Utica and Marcellus Shales in New York State

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New York State Museum

Reservoir Characterization Group
at the New York State Museum

New York State Geological Survey
Est. 1836
New York State Museum

NYSERDA

Core Workshop Schedule

- 2:00-3:00 Intro and Marcellus Slides and Poster
- 3:00-345 Marcellus core viewing, poster and discussion
- 3:45-4:30 Utica Slides
- 4:30-5:15 Utica core viewing, poster and discussion
- 5:15-5:30 Intro to field trip

Acknowledgements

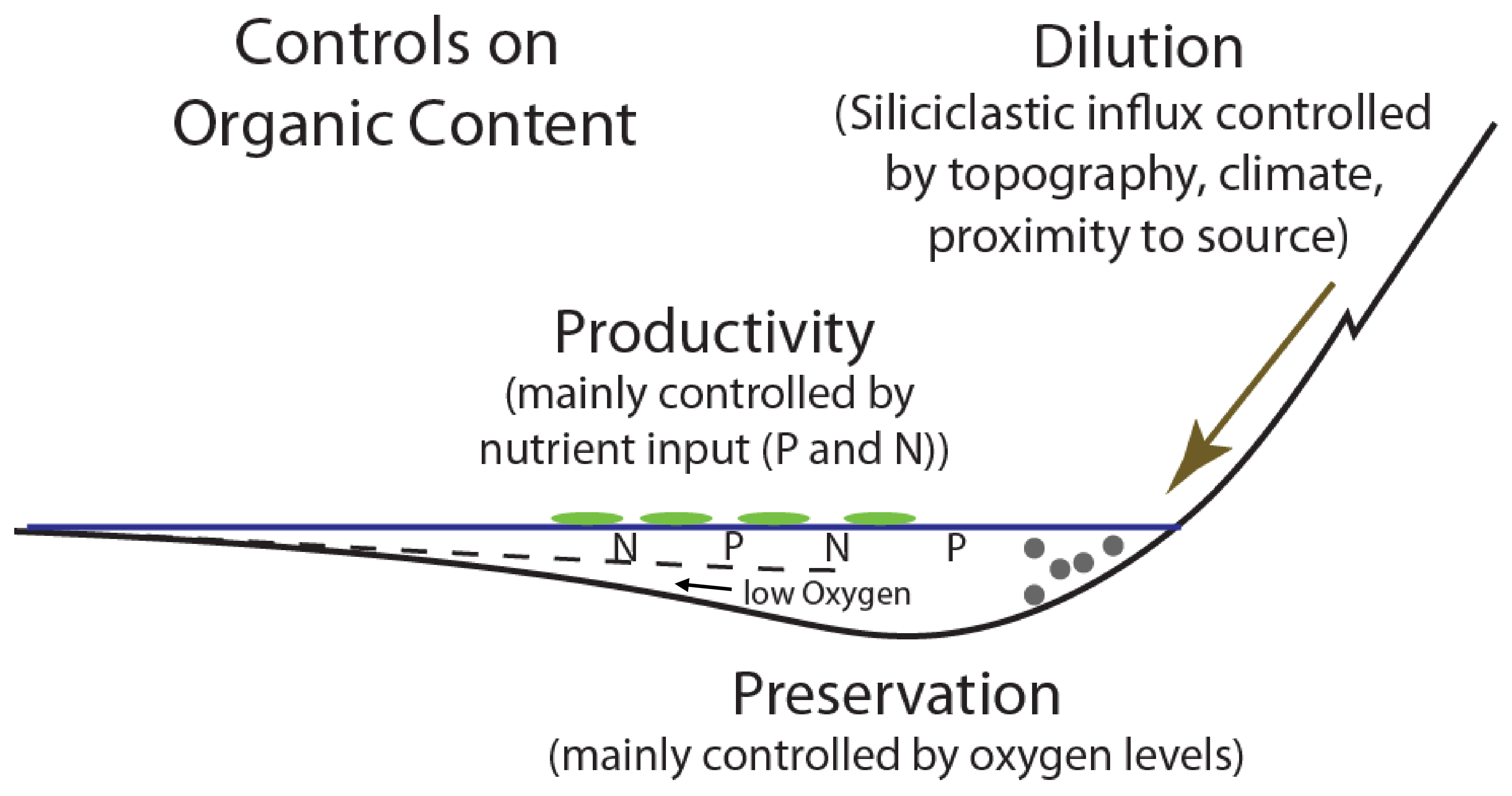
- Eric Ober and PAPG, Doug Patchen and PTTC
- Reservoir Characterization Group
- Richard Nyahay, Richard Tyson, Juergen Scheiber, Ed Landing, Chuck ver Straetten, Gordon Baird and Carlton Brett for technical discussions
- Hanson Aggregates, NYS Thruway Authority for allowing us to view outcrops

Goals of Workshop and Field Trip

- Stratigraphy, sedimentology, depositional Setting, Structural Setting and Vertical and lateral distribution of organic-rich black shales in NY
  - Relatively shallow not deep and onlapping unconformities
  - Formed from moving bottom currents in periodically anoxic water, not from suspension in permanently anoxic water
  - Faults, natural fractures and mineralization may play a role in both but especially in Utica

Black Shale Depositional Models

- Depositional models are interesting in an academic sense, but can also help refine exploration concepts
- In black shales, there are three important variables
  - Organic productivity (mainly driven by nutrient supply)
  - Preservation (driven mainly by oxygen levels)
  - Dilution (need limited siliciclastic influx or carbonate deposition)



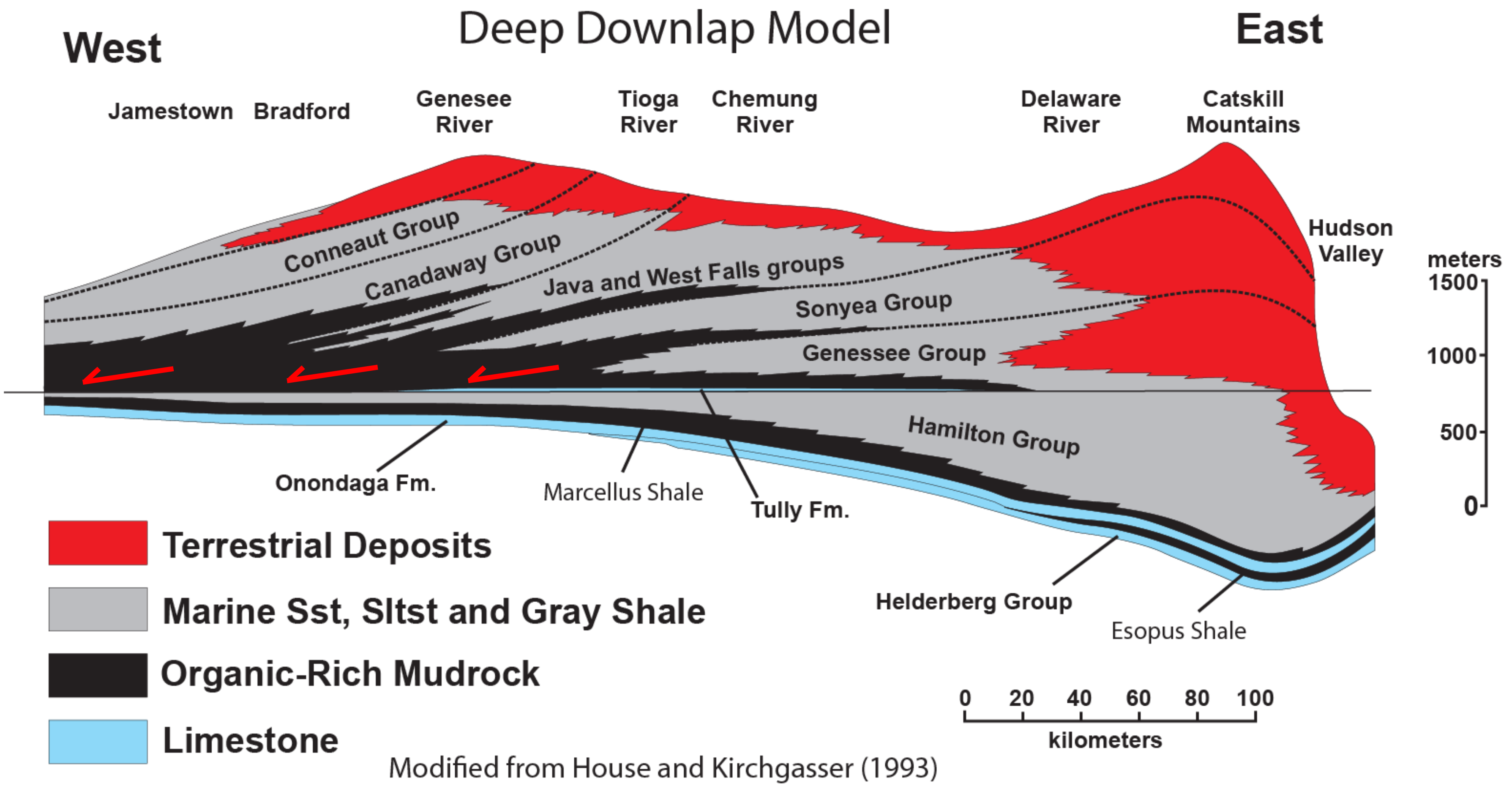
Controls on Organic Content

Dilution
(Siliciclastic influx controlled by topography, climate, proximity to source)

Productivity
(mainly controlled by nutrient input (P and N))

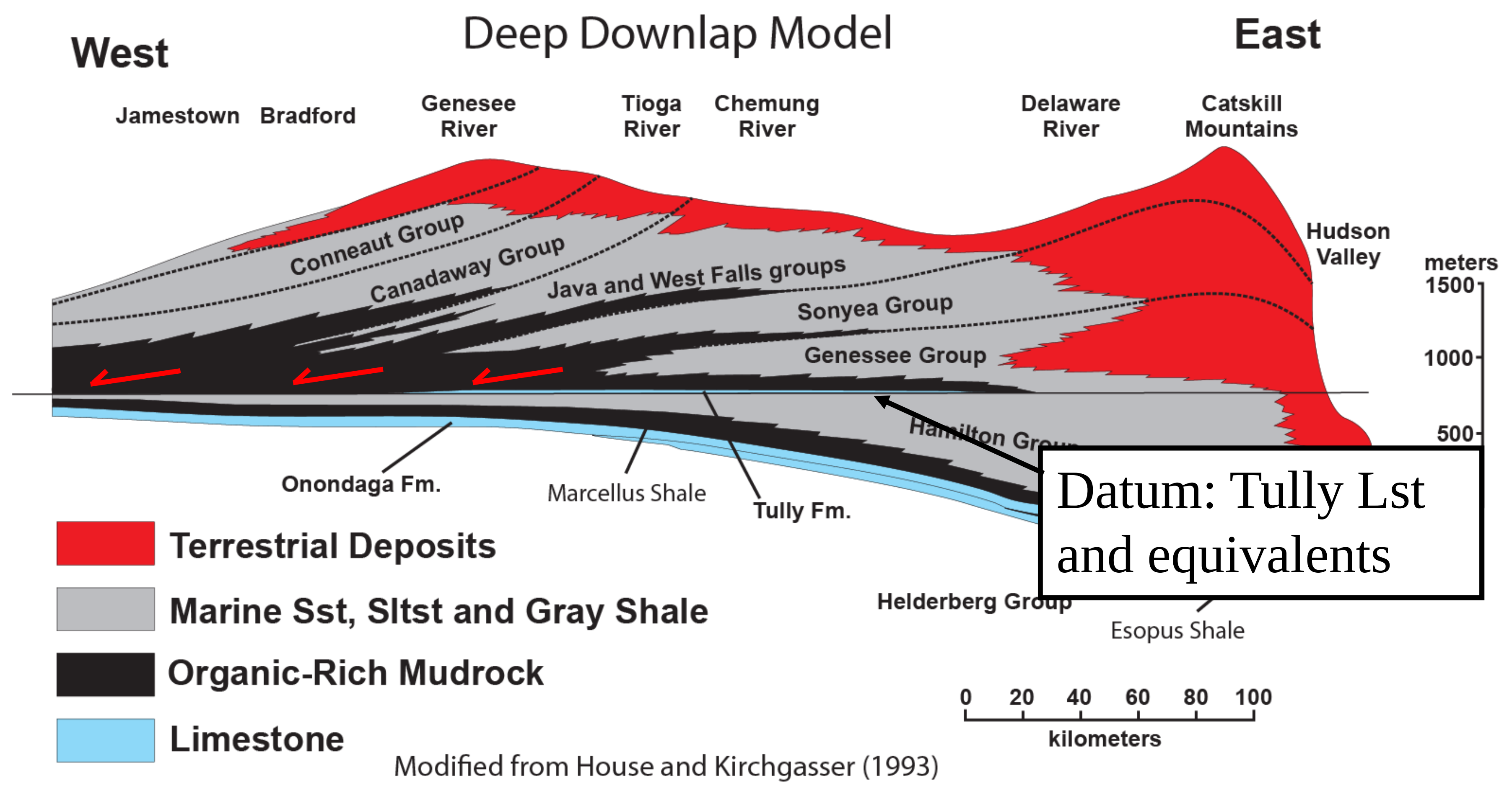
Preservation
(mainly controlled by oxygen levels)

High productivity, high preservation and low dilution best to generate high organic content in shale – it is not necessary to have all three conditions; if productivity is high and dilution is low, preservation could be fairly low but organic matter could still accumulate; if productivity and preservation are high, dilution could be pretty high and %TOC could still be relatively high


Deep Downlap Model

Modified from House and Kirchgasser (1993)

A commonly applied model for the Devonian organic-rich shales in NY is that they were deposited in deep permanently anoxic water (>>100 m) at the toe of the slope and that they downlap on underlying shallow water carbonates onto a drowning unconformity – similar models have been proposed for the Utica



Datum: Tully Lst and equivalents

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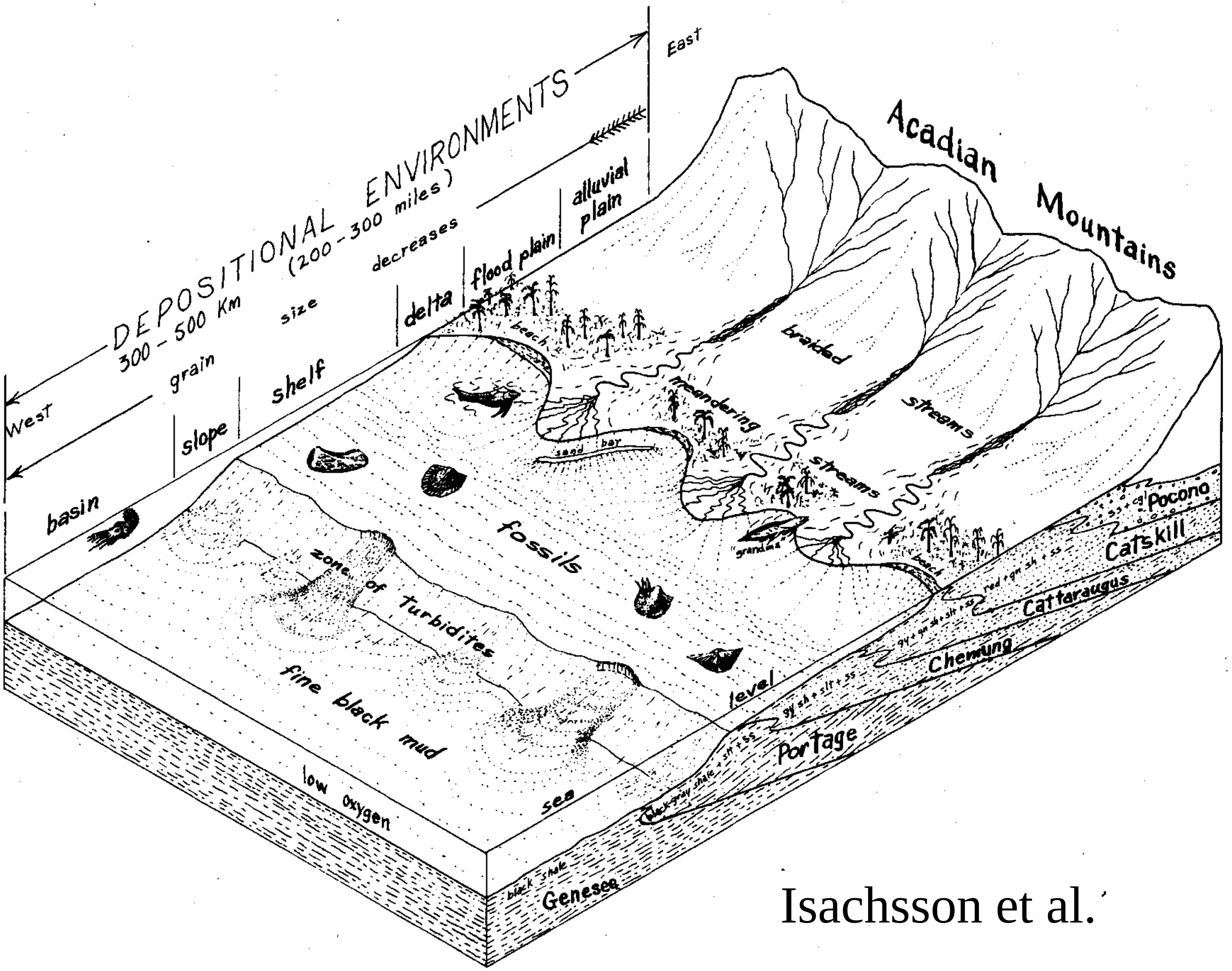
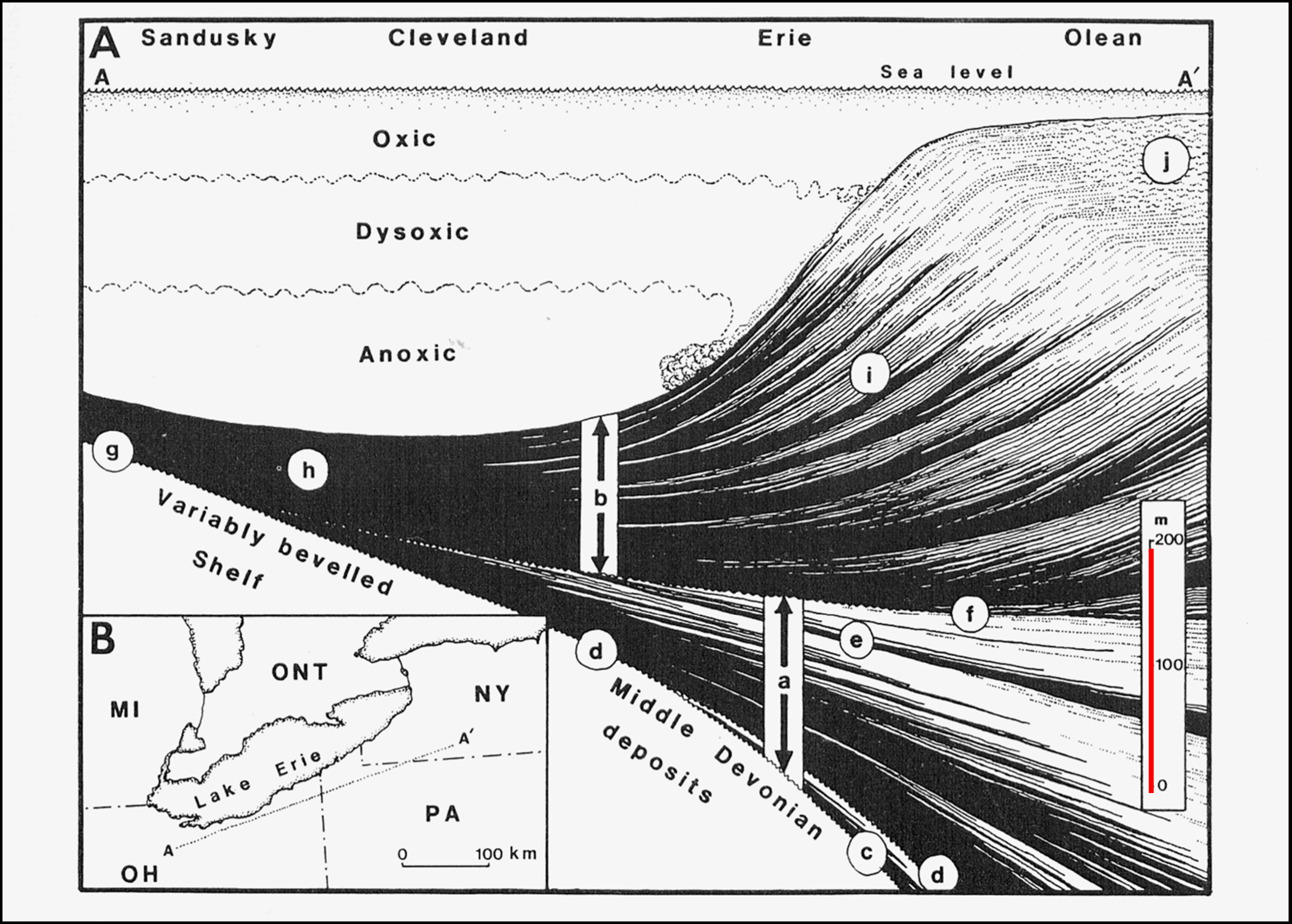
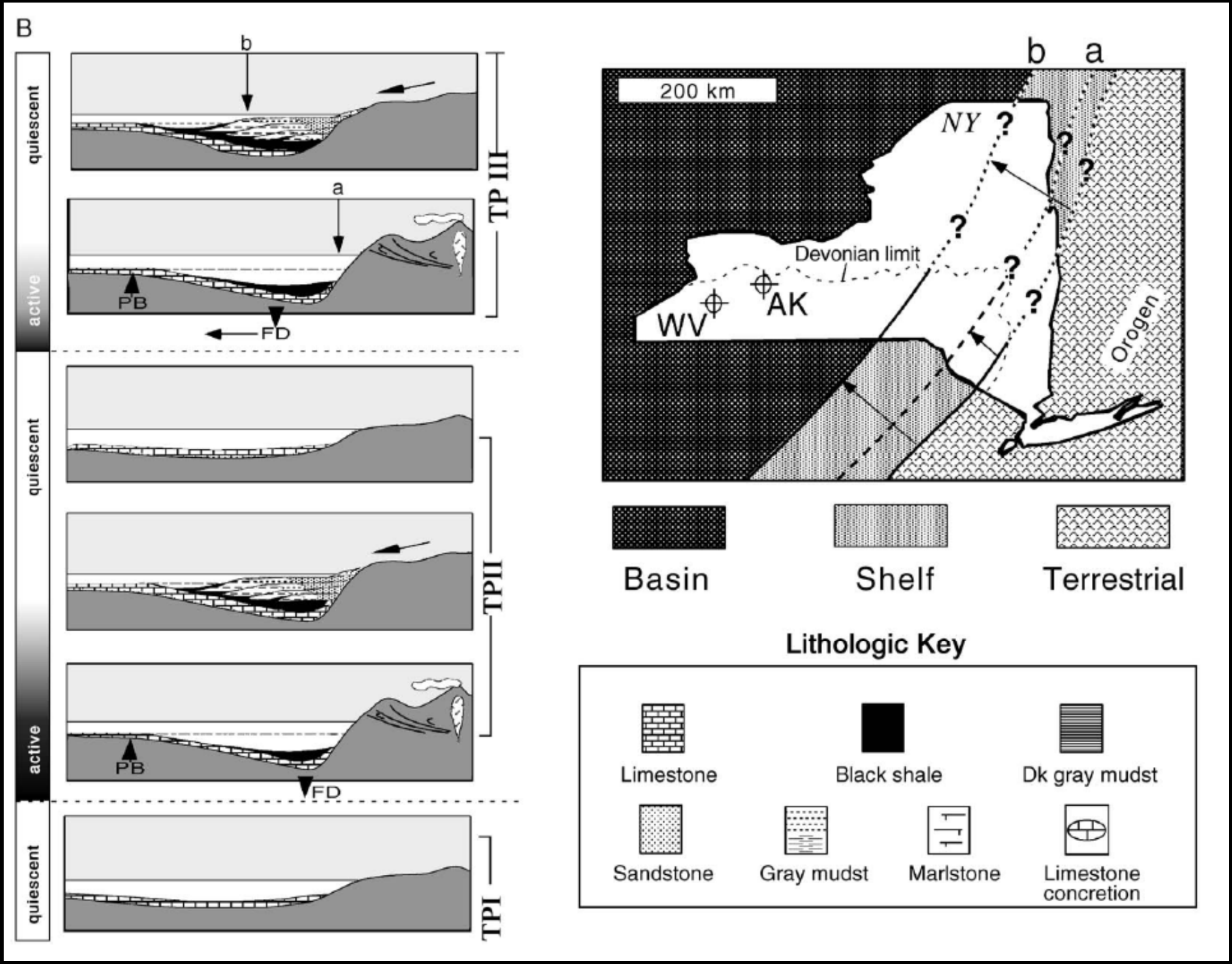


Isachsson et al.

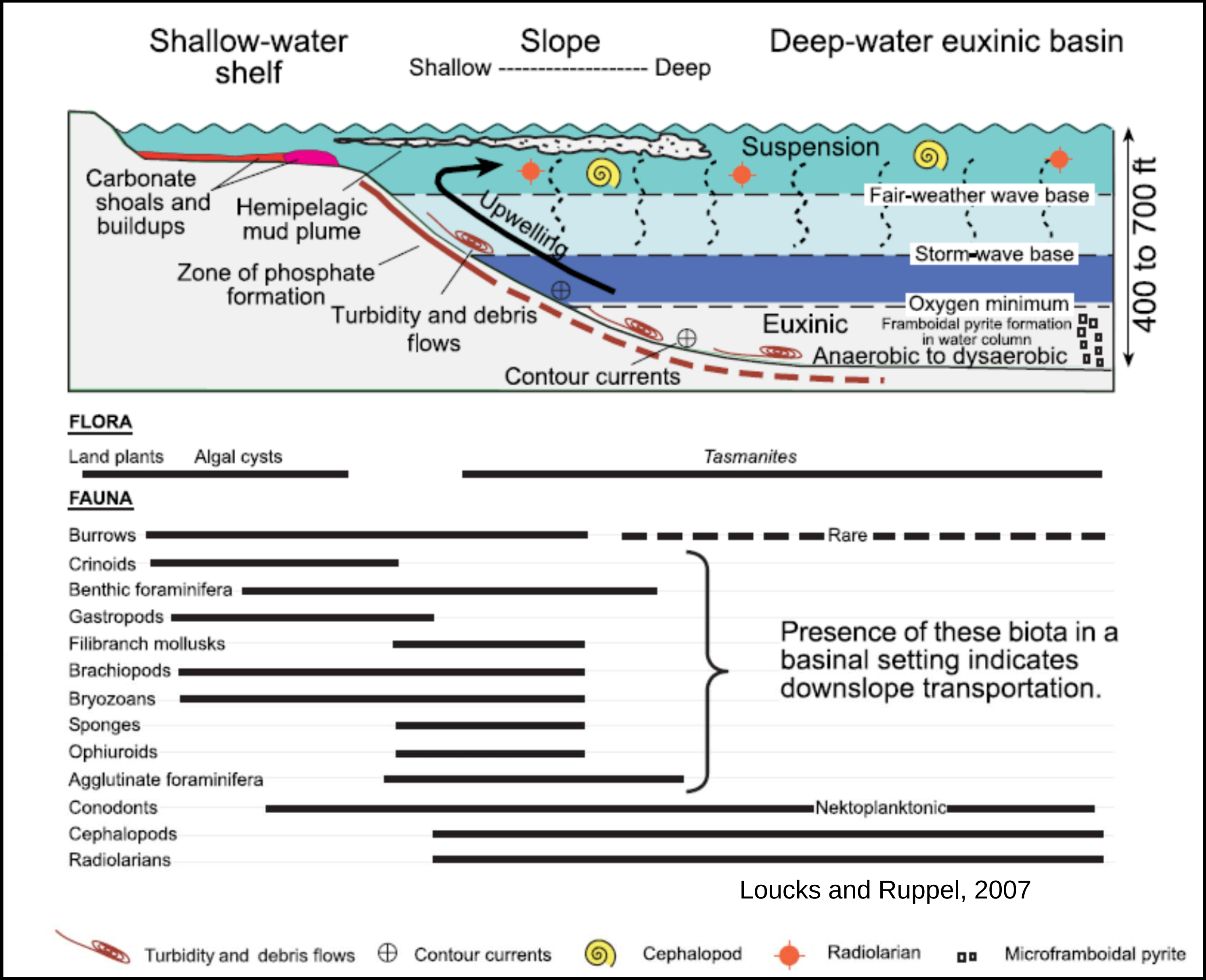
That stratigraphic model is based on a depositional model something like this – organic-rich shale in deep cold basin



Or this model that shows black shale deposition in 200-250 m of water (from Brett and Baird, 1991)



Sageman et al., 2003 have the black shale forming in the deepest part of the basin



Loucks and Ruppel, 2007

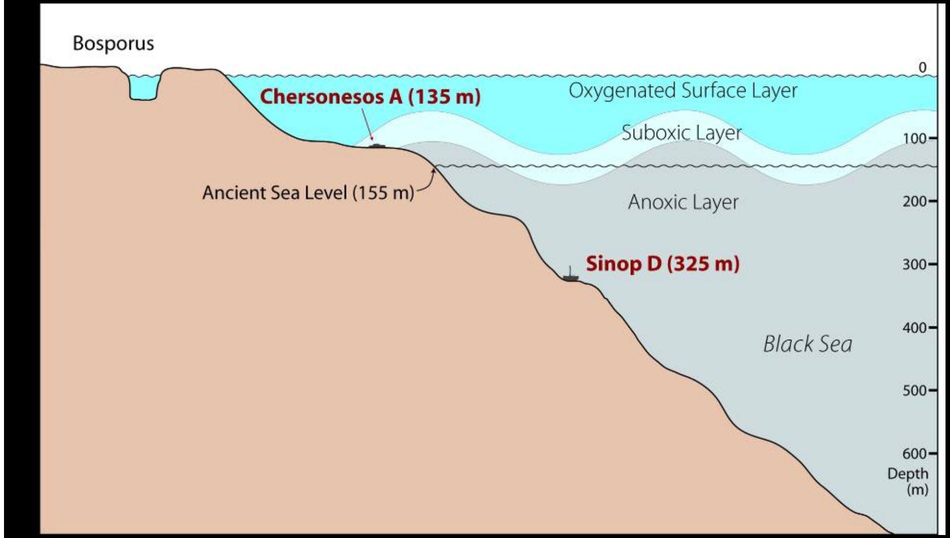
What happens over here?

Or this recent model for the Barnett Shale – clay settles from suspension

Deep Model

- All those models showed the black shale forming in deep, basinal settings >130 meters deep with a permanent zone of anoxia and still water below the pycnocline where organic matter is preserved
- The black color, laminations, pyrite and some of the fossils found look deep because they are so unlike the other sediments we have come to think of as shallow marine deposits

Black Sea Model




Geologic Data Systems

These very deep models are at least in part driven by the modern analog of the Black Sea which is a silled basin up to 2km deep with a pycnocline at 100-200m depth

The Black Sea is a bit of geological oddity though – the basin is nothing like the vast epeirc seas where the Utica and Marcellus were deposited

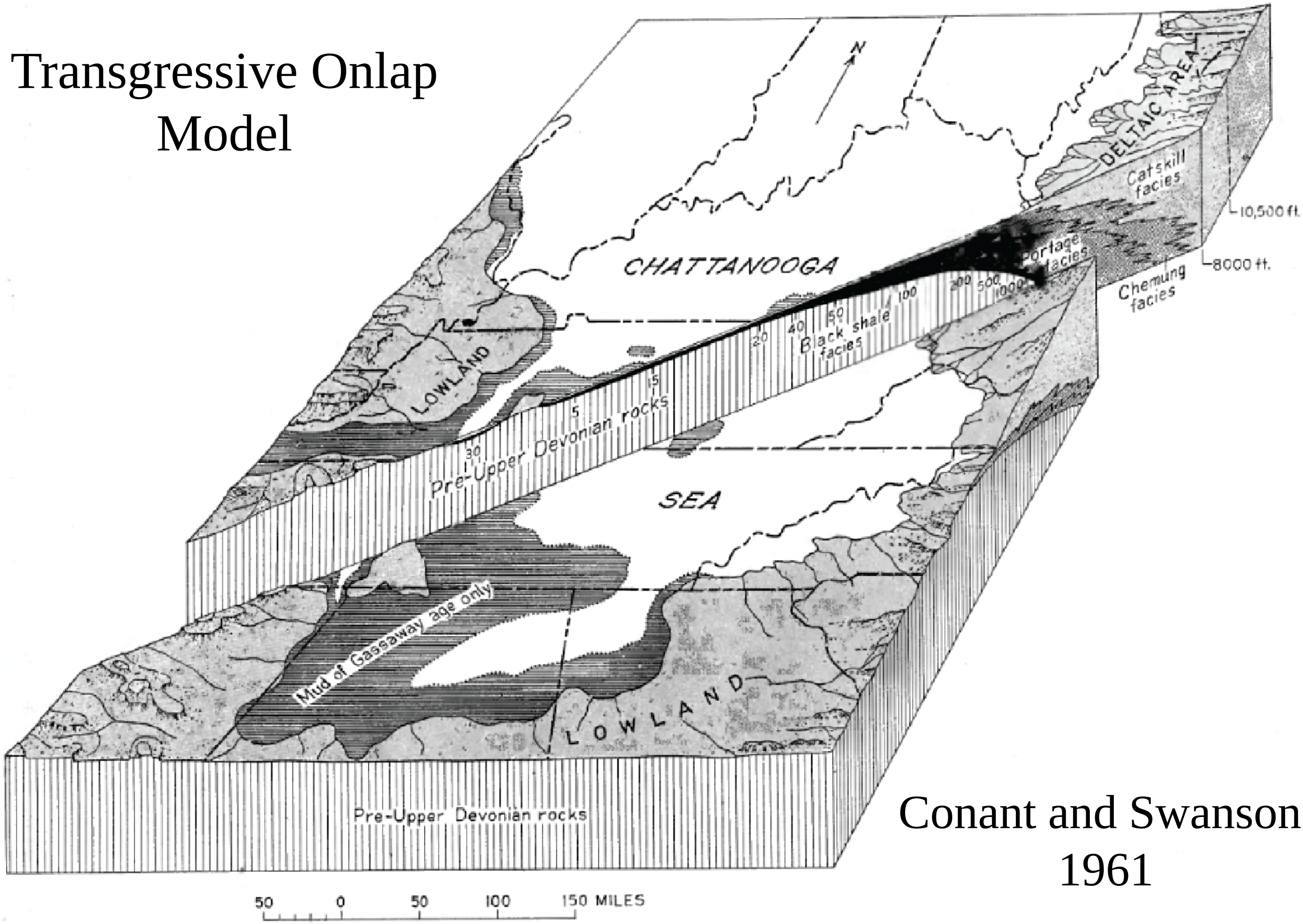
Problems with Deep Model

- Nutrient Trapping
  - Nutrients would fall below pycnocline never to feed again – all nutrients would need to come from land – this will diminish productivity
- Maintaining permanently anoxic water
  - it requires a large volume of organic matter and very still water to maintain an anoxic zone tens of meters deep
- Organic matter gets eaten on the way down
  - the higher the column of oxic water, the lower the chance the organic matter will even make it to the pycnocline
- Dilution
  - what prevents silcicilastics from moving to bottom of slope?
- Stratal Geometry
  - Doesn't explain distribution of organic-rich shale in Utica and Marcellus and link to unconformities

Shallow Versus Deep

- For more than 50 years there have been arguments over whether the Devonian Black Shales were deposited in deep or shallow water
- The distribution of the shales on tectonic highs, the fact that many of them overlie unconformities and are time-equivalent to periods when there was significant exposed land nearby and other factors have led some to interpret a shallow marine origin for the shales

Transgressive Onlap Model



Conant and Swanson, 1961

Organic-rich Devonian Chattanooga Shale overlies and onlaps an unconformity and is time-equivalent to exposure nearby – reasoned that water was likely less than 30m (100 feet) deep

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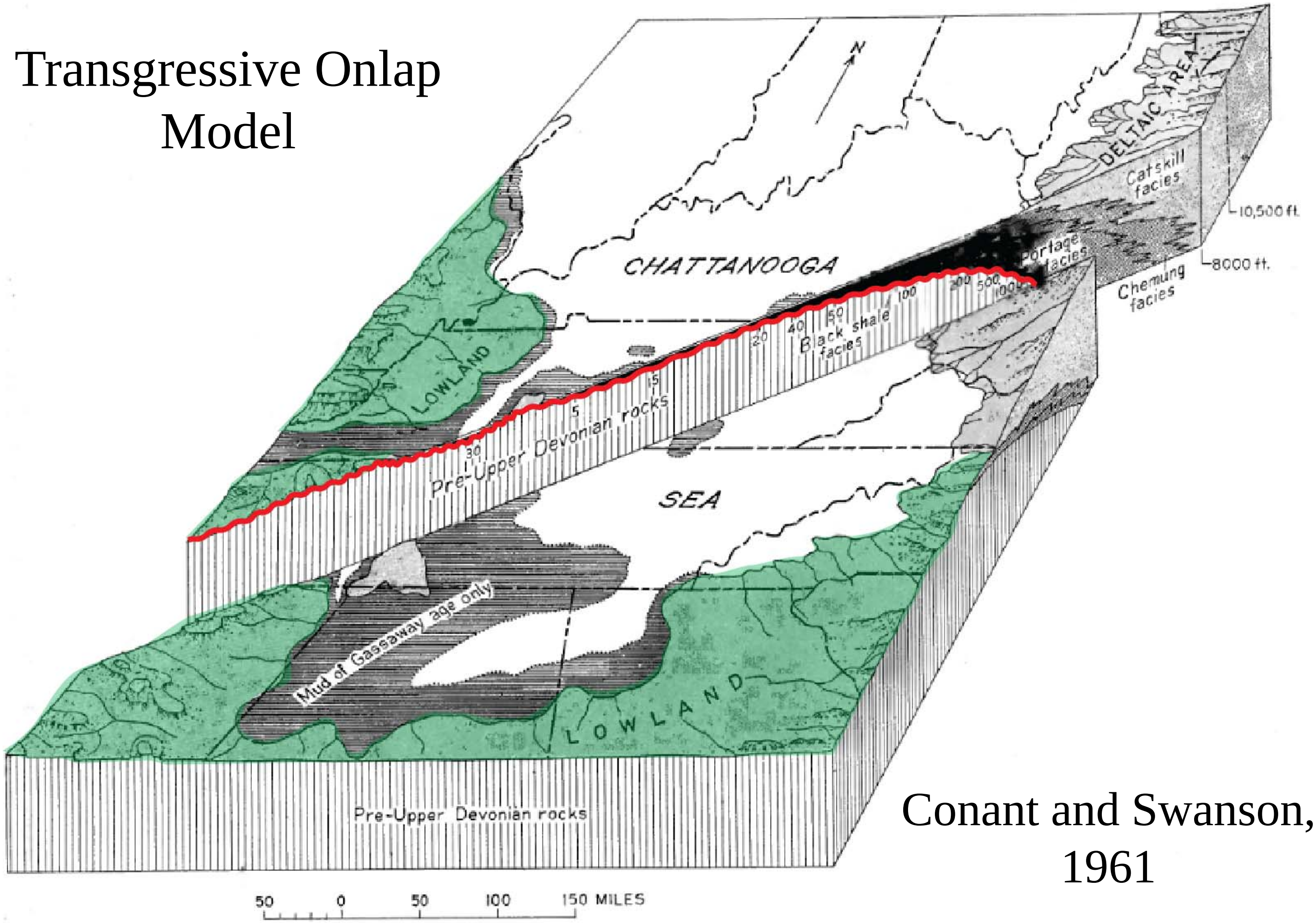

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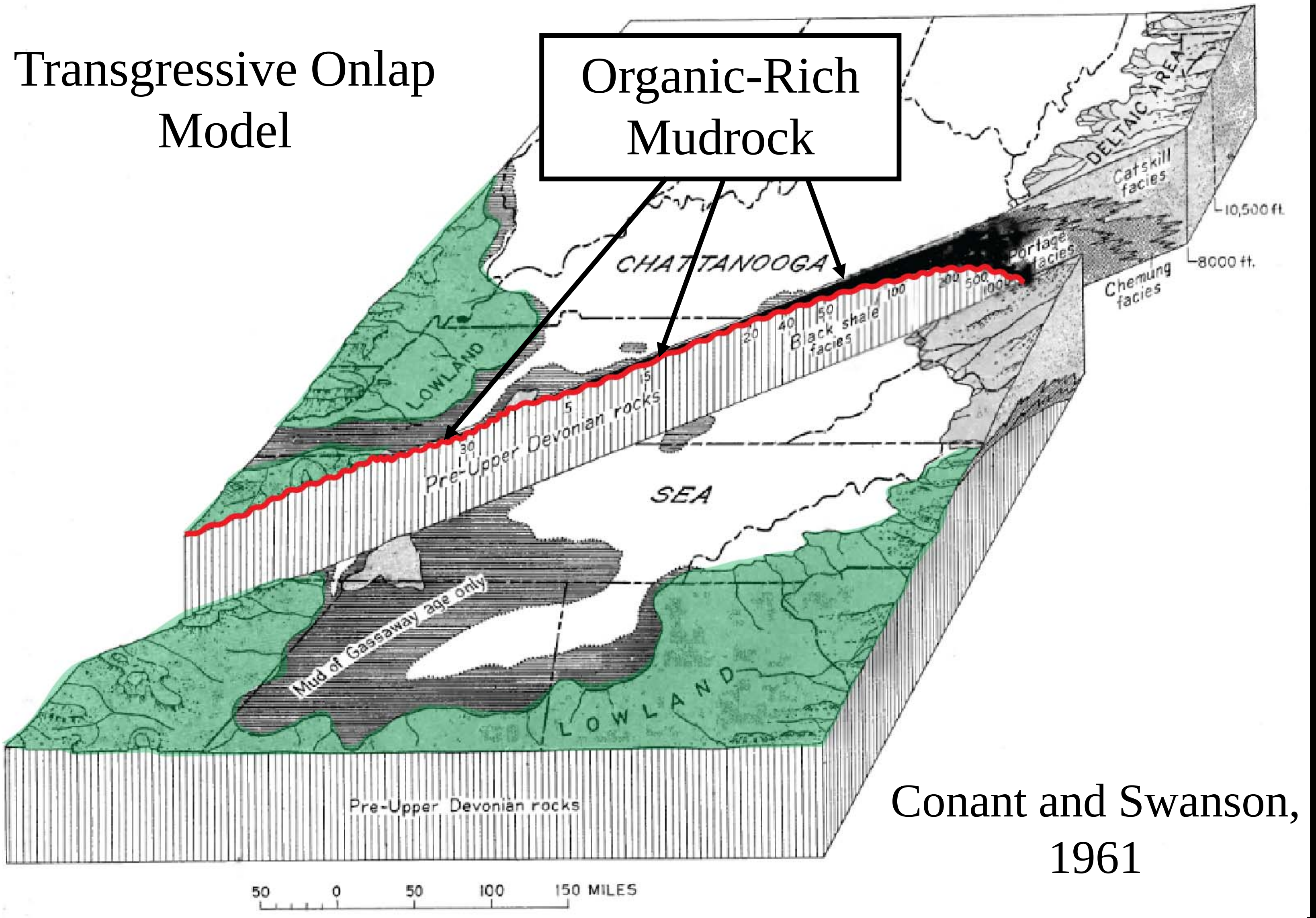

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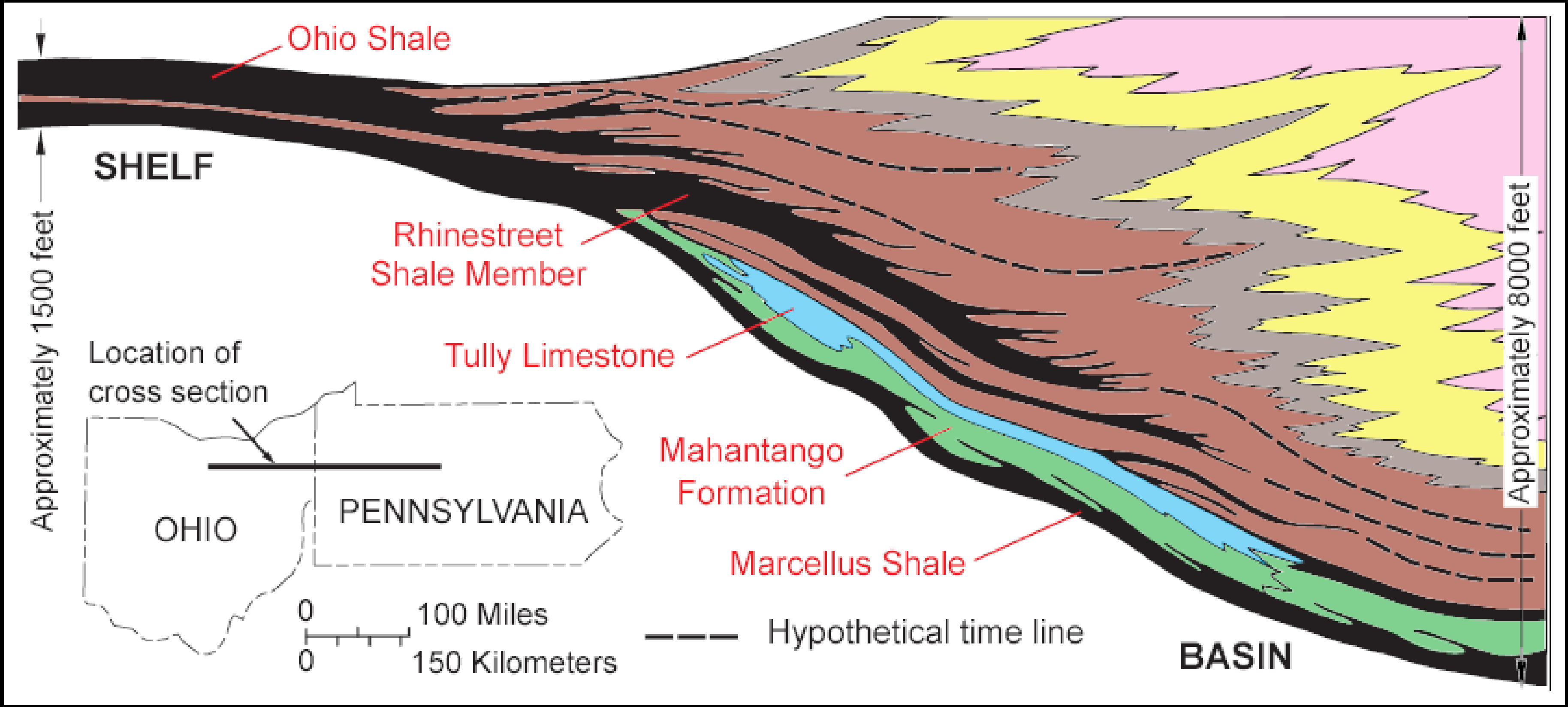
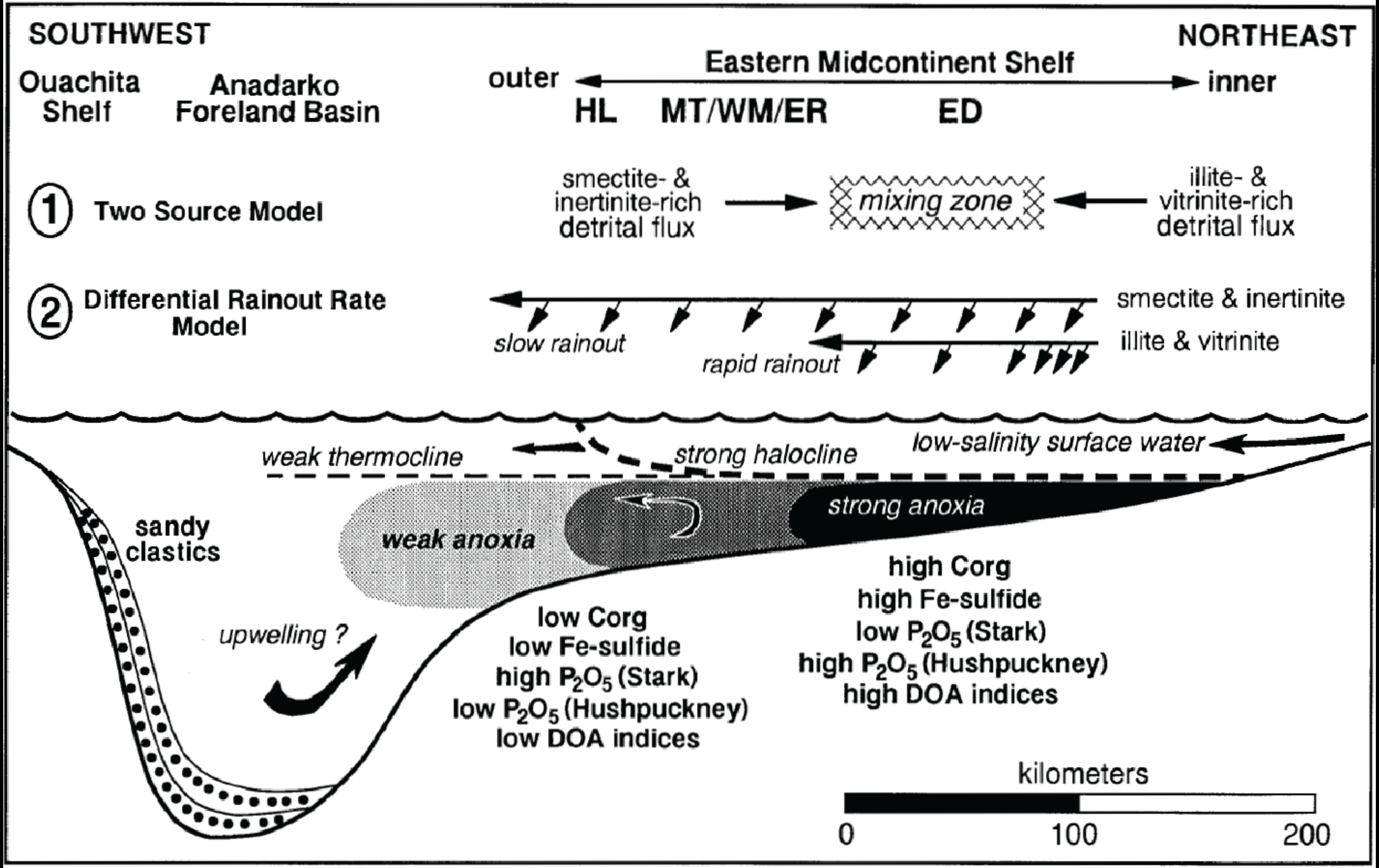


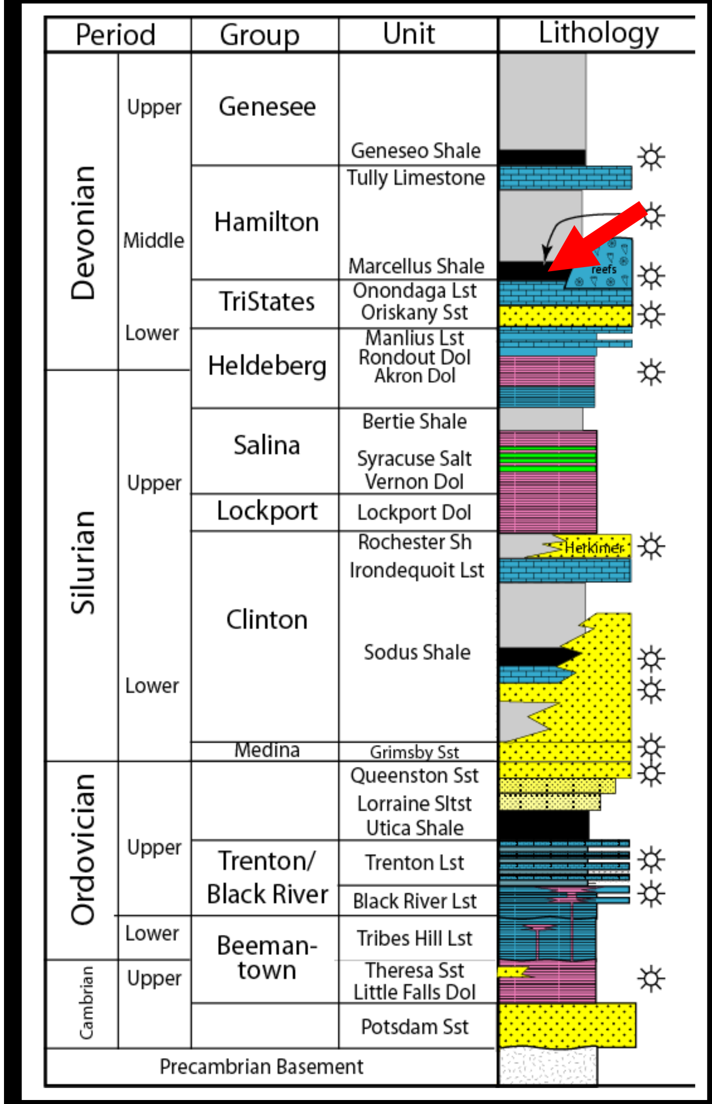
Harper and Laughery, 1978

Looking at the distribution here, it is very difficult to make the black shale the deepest facies – they are the only facies deposited on the tectonic high – if the black color symbolized ooid grainstones or tidal flats would anyone be surprised? It seems like where one would expect to find shallow marine facies

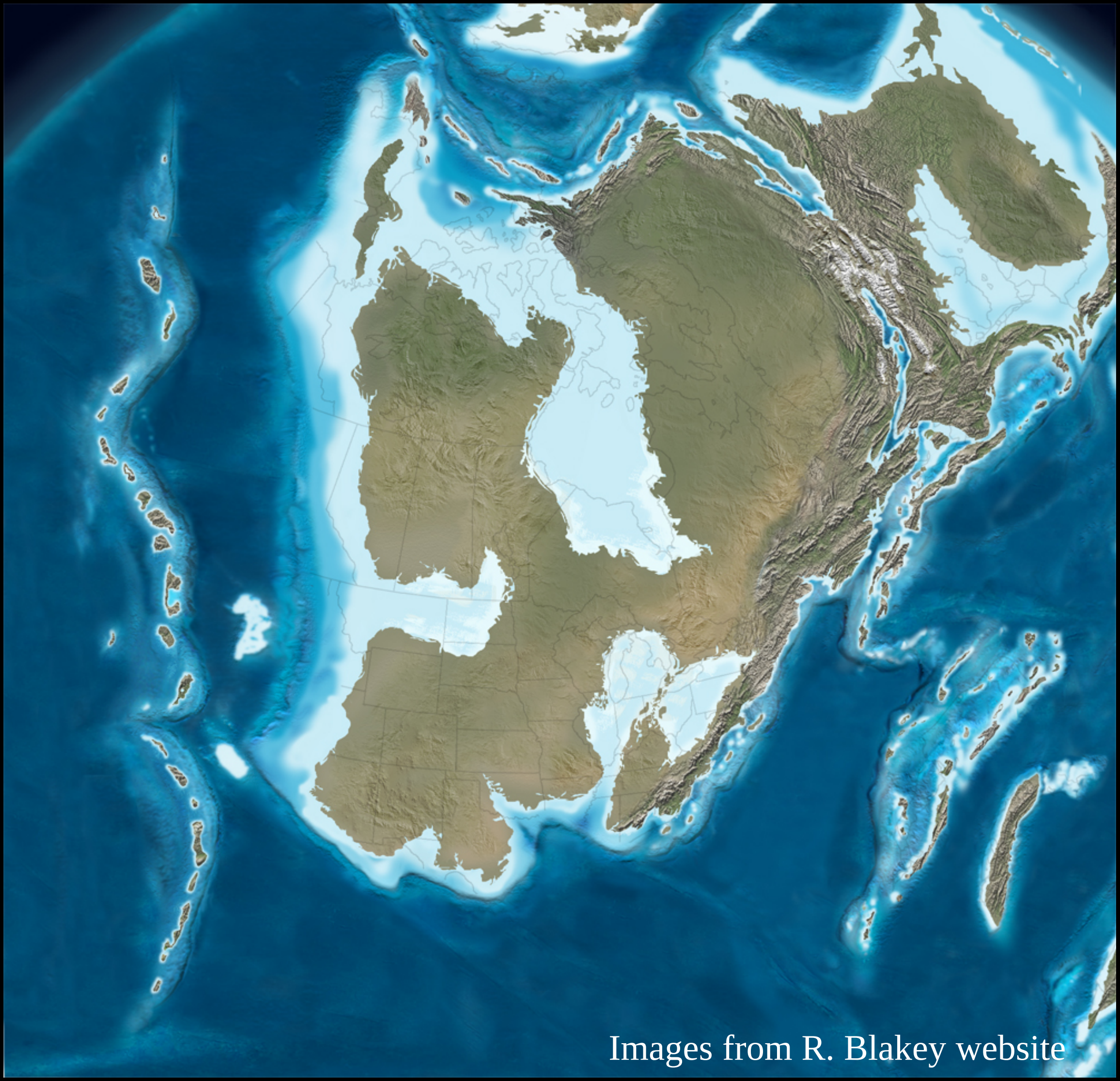


This figure from Algeo et al (1989) for the Pennsylvanian of Anadarko Basin shows the anoxic environment up on the cratonward shelf not in the deepest part of the basin – this looks familiar

Devonian Paleogeography



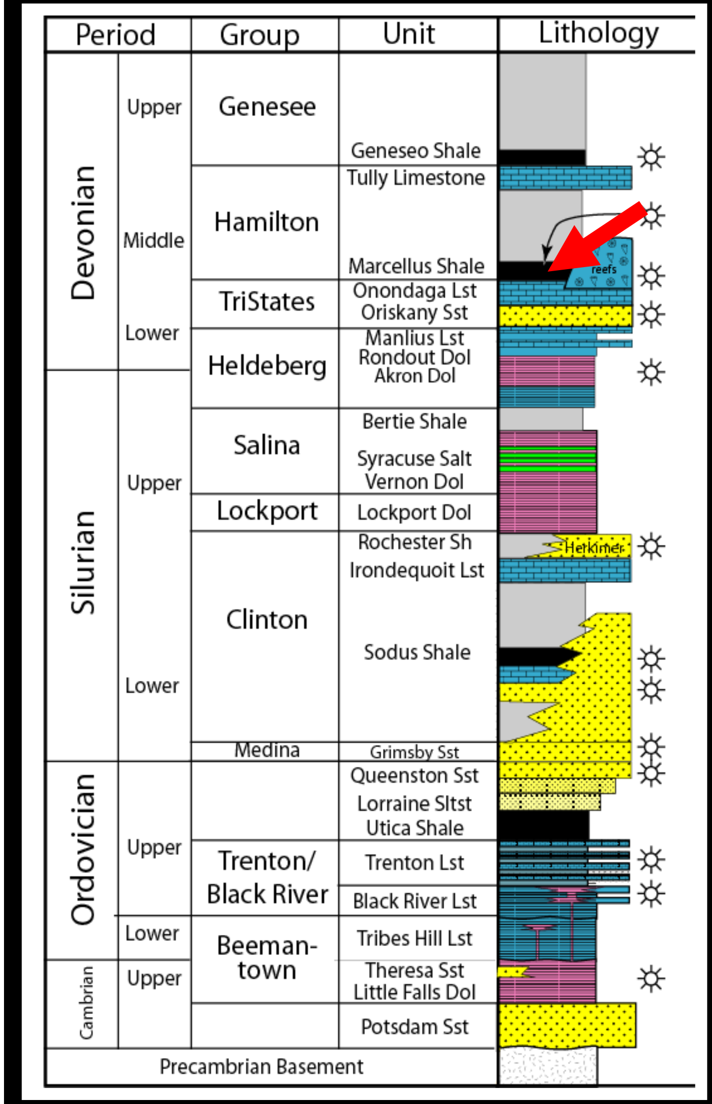
Period		Group	Unit
Devonian	Upper	Genesee	Geneseo Shale
	Middle	Hamilton	Tully Limestone Marcellus Shale
	Lower	TriStates	Onondaga Lst Oriskany Sst
		Heldeberg	Manlius Lst Rondout Dol Akron Dol
Silurian	Upper	Salina	Bertie Shale Syracuse Salt Vernon Dol
		Lockport	Lockport Dol
		Clinton	Rochester Sh Irondequoit Lst
	Lower		Sodus Shale
		Medina	Grimsby Sst
Ordovician	Upper		Queenston Sst Lorraine Sltst Utica Shale
		Trenton/ Black River	Trenton Lst Black River Lst
	Lower	Beeman-town	Tribes Hill Lst
Cambrian	Upper		Theresa Sst Little Falls Dol
			Potsdam Sst
Precambrian Basement			



Images from R. Blakey website

Marcellus deposited during early stages of Acadian Orogeny

Devonian Paleogeography



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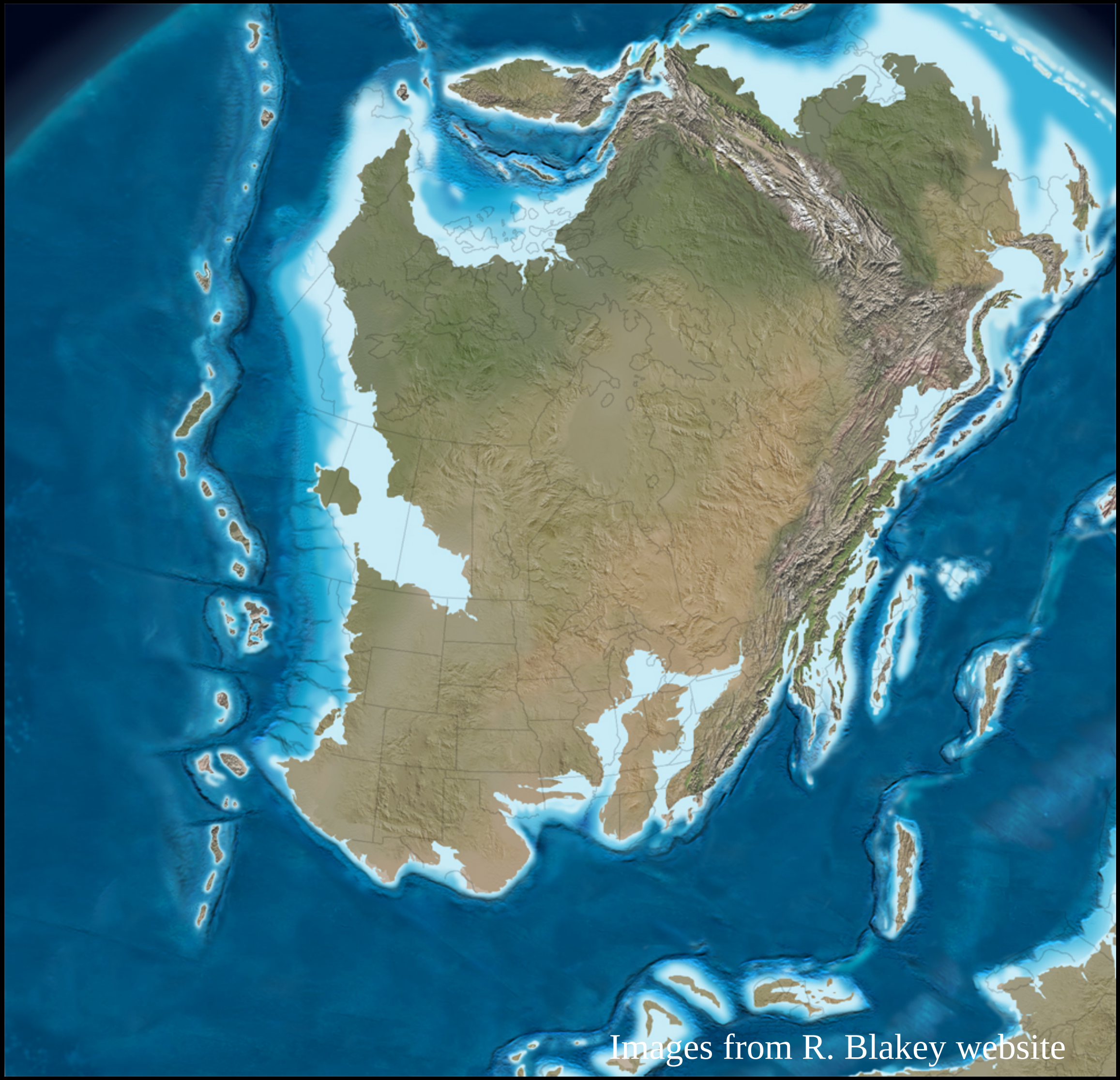

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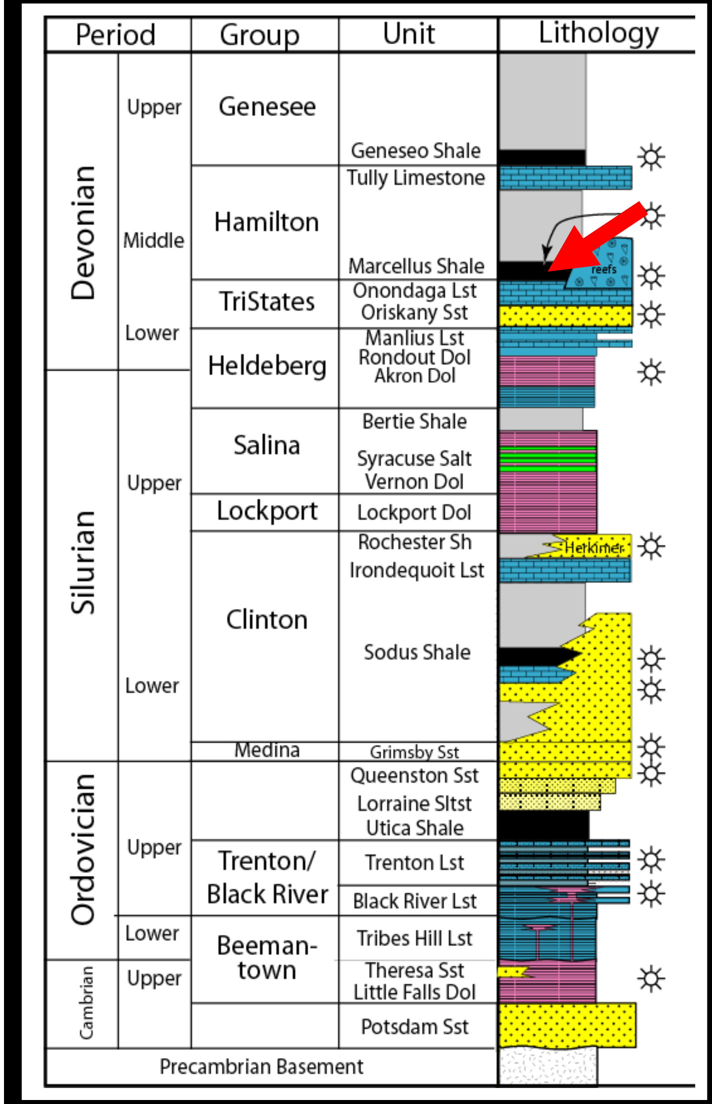

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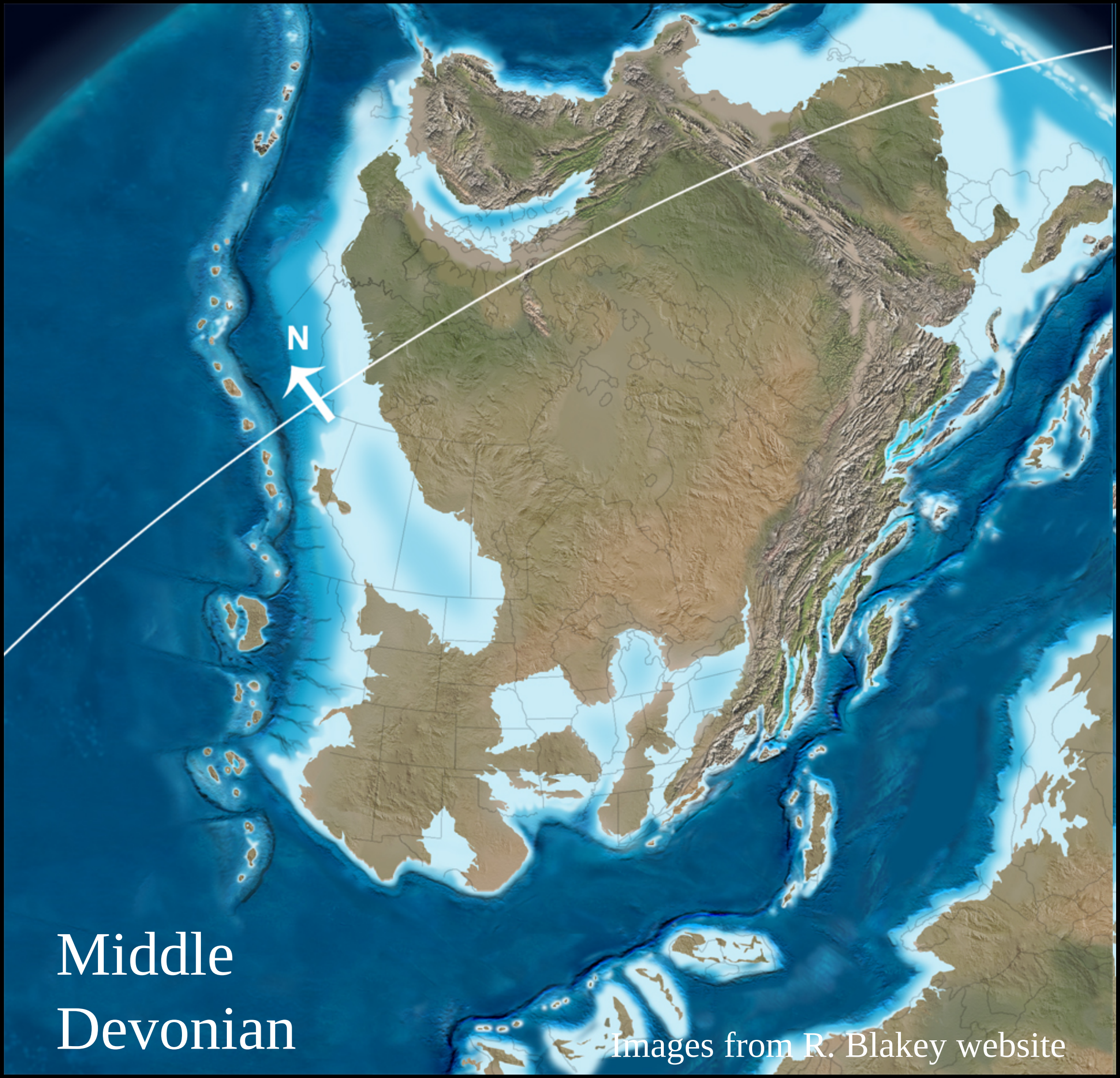

Middle Devonian

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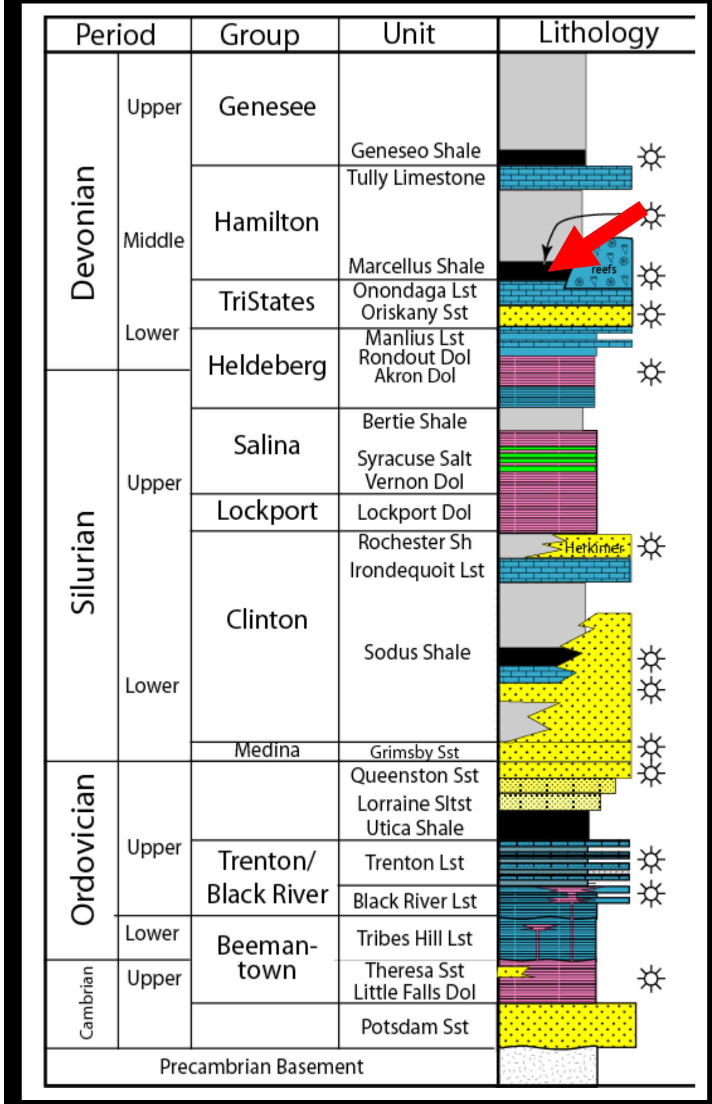

