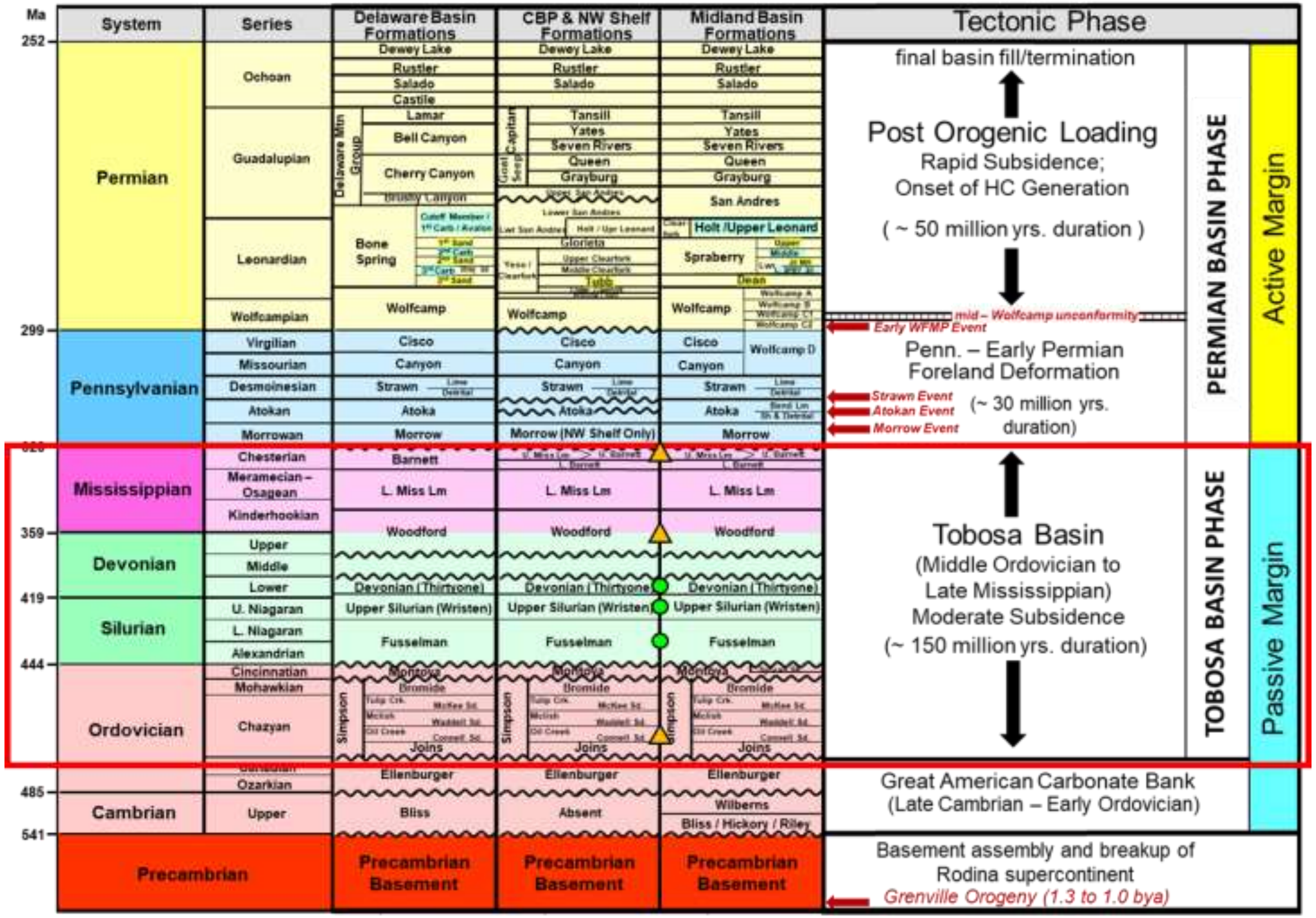
Geology of the Permian Basin

Tobosa Basin Stratigraphy (Mid. Ord. – Miss.)

Permian Basin Stratigraphy and Tectonic History



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Permian Basin Research Lab

10/25/2021

Geology of the Permian Basin: ELS (Endeavor Lecture Series)

Horseshoe Atoll

Tectonic history – Part 1 (Big Picture)

Tectonic history – Part 2 (Regional elements: ARM, CBU, MFB)

Basement

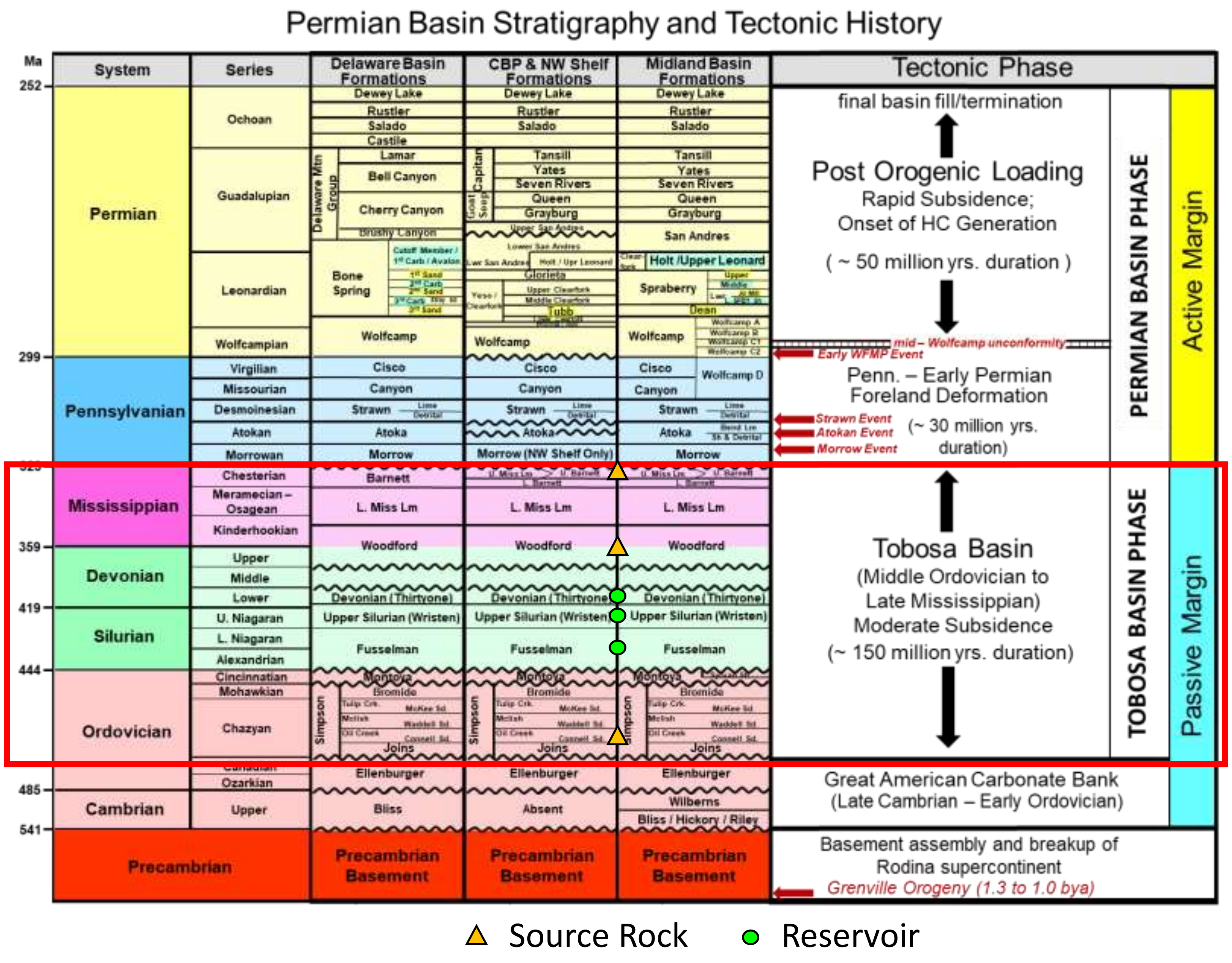
Cambrian – Lower Ord (Wilberns/Bliss Ss., Ellenburger Gp)

Tobosa Basin stratigraphy (Mid Ord. – Mississippian)

Pennsylvanian (Morrow-Atoka-Strawn-Canyon-Cisco)

Lower Permian (Wolfcamp – Spraberry)

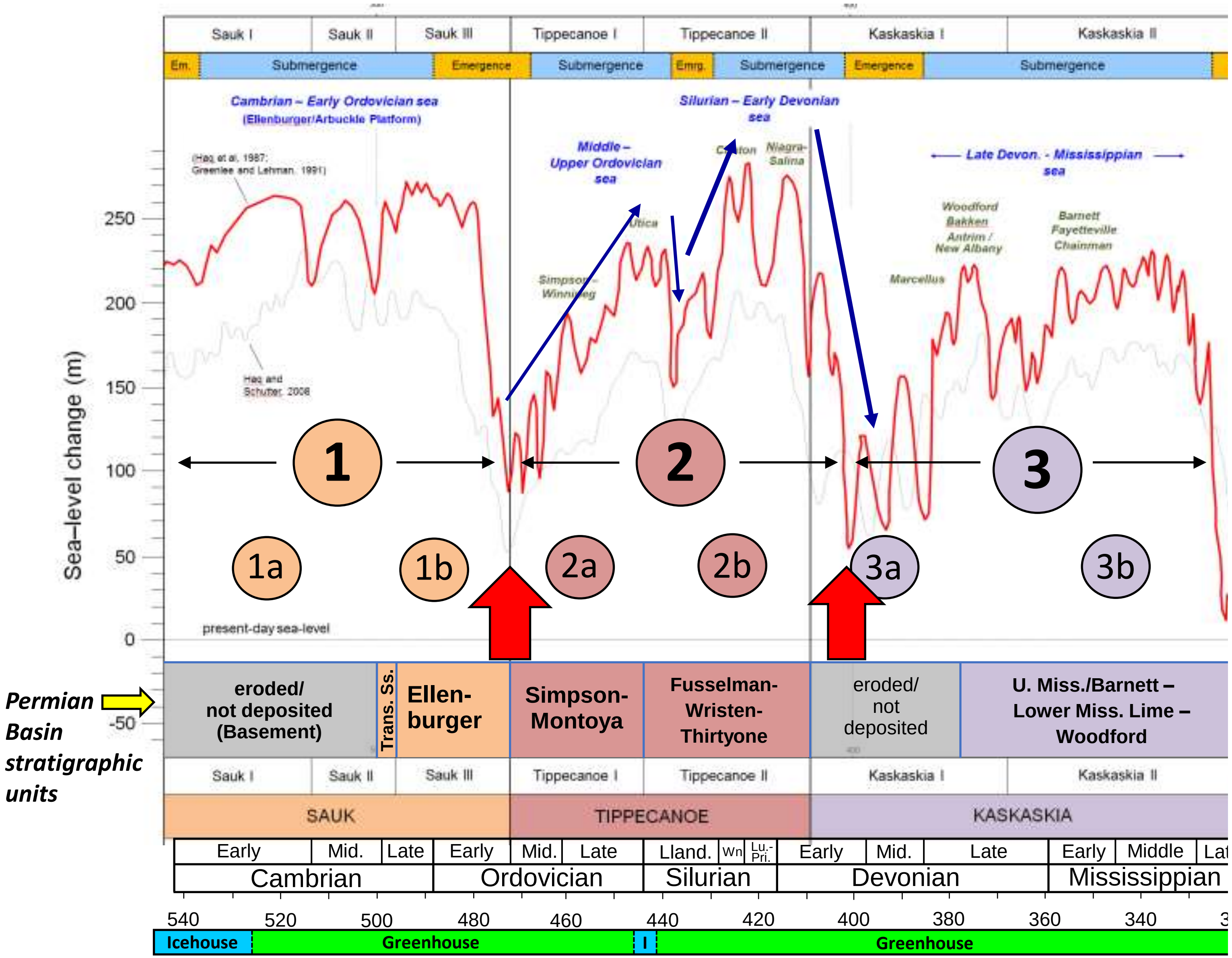
Middle and Upper Permian / Permian Basin petroleum system



Tobosa Basin stratigraphy: overview

- Post-Ellenburger: Tobosa Basin is first isolated as a moderately-subsiding depositional basin
- West Texas region is part of a long-lived passive continental margin (Middle Ordovician to Late Mississippian); approx. 150 million years in duration
- During much of this time, Tobosa Basin was located in low tropical latitudes, far from major sources of terrigenous clastics – perfect setup for massive carbonate production
- Two megacycles of eustatic sea-level
  - Middle Ord. – Early Dev. epeiric sea
  - Late Dev. – Mississippian epeiric sea
- Three major reservoir units (Fusselman, Wristen Gp., and Thirtyone)
- Three major source rocks (Lower Simpson, Woodford, and Barnett)

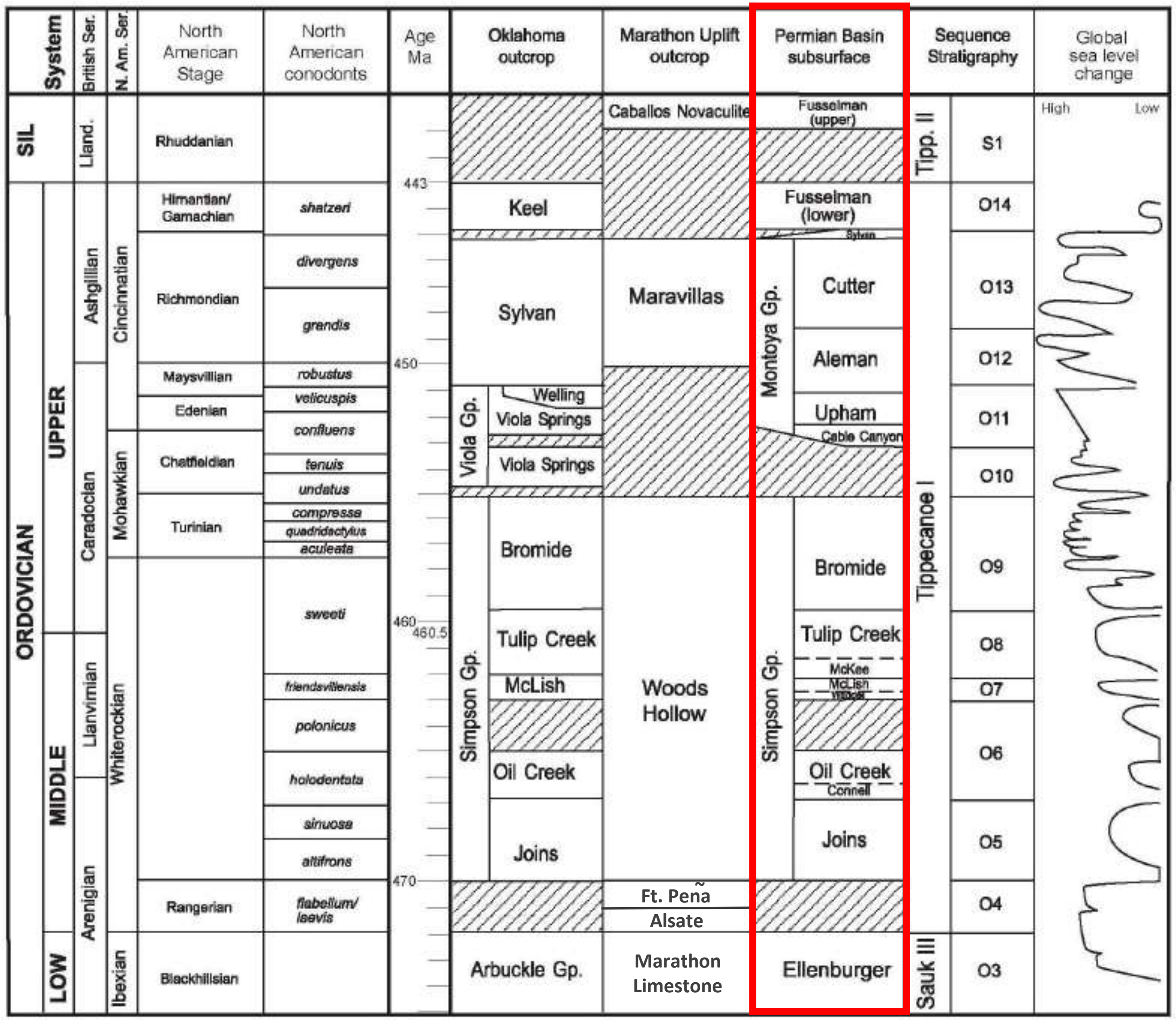
Tobosa Basin: Megacycle 2 (Mid. Ord. – Early Dev.)



Sea-level analysis

- Begins with cratonic submergence and transgression of epeiric sea during Middle Ordovician time (following late Early Ordovician lowering/exposure/karsting)
- Long-term transgression throughout Middle and Late Ordovician time with pronounced lowstand near the Ord – Sil boundary (Subcycle 2a); deposition of Simpson and Montoya Groups
- Renewed transgression thoughout Silurian, with sea-level reaching all-time high during Late Silurian, followed by rapid, significant sea-level fall with widespread exposure/uplift event during Early Devonian (Subcycle 2b); deposition of Fusselman Formation, Wristen Group, and Thirtyone Formation
- Greenhouse climate (brief icehouse phase spanning Ord-Sil boundary)

Cycle 2a: Simpson and Montoya Groups



Montoya Group (Upper Ordovician)

- A thick (up to 600 ft) series of carbonate ramp deposits; four formations, from oldest to youngest:
  - **Cable Canyon**: gravel conglomerates and dolomite-cemented quartz sandstones
  - **Upham**: massive coarse-grained skeletal wacke- pack-, and grainstones (open marine fauna)
  - **Aleman**: chert-rich limestones (incl. coral bafflestones)
  - **Cutter**: fine-grained argillaceous dolomudstones and lime mudstones (low energy)

Simpson Group (Middle Ordovician)

- A mixed sandstone/shale/carbonate succession consisting of five formations, from oldest to youngest:
  - **Joins Fm**: argillaceous limestones and dolomites
  - **Oil Creek, McLish, and Tulip Fms**: basal sandstones overlain by shales and shaley limestone
  - **Bromide Fm**: interbedded sandstones, shales, and thick fossiliferous limestones

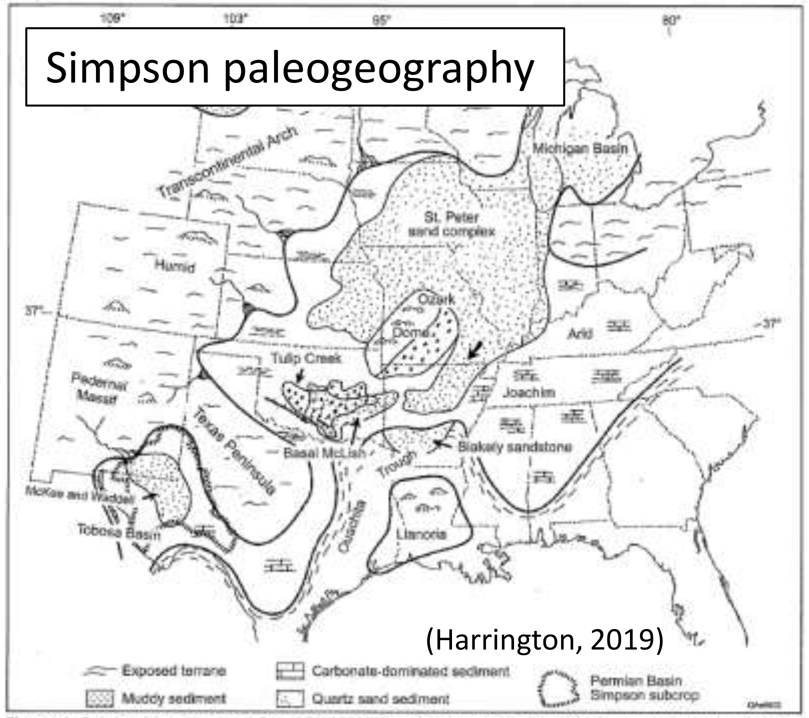
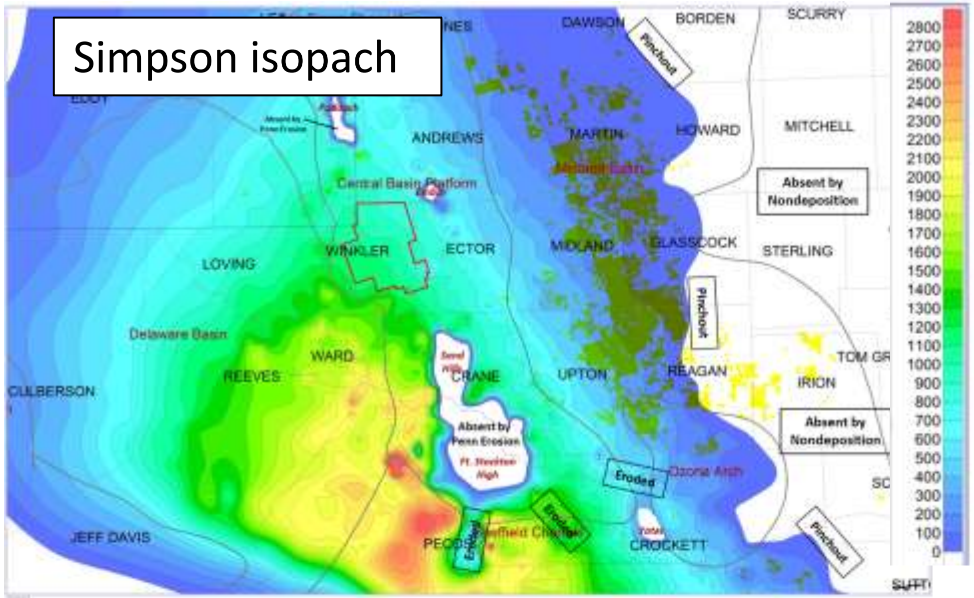
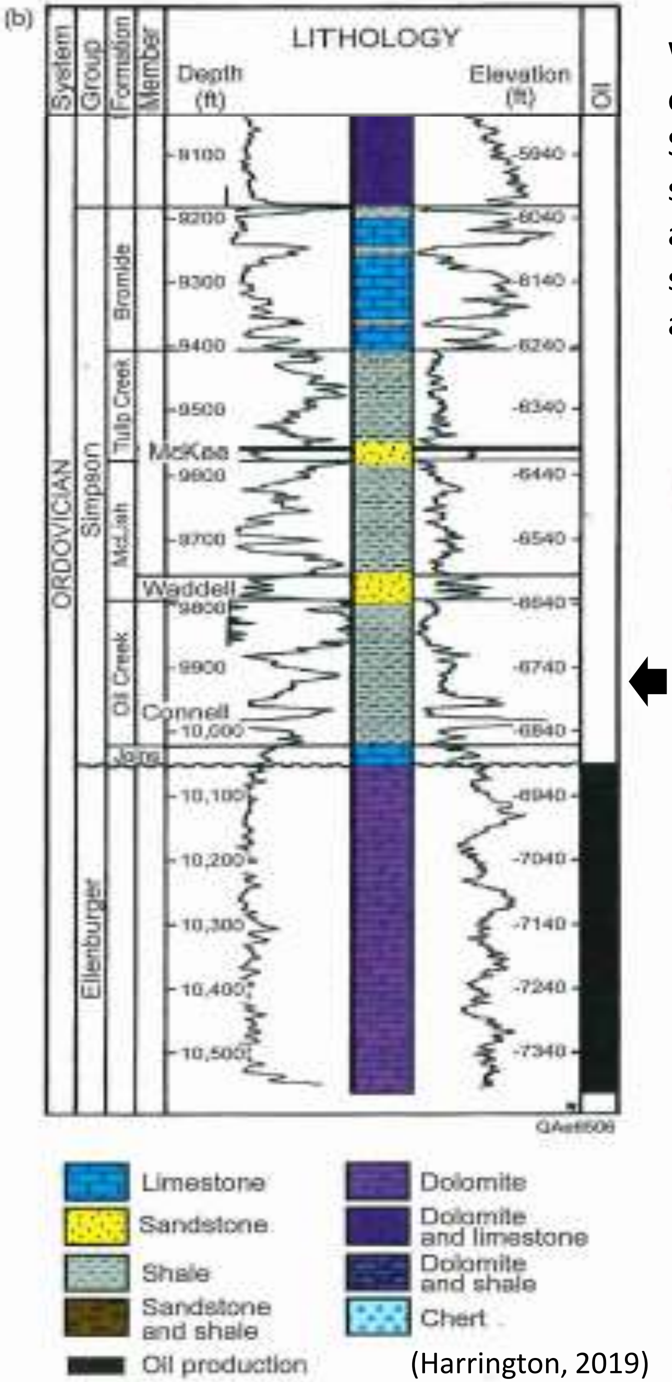


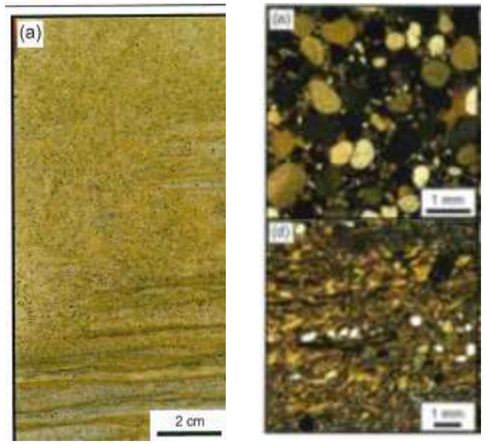
Figure 3. Paleogeographic map of central United States showing distribution of exposed terranes, marine seaways, and sediment types during middle Simpson time. Presence and/or extent of Texas Peninsula at this time is uncertain. Modified from Suhm (1997).





