Regional Interpretation of the Middle-Upper Ordovician Utica Shale Play in the Appalachian Basin*

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Abstract

The Middle-Upper Ordovician Utica shale was deposited in a foreland basin setting adjacent to, and on top of, the Trenton and Lexington carbonate platforms. Initial deposition of the Trenton and Lexington platforms began on the relatively flat Black River passive margin. Early tectonic activity from the Taconic orogeny created the foreland bulge that would become the Trenton and Lexington platforms. Carbonate deposition was able to keep up with the overall rise in sea level while the areas between remained relatively deeper until increased subsidence in the foreland basin lowered the ramps out of the photic zone and inundated the passive margin with fine-grained clastics.

While the number of producing Utica wells is still small, there is sufficient data to construct a regional framework. Facies determinations from a regional data set of well logs help identify the platform, slope, and trough facies. A regional sequence stratigraphic interpretation of the Upper Ordovician succession allows for correlation between the carbonate platforms and through the trough. Sequences are identifiable as a series of transgressive and highstand systems tracts. Lowstand systems tracts are not commonly deposited on the platforms tops and often are difficult to discern within the trough. Mapping the facies for each sequence over the complete succession shows the evolution of the basin. Facies modeling, when incorporated with core, XRD, and mineral models allow for reservoir prediction and the development of completions strategies.

Deposition and preservation of organic matter is directly tied to the sequence stratigraphic framework and facies. A geographically and stratigraphically extensive database of TOC measurements show a strong correlation, when merged within the sequence stratigraphic framework, with the highest amounts of present-day TOC (TOC_{pd}) occurring in the lateral equivalents to the platform tops. Maturation patterns in the Appalachian basin have also been studied and the CAI has been mapped to identify different phases of hydrocarbons. Maturation patterns are strongly linked to present-day depth of burial, although post-Alleghanian erosion must also be taken into consideration. The results strongly match the existing production. This regional framework incorporating existing well logs and geochemical data, when combined with a geologic model for the depositional history, has proven to be a useful tool in the early evaluation of an emerging play.

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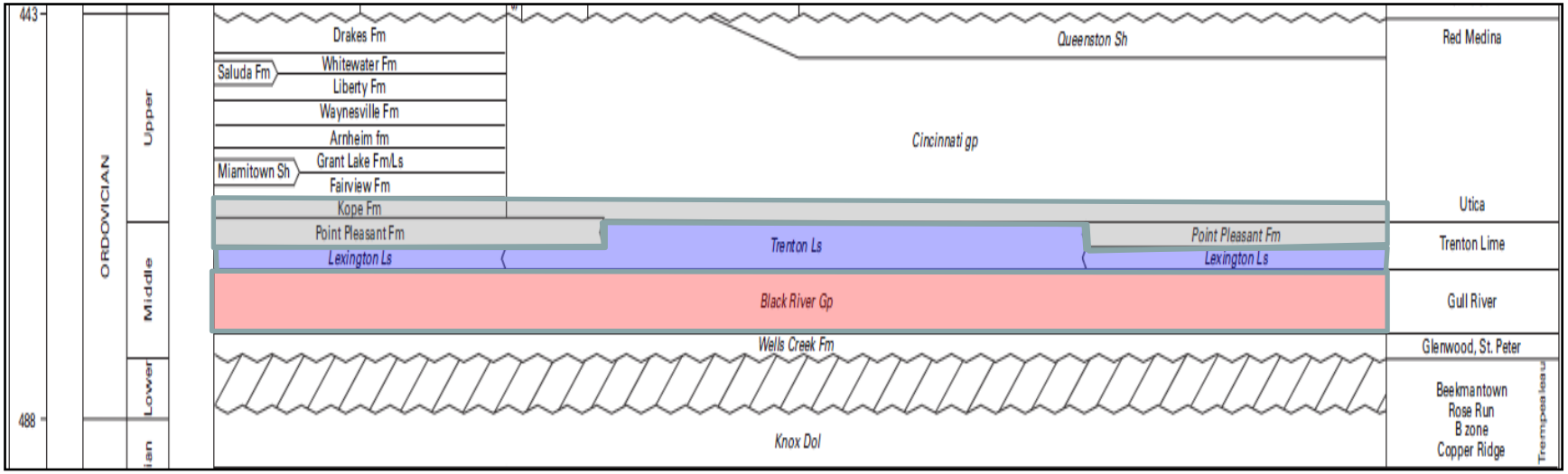
Outline

Where energy meets innovation

- **Background**
  - Tectonic and Climatic Setting
  - Stratigraphic Framework
- **Sequence Stratigraphic Framework**
  - 3rd Order Sequences
  - 4th Order Sequences
- **Mineral Modeling**
- **Ties to Geochemistry**
- **Conclusions**

Middle – Late Ordovician Background

- Widespread CO_3 deposition in North America during Greenhouse conditions
- North America straddled the equator with ~25 deg South running along axis of Appalachian Basin

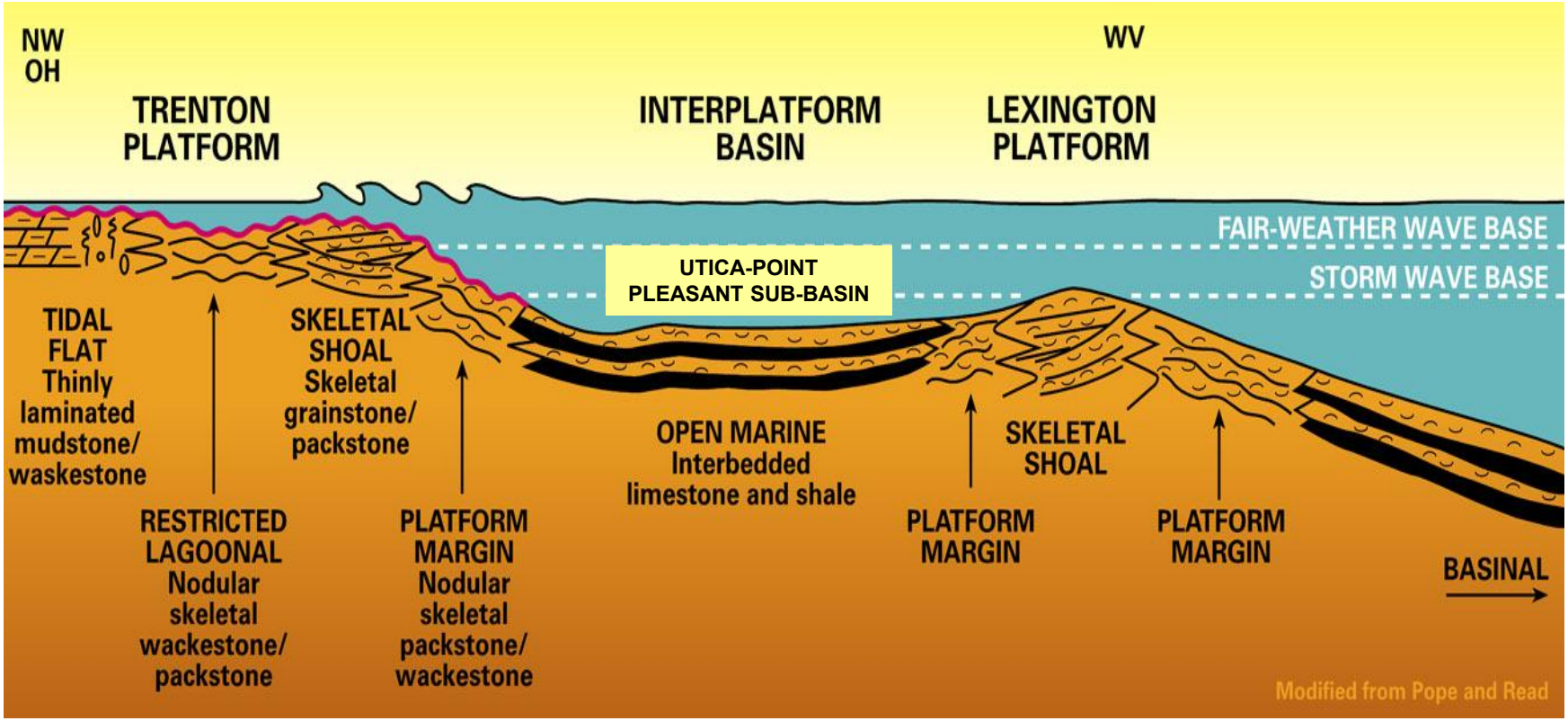


(ODNR)

Utica / Pt Pleasant Depositional Setting

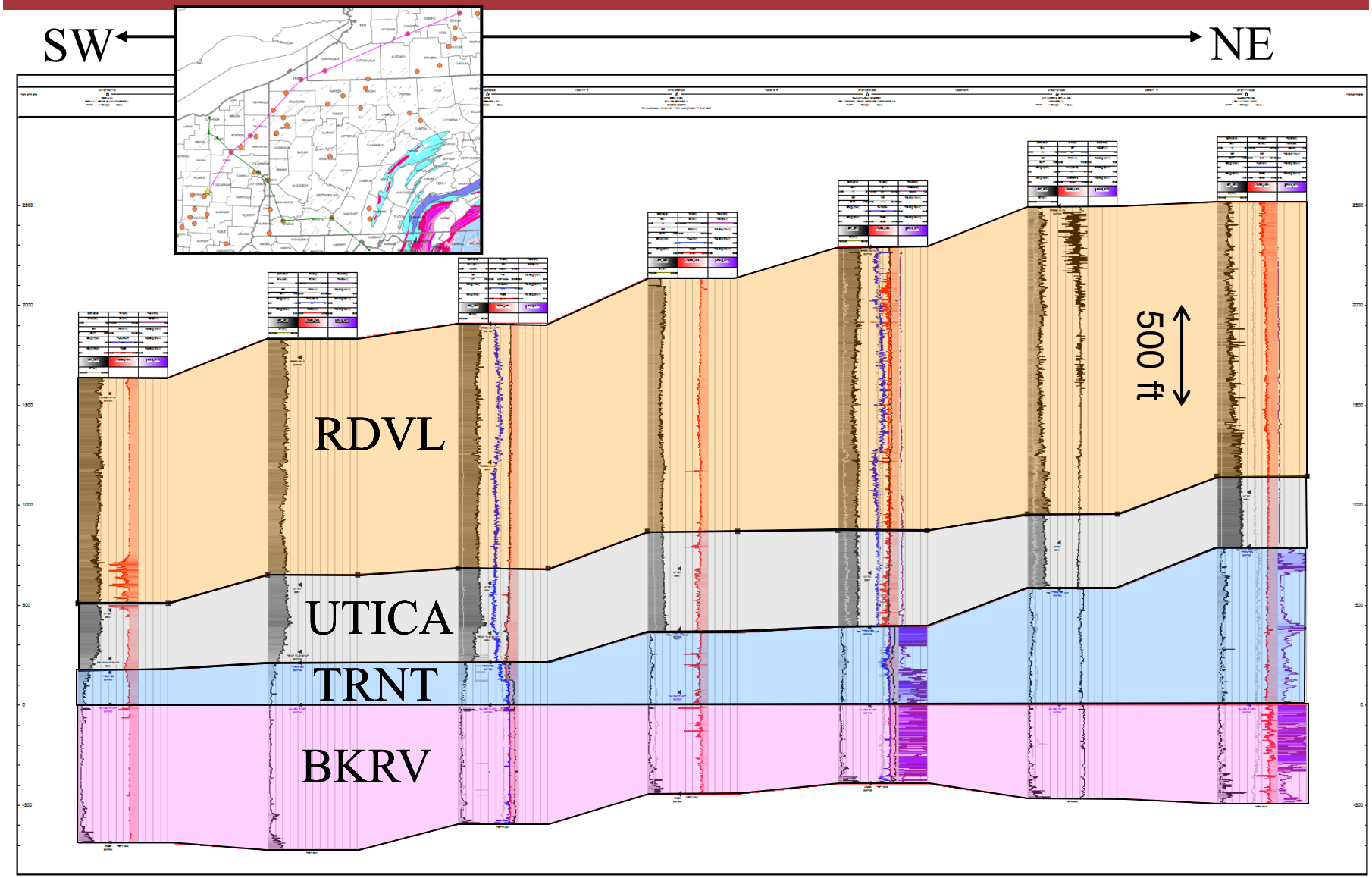
- Point Pleasant deposited in relatively shallow sub-basin adjacent to Taconic foreland basin bordered by Trenton / Lexington Ramps

