Shallow Onlap Model for Ordovician and Devonian Organic-Rich Shales, New York State*

Taury Smith[1] and Jim Leone[2]

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Abstract

Sedimentology, field relations and regional correlations show that organic-rich mudrocks in the Devonian Marcellus to Dunkirk Shales and the Ordovician Utica Shale of New York, which have historically been interpreted to have been deposited in deep anoxic basins greater than 150 meters deep, may in fact have been deposited in relatively shallow water of less than 50 meters. These black shales were mainly deposited on the present-day western or cratonward side of the basin, not in the deepest part or at the toe of a prograding clastic wedge as is commonly interpreted. The organic-rich black shales commonly overlie, onlap, and pinch out on unconformities, some of which are demonstrably subaerial in origin. Both the Ordovician and Devonian black shales were deposited during periods of high tectonic subsidence driven by thrust-loading to the east. Black shale deposition occurred in the Appalachian Basin while areas to the west were exposed land suggesting relatively low eustatic sea level during deposition.

These observations have led to the development of a new depositional model for black shales in actively subsiding foreland basins. In this model, eustatic sea level is interpreted to have been relatively low and there is subaerial exposure on the arches to the west of the basin. Black shale is deposited in relatively shallow water (most likely <50 meters deep) on the western, cratonward flank of the basin in what are likely to have been seasonally anoxic or dysoxic conditions. The zone of anoxia may have mainly been at or slightly above the sediment-water interface. In situ benthic fossils are abundant in some of these organic-rich shales suggesting periods when the water was tolerable for some organisms. Cross-lamination and scour surfaces in most of the shales suggest conditions above storm wave base. The black shale is most organic-rich where it was deposited in the shallowest water to the west and becomes progressively less organic rich approaching the deepest part of the basin where turbidite and gray shale deposition occurred. This at least in part due to progressively more dilution from clay and silt that are sourced from the highlands to the east but it may be that the longest duration of anoxic conditions occurred in the shallowest water.

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Taury Smith and Jim Leone

New York State Geological Survey

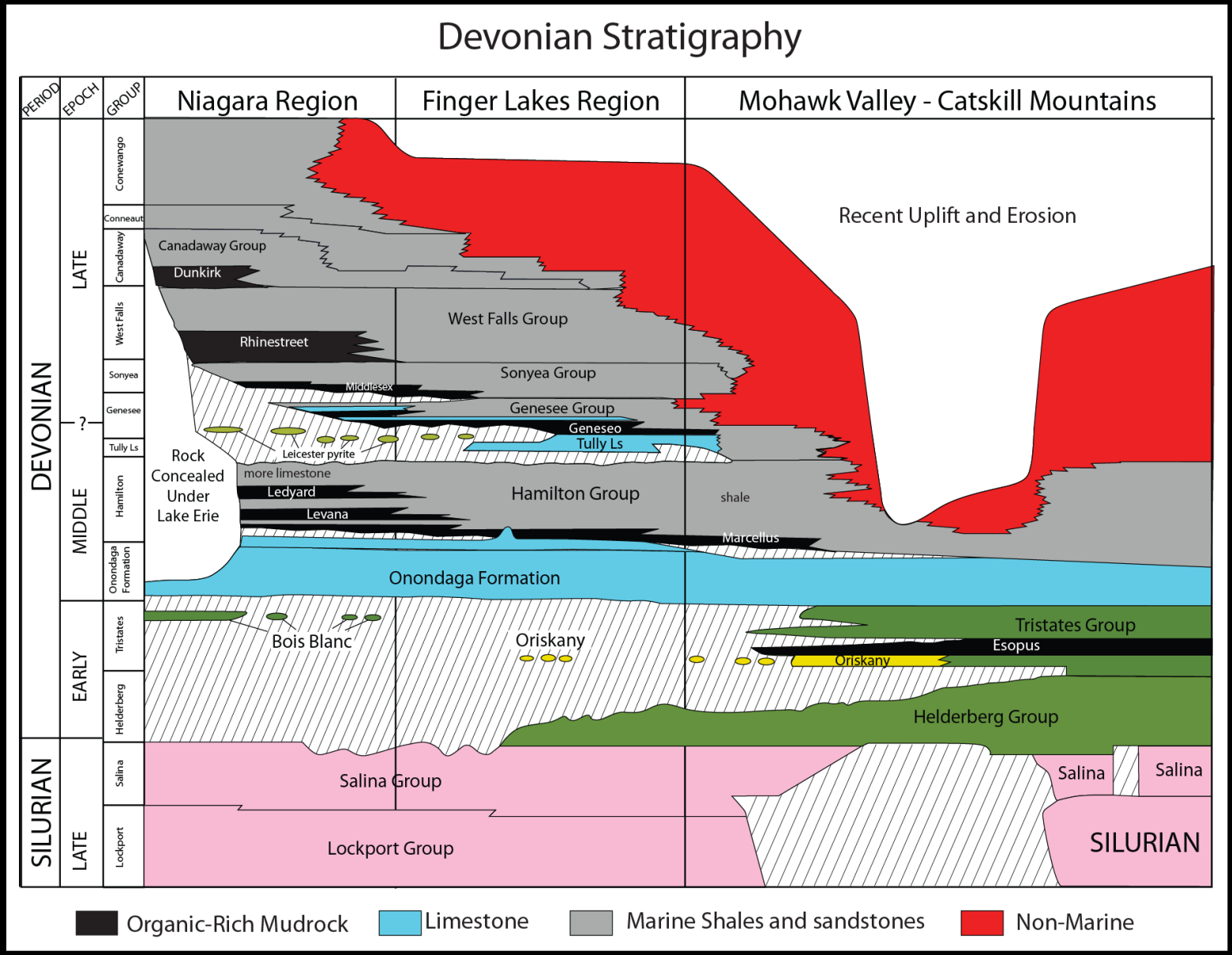
Reservoir Characterization Group at the New York State Museum

NEW YORK STATE GEOLOGICAL SURVEY Est. 1836 NEW YORK STATE MUSEUM

NYSERDA

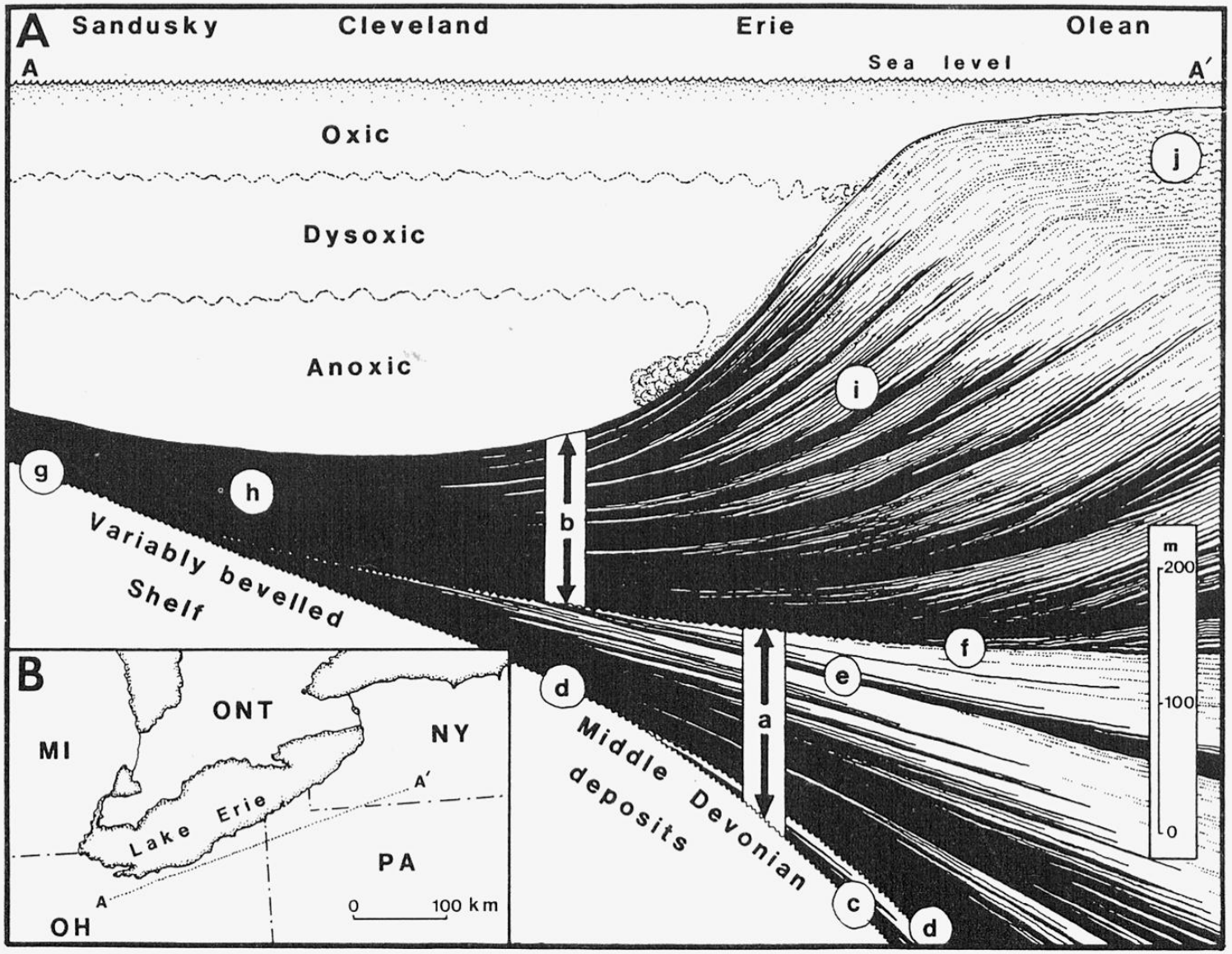
Main Goals

- To show that Ordovician and Devonian organic-rich shales of New York State overlie and onlap what in many cases were subaerial unconformities
- To show that these shales were deposited in relatively shallow, moving water that had periods of oxygenated bottom water

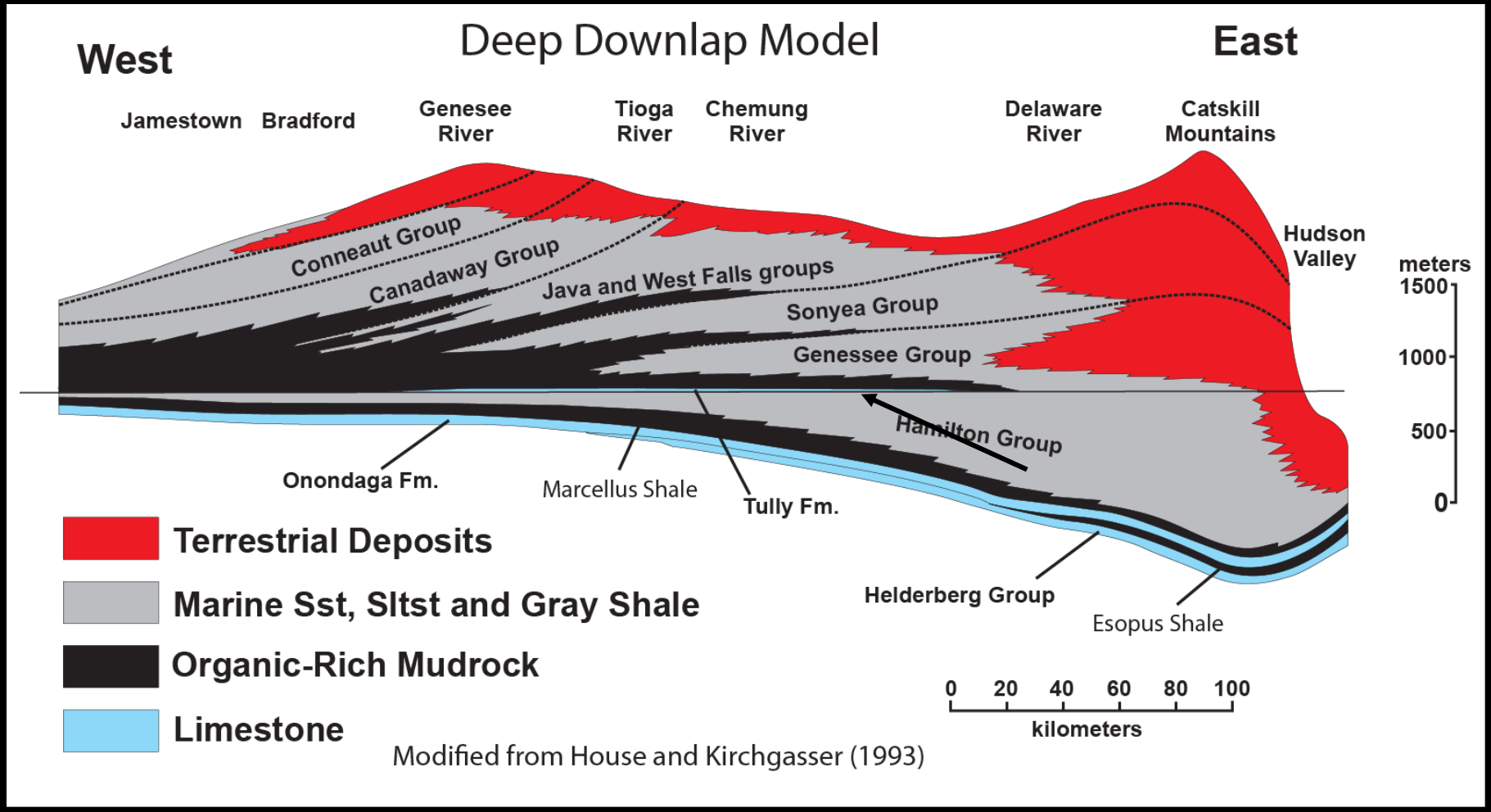


In fact most or all of the black shales in NY overlie and onlap disconformities - tentatively modified from NYS Geologic Highway Map based in subsurface observations

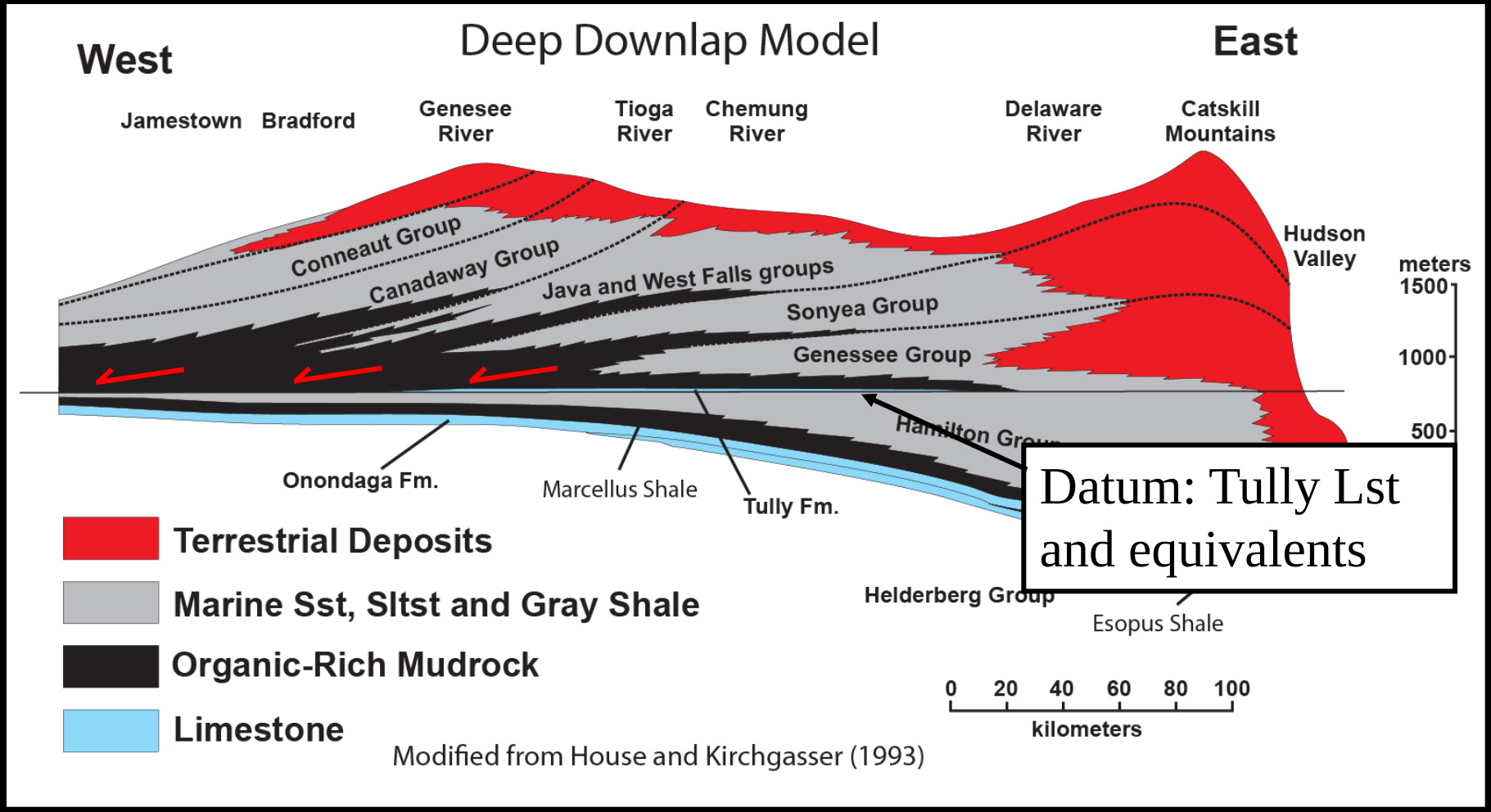
What happens here?



