Far–field Tectonic Controls on Deposition of the Ordovician Utica/Point Pleasant Play, Ohio using Core Logging, Well Logging, and Multi-variate Analysis*

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Abstract

The Ordovician Utica Shale is an extensive and important part of the Appalachian Basin subsurface, providing a source for hydrocarbon reservoirs, acting as an unconventional hydrocarbon reservoir, and of interest as an impermeable cap rock for carbon dioxide sequestration in Cambrian formations. The Utica Shale and adjacent formations (Point Pleasant Formation, Trenton/Lexington Limestones) are a mixed siliciclastic-carbonate system that is mostly in the subsurface in areas of interest within the Appalachian Basin. Most outcrops are located to the east, in the Appalachian fold and thrust belt, and few public cores are available for study from key areas in the basin. Using a combination of core/well logging and multi-variate analysis with GAMLS software, lithofacies based upon mineralogical variations and sedimentology were extrapolated to electrofacies across the state of Ohio. These electrofacies were then mapped to identify controls on deposition during the Upper Ordovician time in Ohio. It typically is assumed that the primary control on regional deposition during this time period was the Taconic tectophase of the Taconian Orogeny; however, Precambrian basement structures appear to have localized influence on deposition also, such as the Waverly Arch, Utica Mountain Fault, and Harlem Fault. Also, the Sebree Trough has previously been reported to end in southwest Ohio, yet electrofacies mapping shows that the dark, calcite-poor shales that infilled the Sebree Trough continue towards northeast Ohio in a possible trough-like feature. These shales may have later timing compared to the Sebree Trough proper. Overall, lithofacies mapping combined with electrofacies mapping indicates that these Upper Ordovician formations are not homogenous rock types deposited across the state (such as layer-cake stratigraphy), but rather vary in mineralogy and thickness both horizontally and vertically across the region due to multiple controls on deposition.

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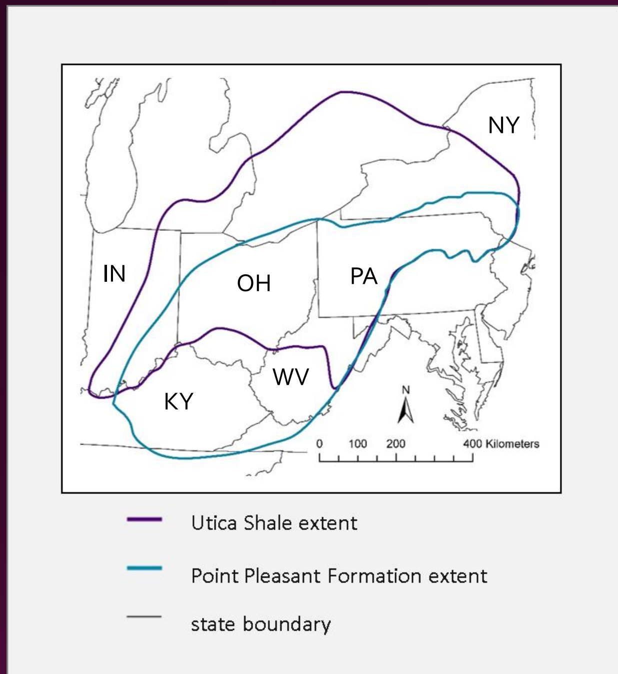
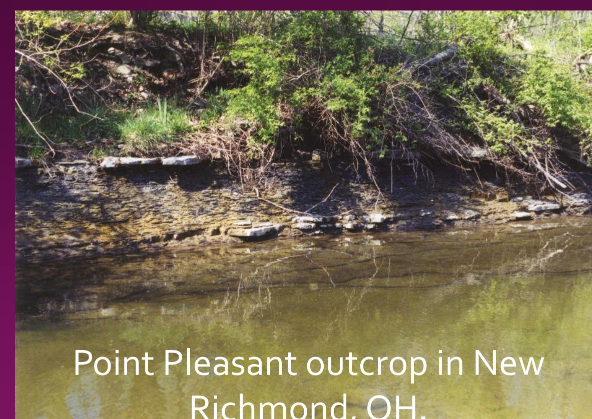
Dr. Julie M. Bloxson
Stephen F. Austin State University

Oct 15th, 2019



The Utica Shale has long been known as a dark, organic rich shale in the Appalachian Basin.

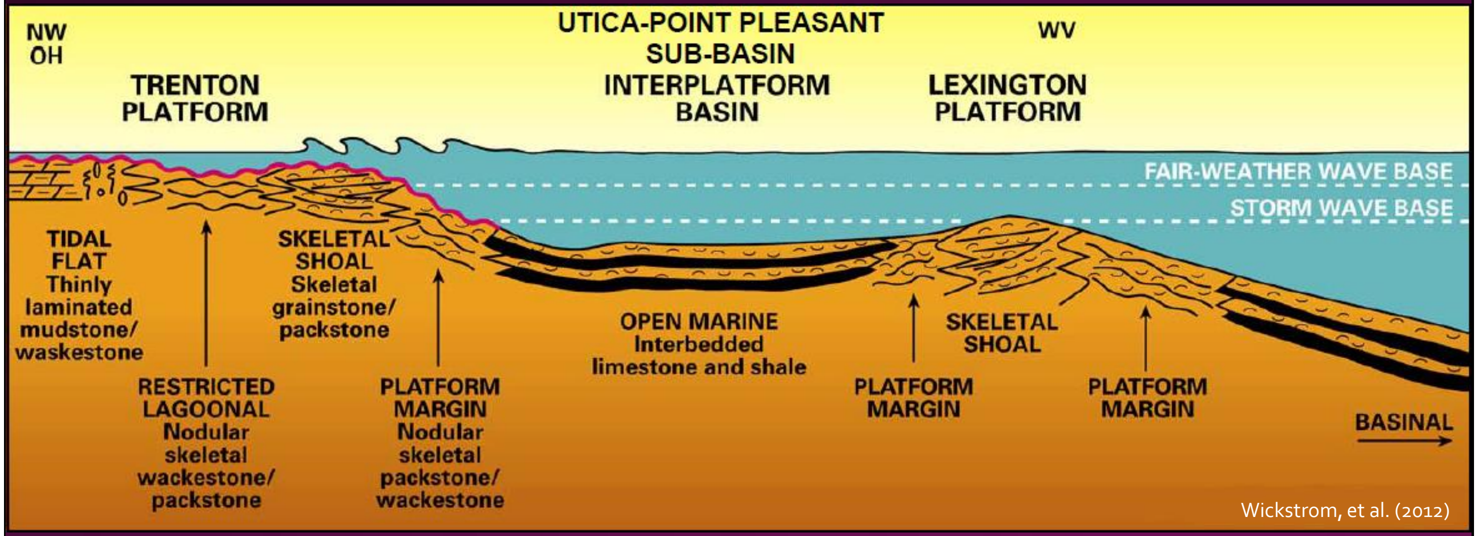
Is it a blanket shale, or are there heterogeneities throughout?