- Utica overlies Point Pleasant and Trenton / Lexington



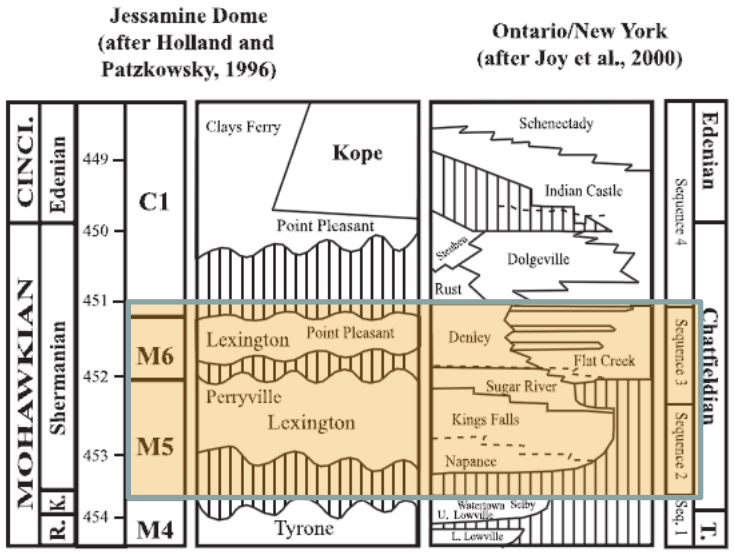
Ordovician Sequences – Early Interpretations

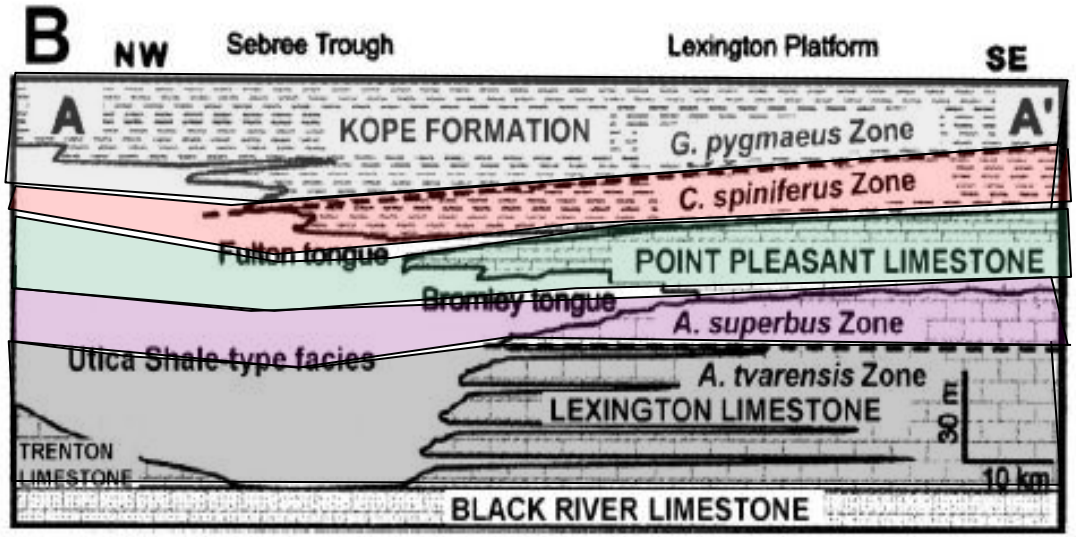
Where energy meets innovation



3rd Order Sequence Framework

- Initial work correlated 2 3rd Order Sequences for the Trenton/Lexington and Pt Pleasant interval in the Appalachian Basin
- Possible to Correlate between Lexington and Trenton Platforms
- Provides little help in the Sebree trough



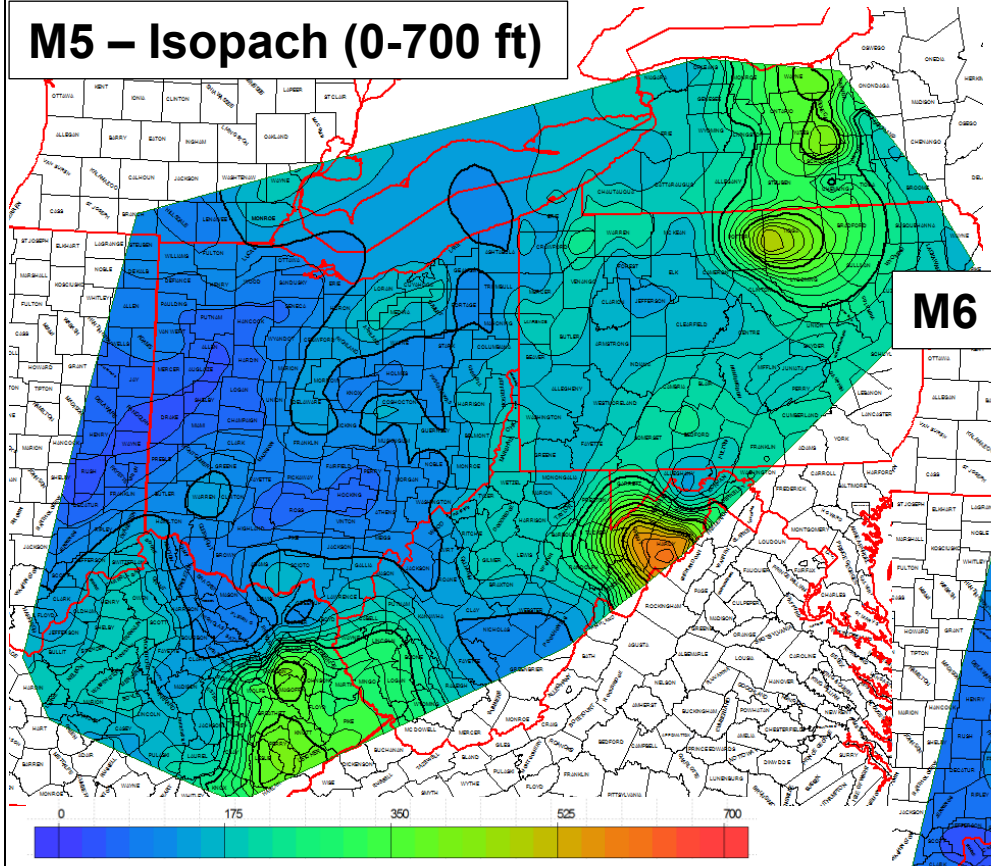


Modified from Kirchner and Brett (2008), Ettensohn (2010)

3rd Order Sequence Isopach Maps

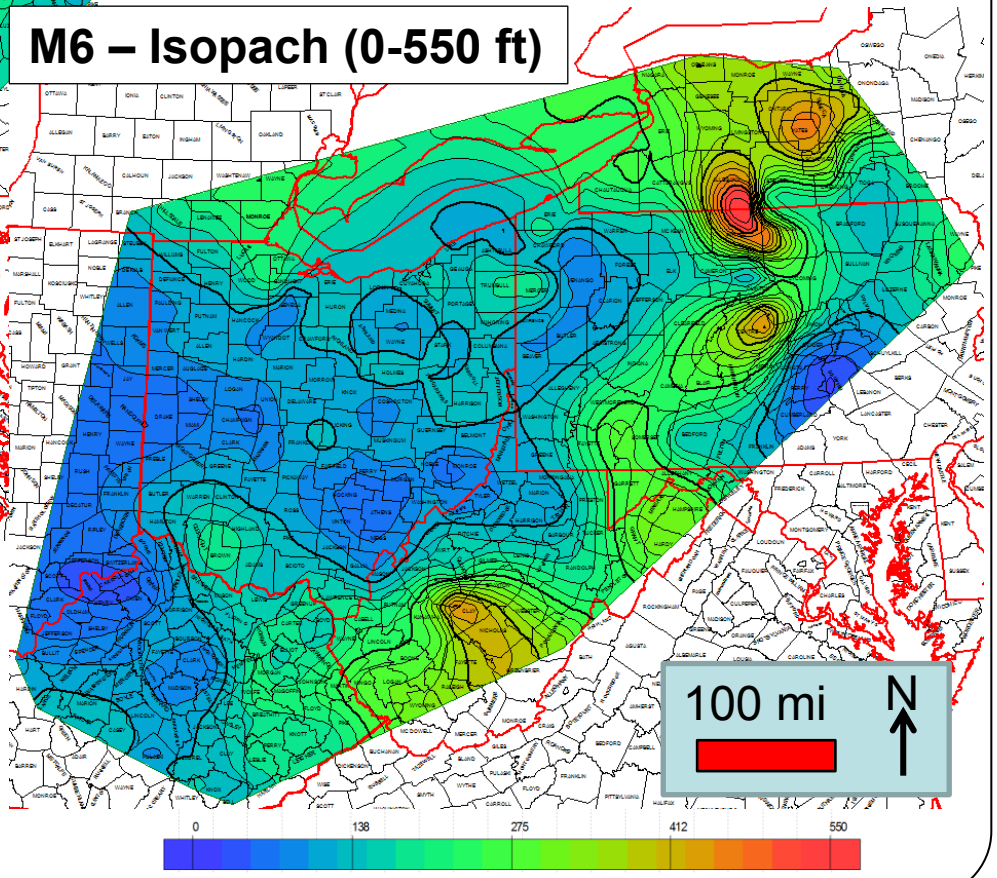
Where energy meets innovation

M5 – Isopach (0-700 ft)



- M5 deposited onto a relatively flat surface
- Most thicks are in foreland basin or at platform / ramp