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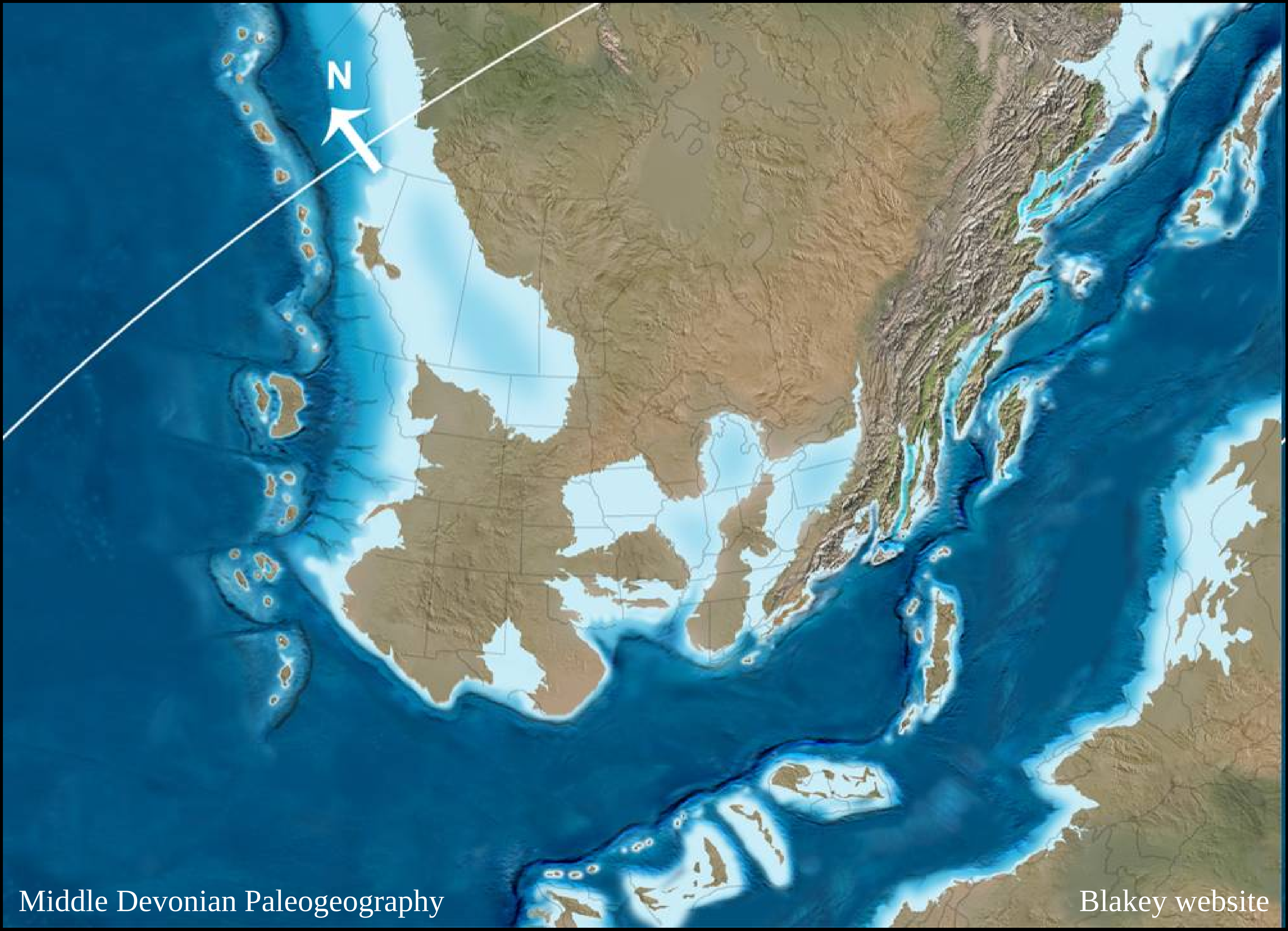
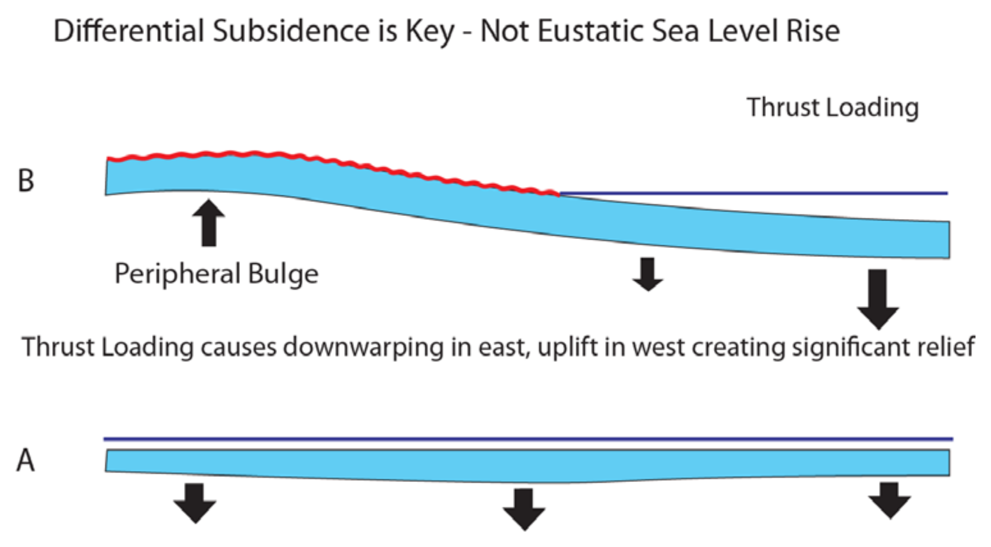
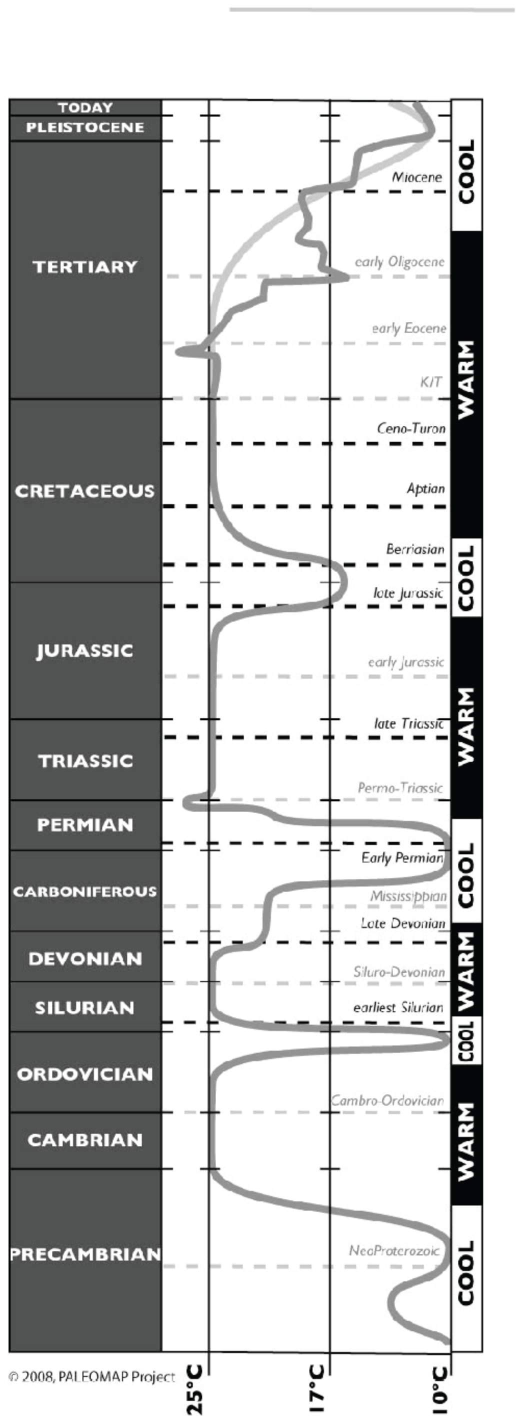


How deep can this be? Most of North America is land at this time

Sea Level Rise

- The transgressions in the cases of both the Utica and Marcellus come more as a result of increased subsidence related to mountain building than of a eustatic sea-level rise – in fact eustatic sea level appears to have been pretty low
- Both deposited during greenhouse times of low amplitude eustatic sea level changes





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Paleomap project, 2008

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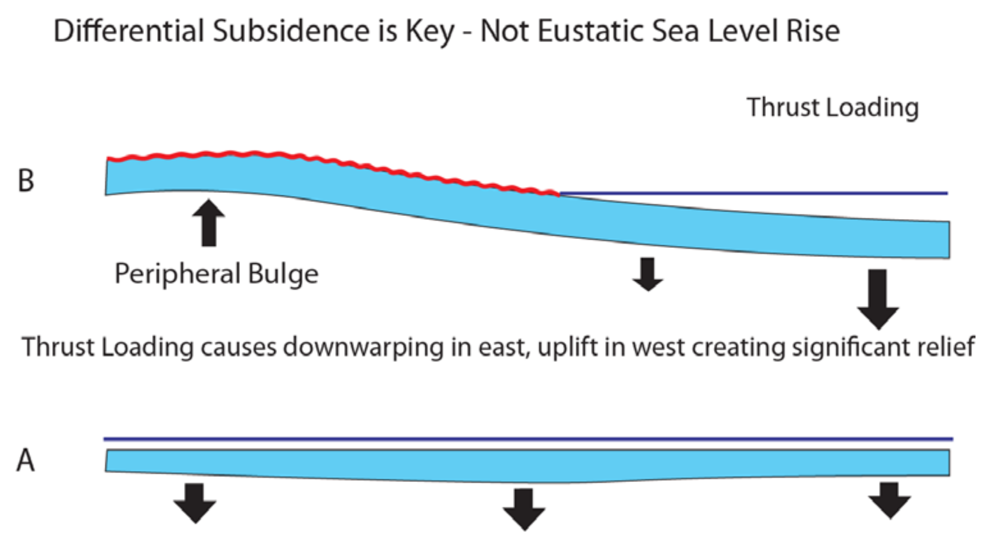
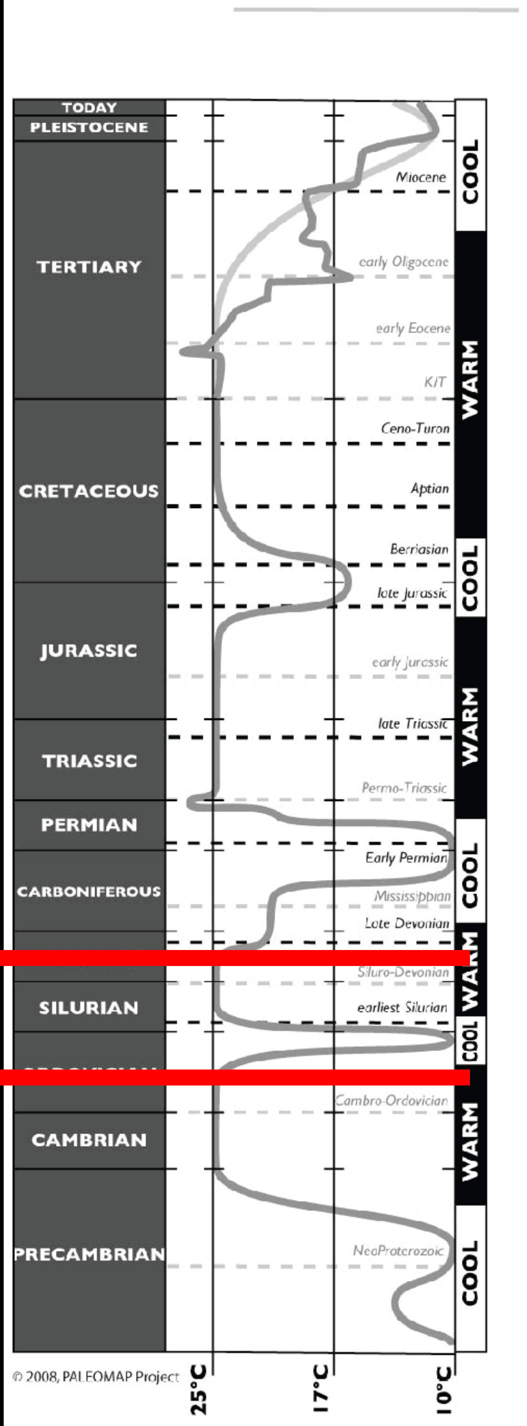


Marcellus

Utica



Paleomap project, 2008

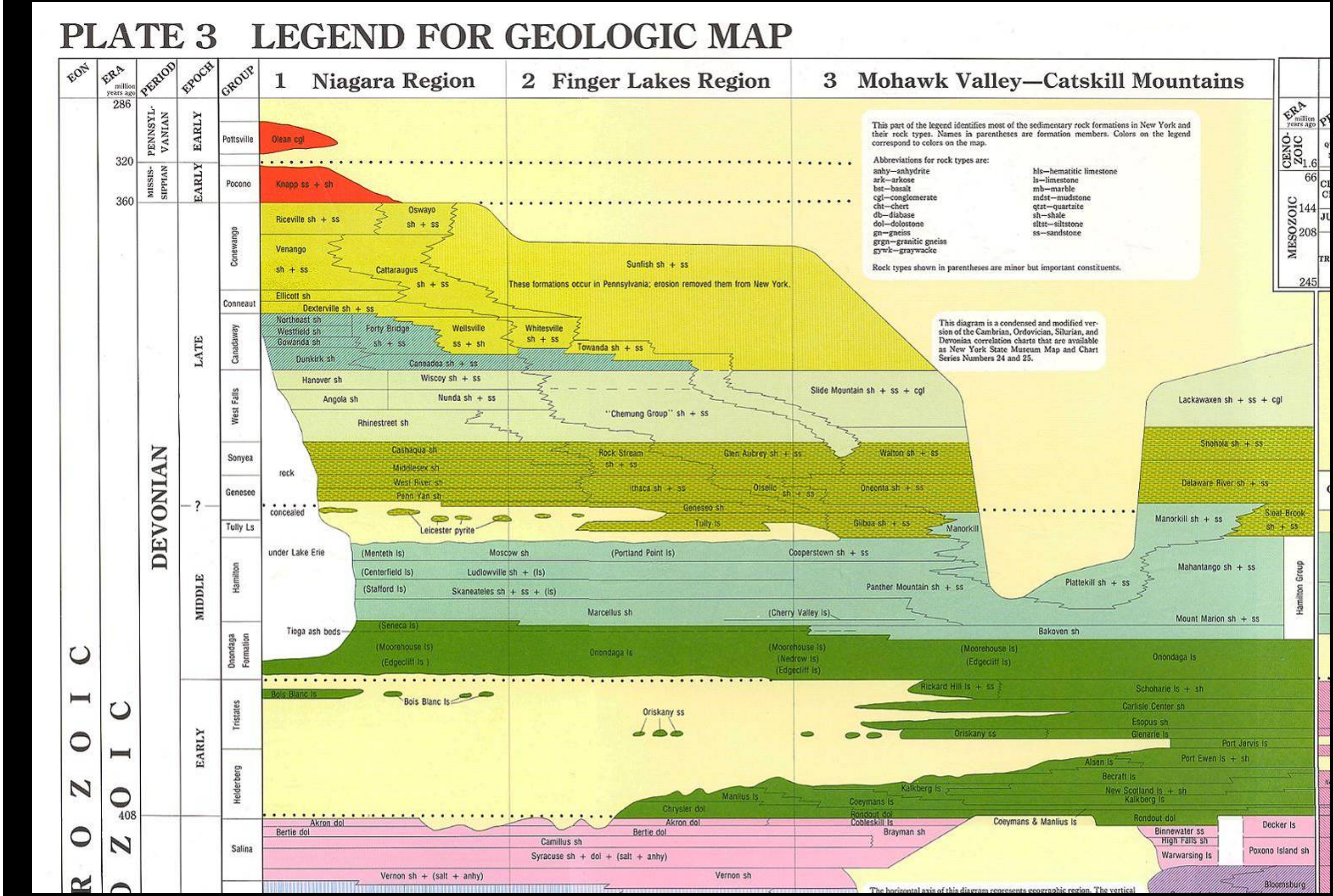


PLATE 3 LEGEND FOR GEOLOGIC MAP

This part of the legend identifies most of the sedimentary rock formations in New York and their rock types. Names in parentheses are formation members. Colors on the legend correspond to colors on the map.

Abbreviations for rock types are:

anhy—anhydrite	hls—hematitic limestone
ark—arkose	ls—limestone
bst—basalt	mb—marble
cgl—conglomerate	mdst—mudstone
cht—chert	qtzt—quartzite
db—diabase	sh—shale
dol—dolostone	sltst—siltstone
gn—gneiss	ss—sandstone
grgn—granitic gneiss	
gywk—graywacke	

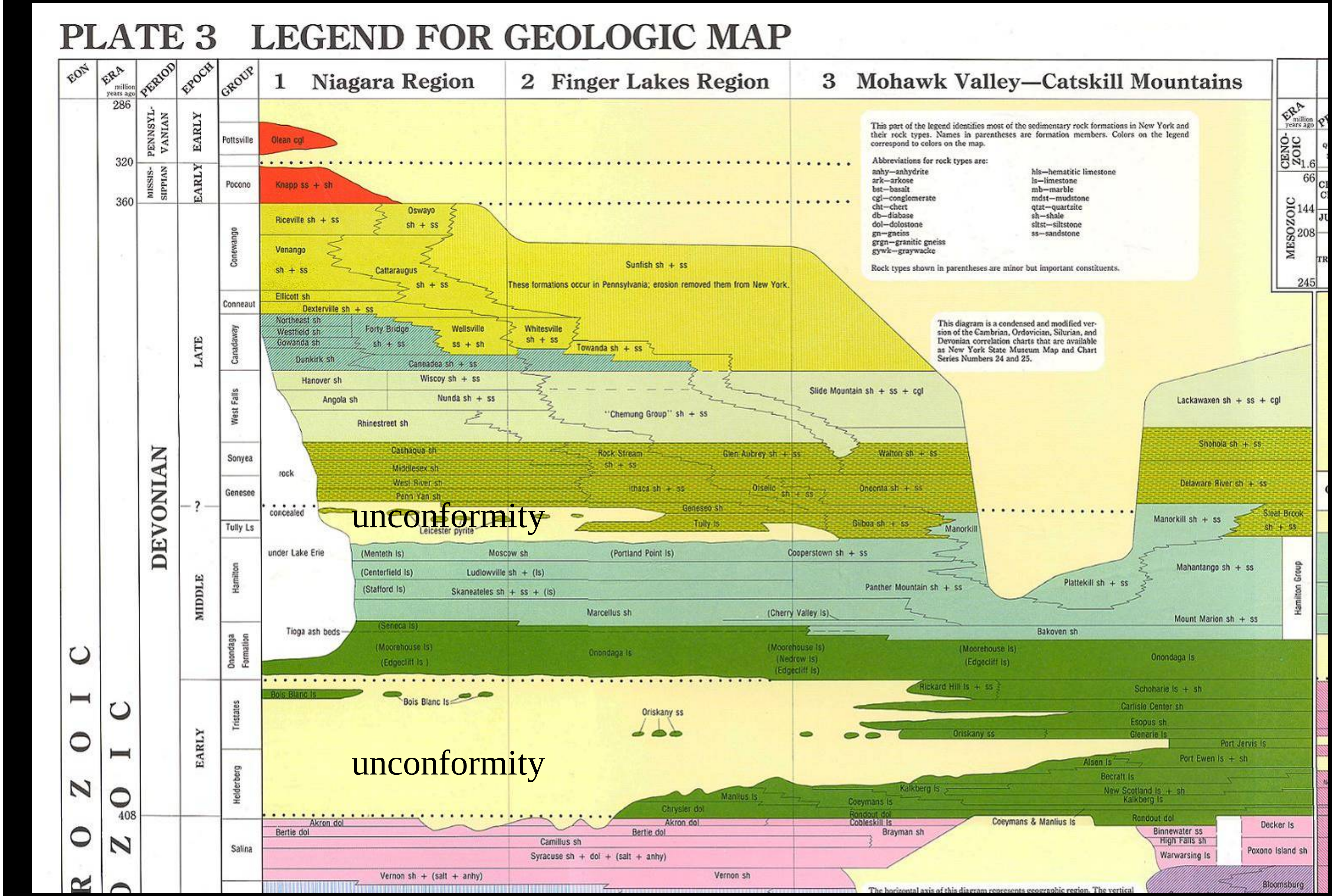
Rock types shown in parentheses are minor but important constituents.

This diagram is a condensed and modified version of the Cambrian, Ordovician, Silurian, and Devonian correlation charts that are available as New York State Museum Map and Chart Series Numbers 24 and 25.

These formations occur in Pennsylvania; erosion removed them from New York.

The horizontal axis of this diagram represents geographic region. The vertical

Legend from geological highway map of NY – there are some mistakes on this though it does show some important unconformities



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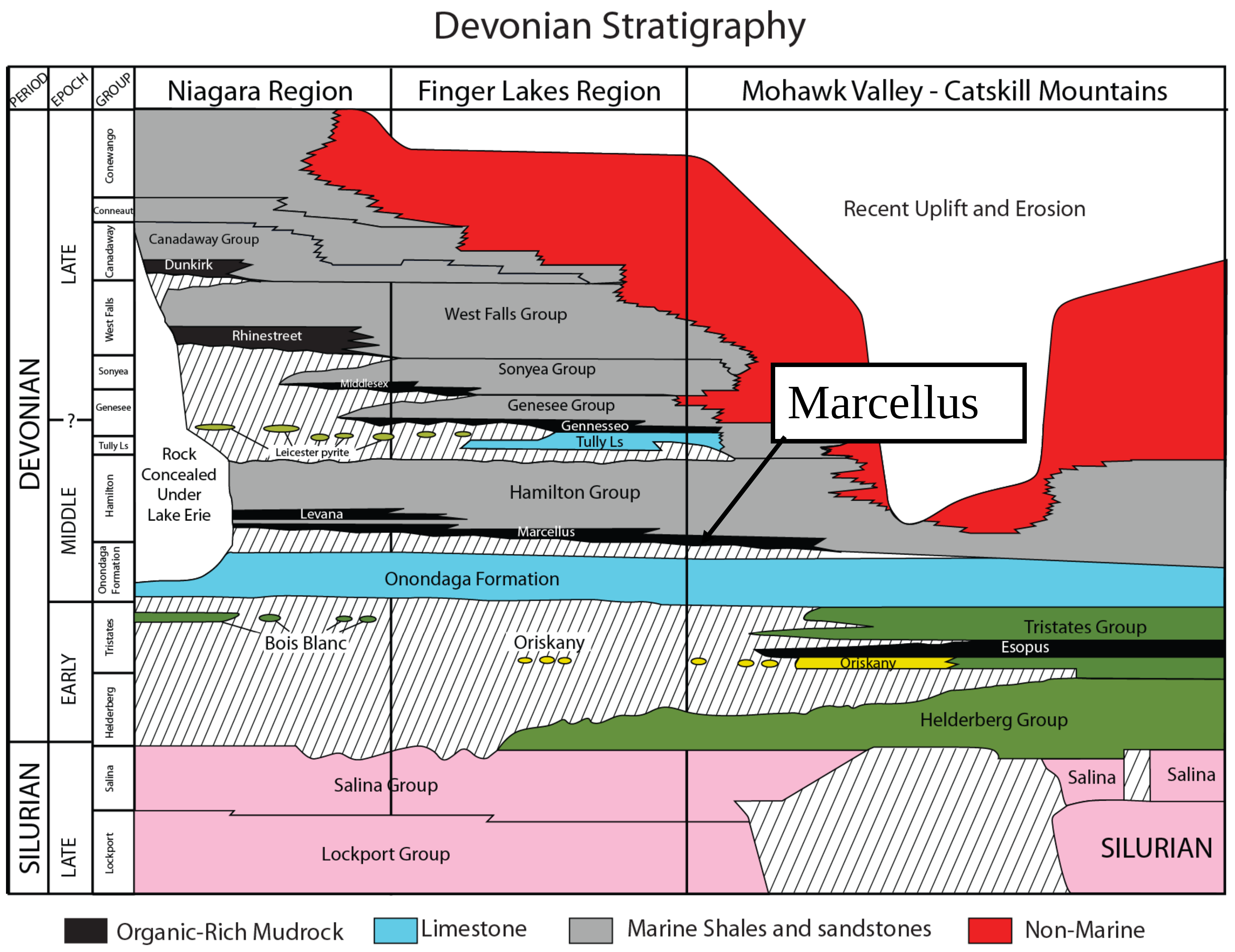


Marcellus is Middle Devonian – overlies and is laterally equivalent to unconformity as are all black shales in NY

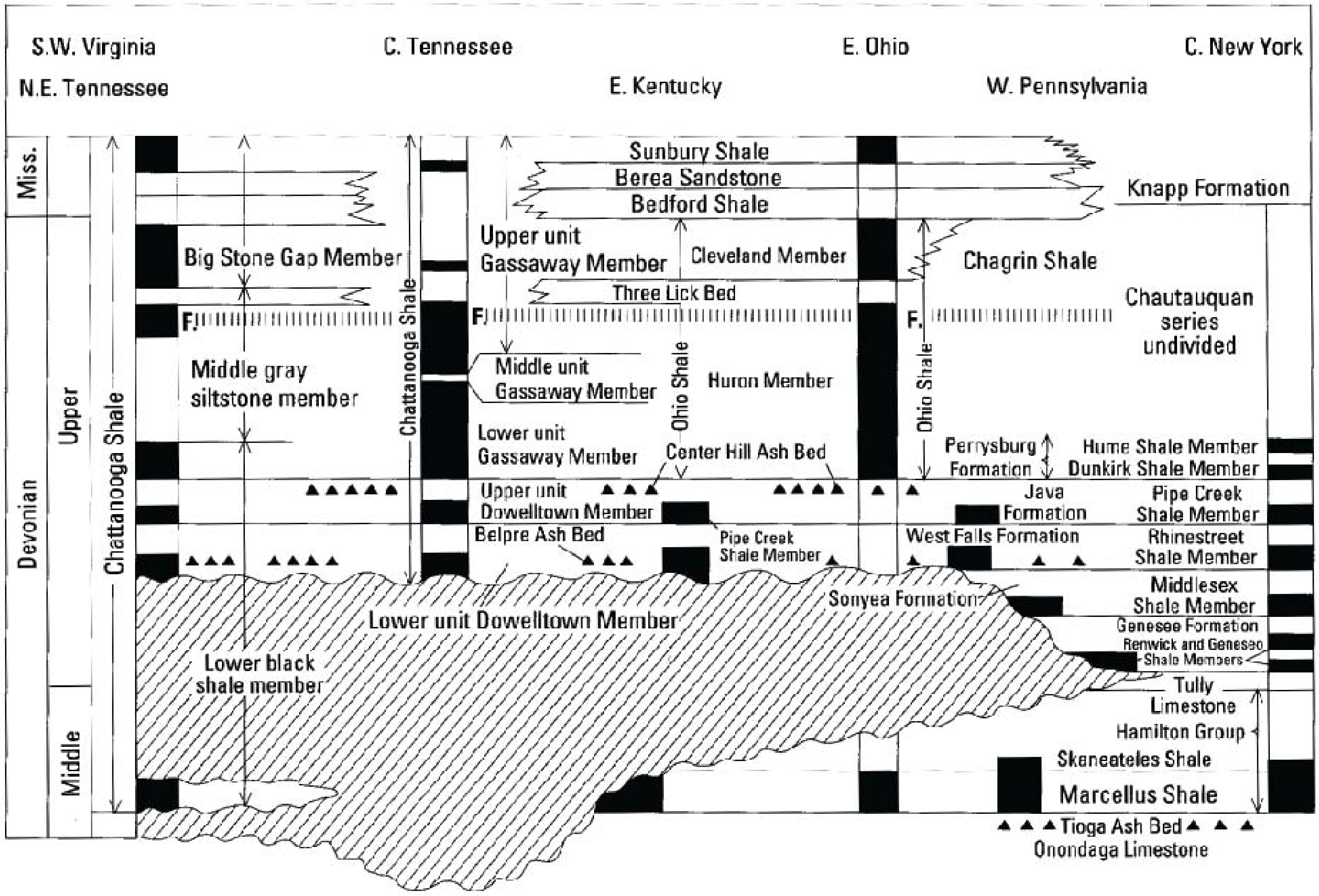
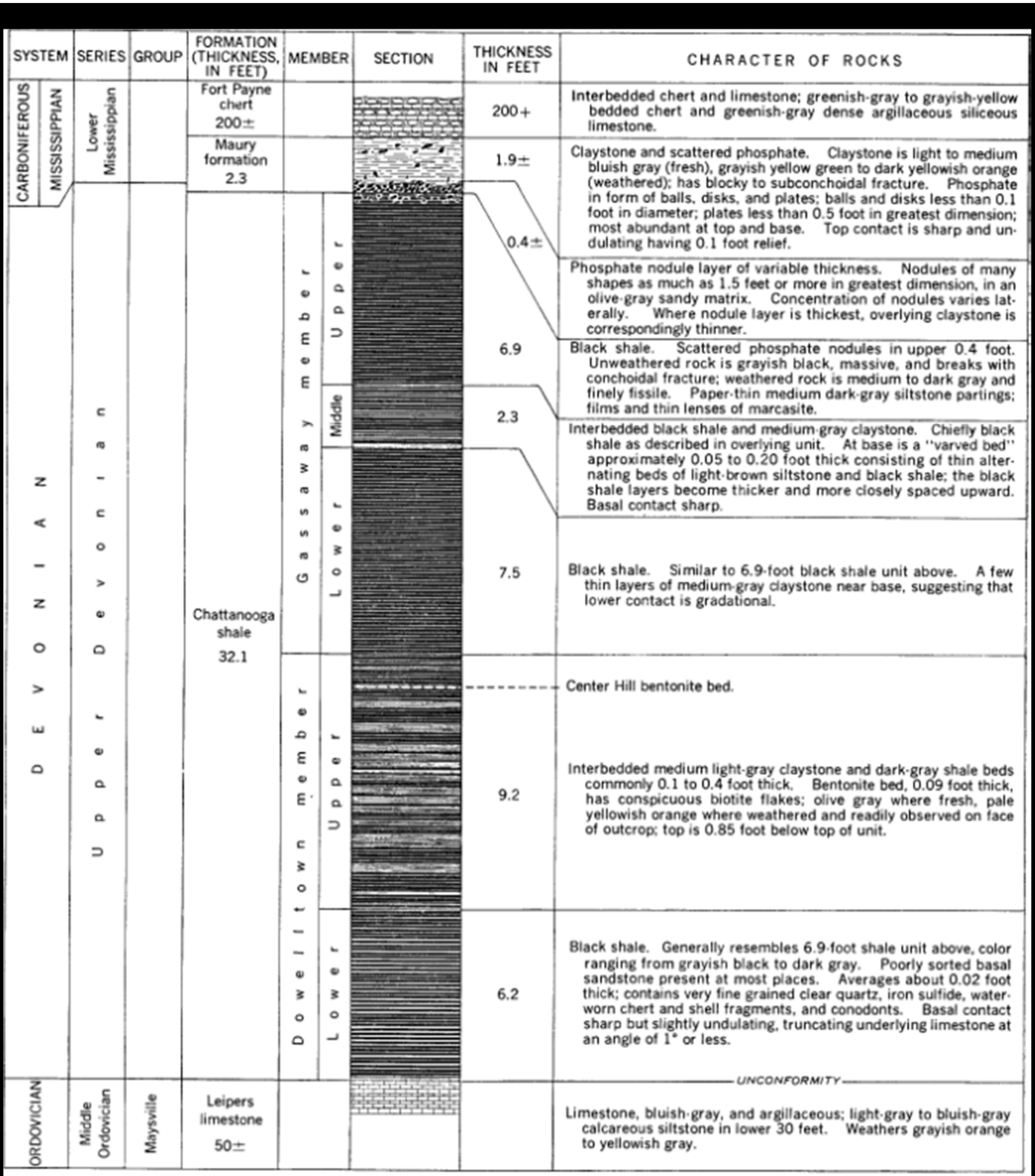


Figure 4. Correlation of Devonian and Mississippian black gas shales and some related rocks in the Appalachian basin. |||| *F.* ||||, *Foerstia* zone; ▲, ash bed.

Although there may be some issues with this deWitt et al. (1990) cross section – it shows that many black shales overlie and are time-equivalent to major unconformity

Drowning versus Subaerial Unconformites

- Some authors have suggested that these unconformities are drowning unconformities where there are long periods (millions of years in some cases) where there is non-deposition and even corrosion in deep anoxic water (Brett and Baird, 1991; others)
- Evidence includes phosphatized deposits, reworked pyrite, bone beds
- It is clear, however, that at least some of them are at least initially subaerial
- Perhaps some or all start out as subaerial unconformities where most of the time is missing, but the phosphate, pyrite, bone material, etc are all deposited during the subsequent transgression

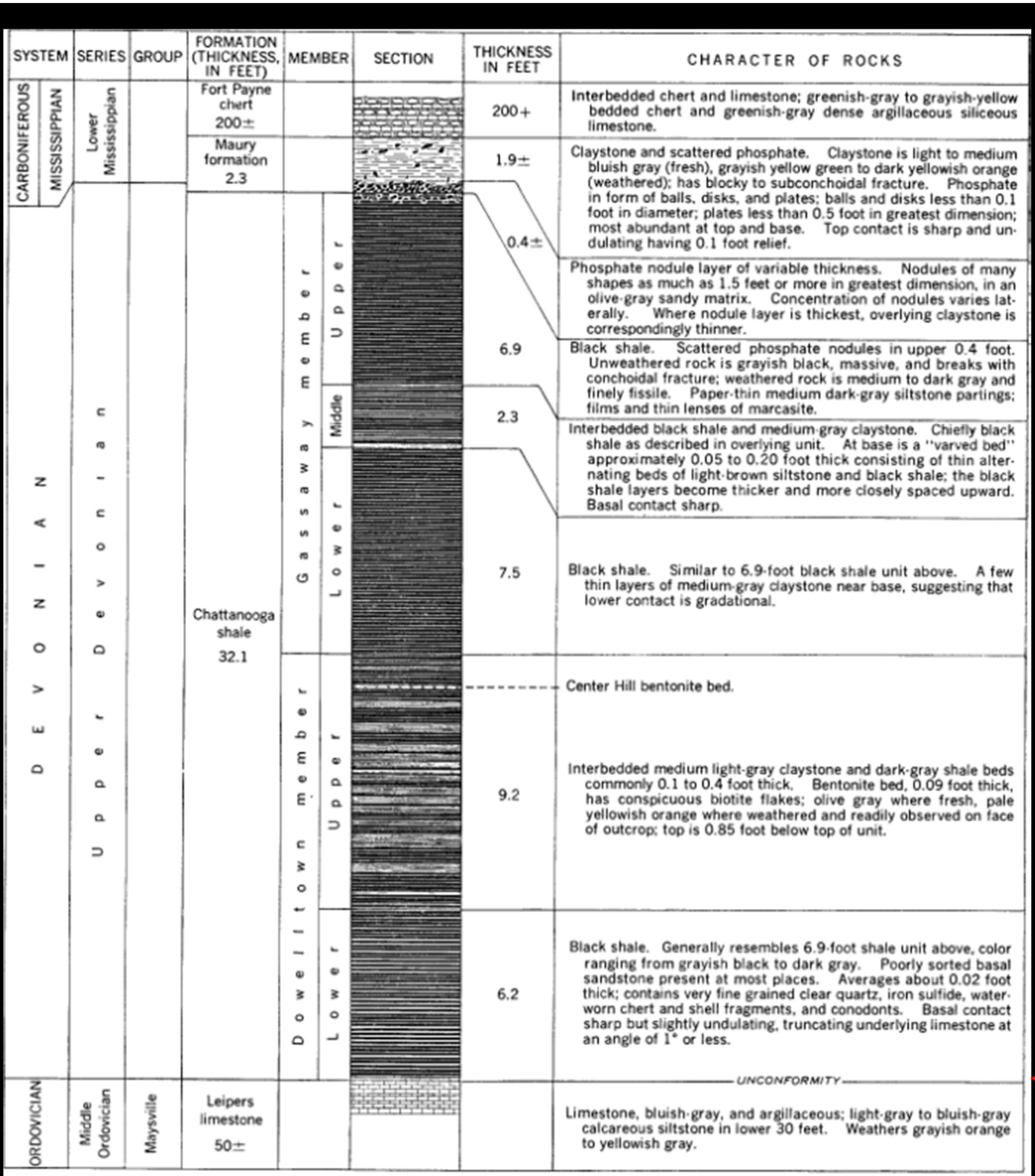


SYSTEM	SERIES	GROUP	FORMATION (THICKNESS, IN FEET)	MEMBER	THICKNESS IN FEET	CHARACTER OF ROCKS
CARBONIFEROUS MISSISSIPPIAN	Lower Mississippian		Fort Payne chert 200±		200+	Interbedded chert and limestone; greenish-gray to grayish-yellow bedded chert and greenish-gray dense argillaceous siliceous limestone.
			Maury formation 2.3		1.9±	Claystone and scattered phosphate. Claystone is light to medium bluish gray (fresh), grayish yellow green to dark yellowish orange (weathered); has blocky to subconchoidal fracture. Phosphate in form of balls, disks, and plates; balls and disks less than 0.1 foot in diameter; plates less than 0.5 foot in greatest dimension; most abundant at top and base. Top contact is sharp and undulating having 0.1 foot relief.
					0.4±	Phosphate nodule layer of variable thickness. Nodules of many shapes as much as 1.5 feet or more in greatest dimension, in an olive-gray sandy matrix. Concentration of nodules varies laterally. Where nodule layer is thickest, overlying claystone is correspondingly thinner.
DEVONIAN	Upper Devonian		Chattanooga shale 32.1	Gassaway member: Upper	6.9	Black shale. Scattered phosphate nodules in upper 0.4 foot. Unweathered rock is grayish black, massive, and breaks with conchoidal fracture; weathered rock is medium to dark gray and finely fissile. Paper-thin medium dark-gray siltstone partings; films and thin lenses of marcasite.
				Gassaway member: Middle	2.3	Interbedded black shale and medium-gray claystone. Chiefly black shale as described in overlying unit. At base is a "varved bed" approximately 0.05 to 0.20 foot thick consisting of thin alternating beds of light-brown siltstone and black shale; the black shale layers become thicker and more closely spaced upward. Basal contact sharp.
				Gassaway member: Lower	7.5	Black shale. Similar to 6.9-foot black shale unit above. A few thin layers of medium-gray claystone near base, suggesting that lower contact is gradational.
				Dowelltown member: Upper	9.2	Center Hill bentonite bed. Interbedded medium light-gray claystone and dark-gray shale beds commonly 0.1 to 0.4 foot thick. Bentonite bed, 0.09 foot thick, has conspicuous biotite flakes; olive gray where fresh, pale yellowish orange where weathered and readily observed on face of outcrop; top is 0.85 foot below top of unit.
				Dowelltown member: Lower	6.2	Black shale. Generally resembles 6.9-foot shale unit above, color ranging from grayish black to dark gray. Poorly sorted basal sandstone present at most places. Averages about 0.02 foot thick; contains very fine grained clear quartz, iron sulfide, water-worn chert and shell fragments, and conodonts. Basal contact sharp but slightly undulating, truncating underlying limestone at an angle of 1° or less. *UNCONFORMITY*
ORDOVICIAN	Middle Ordovician	Maysville	Leipers limestone 50±			Limestone, bluish-gray, and argillaceous; light-gray to bluish-gray calcareous siltstone in lower 30 feet. Weathers grayish orange to yellowish gray.

FIGURE 5.—Standard section of the Dowelltown and Gassaway members of the Chattanooga shale. Vertical cut along east approach to Sligo bridge on State Route 26 (loc. 76), about 7 miles east of Smithville, DeKalb County, Tenn.

Conant and Swanson (1961) shows that the Chattanooga Shale overlies many different formations including some as old as the Middle Ordovician (>75 million years missing)

That shows that the unconformity is at least initially a subaerial unconformity rather than a drowning unconformity



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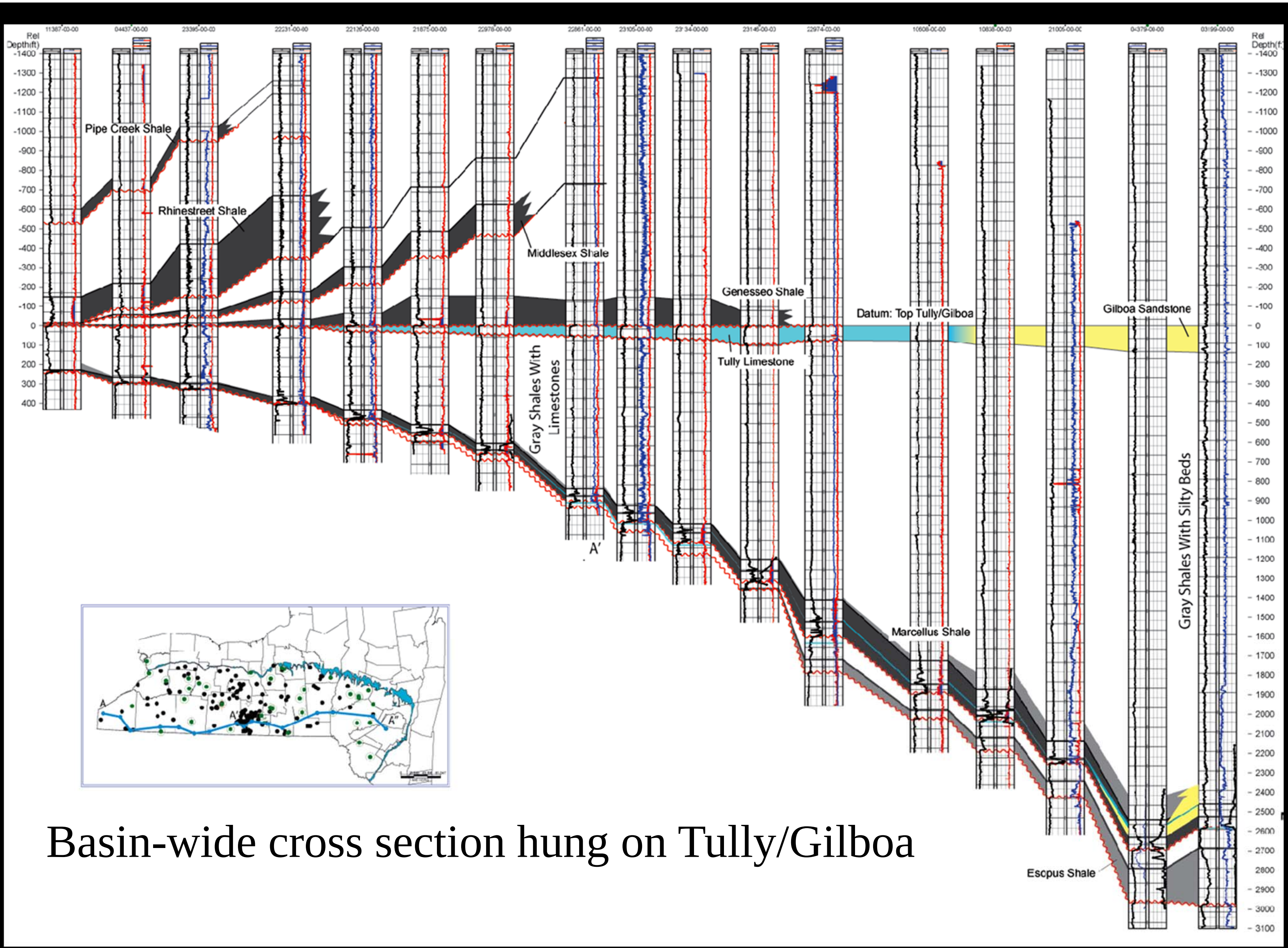
				Lower	7.5	Black shale. Similar to 6.9-foot black shale unit above. A few thin layers of medium-gray claystone near base, suggesting that lower contact is gradational.
				Dowelltown member Upper	9.2	Center Hill bentonite bed. Interbedded medium light-gray claystone and dark-gray shale beds commonly 0.1 to 0.4 foot thick. Bentonite bed, 0.09 foot thick, has conspicuous biotite flakes; olive gray where fresh, pale yellowish orange where weathered and readily observed on face of outcrop; top is 0.85 foot below top of unit.
				Lower	6.2	Black shale. Generally resembles 6.9-foot shale unit above, color ranging from grayish black to dark gray. Poorly sorted basal sandstone present at most places. Averages about 0.02 foot thick; contains very fine grained clear quartz, iron sulfide, water-worn chert and shell fragments, and conodonts. Basal contact sharp but slightly undulating, truncating underlying limestone at an angle of 1° or less.
						UNCONFORMITY
ORDOVICIAN	Middle Ordovician	Maysville	Leipers limestone 50±			Limestone, bluish-gray, and argillaceous; light-gray to bluish-gray calcareous siltstone in lower 30 feet. Weathers grayish orange to yellowish gray.

FIGURE 5.—Standard section of the Dowelltown and Gassaway members of the Chattanooga shale. Vertical cut along east approach to Sligo bridge on State Route 26 (loc. 76), about 7 miles east of Smithville, DeKalb County, Tenn.

Conant and Swanson (1961) shows that the Chattanooga Shale overlies many different formations including some as old as the Middle Ordovician (>75 million years missing)

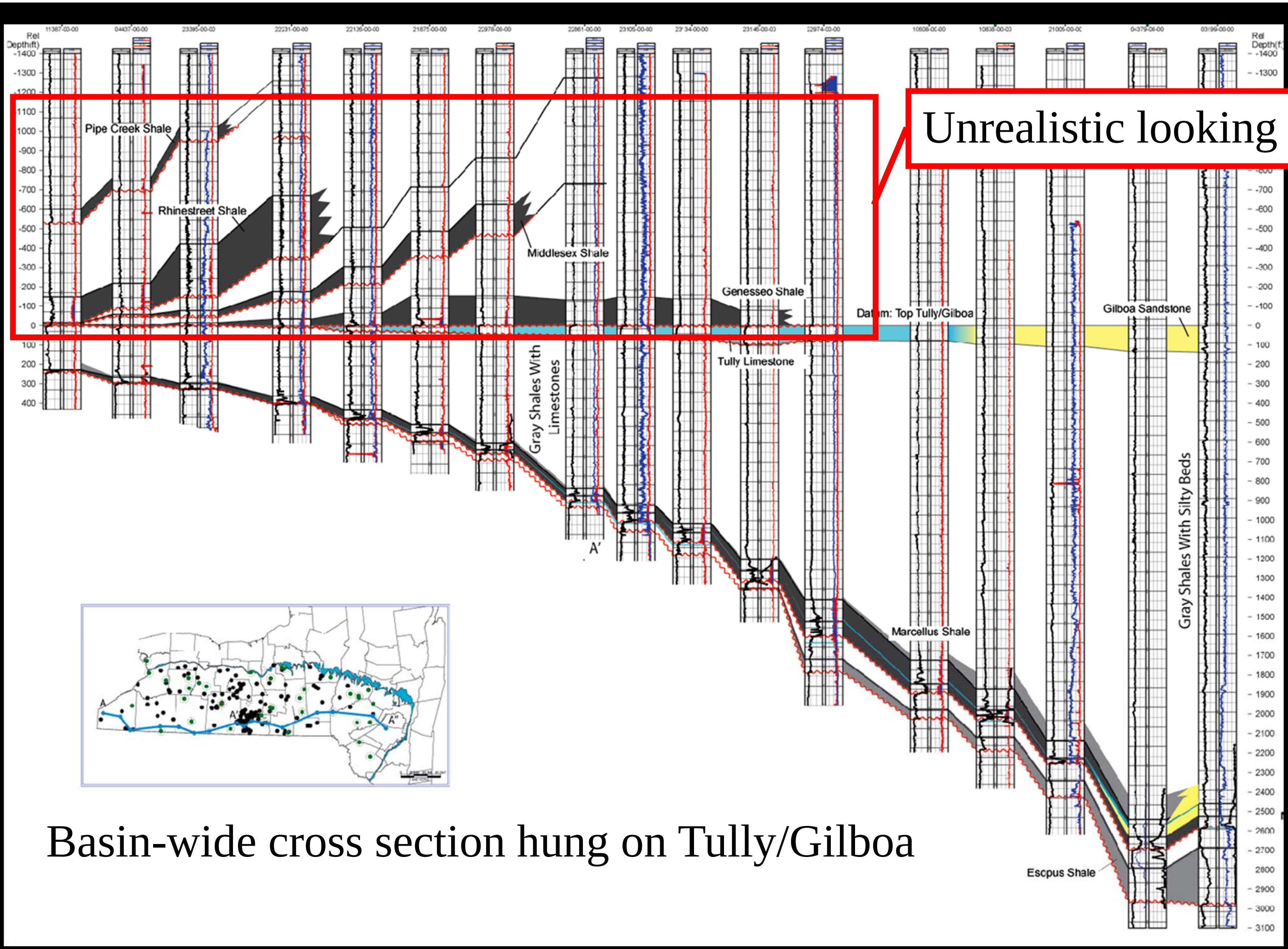
That shows that the unconformity is at least initially a subaerial unconformity rather than a drowning unconformity

← Knox Unconformity



Basin-wide cross section hung on Tully/Gilboa

This is a good datum for the underlying Marcellus but not for any overlying shales - must datum above shale of interest to see true stratal architecture



Unrealistic looking

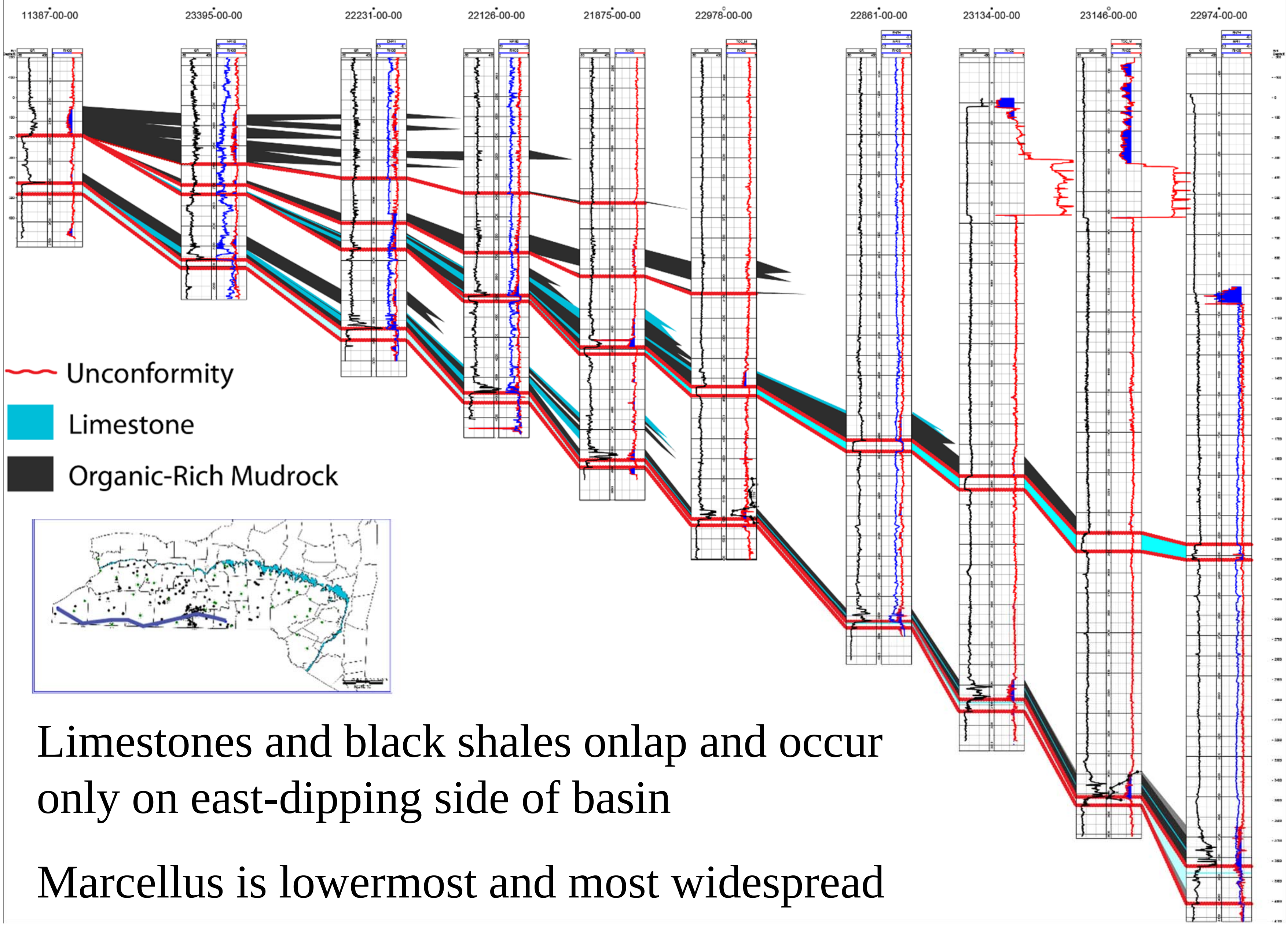
Basin-wide cross section hung on Tully/Gilboa

This is a good datum for the underlying Marcellus but not for any overlying shales - must datum above shale of interest to see true stratal architecture

What a difference a datum makes

- In viewing these black shales it is very important to hang cross sections somewhere above the shale of interest
- When one does that the onlapping geometry becomes clear
- The Tully Limestone and time-equivalent Gilboa Sandstone are the last good basin-wide datum and therefore they get used in some cross sections

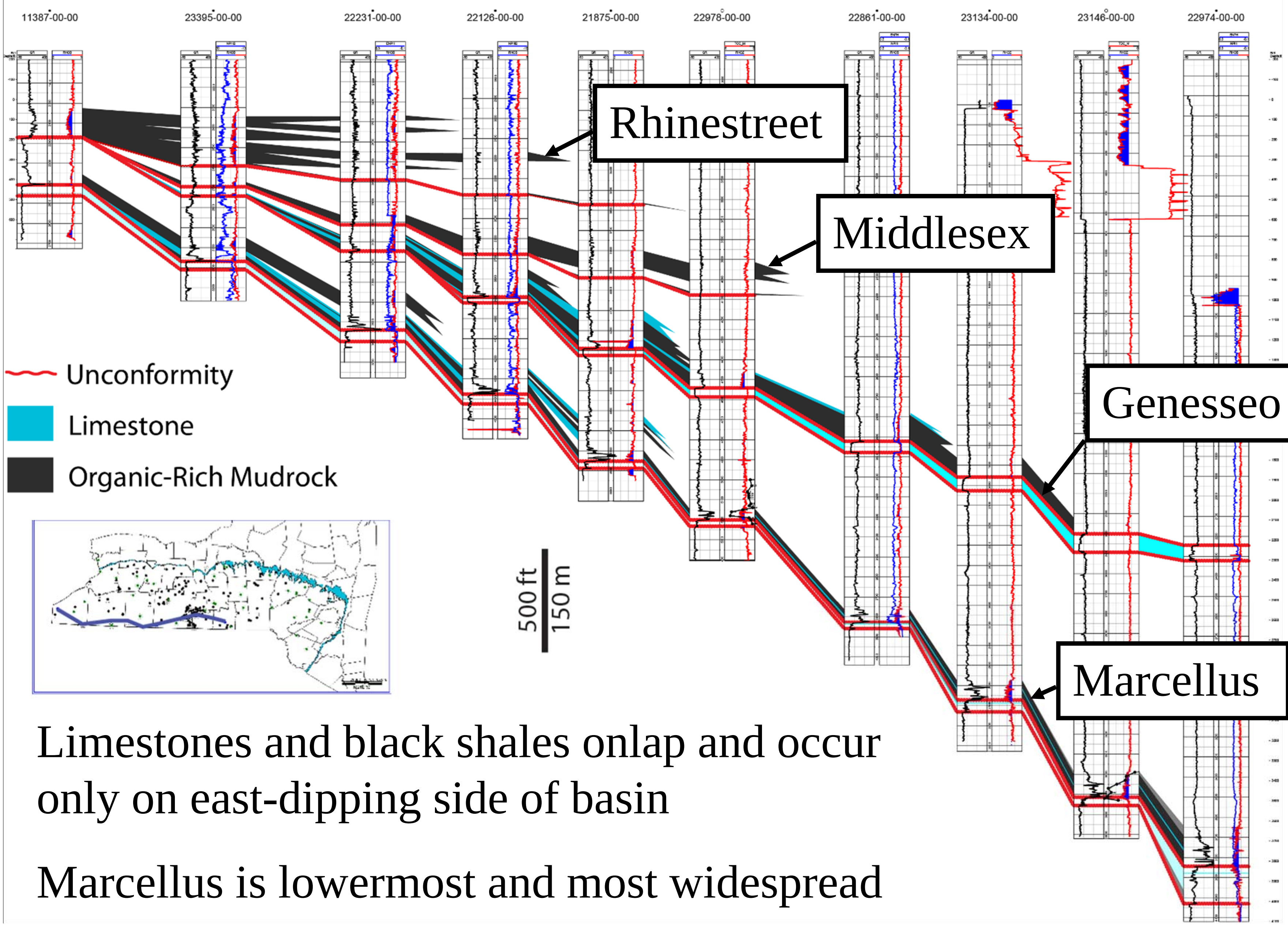
Devonian Shales of Western NY - Transgressive Onlap Model



Limestones and black shales onlap and occur only on east-dipping side of basin

Marcellus is lowermost and most widespread

Devonian Shales of Western NY - Transgressive Onlap Model



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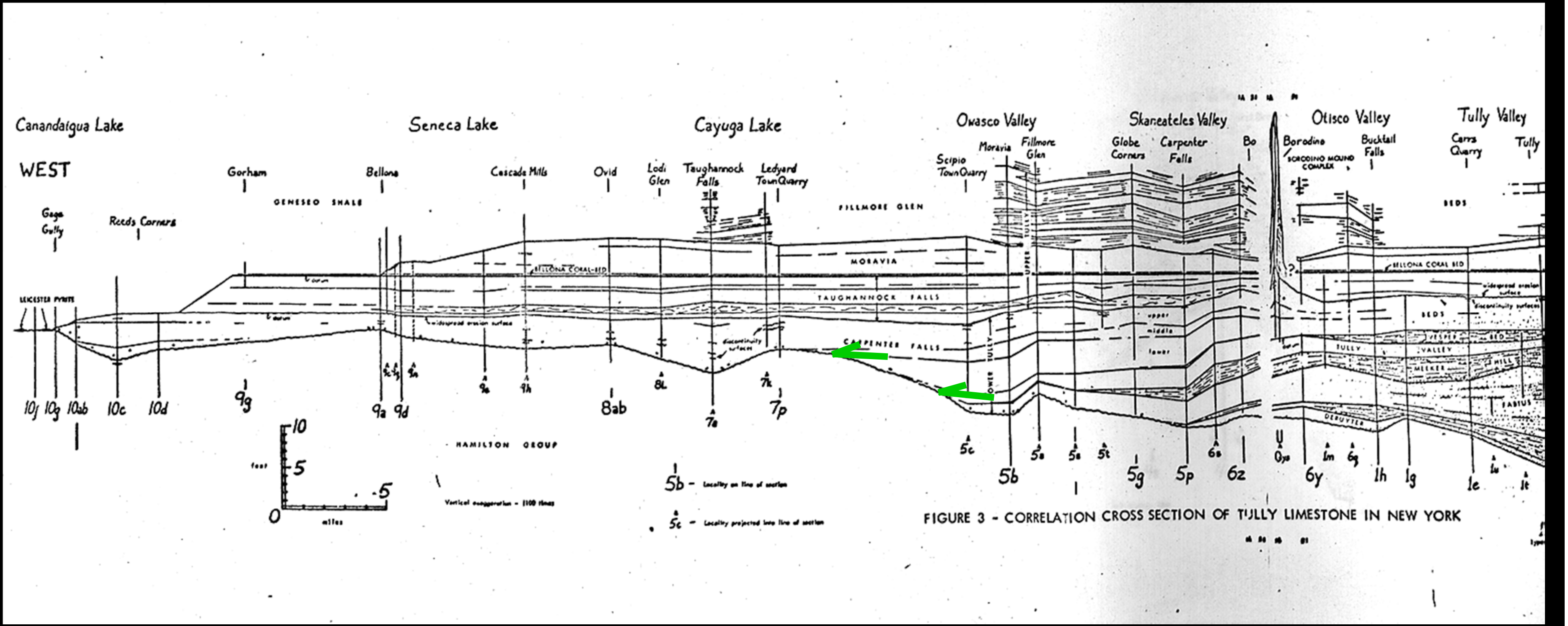
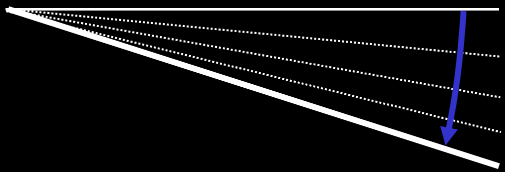


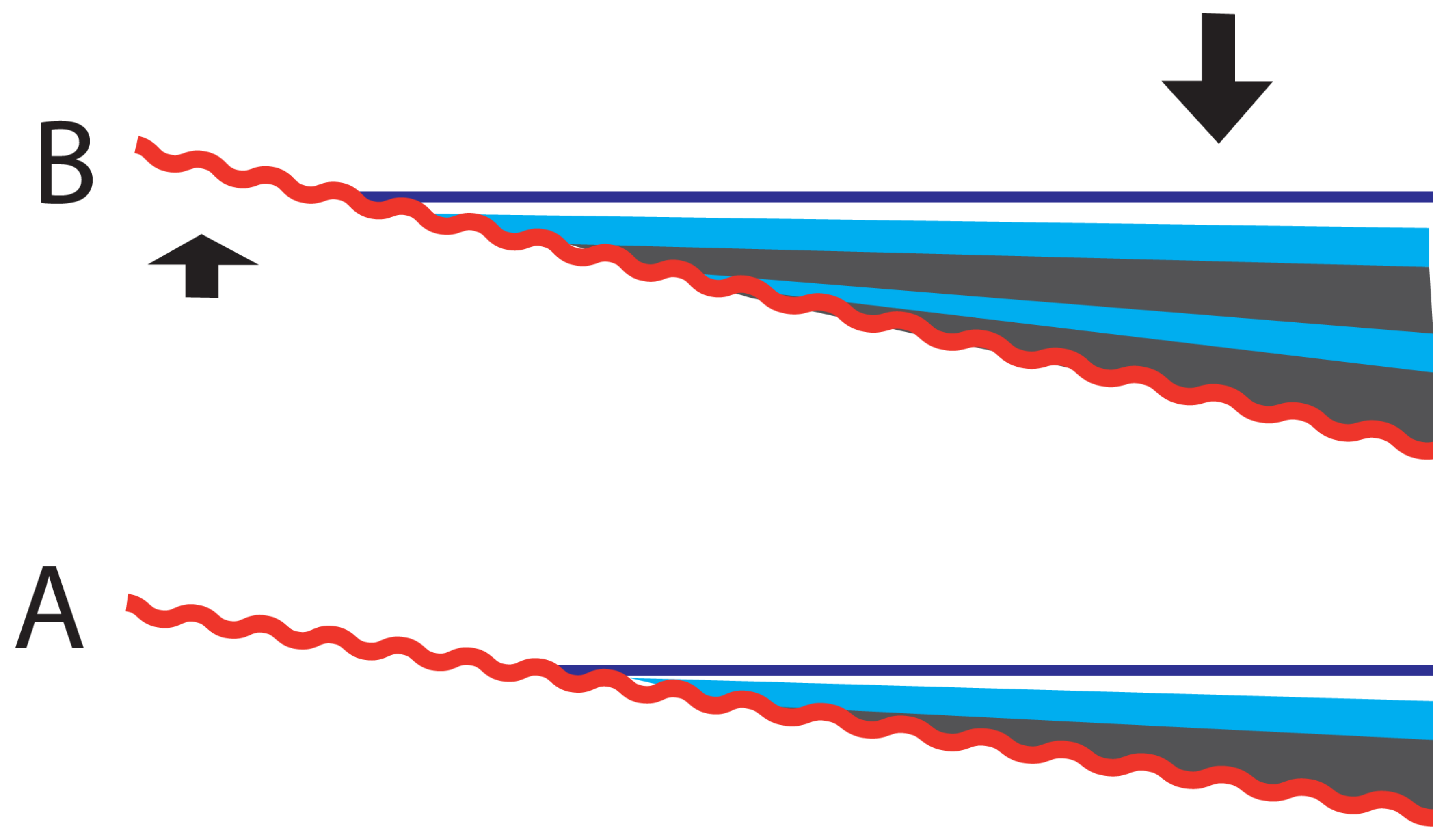
FIGURE 3 - CORRELATION CROSS SECTION OF TULLY LIMESTONE IN NEW YORK

Detailed cross section of Tully Limestone from Heckel (1966) shows progressive onlap of sub-Tully Unconformity and pinchout of beds within Formation to west

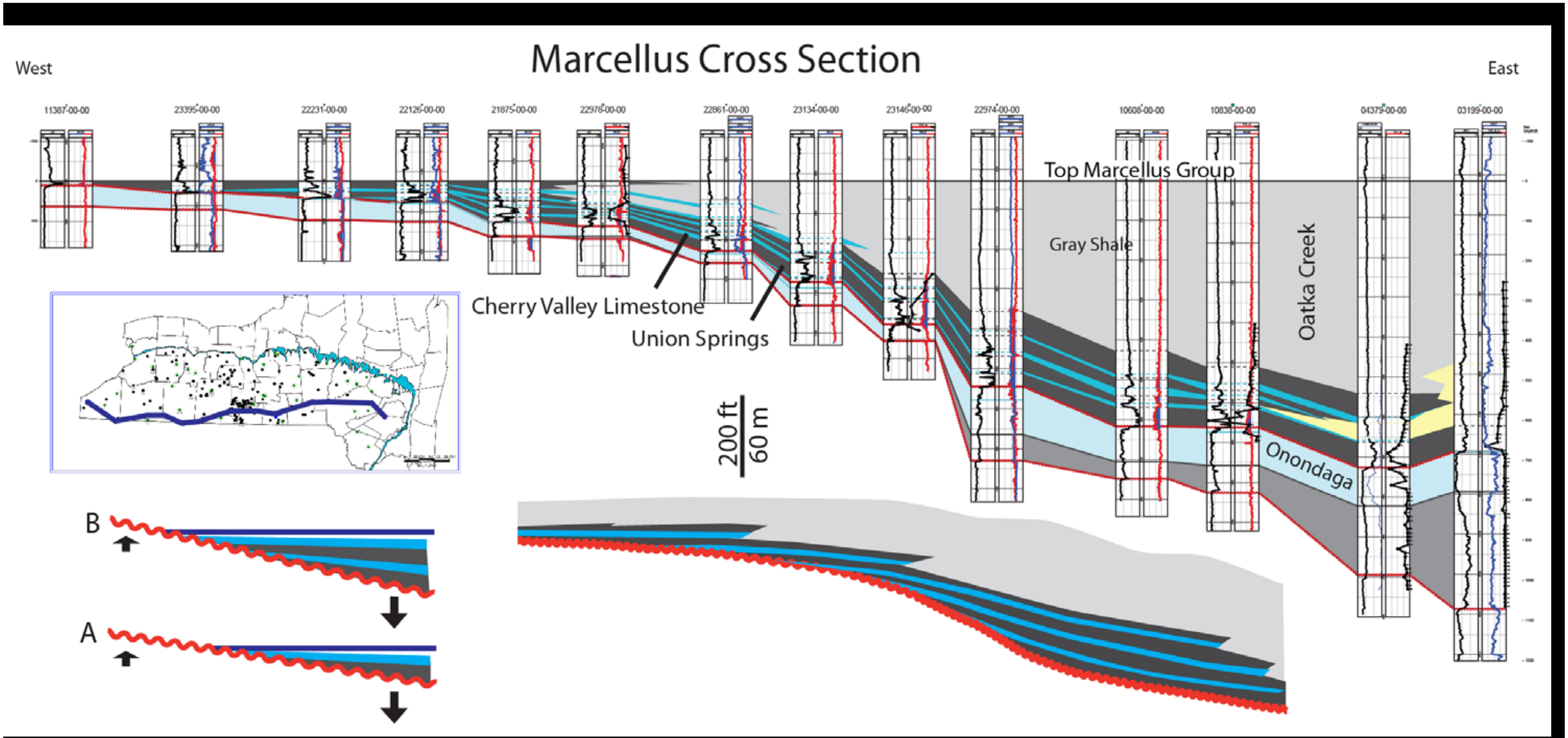
Onlap driven by greater subsidence to east



Onlapping is clear in Marcellus as well



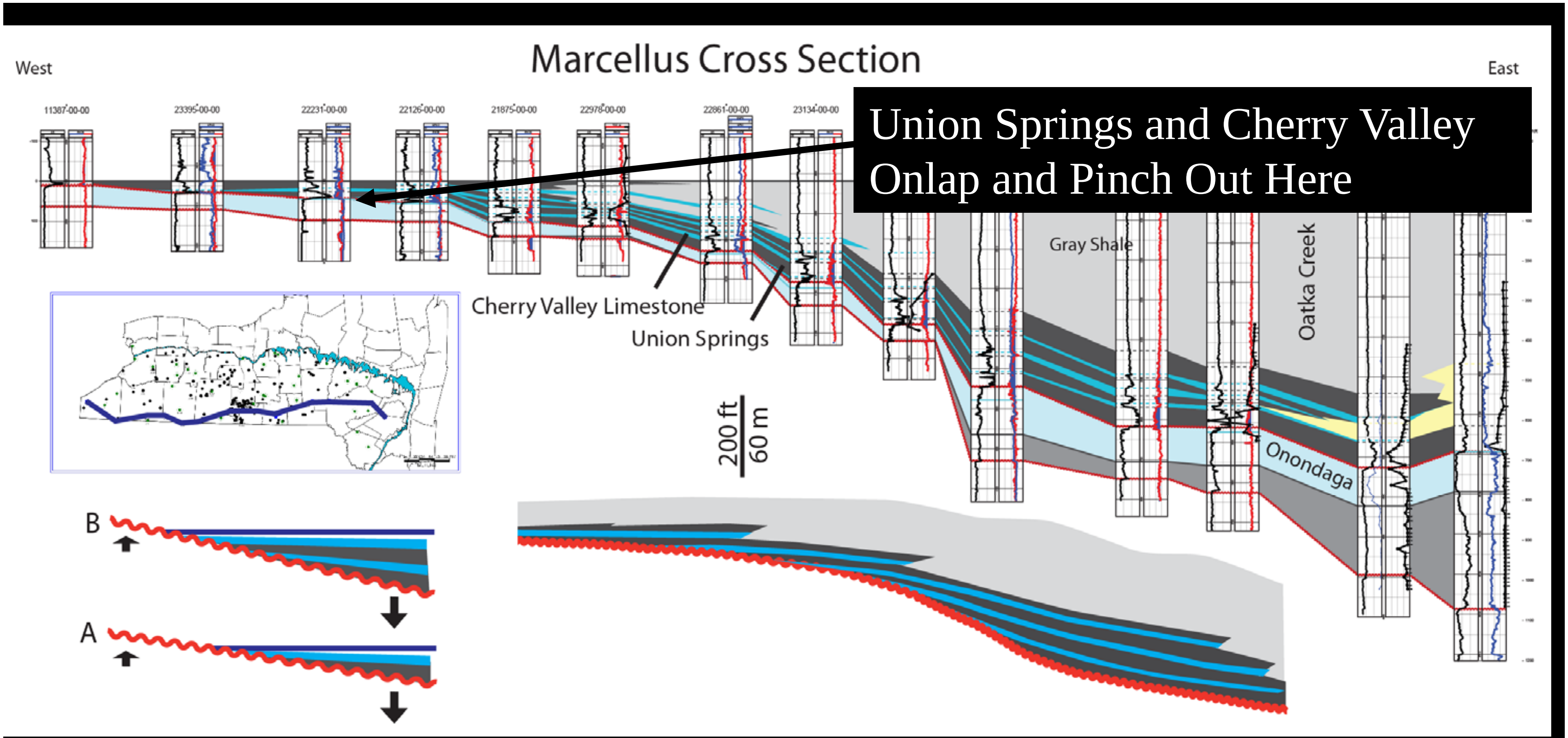
The onlap is driven by continued higher rate subsidence to the east during deposition – more space is consistently made in the east than it is in the west – minor eustatic sea level changes still produce cyclicity



Each TOC rich mudrock unit becomes more OC-rich to west until it pinches out and more clay rich and less OC-rich to the east

Limestones onlap and pinch out to west and grade into siltstone or shale to east

The Union Springs Shale and Cherry Valley Limestone pinch out in western NY, Oatka Creek pinches out under Lake Erie to west



Union Springs and Cherry Valley Onlap and Pinch Out Here

Each TOC rich mudrock unit becomes more OC-rich to west until it pinches out and more clay rich and less OC-rich to the east

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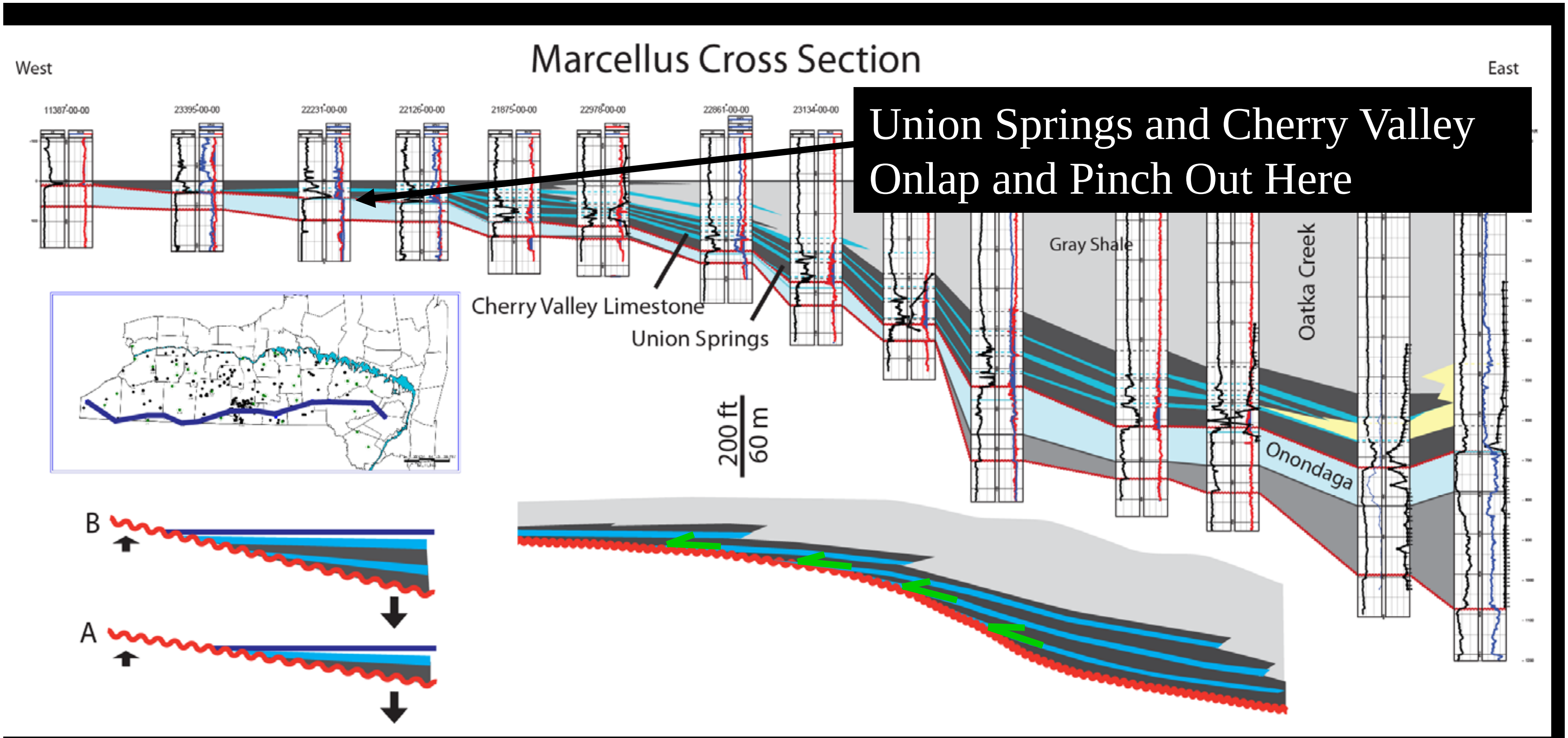