This model shows black shales forming in 200-250 m of water at toe of slope and deepest part of basin (from Baird and Brett, 1991)



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



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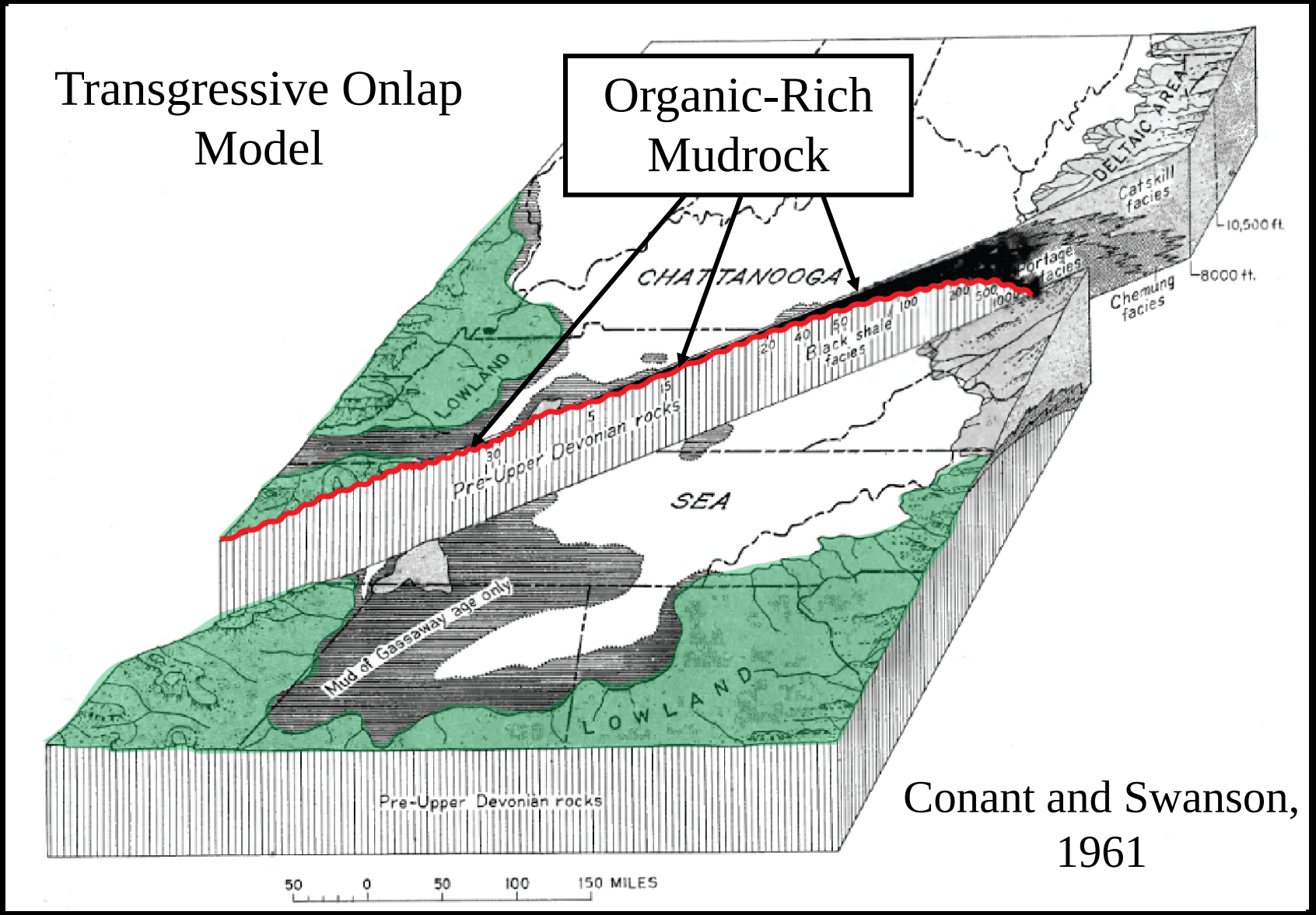
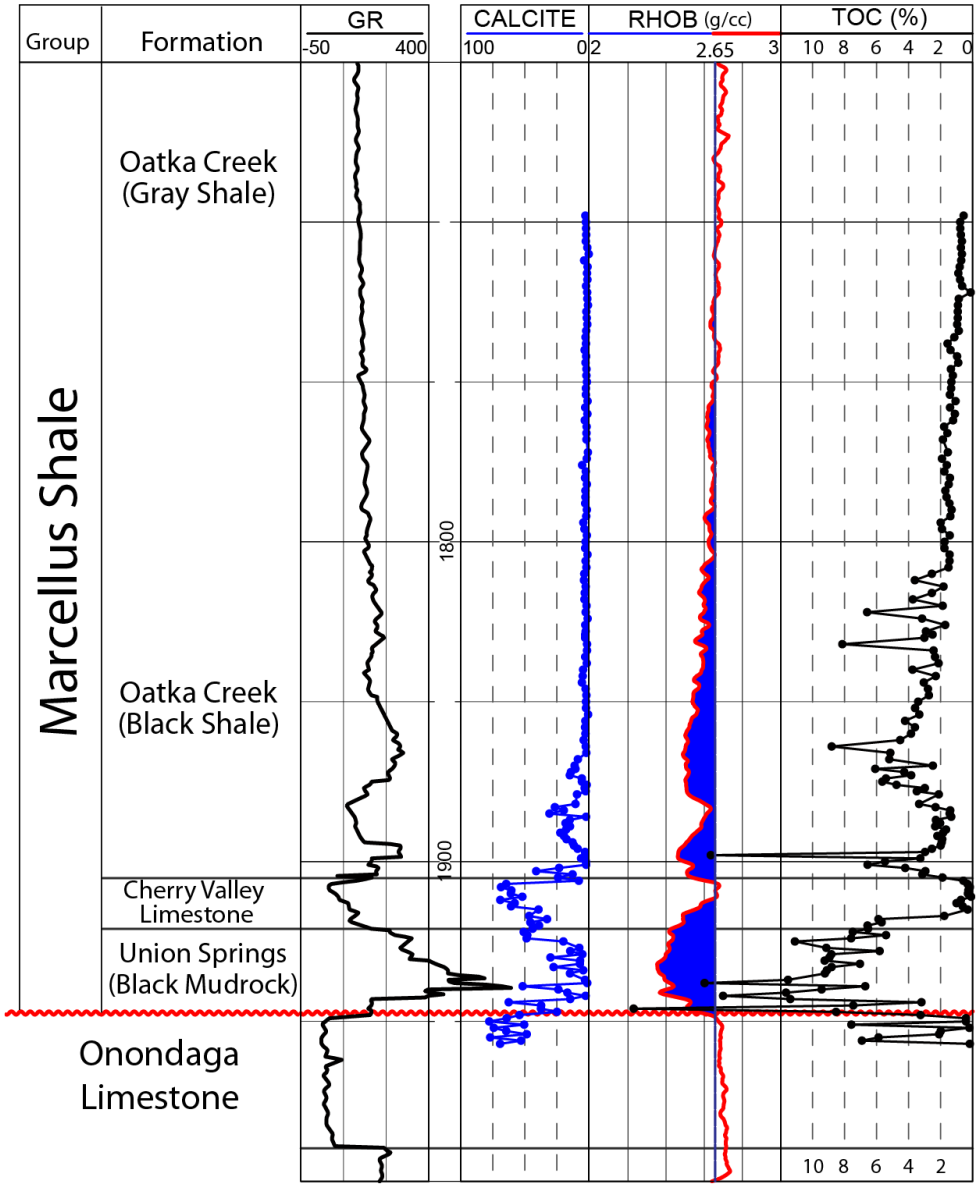


Organic-rich Devonian Chattanooga Shale overlies and onlaps an unconformity and is time-equivalent to exposure nearby – reasoned that water was likely less than 30m (100 feet) deep

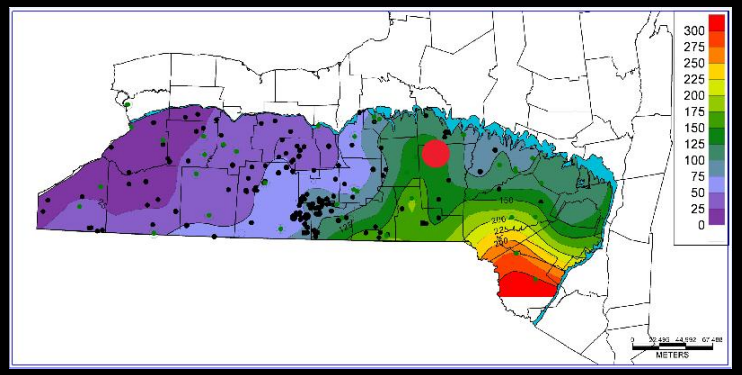
Beaver Meadows #1 Core

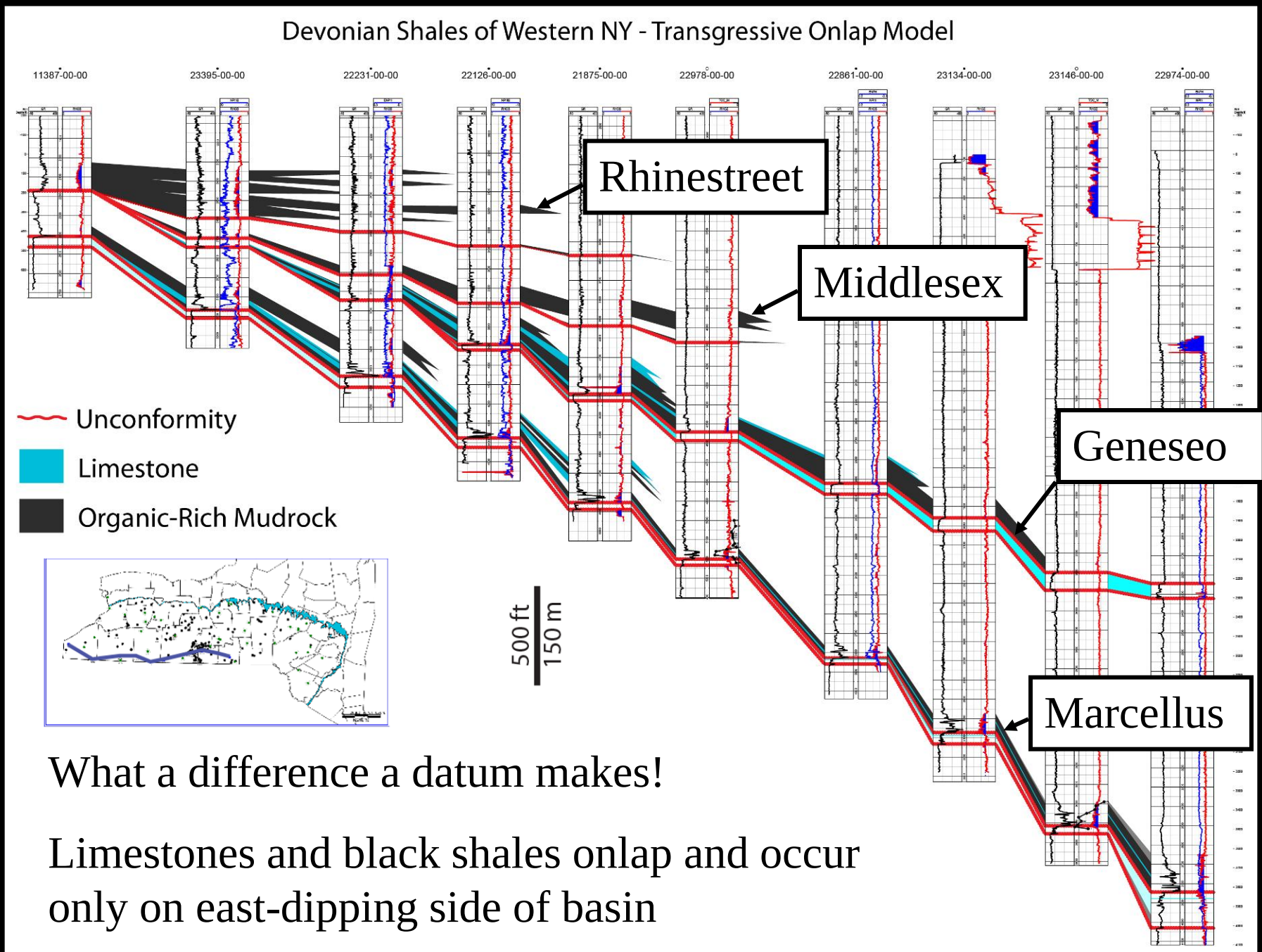


Measured TOC and calcite content on Beaver Meadows core 1 per foot

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

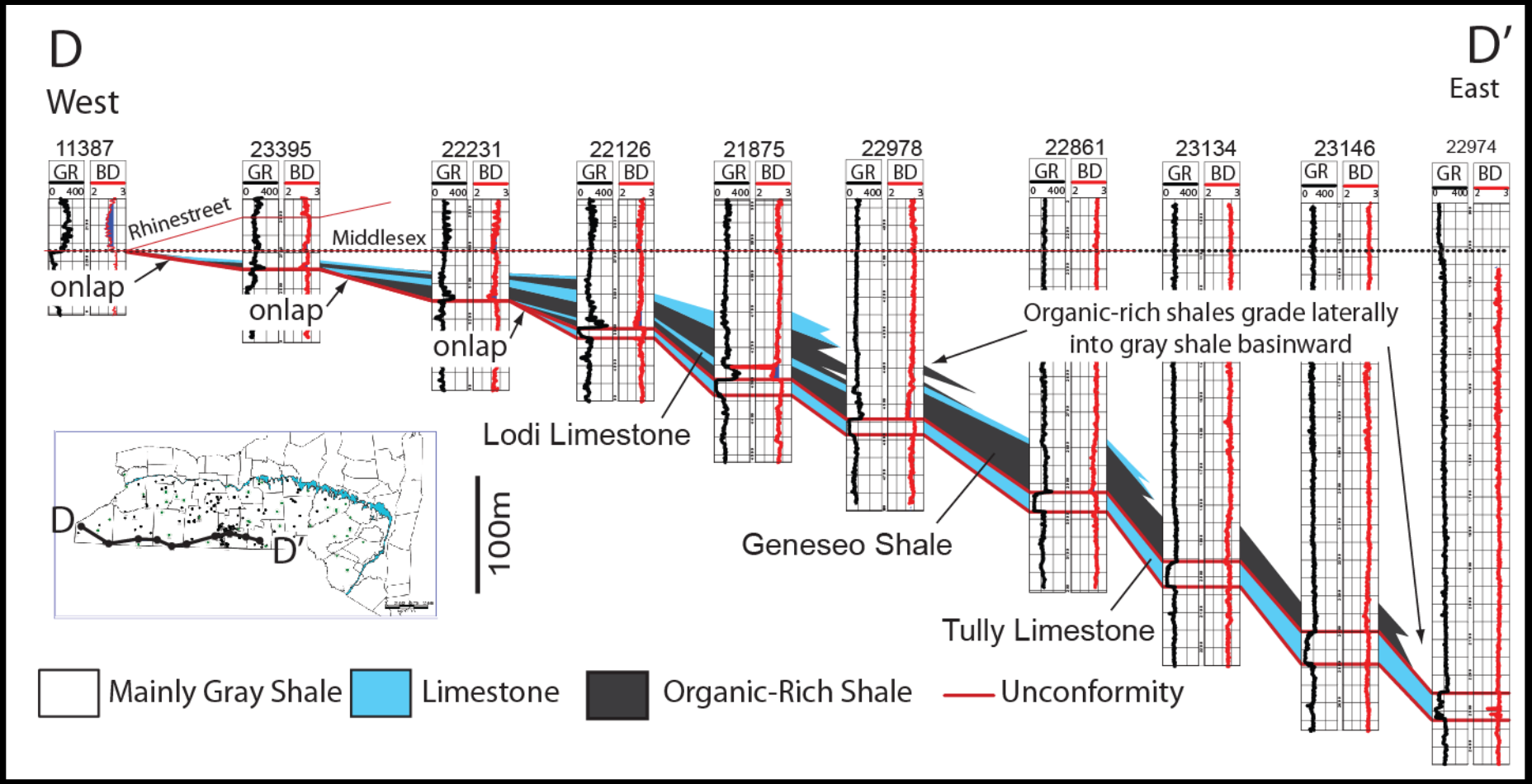
Calcite percentage also closely tracks GR at base, gray (silty) shale at top



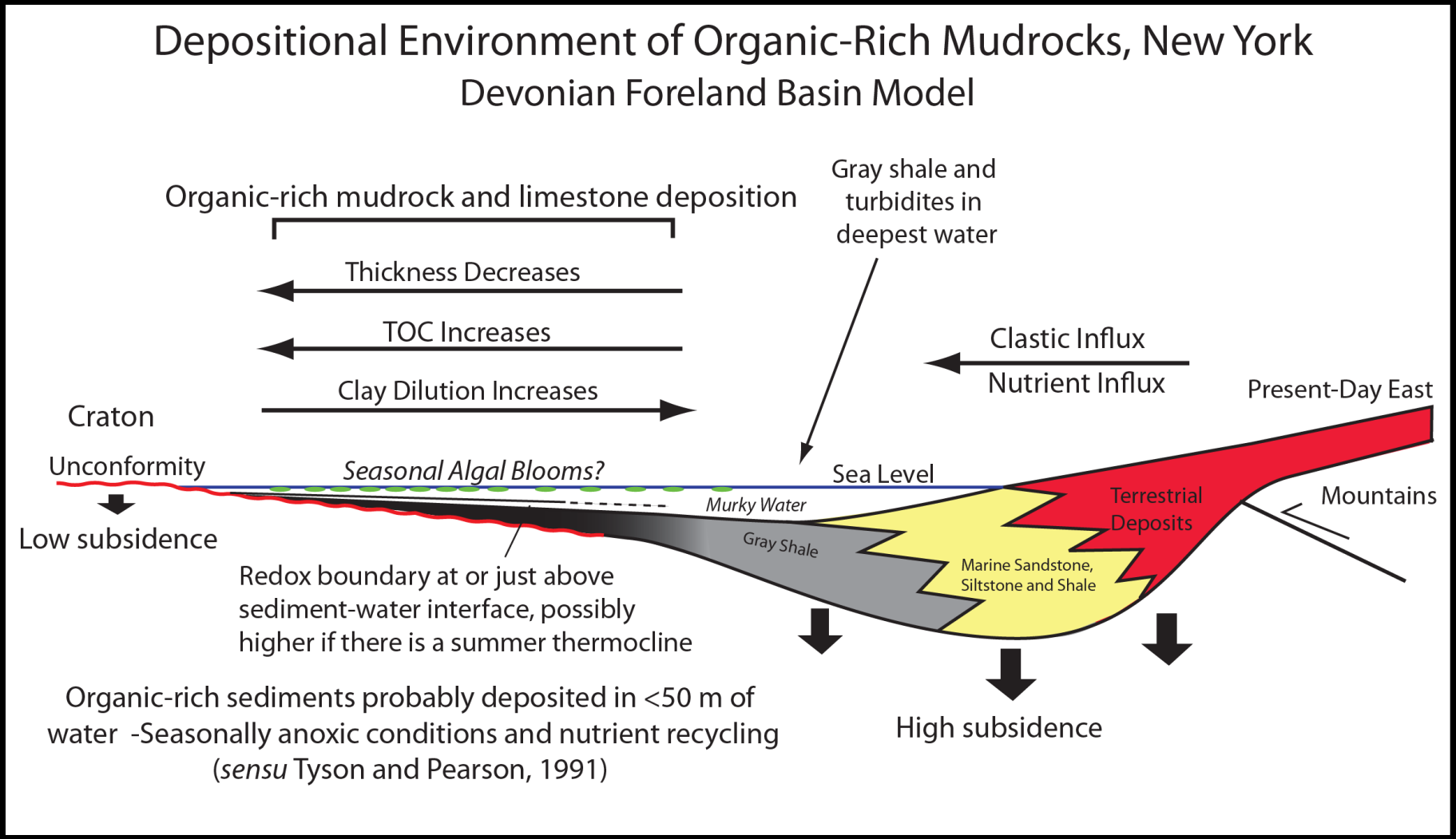


What a difference a datum makes!