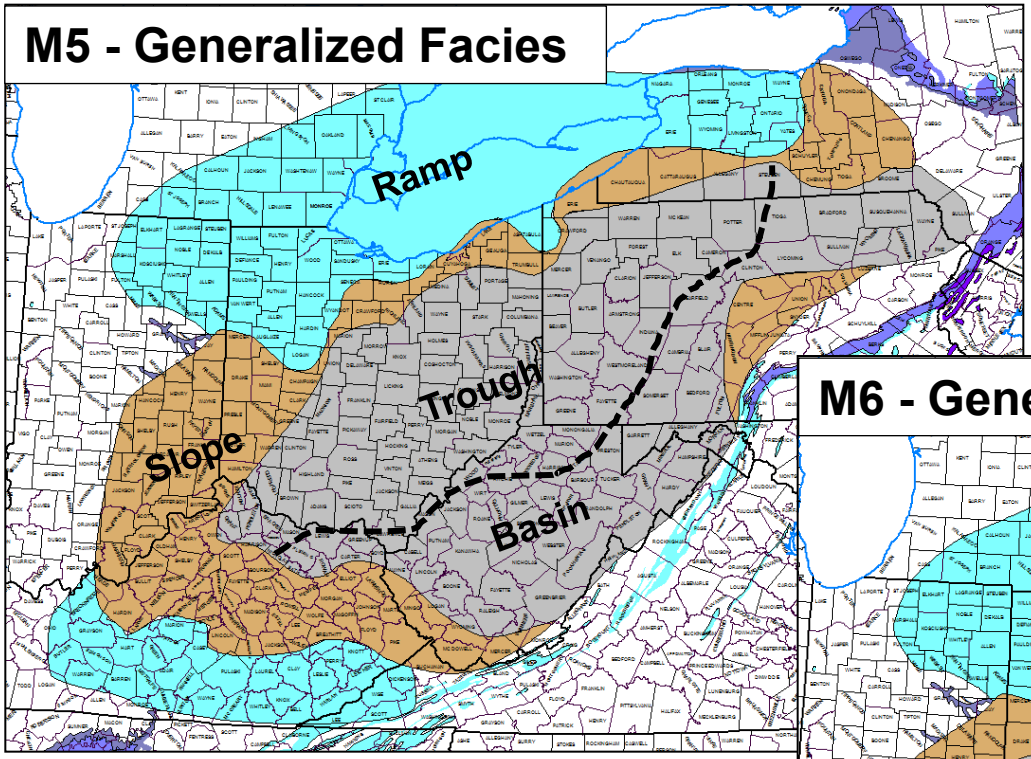
M6 – Isopach (0-550 ft)



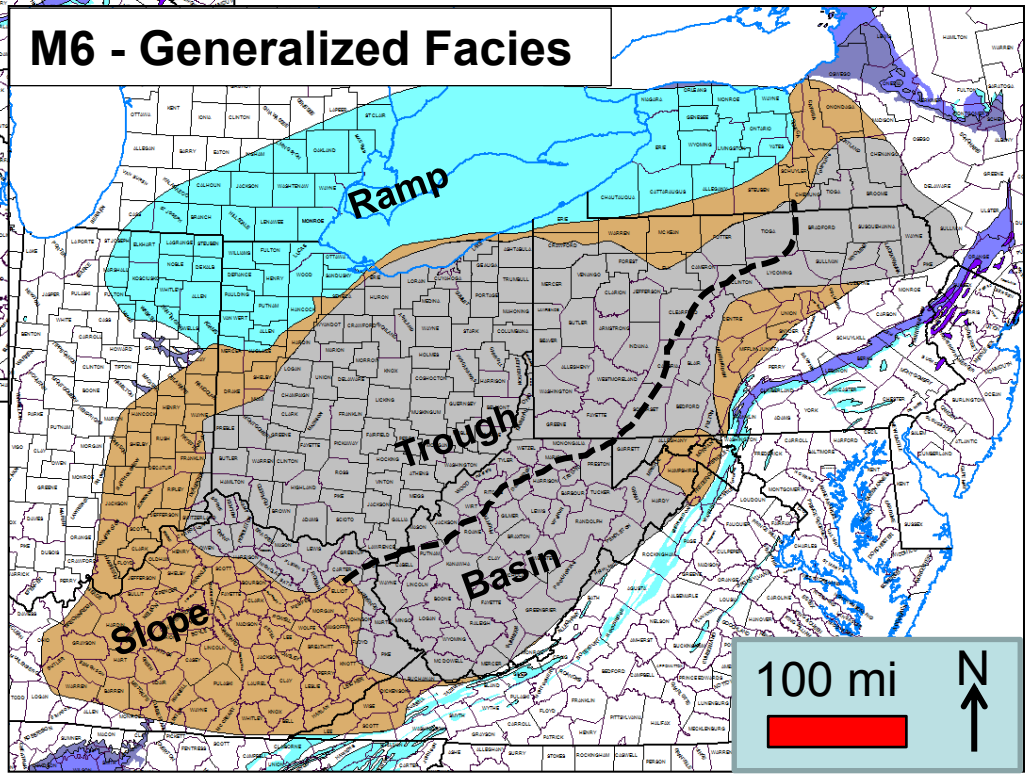
- M6 shows isopach thicks around sub-basin margin
- Overall confinement of the basin

3rd Order Sequence Facies Maps

Where energy meets innovation

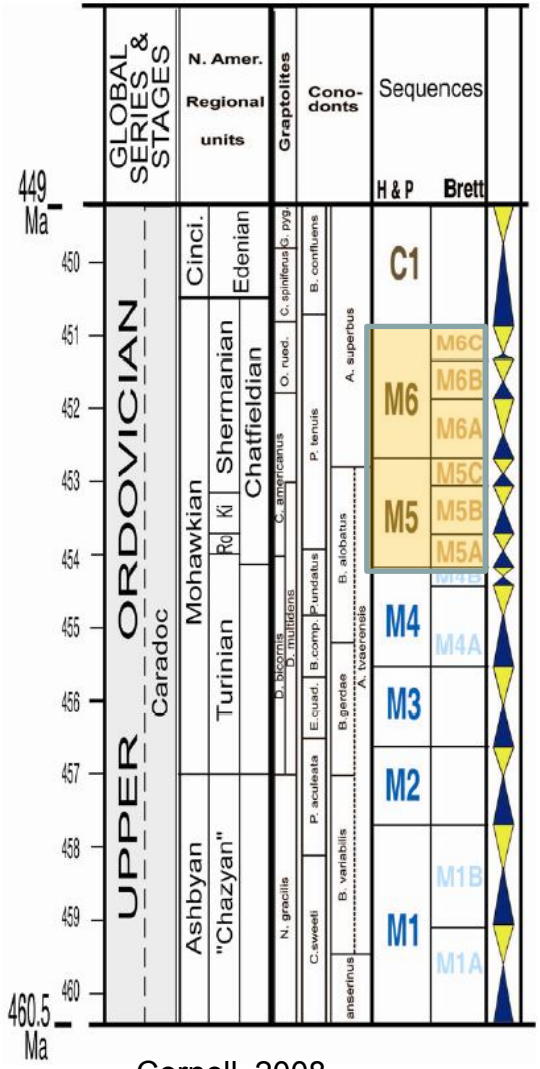


- Log derived facies
- Trough Facies is primary target
- Basin has high clay percentage, but also has higher clastic input



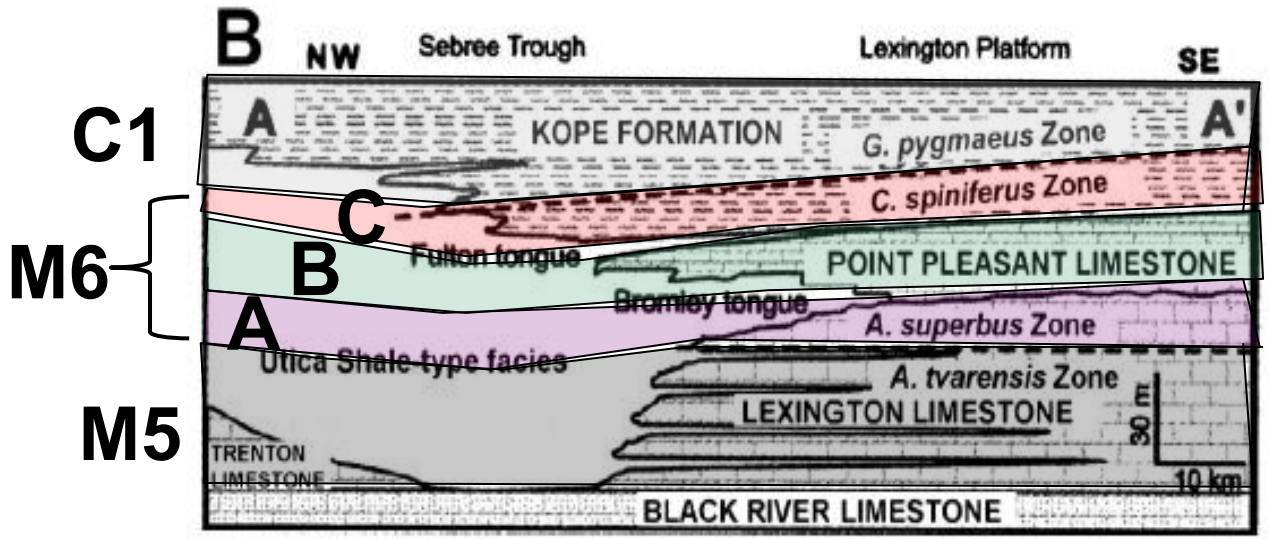
- M5 to M6 transition shows drowning of the Lexington Platform shrinking of the Galena Ramp
- Trough Facies is also becoming inc. restricted as sub-basin fills in

4th Order Sequence Framework



Cornell, 2008

- 4th Order Sequences can be correlated between platforms and within the Sebree trough
- Give a more detailed view of the development of the basin
- Shows early demise of Lexington platform and basin confinement



Modified from Kirchner and Brett (2008), Ettensohn (2010)