Well log response of the Simpson Group showing alternation of shales, sands, and limestones

Oil Creek shales: organic-rich (source rock for underlying Ellenburger reservoir)



- Cumulative oil production of ~ 100 million barrels; individual fields are small
- Main producing units are thin sandstones

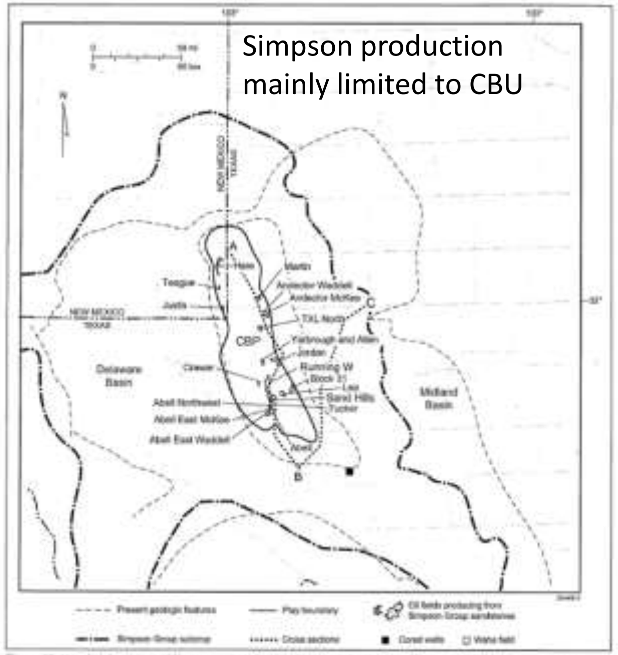
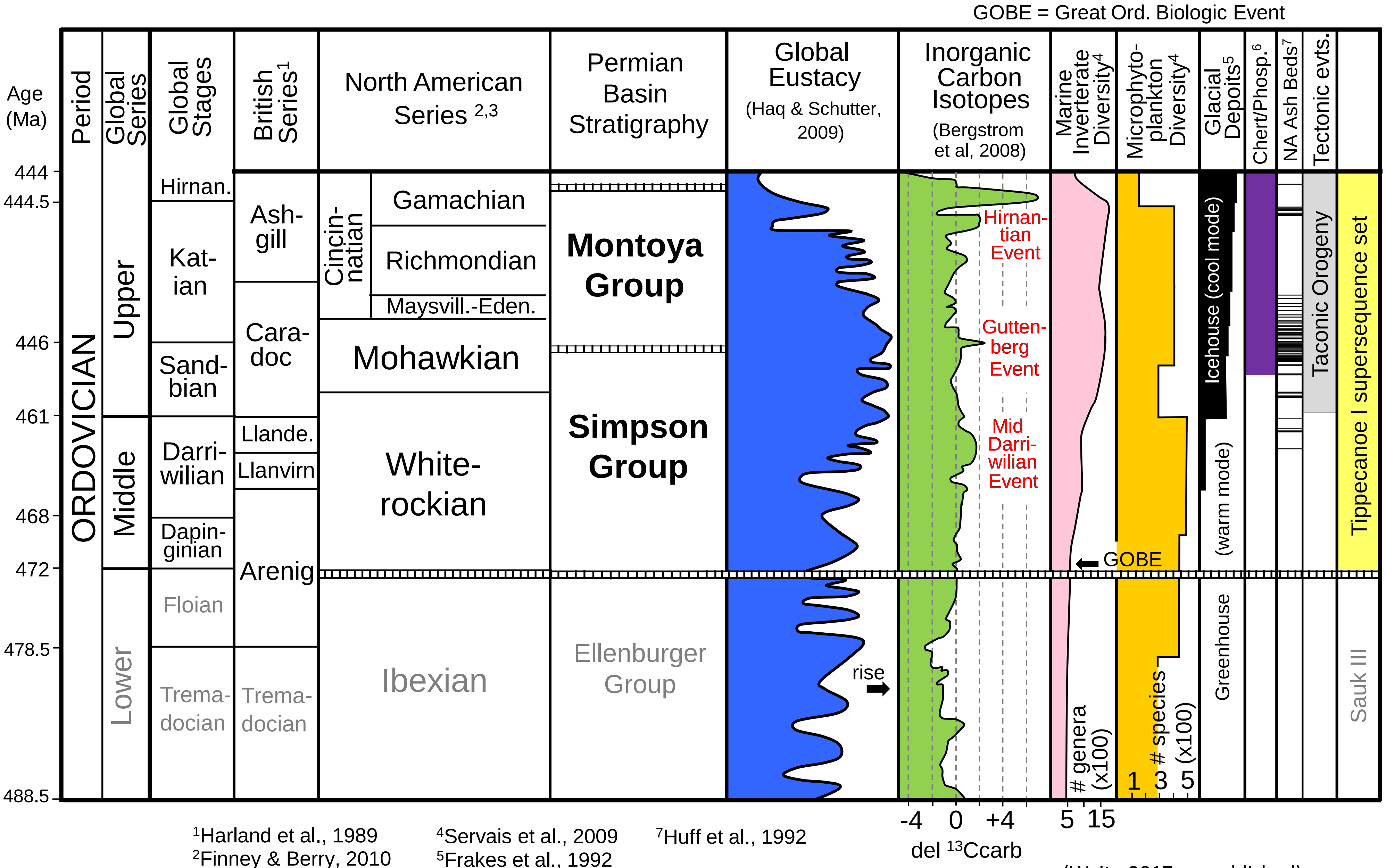


Figure 13. Map showing extent of Simpson rocks in Permian Basin and distribution of Simpson oil fields having cumulative production greater than 1 MMbbl. Modified from Dutton and others (2005).

Upper Ordovician

Montoya Group

Middle – Late Ordovician: Biologic, Climatic, & Tectonic Trends / Events



[1]Harland et al., 1989
[2]Finney & Berry, 2010
[3]Haq and Schutter, 2008
[4]Servais et al., 2009
[5]Frakes et al., 1992
[6]Pope & Steffen, 2003
[7]Huff et al., 1992

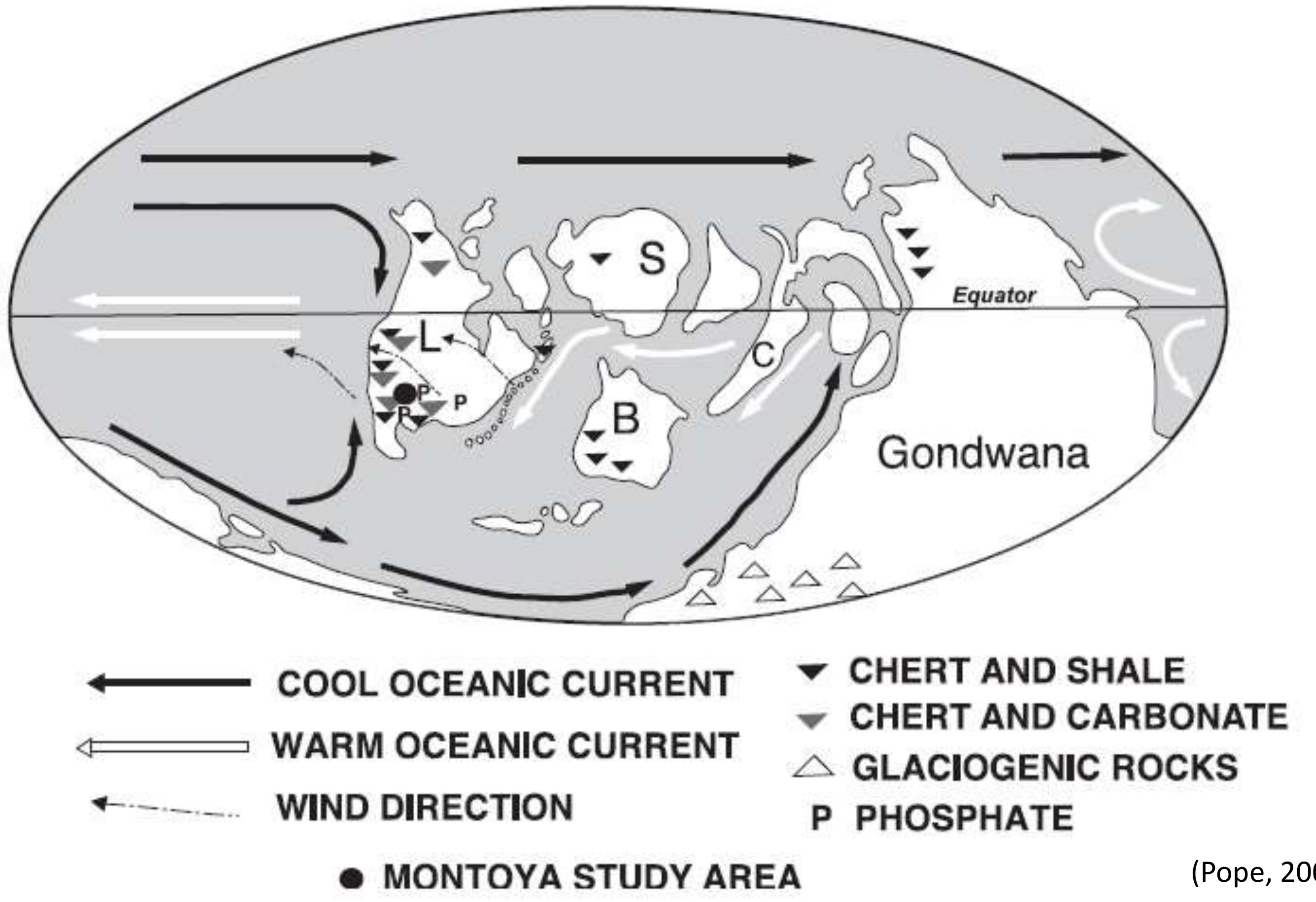
(Waite,2017, unpublished)

Montoya time marked by:

- High marine invert. diversity
- Onset of brief ice age
- High occurrence of sedimentary chert (oceanic upwelling)
- High occurrence of volcanic ash beds
- Taconic orogeny (eastern U.S.)

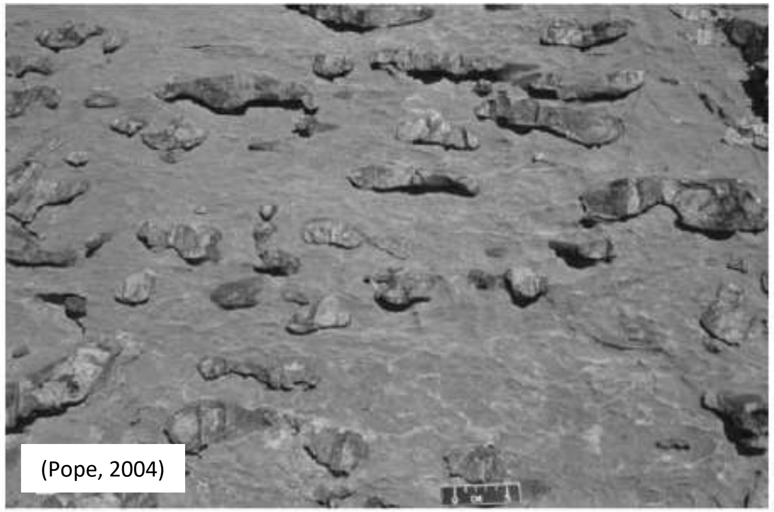
Late Ordovician ocean circulation

- Montoya rocks in the Permian Basin are marine carbonates (dolomites, limestones) that contain a great amount of chert (silica) and phosphate (likely due to upwelling)



(Pope, 2004)

(Harrington and Ruppel, 2019)



(Pope, 2004)

Montoya lithologies

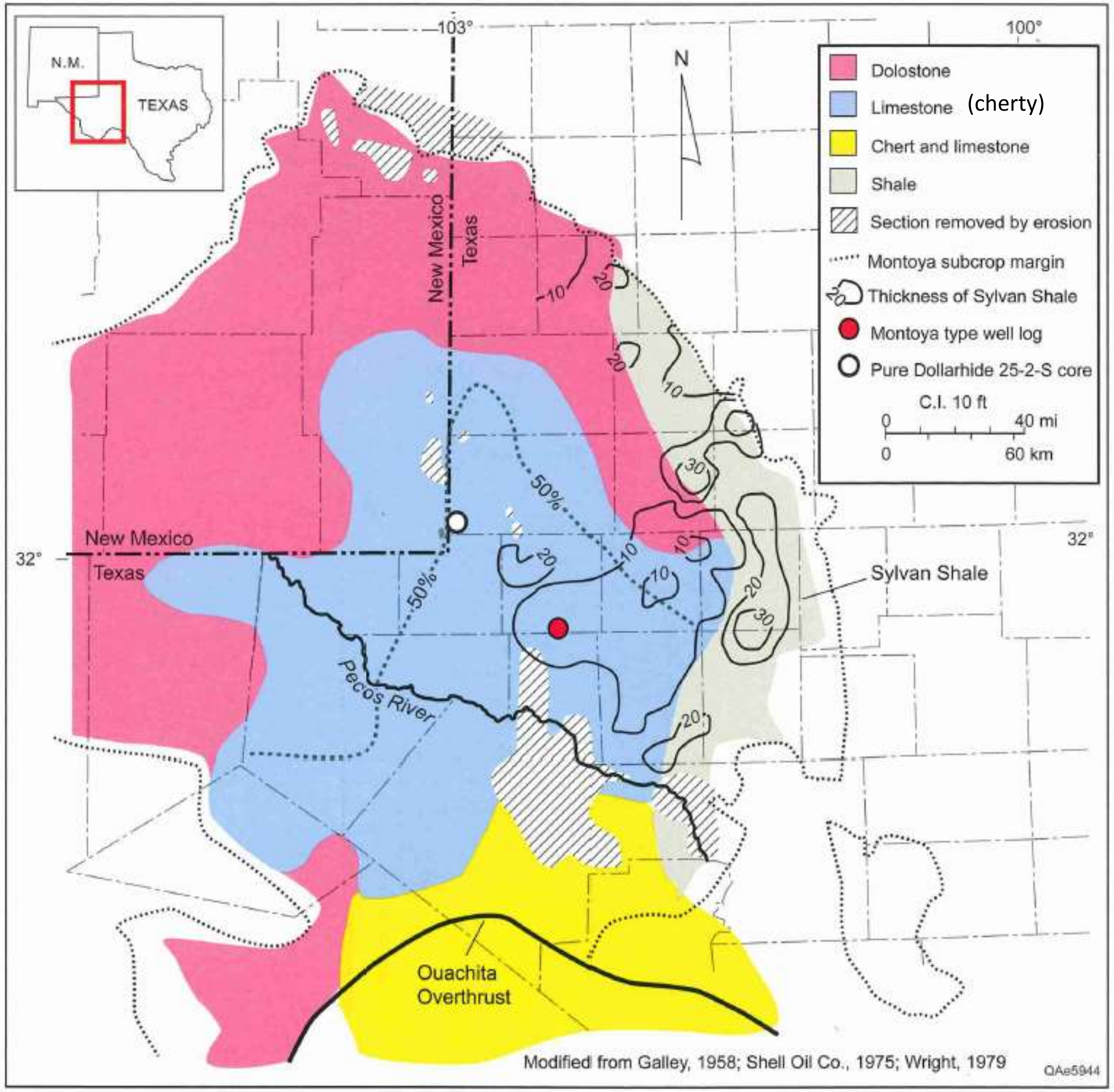


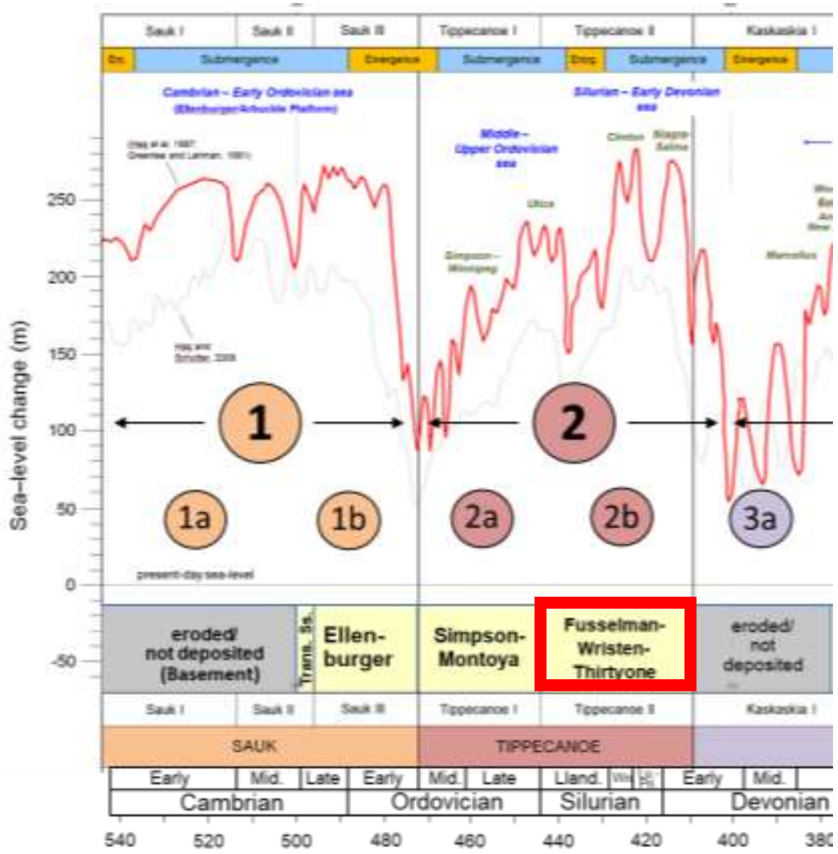
Figure 11. Map showing relative abundance of dominant lithologies in Montoya Group. Mineralogy data modified from Shell Oil Company (1975) and Wright (1979); 50-percent calcite/dolomite line from Galley (1958). Thickness data from Geological Data Services.

