Evolution of the Southwestern Midcontinent Basin During the Middle Pennsylvanian: Evidence From Sequence Stratigraphy, Core and XRF in Southeastern Colorado*

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Abstract

Understanding the interplay of regional tectonic setting, basin geometry, and facies relationships is critical to characterizing the petroleum systems of a basin. This is a challenge for the southwestern Midcontinent Basin due to the lack of outcrops of equivalent lithostratigraphy and facies encountered in the subsurface and the dearth of subsurface studies for this broad region. In order to characterize the stratigraphic relationships and basin architecture of this petroleum-rich area, our study focuses on the Atokan and Desmoinesian stages (Atoka, Cherokee, and Marmaton formations) of the Middle Pennsylvanian. We utilize and integrate subsurface data including well logs, core data, X-ray fluorescence data, and formation image logs to support our sequence stratigraphic interpretation and a spatially and temporally complex facies model that encompasses southeastern Colorado to central Kansas. Our results reveal a dynamic character to the southwestern Midcontinent Basin. During the Atokan Stage, the basin edge was characterized by interbedded carbonaceous shale, coal, and limestone with facies suggesting a lagoonal margin periodically dominated by cyclothemic marine flooding events. Trace elements suggest a strongly restricted basin within an overall marine transgression trend. The basin morphology is interpreted as a sedimentary wedge, rapidly thinning to the east towards the basin center. During the subsequent Desmoinesian Stage, this region was characterized by interbedded carbonaceous shale and limestone, dominantly controlled by large-scale glacio-eustastic cyclothems in an open marine setting. Depositional environments range from intertidal platform, tidal flats, and shoals to deep, subtidal platform. In contrast to the Atokan Stage, trace elements suggest a weakly restrictive basin. Carbonate buildups, shoals, and paleosols are possibly coincident with an activated flexural forebulge and sediment baffle within the basin but peripheral to the basin center and its sediment-starved stratigraphic section. Our data and analysis support a model of dramatic glacio-eustatic transgression-regression cycles within an overall marine transgression from Atokan through Desmoinesian time. Our observations have implications for purported superestuarine circulation, the degree of Midcontinent basin restriction, and patterns of thinned vs thickened stratigraphic sections, all of which are important to historic and emerging petroleum systems of the region.

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Evolution of the southwestern Mid-Continent Basin during the Middle Pennsylvanian: Evidence from sequence stratigraphy, core, and XRF in southeastern Colorado

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AAPG ACE, Denver, CO
May 31 – June 3, 2015

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NATURAL RESOURCES

Mid-Continent Basin during Desmoinesian (Middle Penn)

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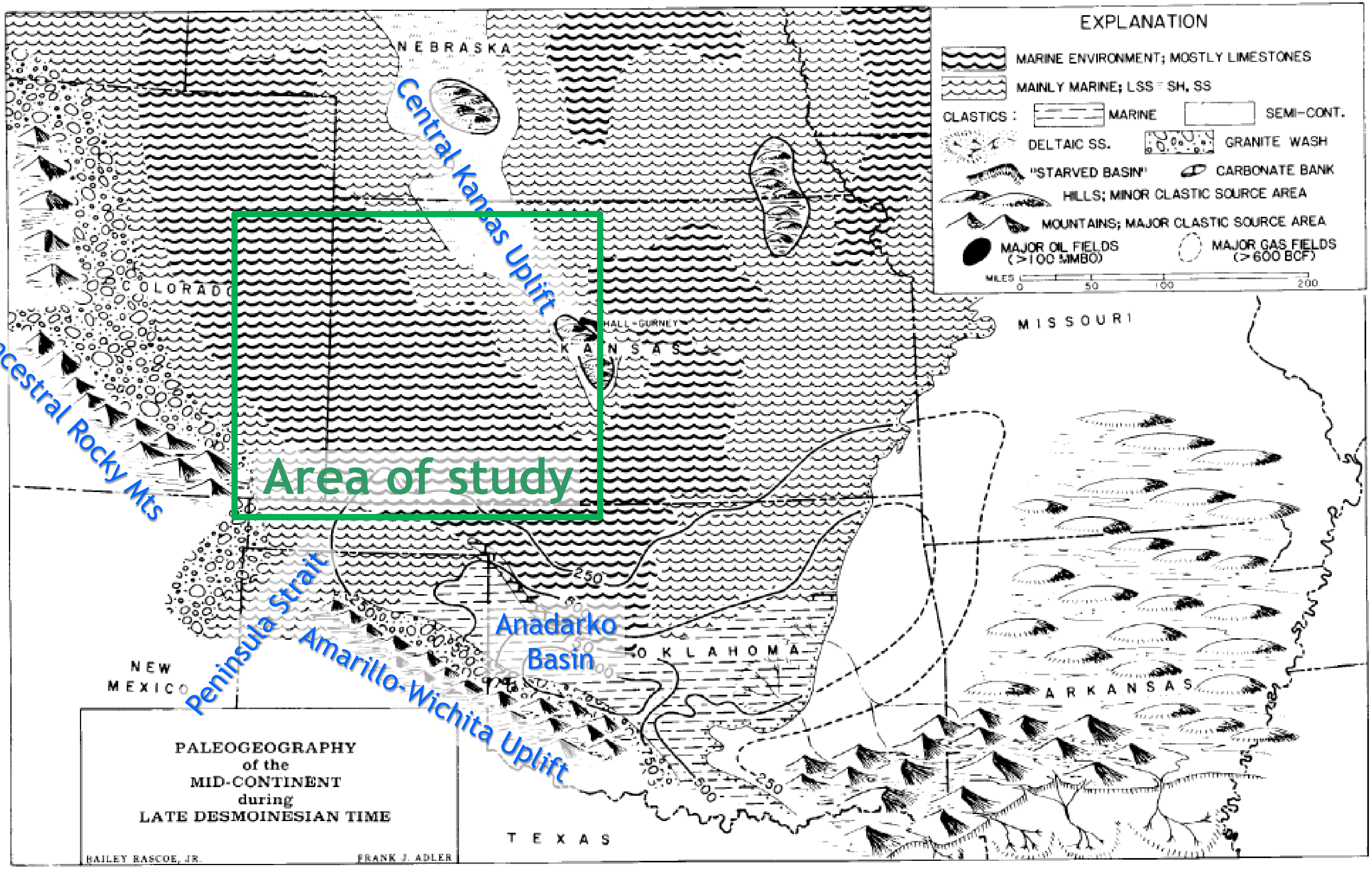
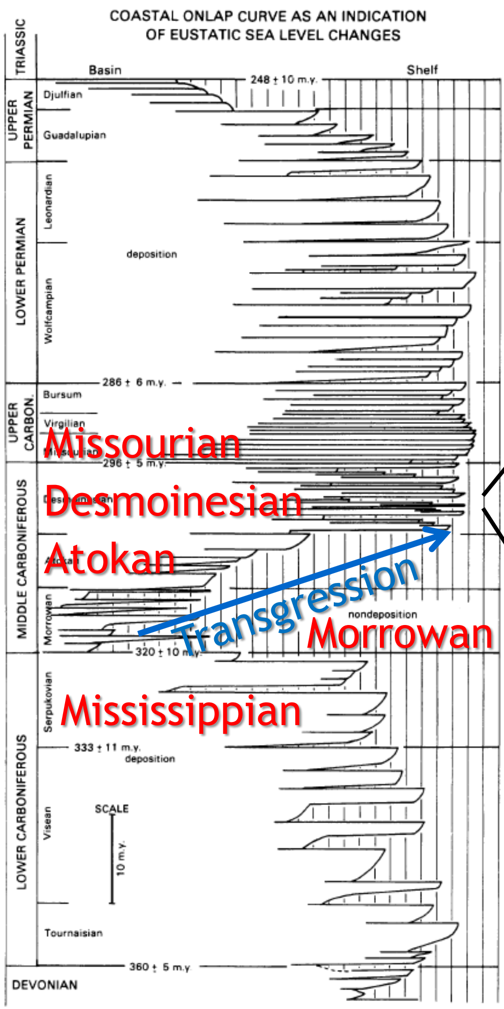


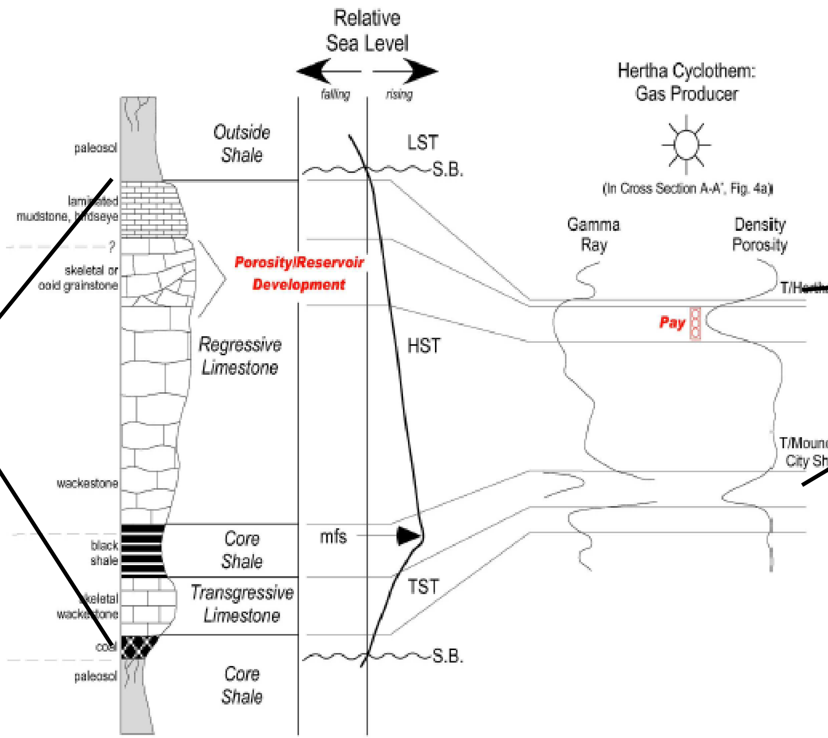
Modified from Roscoe and Adler, 1983

Pennsylvanian Cyclothems in Kansas



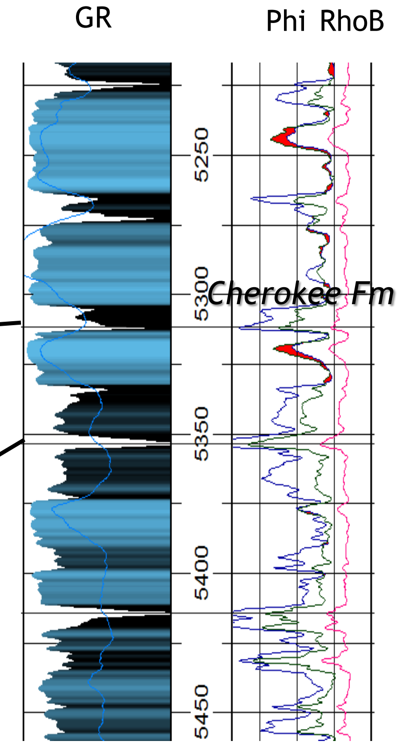
after Ross and Ross, 1988

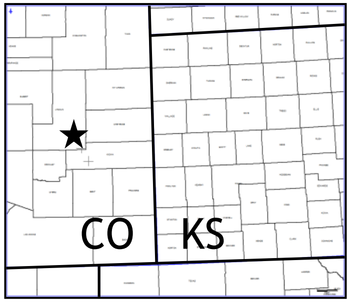
Kansas-Type Major Cyclothem & Log



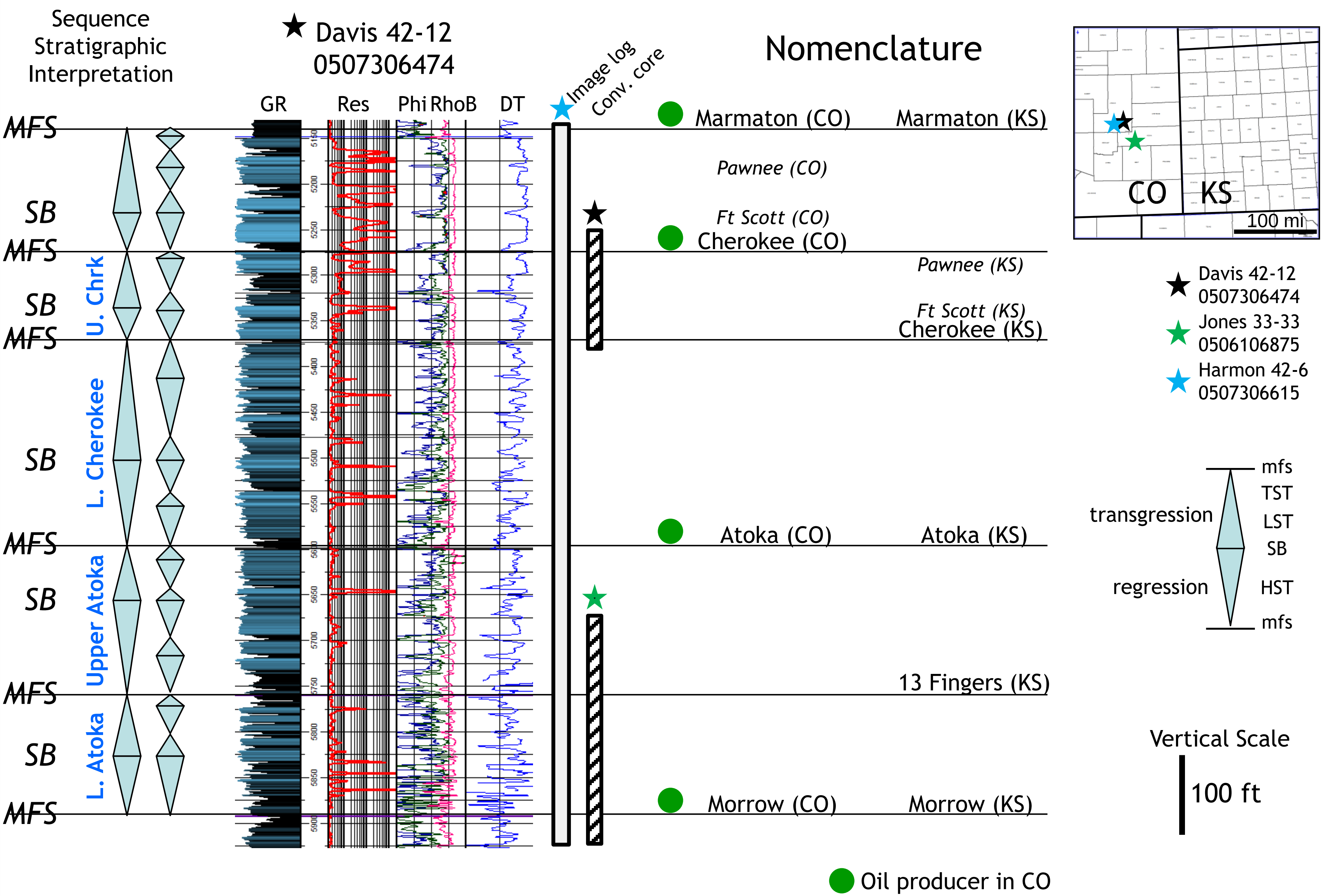
Wilhite et al., 2005 (after Heckel, 1994; Feldman et al., 2005)

