Stratigraphic Framework of the Wolfcamp – Spraberry of the Midland Basin

Roswell Geologic Society

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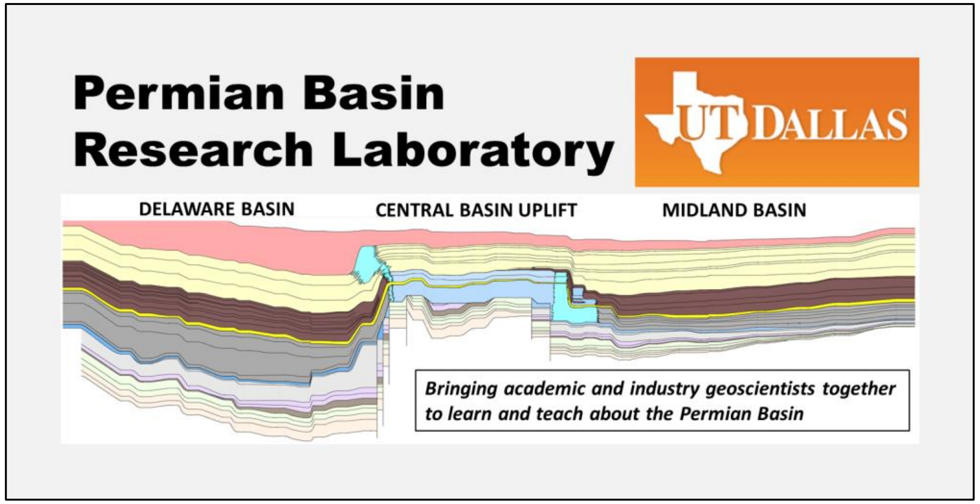
-- established January, 2019 --



Goals:

- Advance understanding of all geologic aspects of the Permian Basin through open applied research, **linking academia and industry**

- Educate and better prepare students for professional careers in the oil and gas industry
  - Graduate courses offered:
    - Geology of the Permian Basin
    - Petroleum Geoscience
    - Paleo Earth Systems: Global Themes

https://labs.utdallas.edu/permianbasinresearch/

Stratigraphic framework of Wolfcamp – Spraberry: Objectives

- Review the tectono-stratigraphic framework of the Wolfcamp and Spraberry deep-water units of the Midland Basin, west Texas

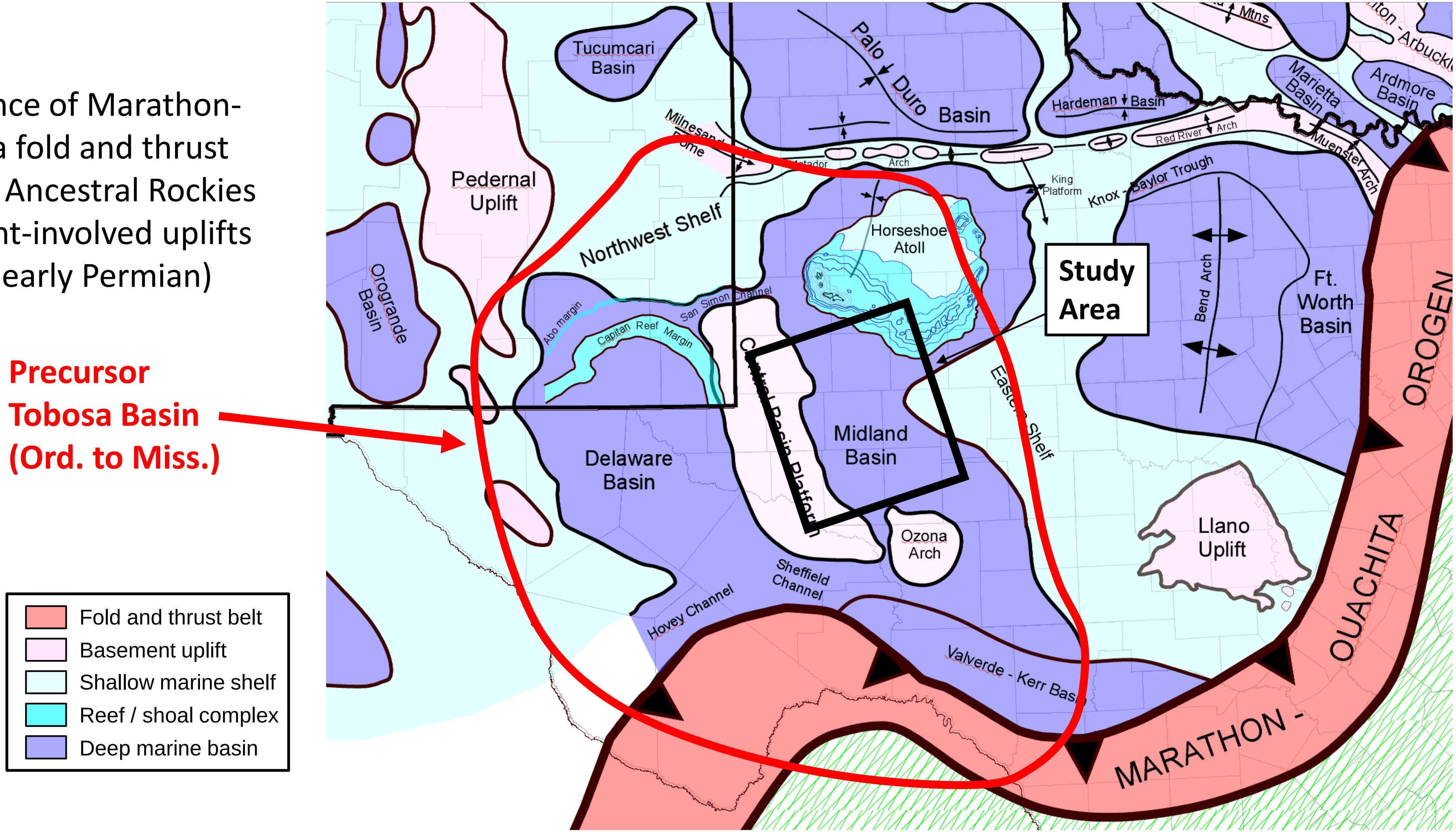
- Briefly discuss the facies/characteristics of these rocks

