Syndepositional Tectonism and its Effects on Mississippian (Kinderhookian to Osagean) Lithostratigraphic Architecture: Part 1 – Based on Exposures in the Midcontinent USA*

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Abstract

Exposures of Kinderhookian to Osagean carbonates in Missouri and adjoining Arkansas and Oklahoma, deposited on the flank of the Ozark Uplift inboard of the Ouachita thrust-belt to the south, record aggradational followed by progradational sedimentation. Deposition responded to long-term tectono-eustasy. Early pulses of Ouachita collision resulted in areal shifts of fore-bulge arches and basins, and movement along associated faults during deposition. This syndepositional tectonism overprinted the fundamental lithostratigraphic and apparent sequence-stratigraphic architecture of this section, the manifestations of which include: (1) periodic uplift and unconformity formation within marine and subaerial meteoric environments; (2) northward progradation of relatively thick sections of strata that downlap regional unconformities and not maximum flooding surfaces; (3) the presence of allochthonous reefs that detached and slid downslope to the north within downlapping strata; (4) the formation of submarine erosionally-truncated folds at several horizons in the section, the axes of which uniformly trend E-W; and (5) regional down-dip (to the south) thinning that resulted from erosional truncation on uplifted, shallow-water arches and not from depositional thinning into deep water. The recognition of such processes and products has important bearing on the nature, types, and locations of petroleum reservoirs in the subsurface, and accordingly, on our exploration models for them.

Reference

Noble, P.J., 1995, Regional sedimentation patterns associated with the passive-to active-margin transition, Ouachita orogeny, southern midcontinent, USA, *in* K.S. Johnson, (ed.) Structural Styles in the Southern Midcontinent, 1992 Symposium: Oklahoma Geological Survey, Norman, Oklahoma, Circular No. 97, p. 99-112.

Website

Blakey, R.C., Paleogeography: Web accessed 8 November 2011, http://www2.nau.edu/rcb7/

SYNDEPOSITIONAL TECTONISM AND ITS EFFECTS ON MISSISSIPPIAN (KINDERHOOKIAN TO OSAGEAN) LITHOSTRATIGRAPHIC ARCHITECTURE

PART 1

BASED ON EXPOSURES IN THE MID-CONTINENT USA

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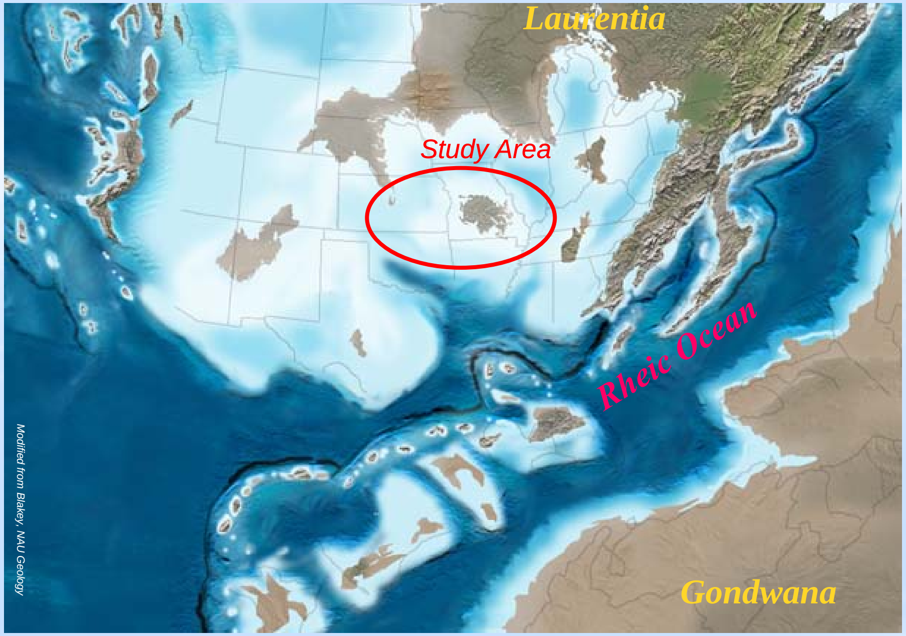
Current Belief…

The Rheic Ocean diachronously ‘zippered’ shut, from NE to SW, during plate convergence of Laurentia and Gondawana.

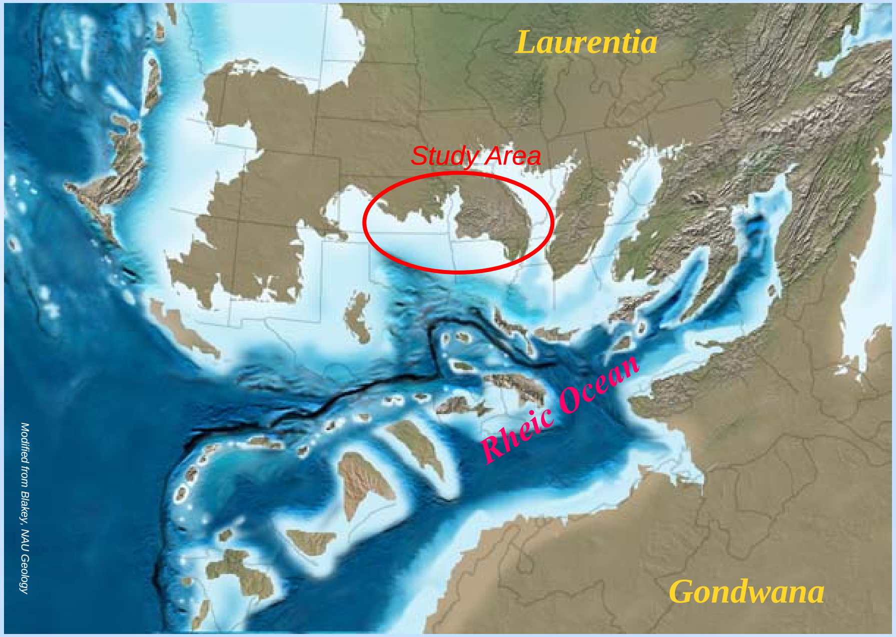
Timing of that crustal compression & onset of associated

Mid-Continent tectonics is widely believed to be -
late-Mississippian (Mrmc-Chster) to middle Pennsylvanian time……..

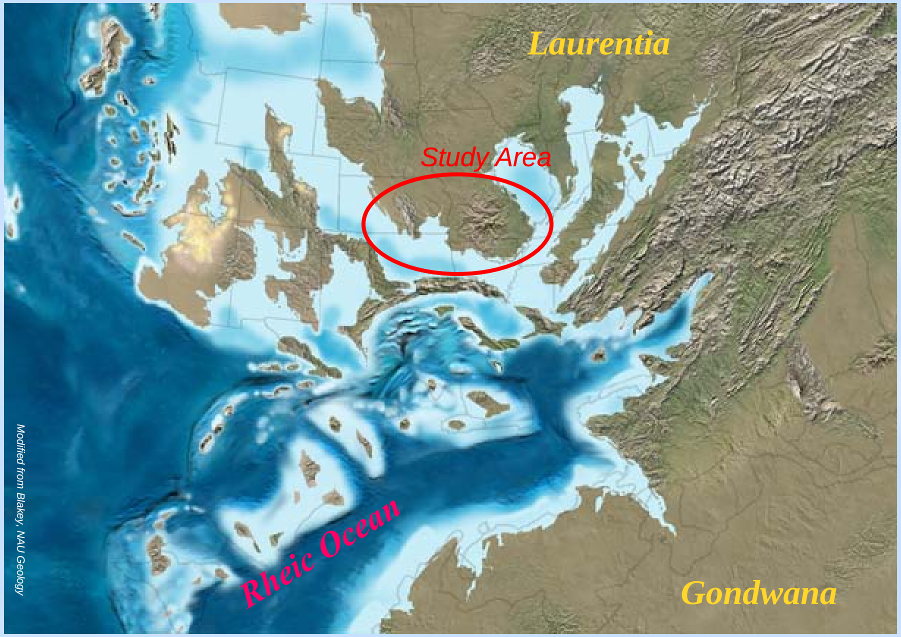
KINDERHOOK & OSAGE TIME: TECTONIC QUIESCENCE



LATE MERAMEC-CHESTER TIME: ONSET OF MID-CON TECTONICS & OUACHITA OROGENY



EARLY PENNSYLVANIAN TIME: CONTINUATION OF OUACHITA OROGENY

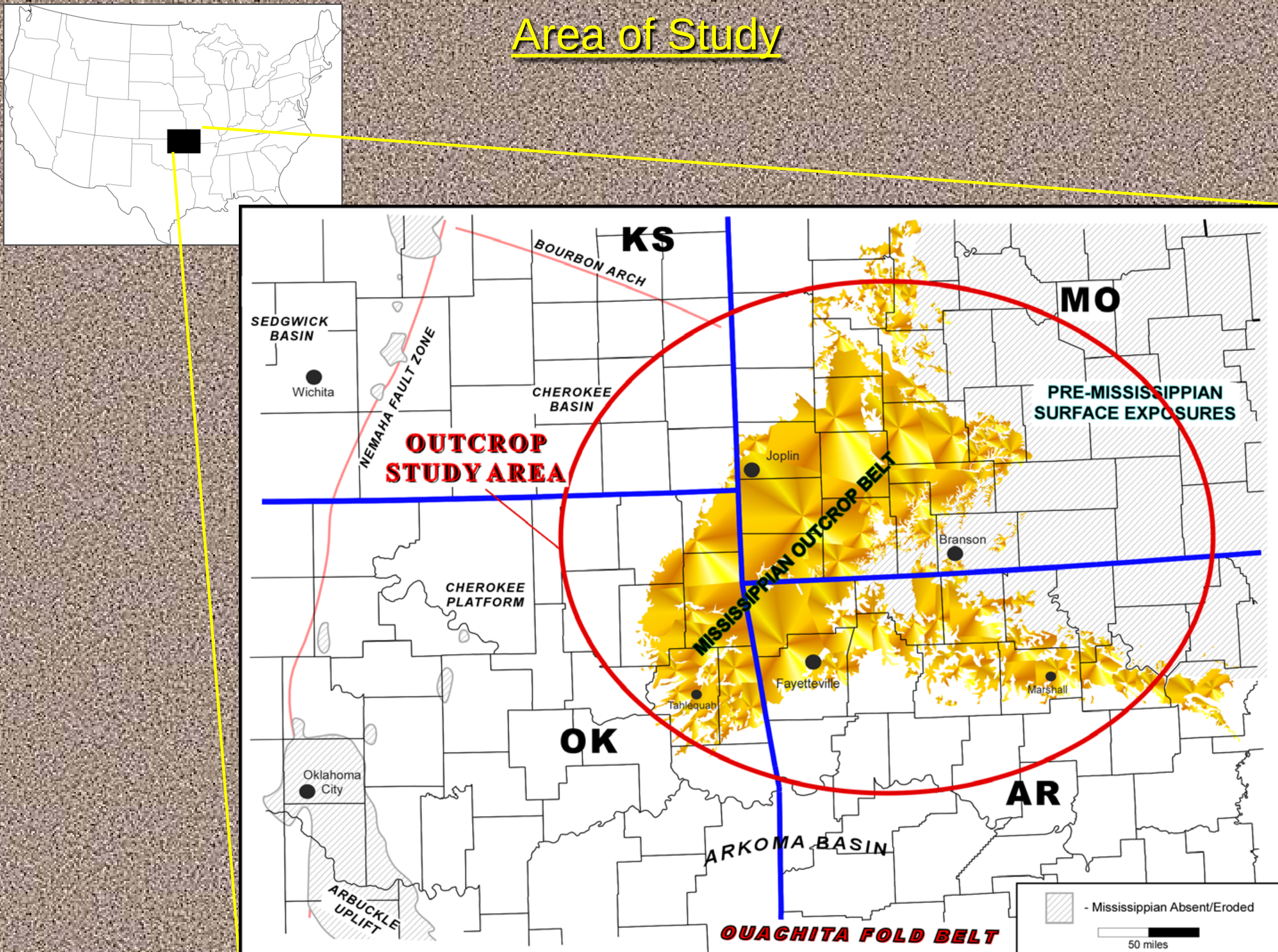


...a contention with which we do not agree.

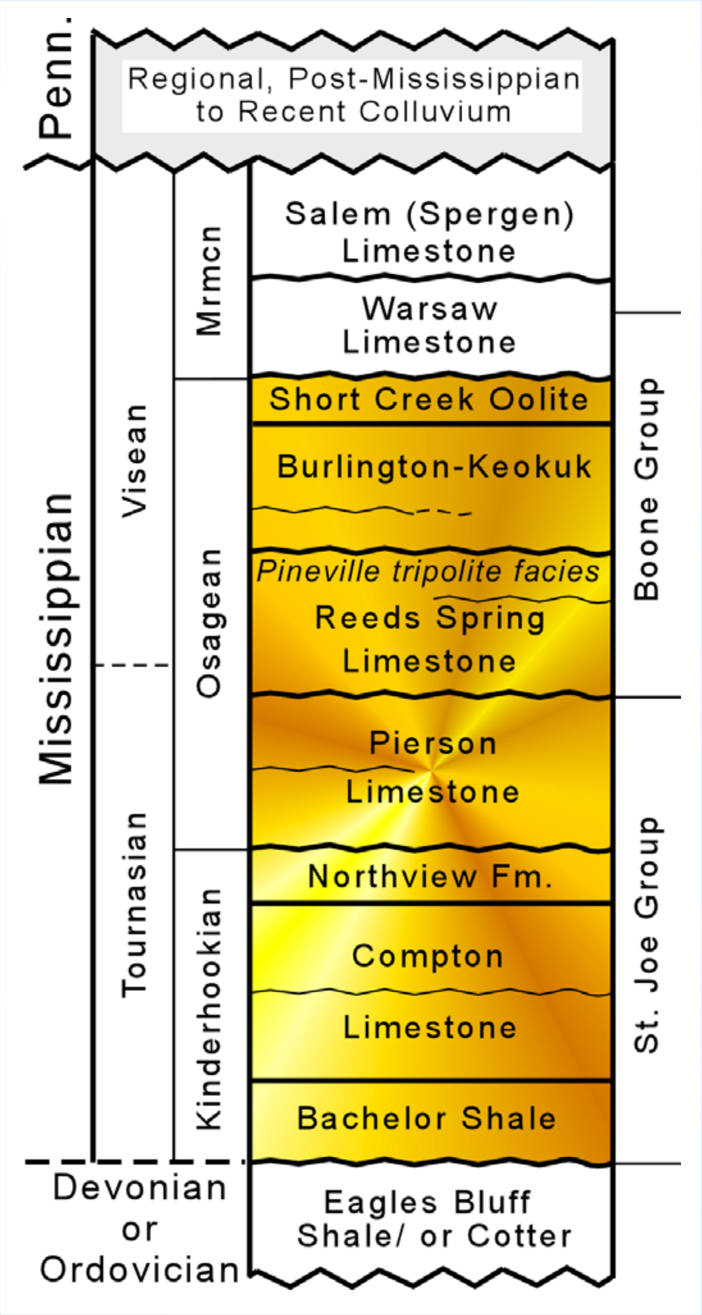
Herein we'll illustrate
stratigraphic,
biostratigraphic,
facies,
& structural
evidence, from the outcrop, to suggest otherwise.

Rather, we'll show that *Ouachita tectonism effecting the Mid-Continent was initiated in Kinderhookian, and continued through Osage time.*

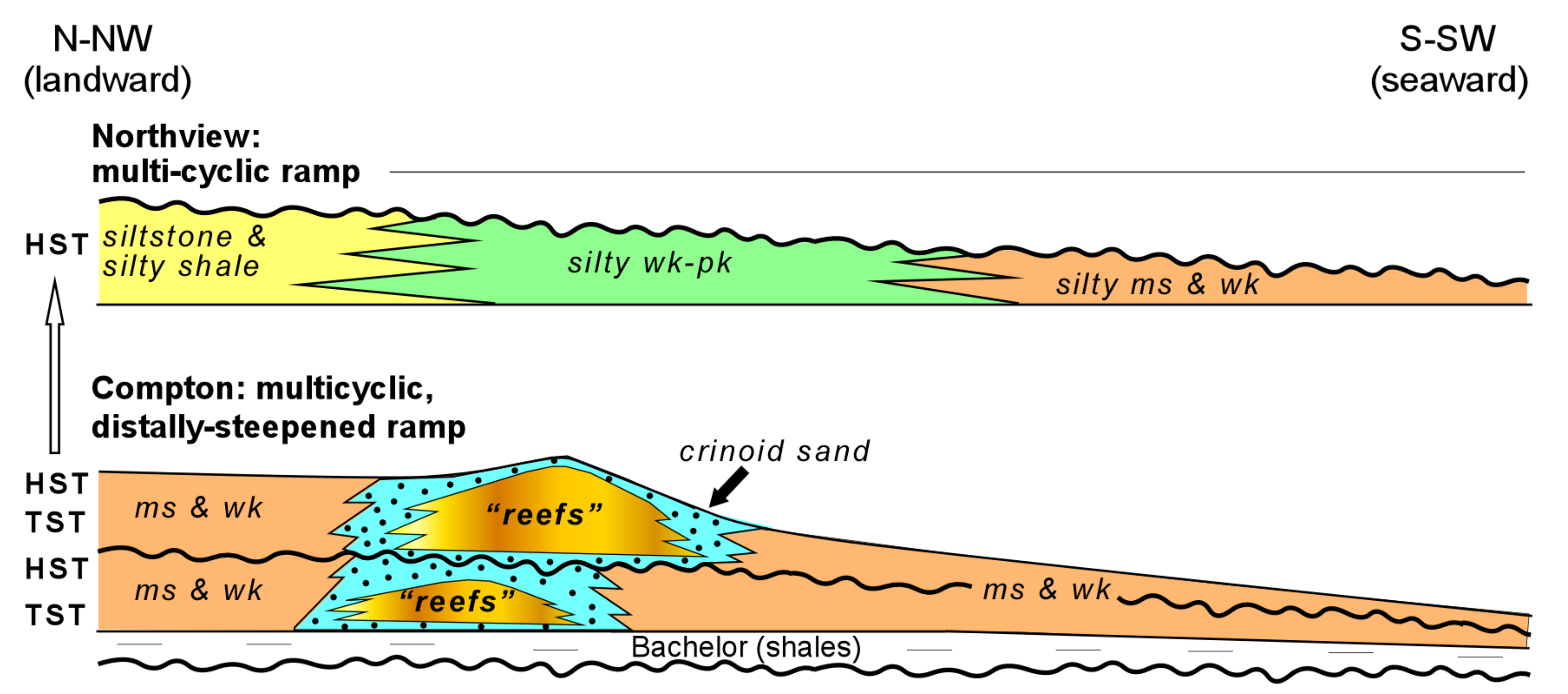
Area of Study



Stratigraphy of the Outcrop Area



Depositional systems of Kinderhookian
COMPTON & NORTHVIEW



Multicyclic, shallow water ramps where platform architecture is aggradational.