★ Harmon 42-6
0507306621
Lincoln Co, CO

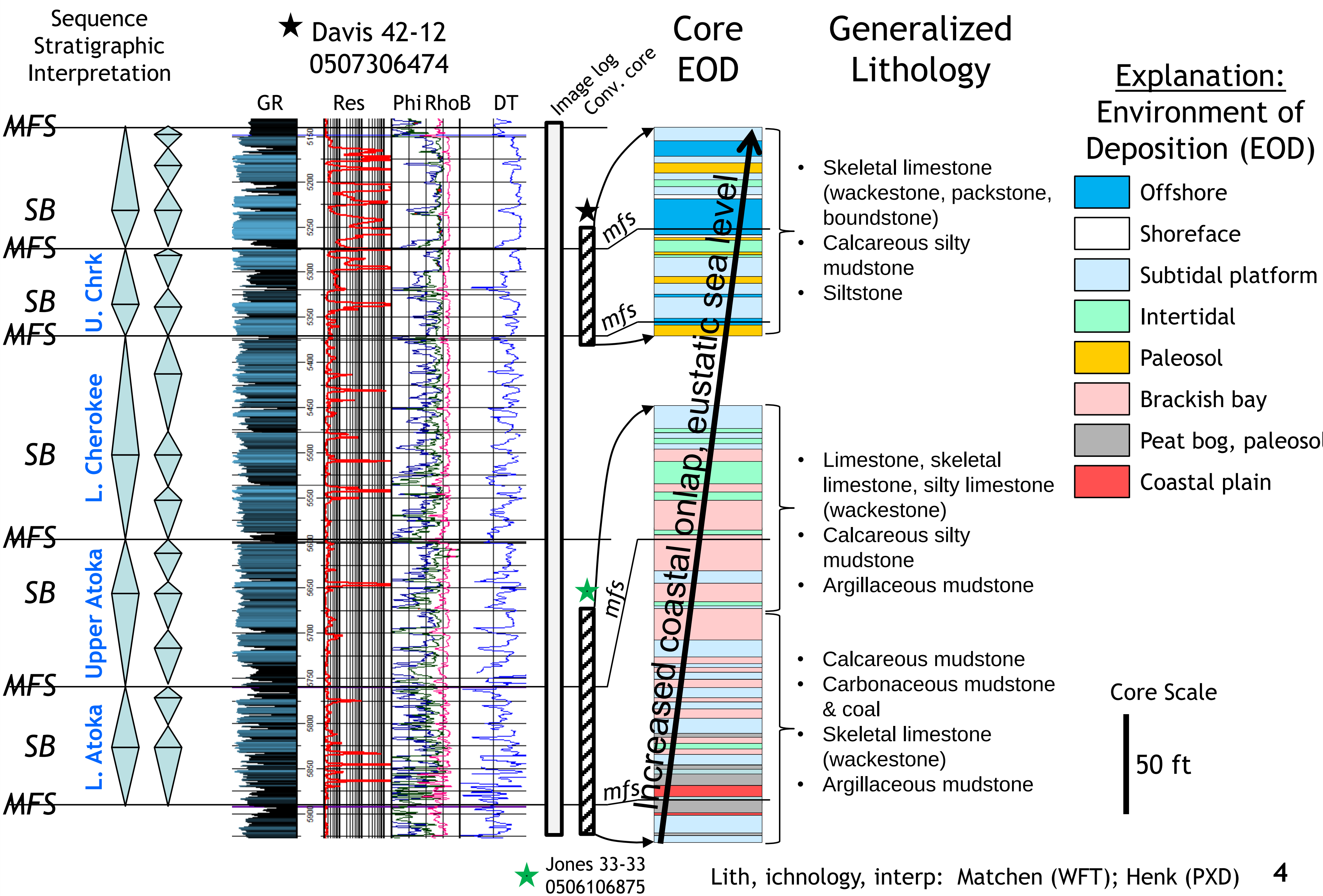




Type Log, Sequence Stratigraphy, Nomenclature

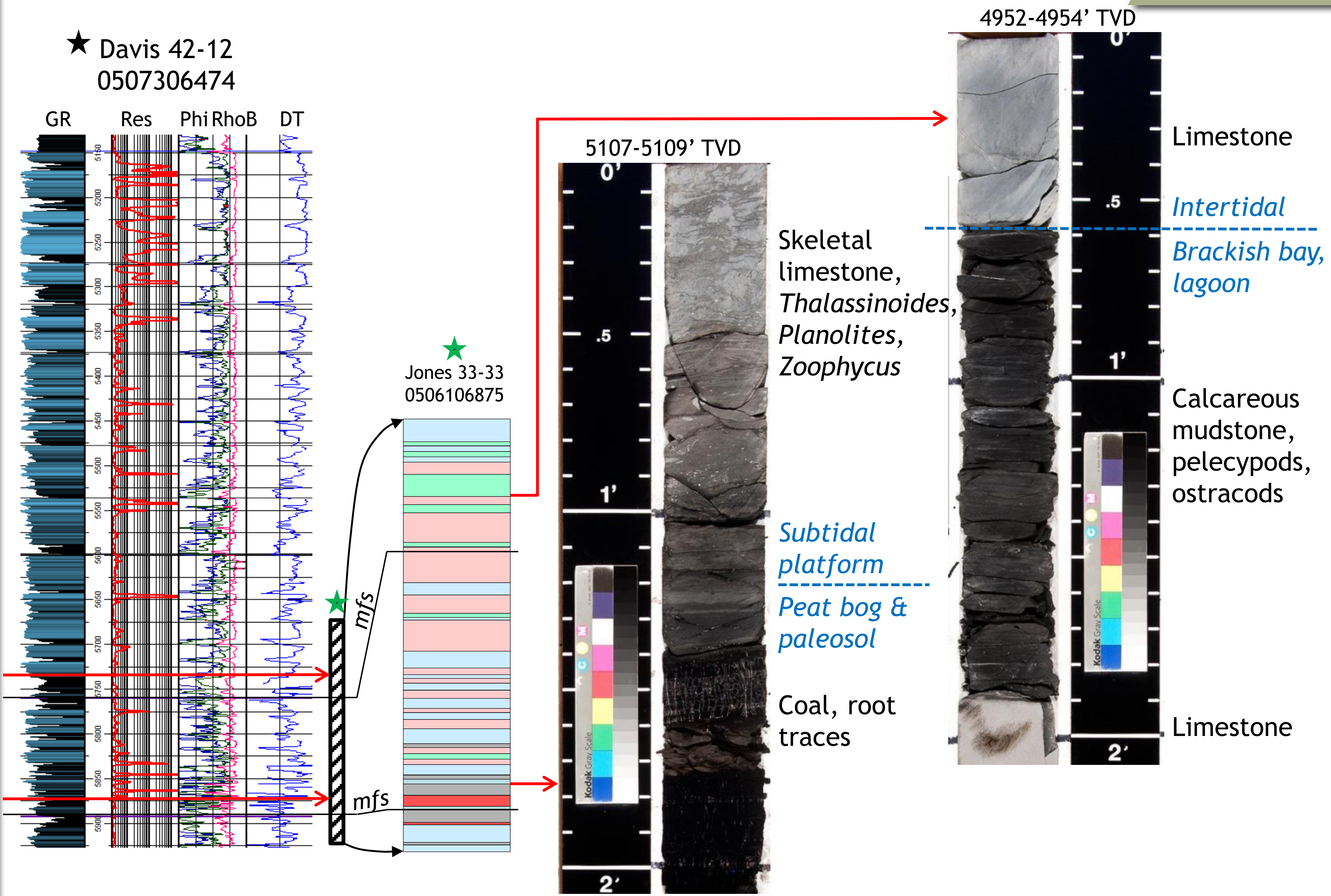


Core Descriptions and Interpretation



Lith, ichnology, interp: Matchen (WFT); Henk (PXD)

Lower Atoka Core



Upper Cherokee Core (Cyclothem)

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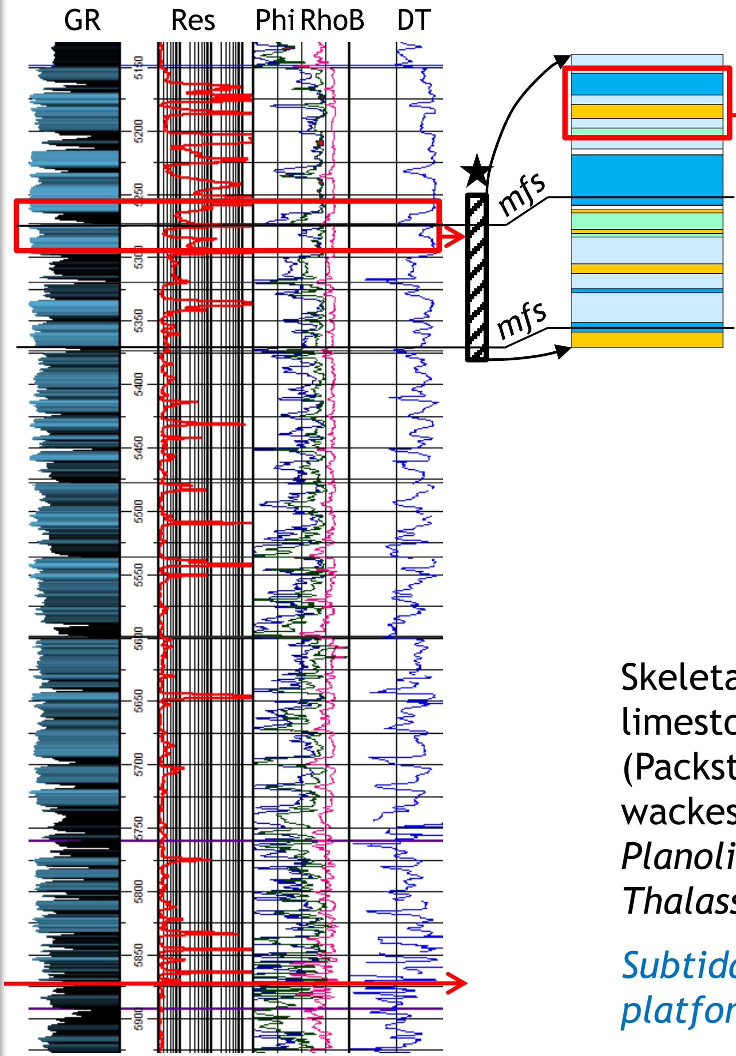
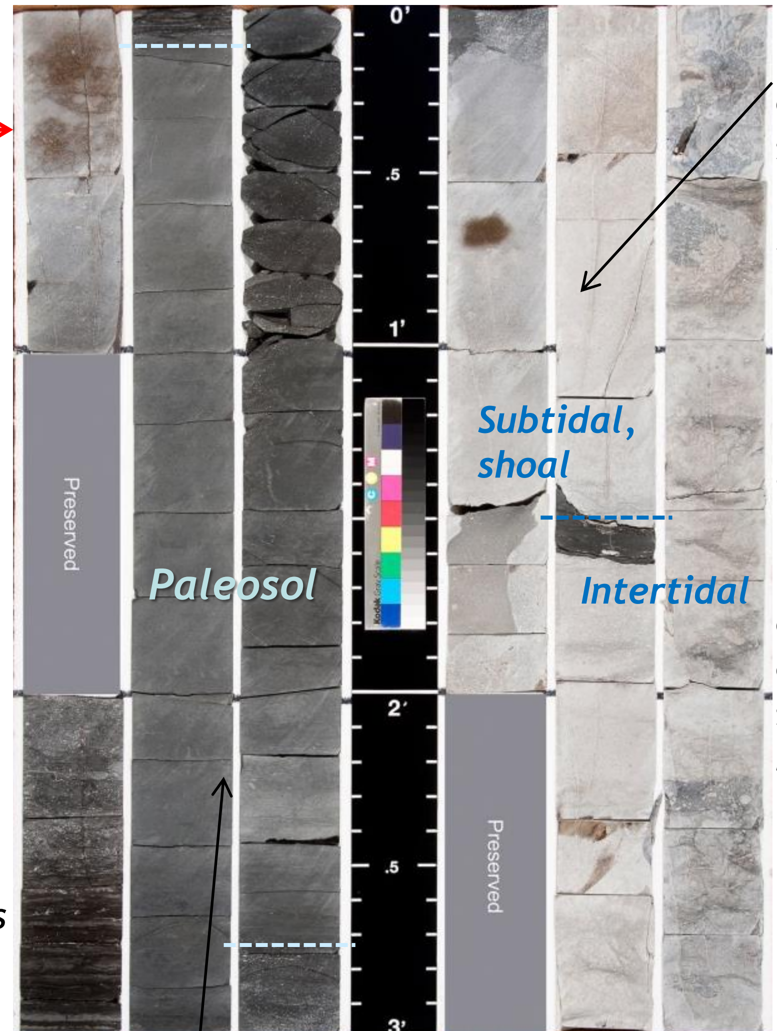
★ Davis 42-12
0507306474



5278-5296’ TVD



Skeletal limestone (Packstone), calcareous sandstone, burrows, *Rosselia*, *Scolicia*

Skeletal limestone (wackestone), chaotic fabric, exposure surfaces, *Planolites*, *Thalassinoides*

Skeletal limestone (Packstone - wackestone), *Planolites*, *Thalassinoides*

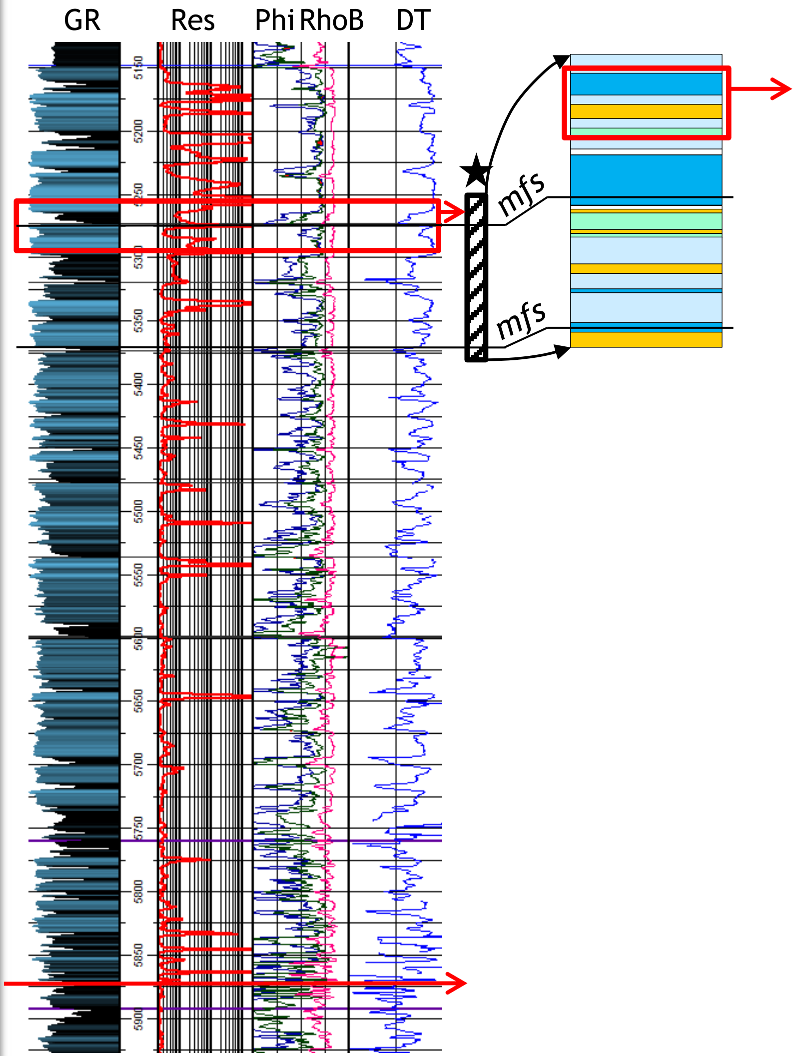
Subtidal platform

Siltstone, root traces

Upper Cherokee Core (Cyclothem)

PIONEER NATURAL RESOURCES

★ Davis 42-12
0507306474

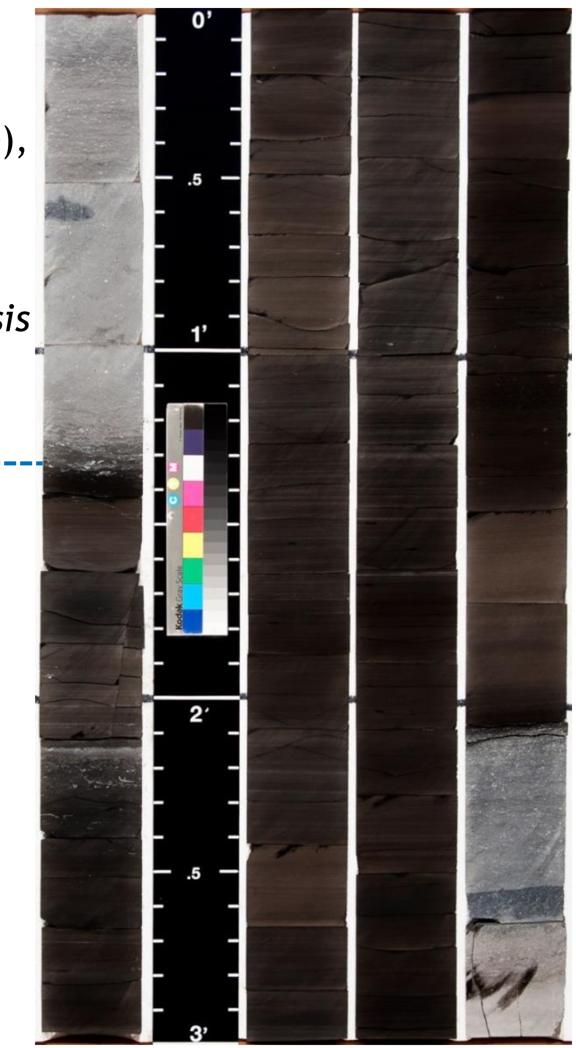


Skeletal limestone (wackestone), pelecypods, burrows, *Planolites*, *Helminthopsis*

Subtidal platform

Offshore

5266-5278’ TVD



Organic-rich mudstone, calcareous, argillaceous, siliceous, *planolites*

Offshore

Subtidal platform

Silicified hardground?

