DISCLAIMER:

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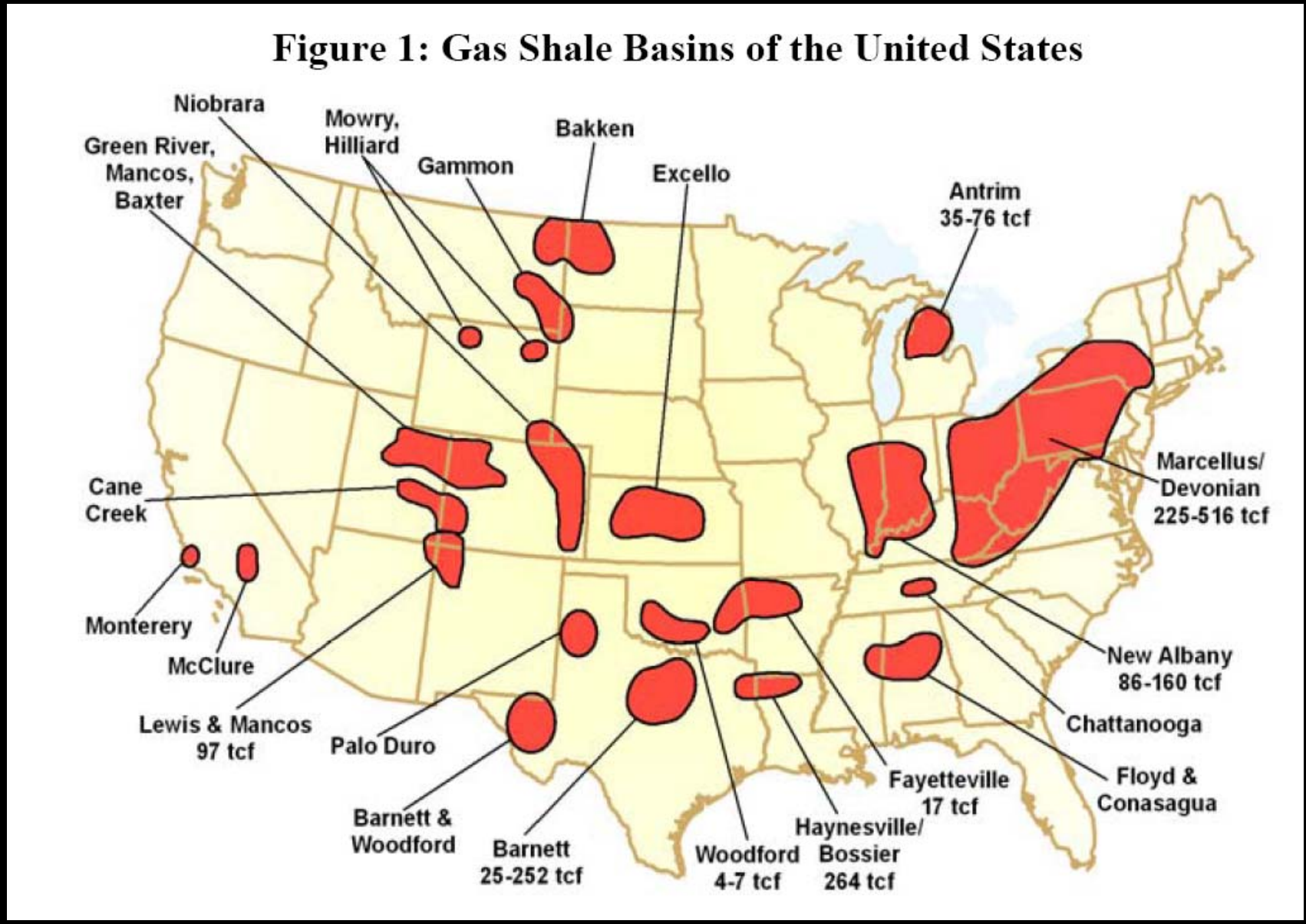
Integrated Characterization of the Devonian Marcellus Shale Play in New York State

Taury Smith and Jim Leone

New York State Museum

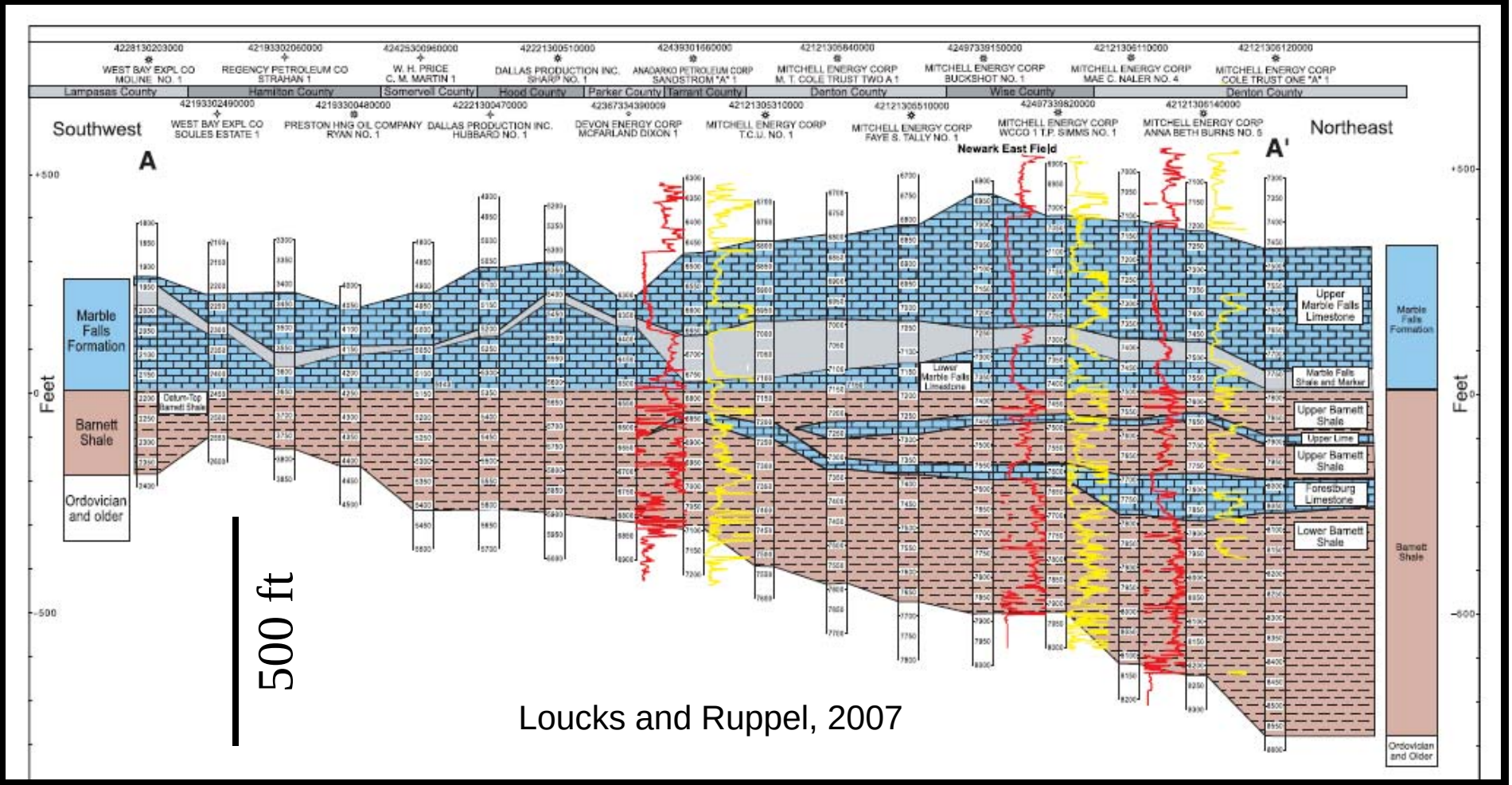


Shale Gas has recently become a primary target for exploration and development in the United States – potential for hundreds of TCF

Barnett Shale Characteristics

- Barnett Shale Special Issue of AAPG Bulleting suggests that most gas produced from areas where shale has:
  - TOC 3-12 wt%
  - Vitrinite reflectance 1.1-2.0
  - Burial Depth >4000 feet
  - 300-600 feet thick
  - Slightly overpressured
  - Clay Content < 50%
  - Areas with few natural fractures and faults

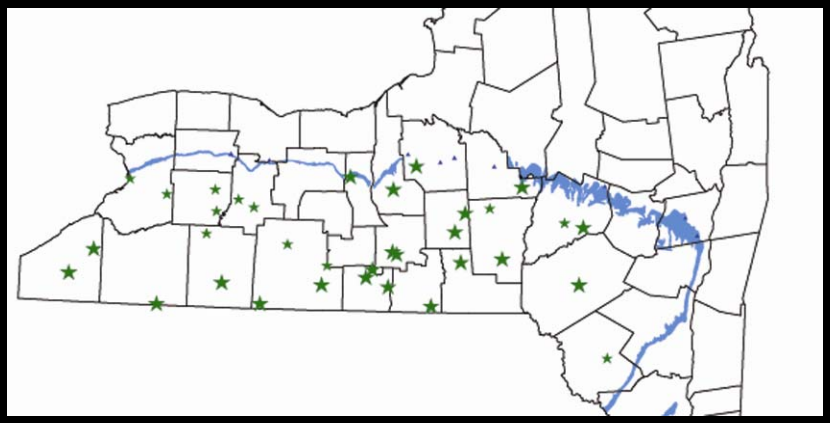
Pollastro, 2007



Loucks and Ruppel, 2007

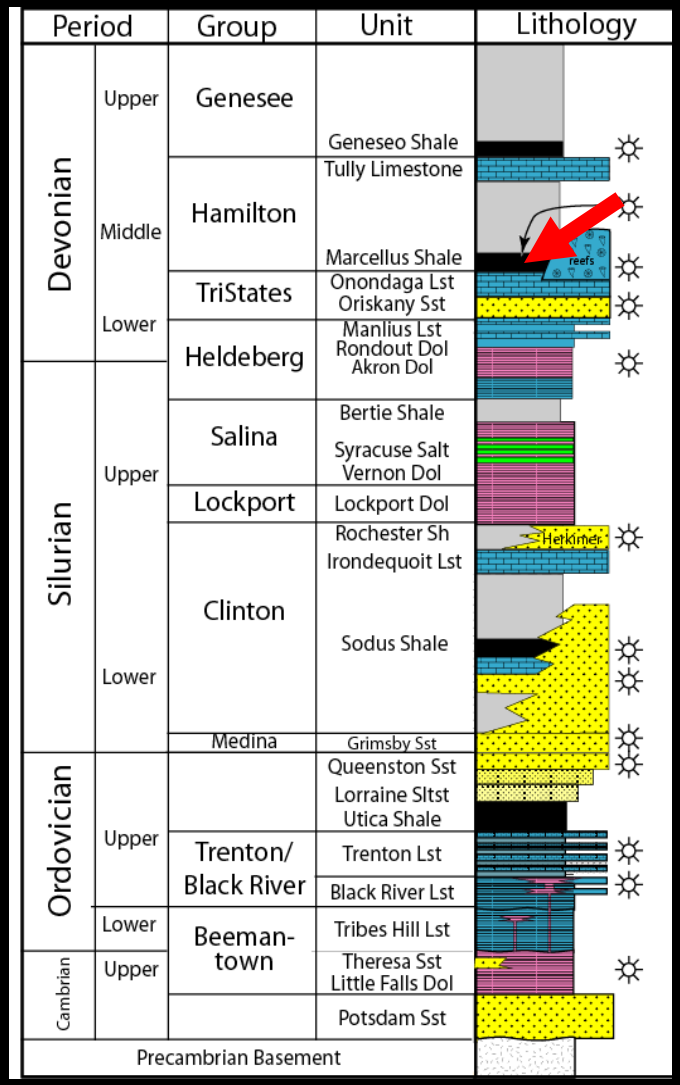
Cross section shows thickness of Barnett Shale in brown and the sealing Marble Falls Limestone – Barnett Shale thickness 300-600 feet in productive area - overpressure has built up in the shale and the limestone is a seal that helps maintain overpressure

Integrated Geochemical and Stratigraphic Study

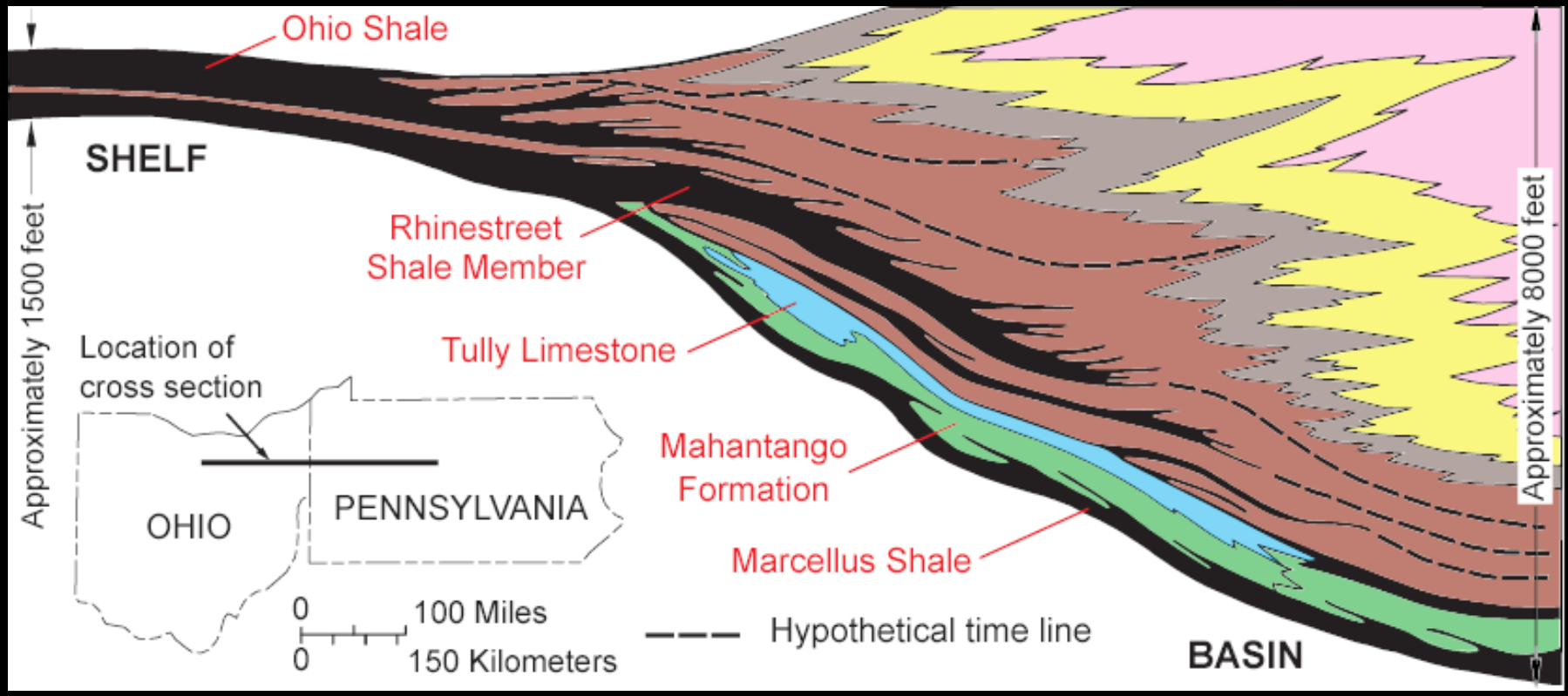


- Have undertaken an integrated stratigraphic and geochemical study of the Marcellus Shale to delineate potential fairways
- Have correlated hundreds of wells
- Have done rock eval geochemistry on > 30 sets of well cuttings, 2 cores and numerous outcrops

Devonian Paleogeography



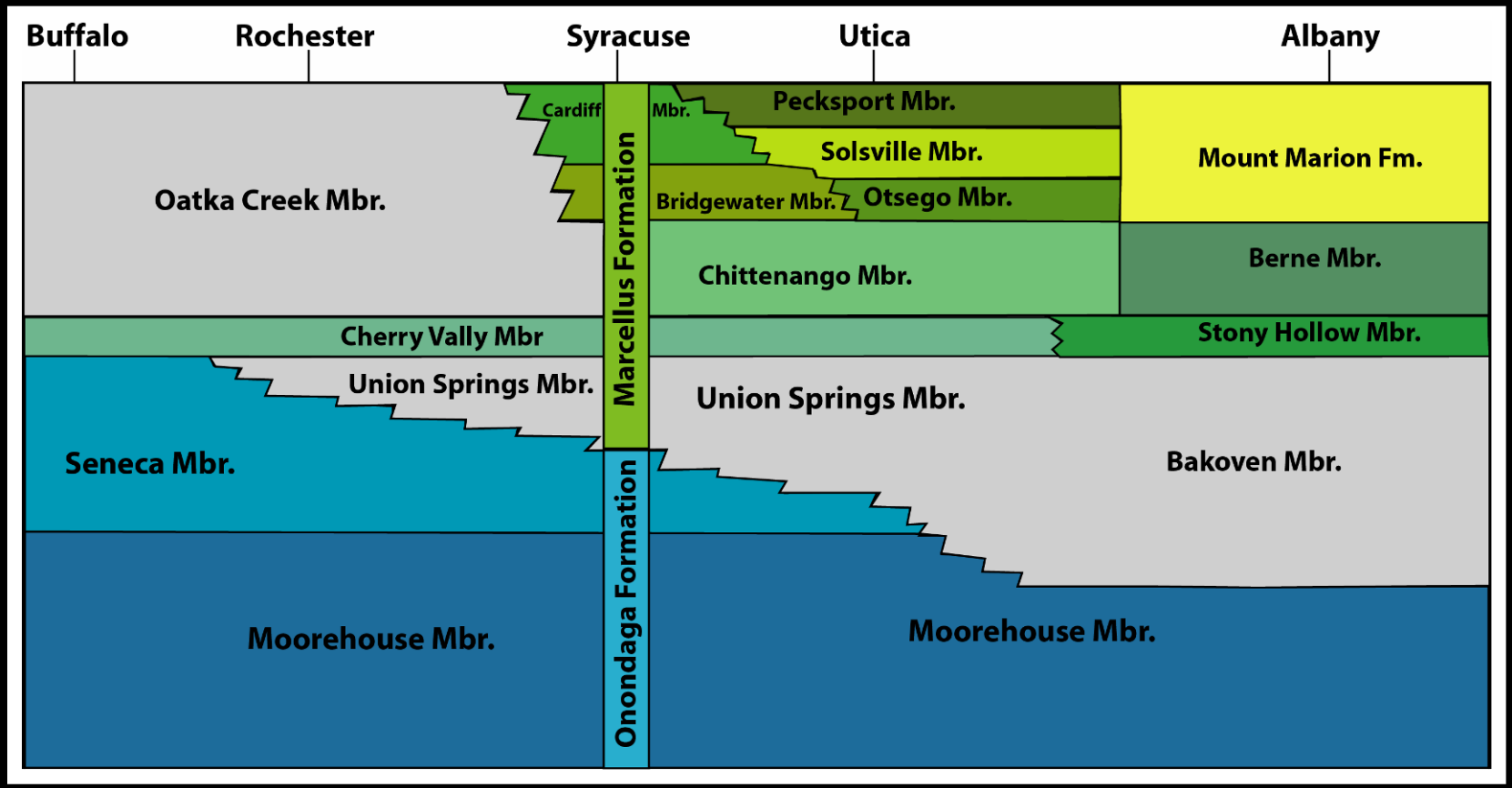
Marcellus deposited during early stages of Acadian Orogeny



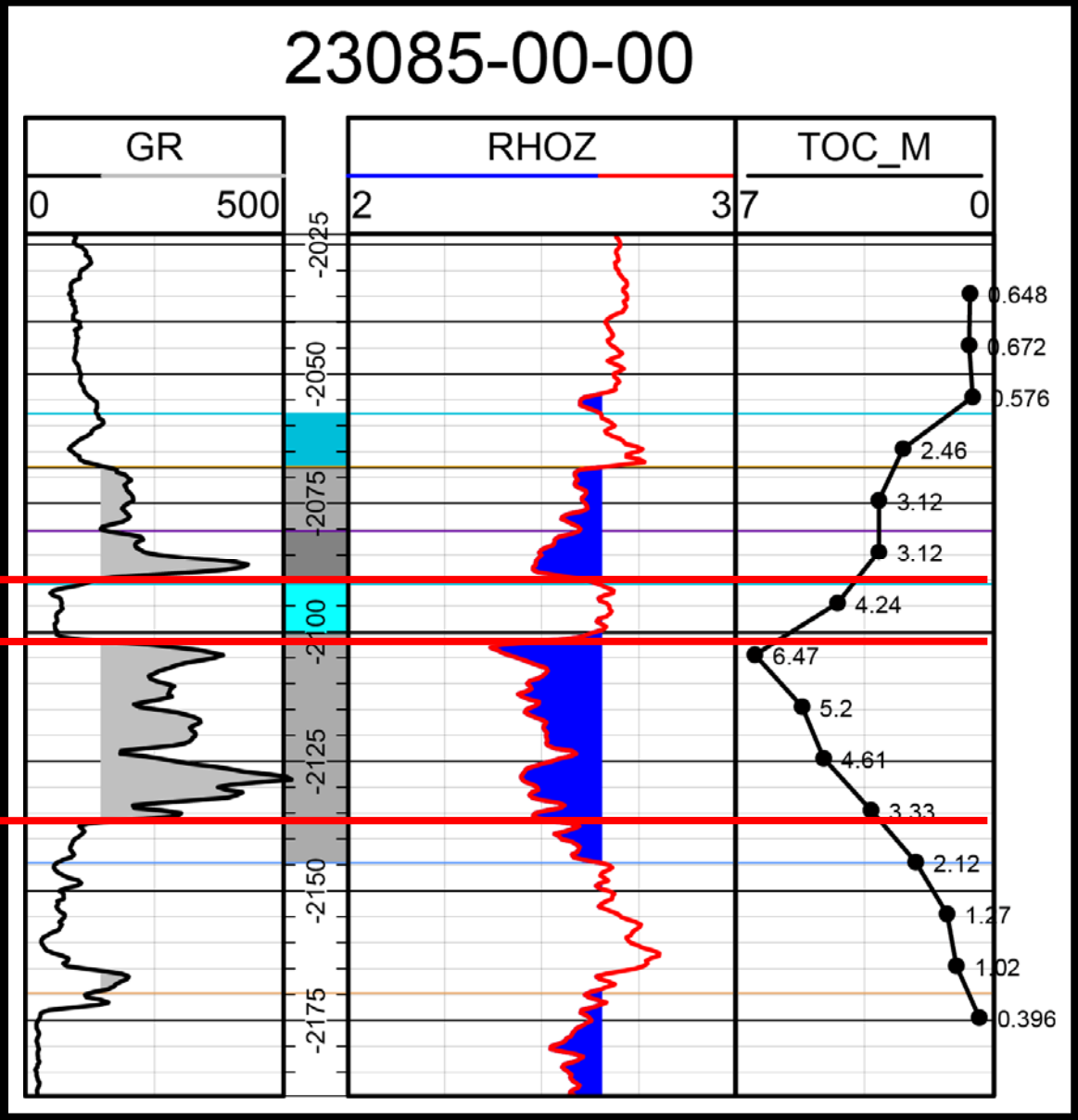
The Marcellus Shale is at the base of the Catskill Deltaic sequence and marks the onset of the Acadian Orogeny – there are several other black shales that are part of this sequence, but most are not buried deeply enough to be reservoirs in New York