- Highlight the differences between the Wolfcamp shale (A – D) and Spraberry depositional systems

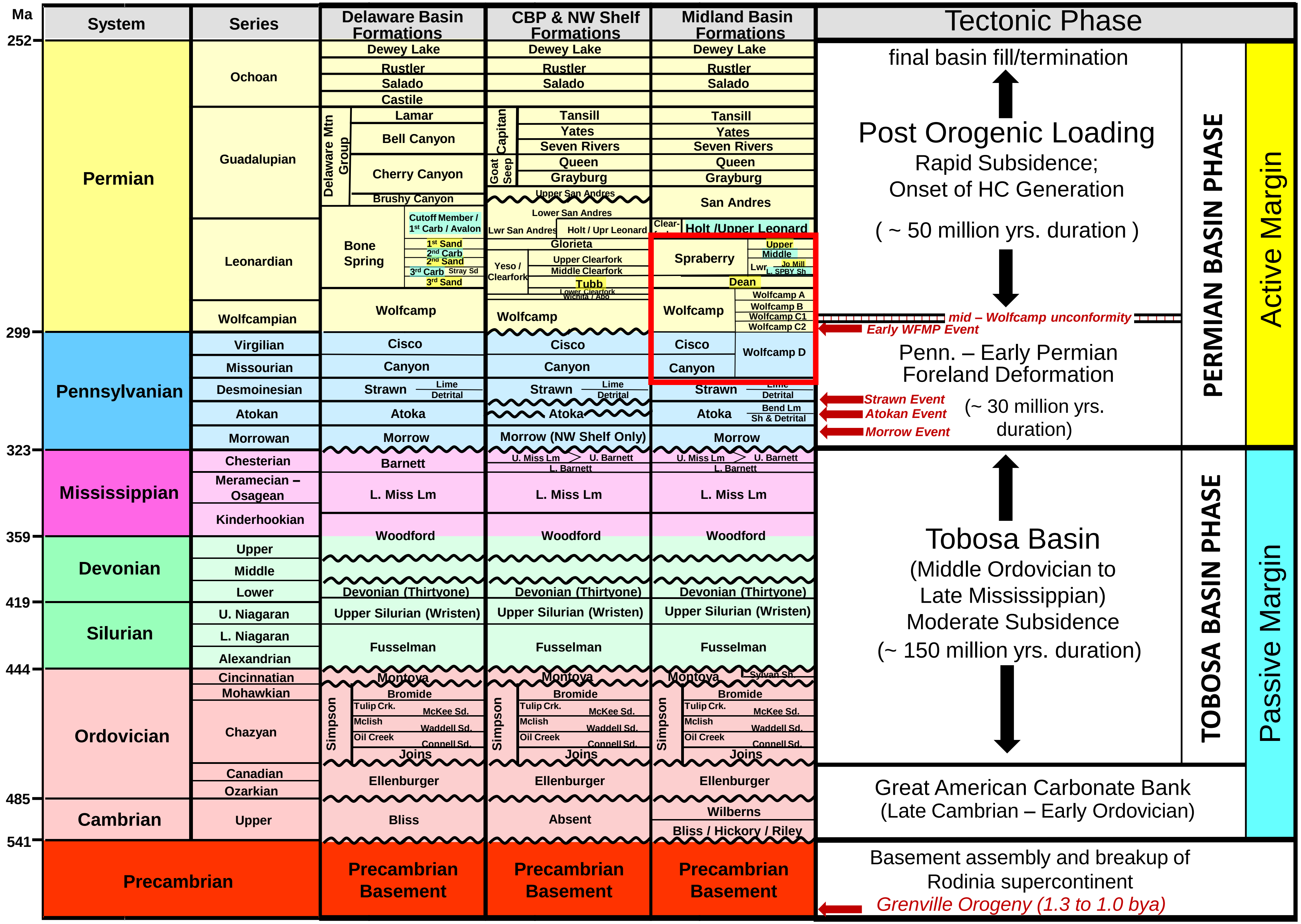
Note: although not specifically addressed, the framework outlined here is applicable to the Delaware Basin

Greater Permian Basin Region

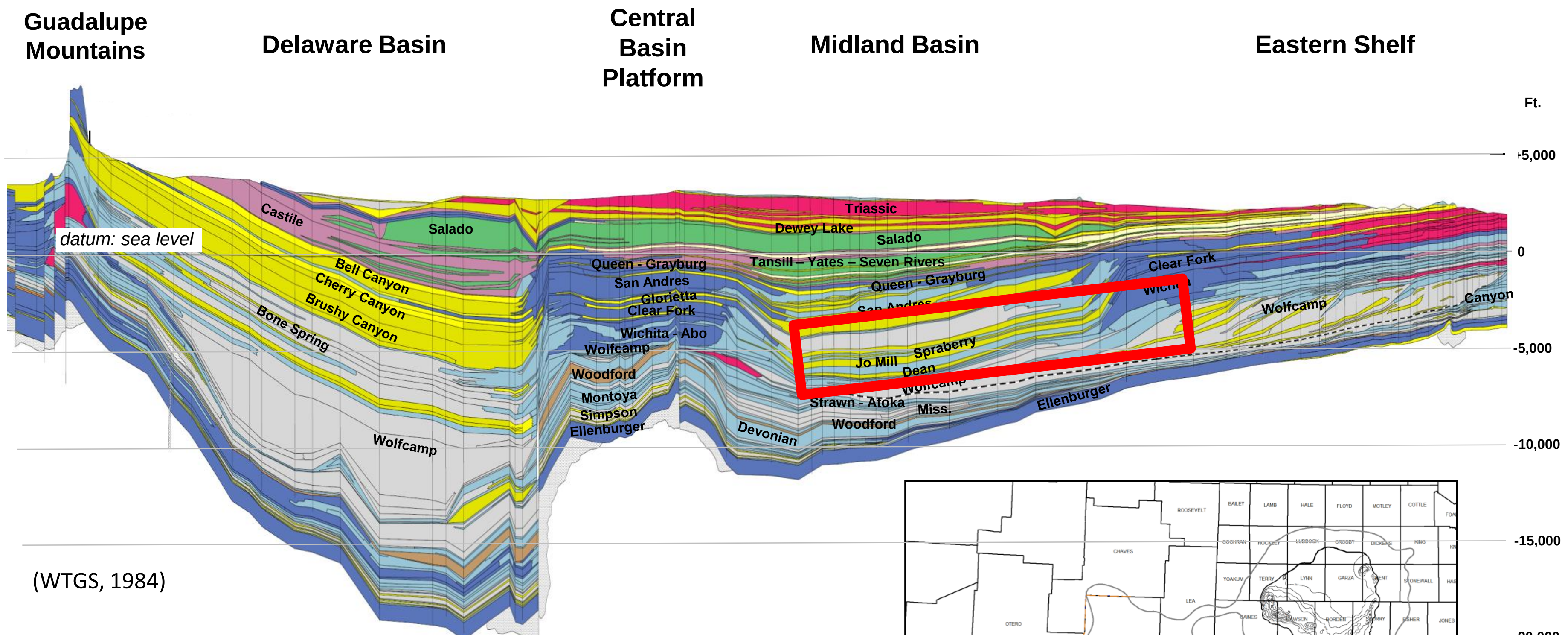
- Confluence of Marathon-Ouachita fold and thrust belt and Ancestral Rockies basement-involved uplifts (Penn. – early Permian)