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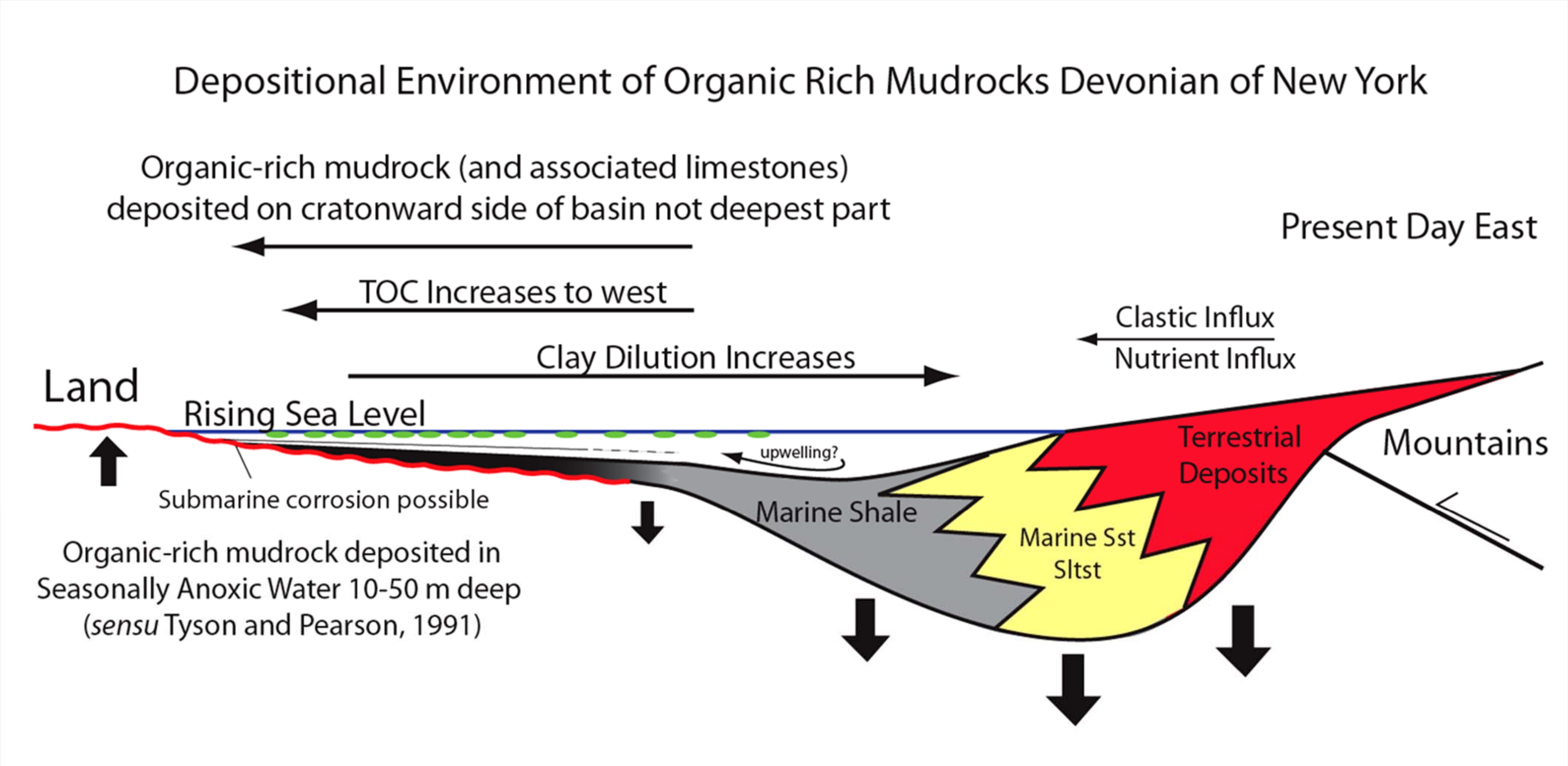
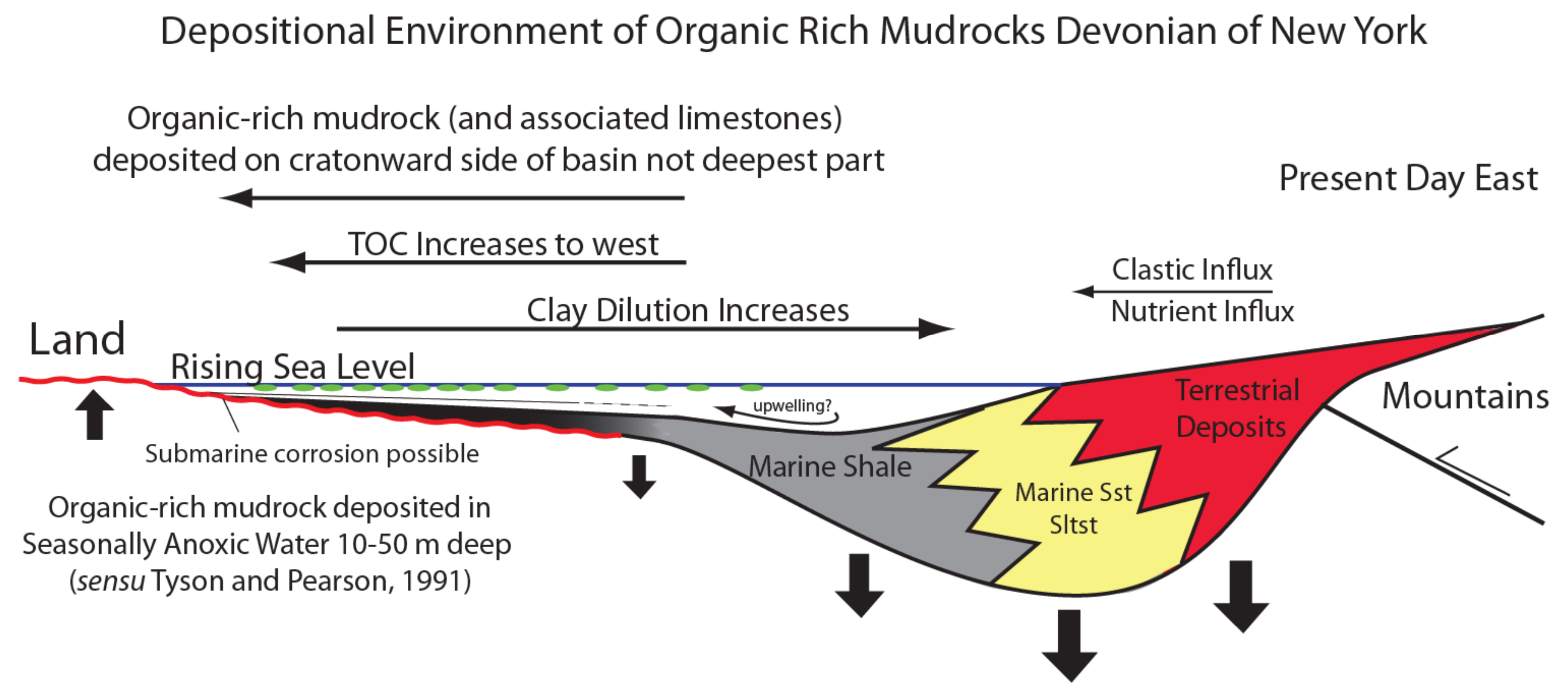


Marcellus and other Devonian organic-rich mudrocks formed primarily on the cratonward side of the foreland basin in relatively shallow water (10-50m) – not in the deepest part – shallow, warm, higher salinity water would have less oxygen to begin with - water might be murky which would cut down on photosynthesis in all but shallowest waters which would further decrease oxygen levels

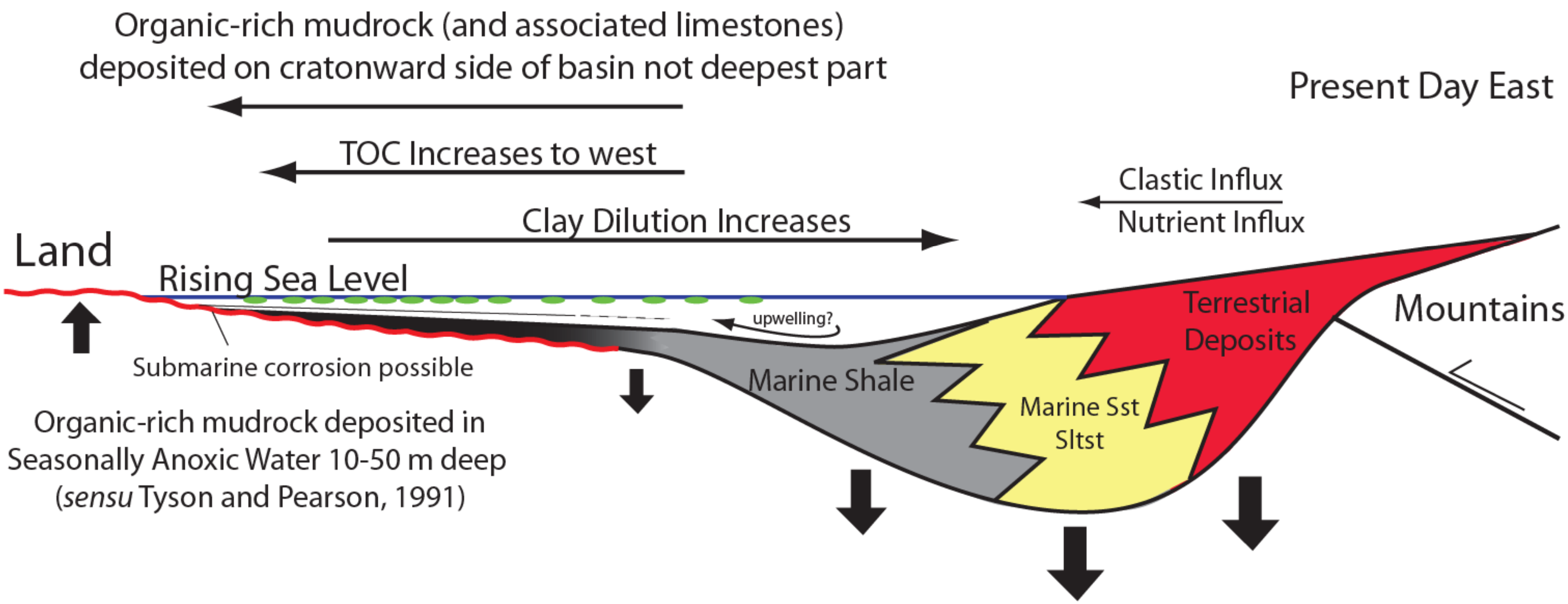
Tyson and Pearson (1991) Model for Seasonal Anoxia

- Spring: Phytoplankton bloom - they remove oxygen from very bottom of warm, shallow water as they die
- Summer and Fall: Thermocline develops in shallowest water first and organic matter accumulates, conditions become euxinic causing phosphate to be separated from organic matter (Kump and Meyer, 2008) – bottom water zone might only be a few cm thick
- Winter: Thermocline breaks down during winter as storms stir up bottom, remobilizing phosphate back to surface and oxidizing some (but not all) organic matter - over time it accumulates



Productivity: marine algae feed on nutrients that might come from rivers, possible upwelling but mainly from recycling off the seafloor which is far more likely in shallow, seasonally anoxic water

Depositional Environment of Organic Rich Mudrocks Devonian of New York



Organic-rich mudrock (and associated limestones)
deposited on cratonward side of basin not deepest part

TOC Increases to west

Clay Dilution Increases

Present Day East

Clastic Influx
Nutrient Influx

Land

Rising Sea Level

upwelling?

Submarine corrosion possible

Marine Shale

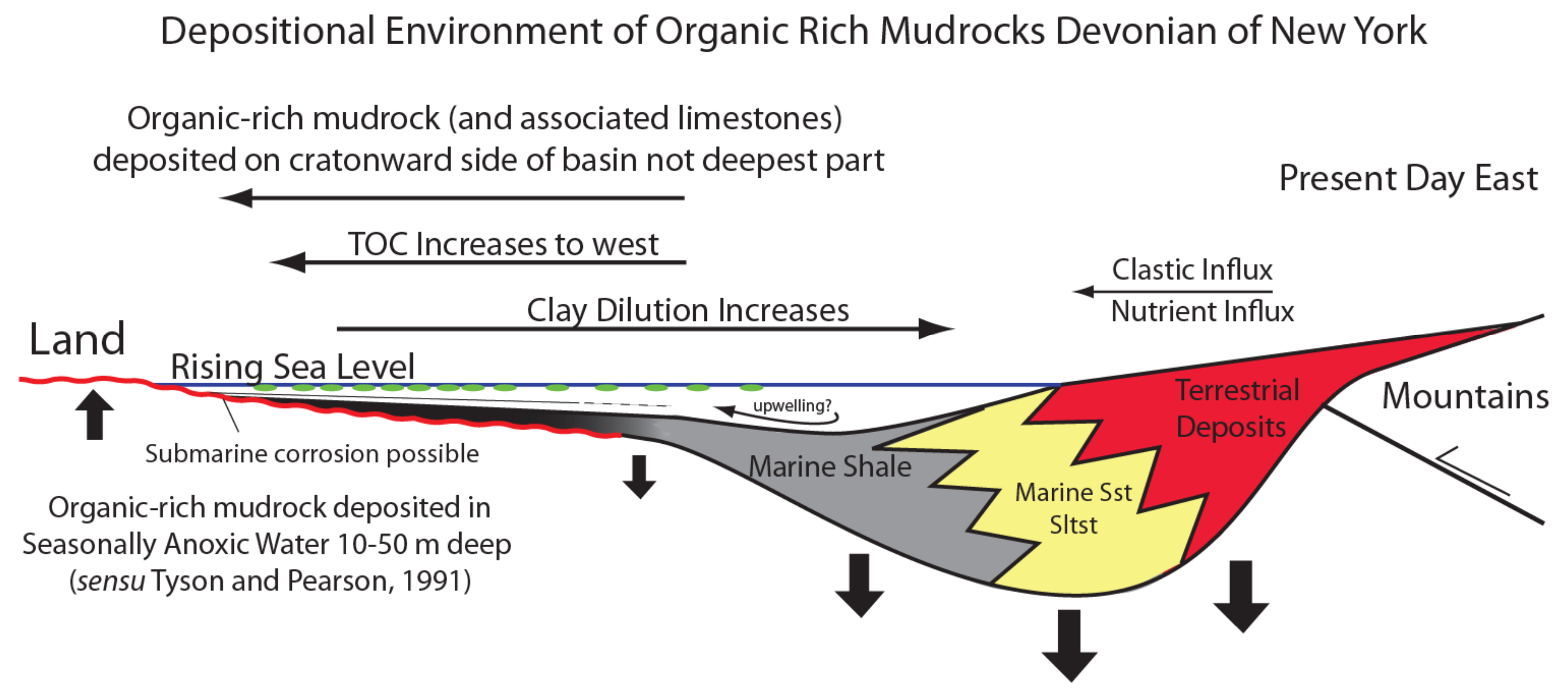
Marine Sst
Sltst

Terrestrial
Deposits

Mountains

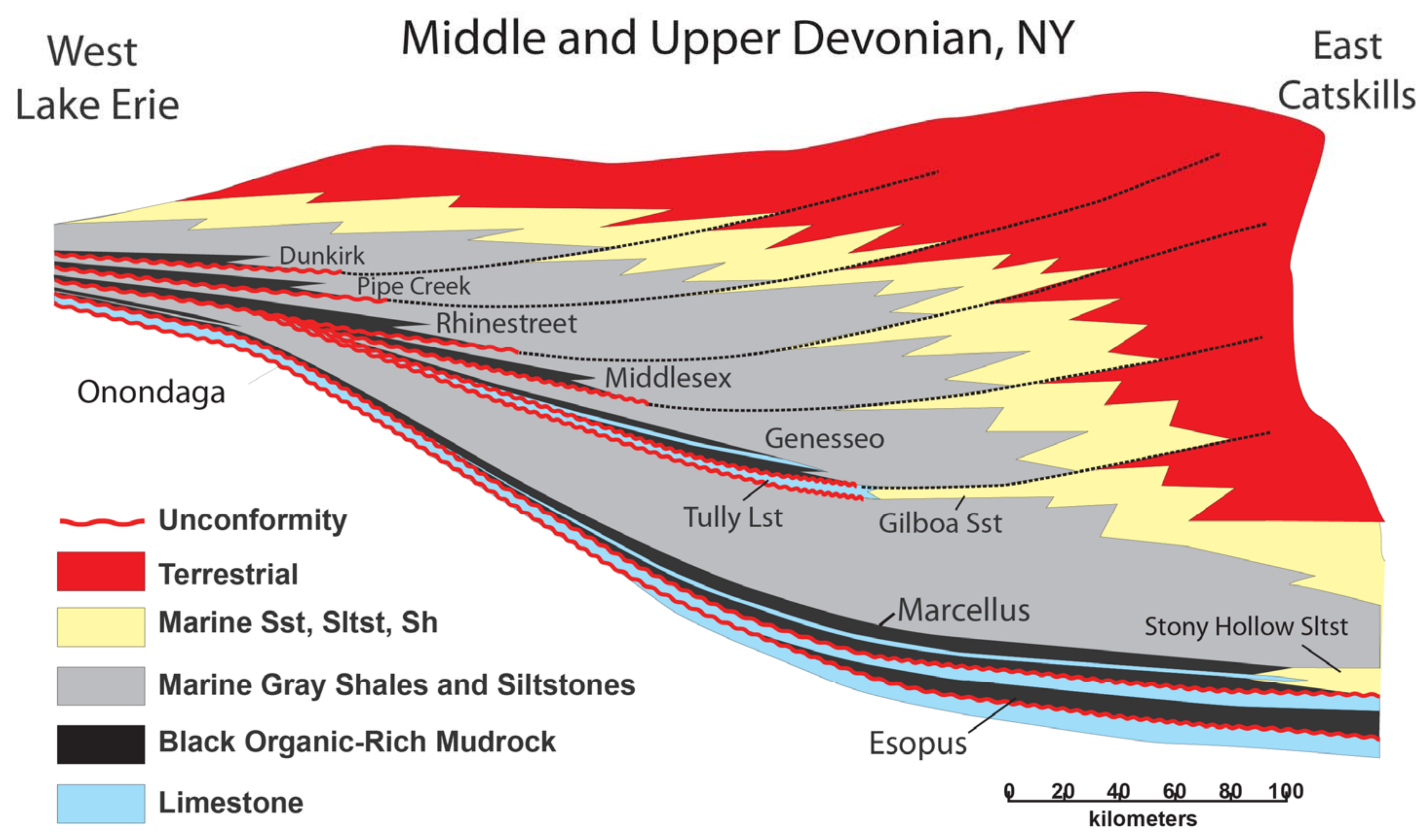
Organic-rich mudrock deposited in
Seasonally Anoxic Water 10-50 m deep
(*sensu* Tyson and Pearson, 1991)

Preservation: organic-rich sediments would be deposited most years during spring, summer and fall months – some or all of the organic matter might be eroded during winter storms but over time enough would be preserved to make a black shale - Seasonal zone of anoxia might only be a few cm thick

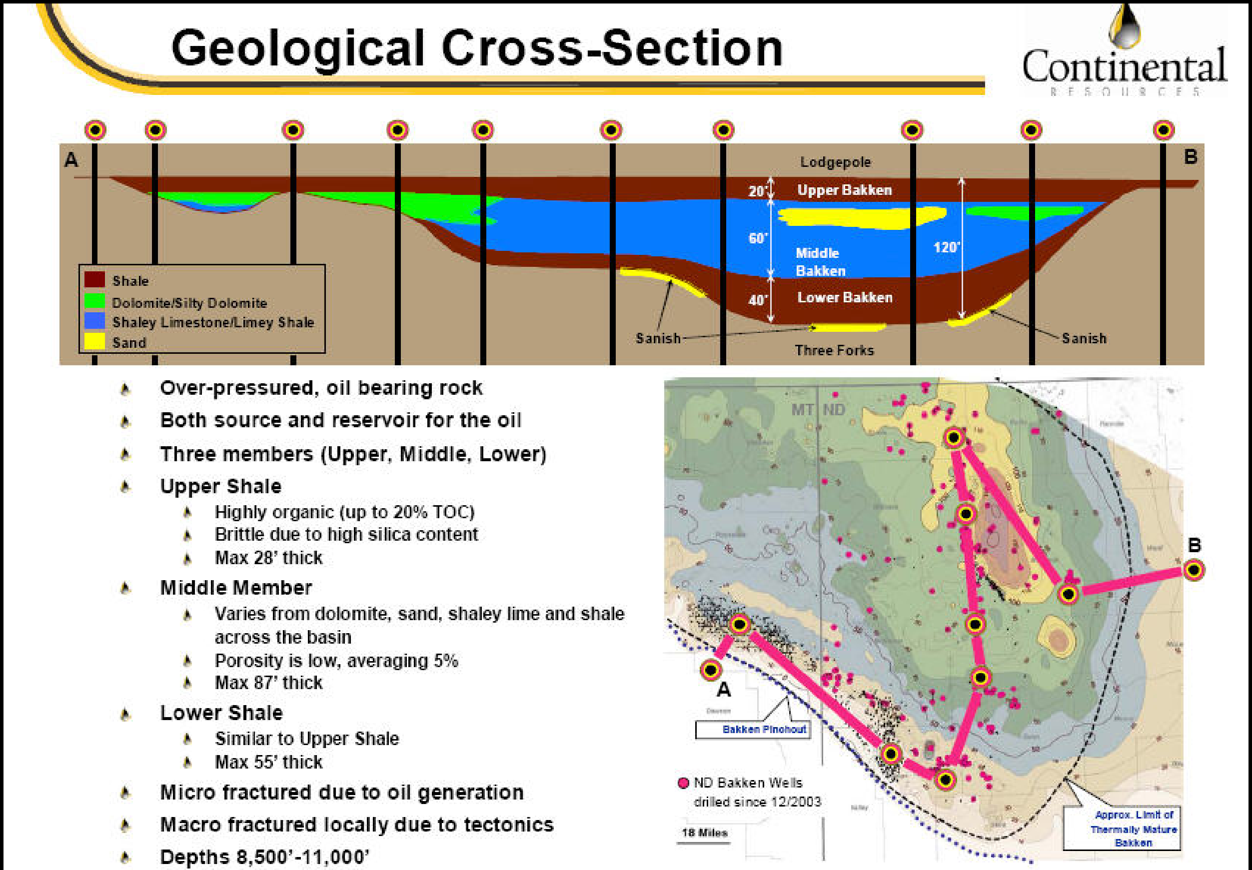


Depositional Environment of Organic Rich Mudrocks Devonian of New York

Dilution: Sediment influx will be high on east side to depocenter of basin but progressively lower on west side – sand unlikely to be moved uphill, very likely to be moved downhill – this is why the organic rich shales primarily form on cratonward side of basin where dilution is minimal – limestones are also mainly on western side and sandstones mainly on eastern side



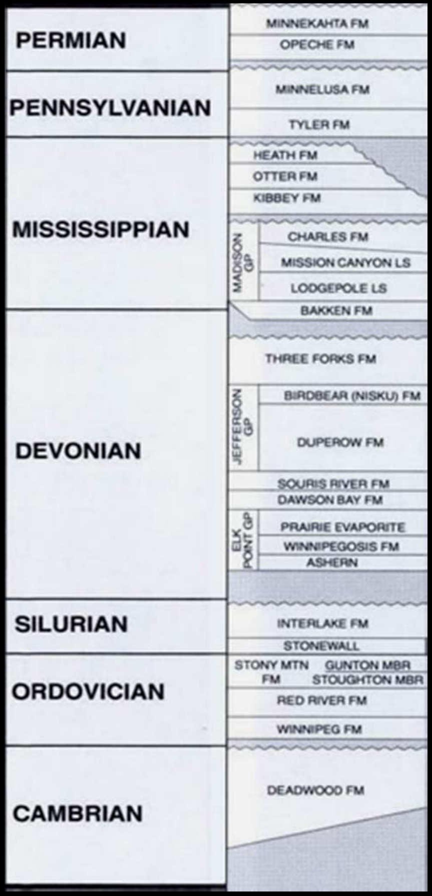
Transgressive Onlap Model – Shales only occur on cratonward side of basin, onlap and are time-equivalent to unconformities



Geological Cross-Section

Continental RESOURCES

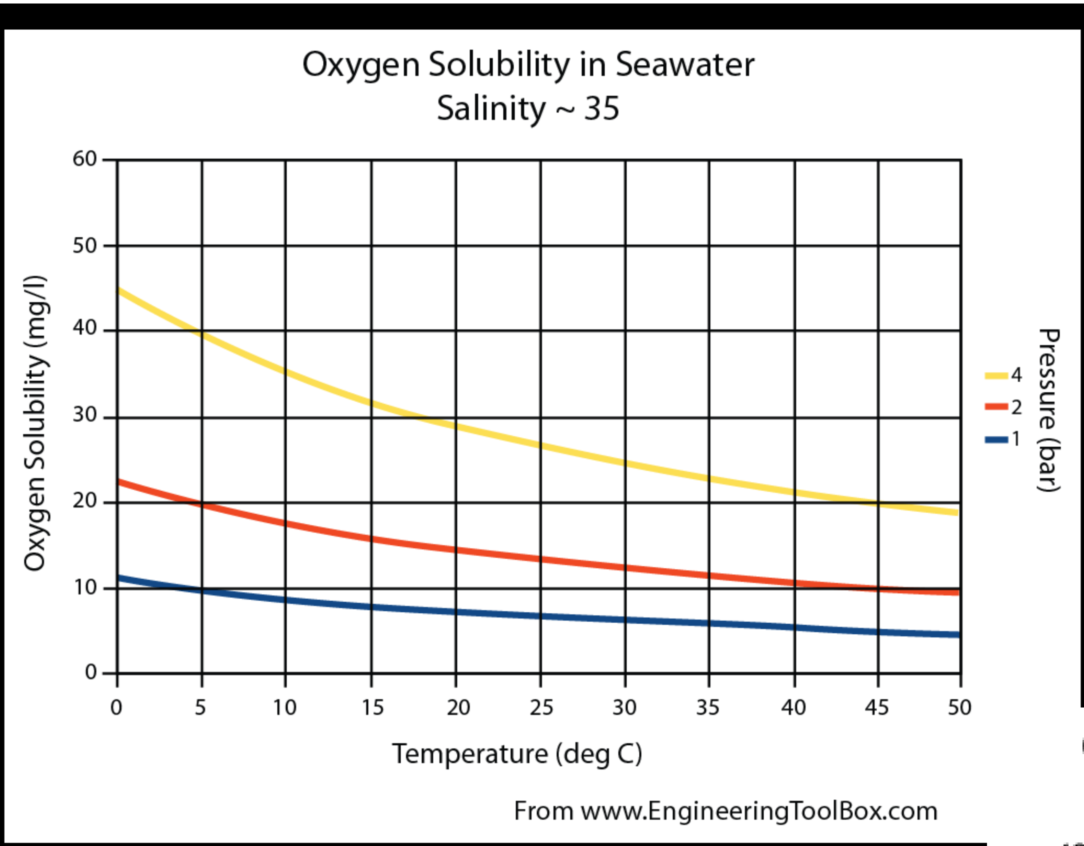
- Over-pressured, oil bearing rock
- Both source and reservoir for the oil
- Three members (Upper, Middle, Lower)
- Upper Shale
  - Highly organic (up to 20% TOC)
  - Brittle due to high silica content
  - Max 28' thick
- Middle Member
  - Varies from dolomite, sand, shaley lime and shale across the basin
  - Porosity is low, averaging 5%
  - Max 87' thick
- Lower Shale
  - Similar to Upper Shale
  - Max 55' thick
- Micro fractured due to oil generation
- Macro fractured locally due to tectonics
- Depths 8,500'-11,000'



PERMIAN		MINNEKAHTA FM
		OPECHE FM
PENNSYLVANIAN		MINNELUSA FM
		TYLER FM
MISSISSIPPIAN		HEATH FM
		OTTER FM
		KIBBEY FM
	MADISON GP	CHARLES FM
		MISSION CANYON LS
		LODGEPOLE LS
		BAKKEN FM
DEVONIAN		THREE FORKS FM
	JEFFERSON GP	BIRDBEAR (NISKU) FM
		DUPEROW FM
		SOURIS RIVER FM
		DAWSON BAY FM
	ELK POINT GP	PRAIRIE EVAPORITE
		WINNIPEGOSIS FM
		ASHERN
SILURIAN		INTERLAKE FM
		STONEWALL
ORDOVICIAN	STONY MTN FM	GUNTON MBR
		STOUGHTON MBR
		RED RIVER FM
		WINNIPEG FM
CAMBRIAN		DEADWOOD FM

Similar story in Bakken Shale – sea level was low

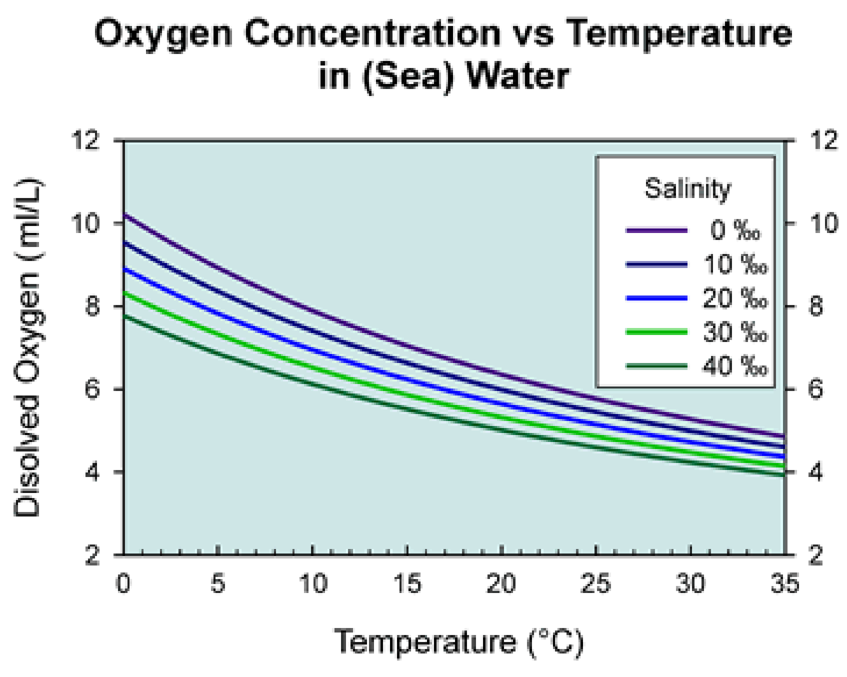
Looks like it might be the case in the Woodford, Haynesville and other shales



From www.EngineeringToolBox.com

Shallow water is more likely to be warm, lower pressure and more saline (due to evaporation) and therefore requires less to make anoxic

Oxygen has retrograde solubility so the warmer the water is the less oxygen it can hold – solubility is also lower at lower pressures and higher salinities

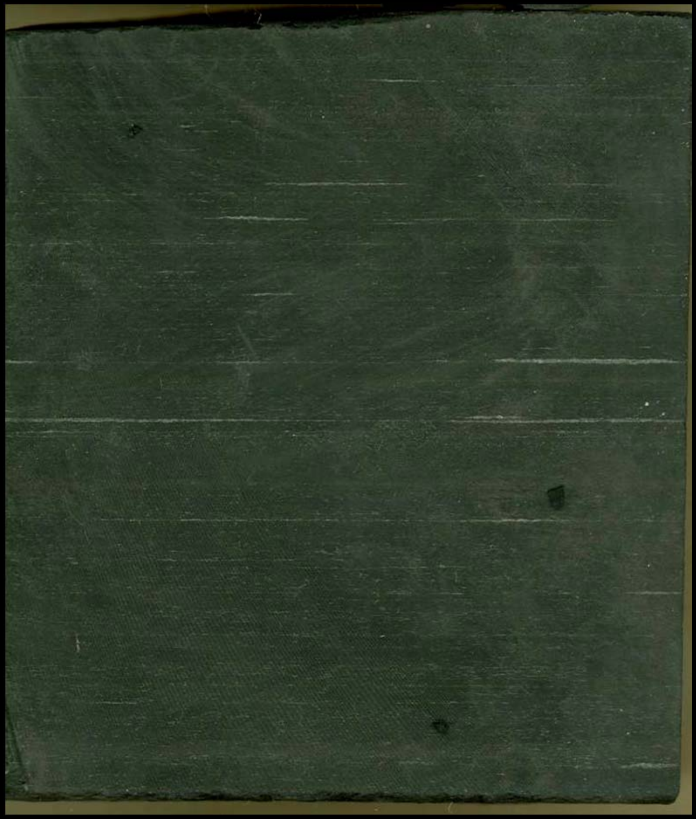


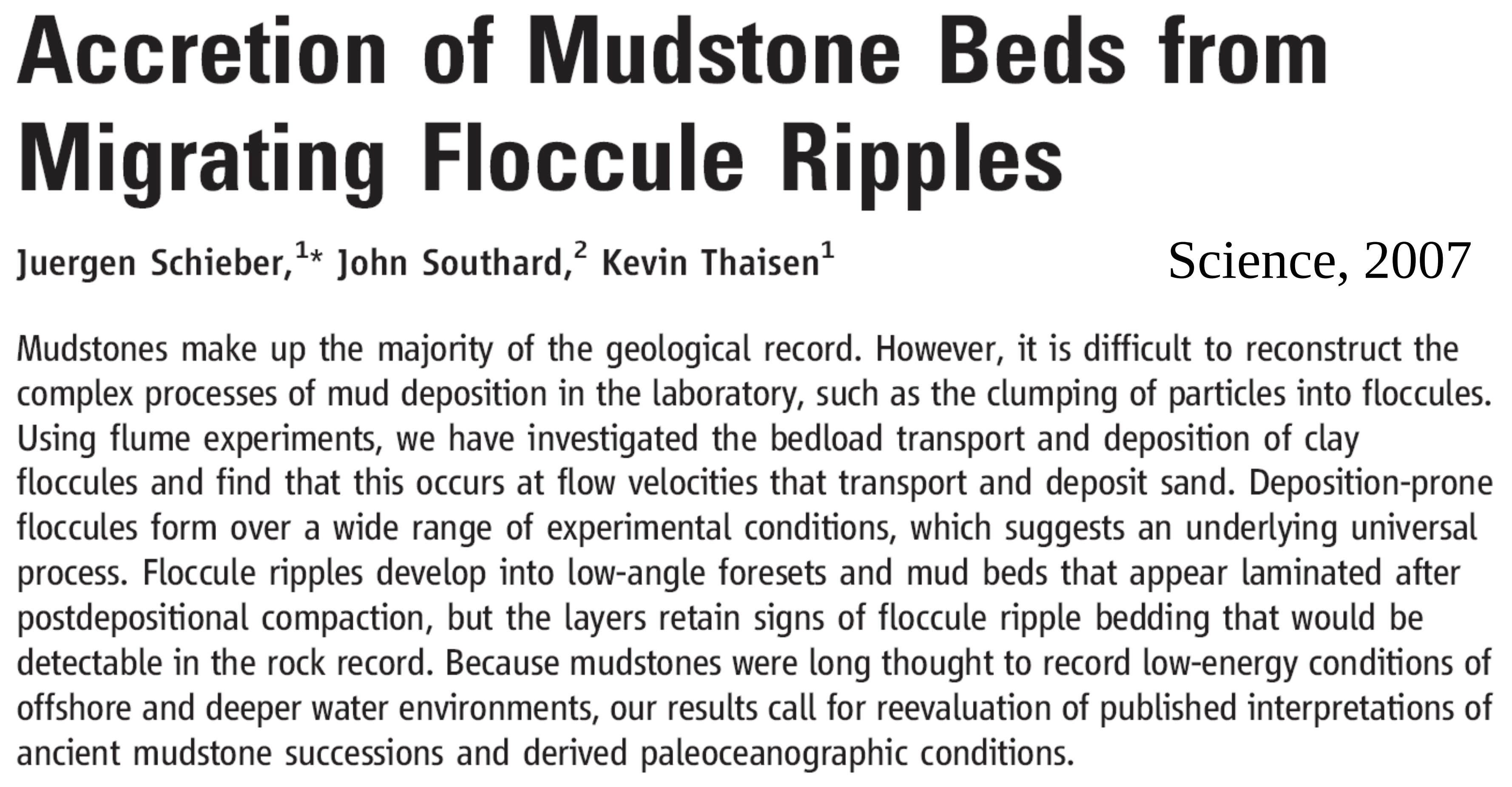
Shallow Water Model

- Explains distribution, stratal geometry, link to unconformities
- Warm, shallow, saline water has less oxygen to start with which makes it easier to deoxygenate
- Probably a seasonal anoxia model – a periodic breakdown in the pycnocline helps recycle nutrients from bottom to increase productivity
- Should probably see evidence for currents if that shallow

Laminations

- Laminations are common in black shales and are commonly used as evidence of deep quiet deposition as clay settled out of suspension
- New research suggests, however, that these laminations may actually form in moving water with flow rates up to 30 cm/s





Accretion of Mudstone Beds from Migrating Floccule Ripples

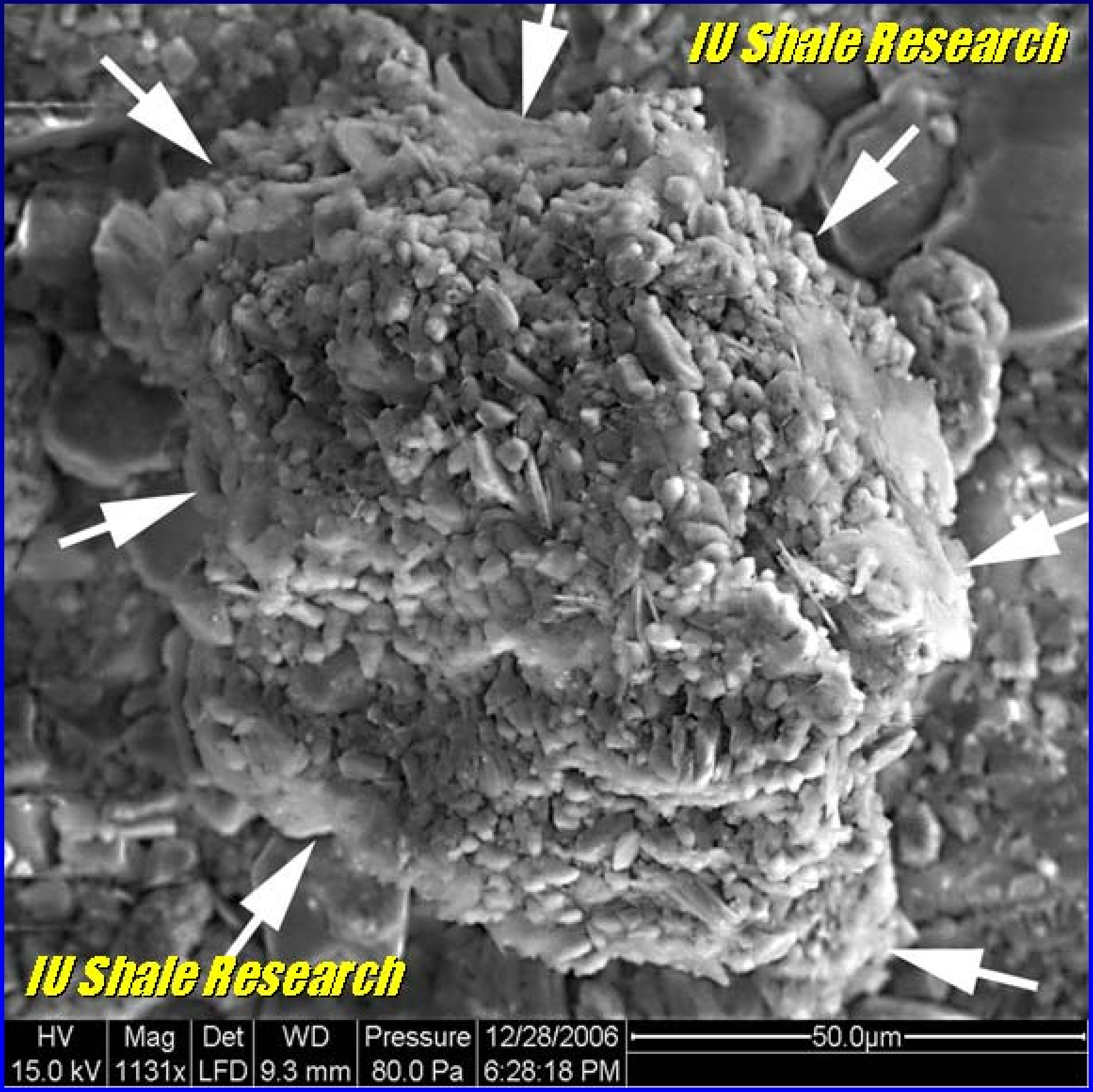
Juergen Schieber,[1]* John Southard,[2] Kevin Thaisen[1]

Science, 2007

Mudstones make up the majority of the geological record. However, it is difficult to reconstruct the complex processes of mud deposition in the laboratory, such as the clumping of particles into floccules. Using flume experiments, we have investigated the bedload transport and deposition of clay floccules and find that this occurs at flow velocities that transport and deposit sand. Deposition-prone floccules form over a wide range of experimental conditions, which suggests an underlying universal process. Floccule ripples develop into low-angle foresets and mud beds that appear laminated after postdepositional compaction, but the layers retain signs of floccule ripple bedding that would be detectable in the rock record. Because mudstones were long thought to record low-energy conditions of offshore and deeper water environments, our results call for reevaluation of published interpretations of ancient mudstone successions and derived paleoceanographic conditions.

Floccules form from small clay particles and then behave like sand grains – low-angle cross laminations form from migrating ripples and then after compaction they look like laminations – And lamiantions formed in such conditions might be shallow

Flocculation is Immediate

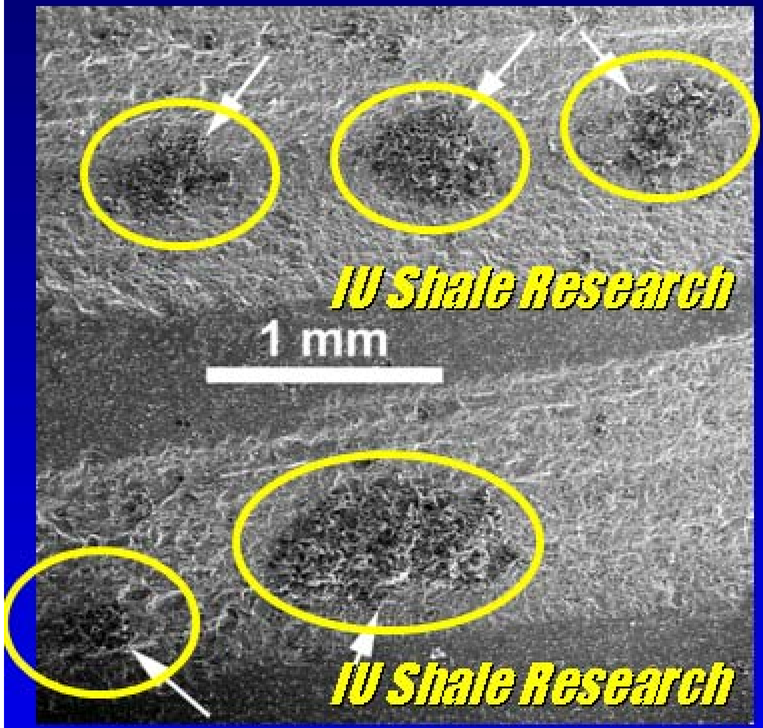


Floccules form immediately after clay addition to flume current.

Fundamentally it does not matter whether
  - distilled,
  - freshwater, or
  - seawater
is used.

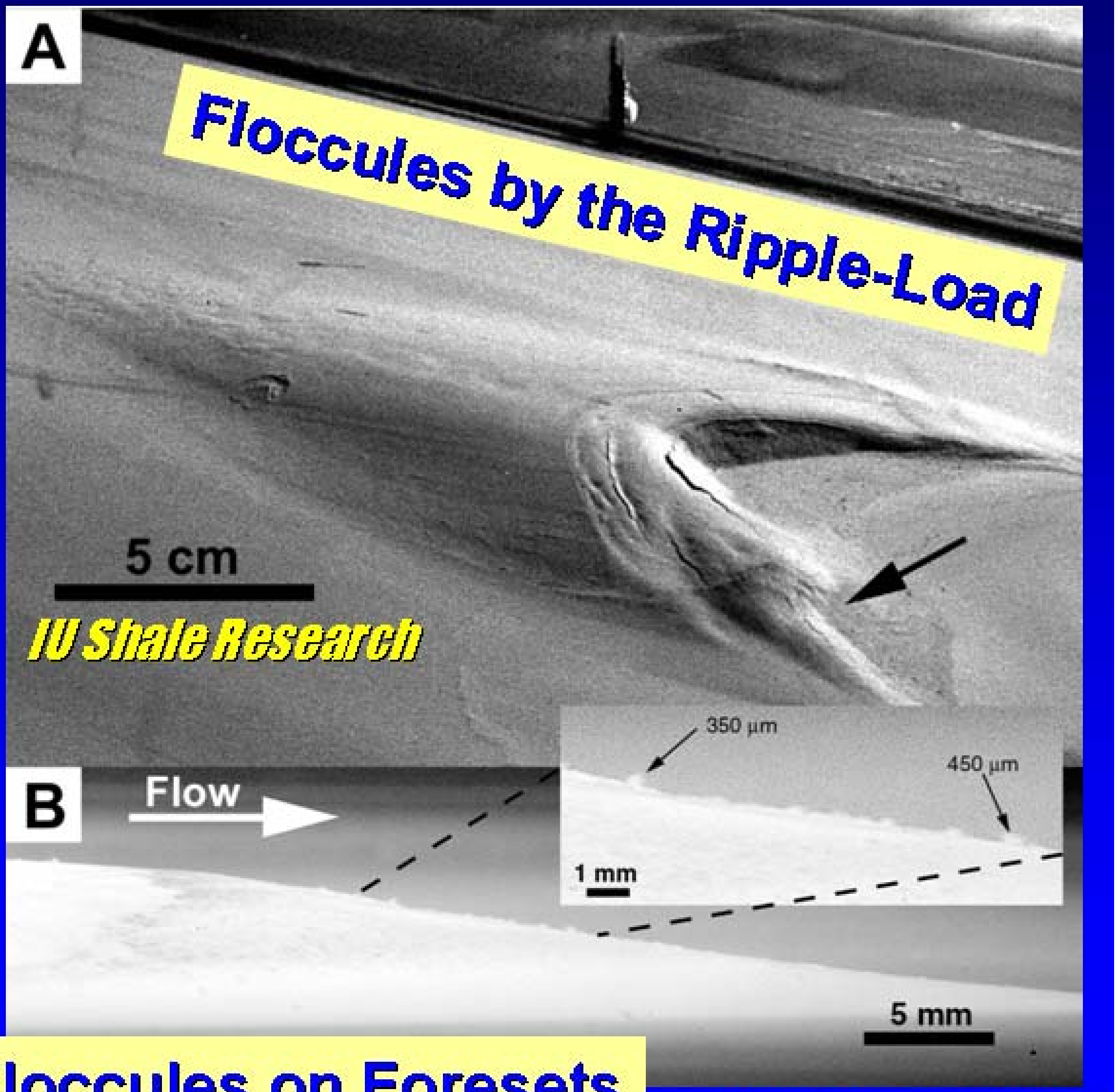
IU Shale Research

The Inside Scoop on Floccules……



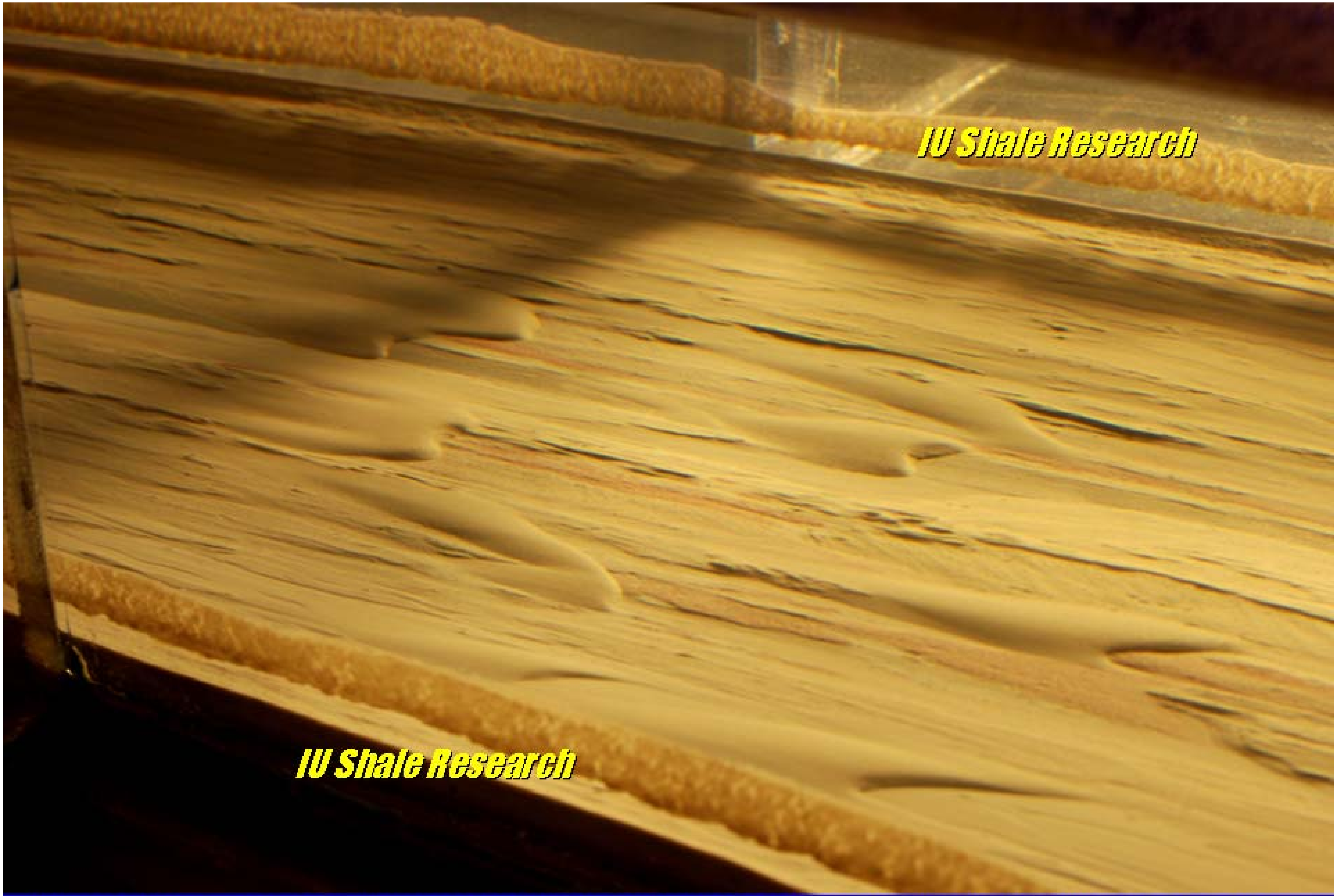
Retail Floccules…..

It's All in the Floccules….

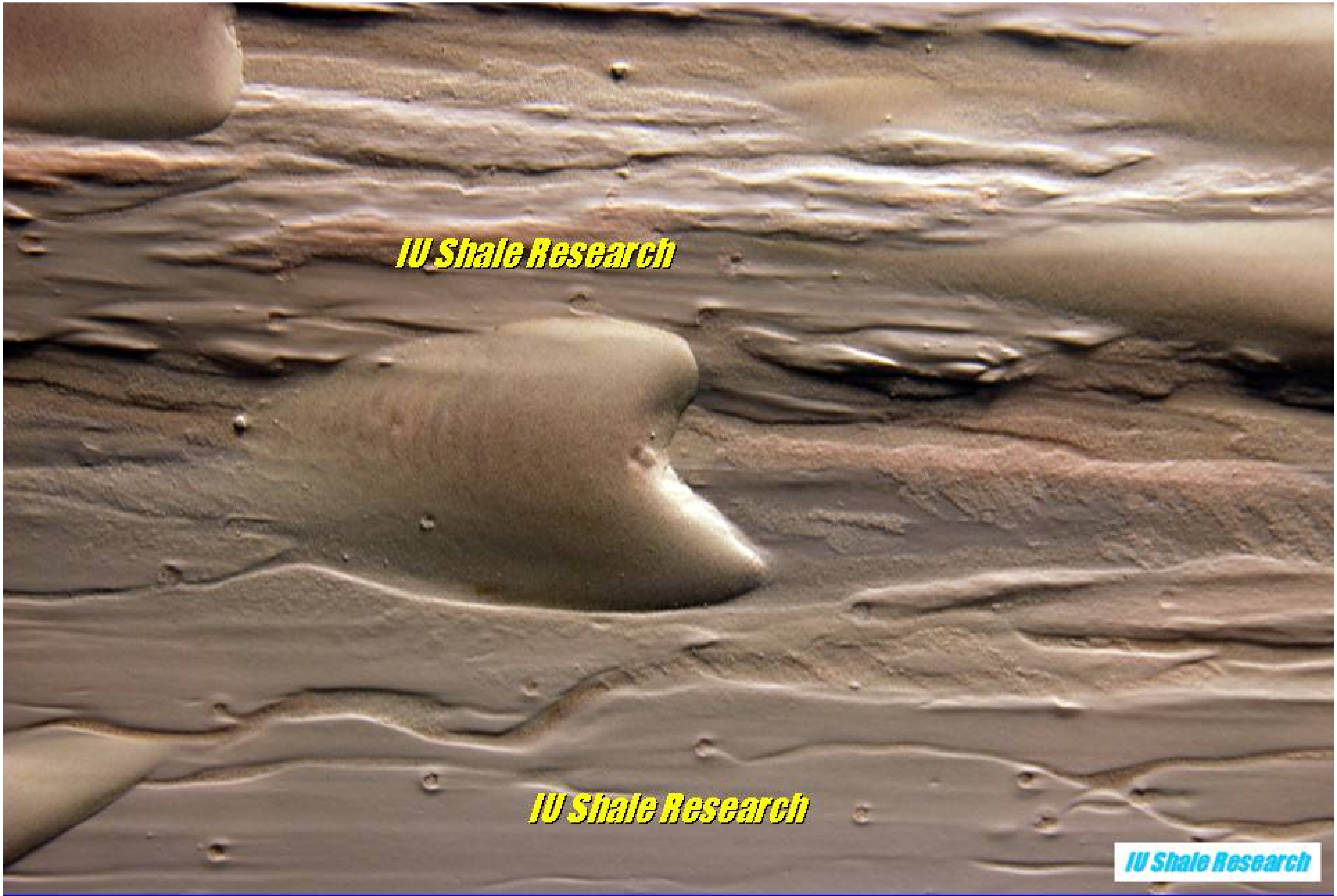

Floccules by the Ripple-Load

Lonely Floccules on Foresets

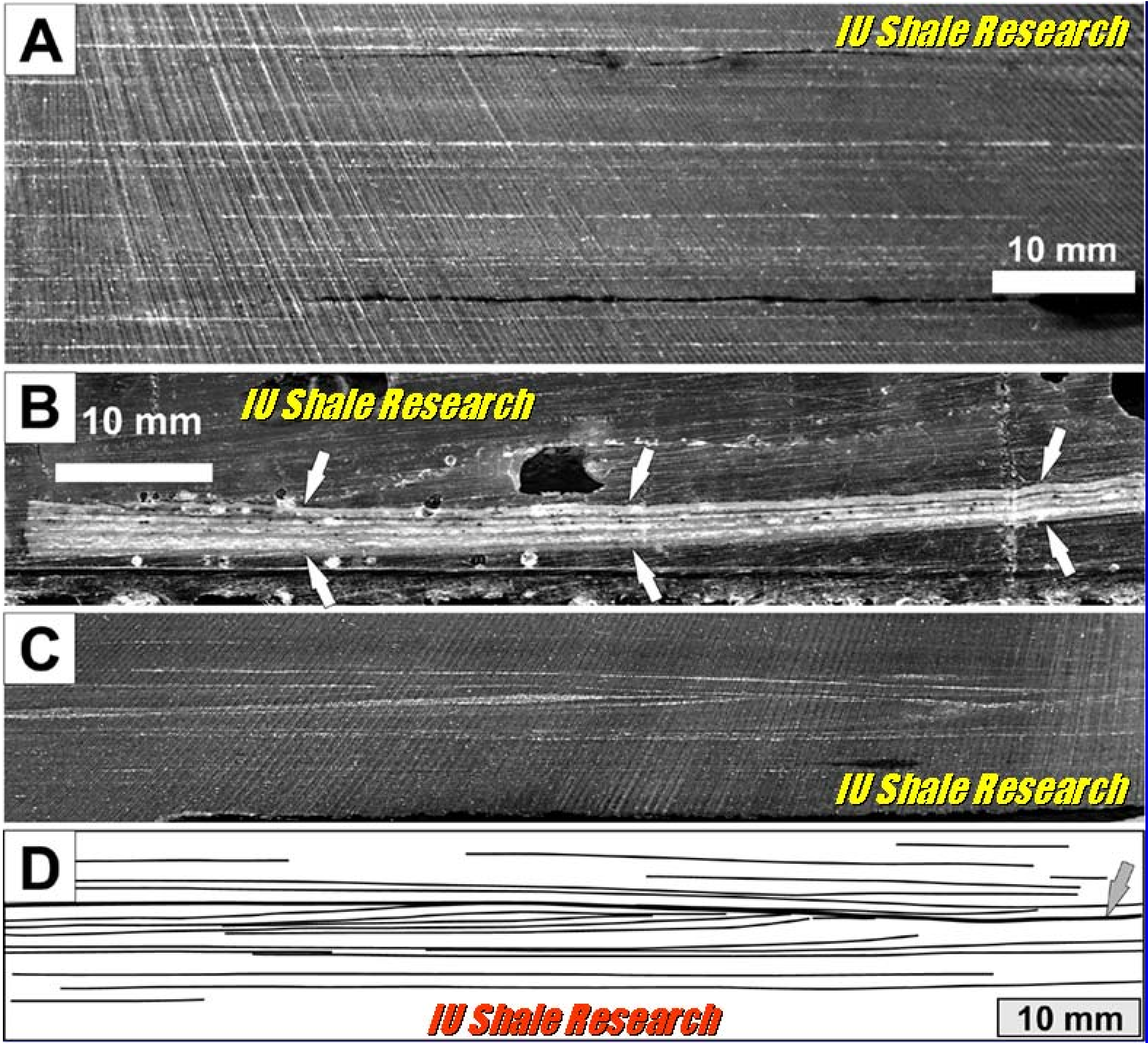
"Bedload" Mud Travels as Ripples………………



Clay ripples on a partially eroded clay bed (also consisting of ripples), flume channel is 25 cm wide.

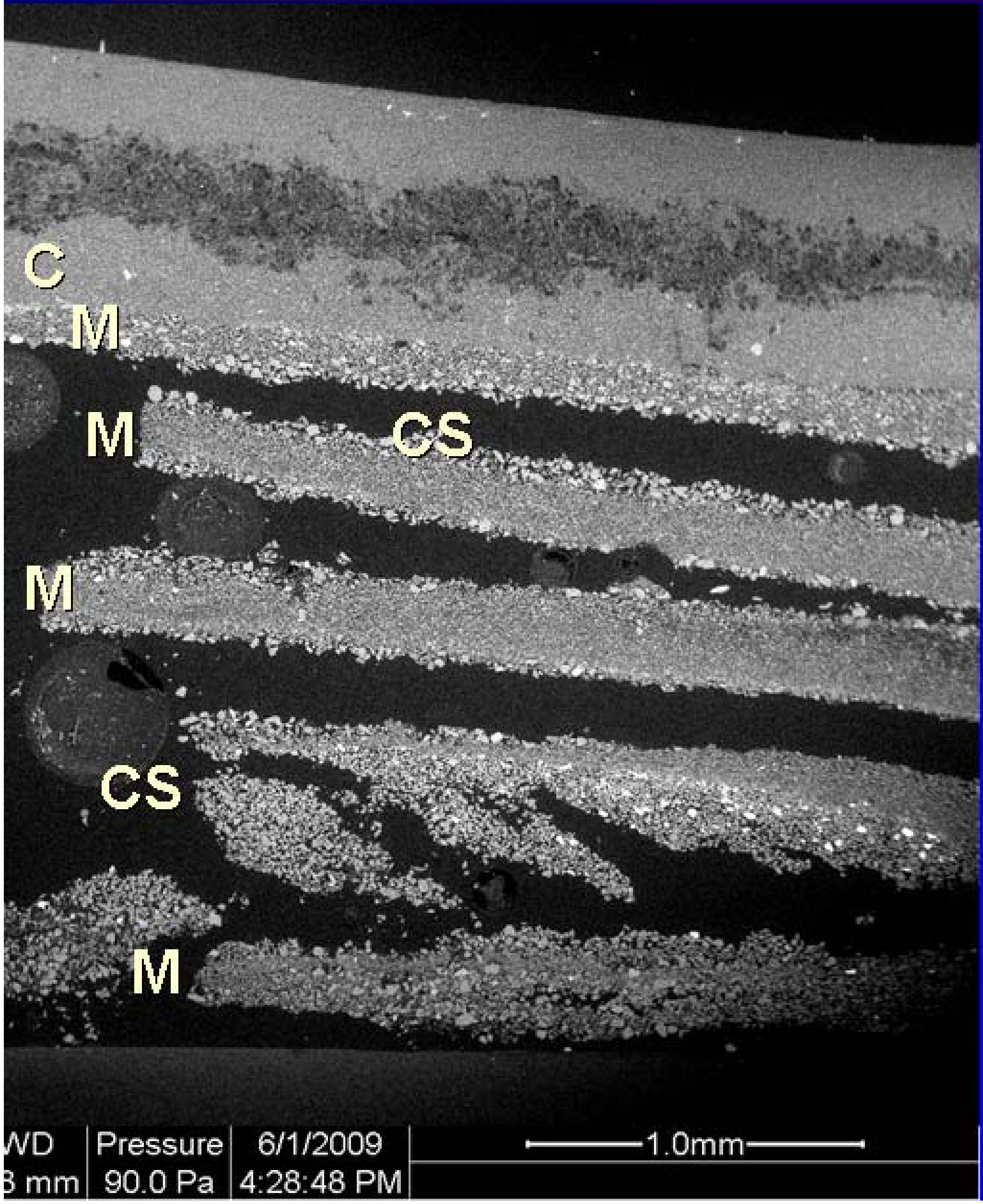


Closeup from previous slide



Caption, (see next slide)

Reasons for Silt-Clay Interlamination ?



Fluctuating Flow Strength?

NO – Flow is Constant

Overriding Travelling Cohorts of Similar Grains?

C = clay floccules

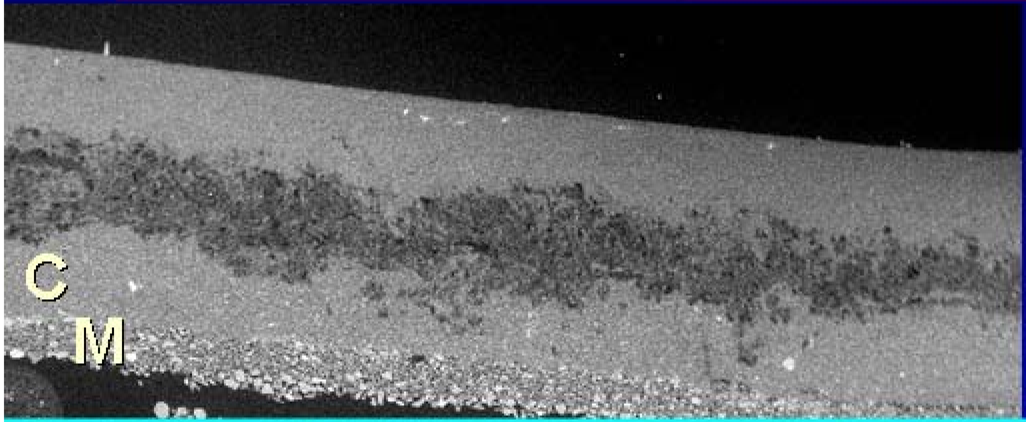
M = mixed clay/fine silt floccules

CS = coarse silt

IU Shale Research

[redacted]

Reasons for Silt-Clay Interlamination ?