Point Pleasant outcrop in New Richmond, OH.

Schumacher, et al. (2013)

Presenter's notes: What are some of the other influences on deposition, especially because there is evidence further up section of fault reactivation throughout time.

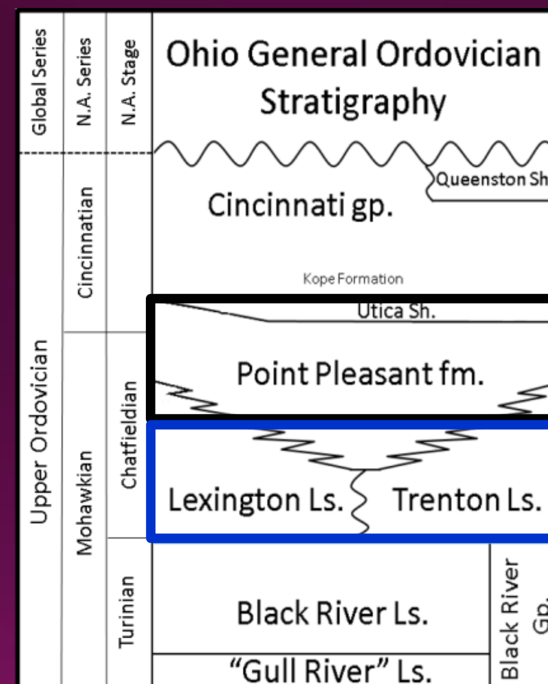
Cores indicate a variety of environments.



Discontinuous layers of deposition, including organic material.

Presenter's notes: When we are looking at cores across the state, there are a variety of environments. We transition from relatively clean Trenton Platform, into a "dark" shale Utica/Point Pleasant sub-basin and finally into the Lexington Platform, where it's a mix of siliciclastics and carbonates.

To assess controls on deposition during this time period, we need to spatially evaluate the distribution of these facies across the state.



Facies Mapping

- Core and well analysis

Two time intervals were identified:

- one with mostly carbonate deposition (Lexington and Trenton)
- one with mostly shale deposition (Point Pleasant and Utica Shale)

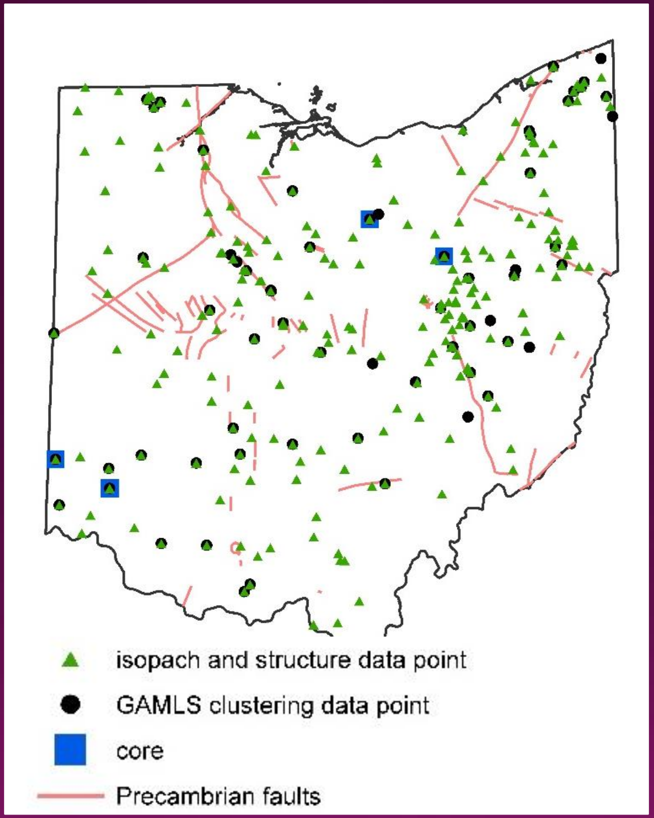
Presenter's notes: To get an idea on controls on deposition during this time period, we need to spatially assess the distribution of these facies we have identified across the state. (*Presenter's notes continued on next slide.)*

(*Presenter's notes continued from previous slide.)*
We could make a map for a specific point in time, but these formations do not have adequate age control to identify time horizons. Rather, I looked at two time intervals: one where there was mostly carbonate deposition occurring throughout the region, and one where there was mostly clay deposition. The carbonate platforms, the Trenton and Lexington limestones, were grouped together, and then the Utica and Point Pleasant formations were grouped together. The dominant facies identified were then mapped across the state to assess controls on deposition.

We took each individual well spot, and calculated the percent of each facies grouping at those locations, and contoured the percentages.

Methods

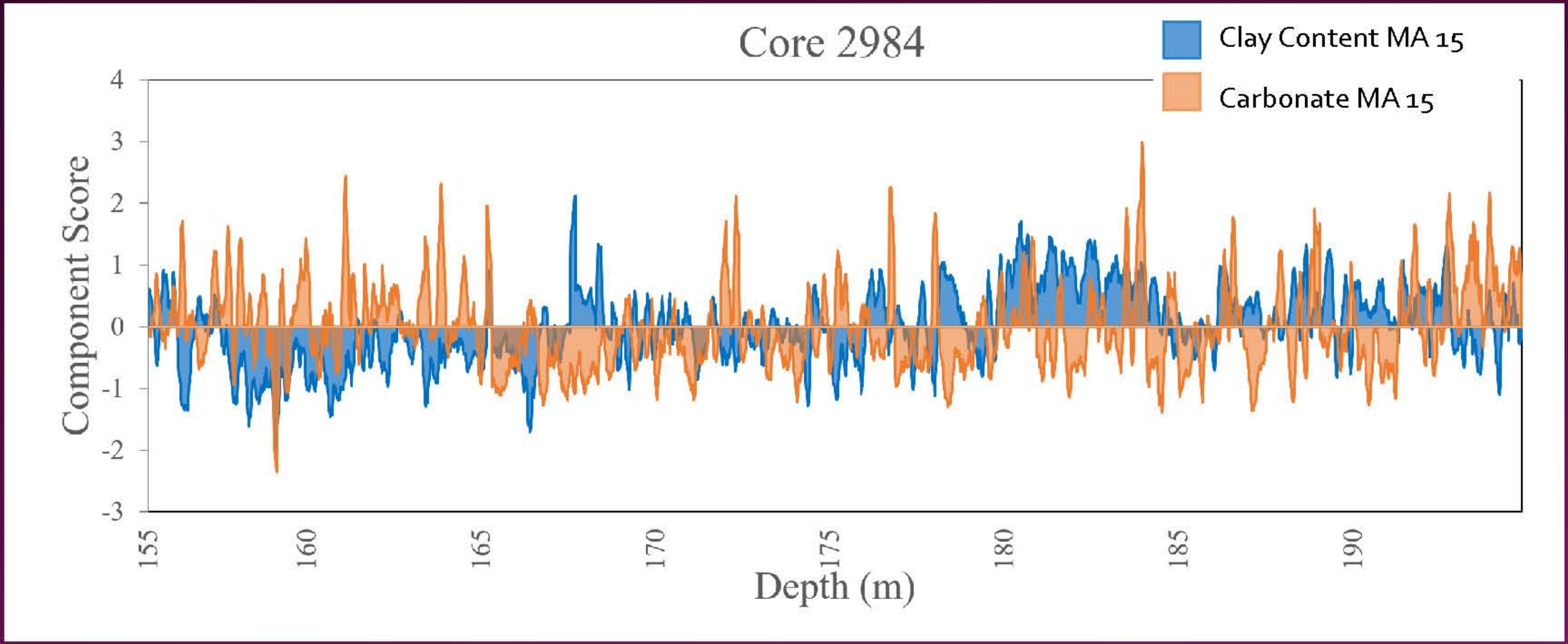
- Core Log Analysis- *lithofacies*
  - Four cores with measured mineralogy
- Well Log Analysis- *electrofacies*
  - 62 wells for lithology cluster analysis via GAMLS- five well log tools
  - 268 wells for correlation (thickness and structure)- one or two well log tools