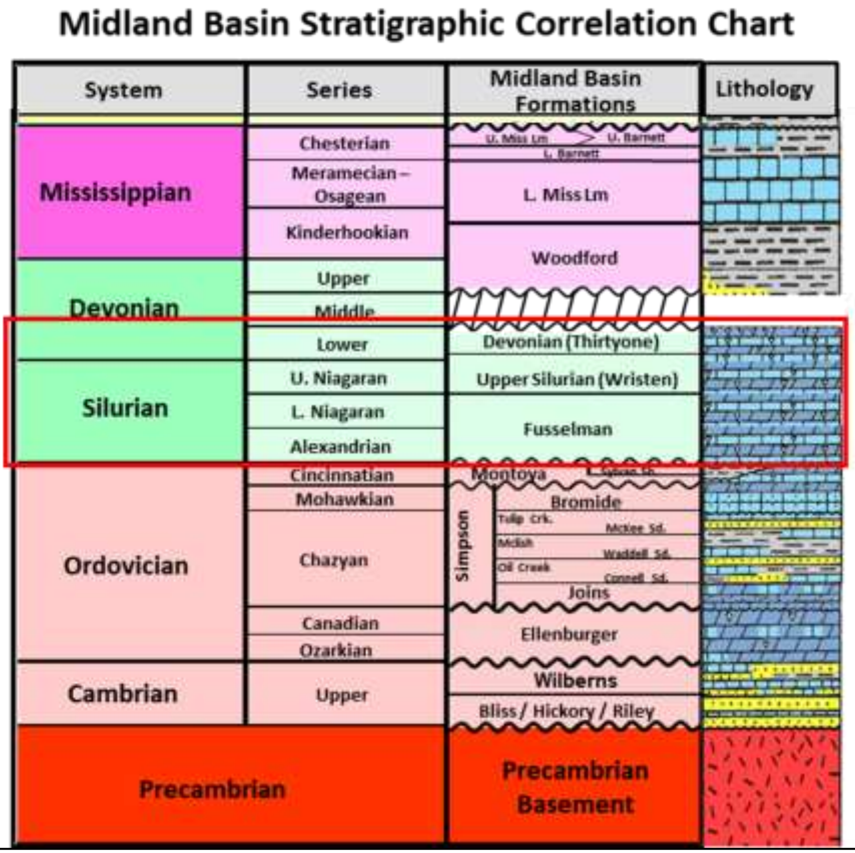
(Harrington and Ruppel, 2019)

- Dolomite facies are prevalent to the north and west in New Mexico
- Shallow water cherty limestone facies occur to the south and east throughout west TX, changing southward to chert and deep-water limestones in the Marathon foredeep
- Note the limited distribution of the Sylvan Shale along the eastern side of the Tobosa Basin (Midland Basin – Howard-Glasscock-Reagan Cos.)
- Little to no oil or gas production from Montoya rocks in the Permian Basin

SUBCYCLE 2b:
SILURO-DEVONIAN

FUSSELMAN FORMATION
WRISTEN GROUP
THIRTYONE FORMATION





- Thirtyone Fm. – Lower Devonian
- Wristen Gp. – Upper Silurian
- Fusselman Fm. – Lower to Middle Silurian

Note main lithology of all three units (limestone and dolomite)

West – East cross-section across Tobosa Basin showing thickness and facies of Siluro-Lower Devonian units

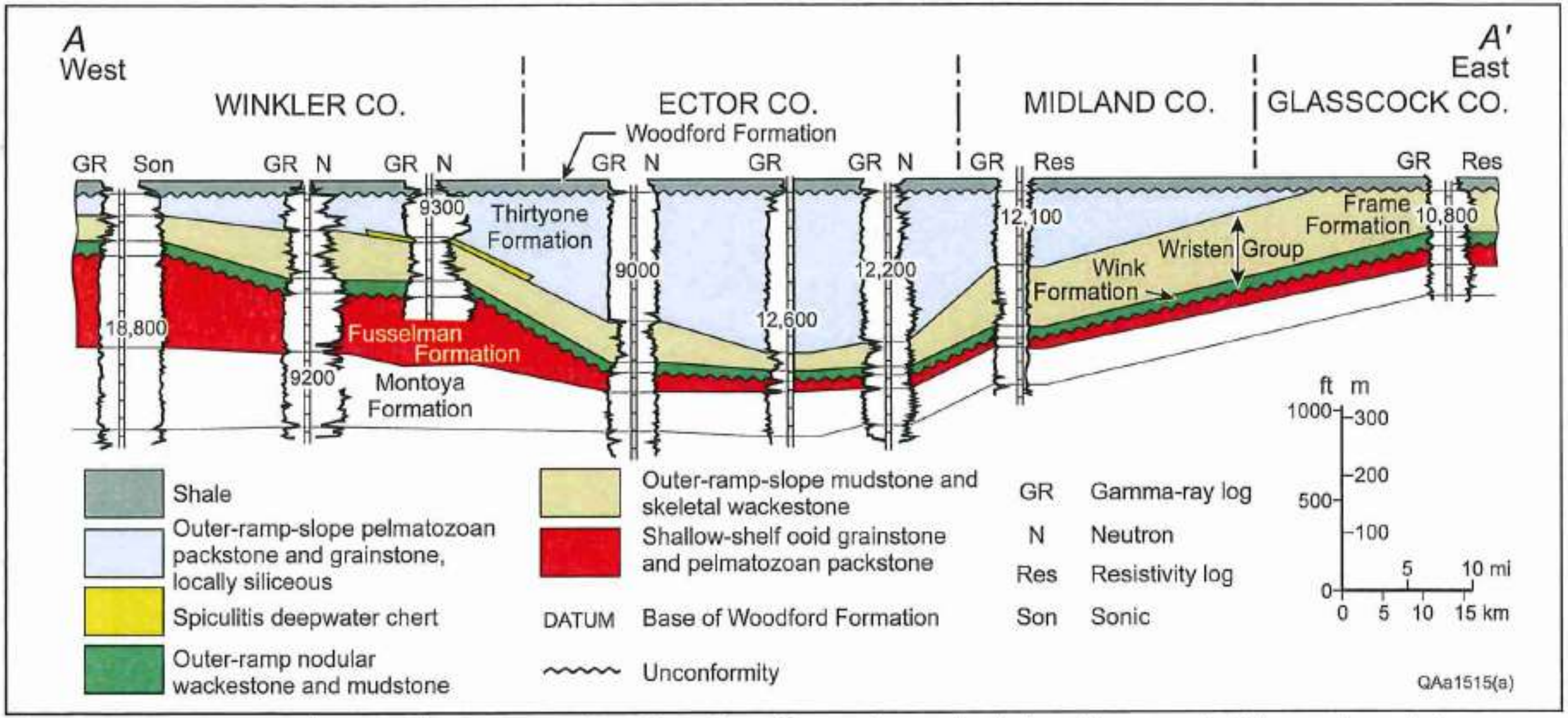
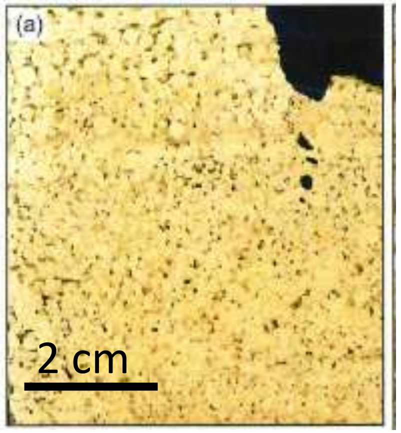


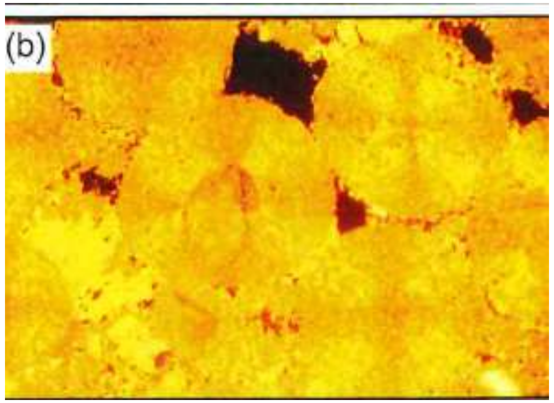
Figure 5. Cross section showing thickness trends of Fusselman Formation and relationships to underlying and overlying Silurian and Devonian units. Line of section shown in figures 2 and 11. Modified from Ruppel and Holtz (1994).

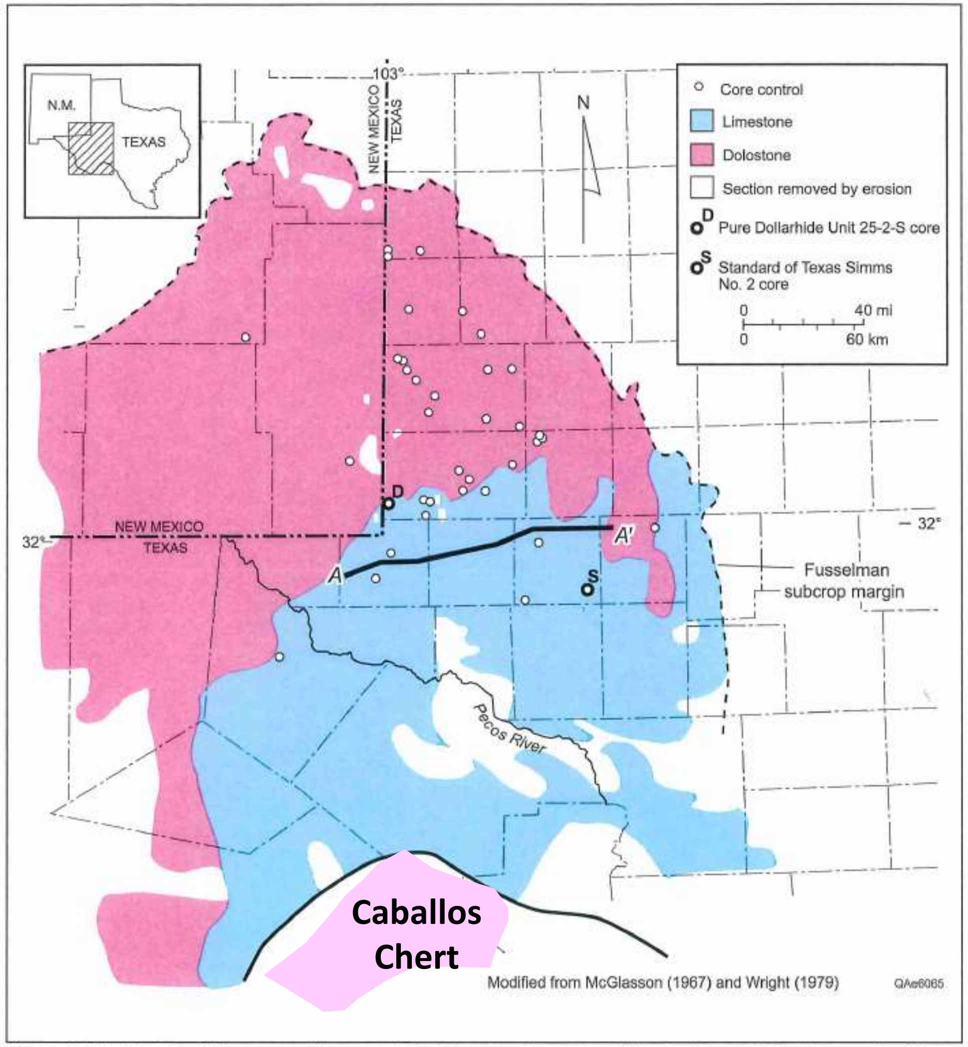
(Ruppel, 2019)

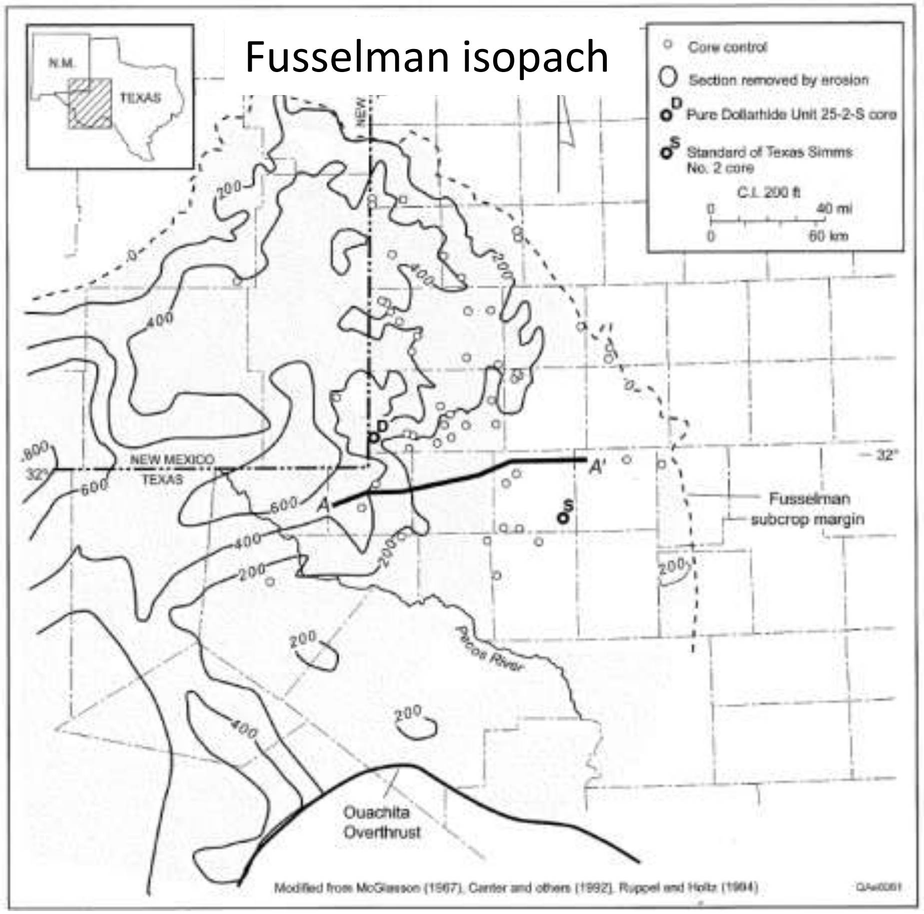
Lower Silurian Fusselman Fm. facies

- Shallow-water carbonates, fining-upward icehouse cycles w/ high-energy ooids at base of cycles
- Dolomite to NW, limestone in SE



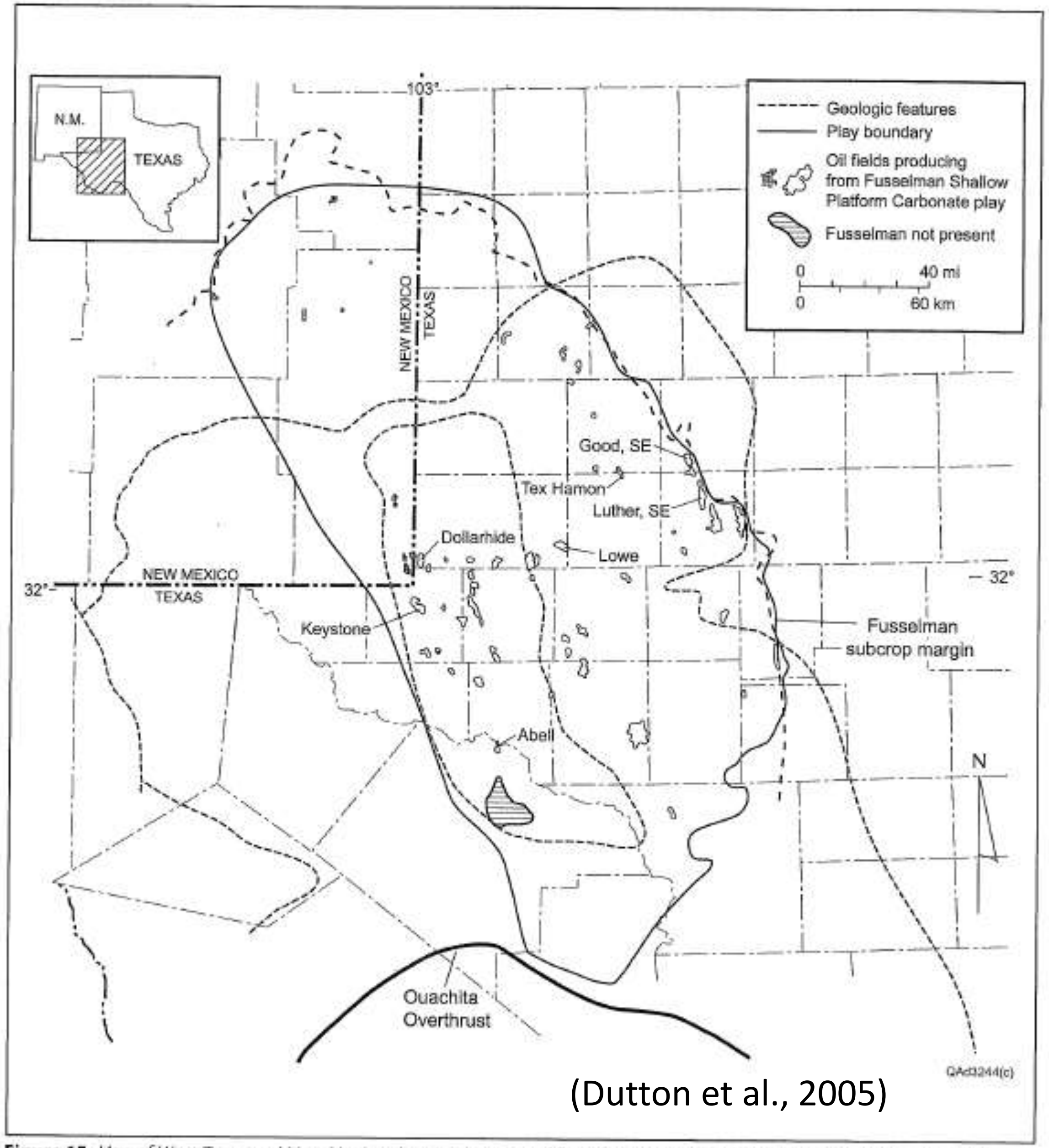






(Ruppel, 2019)

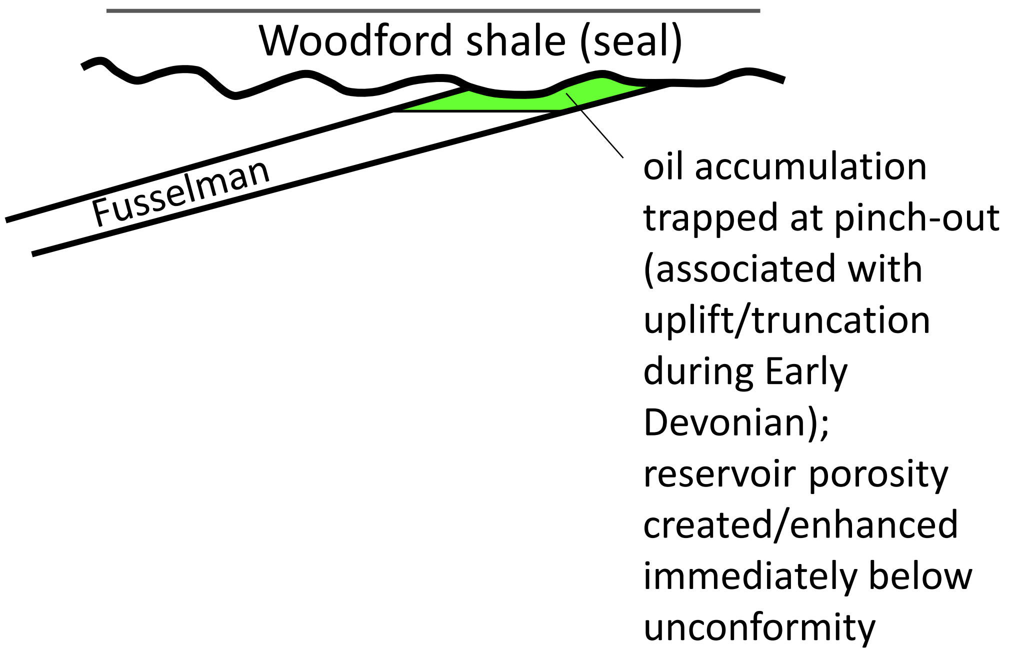
FUSSELMAN OIL FIELDS OF THE PERMIAN BASIN



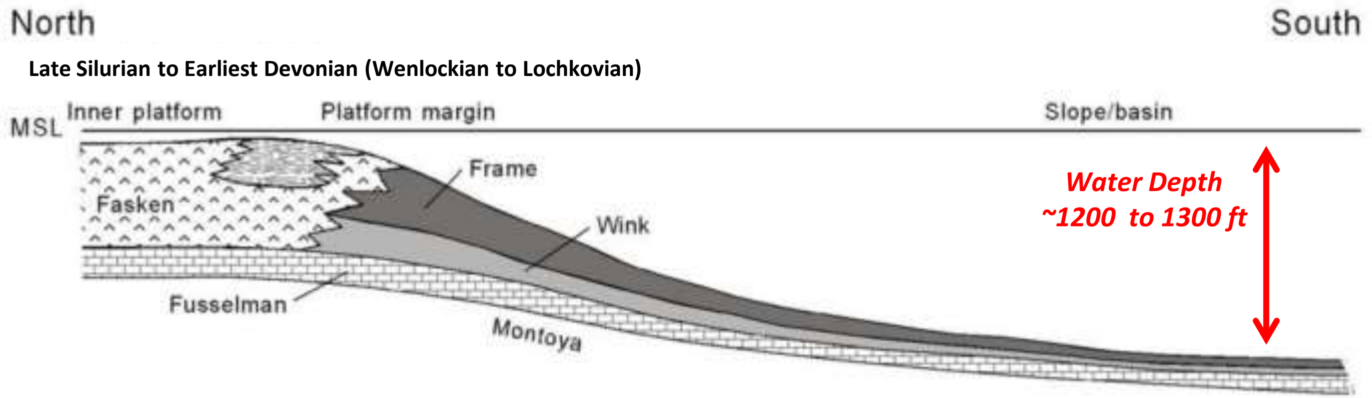
(Dutton et al., 2005)

Figure 15. Map of West Texas and New Mexico showing location of Fusselman reservoirs from which more than 1 MMbbl of oil had been produced as of January 1, 2000. Modified from Dutton and others (2005).

- Two producing trends:
  - Structures on CBP
  - Strat traps on erosional subcrop
- Cumulative oil production > 355 million barrels



Mid – Upper Silurian Wristen Group



- Fasken Fm: Reef-bearing shallow-water carbonates in north; platform margin
- Frame and Wink Fms: Deeper-water carbonate facies (slope to basinal) in south

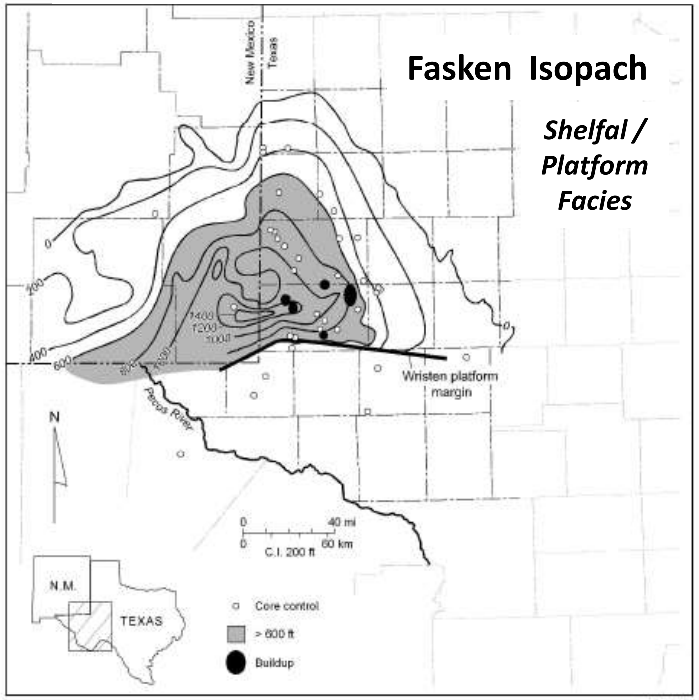


Figure 11. Thickness and distribution of the Fasken Formation. The formation thickens to more than 1,500 ft in extreme western Gaines and Andrews Counties, Texas, and southeasternmost Lea County, New Mexico. Northeastward thinning in the northern part of the area is due to truncation of the Silurian section by Middle Devonian (pre-Woodford) erosion.