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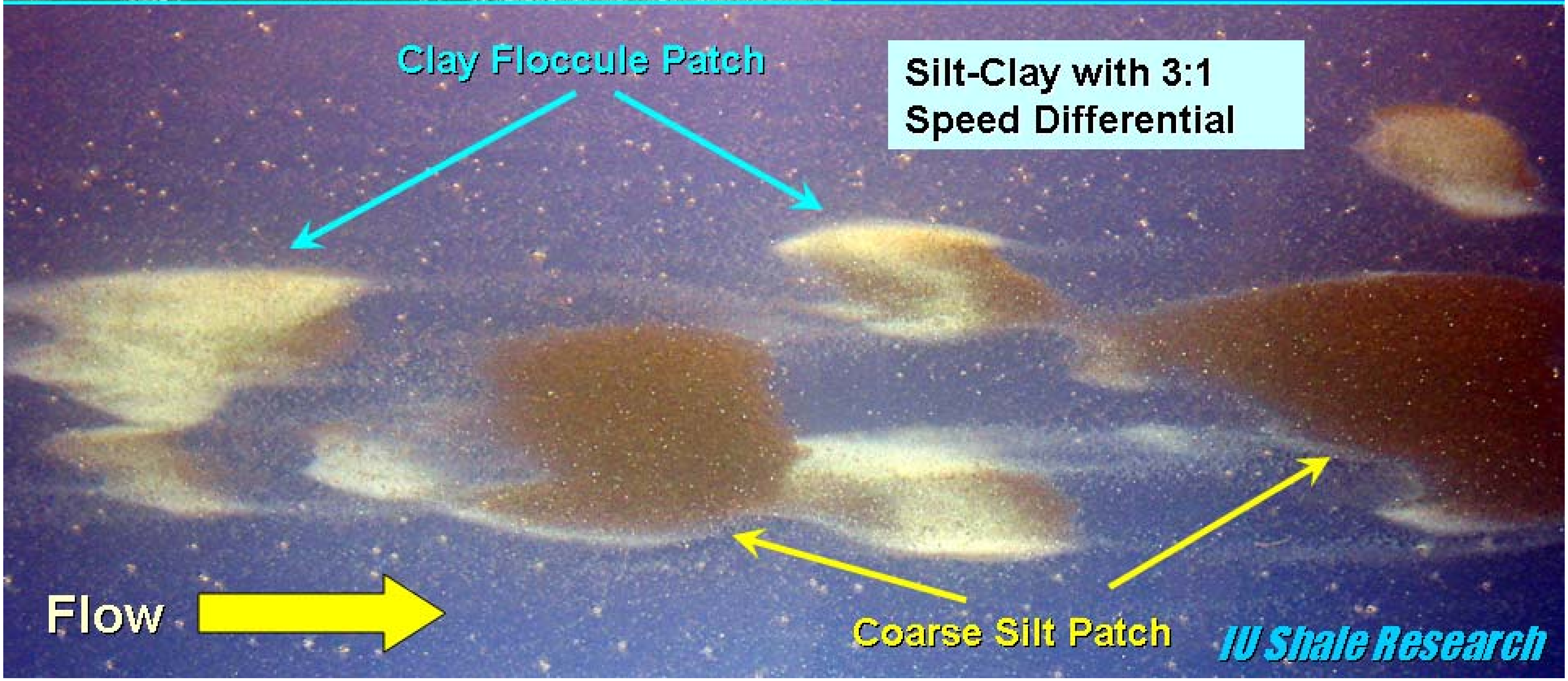
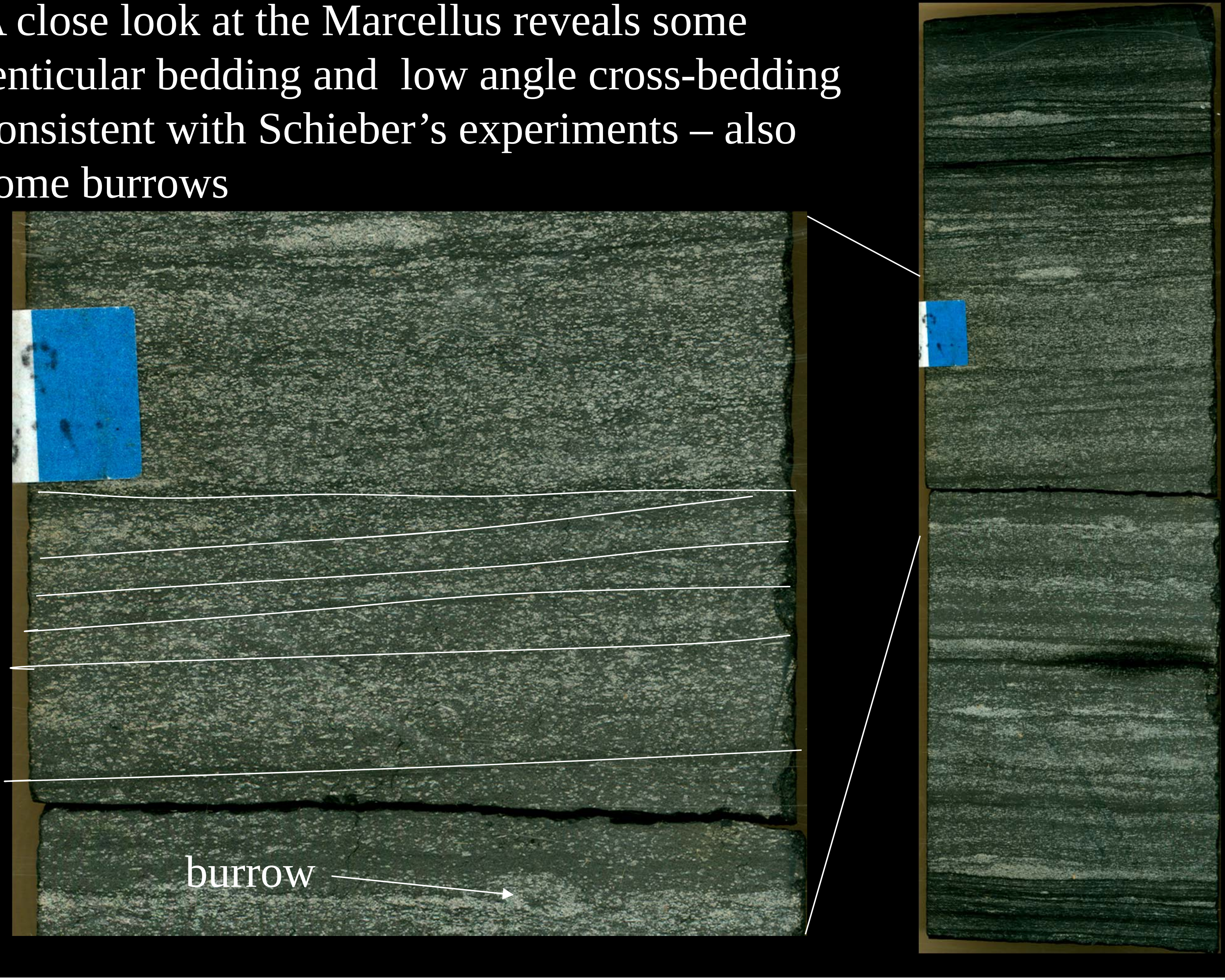


Silt-Clay with 3:1 Speed Differential

IU Shale Research

A close look at the Marcellus reveals some lenticular bedding and low angle cross-bedding consistent with Schieber's experiments – also some burrows



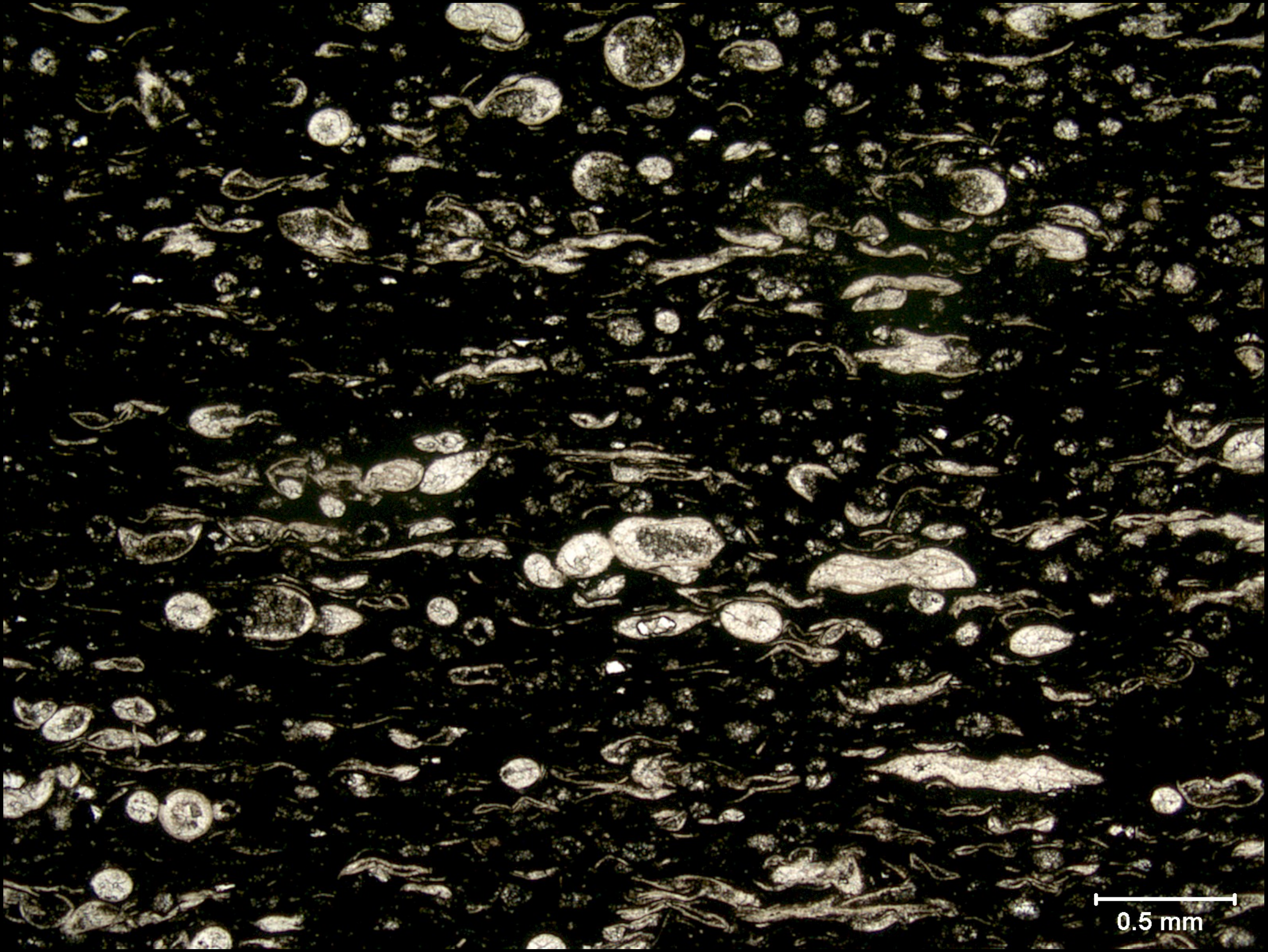
Laminations form in moving water

- Schieber’s work shows that at least some laminations in shale are produced not in still water but in moving water up to 30 cm/s as ripples of clay floccules migrate across sea floor
- Silt/clay laminations don’t have to indicate major changes in energy but can form at the same time due to segregation of clay and silt into alternating migrating ripples that again can form in water moving at 30 or 35 cm/s.
- This helps a shallow water model and Schieber has published extensively on other evidence that black shales are deposited in shallow water– he will be working with organic matter this fall and is looking for industrial support - jschiebe@indiana.edu

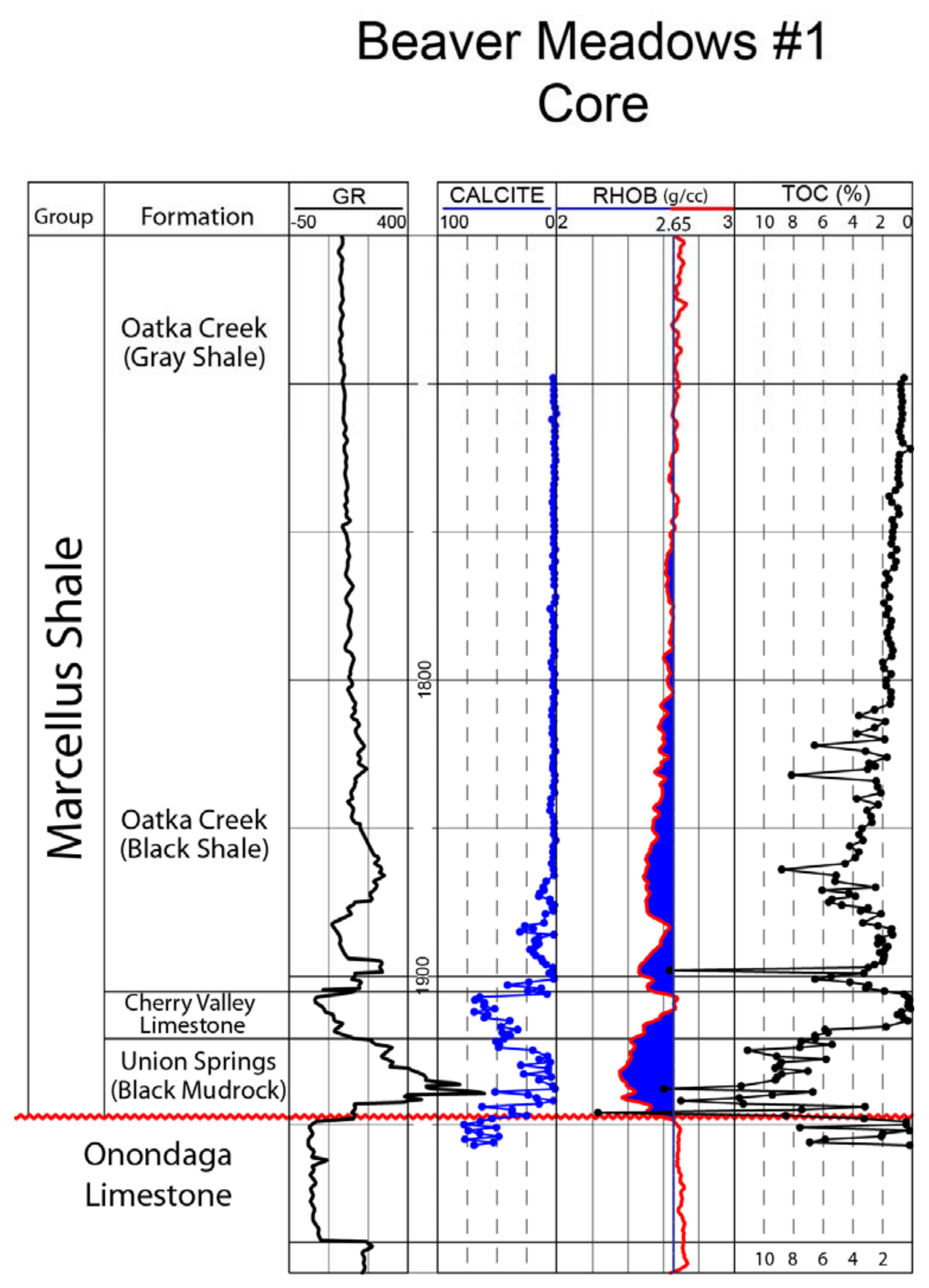
Some beds are laminated while others look more disturbed- these could be storm beds

Light colored grains in core are not silt but small fossils

Fossils present mainly planktonic, but some benthic forams and ostracodes have been found



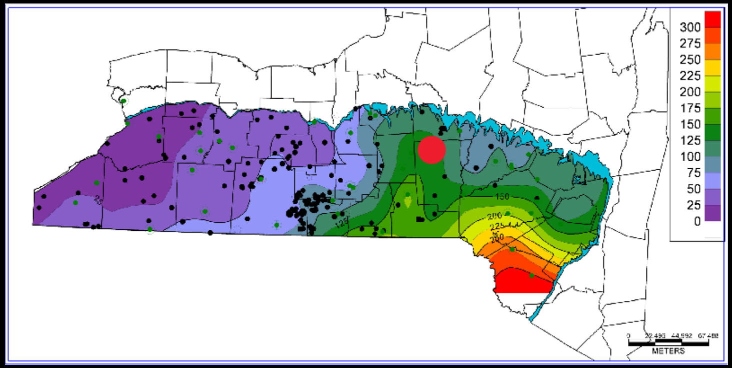
1925 ft. Styliolina fissurella and ostracode fragments and possible forams (Terra Tek)

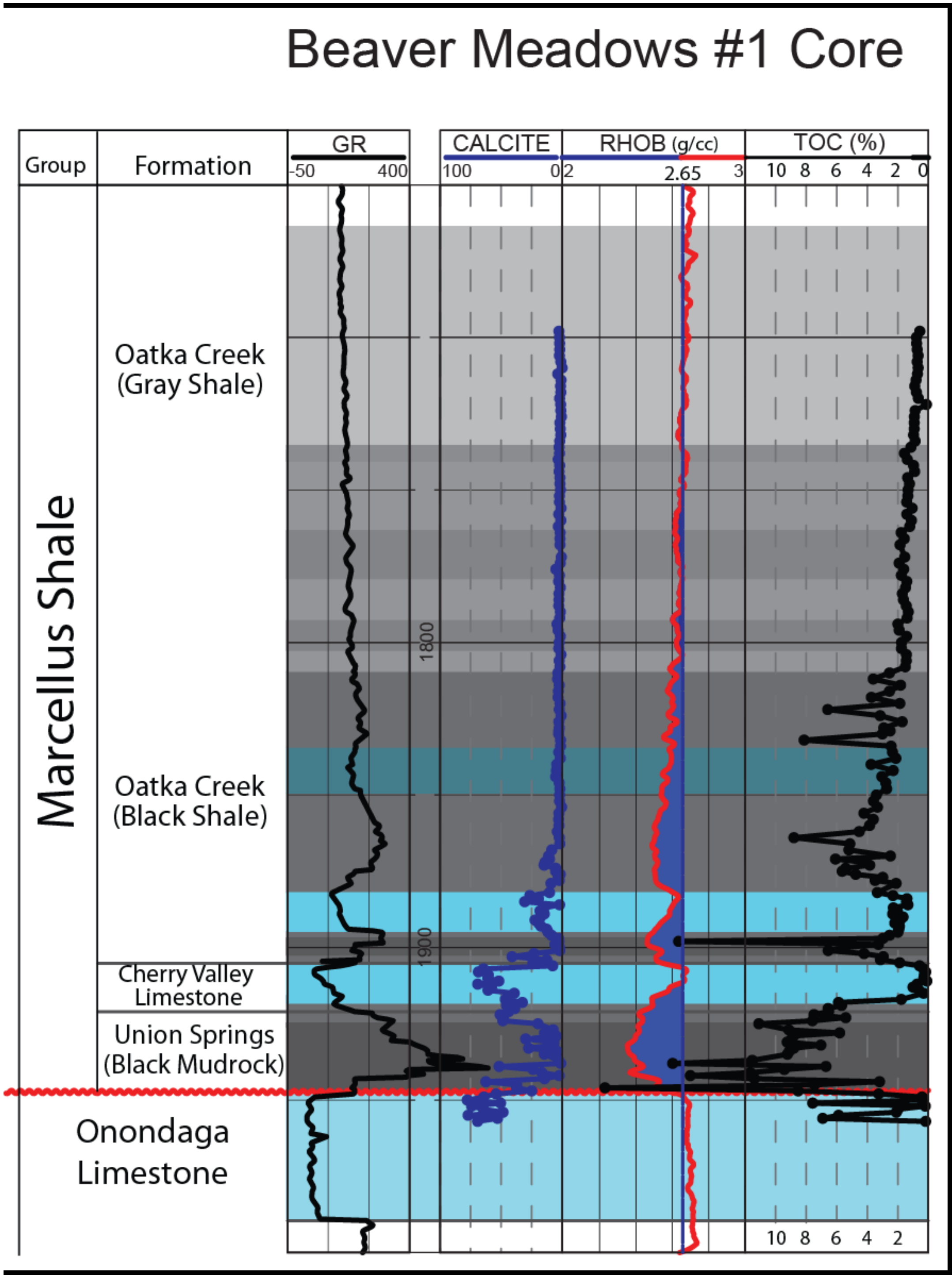


Measured TOC and calcite content on Beaver Meadows core 1 per foot

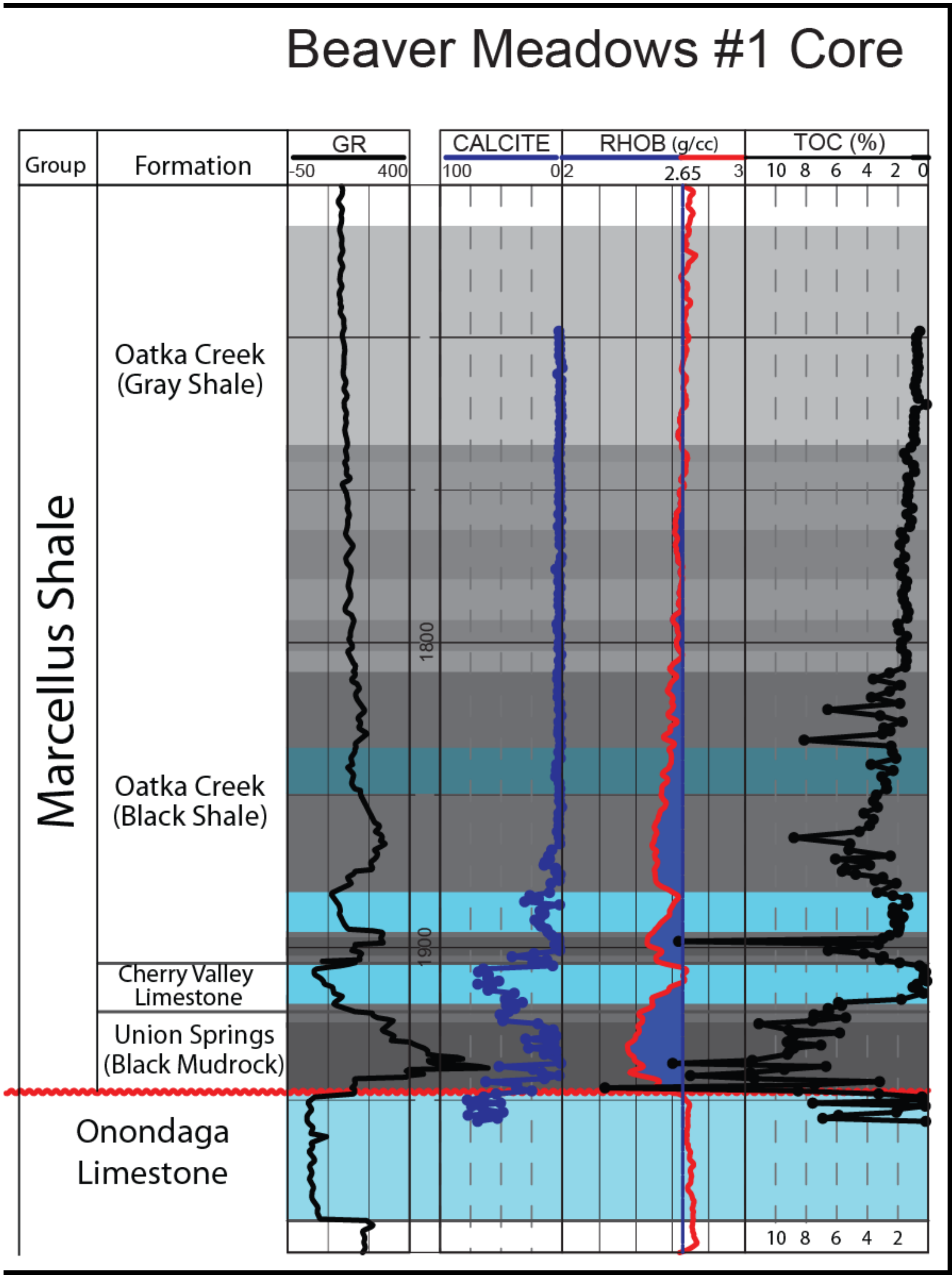
TOC matches density – shading values below 2.65 g/cc seems to line up well with TOC>1.5%

Calcite percentage also closely tracks GR at base, gray (silty) shale at top



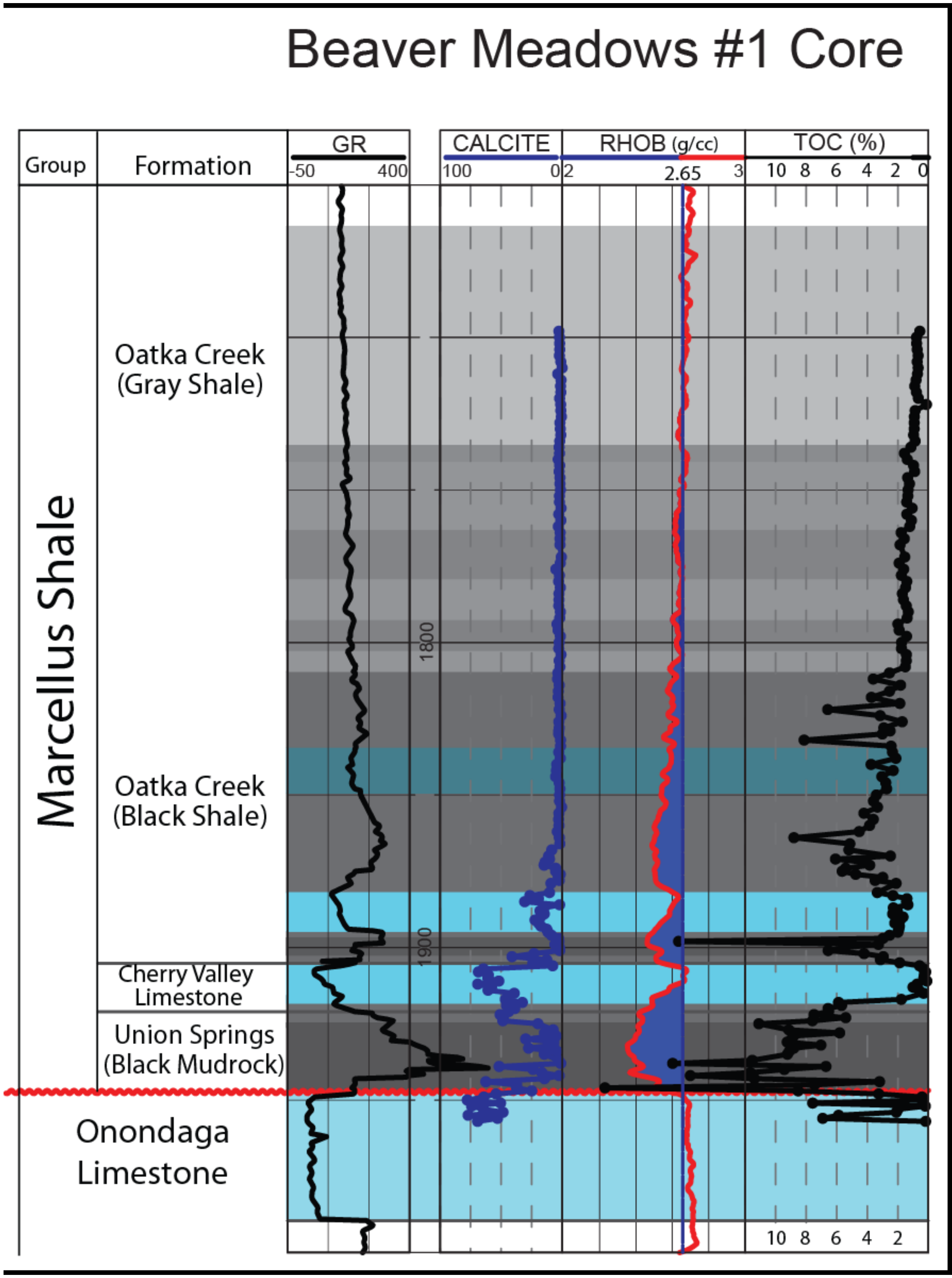

Beaver Meadows #1 Core

Darker gray = more organic rich



Darker gray = more organic rich

Unconformity at top of Onondaga

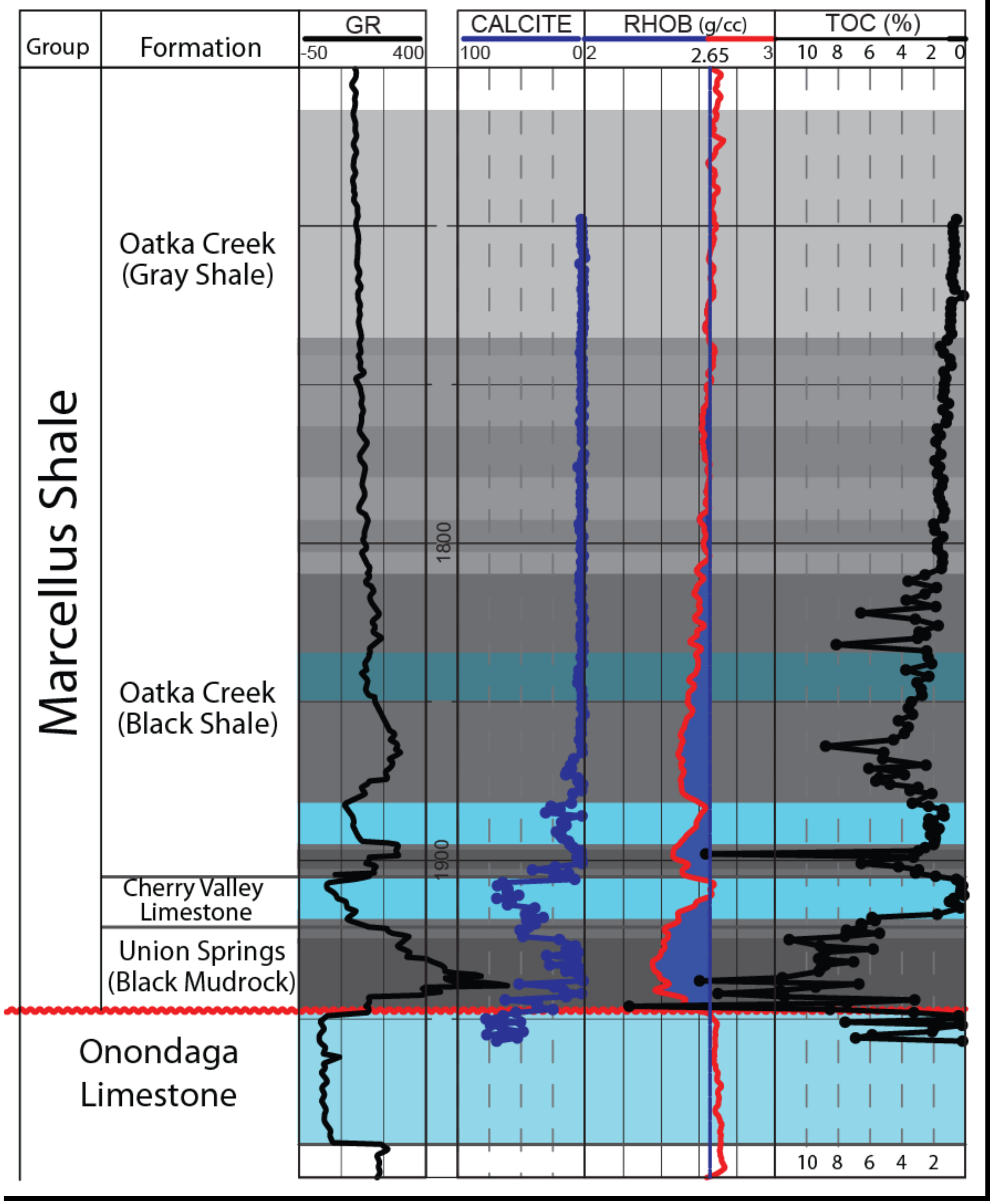


Darker gray = more organic rich

Highest TOC (up to 20%)

Unconformity at top of Onondaga

Beaver Meadows #1 Core

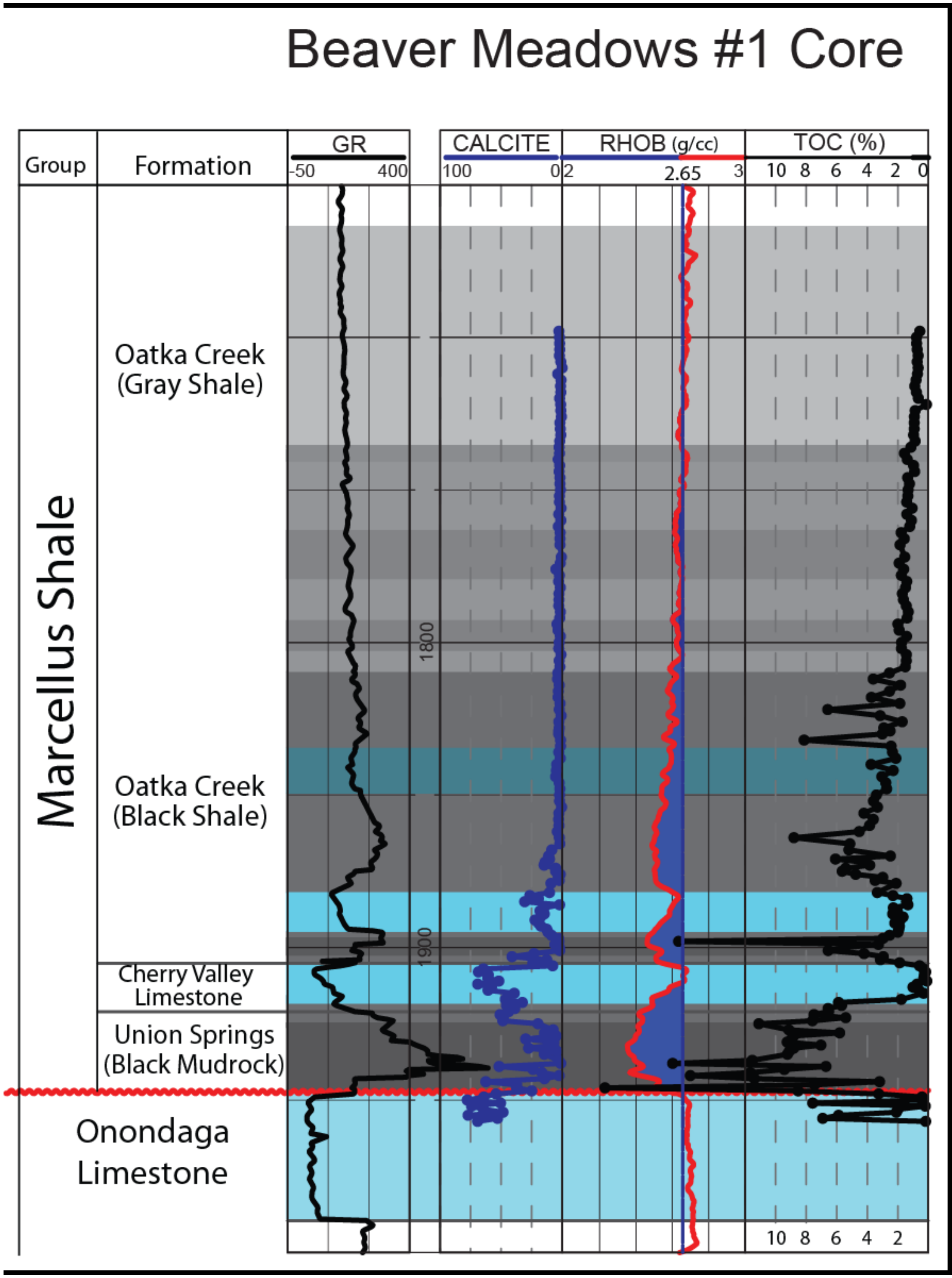


Darker gray = more organic rich

Very low TOC in limestones

Highest TOC (up to 20%)

Unconformity at top of Onondaga



Darker gray = more organic rich

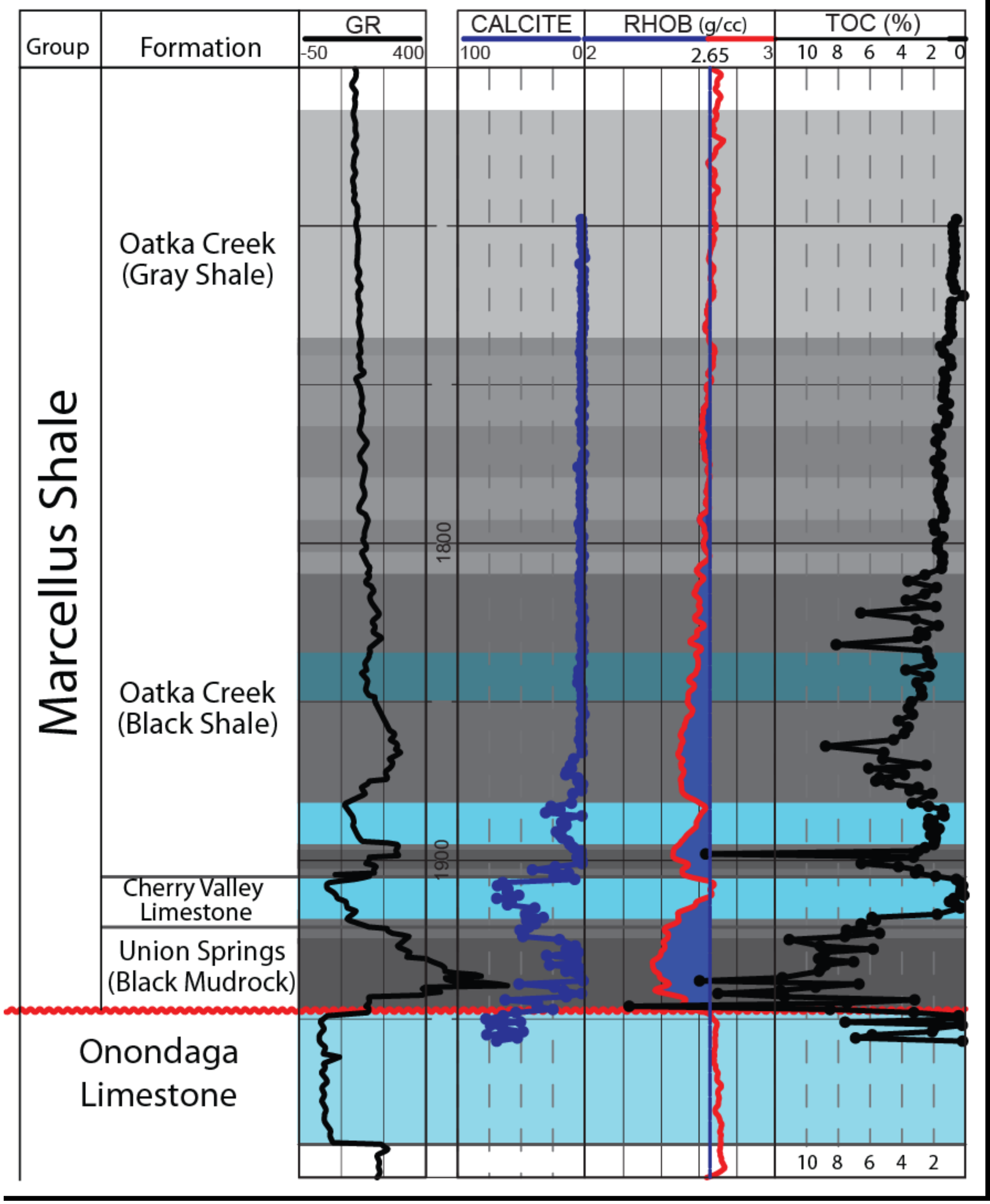
Less Limestone, More Clay

Very low TOC in limestones

Highest TOC (up to 20%)

Unconformity at top of Onondaga

Beaver Meadows #1 Core



Darker gray = more organic rich

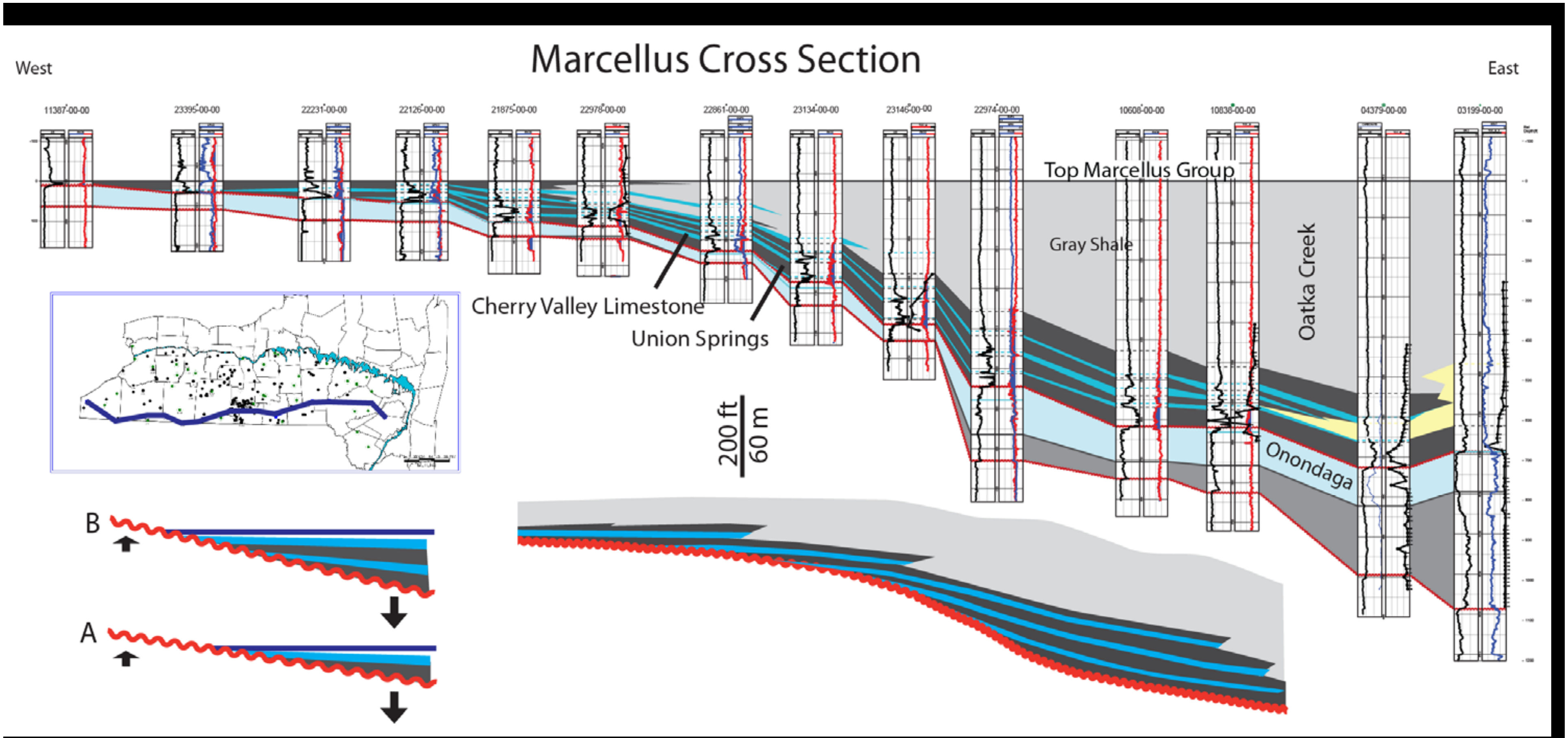
Less Limestone, More Clay

Lower TOC

Very low TOC in limestones

Highest TOC (up to 20%)

Unconformity at top of Onondaga



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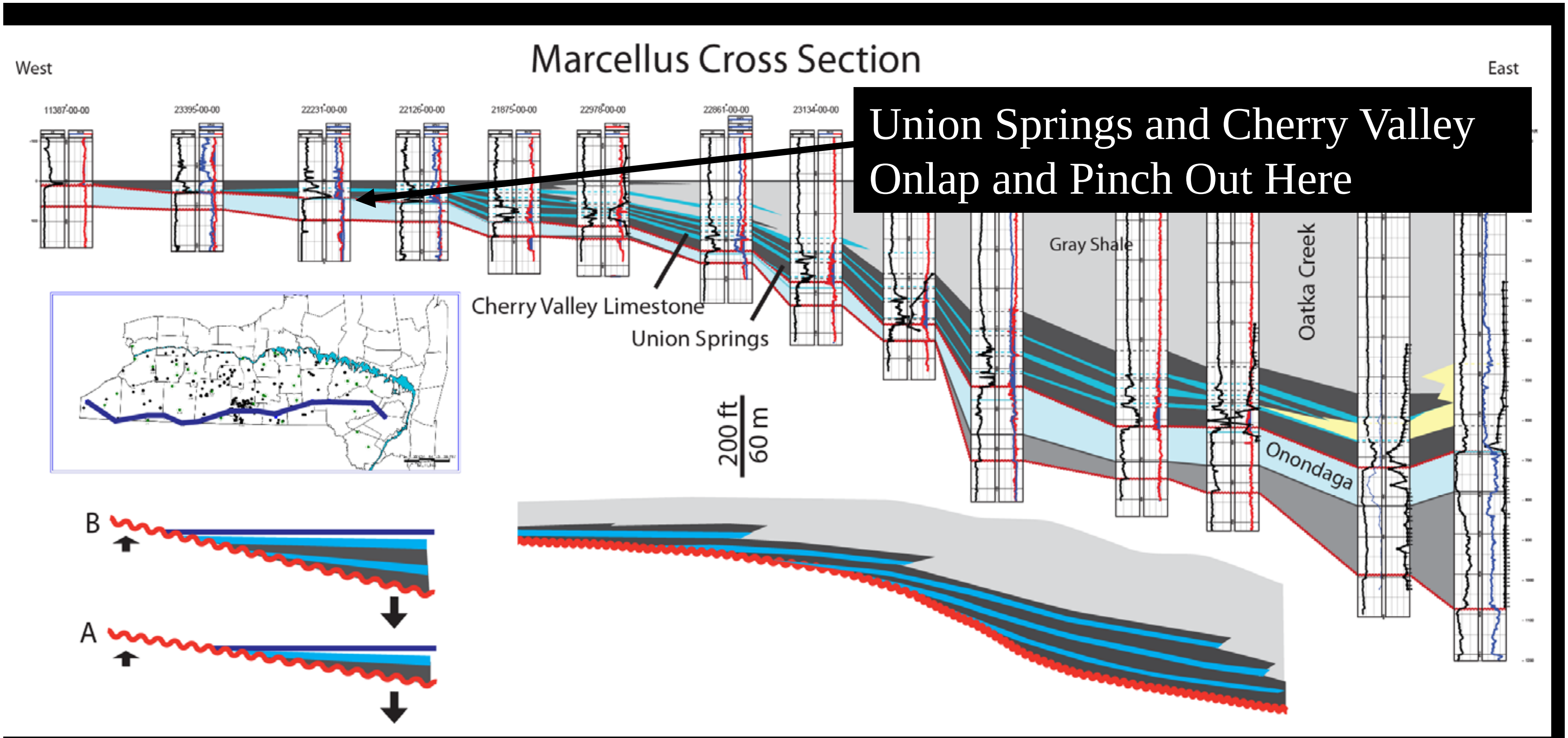
The Union Springs Shale and Cherry Valley Limestone pinch out in western NY, Oatka Creek pinches out under Lake Erie to west



Union Springs and Cherry Valley Onlap and Pinch Out Here

Each TOC rich mudrock unit becomes more OC-rich to west until it pinches out and more clay rich and less OC-rich to the east

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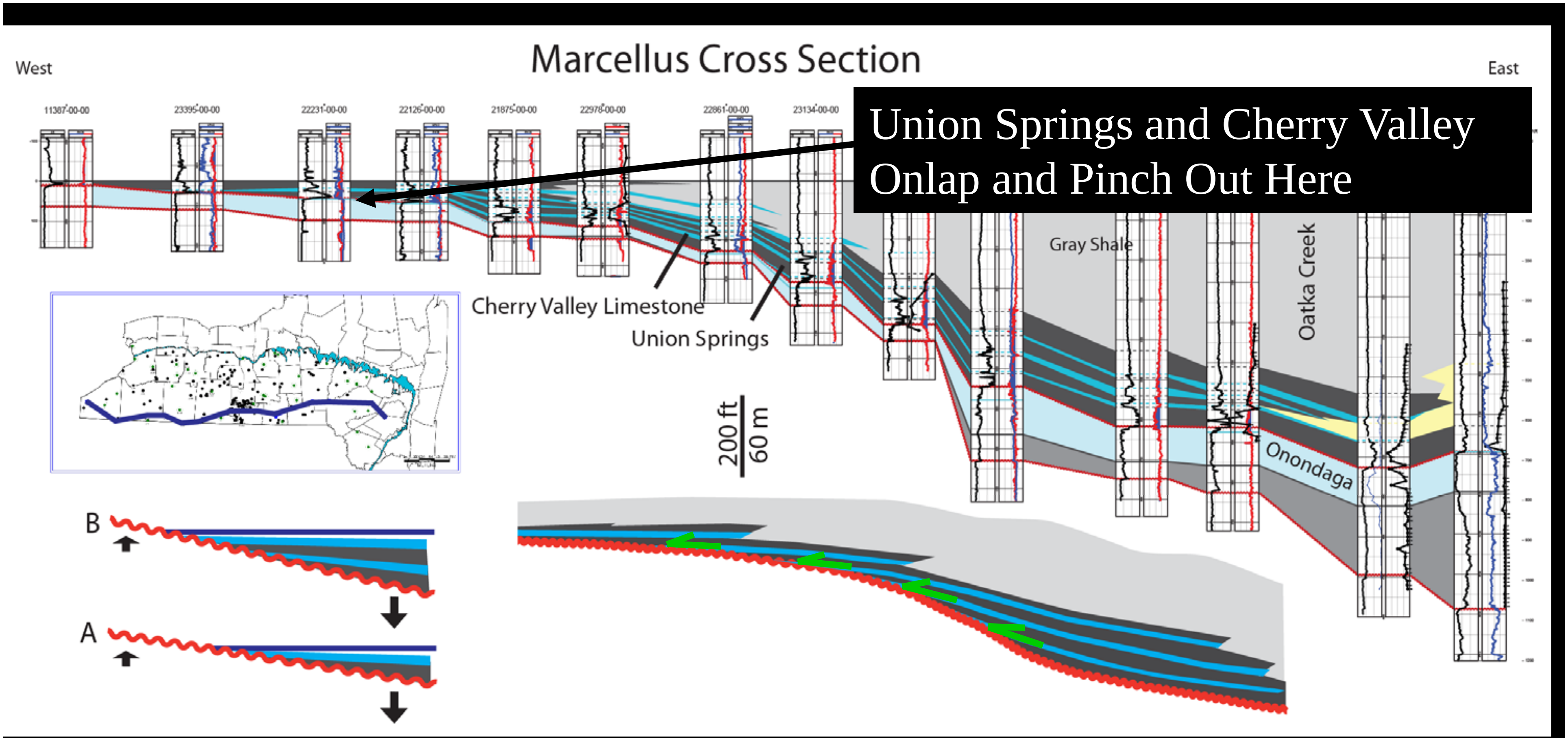

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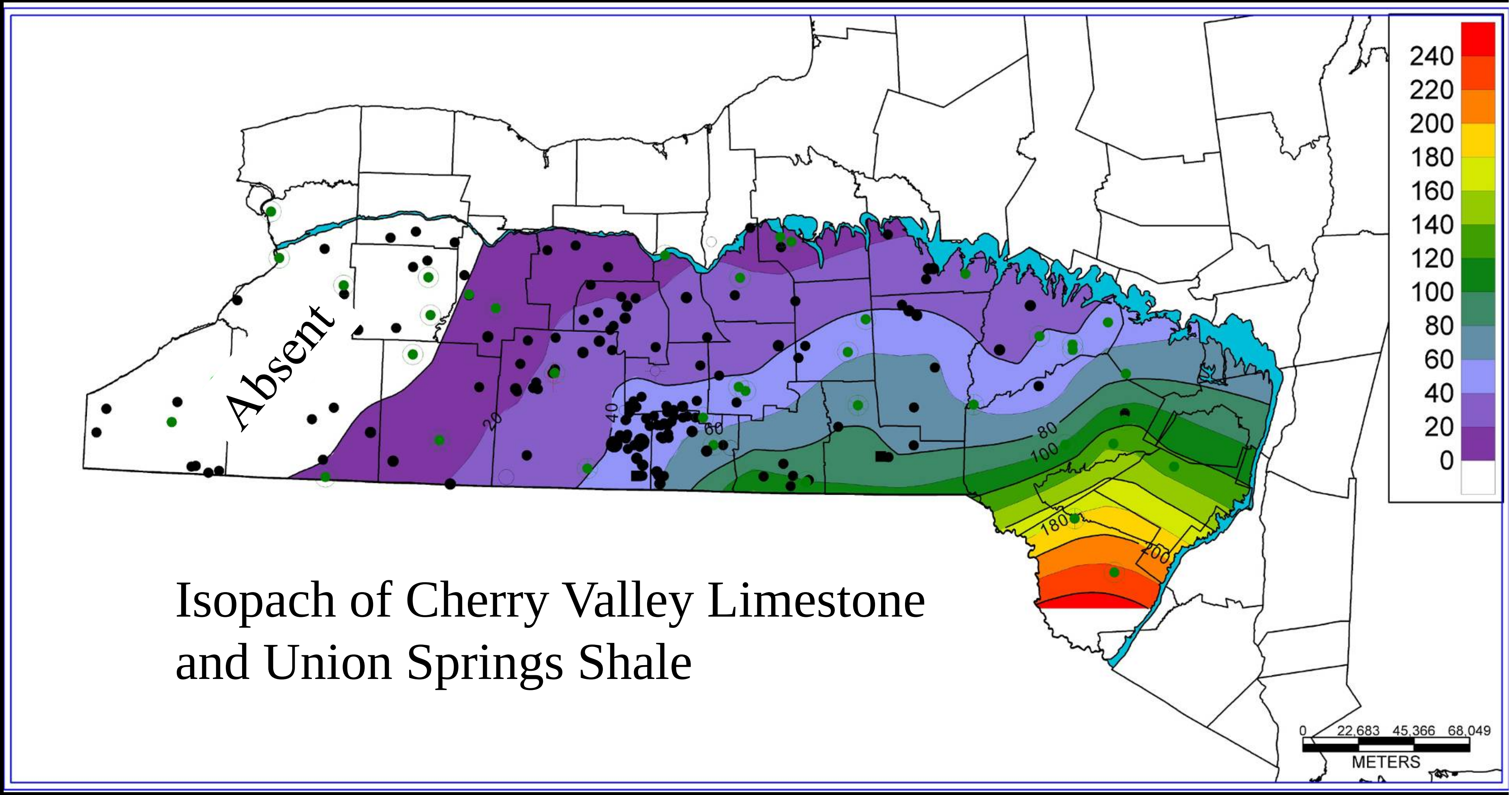
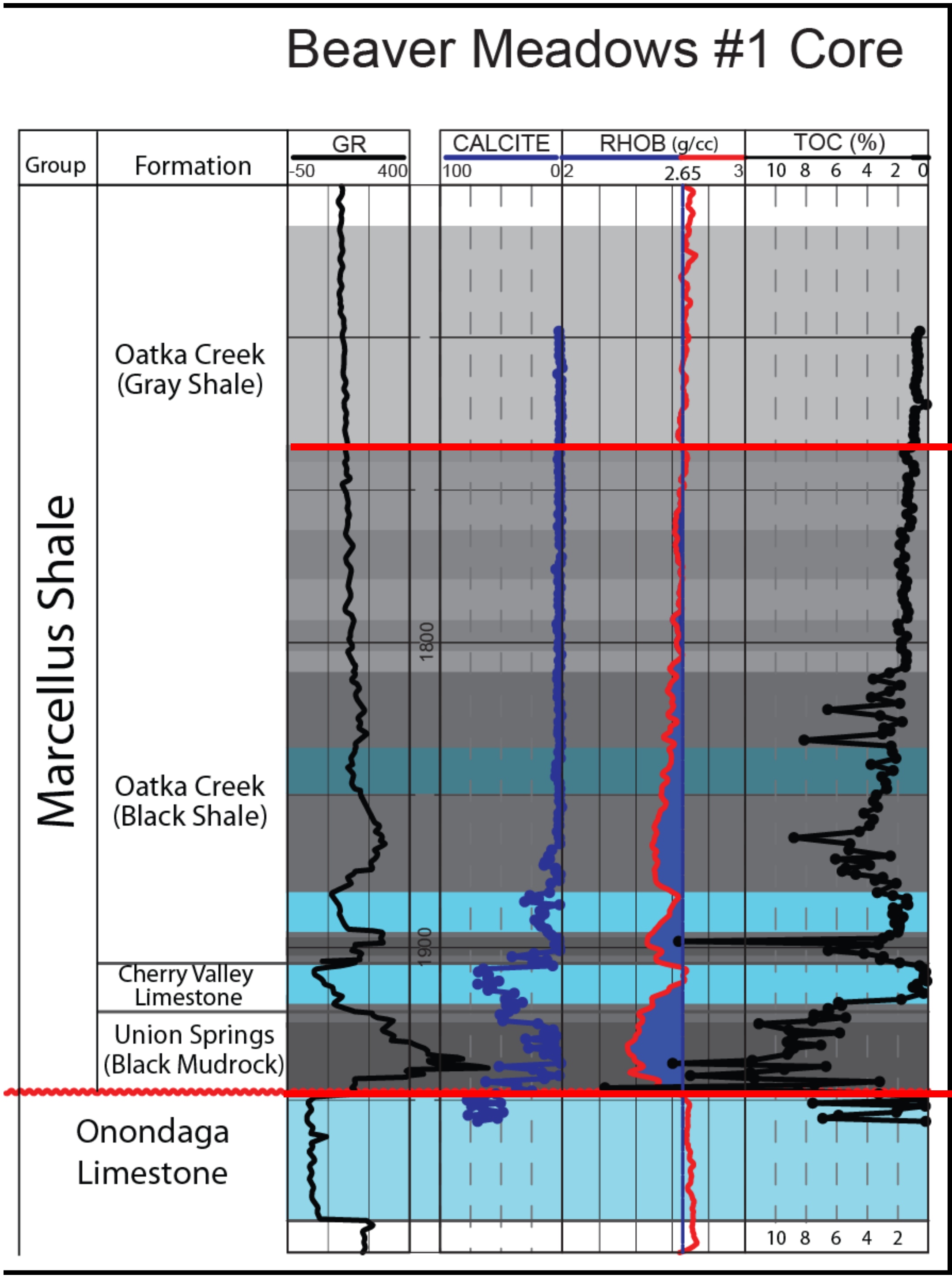


Isopach of Cherry Valley Limestone
and Union Springs Shale

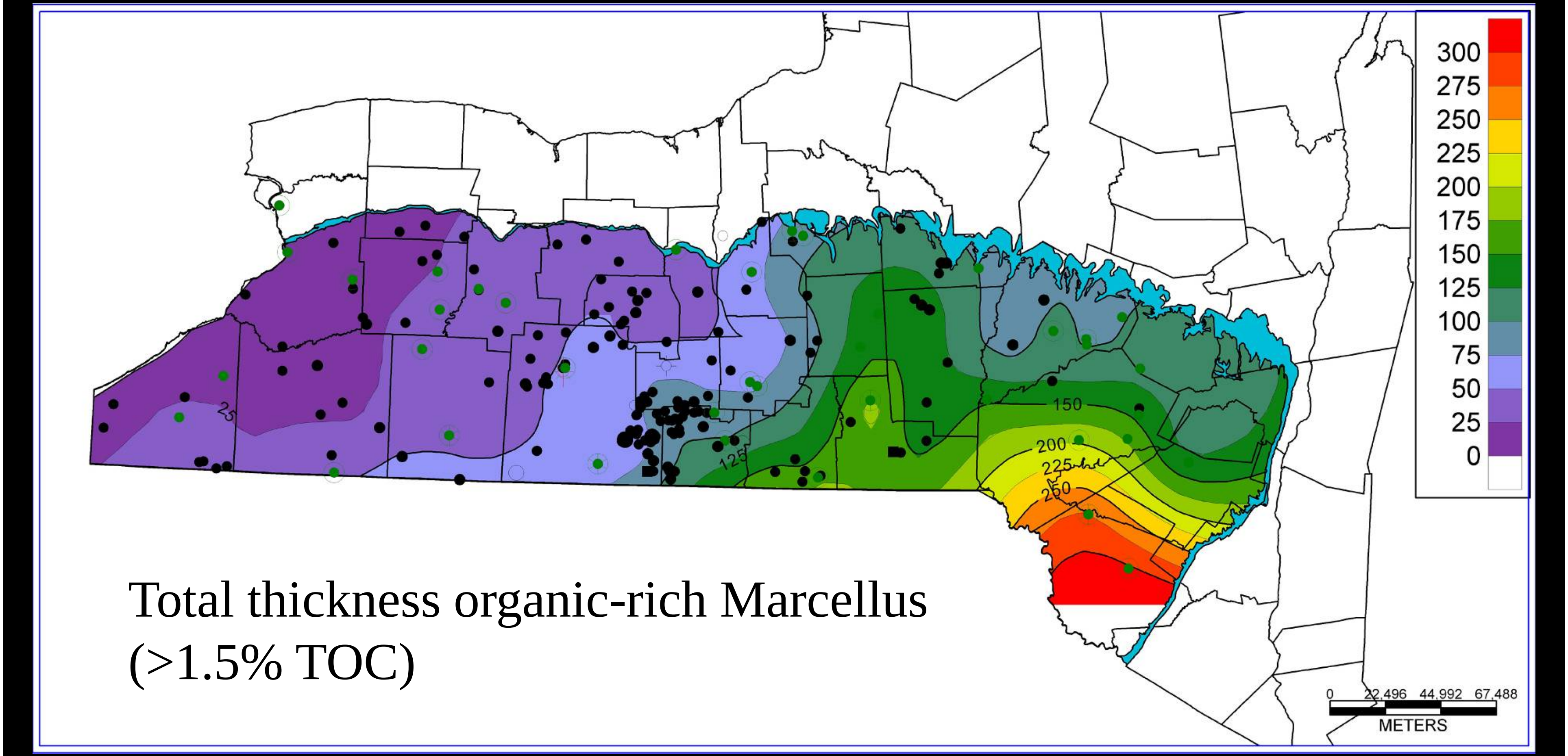
The Marcellus Shale is absent from western NY where they onlap and pinch out and thickest in southeast – There is no Marcellus equivalent to the west and this area was probably exposed land - how deep could the water have been during Union Springs deposition?



Top Organic-Rich Marcellus

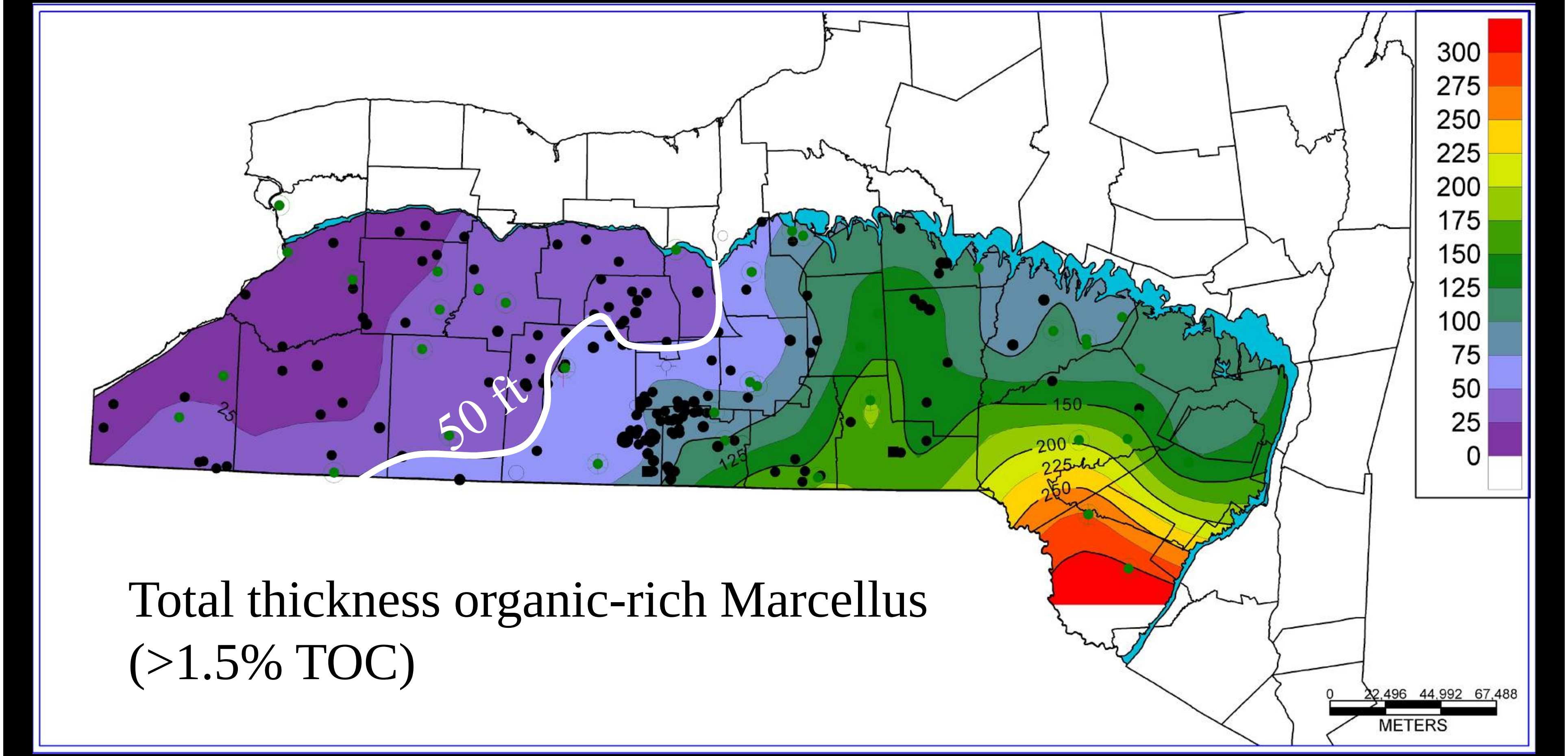
Next Map Shows
this total thickness

Base Organic-Rich Marcellus



Total thickness organic-rich Marcellus (>1.5% TOC)

If all the organic-rich beds are summed, the map looks like this – thin to west, much thicker to east – one critical question is how thick does the formation need to be to make economic wells – some have suggested 50 feet – it is a moot point for anything thinner than 50 ft…



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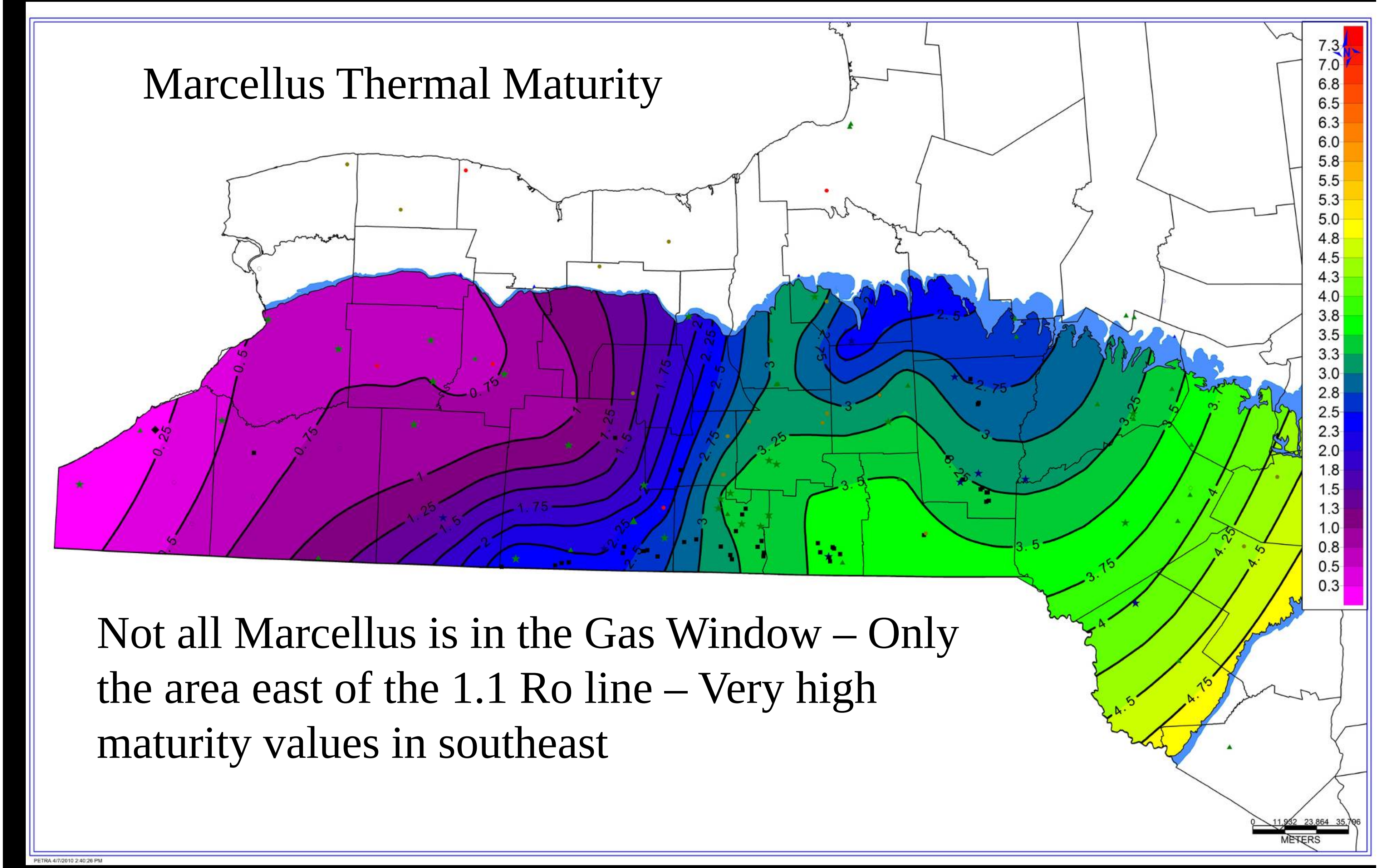
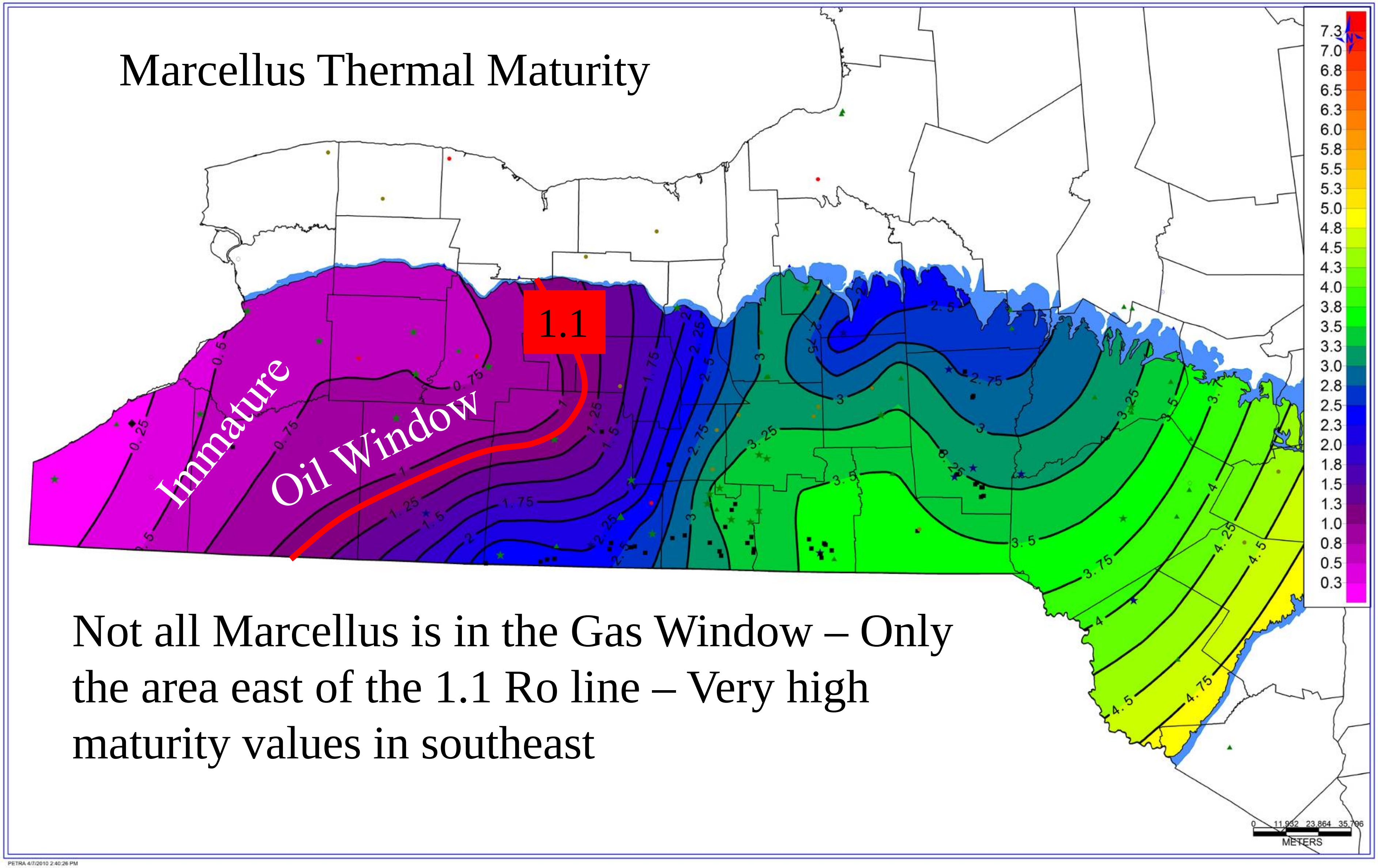
Marcellus Thermal Maturity



Not all Marcellus is in the Gas Window – Only the area east of the 1.1 Ro line – Very high maturity values in southeast

Western NY is not mature anyway

Marcellus Thermal Maturity



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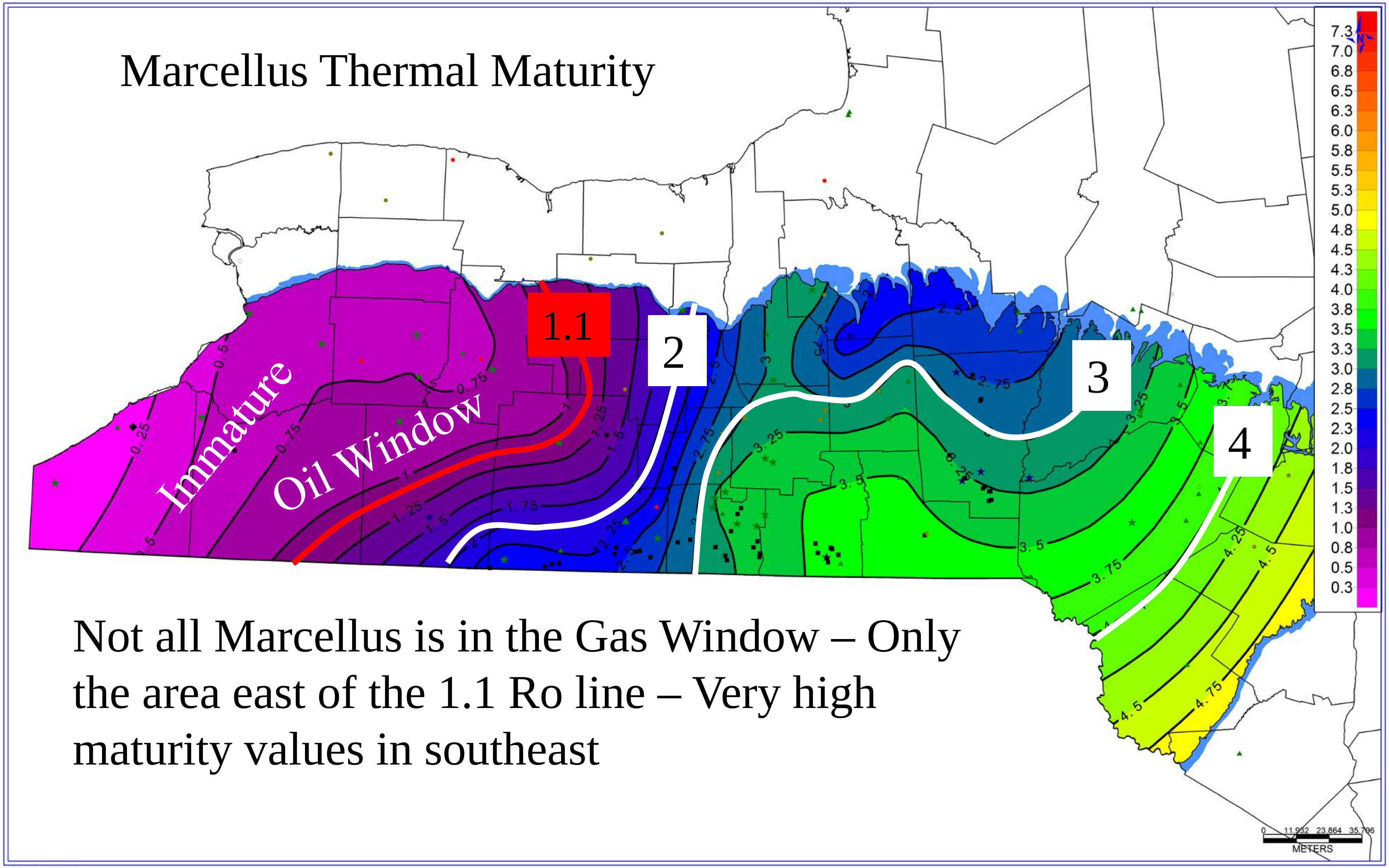

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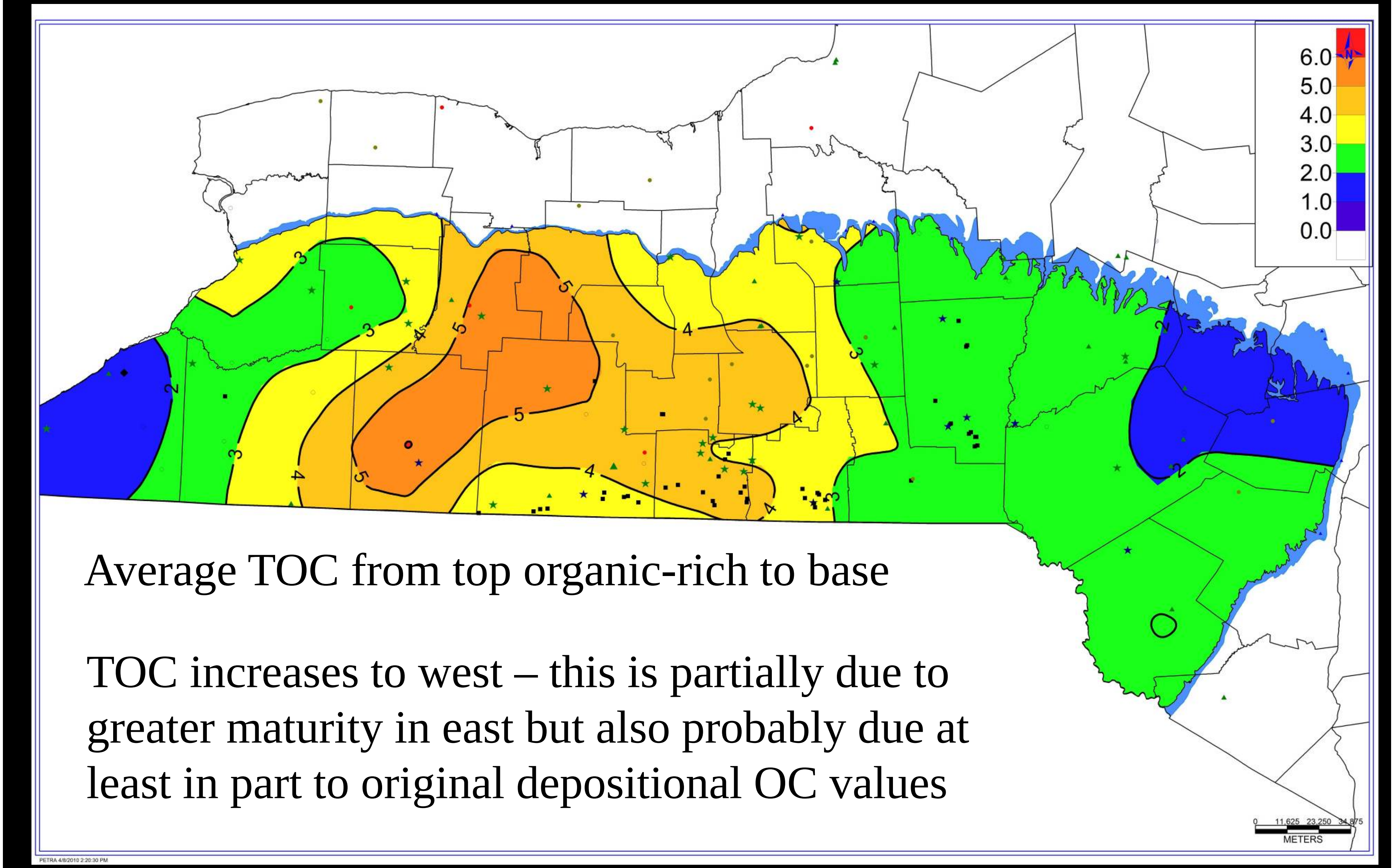
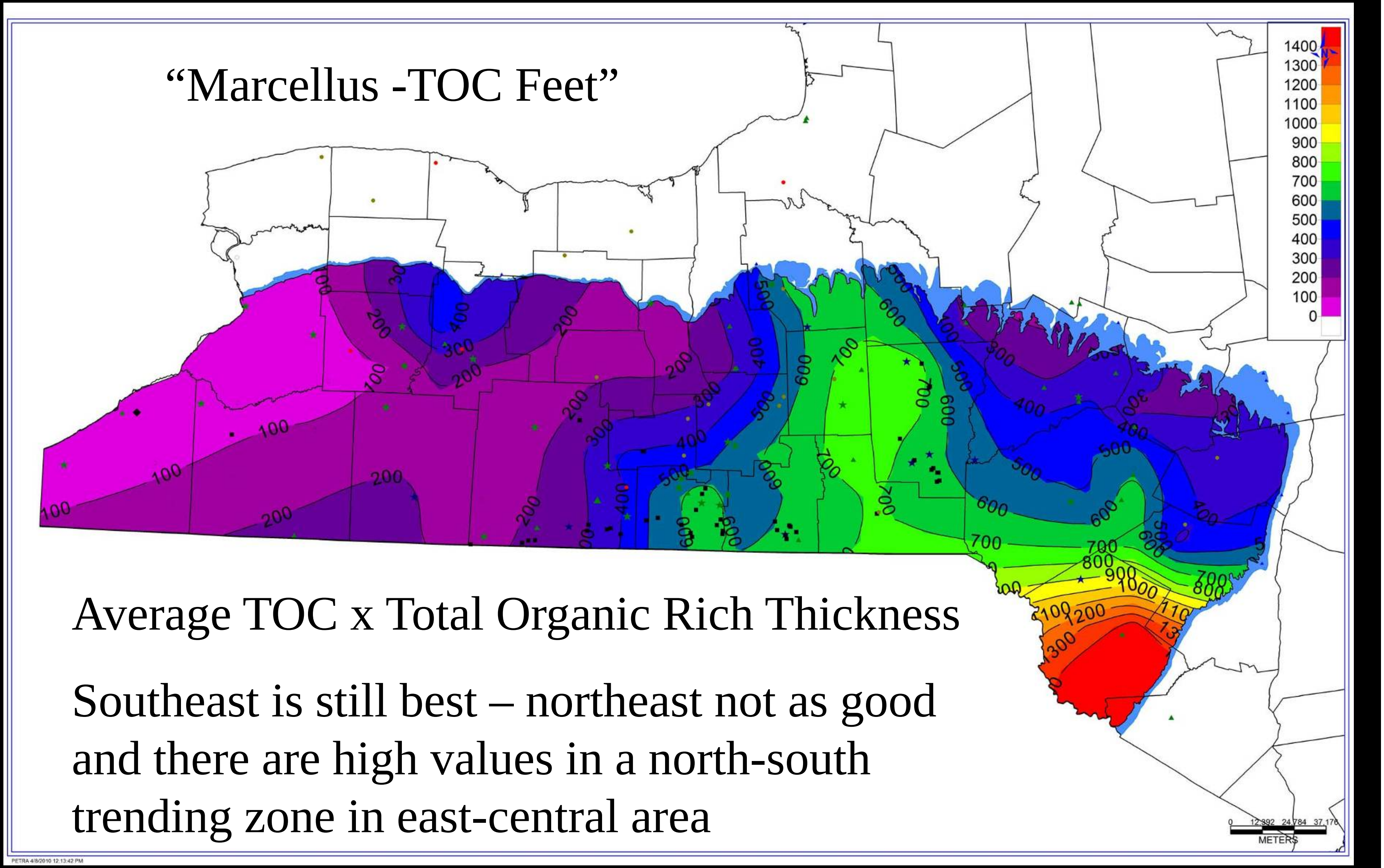