Lower Cherokee in Image Log (Harmon 42-6)

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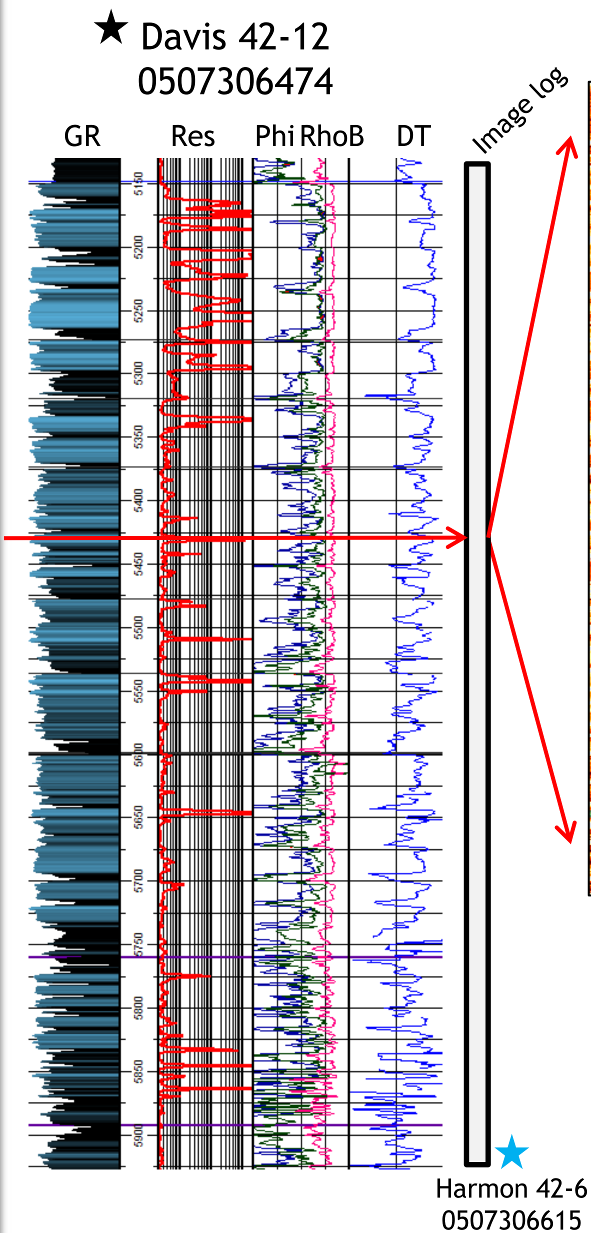
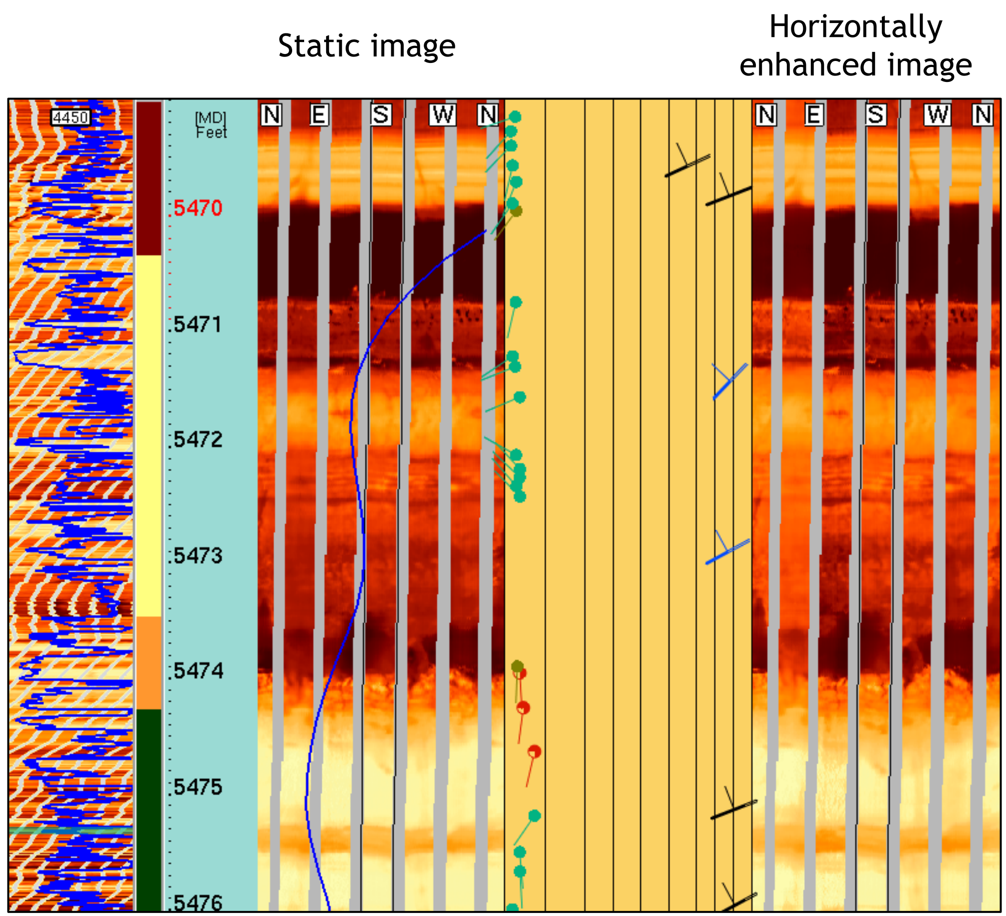
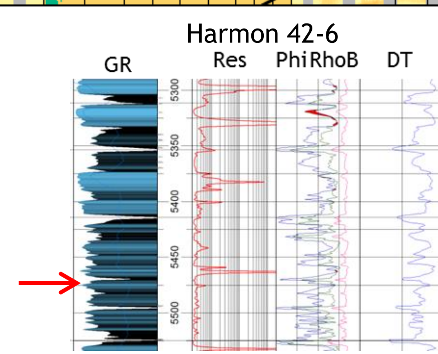
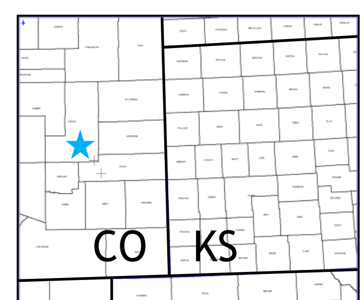




Paleosol feature at 5474-5474.75’
Possible root traces





Lower Cherokee in Image Log (Harmon 42-6)

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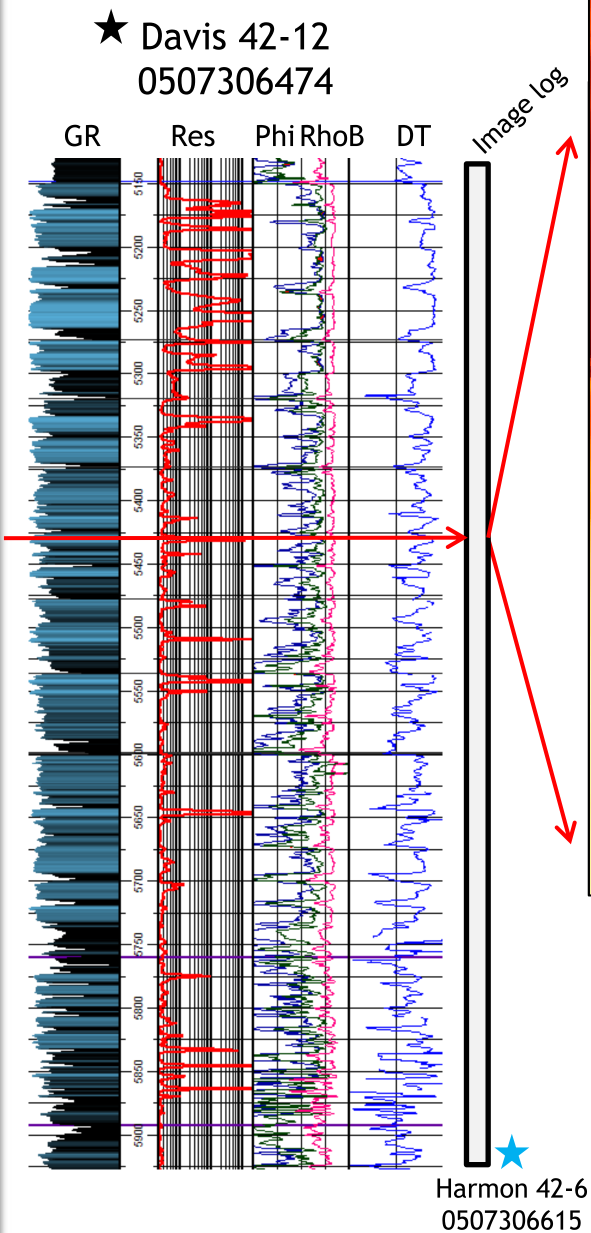
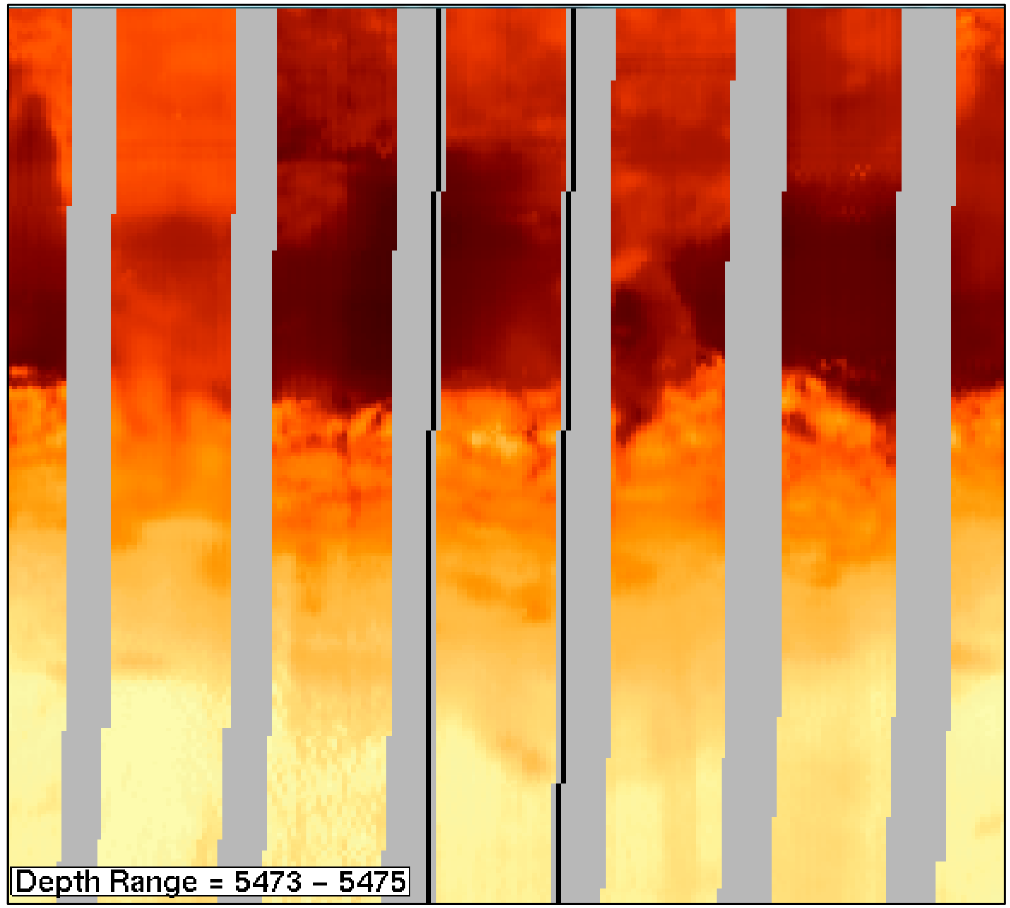
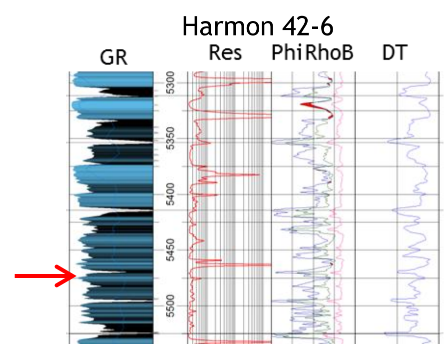
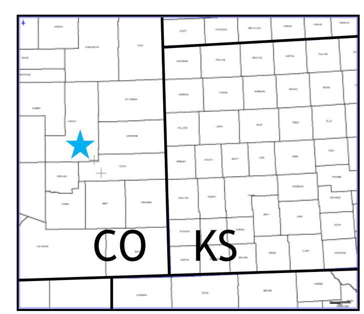




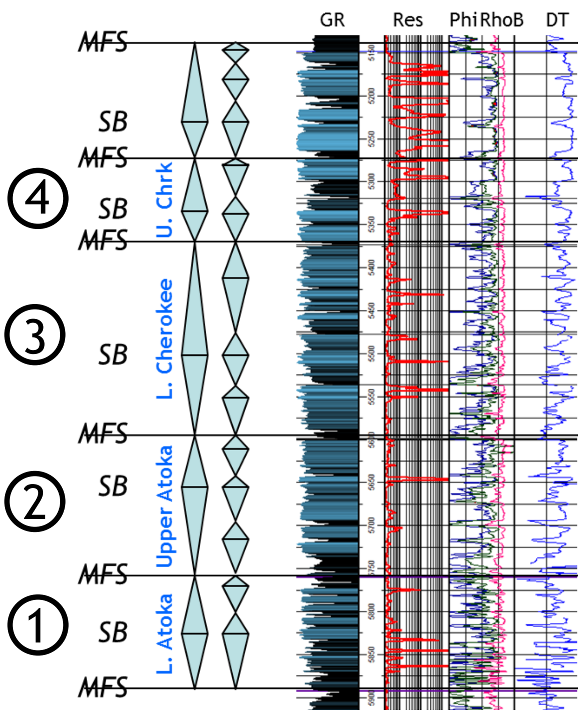
Paleosol feature at 5474-5474.75'
Possible root traces