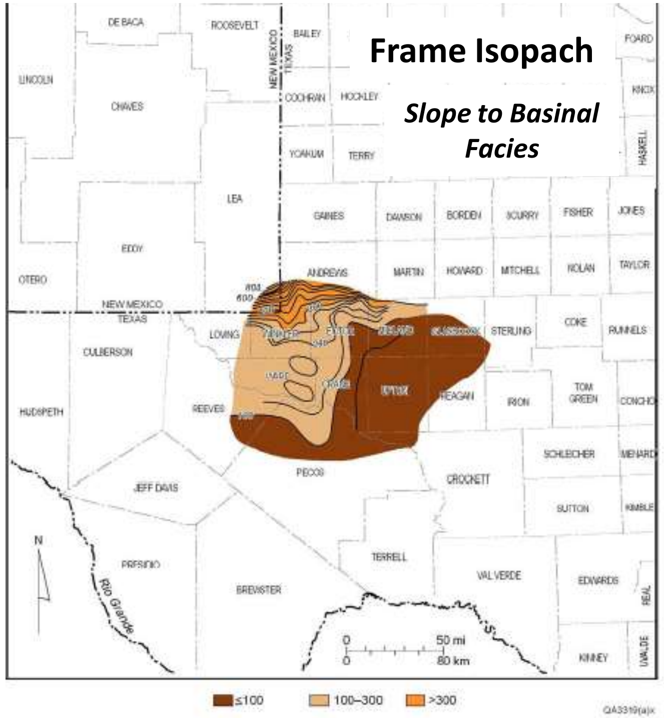


Figure 9. Thickness of the Frame Formation. Neither the Wink nor the Frame Formation is readily separable from the Fasken Formation north of the Wristen platform margin in central Andrews County.

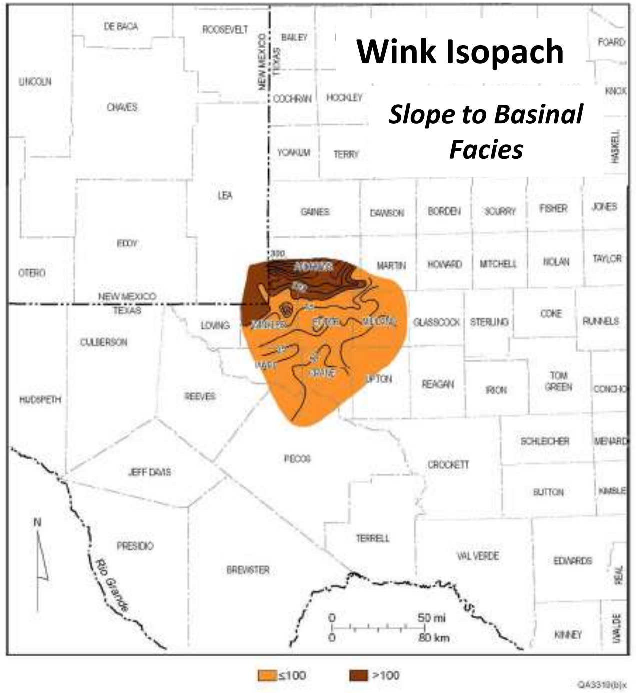
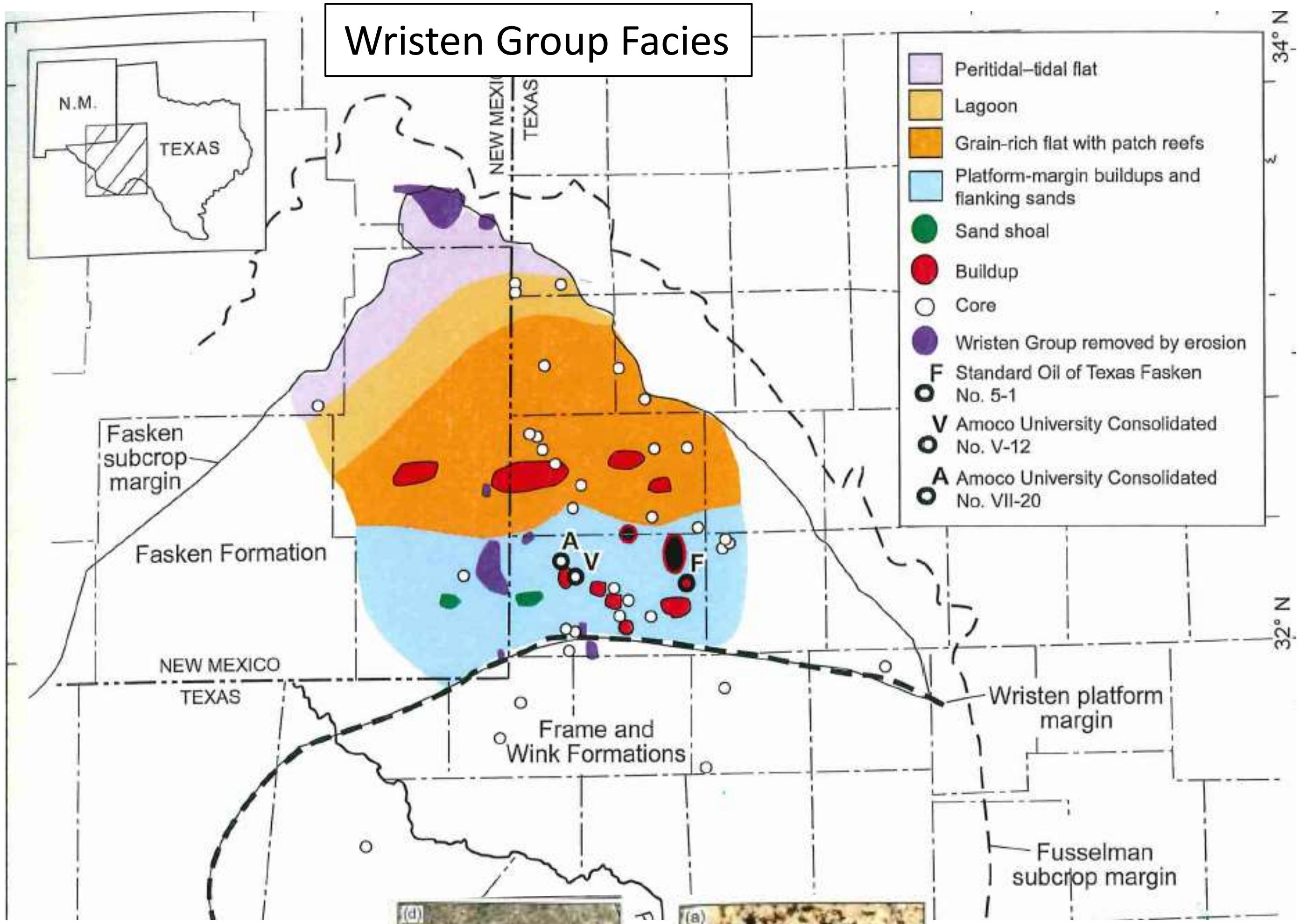


Figure 6. Thickness of the Wink Formation. Neither the Wink nor the Frame Formation is readily separable from the Fasken Formation north of the Wristen platform margin in central Andrews County.

(From Ruppel, Undated BEG Wristen Draft Report)

Wristen Group Facies



Stromatoporoid packstone

Coral boundstone

(Ruppel et al., 2020)

- Wristen (Fasken) buildups and shelf carbonates have produced more than 880 million bbls

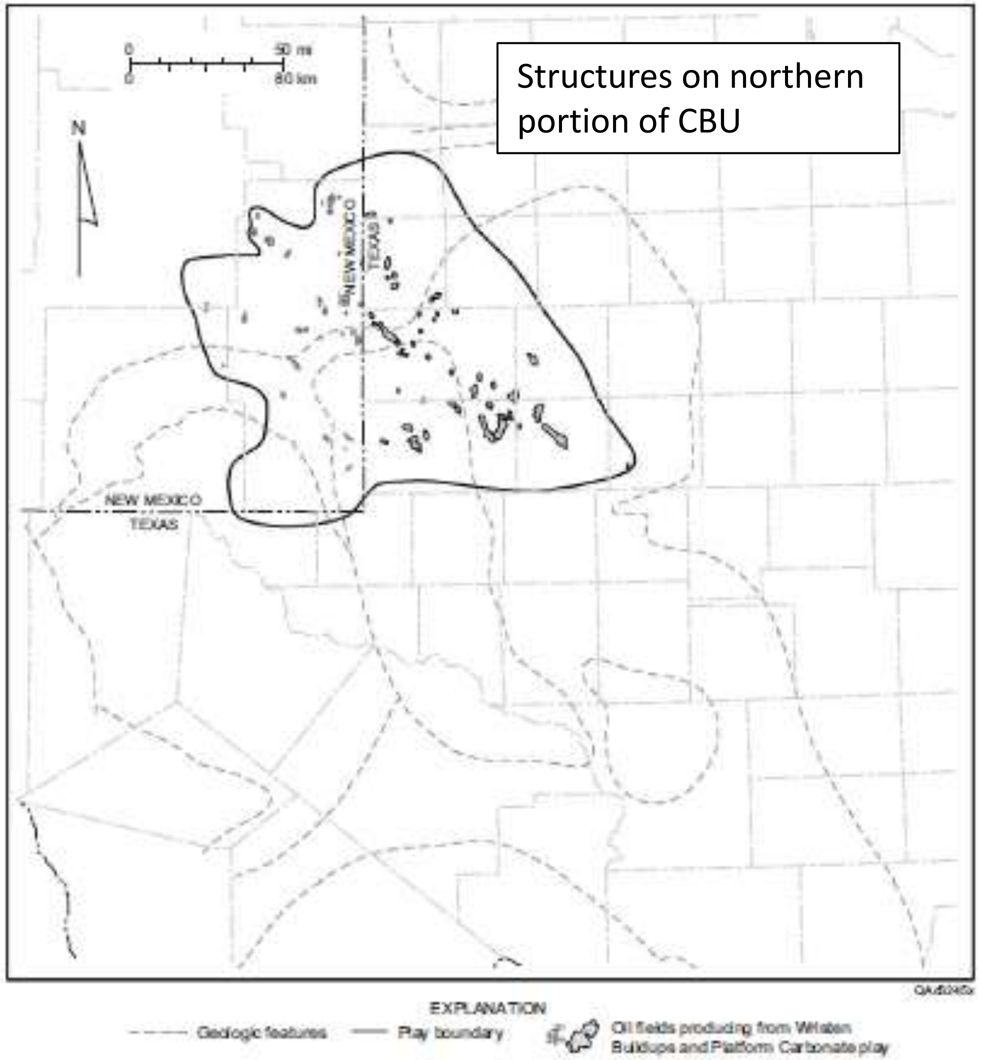


Figure 17. Play map for the Wristen Buildups and Platform Carbonate play, showing location of reservoirs having >1 MMbbl cumulative production, the play boundary, and geologic features. See figure 1 for county names and figure 2 for identification of geologic features.

(Dutton et al., 2004)

Lower Devonian Thirtyone Formation

- Oversteps underlying Wristen Group, filling-in basin during Early Devonian lowering of sea-level

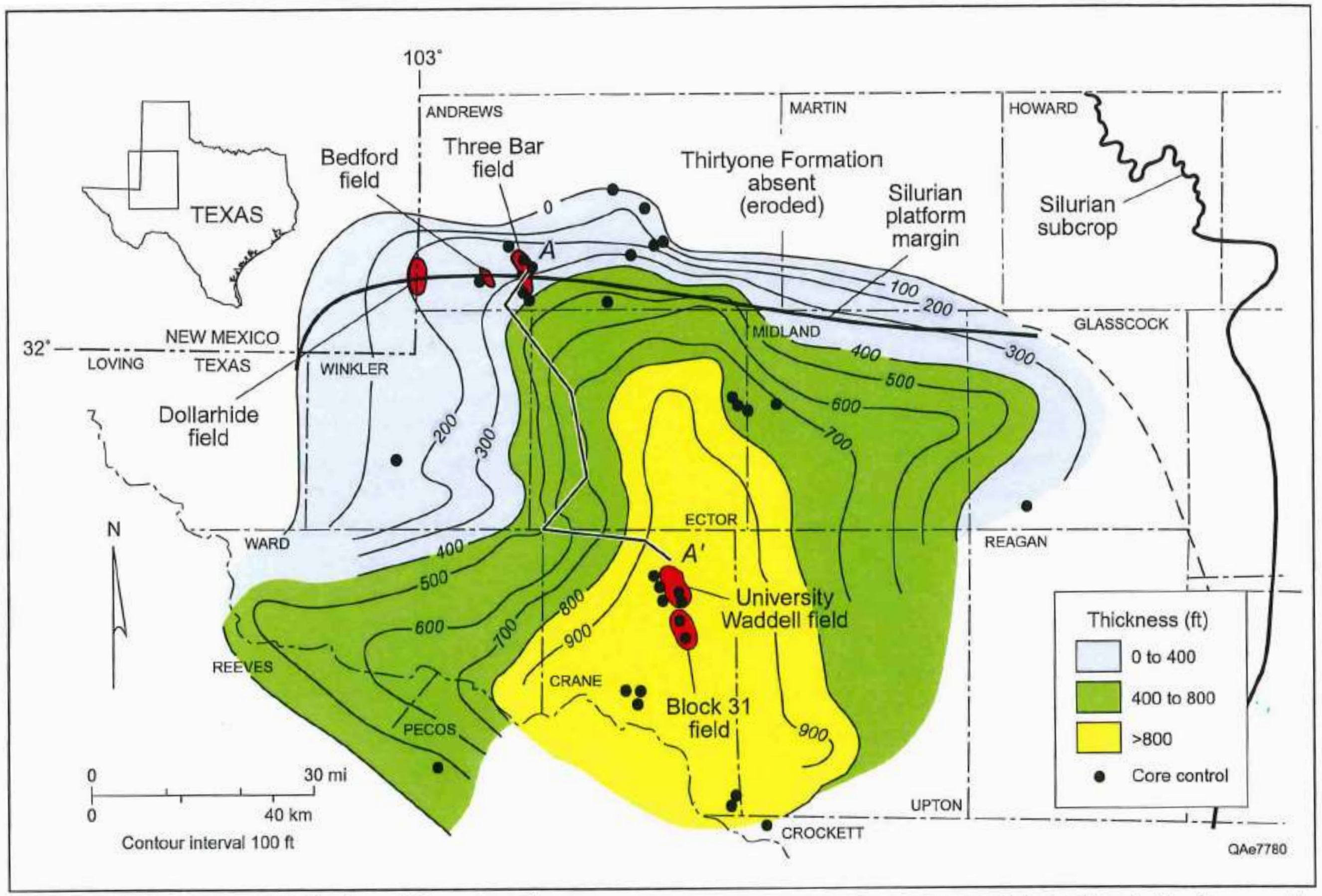
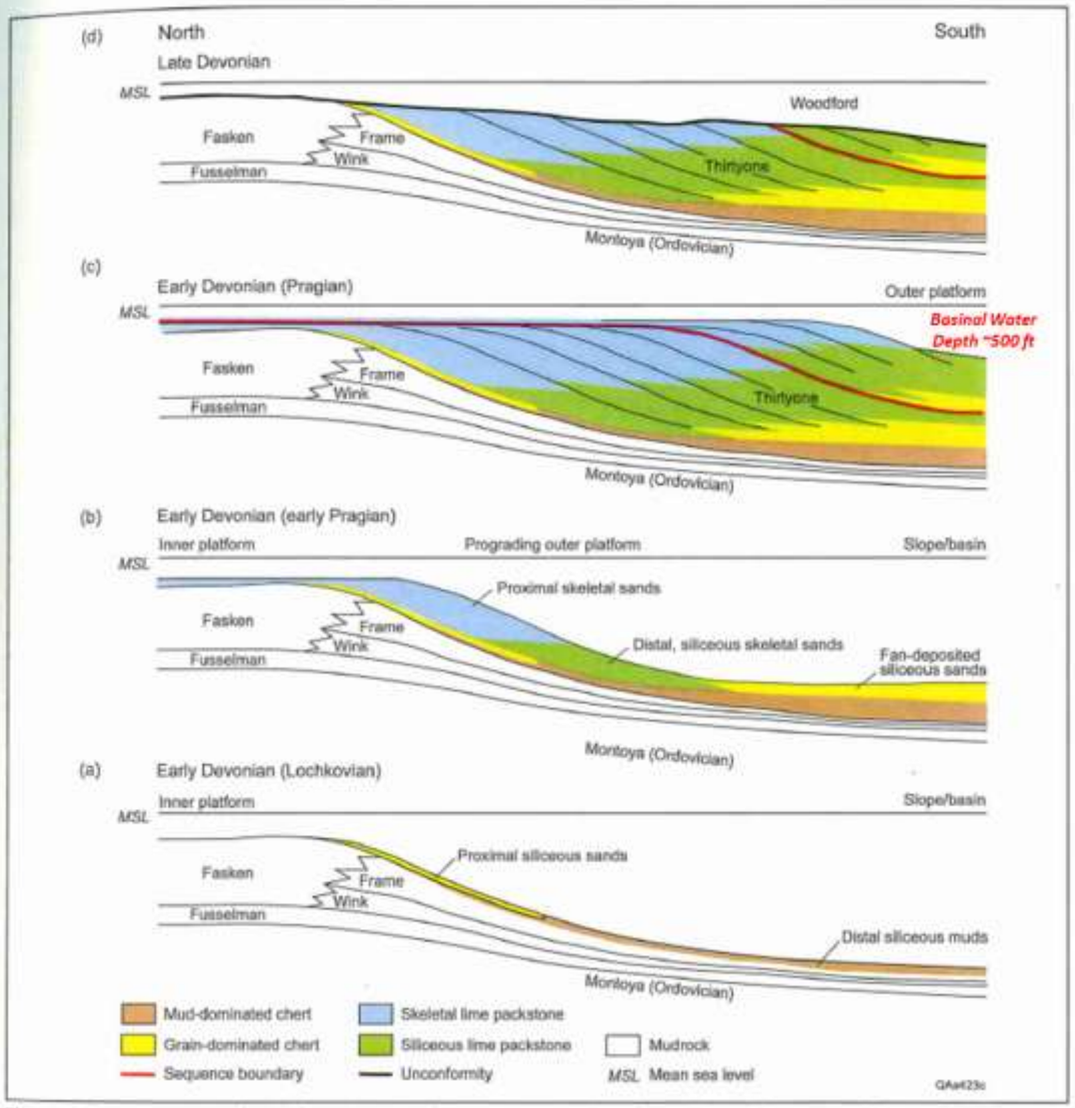
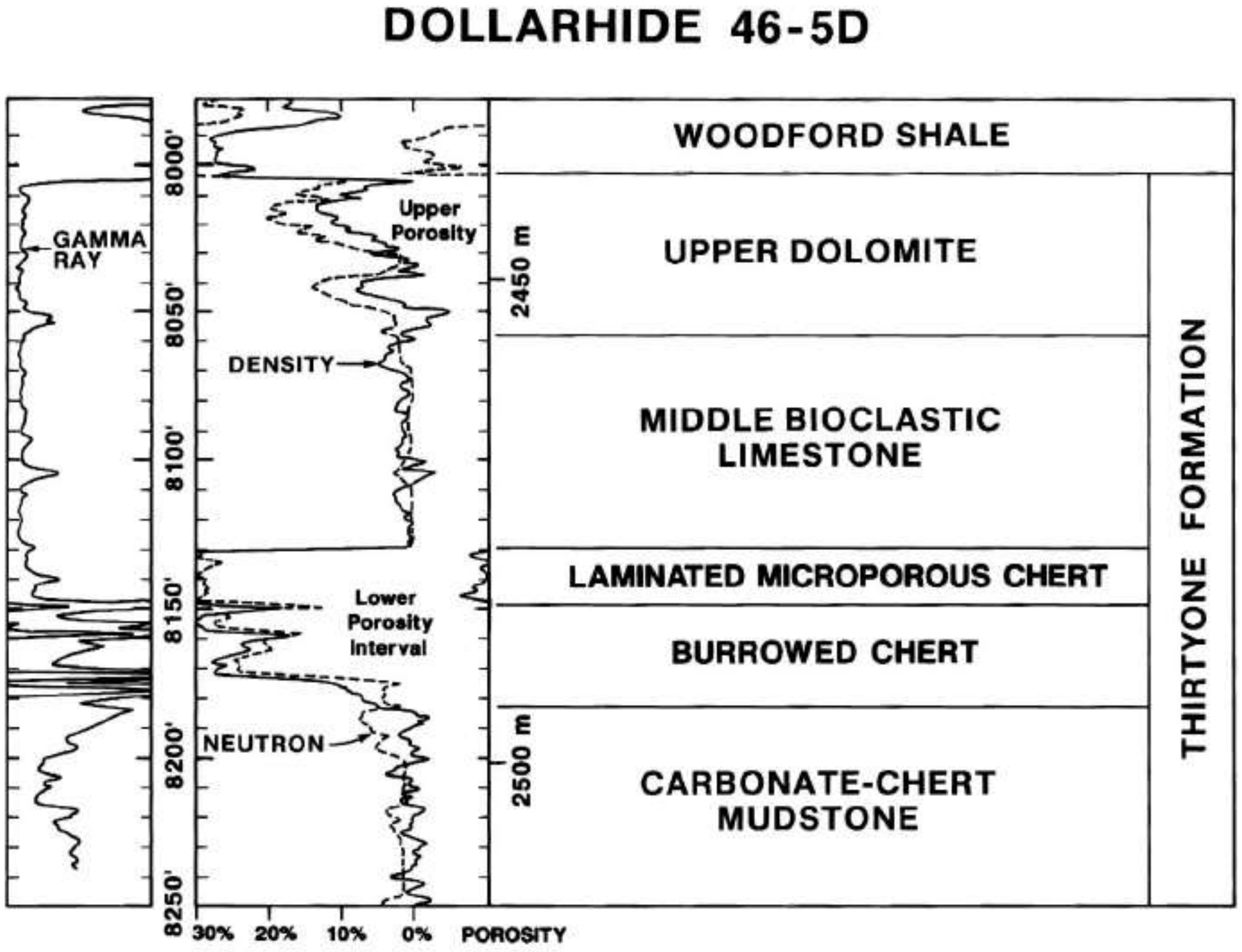


Figure 2. Thickness and distribution of Devonian Thirtyone Formation in West Texas showing location of key fields discussed in this paper. From Ruppel and Barnaby (2001). Cross section A–A' shown in figure 3.