4th Order Seq. Strat. Framework

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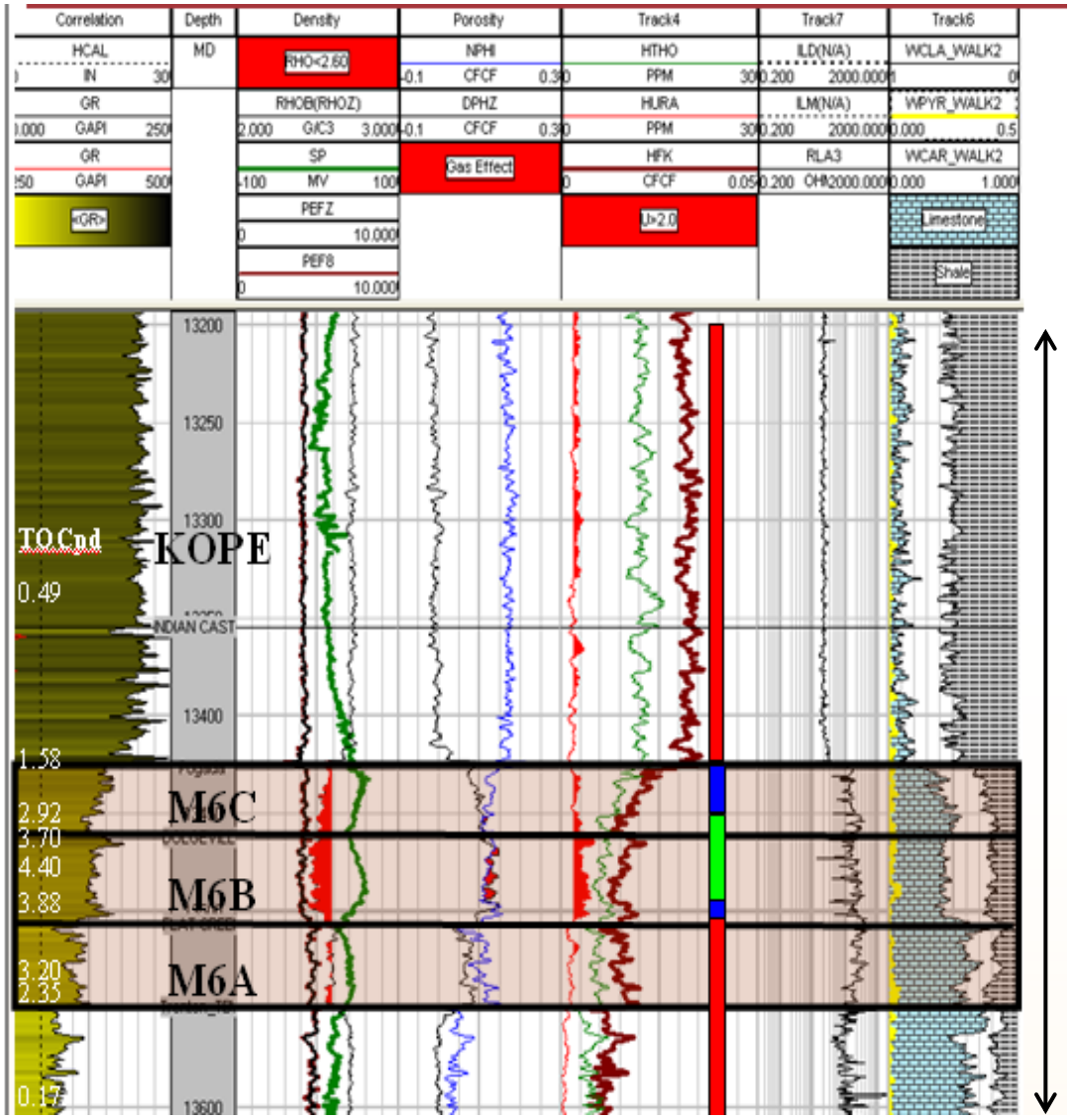
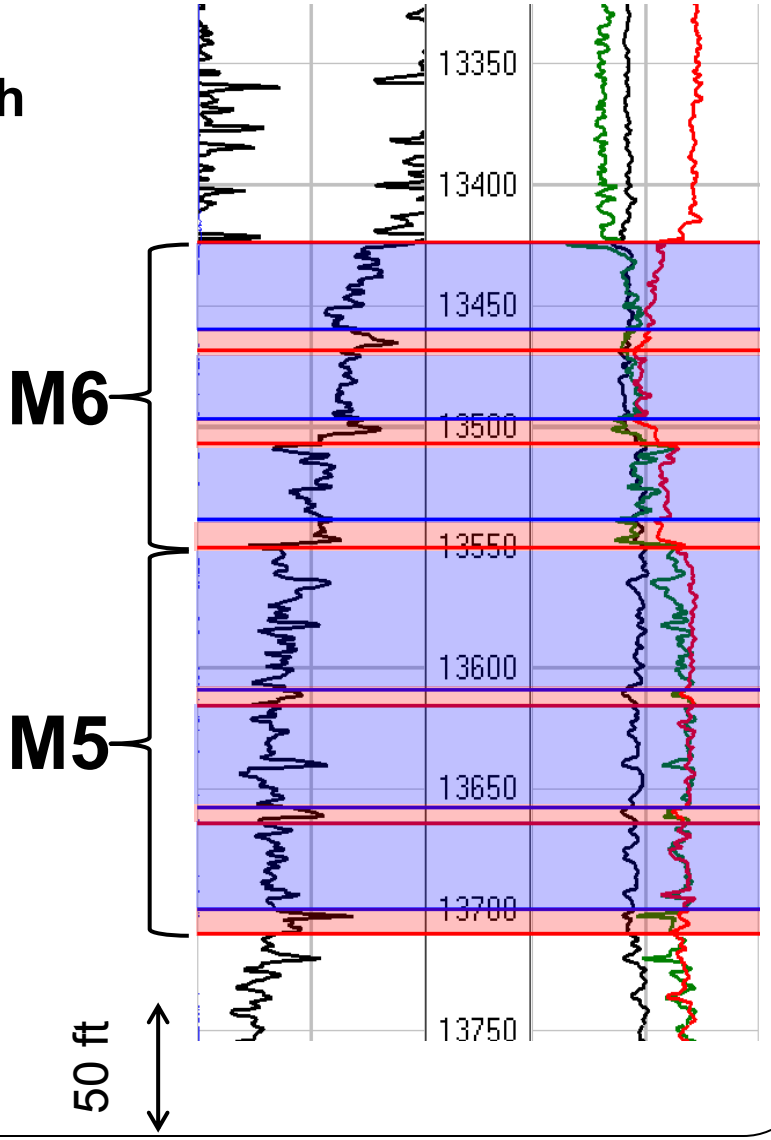
- **M6 Interval (in SW PA)**
  - Highest TOC
  - Not highest GR
  - Lowest Density
  - Neut – Rhob Cross Over
  - Most Gas Filled Porosity

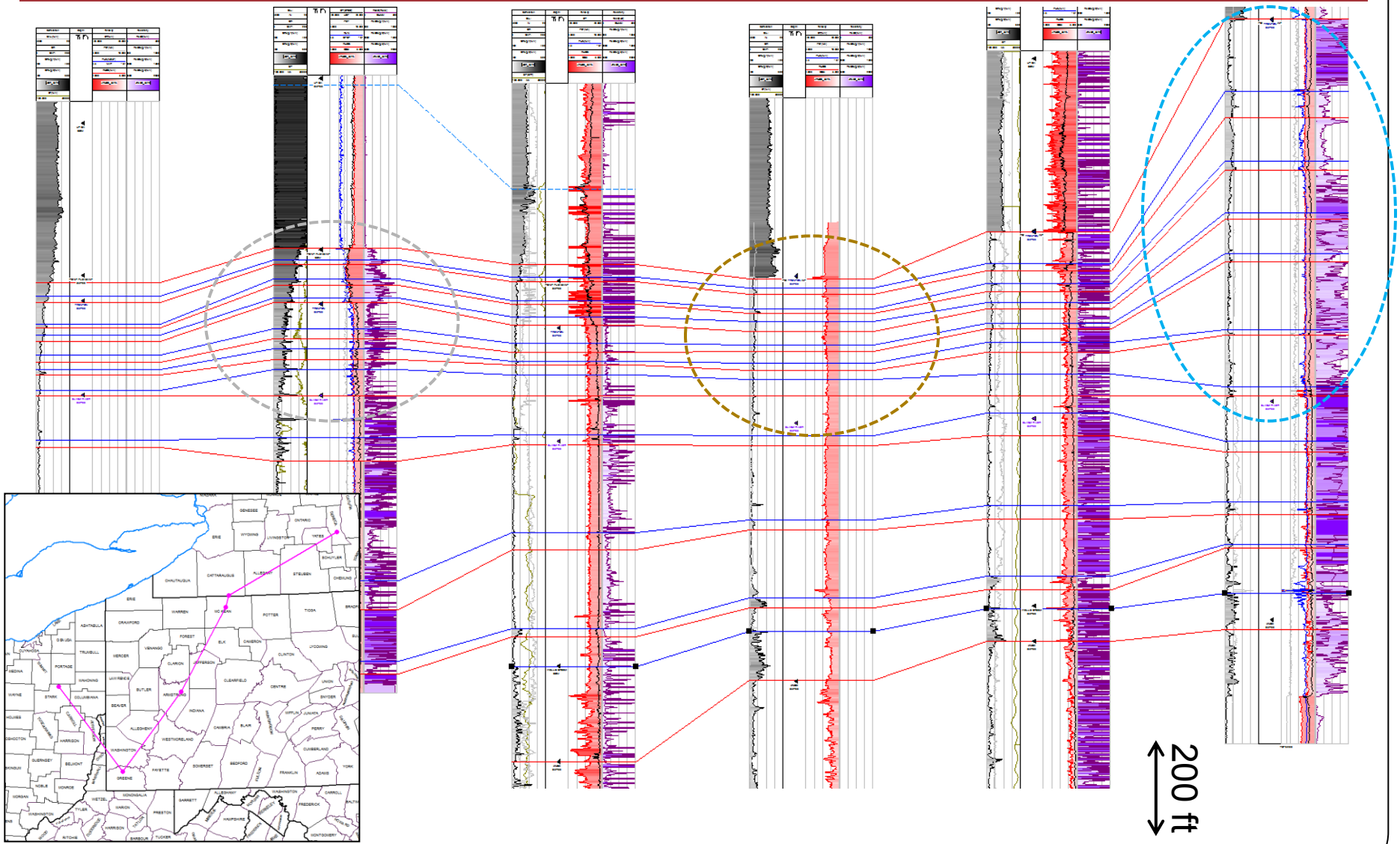


4th Order Sequence Stratigraphic Fwk

- 4th Order Sequences can be correlated between platforms and within the trough
- 6 4th Order Sequences Mapped in the Appalachian Basin
- TSTs (pink) are characterized by GR highs and density lows
- HSTs (blue) are characterized by GR lows and density highs
- LSTs not mapped
- Bentonites are a concern