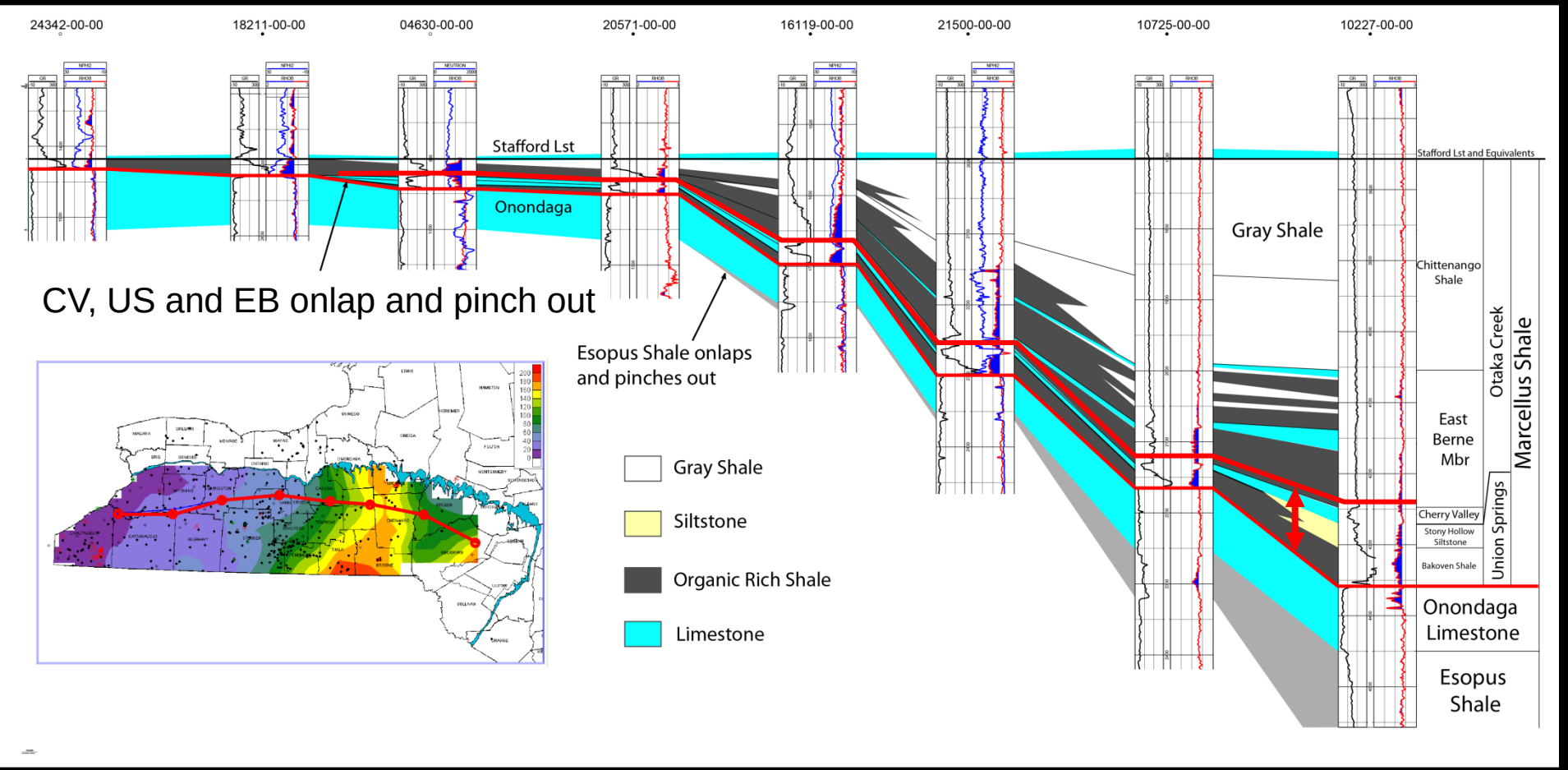
Limestones and black shales onlap and occur only on east-dipping side of basin



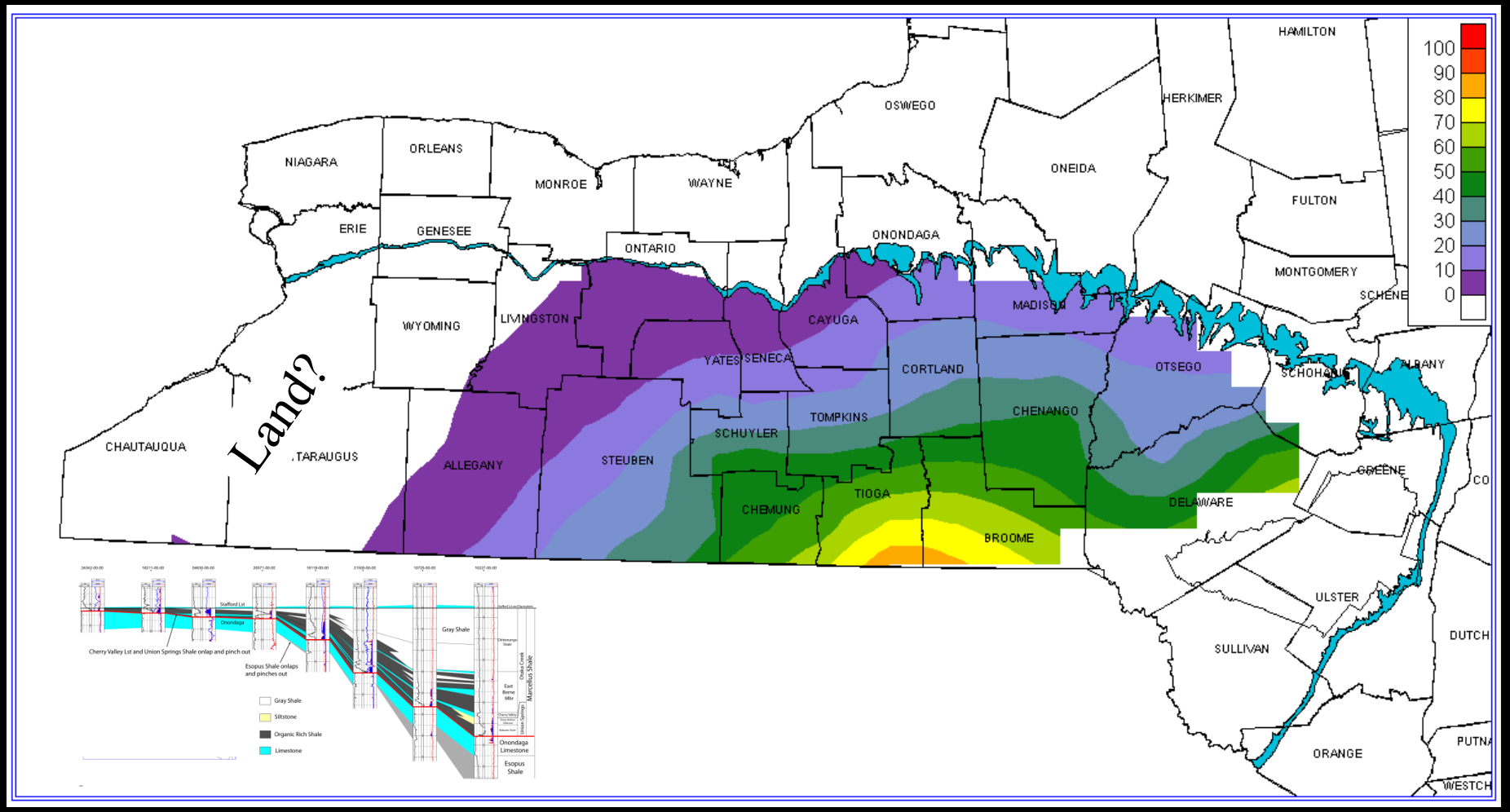
Geneseo Shale and Tully Limestone - The logs suggest that the organic rich layers have progressively higher TOC and are interbedded with more limestone to the west until they thin and onlap or pinch out on the basal unconformity - to the east these beds become less organic-rich and grade into gray shale



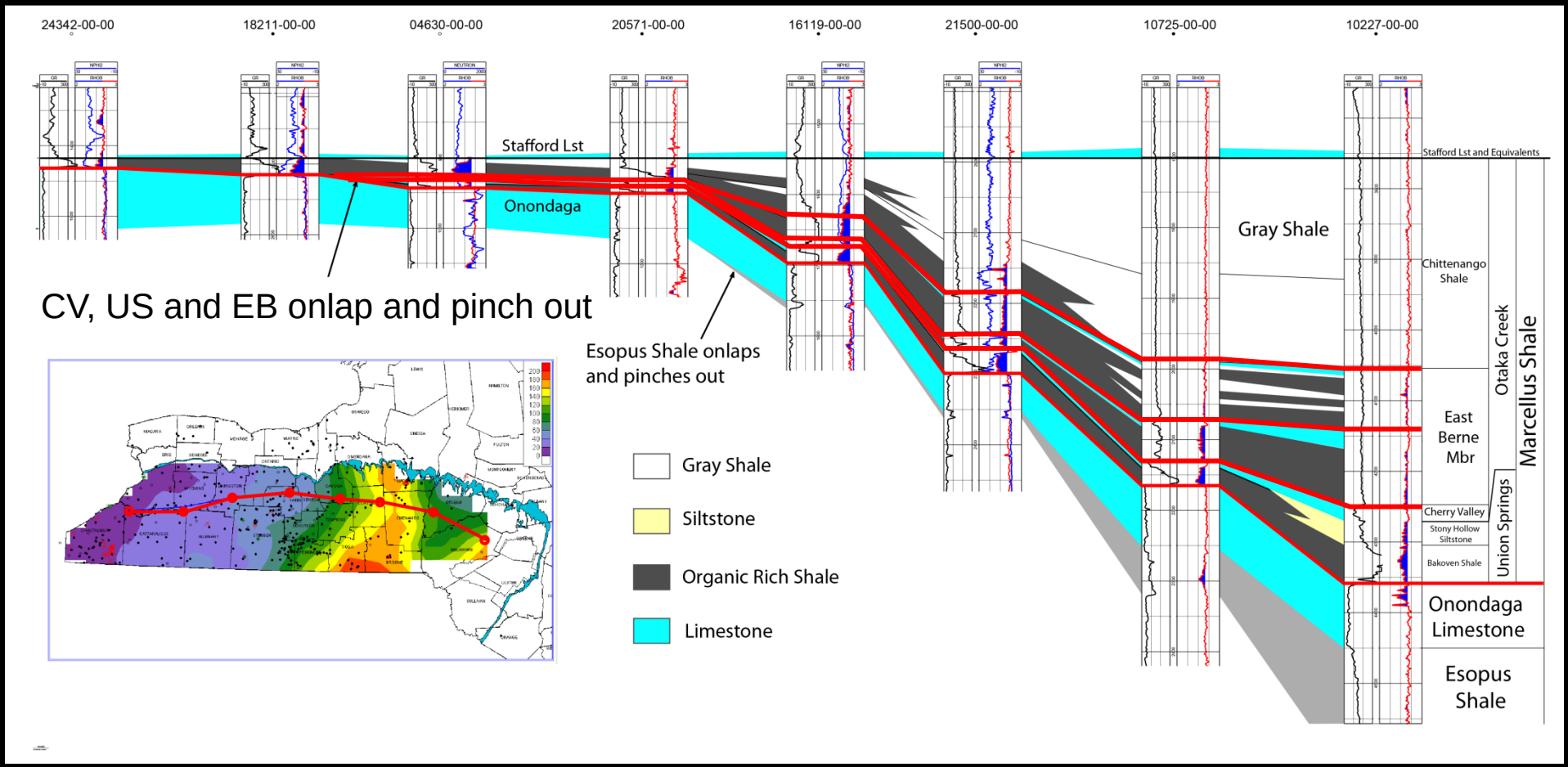
Organic-rich facies deposited on cratonward side of foreland basin along with limestones – TOC increases into what was probably shallower water due to lower dilution and higher percentage reaching sea floor - water depth probably a few meters up to 50 m



Next map shows Union Springs Only (from top Onondaga Limestone to base of Cherry Valley Limestone - absent to west where it onlaps and pinches out

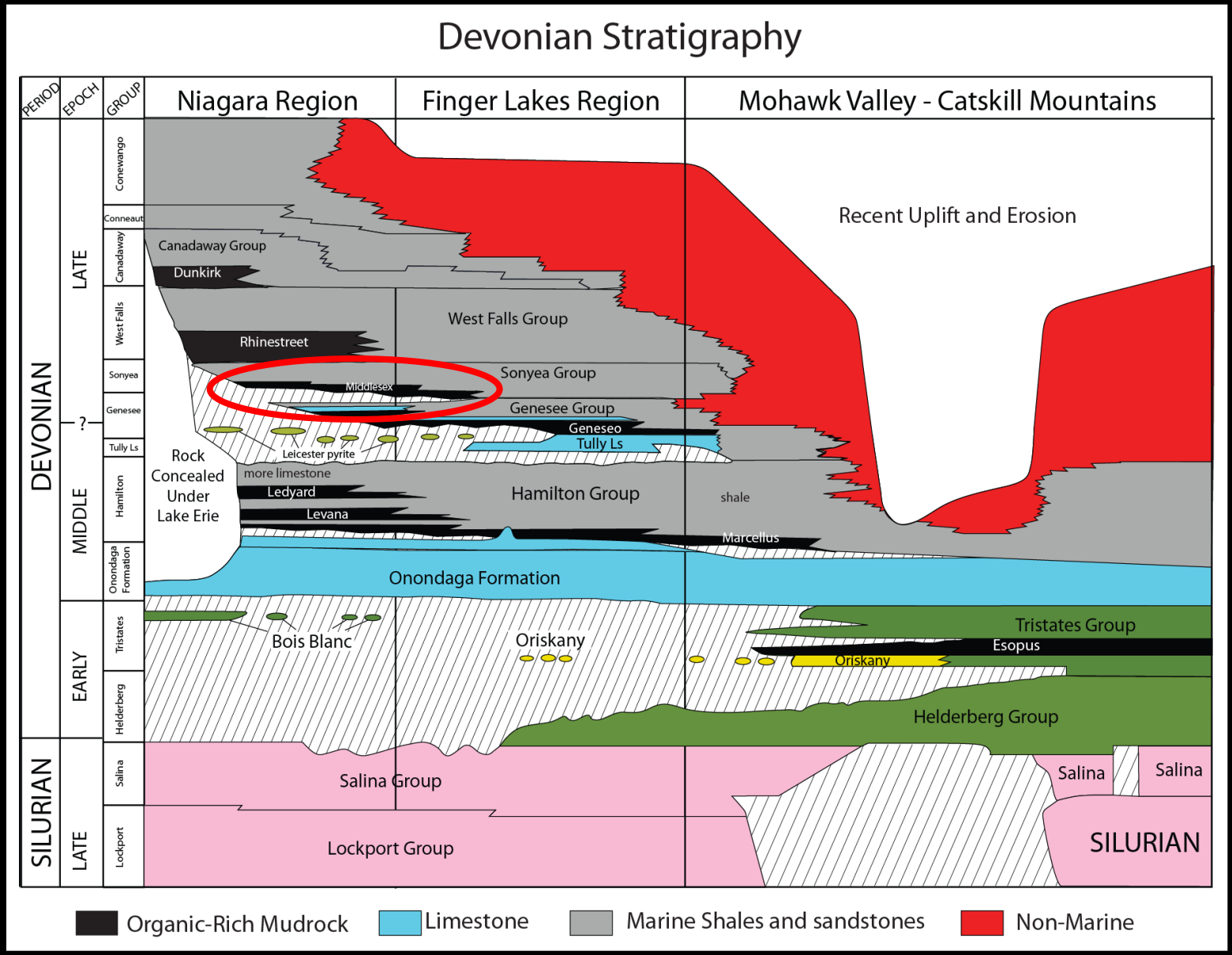


Union Springs Shale net thickness or organic-rich shale – area to west may be exposed land during deposition of most organic-rich strata

