Tectonic and Depositional Setting of Marcellus and Utica Black Shales, New York State

Reservoir Characterization Group
at the New York State Museum

Taury Smith and Jim Leone
New York State Museum
Room 3140 CEC
Albany, NY 12230
Lsmith@mail.nysed.gov

NYSERDA

Acknowledgements

We would like to thank John Martin and NYSERDA as well as Range Resources, Talisman Energy, Anadarko Petroleum, Chesapeake Energy, Southwest Energy, Anschutz Petroleum and East Resources for their support of this research

Abstract

The Ordovician Utica and Devonian Marcellus black shales both have potential to produce gas in New York State and share some common attributes in their distribution and interpreted depositional setting. Both were deposited during the early stages of mountain building events, overlie and/or have internal unconformities and deposited in relatively shallow water on the craton-ward side of foreland basin axes.

The Marcellus Shale disconformably overlies the Onondaga Limestone and is composed of a basal black shale, a widespread limestone unit and an upper black shale. The lower black shale and the limestone onlap and pinch out on a tectonic high to the west that was likely exposed during their deposition. This onlapping relationship suggests that water depths cannot have been more than a few tens of meters. It is interpreted that more siliciclastic-rich and organic-poor turbidites were deposited to the east, but this section is largely eroded. Other organic-rich Devonian black shales also overlie unconformities and occur only on tectonic highs.

The Ordovician Utica Shale was deposited in an area of extensive active normal faulting and the most of the organic-rich units are preserved in tectonic lows. The Flat Creek Member of the Utica is an organic-rich calcareous shale that immediately overlies a subaerial unconformity and is time-equivalent to the Trenton Limestone. The lower part of the Flat Creek is the most organic-rich and this interval and its Trenton equivalents thin and pinch out over tectonic highs suggesting relatively shallow water conditions. The upper Flat Creek grades laterally into an interbedded limestone and organic-rich black shale called the Dolgeville Formation that then grades laterally into an organic-rich member of the shallow marine Trenton Limestone. The Trenton and Dolgeville are eroded and capped by an angular unconformity that is overlain by the organic-rich Lower Indian Castle Member of the Utica which thickens and is best developed in fault-bounded lows. During deposition of the Lower Indian Castle, most of western New York was probably subaerially exposed suggesting relatively shallow water depths for shale deposition. The Utica Shale can be correlated eastward into a succession of siliciclastic-rich, organic-poor turbidite facies that is up to eight times thicker than the organic-rich shale succession suggesting that the Utica was deposited on the cratonward margin of the basin in relatively shallow water conditions.

Main Points

1. Both the Utica and Marcellus were deposited during mountain building events when there was high subsidence to east and uplift to west which created depositional relief - eustatic sea level was relatively low

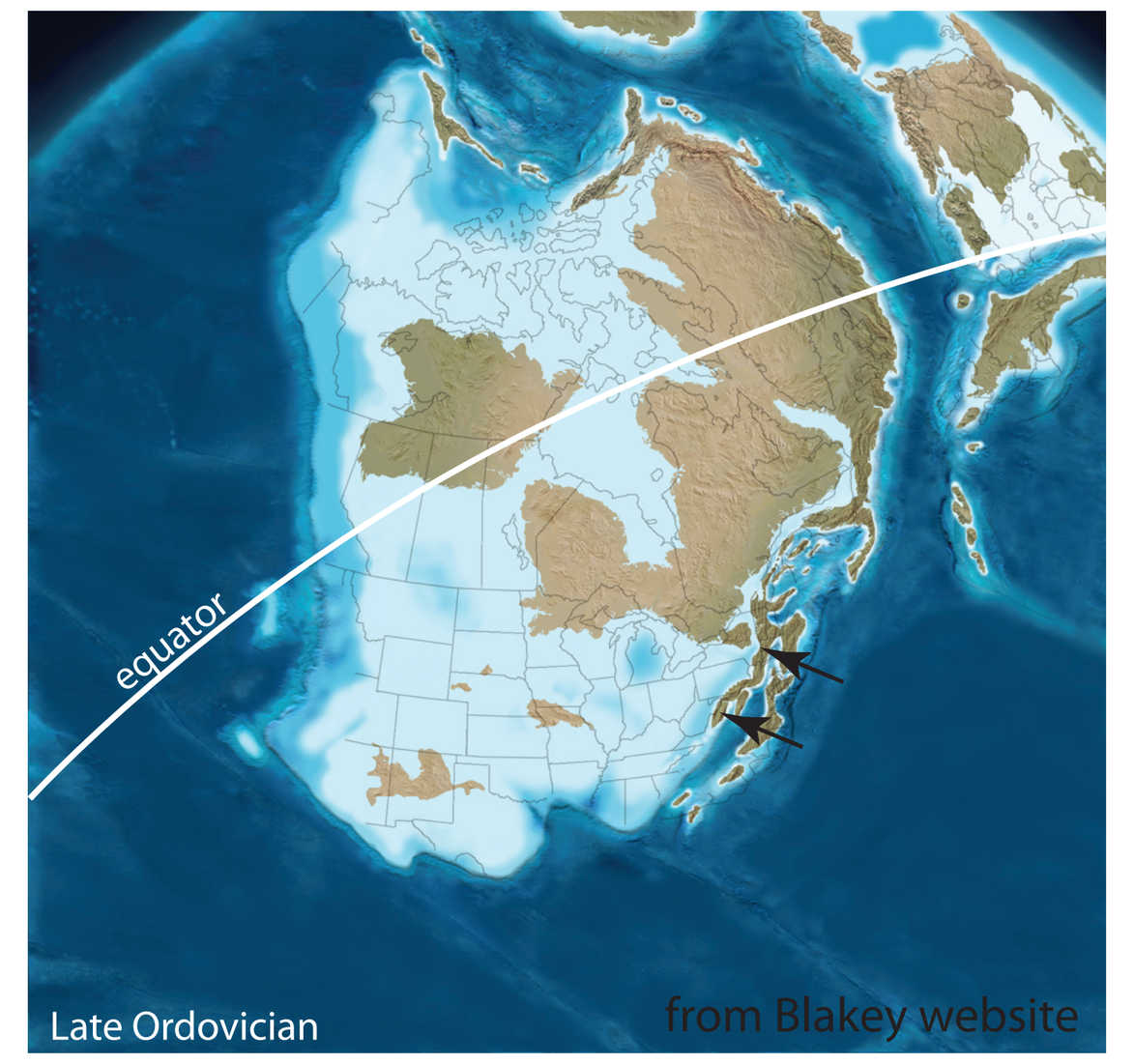
2. The organic-rich mudrocks in both Ordovician and Devonian form on the east-dipping craton-ward side of the basin, not the deepest part

3. Both the Utica and Marcellus black shales immediately overlie and progressively onlap unconformities and were at least in part deposited when subaerial exposure was occurring elsewhere in the State - most organic rich were when sea level was lowest