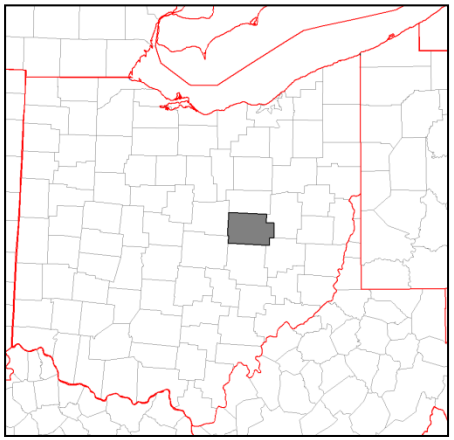


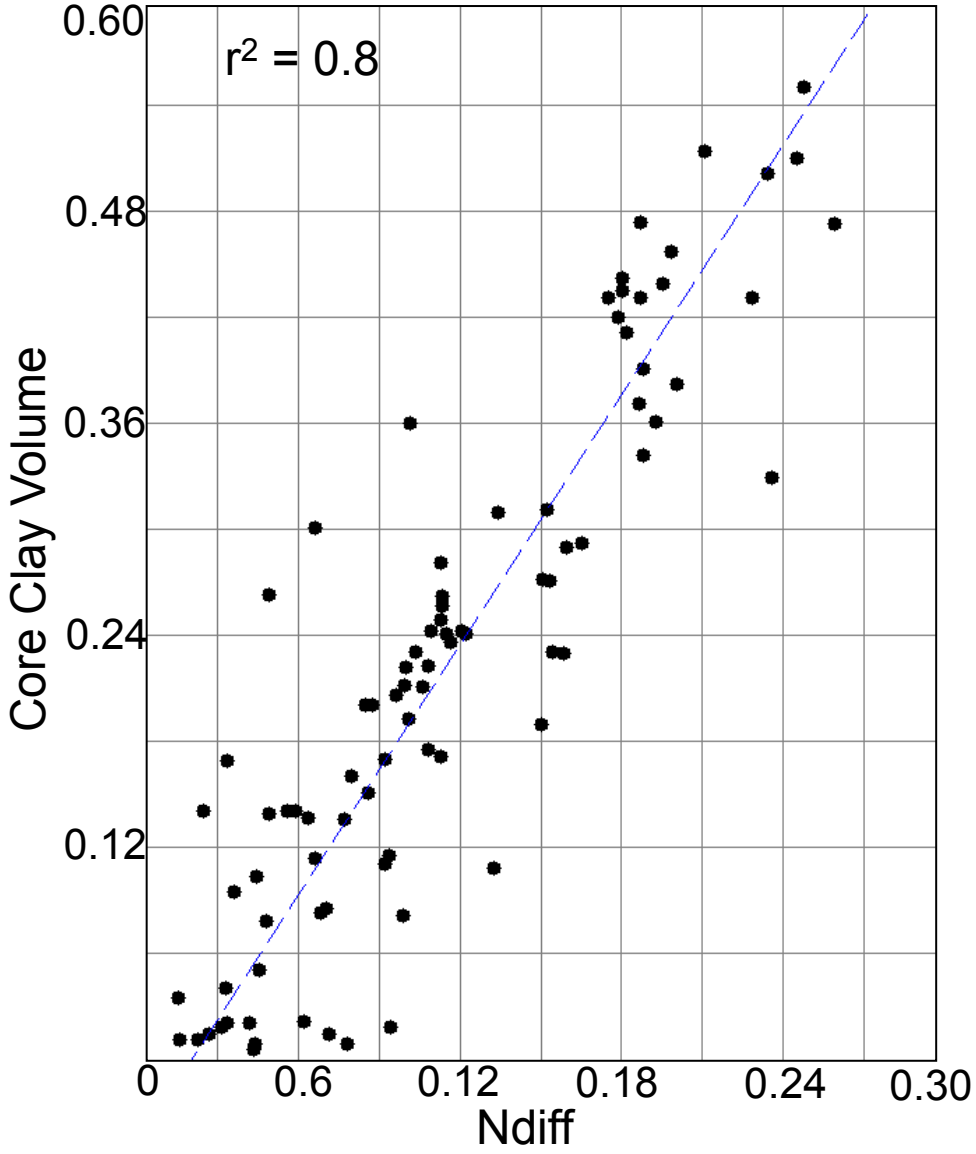
Sequence Stratigraphic Framework



Methodology for Clay Volume Prediction

- XRD Core data compiled
- Log data normalized
- TOC effects accounted for
- Ndiff calculated
  - Ndiff = PHIN – PHID
- Ndiff cross-plotted with core clay volume (r^2 = 0.8)
- Clay volumes mapped for selected systems tracts





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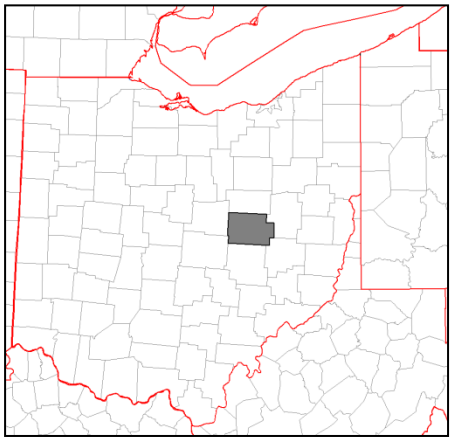

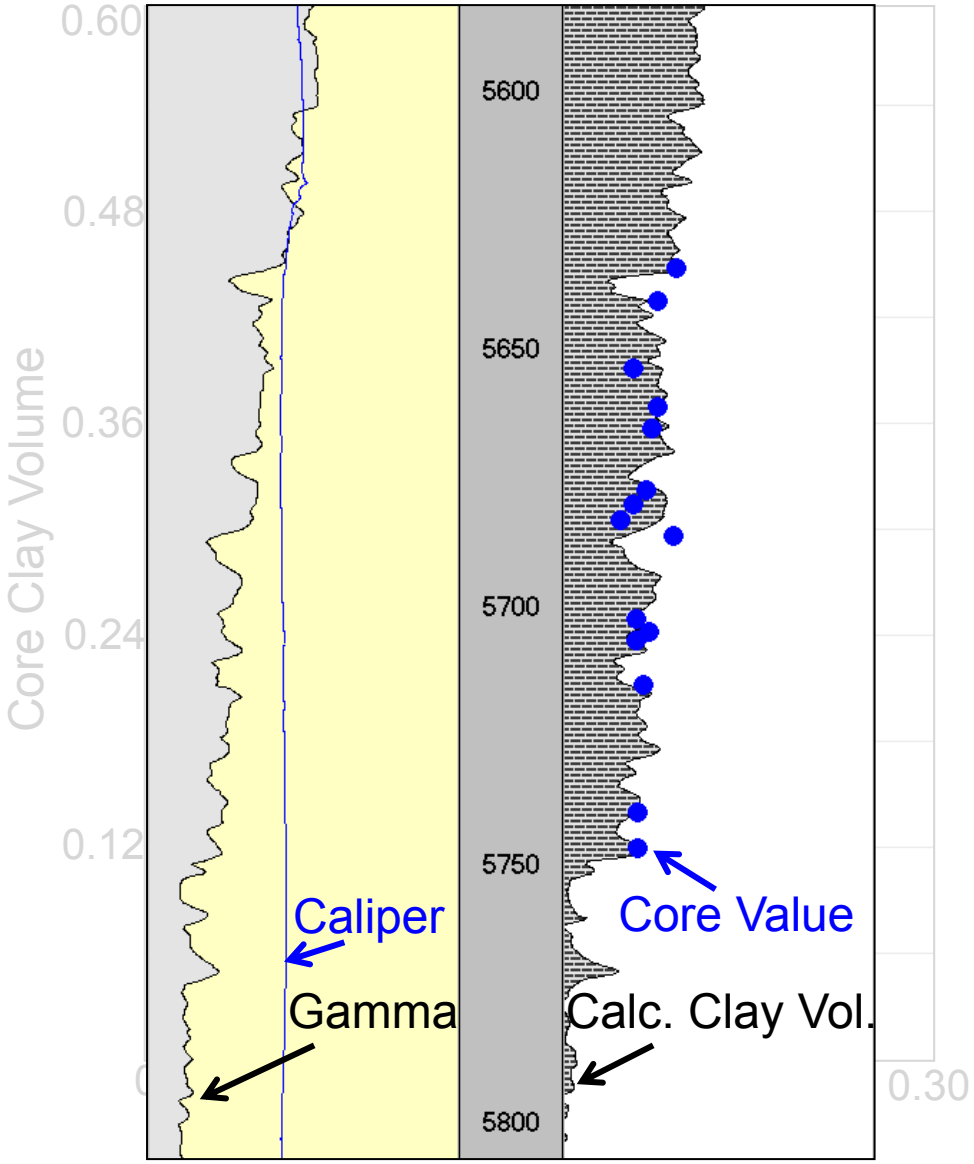

M5-C1 Clay Map Compilation (% Clay)

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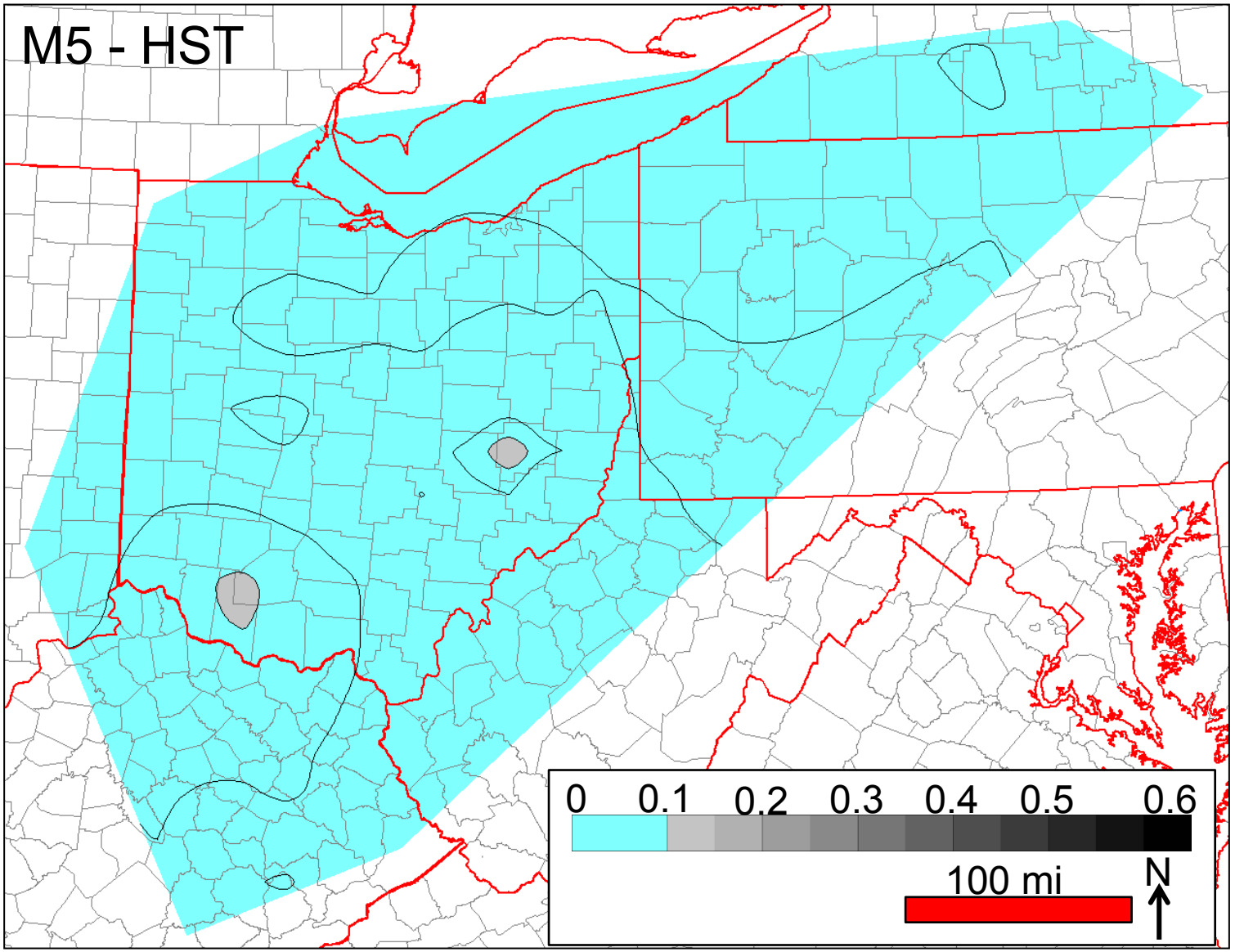