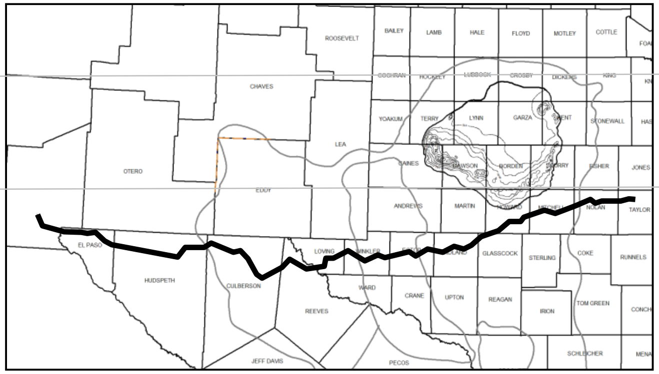


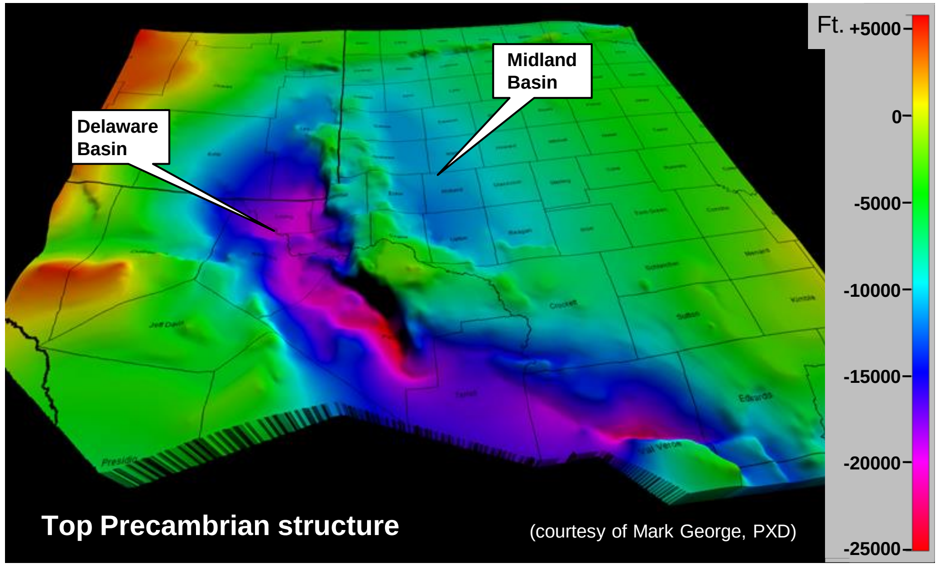
Permian Basin Stratigraphy and Tectonic History



(modified from Reed, unpub., 2016)