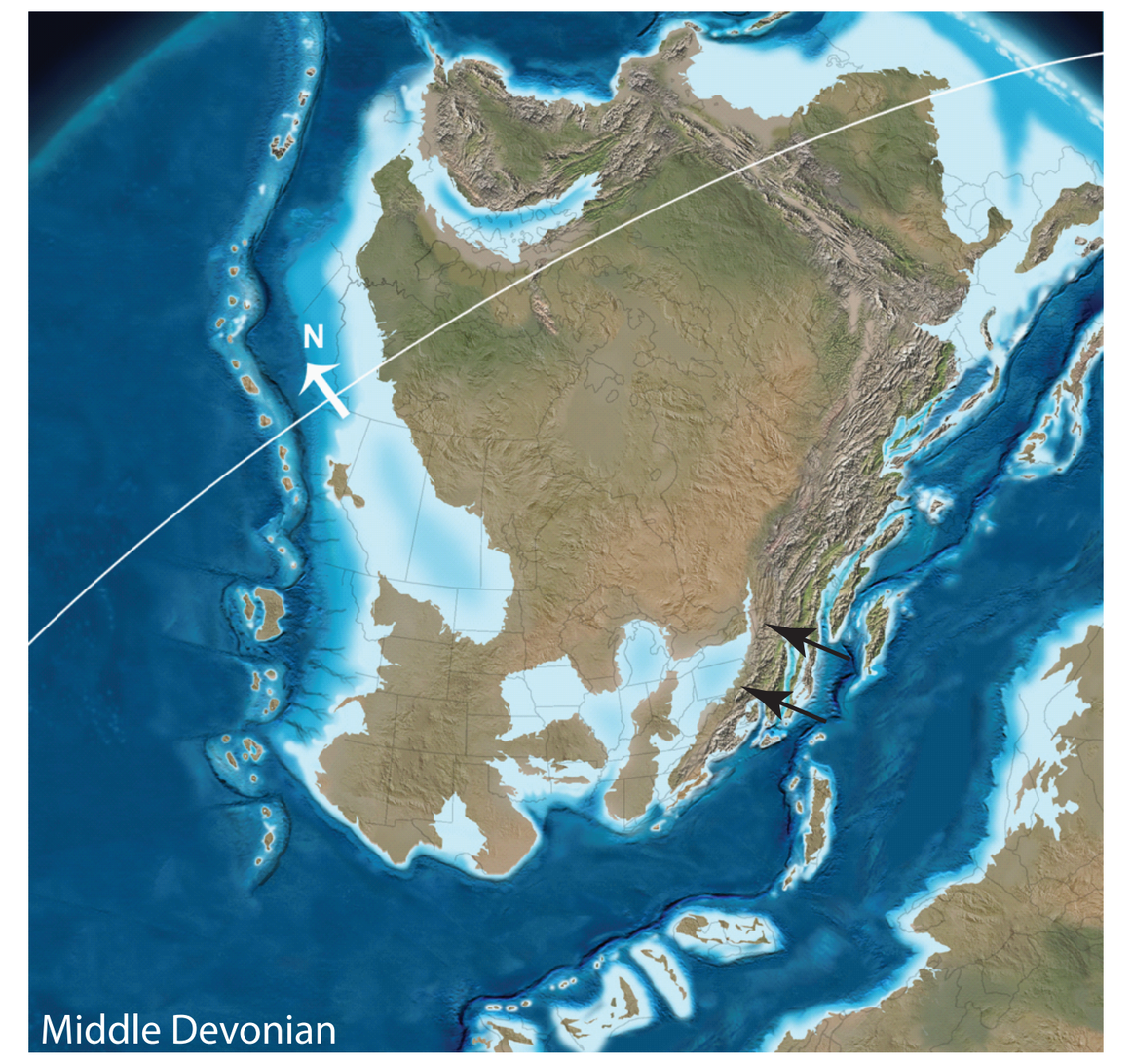
4. Both the Utica and Marcellus probably deposited in water less than 50 meters deep

5. Many other black shales also immediately overlie subaerial unconformities and appear to have been deposited in similar conditions

Organic Rich Mudrocks in New York Deposited During Times of Tectonic Activity

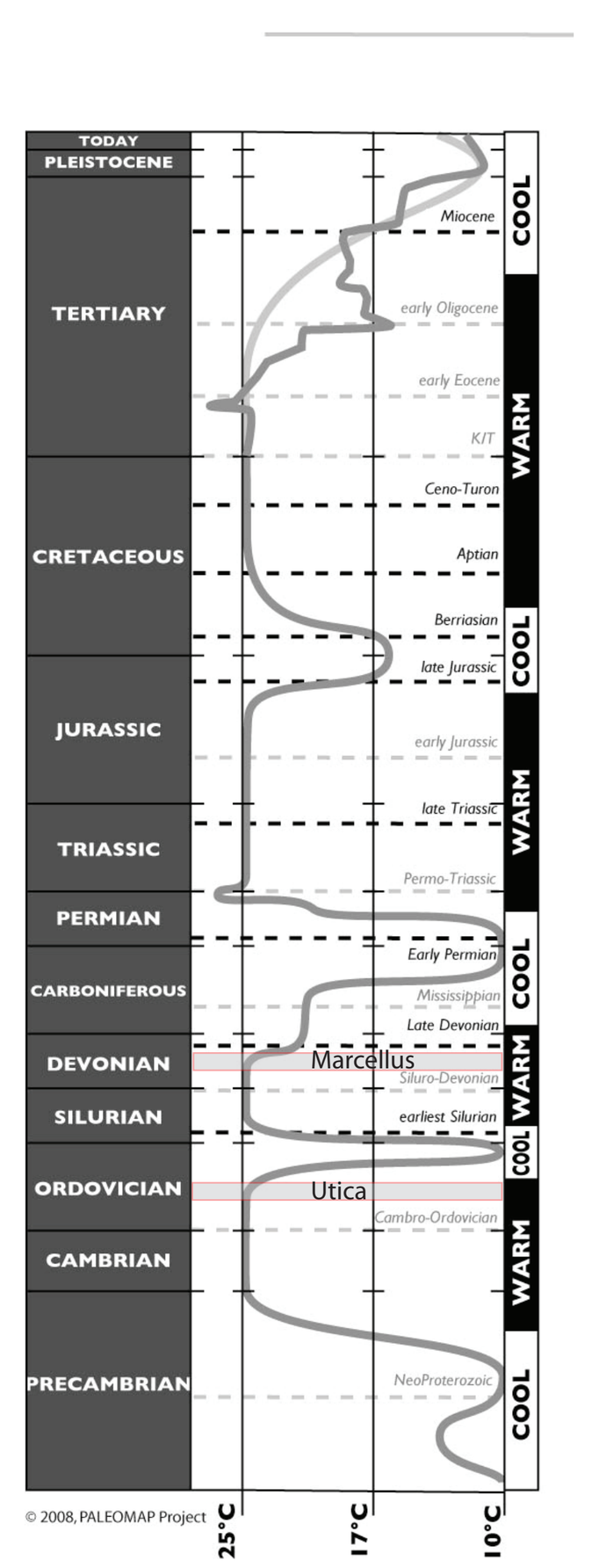


Utica Shale deposited during Late Ordovician Taconic orogeny - Island Arc collided with Eastern North America - New York about 15 degrees south of equator