Average TOC from top organic-rich to base

TOC increases to west – this is partially due to greater maturity in east but also probably due at least in part to original depositional OC values

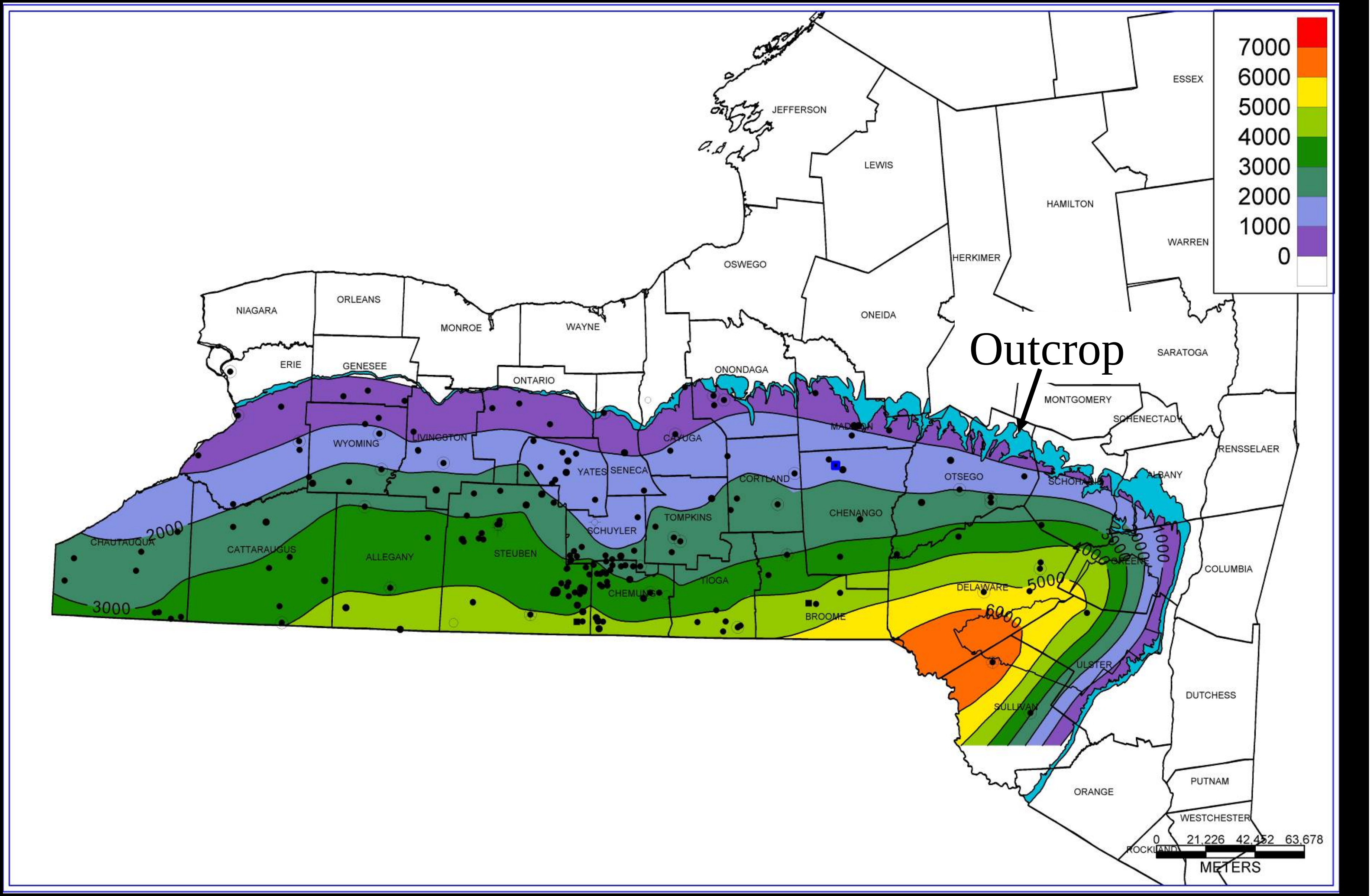
“Marcellus -TOC Feet”



Average TOC x Total Organic Rich Thickness

Southeast is still best – northeast not as good and there are high values in a north-south trending zone in east-central area

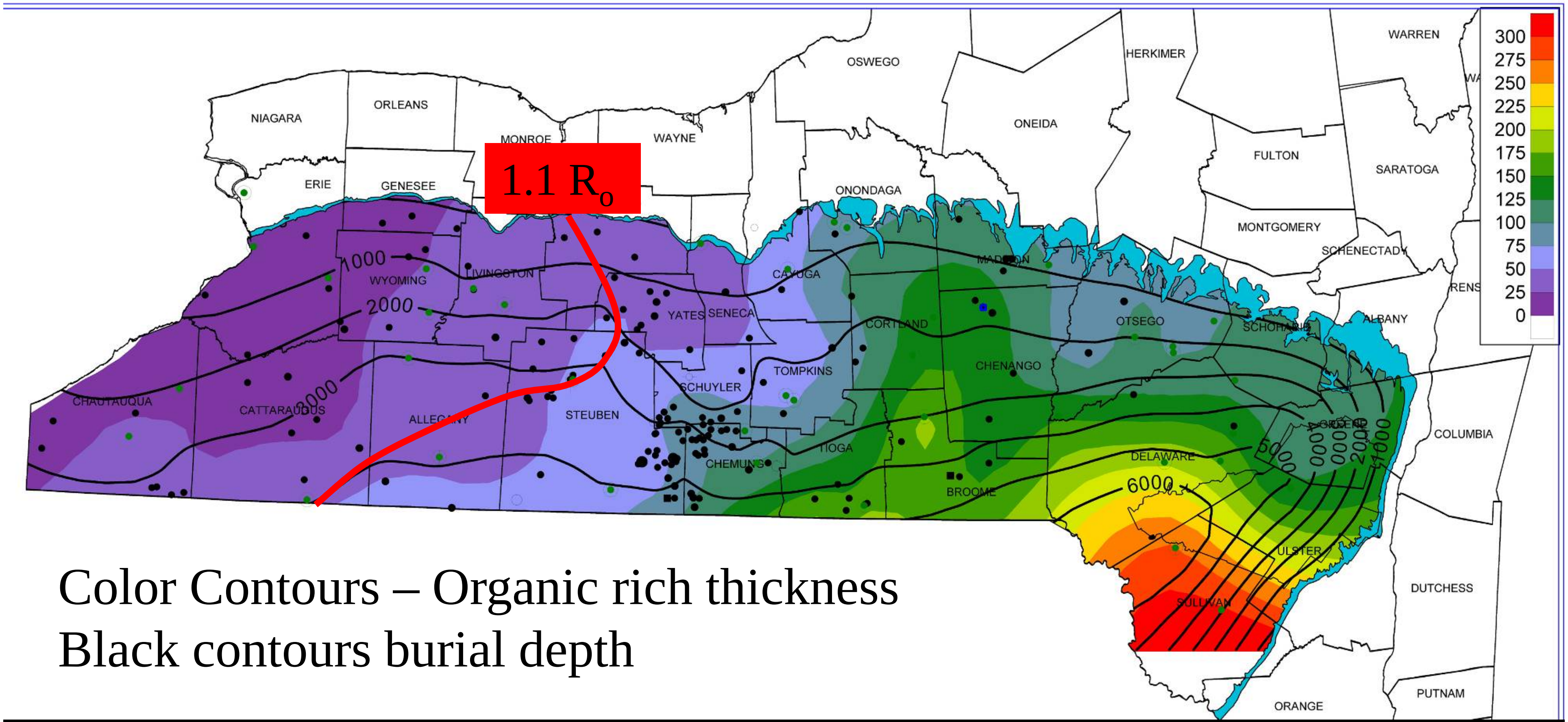
This is an attempt to capture organic richness and thickness – this map will improve with more data



Outcrop

Burial Depth – Marcellus outcrops to north and east and is more than 6000 feet deep in Sullivan and Delaware Counties

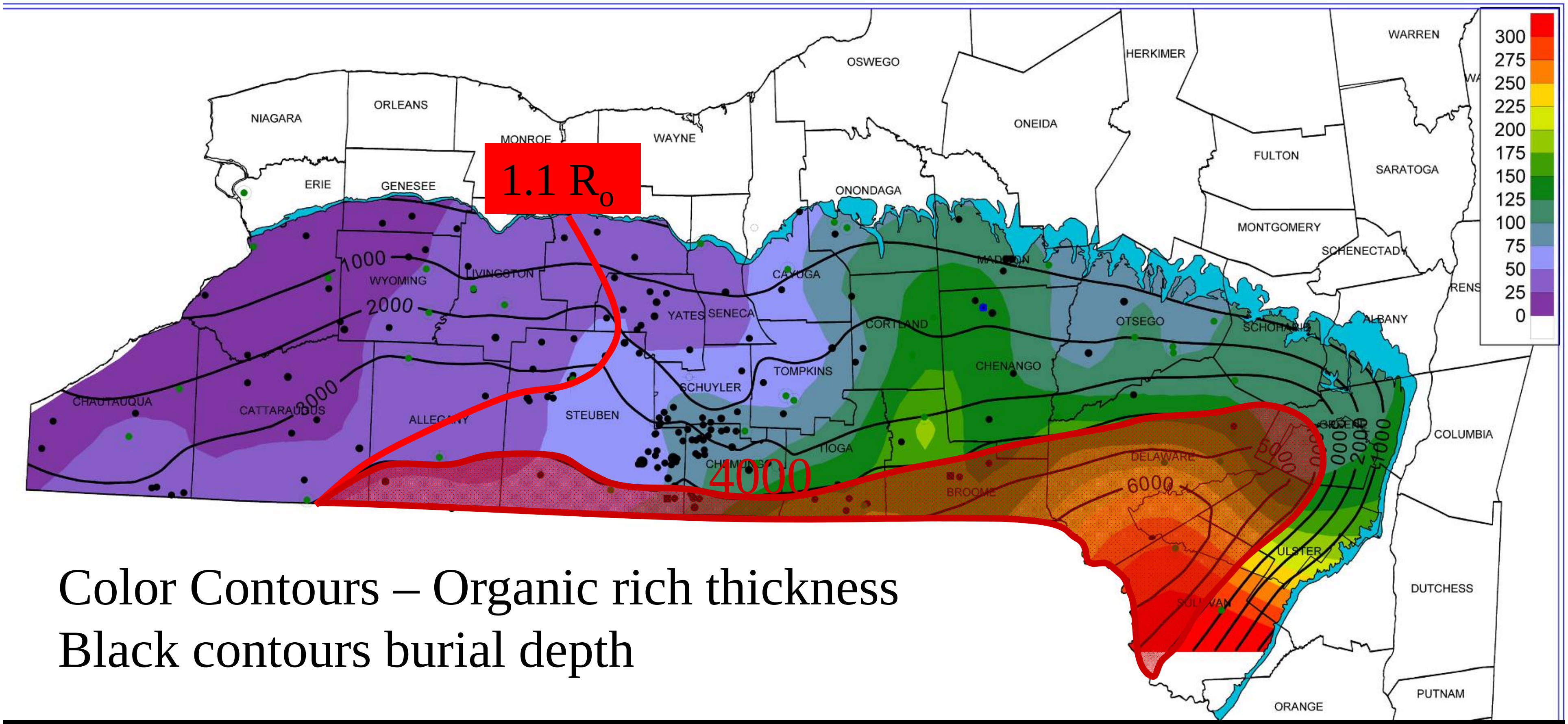
Fairway Map – Marcellus Shale



Color Contours – Organic rich thickness
Black contours burial depth

Best areas probably where thickest and deepest – A key question is how deep the shale needs to be to produce economically – some shales are only economic at >4000 feet, others appear to be profitable at shallower depths

Fairway Map – Marcellus Shale



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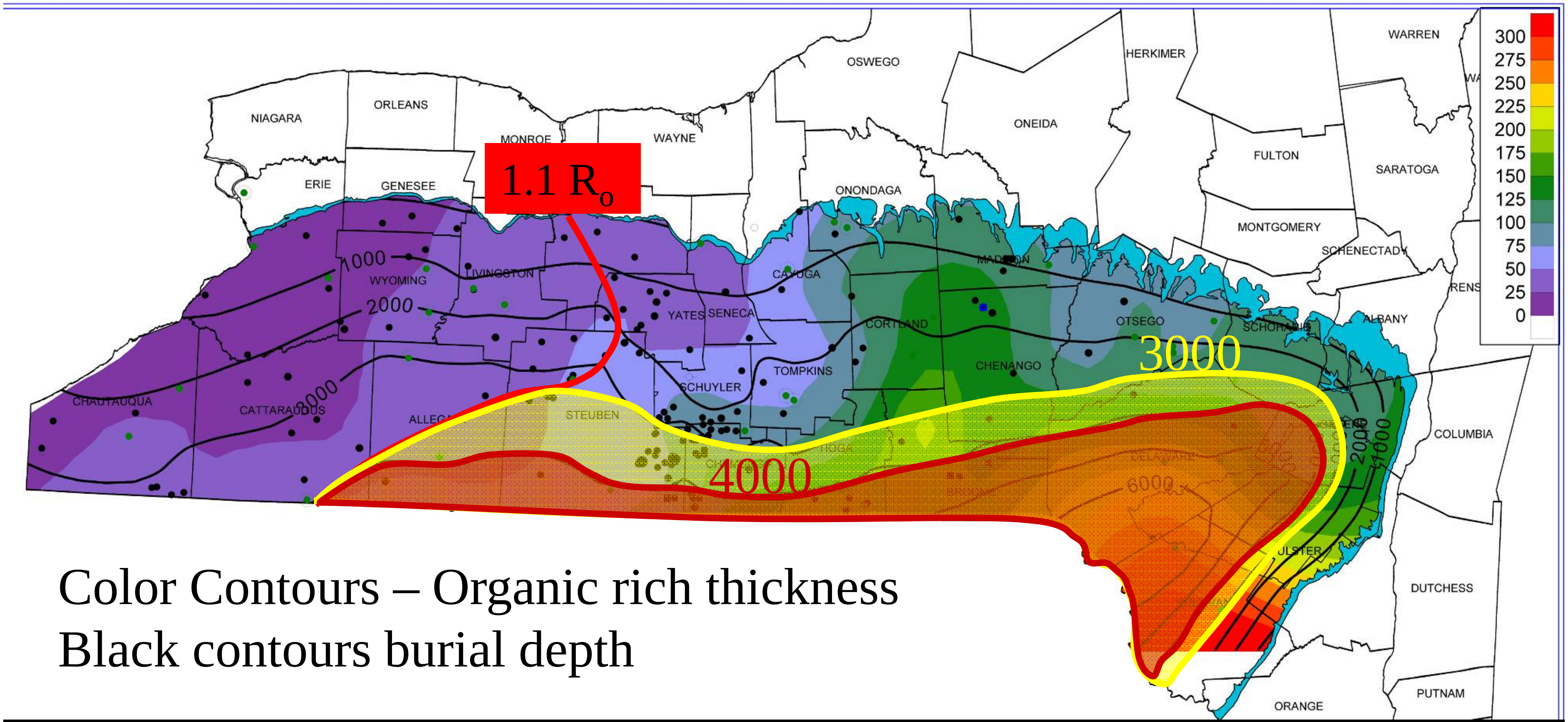

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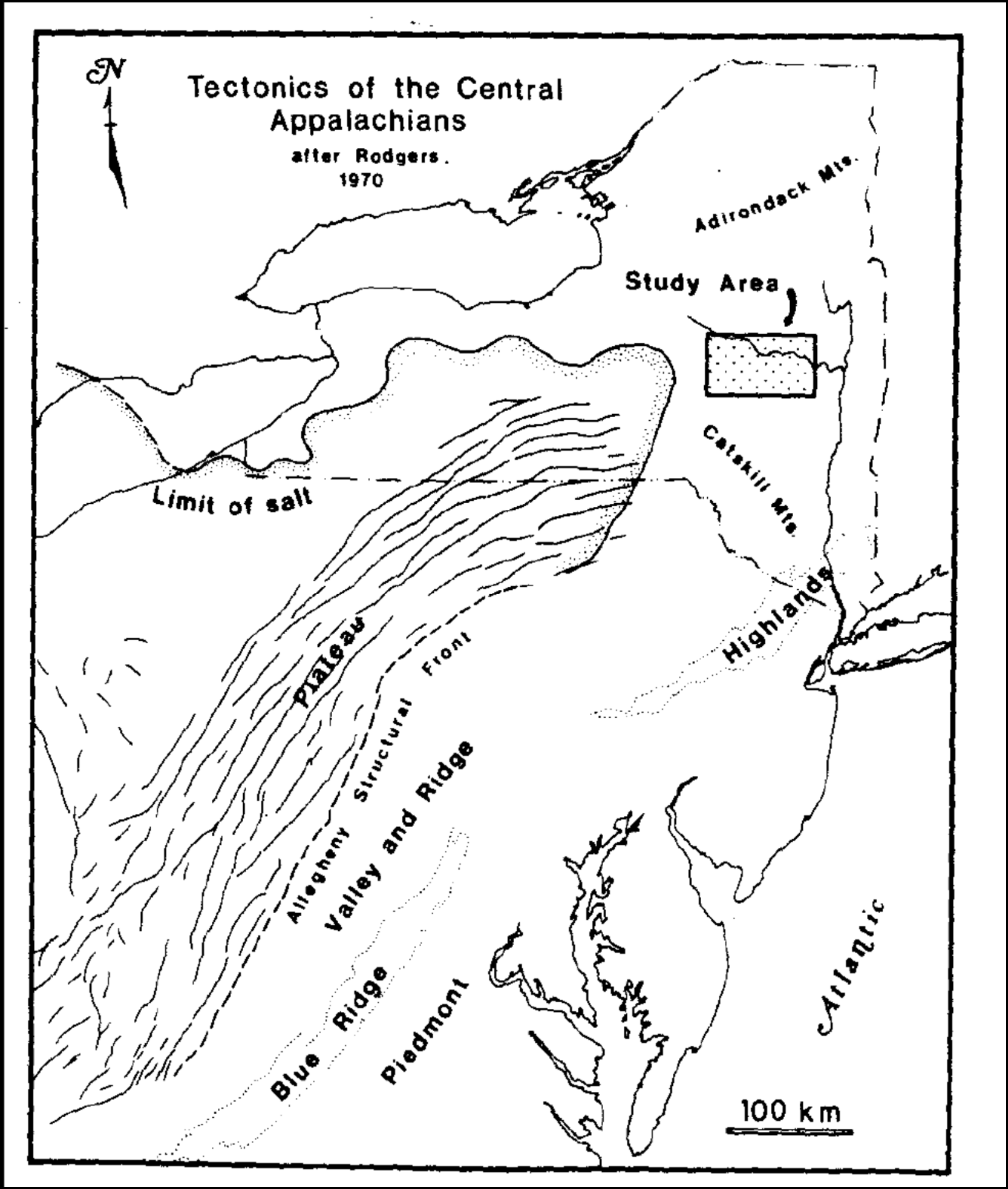
Detacment and Compressional Structural Features in Marcellus

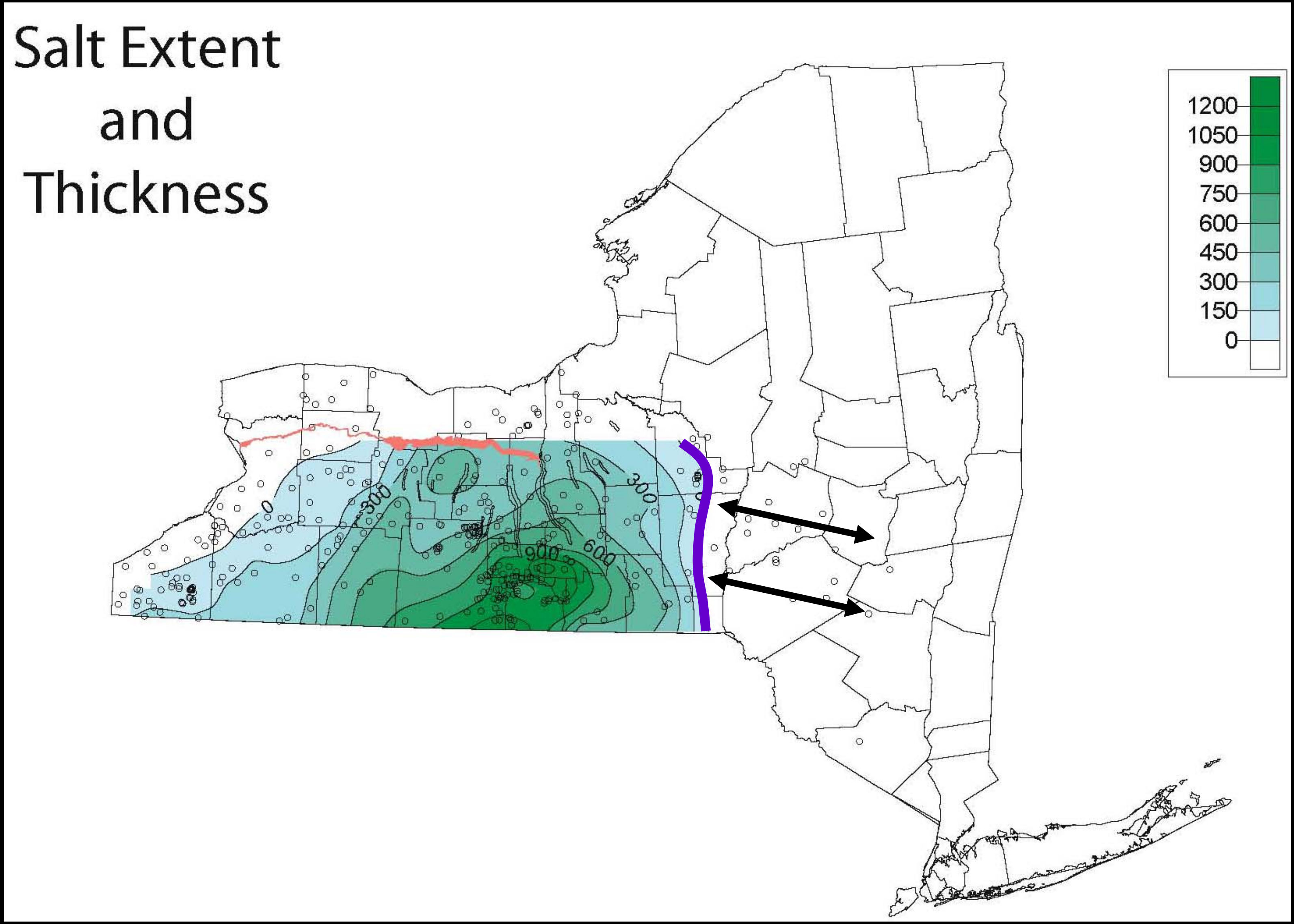
- In the eastern part of NY, there is abundant evidence of bedding plane slip and compressional tectonics in the Union Springs Member of the Marcellus
- This could have a significant impact on production and create heterogeneity within the most organic-rich part of the Marcellus in the east
- It is very clear at out main Marcellus outcrop tomorrow afternoon



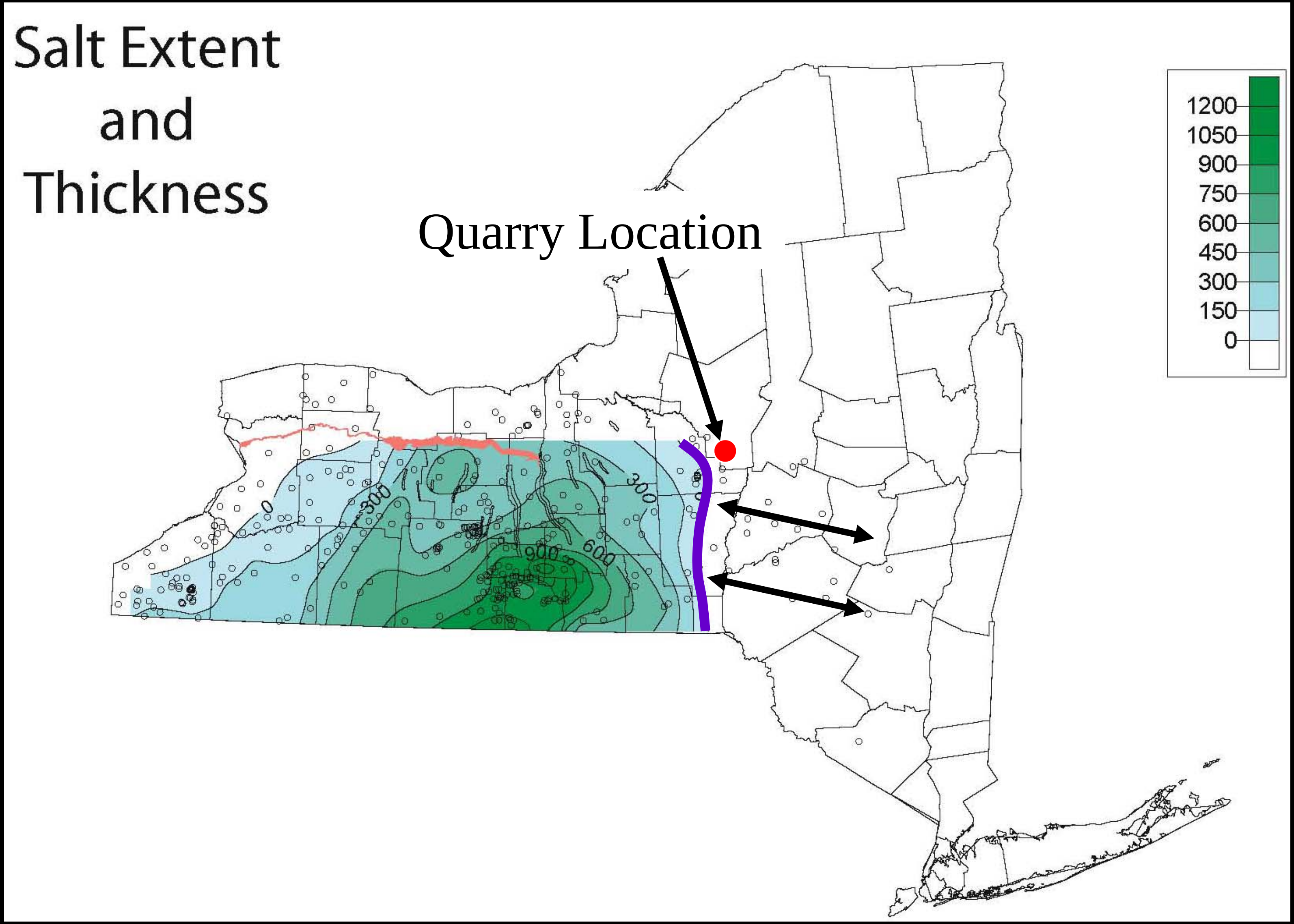
Bosworth, 1984 and others have discussed the structural features found in the Union Springs in eastern NY

Bosworth states that these features only occur east of where salt pinches out in NY

Bedding plane slip, duplexes, contorted bedding, intense fracturing, mineralization and more occur within most organic rich part of Marcellus



If Bosworth (1984) is correct compressional features may occur from pinchout of salt to outcrop belt in east



If Bosworth (1984) is correct compressional features may occur from pinchout of salt to outcrop belt in east

Slickensides formed on bedding plane in lower Union Springs – these were oriented N-S

Some of Union Springs looks like coal due to tectonic movement

Significant compressional features

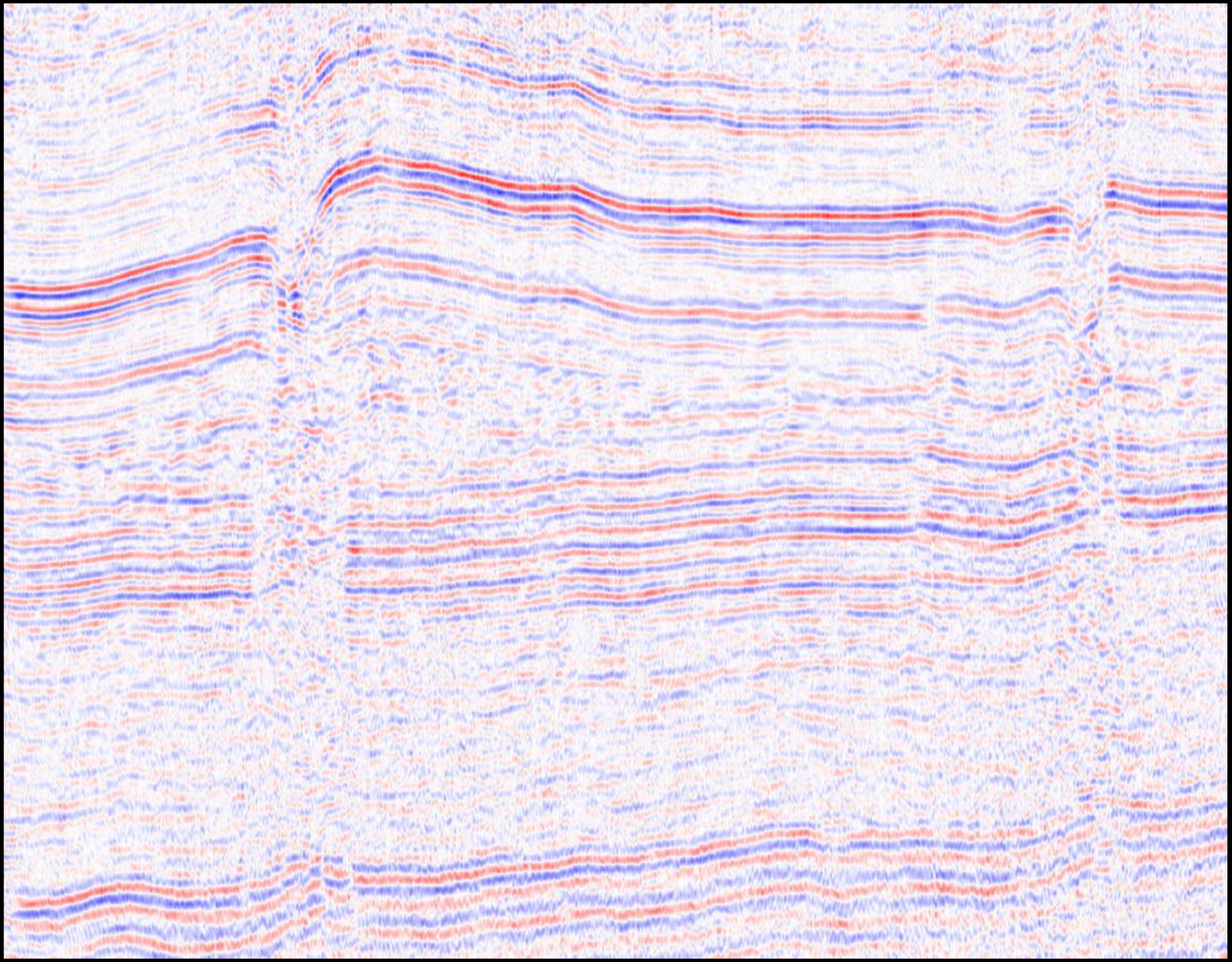
Significant compressional features leading to some fracturing

And mineralization – saddle dolomite and calcite from fracture fill

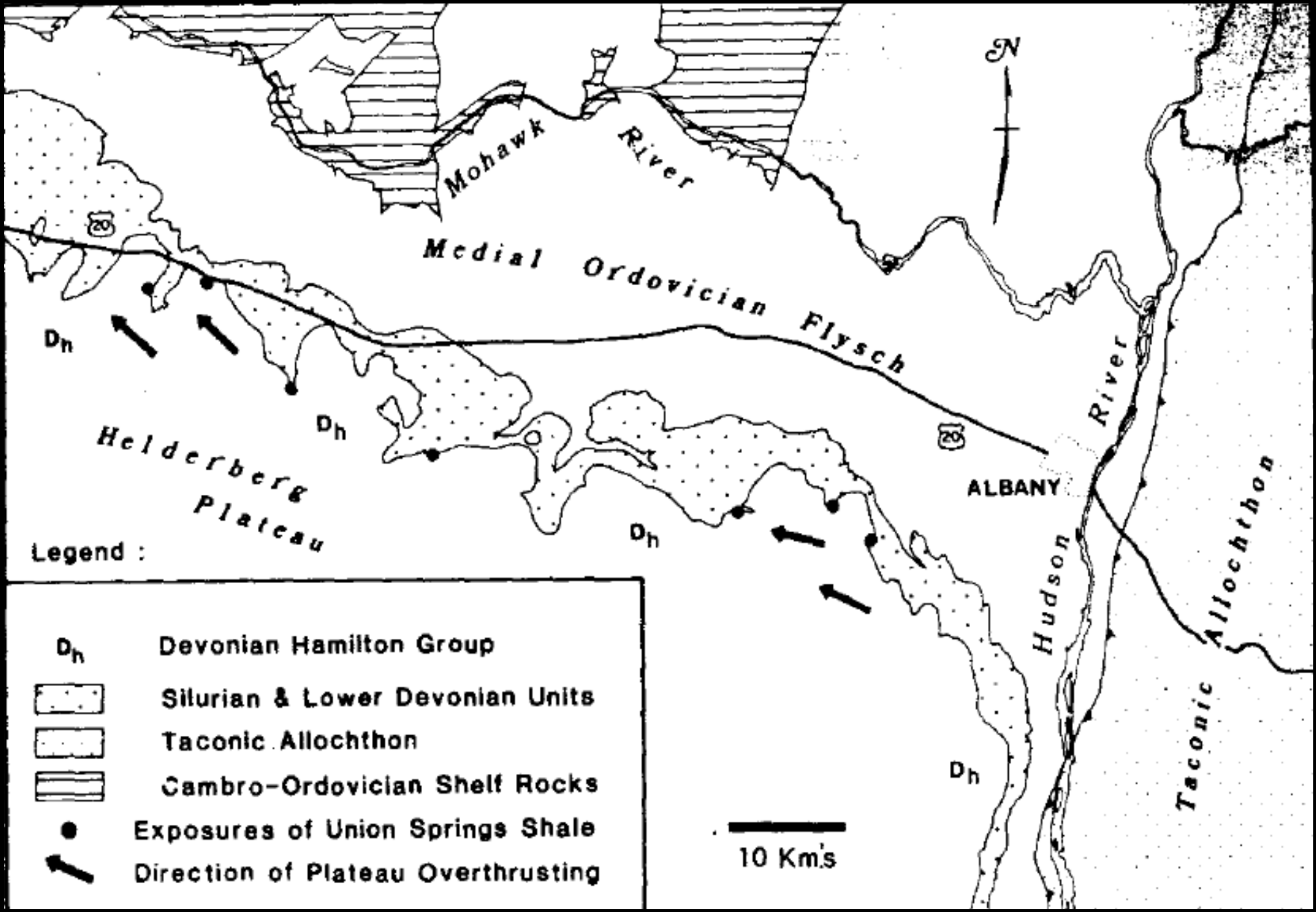
Tectonized beds thicken and thin throughout Union Springs

Tectonized bed truncated in Union Springs

Anticline formed due to slip on salt

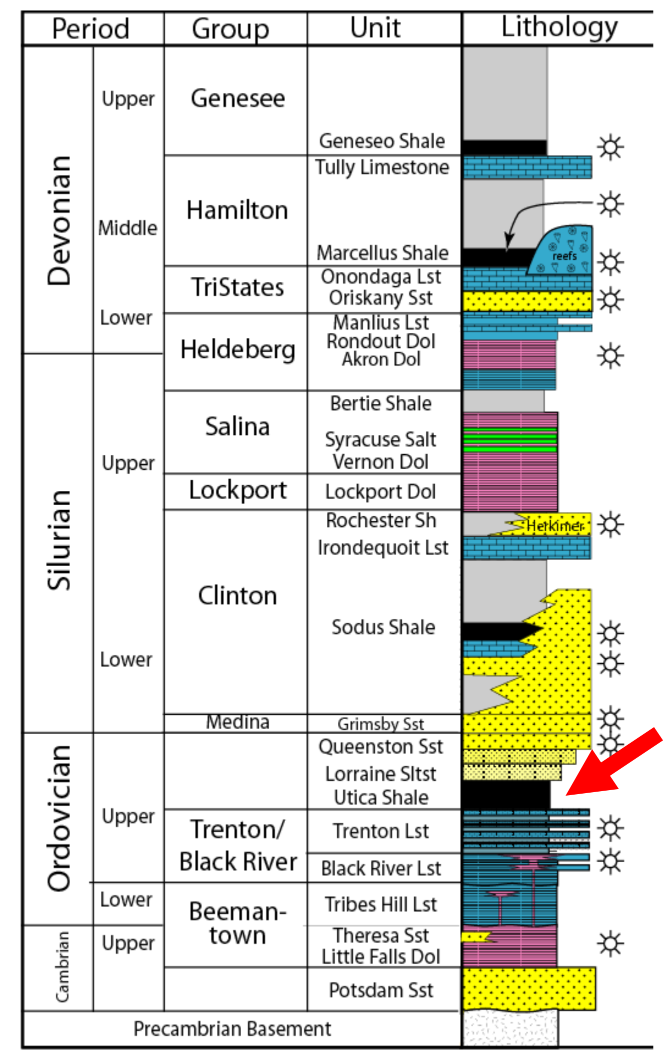


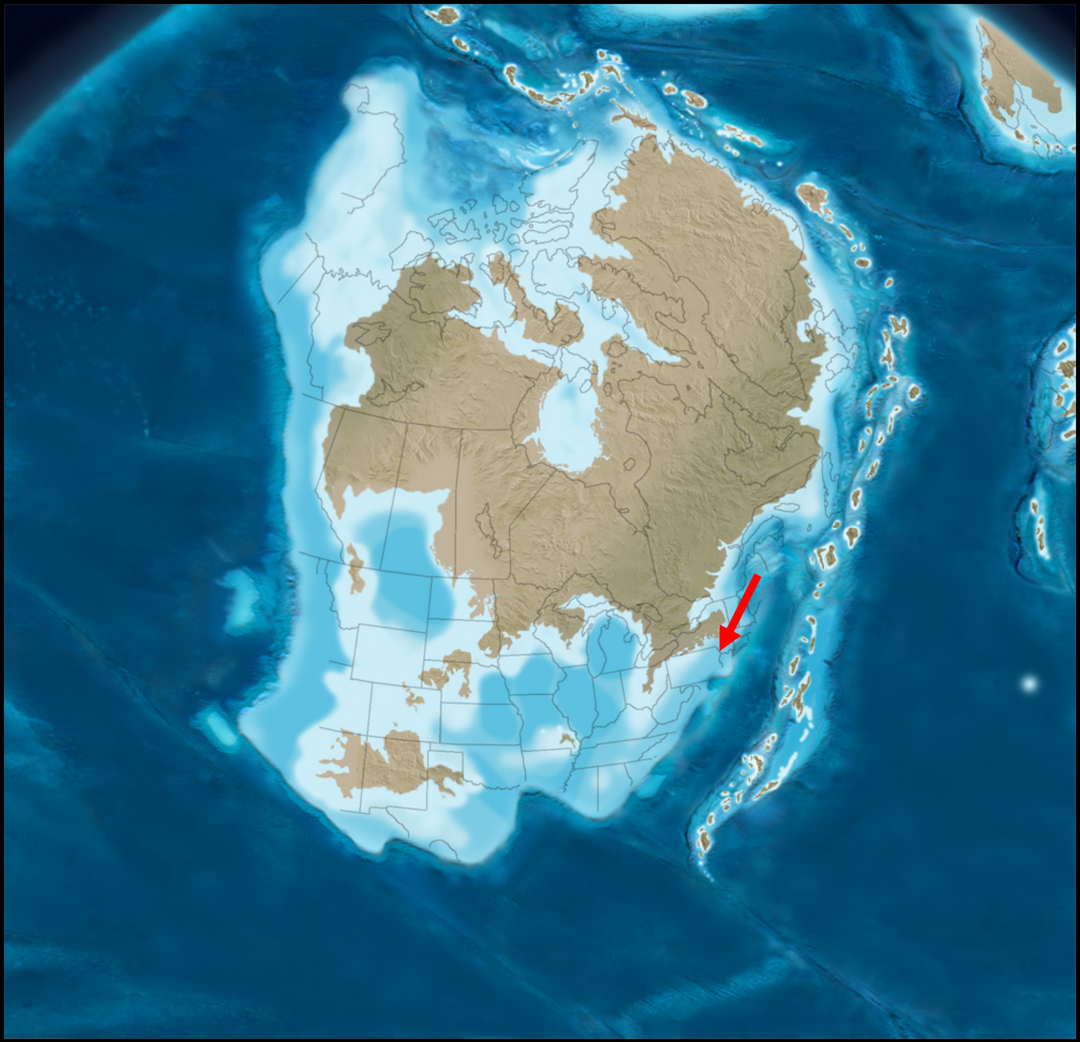
Detachement zone interpreted to jump from salt in west to Union Springs in east – significant amount of movement to make these structures



Bosworth interpreted main direction of slip to be WNW and the timing to be late Acadian or Alleghenian - should it be N-S?

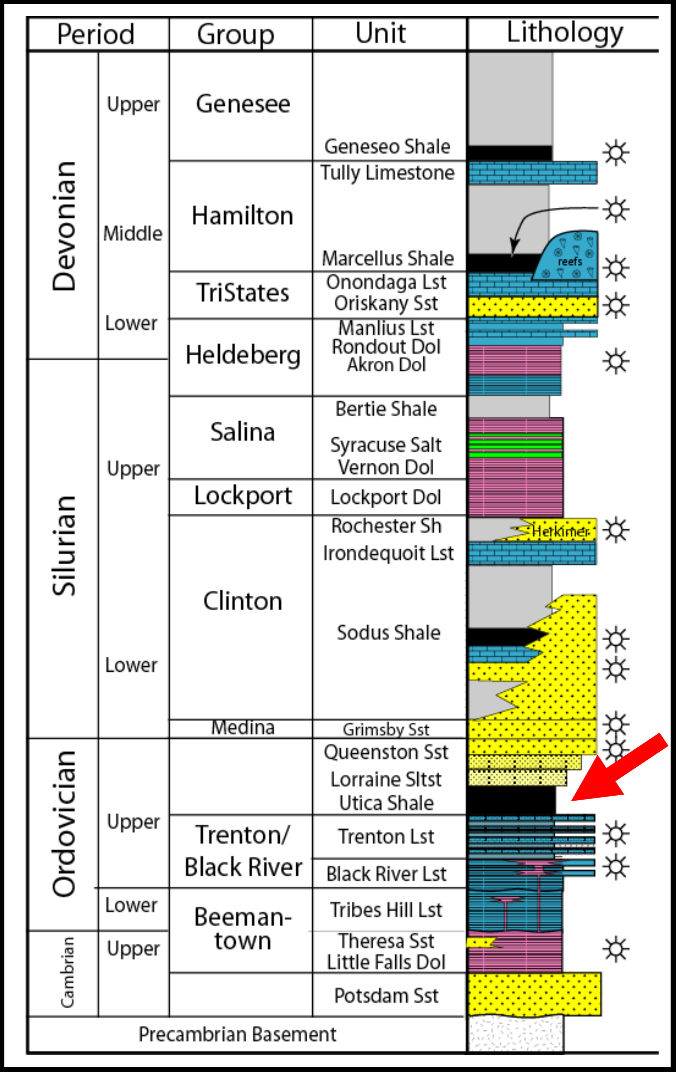
Ordovician Utica Shale





Utica Shale deposited during Ordovician Taconic Orogeny

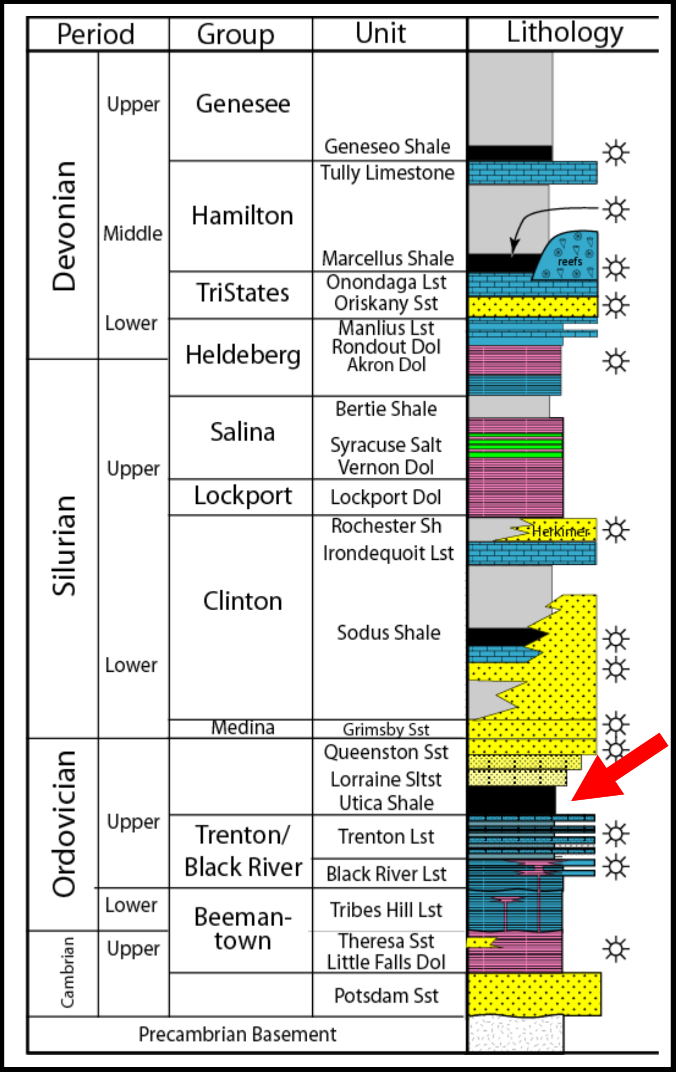
Ordovician Utica Shale

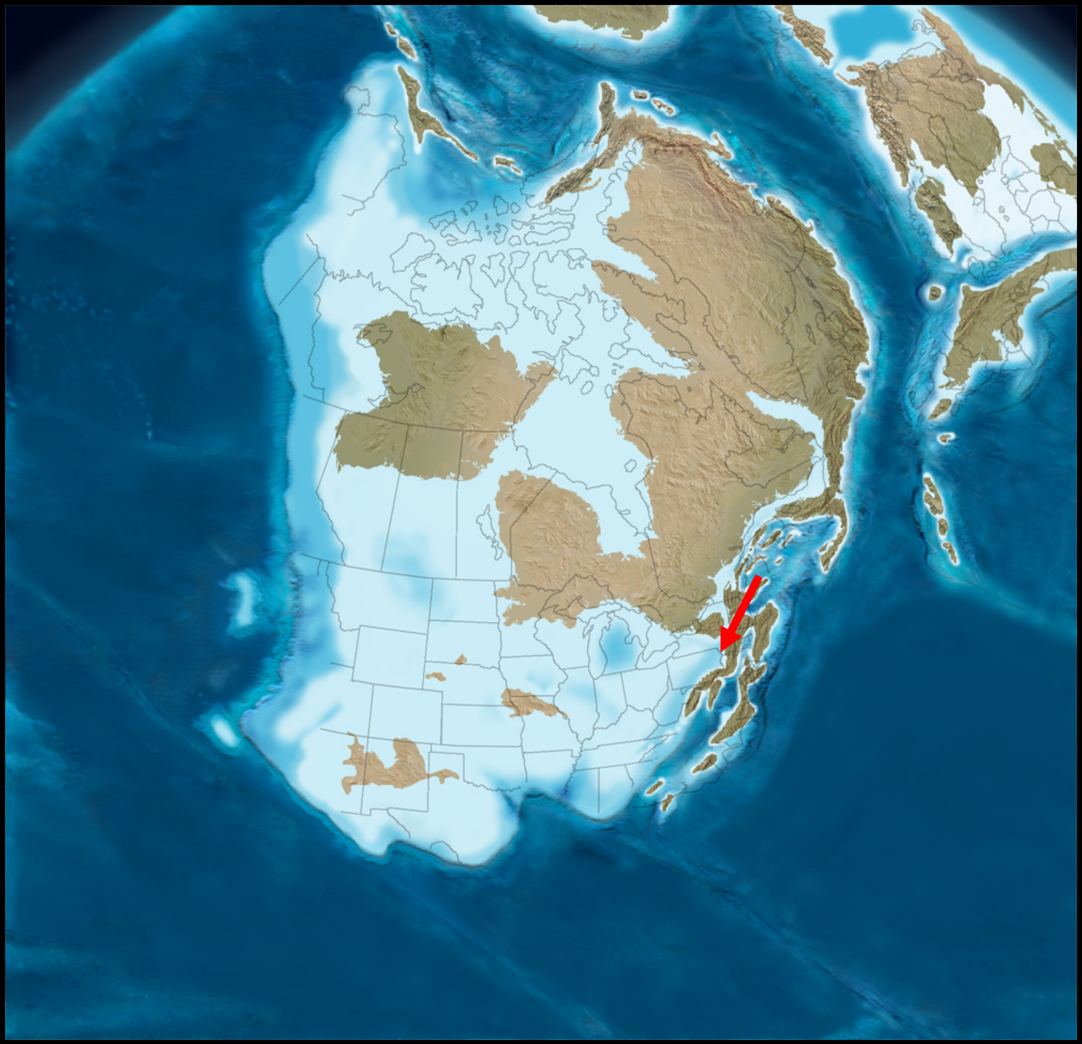


Period		Group	Unit	Lithology
Devonian	Upper	Genesee	Geneseo Shale	
	Middle	Hamilton	Tully Limestone Marcellus Shale	reefs
		TriStates	Onondaga Lst Oriskany Sst	
	Lower	Heldeberg	Manlius Lst Rondout Dol Akron Dol	
Silurian	Upper	Salina	Bertie Shale Syracuse Salt Vernon Dol	
		Lockport	Lockport Dol	
	Lower	Clinton	Rochester Sh Irondequoit Lst Sodus Shale	Herkimer
		Medina	Grimsby Sst	
Ordovician	Upper		Queenston Sst Lorraine Sltst Utica Shale	
		Trenton/ Black River	Trenton Lst Black River Lst	
	Lower	Beeman-town	Tribes Hill Lst	
Cambrian	Upper		Theresa Sst Little Falls Dol	
			Potsdam Sst	
Precambrian Basement				

Utica Shale deposited during Ordovician Taconic Orogeny

Ordovician Utica Shale





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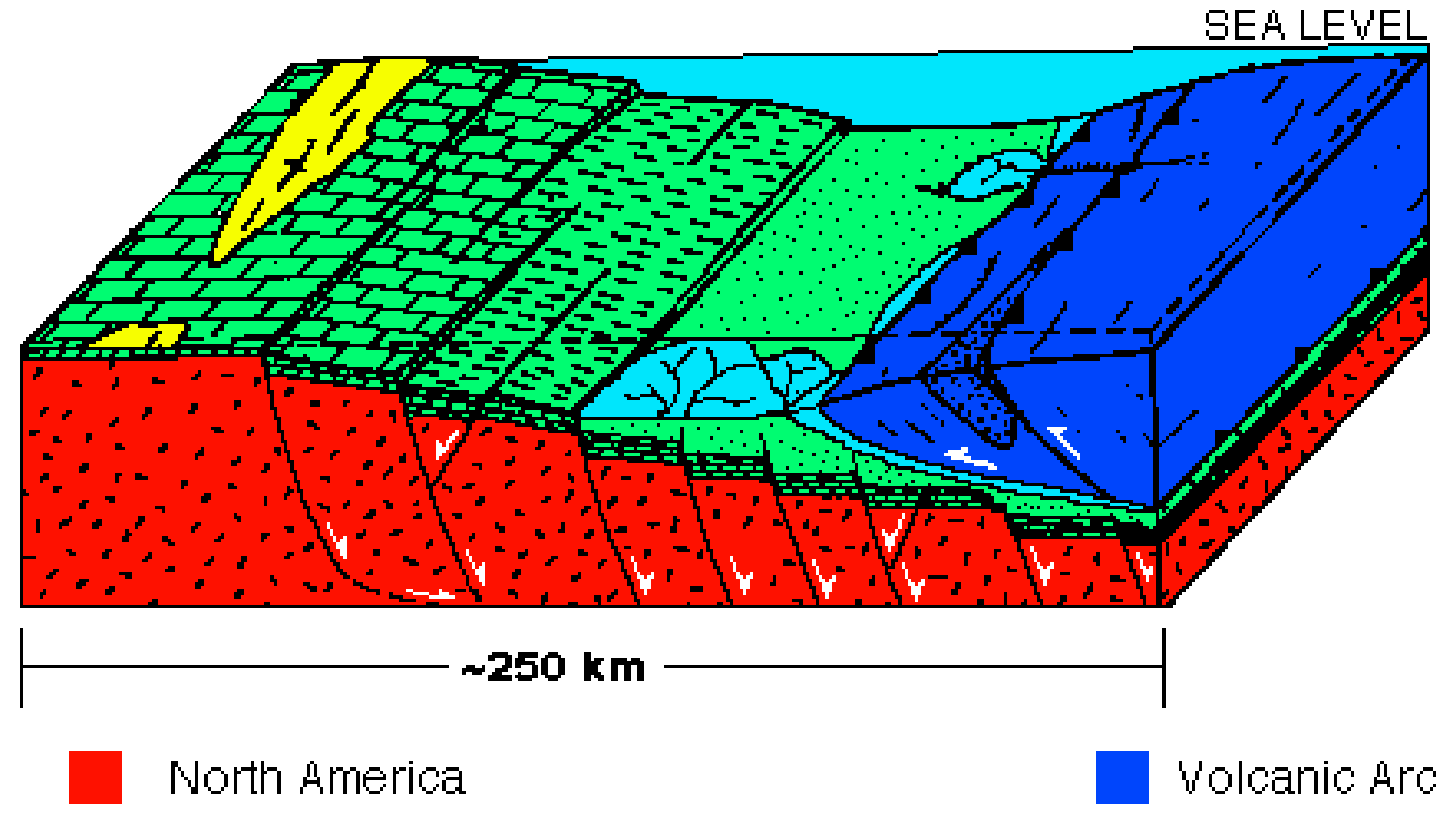
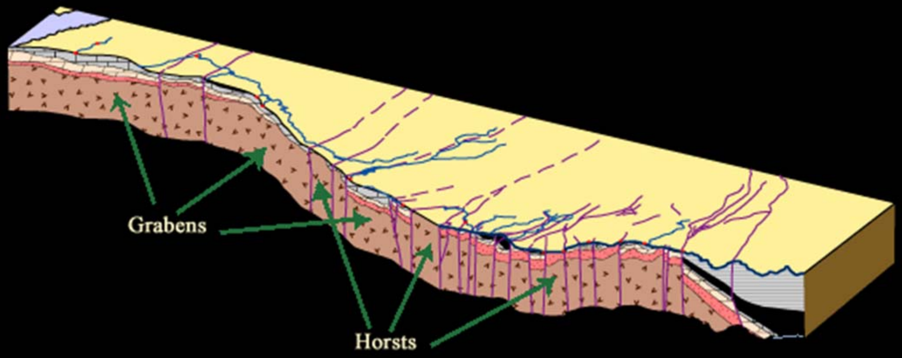
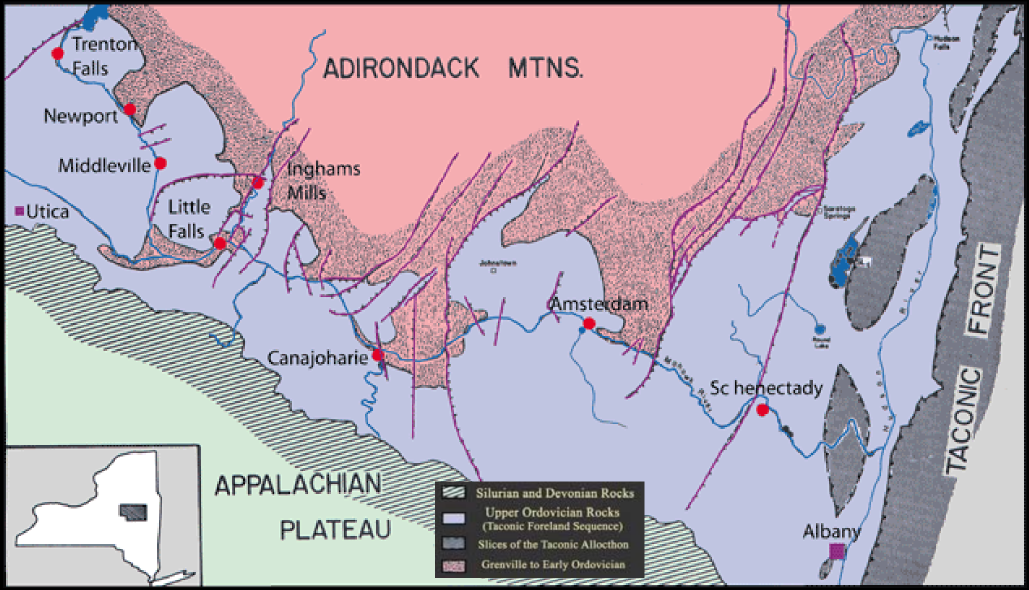


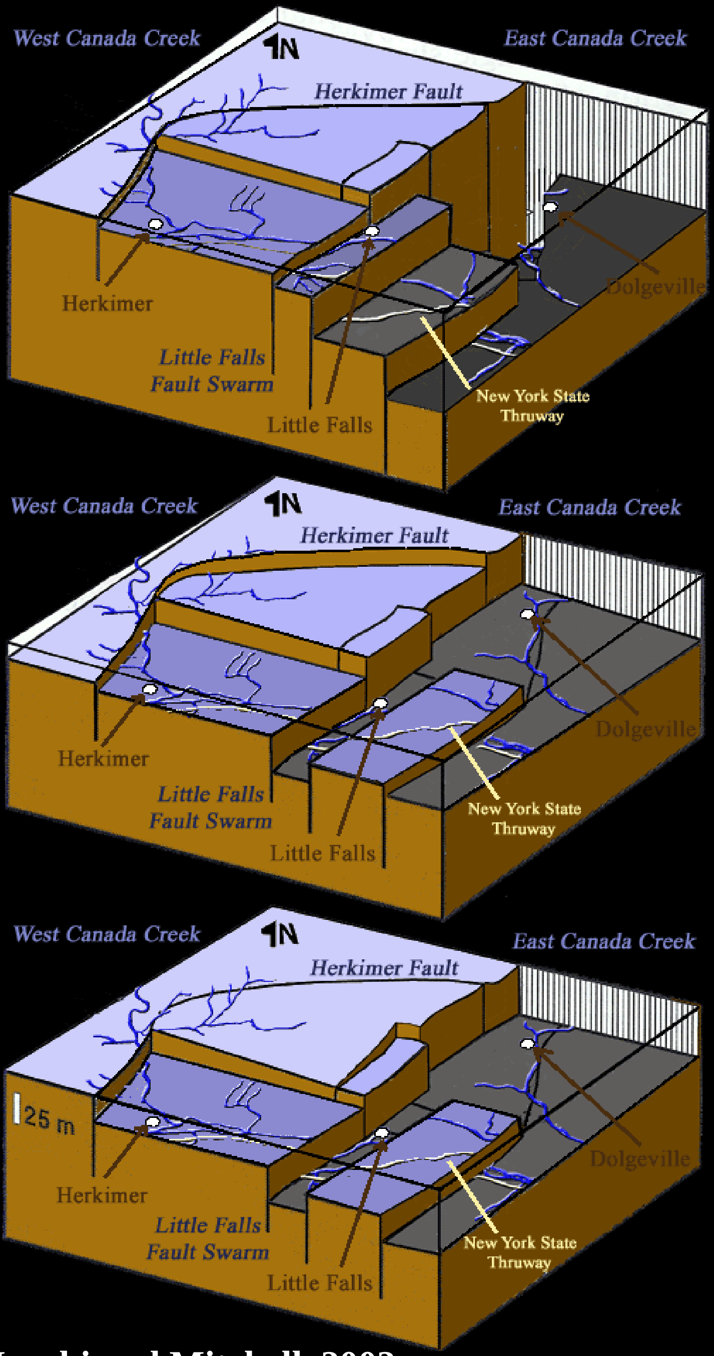
Bradley and Kidd (1991) model for foreland basin response to Taconic Orogeny – During Trenton-Utica deposition, this high breaks down and there is very common normal faulting affecting depositional trends –Jacobi and Mitchell, Brett and Baird and others have long recognized the impact of these faults on sedimentation but it is hard to do this with logs only



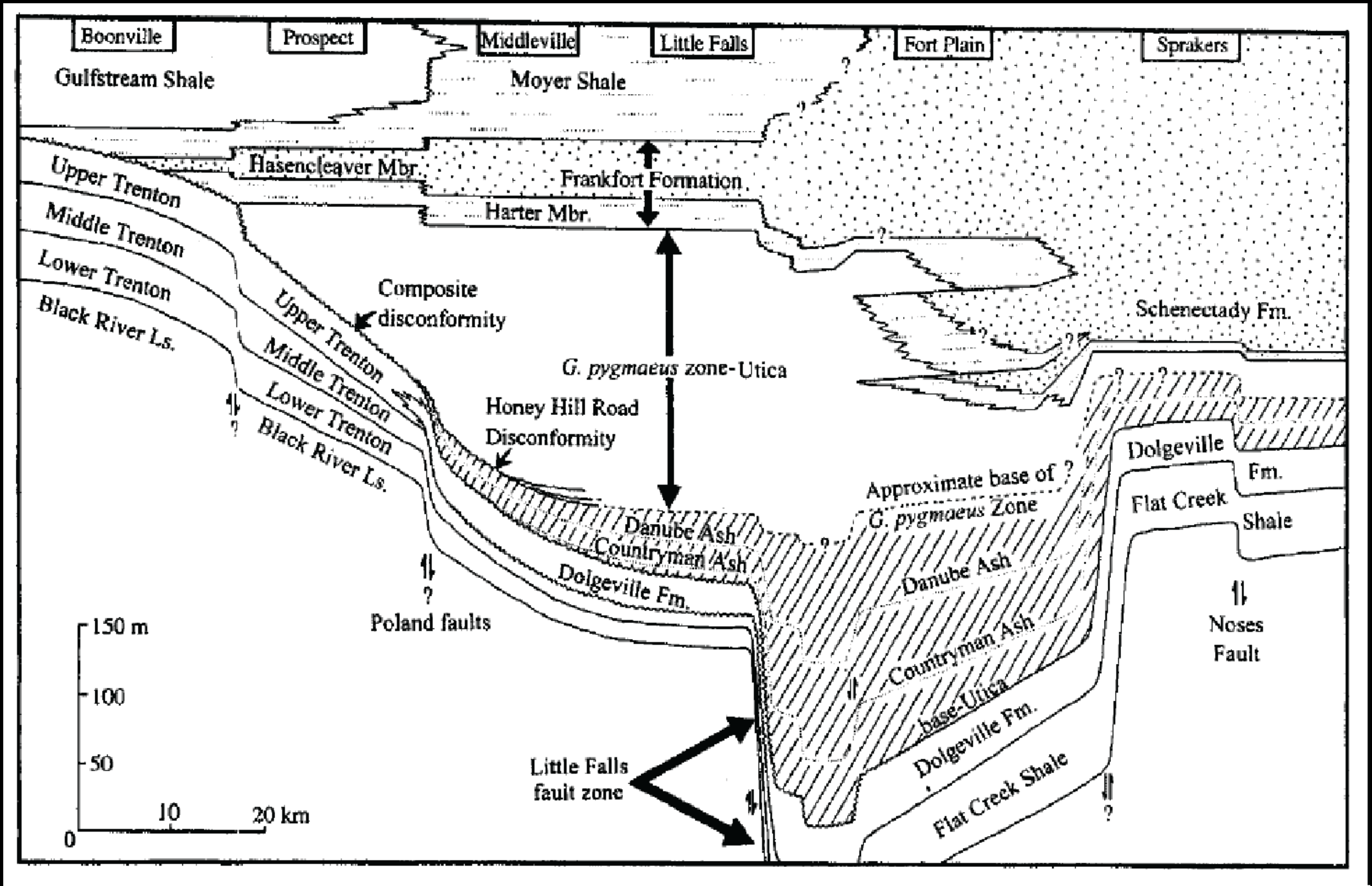
From Trenton Falls Website



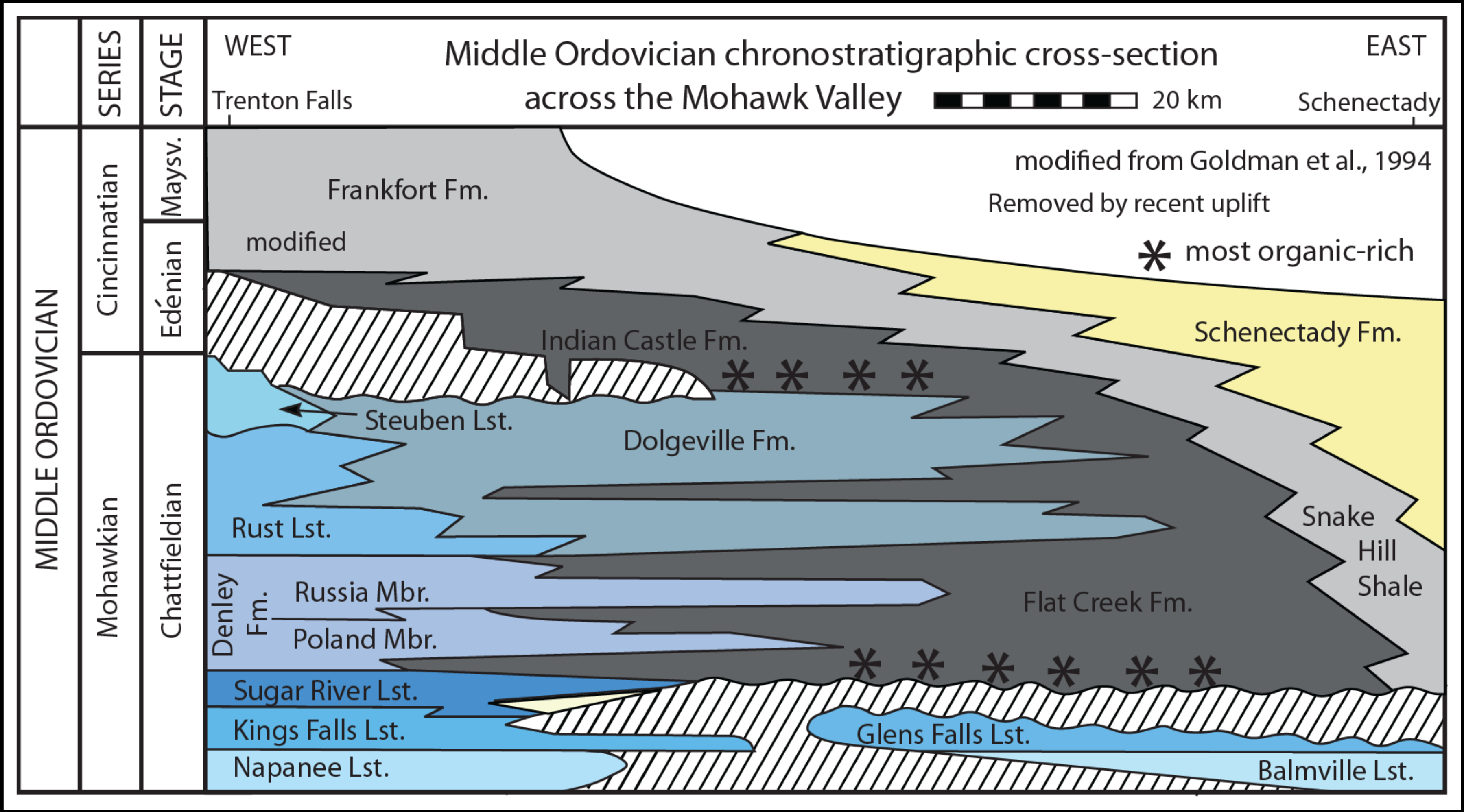
The Mohawk Valley has numerous normal faults that were active during deposition of the Utica, some with thousands of feet of throw, others with less



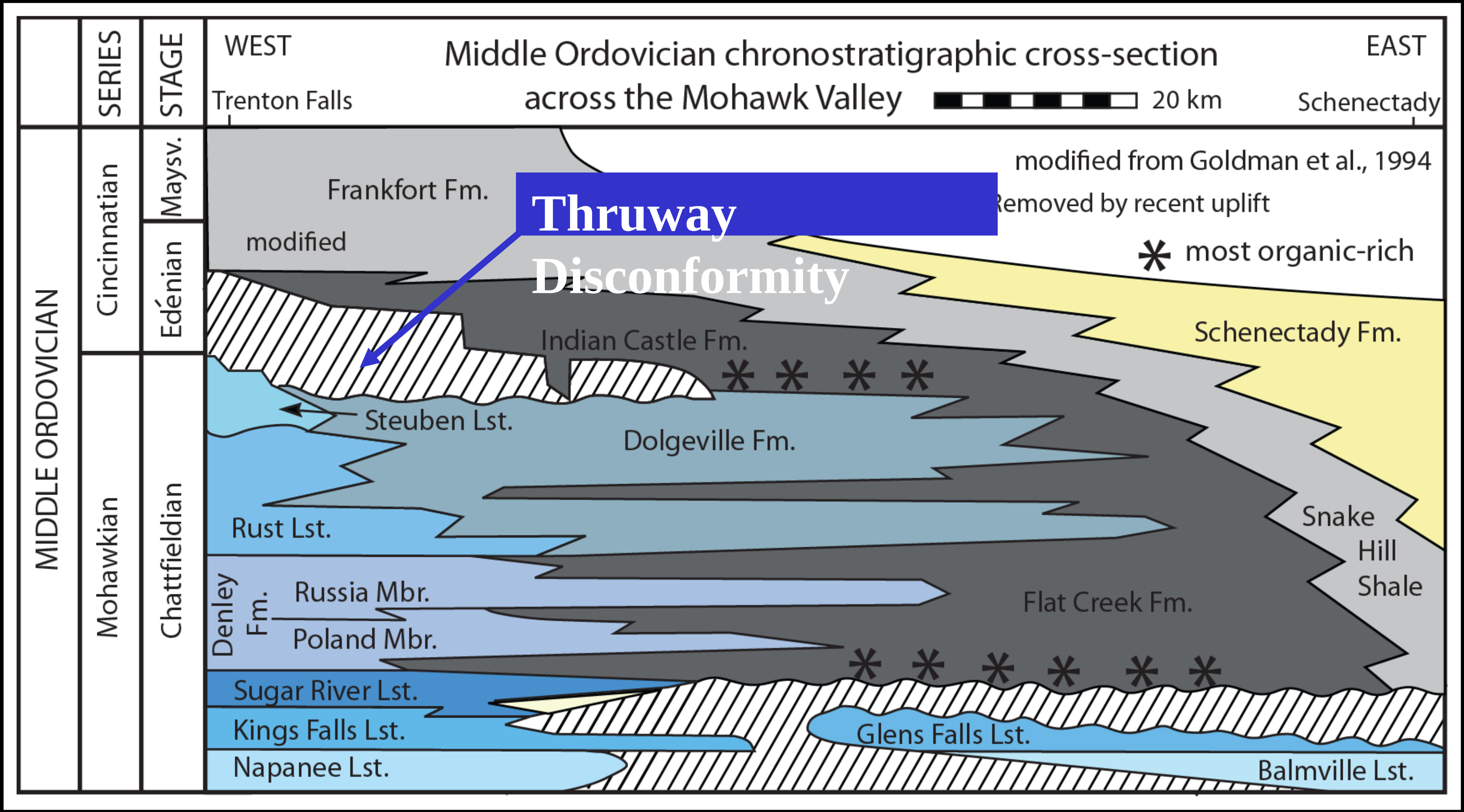
Jacobi and Mitchell, 2002



The organic rich Utica thickens into some of these grabens – this could have a major implication for where the Utica will be economic (from Baird and Brett, 2002)