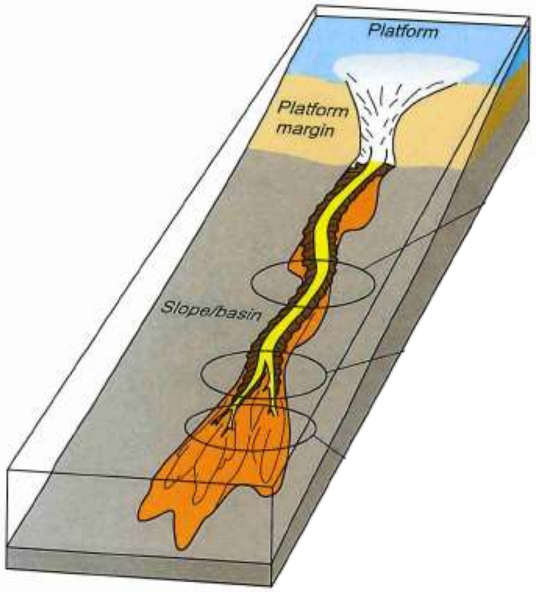
(Ruppel et al., 2020)



- Like the Montoya, carbonates of the Thirtyone are rich in siliceous chert; these cherty limestones contain porosity on many uplifted blocks of the Central Basin Uplift
  - Much of chert derived from sponges (not oceanic upwelling); deep-water flows ?



(Saller et al., 1991)



(Ruppel et al., 2020)

Figure 4. Typical depositional facies and well log for the Devonian Thirtyone Formation at Dollarhide field. Neutron and density porosity curves were calculated assuming a limestone matrix.

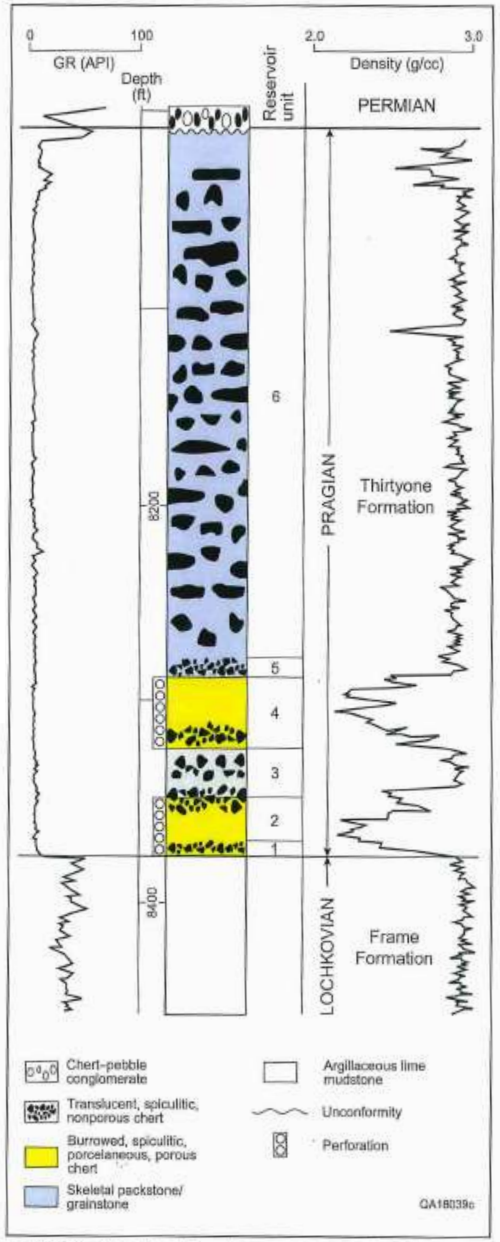
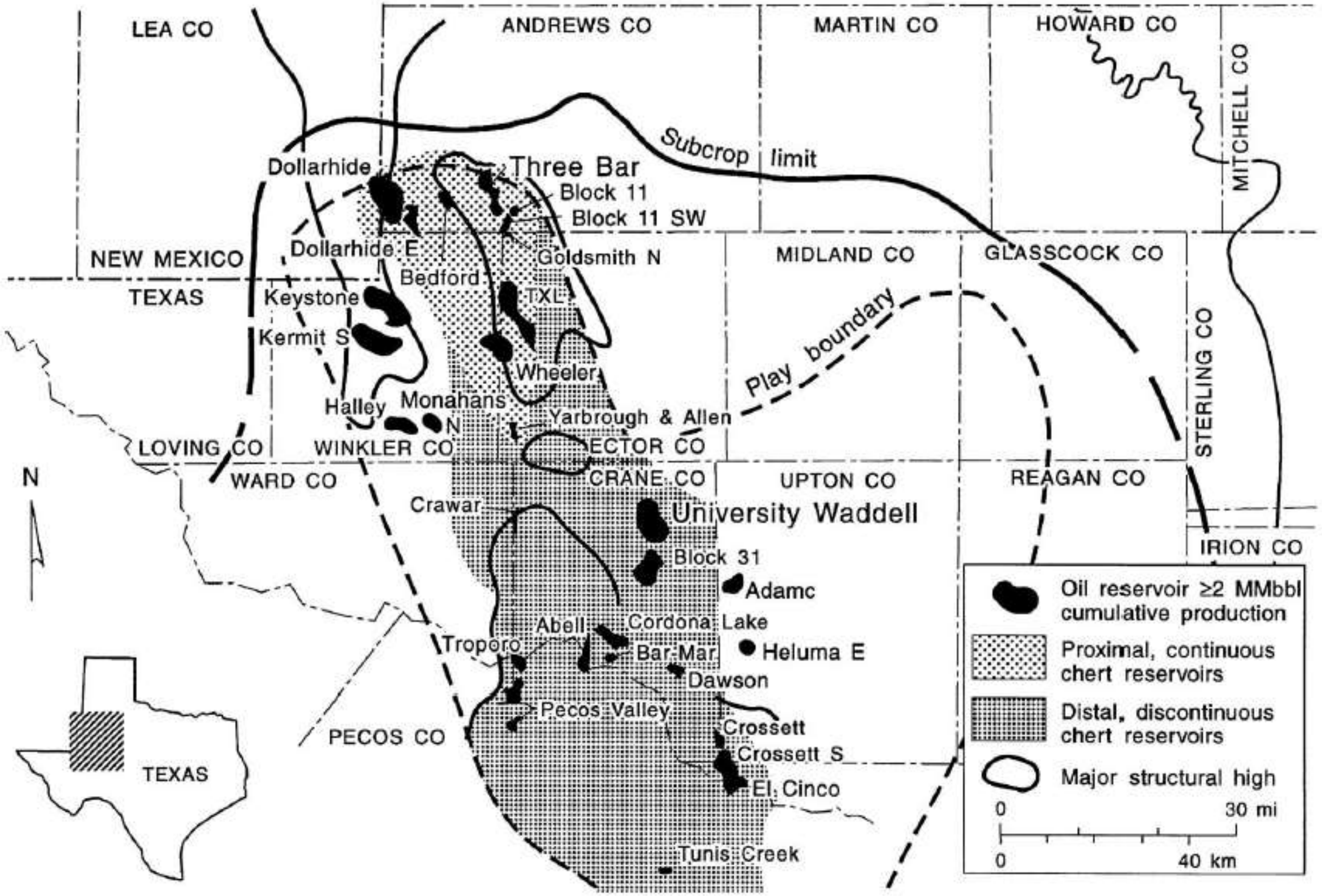
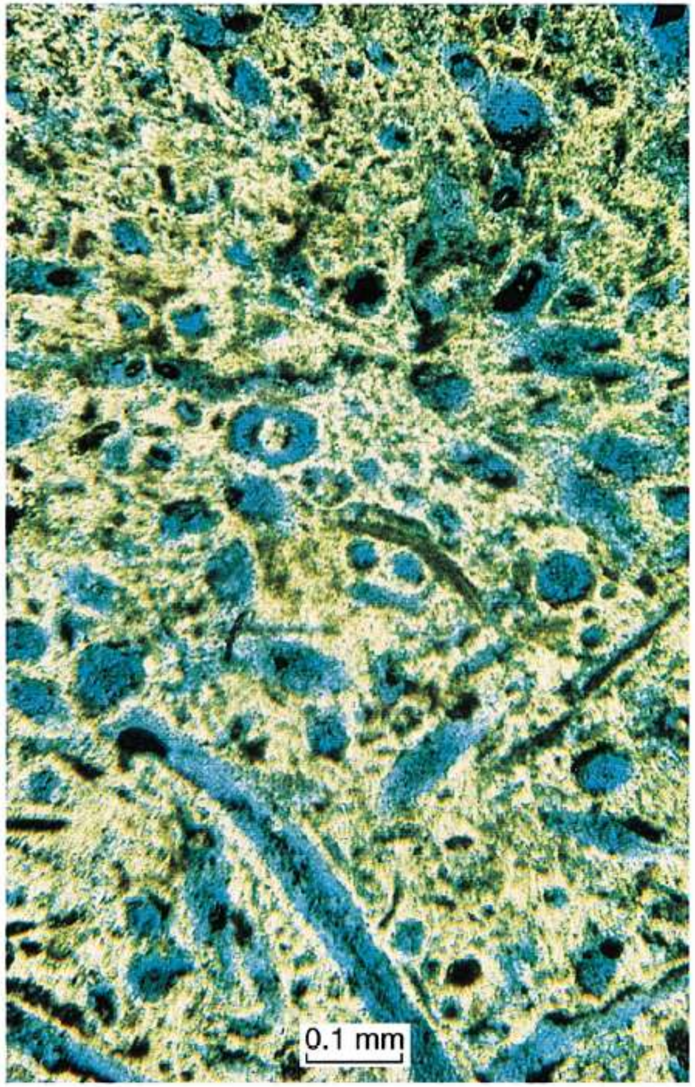


Figure 10. Typical stratigraphic succession and wireline-log signature of Thirtyone Formation in Three Bar field. Amoco Three Bar Unit No. 80. From Ruppel and Barnaby (2001). GR = gamma ray.

Lower Devonian Thirtyone Formation Oil Reservoir (Ruppel and Barnaby, 2001)

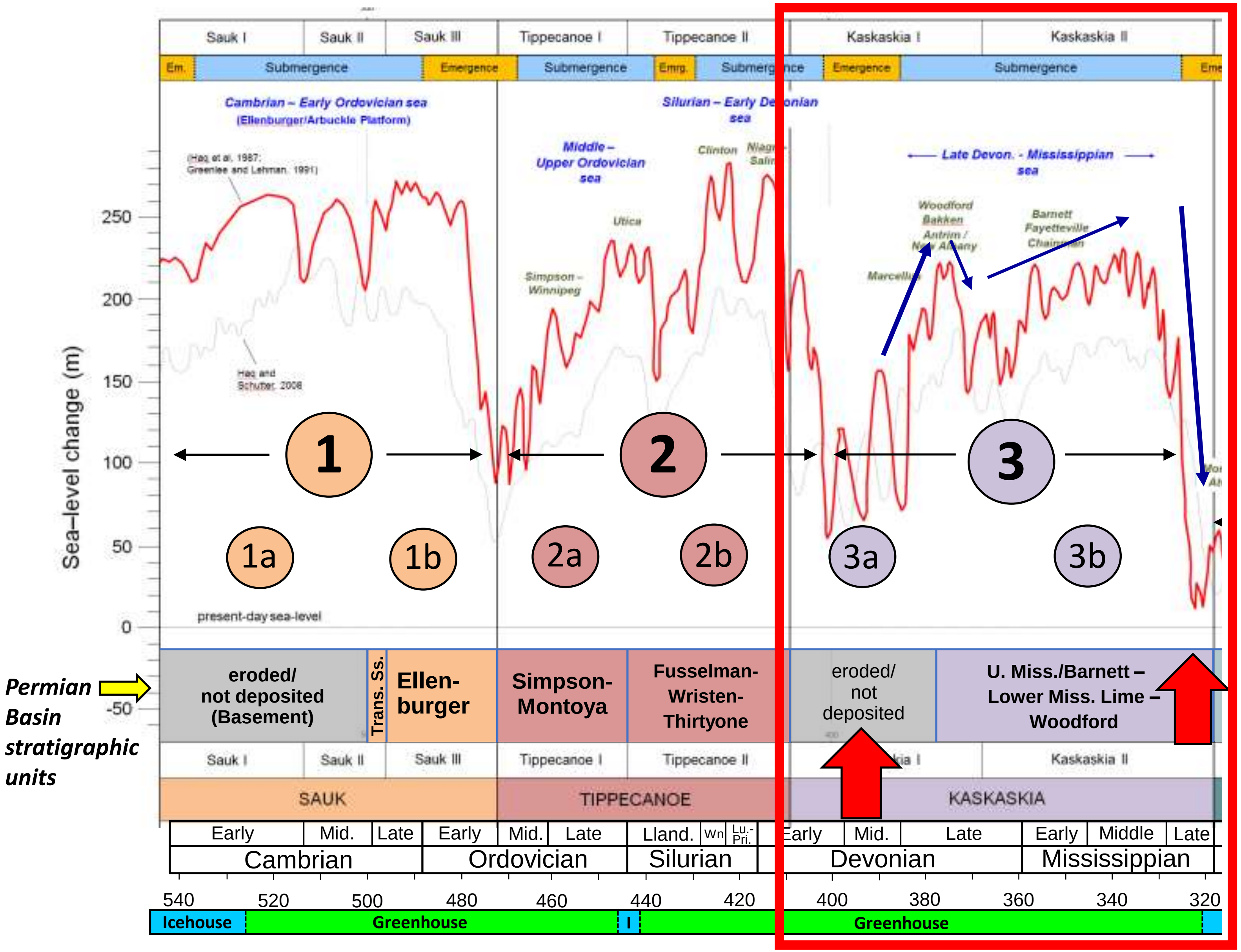


- > 750 million barrels of oil produced
- Potential remaining reserves of 650 MMBO



Thin-section photomicrograph showing spiculitic cherty limestone (sponge-rich) with abundant moldic porosity

Tobosa Basin: Megacycle 3 (Mid Dev. – end Miss.)

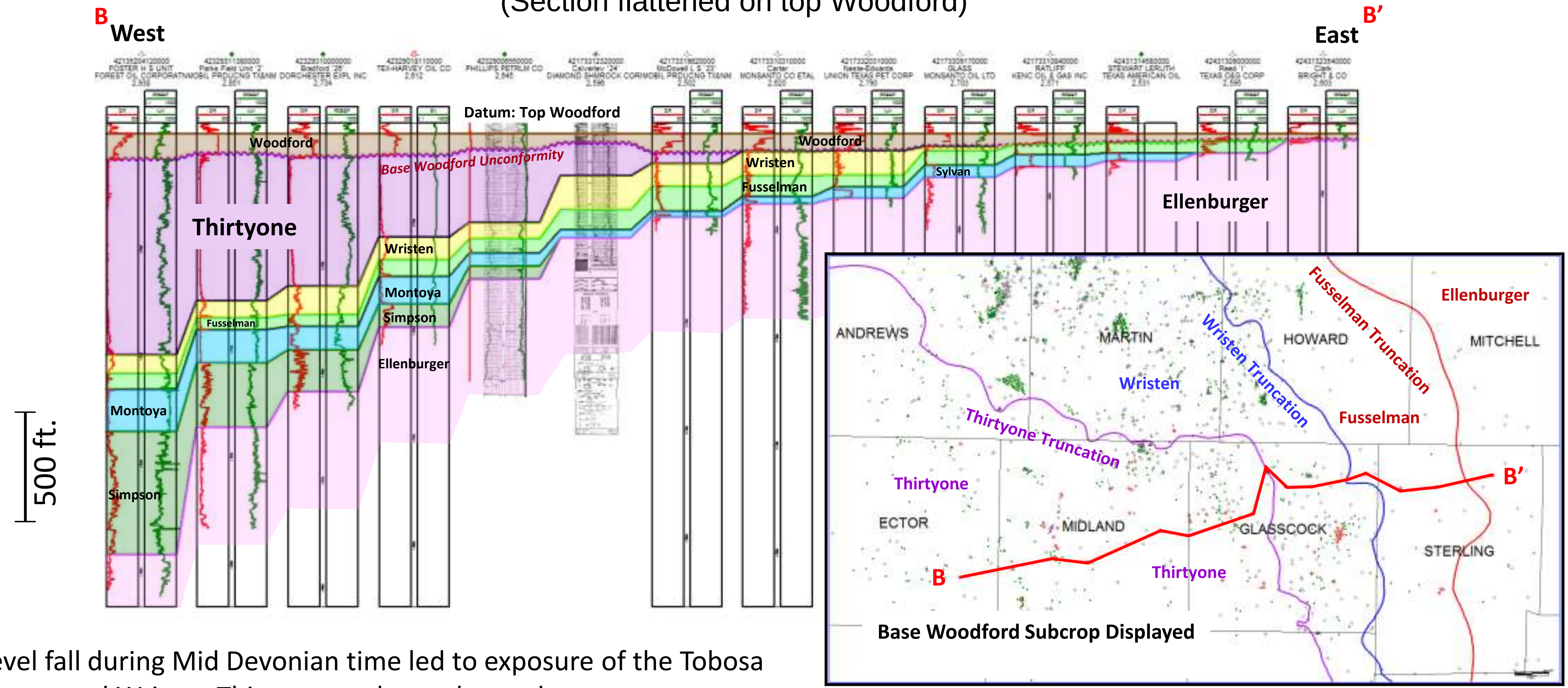


Sea-level analysis

- Follows a sea-level fall of >200 m, resulting in non-deposition/erosion event lasting approx. 30 million years (missing section)
- Rapid, short-term transgression during late Devonian time results in deposition of Woodford Shale, followed by brief SL fall
- Renewed transgression during latest Devonian followed by long-term highstand throughout Mississippian results in deposition of Lower Miss. Lime and Upper Miss Lime / Barnett Shale
- Rapid, significant sea level fall (~200m) terminates Megacycle 3, once again exposing large portions of N.Amer including west Texas; coincides with onset of active tectonic margin
- Greenhouse climate throughout; onset of major ice age at end of cycle

W-E Cross Section Showing Erosional Truncation At Base Woodford Unconformity

(Section flattened on top Woodford)

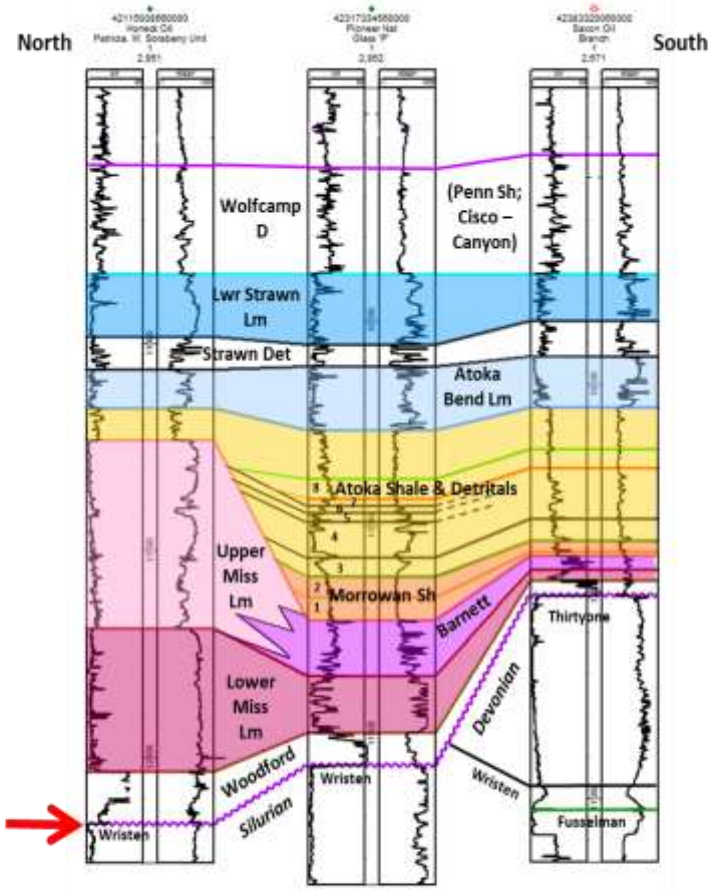


- Sea-level fall during Mid Devonian time led to exposure of the Tobosa Basin; exposed Wristen Thirtyone carbs are karsted
- Associated regional uplift (of uncertain cause) causes tilting along east side of Tobosa Basin and truncation of Siluro-Devonian units: Fusselman, Wristen, Thirtyone (Simpson and Montoya were depositional pinchouts)
- Pinchouts form small stratigraphic traps directly underlying the organic-rich Woodford shale (prolific petroleum source rock)

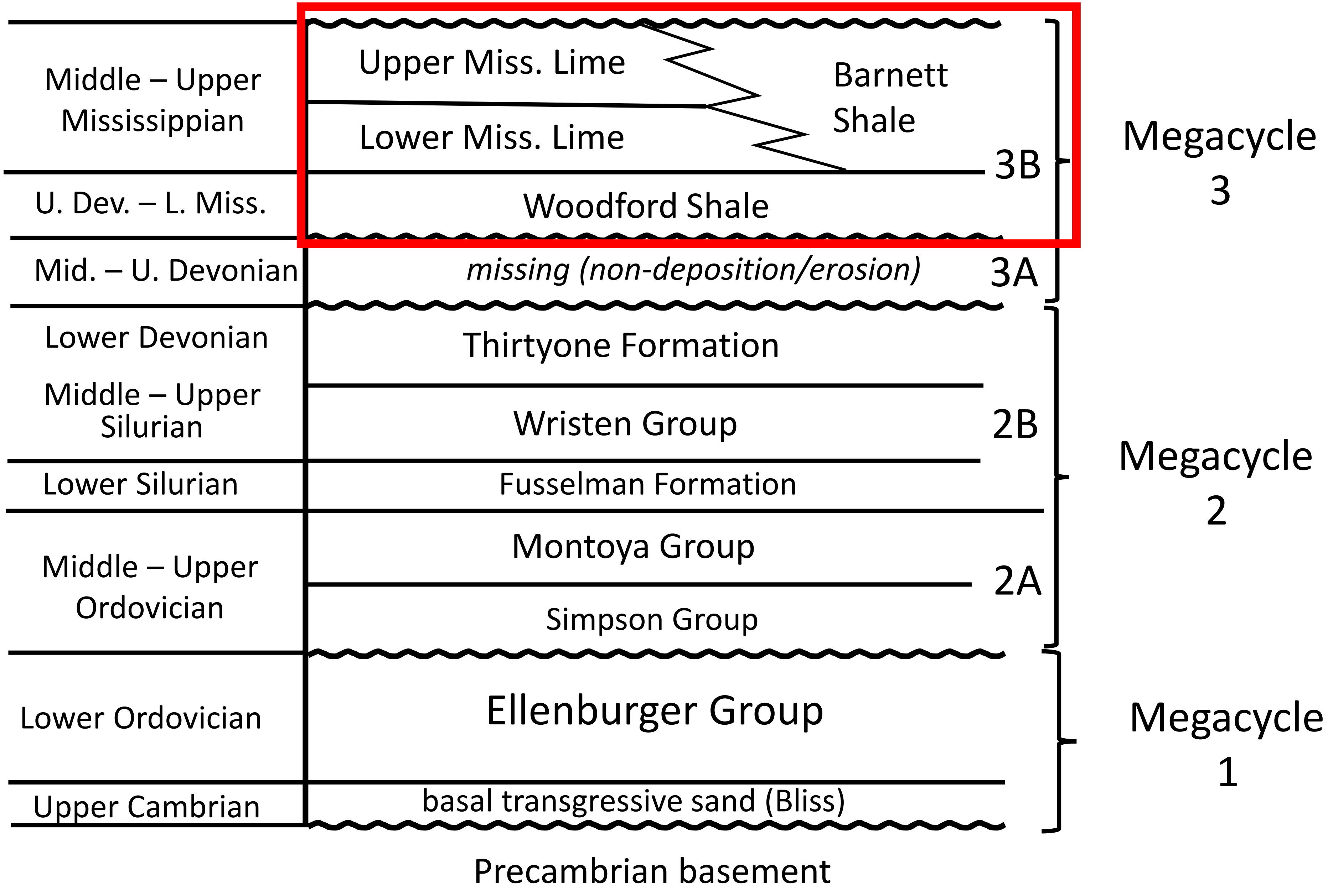
Mid Devonian unconformity in the middle of the Midland Basin

The unconformity as seen here is exposed in a conventional rock core from a measured depth of 11,295 ft.