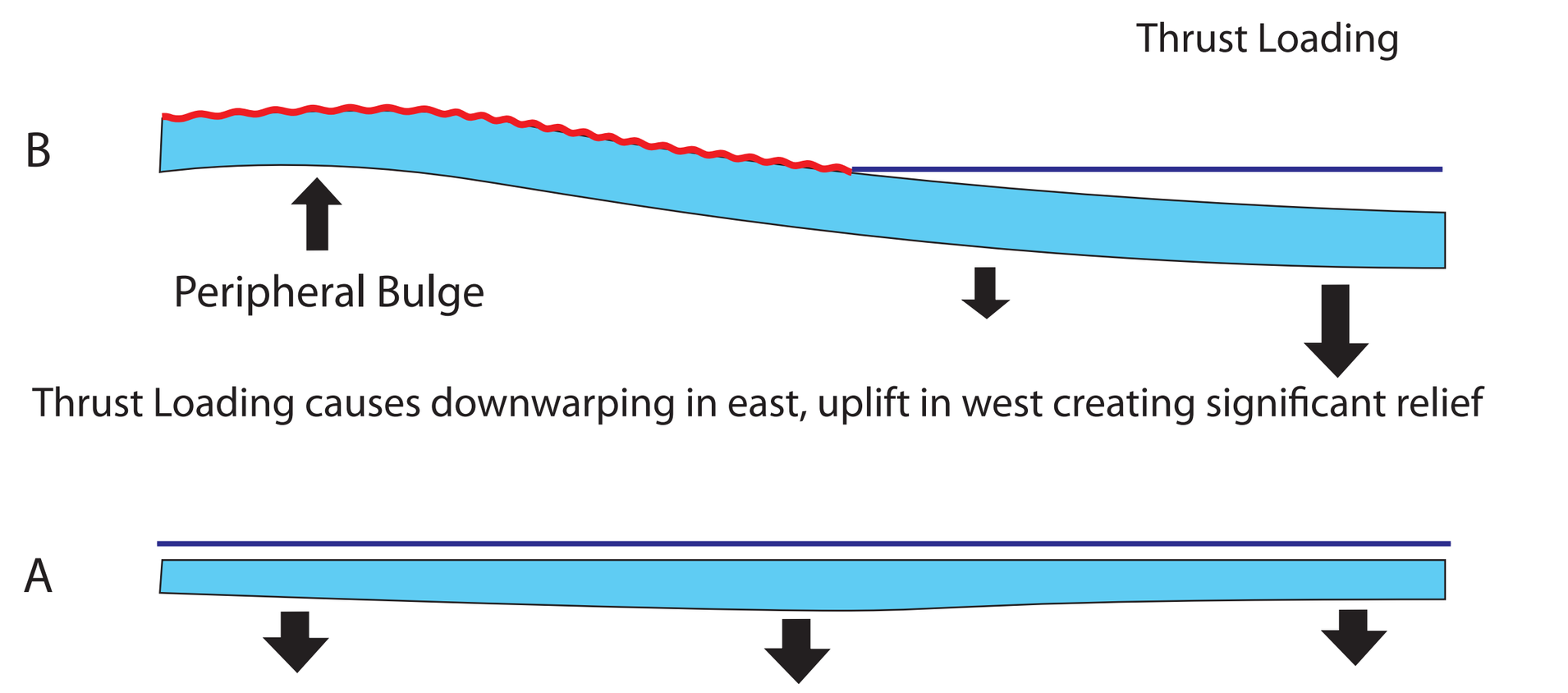
Marcellus Shale deposited during Late Devonian Acadian orogeny to East - New York about 25 degrees south of equator

These mountain building events caused downwarping to east and likely uplift to west in an area that had been very flat and stable previously. In both cases, clastics and possible nutrients would be sourced from southeast. Mountain building caused downwarping to southeast and uplift to northwest. Mountain belts may have changed oceanic and atmospheric circulation patterns.



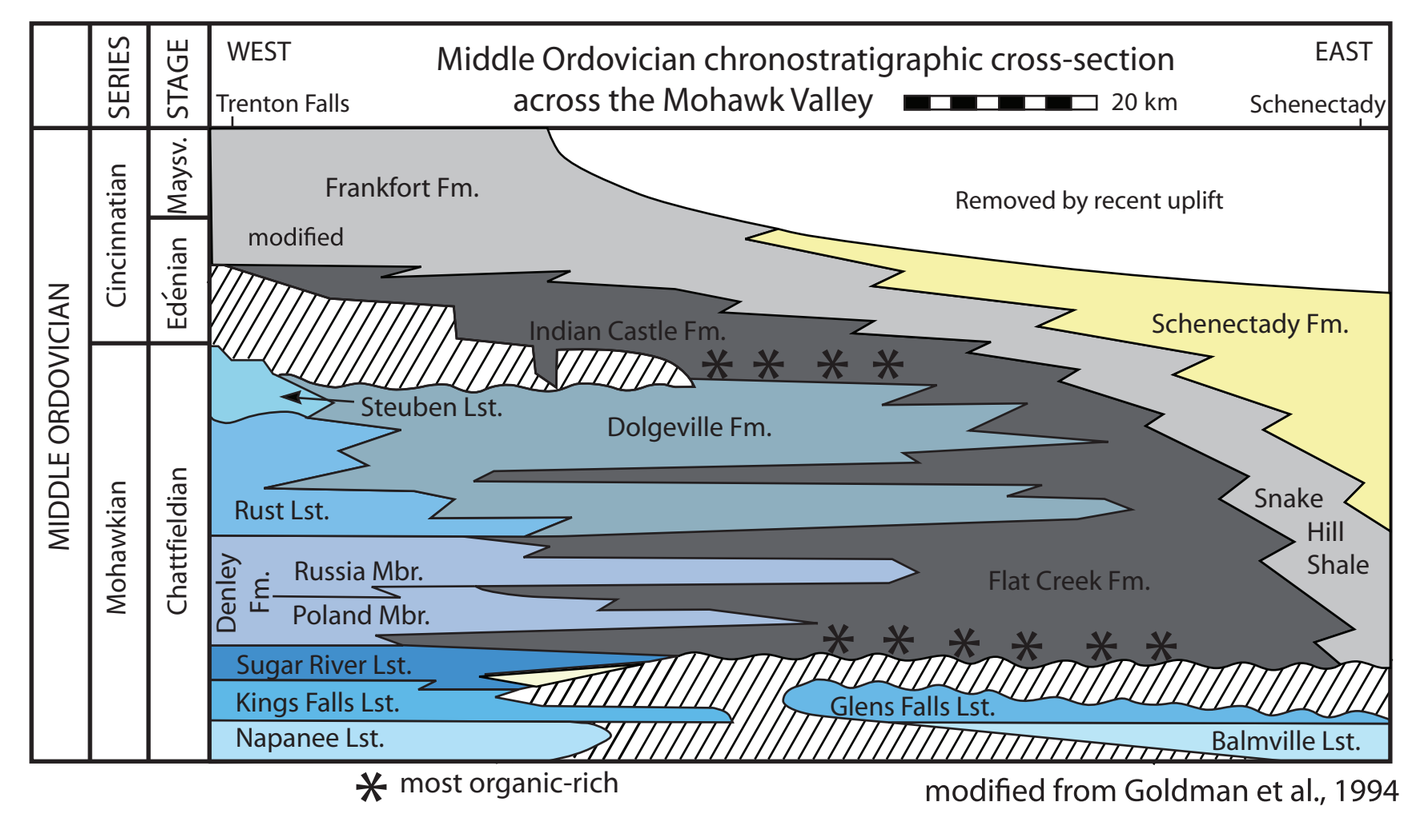
Both the Utica and Marcellus were deposited during greenhouse times - warm temperatures and low amplitude sea-level fluctuations