Harper, 1999

The Devonian Marcellus Shale



The Marcellus Shale has a facies relationship with the underlying Onondaga Limestone – It has thee main members in the subsurface – the organic-rich Union Springs Shale, the Cherry Valley Limestone and the Oatka Creek Shale which is organic rich at the base



Oatka Creek

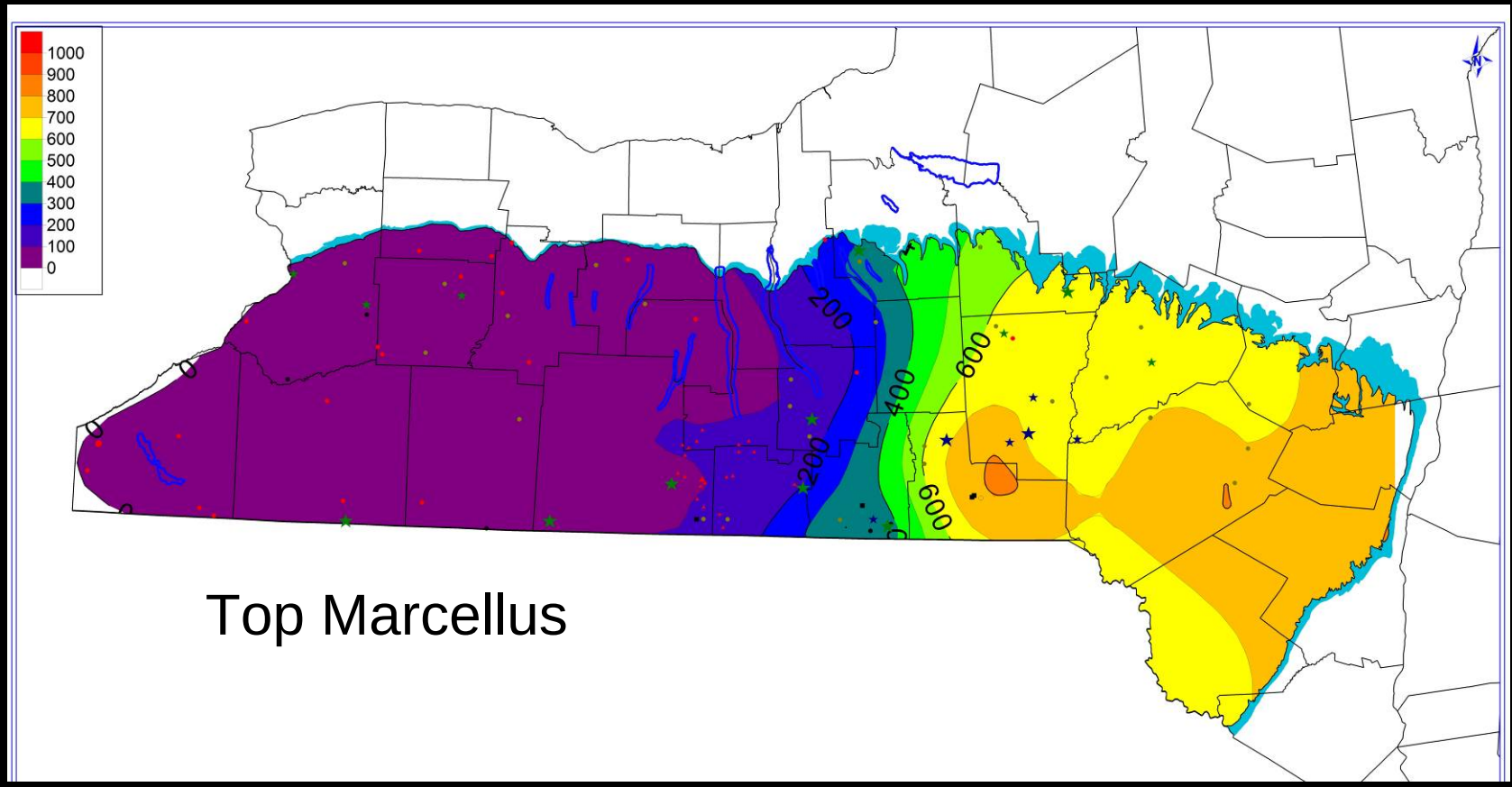
Cherry Valley

Union Springs

Onondaga

Cuttings analysis shows that the basal Oatka Creek, Cherry Valley Limestone, Union Springs and Upper Onondaga all have elevated TOC values

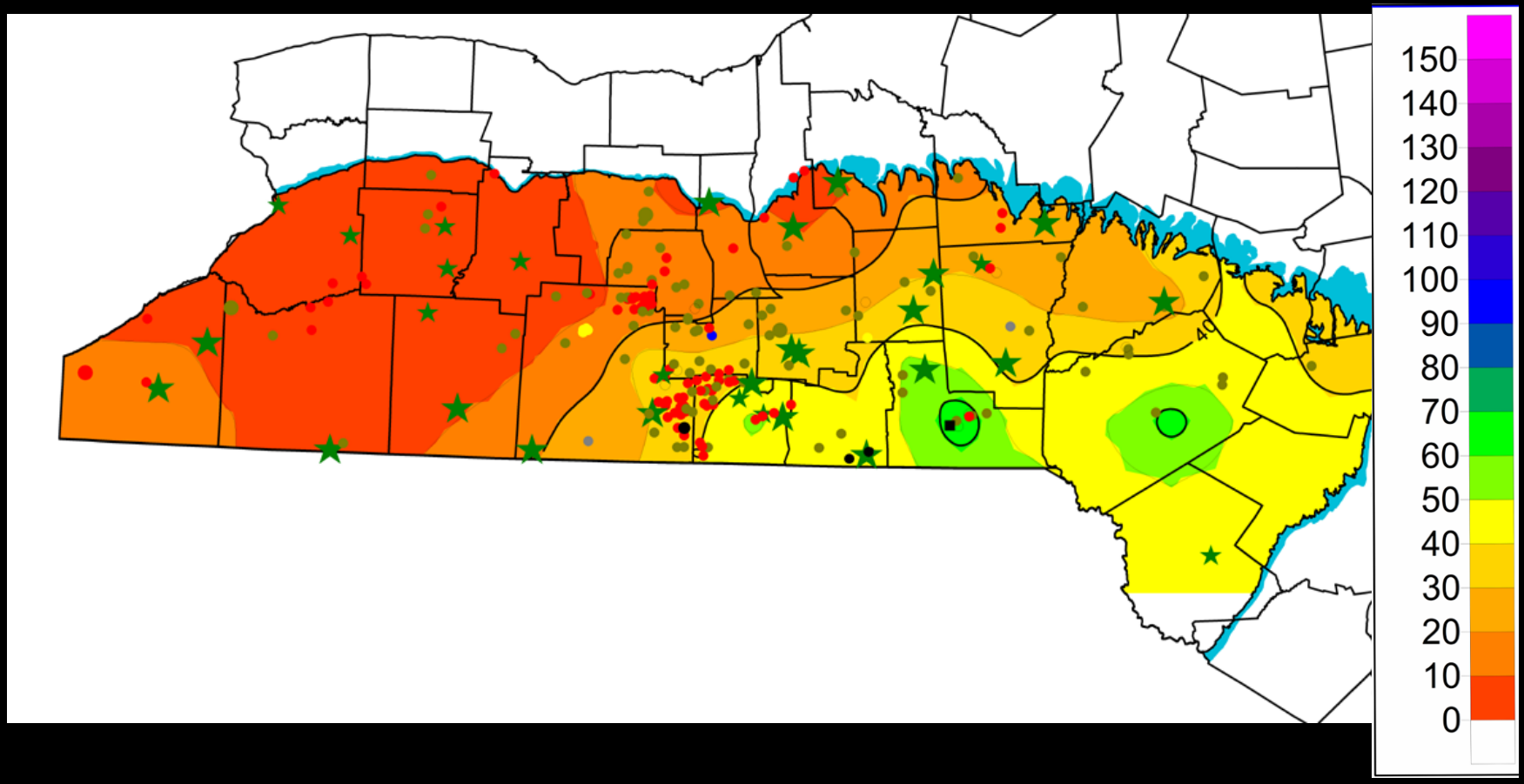
Marcellus Isopach



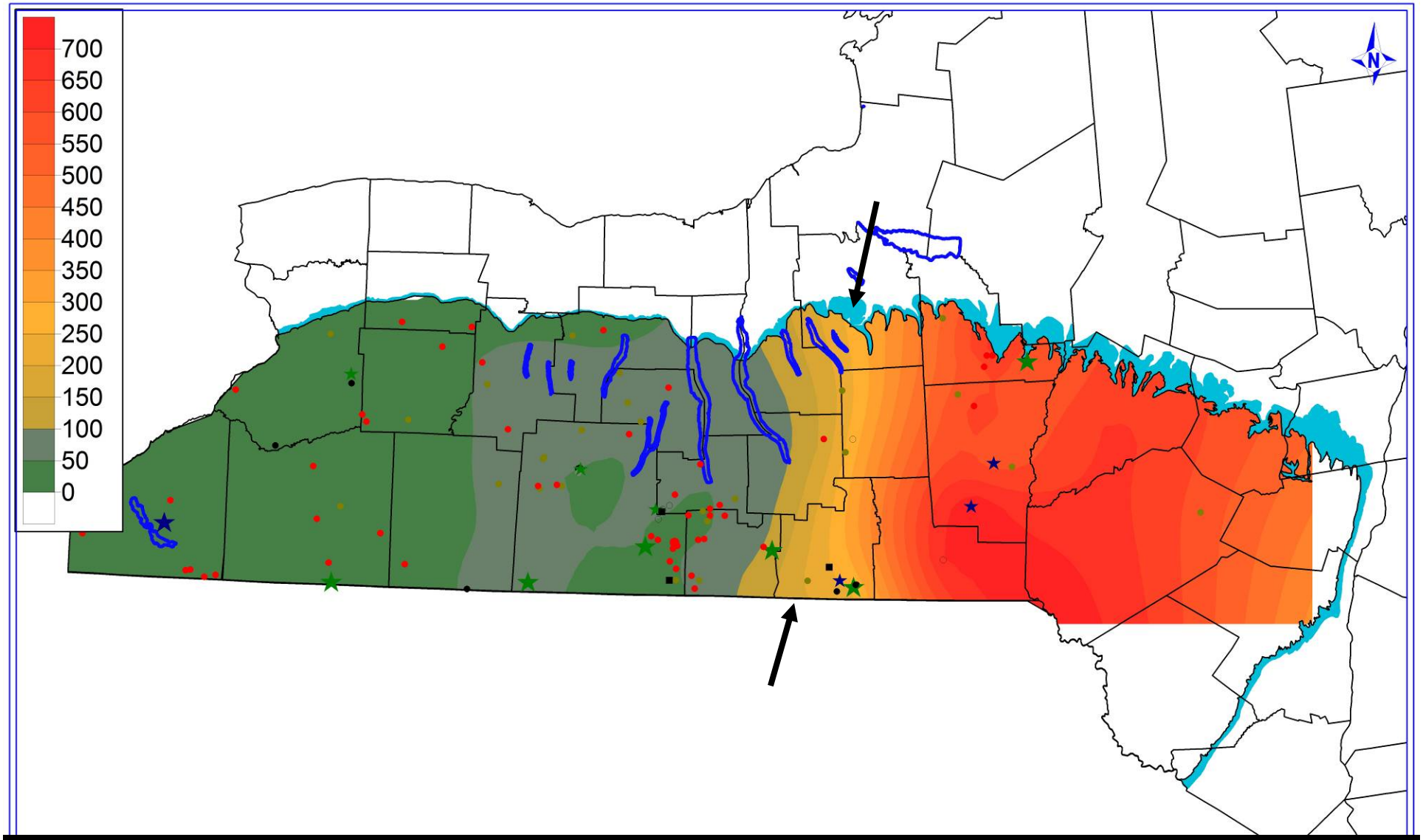
Marcellus thickens to the east, subsidence related to the Devonian-Mississippian Acadian Orogeny to the East

Green stars are geochem data points

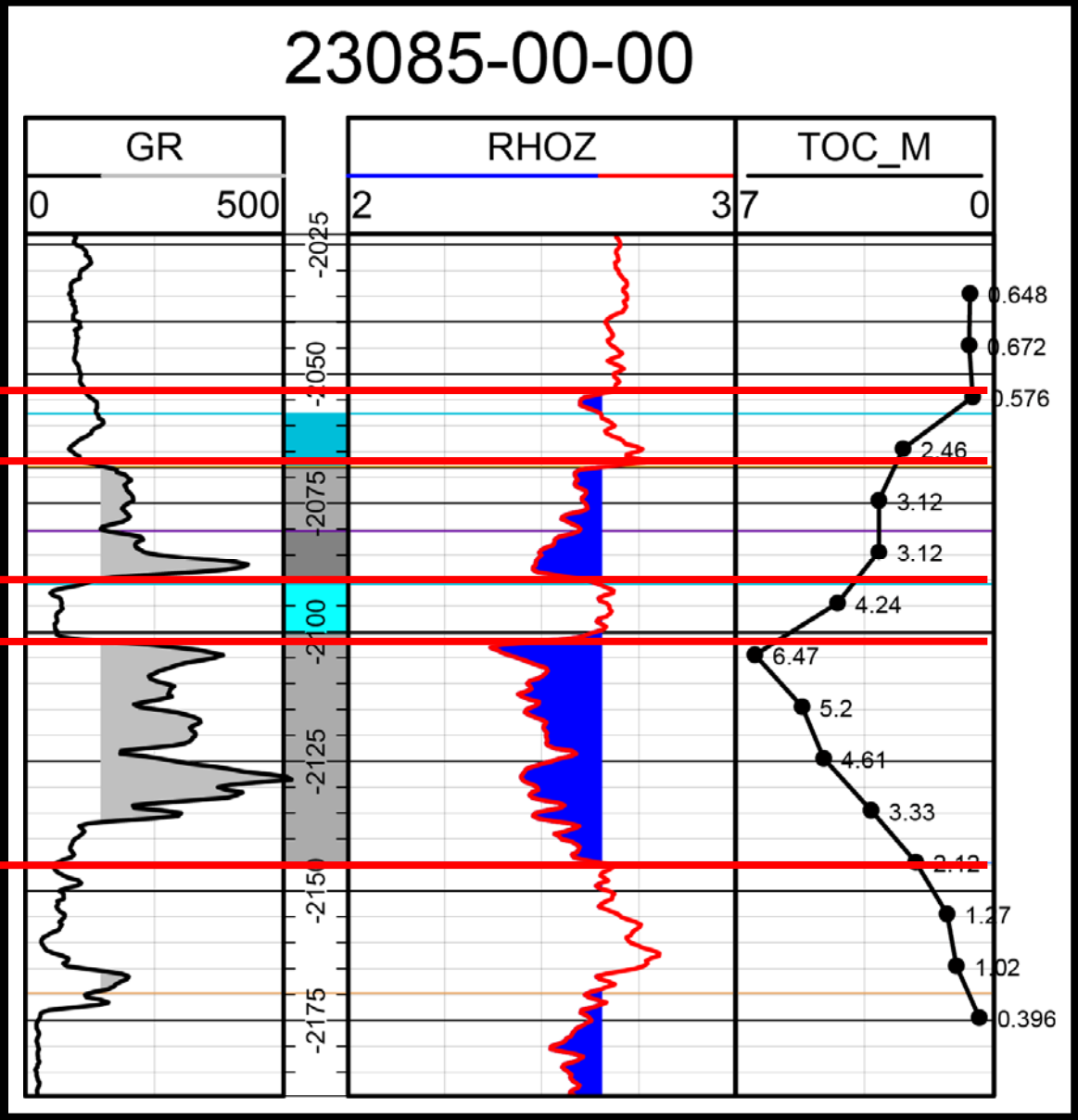
Marcellus (Union Springs Isopach)



The Union Springs Member thickens to southeast and is the most organic–rich part of the Marcellus



Upper Marcellus Isopach – It is in the upper Marcellus that most of the thickening takes place – note tectonic hinge – much of the Upper Marcellus or Oatka Creek is grey shale with no reservoir potential