Presenter's notes: 268 well total that provided either tops and thicknesses for each location, enough well log data to provide GAMLS clustering, or core data.

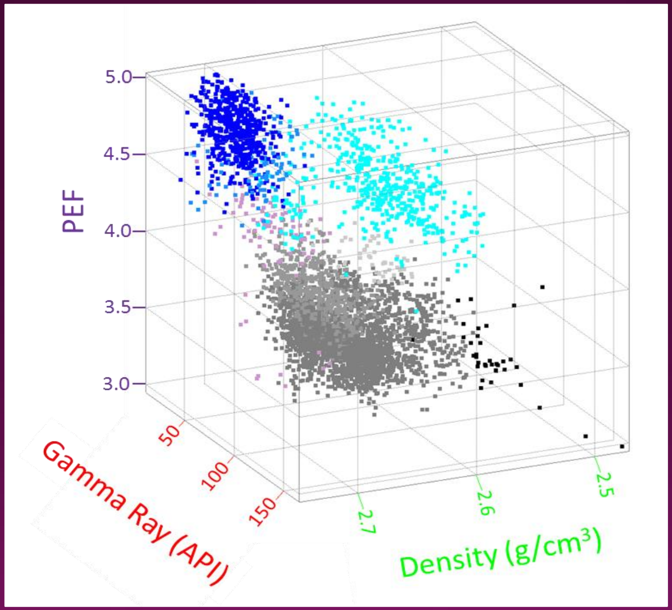
Core Analysis - Reflectance Spectroscopy

- Clays and carbonates are inversely related.
- XRD indicates that other mineral constituents are relatively constant.



Automated Well Log Analysis

- GAMLS- Geological Analysis via Maximum Likelihood (pattern recognition software using MLANS).
- Used multi-dimensional cross plots to identify facies within the shales and limestones.



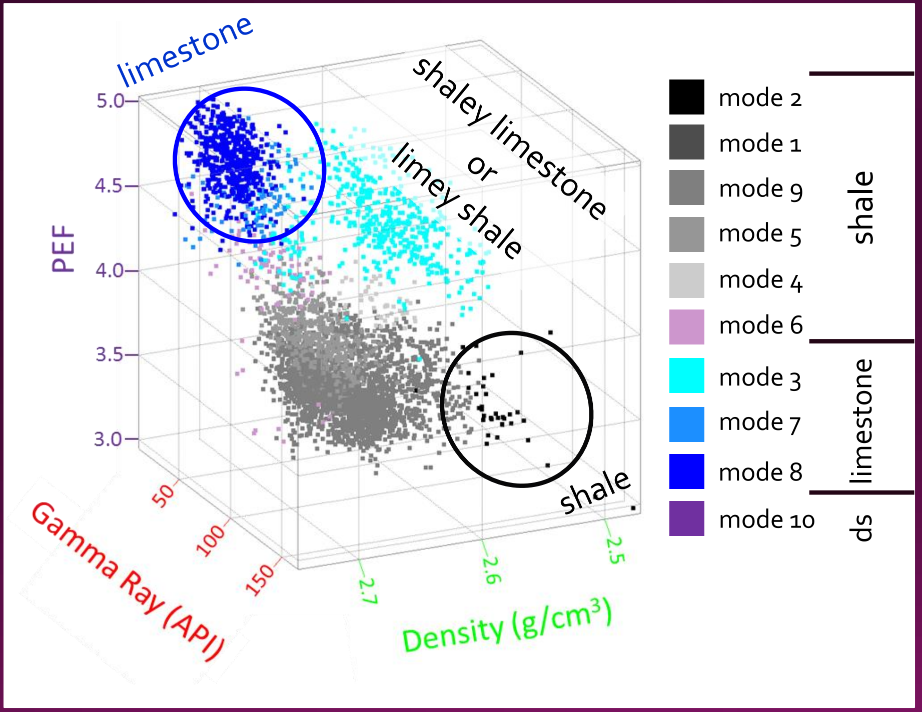
Presenter's notes: One way to automate this process, particularly with large datasets, is to "cluster" the data, or identify similarities, then identifying those sets as electrofacies.

Using known lithology values, it can identify rock types.

GAMLS Utica/PP
Lithology Identification

Ten different rock types were identified.

Six Shales
Three Limestones
One Dolostone



*data from two wells

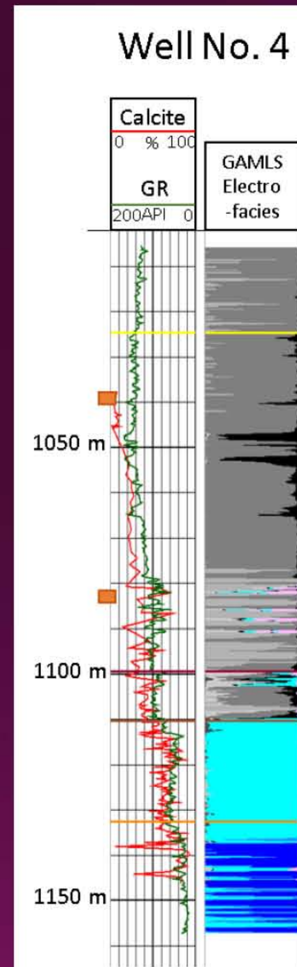
Presenter's notes: But really, rather than having "shales" and "limestones", which we do have these end-members, much of the data falls in between these ideal values.

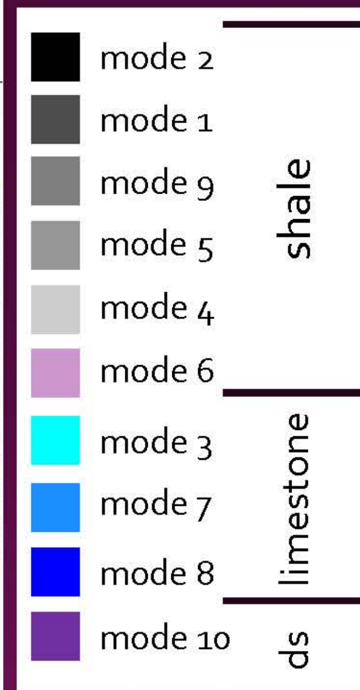
We can call these shaly limestones or limey shales. And give a sense of increased amount of carbonate from the bottom right corner to the top left corner, but really, I want to try to quantitatively assess calcite content within the identified rock types.