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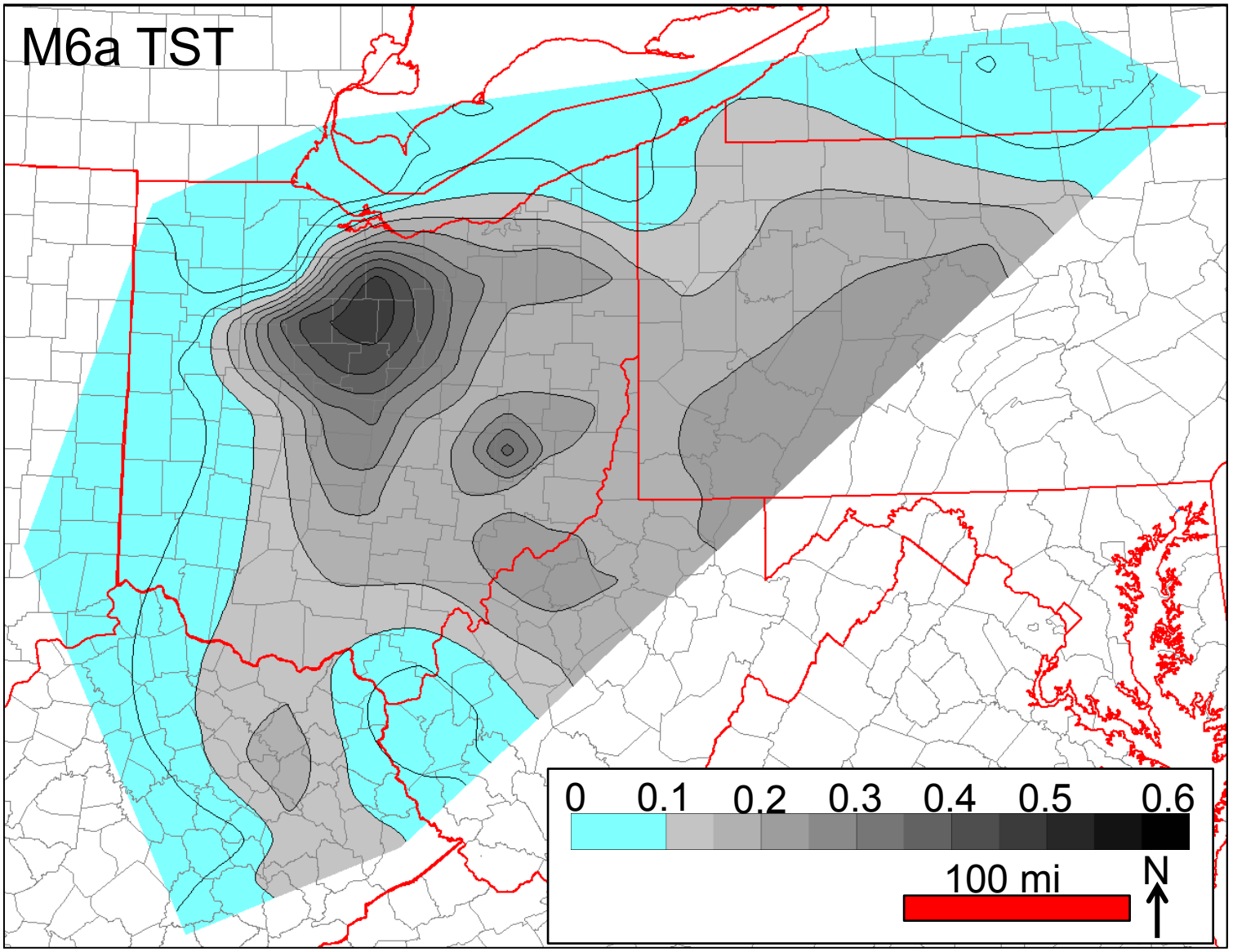
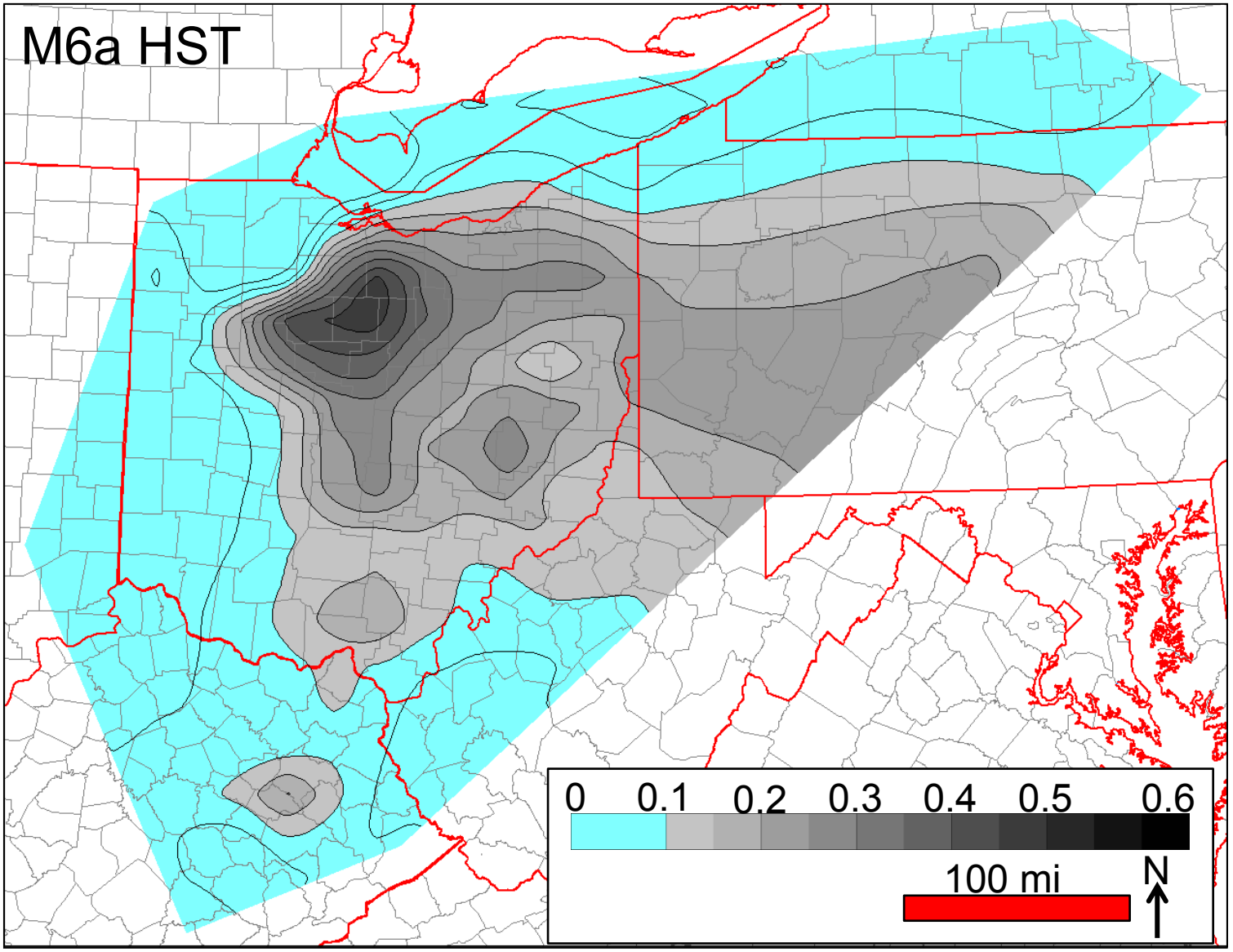
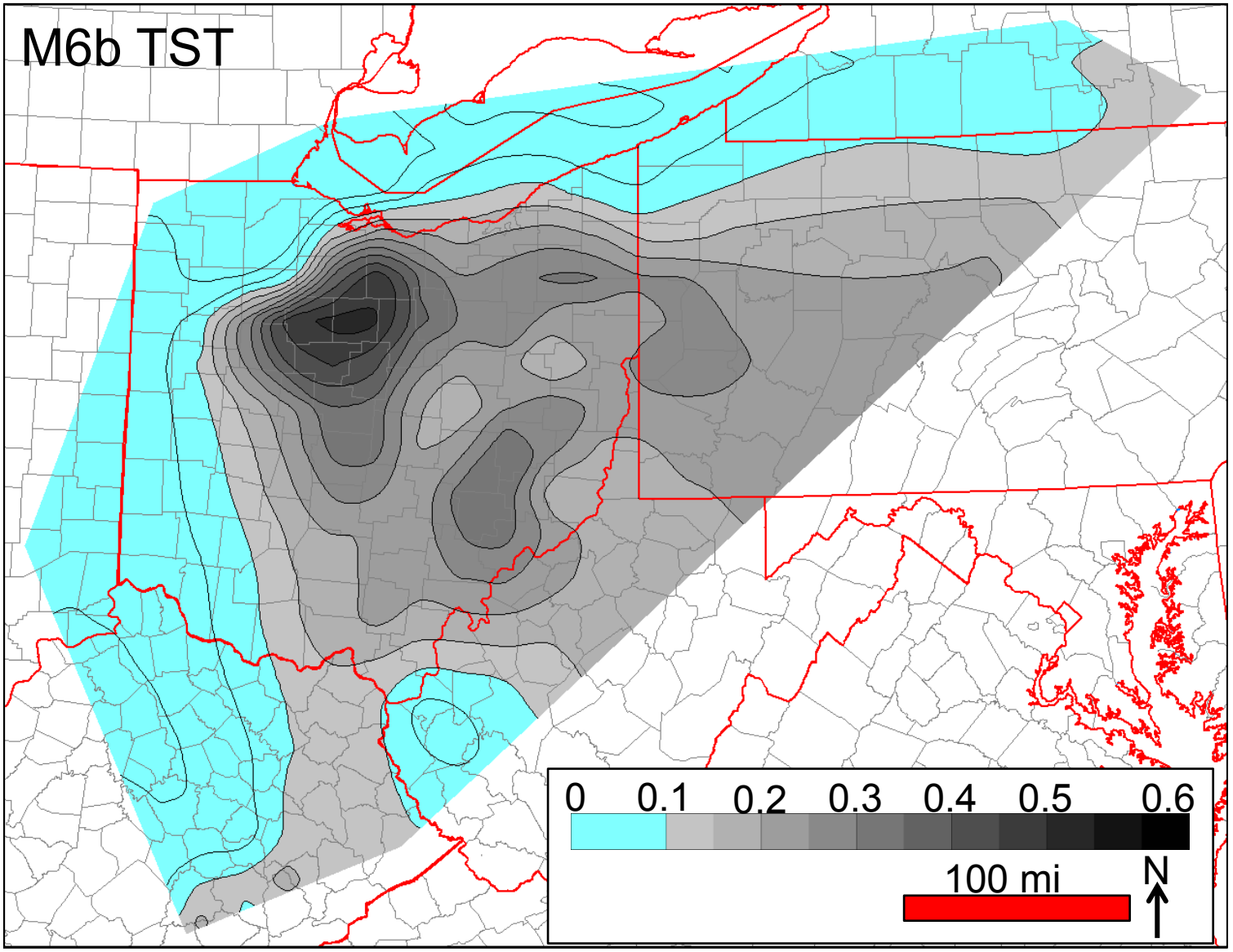