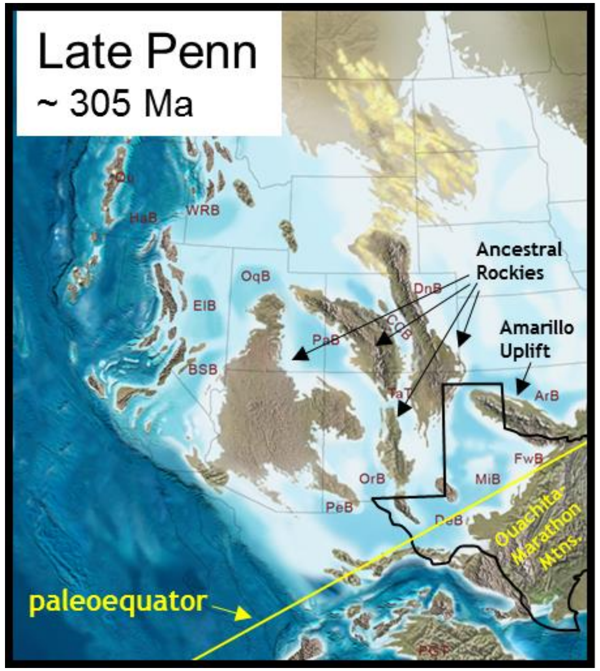






The Permian Basin

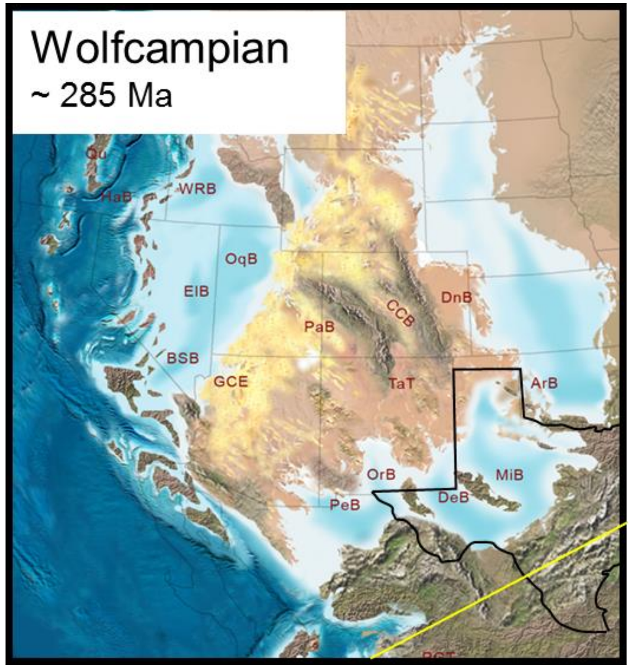
LATE PENNSYLVANIAN – EARLY PERMIAN EVOLUTION OF WESTERN PANGEA

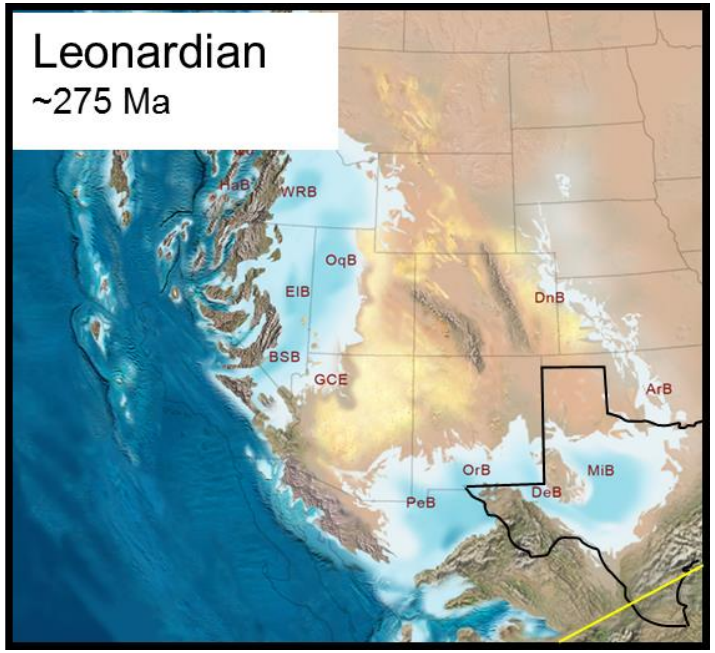


Late Pennsylvanian

- Icehouse climate; PB in humid-tropical setting (abundant rainfall)
- Numerous high-freq., high-amplitude sea-level changes
- Expansion of Penn seaway (long-term rise); stratified water columns
- Continued tectonism in west Texas (Marathon-Ouachita FTB, rise of ARM)

A very dynamic time in Earth history, especially in west Texas





Wolfcampian – Early Leonardian

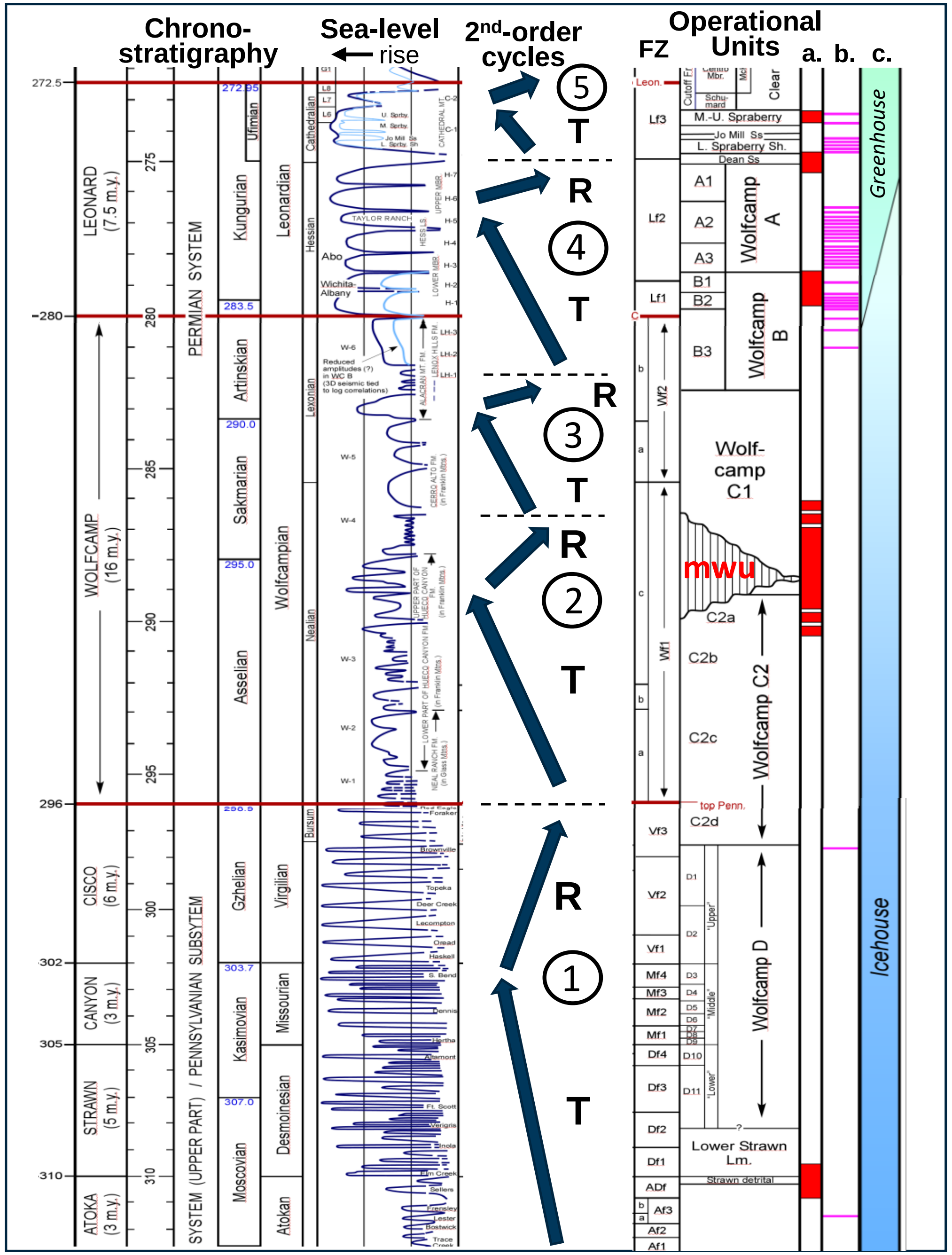
- Waning icehouse, transition to greenhouse
- Northward drift of Pangea
- Increasing aridity & expansion of continental desert in western U.S.
- Cratonic emergence / contraction of seaway (onset of long-term SL fall)
- Culmination of tectonic pulses in W. TX (mid WC); Pacific arc volcanism (Late WC-Leon.); PB enters rapid subsidence phase (Dean - Spraberry)