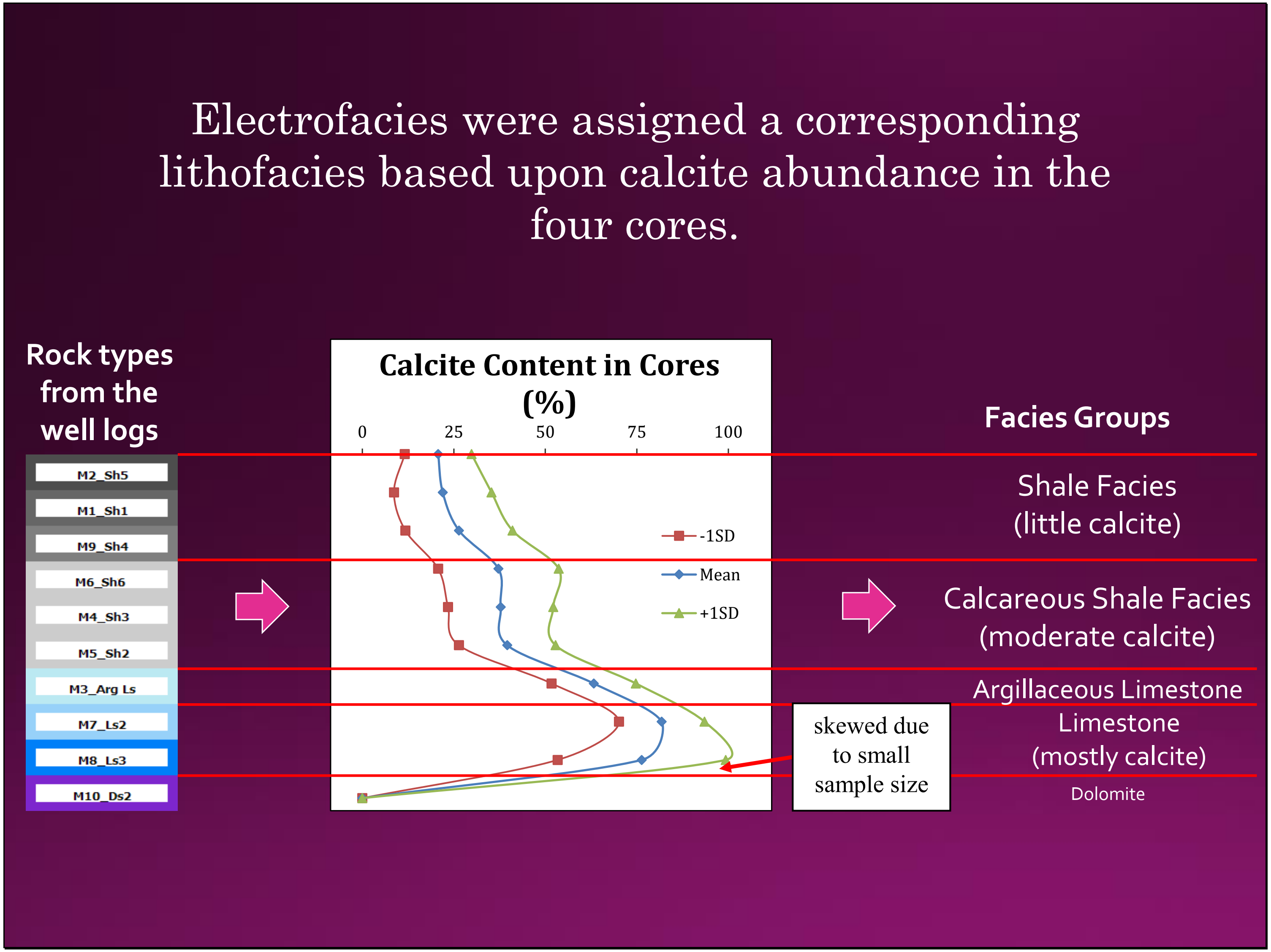
Calibration of Well Log Analysis

Previously measured mineralogy and core descriptions to verify well log analysis.

Correlate calcite content to GAMLS rock type groupings to help constrain calcite content across the state.







Presenter's notes: So using this measured calcite content for four cores, the GAMLS assigned rock types can be regrouped into facies groups based upon average calcite content within each GAMLS rock type. (*Presenter's notes continued on next slide*.)

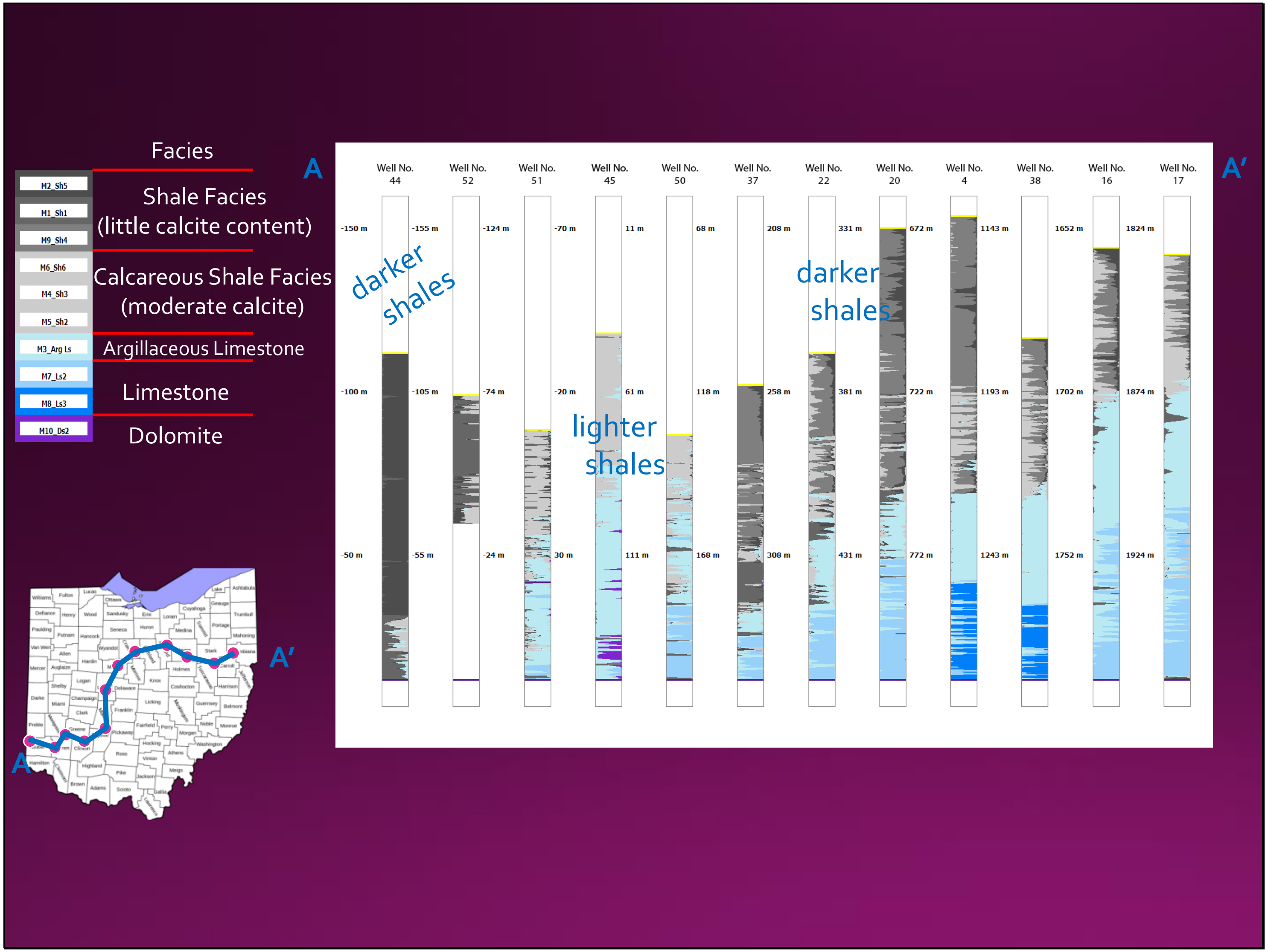
(*Presenter's notes continued from previous slide*.)