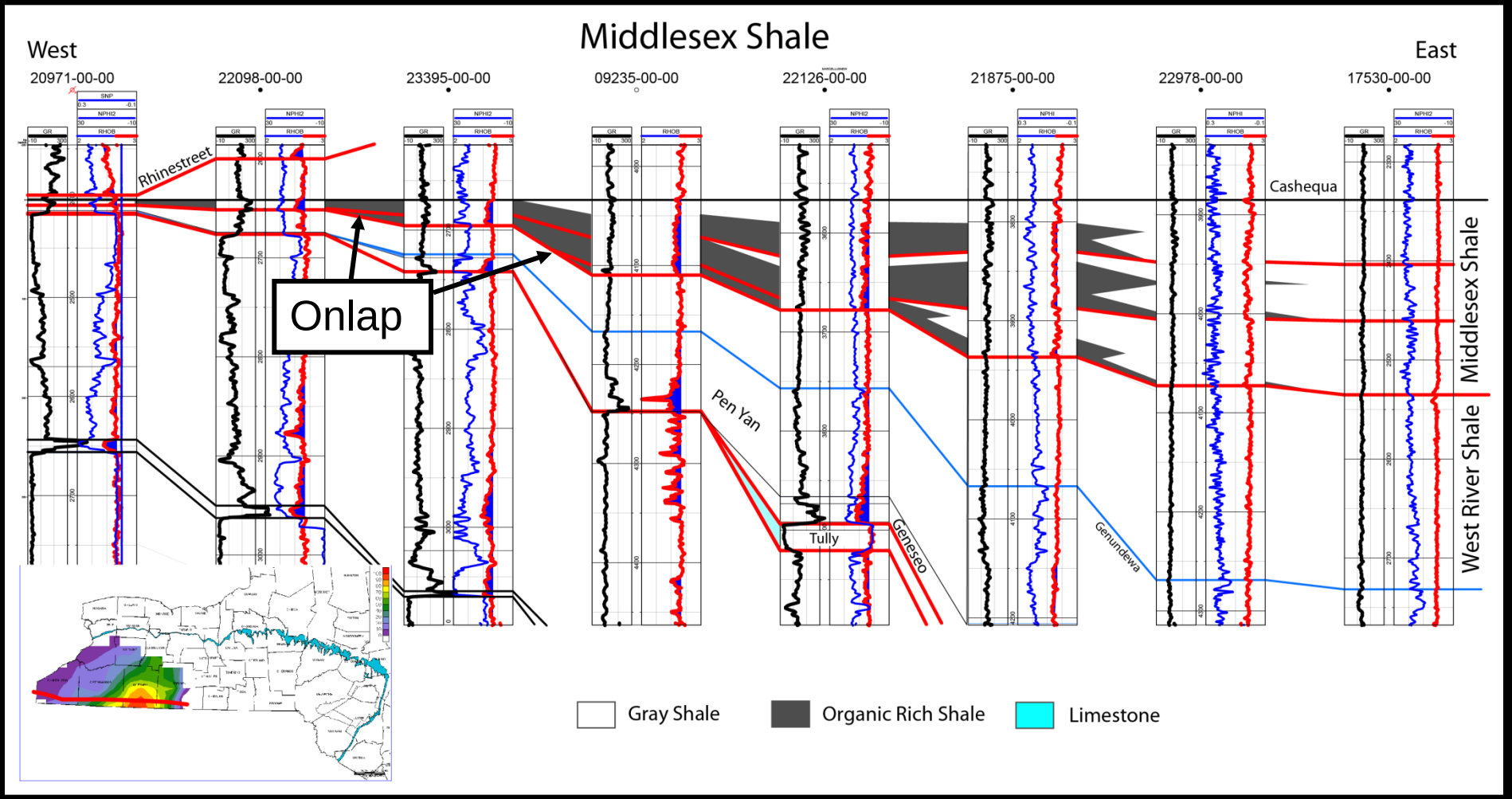


Esopus Shale (slightly organic-rich) - onlaps and pinches out to west

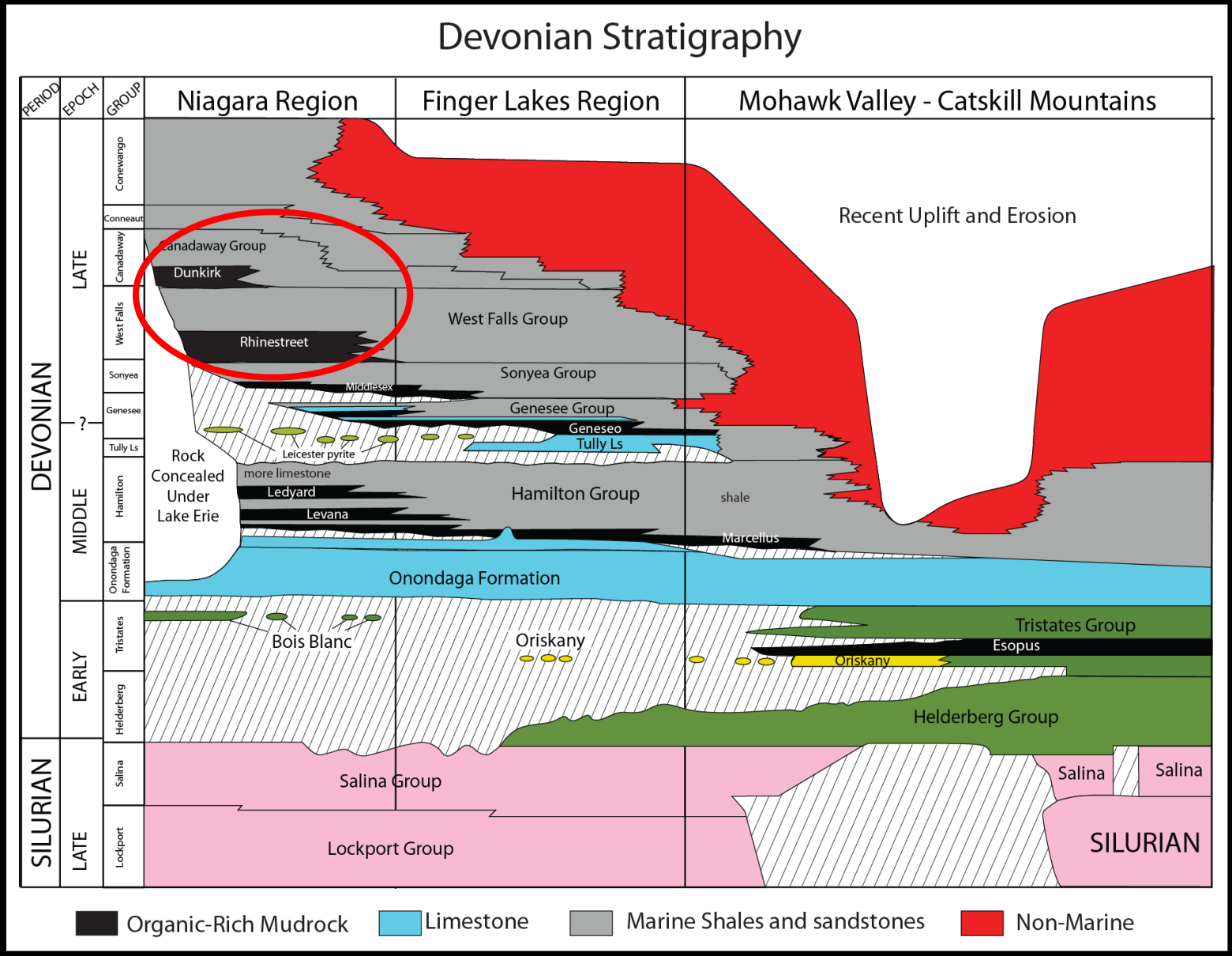
Marcellus Shale – Organic-rich sections in the east onlap and pinch out to west - organic rich section in the west is equivalent to gray shale in the east



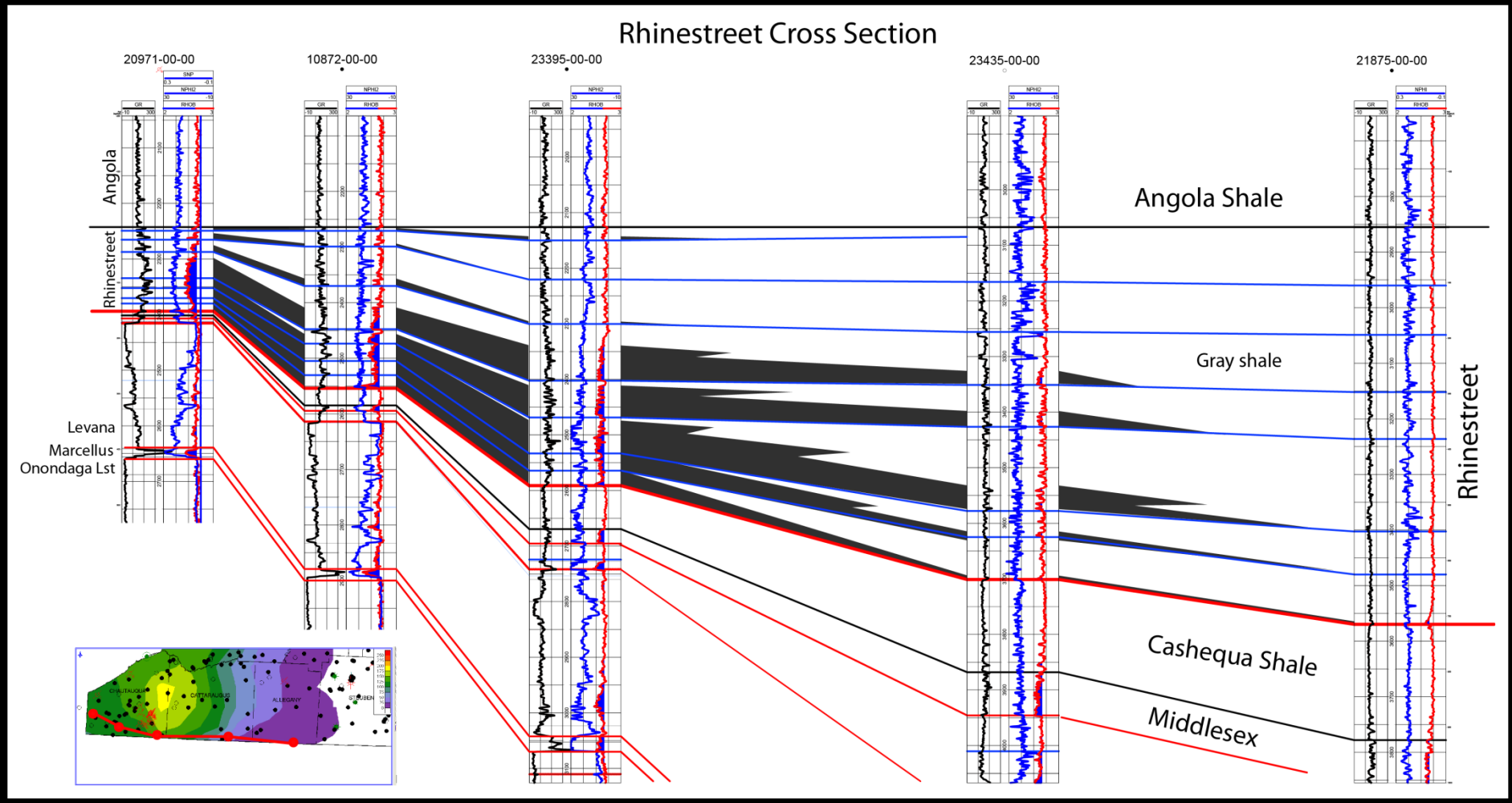
Middlesex Shale onlaps unconformity



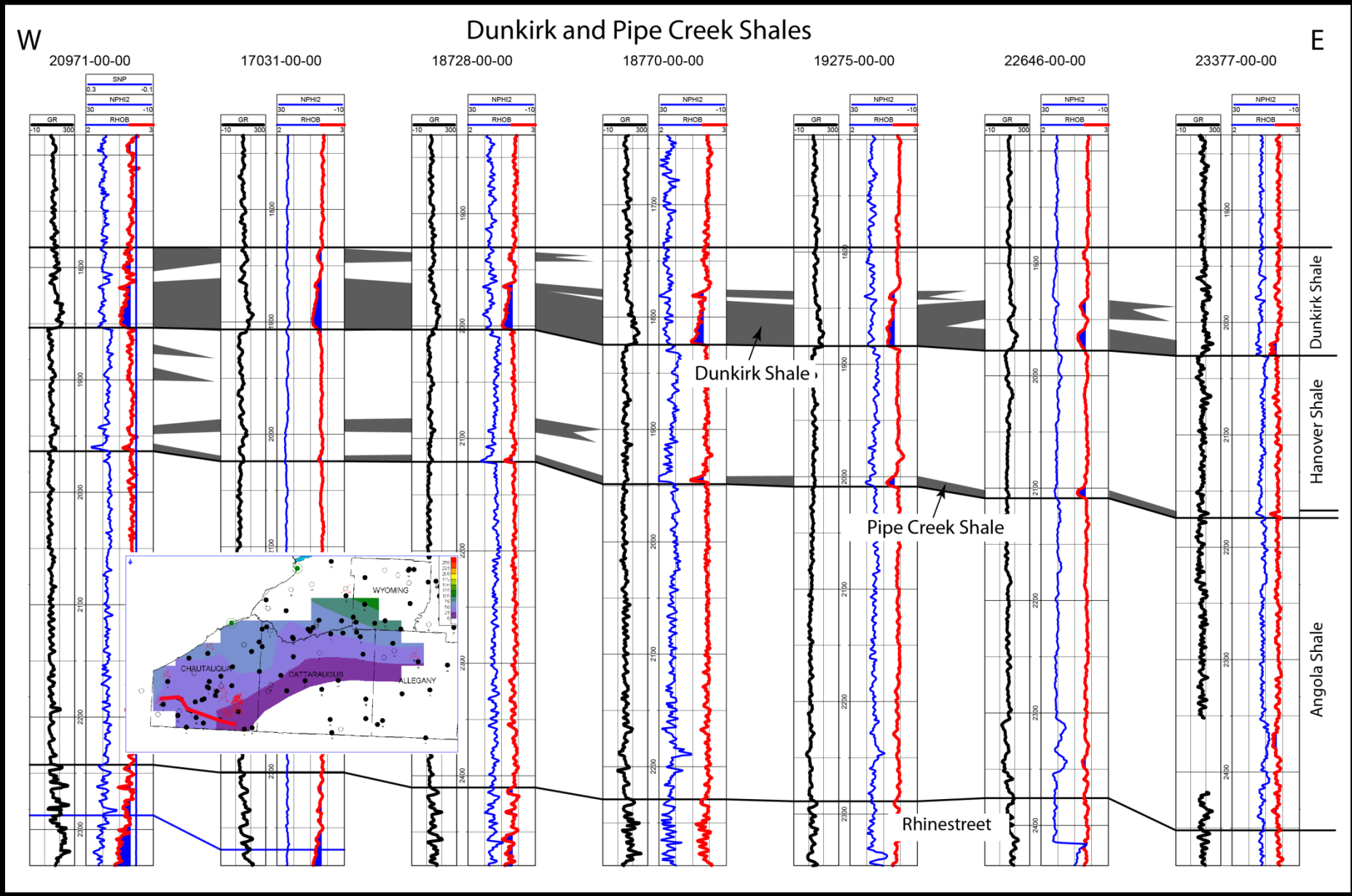
Middlesex Shale shows the same trends – gray shale to east, becoming progressively more organic rich to west where it eventually thins and onlaps unconformity – no obvious limestones in Middlesex – most producing shales have some limestone content