Depositional systems of lower Osagean
PIERSON LIMESTONE

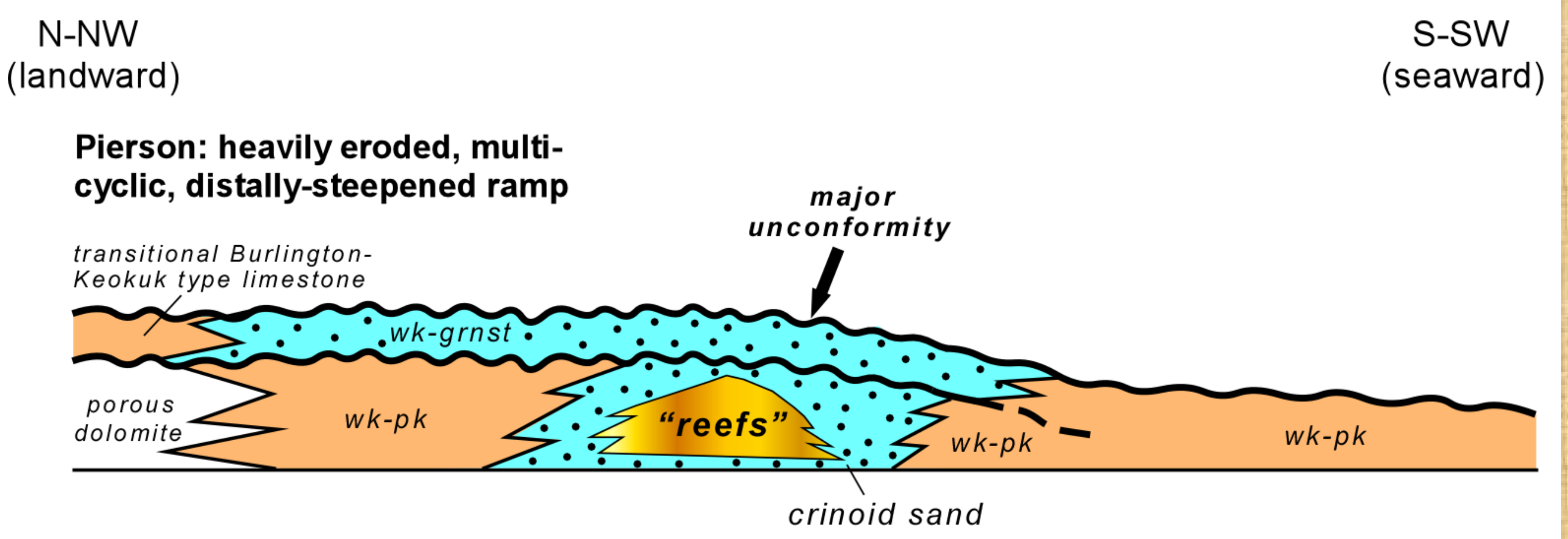
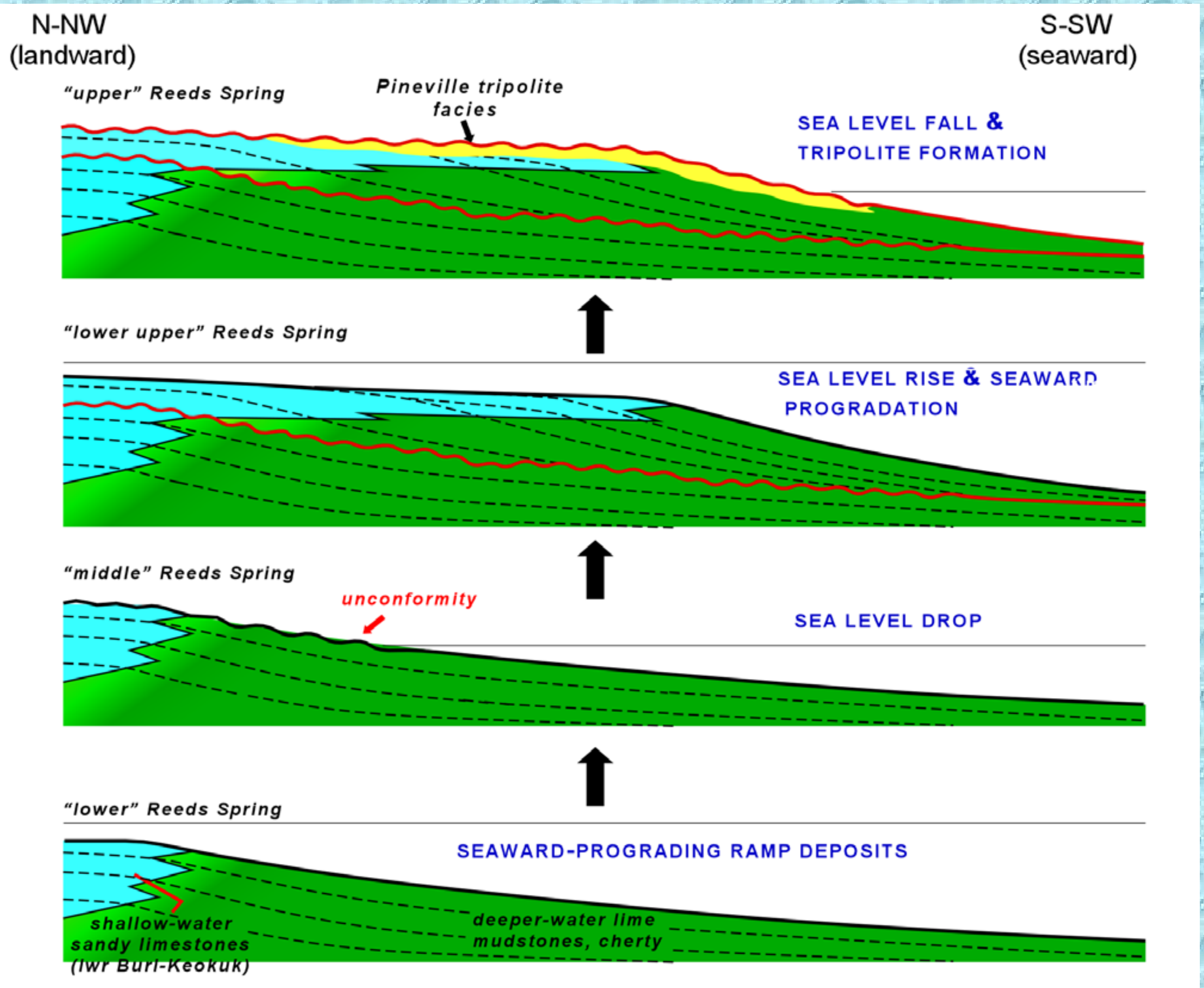


Figure 43. Inferred depositional model and platform architecture of the Pierson Formation in the field area.

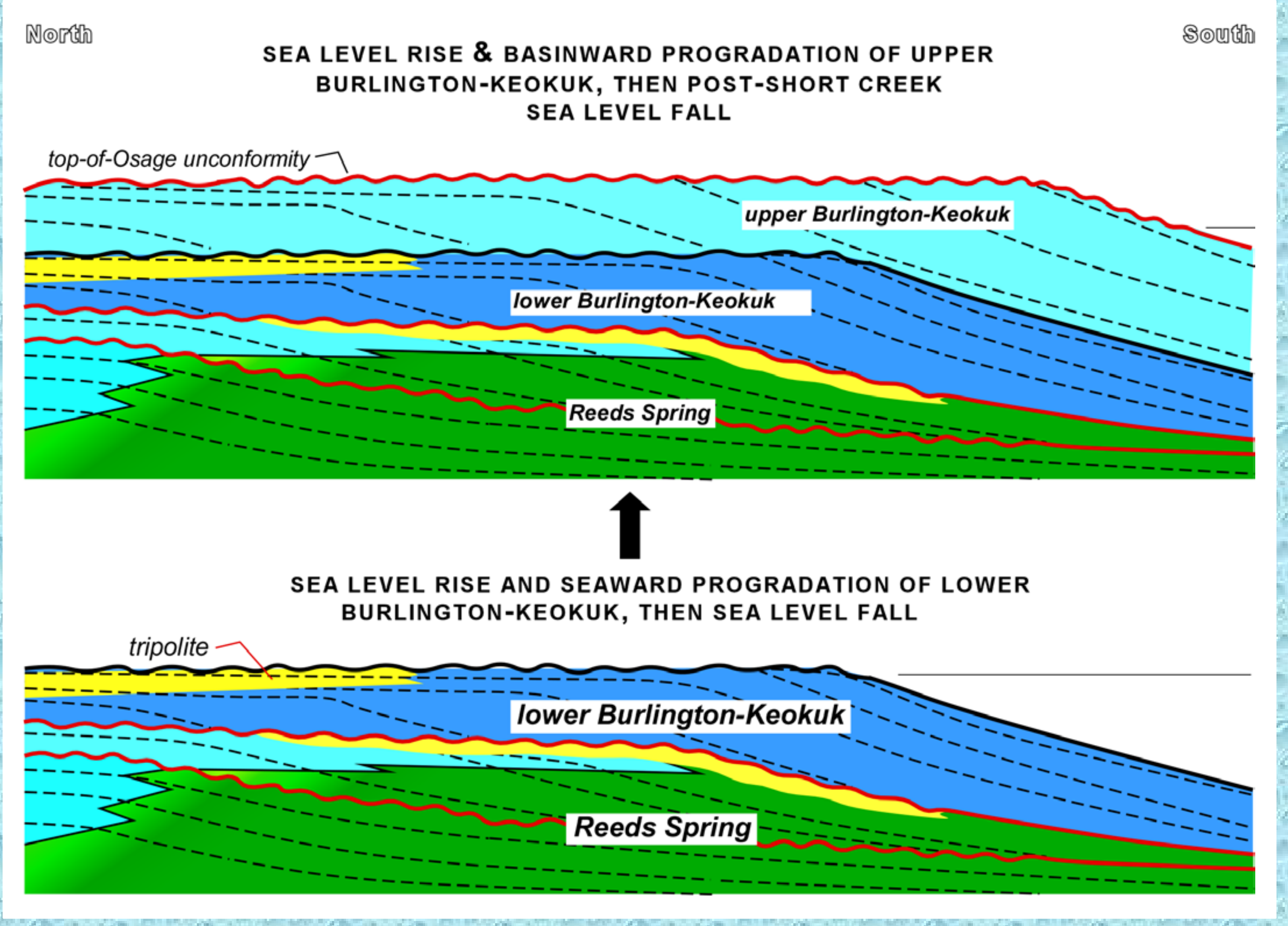
Multicyclic, *distally-steepend* shallow water ramps where platform architecture evolves to a progradational nature.

The Bachelor, Compton, Northview and Pierson are genetically related and make up the St. Joe Group

Depositional systems of Osagean
REEDS SPRING & BURLINGTON-KEOKUK LIMESTONE



Deeper-water muds that grade, updip, into shallow water grainstones of the lower Burlington-Keokuk. Pronounced deeping of the ramp where platform architecture became strongly progradational.

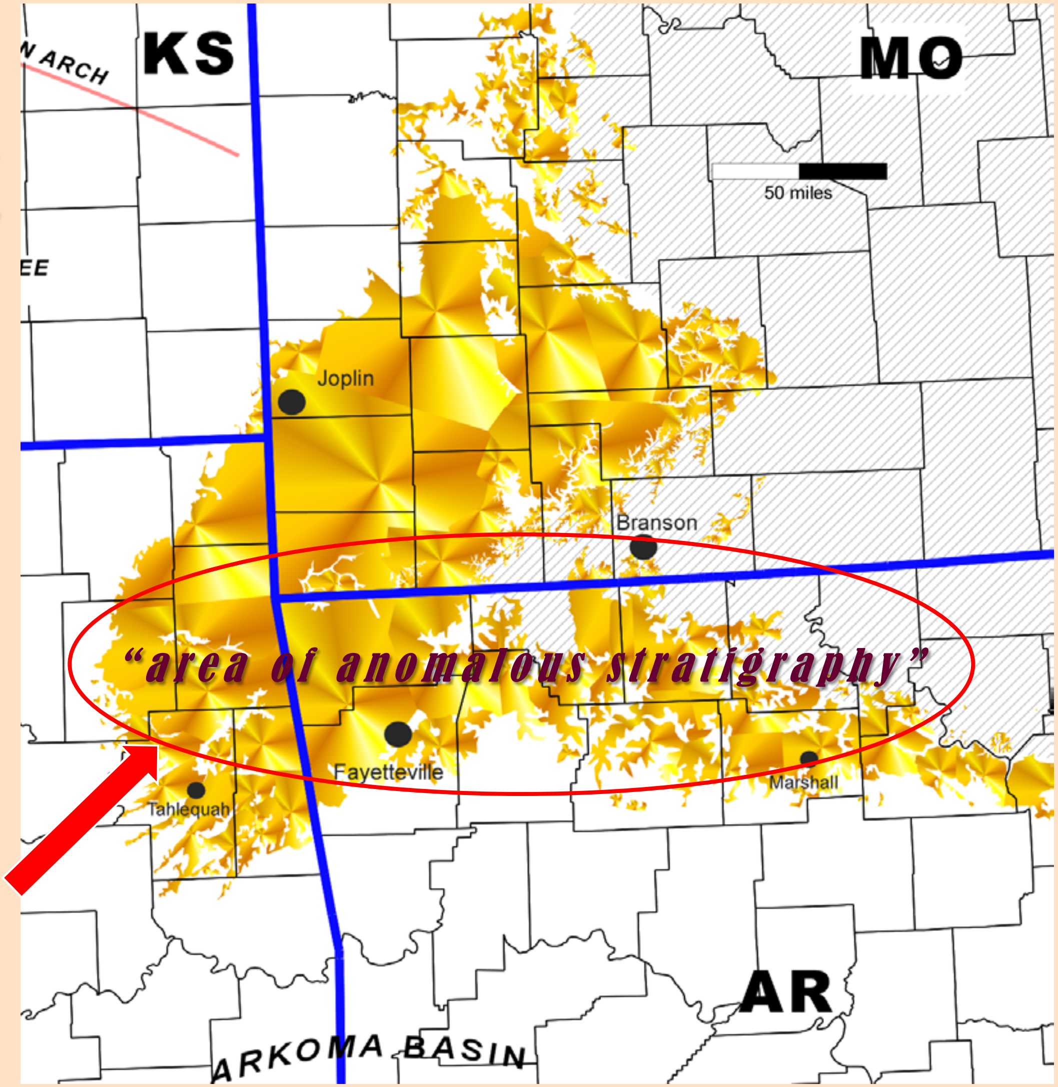


Final progradation of shallow water Burlington-Keokuk Limestone over deeper-water Reeds Spring Limestone.

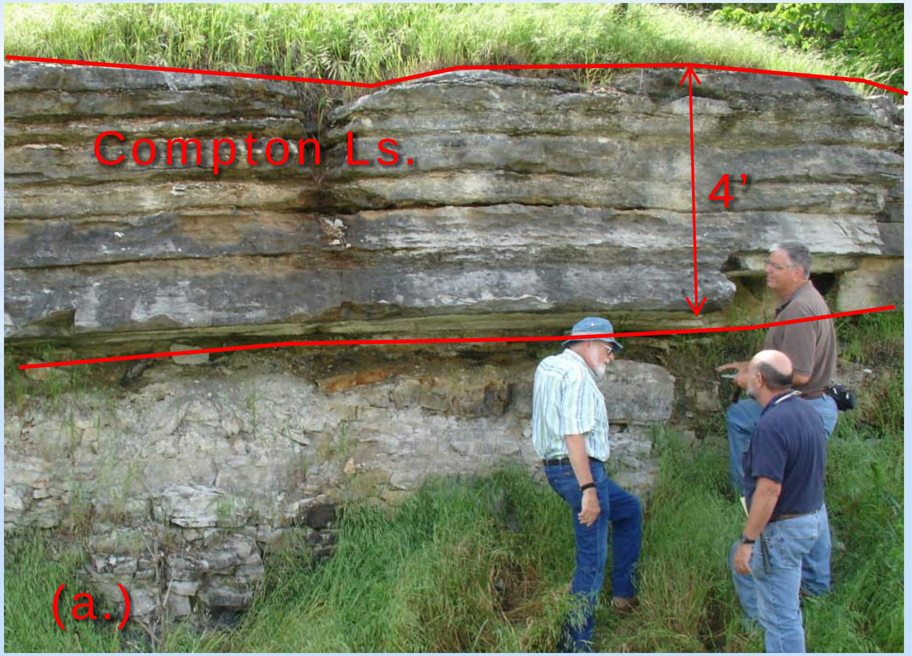
The aforementioned described depositional systems comprise the fundamental sequence-stratigraphic attributes of the lower Mississippian (KH-OS) and are recognized westward into the subsurface.

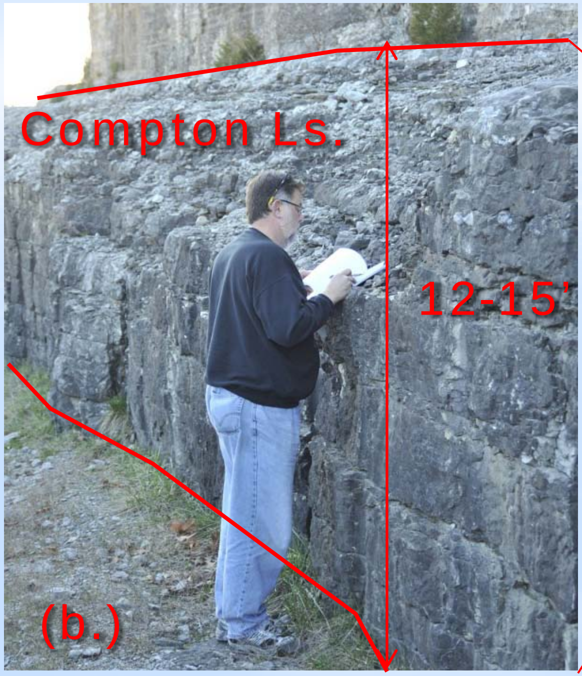
HOWEVER…

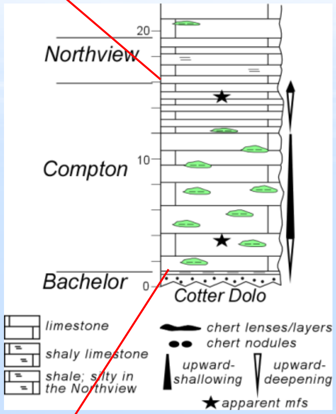
…the Compton through the Burlington-Keokuk show evidence of syndepositional tectonism in the southern part of the study area that overprinted the sequence-stratigraphic architecture of the rocks.