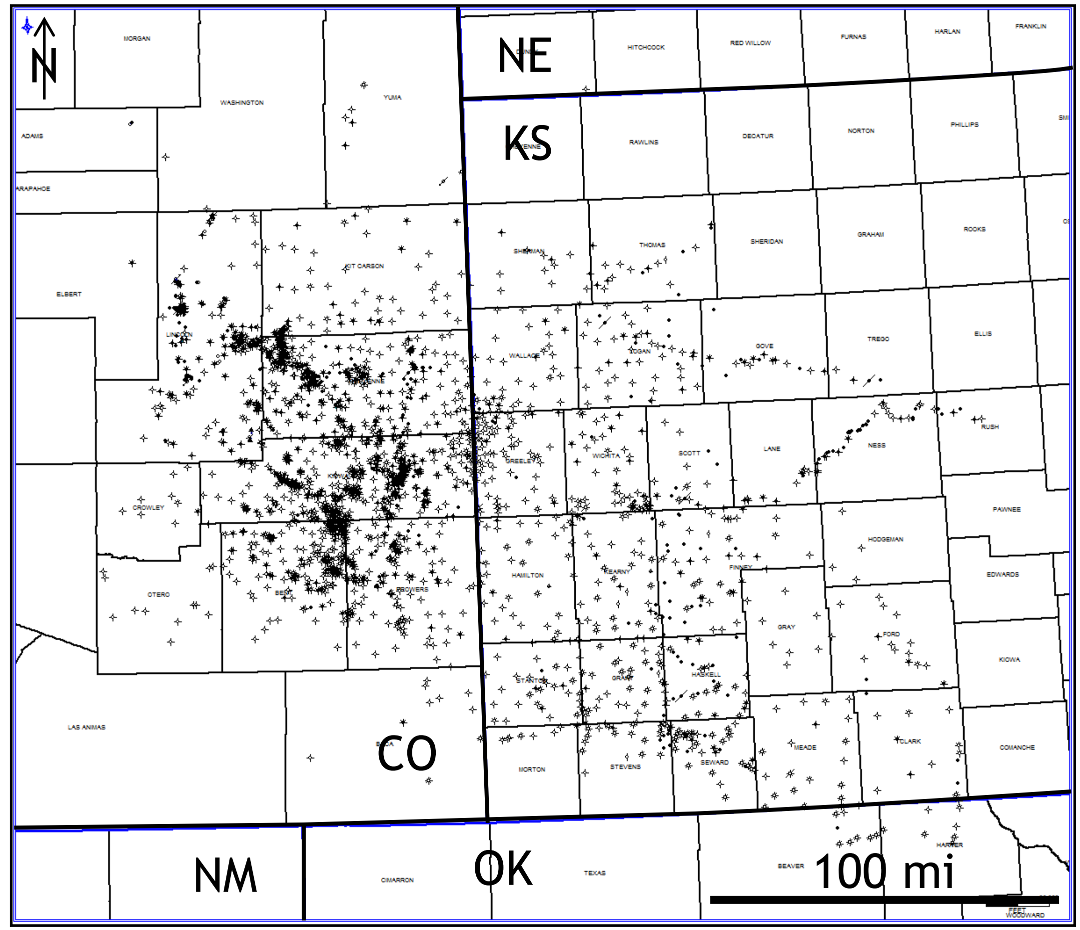


Sequence Maps

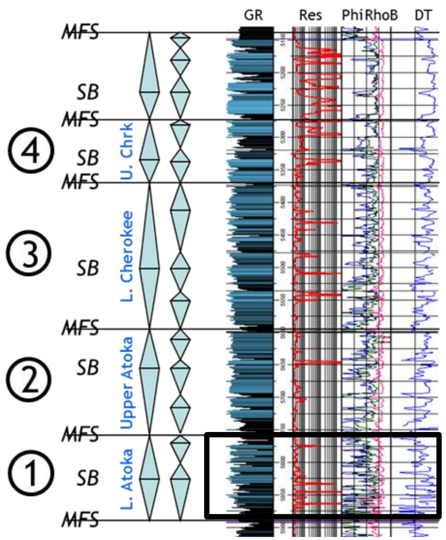
- Strictly sequence stratigraphic tops used in following maps
- Used 5 main laterally-continuous maximum flooding surfaces
- Well Control: >2400 loop-tied wells
- Purpose: Investigate architecture and major facies changes within each of four chronostratigraphic sequences

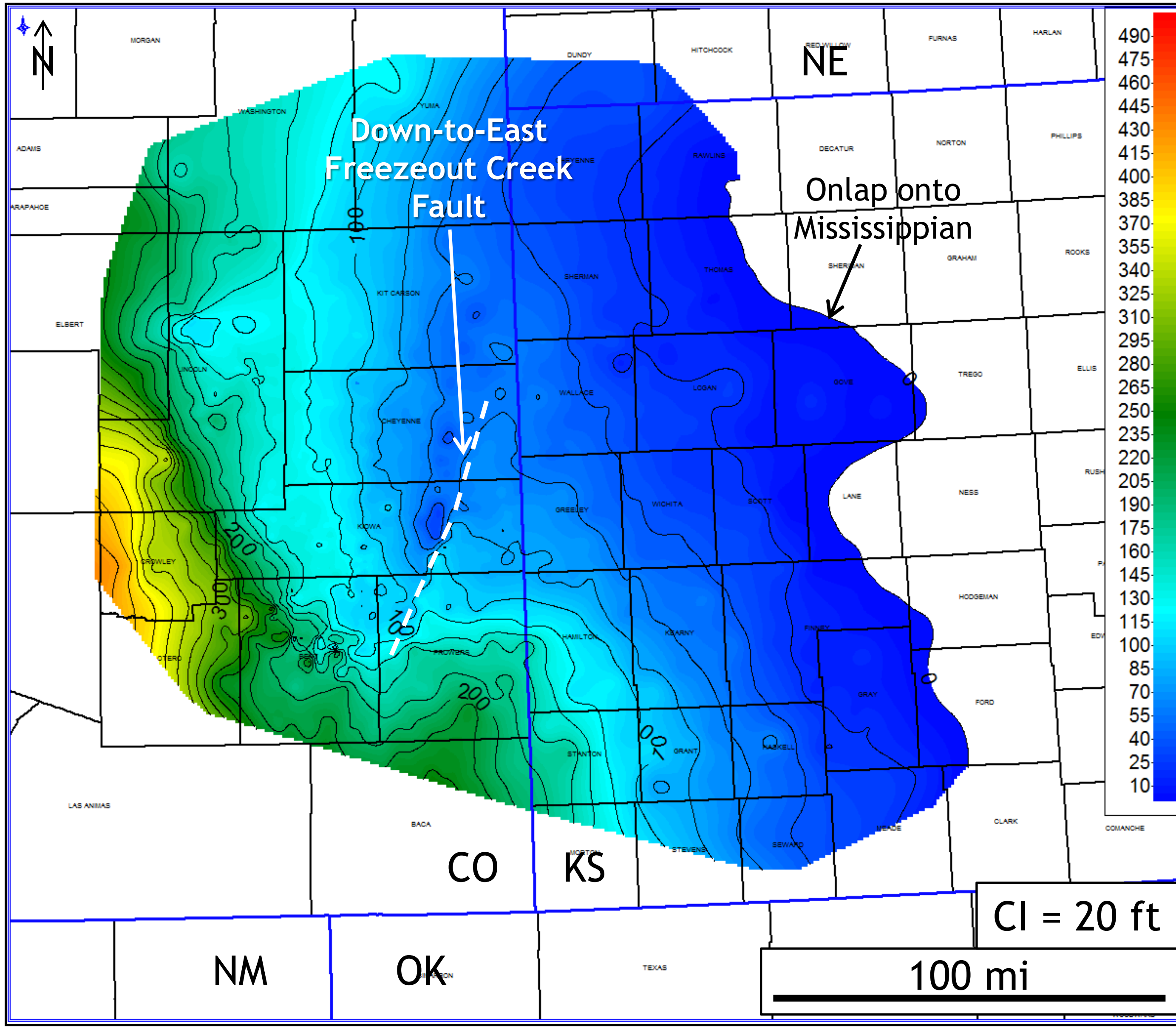


Well Control (n=>2400)



Lower Atoka Isopach





- Rapidly thinning sedimentary wedge to the basin center
- Unconformable onlap to the east
- Freezeout Ck fault was active
- Thick depocenter in W/SW
- *No shoals*

Upper Atoka Isopach

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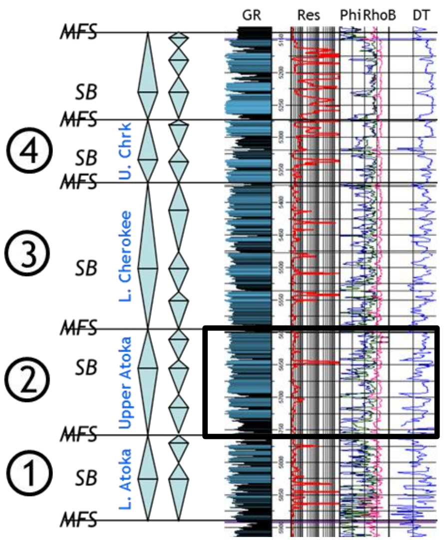
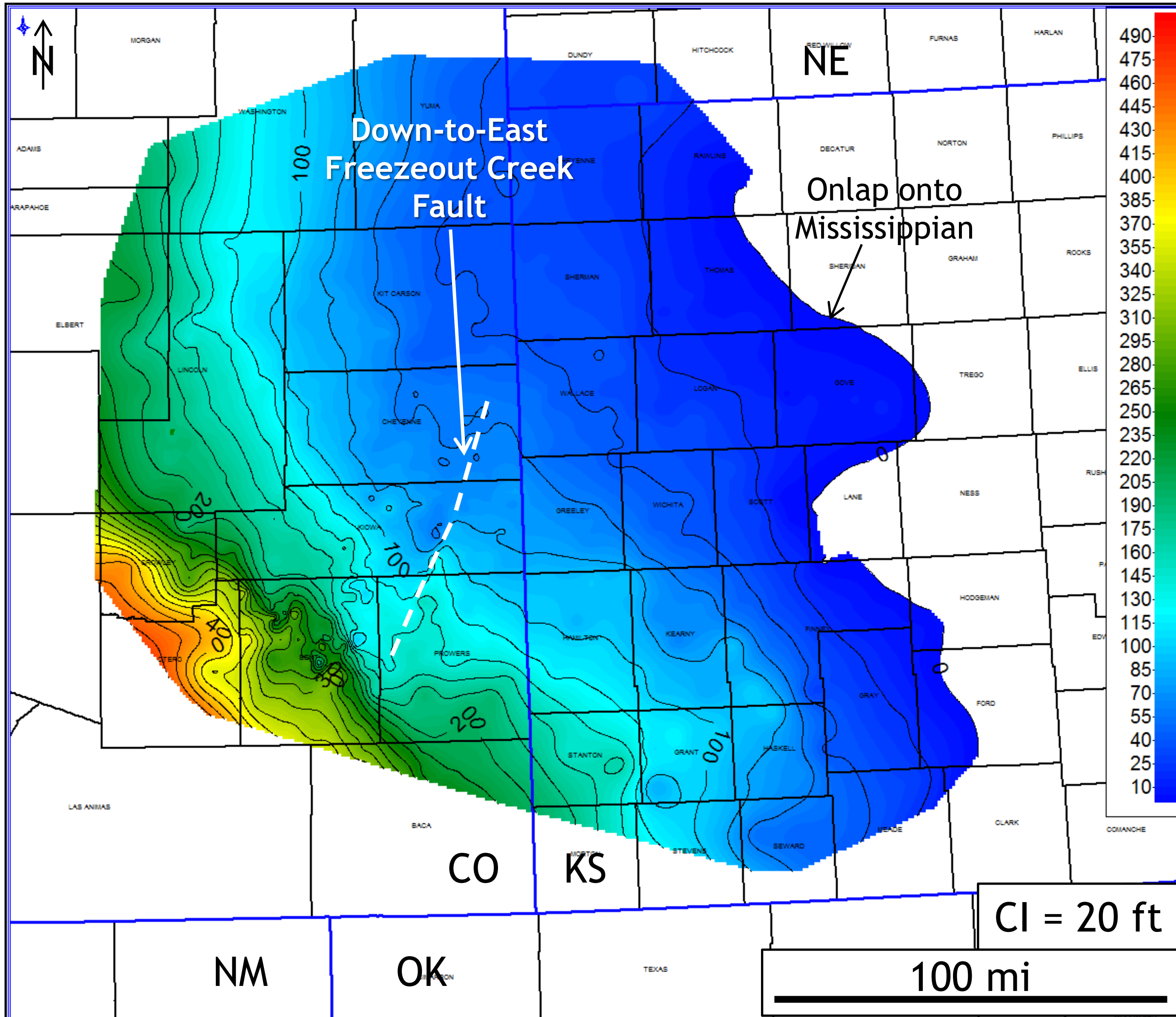
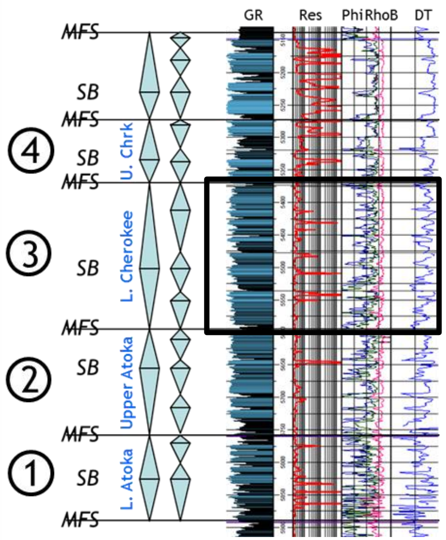


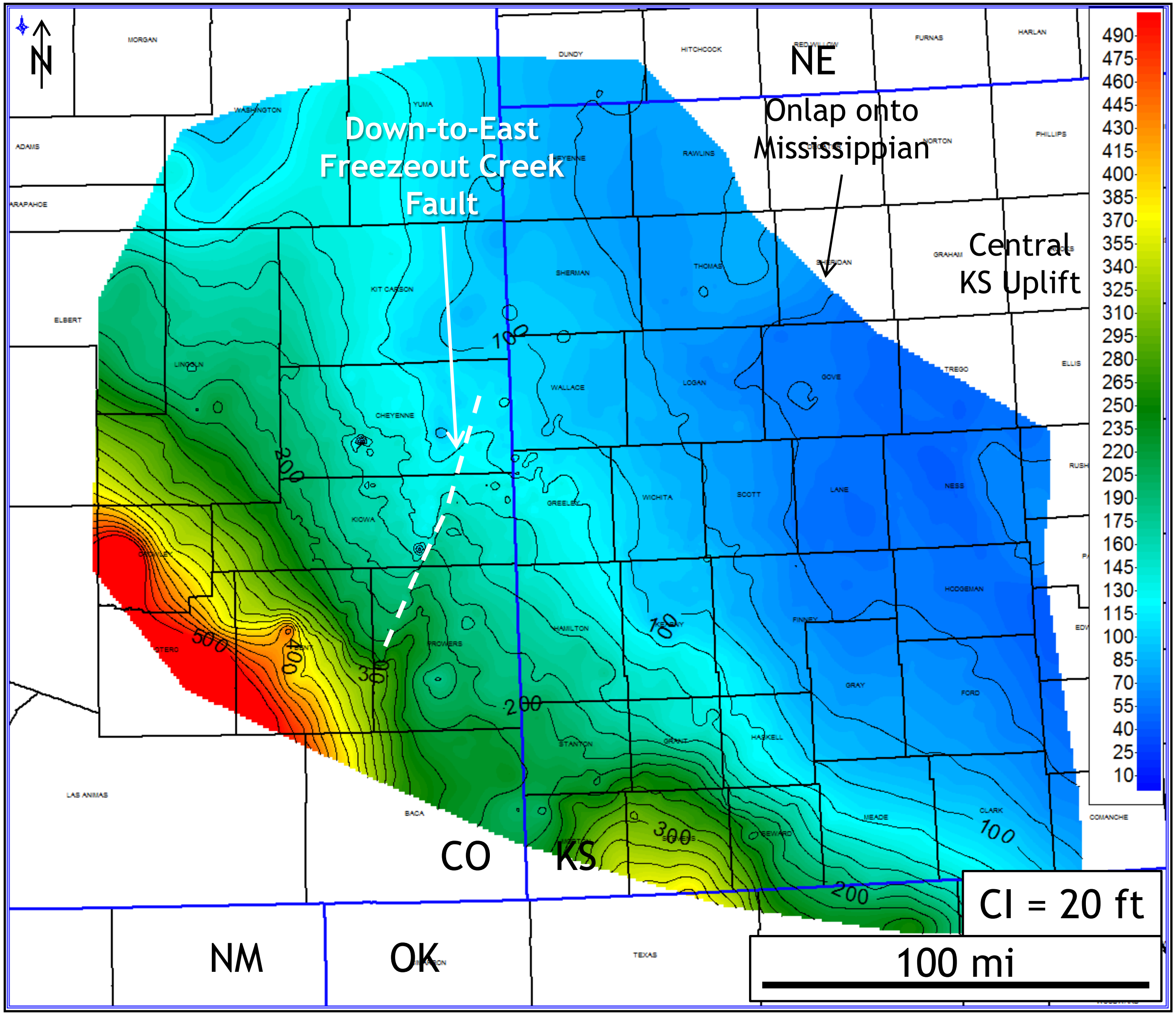
- Rapidly thinning sedimentary wedge to the basin center
- Unconformable onlap to the east
- Freezeout Ck fault was active
- Thick depocenter in SW
- *No shoals*