A “razor-thin” surface with micro-karst separates cherty limestones of the Early Devonian Thirtyone Fm (below) from organic-rich, pyritic black shales of the Late Devonian-Early Mississippian Woodford Fm. (above)

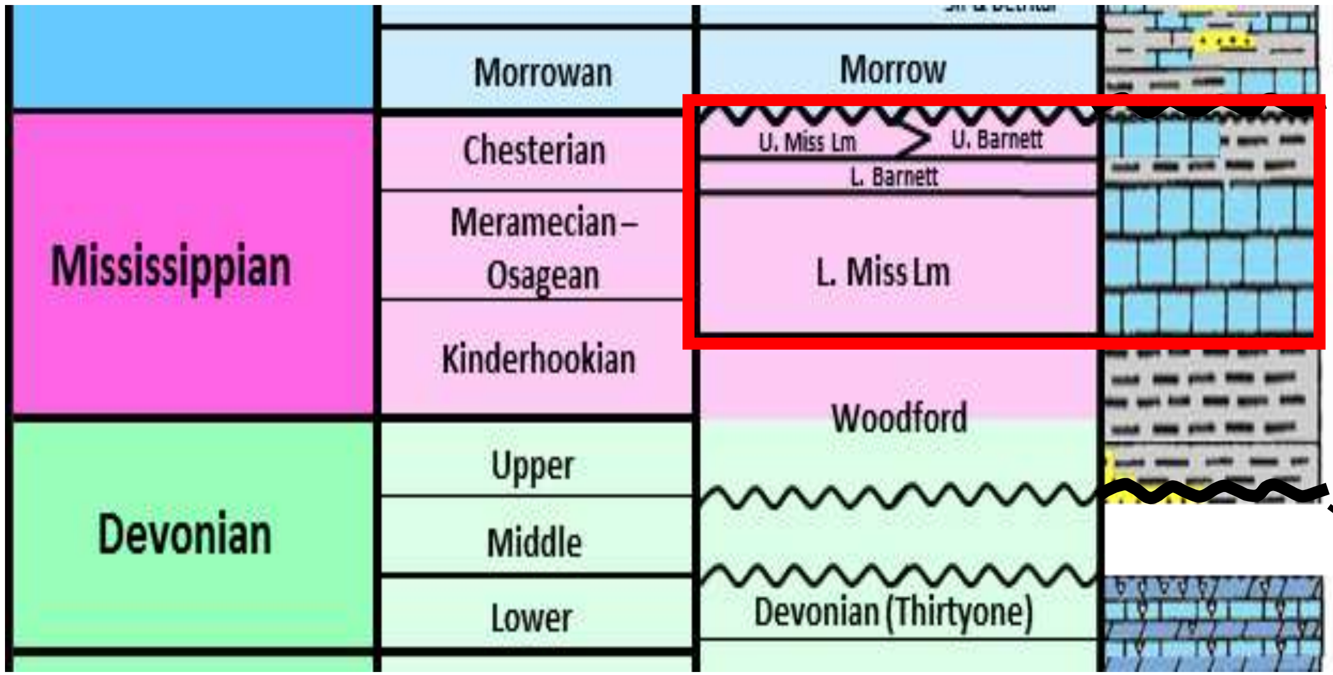


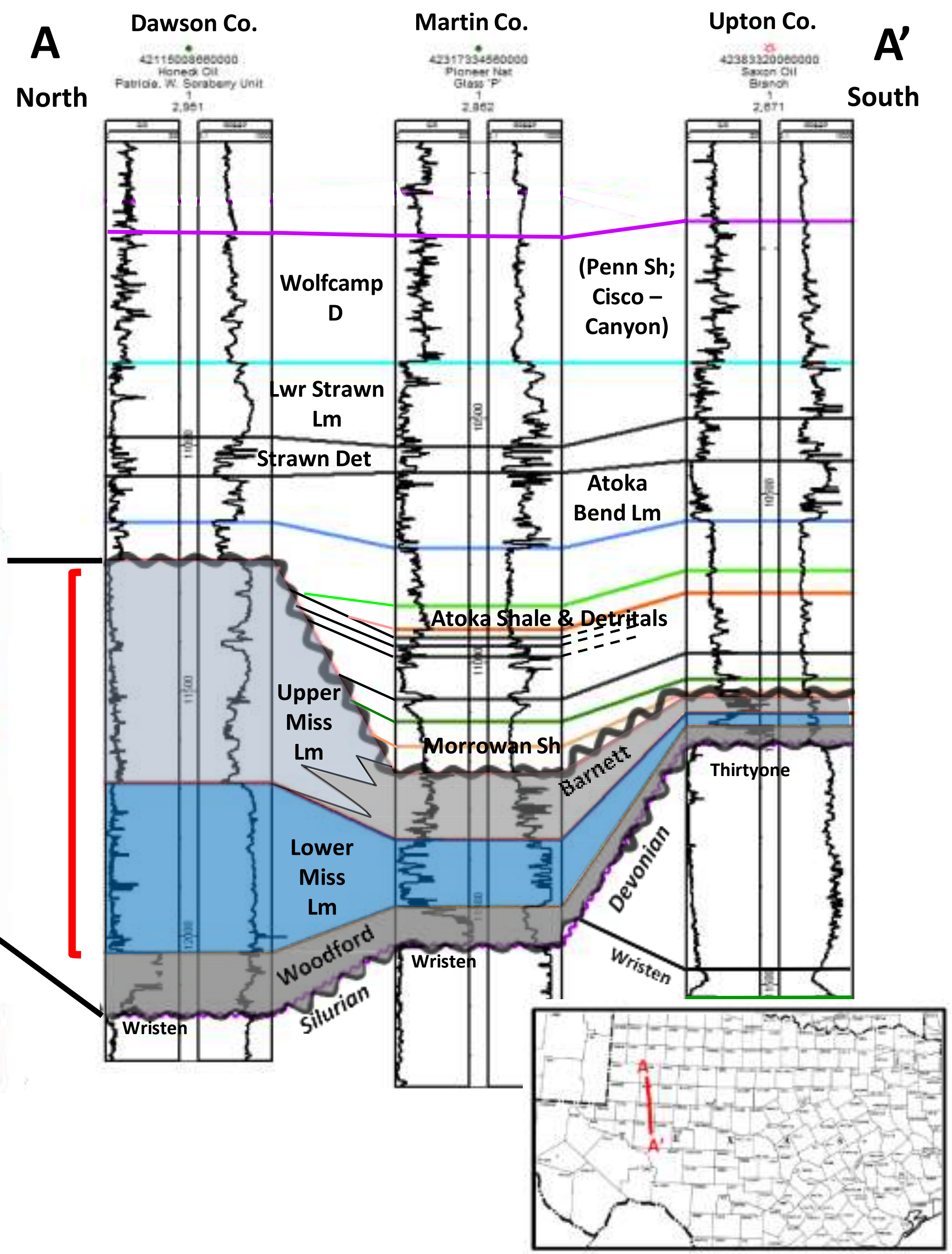
Stratigraphy of the Tobosa Basin



Woodford – Mississippian Limestone - Barnett

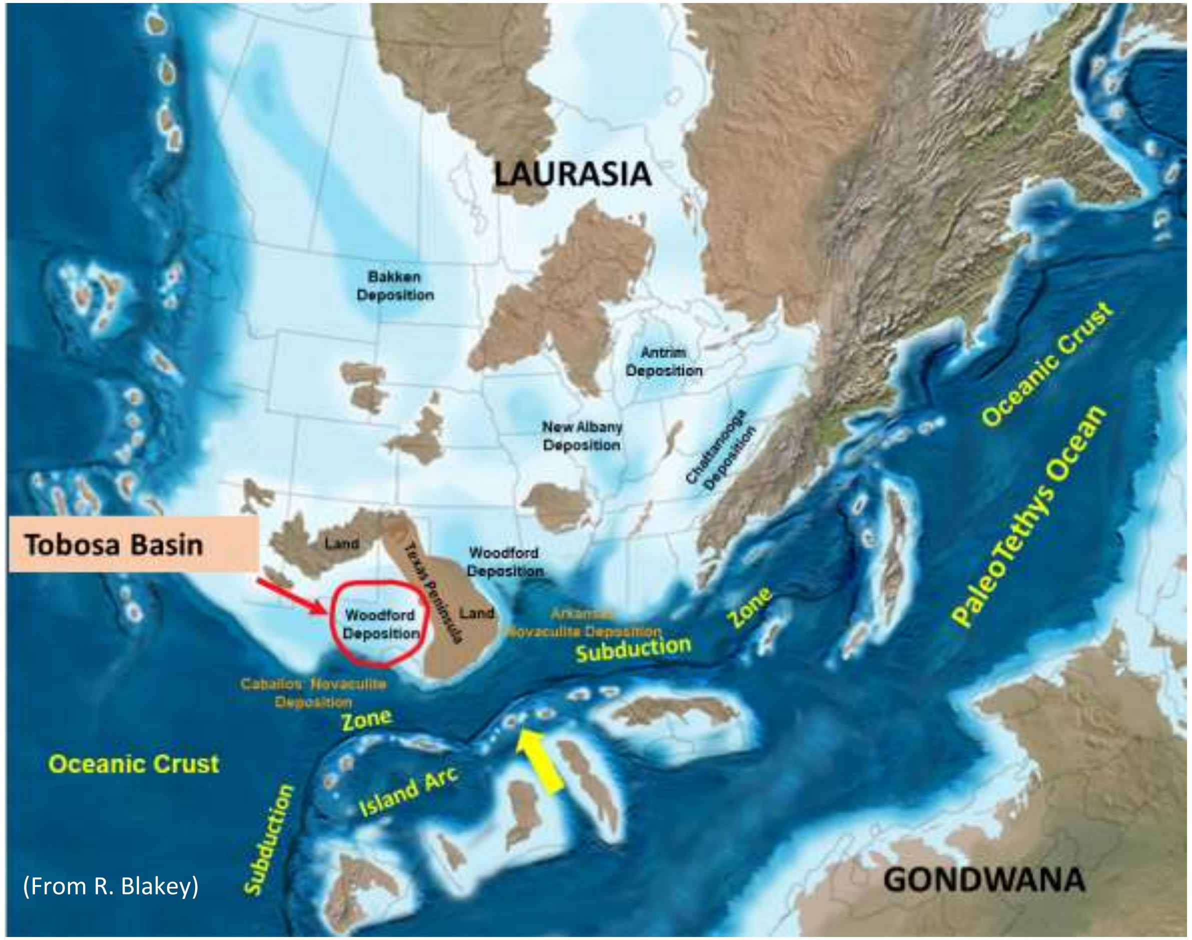
- Tobosa Basin / passive margin tectonic phase ends; coincides with a significant eustatic sea-level rise (birth and development of Mississippian seaway)
- Two source intervals "sandwiched" between a shallow marine limestone



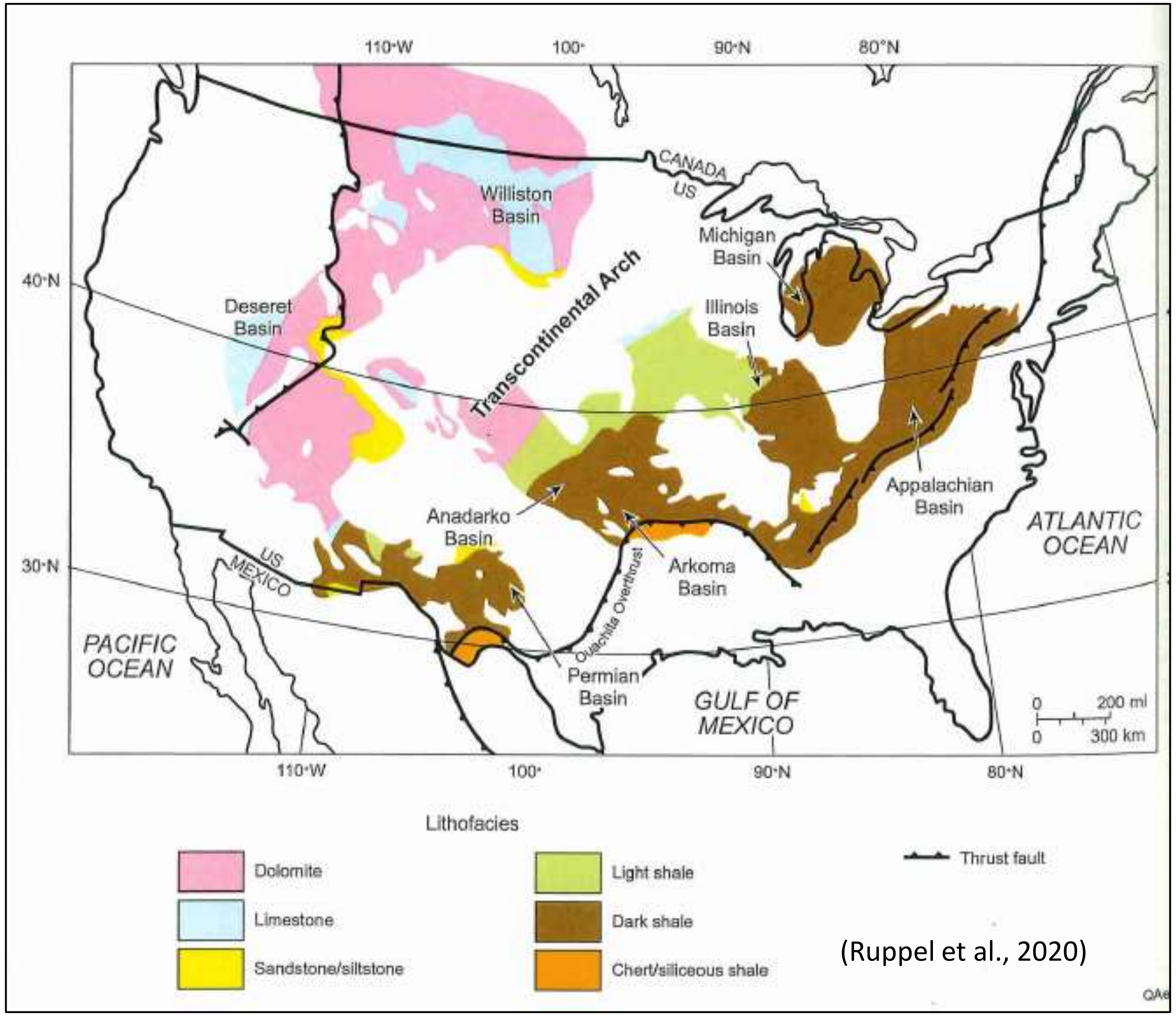


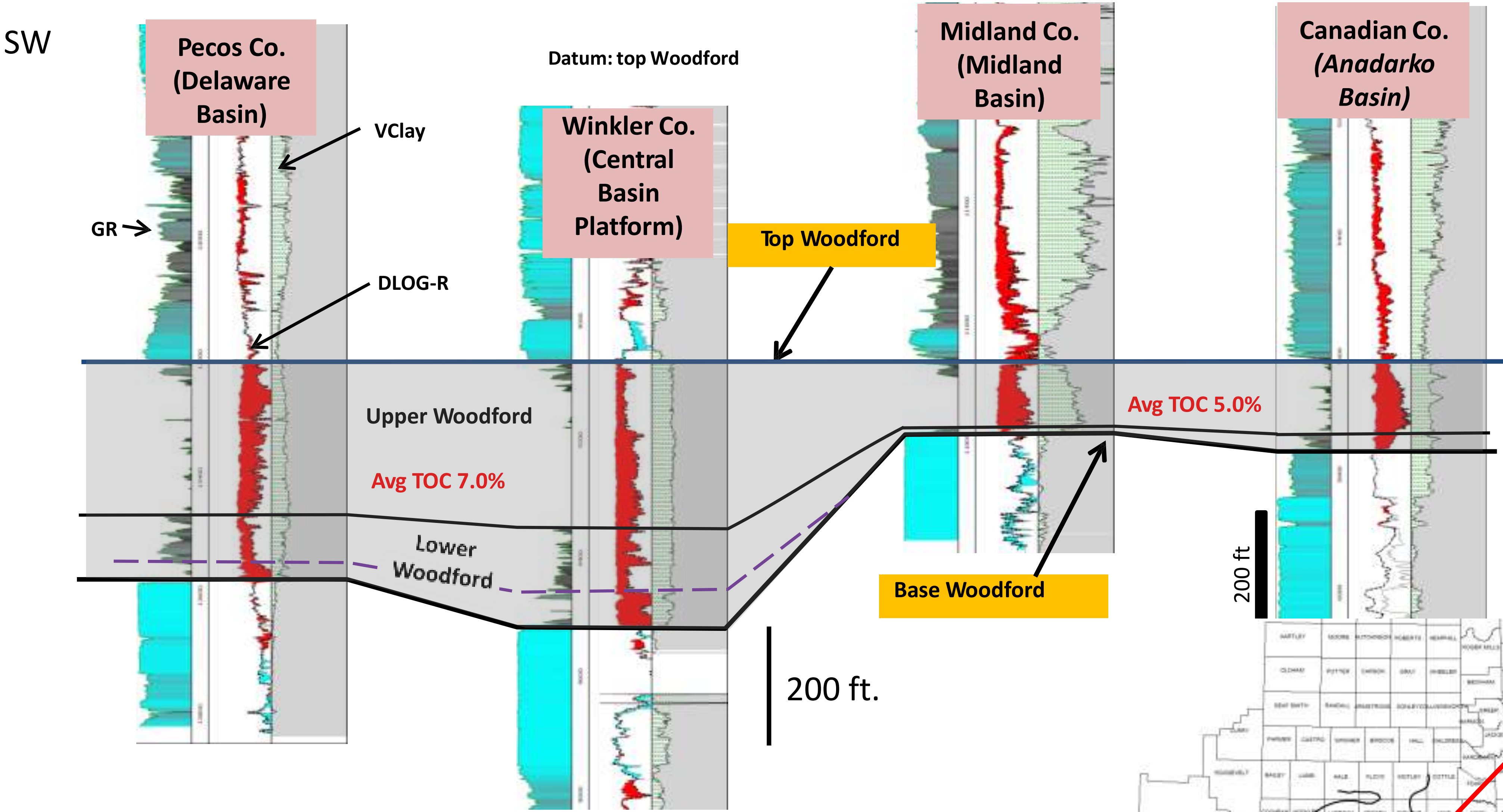
Late Devonian Paleogeography

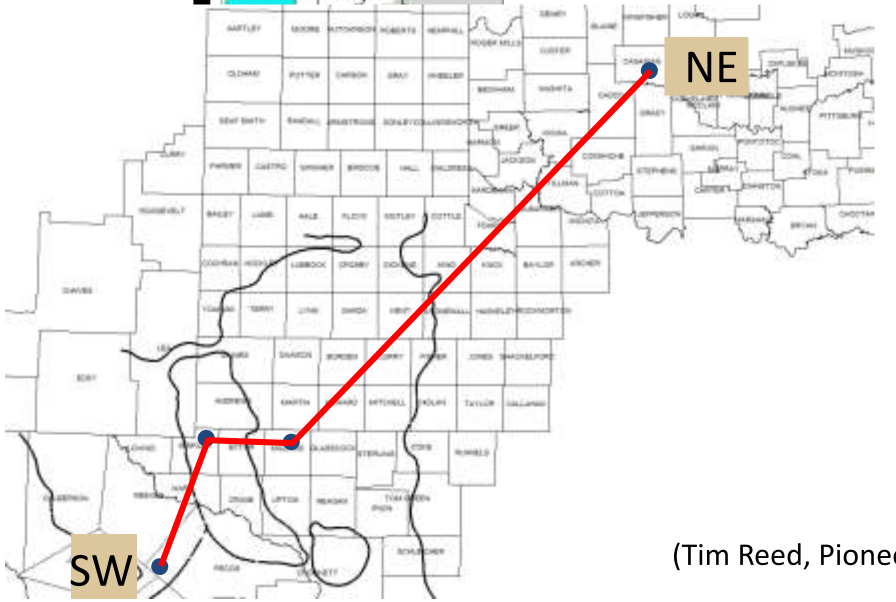
- Widespread flooding of North American craton
- Note low-lying Texas Arch to east of Tobosa Basin