Outcrop Stratigraphy from Mohawk Valley – Utica consists of Flat Creek (which is time-equivalent to Trenton Limestone) and Indian Castle Shales (which postdates Trenton) – the beds with the highest TOC immediately overlie or are laterally-equivalent to unconformities



Thruway Disconformity

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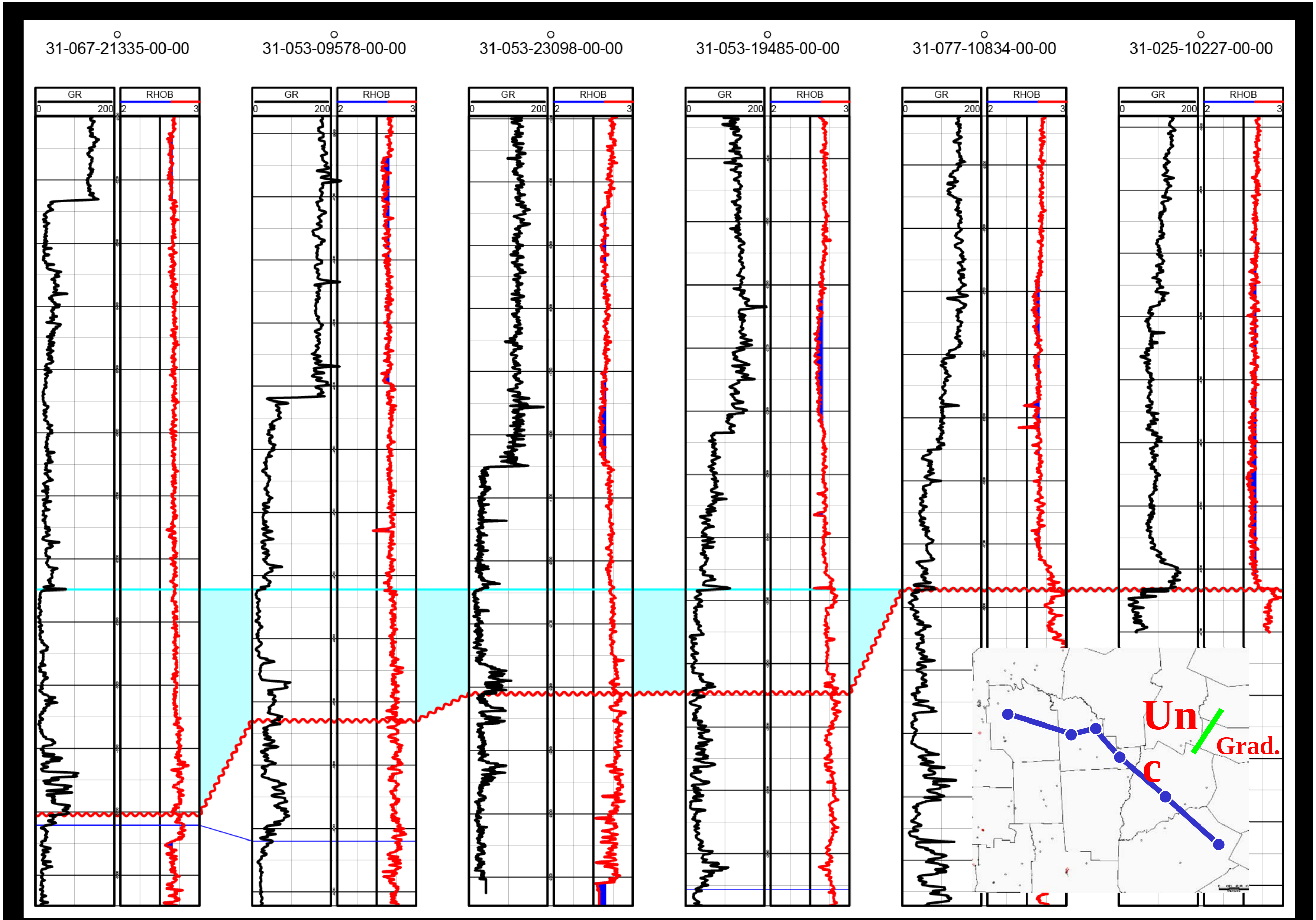
Indian Castle Black Shale (little carbonate, TOC (1-3%)

Thruway Disconformity (up to several million yrs missing) →

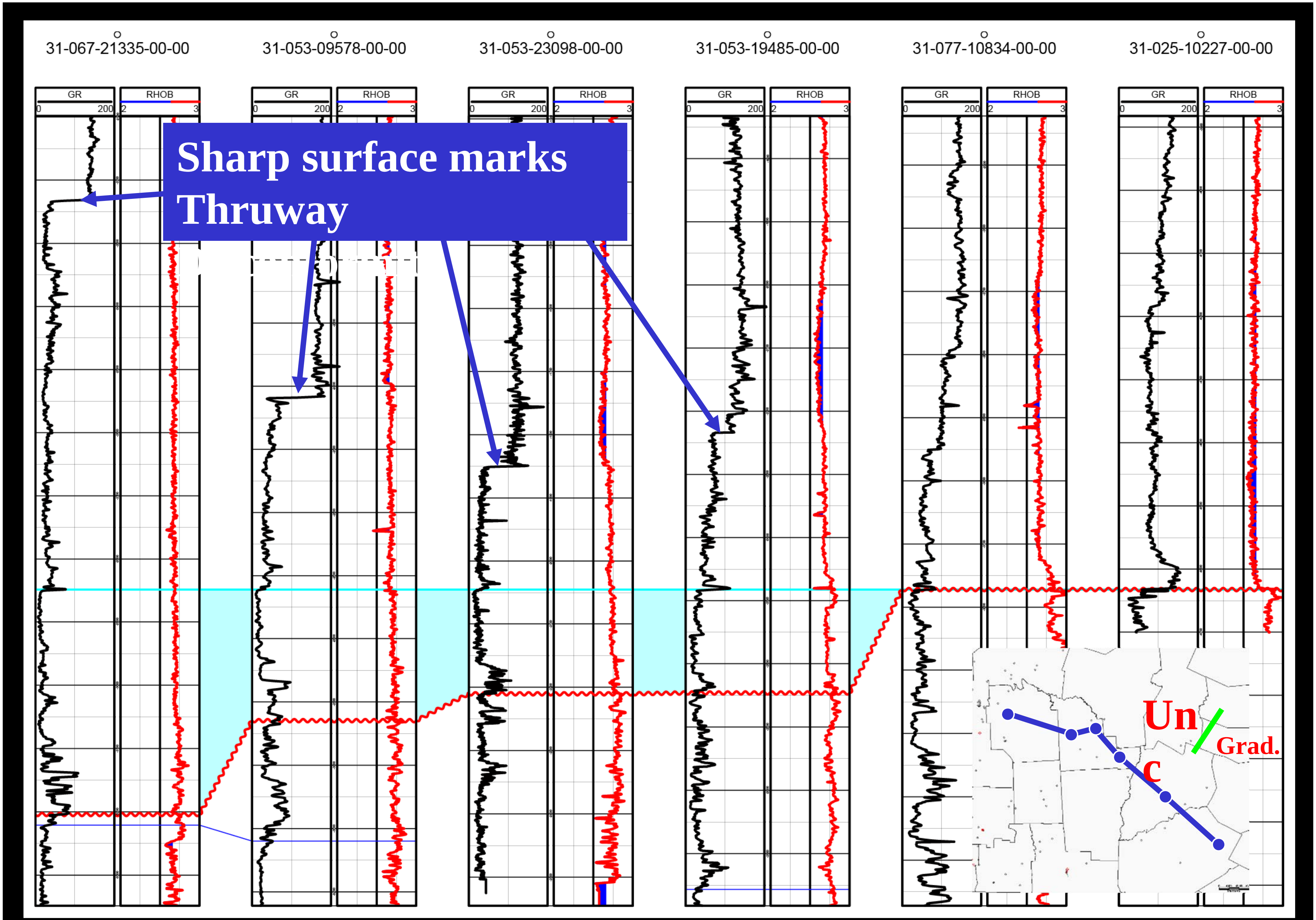
Dolgeville interbedded limestone and black shale (shales have up to 3% TOC)

Thruway Disconformity

- Baird and Brett (2002) - drowning unconformity – deep water throughout but non-deposition for up to several million years
- Jacobi and Mitchell (2002) – Thruway disconformity is a slide scar where upper Trenton slid into trough
- This work – subaerial unconformity modified by transgression in anoxic water where there may have been some corrosion

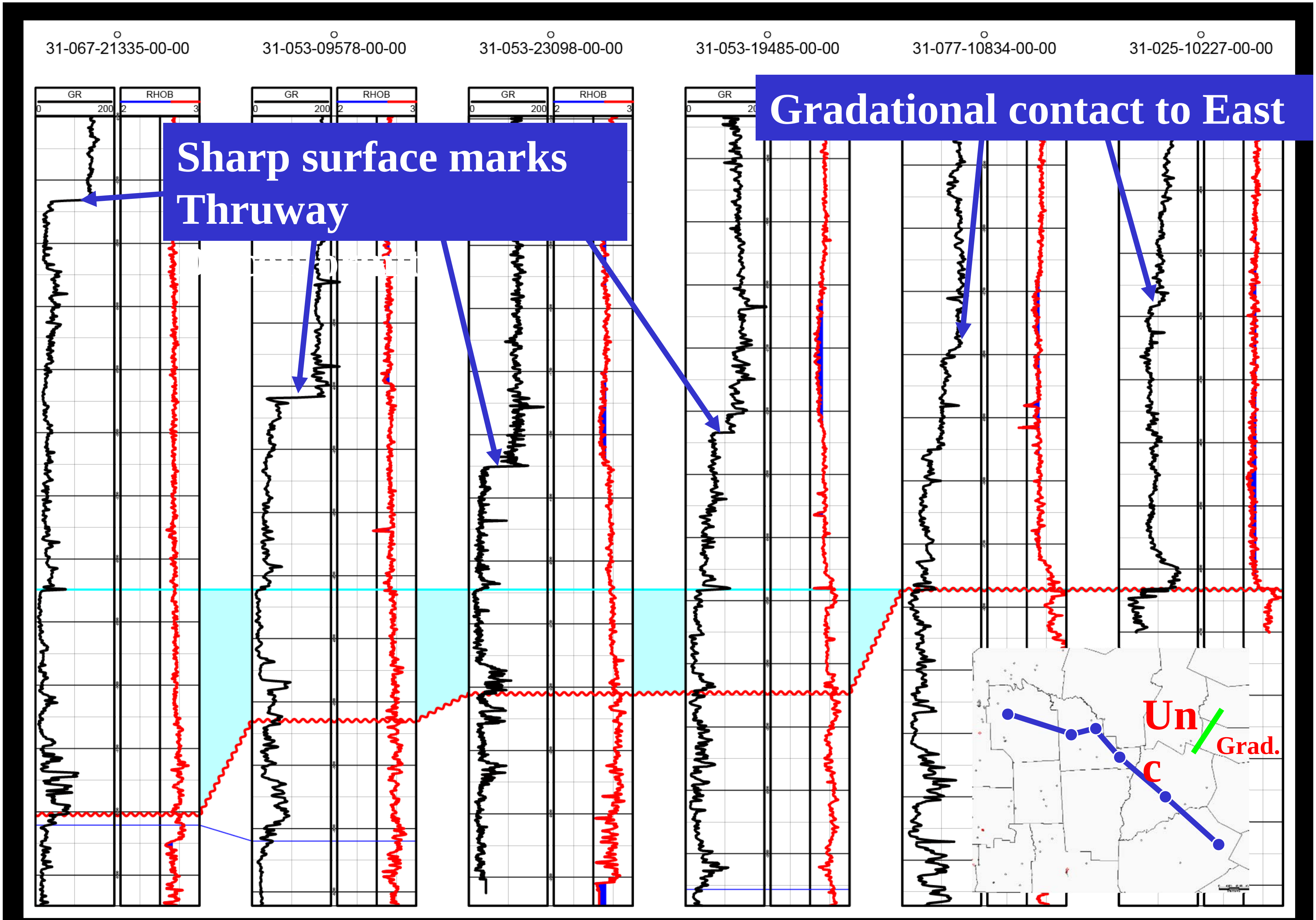


Unconformity cuts down farther in the section to the east



Sharp surface marks Thruway

Unconformity cuts down farther in the section to the east



Sharp surface marks Thruway

Gradational contact to East

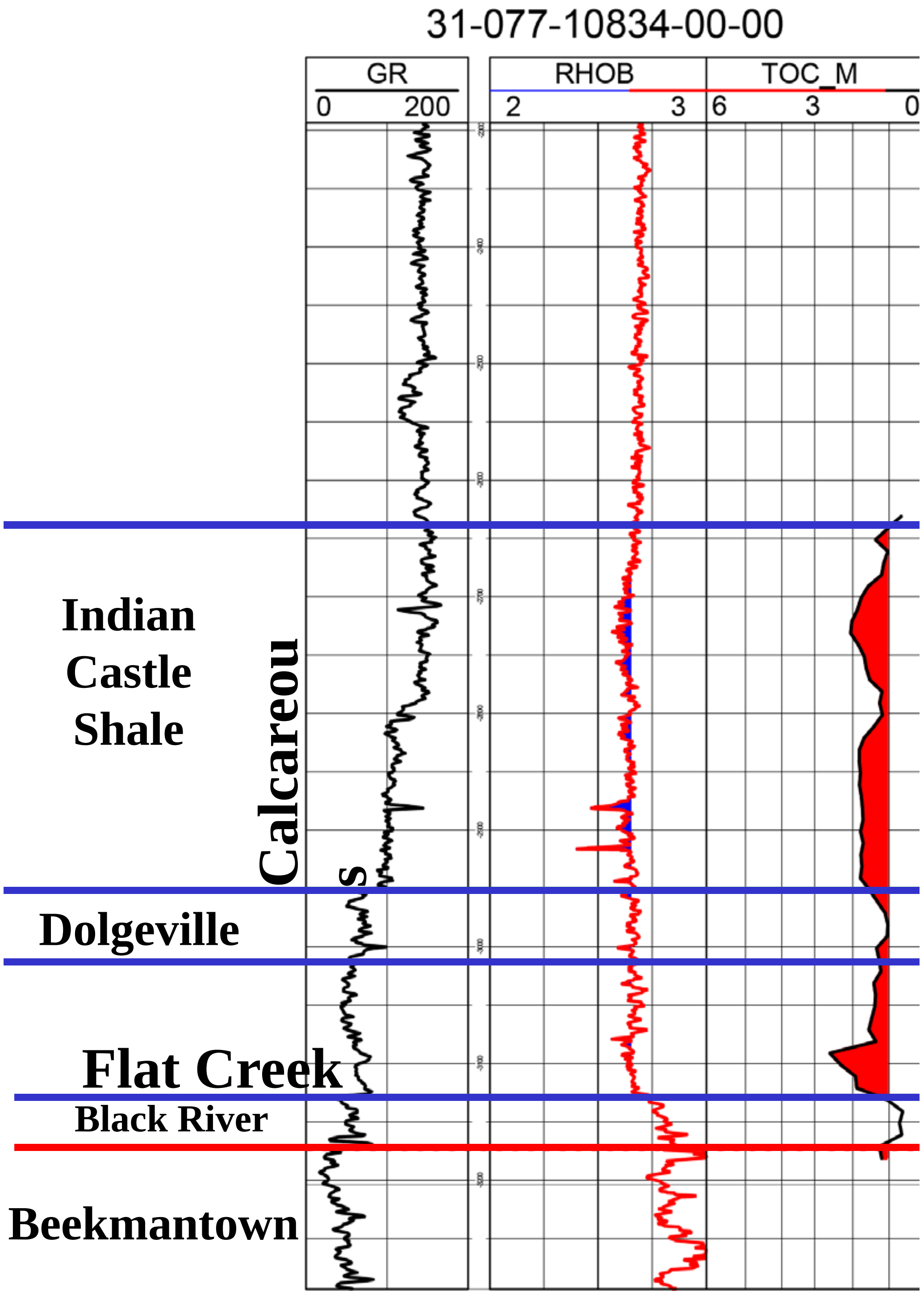
Unconformity cuts down farther in the section to the east

Logs from well with high-TOC in Utica Shale – TOC logs shaded red where TOC>1% (TOC from cuttings analysis)

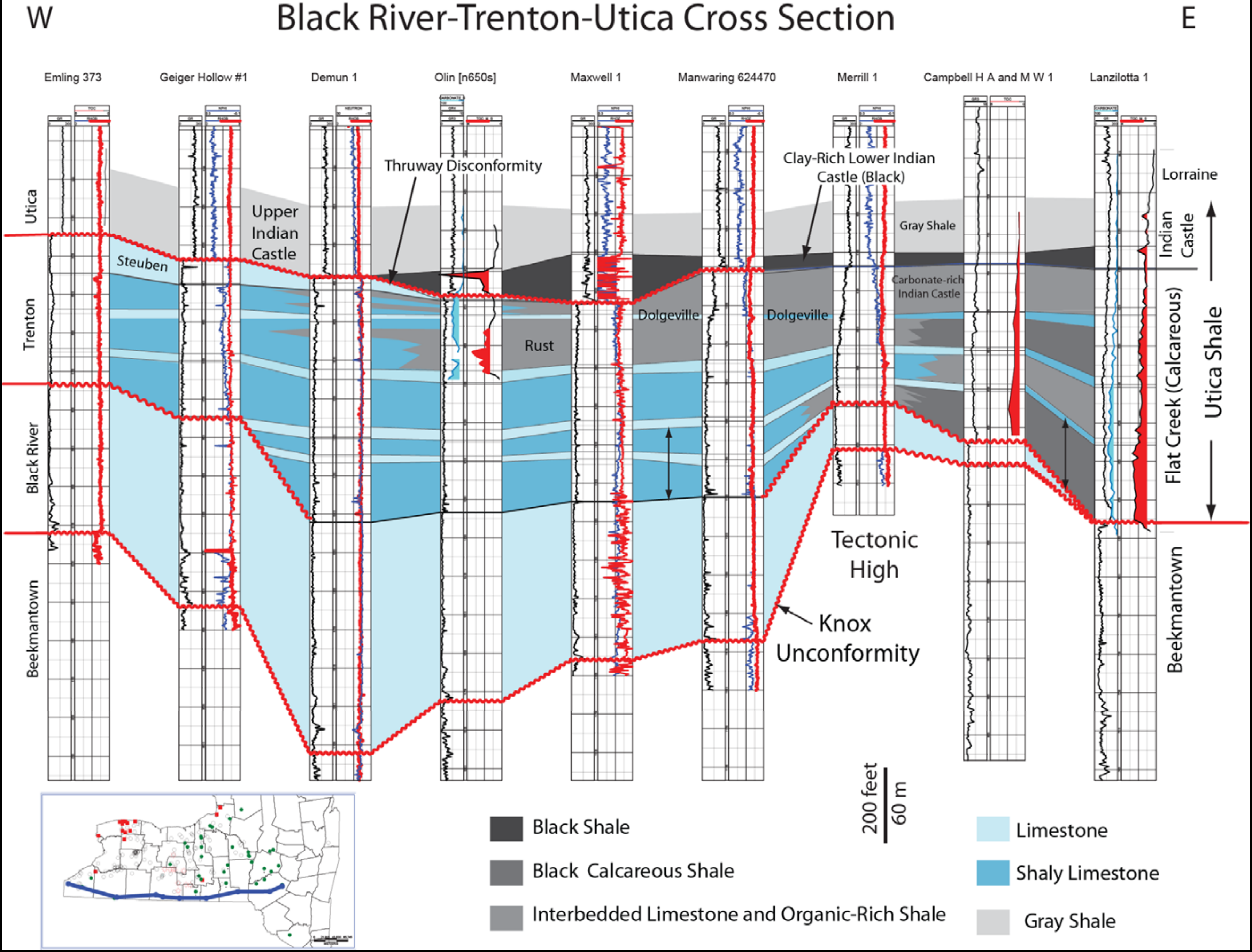
Density log tracks TOC – lower values = higher TOC

Utica is composed of a low Organic regional shale at top and the relatively high-organic Indian Castle Shale

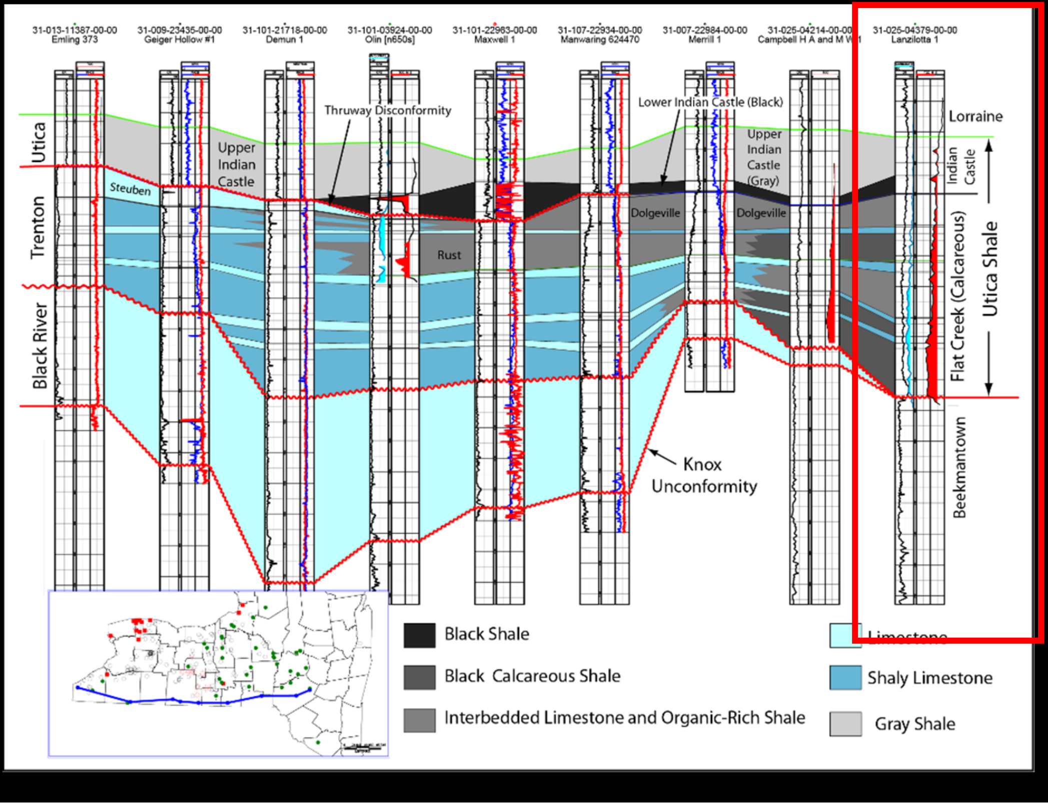
The Dolgeville and Flat Creek are time-equivalent to Trenton and also have relatively high TOC

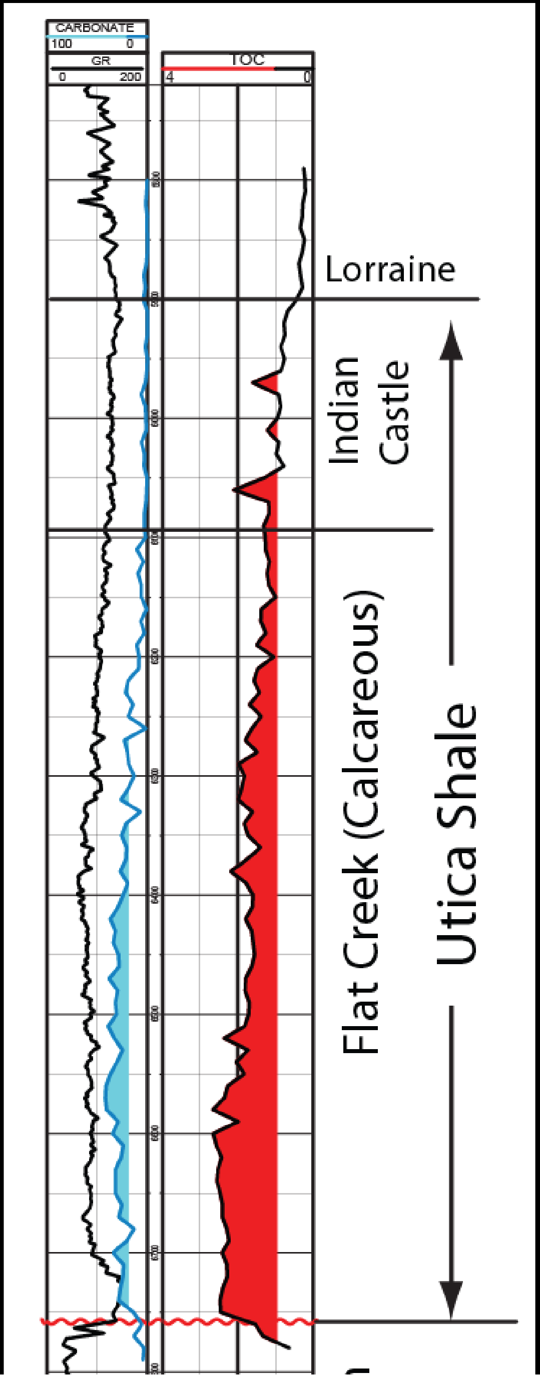


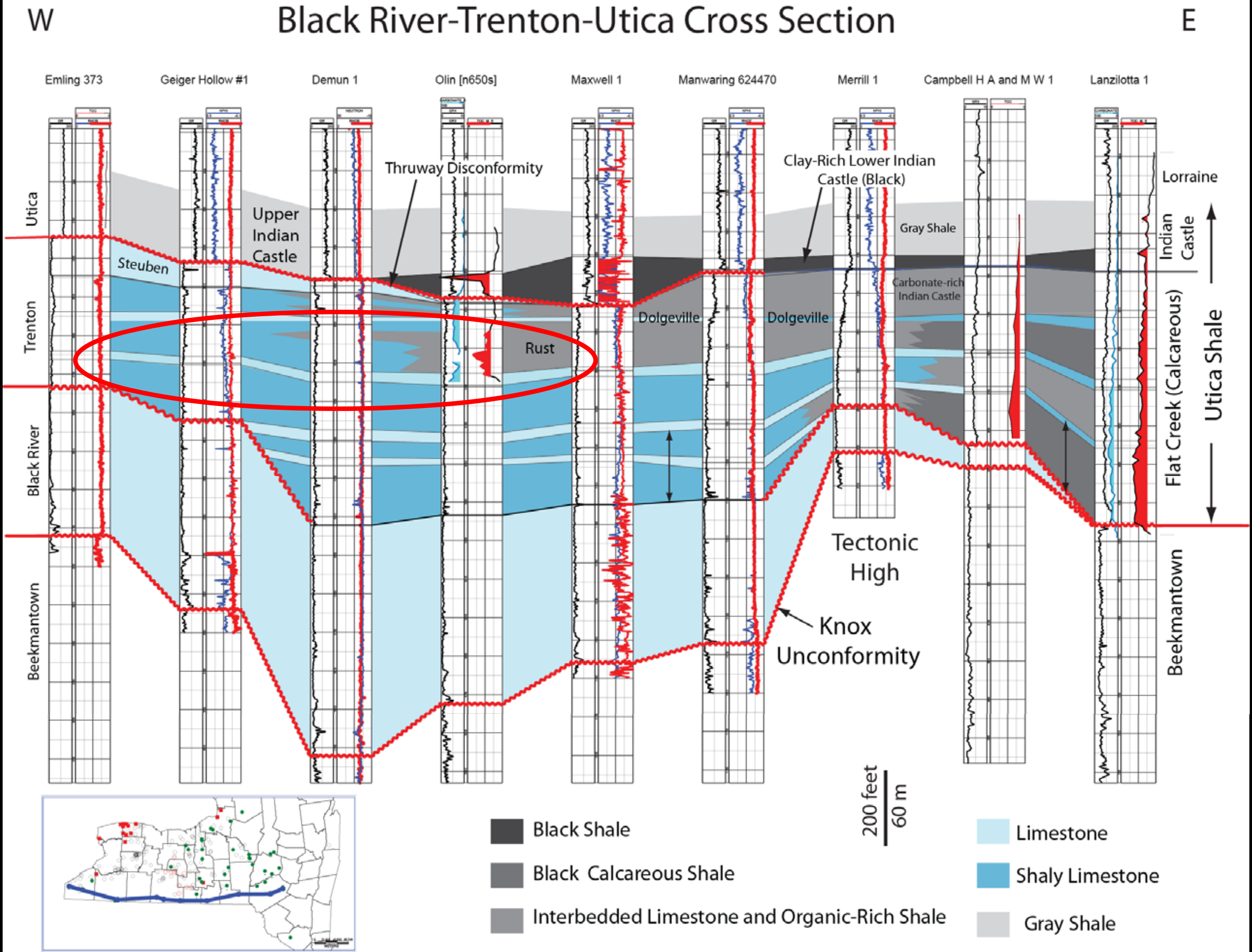
Black River-Trenton-Utica Cross Section



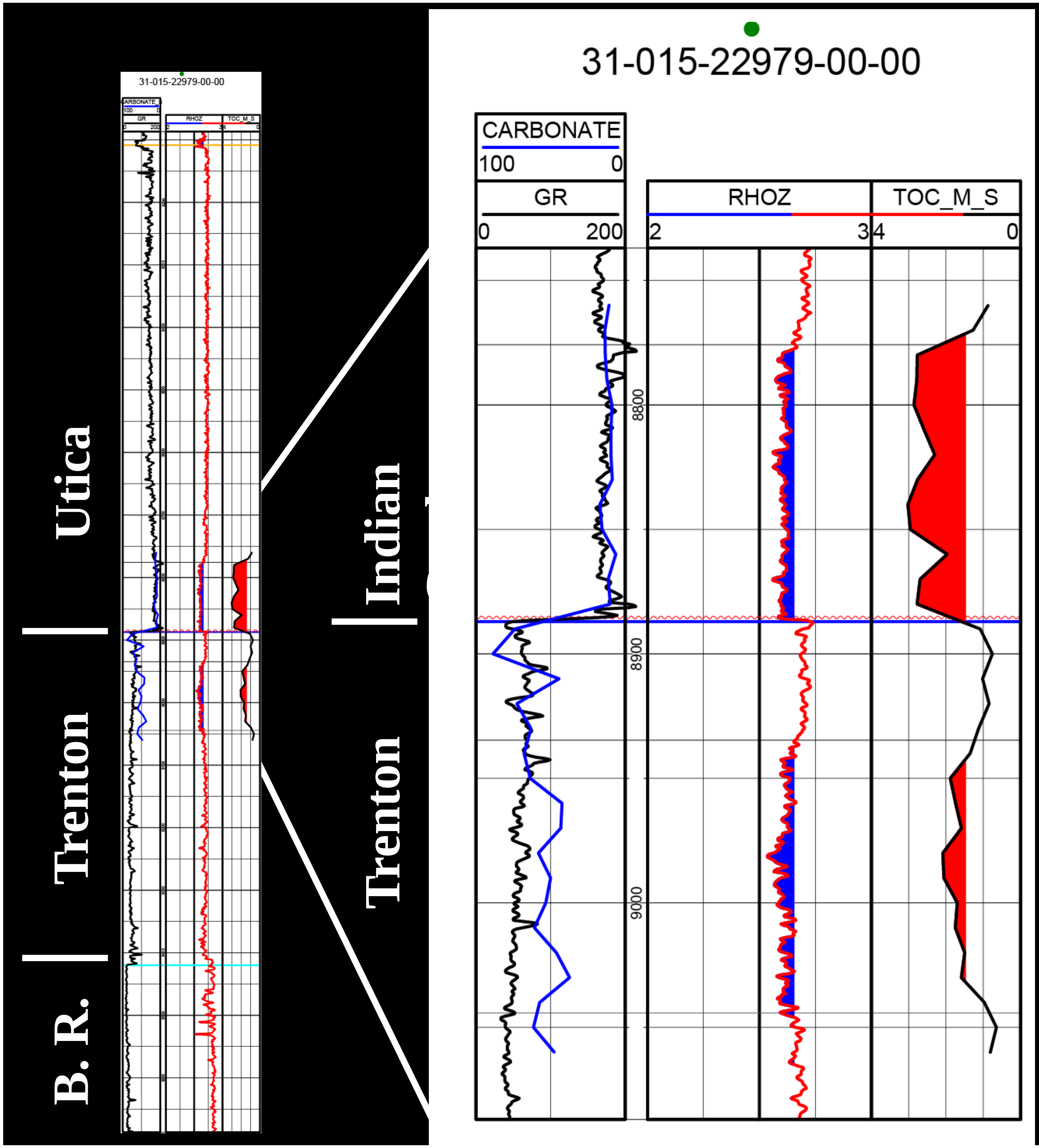
Wells to east have Flat Creek Shale which is a calcareous shale with relatively high carbonate content (25-50% bit also pretty high TOC of 1.5-3.5%







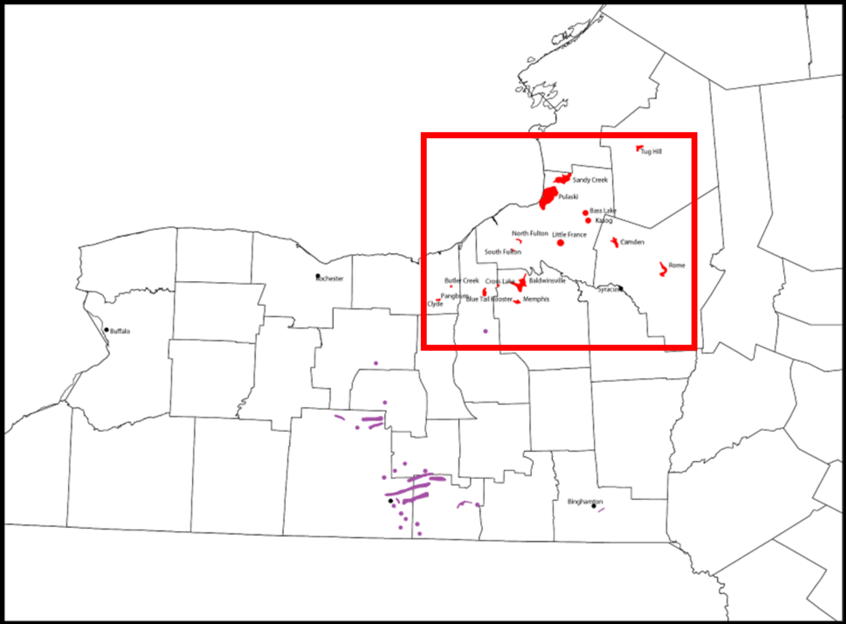
Organic-rich interbeds extend into Trenton Group Limestones – Trenton Limestone Fields occur where Steuben Limestone seals underlying organic rich

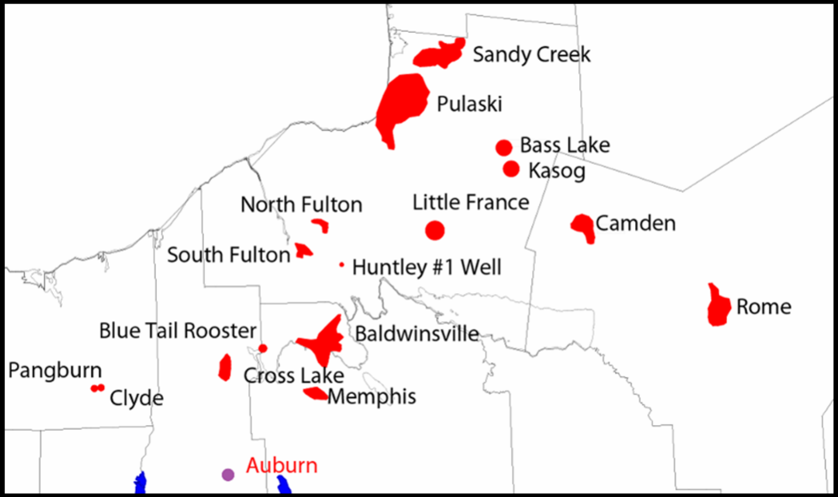


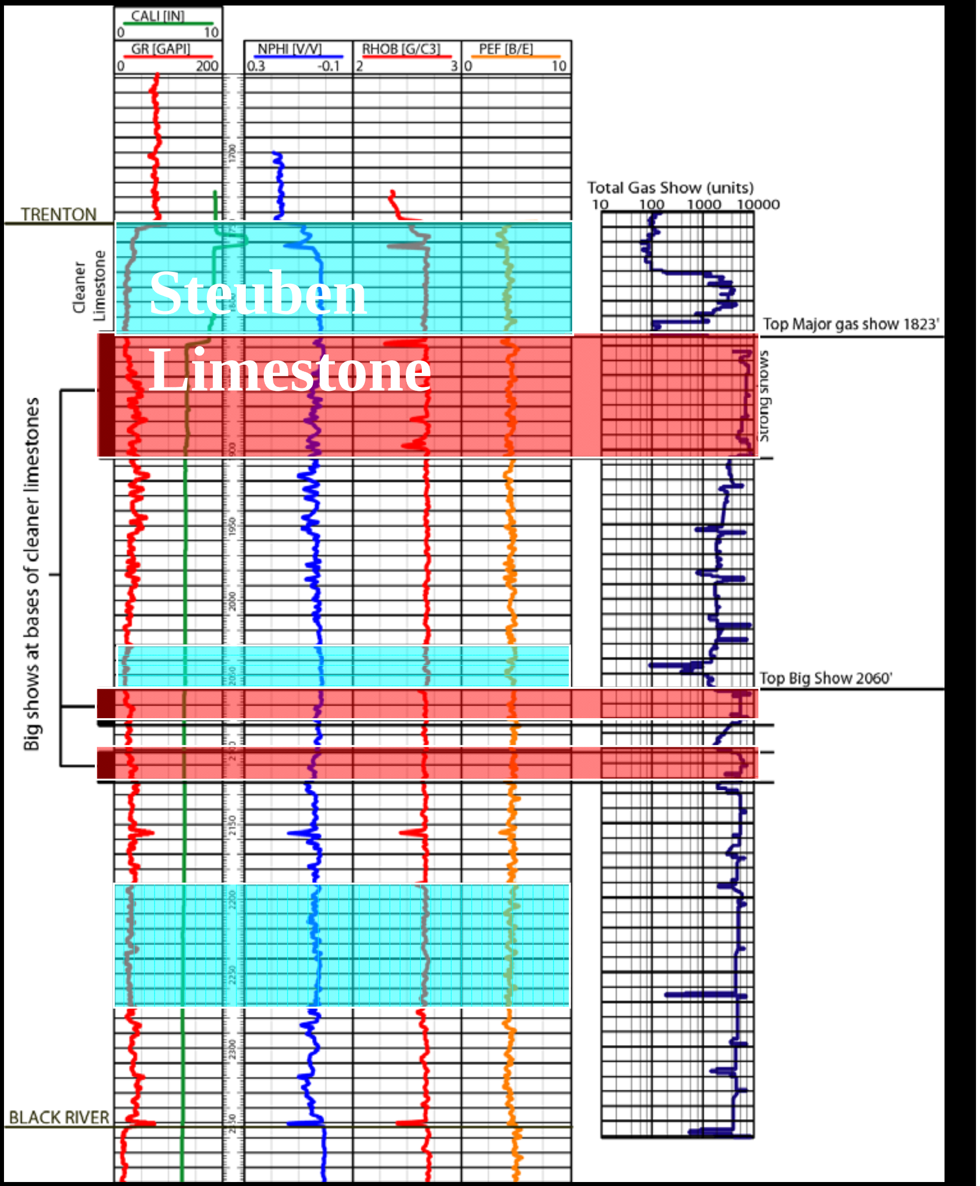
TOC and carbonate content logs – 2.5-3% TOC in Indian Castle Shale at base of Utica – carbonate content ~10%

Intra-Trenton organic-rich zone has 1.5-2% TOC and ~50% carbonate content – would not guess shale content to be 50% from GR log

Will make similar logs for >100 wells

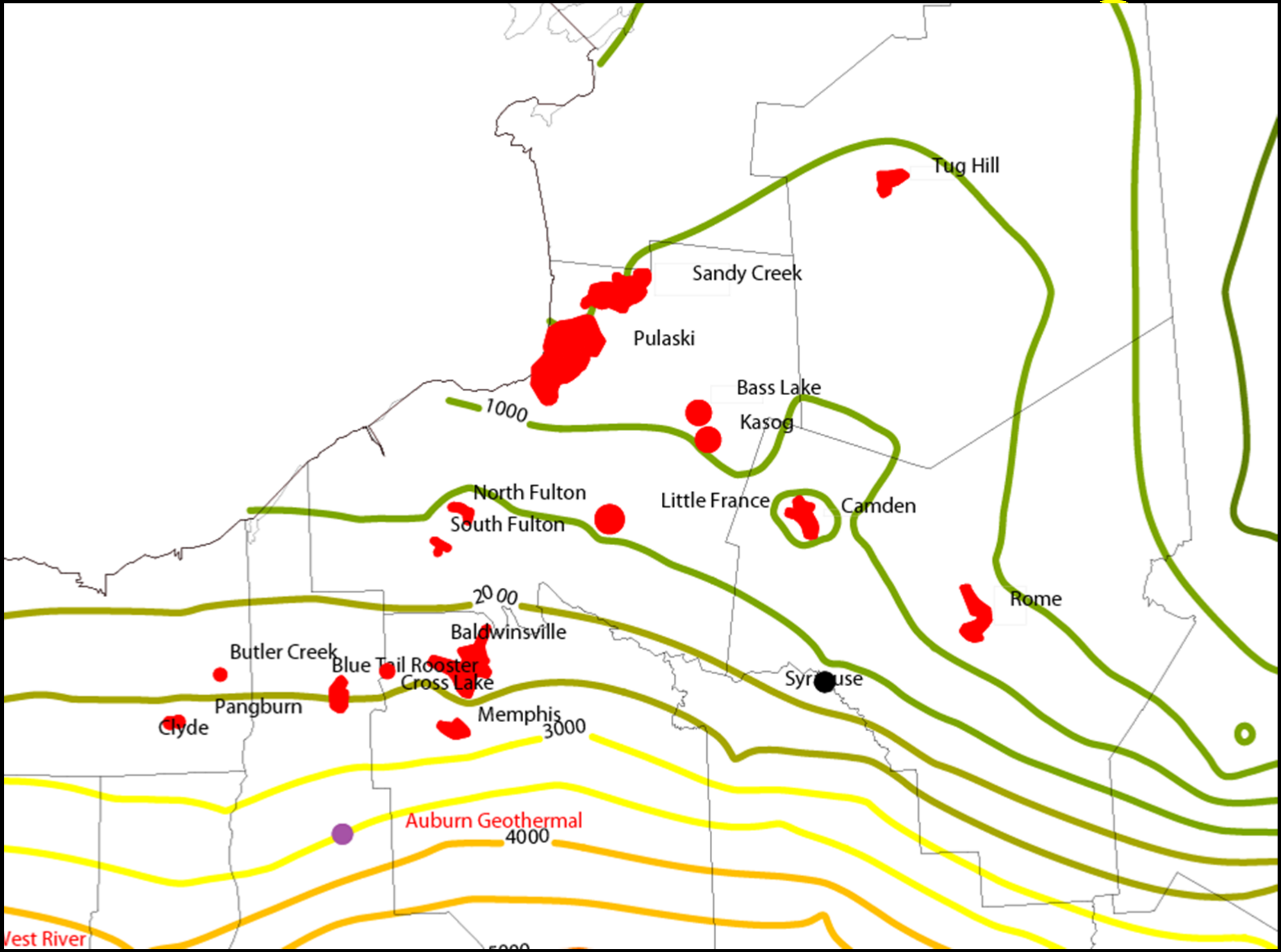






Highly overpressured Trenton Limestone play is in the Rust or Dolgeville-equivalent facies and is likely to be self-sourced

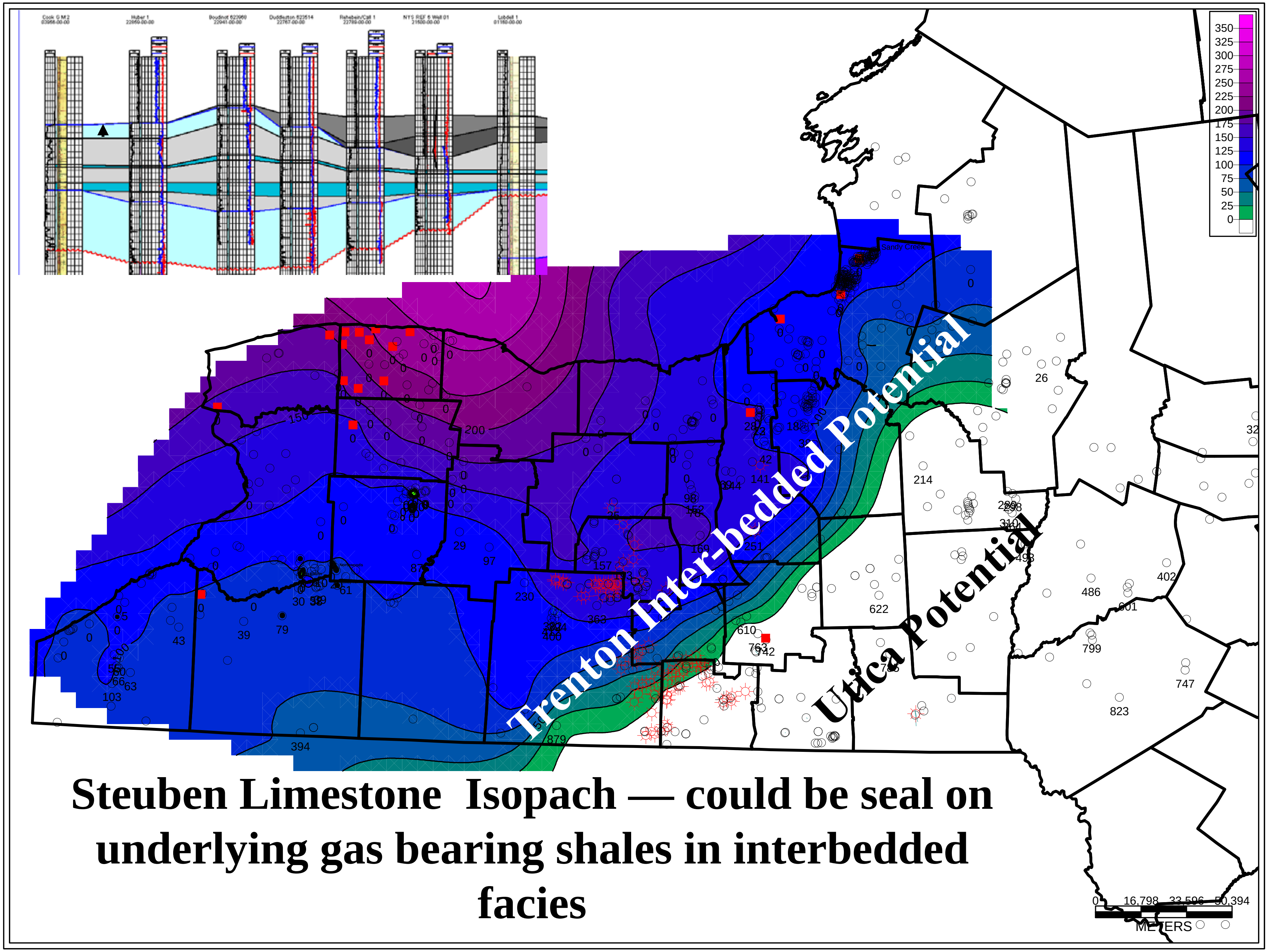
Trenton Structure Map



Top of Trenton in the southern part of the play is at <3000 feet

–

highly overpressured reservoirs (19 pound mud) occur where



Steuben Limestone Isopach — could be seal on underlying gas bearing shales in interbedded facies

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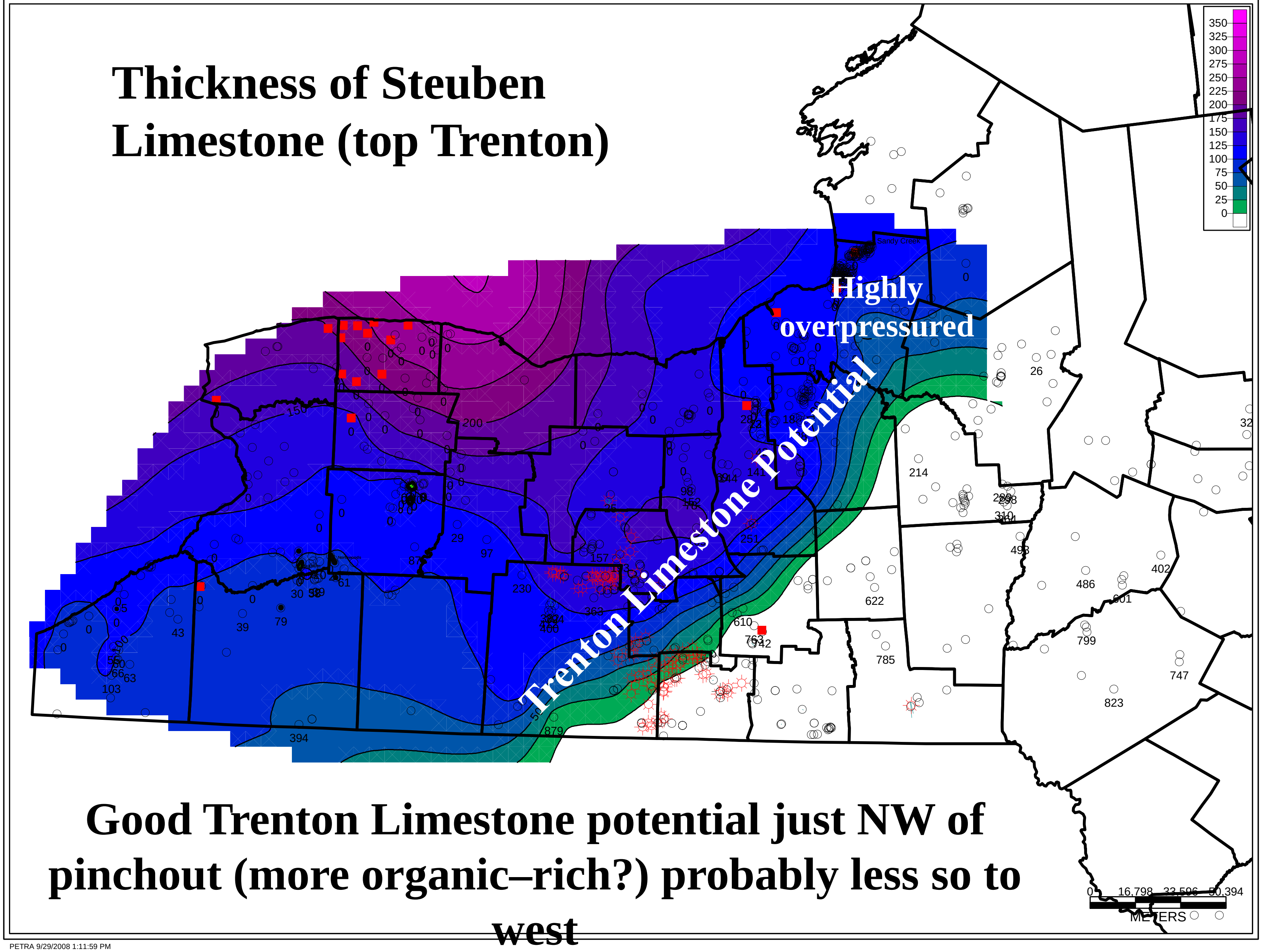
Thickness of Steuben Limestone (top Trenton)



Good Trenton Limestone potential just NW of pinchout (more organic–rich?) probably less so to west

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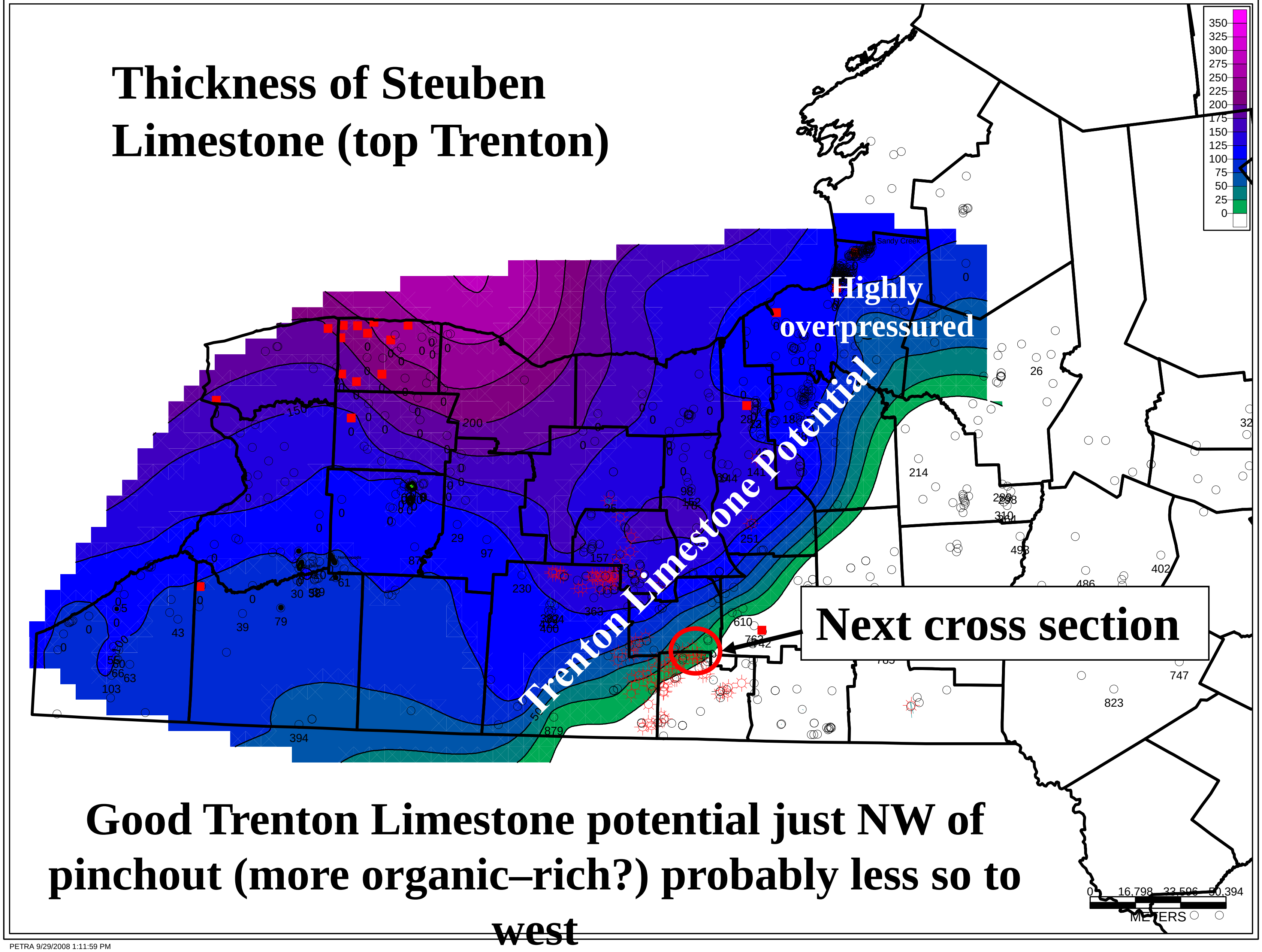
Thickness of Steuben Limestone (top Trenton)



Highly overpressured

Trenton Limestone Potential

Next cross section

Good Trenton Limestone potential just NW of pinchout (more organic–rich?) probably less so to west

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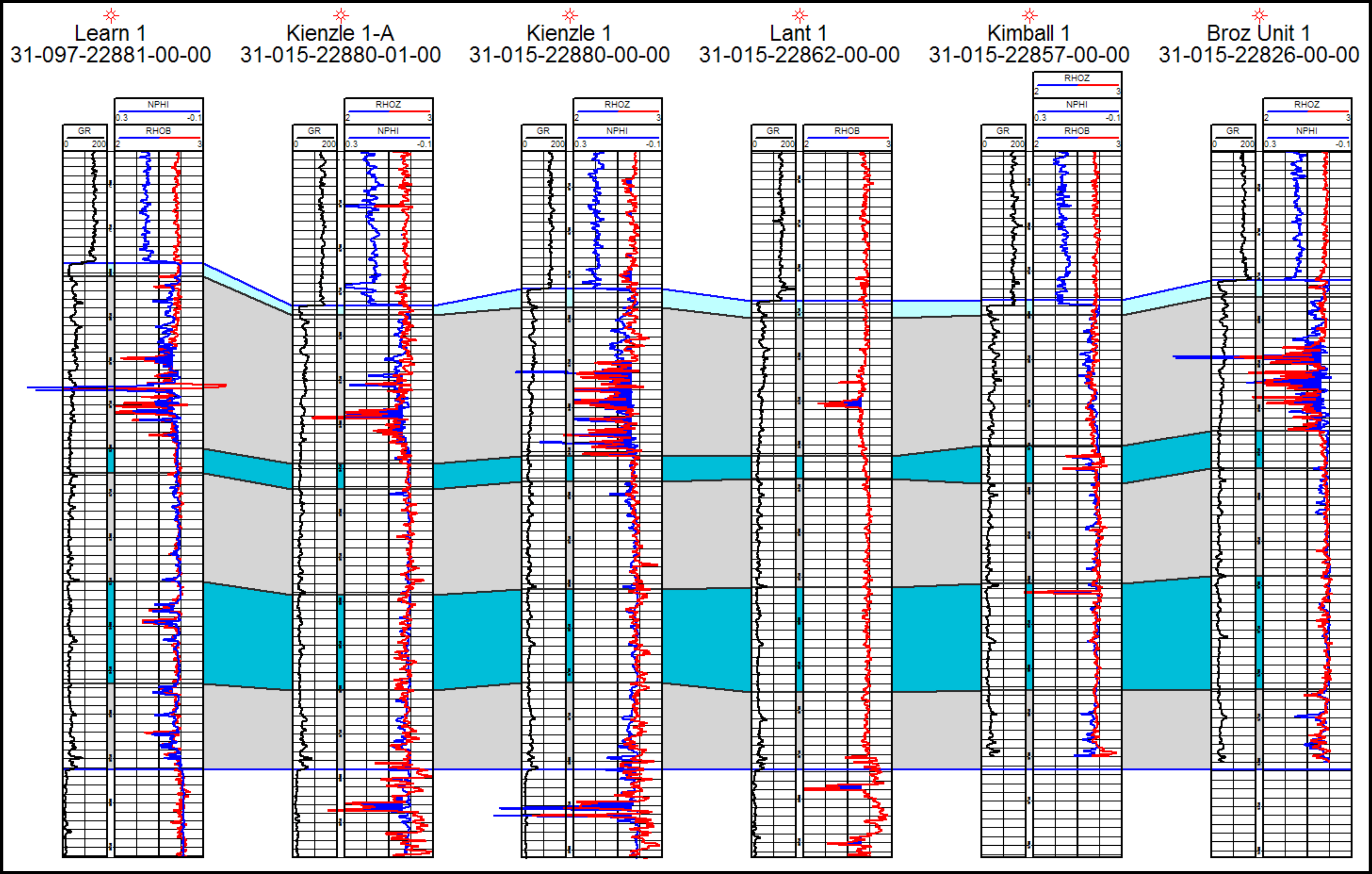
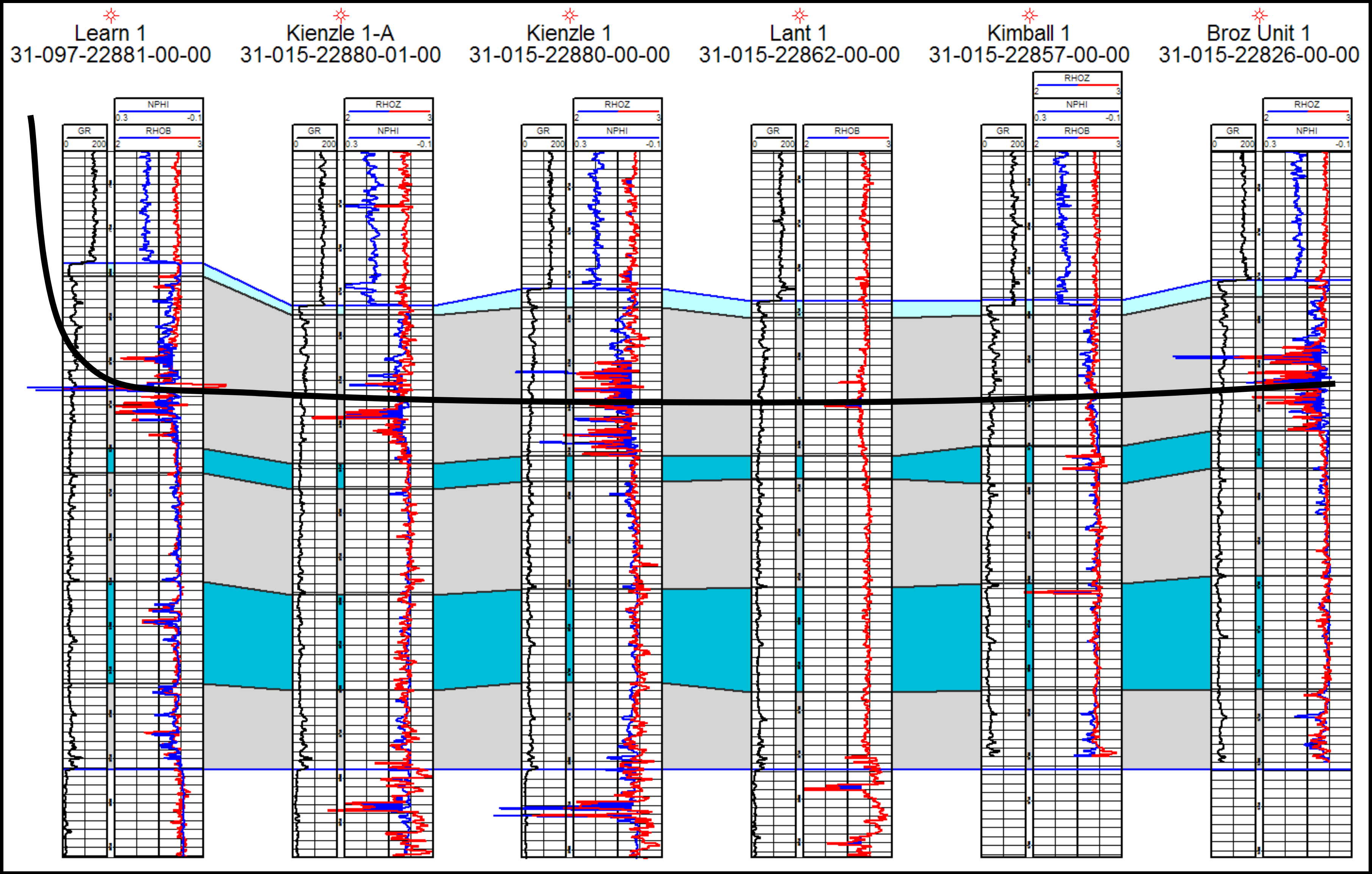
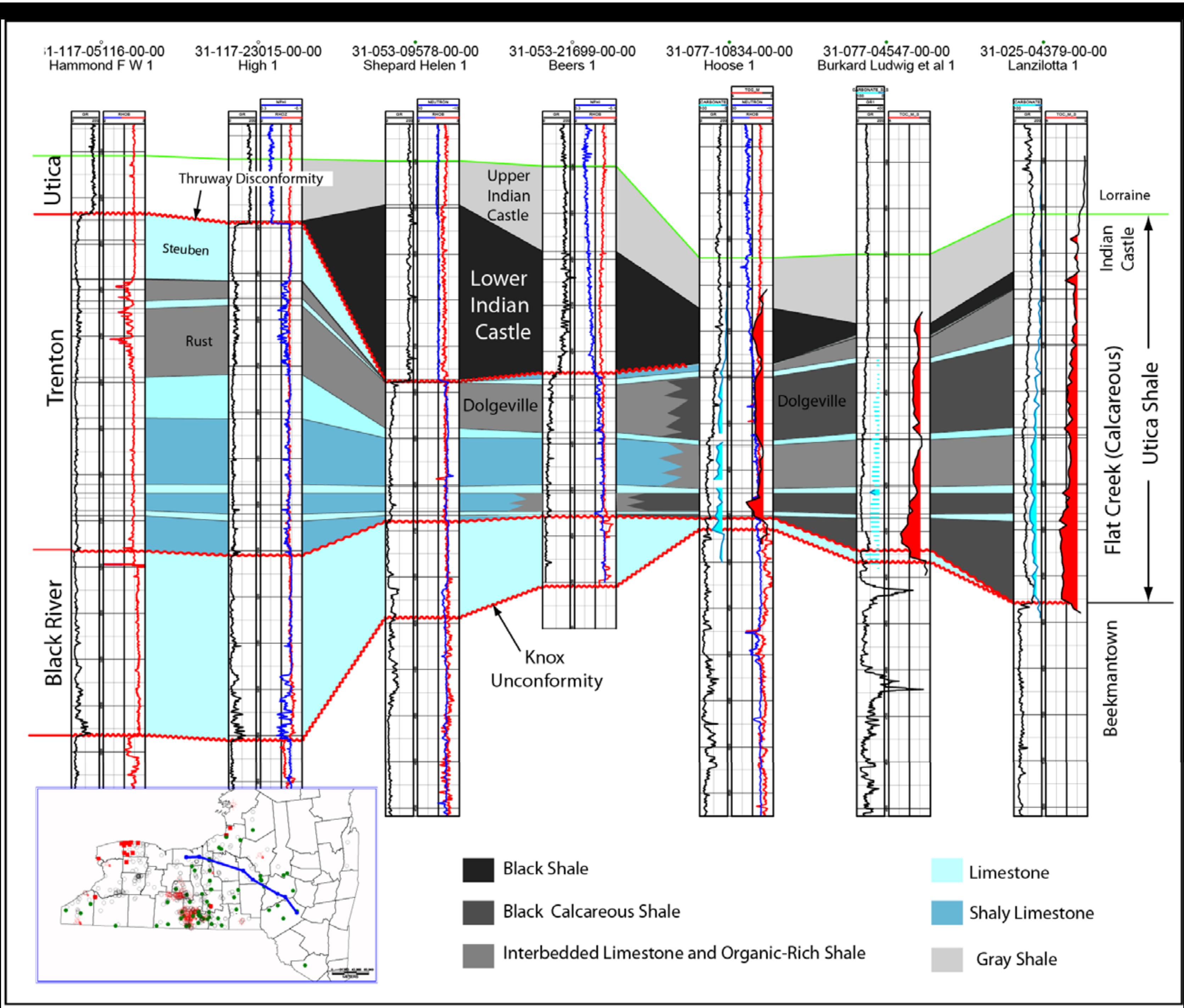


Very promising looking porosity in interbedded facies right near the margin with the shale basin in Terry Hill South Field – may extend northeast along margin



Very promising looking porosity in interbedded facies right near the margin with the shale basin in Terry Hill South Field – may extend northeast along margin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Hammond F W 1
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High 1
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Shepard Helen 1
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Beers 1
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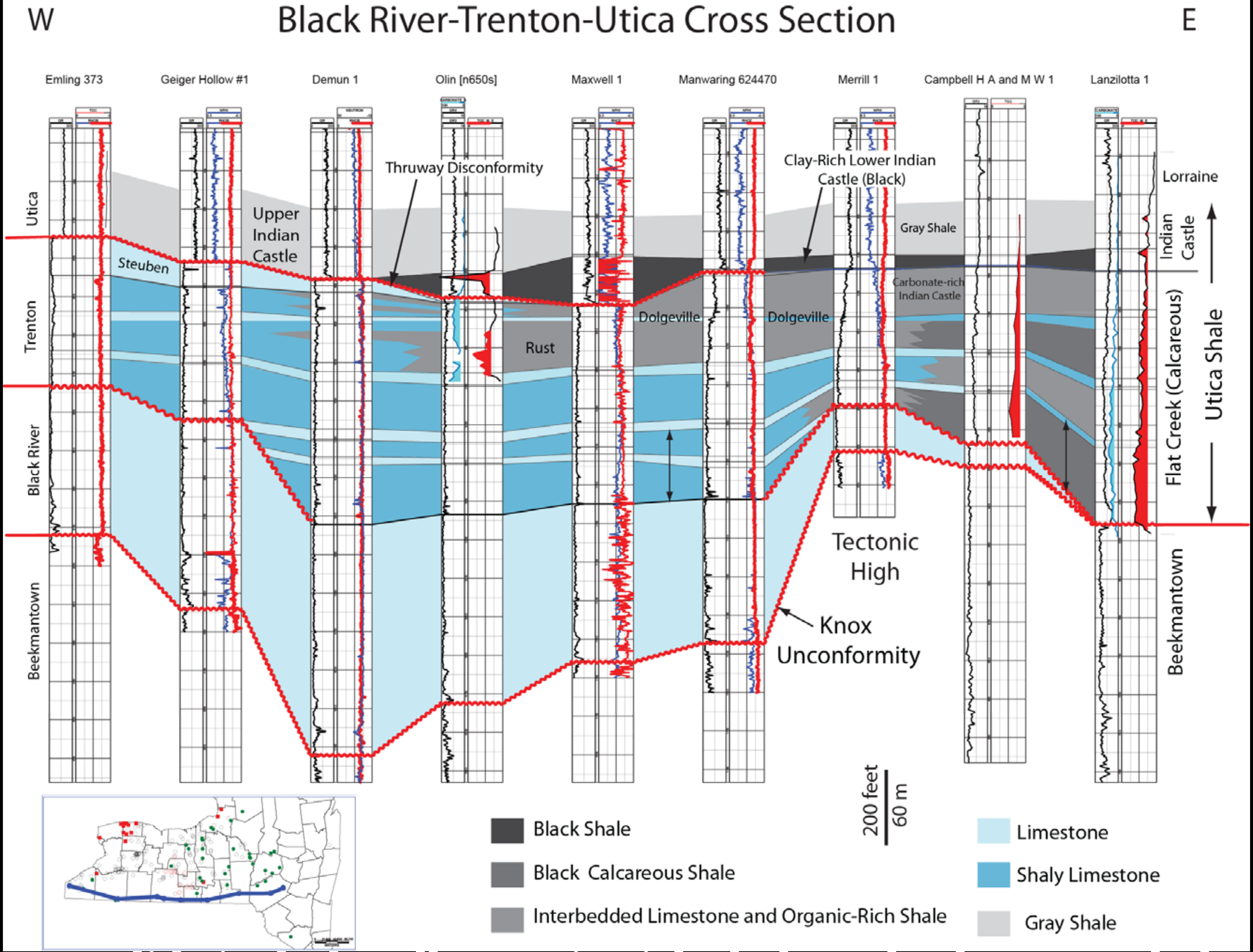
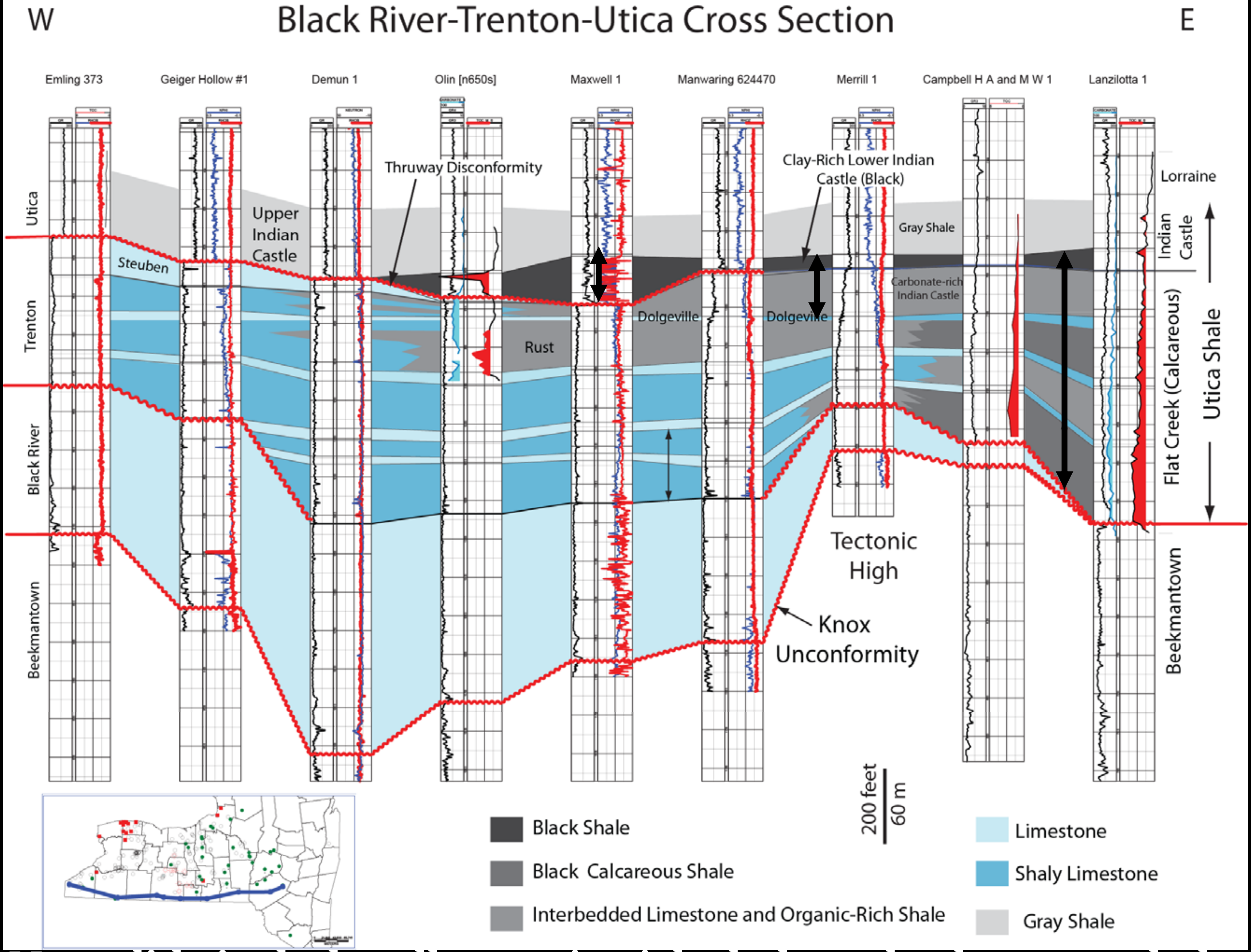
Hoose 1
31-077-04547-00-00
Burkard Ludwig et al 1
31-025-04379-00-00
Lanzilotta 1
Utica
Trenton
Black River
Thruway Disconformity
Steuben
Rust
Upper
Indian
Castle
Lower
Indian
Castle
Dolgeville
Dolgeville
Knox
Unconformity
Lorraine
Indian
Castle
Flat Creek (Calcareous)
Utica Shale
Beekmantown
Black Shale
Black Calcareous Shale
Interbedded Limestone and Organic-Rich Shale
Limestone
Shaly Limestone
Gray Shale