(maps: Ron Blakey, NAU/Colorado Plateau Geosystems)

Stratigraphic framework, Wolfcamp - Spraberry

Numerous 3rd- and higher-order cycles of sea-level change organized into larger 2nd-order trends (5 – 10+ m.y. in duration); from oldest to youngest:

1. **WC D – lowermost WC C2**
2. **WC C2**
3. **WC C1**
4. **WC A - B**
5. **Spraberry – L. Clear Fork**



FZ. Fusulinid zonation

a. Tectonic pulses

b. Ash beds

c. Climate phase

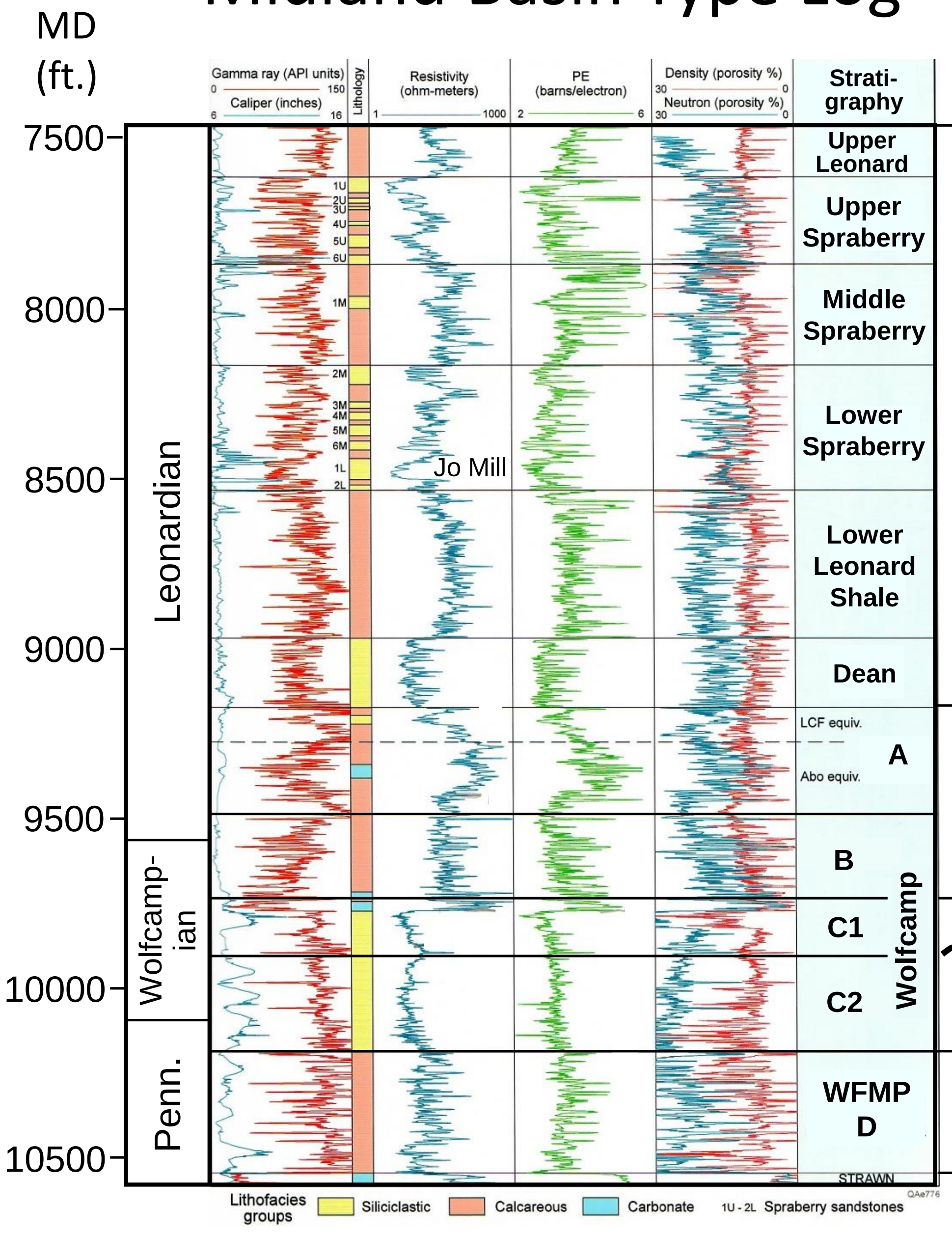
mwu: mid-Wolfcamp unconformity

R = Regression

T = Transgression

(Sea-level curve from Ross and Ross, 2009; Fusulinid zonation from Wahlman, 2019)

Midland Basin Type Log



(modified from Hamlin and Baumgardner, 2012)

GENERAL DESCRIPTION / DEPOSITIONAL FACIES

Spraberry – Dean:
silty mudstones and clay-rich siltstones punctuated by multiple deeper-water submarine fan complexes (incl. massive to laminated, fine-grained sandstones)

Wolfcamp A – B:
silty- and calcareous organic-rich mudstones; carbonate percentage increases upward

mid-WC unconformity

Wolfcamp C: Clay-rich shale (progradation of Eastern Shelf deltas & Glasscock Nose)