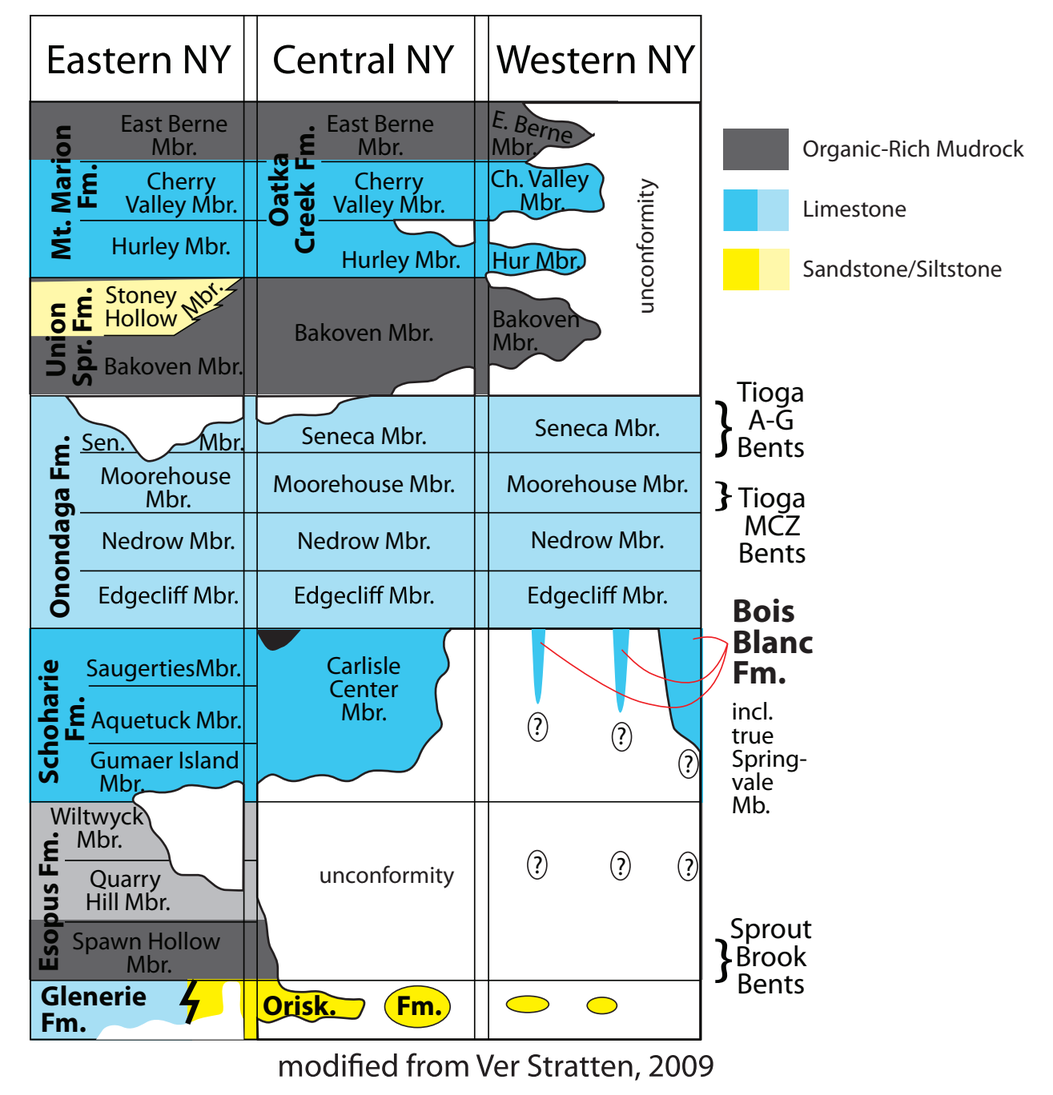
Differential Subsidence is Key - Not Eustatic Sea Level Rise



These black shales are not related to major eustatic sea-level rises but to local geologically rapid subsidence/uplift events that produced significant relief - this could be true in intra-cratonic basins or any basin where there is a rapid subsidence event - a major eustatic rise might actually diminish the chances of making organic-rich strata