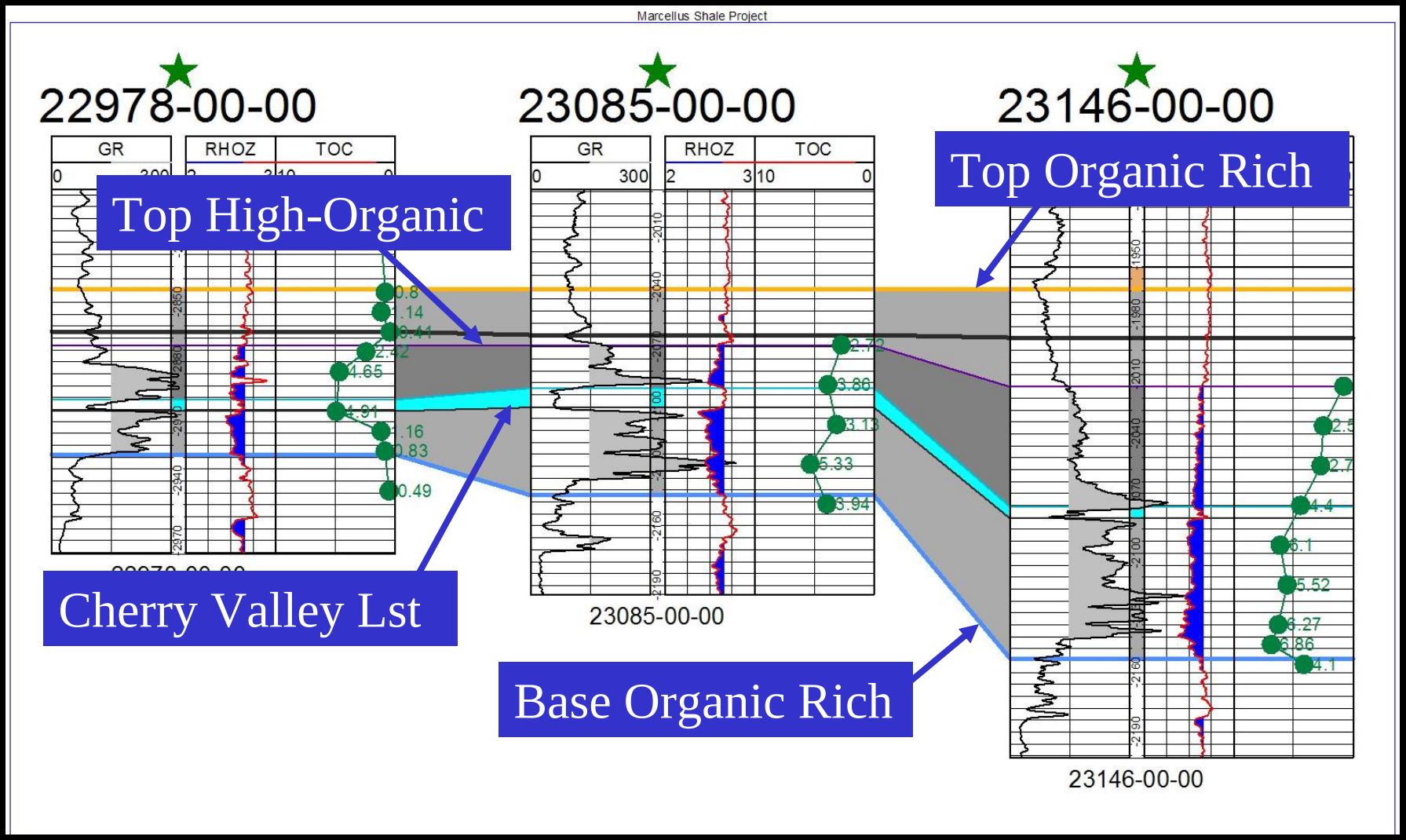
Top Organic Rich

Top High-Organic

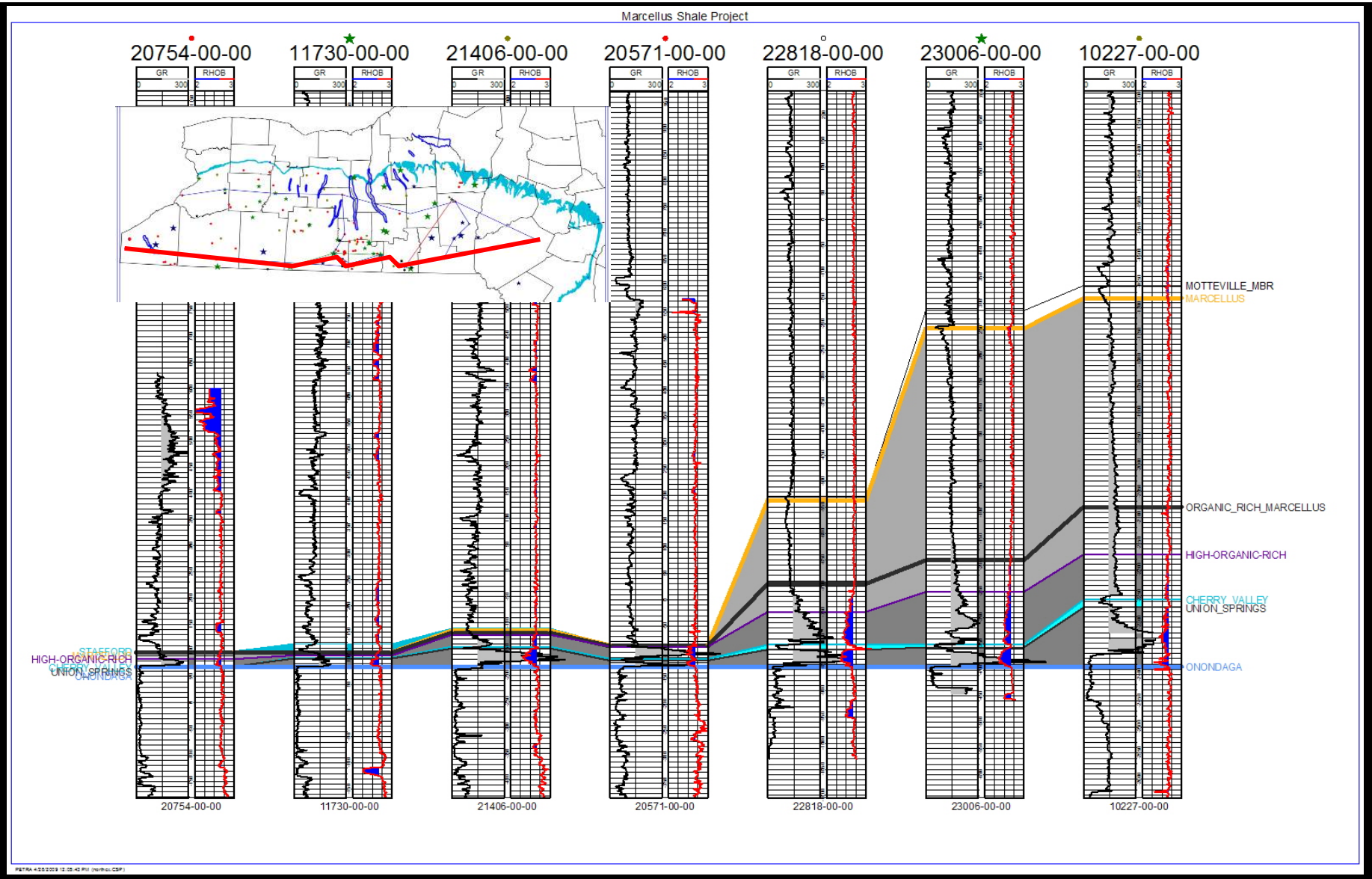
Cherry Valley

Base Organic-Rich

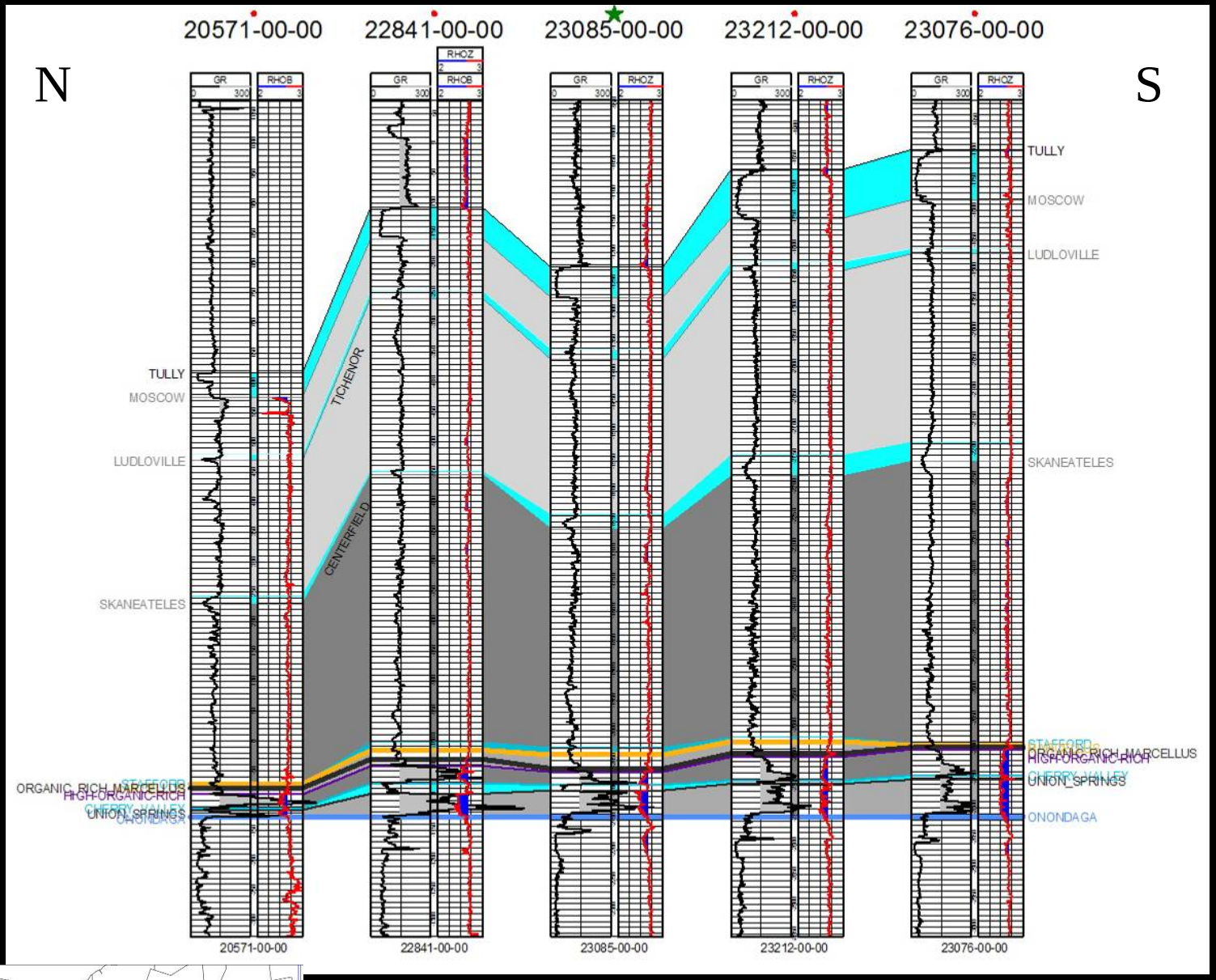
We have made picks based on density response – the top organic rich is picked where density first drops below 2.65 g/cc, the top high-organic is where density is even lower and stays below 2.65 continuously (except for Cherry Valley)

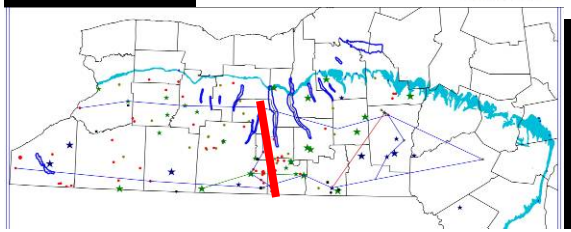


TOC Cross section shows that the TOC values closely track the density logs – where the TOC is high, the density is low – We have picked two tops – one at the first hint of decreasing density and one where it stays consistently below 2.65 g/cc

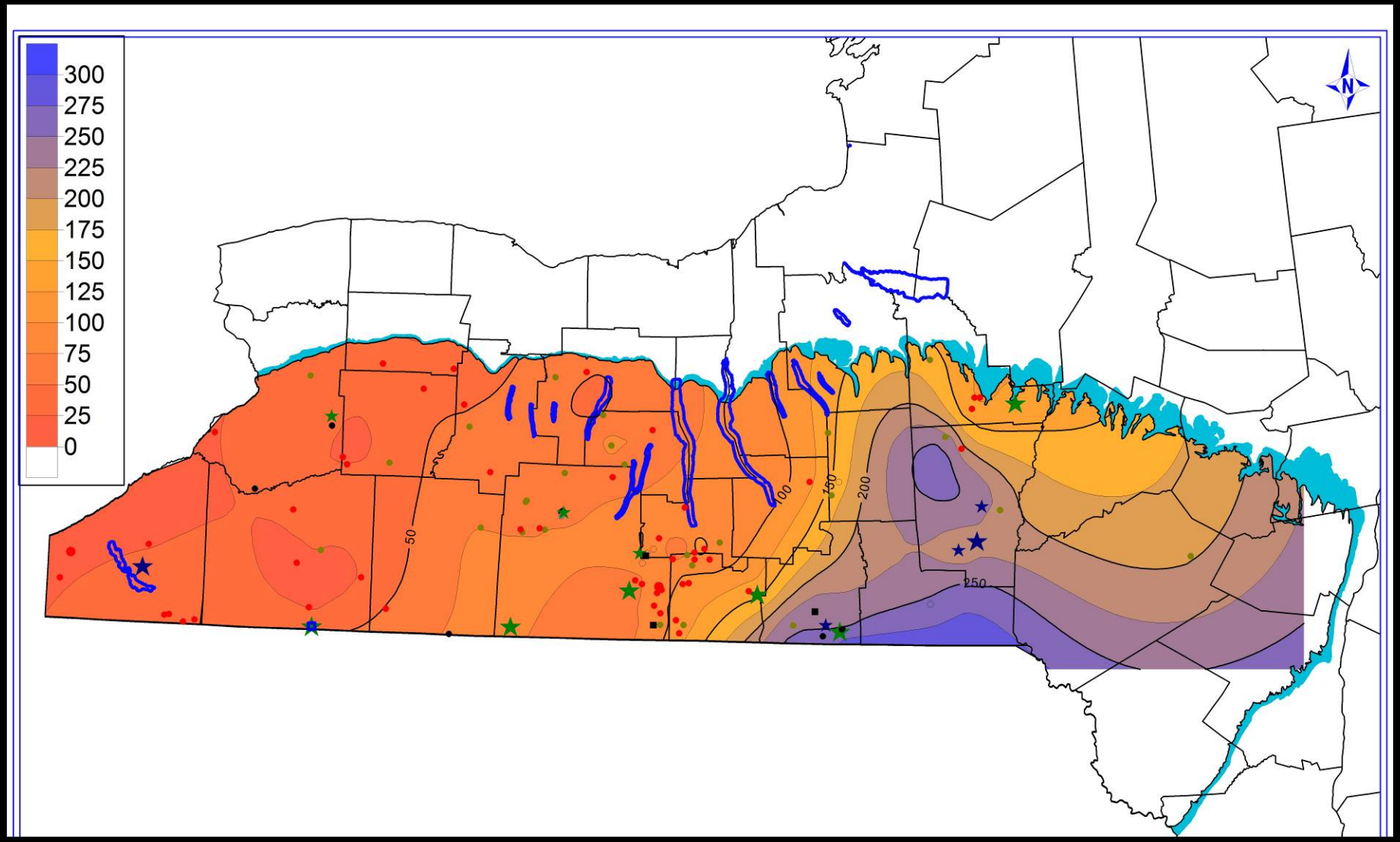


West-East cross section shows thickening of Marcellus Shale to east where it is >700 feet thick with the organic-rich section reaching about 300 feet in thickness and the high-organic about 200 feet

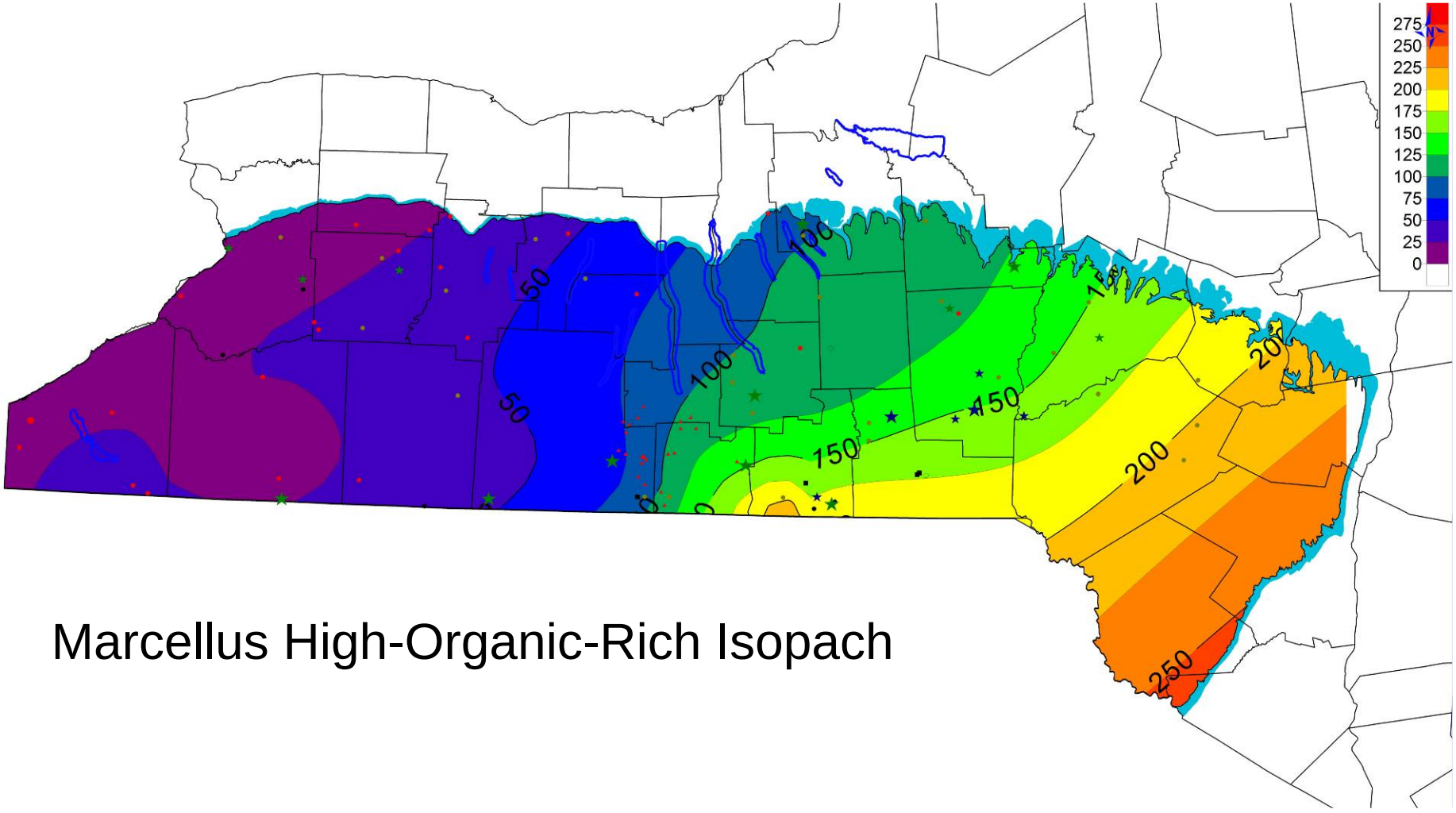




N-S cross section shows gradual thickening to south

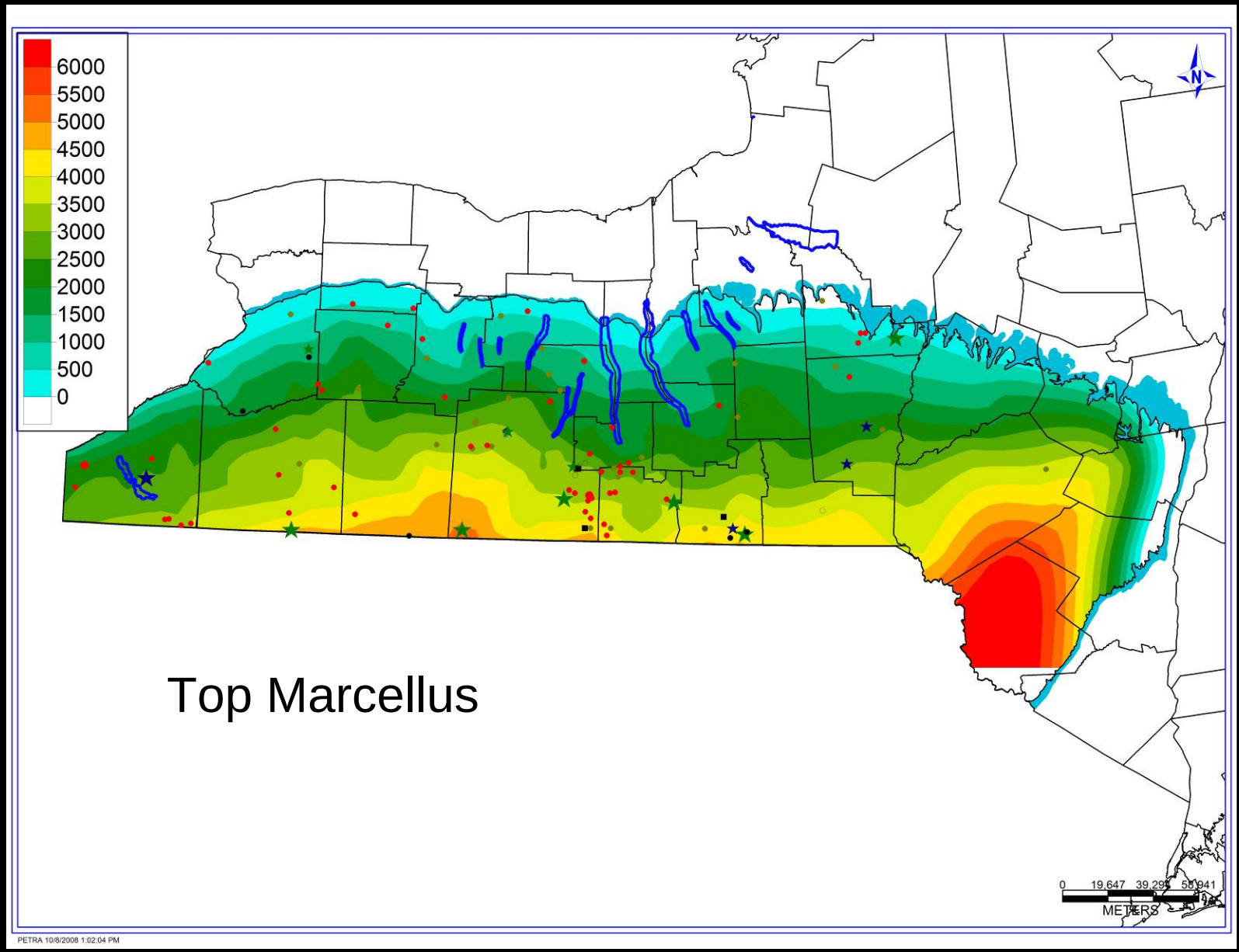


Organic-rich Marcellus (including upper less organic-rich interval) – up to 300 feet thick – how much of this will contribute?

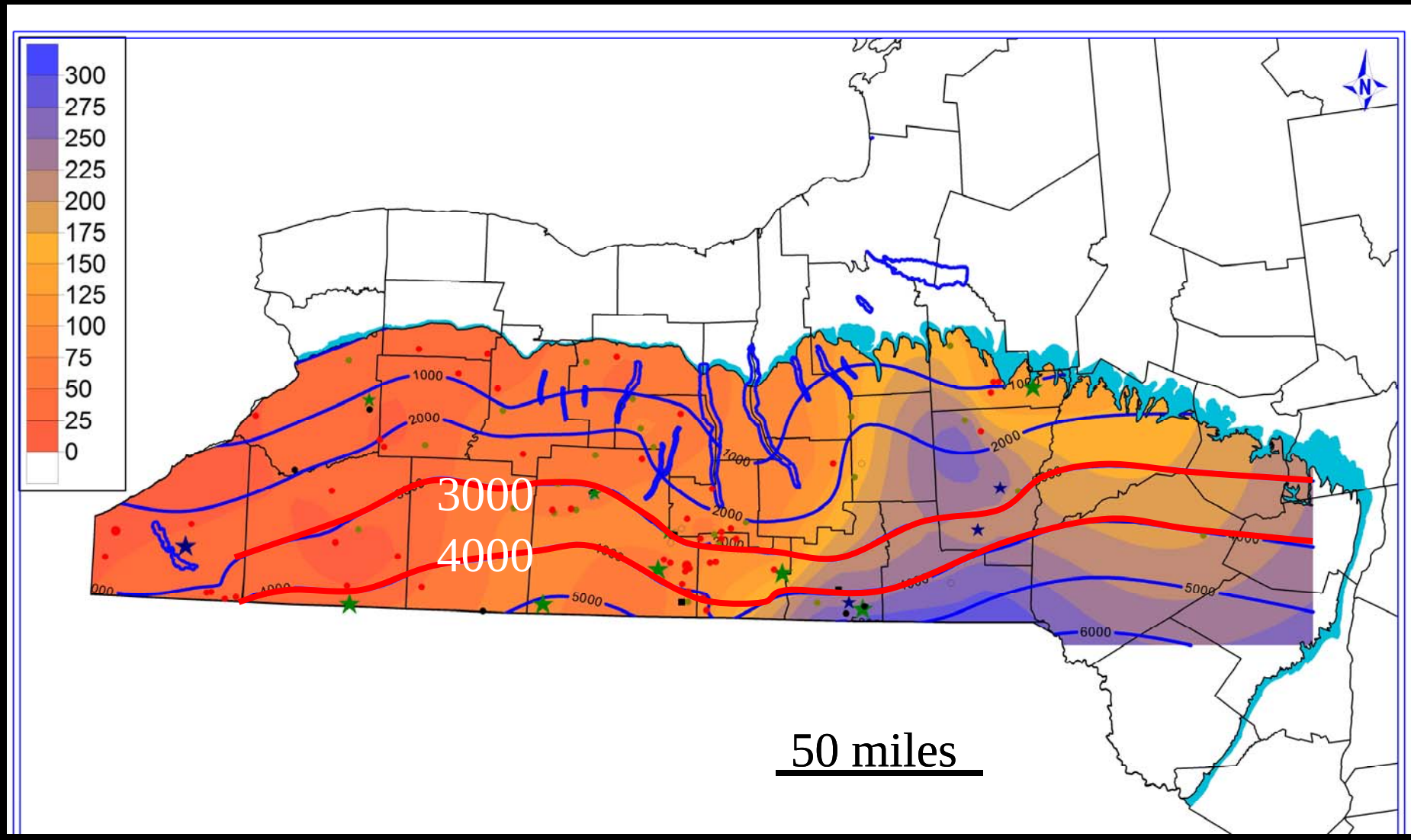


Isopach thickness map of Marcellus high-organic rich section (including Cherry Valley Limestone)