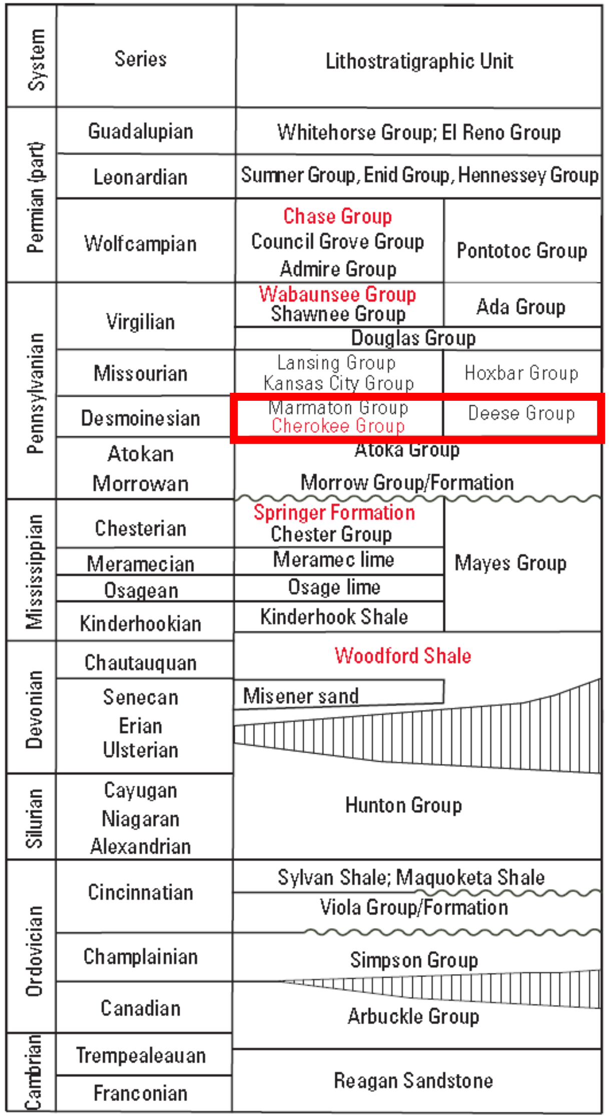
Wolfcamp D: Basinal cyclothems (starved basin)

Lower Strawn: shallow-water platform limestones

Lower Strawn Limestone and Wolfcamp D (Cline)

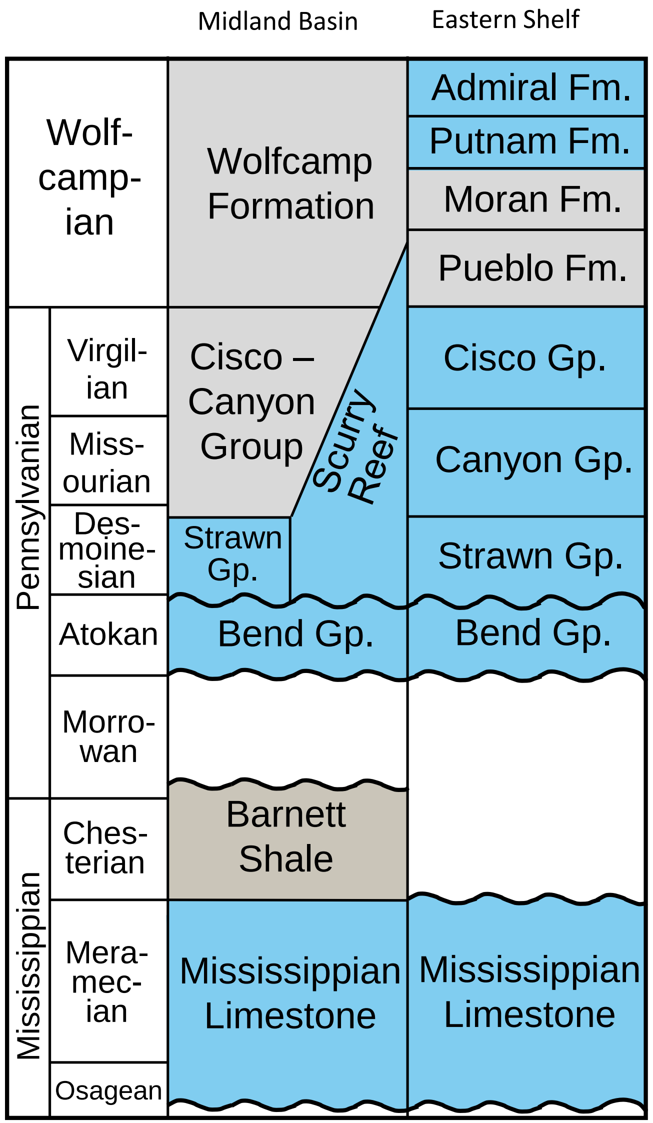
STRAWN GROUP STRATIGRAPHY (DESMOINESIAN SERIES)

Mid Continent / Anadarko Basin



(Gianoutsos et al, USGS, 2014)

AAPG COSUNA chart (1985)