Woodford shale is part of an overall larger system of organic-rich black shale deposition throughout eastern North America during Late Devonian and Early Mississippian time







(Tim Reed, Pioneer)

Late Dev – Early Miss. Woodford Shale: A word-class source rock that blanketed the Tobosa Basin

- One of the main petroleum source rocks in the Permian Basin region
- Dark black, silica- and pyrite-rich mudrocks

Woodford black shale deposition:

- a mixture of pelagic “rain” and deep-water mud-rich gravity flows
- Stratified water body
  - Surface waters are fully oxygenated and support a healthy population of planktonic organisms
  - Bottom waters are anoxic (no bottom fauna to consume deposited organic matter, ensuring burial / preservation

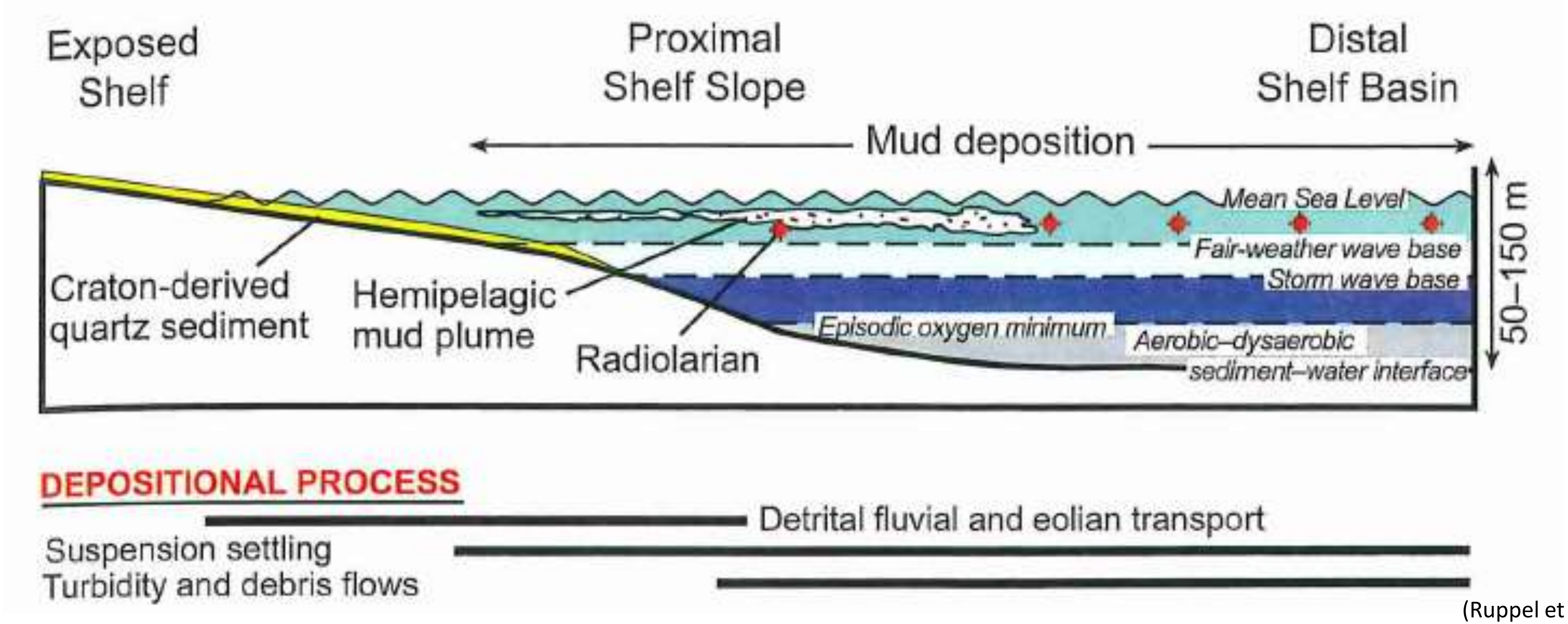
Biogenic Sediment

Siliceous: Planktonic/nektonic fauna and flora (radiolaria, algal cysts)

Calcareous: Planktonic/nektonic fauna and flora

Organic matter

Authigenic–Diagenetic Cements



(Ruppel et al., 2020)

Woodford Thermal Maturity

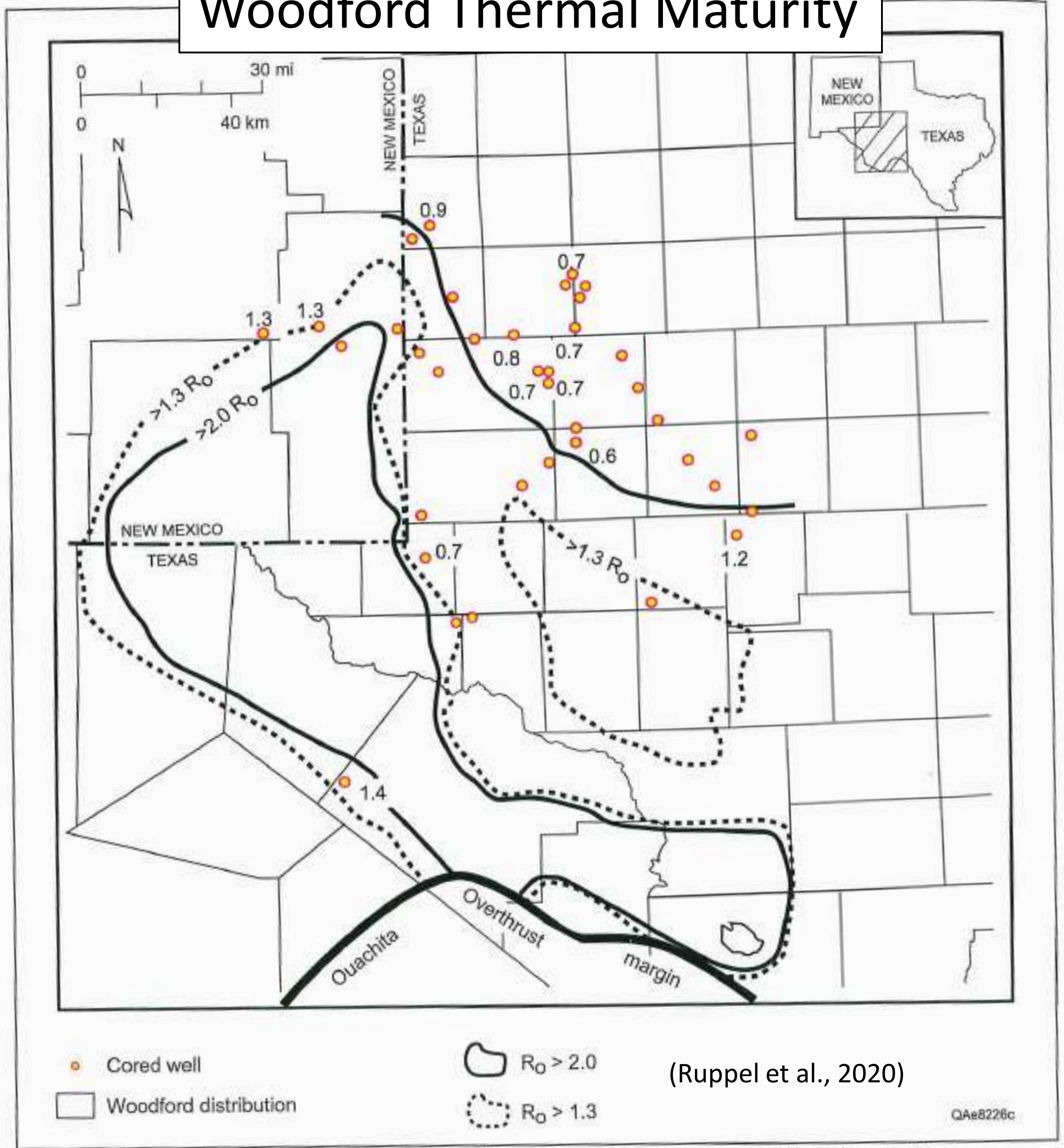


Figure 27. Map showing measured and projected thermal maturity of Woodford strata in Permian Basin region. Data from cored wells in this study and from data in Pawlewicz (2005) and Diaz-Garcia (2014).

(Ruppel et al., 2020)

Ro maturity values

< 0.6	non-generative
0.6-0.8	early oil window
0.9-1.1	peak oil window
1.1-1.3	wet gas window
> 1.3	dry gas window

Woodford as a potential shale play:

- Delaware Basin: dry gas window
- CBP: early oil window
- Midland Basin: wet gas to dry gas (<100 ft. thick)

Woodford Isopach

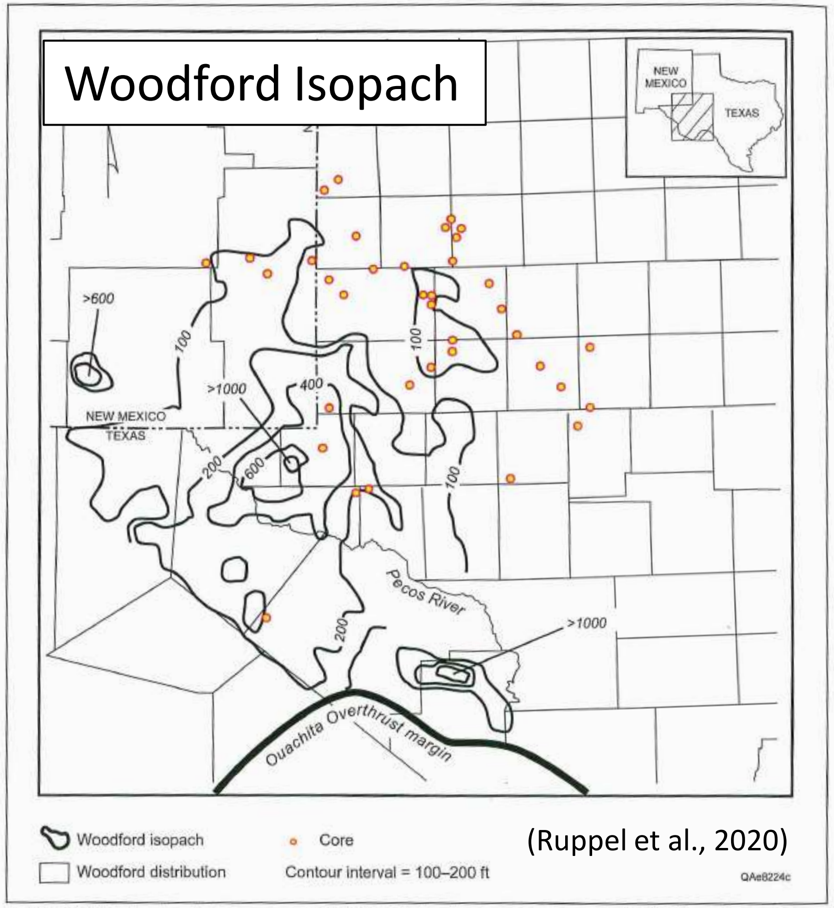


Figure 25. Map showing thickness of Woodford strata in Permian Basin region. Based on data from Comer (1991) and Geological Data Services (now IHS Markit) (2008).

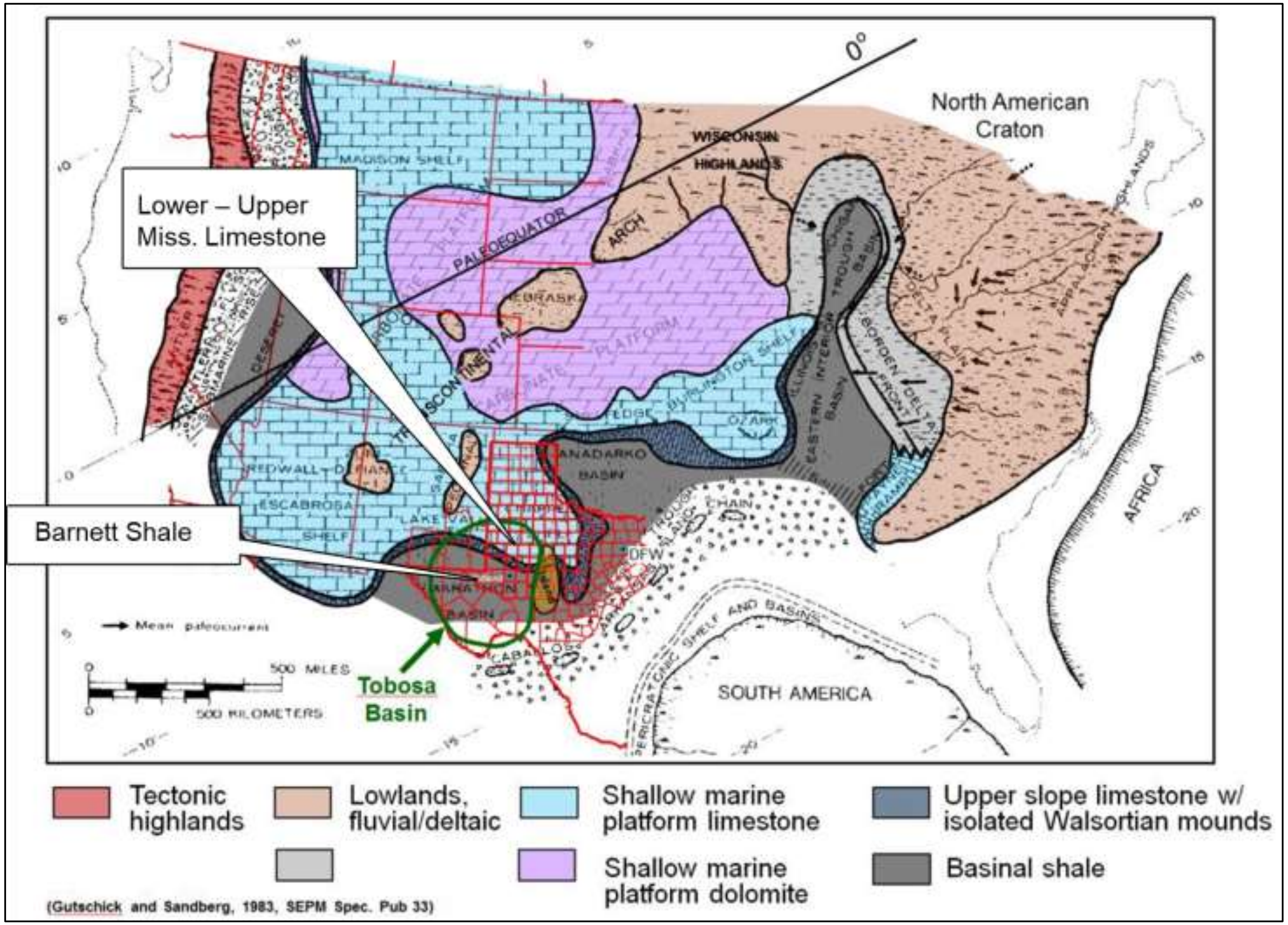
(Ruppel et al., 2020)

MISSISSIPPIAN LIME

AND

BARNETT SHALE

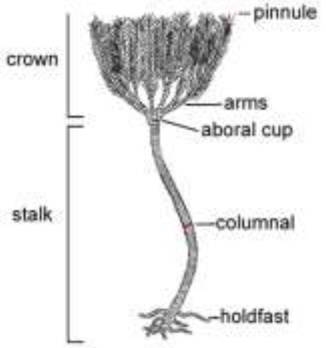
Early to Late Mississippian facies of continental U.S.



- Following deposition of the Woodford Shale, long-term sea-level highstand conditions resulted in development of an extensive shallow-water carbonate platform throughout North America

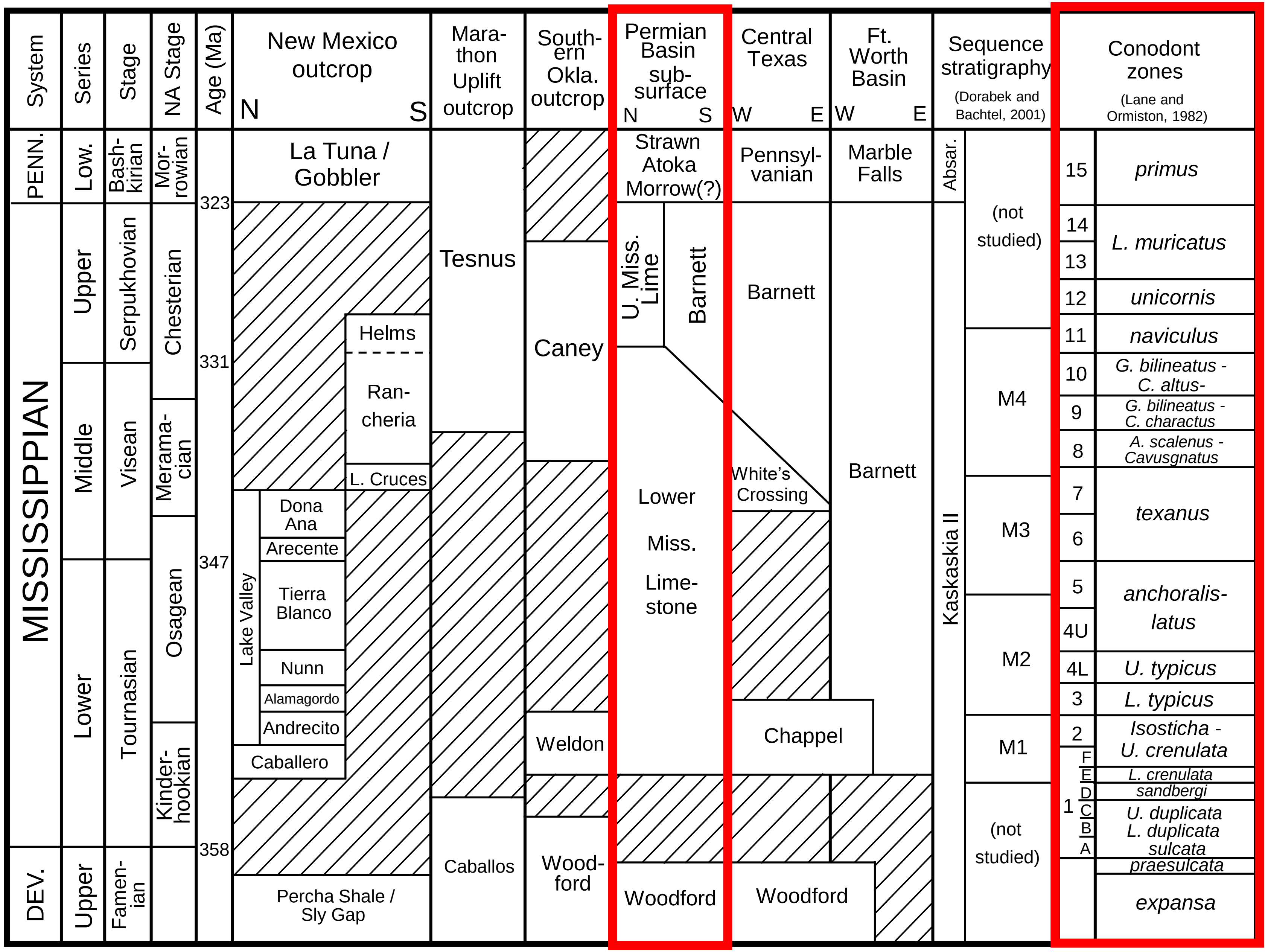
- Note position of Tobosa Basin on southern margin of the platform
  - Updip: shallow-water limestones including crinoid-rich granistones
  - Downdip: small sponge-rich reefs, mud mounds, and deep-water shale

Mississippian: age of the crinoids



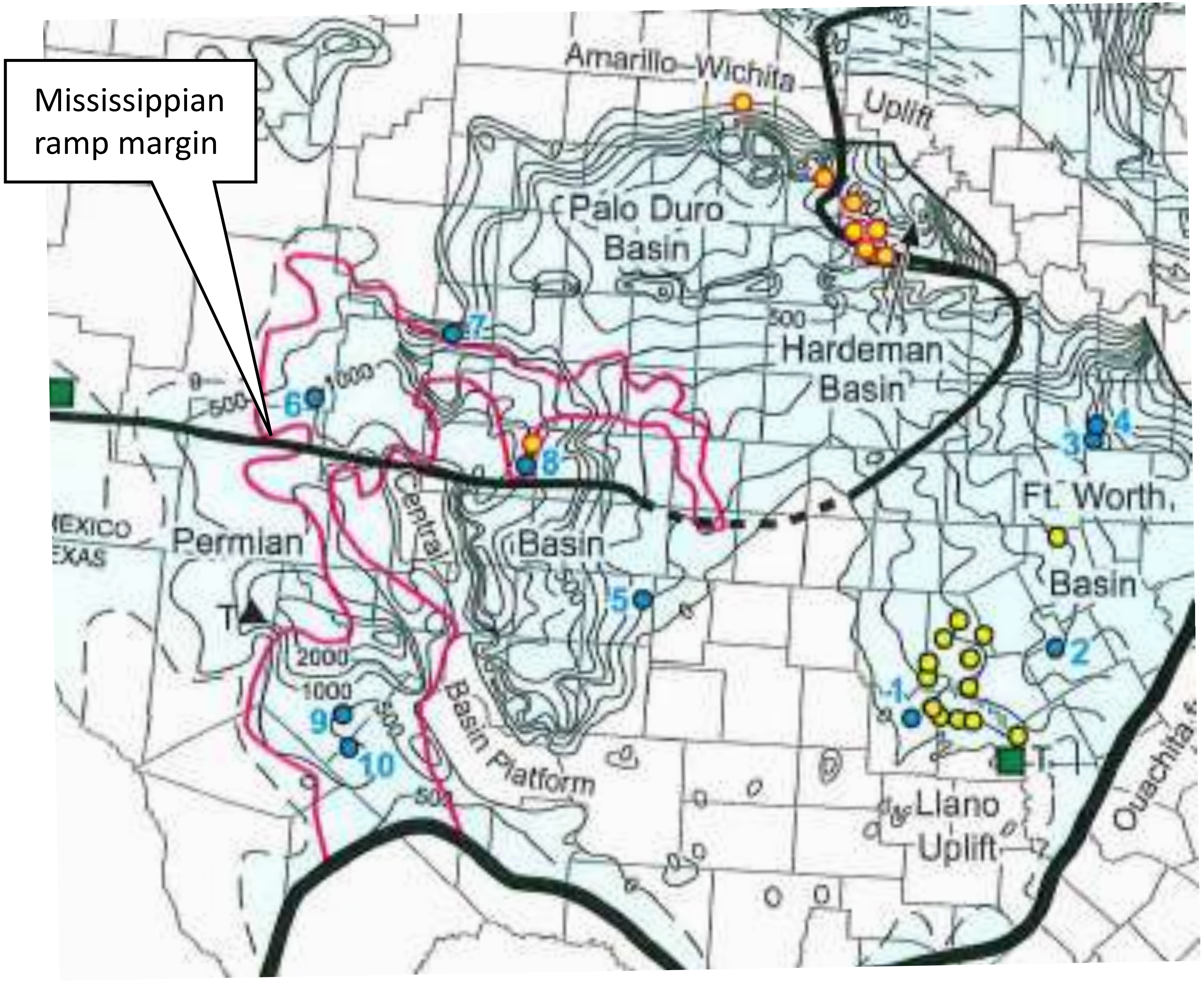
Upper Devonian – Mississippian stratigraphy

Conodonts: an extinct group of jawless vertebrates resembling eels, classified in the class Conodonta. For many years, they were known only from their tooth-like oral elements found in isolation and now called conodont elements. They existed in the world's oceans for over 300 million years, from the Cambrian to the beginning of the Jurassic. Conodont elements are widely used as index fossils index fossil.