Organic-Rich Mudrocks Overlie and Are Time-Equivalent to Unconformities

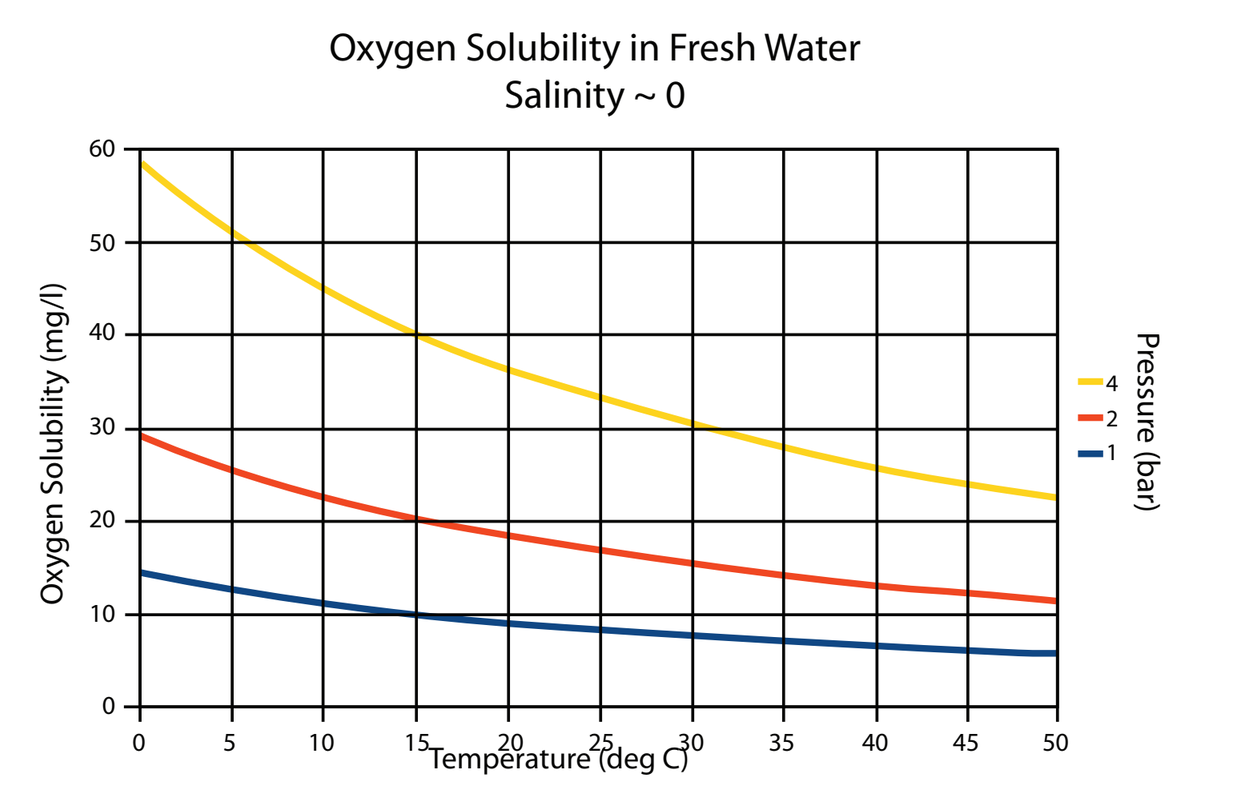


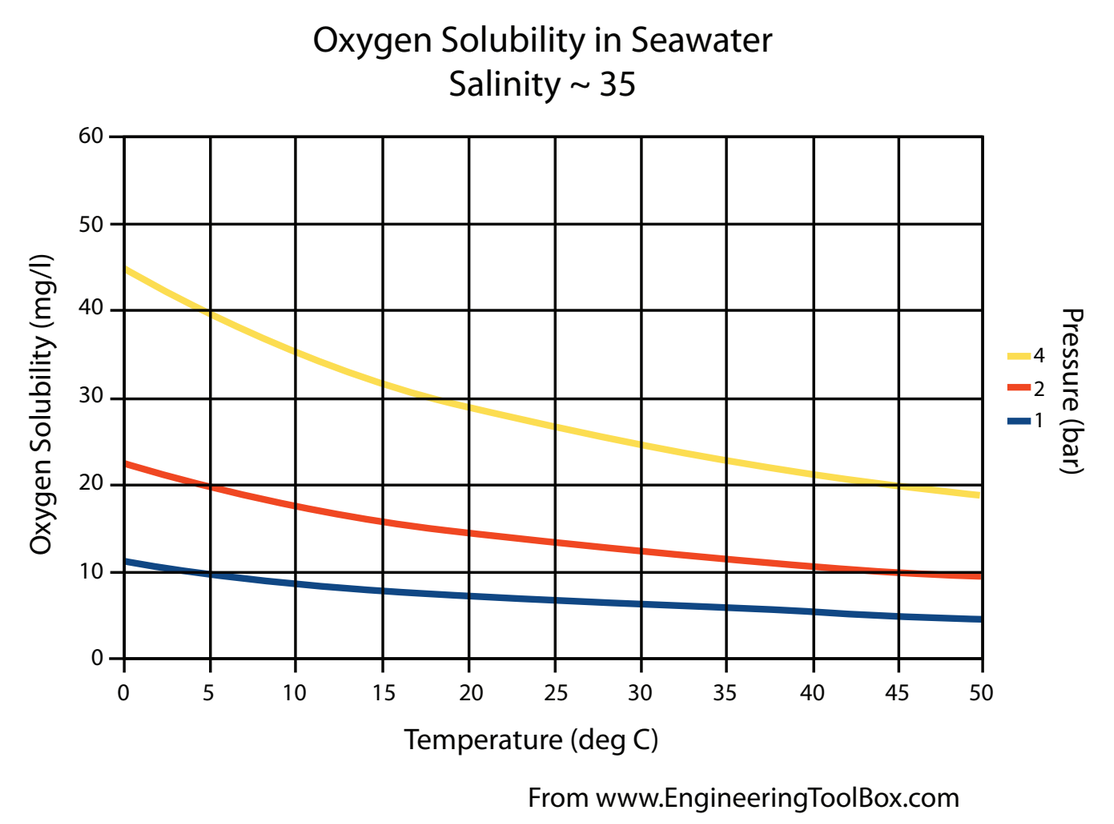


The most organic-rich parts of both the Utica and Marcellus overlie and are time-equivalent to nearby unconformities suggesting relatively low sea level - some have interpreted the unconformities to be submarine "drowning" unconformities, but in some cases they are demonstrably subaerial and have durations of millions of years

Bakken, Barnett, Woodford, Chattanooga and many other organic-rich mudrocks also overlie and onlap demonstrably subaerial unconformities

Shallow, Warm, Low Pressure, High Salinity Water Is Best for Making Organic RIch Sediments (If a pycnocline can develop)





From www.EngineeringToolBox.com

- Shallower water likely to be warmer, and lower pressure both of which lead to lower solubility of oxygen
- Shorter water column for phytoplankton to be eaten on the way down
- Smaller volume of bottom water below pynocline to deplete (could be cm to a few meters - Tyson and Pearson, 1991; Scheiber, pers. comm)
- Shallower water that is periodically euxinic but that also has storms that touch the bottom can recycle nutrients
- Deep and permanently anoxic basins are nutrient traps - all nutrients would have to come from rivers