Midland Basin Fusulinid zonation

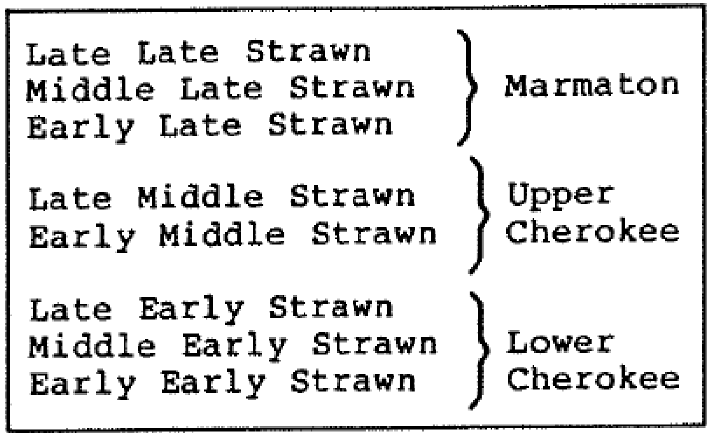
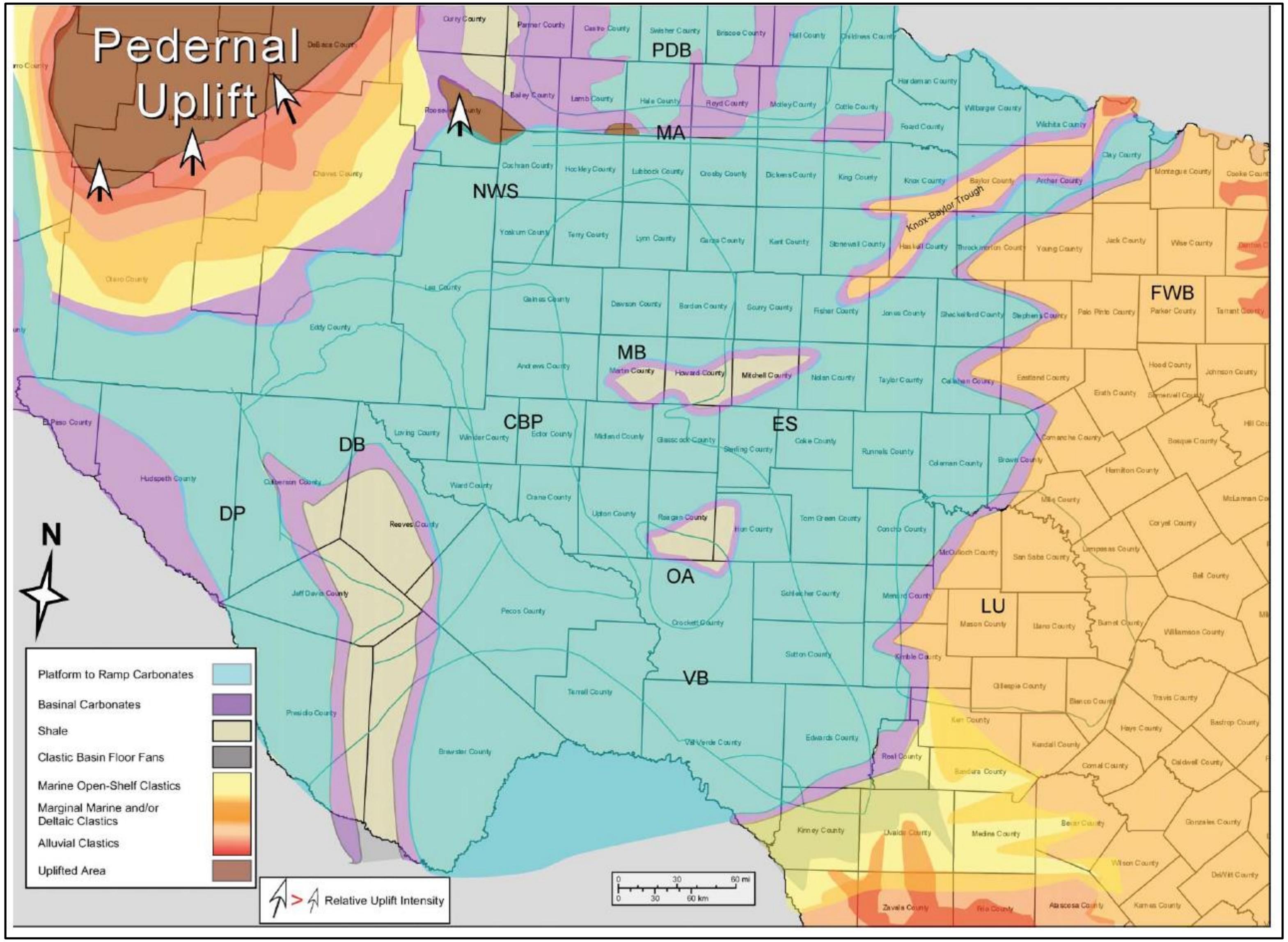


Figure 1. Expanded fusulinid zonation of the Strawn, Hollingsworth approximate equivalents on the right. (Reed and Mazzullo, 1987)

Lower Strawn Limestone = Early Strawn

Middle & Upper Strawn = lower portion of WC D

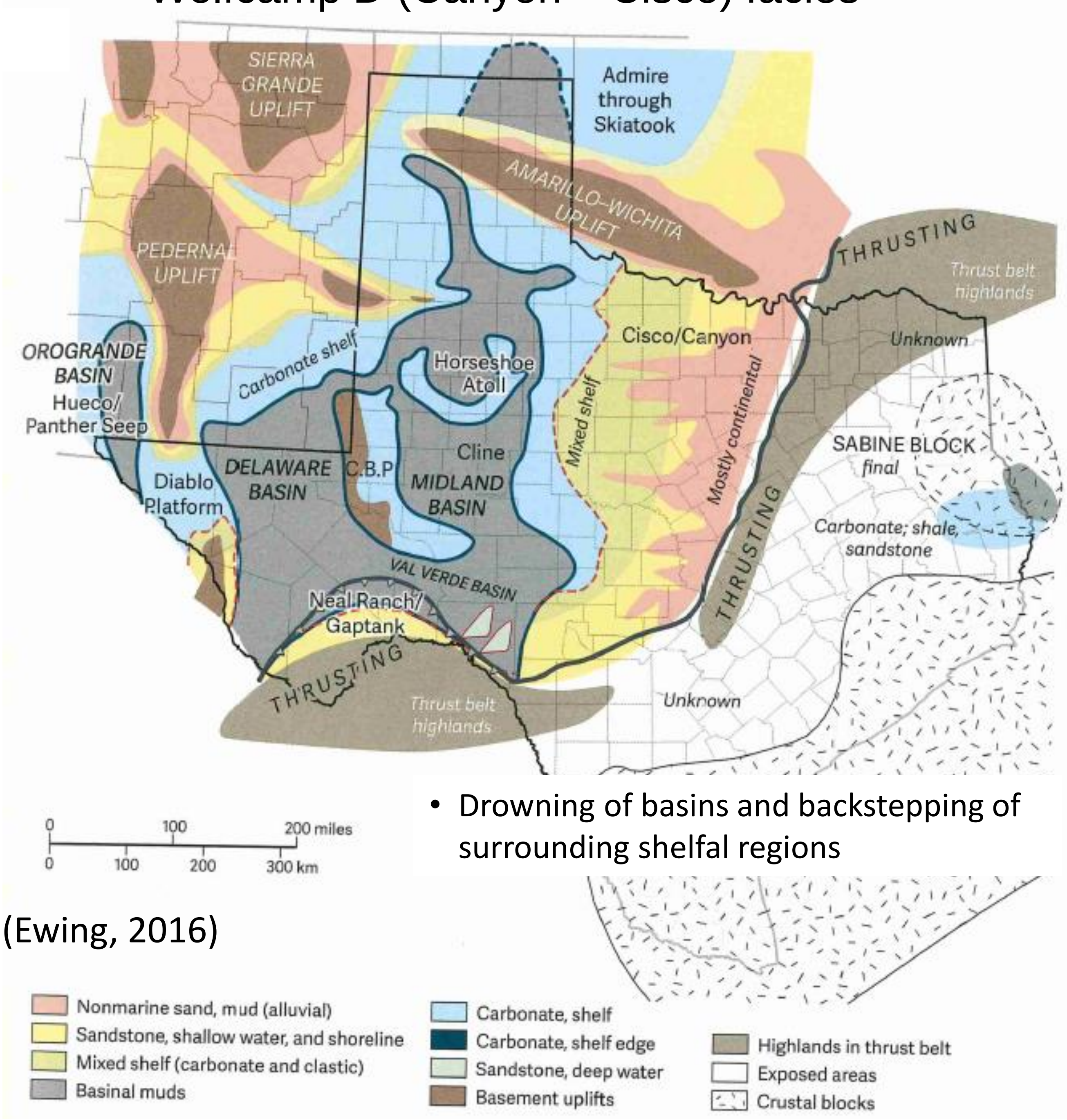
Lower Desmoinesian Facies (Lower Strawn Limestone)