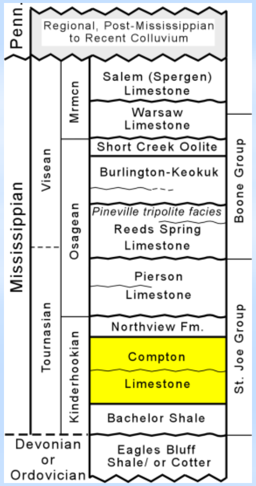


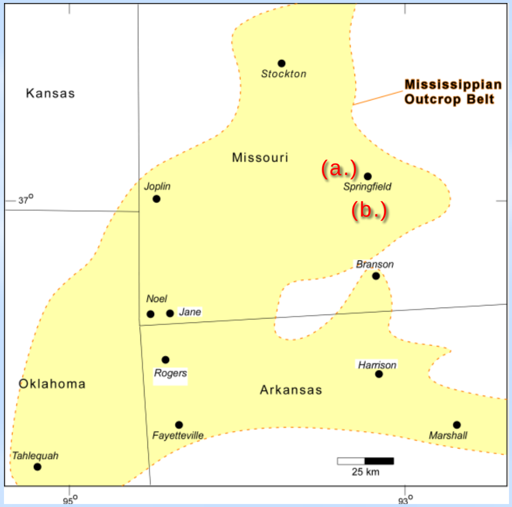
“NORMAL” COMPTON LIMESTONE











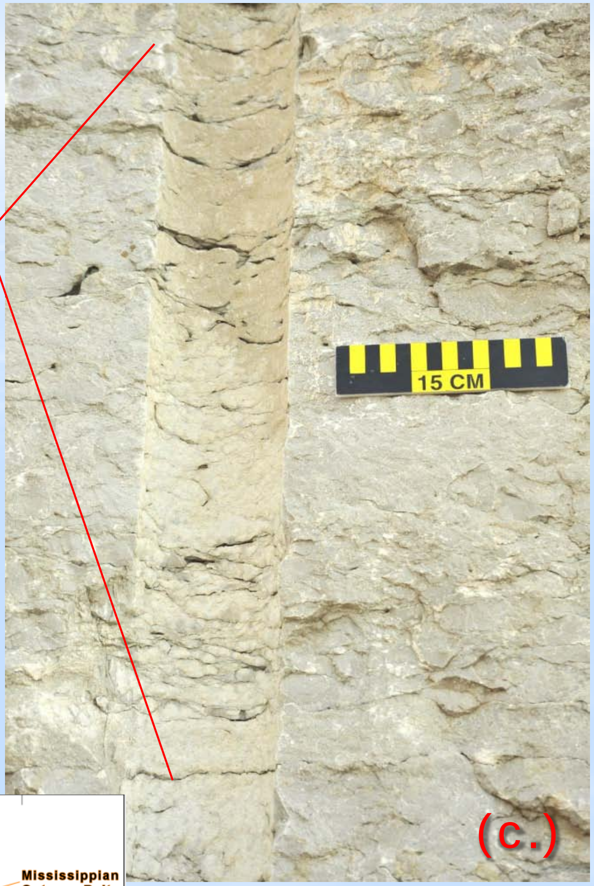
Lithology & Average Thickness

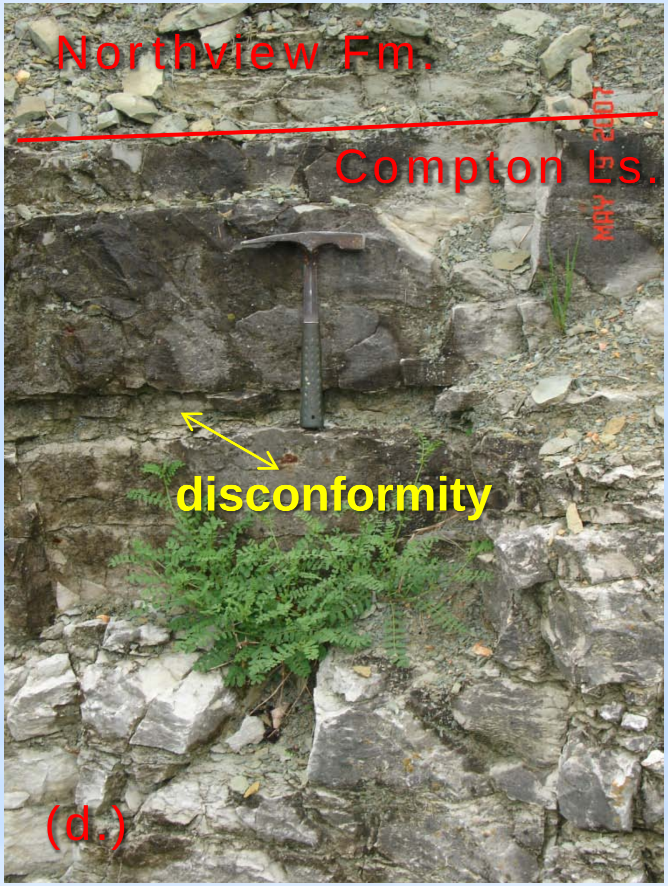
Shallow water lime MS – PS w/green shale wisps.

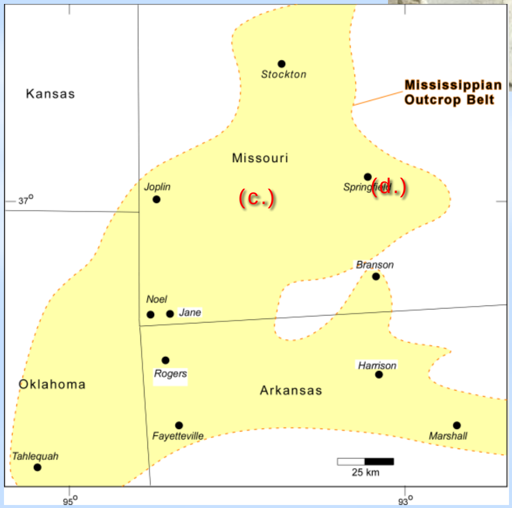
Average thickness 4 - 15 feet.

"NORMAL" COMPTON LIMESTONE

Limestone-clast conglomerate at disconformity

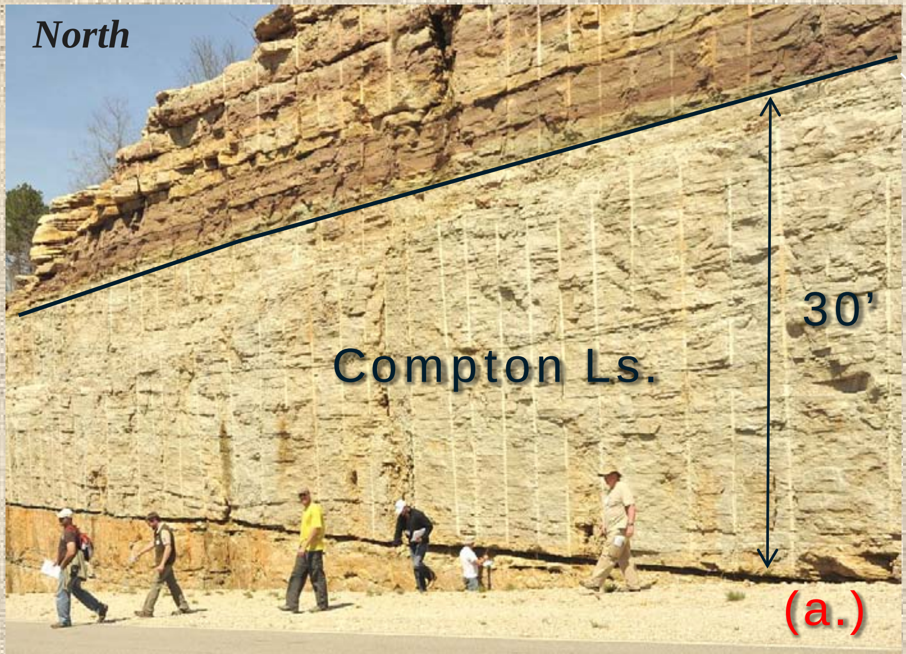


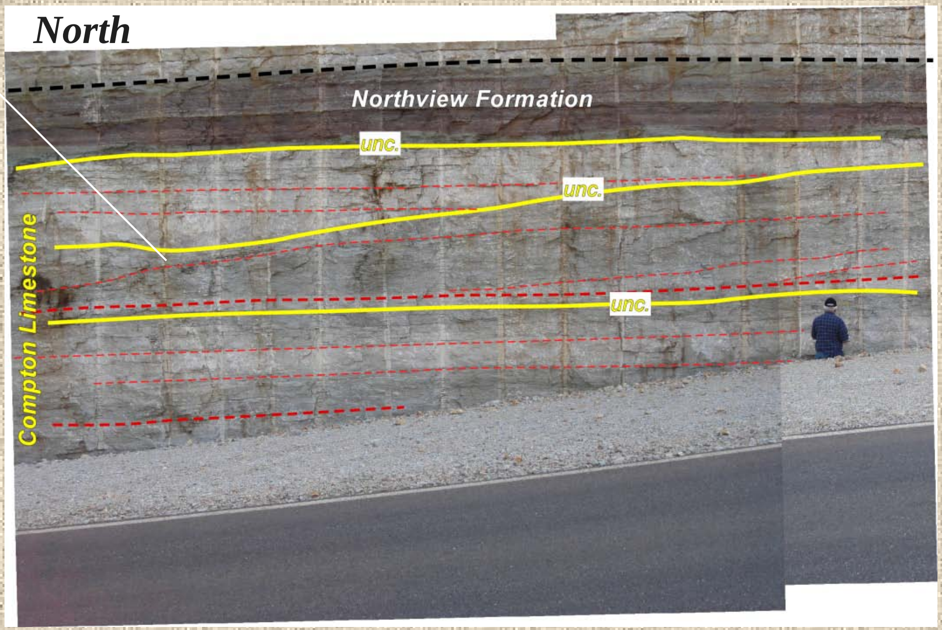




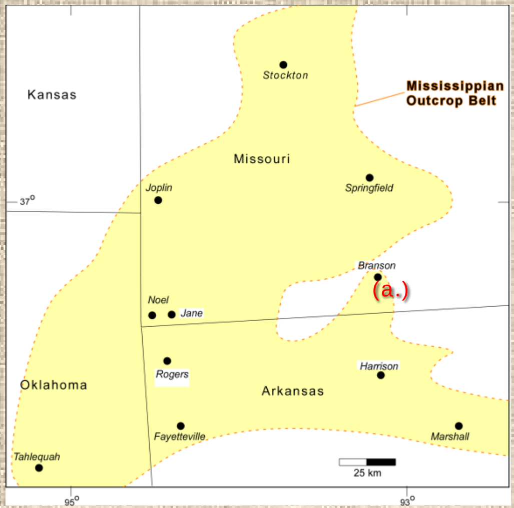
Regional disconformity variously indicated by limestone-clast conglomerate, red and green shale, or quartz sand

"ANOMALOUS" COMPTON LIMESTONE





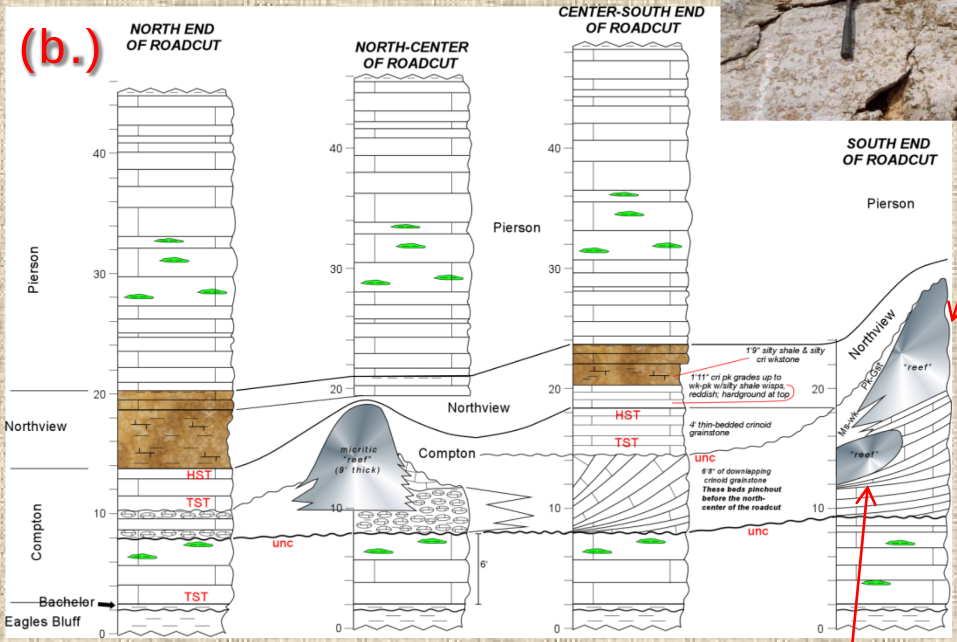
Here, the Compton is separated from the Northview by a low-angle, angular unconformity. Elsewhere, the upper Compton is part of an HST that *includes* the Northview.

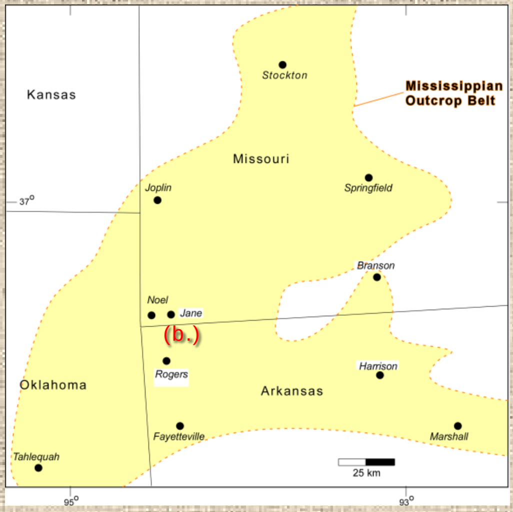


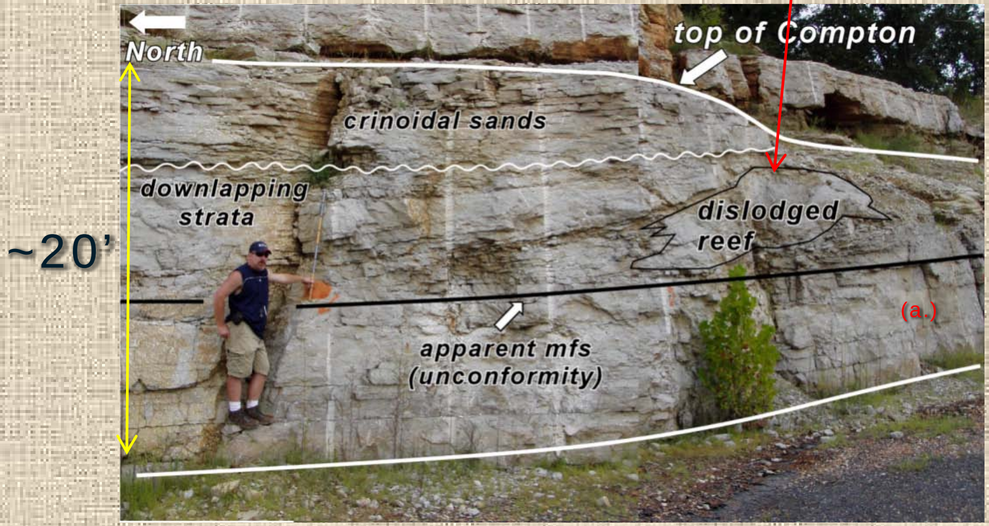
*18 – 30+ feet of very shallow-water, coarse, crinoid grainstones with numerous unconformities and downlapping units that prograde **northward**......counter to, presumed, regional paleodip!*

"ANOMALOUS" COMPTON LIMESTONE

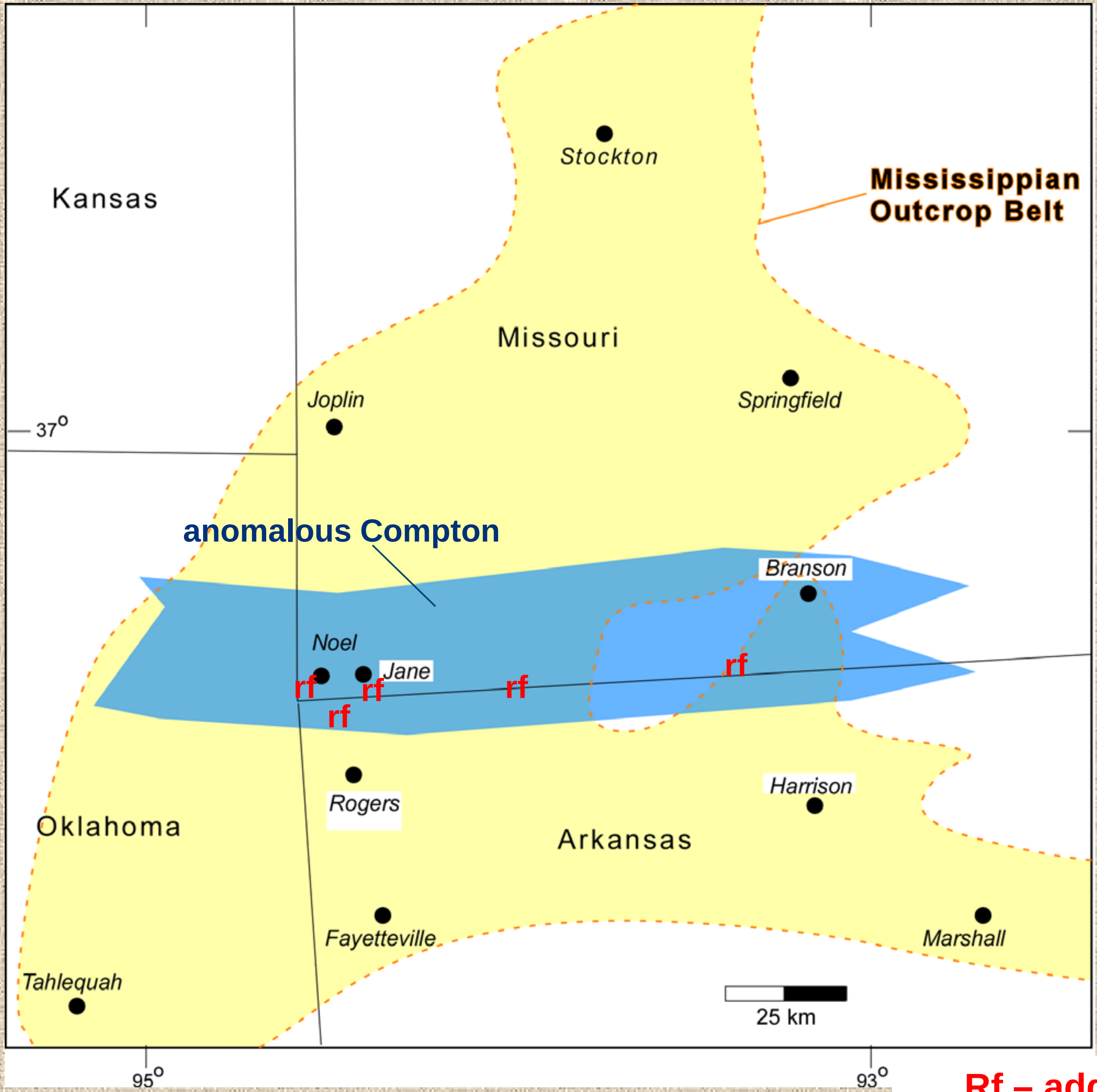
Micritic buildups occur within the crinoid sands and are common in this belt; they too downlap to the north (!) with multiple unconformites within the Compton – here, with evidence of vadose exposure (brown silt-filled vugs).