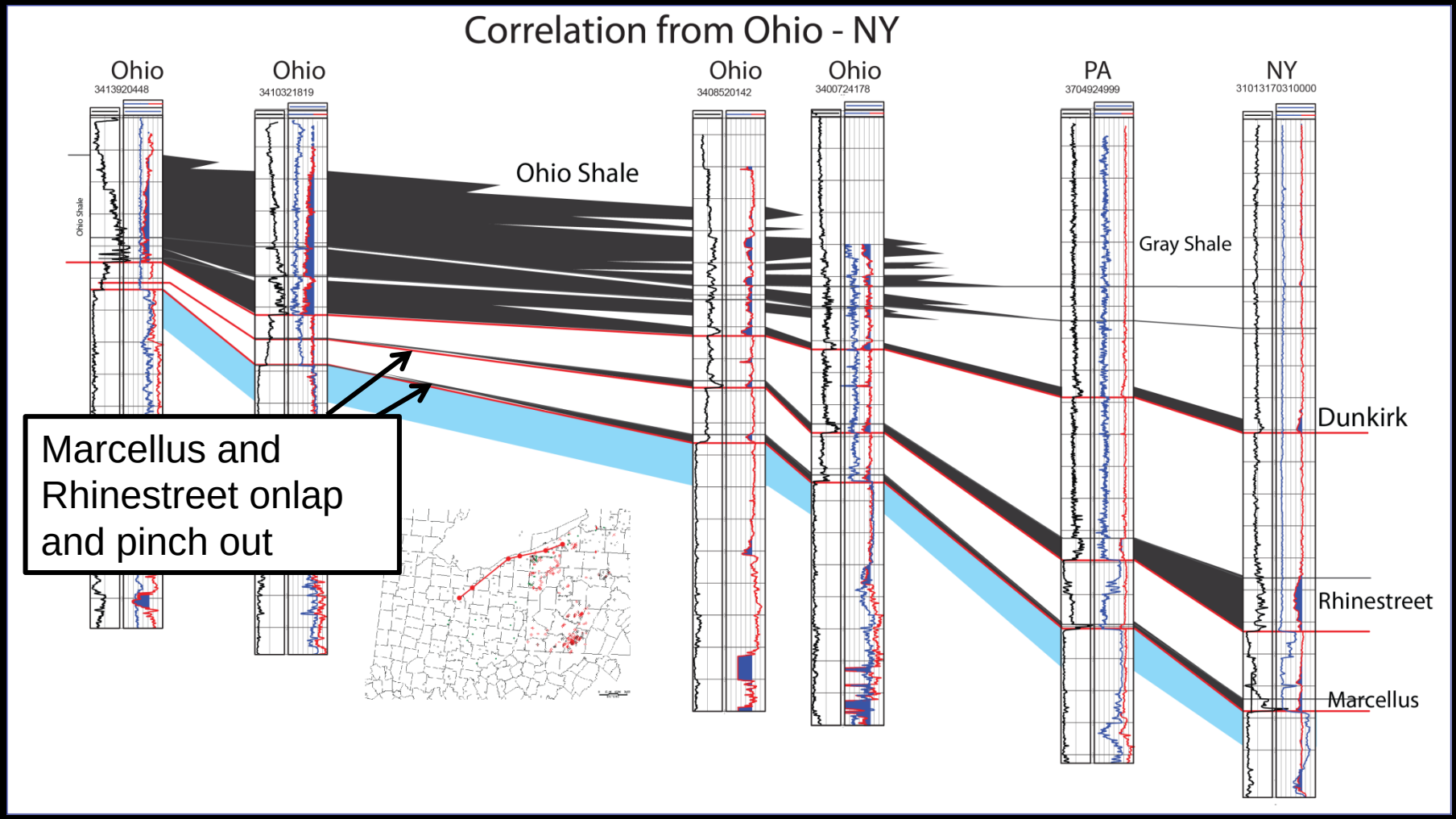
Rhinestreet and Dunkirk Shales occur progressively farther to the west



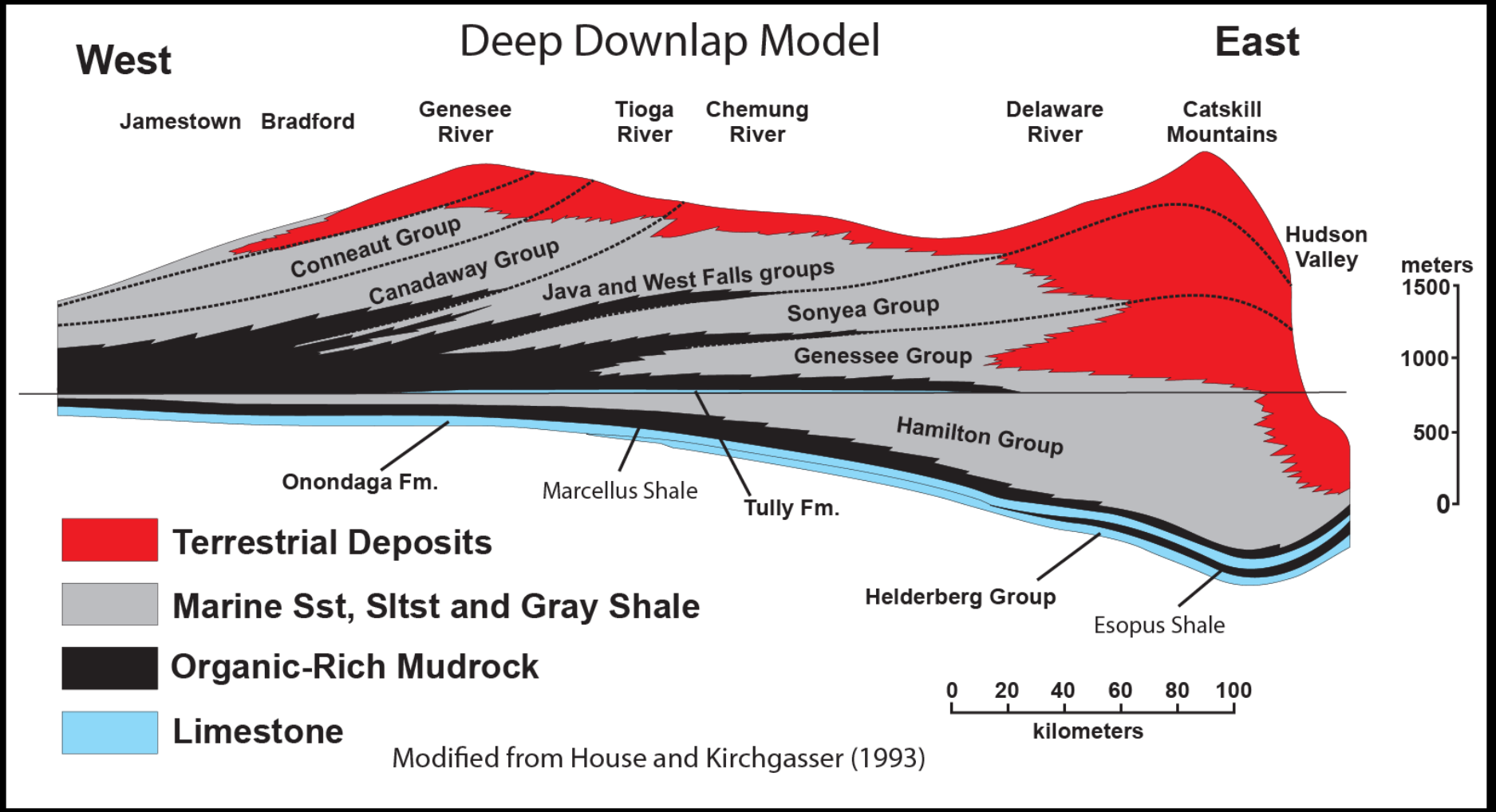
Rhinestreet Shale cross section – like the others, the Rhinestreet grades from gray shale in the east to progressively more organic-rich shale in the west – unlike the underlying shales, there is no onlap – only thinning of units in NY– it does eventually onlap farther to the west



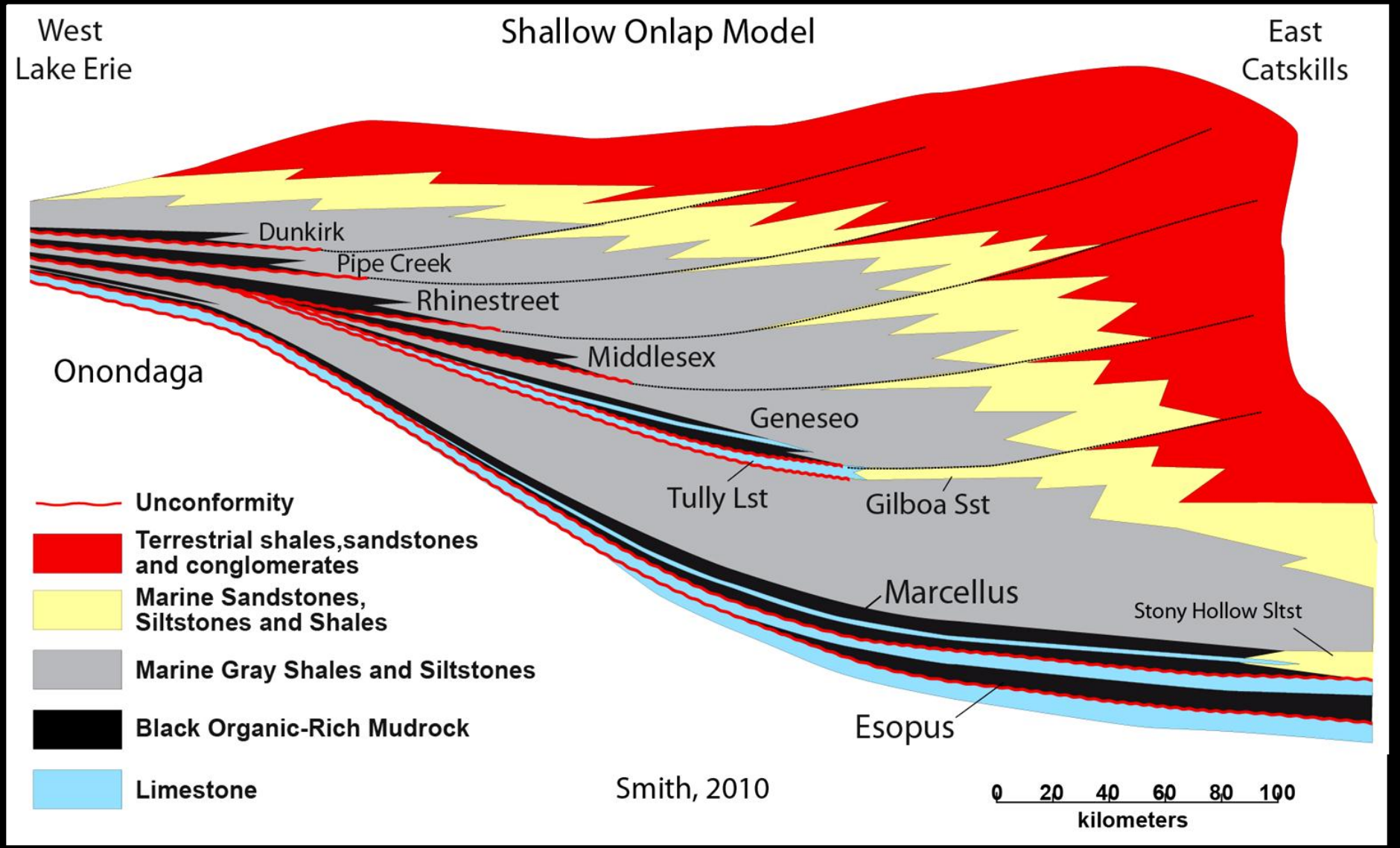
The Dunkirk and Pipe Creek Shales grade from gray shale in east to more organic-rich shale to west but do not onlap in NY



Farther west in Ohio the Rhinestreet and Marcellus onlap and pinch out – the Dunkirk becomes the lowermost part of the Ohio Shale which grades to black organic rich shale from gray shale



So instead of downlapping, the stratigraphy onlaps to the west and is deposited in relatively shallow water during transgressions



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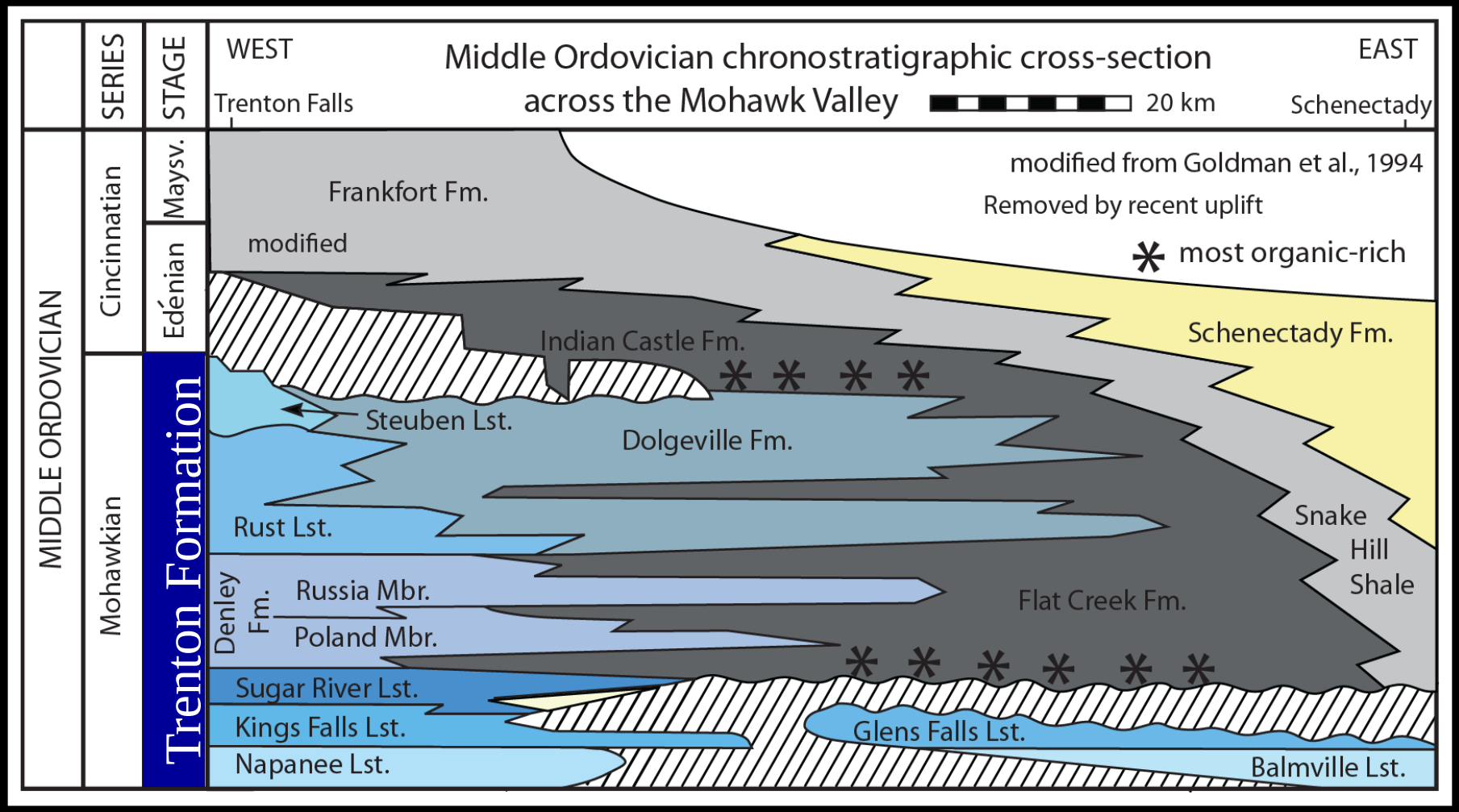
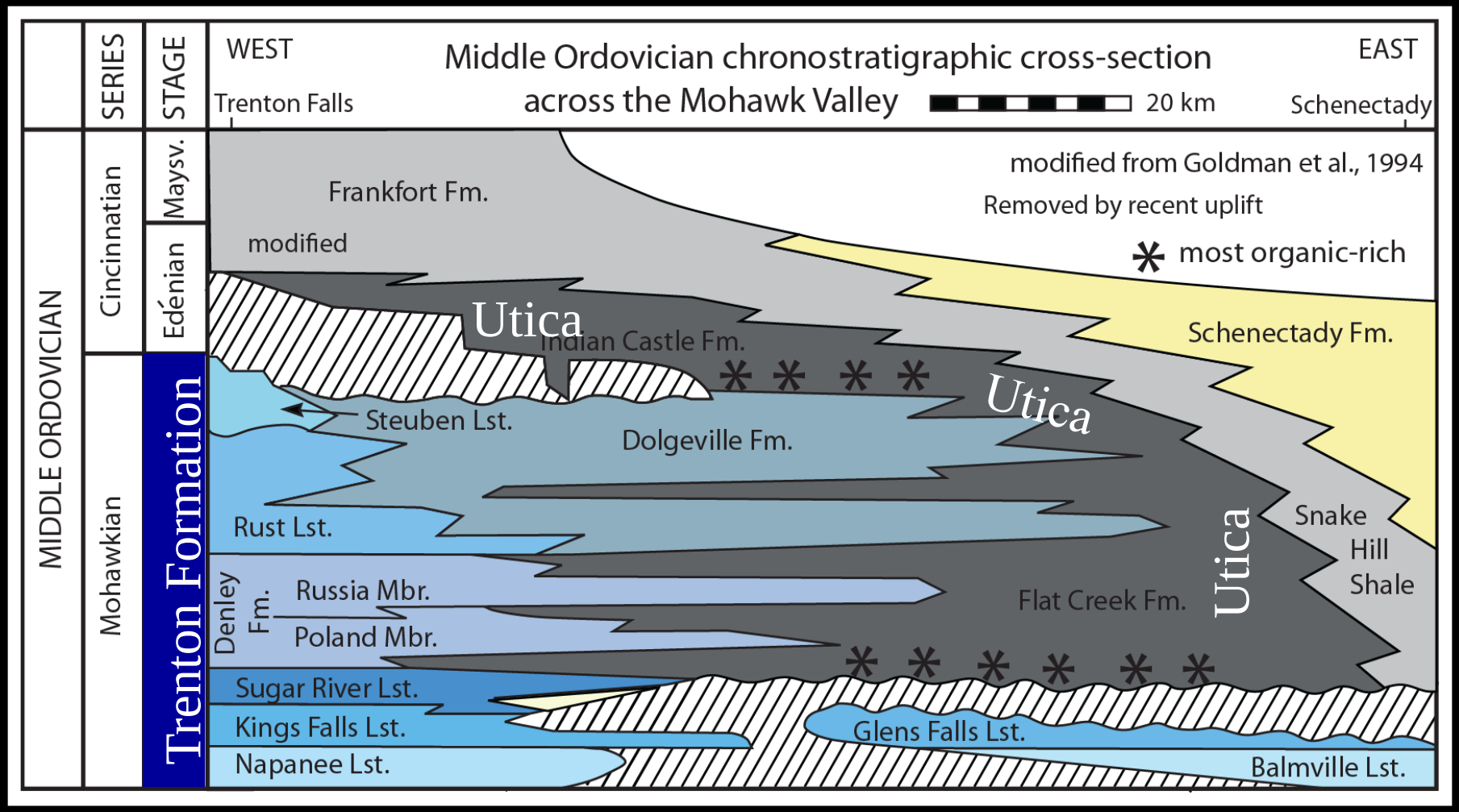