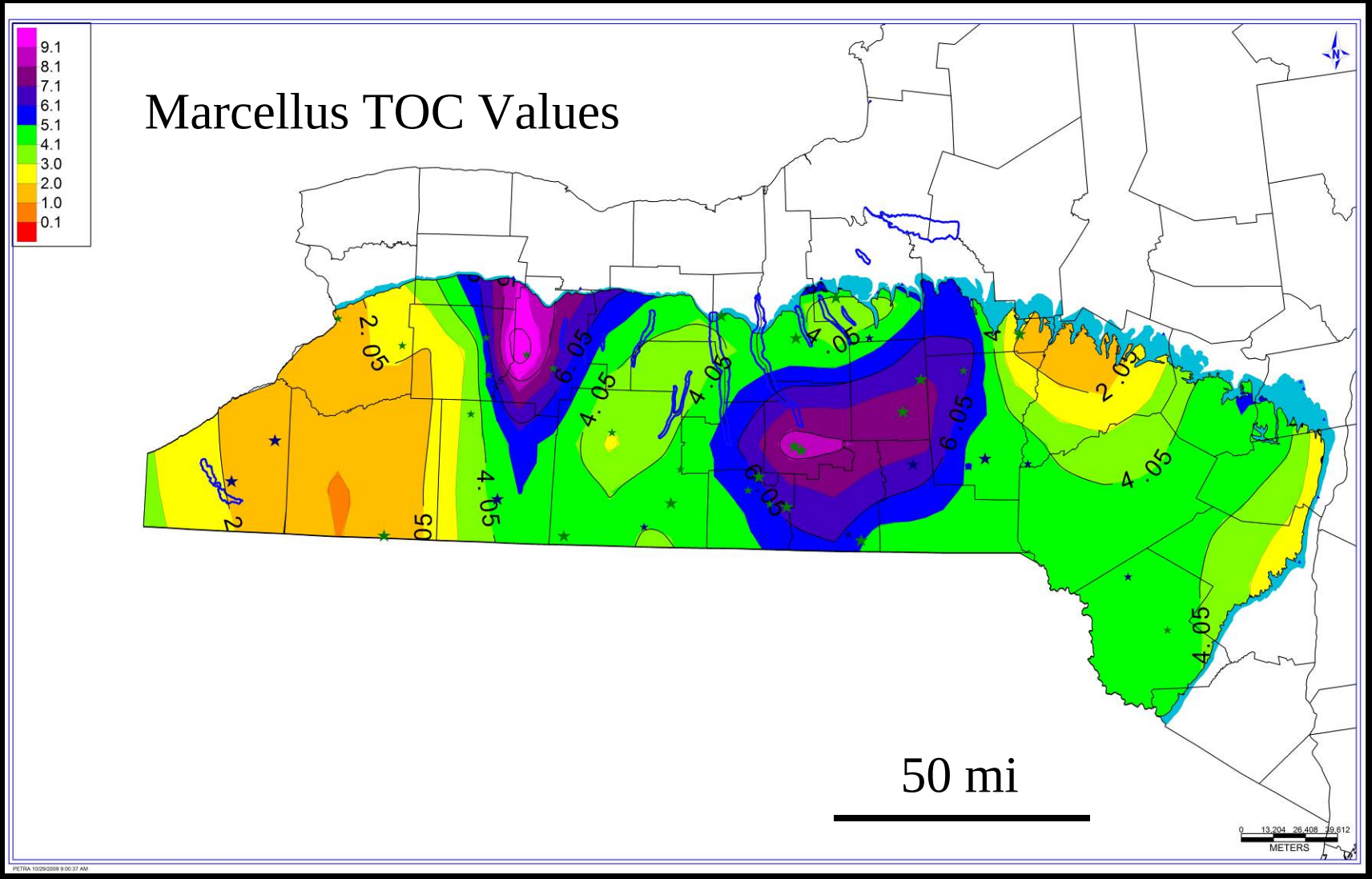
Thickens to south and east



Marcellus structure contour map MD – Deeper to South



Thickness of all organic-rich Marcellus with structure contours – If the Marcellus only is economic <4000 ft like the Barnett, the best area would be in southern Tioga, Broome, Delaware and Sullivan Counties (not coincidentally where most leasing has occurred)

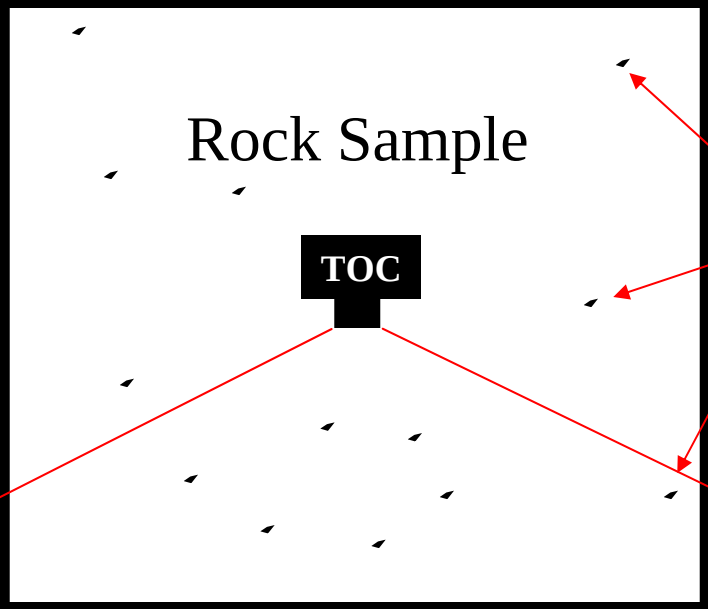


TOC values from the Union Springs – the TOC values are the same or higher than the Barnett Shale across the State (almost all 3-13%) – this was simply from taking the highest value in each well – it will probably even out with more data

Marcellus TOC

- TOC values are very high in the Marcellus in NY typically 4-13% – It is high enough pretty much everywhere in the State
- These values are mainly from cuttings which Jarvie et al (2007) have calculated to come out lower than core TOC by >50% (so actual values may be double the measured values)
- Highest TOC in Union Springs and immediately above Cherry Valley Limestone
- TOC may be higher than Barnett

TOC



Dispersed Organic Matter: the “source” of oil + assoc. gas

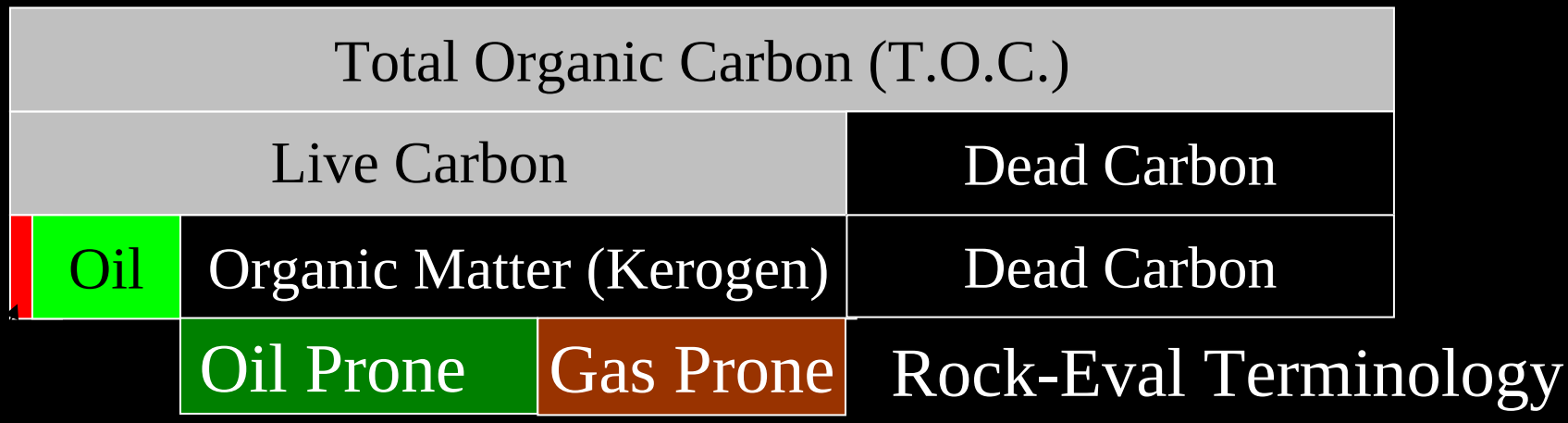
Total Organic Carbon (T.O.C.)	
Live Carbon	Dead Carbon
Oil / Organic Matter (Kerogen)	Dead Carbon

Gas

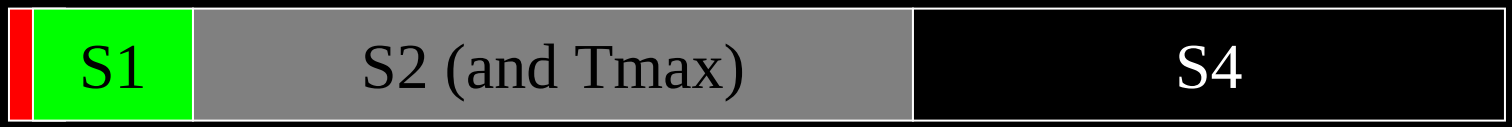
Rock-Eval Terminology

Jarvie, 1991

Distribution of Organic Matter in Rock Sample (low maturity)

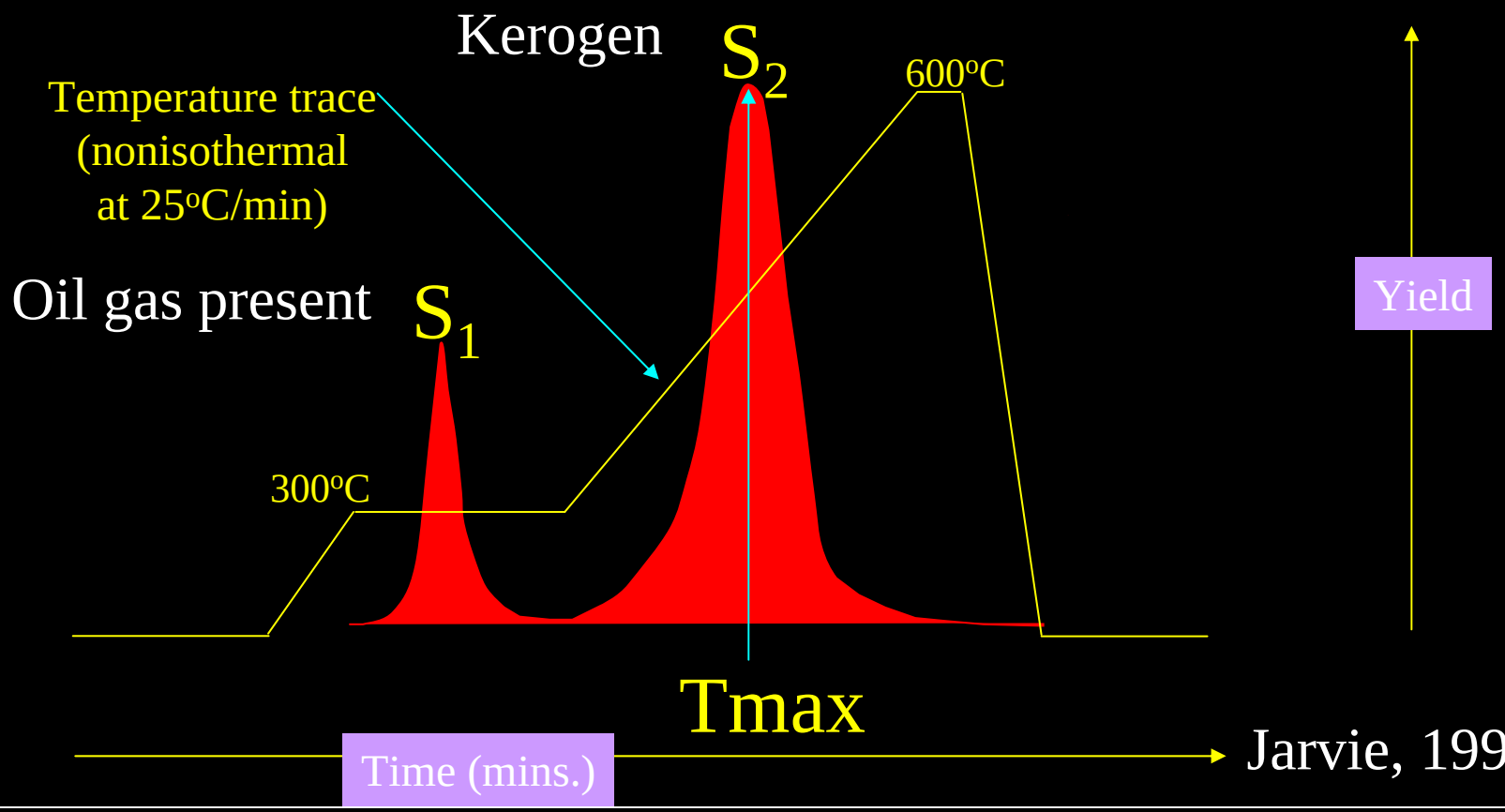


Rock-Eval analysis - terminology



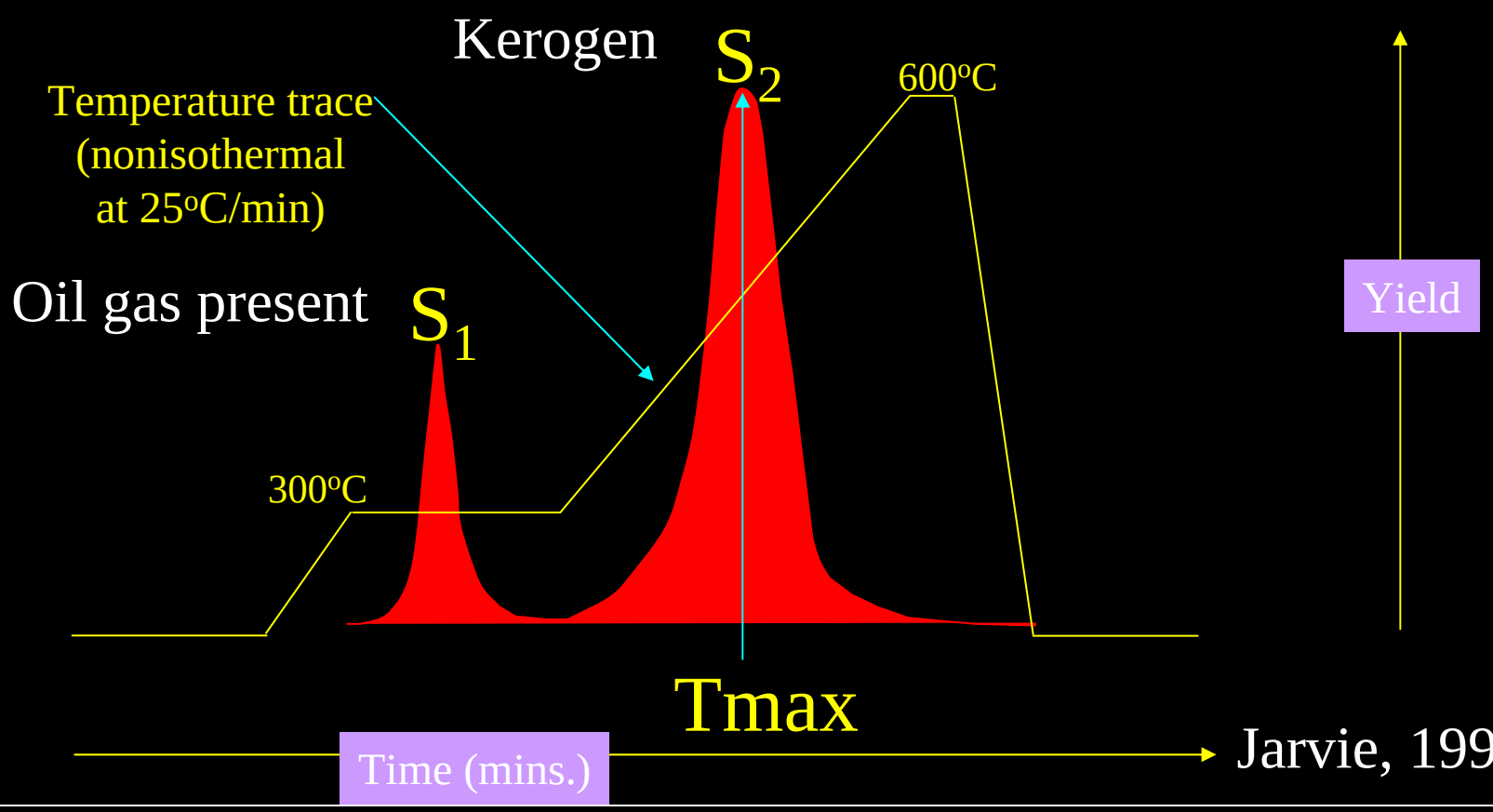
If S_2 is very low, this means that almost all remaining carbon is dead carbon – the rock cannot and will not generate any more hydrocarbons

Rock-Eval or SR Analyzer "Pyrogram"

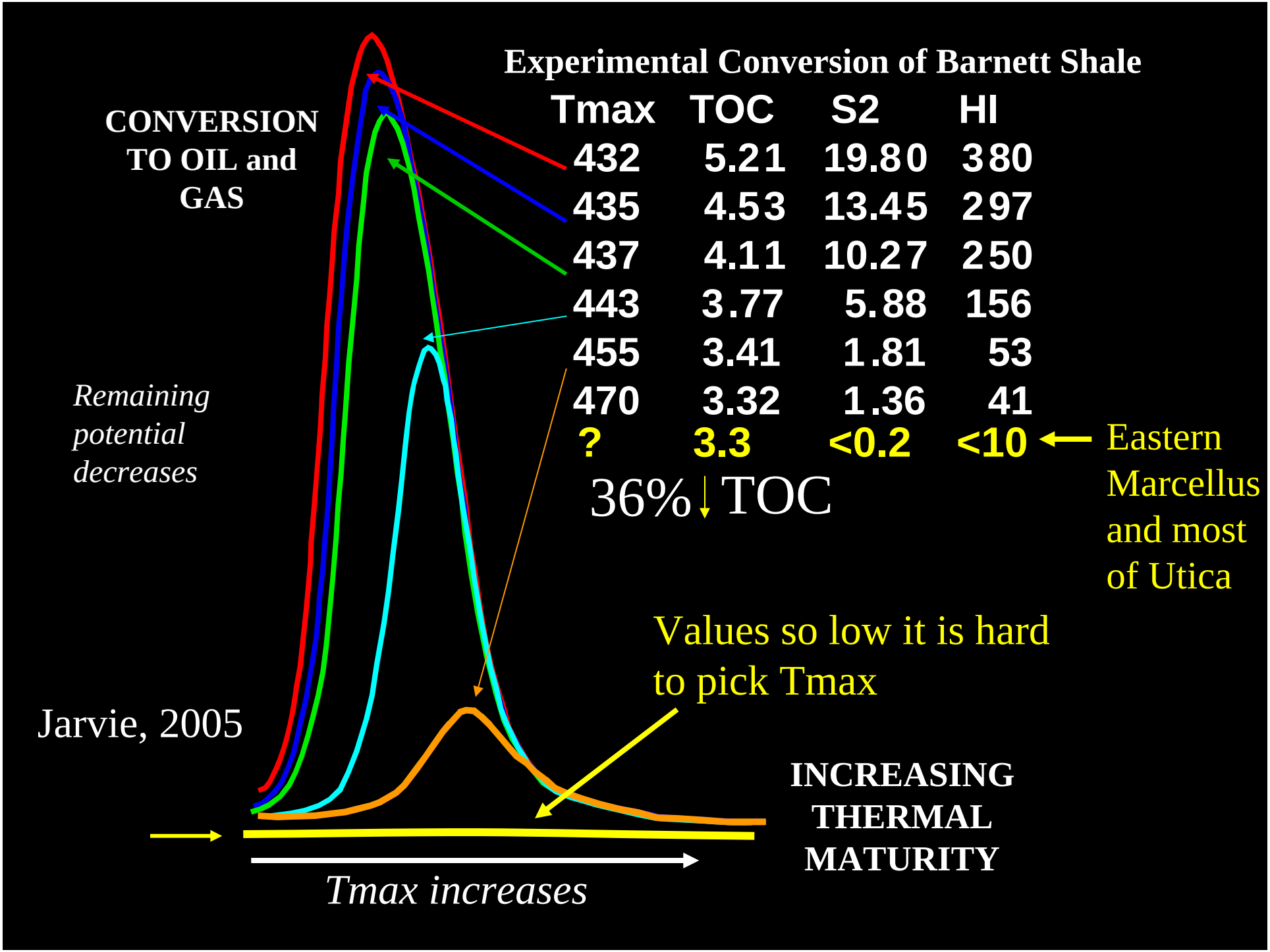


- S_1 = Free volatile hydrocarbons thermally flushed from a rock sample at 300°C
- S_2 =products that crack during standard Rock-Eval pyrolysis temperatures 300°C-600°C

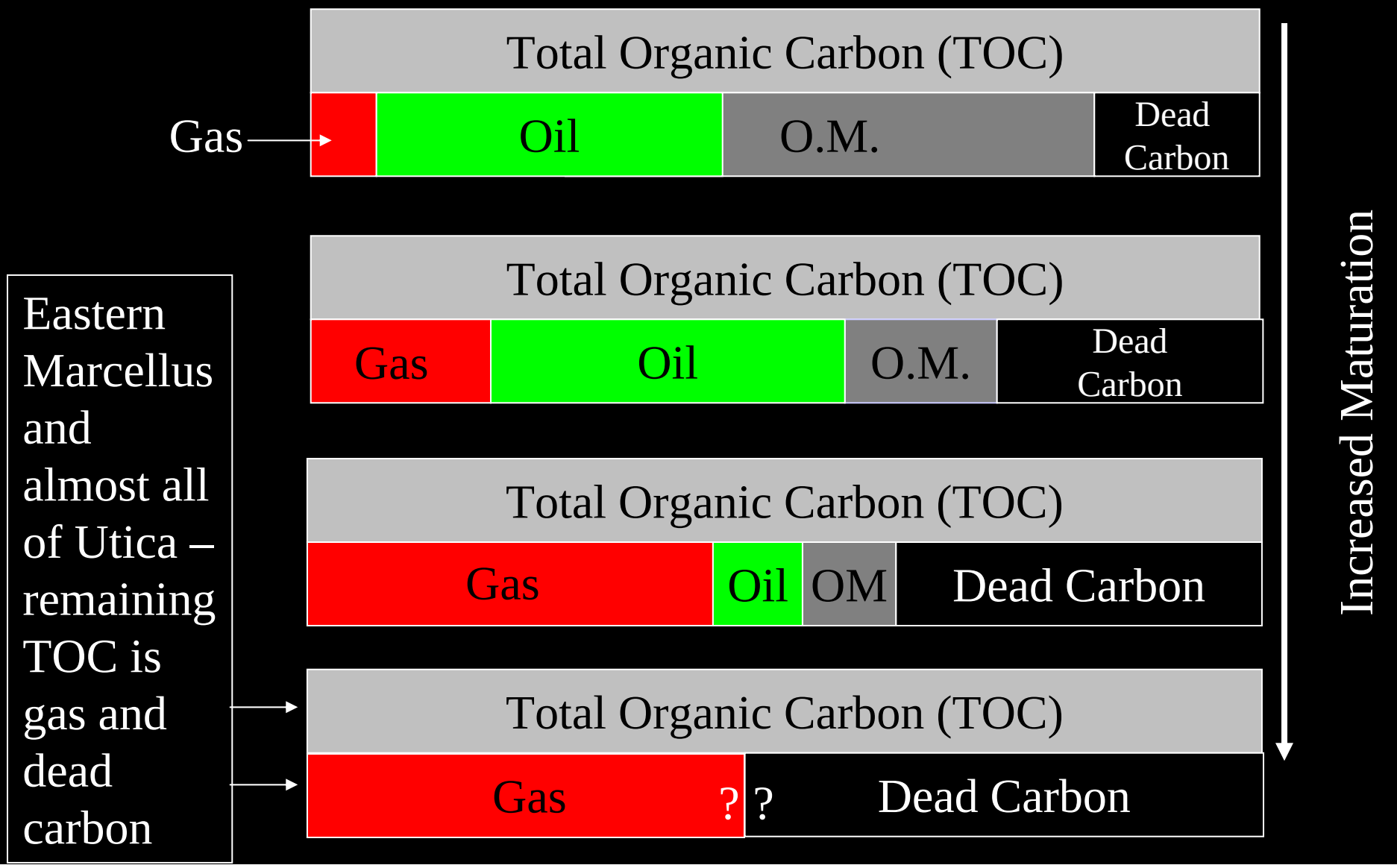
Rock-Eval or SR Analyzer "Pyrogram"