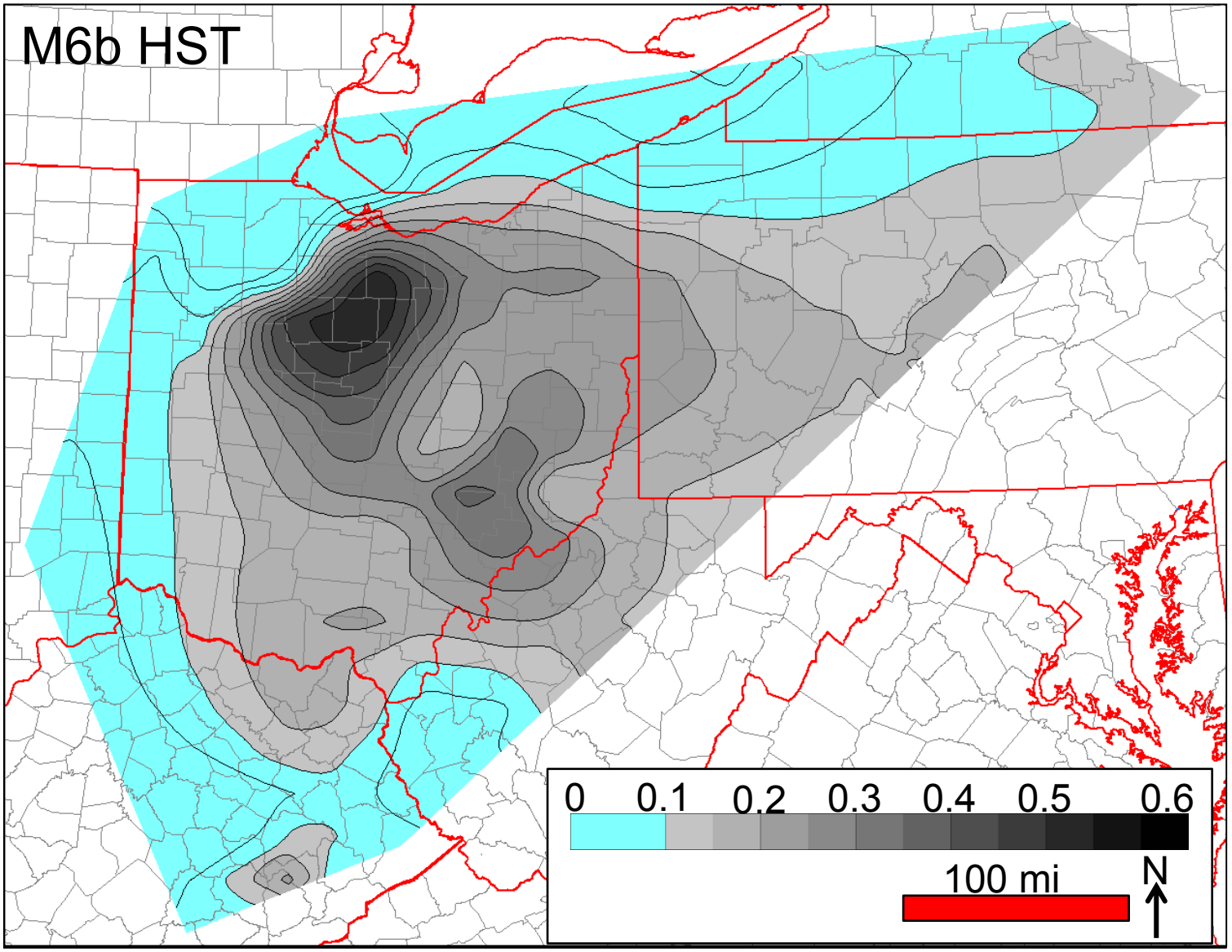
M5-C1 Clay Map Compilation (% Clay)



M5-C1 Clay Map Compilation (% Clay)



M5-C1 Clay Map Compilation (% Clay)



M5-C1 Clay Map Compilation (% Clay)

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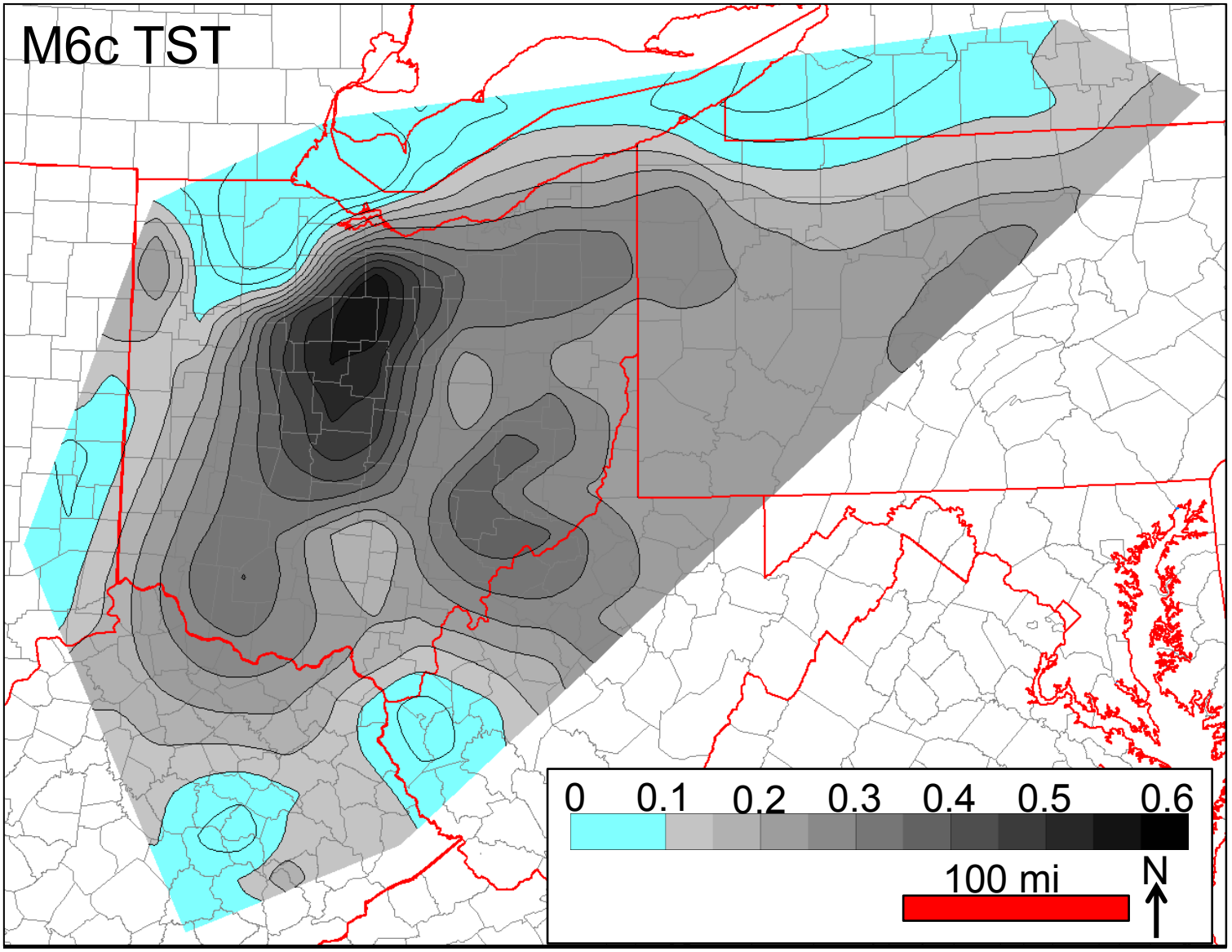
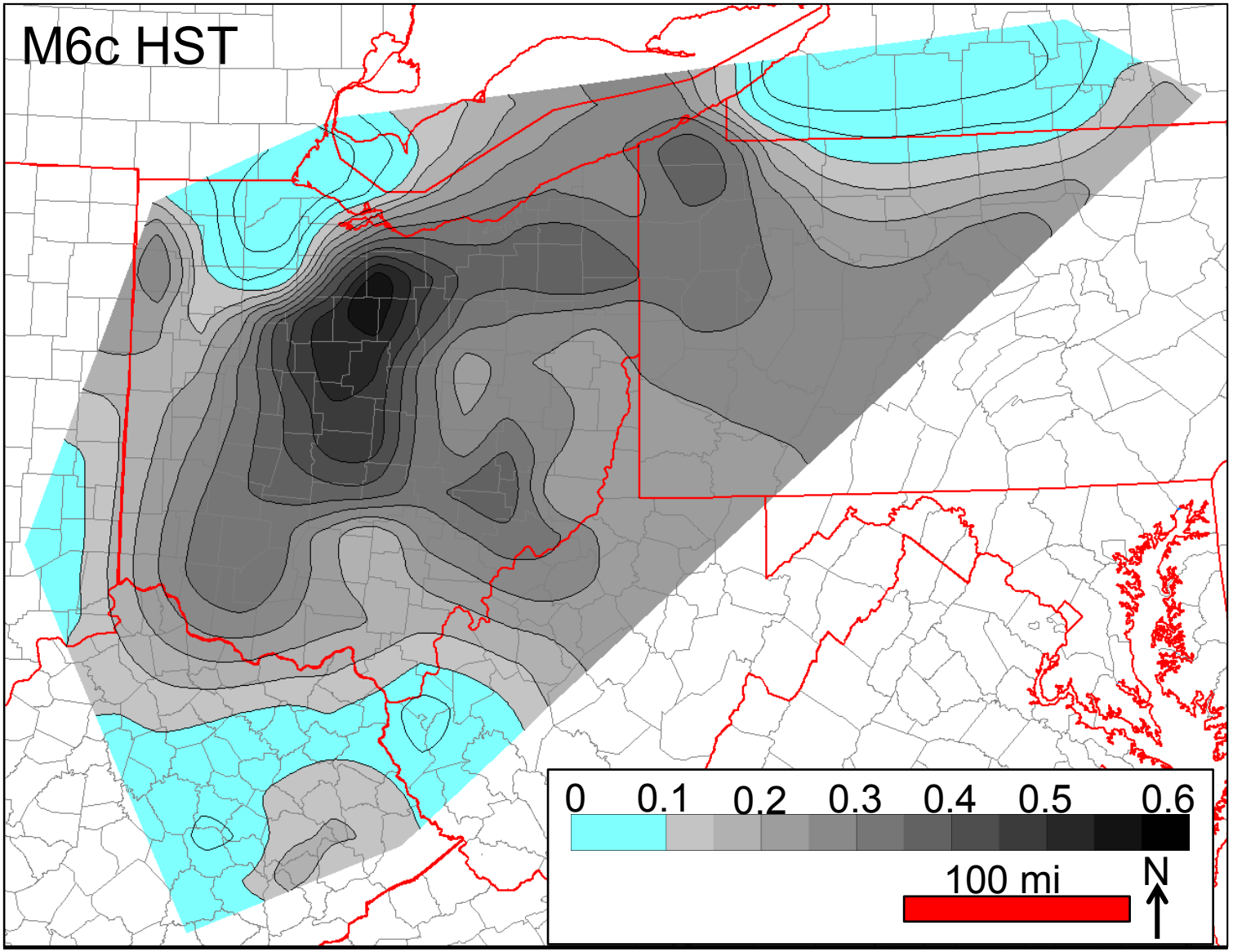


M5-C1 Clay Map Compilation (% Clay)