This is also where I'm going to inject some other information that we just don't have time to thoroughly discuss, but is important to some of our later interpretations, and why I'm ignoring certain minerals in this slide. XRD, both what I've done and by others, shows that the mineralogy is primarily clay minerals, carbonates, and other siliciclastics, but the other siliciclastics remains fairly constant, while the carbonates and clay minerals inversely vary throughout these formations.

So the shale facies group has the least amount of calcite, and has been color coded to be the darkest set of shales. The average values are around 20% calcite.
Calcareous shales can be grouped together, as an increase in calcite content, and their average values are generally around 40%.
We have an argillaceous limestone, which eventually transitions into the limestones, relatively pure calcite content.

Finally, we have a dolostone, which there are no samples for in these cores. Dolostone can be grouped into the limestones, because it is a clean carbonate, with little to no clay content, and is diagenetic in origin. It represents still the same type of depositional environment as the limestone.

This information can then be plotted down well for multiple wells across the state to assess how facies change in a cross section.



Presenter's notes: X-section using GAMLS facies analysis.

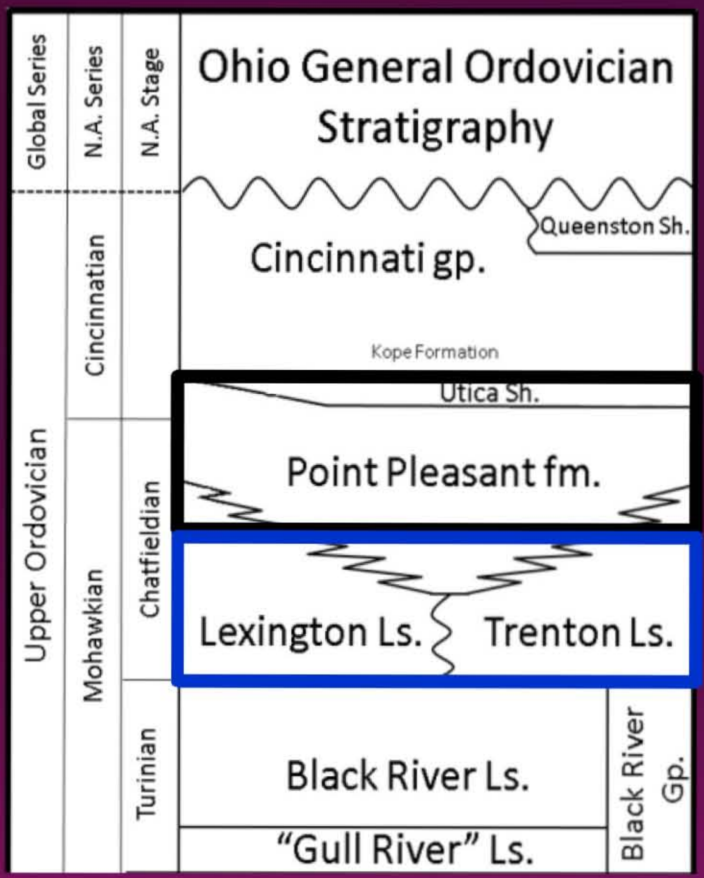
We see that there are changes both laterally and vertically. *(Presenter's notes continued on next slide.)*

(*Presenter's notes continued from previous slide.)*

Instead of creating cross sections, or analyzing individual wells, we want to see areas that have high calcite concentrations and low calcite concentrations within the shale, and also the limestone. So we can take which ever facies occupies the majority of the formation, and map them out for each formation.

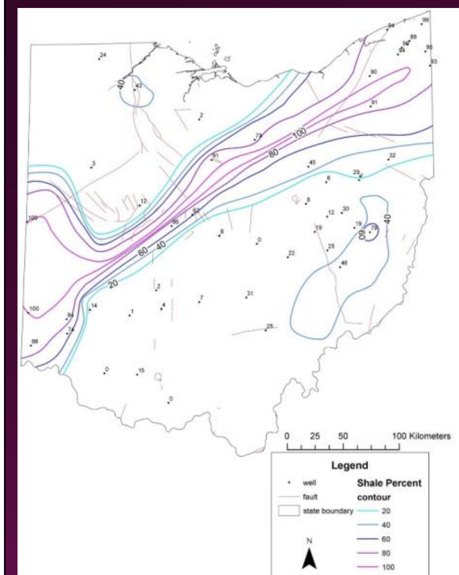
Facies Maps

- Using the GAMLS electrofacies, relative abundance of each were calculated.
- Distribution of each facies for each set of formations was mapped.