(from Ruppel et al., 2020)

Mississippian isopach

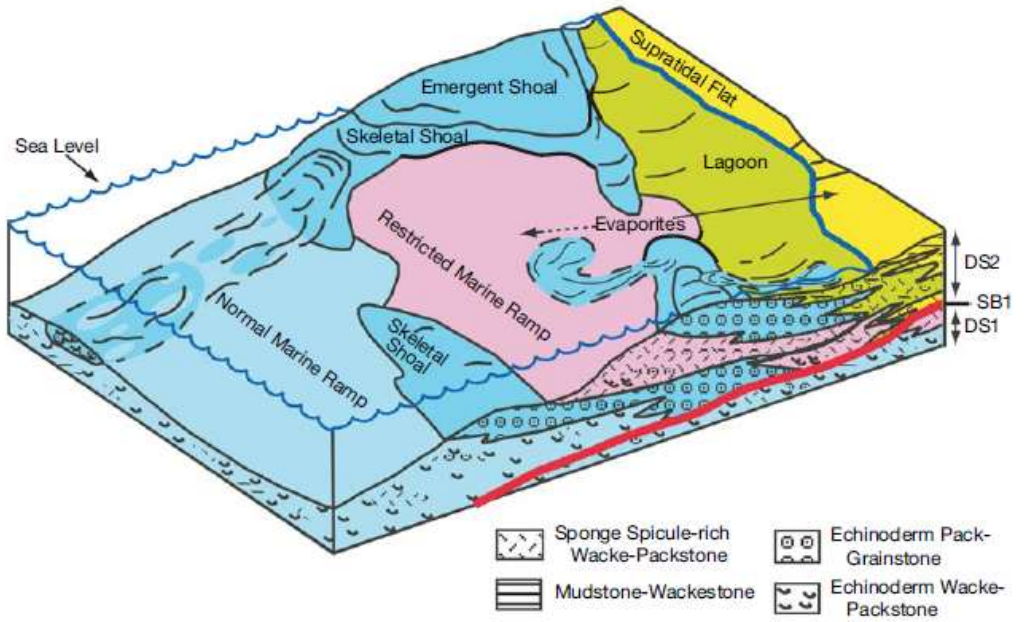


- 500 feet thick in Midland Basin
- Mostly absent on Central Basin Platform
- > 2000 ft thick in Delaware Basin

(from Ruppel et al., 2020)

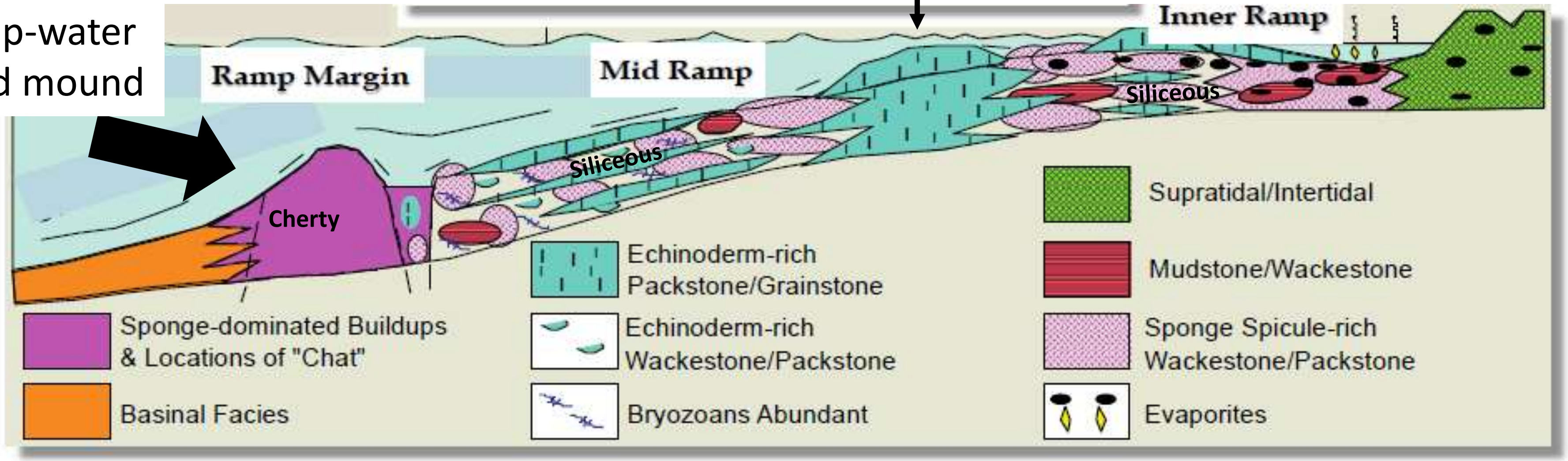
Mississippian Ramp Carbonate Facies Model

This is a generalized facies model for Mississippian deposition in Kansas, but does apply to the Permian Basin. However, evaporite facies are not present in the Permian Basin.



Crinoidal grainstones at ramp margin

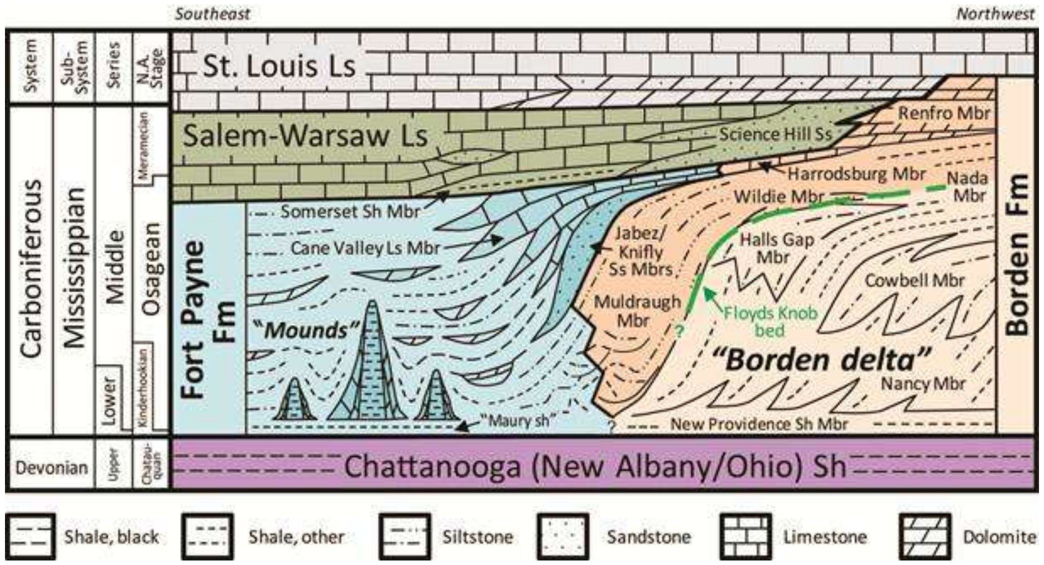
Deep-water mud mound



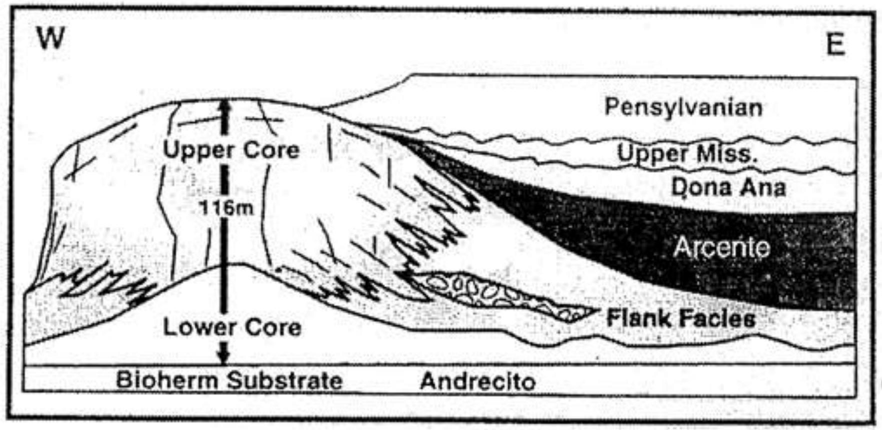
(From Franseen, 2012; Online presentation slides for talk at Kansas Interdisciplinary Carbonates Consortium)

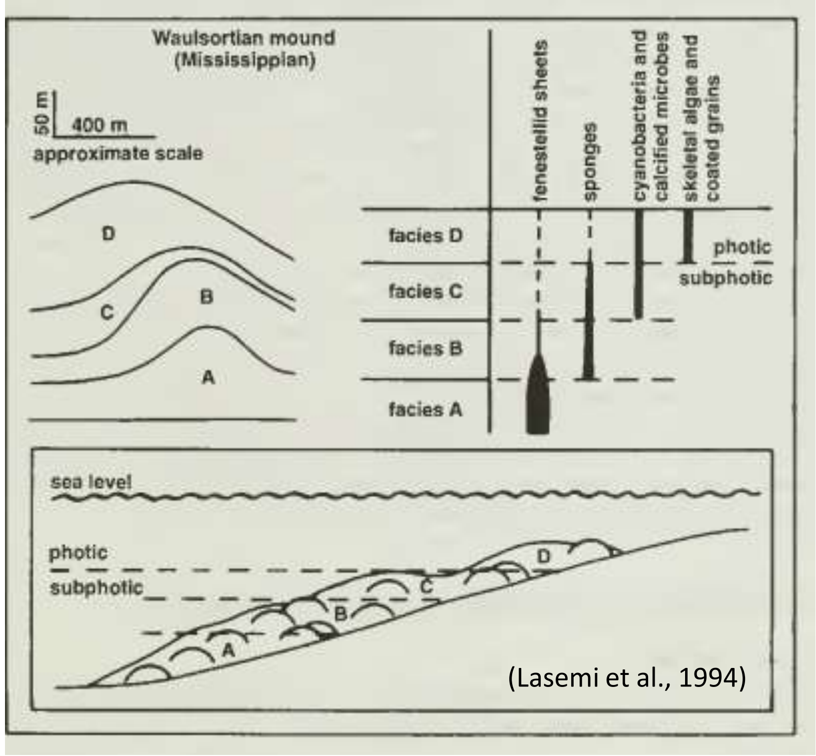
Waulsortian Mud Mounds (Mississippian)

- Deep-water mud mounds (upper slope); chemosynthetic
- Lower - Middle Miss. in age
- Belgium, U.K., France, Montana, New Mexico, Texas (Ft. Worth Basin), Okla., Tennessee
- Exploration targets in some regions

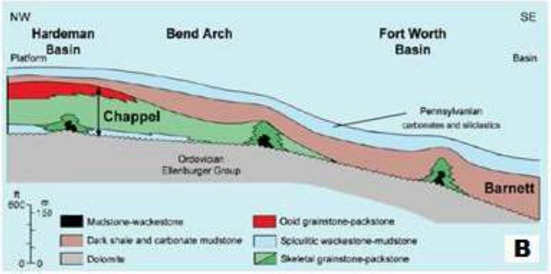


(Greb et al., 2008)



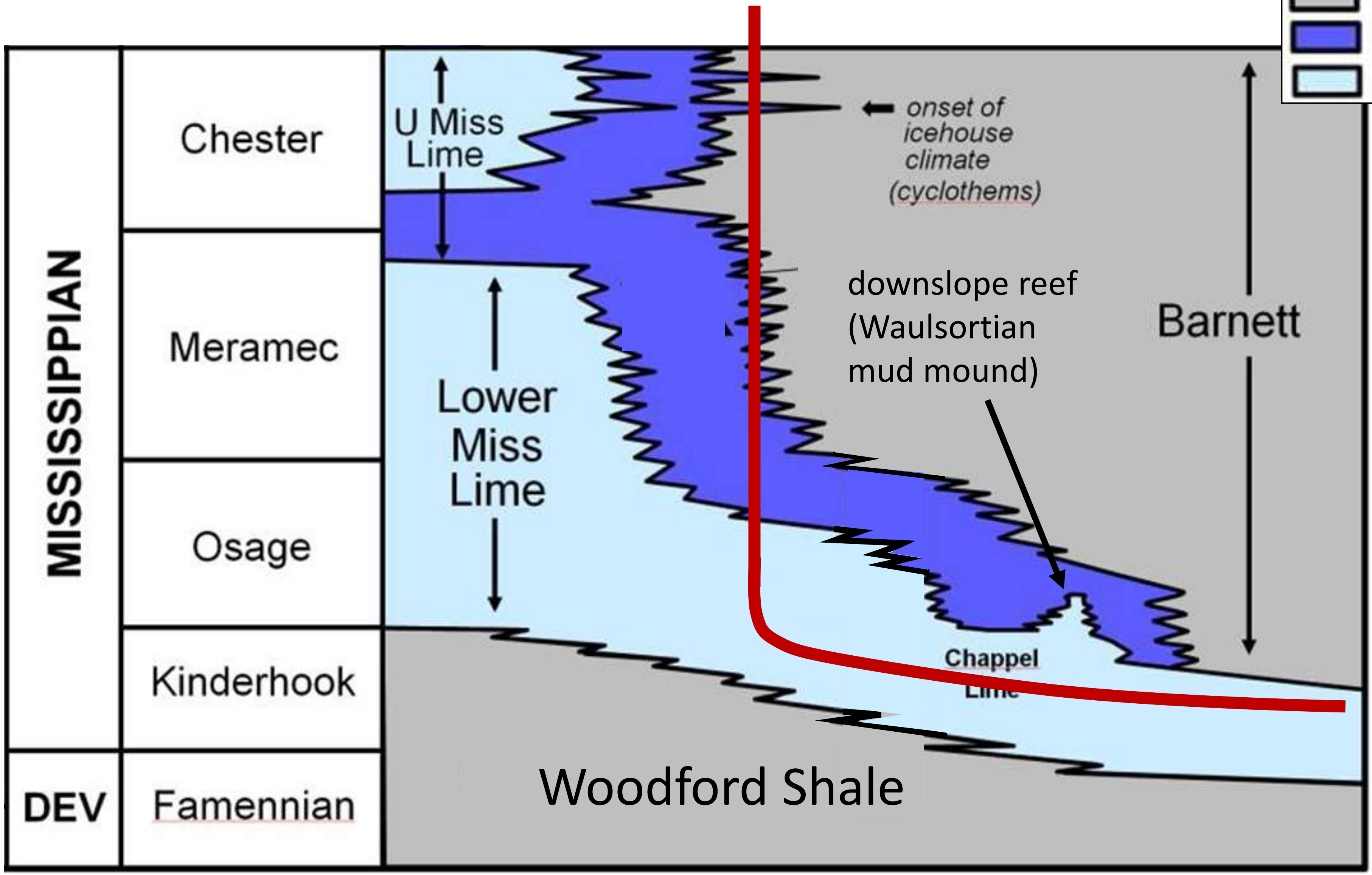


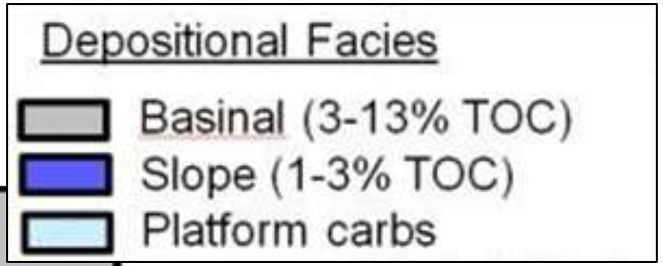
(Lasemi et al., 1994)



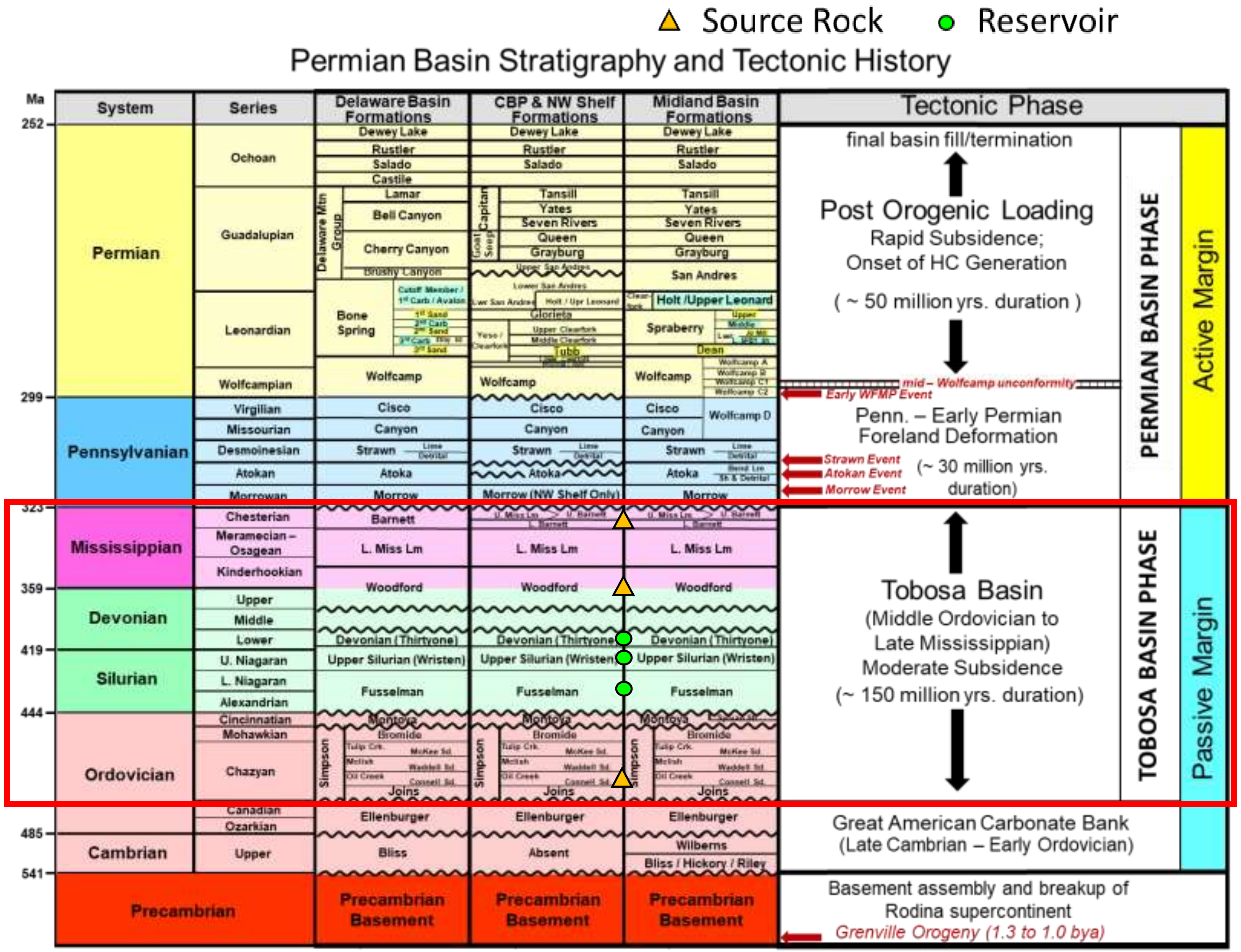
(Ruppel, BEG, 2006)

Mississippian stratigraphy of the Tobosa Basin: Summary





Barnettford play (?)



Tobosa Basin stratigraphy: Summary

- Two megacycles of eustatic sea-level
  - Middle Ord. – Early Dev. epeiric sea
  - Late Dev. – Mississippian epeiric sea
- Mid. Ord. Simpson Group: mixture of shales, thin sands, and limestones
- Upper Ord. Montoya Group: dolomites to the NW, shallow water cherty limestones to the S and E (silica due to upwelling)
- Lower Sil. Fusselman Fm.: dolomites to NW, ooid-bearing ramp limestones to SE
- Mid. – Up. Sil. Wristen Gp.: reef-bearing platform limestones in NW, grading to deep-water limestones to S and E
- Low. Dev. Thirtyone Fm.: prograding shallow water limestones that overstep underlying shelf margin and "fill-in" basin
- Middle Devonian unconformity
- Up. Dev. – Low. Miss. Woodford Fm.: organic rich shales of basinwide extent
- Low. – Up. Miss.: Shallow-water platform limestones grading offshore to basinal shales (Barnett)

- Three major reservoir units (Fusselman, Wristen Gp., and Thirtyone)
- Three major source rocks (Lower Simpson, Woodford, and Barnett)

Geology of the Permian Basin: ELS (Endeavor Lecture Series)

Horseshoe Atoll

Tectonic history – Part 1 (Big Picture)

Tectonic history – Part 2 (Regional elements: ARM, CBU, MFB)

Basement

Cambrian – Lower Ord (Wilberns/Bliss Ss., Ellenburger Gp)

Tobosa Basin stratigraphy (Mid Ord. – Mississippian)

Pennsylvanian (Morrow-Atoka-Strawn-Canyon-Cisco) **NEXT TIME**

Lower Permian (Wolfcamp – Spraberry)

Middle and Upper Permian / Permian Basin petroleum system