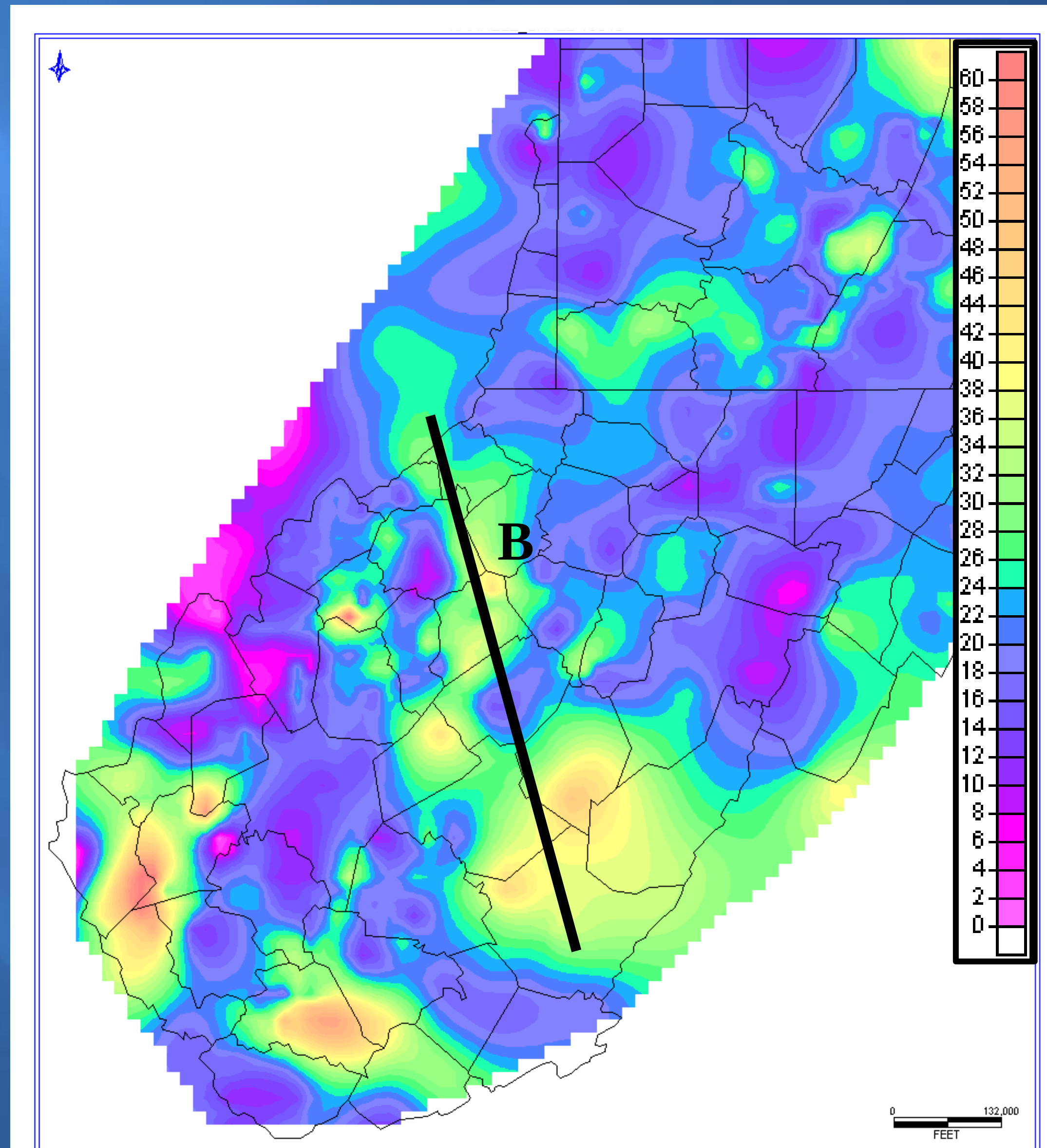


- ❑Continued subsidence, relative drop in sea level, and the halt of sediment supply
- ❑Tully Limestone deposited to the NE
- ❑To the SW Tully is absent