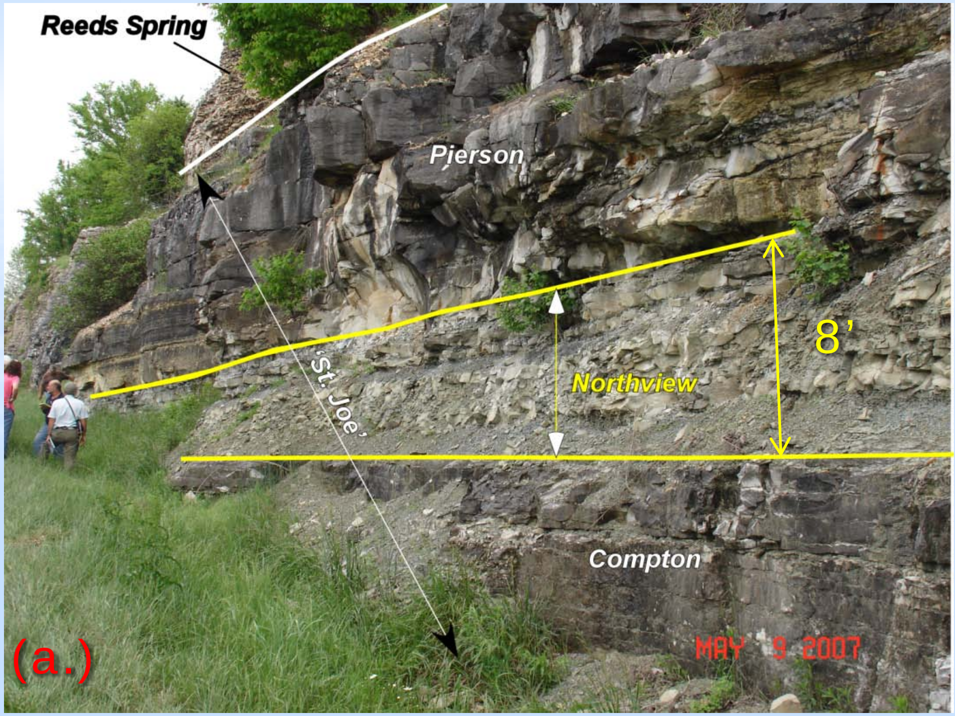


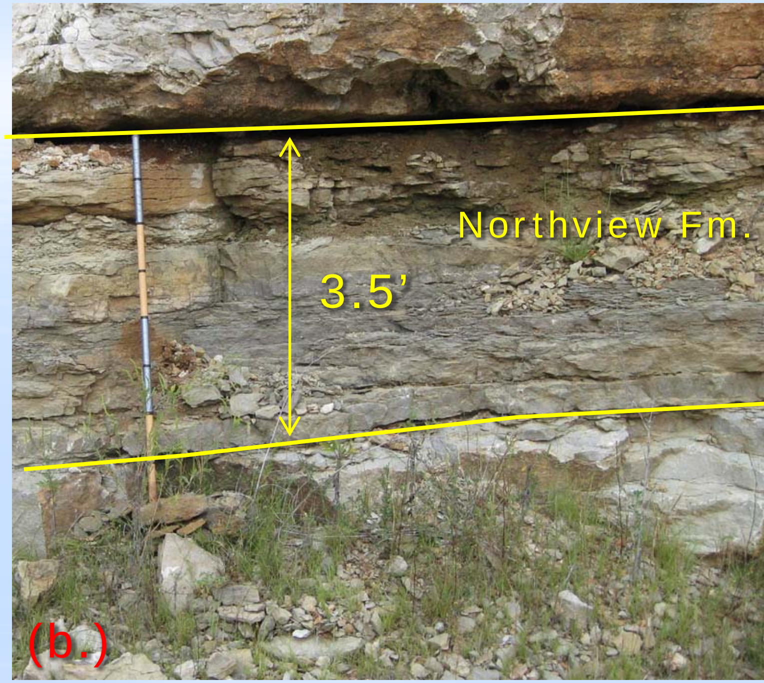
"ANOMALOUS" COMPTON *BELT*

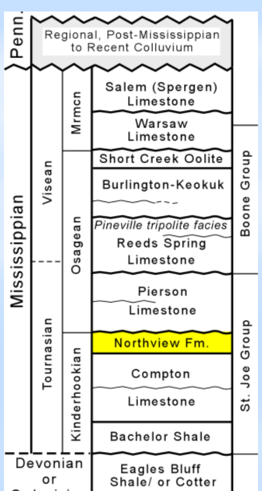


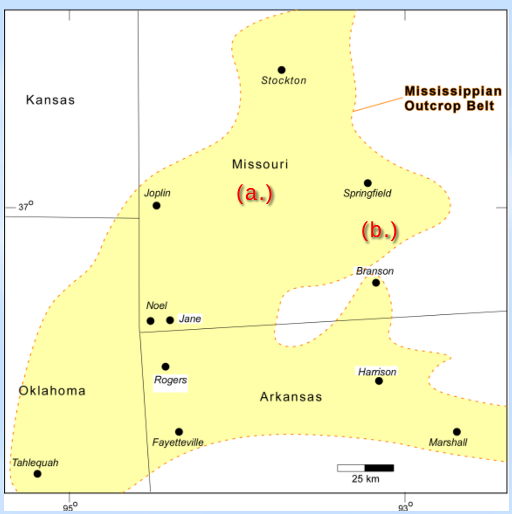
Rf – addional reefs

"NORMAL" NORTHVIEW FM.









Lithology & Average Thickness

Mixed lithologies of shale, silty shales, siltstones, argillaceous limestone and limestone. These deposits represent shallow (shallower than Cptn) water deposition. Average thickness 2 – 8' feet.

"ANOMALOUS" NORTHVIEW FORMATION

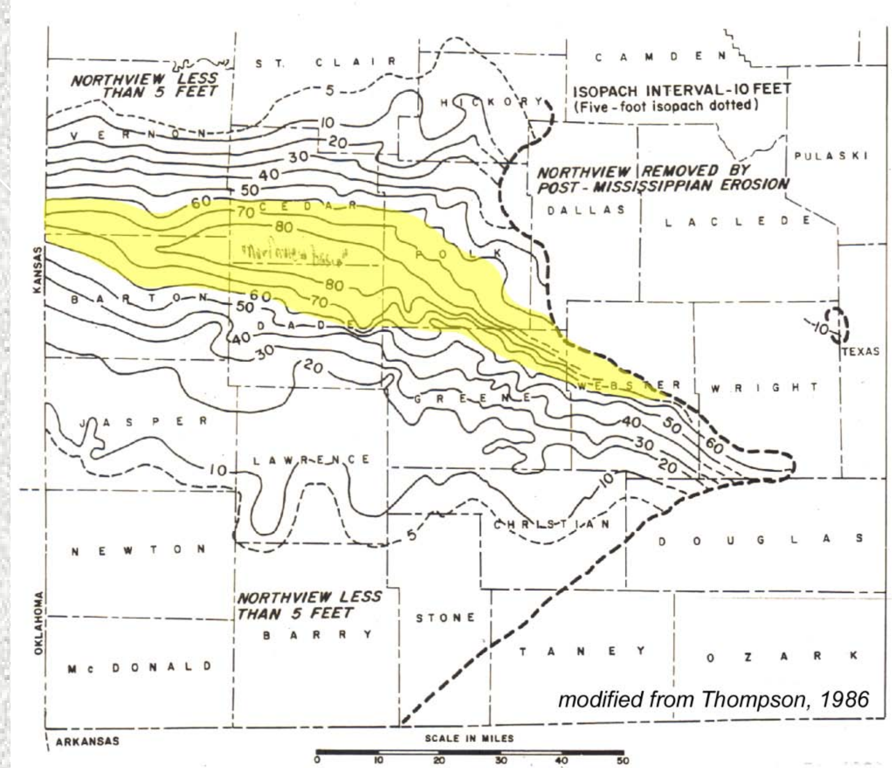
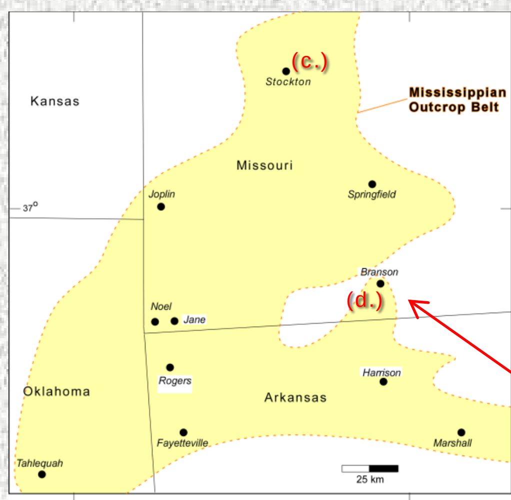


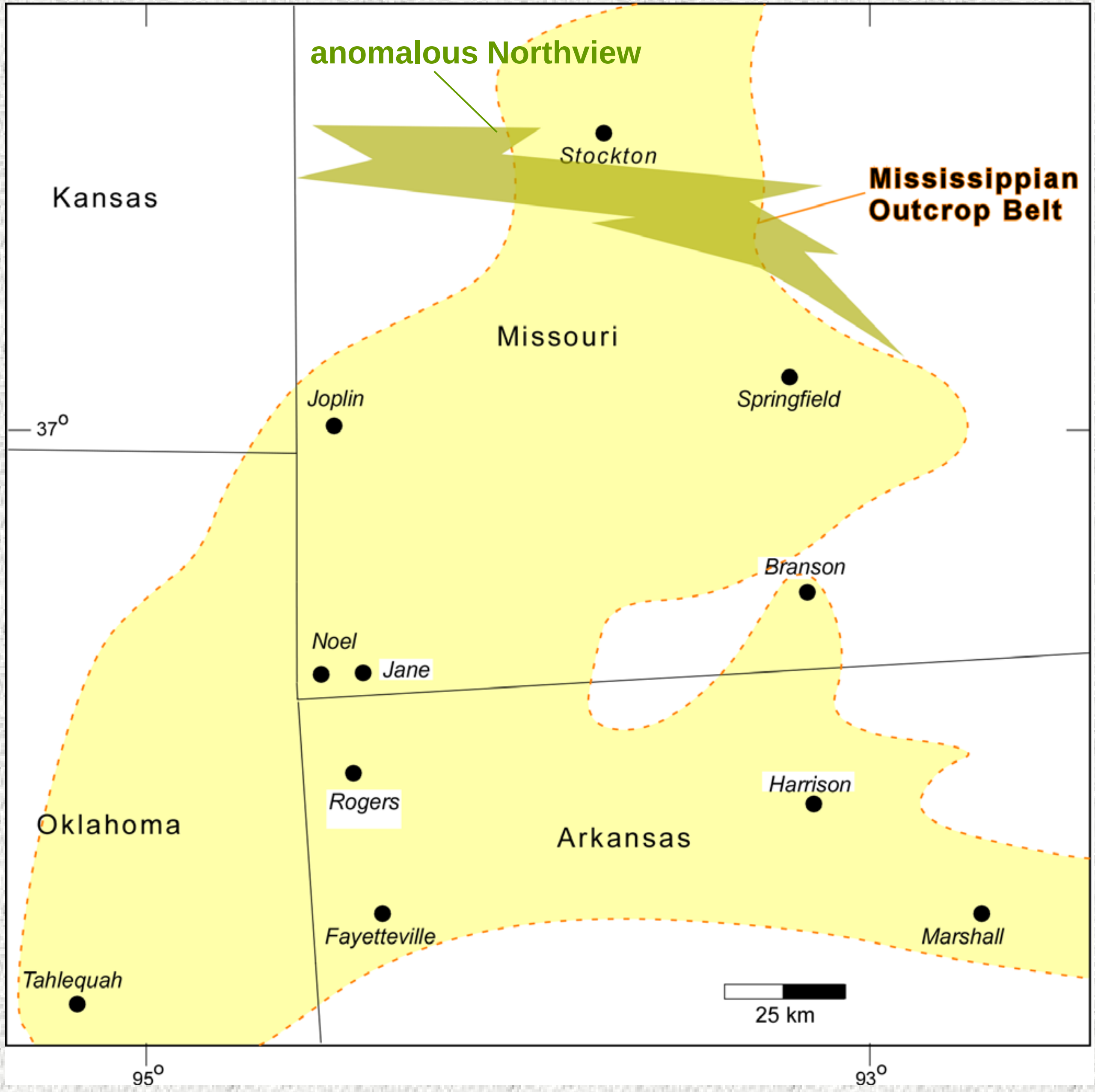
Figure 51. *Isopach map of the* **Northview Formation** *in southwestern Missouri, showing position of the "Northview basin." Adapted from Beveridge and Clark (1952, fig. 3).*



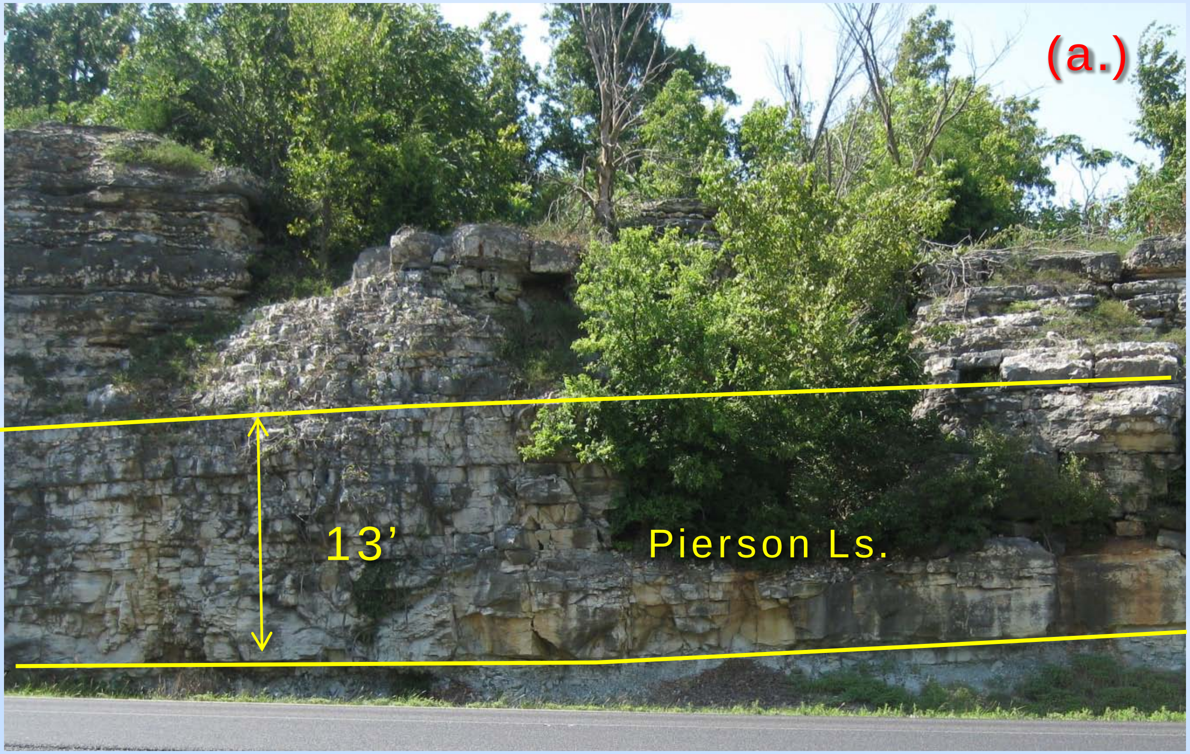
50 – 80+' of siltstones and shaly siltstones of shallow-marine nearshore origin deposited in a, more-or-less, east-west trending trough.

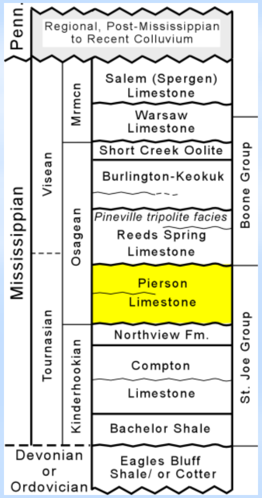
Note, locality "d" in the adjoining map shows the area at which paleosols were recorded in the Northview Formation.