Previous Work: Depositional Environment of Organic-Rich Mudrocks

Deep Basin Models

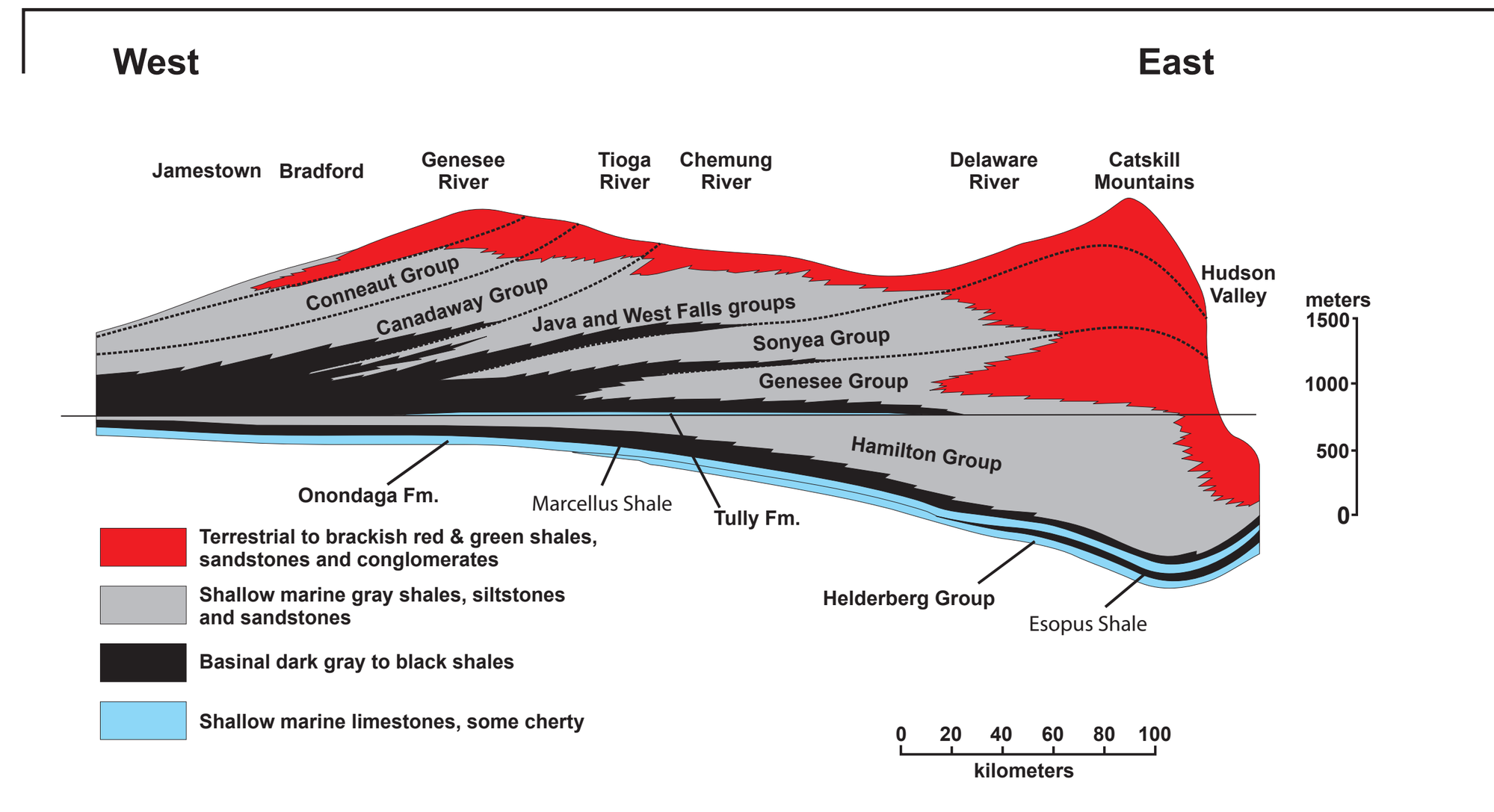
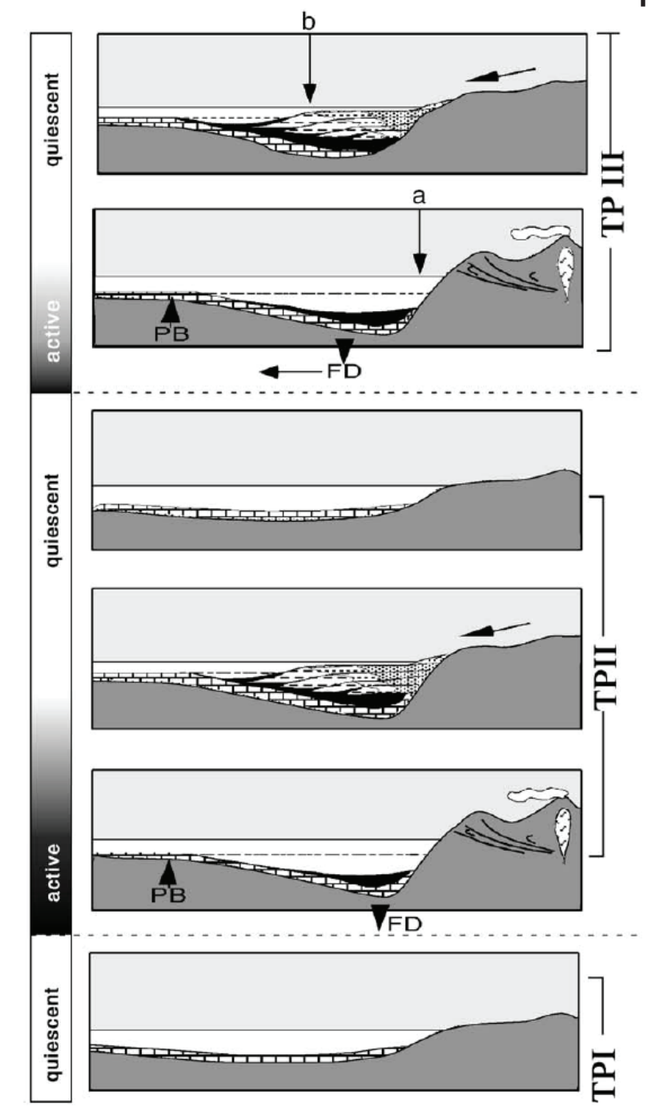
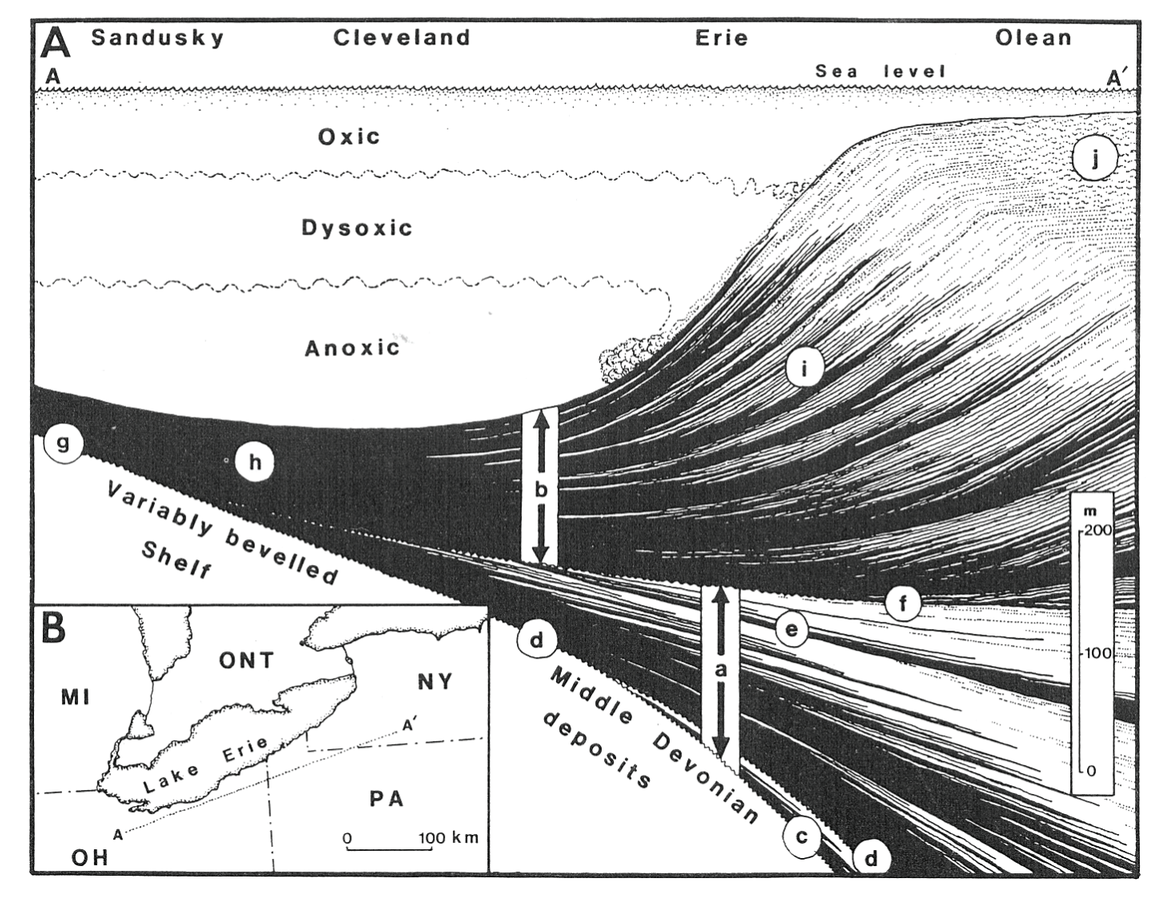


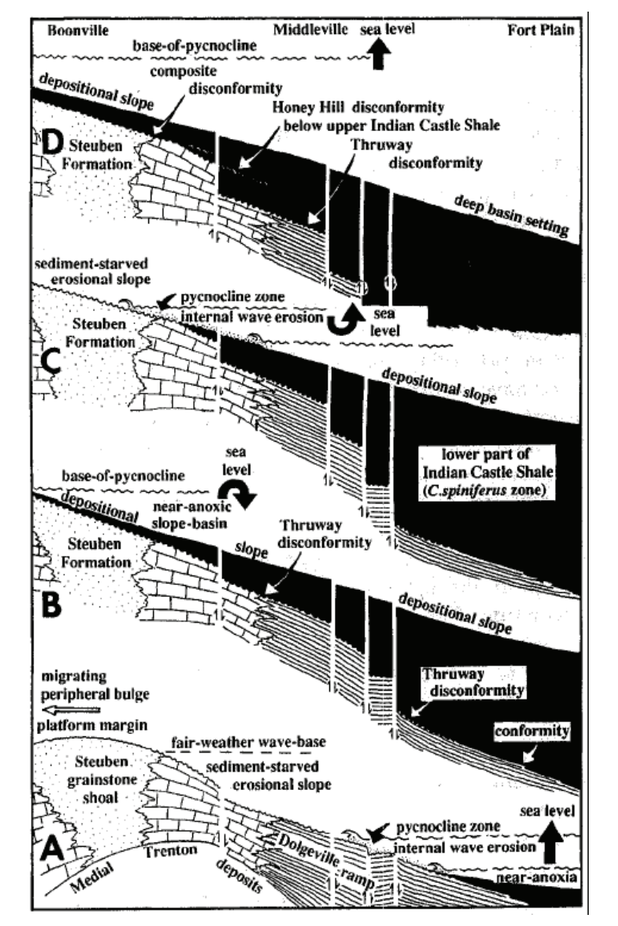
Figure modified from House and Kirchgasser (1993) for Devonian of NY has been published many times and shows shales forming at toe of slope and the deepest part of the basin