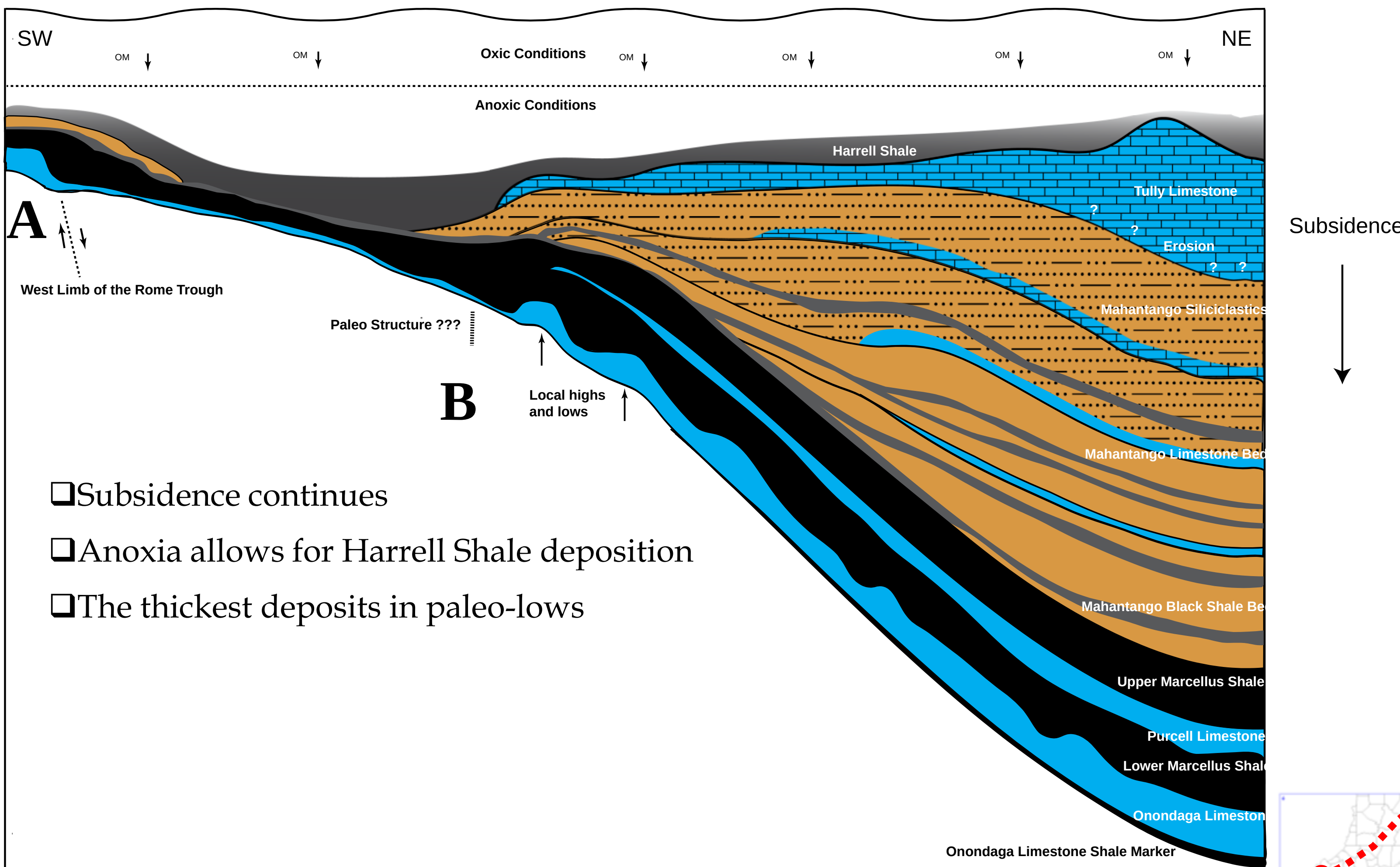


Regional Relationships: Harrell Isopach

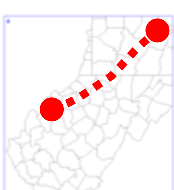
Age	Formation	Member
Upper Devonian	Alexander	
	Huron	
	Rhinestreet Shale	
	Harrell Shale	
Middle Devonian	Tully Limestone	
	Mahantango Shale	
	Marcellus Shale	Purcell Limestone
	Onondaga Limestone	
	Huntersville Chert	
	Needmore Shale	
	Oriskany Sandstone	