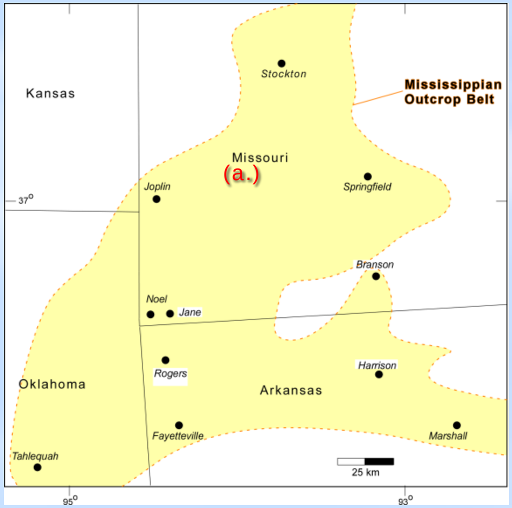
“ANOMALOUS” NORTHVIEW *BELT*



"NORMAL" PIERSON LIMESTONE



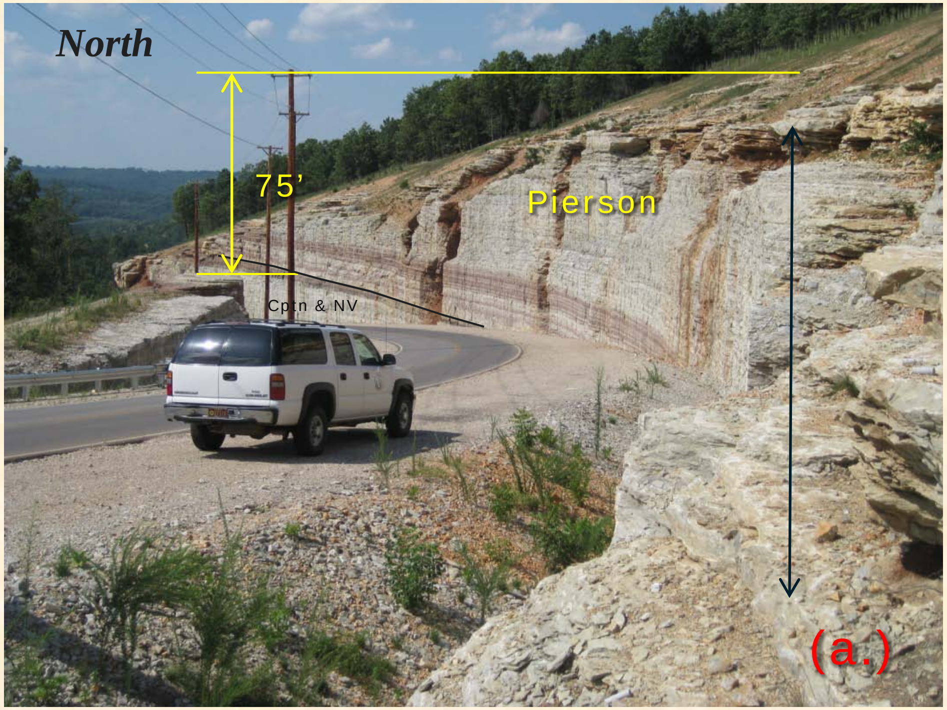


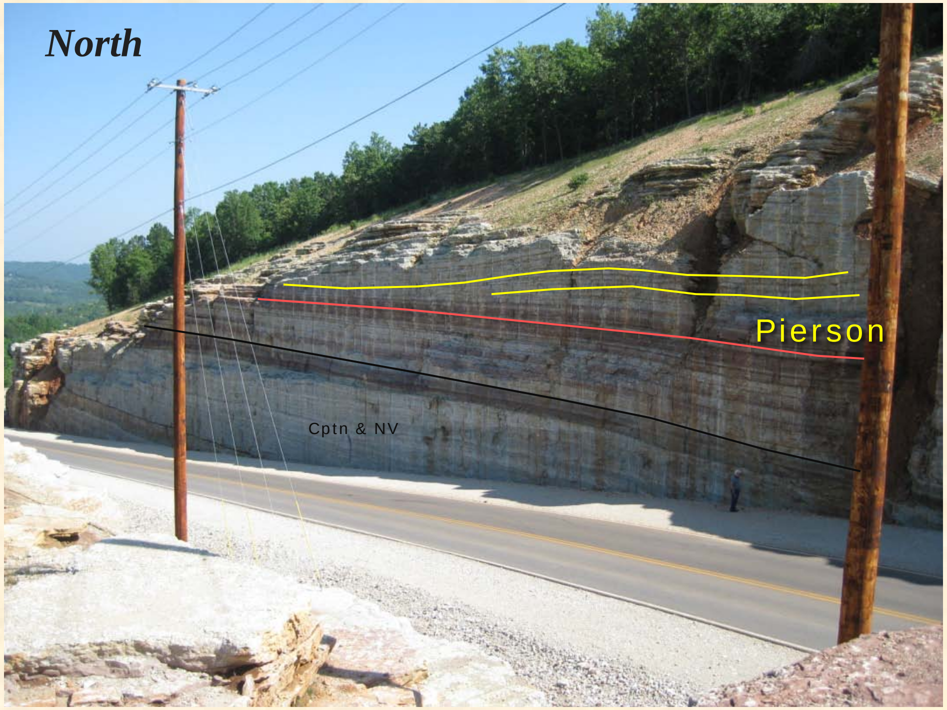


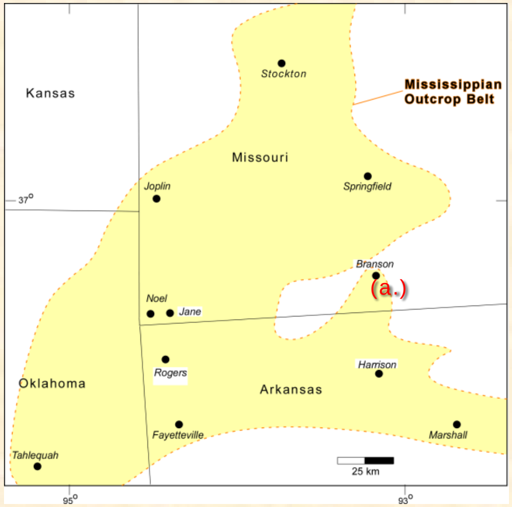
Lithology & Average Thickness

The Pierson is composed of relatively shallow-water lime MS-PS, and in the northern part of the study area, dolomitic. Average thickness 4 -18 feet.

"ANOMALOUS" PIERSON LIMESTONE

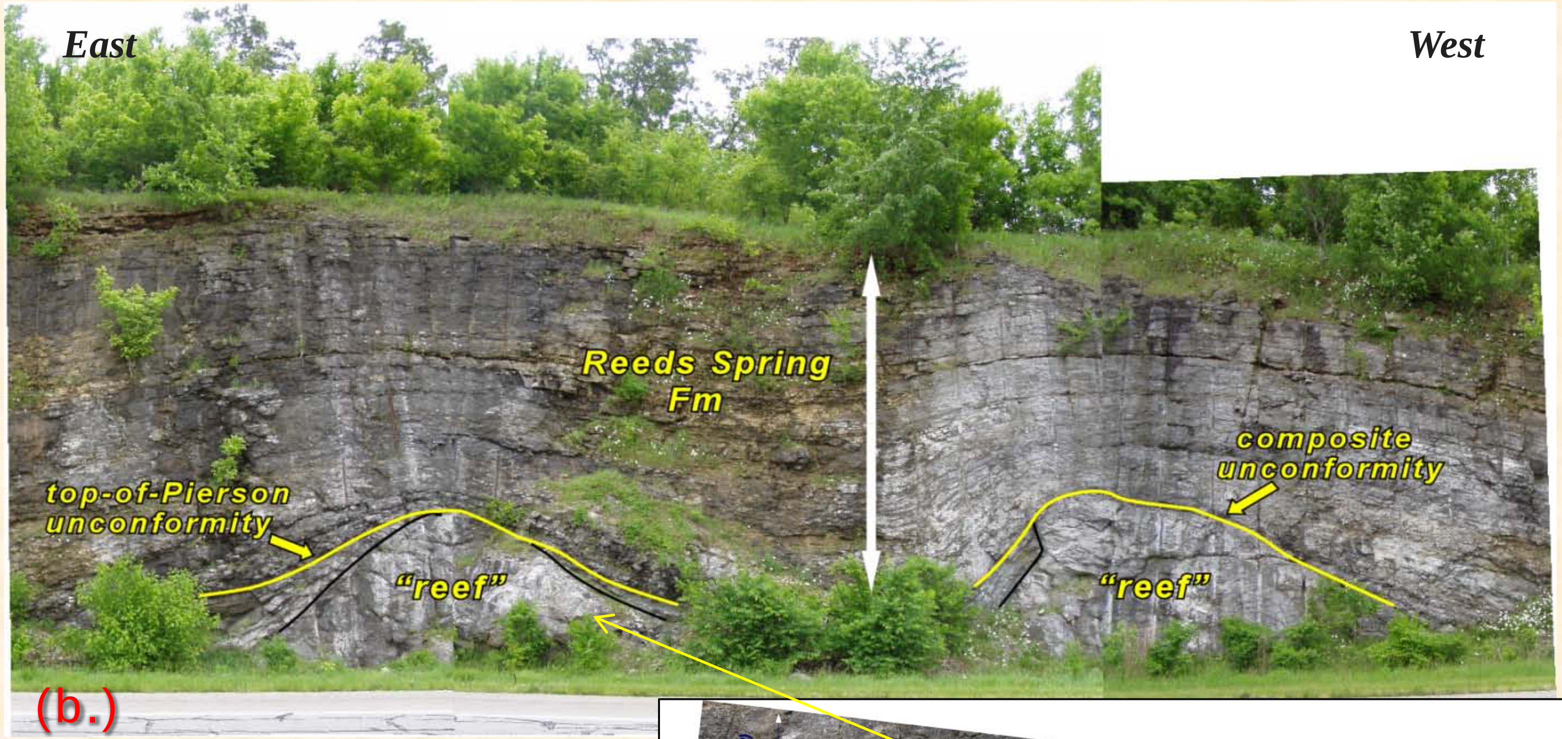


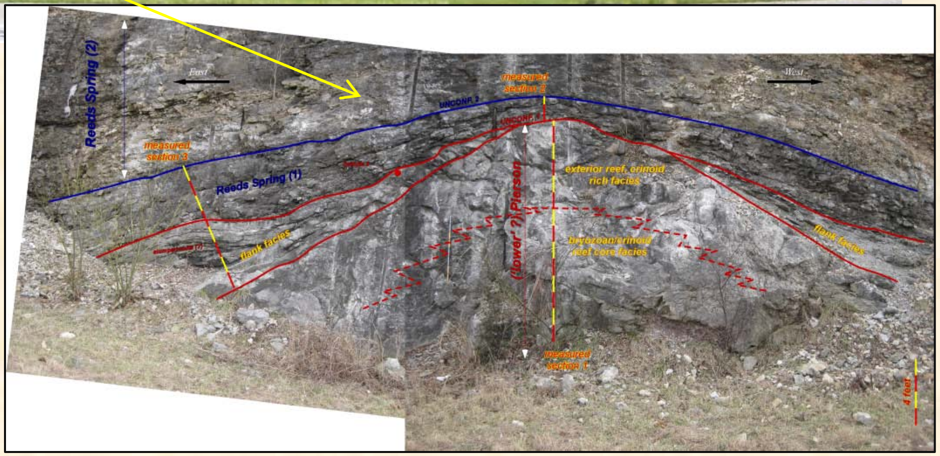


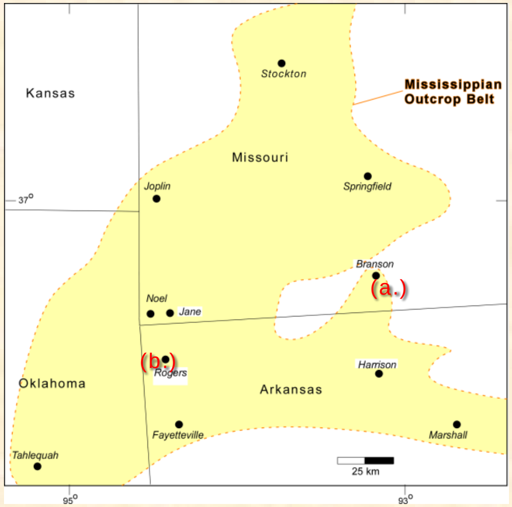


45 - 75+ feet of very shallow-water, coarse-very coarse, crinoid grainstones that downlap and prograde ***northward.***

"ANOMALOUS" PIERSON LIMESTONE





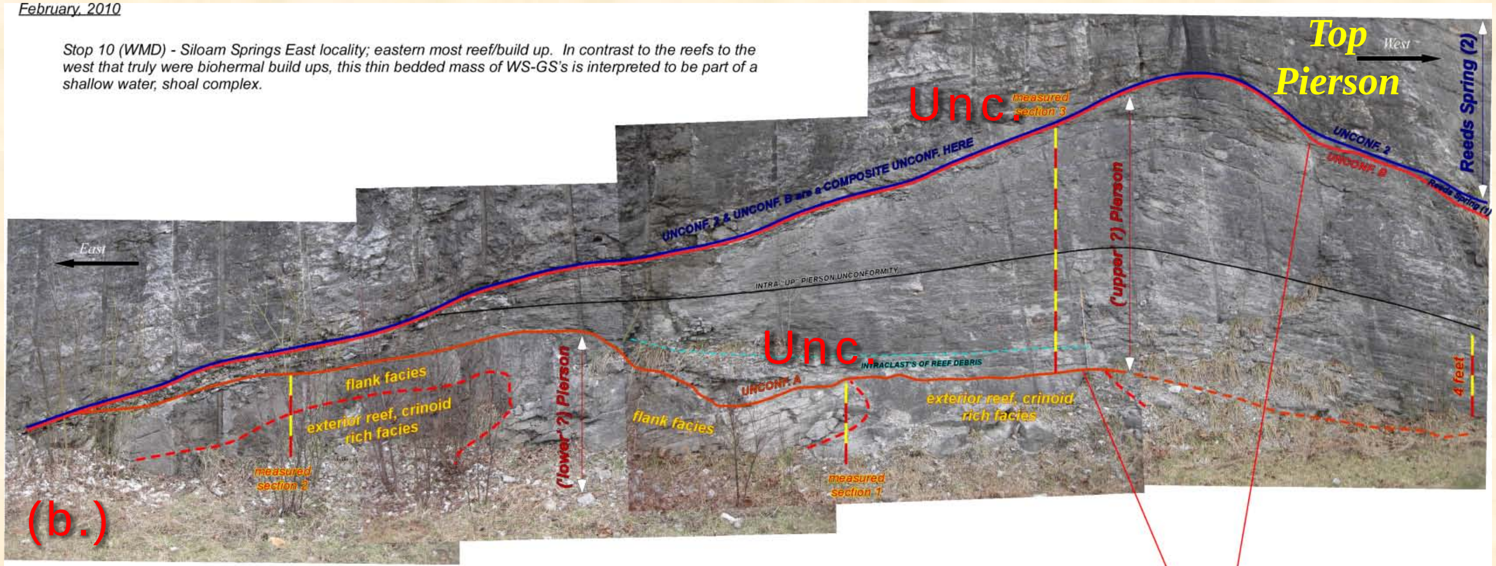


Bryozoan cored reefs with intra-formational unconformities.

“ANOMALOUS” PIERSON LIMESTONE

February, 2010

Stop 10 (WMD) - Siloam Springs East locality; eastern most reef/build up. In contrast to the reefs to the west that truly were biohermal build ups, this thin bedded mass of WS-GS's is interpreted to be part of a shallow water, shoal complex.



15 - 30' Reeds Spring "2": (thickness from photos) as described previously with the western & middle reef, with a sliver of Reeds Spring "1" on the western edge.

REEDS SPRING

PIERSON

2' 6" - 9' 6" (from measured sections 3) thin to medium bedded, medium to dark gray alternating lithologies of wackestone and packstone with various sizes, small to large, crinoids and oxidized marcasite. Thin lenses and wisps of green to greenish gray shale are present however, less abundant than below. In contrast to the previously described unit, the chert here is different and more plentiful. The chert occurs as blebs and discontinuous bands (2-4" thick) of dark gray/bluish gray to black mottled chert with a relative abundance of crinoid debris. According to Beau, after scaling and walking out this section, the overall limestone lithology shallows upward in the section as the units become more of a packstone to grainstone. This unit is truncated by ***unconformities B & 2.***

2' 6" - 3' 6" (from measured sections 3) thin bedded (2-3") medium to dark gray wackestone with lenses of packstones composed of various size, small to large, crinoids. Thin lenses and wisps of green to greenish gray shale are present and occur between the thin bedded limestones. Chert is sparsely disseminated throughout the section as thin 1-2" discontinuous bands of very dark gray chert with light gray interiors a very few crinoids. It was noted that the chert bands were truncated on the east side and hence, the intra-'upper' Pierson ***unconformity; submarine erosion****?*

1' 6" (from measured sections 3) thin to medium bedded (2-5") of medium gray crinoid wackstone to packstone with thin green to green-gray fossiliferousshale wisps; some shales are more continuous and up to 1/2 - 3/4" thick. This section grade upward into--

0' 10" - 1' 8" (from measured sections 3) thin bedded (2-3") of light to medium gray crinoid packstone to grainstone, medium grained (with some larger fragments) and oxidized marcasite. The thin limestone units are separated by 1/4" to 2" thick greenish-gray fossiliferous shale beds with crinoids; the basal shale on the unconformity is upwards of 3" thick. Throughout this interval there are quarter to softball sized clasts of reef crest and/or flank bed facies composed primarily of crinoid P-G. Some of the clasts are dark gray muddy wackestone; source? possibly the outer 2-3" rim of wackestone record- ... ward into--

'upper' Pierson

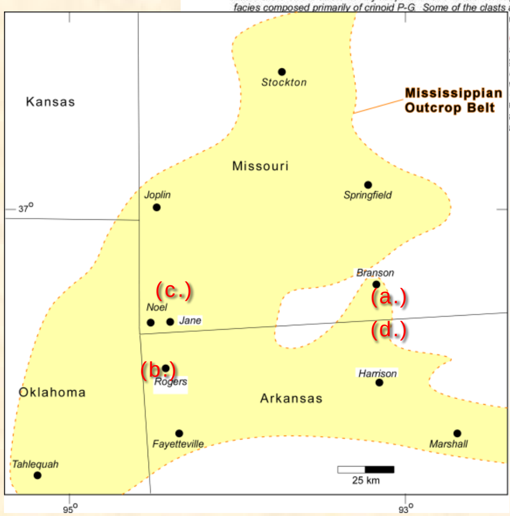
... ns 1&2) the flank beds between the measure sections consist of medium bedded (2-6") light ... s, all separated by thin greenish gray shale and shale wisps. Those overlying the reef in ... gray wackestone with various sized (some very large) crinoid grains, and some thin discon- ... n what we feel is an oblique view at possibly 2 different reefs it was tough to outline accu- ... facies too are truncated by ***Unconformity A****.*

... nassive, non-bedded light gray crinoid packstone to grainstones, med to coarse grained, and ... tern reefs it is inferred that these facies are truncated (by ***Unconformity A****) exterior or reef ... l above.*