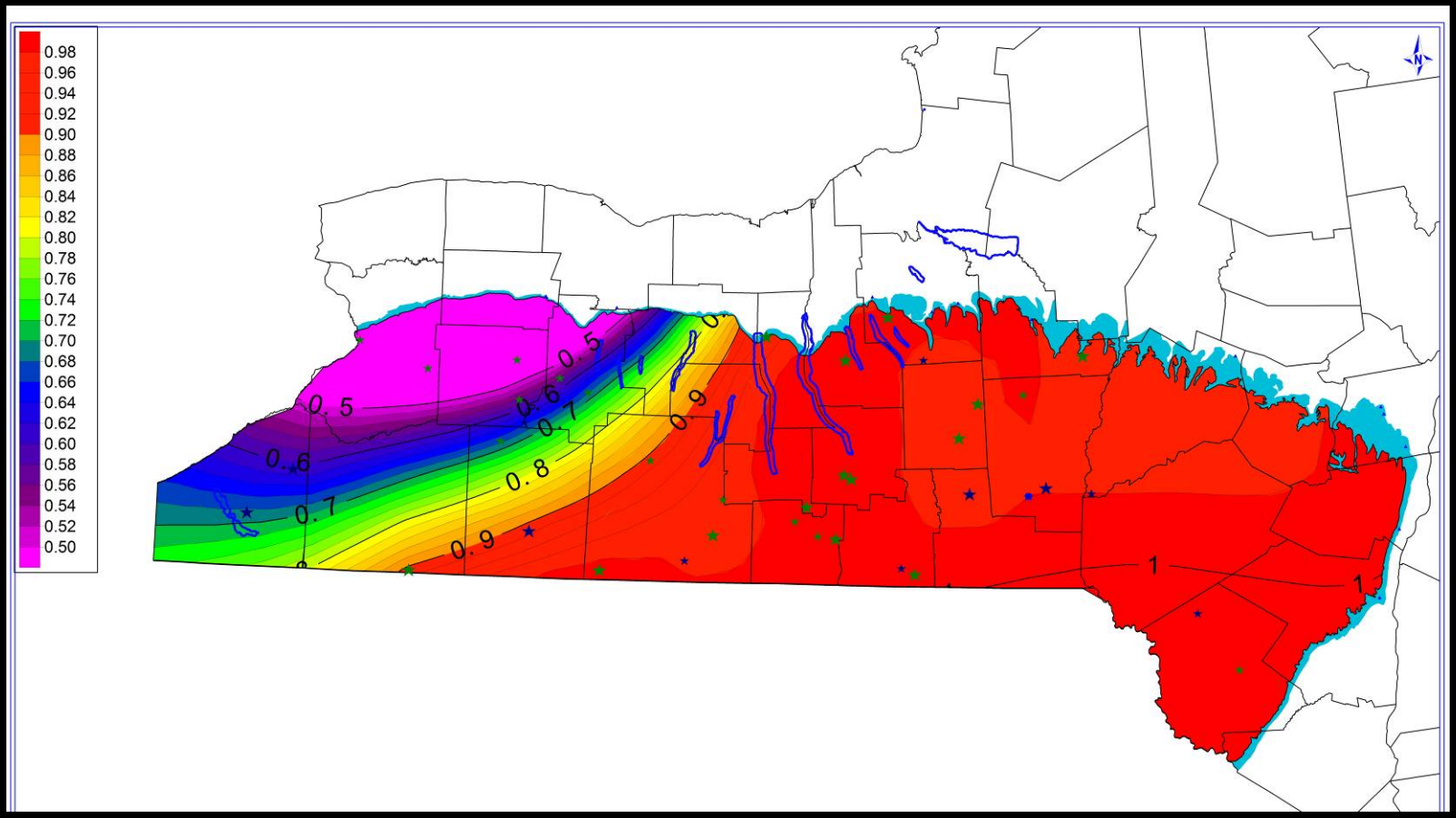
In order to get a reliable Tmax, it is necessary that $S_2 > S_1$ and the value of $S_2 > 0.2$ - If $S_1 > S_2$ or S_2 has very low values (<0.2) that means that there is very little remaining live carbon (kerogen or oil and gas)


Experimental Conversion of Barnett Shale
Tmax TOC S2 HI
432 5.21 19.80 380
435 4.53 13.45 297
437 4.11 10.27 250
443 3.77 5.88 156
455 3.41 1.81 53
470 3.32 1.36 41
? 3.3 <0.2 <10
Eastern Marcellus and most of Utica
36% ↓ TOC
CONVERSION TO OIL and GAS
Remaining potential decreases
Values so low it is hard to pick Tmax
Jarvie, 2005
INCREASING THERMAL MATURITY
Tmax increases

Maturation of Organic Matter – modified from Jarvie



Marcellus Transformation Ratio



Transformation ratio measures the percentage of available kerogen that has been converted to hydrocarbons – values greater than 0.9 are considered to be good – note the very high values in the east where it is all converted due to very deep burial (very very low S_2 values)

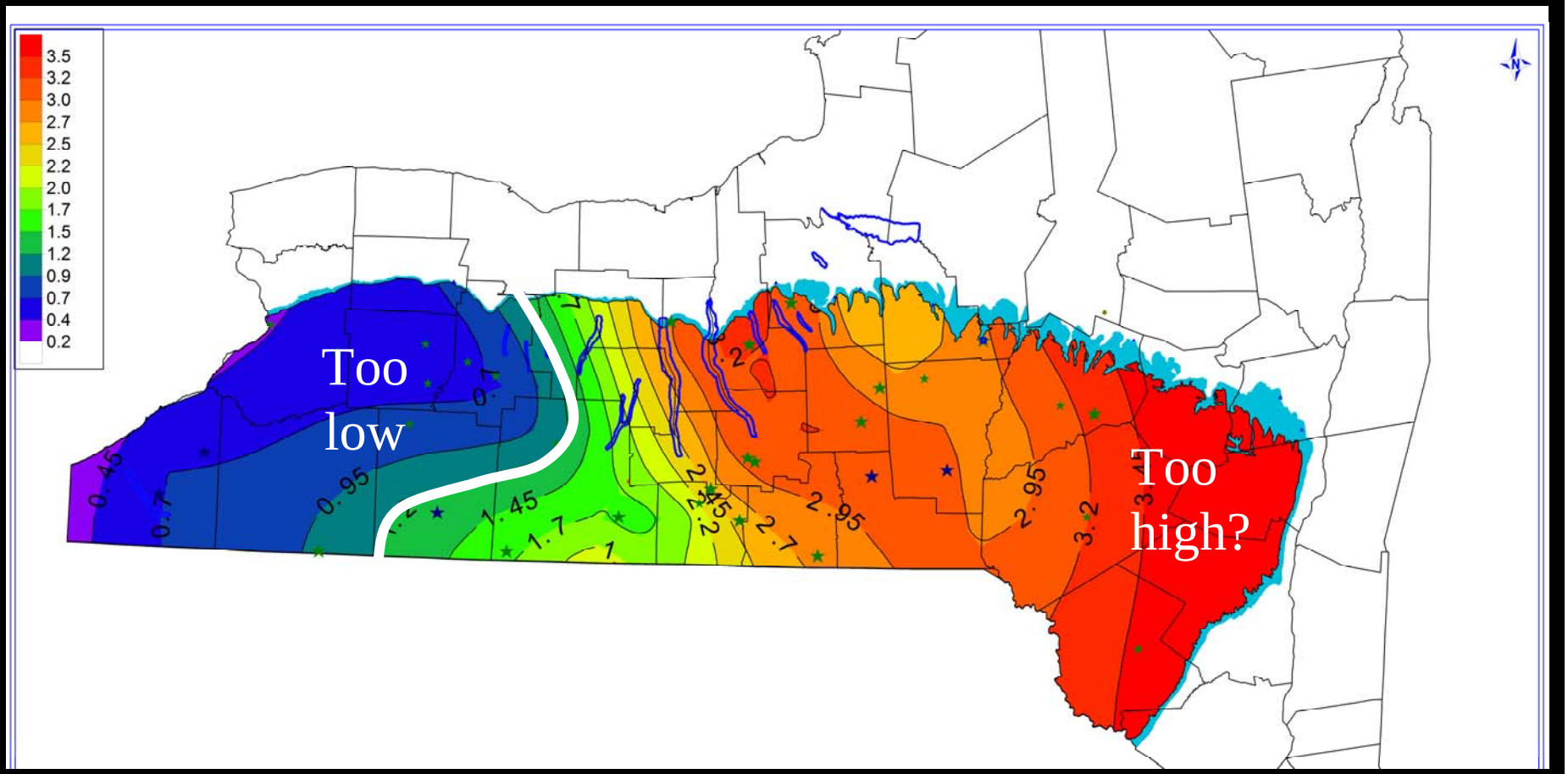
Vitrinite Reflectance (Ro%)

- Low maturity source rocks 0.0 – 0.55%
- Oil window 0.55% -1.0%
- Condensate - wet gas window 1.0 %- 1.40%
- Dry gas window 1.40%
- Productive gas wells in the Barnett generally have vitrinite reflectance values 1.2-2.0%

One question that needs to be answered for the Marcellus and the Utica is if there is an upper limit to maturity – we have very high values

based on Jarvie, et al, 2005

Marcellus (Union Springs) Ro%



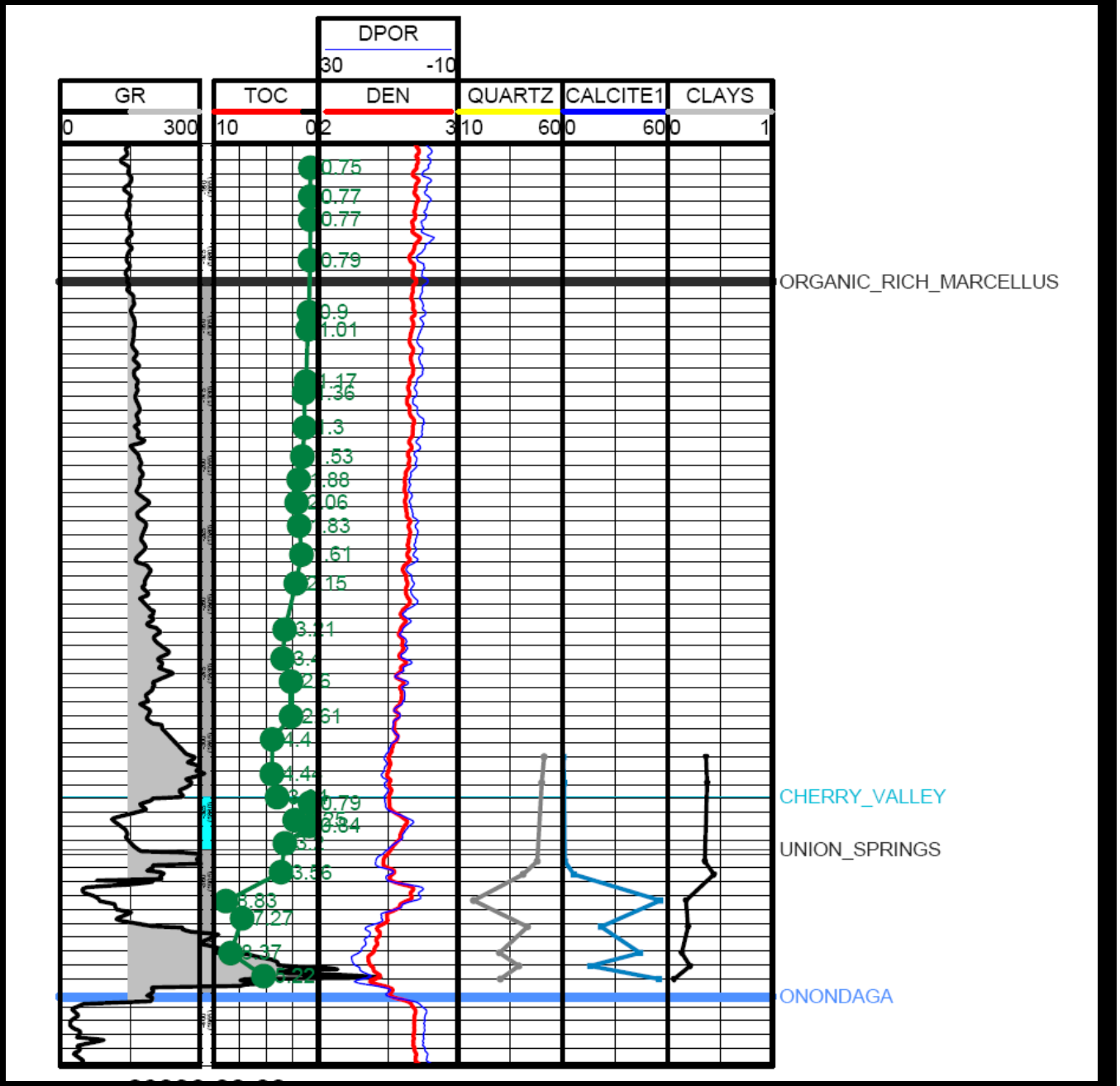
Optimum R_o% (vitrinite reflectance) for Marcellus is lower in west and very high in east – the productive shale in the Barnett is 1.2-2.0, but the Marcellus may go as high as 3.4 – Is this too high?

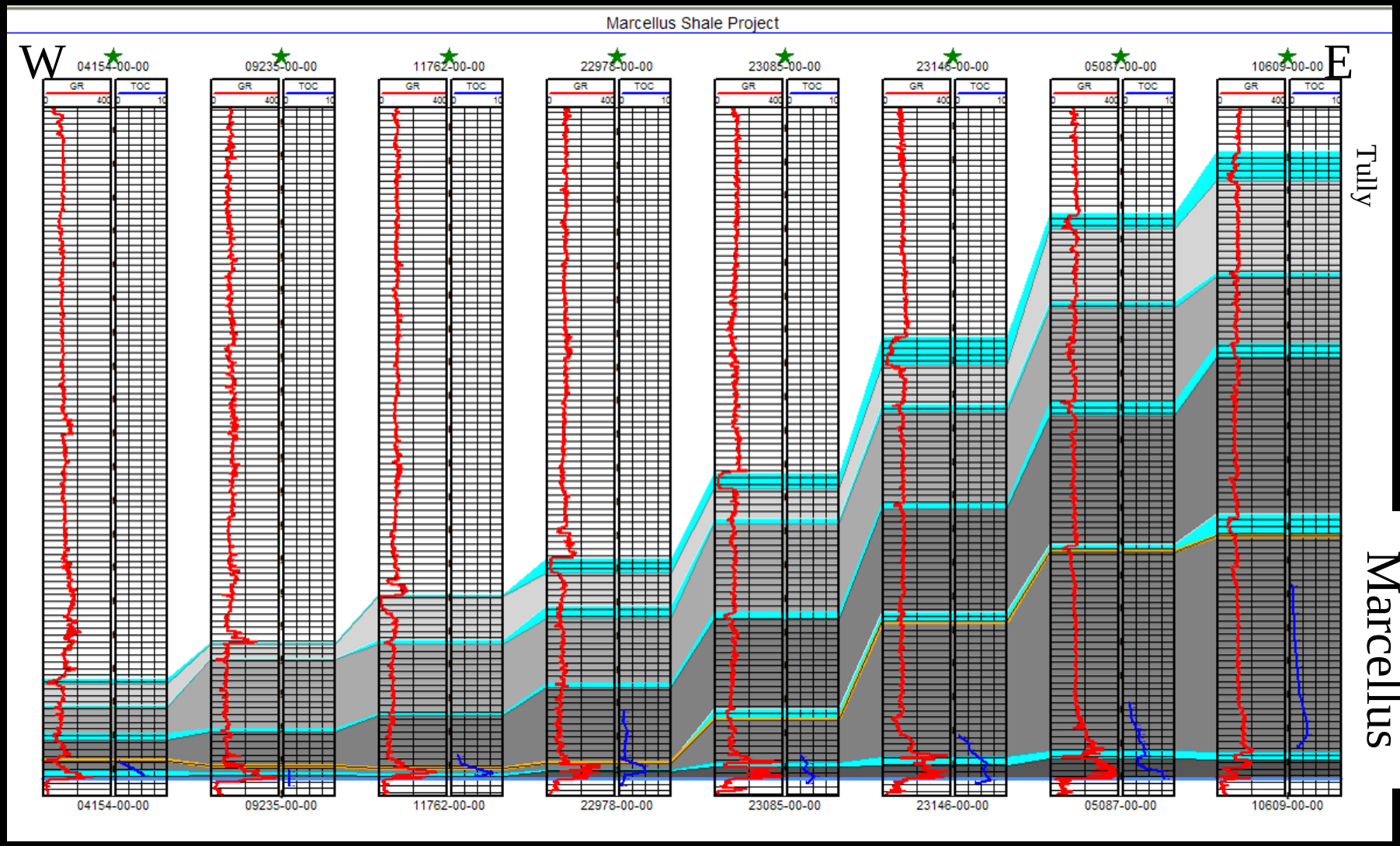
Thermal Maturity

- The Barnett Shale still has live organic carbon that is capable of cracking to gas today across the productive region
- In the eastern part of NY where the Marcellus is thickest, all of the organic carbon that can be converted to hydrocarbons has been cooked and expelled
- Question: Does this matter? Is there still just as much gas in place as there would be if it were less mature?

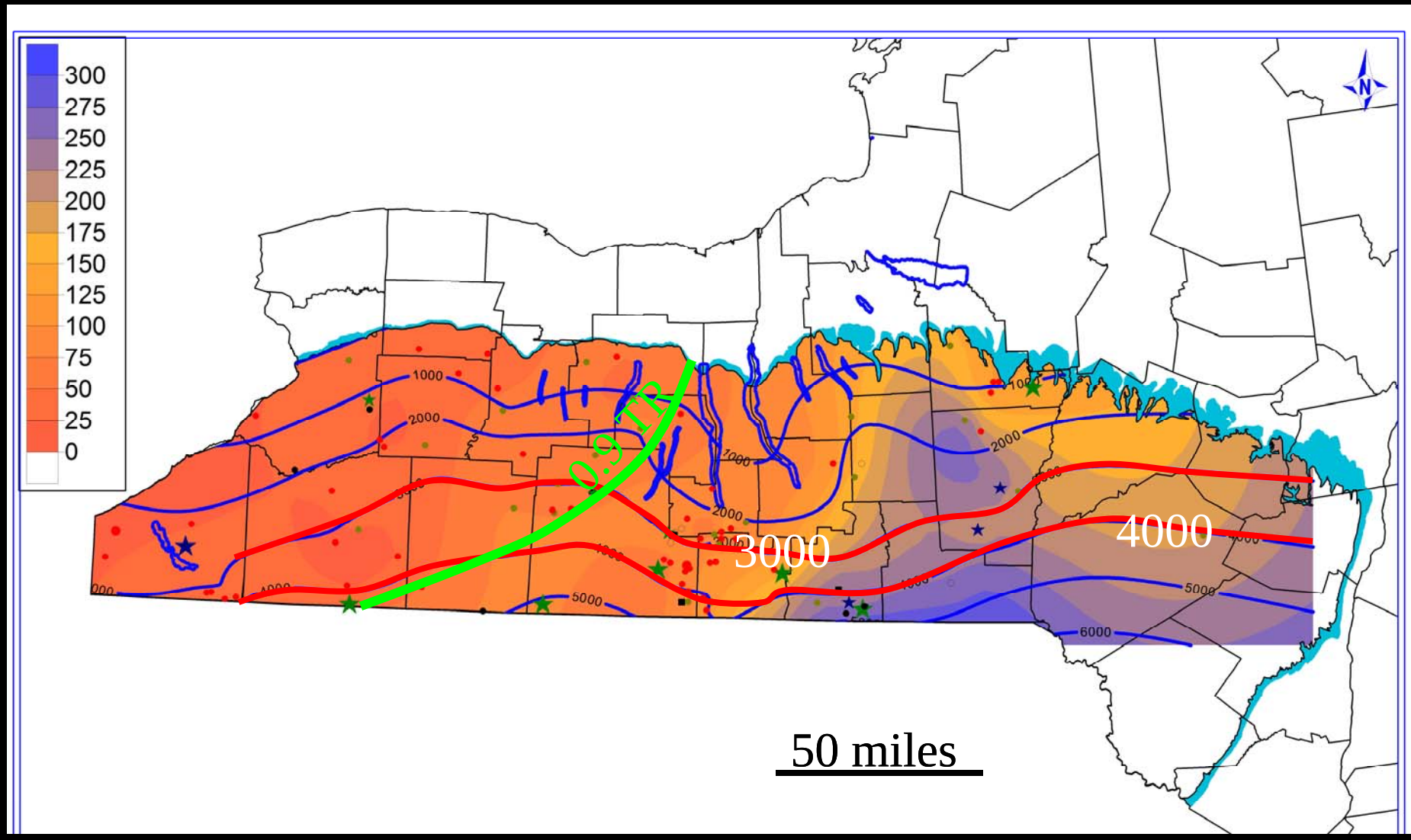
XRD shows that the shale has clay content less than 50% - this was noted as an important feature by people working on the Barnett Shale

Low clay content makes the rock easier to frac (Bowker, 2007)