Depositional Model: Harrell Shale



- ❑Subsidence continues
- ❑Anoxia allows for Harrell Shale deposition
- ❑The thickest deposits in paleo-lows



Conclusions

- Definition of stratigraphic units

Defining Characteristics			
Stratigraphic Unit	**Gamma Ray**	**PE Value**	**Bulk Density**
Onondaga Limestone	Clean (30-110 API)	Approx. 5	2.71
Marcellus Shale	> 200 API	N/A	< 2.55
Purcell Limestone	< 200 API	Approx. 5	2.71
Mahantango Shale	< 200 API	N/A	> 2.55
Tully Limestone	Clean (30-110 API)	Approx. 5	2.71
Harrell Shale	> 200 API	N/A	< 2.55

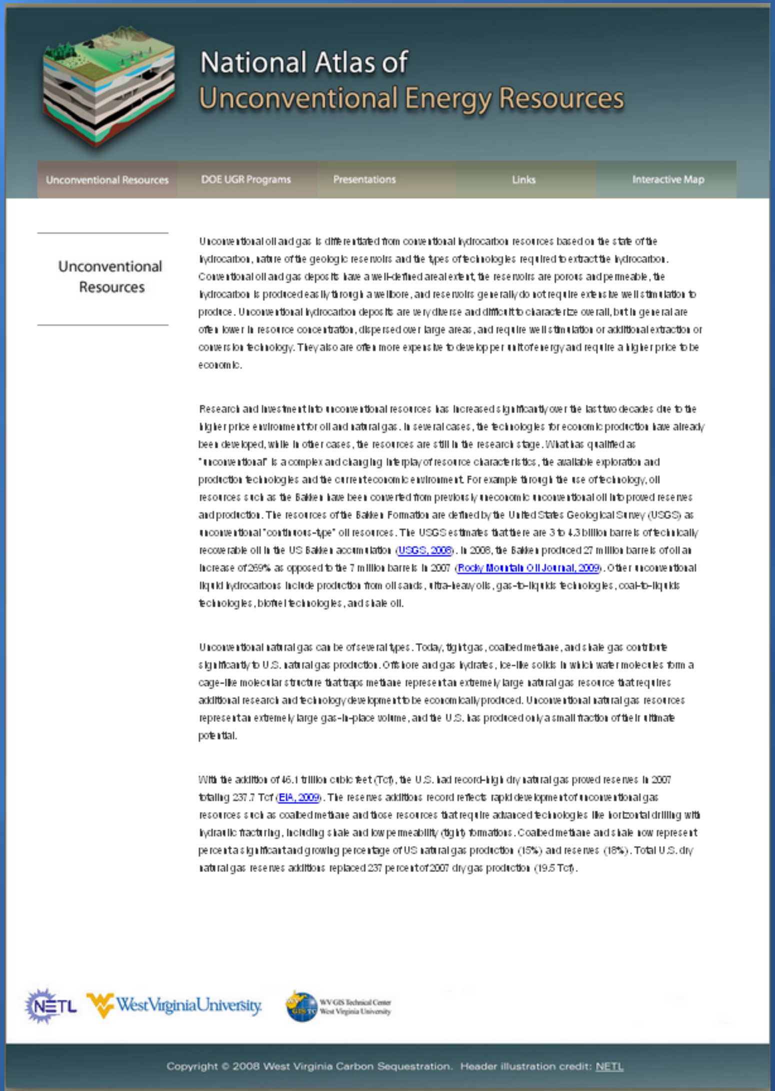
- Offshore eperic sea ramp environment
  - Limestone and black shale are facies
  - Oxic and anoxic conditions in formations overlying the Marcellus
- The Marcellus is not a true "shale"
- TOC preservation controlled by Onondaga highs and lows
- Shelf Break and Marcellus TOC relationship
- New method of recognition gas potential
  - Potential for Mahantango and Harrell
- Correlation between uranium and TOC

Future Work at WVU

- Expanded Mapping and Petrophysics
  - Work in Western Pennsylvanian (Anne Yanni)
- Improved Core to Log Integration
  - Conventional and Sidewall Core Samples
  - Thin Sections/SEM/XRD/Organics
  - NeuralNet Solutions
- Outcrop Work (Meg Walker-Milani, Others)
  - Tie Surface to subsurface
  - Spectral Scintillometer
- Geochemistry (Isoptopic - Shikha Sharma)
  - Flowback Water
  - Gas
- Information Transfer (Tim Carr)
  - MapServer Improvements
- Work is funded and is in cooperation with the National Energy Technology Laboratory of the US Department of Energy.