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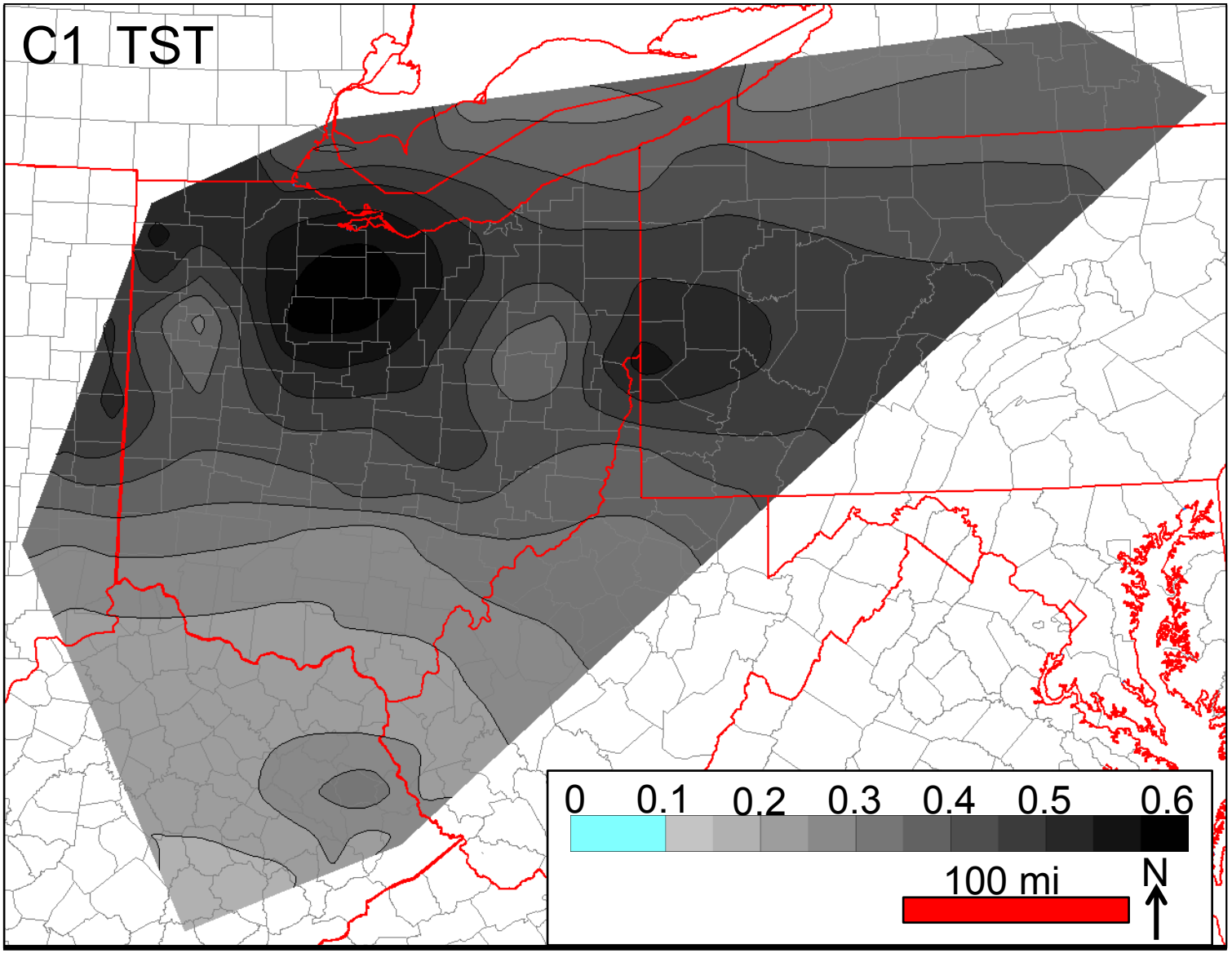


Sequence Mapping Observations

- **Sequences (and systems tracts) reflect general changes in thickness through the M5 and M6 intervals**
  - Show the growth of the CO_3 ramp and platforms
  - Show the infilling of the foreland basin
  - Show the restriction of the basin through time
  - Development of the Sebree Trough

- **Changes in mineralogy between systems tracts and through time**
  - M5 is dominated by carbonate, very little clay
  - M6 TSTs are dominated by higher clay in and out of the trough
  - M6 HSTs are dominated by clay in the trough and CO_3 out of the trough
  - C1 Sequence is clay-dominated

- **Implications for geochemistry….**

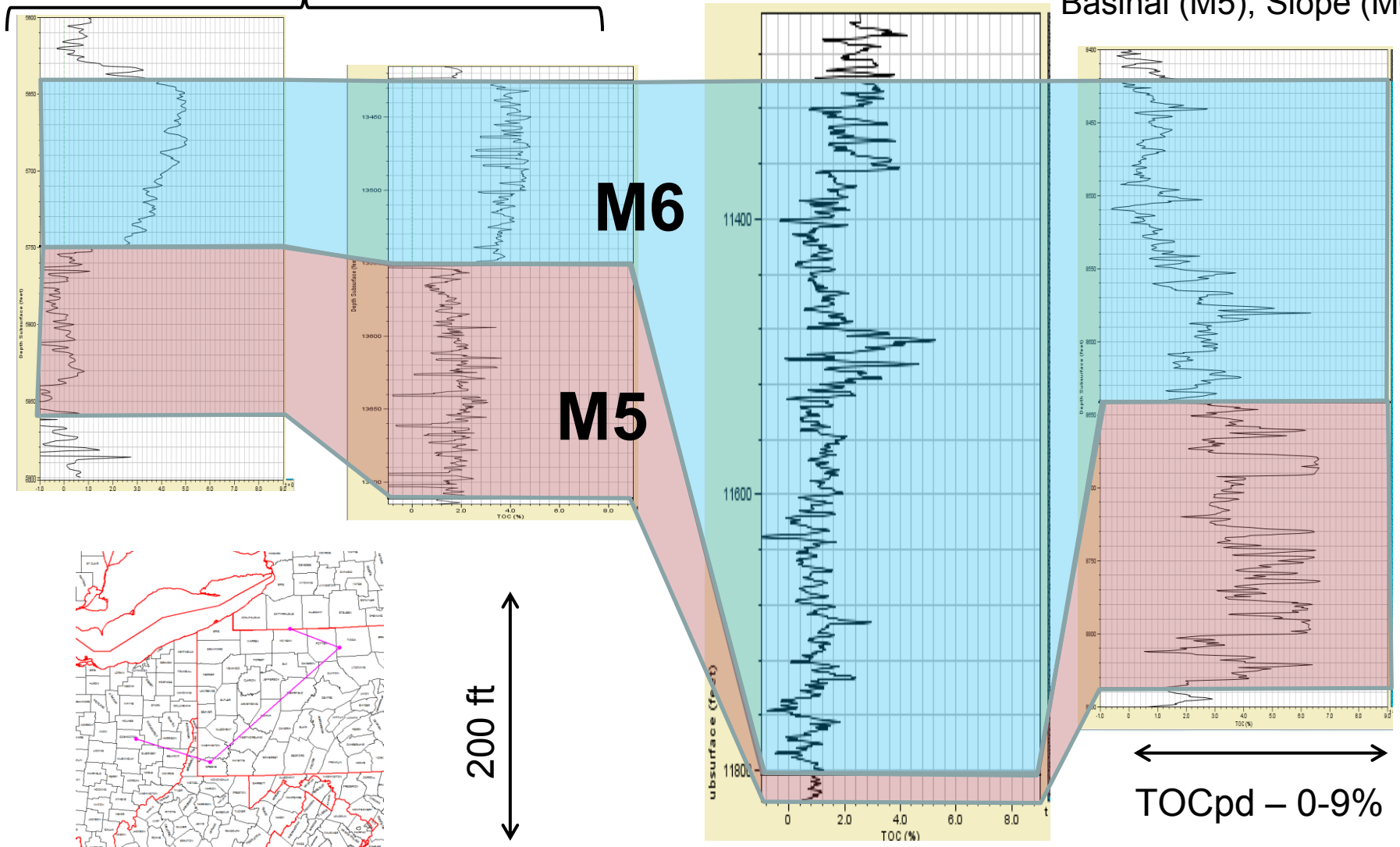
3rd Order Seq / TOCpd Cross-Section

Where energy meets innovation

M5/M6 Basinal, Distal (changes in circulation)

M5/M6 Basinal, Proximal

Basinal (M5), Slope (M6)

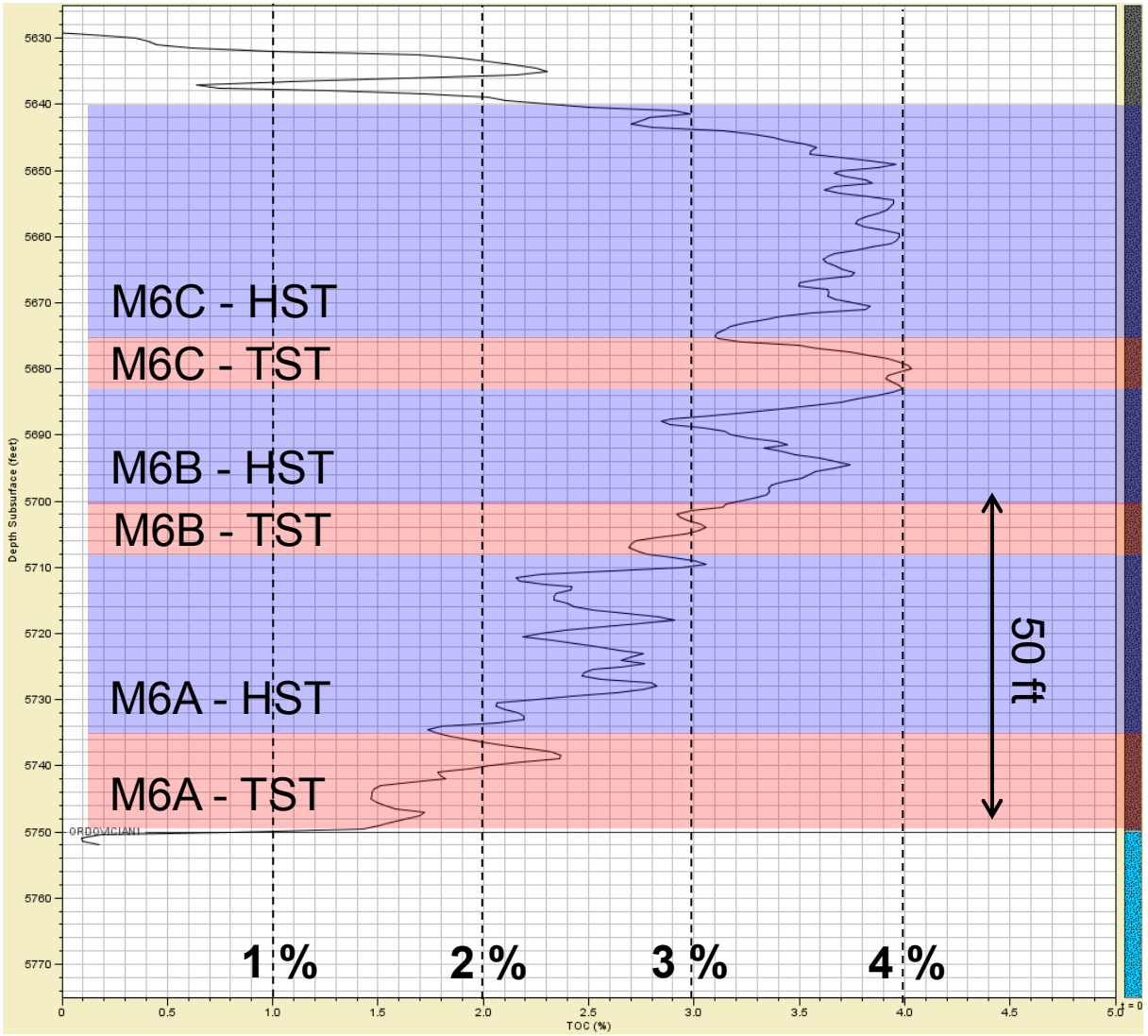


200 ft

TOCpd – 0-9%

4th Order Sequences and TOCpd

- Calculated TOC from a well in Eastern OH
- 4th Order systems tracts shown
- Some correlation to systems tracts (inc. TOC in TSTs)
- Not definitive



Conclusions

- 3rd and 4th Order Sequence Stratigraphic Framework developed for the Mid-Upper Ordovician sequence in the Appalachian Basin
- Petrophysical model calibrated to core data and merged with Sequence Stratigraphic interpretations
- Shows a picture of the development of the basin during Trenton / Point Pleasant / Utica Deposition
- Sequence Stratigraphic ties to geochemical parameters still evolving
- Useful as an exploration tool to evaluate acreage
- Useful as a development tool in targeting and completions design