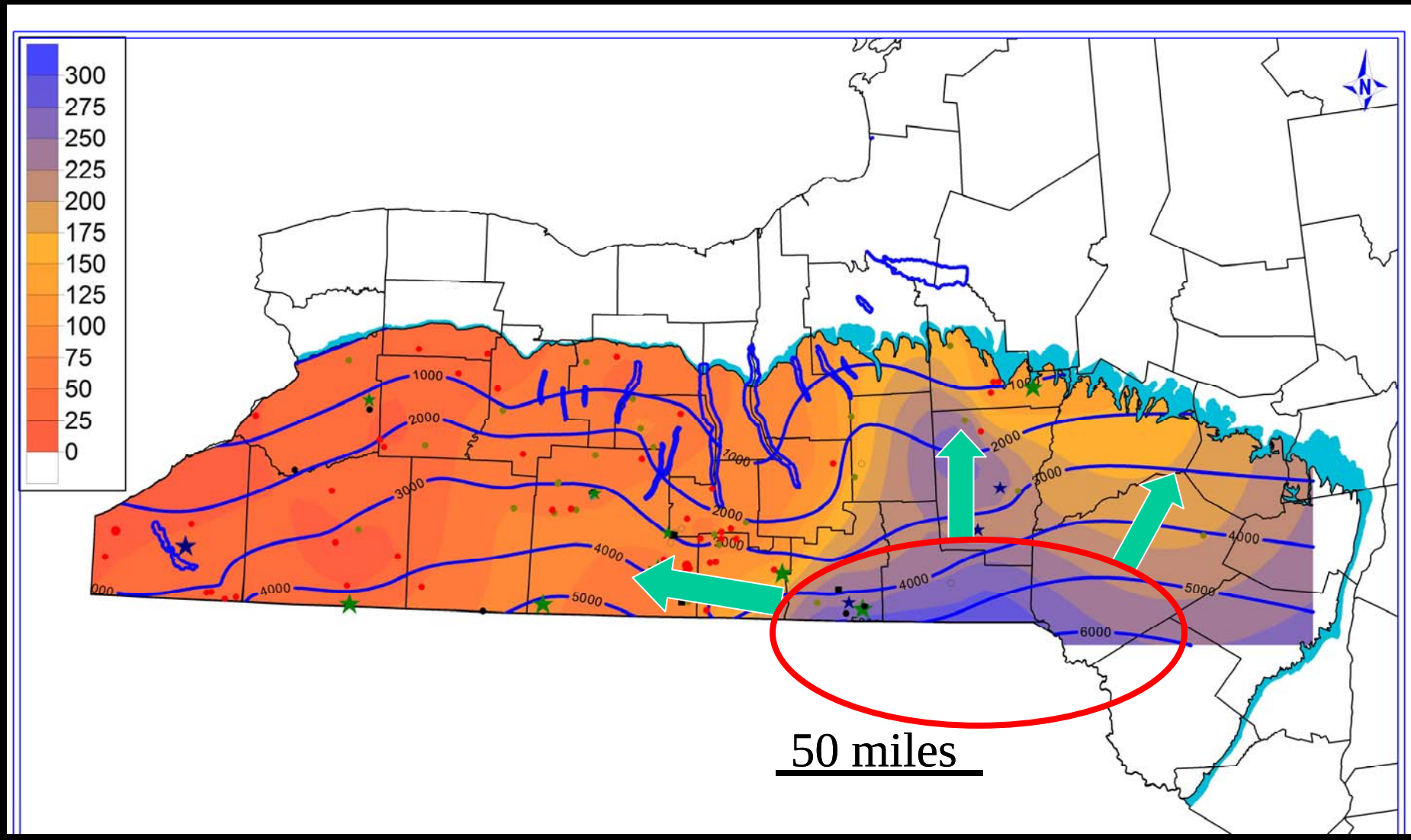




Another question is whether there is whether the Marcellus is overpressured – Is there enough of a seal to preserve overpressure in the shale or it the gas can just seep upward into overlying non-organic shale – Barnett has a thick limestone



Thickness of all organic-rich Marcellus with structure contours – If the Marcellus only is economic <4000 ft like the Barnett, the best area would be in southern Tioga, Broome, Delaware and Sullivan Counties (not coincidentally where most leasing has occurred)

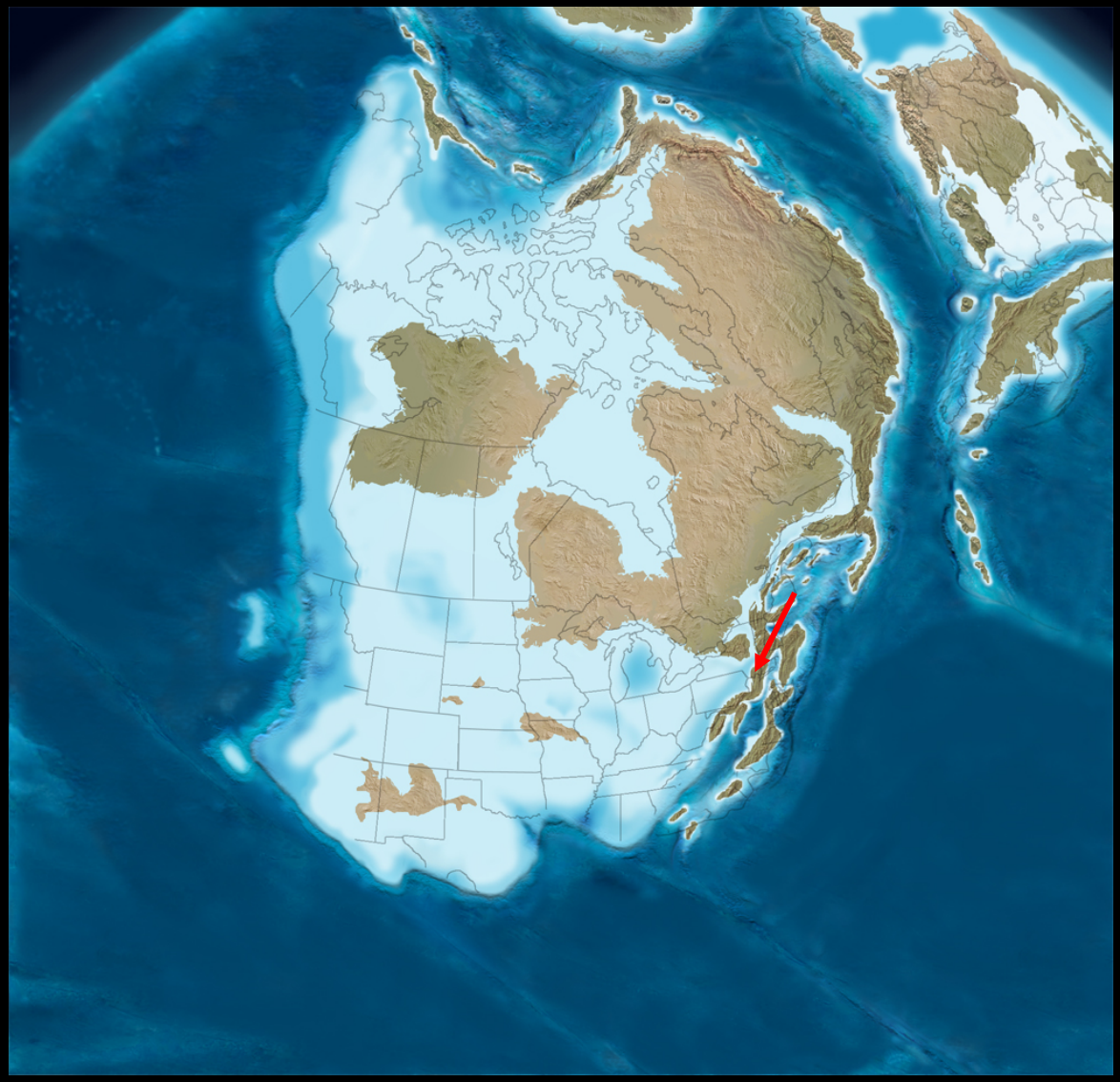


Fairway is really yet to be determined but drilling likely to start in southeastern area where it is thickest and deepest and near a major new pipeline and then move north and west to find limits

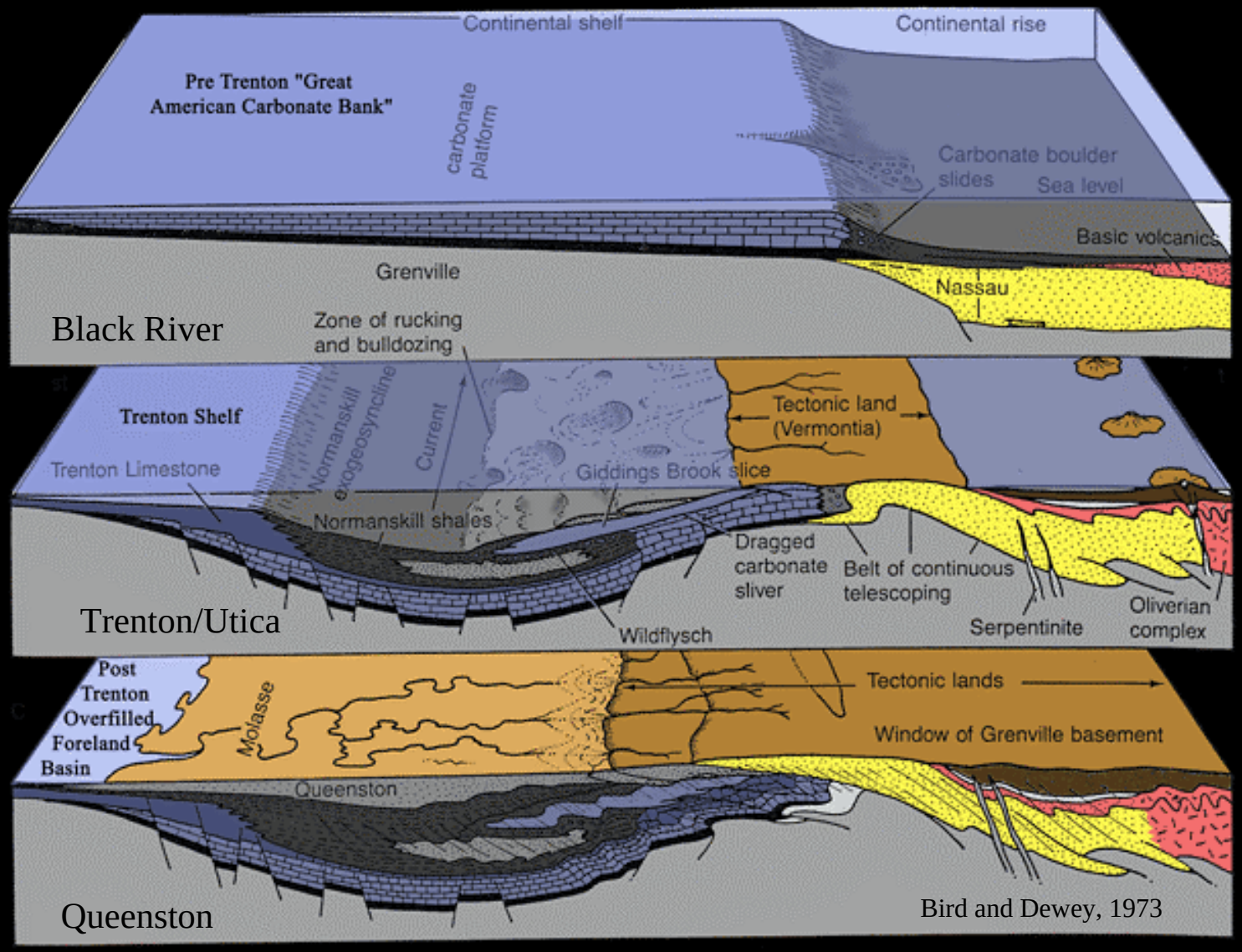
Marcellus Summary

- Positives: Good TOC, high maturity, clay <50% some that is deeply buried, has produced at high initial rates (3MMCF/d)
- Questions:
  - Is there enough gas left in the rock in areas that are supermature?
  - Is it overpressured?
  - How shallow can wells be drilled that are economic?
  - Is the shale thick enough?
  - Will organic-rich limestone produce?

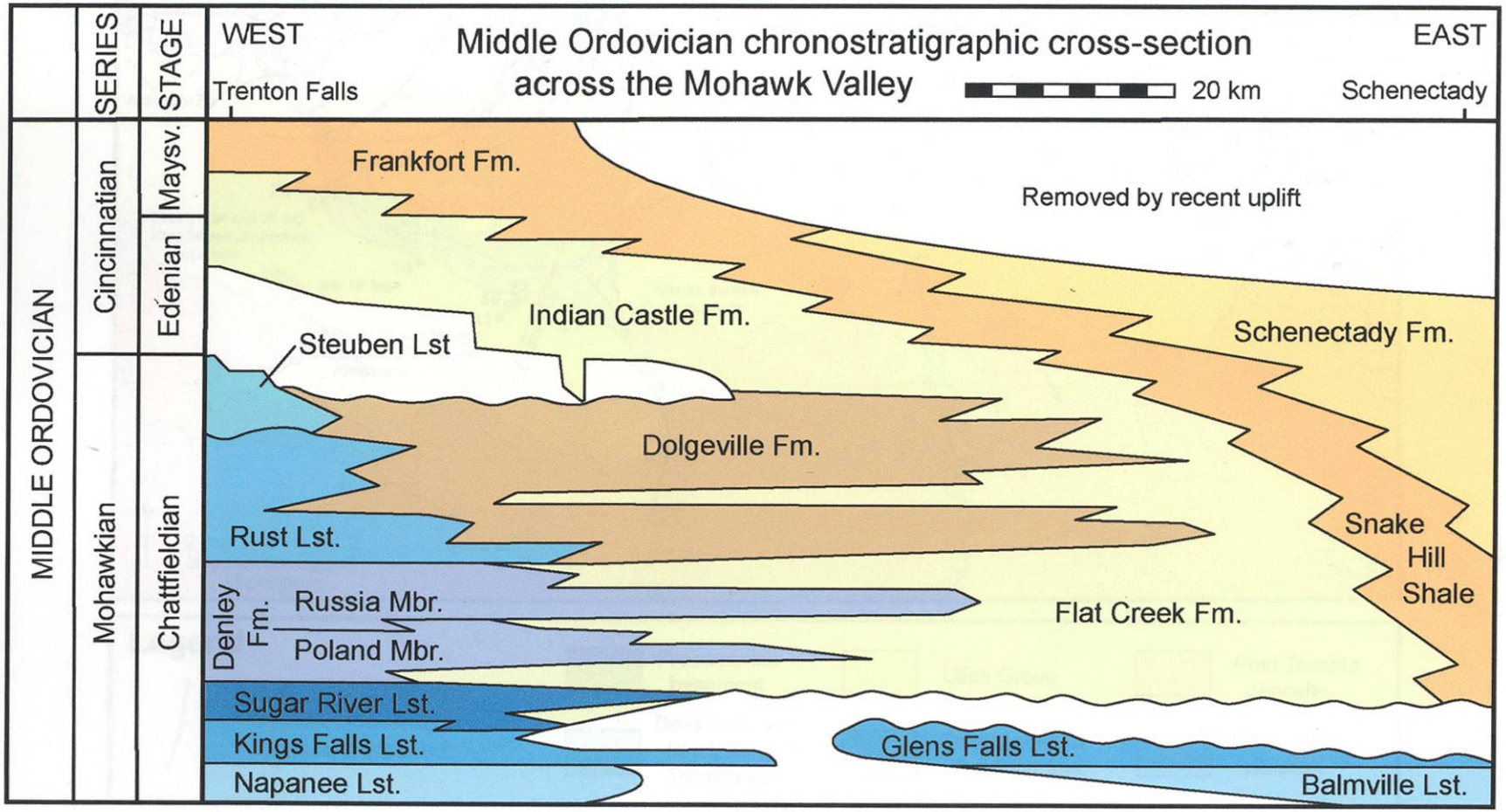
Ordovician Paleogeography



Utica Shale deposited during Ordovician Taconic Orogeny



As orogeny proceeded, crust was downwarped and faulted setting up carbonate platform to west and shale basins to east



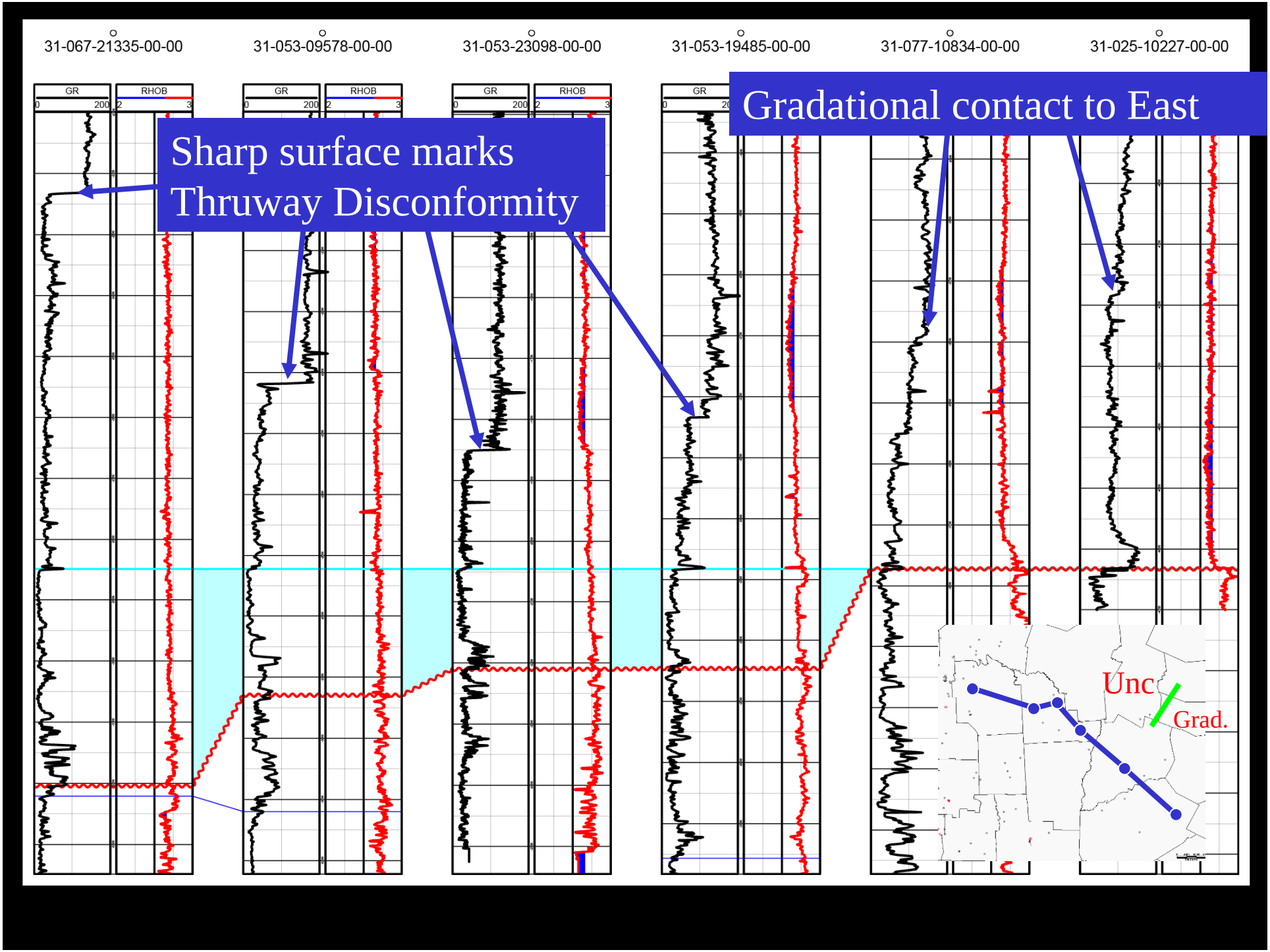
(Goldman, et al 1994)

Outcrop Stratigraphy from Mohawk Valley – Indian Castle Shale (which postdates Trenton), Dolgeville Limestone and Shale and Flat Creek Shale (which are time-equivalent to Trenton) all have potential to produce

Indian Castle is a fissile black shale (Little Falls Exit photo from John Martin)

Dolgeville is an interbedded limestone and shale (photo from Rich Nyahay)

Flat Creek is a dark argillaceous lime mudstone or calcareous shale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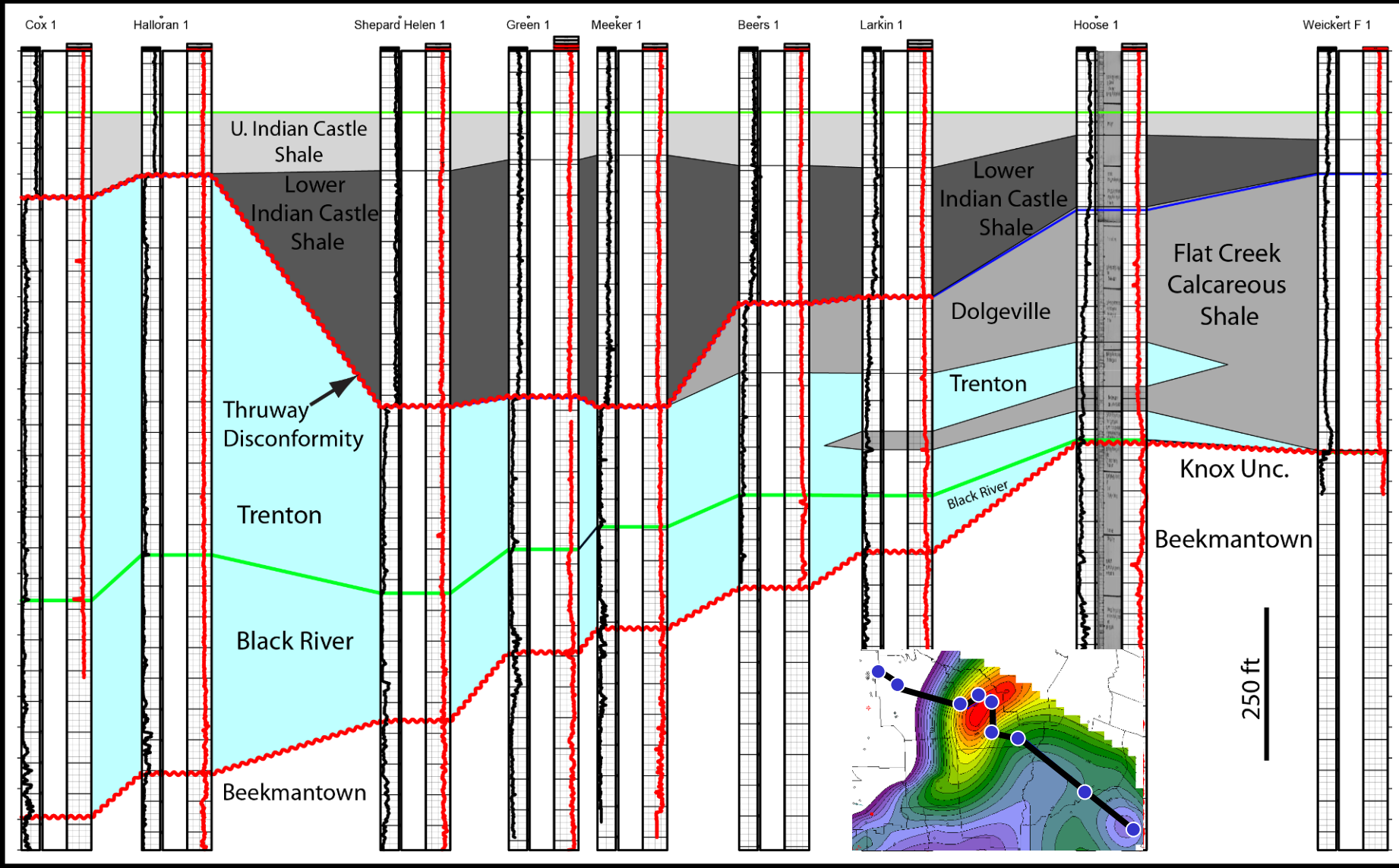
31-053-19485-00-00
31-077-10834-00-00
31-025-10227-00-00
GR
RHOB
Sharp surface marks
Thruway Disconformity
Gradational contact to East
Unc
Grad.