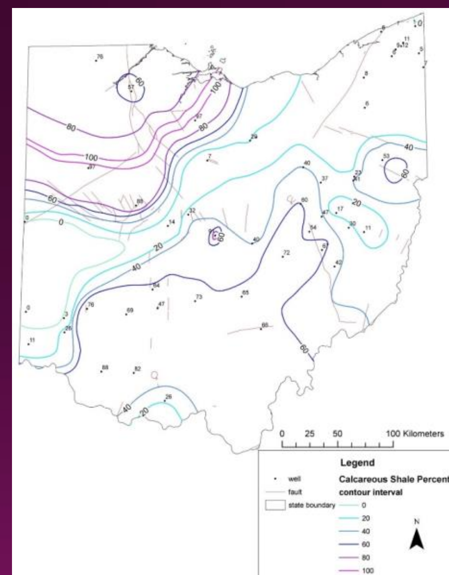


Abundance of Facies Groups in the Point Pleasant and Utica Shale

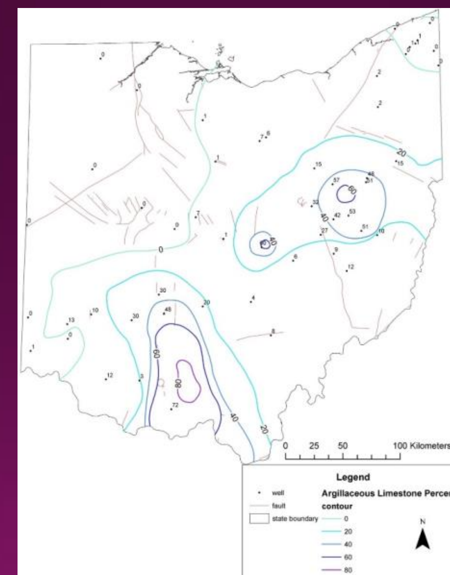
Dark Shale Facies
little to no calcite



Calcareous Shale Facies
moderate calcite



Argillaceous Limestone Facies
abundant calcite



Presenter's notes: Sense of individual facies for Individual wells for individual time periods, towards a dominant lithology across the state.

Figure is showing the percent of dark shale within the Point Pleasant and Utica. (*Presenter's notes continued on next slide*.)

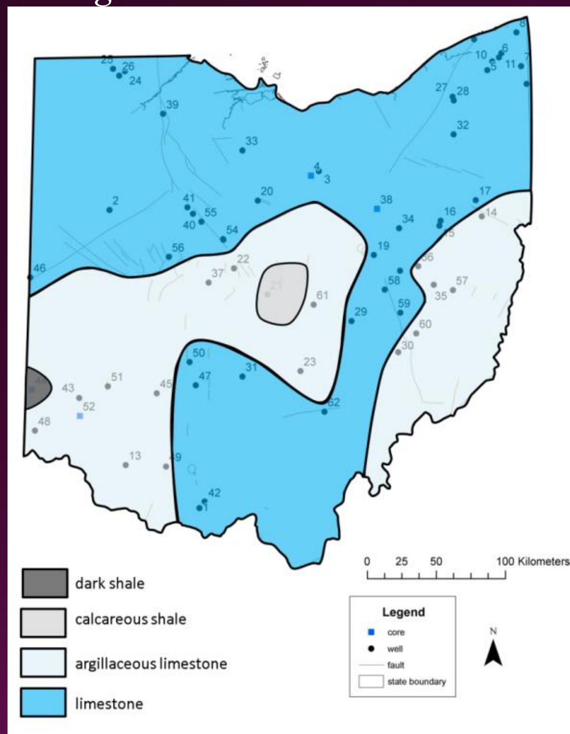
(*Presenter's notes continued from previous slide*.)

Look at the Utica Shale and Point Pleasant interval. This figure is showing the percent of formation occupied by the dark shale facies group (little to no calcite content).

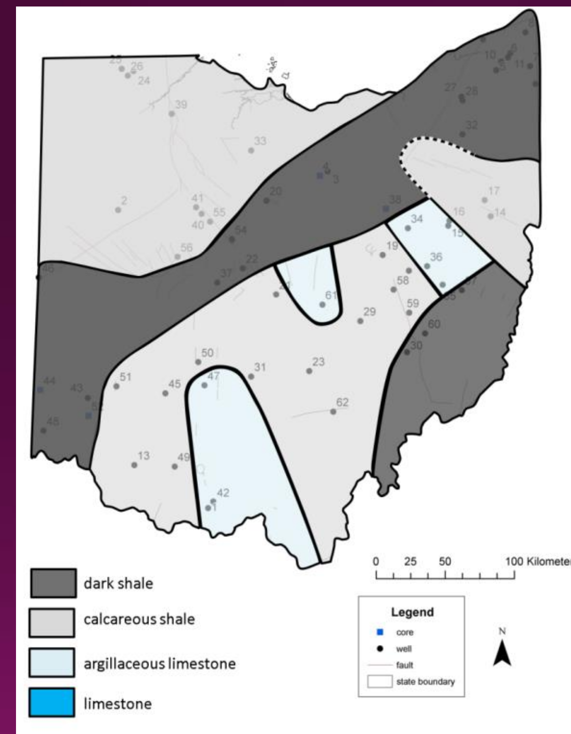
Several prominent features standout, we need to assess relationships of facies to each other also. So I took the most abundant facies for each location within each "time period" identified, and then mapped those.

These are somewhat difficult to assess, so I mapped the most abundant facies with each of the time periods.

Major facies distribution of the Lexington and Trenton Limestones



Major facies distribution of the Utica Shale and Point Pleasant Formation



Presenter's notes: When we map the bulk facies, i.e., what comprises the majority of the facies at each location, we can start to see trends in the data. (*Presenter's notes continued on next slide.)*

(*Presenter's notes continued from previous slide.)*

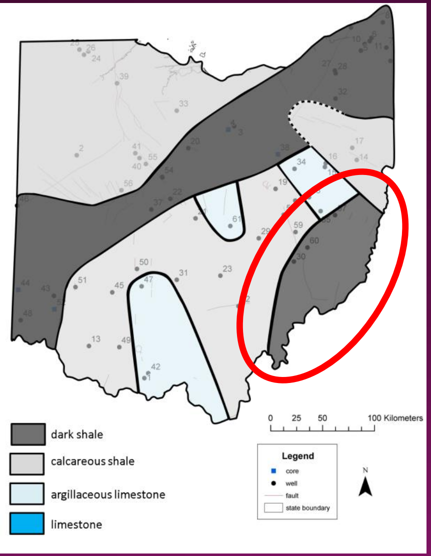
"less shaly"
No pure Limestone
Pure shales

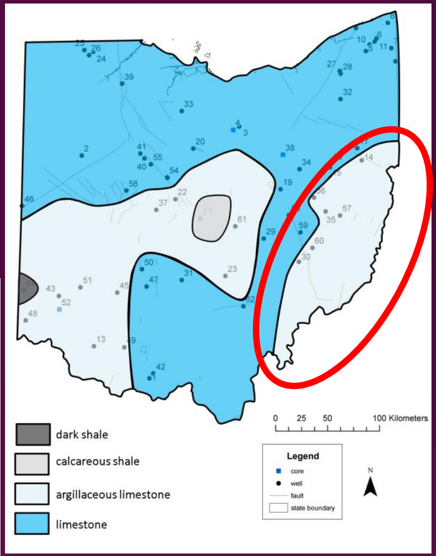
Big picture of where shale is located, clean carbonates. Then we can assess specific locations, and interpreted what they are telling us on paleogeographic features during the time period.

Paleogeographic Controls on Facies Deposition

Appalachian Basin

As we have mountains building towards the east, the increased load on the crust is pushing down the area directly adjacent to the mountains (NY, PA, Eastern OH), causing deepening and thickening of the sediments.