Outcrop Stratigraphy from Mohawk Valley, NY – Some Utica is Trenton-equivalent, some is younger than Trenton – Note that the most organic-rich parts overlie or are time-equvalent to unconformities



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Black River-Trenton-Utica Cross Section

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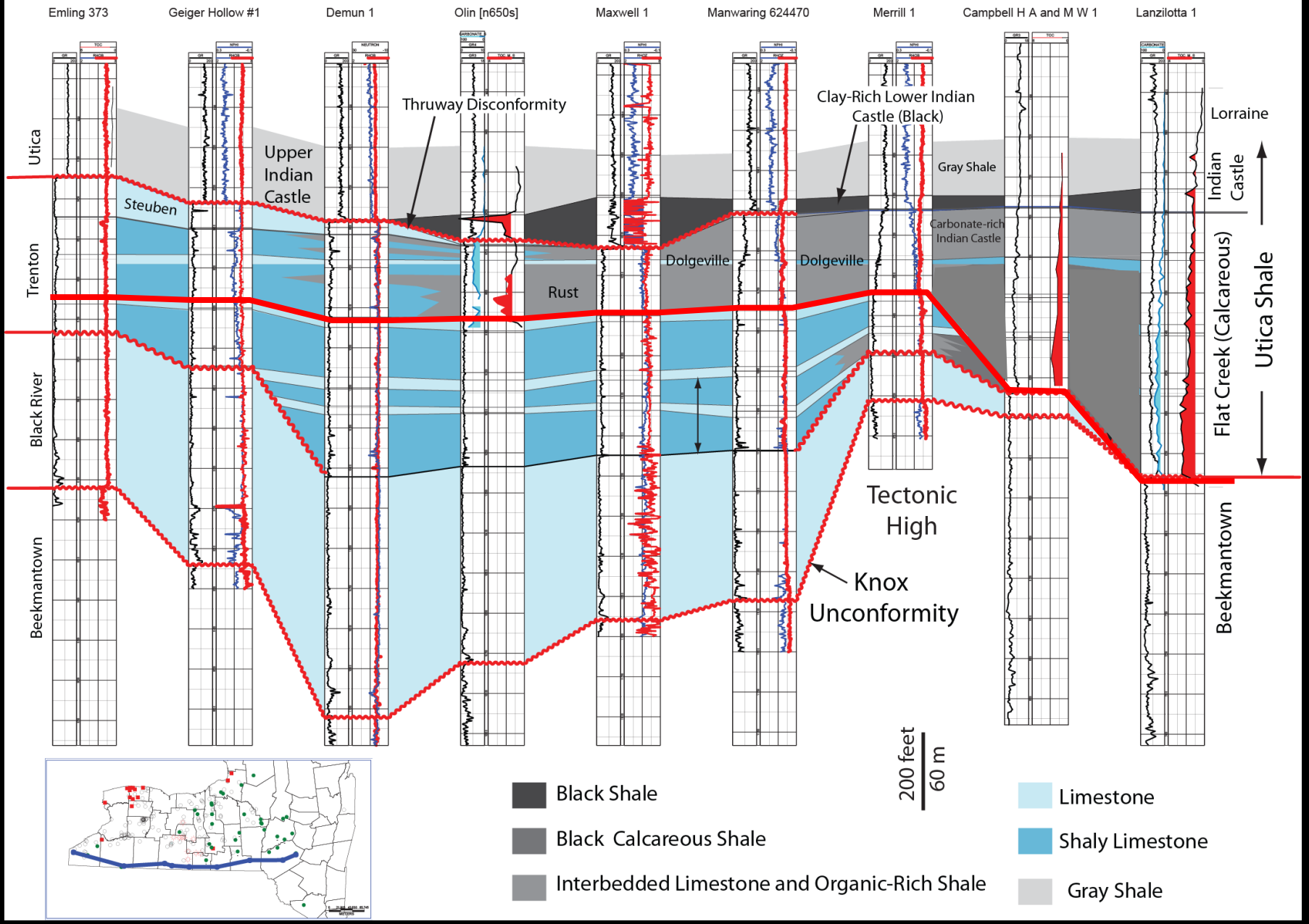

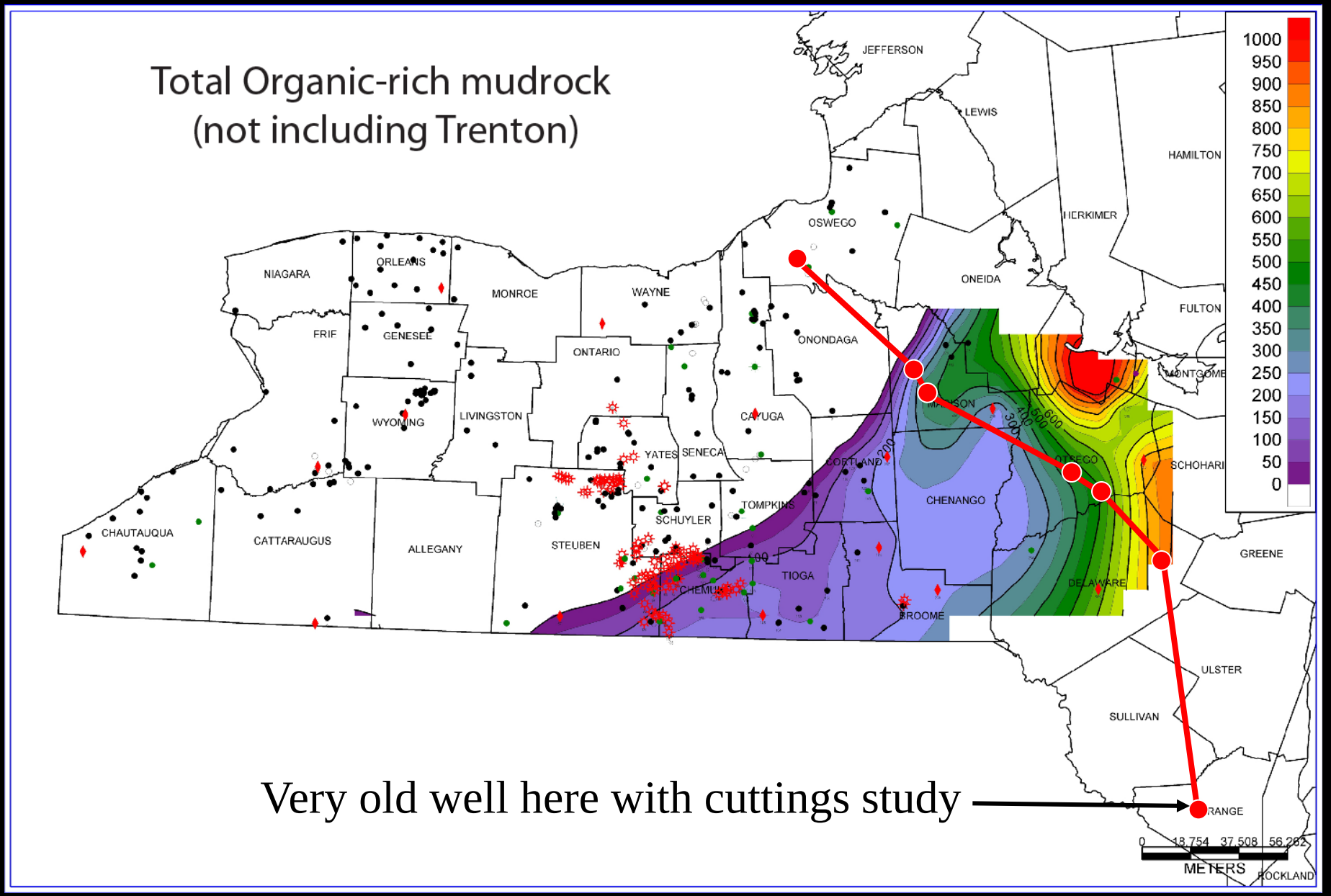
Total Organic-rich mudrock
(not including Trenton)
JEFFERSON
LEWIS
HAMILTON
HERKIMER
OSWEGO
ONEIDA
FULTON
NIAGARA
ORLEANS
MONROE
WAYNE
ONONDAGA
FRIE
GENESEE
ONTARIO
MONTGOME
WYOMING
LIVINGSTON
CAYUGA
YATES
SENECA
CORTLAND
OTSEGO
SCHOHARI
CHENANGO
TOMPKINS
SCHUYLER
CHAUTAUQUA
CATTARAUGUS
ALLEGANY
STEUBEN
TIOGA
CHEMUNG
BROOME
DELAWARE
GREENE
ULSTER
SULLIVAN
ORANGE
ROCKLAND
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
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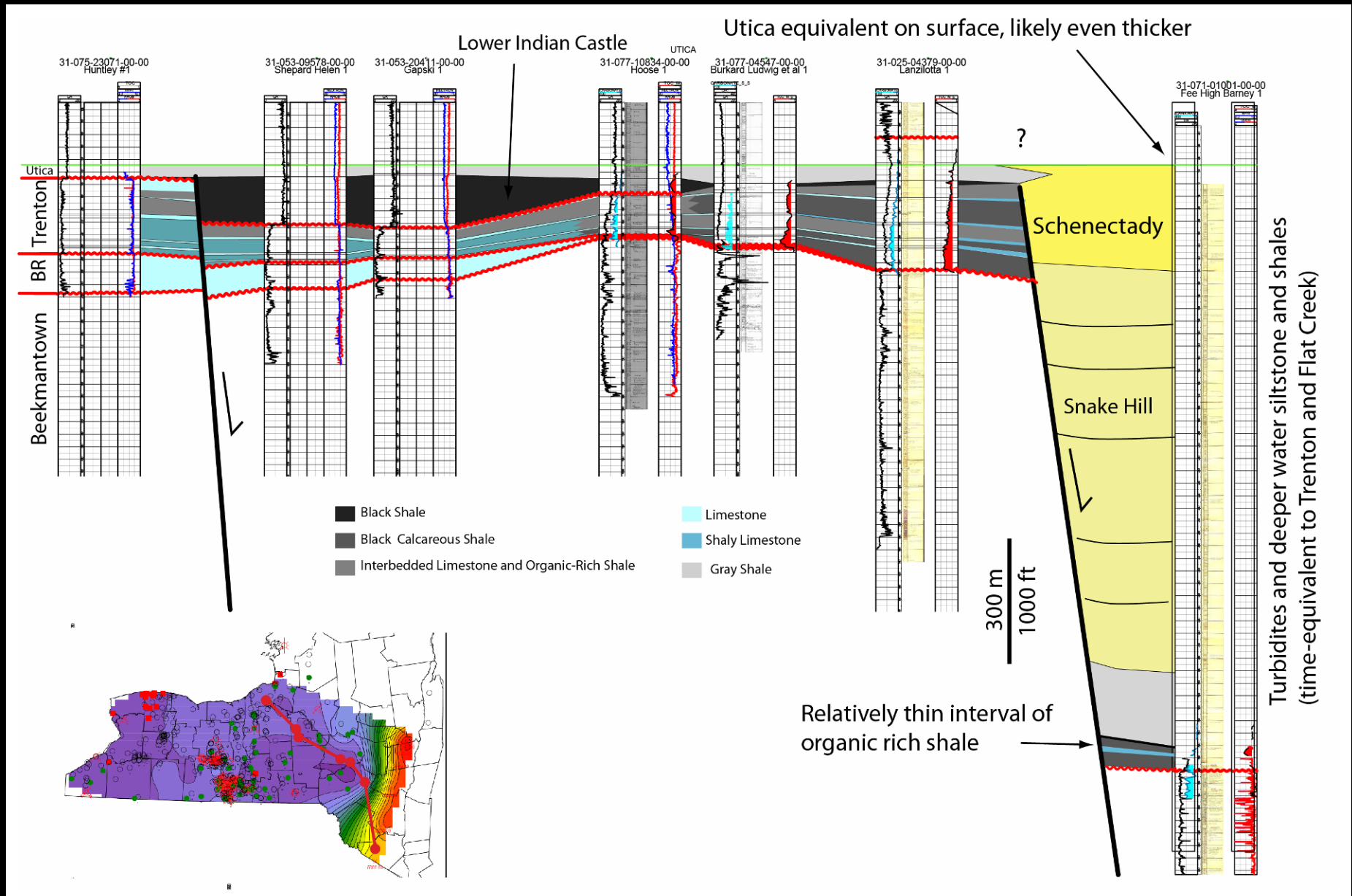
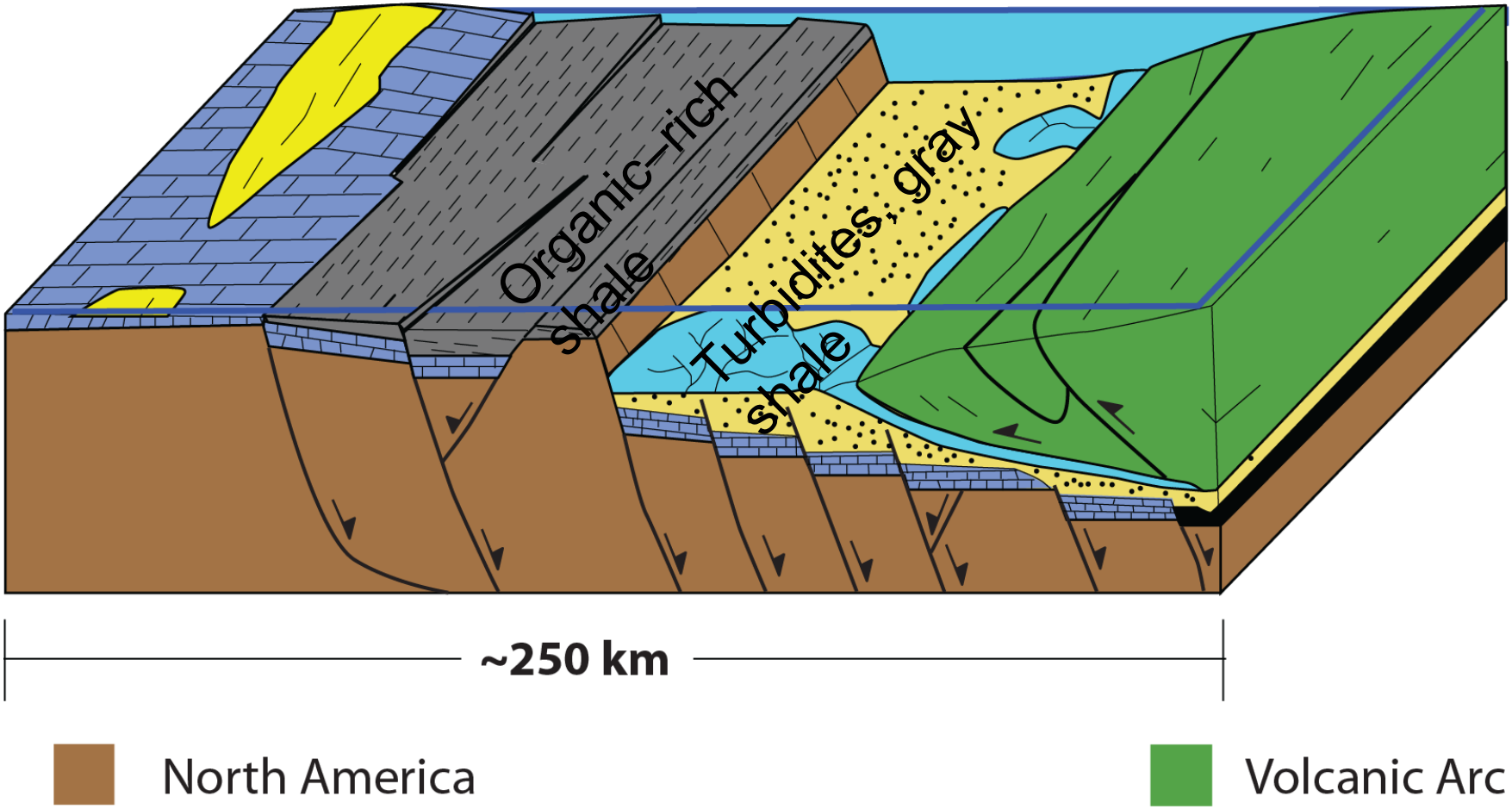
150
100
50
0
0 18,754 37,508 56,262
METERS
Very old well here with cuttings study



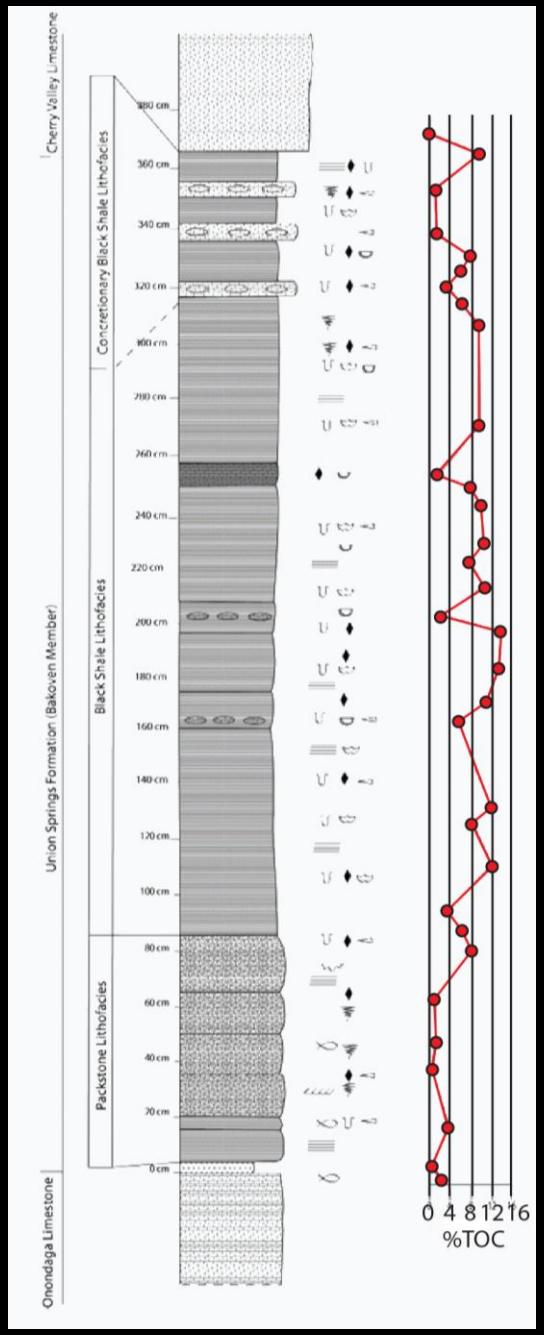
5500 feet of Utica equivalent clastics on downthrown side of fault with only minor organic-rich shale at base