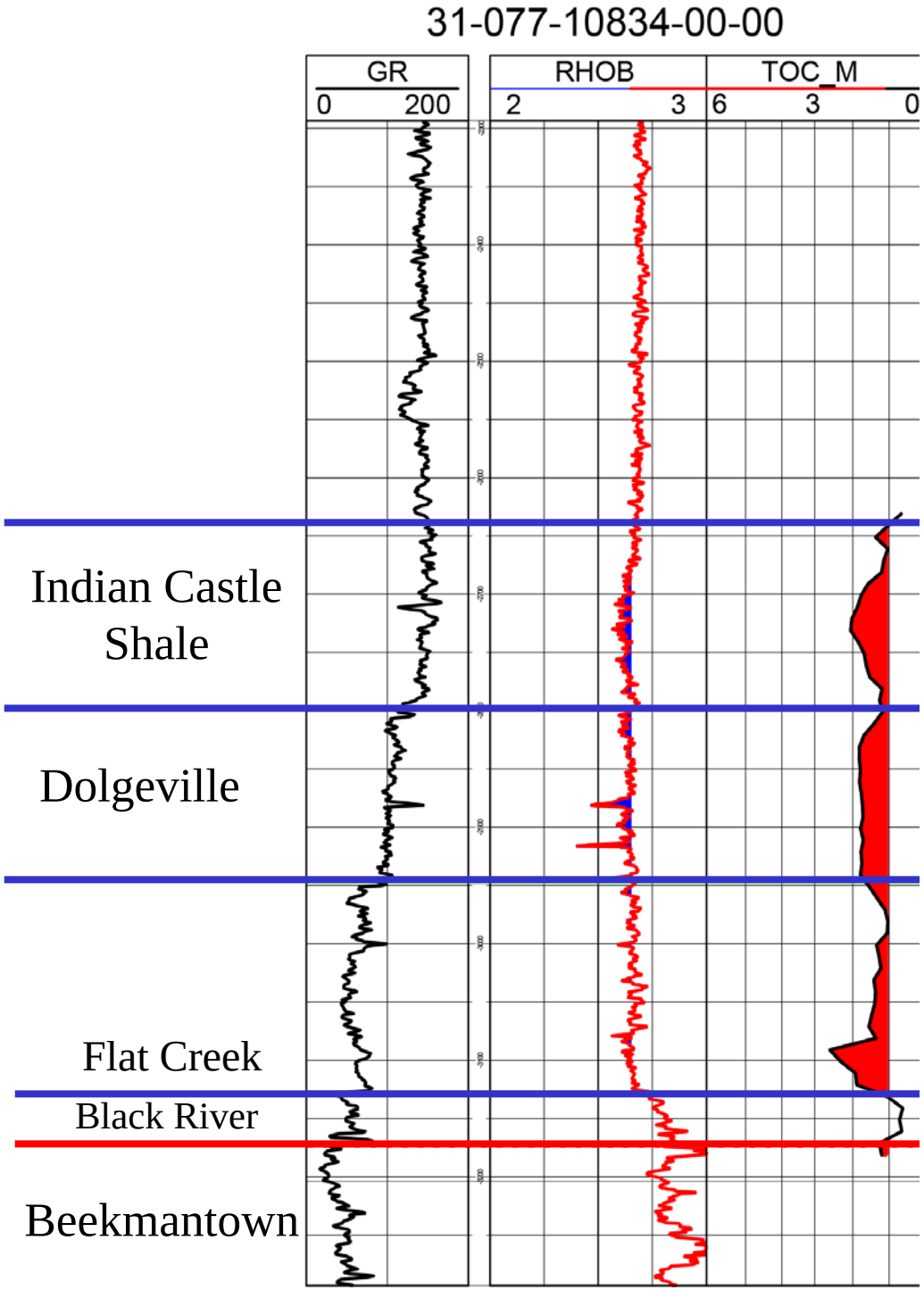
NW-SE cross section from Onondaga to Delaware County (parallel to Mohawk Valley outcrop belt) shows similar relationships – Indian Castle, Dolgeville and Flat Creek all have potential

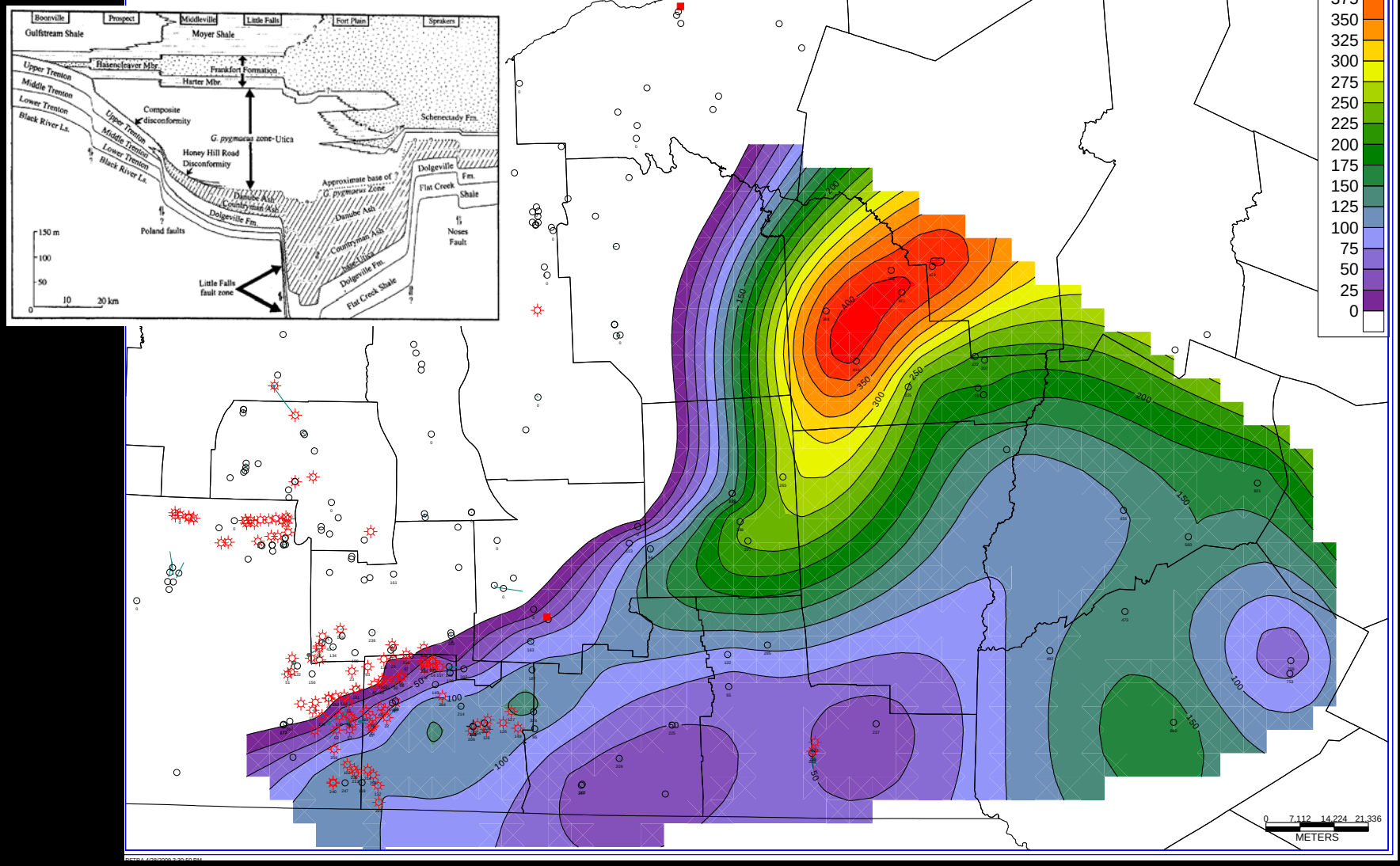
Logs from well with high-TOC in Utica Shale – TOC logs shaded red where TOC>1% (TOC from cuttings analysis)

Density log tracks TOC – lower values = higher TOC

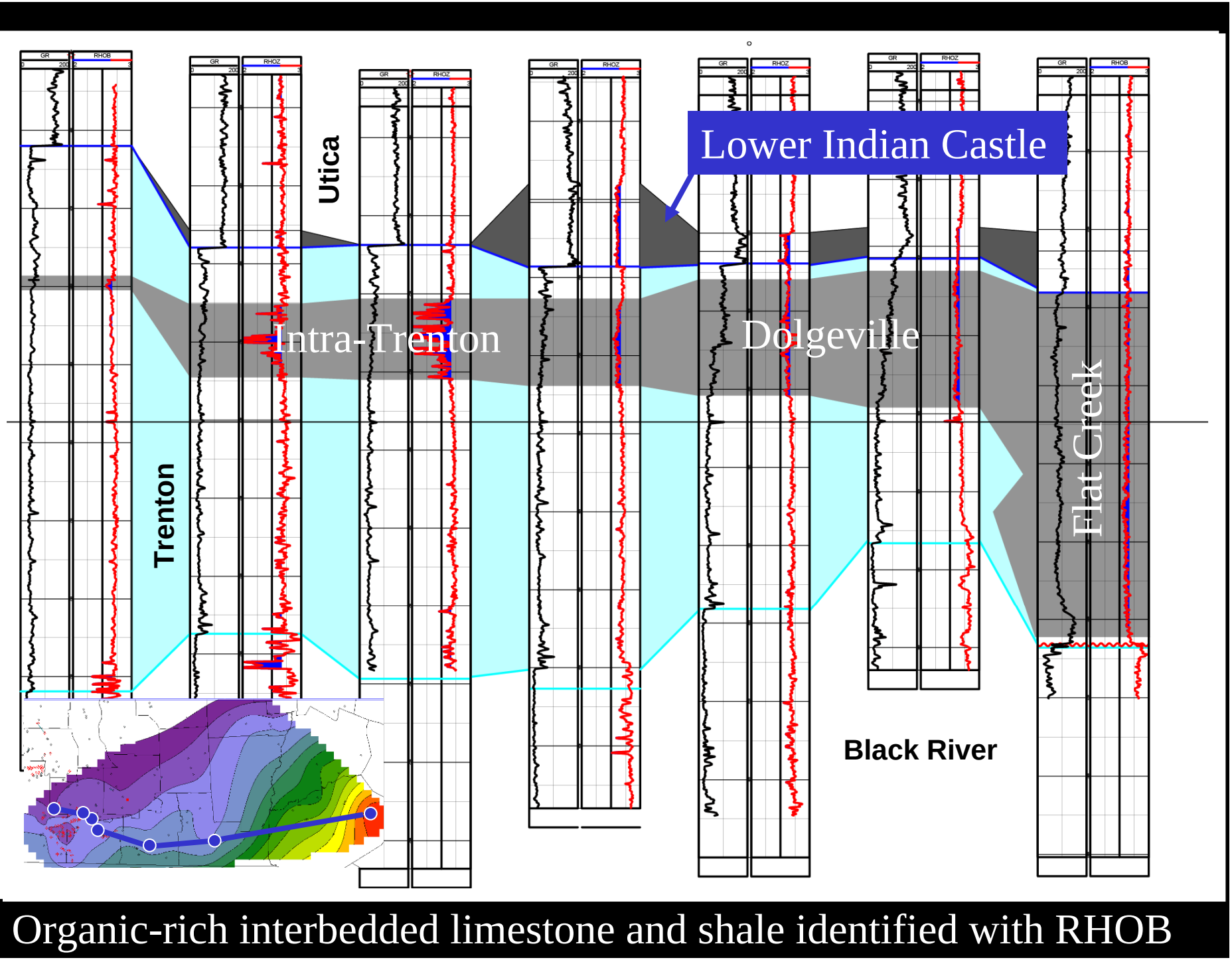
Utica is composed of a low Organic regional shale at top and the relatively high-organic Indian Castle Shale

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

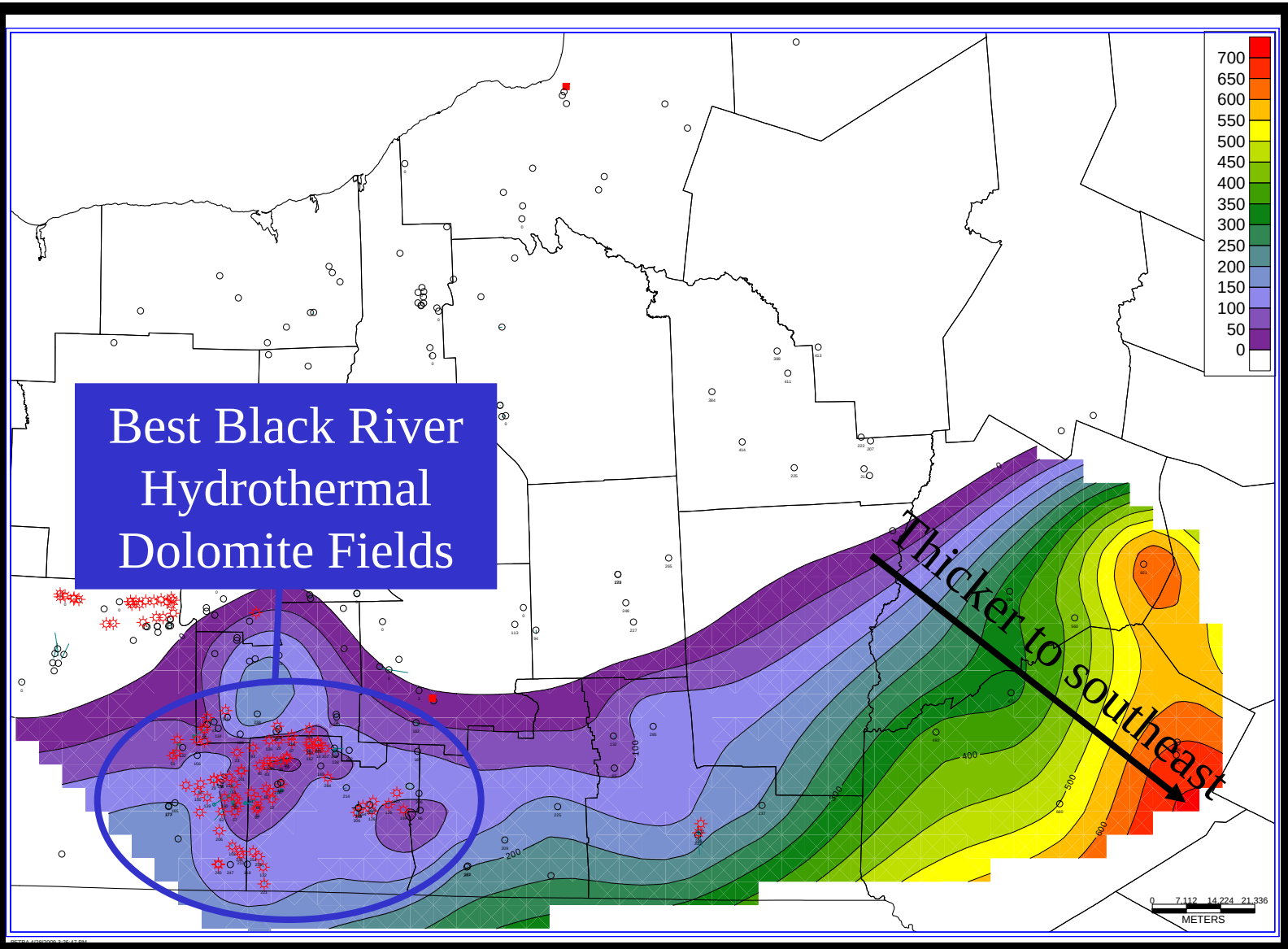




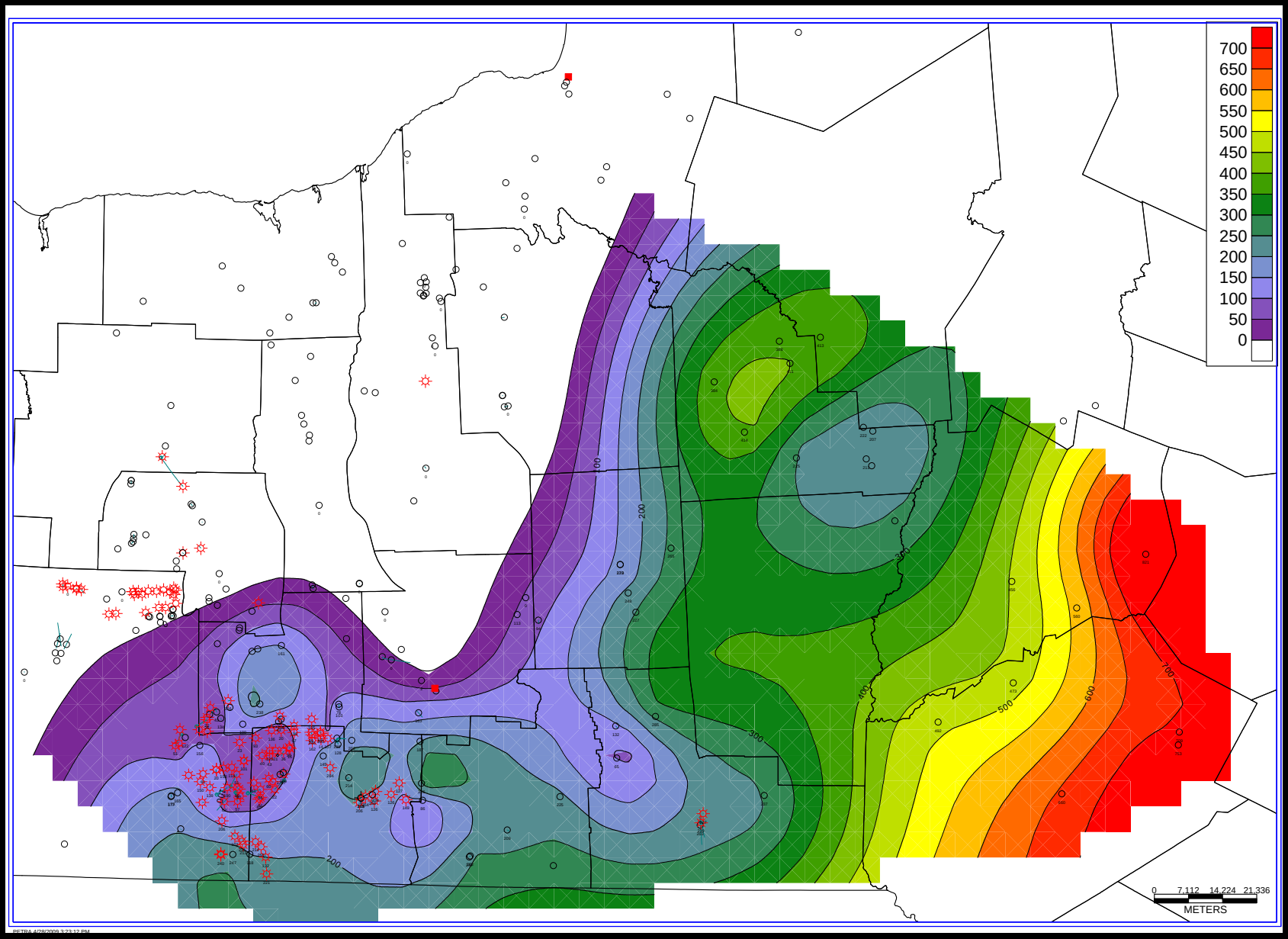
Thickness of organic-rich Lower Indian Castle Shale – trends appear to be fault-controlled – Brett and Baird (2002) found a similar abrupt thickening they interpreted to be fault-controlled in outcrop study



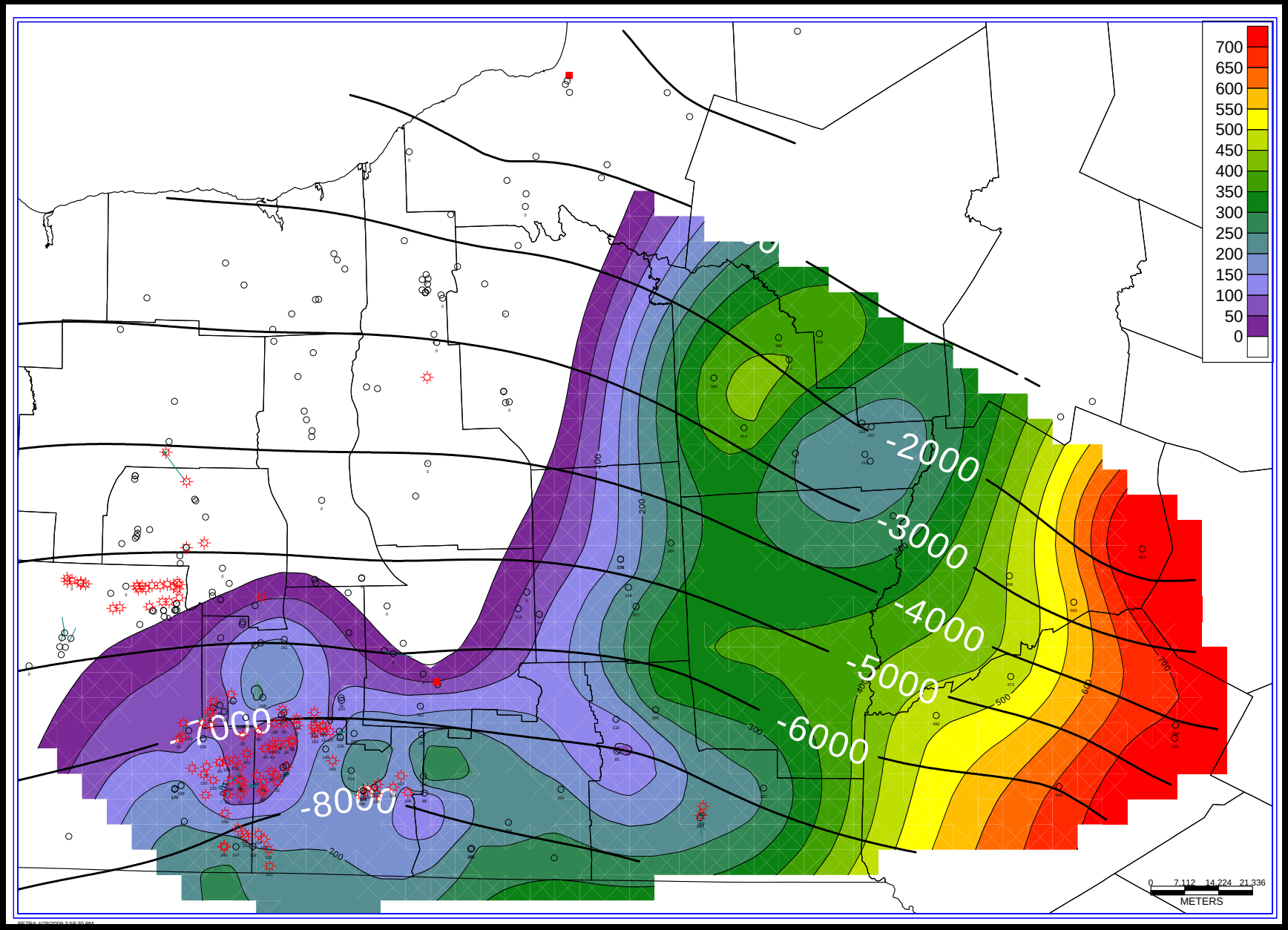
Organic-rich interbedded limestone and shale identified with RHOB



Total thickness of Organic-Rich Dolgeville/FlatCreek/Trenton - generally thickens to east – more to be done on this – will this interbedded limestone and shale produce as well as black shale?