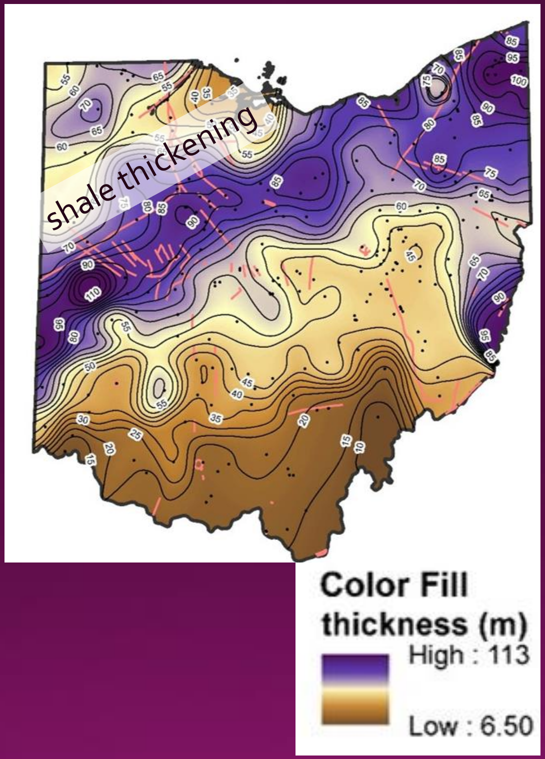


Presenter's notes: Think about dynamics on carbonate deposition and clay deposition. Oceanographic controls- depths vs carbonate deposition. Sources vs sinks. Topographic highs and lows.

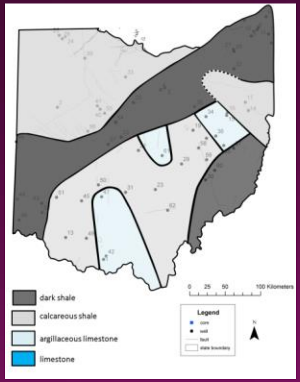
Sebree Trough

An extension of the Sebree Trough into Ohio.

Bathymetric low during the Ordovician that filled with shales while the carbonates deposited on either side.

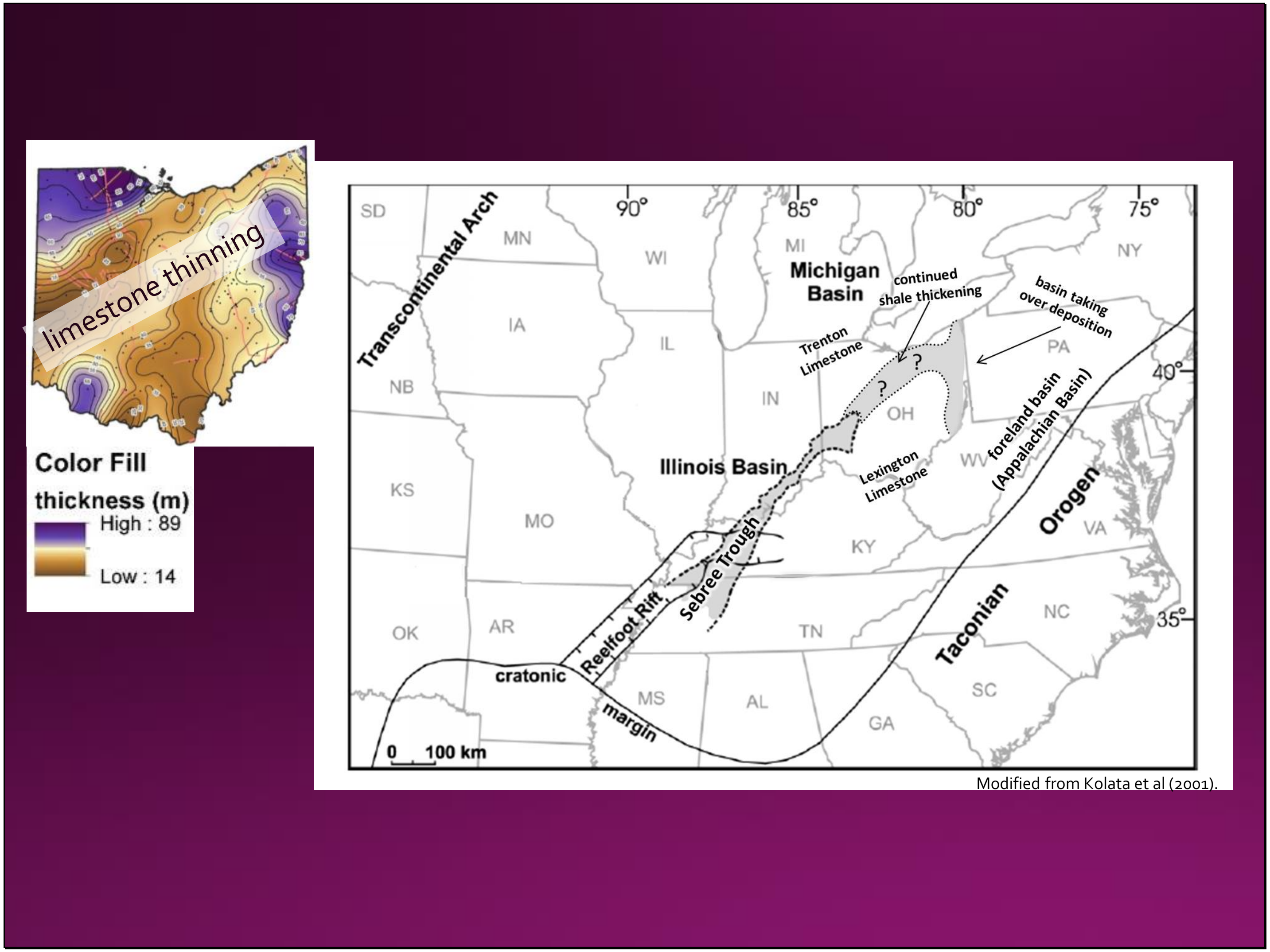


Calcite was not transported into this area. Thinning of the Limestone Platform underneath. Both suggest an extension of the trough.



Presenter's notes: This linear dark shale is also an area of shale thickening.

The Sebree Trough was a linear bathymetric low that developed during the Ordovician, most likely due to upwelling from the failed Reelfoot Rift towards the south. The upwelling caused a lack of carbonate deposition, and increased amounts of clay deposition along this linear feature.