Lower Cherokee Isopach



- Rapidly thinning sedimentary wedge to the basin center
- Unconformable onlap to the east expands onto Central KS Uplift
- Freezeout Ck fault was active
- Two thick depocenters along SW margin
- *No shoals*



Upper Cherokee Isopach

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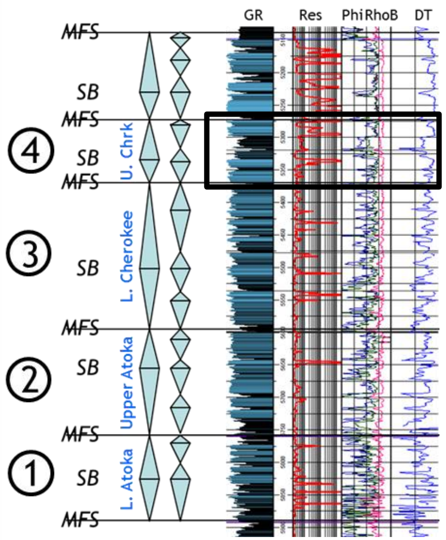
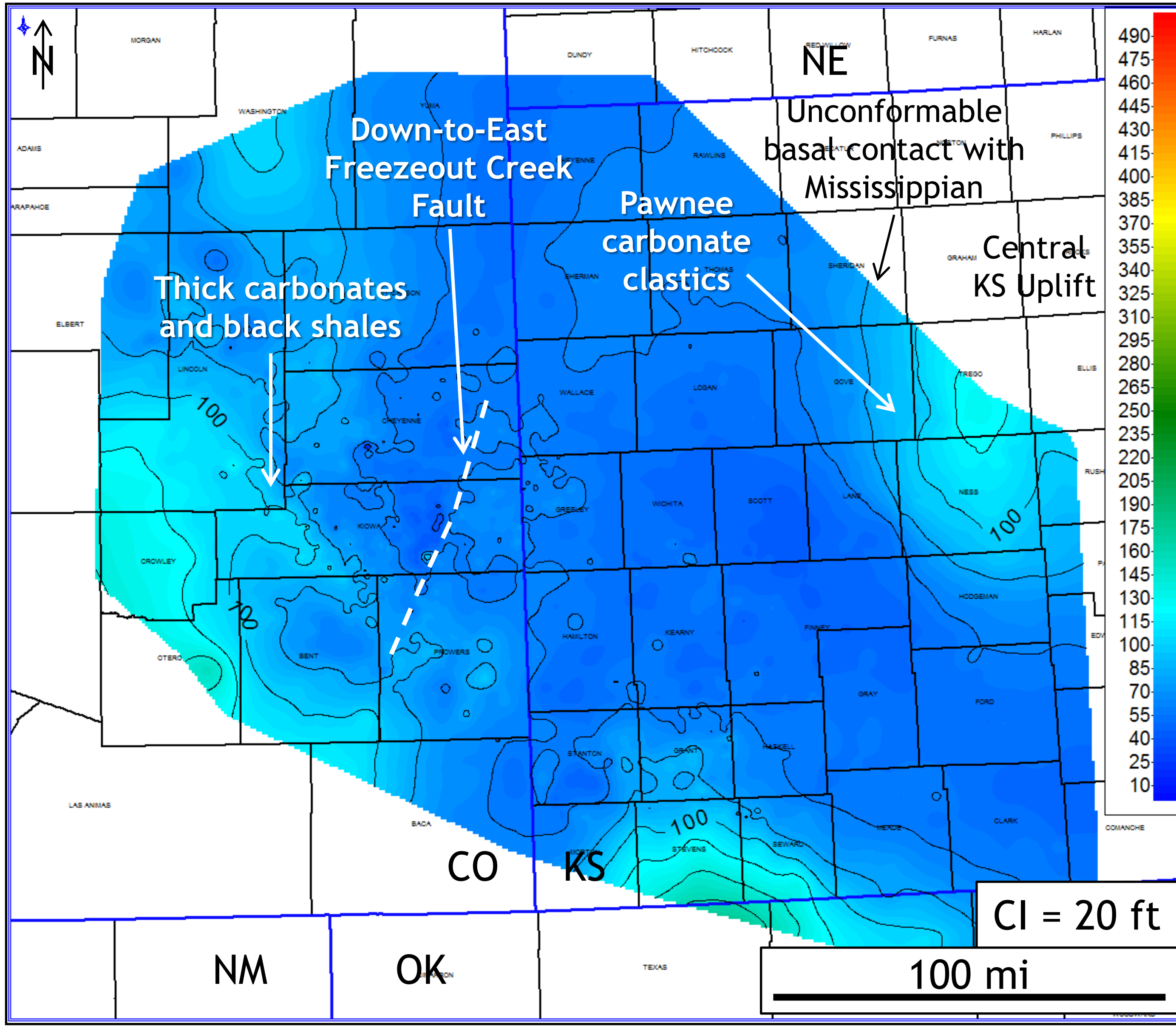


- *NW-SE-trend of thick carbonates (including shoals) and black shales*
- Unconformable onlap to the east expands further onto Central KS Uplift
- Freezeout Ck fault was active
- Two thick depocenters along SW margin



Upper Cherokee Isopach and Carbonate Shoals

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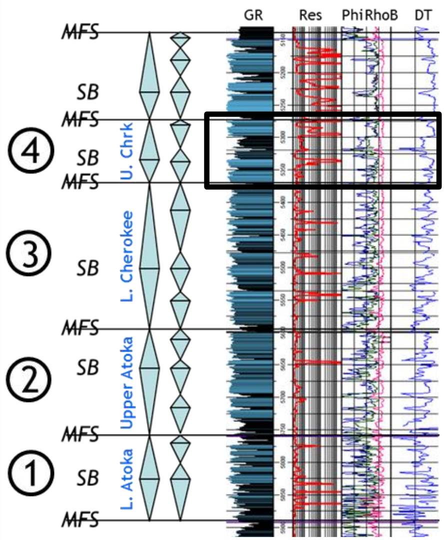
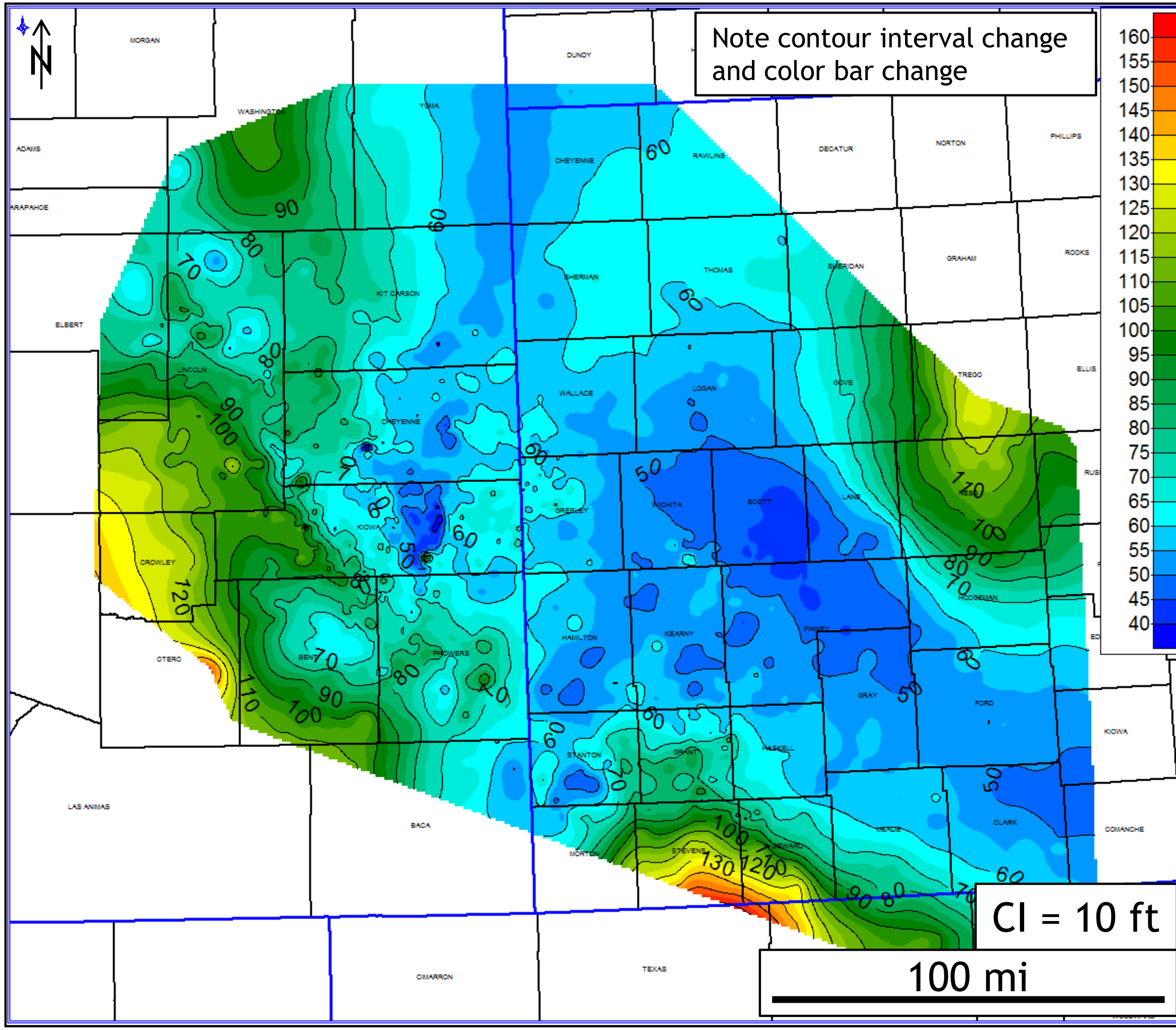
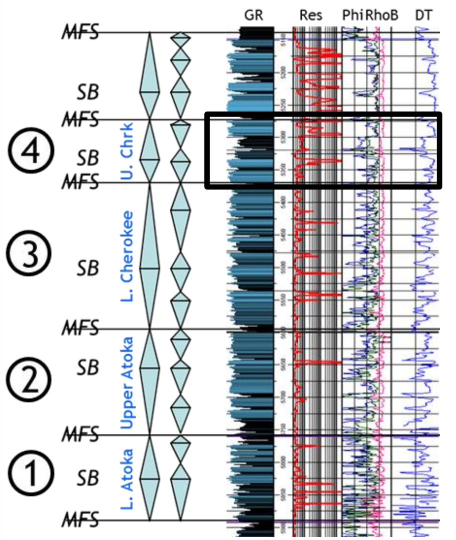
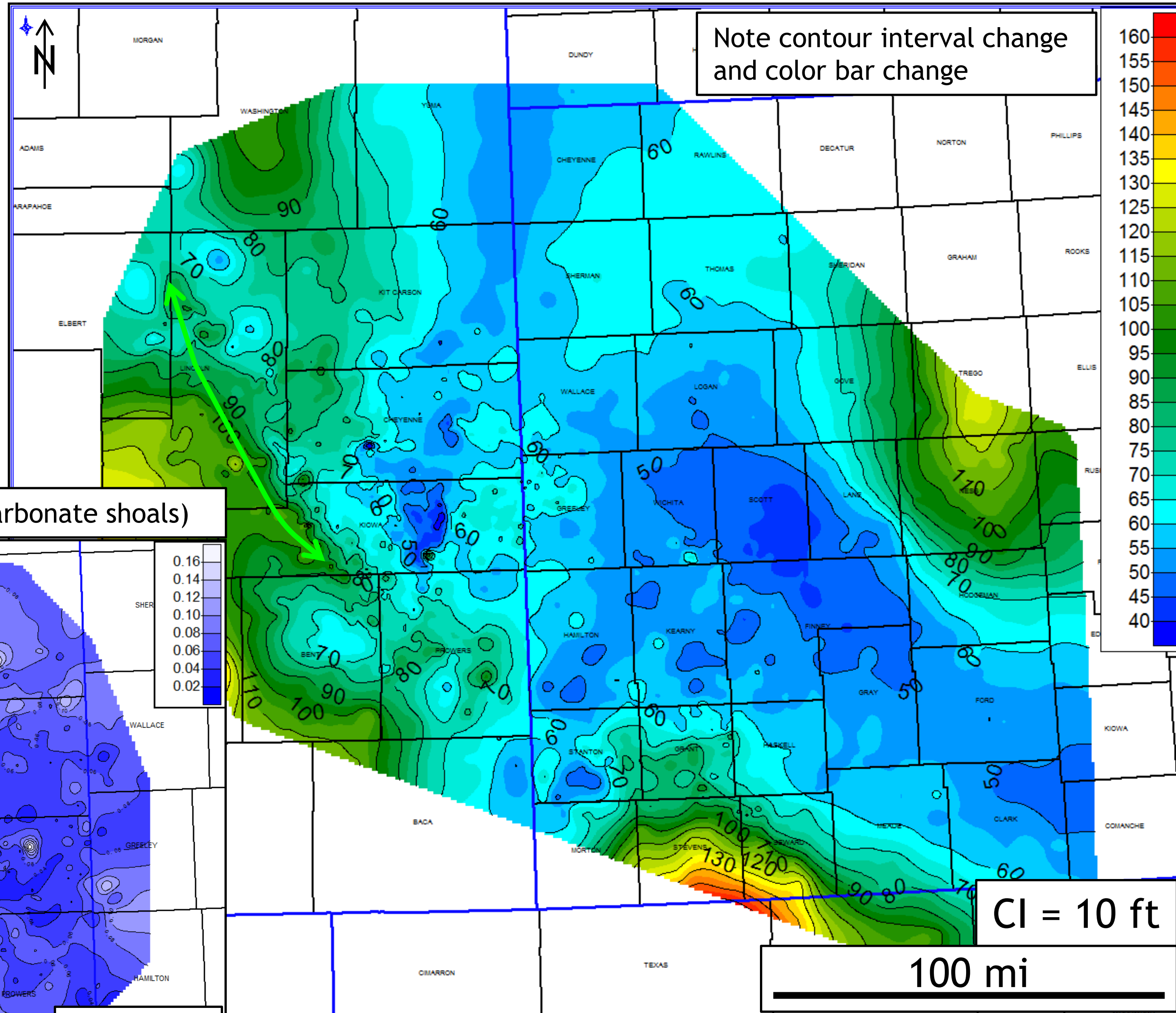