Sageman et al., 2003 model for Devonian shales in New York shows black shales forming in deepest part of basin

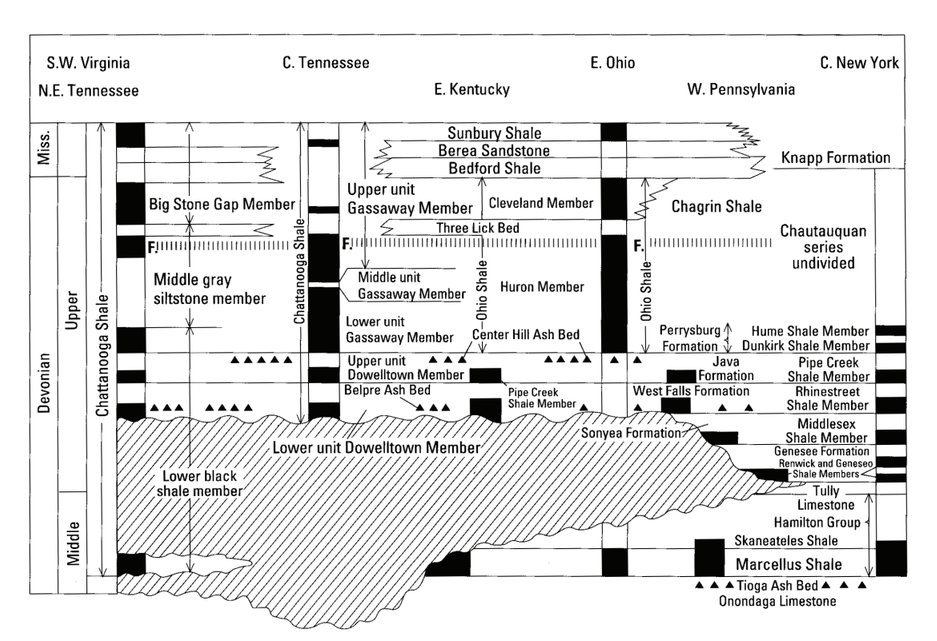


Baird and Brett, 1991 model for Devonian Black Shales of western NY showing downlap on unconformities with organic rich mudrock deposited on downslope, in basin and on cratonward side of margin

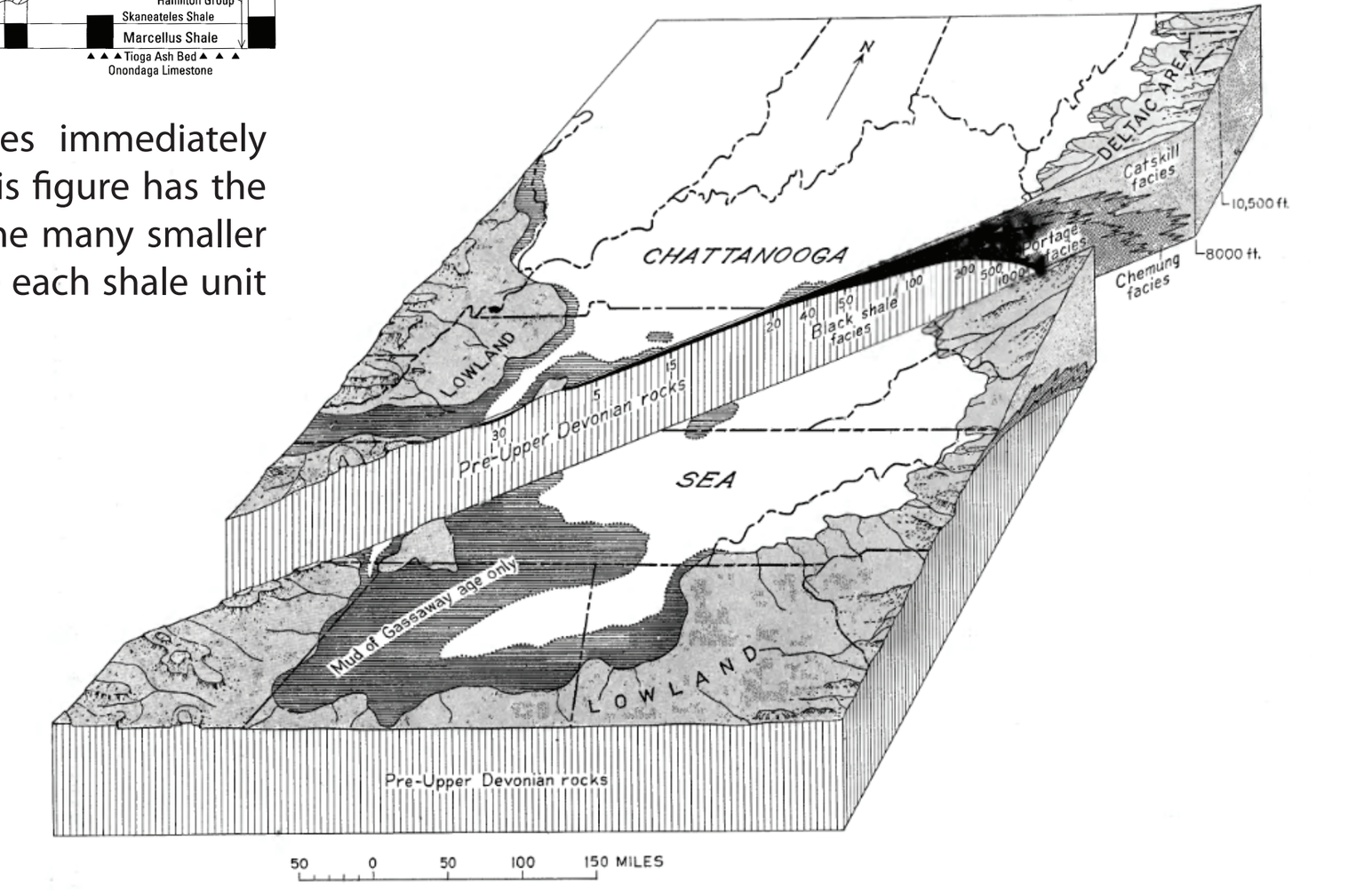


Baird and Brett, 2002 model for Utica Shale - Shale deposited in deep basin, Cisne et al. (1982) interpreted water depths >500 meters for Utica