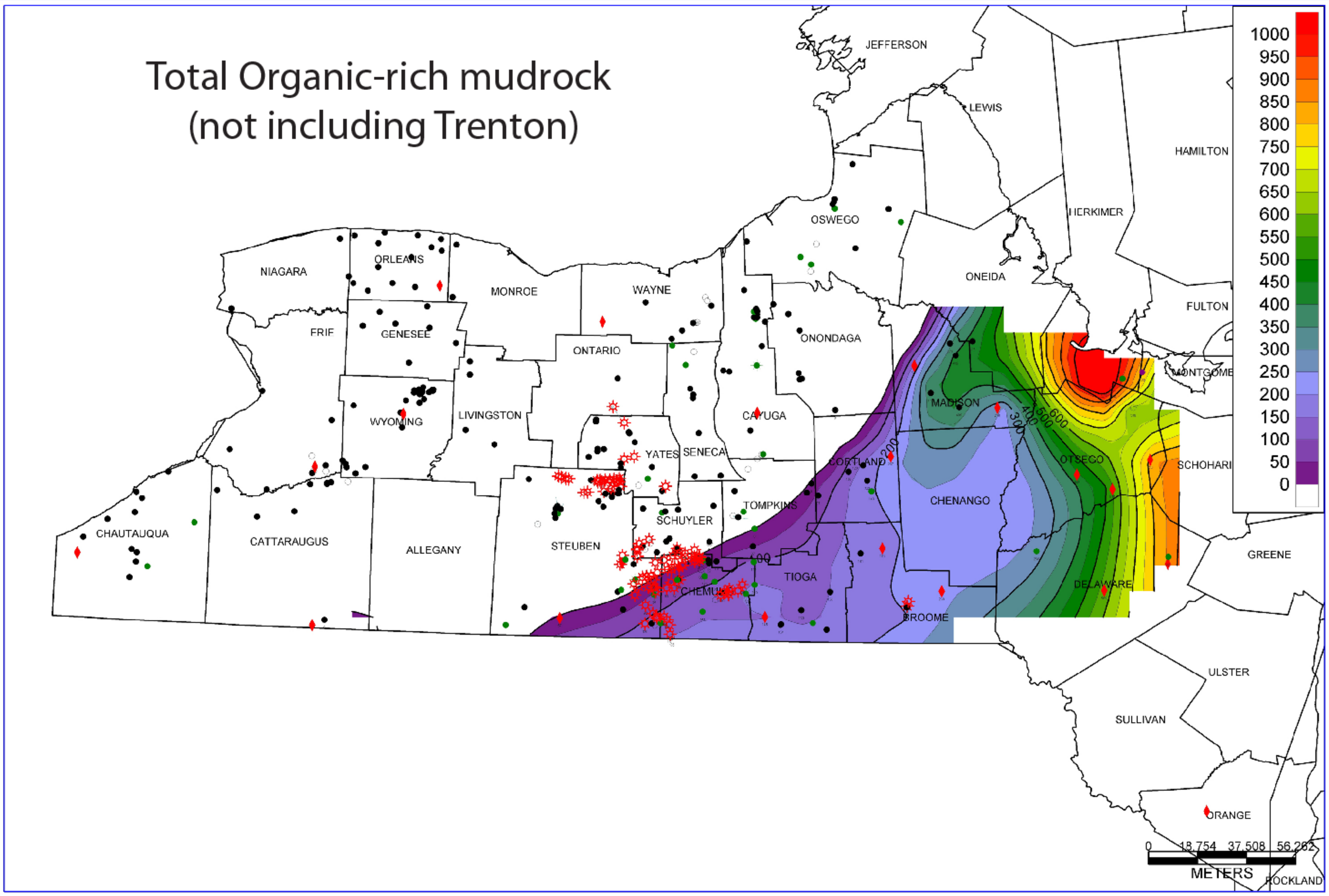
Black River-Trenton-Utica Cross Section

Next slide includes all organic-rich shale and calcareous shale



Next slide includes all organic-rich shale and calcareous shale

Total Organic-rich mudrock
(not including Trenton)



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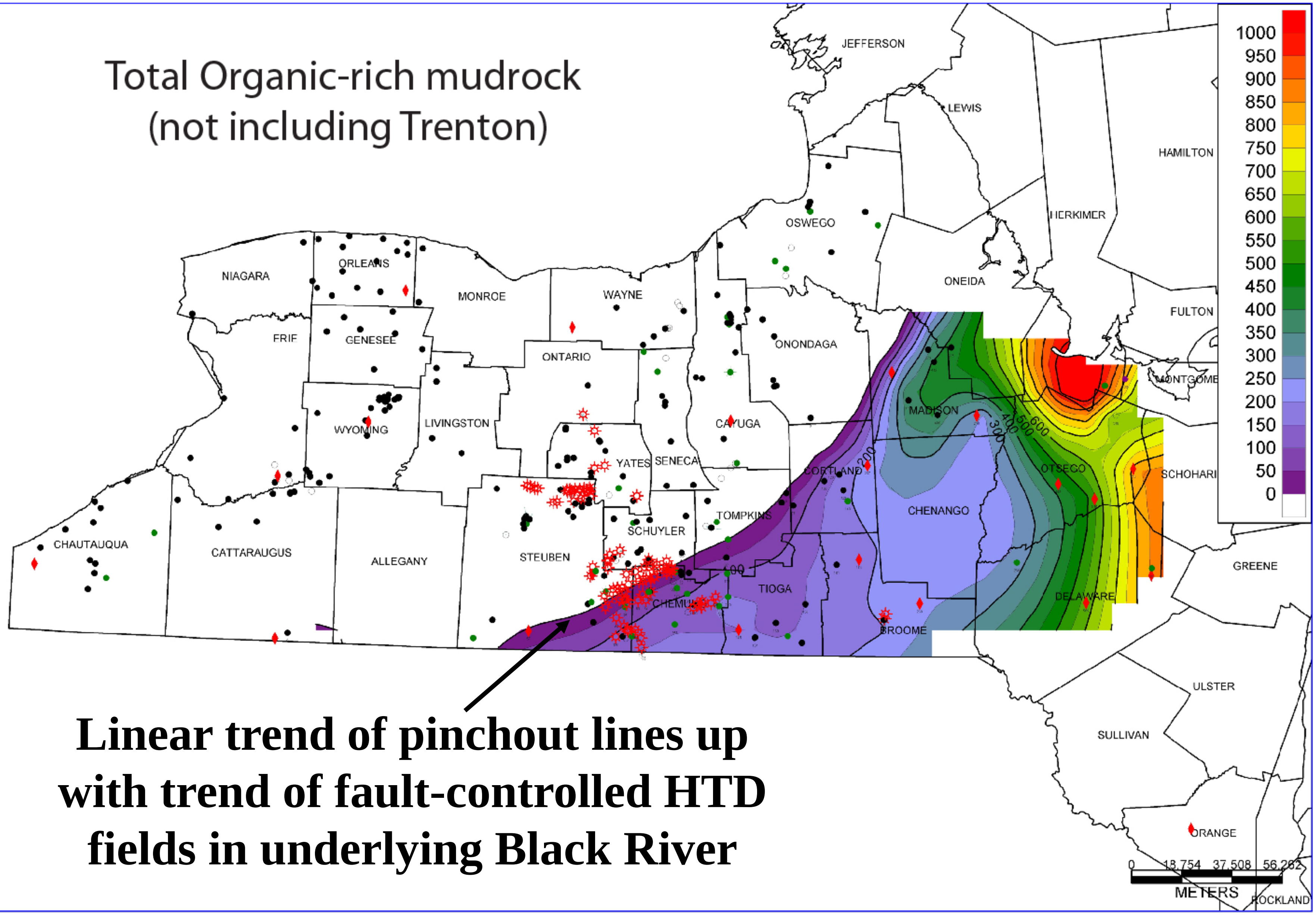
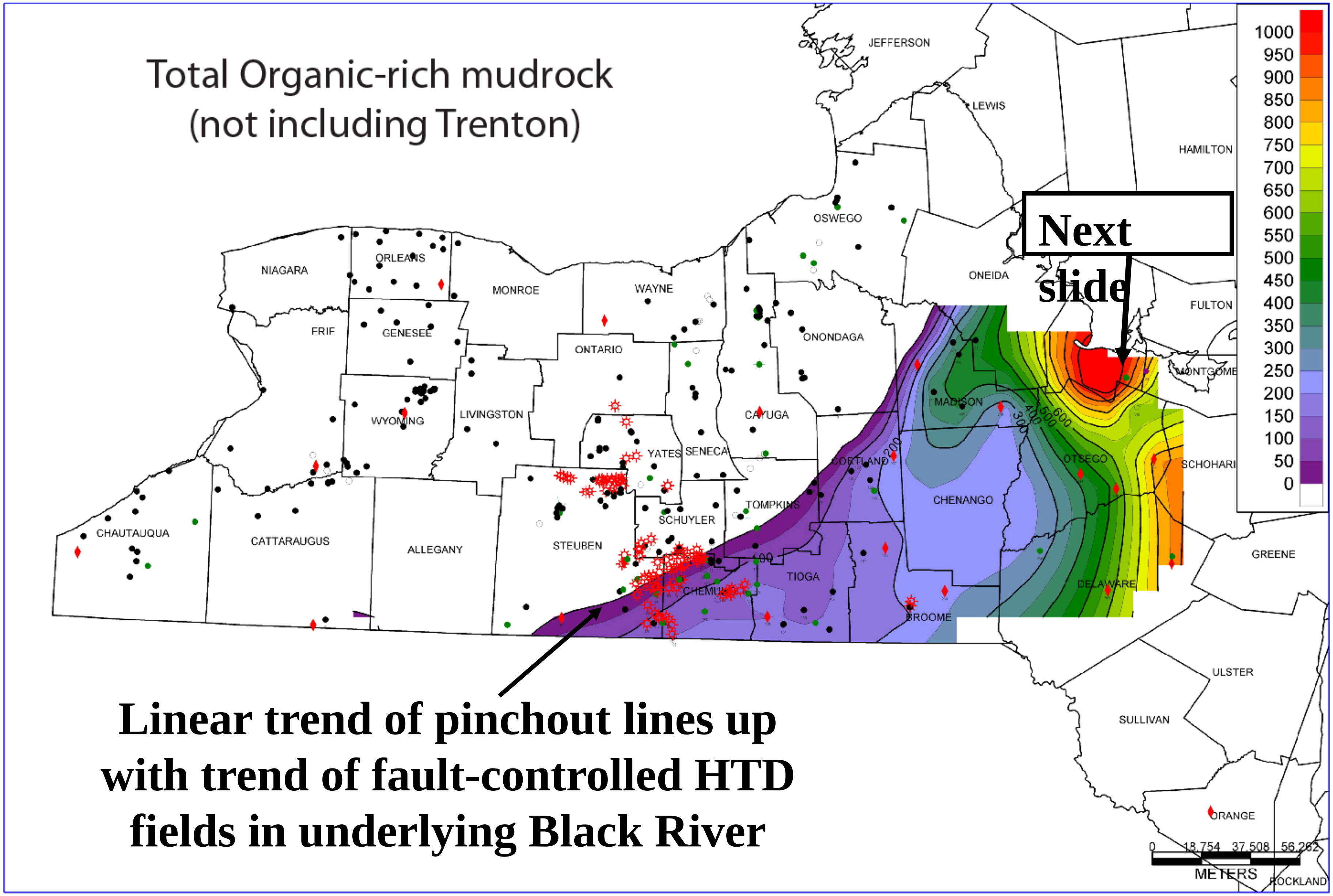


Linear trend of pinchout lines up with trend of fault-controlled HTD fields in underlying Black River

Total Organic-rich mudrock (not including Trenton)



Next slide

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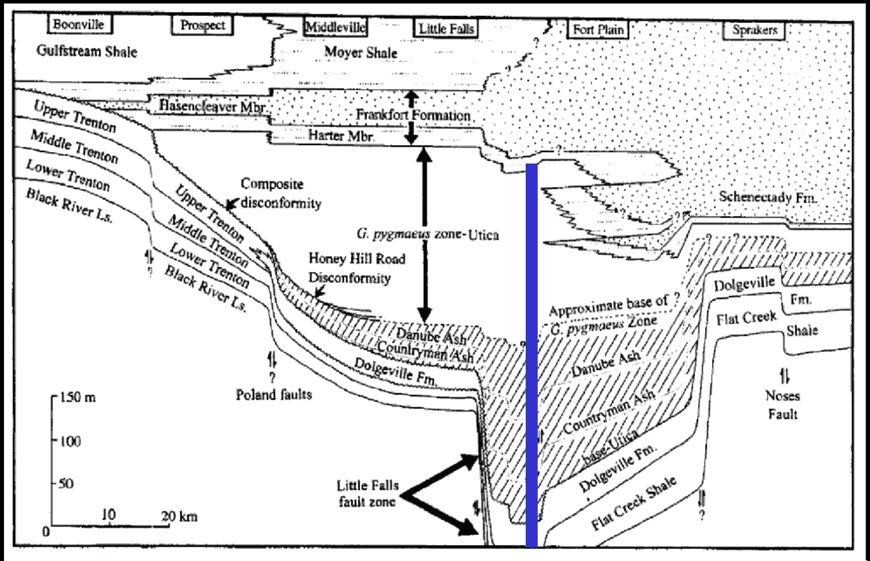
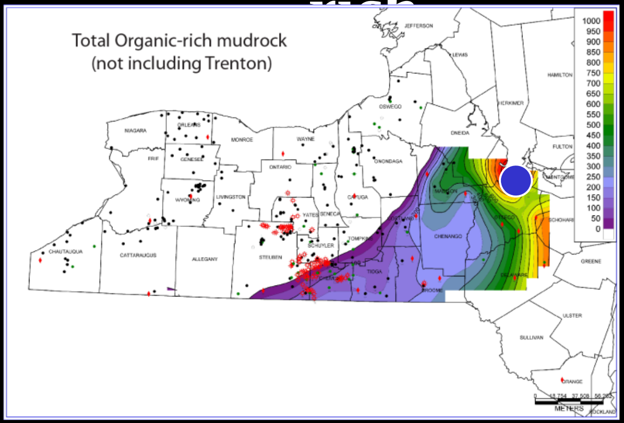
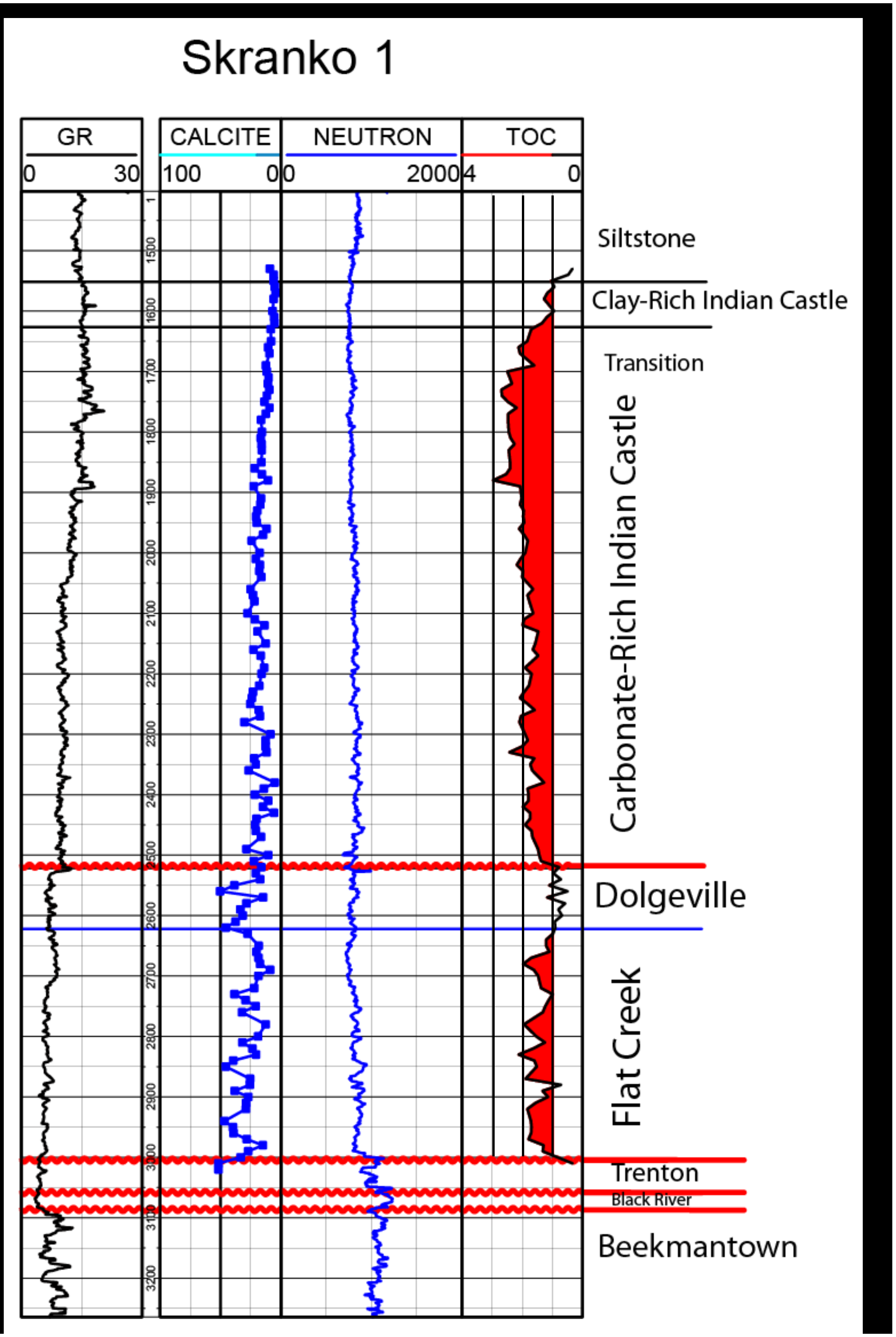
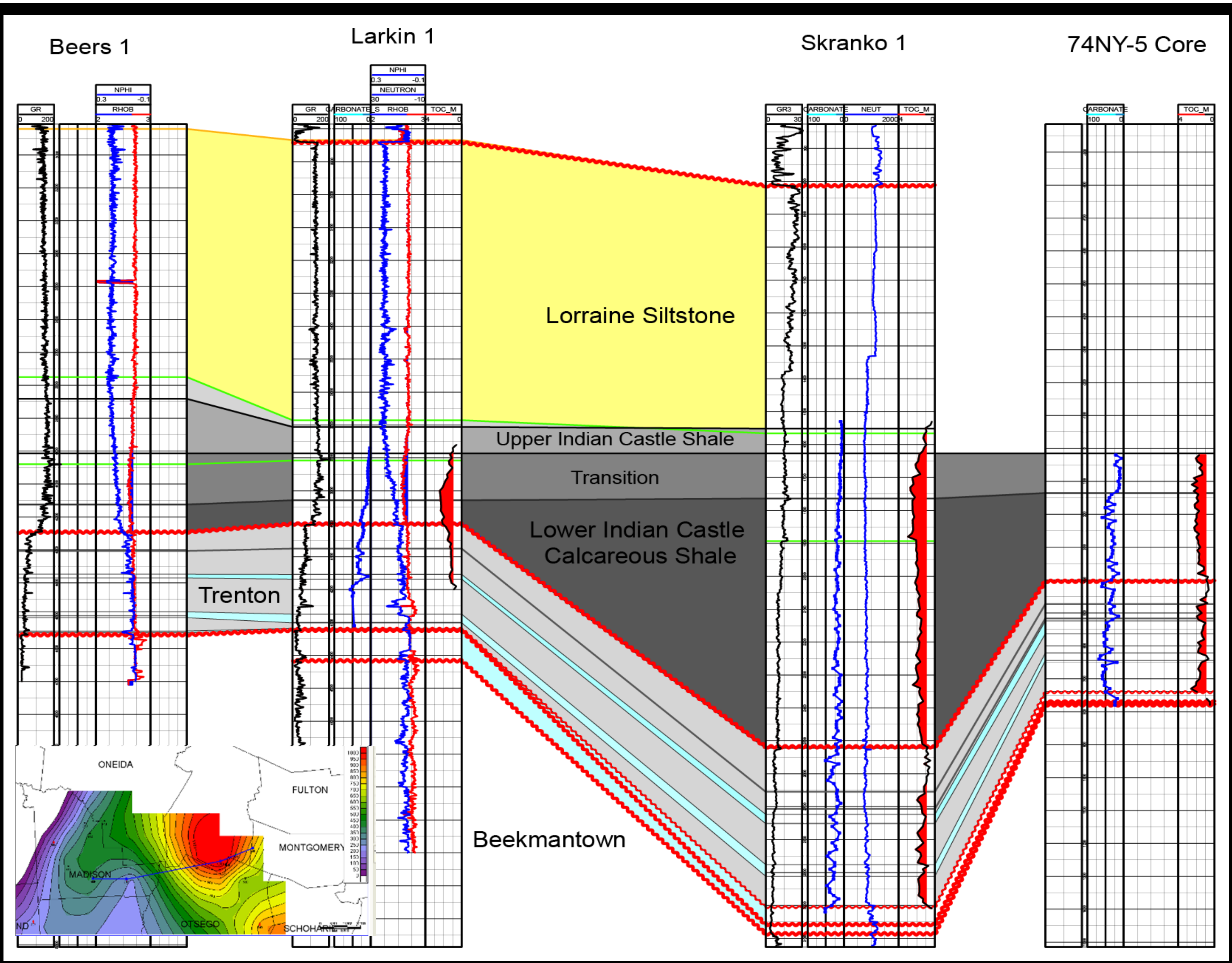


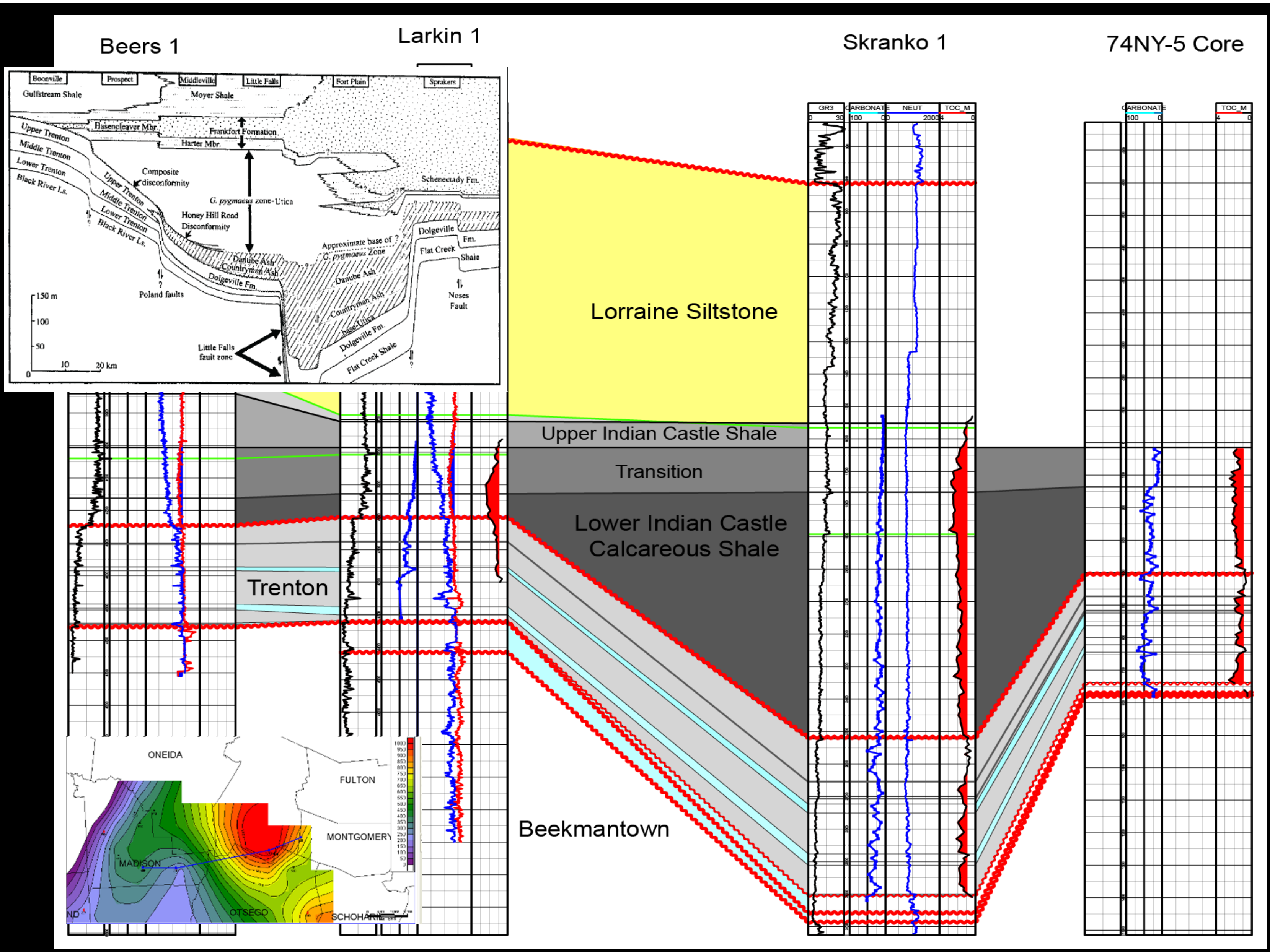
Thickest organic-rich Utica well has more than 1200 feet of >1.5% TOC –drilled into graben – most of it calcite rich




Skranko 1



Cross section through Little Falls Graben – organic rich shale section thickens – mostly calcareous shale and transitional from calcareous to non-calcareous shale - - faults moved in Lower Indian Castle time – likely to be more of these features



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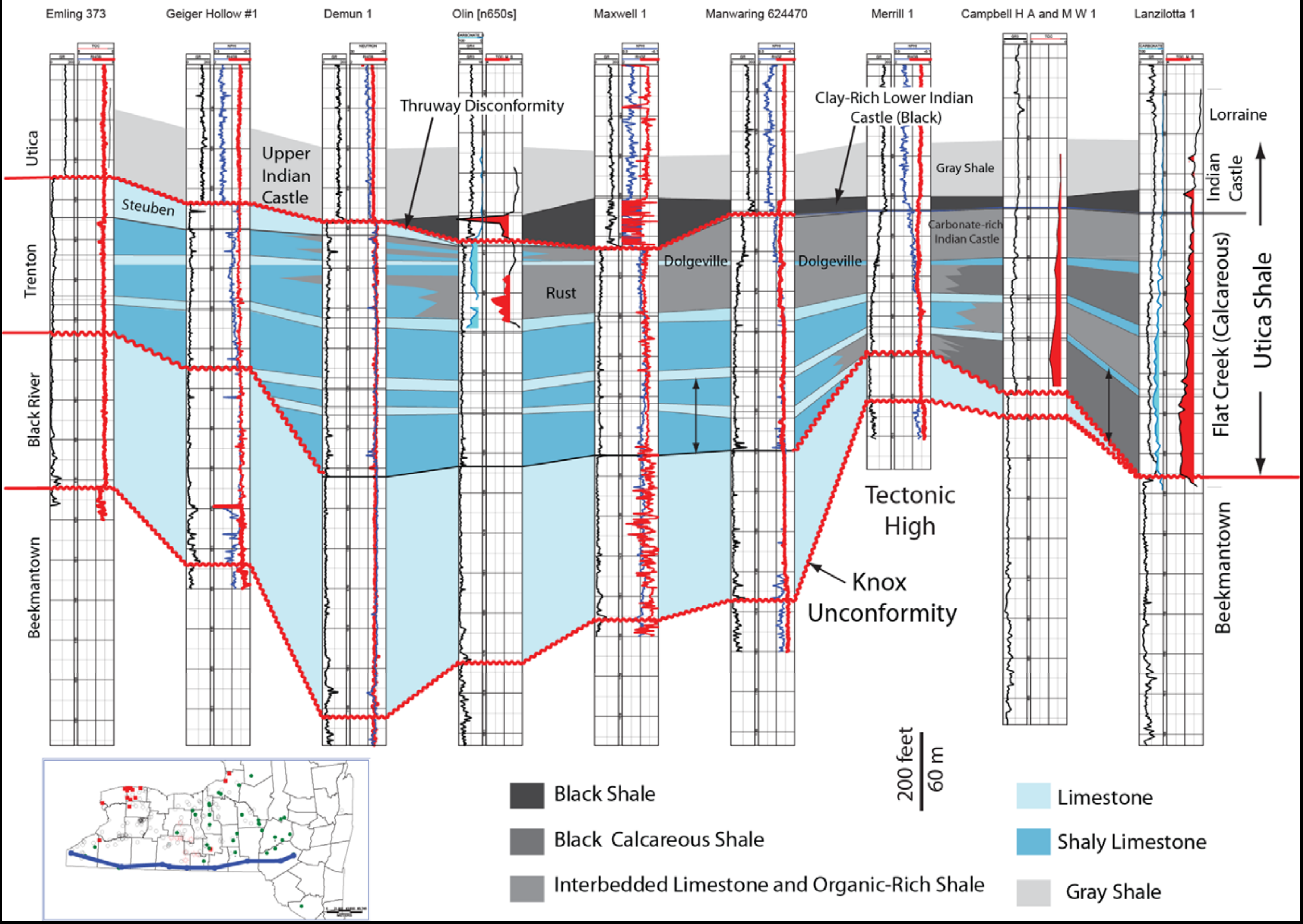
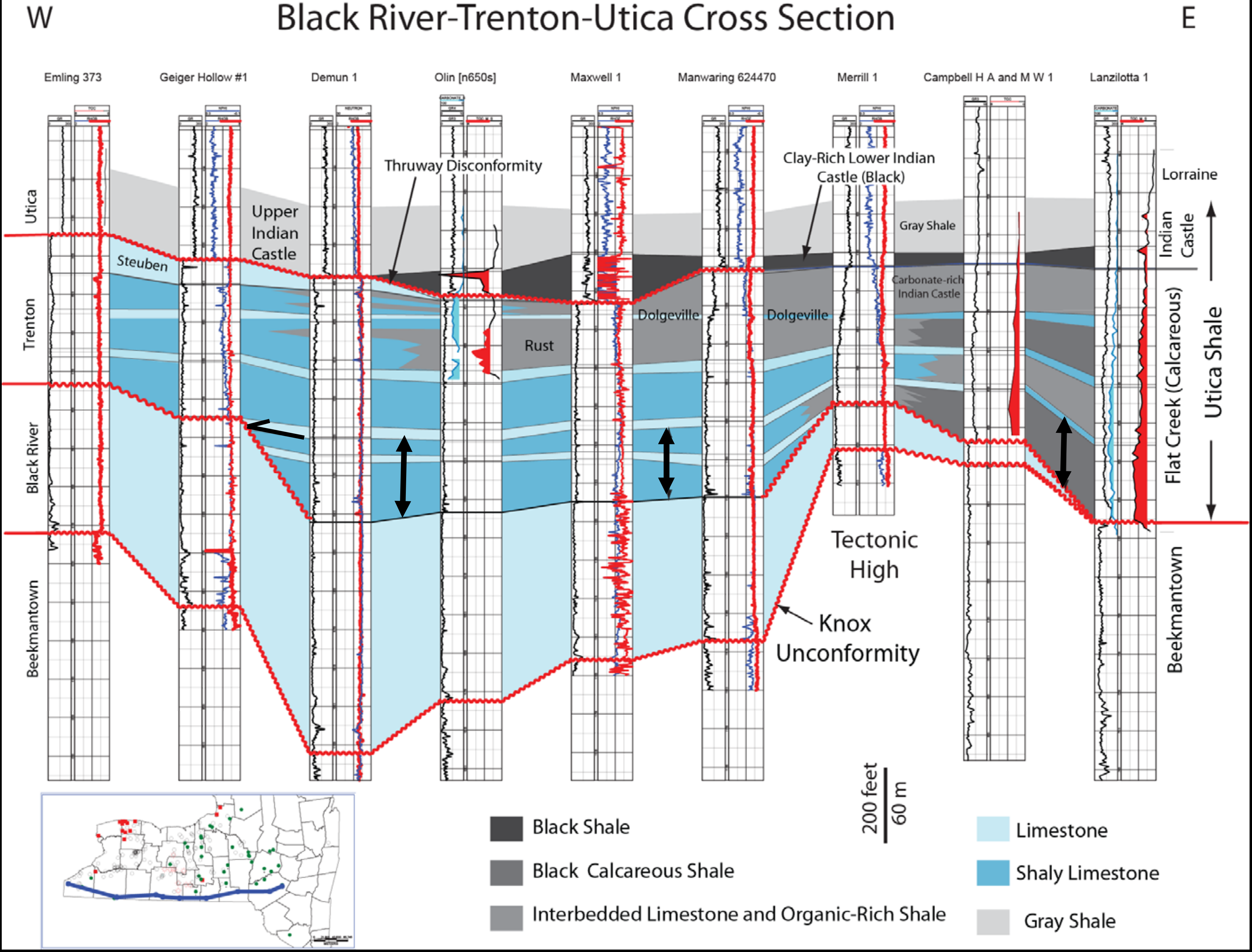
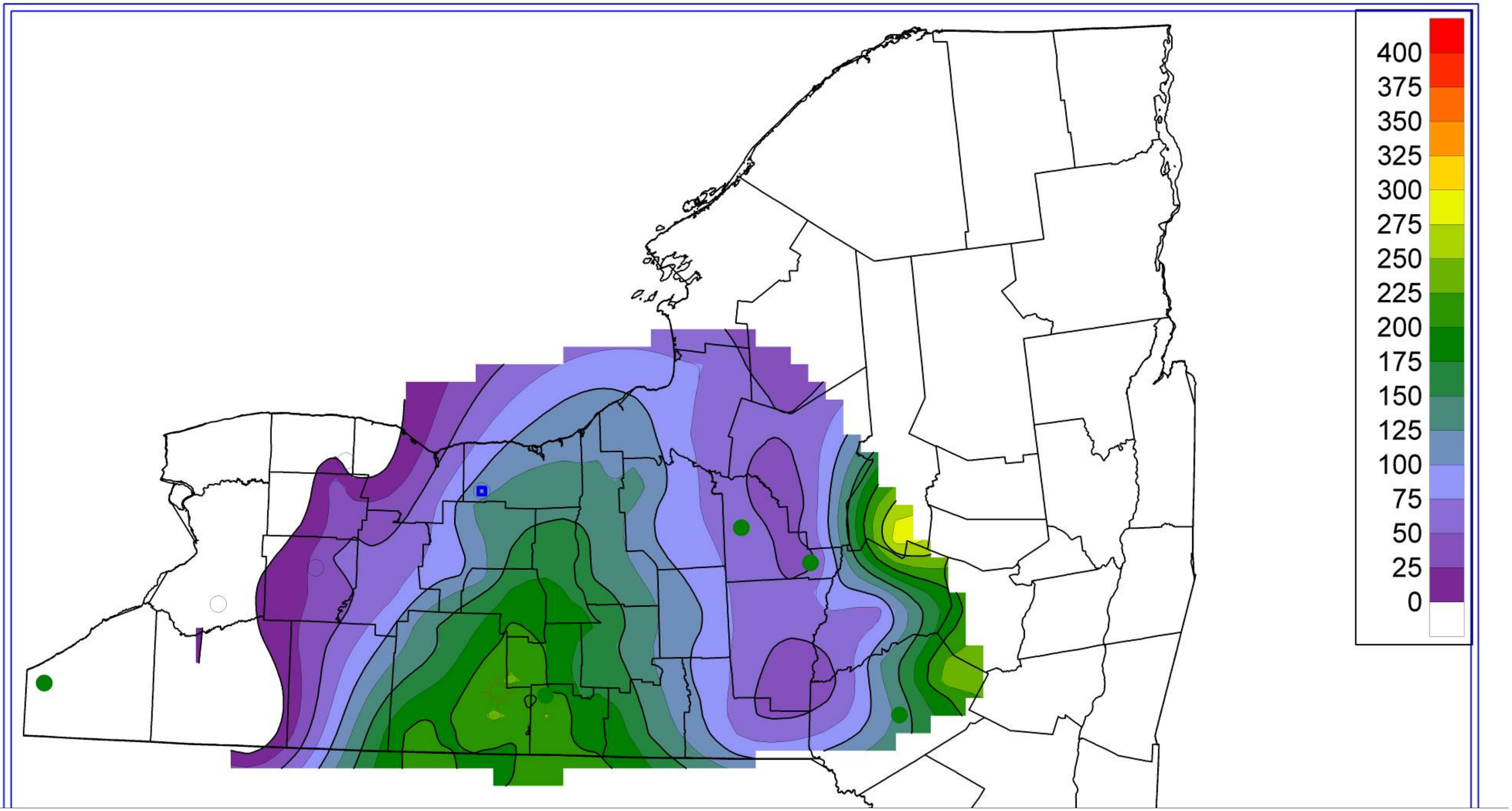
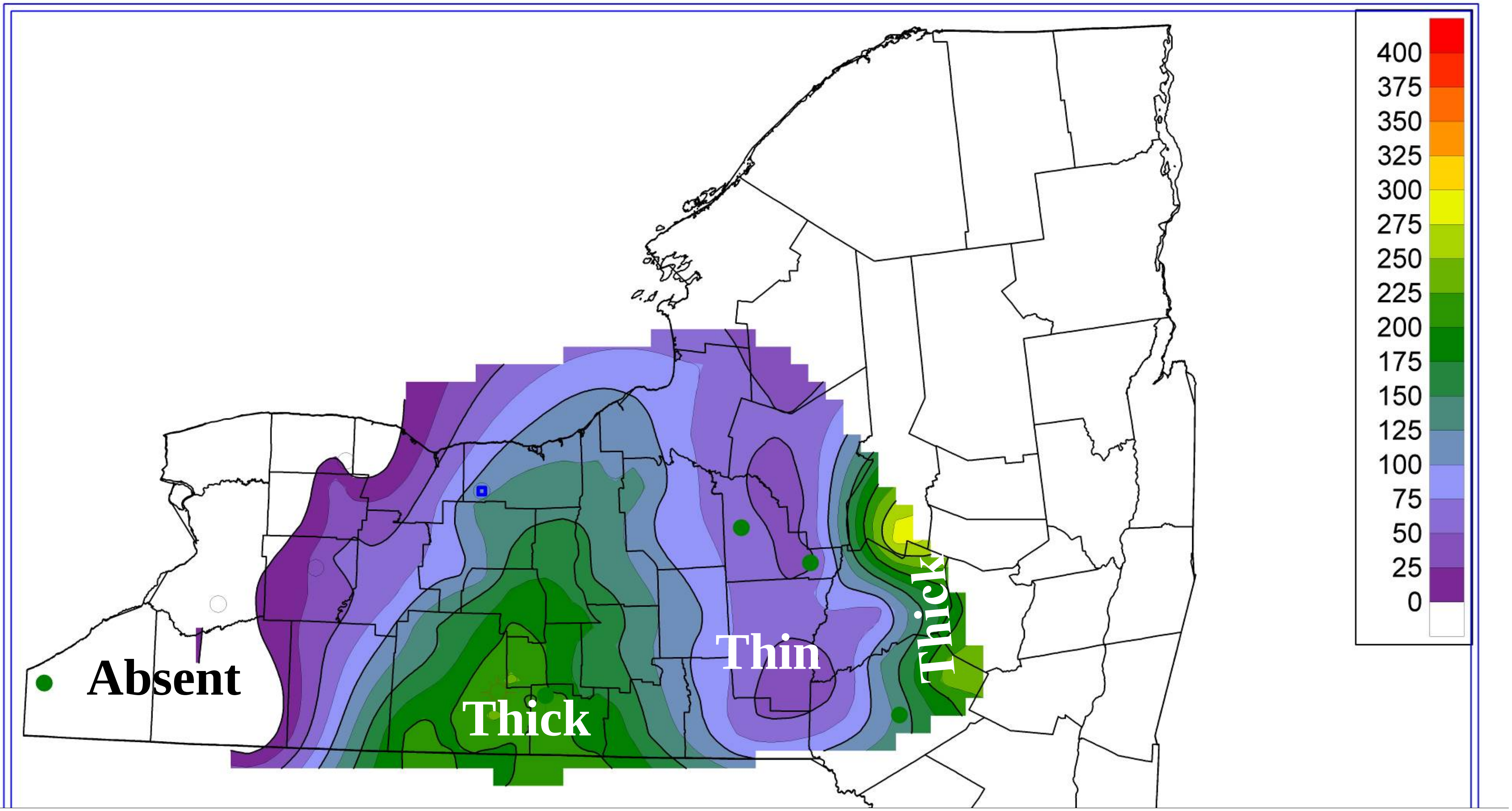


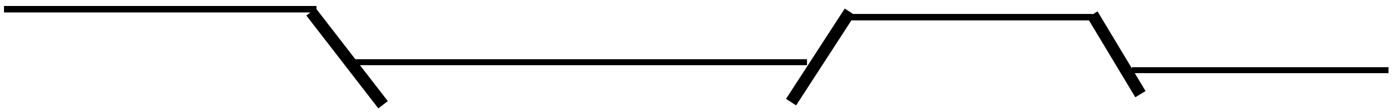
Black River-Trenton-Utica Cross Section





Map of lower Trenton and Flat Creek Thickness – likely to be structurally controlled – basal Trenton and Flat Creek only in lows





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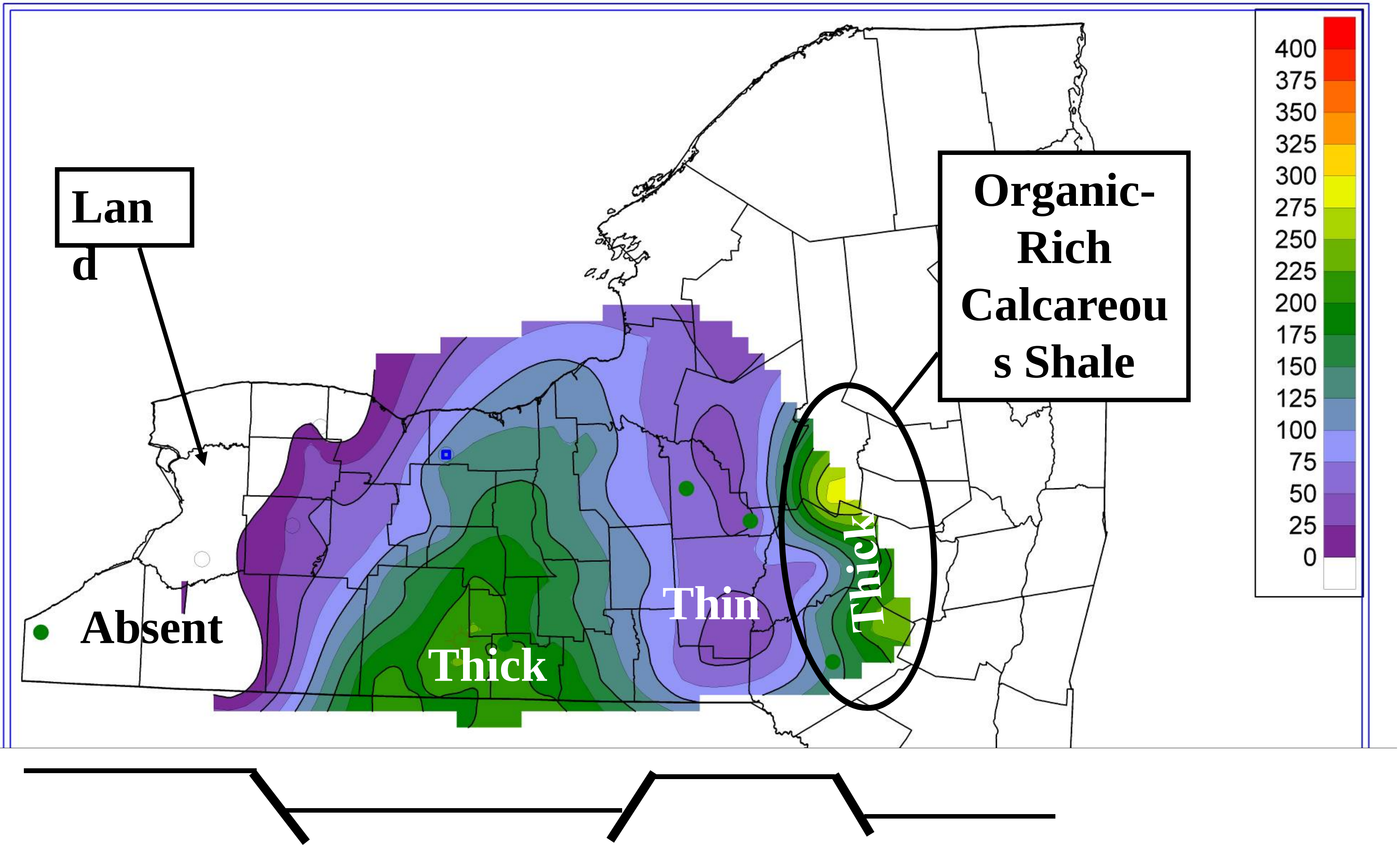

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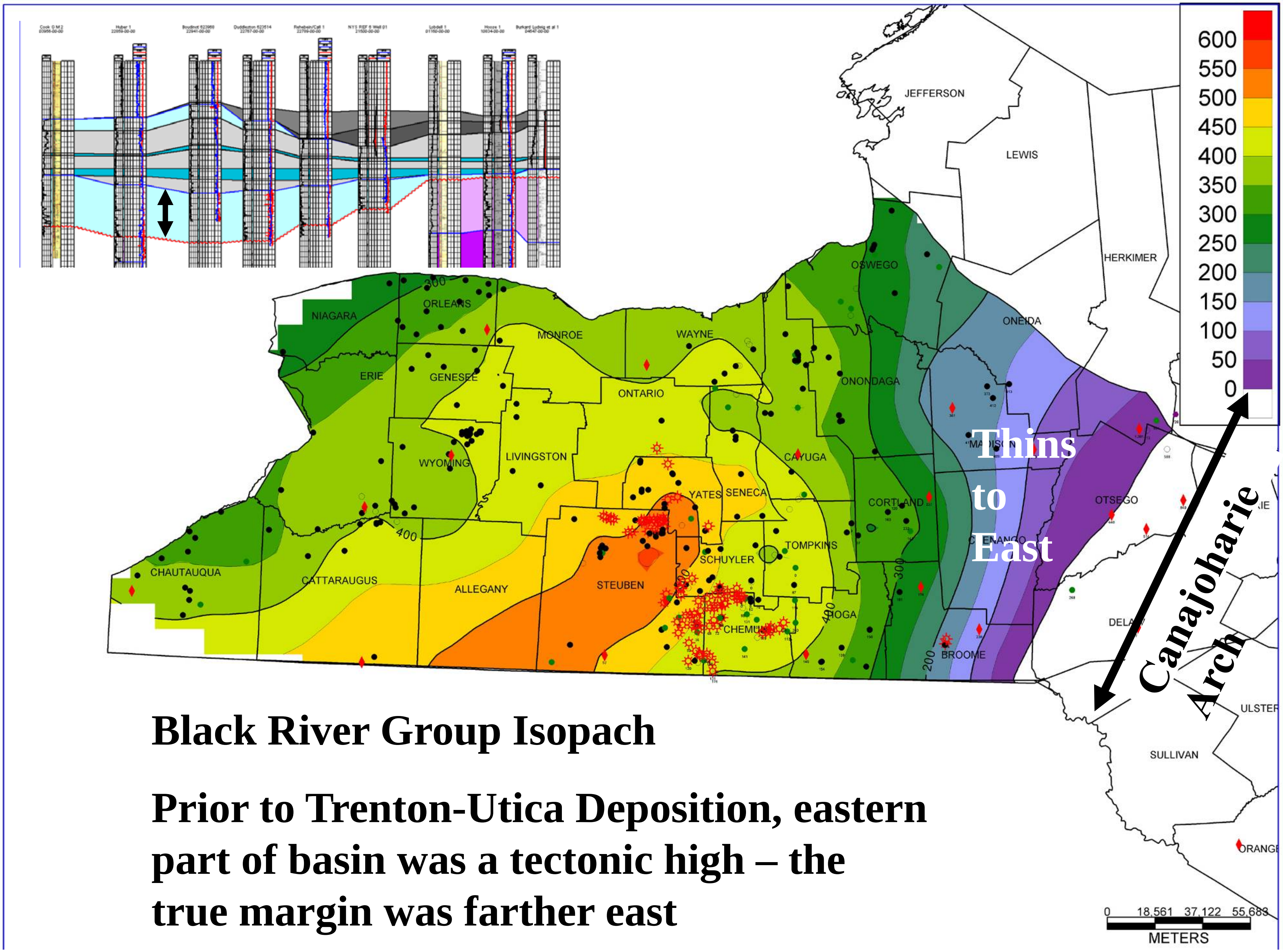
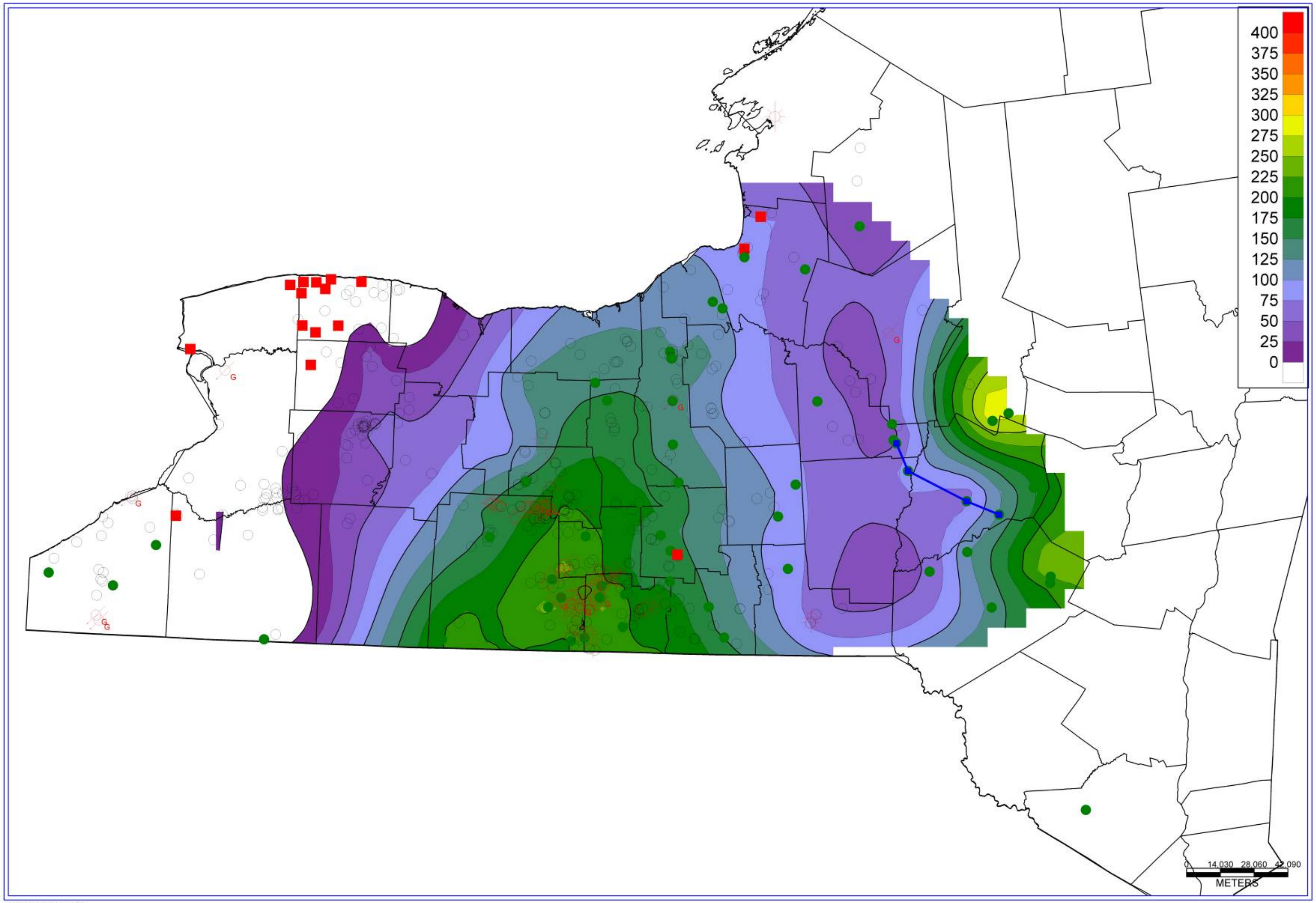
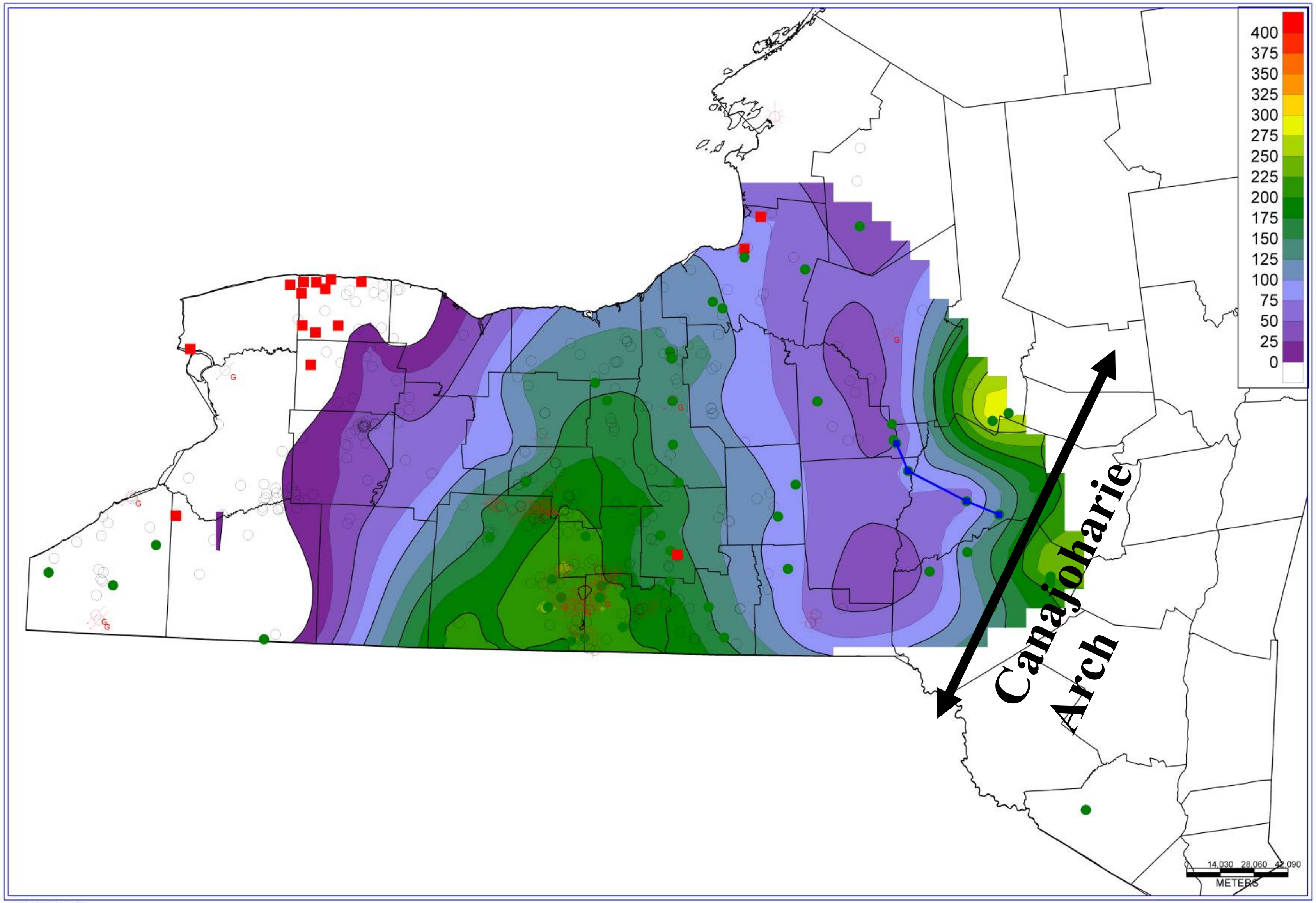


Black River Group Isopach

Prior to Trenton-Utica Deposition, eastern part of basin was a tectonic high – the true margin was farther east



Tectonic high moves to west from Black River to basal Trenton time – western NY also becomes a high – fault-controlled



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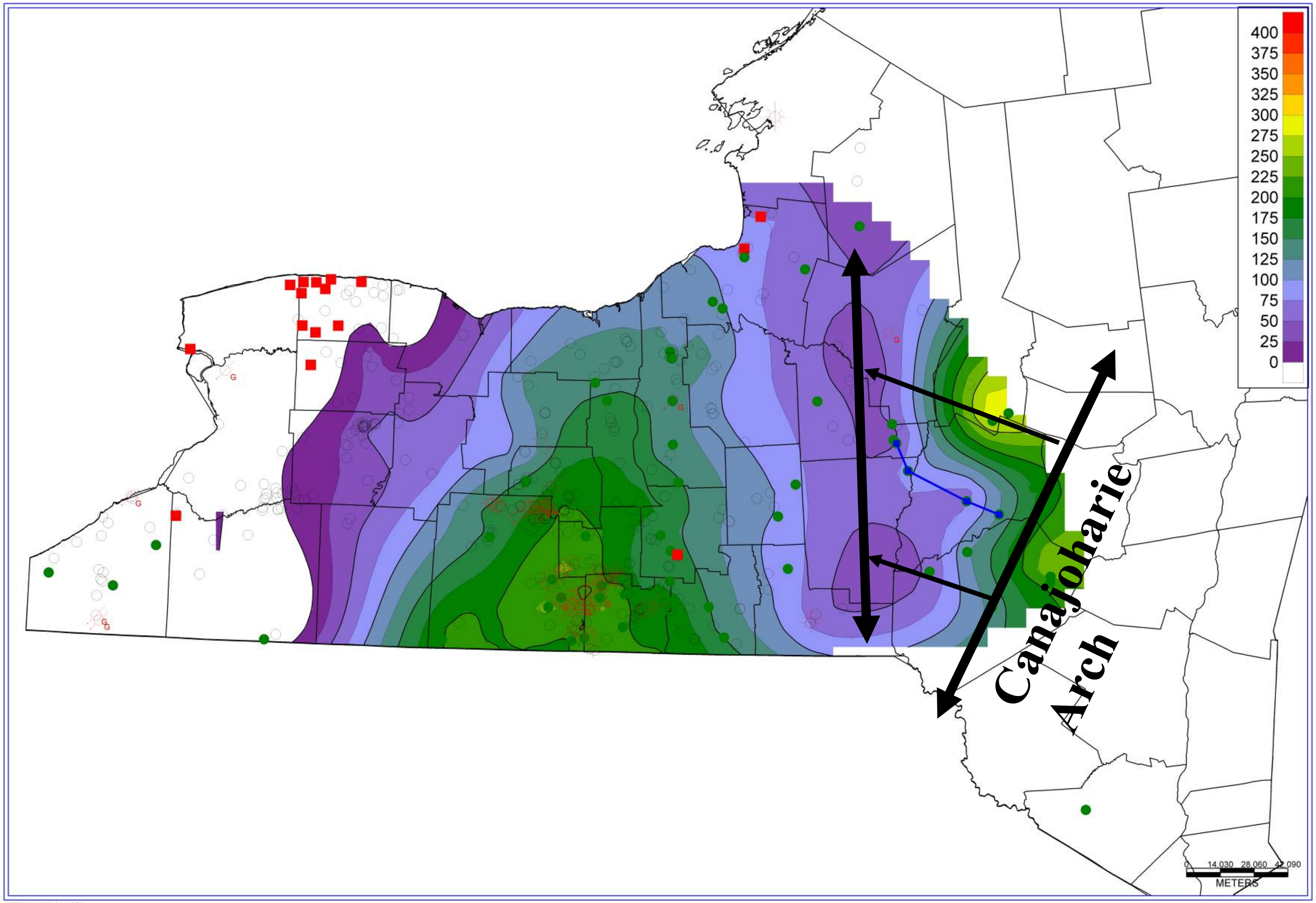
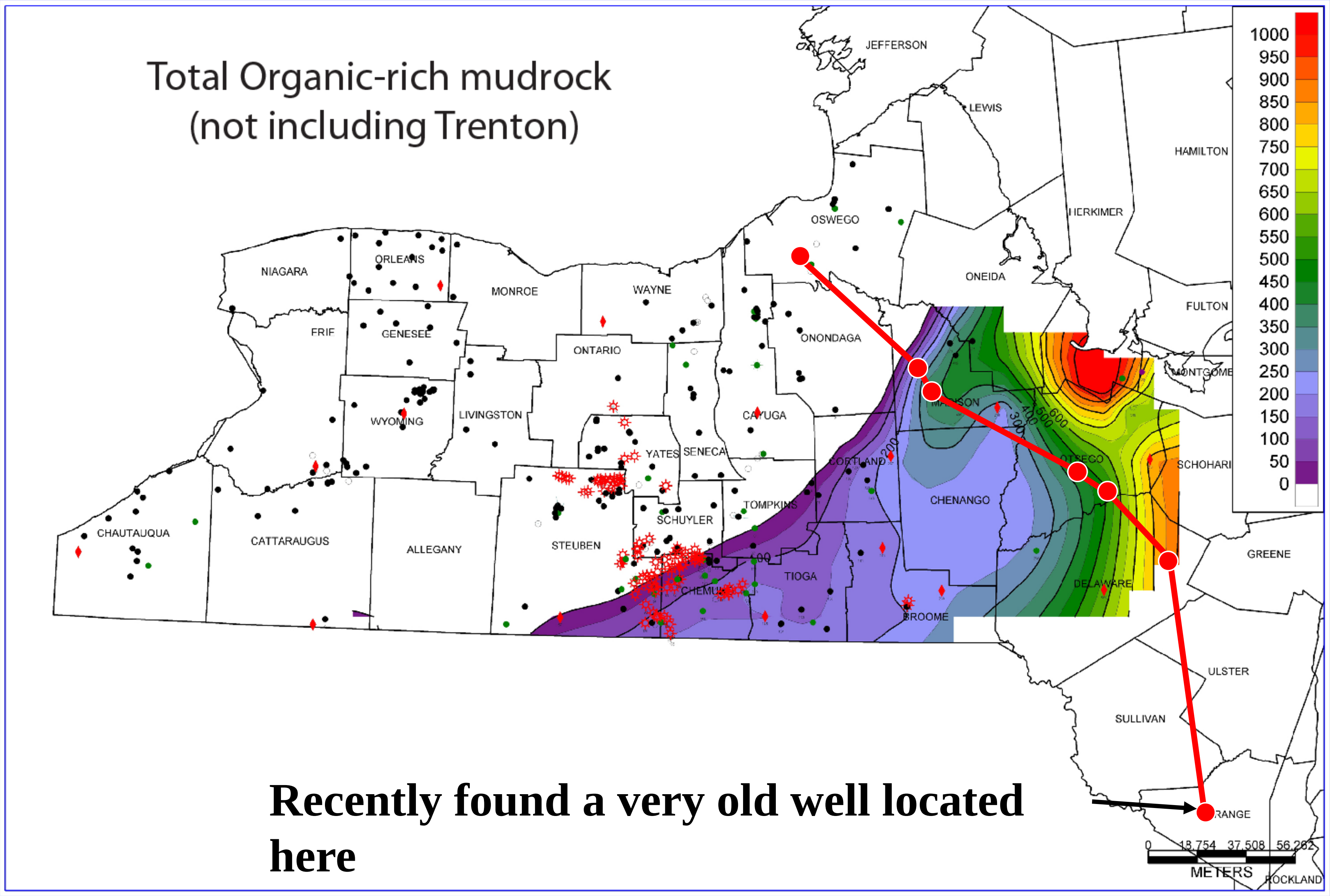


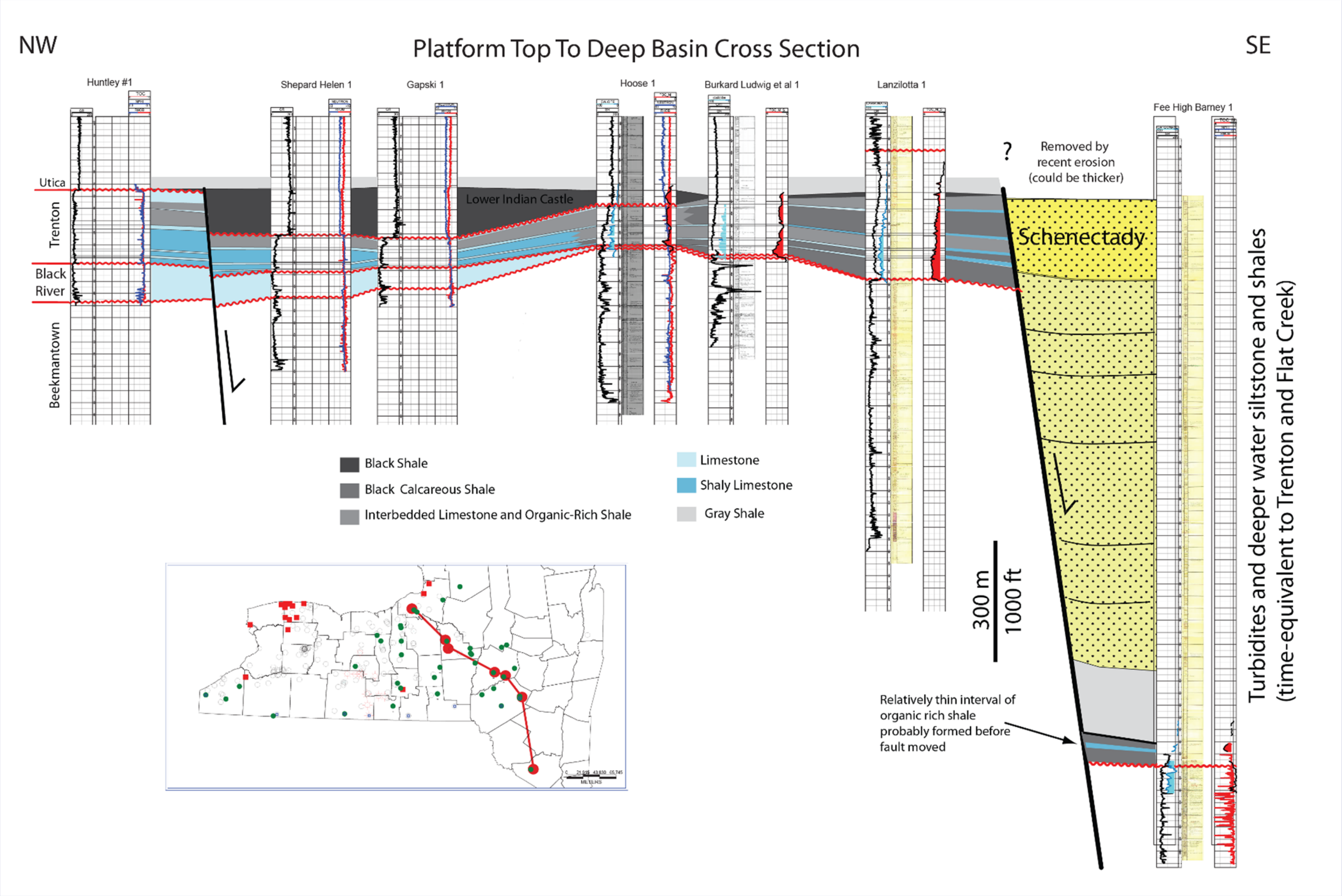
Tectonic high moves to west from Black River to basal Trenton time – western NY also becomes a high – fault-controlled

Total Organic-rich mudrock (not including Trenton)

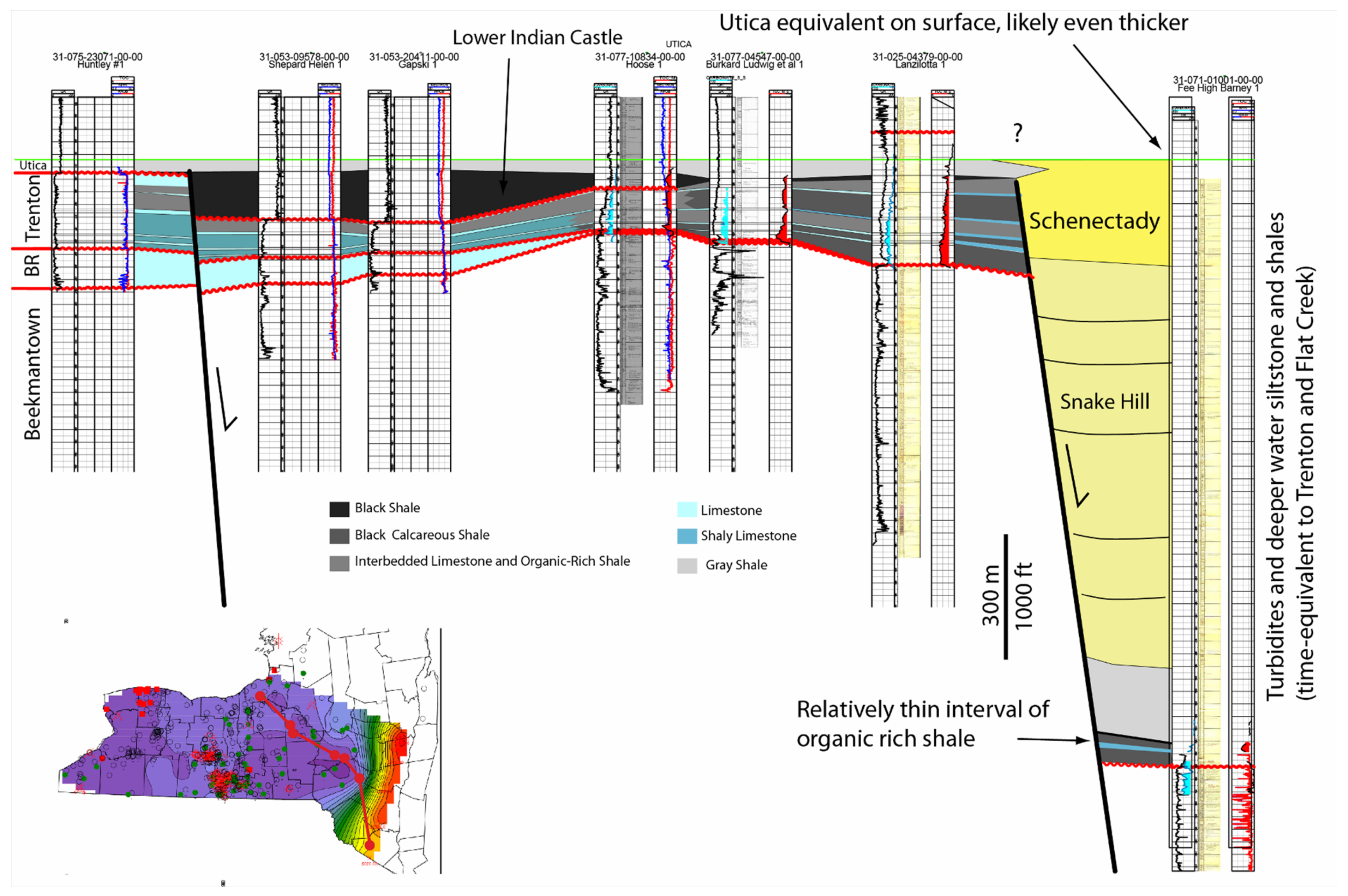


Recently found a very old well located here

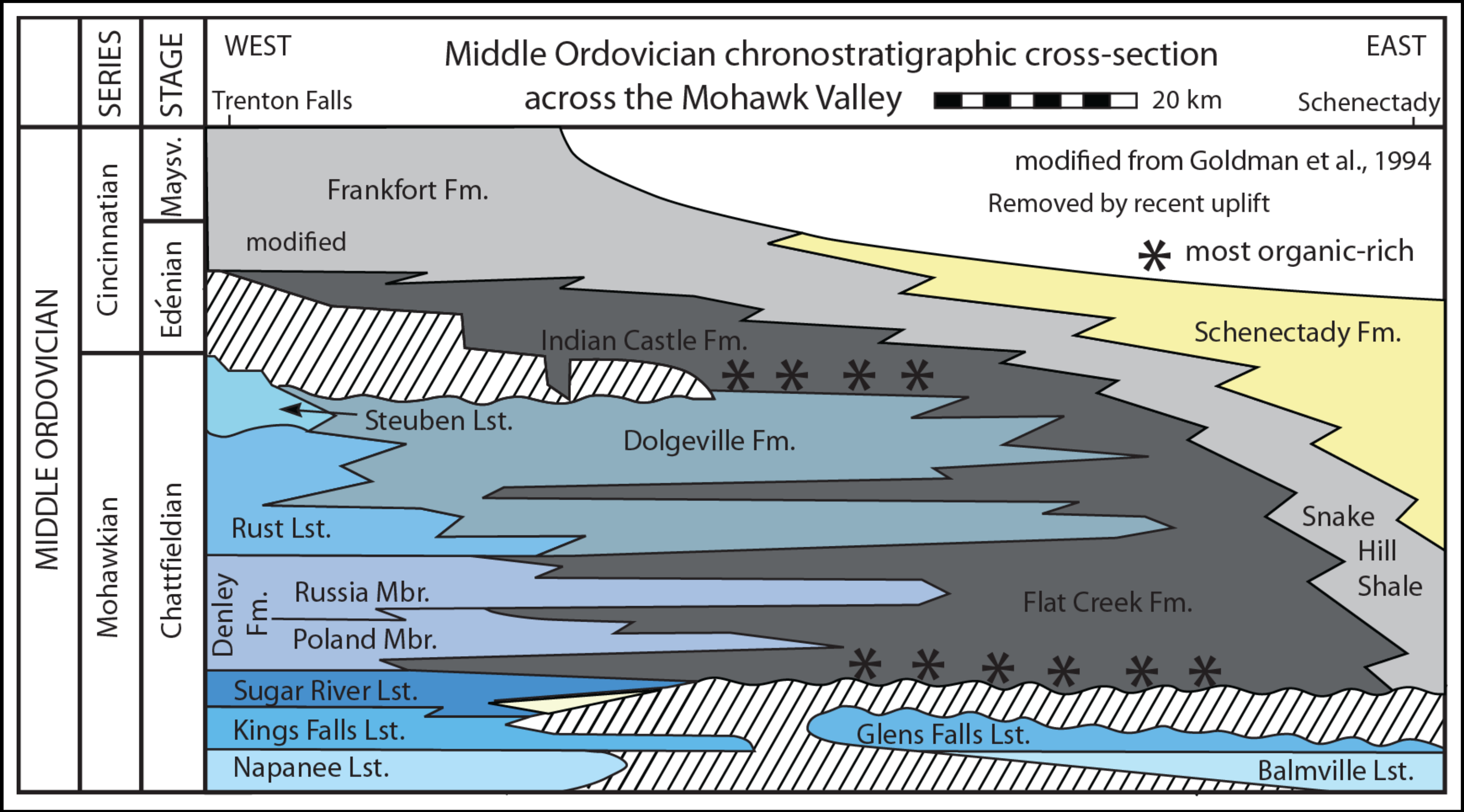
Platform Top To Deep Basin Cross Section