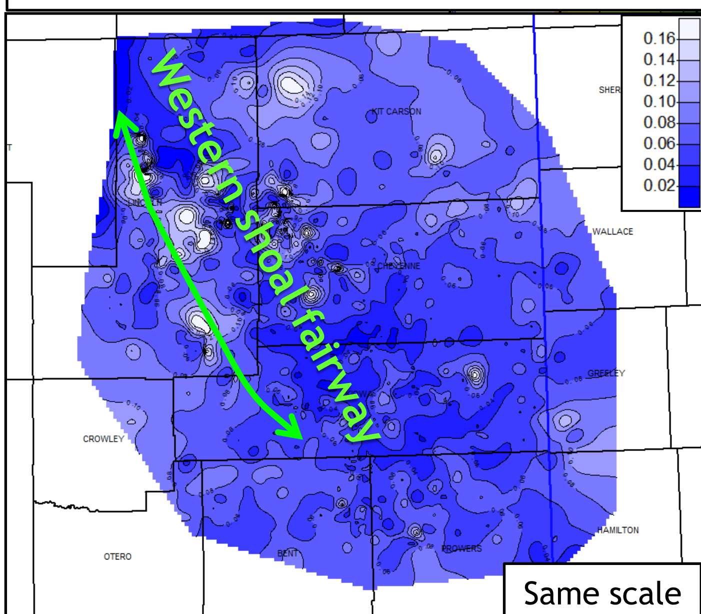


Upper Cherokee Isopach and Carbonate Shoals





Max Dphi map (proxy for carbonate shoals)



Same scale

Mud Logs and Facies Mapping

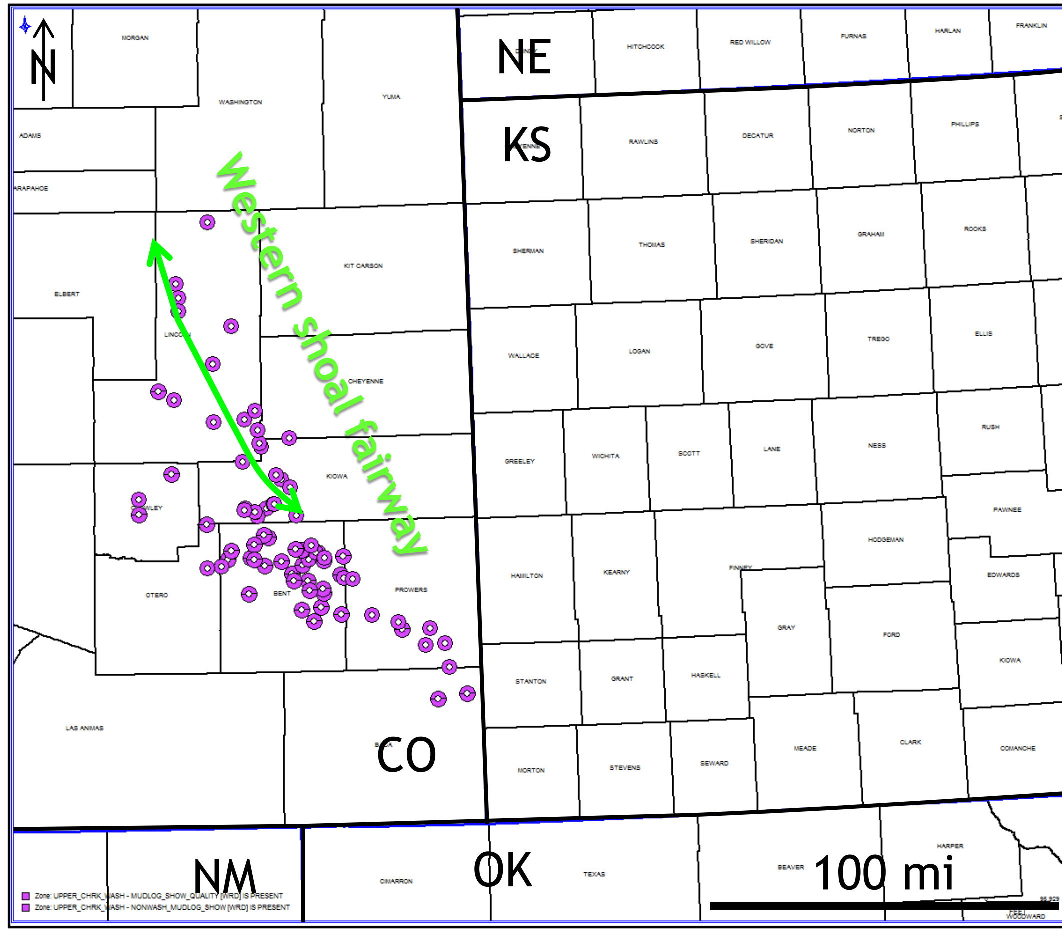
Purpose:

- In absence of outcrop, use available mud logs to map major facies changes within each of four chronostratigraphic sequences

Methodology:

- Flag lithology of mud logs (arkose, siliciclastic sandstone, siltstone, maroon shale, carbonaceous shale, limestone) in cross section
- Map cross-sectional facies changes in map view

Western Mud Log Well Control



Example X-Section and Facies Mapping Methodology

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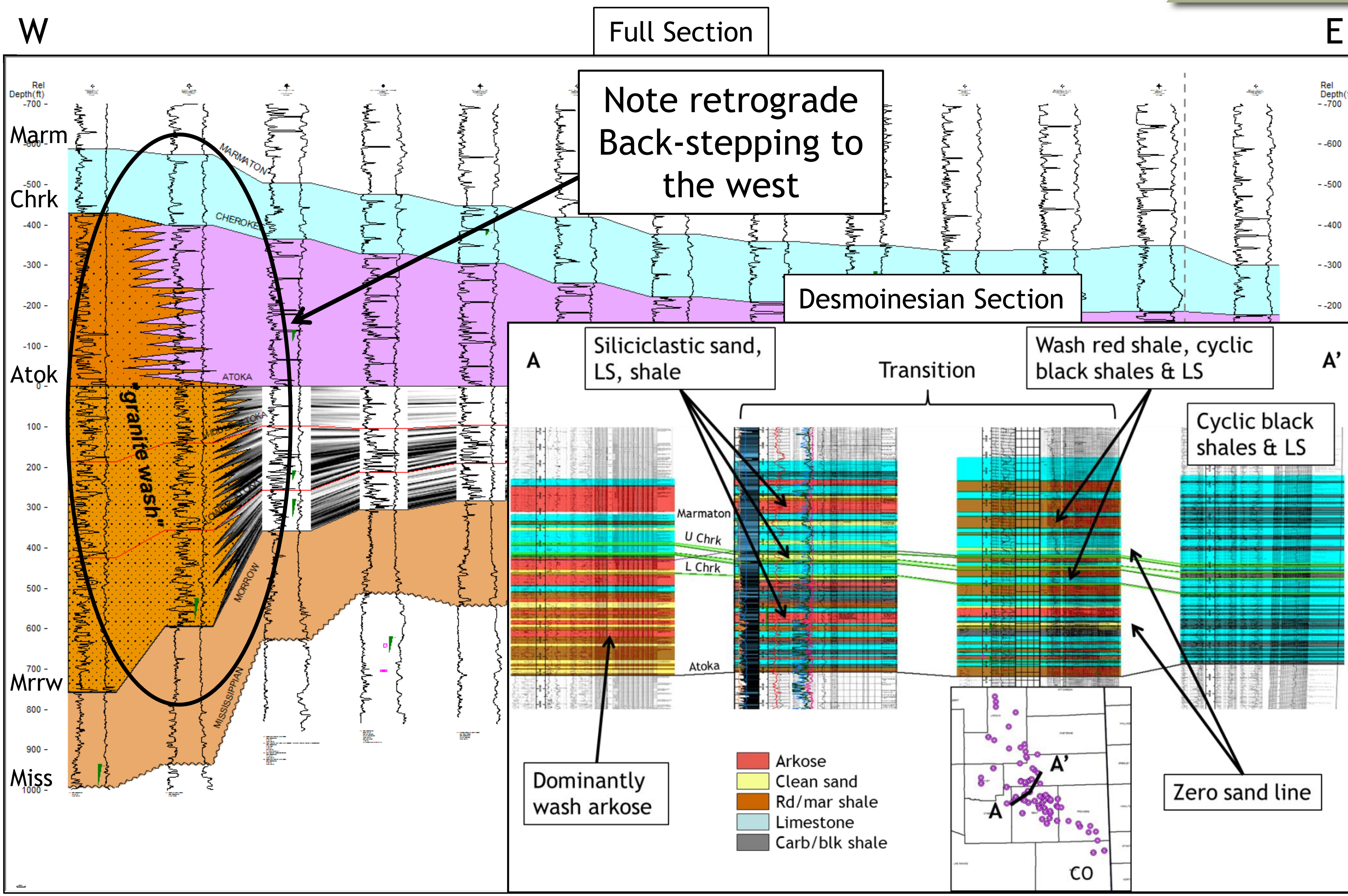

Shoreward Shift in Zero Sand Line

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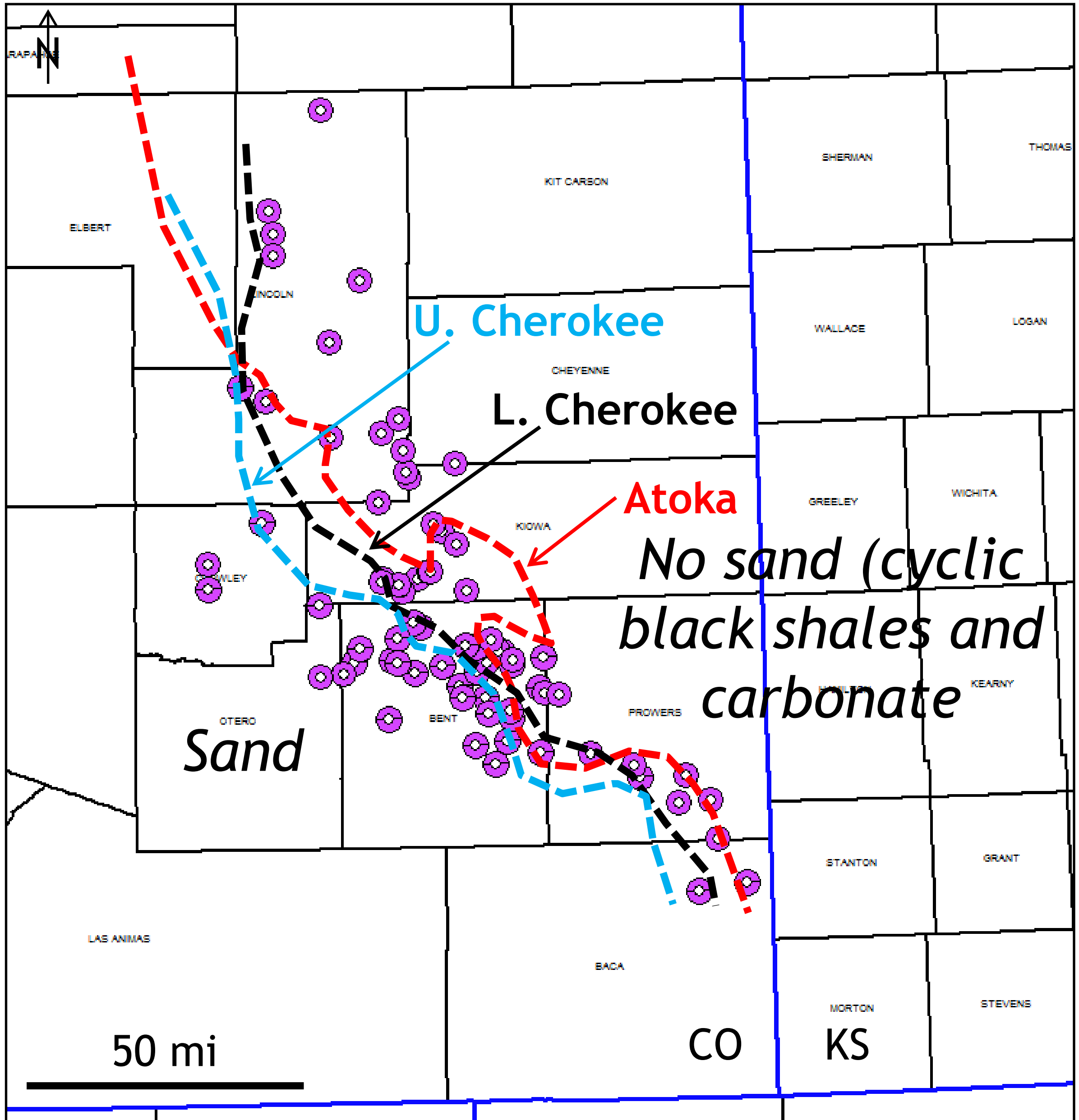

W-E Conceptual Strat and Basin Architecture

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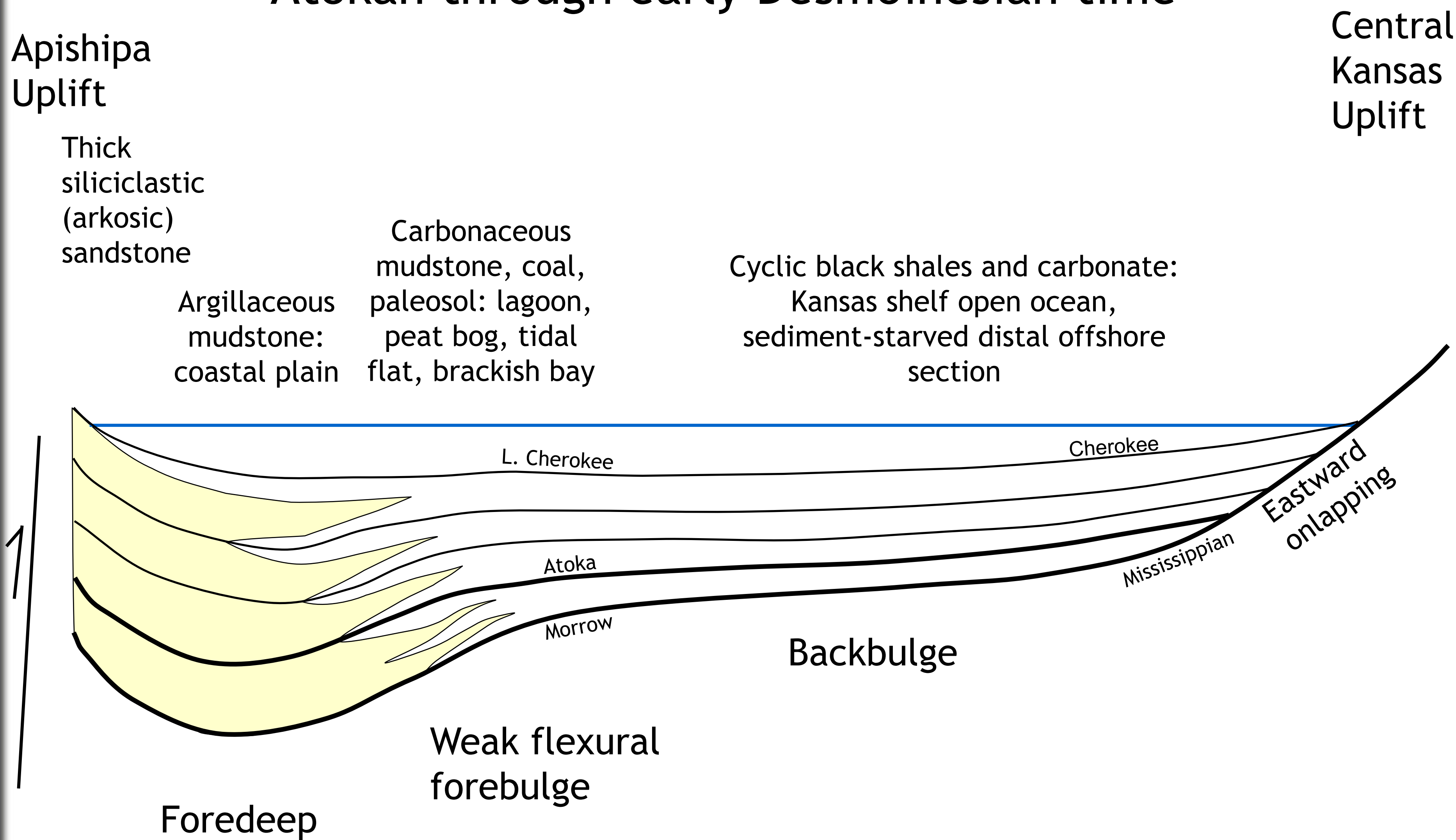
Atokan through early Desmoinesian time