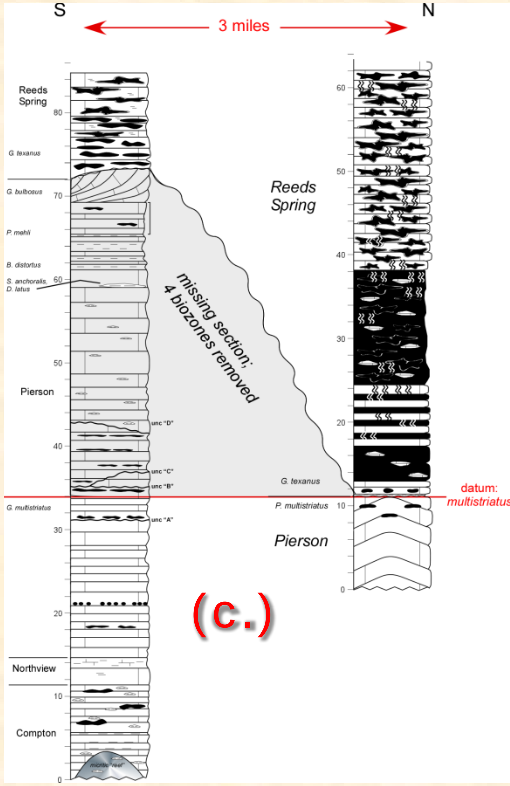
'lower' Pierson

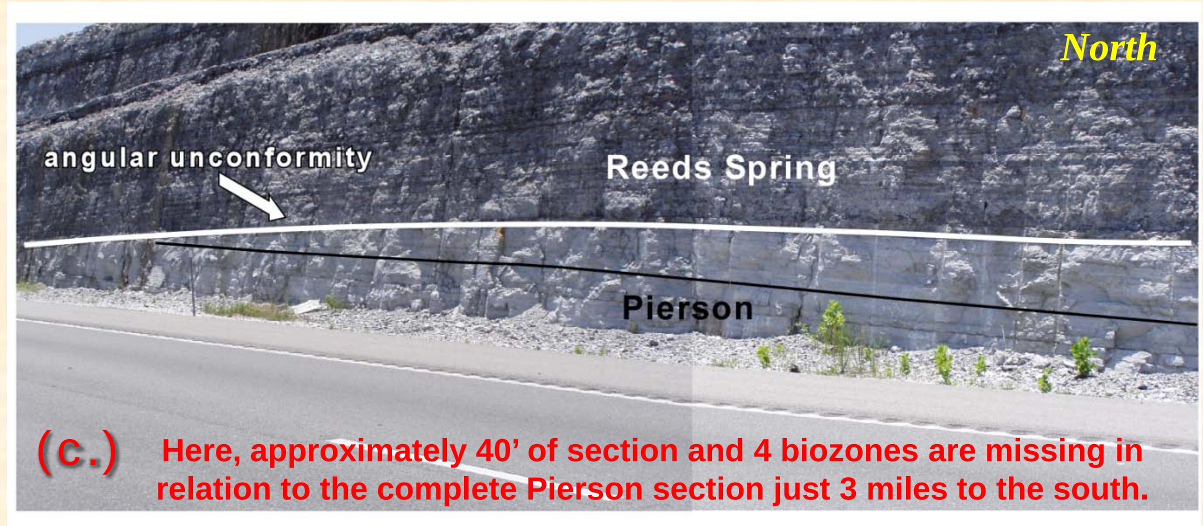
Based or correlation and recognition of unit specific lithologies, it is our opinion and interpretation that Unconformities B and A, shown here, become one composite unconformity behind/beneath the talus slope just to the west of this photo and correlates to Unconformity 1 shown in the previous reef descriptions. Basis for this is, the lack of 'upper' Pierson lithologies are seemingly missing to the west.*

**Note: with the possible exception in the vicinity of the small reef between this locality and the western reefs, where crin PS-GS with black chert was found overlying reef flank facies and was capped by Reeds Spring.*

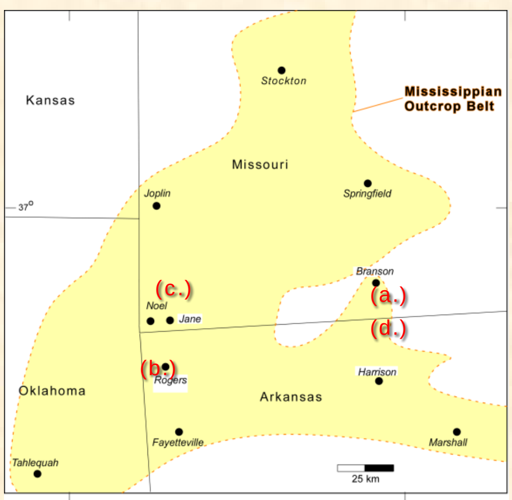


"ANOMALOUS" PIERSON LIMESTONE

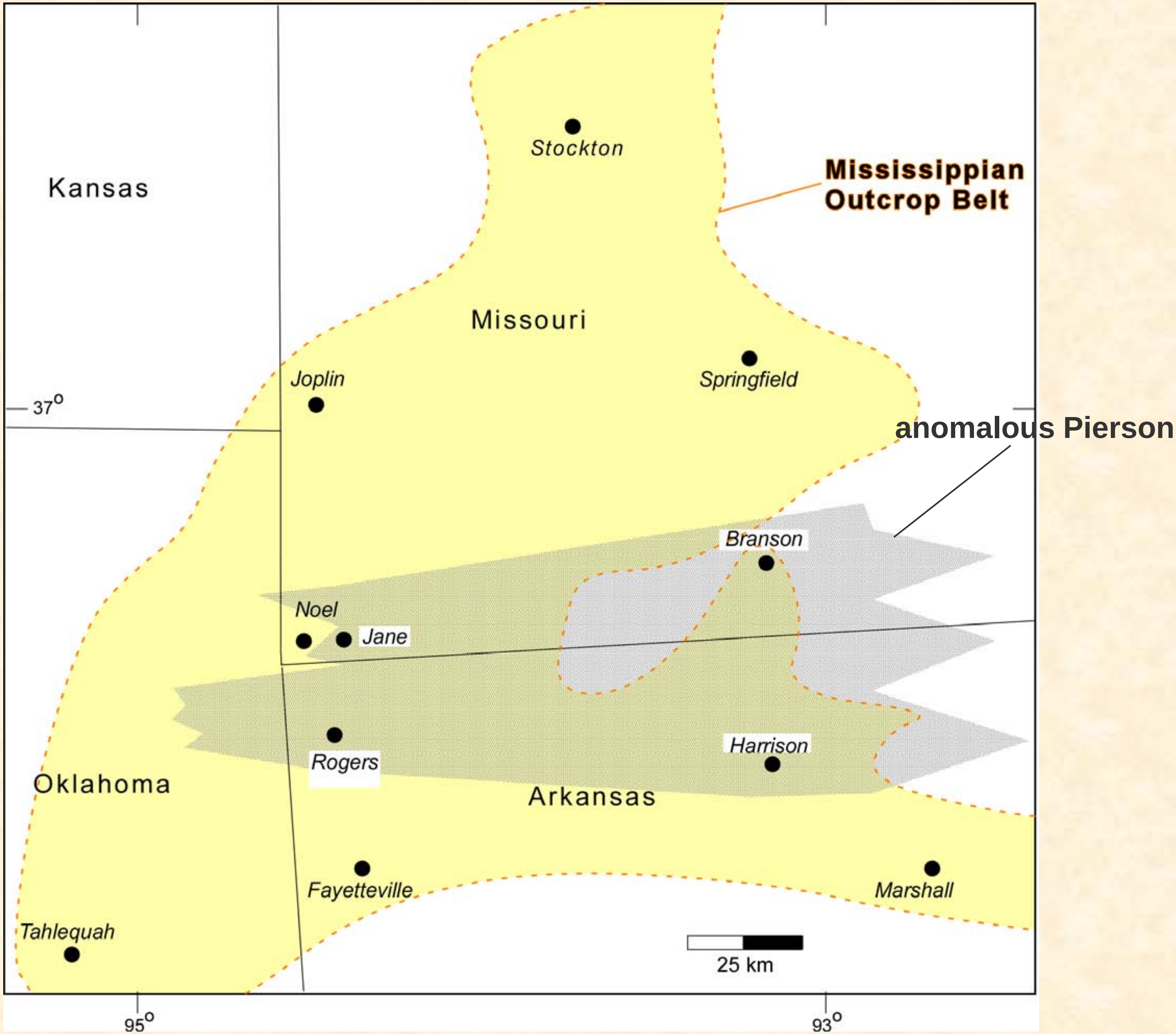




Angular unconformities at the top of the Pierson; breached ***East-West*** *trending anticlines!*

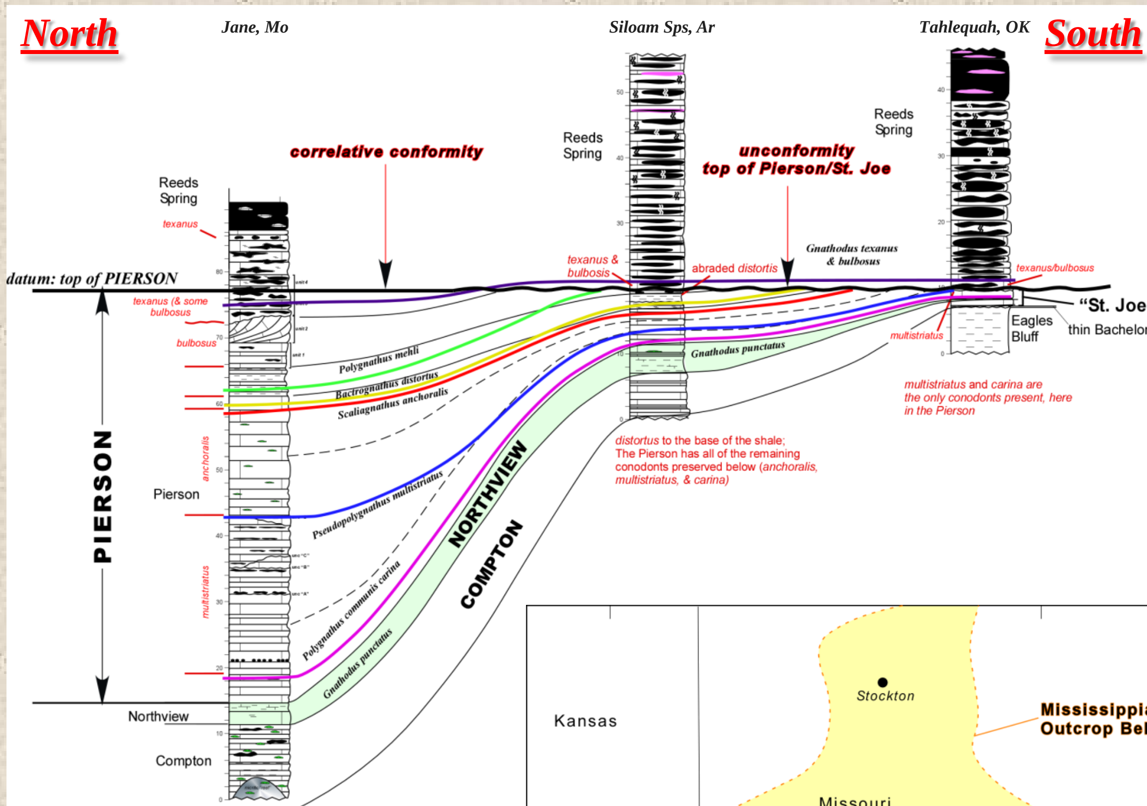


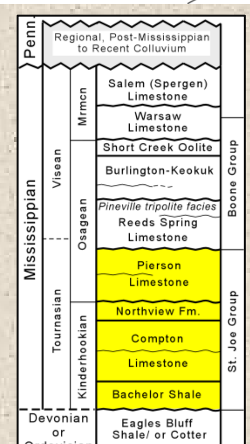
“ANOMALOUS” PIERSON *BELT*

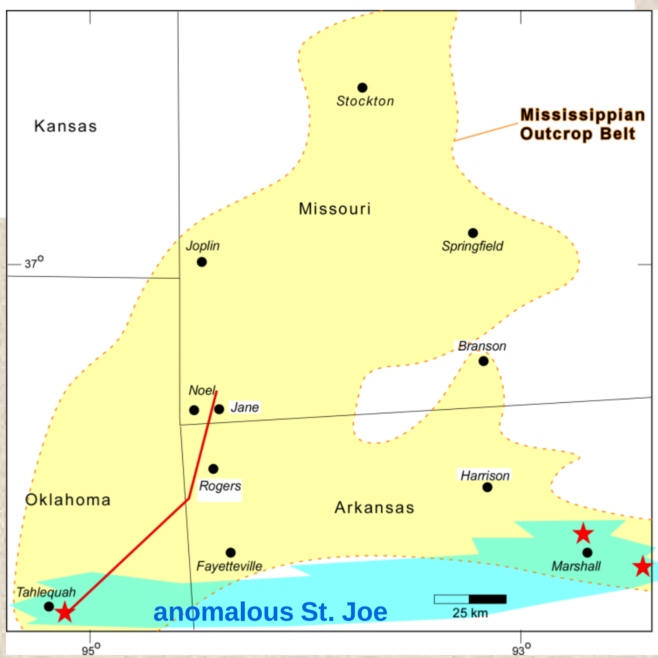


"ANOMALOUS" ST. JOE (Bachelor, Compton, Northview, Pierson)

These Kinderhookian and basal Osagean units represent an overall lower order sequence composed of 3, regional, higher frequency T-R cycles.







Not only do the units of the St. Joe erosional thin to the south, they also depositional thin (avg. 3.5', total) ***and maintain their shallow-water characteristics!!*** *These units are NOT condensed. In addition, soil pisolites are typically seen at the top of the St. Joe, beneath the next sequence of Reeds Spring/Burlington-Keokuk.*

....this greatly contrasts the existing models....

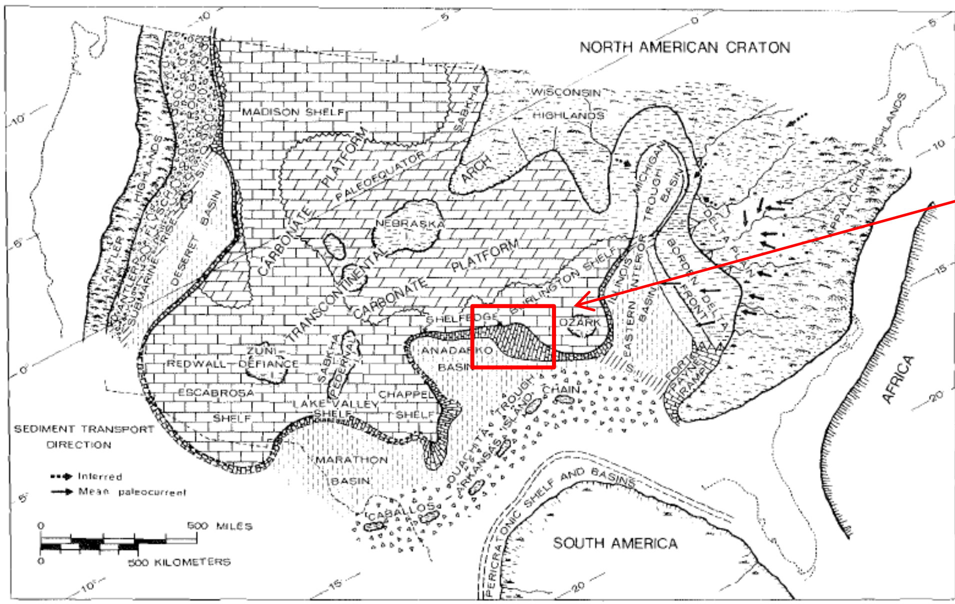
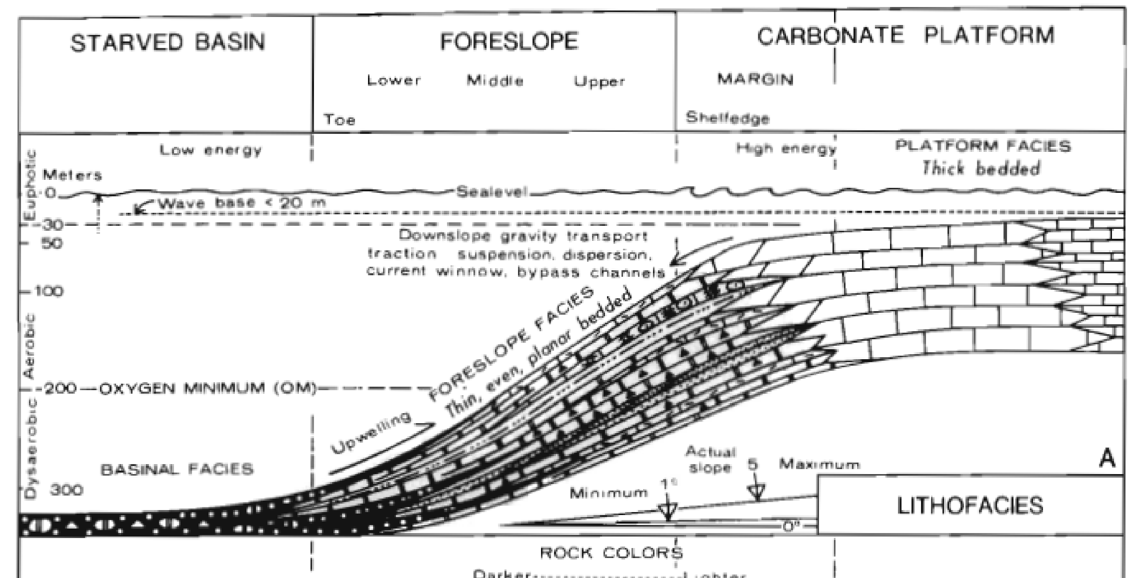


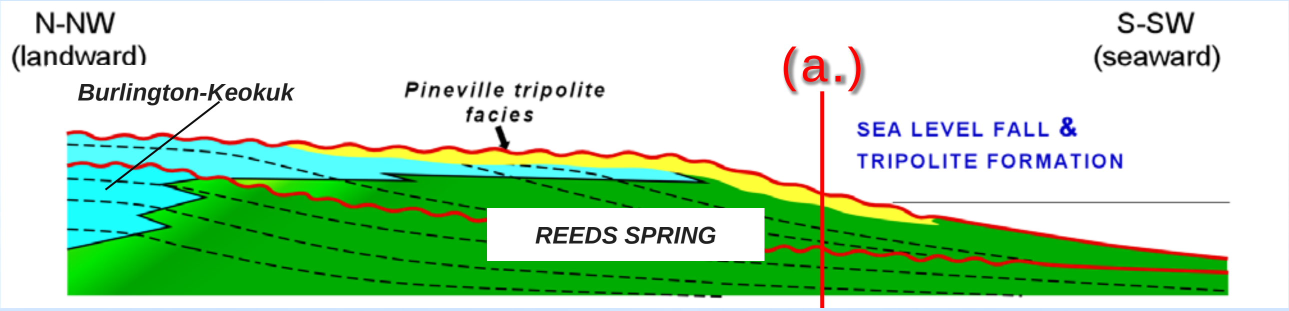
FIG. 5.—Paleogeographic and lithofacies map of conterminous United States at time of *anchoralis-latus* conodont Zone. Data unavailable in blank areas.

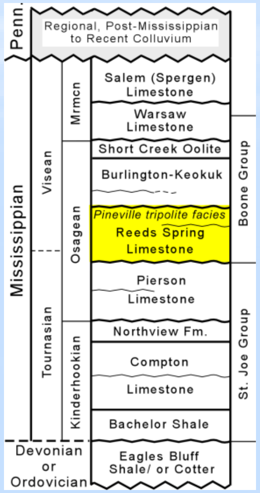
OUR AREA OF STUDY

...the basin wasn't to the south,
it was to the north during KH & early OS!