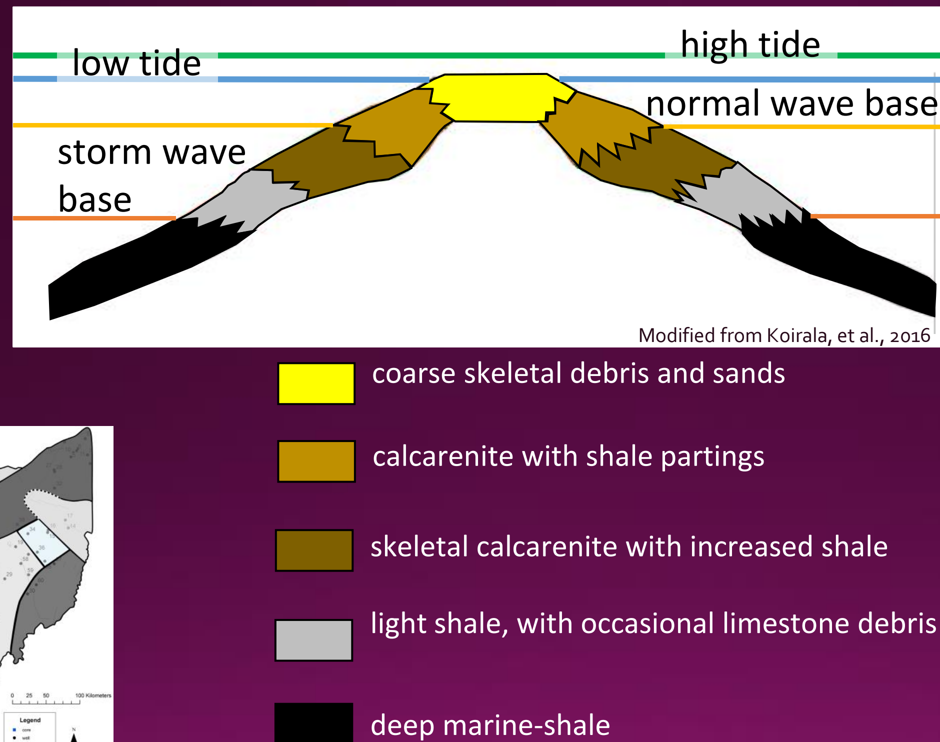


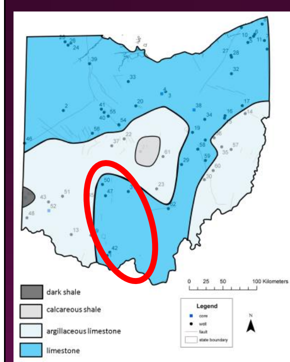
Presenter's notes: Typically the Sebree Trough is taken into southwestern Ohio. It has been previously mapped by a lack of carbonate platform underneath the shales. While there is still carbonate deposition at this location, it appears that mechanisms affecting carbonate and clay deposition towards the south may have eventually migrated towards the north, affecting deposition in Ohio.

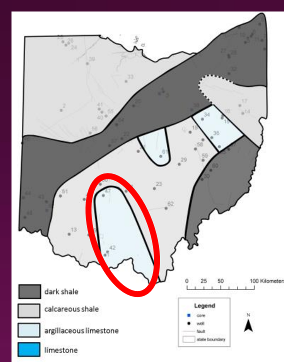
Waverly Arch

Precambrian structural high that was thought to be gone by the beginning of the Ordovician.

Affected transport and deposition of calcite and siliciclastics.





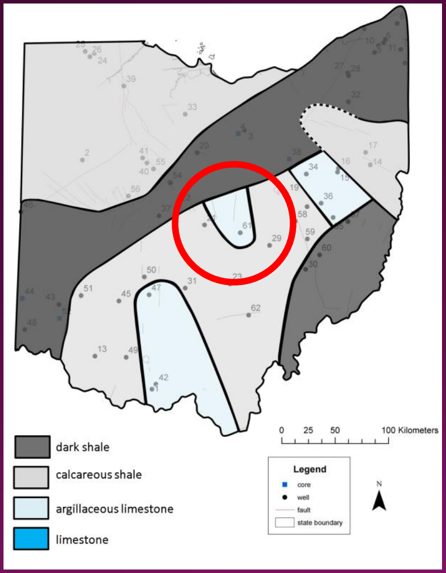


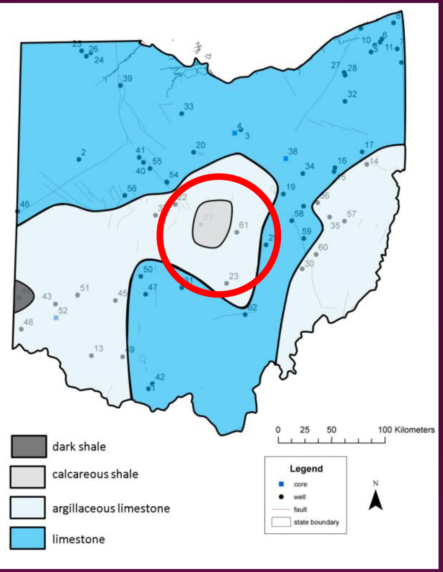
Presenter's notes: And when looking at structure maps of the area, there is no indication that it existed during this time period. But when mapping the facies, there was still some topographic relief affecting deposition.

Migrating peripheral bulge, due to loading on mountain belts towards the east.

Precambrian Utica Mountain and Harlem Faults

Reactivated to create topographic high's and low's.





Overall, deposition within the Utica/Point Pleasant is influenced by Precambrian topographic high's and low's.

- High's create an area of preferential carbonate deposition (ex., Waverly Arch).
- Low's create an area of either carbonate dissolution, non-deposition, or preferential clay deposition.

Presenter's notes: So in conclusion…

But, the Precambrian still had influence on deposition throughout this time period, even if the structure maps are unable to determine relief.

Furthermore

- The Sebree Trough does extend somewhat into Ohio based upon facies and isopach maps, but we still need to know whether shale deposition is because of decreased influx of carbonate, dissolution, or increased deposition of clay.
- Knowing the controls and specific locations of facies deposition will allow for more efficient and better prediction of resources, whether for extraction, caprock potential, or CO_2 adsorption.

Presenter's notes:

Overview of facies distribution:
Evidence of Reactivation of Precambrian faults.
Evidence of influence from the Waverly Arch, which was eroded during the Knox.
We have ideas of where carbonate and clay vary spatially, relative to known paleogeographic features, and have implication for resource extraction.


Thank you
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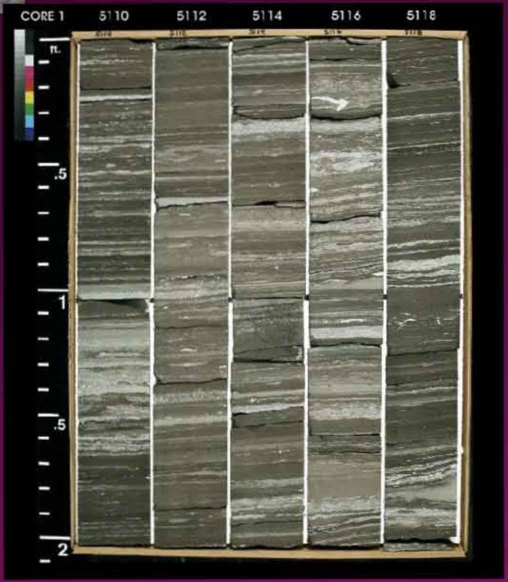
Upper portion of the Lexington Limestone outside Lexington, KY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