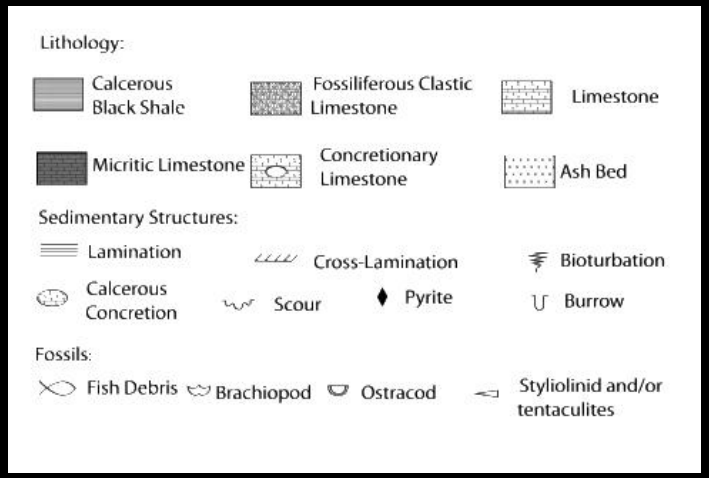
This block model shows the organic rich shale forming in relatively shallow water (<50m) on the upthrown side of a major down to the east fault system - the major fault system cut the dilution by siliciclastics coming in from the present day east

Not Permanently Anoxic

- Organic-rich strata commonly have thin beds of in situ benthic fossils and common bioturbation that show that the water was not permanently anoxic but instead had periods of oxygenated bottom waters
- Both the Utica and Marcellus have beds of brachiopods and trilobites within organic rich sections

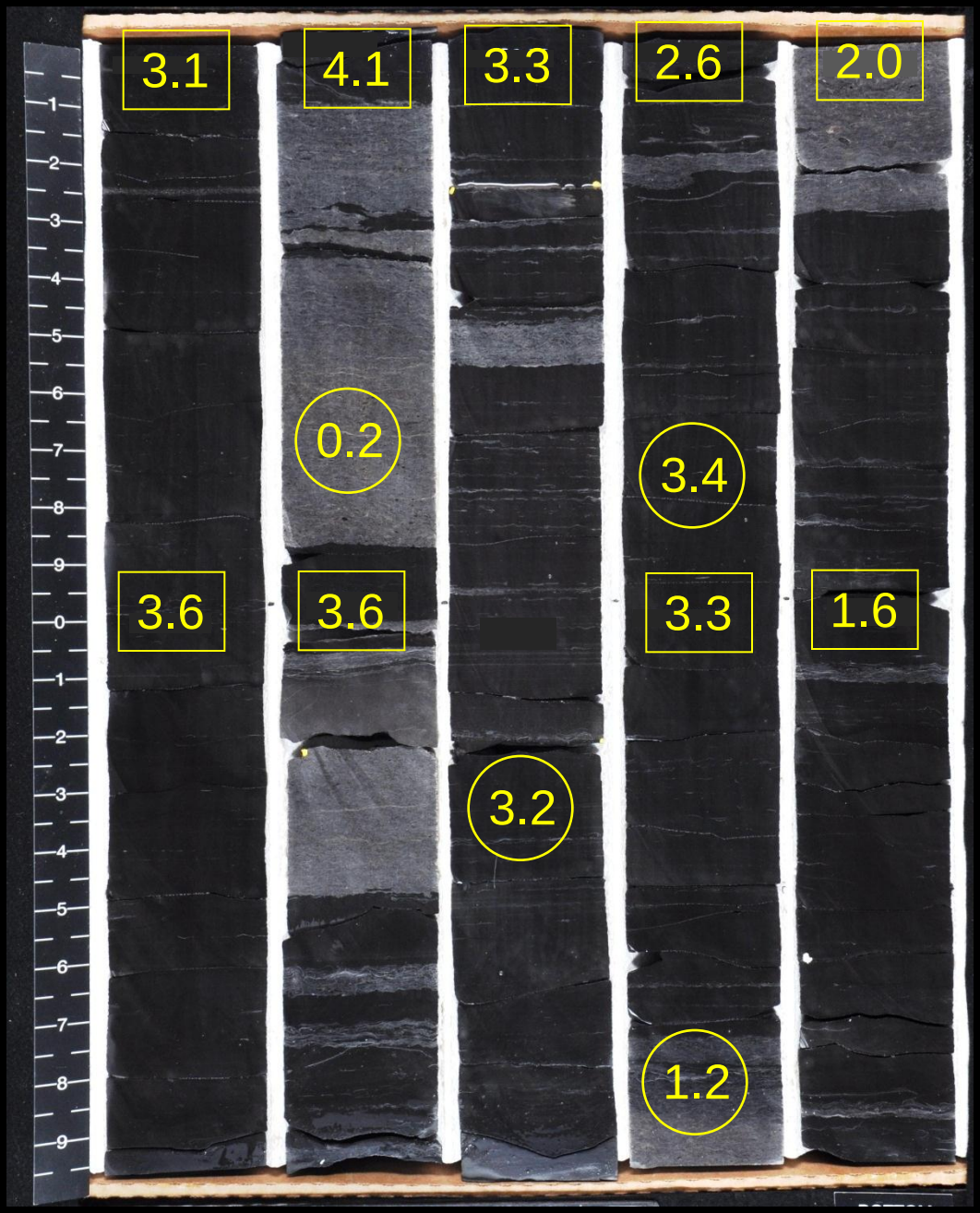


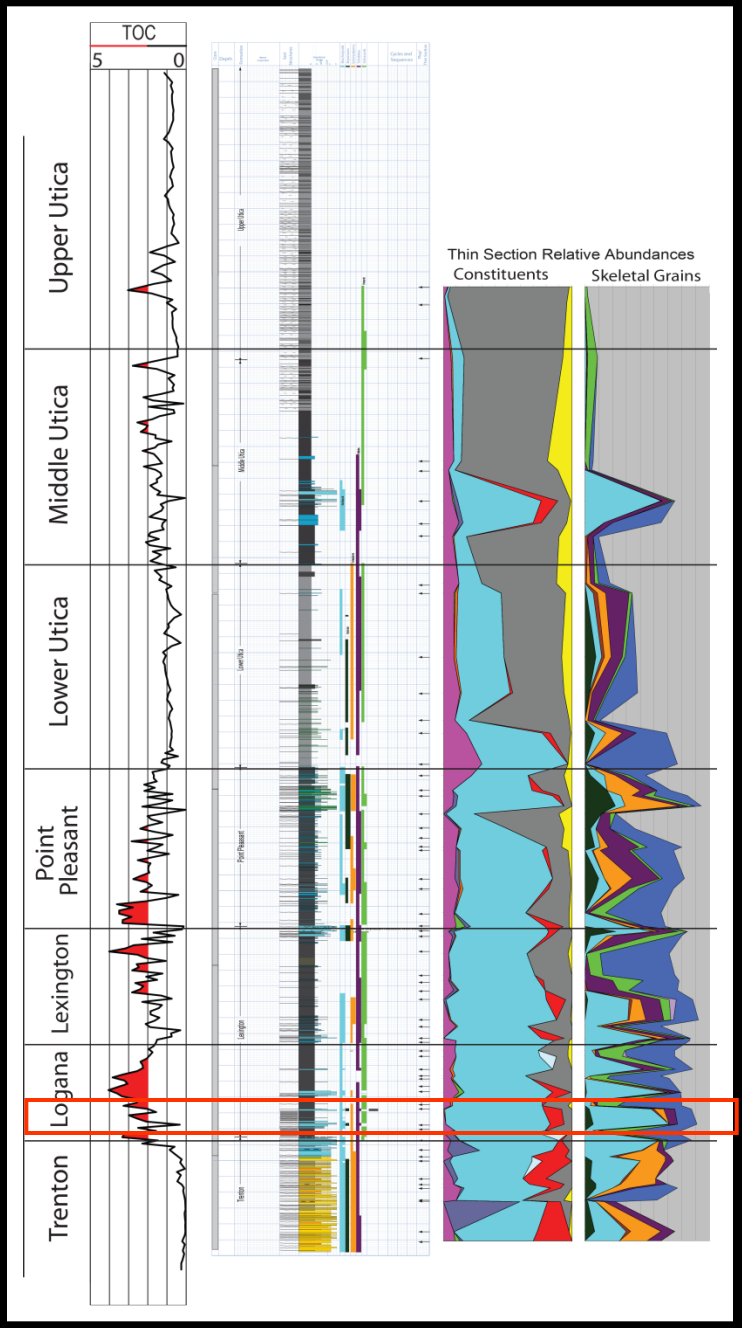
Karaca and Jordan, 2011



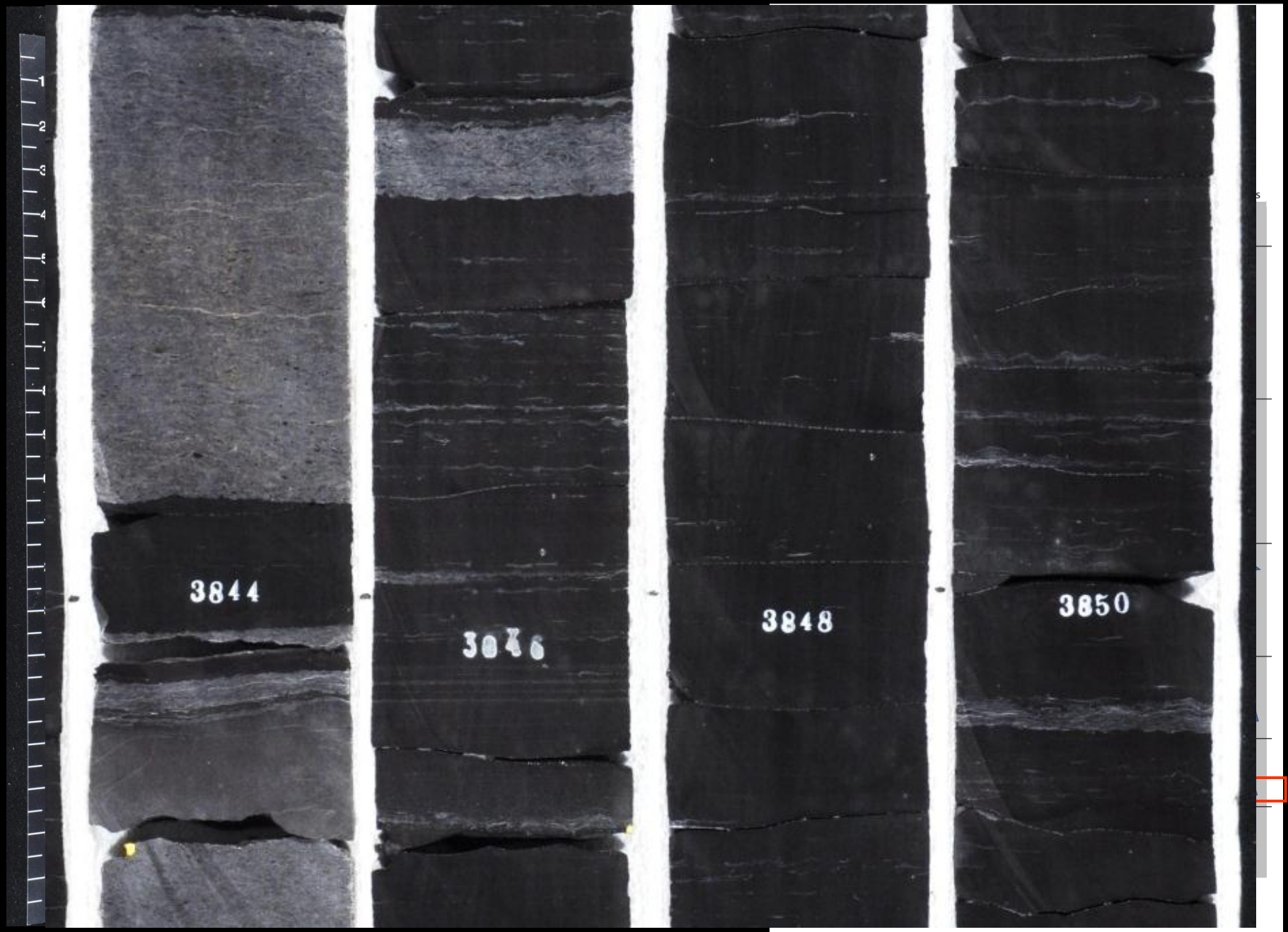
Union Springs Organic-rich shale and limestone from Marcellus Group has up to 14% TOC and thin beds of brachiopods and burrows throughout at this location

Beds covered with abundant *Leiorhynchus* (rhynchonellid) brachiopods interlaminated within organic-rich strata (Seneca Stone Quarry, NY)





Samples are from the depths above the values

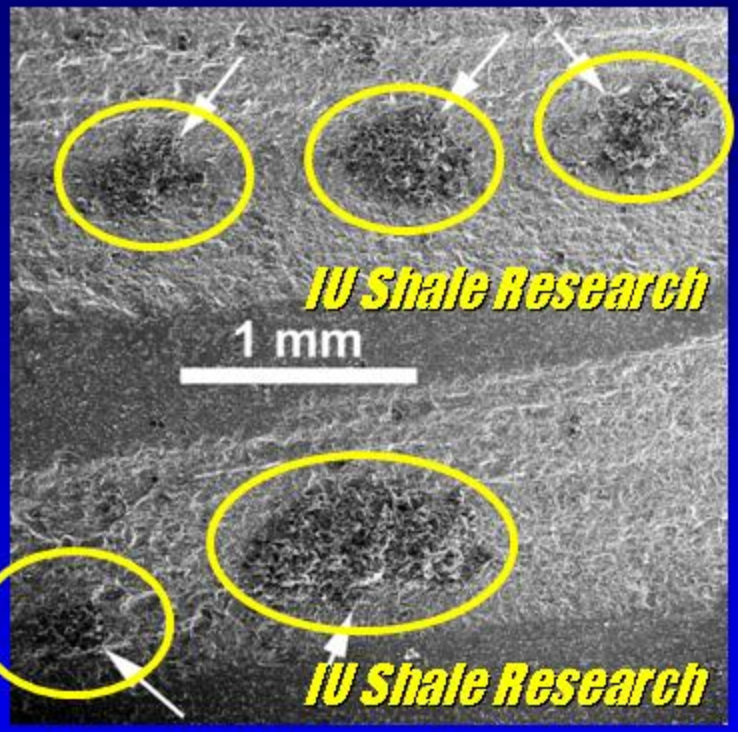


Samples are from the depths above the values

Laminations Produced by Moving Bottom Currents

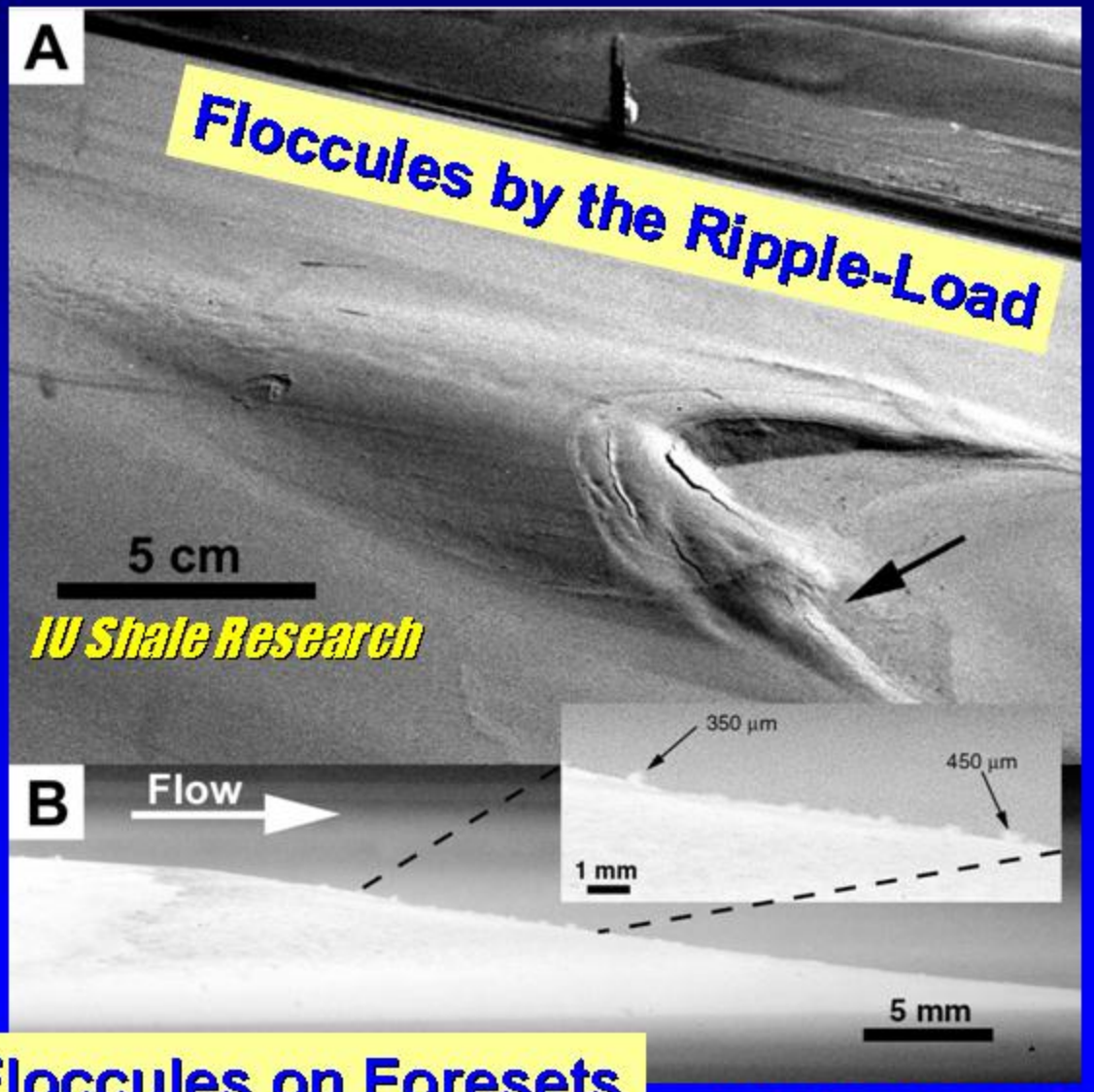
- Laminations are common in black shales and are commonly used as evidence of deep quiet deposition as clay settled out of suspension
- New research suggests, however, that these laminations may actually form in moving water with flow rates up to 30 cm/s
- Organic-matter may have been protected by clay floccules which maintained anoxic microenvironment

The Inside Scoop on Floccules.....