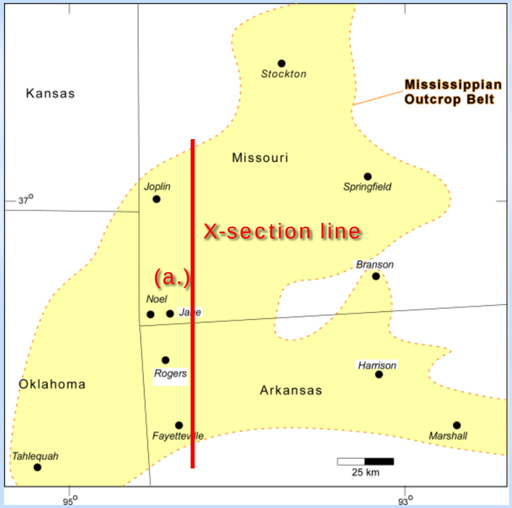
“NORMAL” REEDS SPRING LIMESTONE



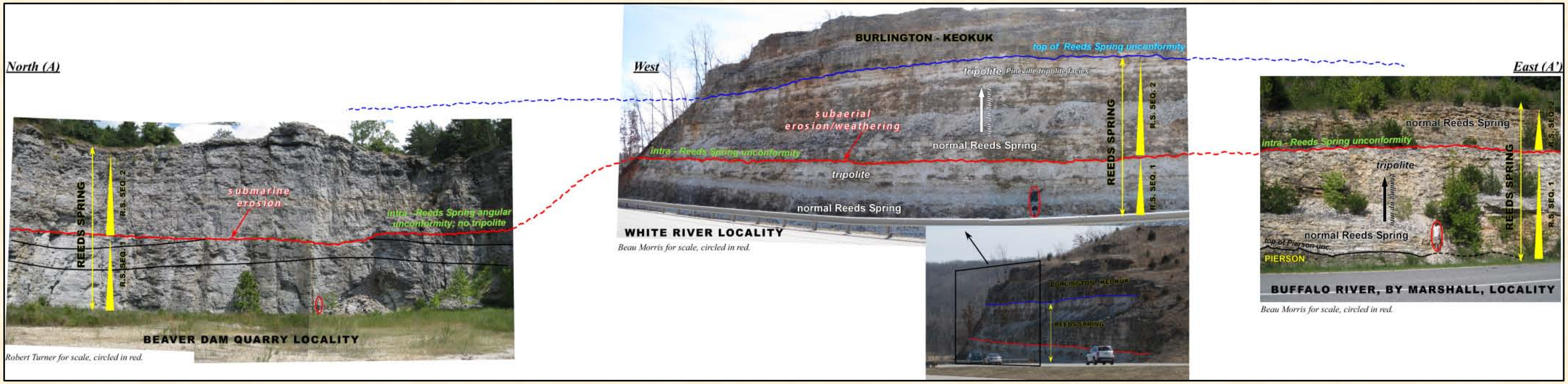


Deep(er) water, cherty lime MS. Downdip equivalent to the shallow-water, Burlington-Keokuk. When exposed during Mississippian time substantial tripolite is developed with attendant meteoric exposure.

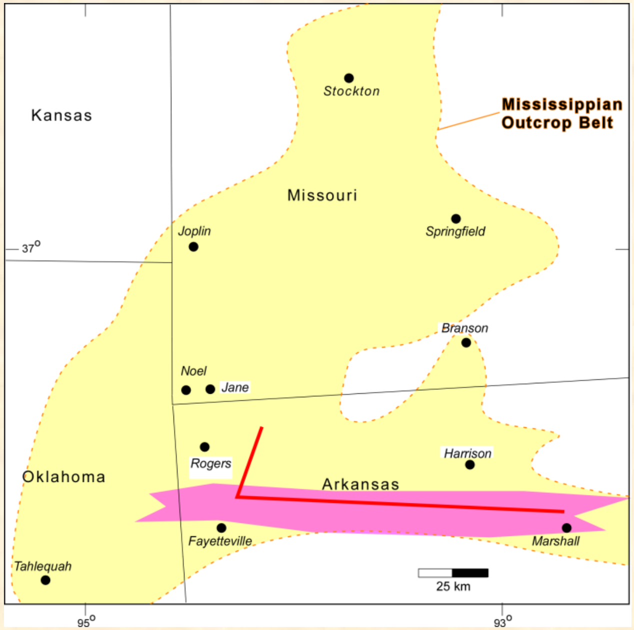
Average thickness 75 -120 feet.



“ANOMALOUS” REEDS SPRING LIMESTONE



Angular unconformity within the deep-water Reeds Spring; a breached East-West trending anticline.



Evidence of subaerial exposure in deep-water deposits in our southernmost Reeds Spring; most basinward exposures.

WHAT IS THE MECHANISM THAN CAN ACCOUNT FOR THE ANOMALOUS BELTS OF STRATIGRAPHIC CHANGE?

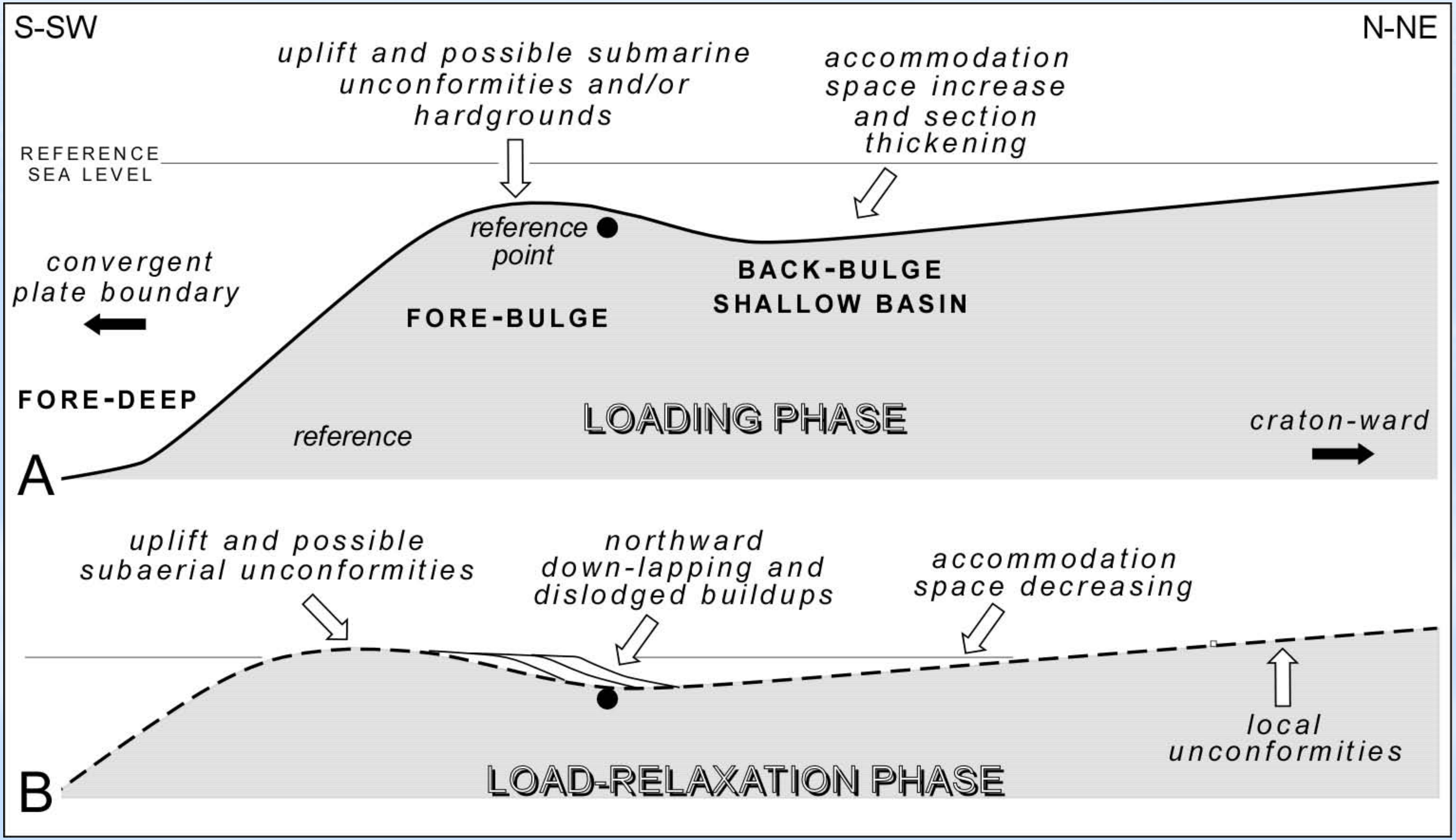
I.E.

Relative Facies Changes in contrast to, and reversal of regional paleodip?

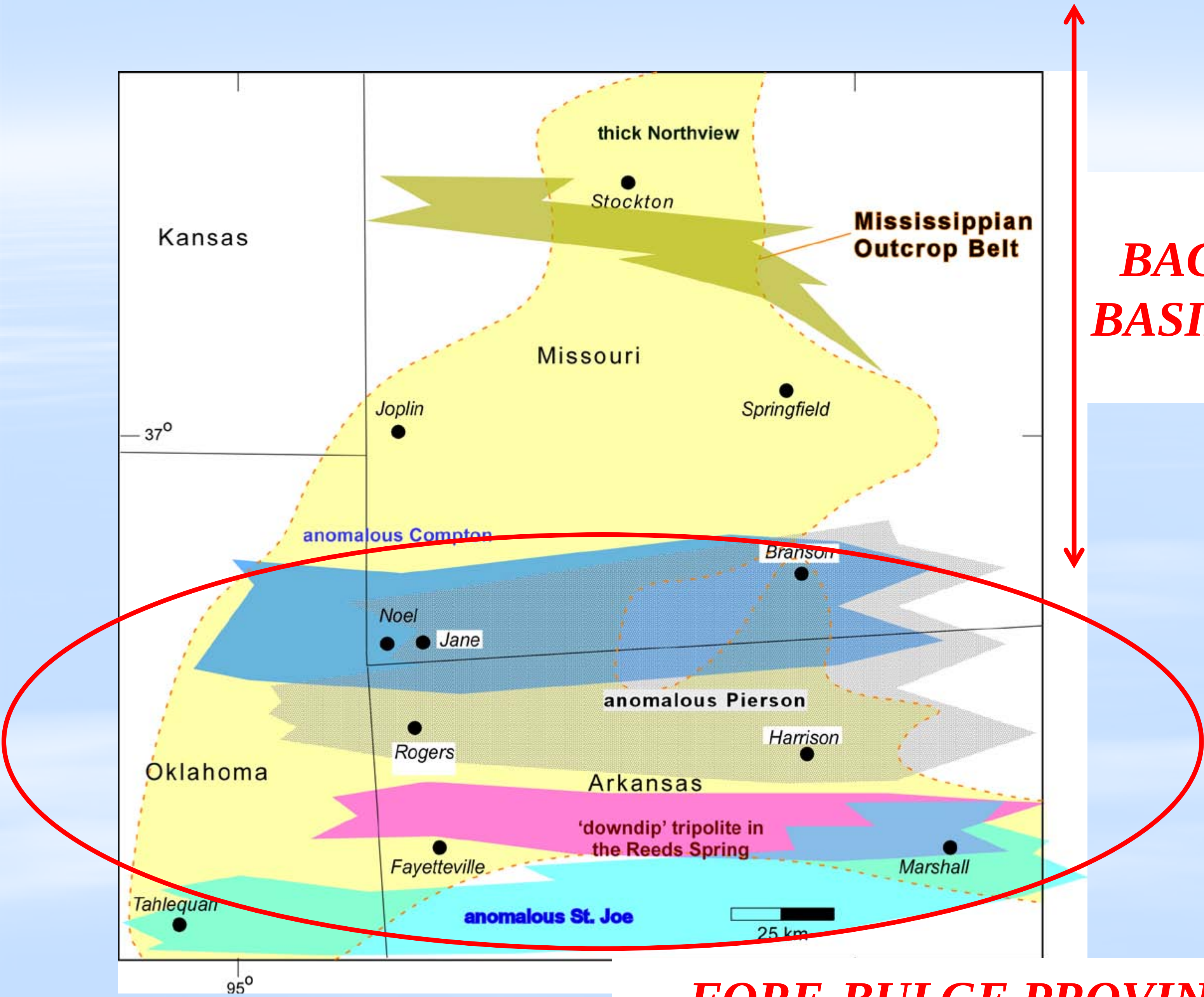
Anomalous Thickening & Northward Progradation (& allochthonous buildups)?

Multiple Unconformities, Syndepositional Folding & Resultant Non-Systematic Lithostratigraphic Architecture?

SYNDEPOSITIONAL TECTONISM RELATED TO FORE-BULGE VACILLATIONS IN RESPONSE TO OUACHITA OROGENY

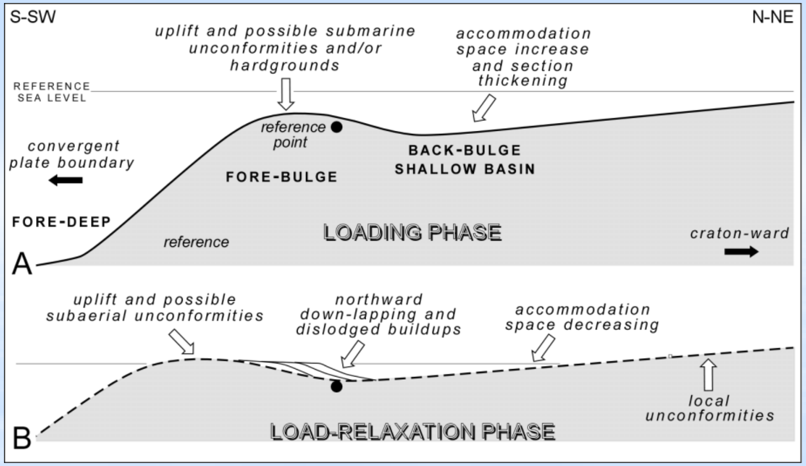


Fore-bulge migration and back-stepping in response to N-S compression associated with Ouachita Orogeny



BACK-BULGE
BASIN & SHELF

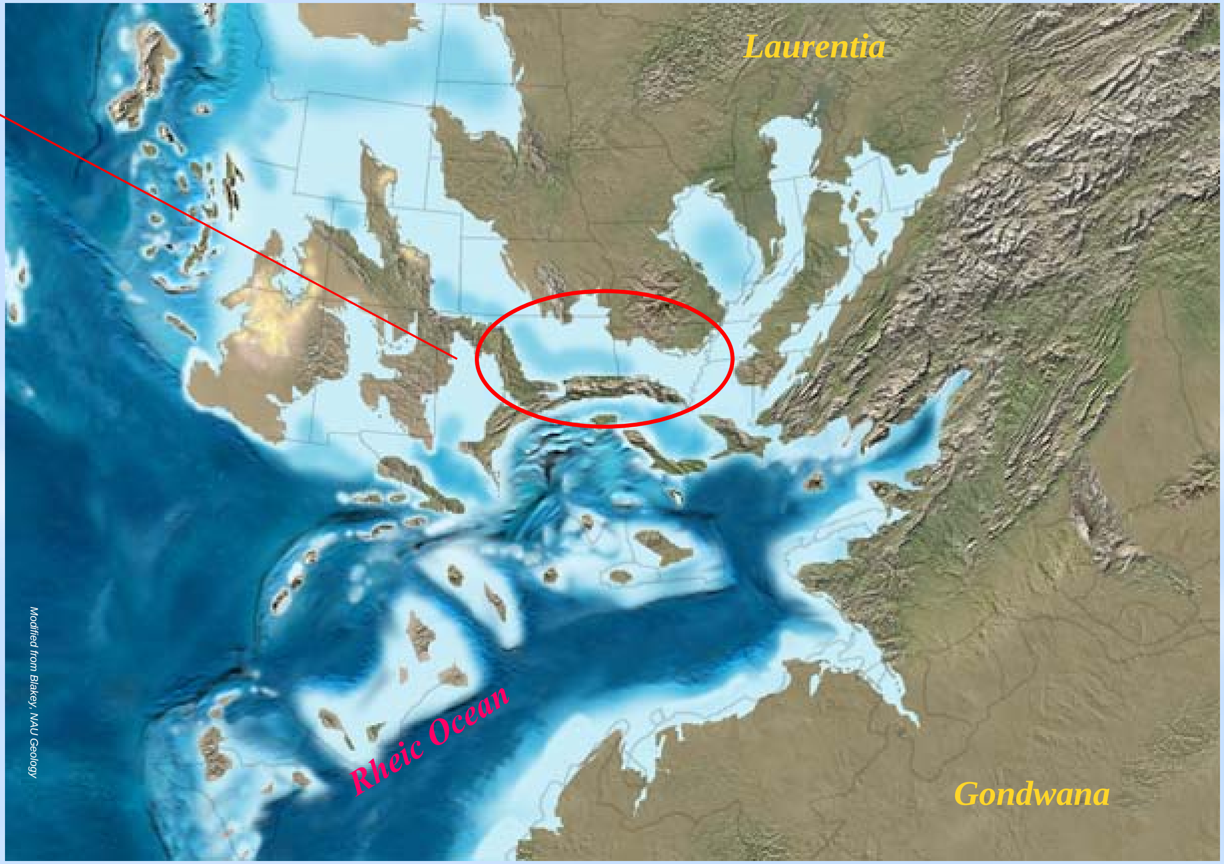
FORE-BULGE PROVINCE



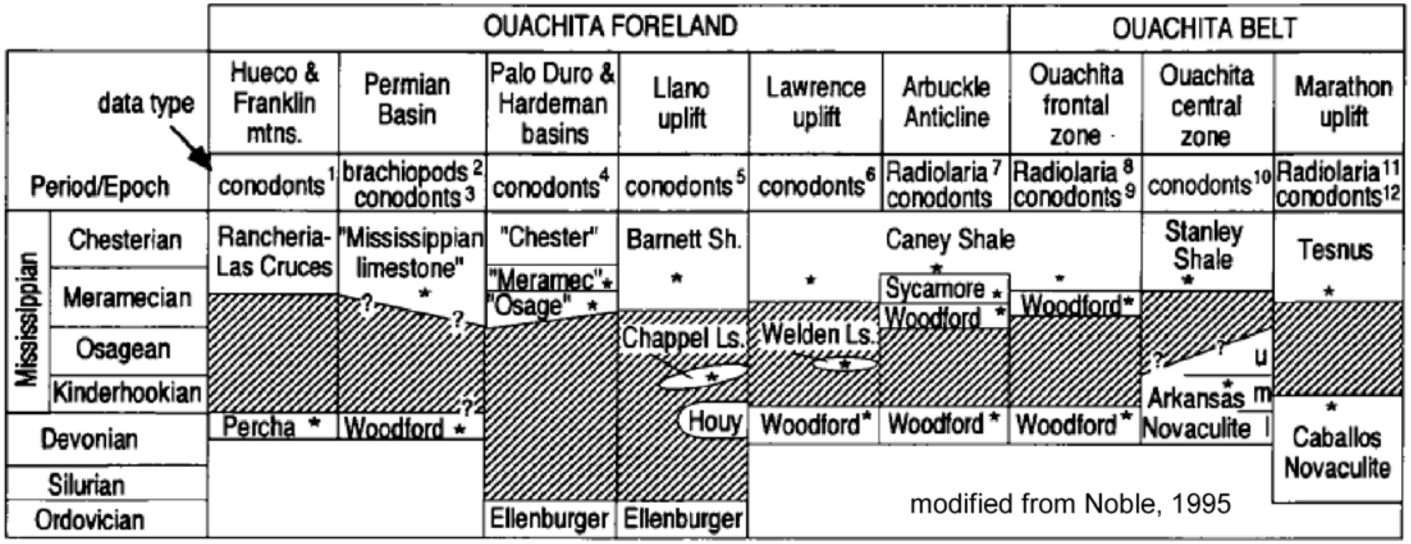
The anomalous lithostratigraphy and syndepositional folding must incorporate the impending Ouachita island arc-continent collision as seen below.