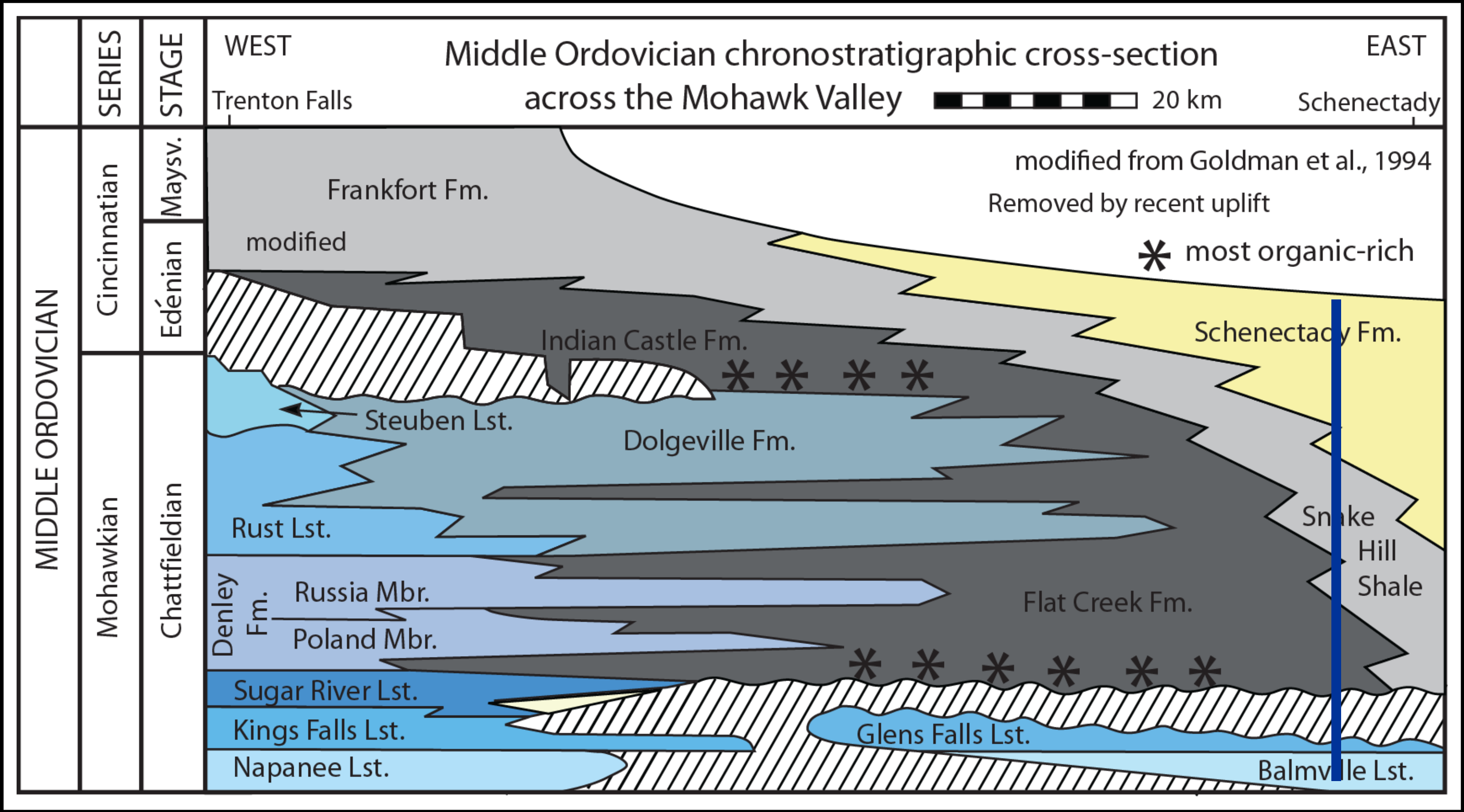
5500 feet of Utica equivalent clastics on downthrown side of fault with only minor organic-rich shale at base



Major normal fault(s) down to east accommodate sediment load from Taconic Mountains – Black shales mainly form on tectonic high



The Schenectady and Snake Hill Formations are siliciclastics that are Trenton and Utica equivalents to east – mainly turbidites that are called the Martinsburg further south



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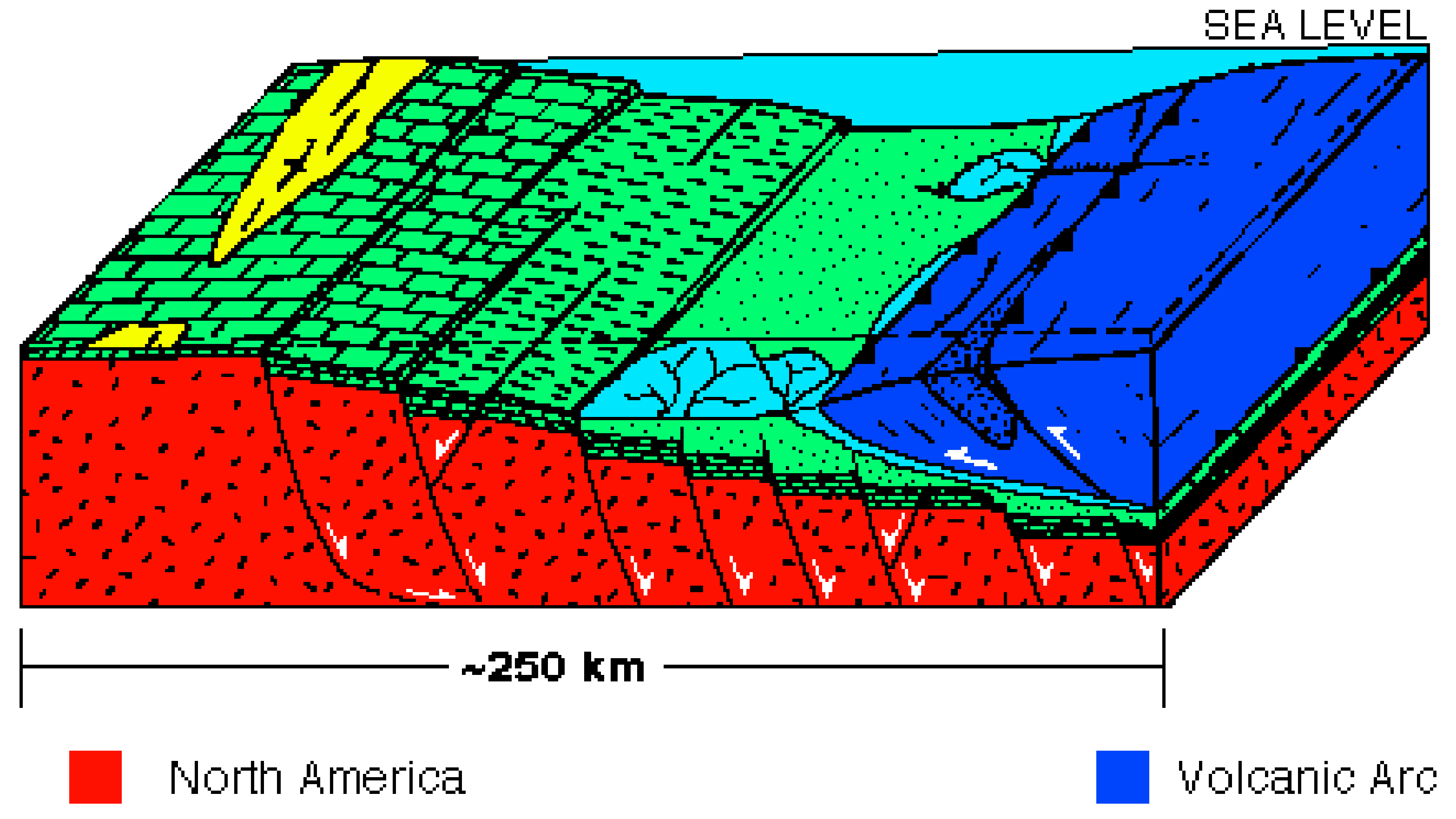
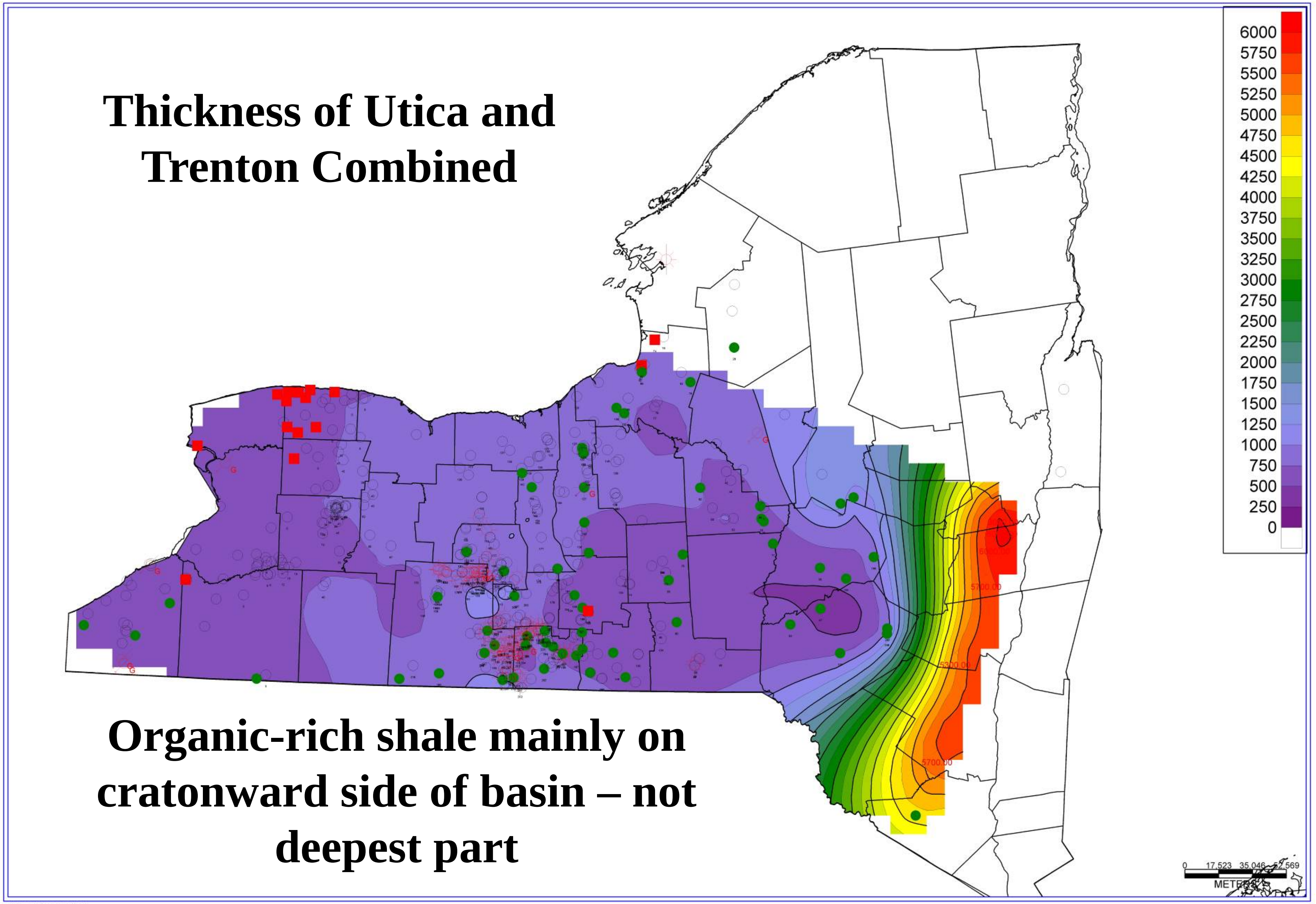


Bradley and Kidd (1991) model for Taconic – clastics coming off Taconic mountains butting up against normal faults – scale may be a little off - up to 2km (6500 feet) of Turbidites, <250m (800 feet) of shale and limestone to west

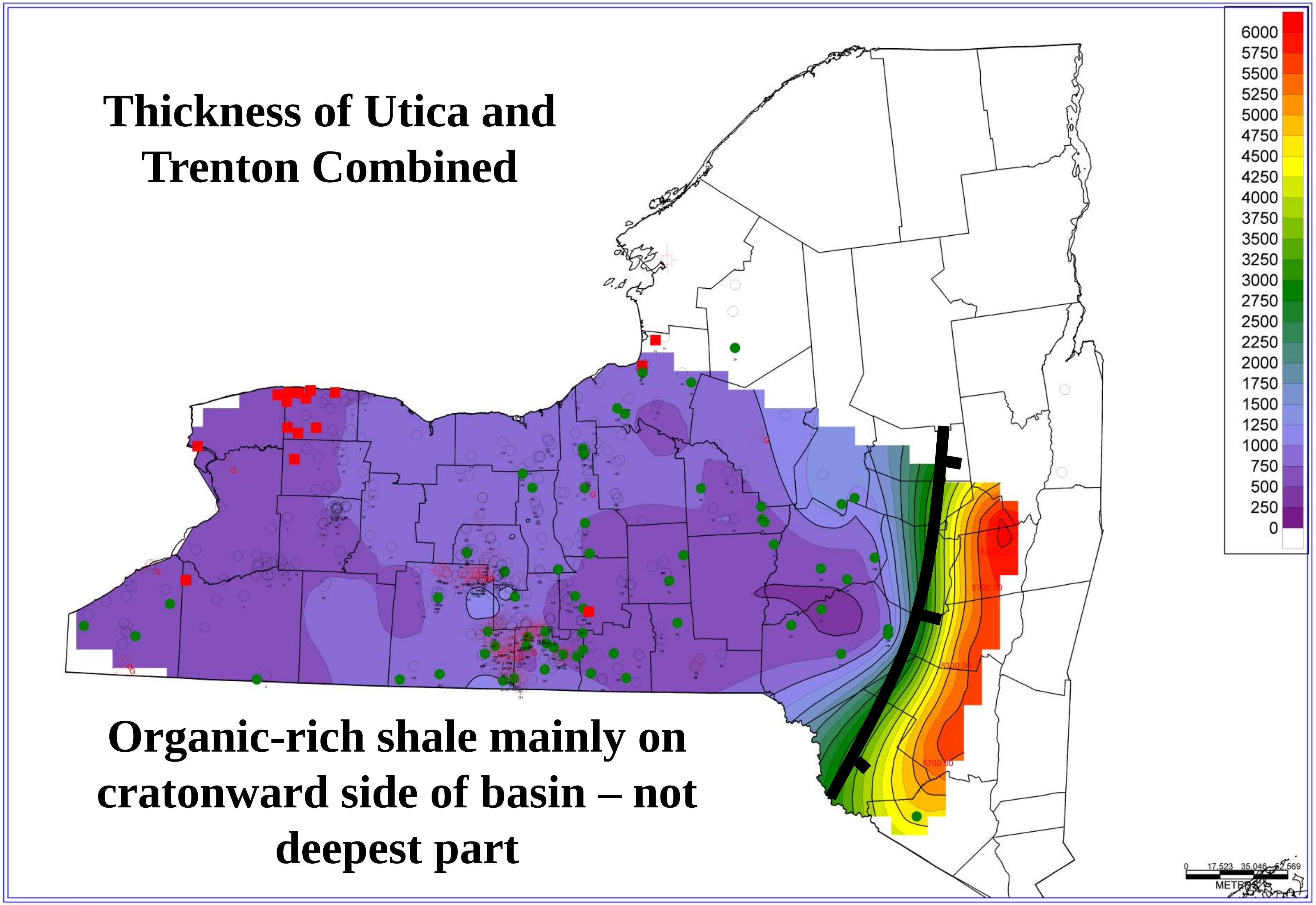
Thickness of Utica and Trenton Combined



Organic-rich shale mainly on cratonward side of basin – not deepest part

Organic-rich shale mainly on upthrown shallow side of fault

Thickness of Utica and Trenton Combined



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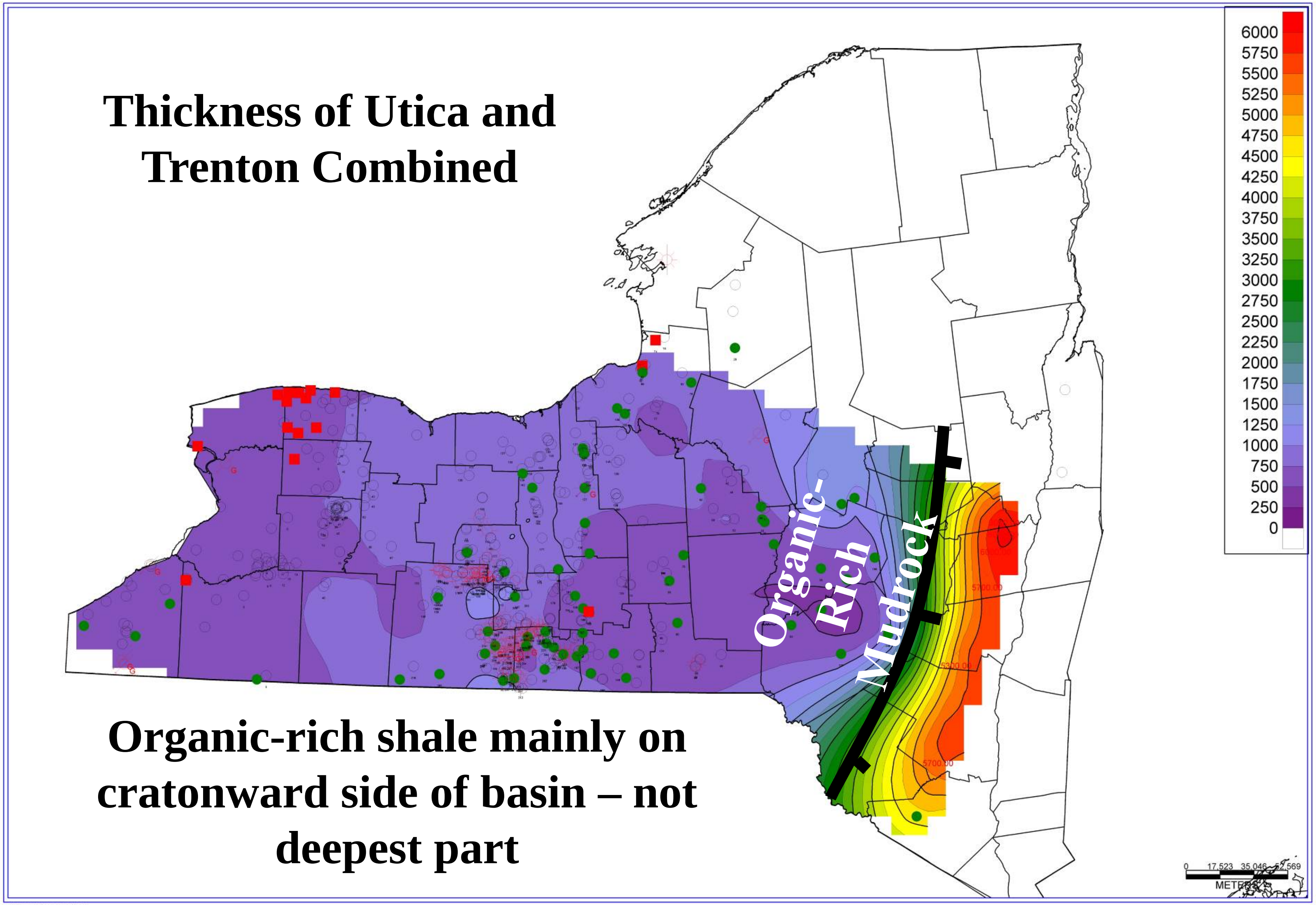

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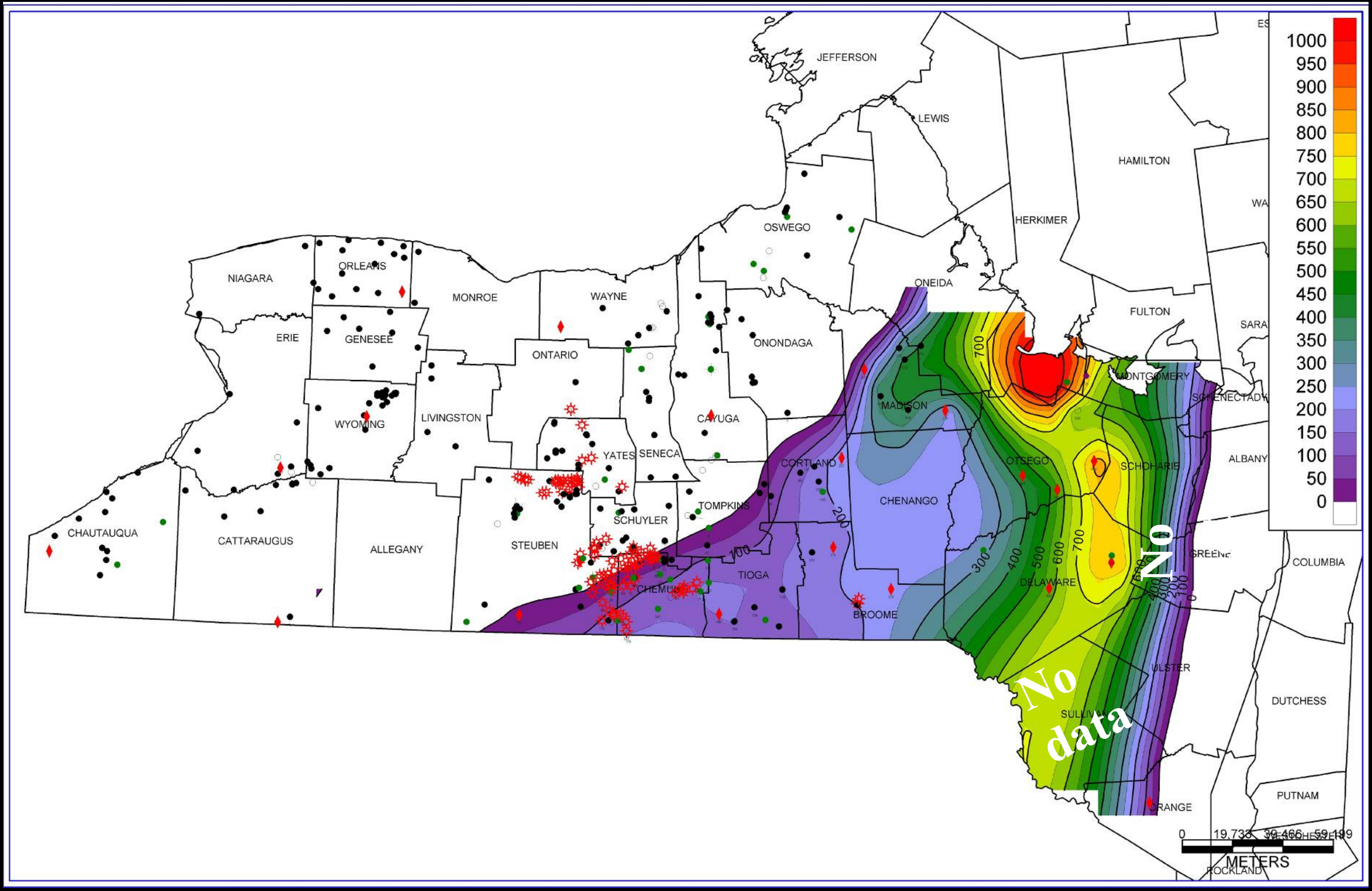
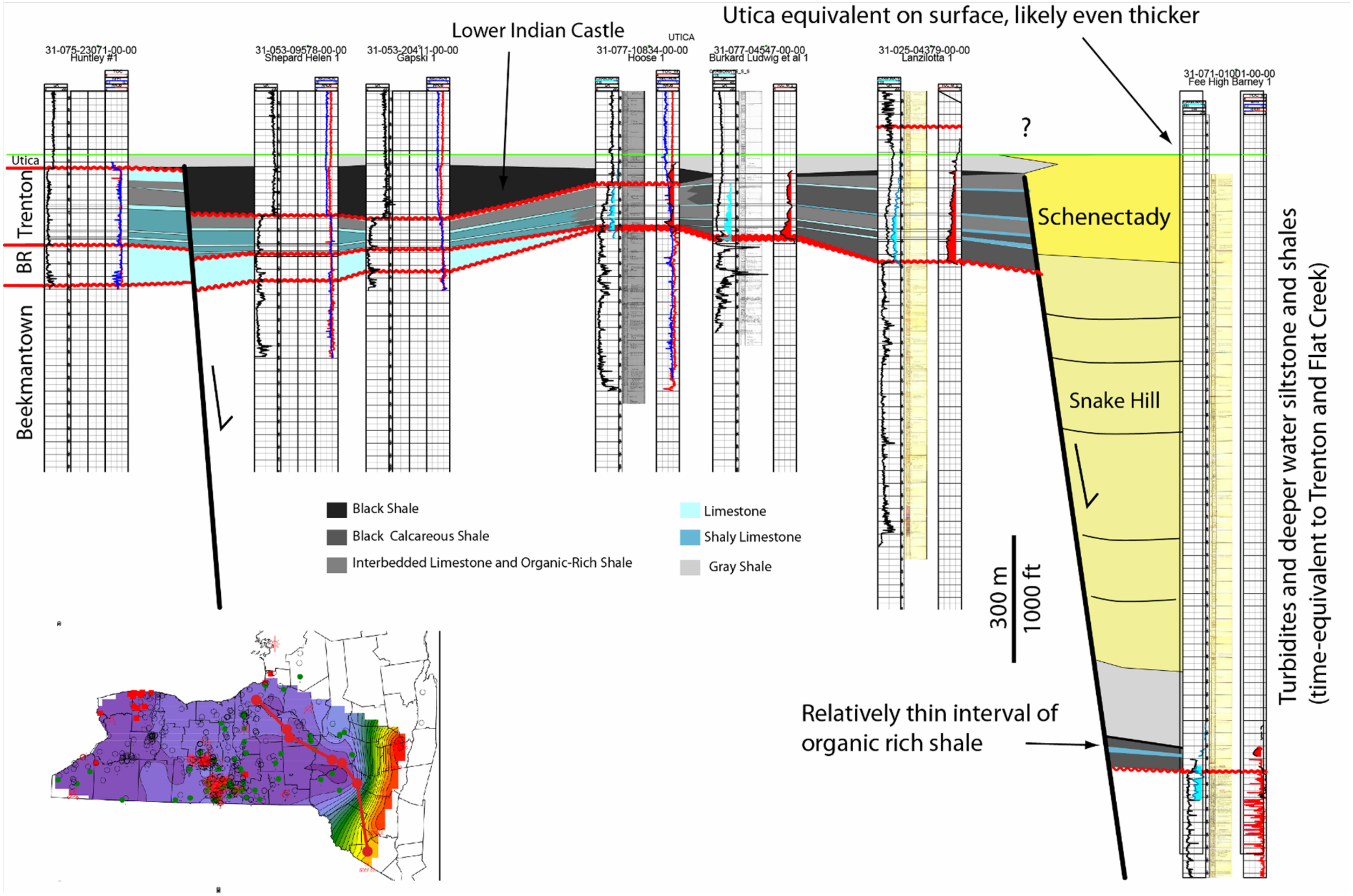
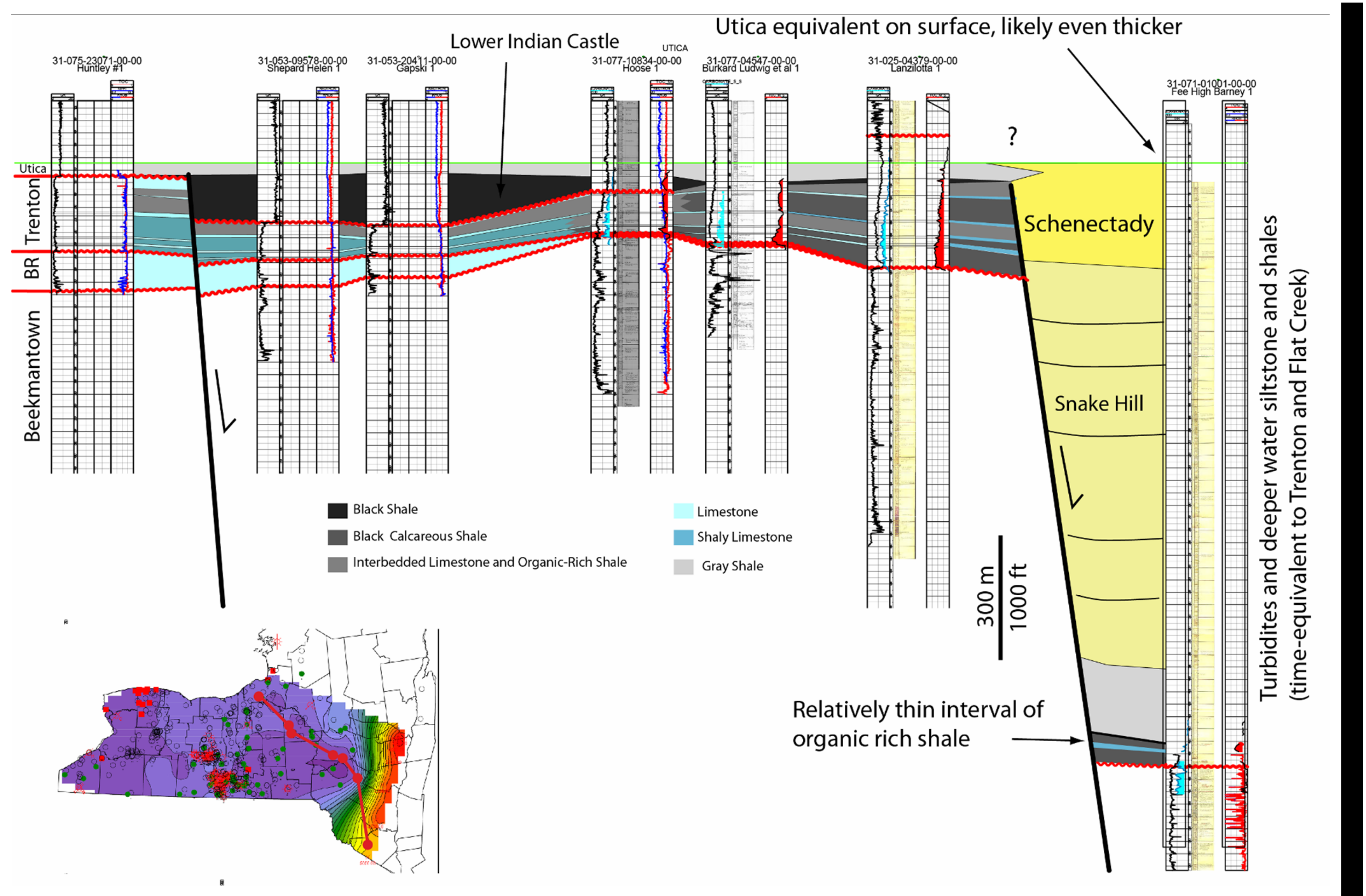


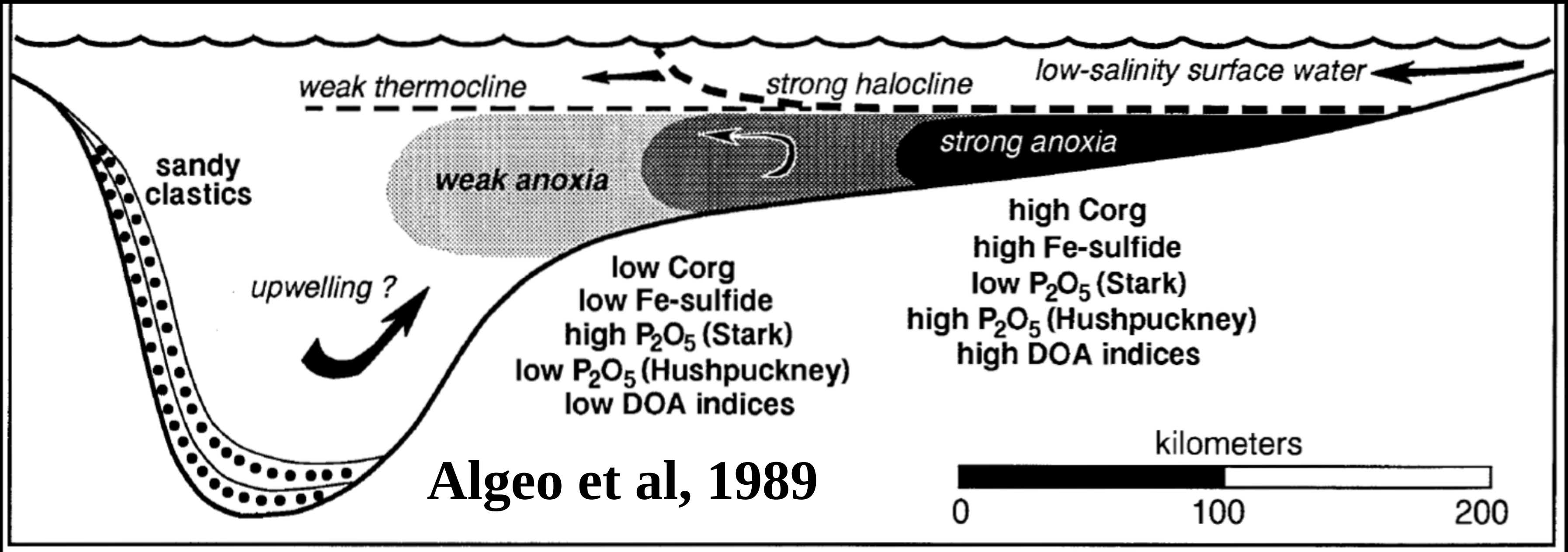
Estimated total thickness of organic-rich Utica (including Flat Creek, Indian Castle speculative in east where there is little data



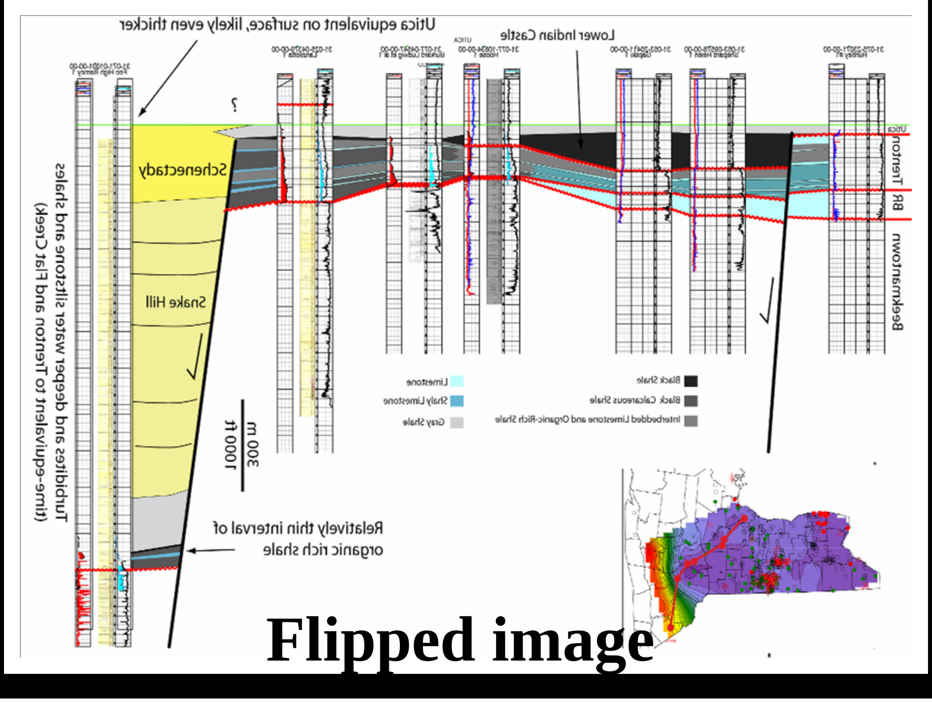
Major normal fault(s) down to east accommodate sediment load from Taconic Mountains – Flat Creek forms on tectonic high between basin and positive feature, Indian Castle mainly fills fault-bounded low



How deep can the shales be? The real deep water is to east – the shales are filling lows on the tectonic high and are equivalent to periods of non-deposition on highest highs – they can't be too deep (<10-50m?)



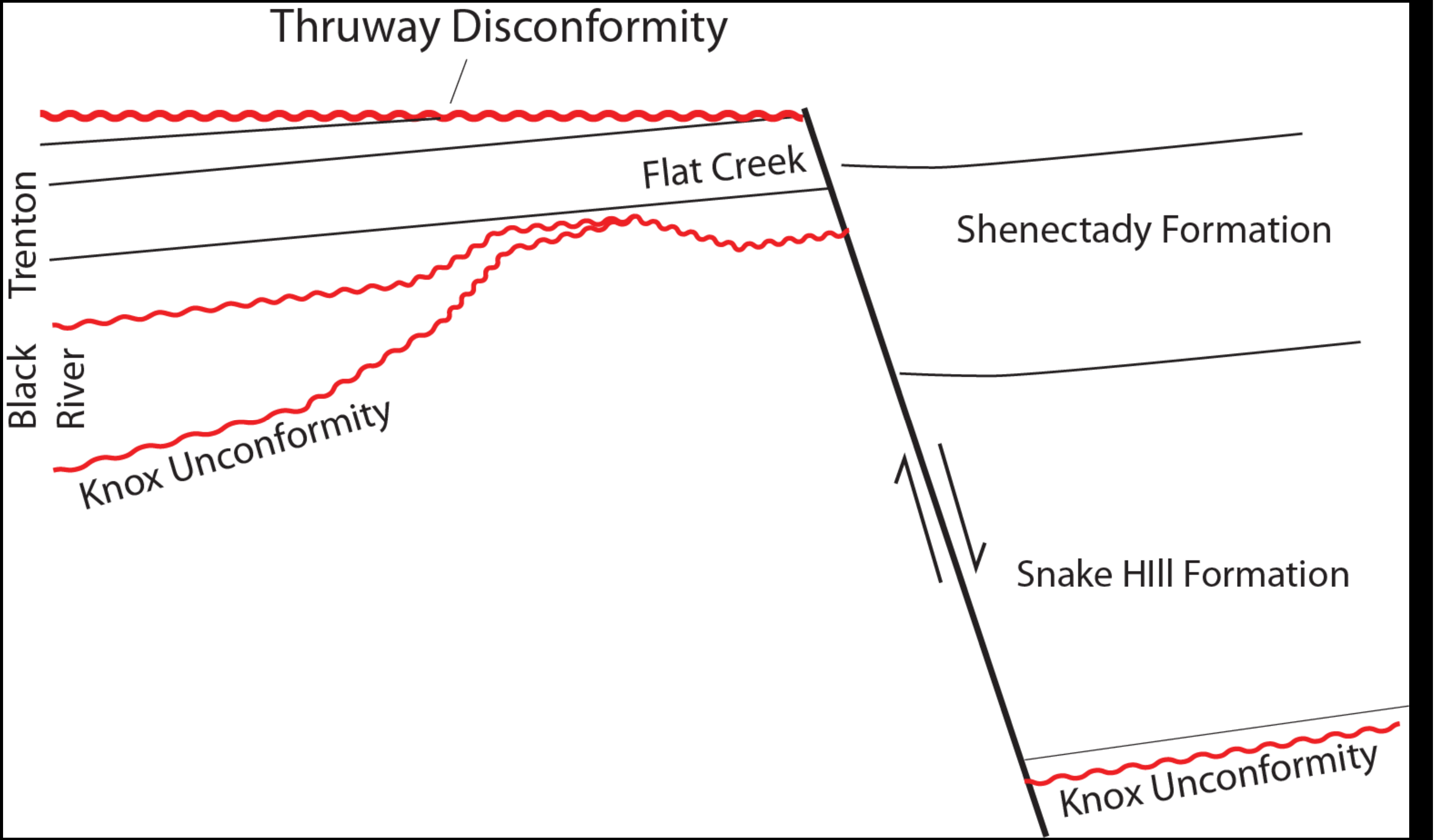
Algeo et al, 1989



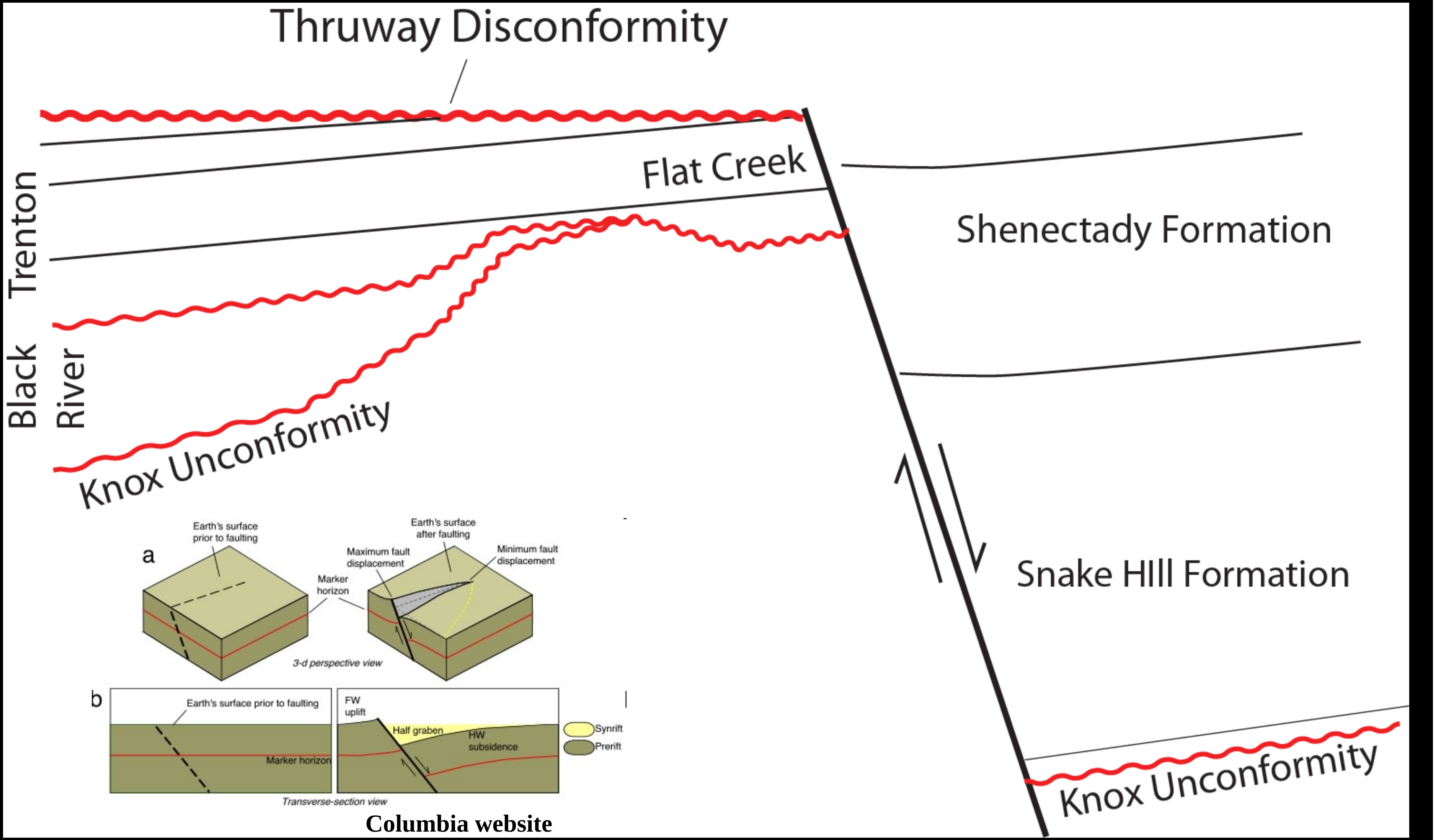
Flipped image

Organic-rich shale mainly on western margin, not deepest part of basin – very much like Algeo et al (1989) figure

Turbidites and siliciclastics in deepest water, organic-rich shales in shallower water on western side of



Model for the origin of Thruway Disconformity – "footwall uplift" - as big normal faults move to east, crust must rise to west to accommodate – it really is an angular unconformity – this is highly oversimplified but the idea may apply here



Columbia website

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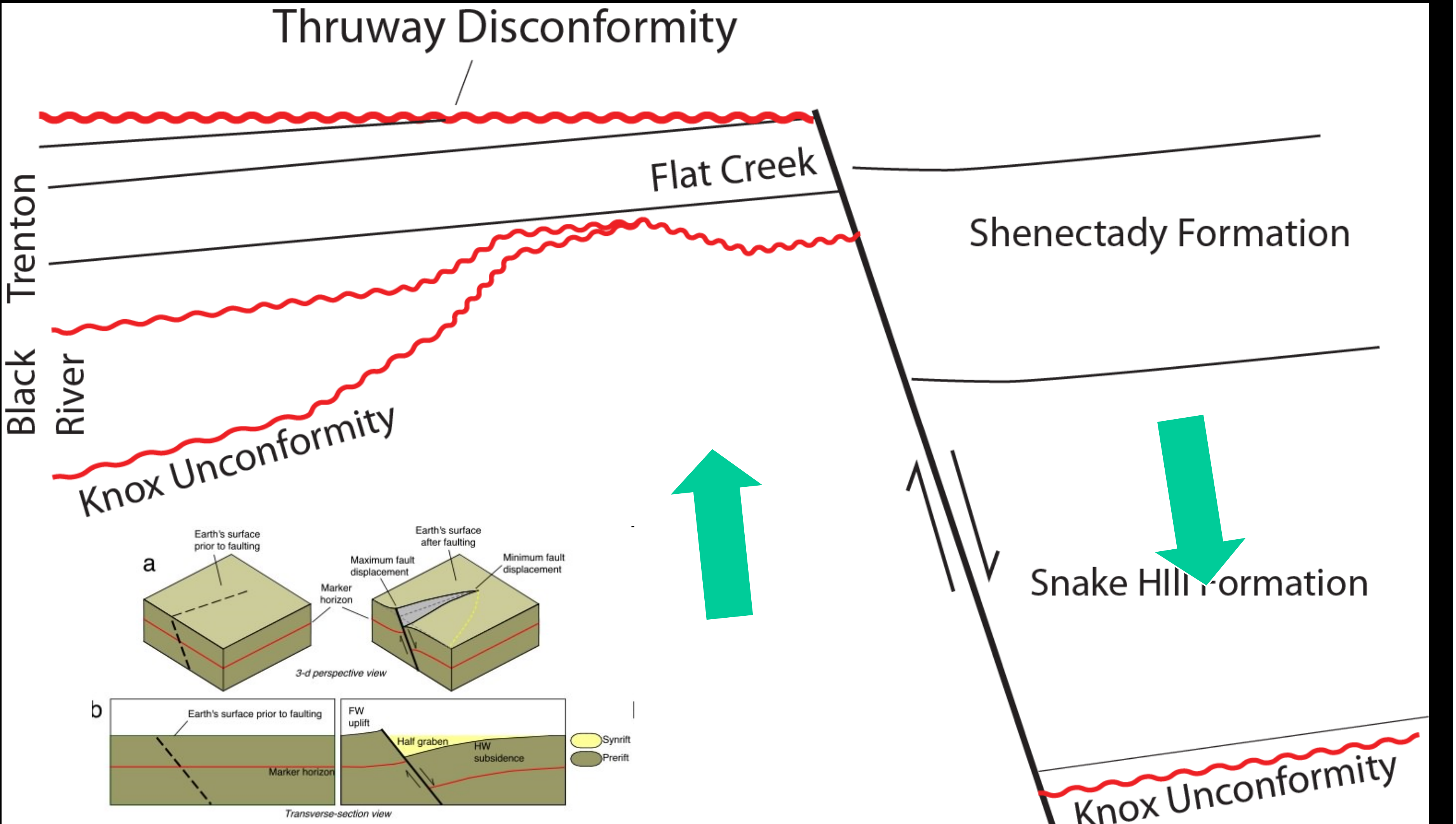

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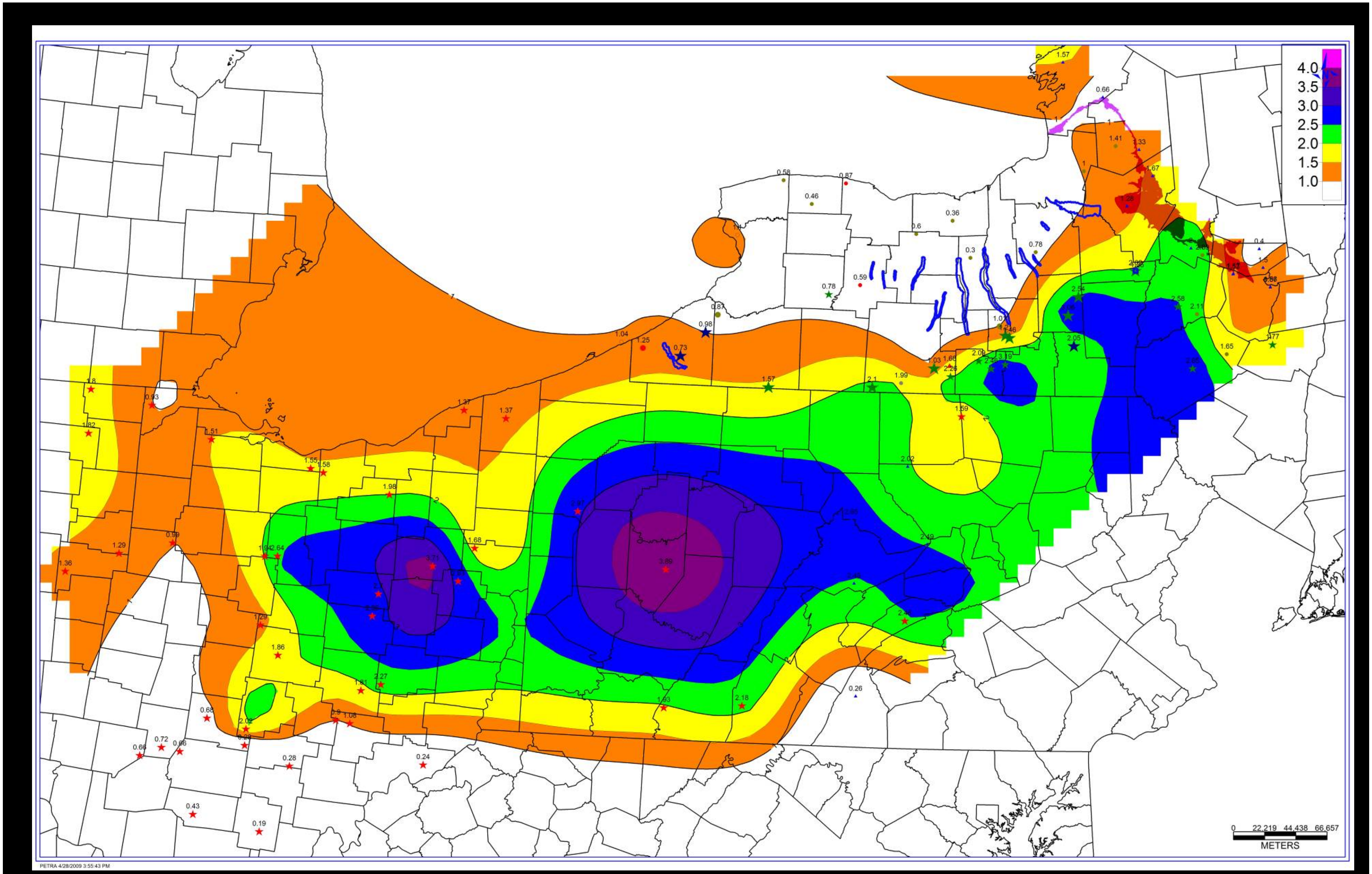
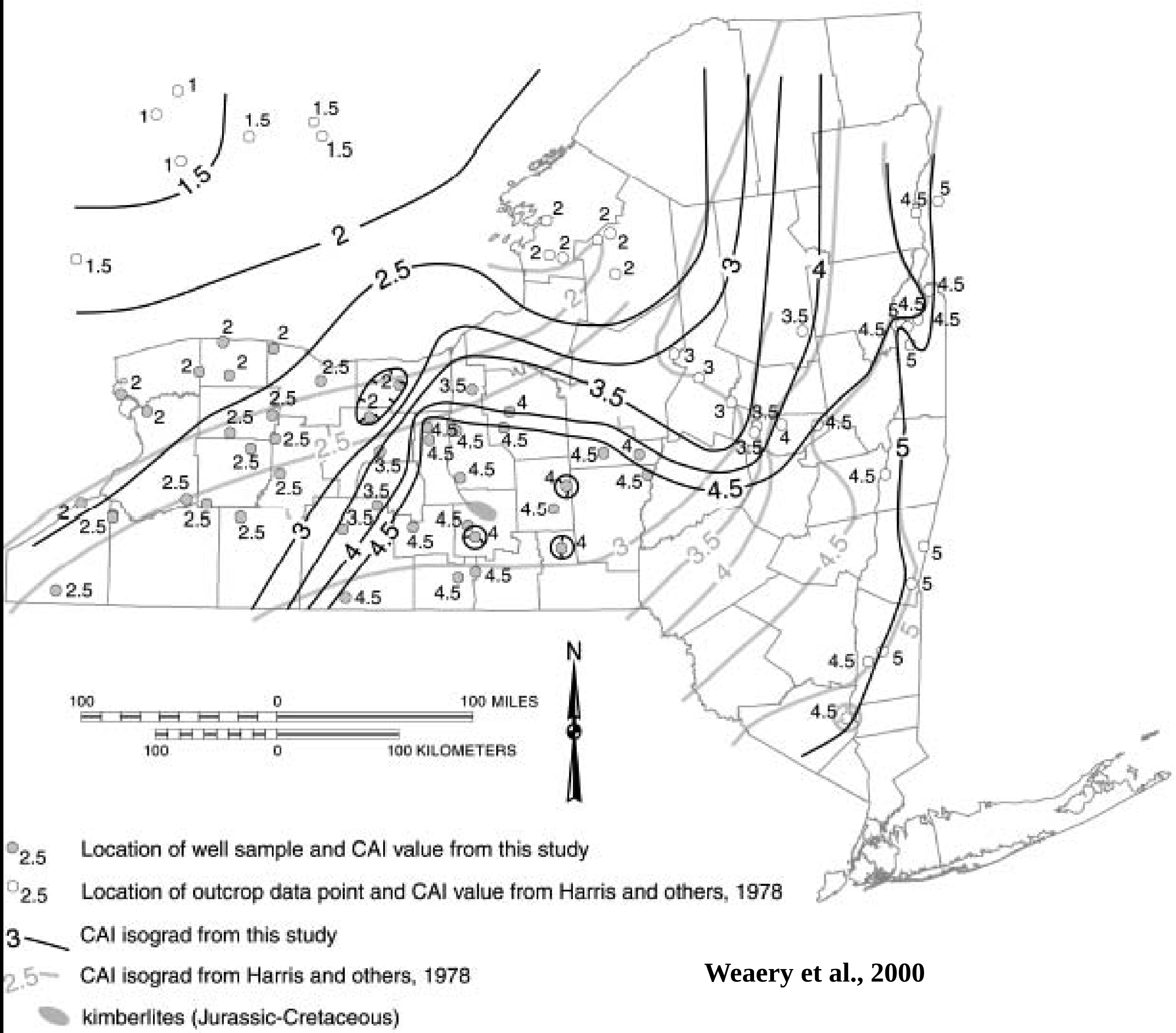


TOC map for Ordovician Utica Shale plotting highest value for each well in northeastern US – IN NY highest TOC to southeast

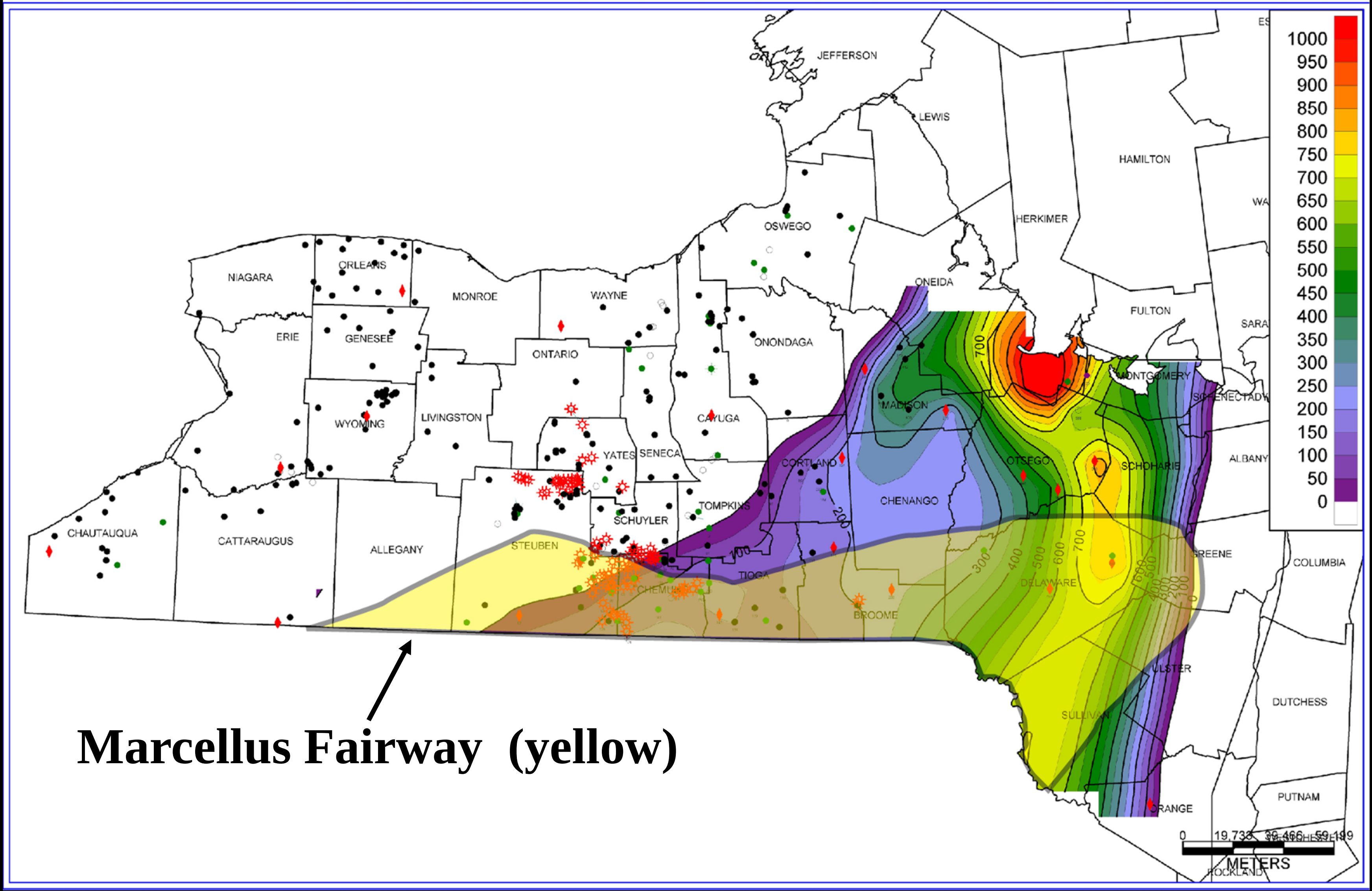
Middle to Upper Ordovician Conodont Alteration Index Isograds



Weaery et al., 2000

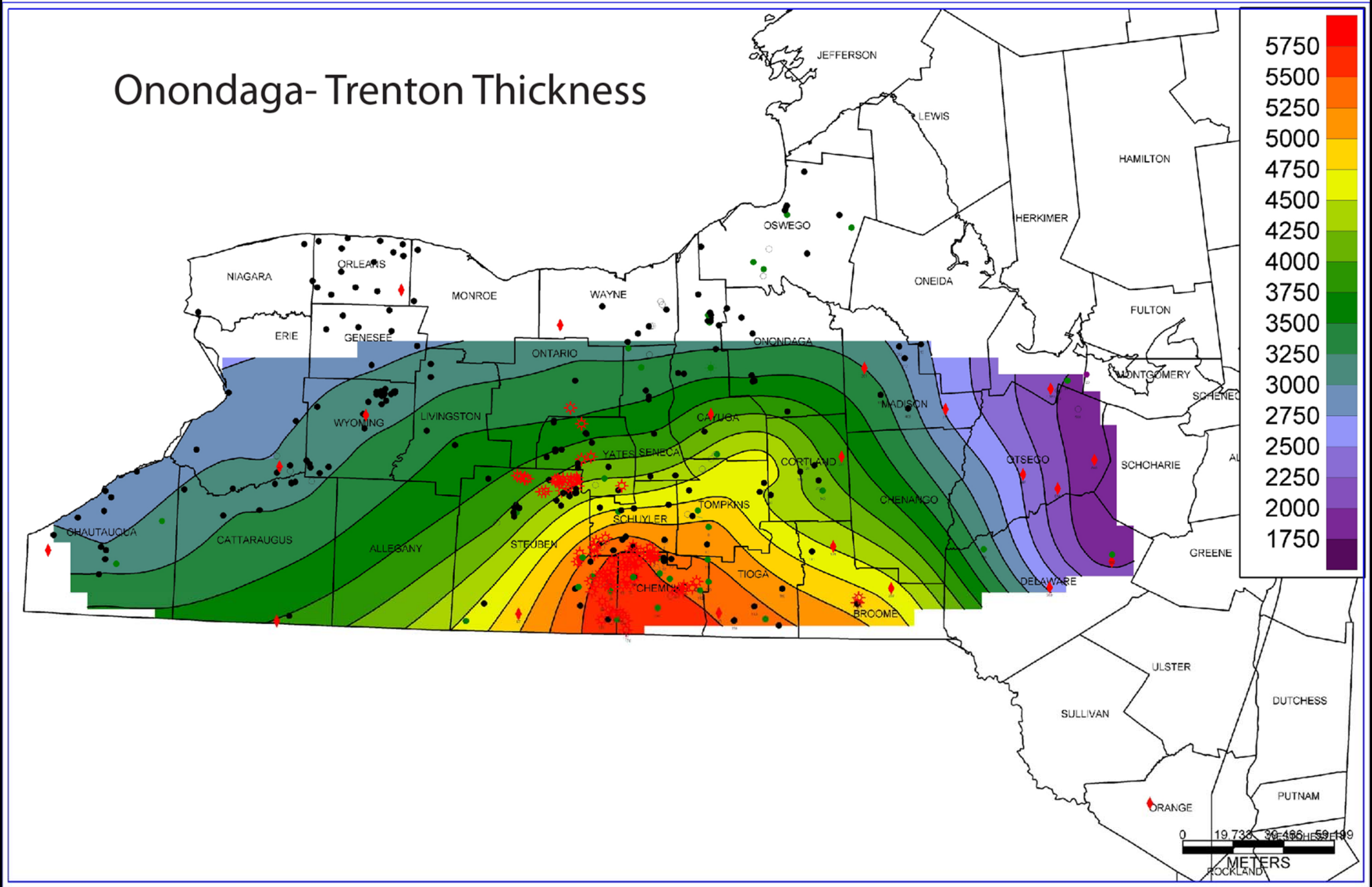
Vitrinite reflectance does not work in the Ordovician

Conodont Alteration Index shows very high thermal maturity equal to very high R_o (>3.5 or 4) in the east



Marcellus Fairway (yellow)

Special: 2 for 1- Utica and Marcellus fairways overlap in southern counties

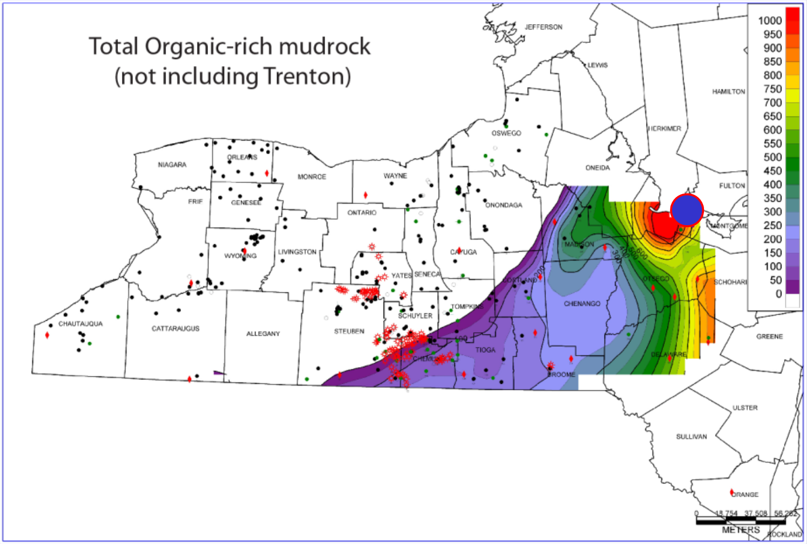


Thickness between Utica and Marcellus not the same everywhere – it is less in eastern NY

Summary

- Utica also appears to have been deposited in relatively shallow water on the west side of the basin, not the deepest part which is filled with organic-poor siliciclastics
- Utica was deposited during period of tectonic activity and best wells might be drilled into grabens where organic-rich section is thickest

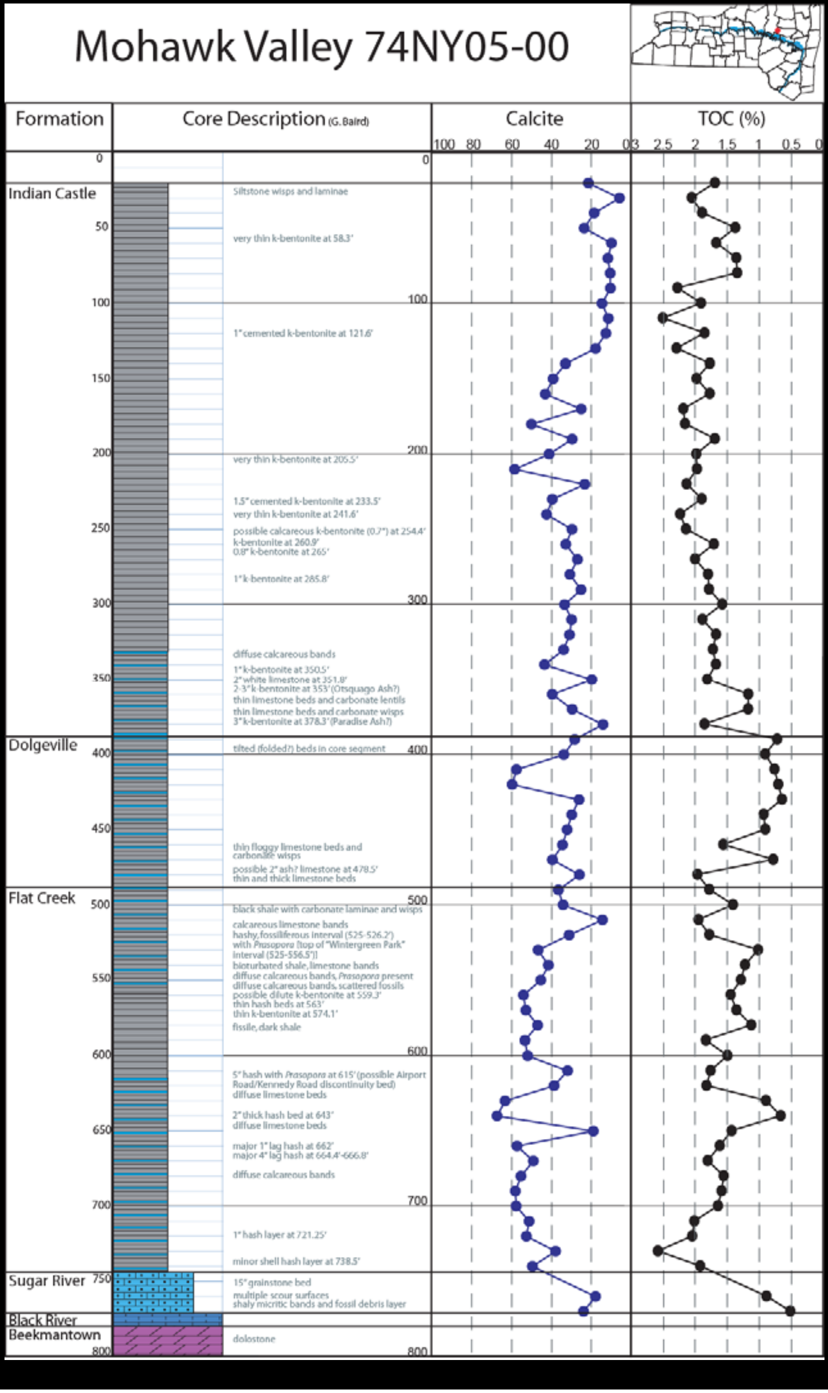
Thank You

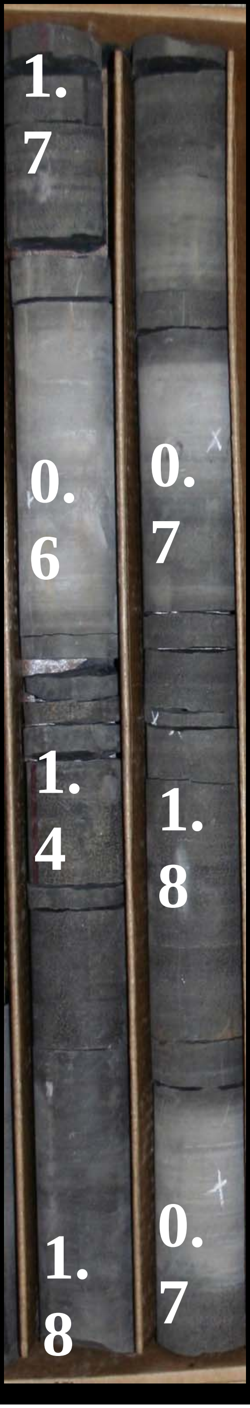


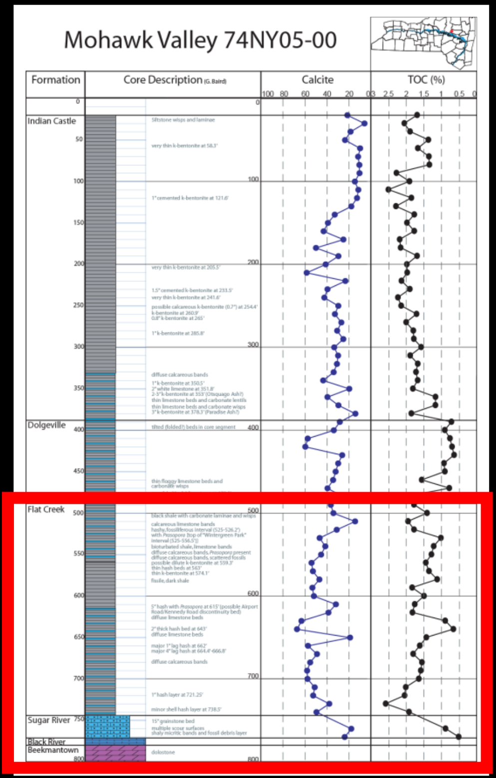
74-NY 5 has Lower Indian Castle, Dolgeville and Flat Creek Members of Utica

Highest TOC values in basal Flat Creek immediately over unconformity and in Lower Indian Castle

This may be from the east side of the graben







More detailed analysis shows that interbedded limestone and shale go back and forth between about 2% and <0.8% at very high frequency - this work in progress