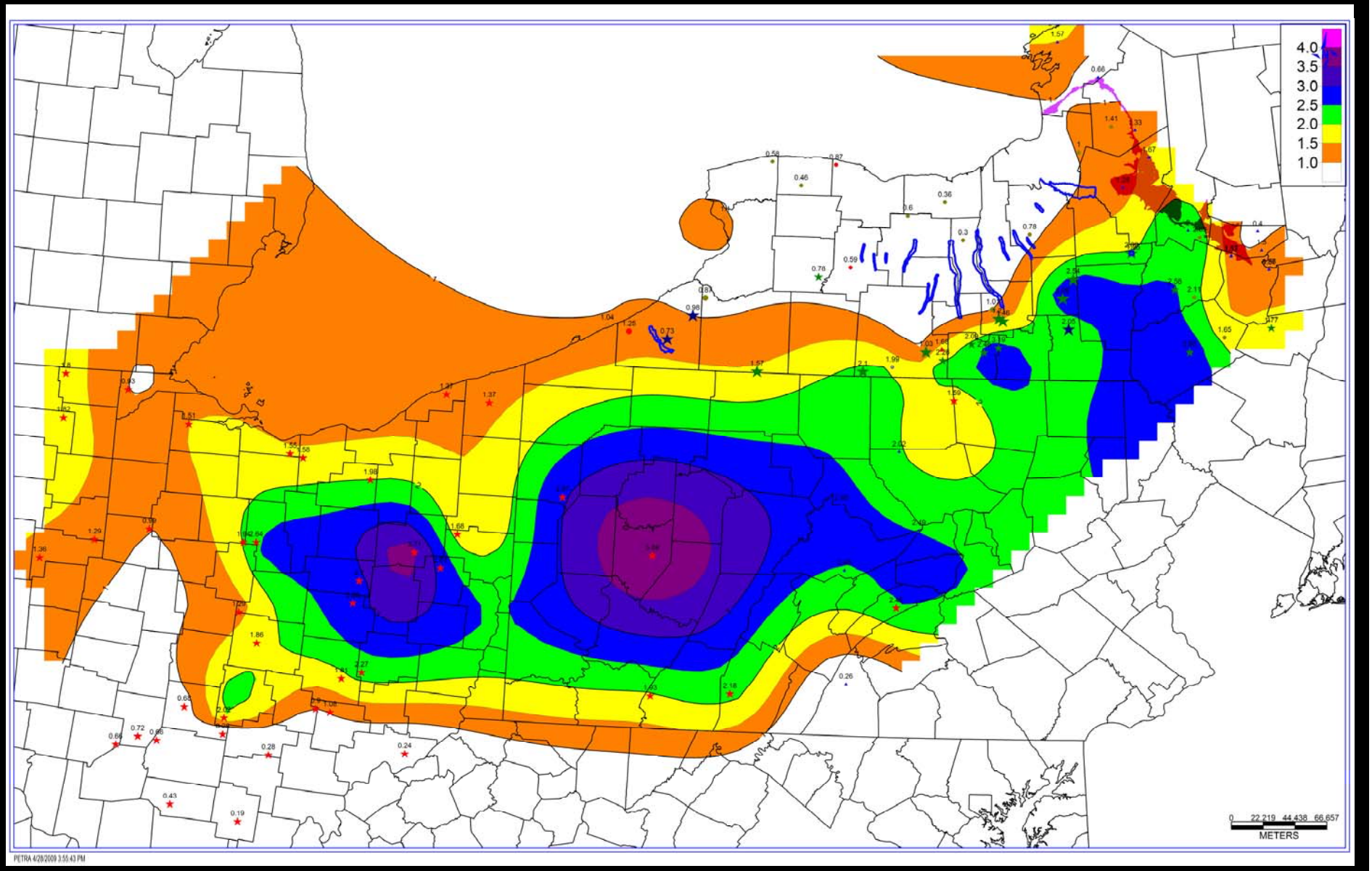
Total thickness of Organic-rich Indian Castle plus organic-rich Dolgeville, Flat Creek and Trenton



Total thickness of Ordovician organic-rich with burial depth contours – a significant portion of the total is buried below 3000-4000 feet

Utica Thickness and Burial

- The Utica/Dolgeville/Flat Creek/Trenton has a much greater potential thickness of organic rich shale and limestone than the Marcellus with some areas having more than 700 feet
- A lot depends on how well the organic rich limestones and interbedded limestone and shale produces
- There is a much broader area where the Utica might produce in NY

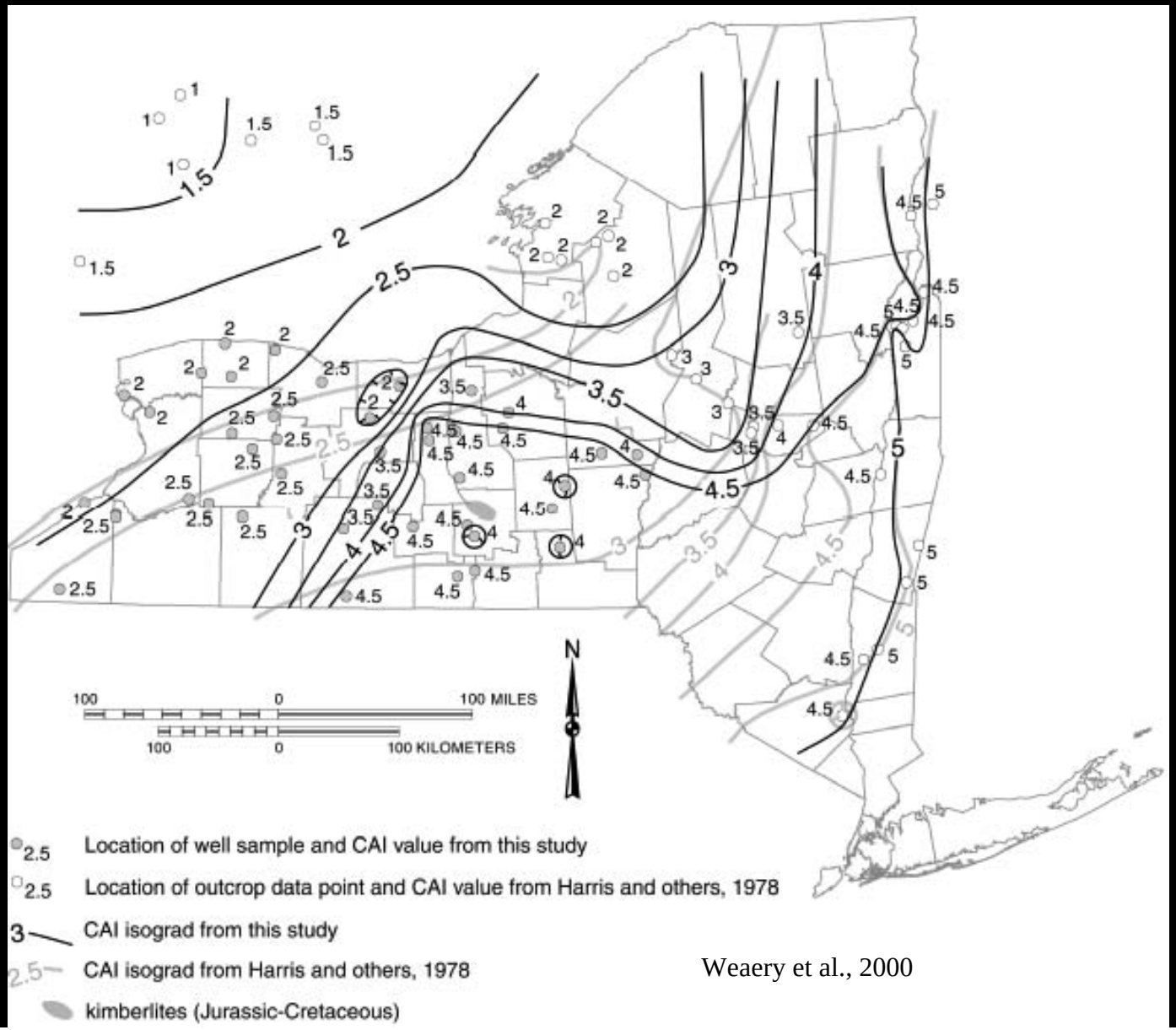


TOC map for Ordovician Utica Shale plotting highest value for each well in northeastern US – IN NY highest TOC to southeast

Utica TOC

- The TOC values in the Utica are lower than those in the Marcellus with the best values between 1.5 and 3 wt%
- These values are from cuttings which may be 50% lower than actual (so the actual could be 3-6%) (Jarvie et al, 2007)
- Original TOC prior to burial and hydrocarbon generation also may have been ~twice as high so the original TOC in the Utica could have been as high as 5-10%

Middle to Upper Ordovician Conodont Alteration Index Isograds



Weaery et al., 2000

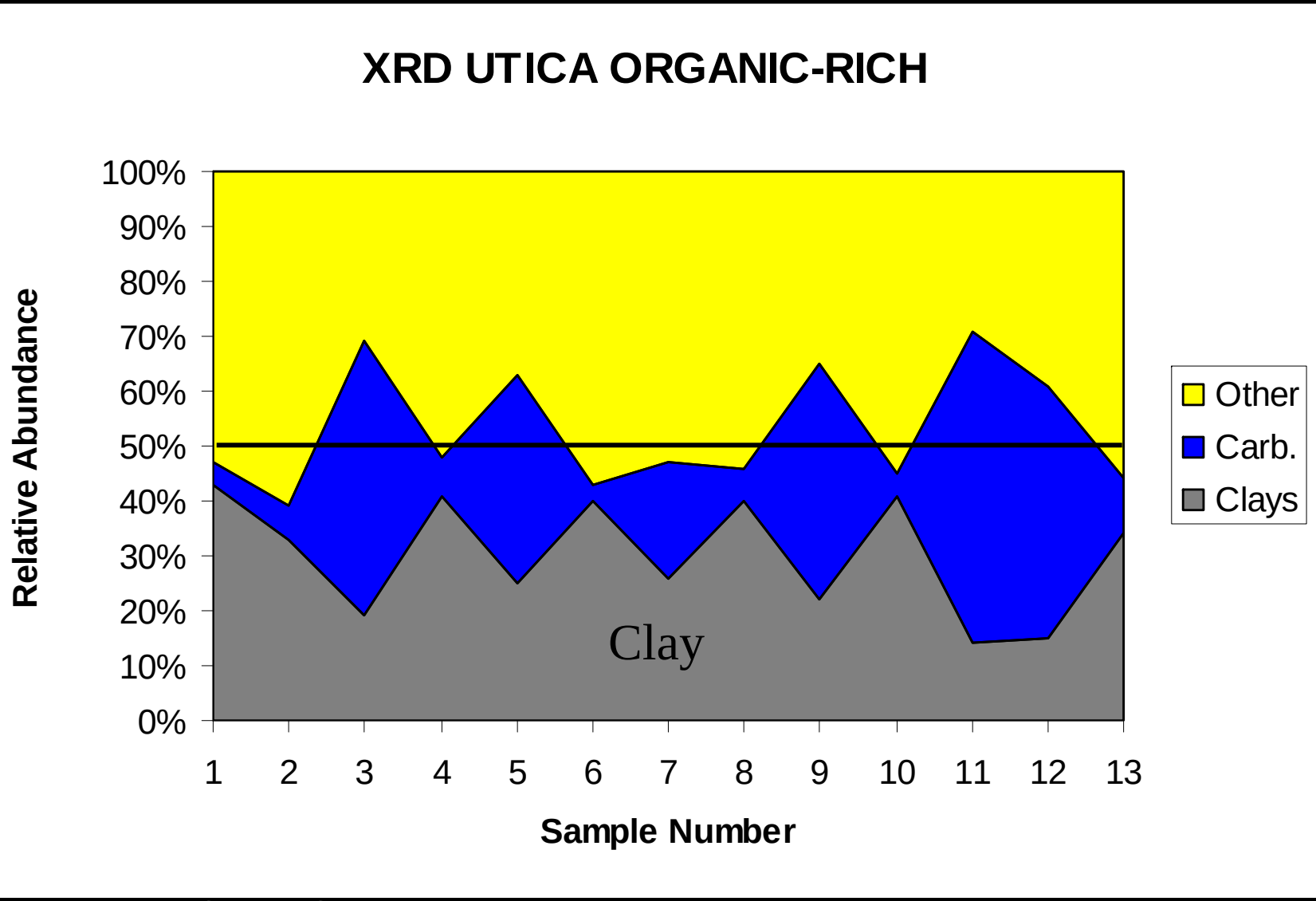
Vitrinite reflectance does not work in the Ordovician

Conodont Alteration Index shows very high thermal maturity equal to very high R_o (>3) in the east

Barnett 1.2-2

Maturity

- Rock Eval geochemistry shows that Utica has seen very high burial temperature and all of the live kerogen that has potential to make oil or gas has cracked (very very low S2 values)
- The Barnett, on the other hand still has live kerogen and still has potential to make gas
- The Utica *may* have less gas in place as a result because a higher percentage may have migrated out of the Formation
- Key question: Does this matter? It is an issue in the Marcellus of eastern NY as well



Samples from five wells - Utica Shale has less than 50% clay in organic rich interval – Low clay content makes wells easier to frac – this is roughly the same as the Barnett Shale

Utica Summary

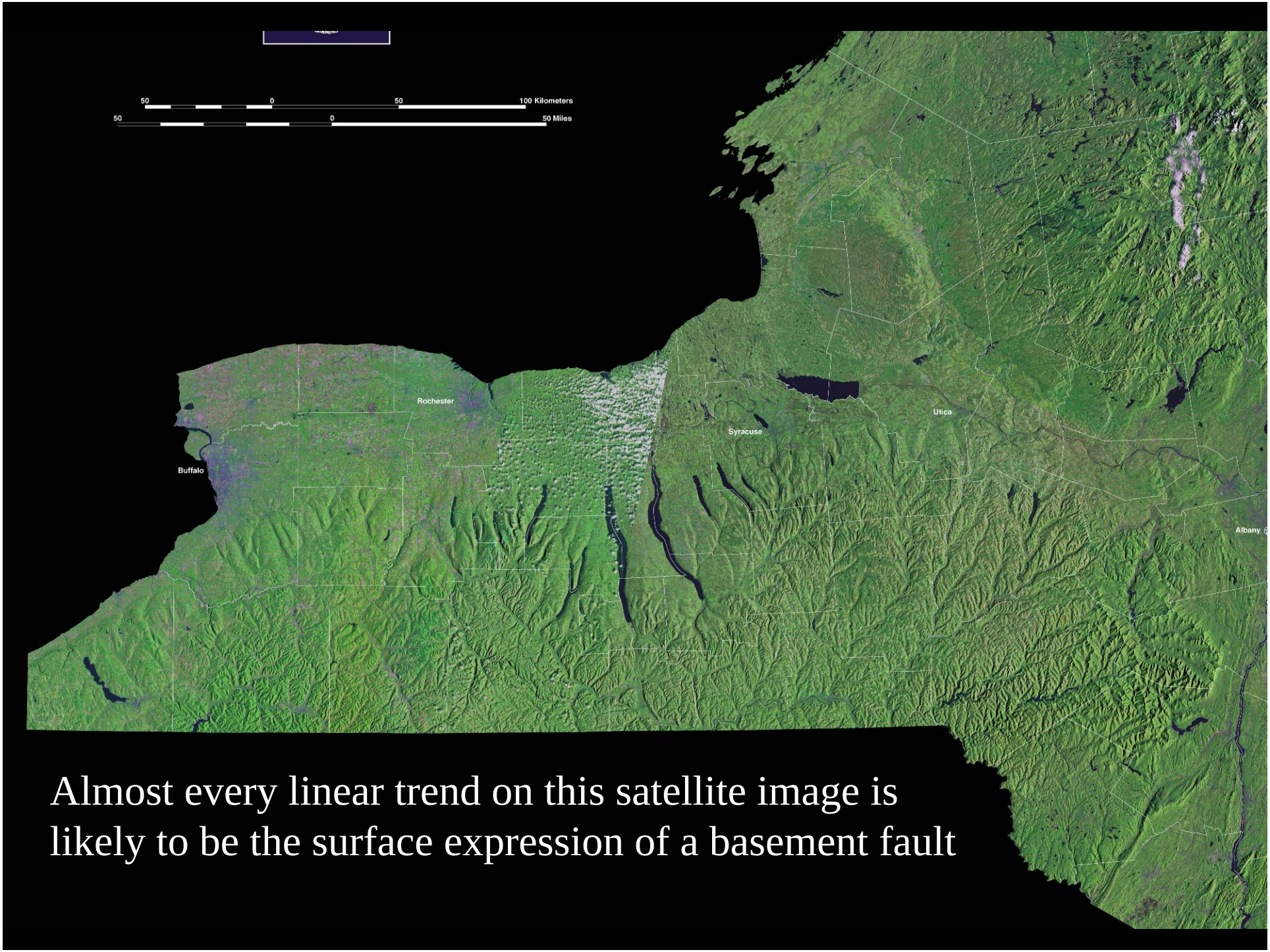
- Good thickness up to 700 ft
- Large area of organic-rich shale and shale and limestone below 4000 ft
- TOC values lower than Marcellus by 1-2% (could still be high enough)
- Thermal maturity much higher than Barnett
- Clay percentage lower than 50%

Utica Questions

- Is organic-rich interbedded shale and limestone as good as just shale? Should it be drilled and completed differently?
- The Utica is supermature in the East – is this a problem – there are still good gas shows
- Not a great top seal to help develop overpressure – is this necessary?
- Was the TOC high enough to begin with? Lower values than Barnett and Marcellus
- What is the minimum depth to obtain pressures needed to flow economic quantities of gas?

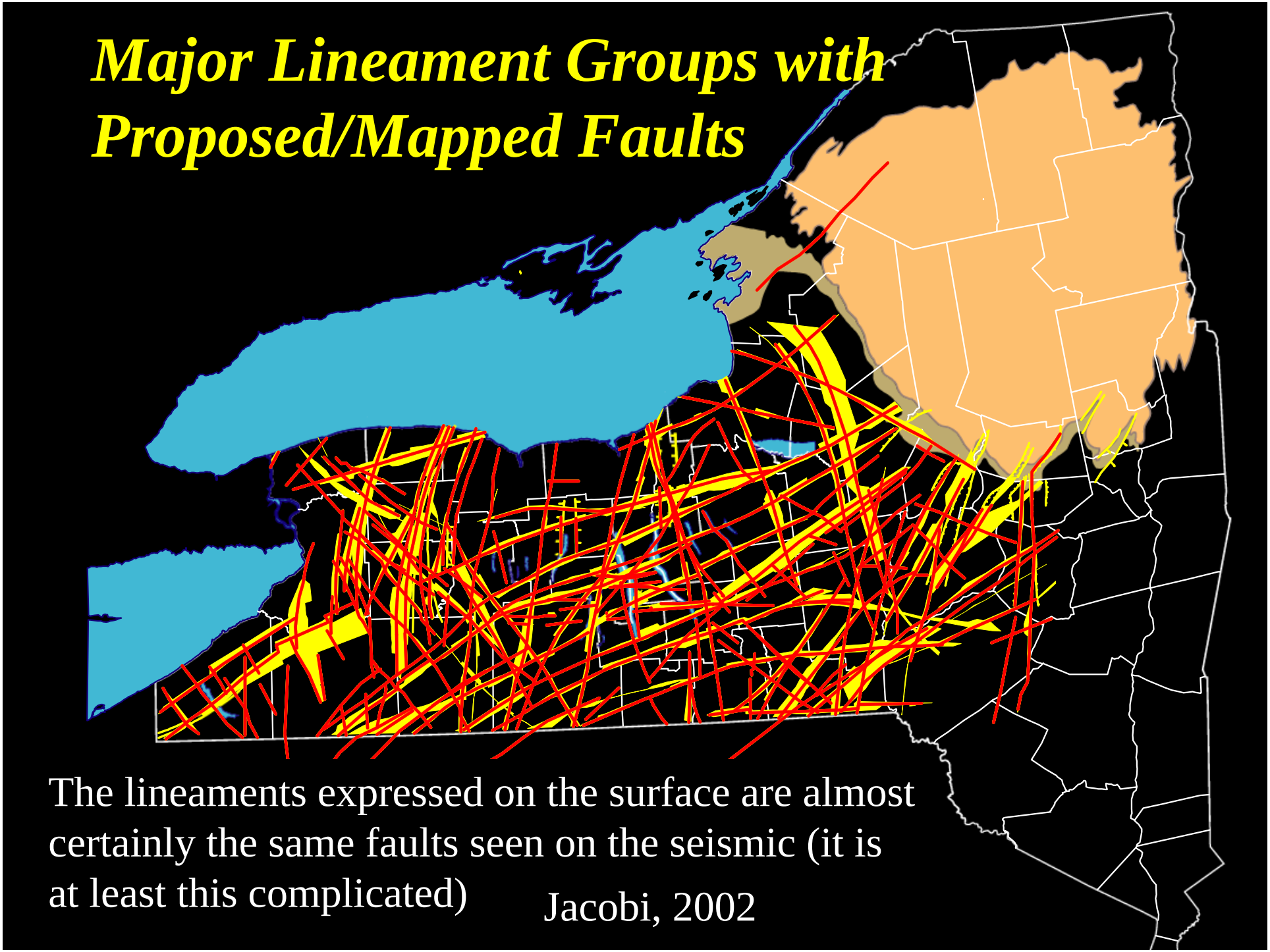
Faults and Fractures

- Early work on producing the shales was focused on finding and penetrating natural fractures and using those fractures to produce the gas
- The opposite is true in the Barnett Shale where they use seismic data there to plan wells away from faults and natural fractures
- In the Barnett, the faults suck all of the energy out of the frac and may bring water up from lower formations
- If permeable, they could potentially cause problems at shallower horizons
- It is currently not known whether faults are beneficial or not beneficial in the Utica and Marcellus



Almost every linear trend on this satellite image is likely to be the surface expression of a basement fault

Major Lineament Groups with Proposed/Mapped Faults



The lineaments expressed on the surface are almost certainly the same faults seen on the seismic (it is at least this complicated)

Jacobi, 2002

Future Work at NYSM

- Planning to conduct industry-funded comprehensive cuttings, core and outcrop study of TOC distribution in Utica and Marcellus Shales and Limestones
  - Cuttings from 60 wells in Devonian Marcellus from inorganic shale at top to inorganic limestone at base
  - Cuttings from 40 wells in Ordovician Utica/Dolgeville/Flat Creek/Trenton from inorganic shale at top to inorganic limestone at base (could be up to 800 feet)
  - Also core and outcrop studies, especially of interbedded limestones and shales to learn levels of TOC in limestones
- Compare cores and outcrops to cuttings to see if TOC is underrepresented in cuttings
- $CaCO_3$ percentage logs from cuttings

NY Shale Gas Potential

- A lot to like about the Utica and Marcellus, but some questions too
- The biggest question for me is whether they shales are overcooked and too much gas has escaped over time – if the Marcellus works, then I think the Utica has a much higher chance of success and vice versa
- Another question is the reservoir potential of organic-rich limestones and interbedded limestones and organic rich shales