More plausible of a scenario during KH – OS time

The fore-bulge belt in the outcrop area was ~100 km inboard of the Ouachita belt however, albeit mild, the tectonics were significant on deposition.

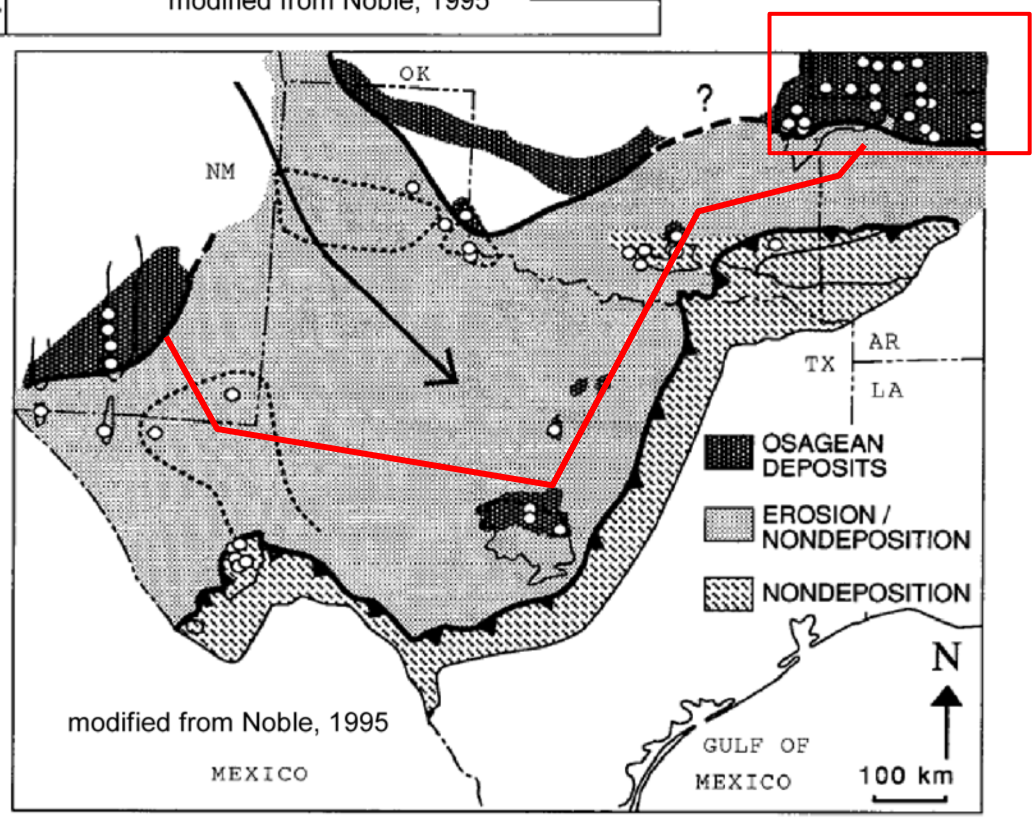


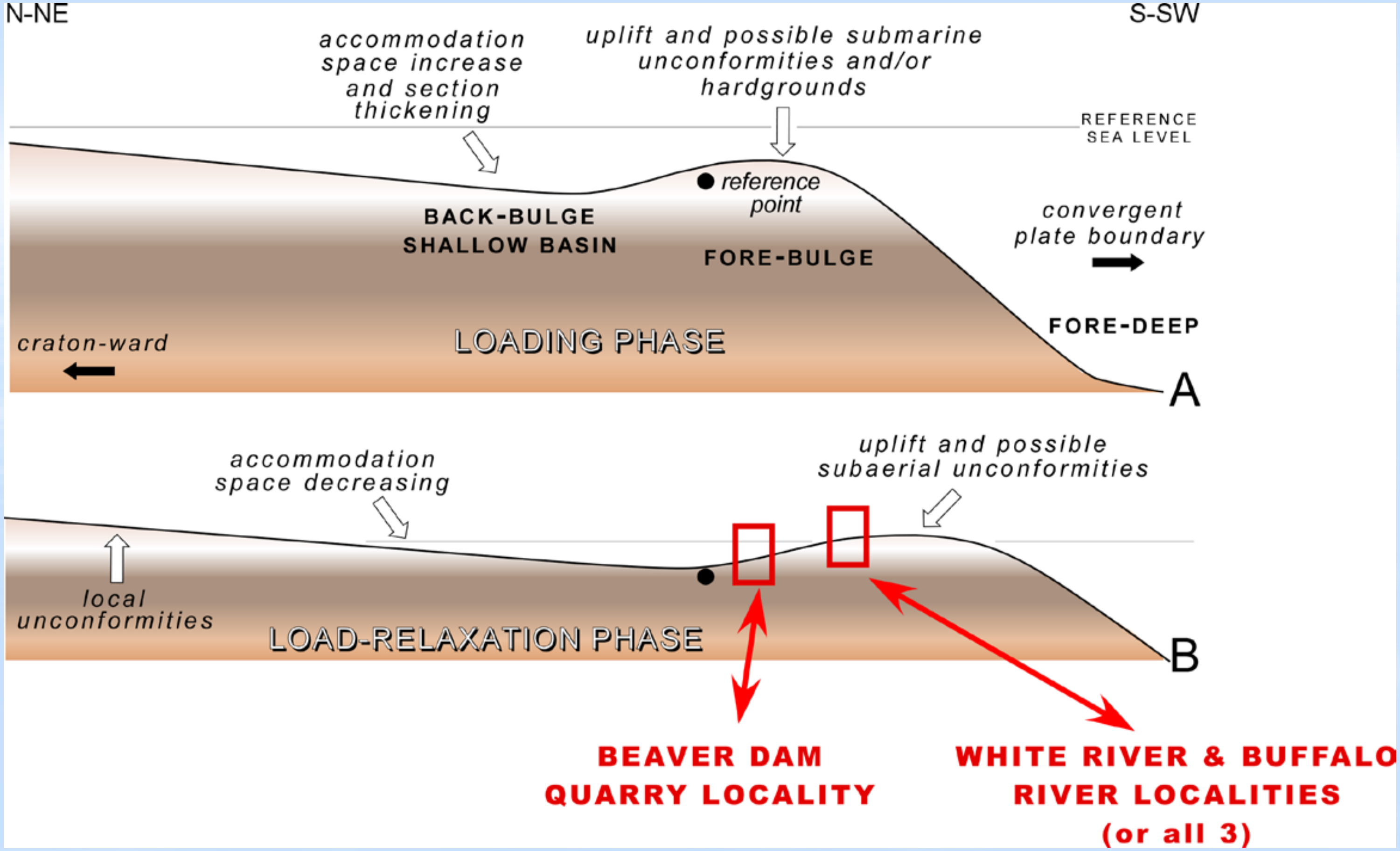
REWRITING BASIN HISTORY



The relationships seen at the outcrop, supported by conodont biostratigraphy, suggest that fore-bulge tectonics may be responsible for the absense of the KH-OS across the mid-continent, particularly adjacent to the Ouchita & Marathon thrust belt.

OUR AREA OF STUDY





*-Based on the data and our interpretations, the Compton, Northview and Pierson were primarily back-bulge basin deposits where depositional architecture was aggradational.

*-Due to the strongly progradational nature of the (Burl-Keok) Reeds Spring, this formation extended beyond the fore-bulge area however, was effected by thrust loading and fore-bulge vacillations as is evident by the unconformities within the section.

SIGNIFICANCE IN EXPLORATION

Is there expression of this early, syndepositional, Mississippian fore-bulge tectonics in the subsurface? YES!

Both directly and indirectly.

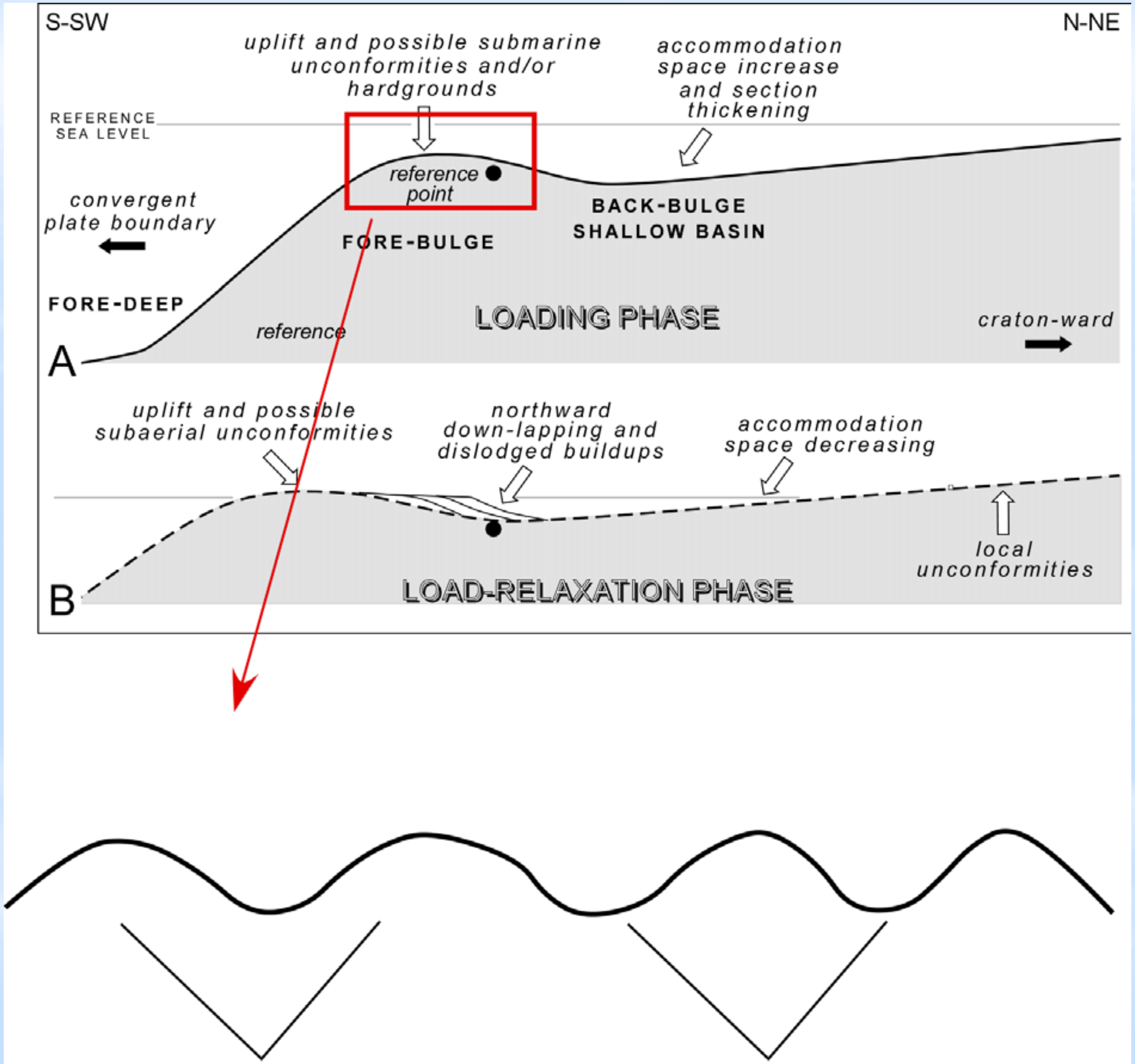
- Understanding and recognition of paleo-geography is paramount in recognizing structurally positive areas and basins.
- Knowledge of syndepositional tectonics will aid in the recognition of correct correlations; to make that leap of faith.
- Understanding of the tectonics should aid in recognizing unconformities and associated porosity zones and traps.

These relationships are recognized in both subsurface and on seismic.

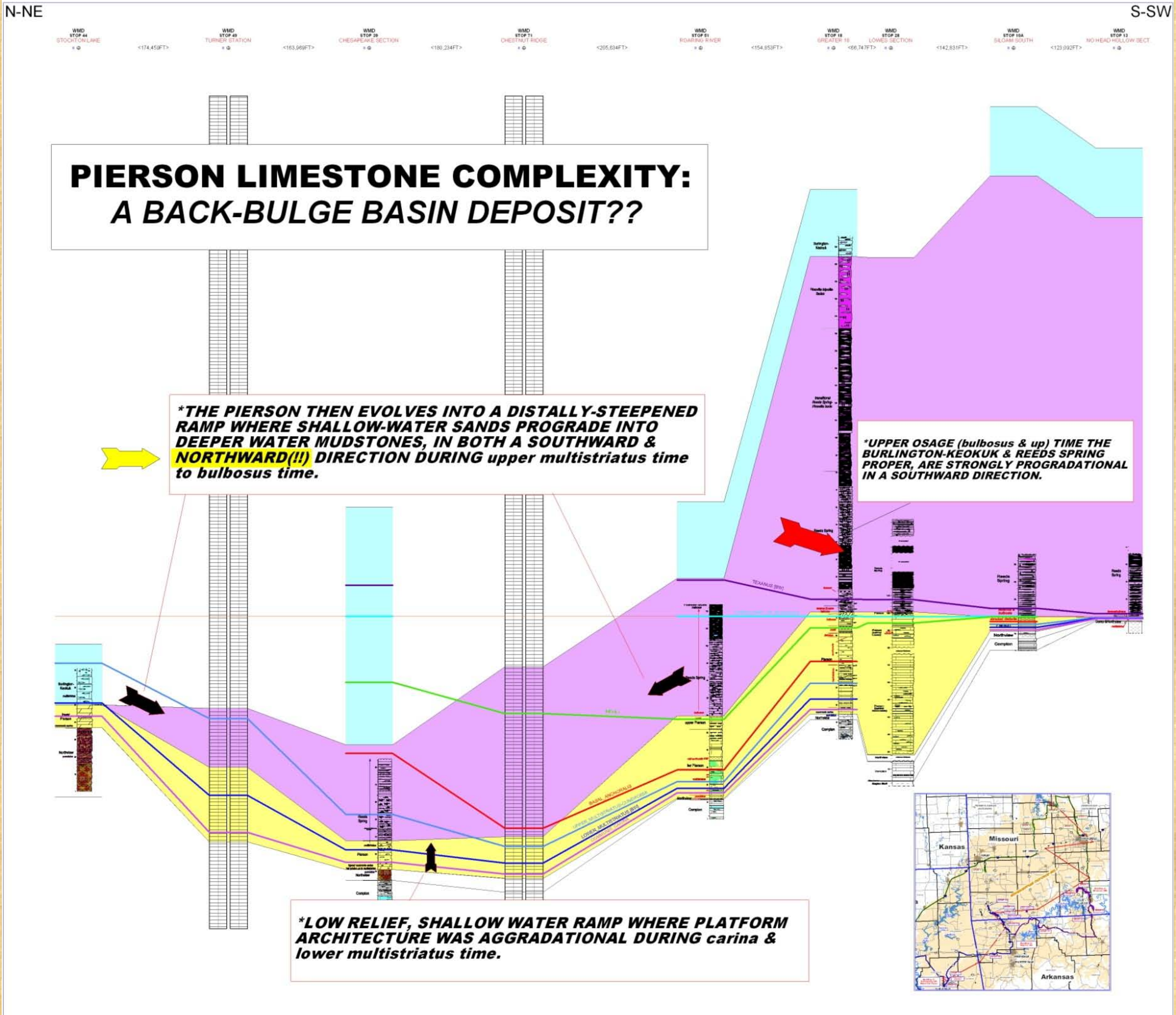
Conclusions:

- Ouachita orogeny began in early Mississippian, Kinderhookian time – much earlier than previously postulated.
- Regional tectonics overprinted the “normal” stratigraphy of the KH – OS units and negates a sequence-stratigraphic interpretation. Instead, the lithostratigraphic architecture of the rocks is solely tectonic origin as opposed to eustatic.
- Facies belts and lithostratigraphic changes coincide with syndepositional tectonics.
- Such changes can and should be recognized in the subsurface based on the outcrop model.

Thank You



"abnormal" stratigraphy/thickness "normal" stratigraphy/thickness


N-NE
S-SW
WMD STOP 44 STOCKTON LAKE
<174,459FT>
WMD STOP 49 TURNER STATION
<163,969FT>
WMD STOP 39 CHESAPEAKE SECTION
<180,234FT>
WMD STOP 71 CHESTNUT RIDGE
<205,634FT>
WMD STOP 51 ROARING RIVER
<154,853FT>
WMD STOP 18 GREATER 16
<66,747FT>
WMD STOP 28 LOWES SECTION
<142,831FT>
WMD STOP 10A SILOAM SOUTH
<123,092FT>
WMD STOP 13 NO HEAD HOLLOW SECT
PIERSON LIMESTONE COMPLEXITY:
A BACK-BULGE BASIN DEPOSIT??
*THE PIERSON THEN EVOLVES INTO A DISTALLY-STEEPENED RAMP WHERE SHALLOW-WATER SANDS PROGRADE INTO DEEPER WATER MUDSTONES, IN BOTH A SOUTHWARD & NORTHWARD(!!) DIRECTION DURING upper multistriatus time to bulbosus time.
*UPPER OSAGE (bulbosus & up) TIME THE BURLINGTON-KEOKUK & REEDS SPRING PROPER, ARE STRONGLY PROGRADATIONAL IN A SOUTHWARD DIRECTION.
*LOW RELIEF, SHALLOW WATER RAMP WHERE PLATFORM ARCHITECTURE WAS AGGRADATIONAL DURING carina & lower multistriatus time.
Kansas
Missouri
Arkansas

- Subsurface lithostratigraphy mimics and DIRECTLY CORRELATES to exposures in the Mississippian outcrop belt of NE Oklahoma, SW Missouri and NE Arkansas
- Outcrop-based models aid and are intergral in interpretating depositional systems in the subsurface
- Depositional motifs and platform architecture are aggradational during Kinderhookian time and evolve to progradational during Osagean across the midcontinent, from the outcrop belt to the subsurface of Kansas and Oklahoma