Atlas of Unconventional Energy Resources

http://www.mapwv.gov/unconventionalresources/



National Atlas of
Unconventional Energy Resources

Unconventional Resources | DOE UGR Programs | Presentations | Links | Interactive Map

Unconventional Resources

Unconventional oil and gas is differentiated from conventional hydrocarbon resources based on the state of the hydrocarbon, nature of the geologic reservoirs and the types of technologies required to extract the hydrocarbon. Conventional oil and gas deposits have a well-defined areal extent, the reservoirs are porous and permeable, the hydrocarbon is produced easily through a wellbore, and reservoirs generally do not require extensive well stimulation to produce. Unconventional hydrocarbon deposits are very diverse and difficult to characterize overall, but in general are often lower in resource concentration, dispersed over large areas, and require well stimulation or additional extraction or conversion technology. They also are often more expensive to develop per unit of energy and require a higher price to be economic.

Research and investment into unconventional resources has increased significantly over the last two decades due to the higher price environment for oil and natural gas. In several cases, the technologies for economic production have already been developed, while in other cases, the resources are still in the research stage. What has qualified as "unconventional" is a complex and changing interplay of resource characteristics, the available exploration and production technologies and the current economic environment. For example through the use of technology, oil resources such as the Bakken have been converted from previously uneconomic unconventional oil into proved reserves and production. The resources of the Bakken Formation are defined by the United States Geological Survey (USGS) as unconventional "continuous-type" oil resources. The USGS estimates that there are 3 to 4.3 billion barrels of technically recoverable oil in the US Bakken accumulation (USGS, 2008). In 2008, the Bakken produced 27 million barrels of oil an increase of 269% as opposed to the 7 million barrels in 2007 (Rocky Mountain Oil Journal, 2009). Other unconventional liquid hydrocarbons include production from oil sands, ultra-heavy oils, gas-to-liquids technologies, coal-to-liquids technologies, biofuel technologies, and shale oil.

Unconventional natural gas can be of several types. Today, tight gas, coalbed methane, and shale gas contribute significantly to U.S. natural gas production. Offshore and gas hydrates, ice-like solids in which water molecules form a cage-like molecular structure that traps methane represent an extremely large natural gas resource that requires additional research and technology development to be economically produced. Unconventional natural gas resources represent an extremely large gas-in-place volume, and the U.S. has produced only a small fraction of their ultimate potential.

With the addition of 46.1 trillion cubic feet (Tcf), the U.S. had record-high dry natural gas proved reserves in 2007 totaling 237.7 Tcf (EIA, 2009). The reserves additions record reflects rapid development of unconventional gas resources such as coalbed methane and those resources that require advanced technologies like horizontal drilling with hydraulic fracturing, including shale and low permeability (tight) formations. Coalbed methane and shale now represent percent a significant and growing percentage of US natural gas production (15%) and reserves (18%). Total U.S. dry natural gas reserves additions replaced 237 percent of 2007 dry gas production (19.5 Tcf).

NETL West Virginia University WV GIS Technical Center West Virginia University

Acknowledgments

NETL

West Virginia University

EQT Where energy meets innovation.

Dominion

2010 Second Annual West Virginia Geology Spring Golf Classic

- Where: Mountainview Golf Course
- When: 8:00am Tee Times on Saturday May 1st
- Format: Four person Scramble
- How Much: $100 a person or $400 per team

Sponsorship Opportunities

PLATINUM SPONSOR
Greater than $2000
2 four person teams
Sponsor signs

GOLD SPONSOR
$1500 - $2000
1 four person team
Sponsor signs

SILVER SPONSOR
$1000-$1500
Sponsor Signs

BRONZE SPONSOR
$500-$1000
Sponsor Sign

Beer Cart (2 Carts)
$600 each
Name on Cart

Hole Sponsors
$100 each
4 per hole

Contact Matt Boyce (mboyce5@mix.wvu.edu) or Christian Figueroa-Tyler (cfiguer1@mix.wvu.edu) for more details