Retail Floccules.....

It's All in the Floccules....

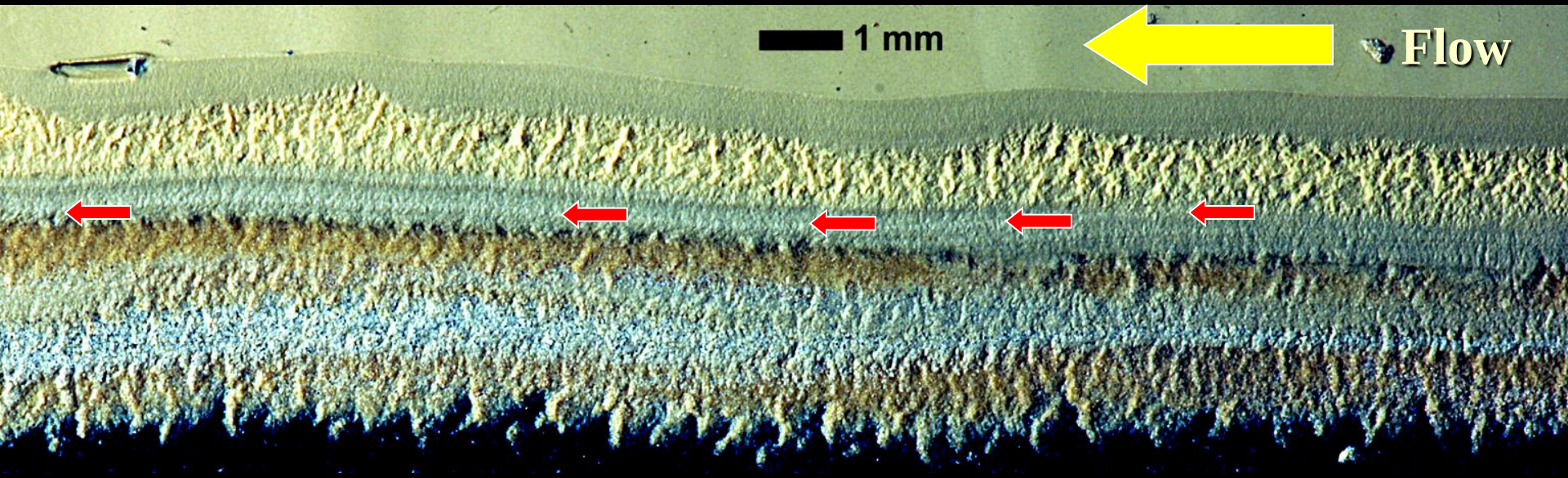


Lonely Floccules on Foresets

J. Schieber

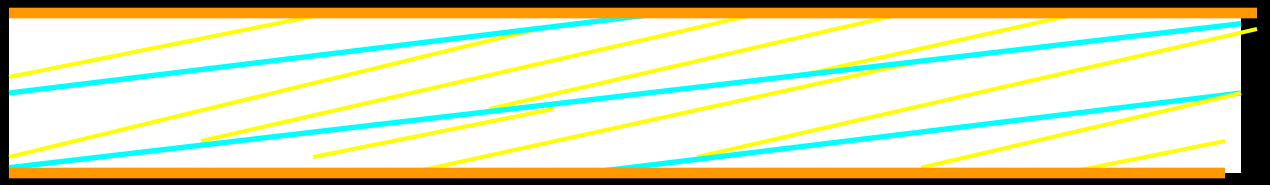
IU Shale Research

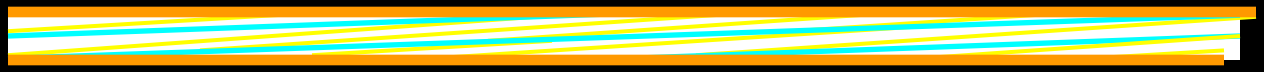
Internal Cross-Laminae



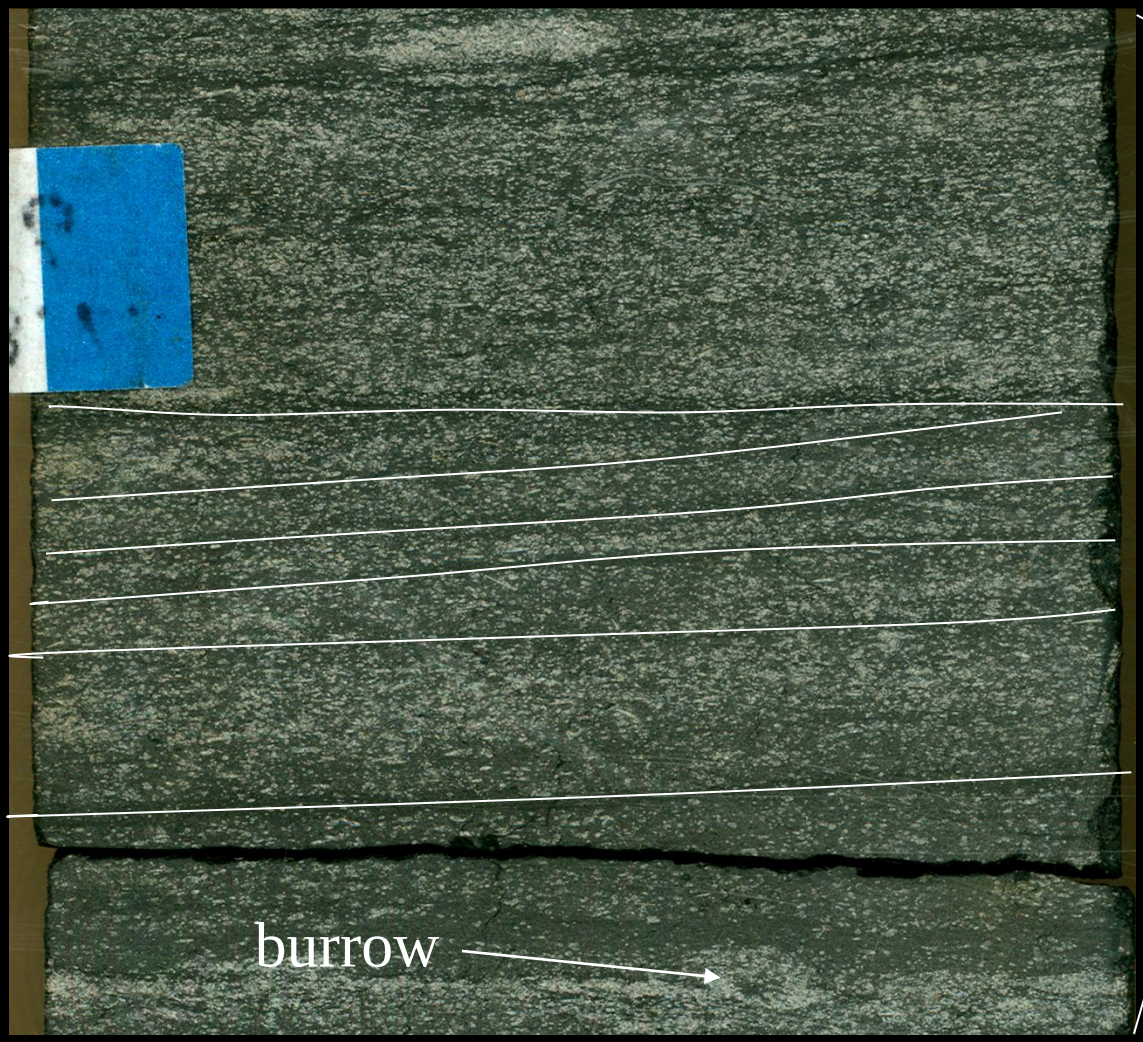
In cross-section the layers that constitute clinoforms show low-angle laminae, inclined in downcurrent direction. The latter are compacted foresets of initially water-rich muddy ripples.

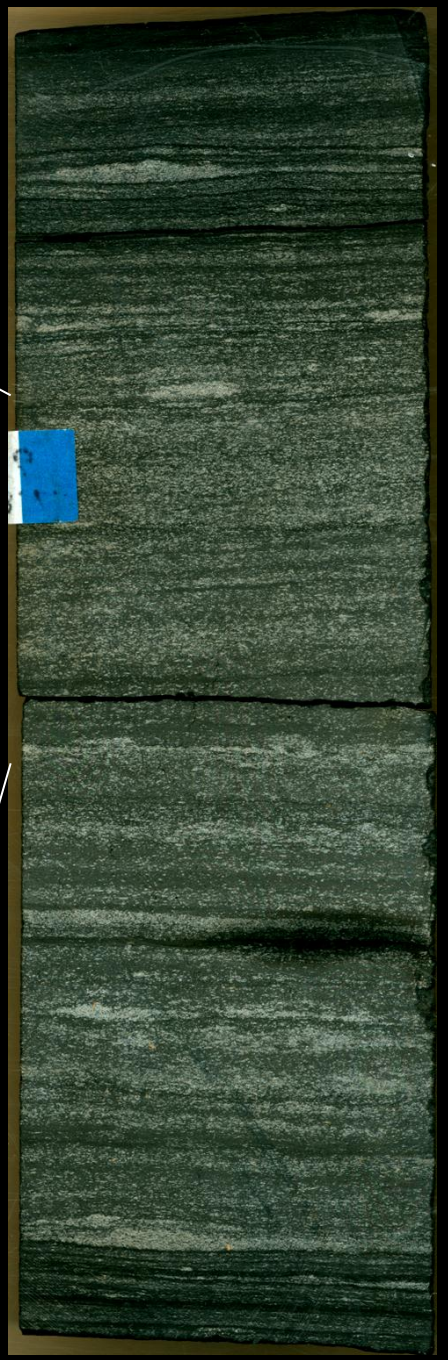
J. Schieber

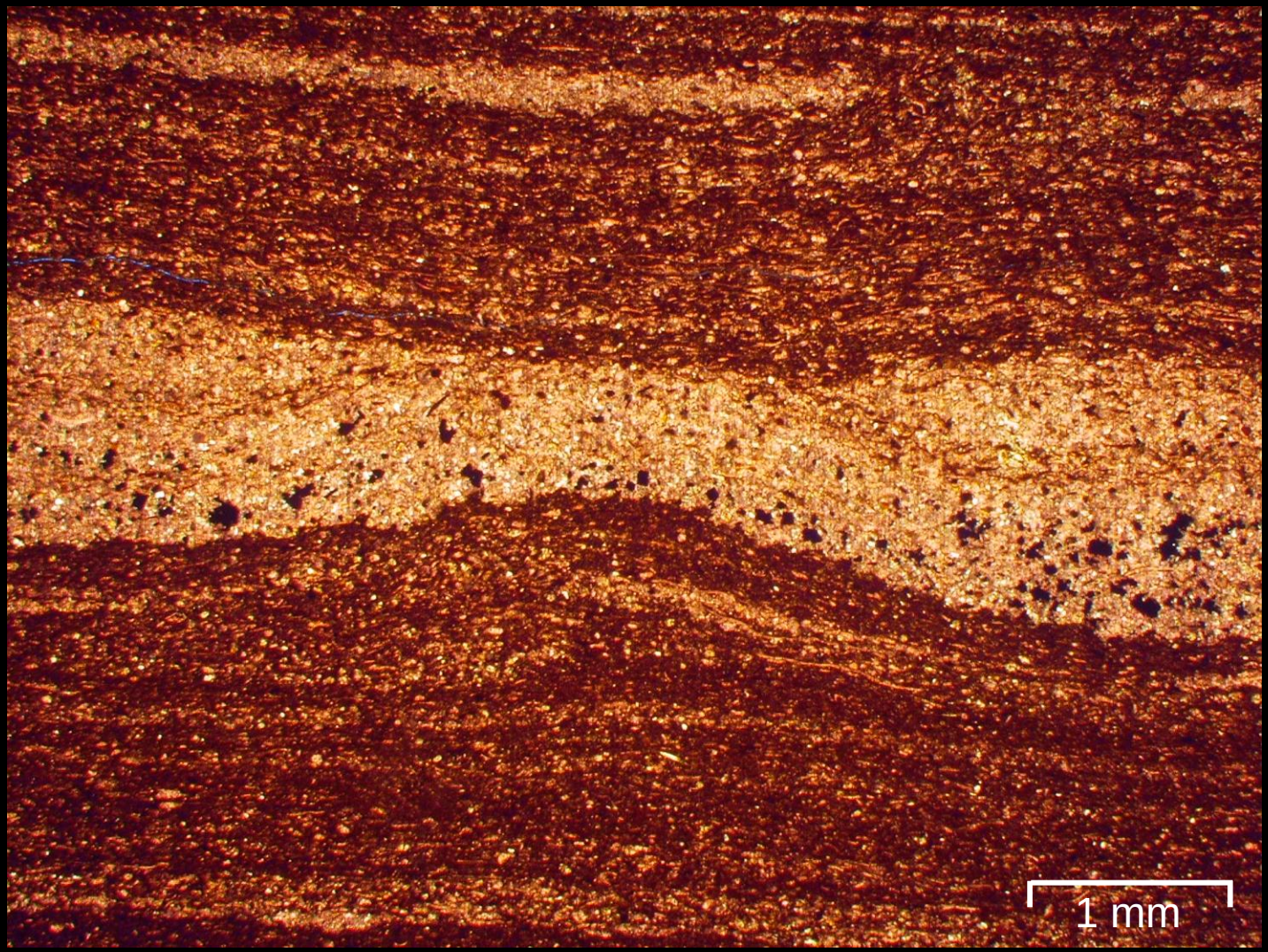




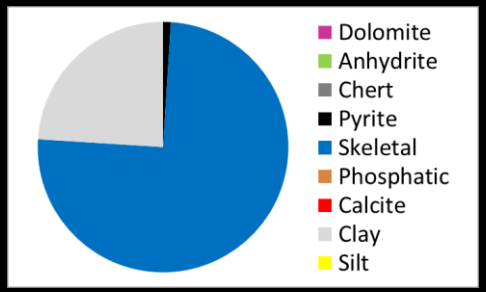
A close look at the Marcellus reveals some lenticular bedding and low angle cross-bedding consistent with Schieber's experiments – also some burrows

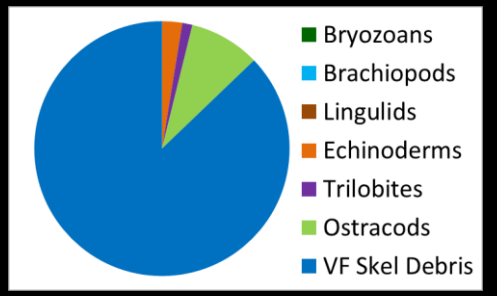




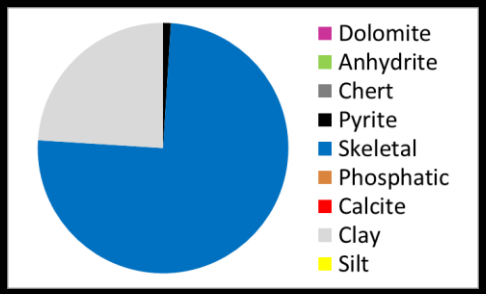


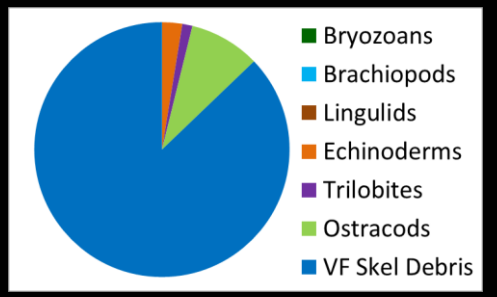
Organic-rich argillaceous limestone from Utica with scour surface and lenticular bedding – this was likely deposited in moving water





Organic-rich argillaceous limestone from Utica with scour surface and lenticular bedding – this was likely deposited in moving water





Conclusions

- Both Ordovician and Devonian organic-rich shales in New York overlie and onlap unconformities suggesting a relatively shallow depositional environment (<50 meters and commonly <30 meters)
- The water was not permanently anoxic, but rather had periods of oxygenated bottom water when tolerant benthic fossils thrived on bottom
- The water was also moving at times and most laminations are produced by currents rather than suspension settling

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