Not to scale

W-E Conceptual Strat and Basin Architecture

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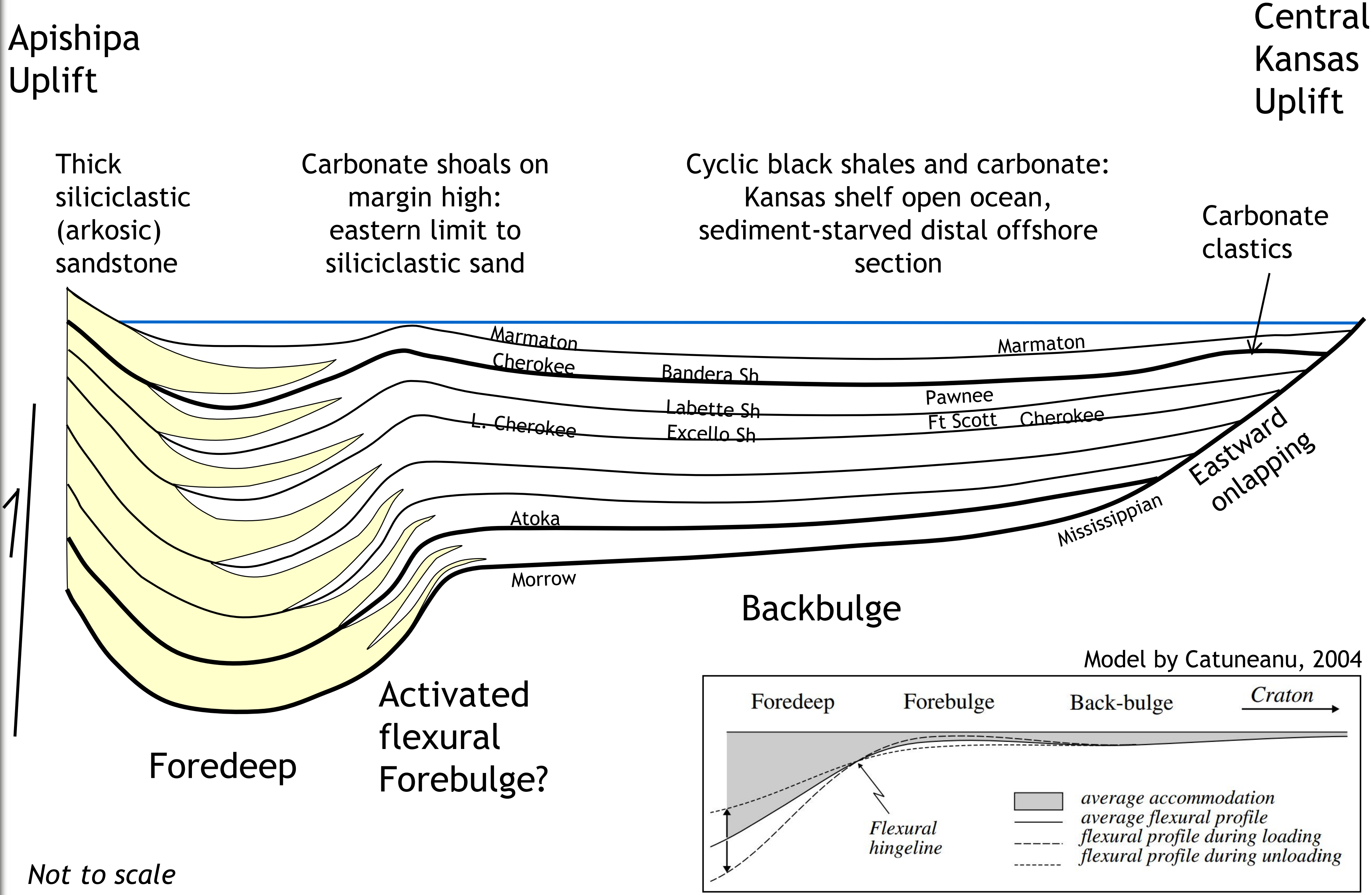
Desmoinesian time



Not to scale

Gross Cherokee Isopach in Regional Context

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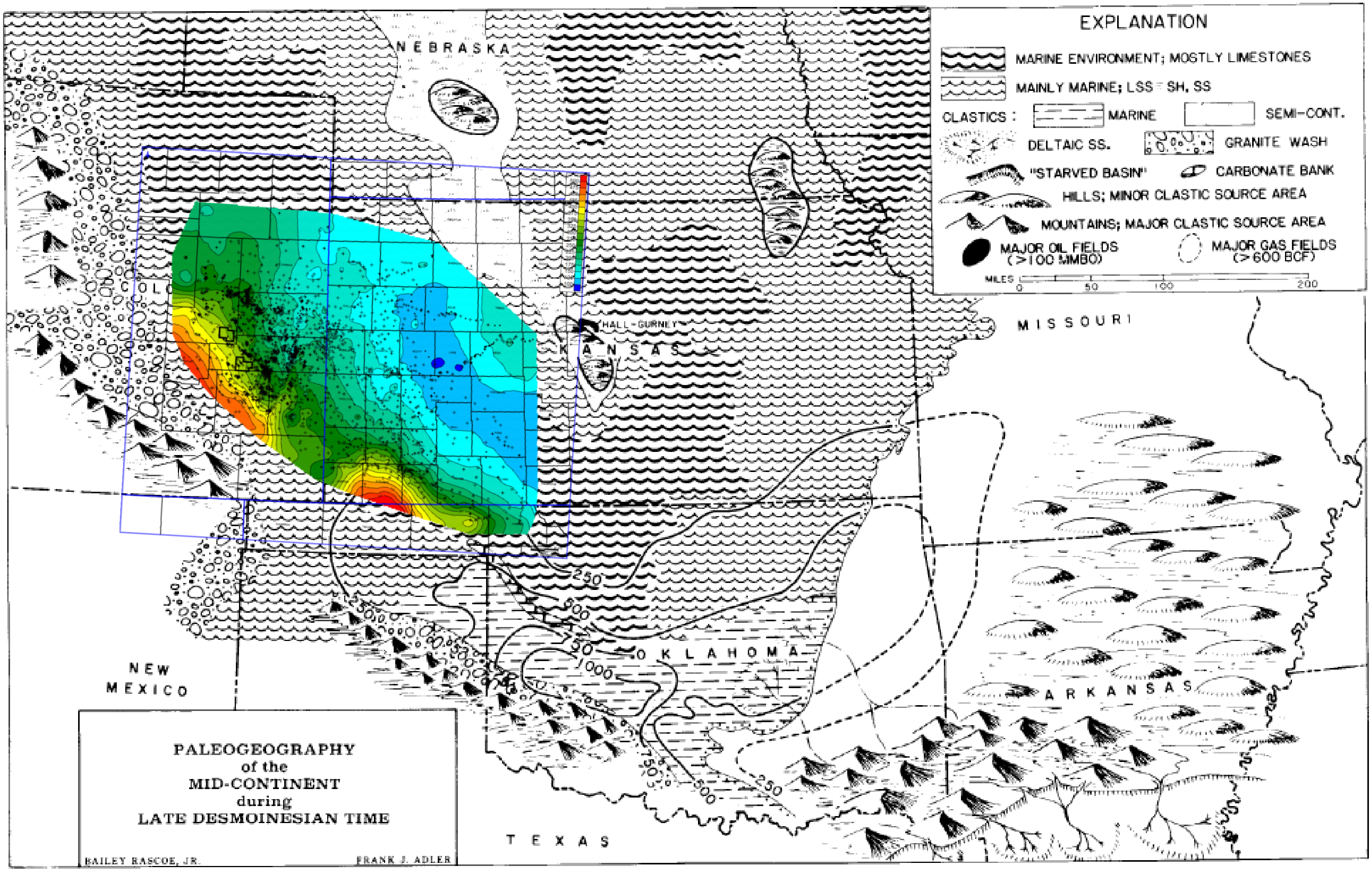

Modified from Roscoe and Adler, 1983

Interpretation of Gross Cherokee Isopach

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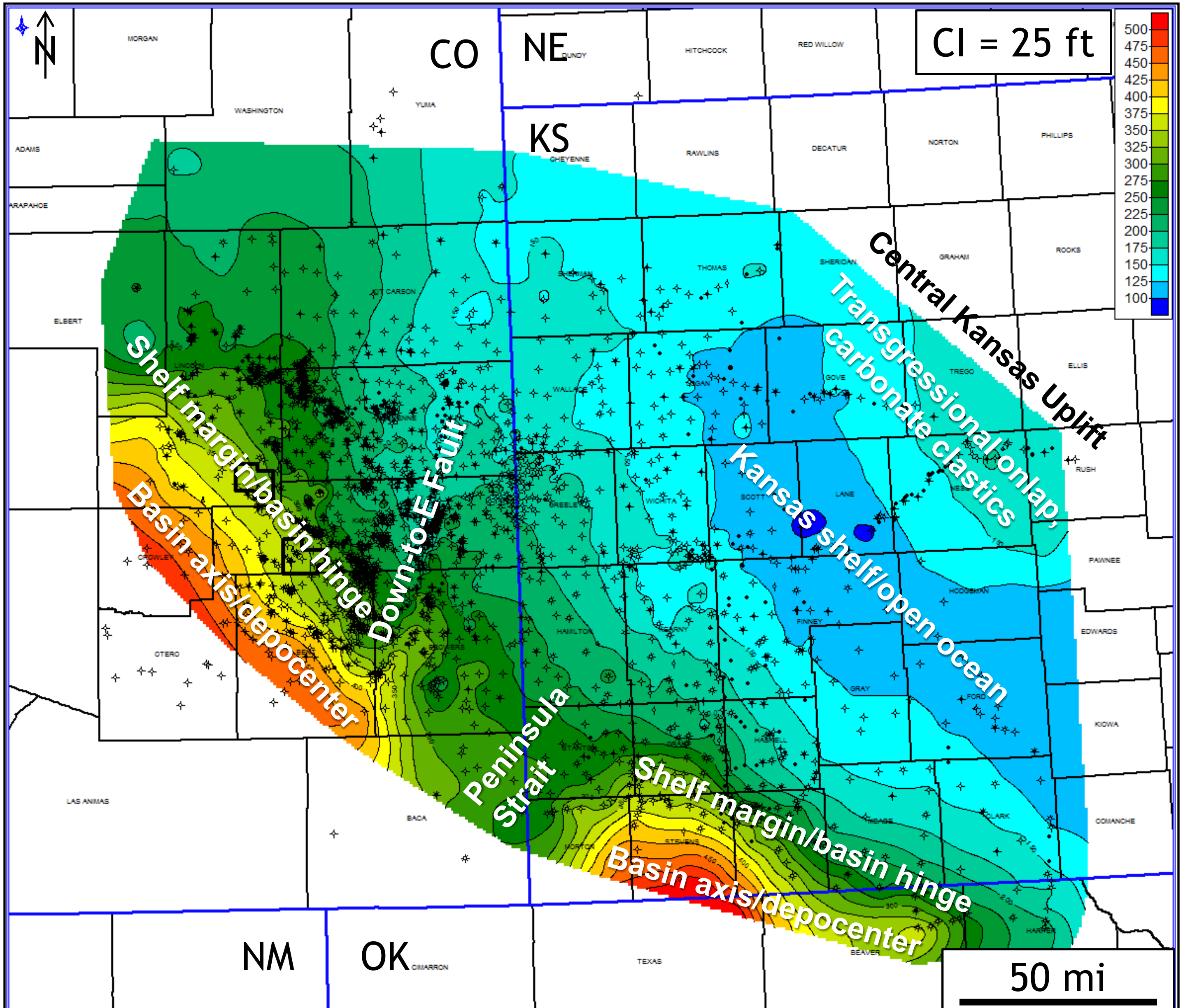

XRF Data Analysis and Basin Restriction

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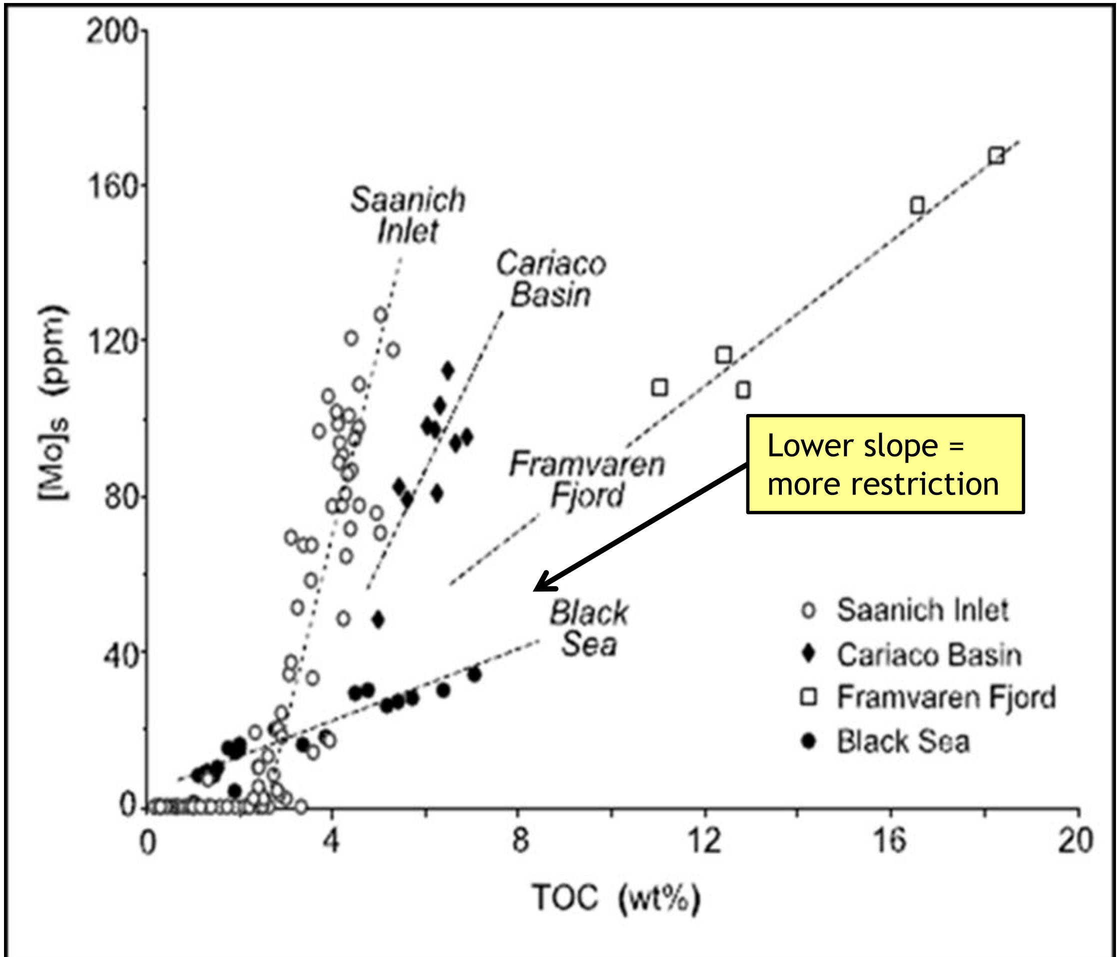
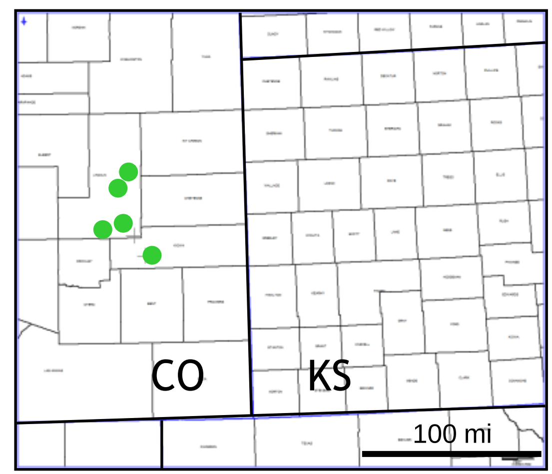
Mo/TOC slope as indicator of basin restriction