Shallow Water Transgressive Onlap Models

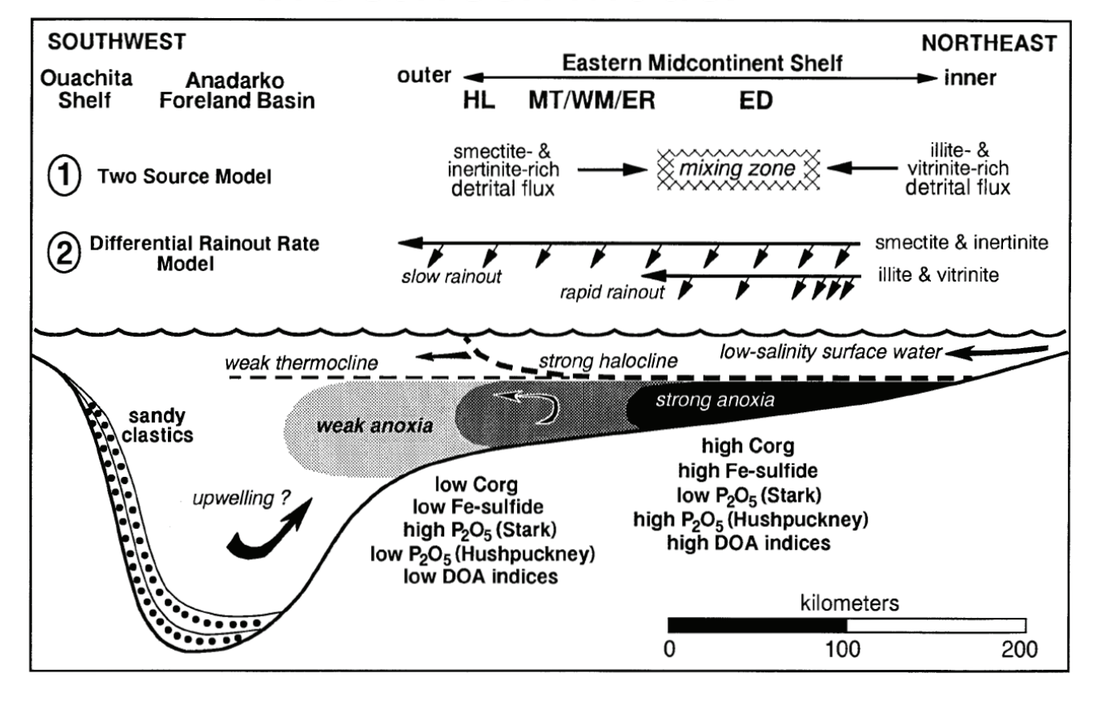


Many Devonian Black Shales immediately overlie an unconformity - this figure has the major unconfmity but not the many smaller unconformities that underlie each shale unit (de Witt et al., 1990)

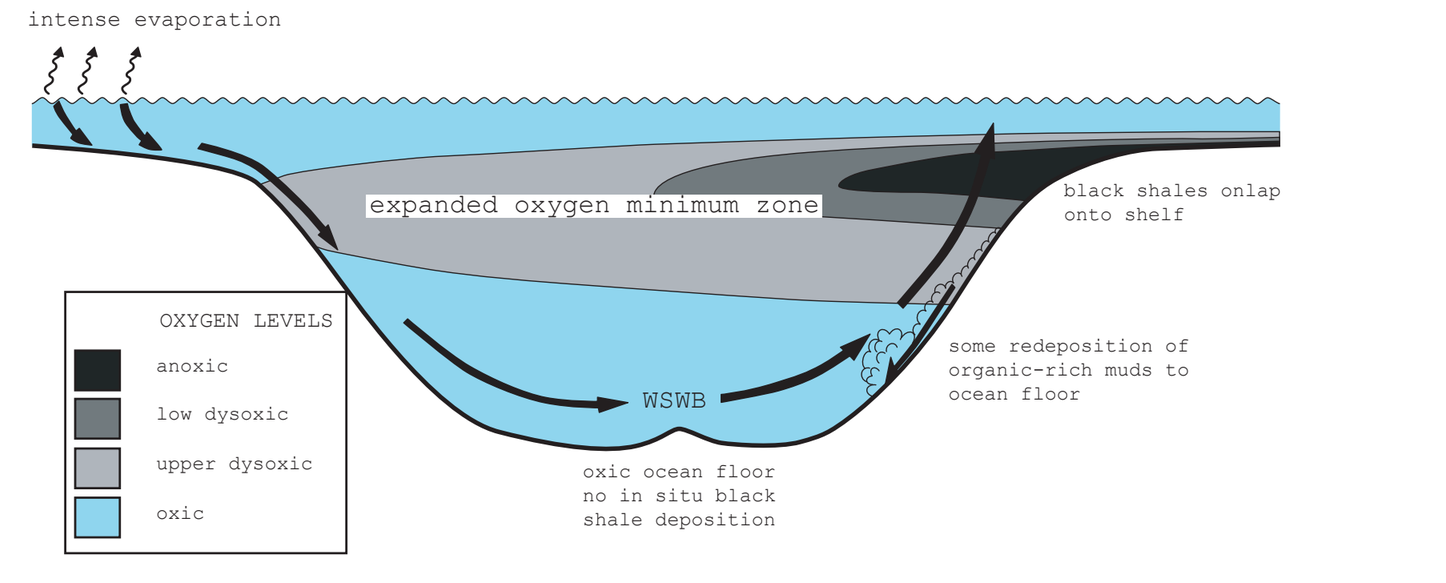


Conant and Swanson, 1961diagram of Chattanooga Black Shale (time-equivalent to youngest NY shales organic-rich mudrocks) - They interpreted the shale to have formed in <100 feet (30 meters) of water based on onlap of unconformity, other field relations, presence of plant fossils, more

In Between Model

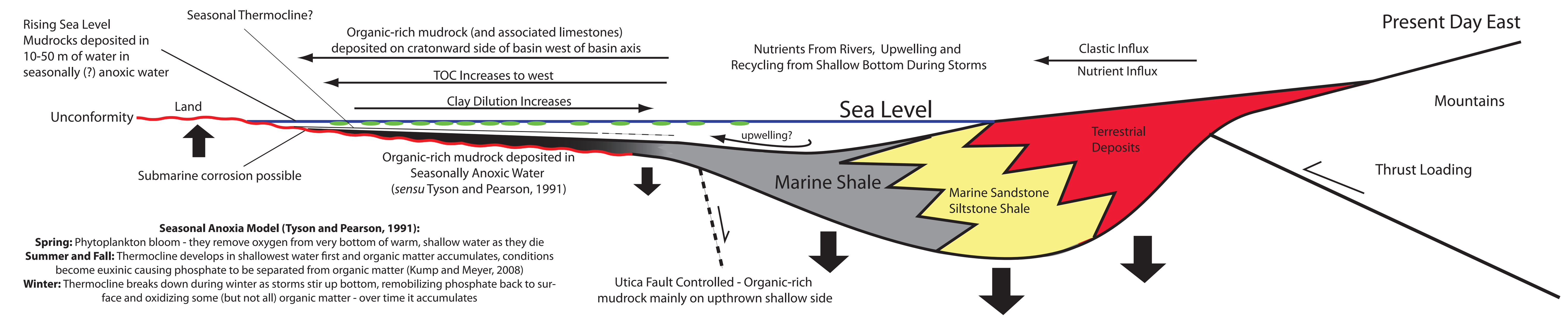


Algeo et al. (1997) model for Pennsylvanian black shales of midcontinent - Although they interpreted water depths to be relatively deep, this diagram shows that the shale formed on the cratonward side of the basin, not the deepest part of the basin and that organic content increases landward



Wignall (1994) model for Cenomanian black shales whcih occur on shallow shelf, not deep basin

Depositional Environment of Organic Rich Mudrocks in New York



Seasonal Anoxia Model (Tyson and Pearson, 1991):
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)
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