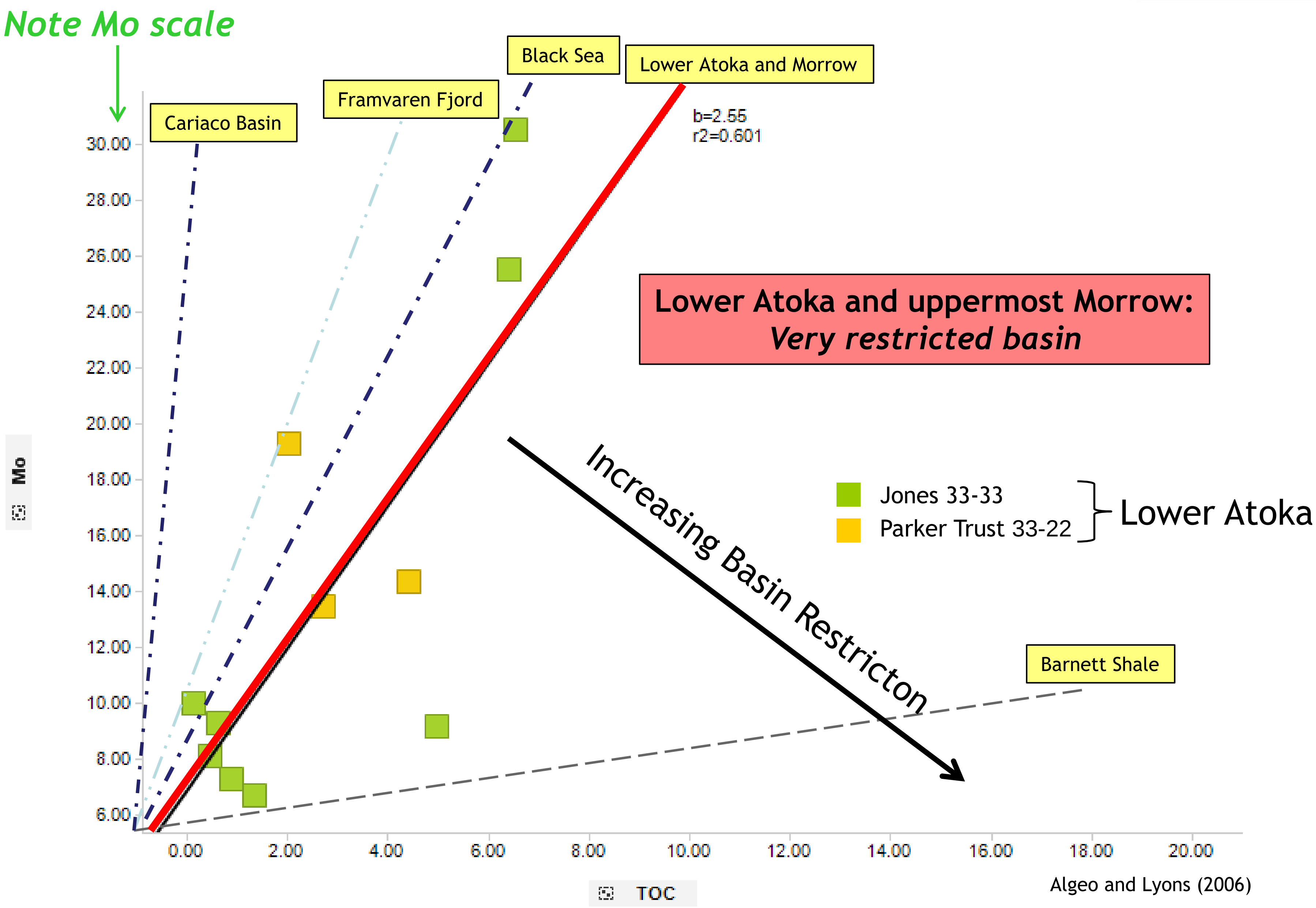
Algeo and Lyons (2006)

<u>Core used for XRF Analysis:</u>
Clay 24-35 (050730616) - CHRK
Davis 42-12 (0507306474) - CHRK
Mosher 1-1H (0507306393) - CHRK
Jones 33-33 (0506106875) - ATOK
Parker Trust 33-22 (050730651) - ATOK

Core locations

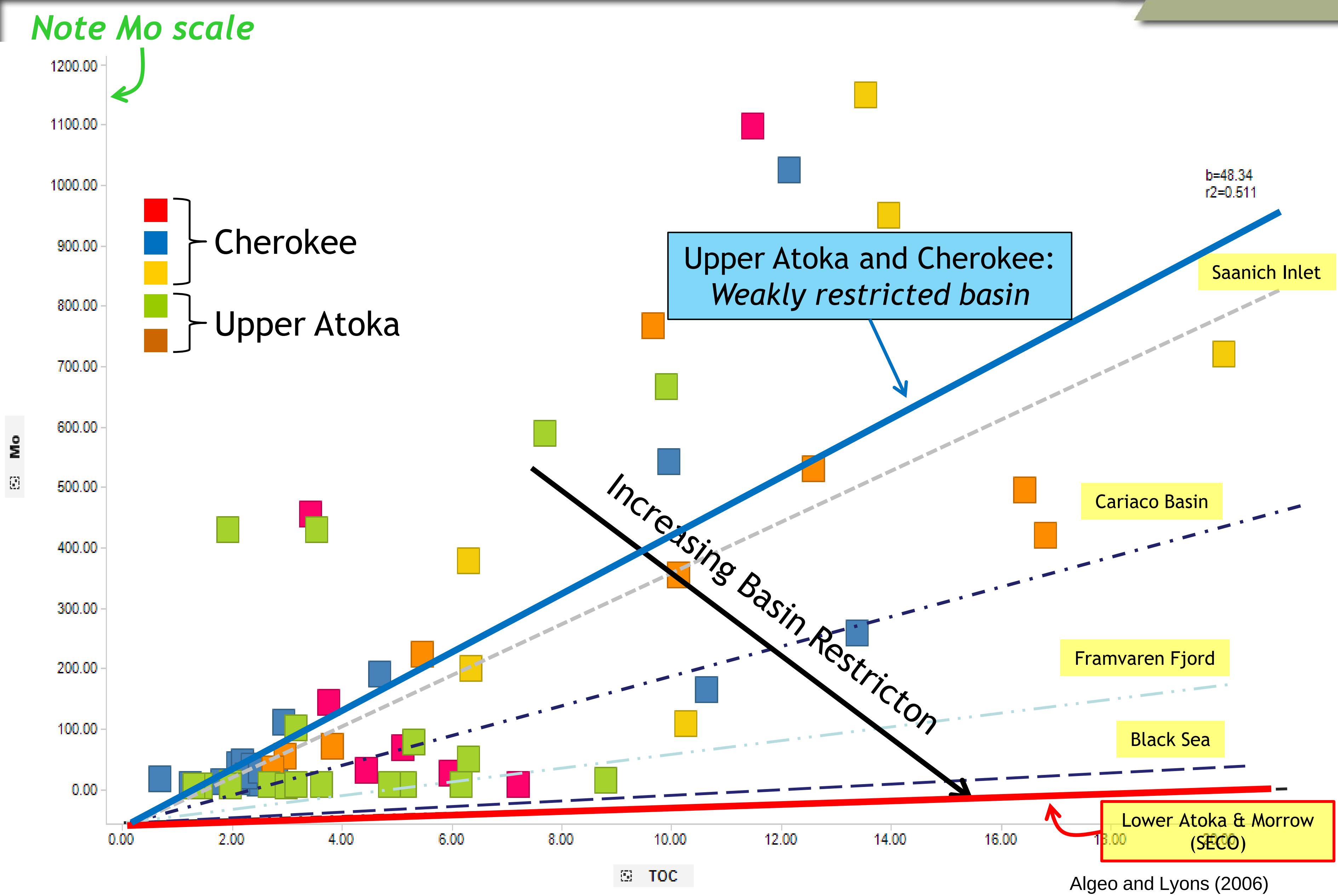


Lower Atoka and Morrow



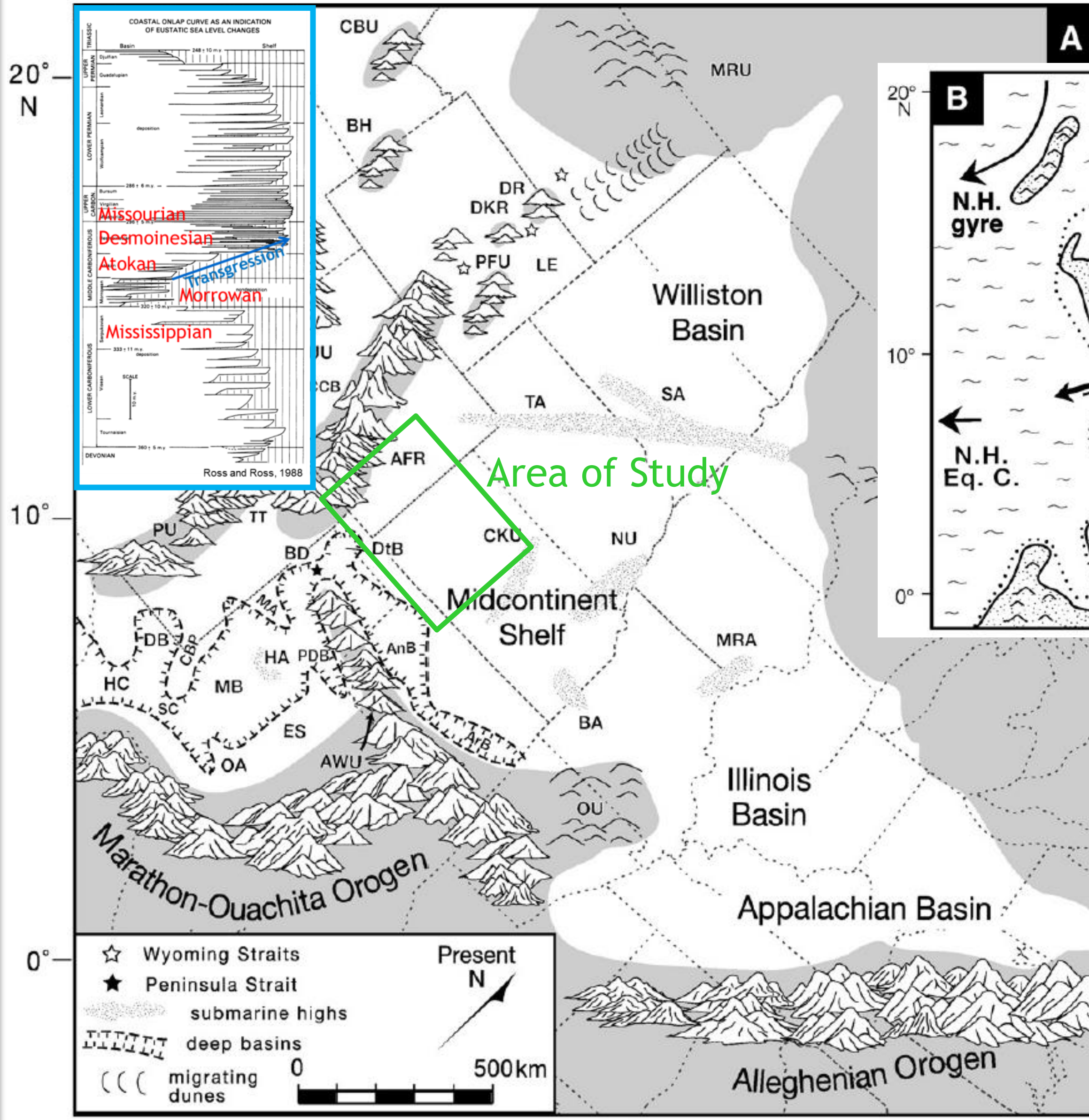
Algeo and Lyons (2006)

Upper Atoka and Cherokee

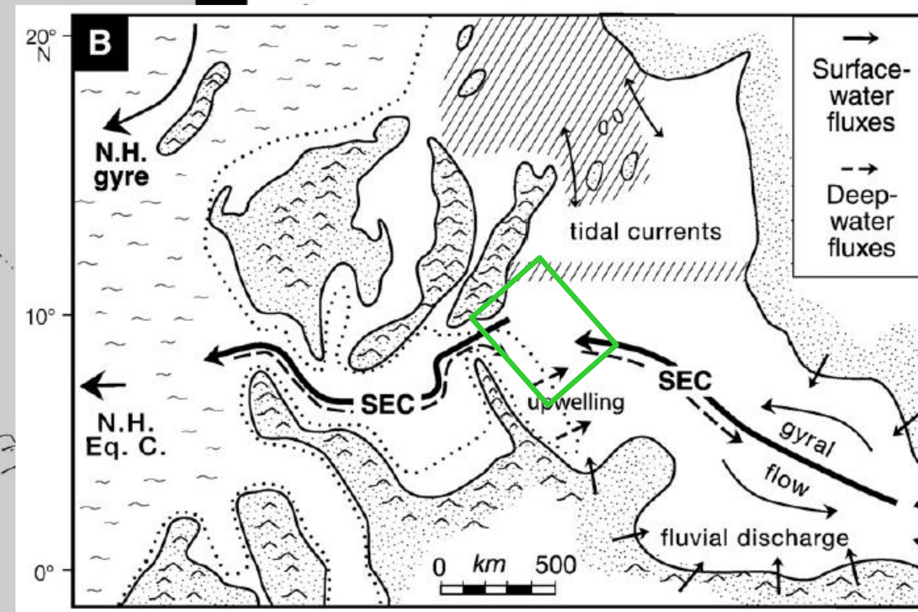


Algeo and Lyons (2006)

Implications for Onlap and Super-estuarine Model



Super-estuarine Circulation



Algeo and Heckel, 2008

Implications of area of study:

- Paleoconditions – shift from very restricted to weakly restricted basin
- Basin architecture changes
- Emergent western shoal fairway
- Increasingly pronounced Peninsula Strait

Conclusions: Middle Penn of SW Mid-Con Basin

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- Dynamic basin architecture and facies shifts through time
- Atokan stage:
  - Lagoonal margin with periodic cyclothemic marine flooding events
  - Very restrictive basin, but trending later to less restrictive
  - Architecture - sedimentary wedge, rapidly thinning towards basin center
- Desmoinesian stage:
  - Intertidal platform, tidal flats, and shoals to deep subtidal platform; dominated by glacio-eustatic cyclothems in open marine setting
  - Weakly restrictive basin
  - Linear trend of shoals, carbonate buildups, paleosols possibly coincident with activated flexural forebulge
- Our model supports dramatic glacio-eustatic T-R cycles with overall marine transgression during Middle Pennsylvanian
- Dynamics of basin architecture and degree of basin restriction affect thinned vs. thickened sections and superestuarine circulation pattern
  - All important to emerging petroleum systems in the SW Mid-Continent