(Wright, 2011)

- Shallow water platform carbonate facies extend across entire Midland Basin and Eastern Shelf region
- Lower Strawn Limestone is generally < 200 ft. thick in Midland Basin
- Core analyses indicate typical Penn shelf cyclothem deposits: burrowed skeletal wackestones grading upward into phylloid algal packstones and skeletal grainstones, capped by exposure surfaces
- Pre-dates drowning of Midland, Delaware basins

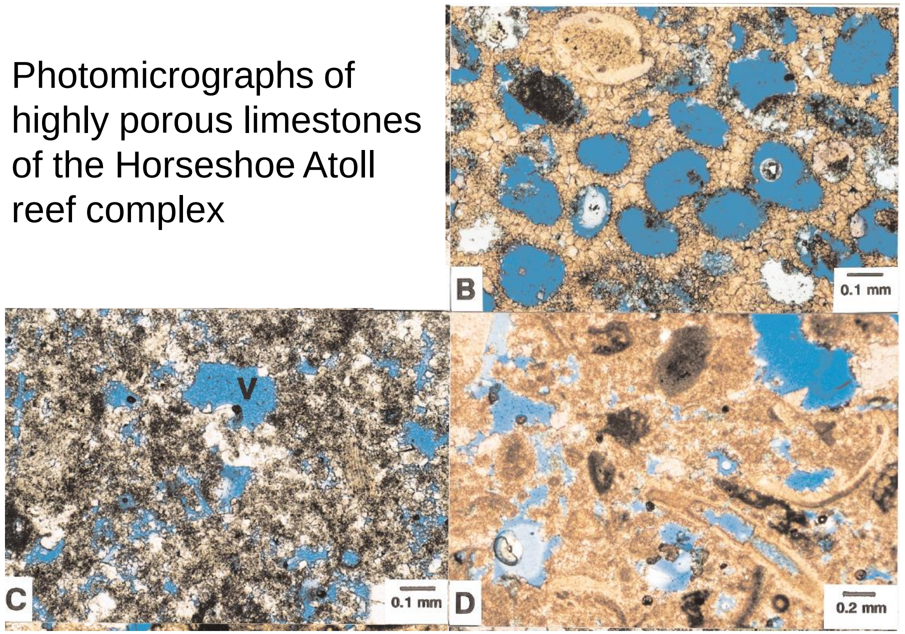
Wolfcamp D (Canyon – Cisco) facies



- Drowning of basins and backstepping of surrounding shelfal regions

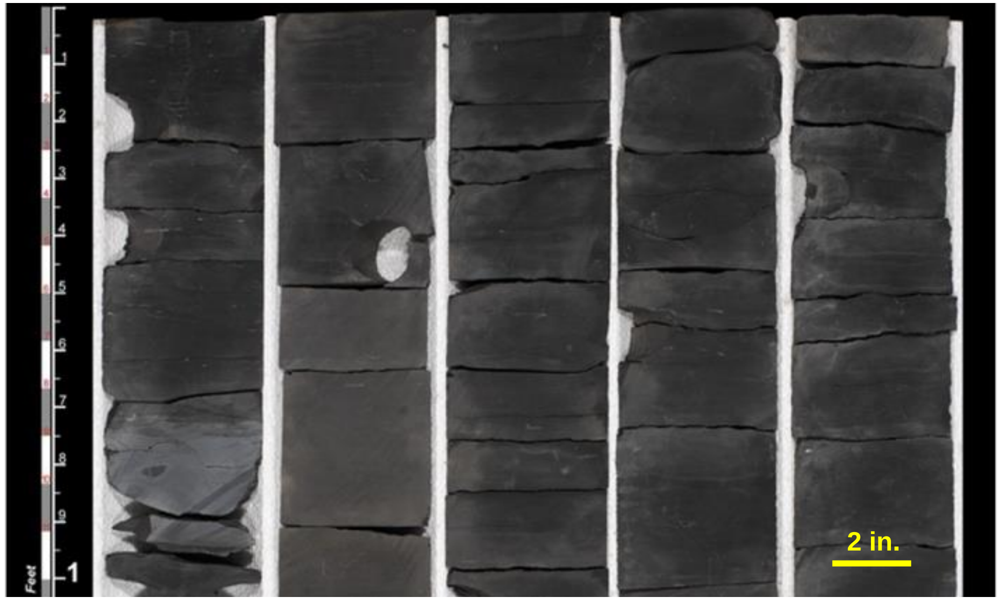
(Ewing, 2016)

Photomicrographs of highly porous limestones of the Horseshoe Atoll reef complex

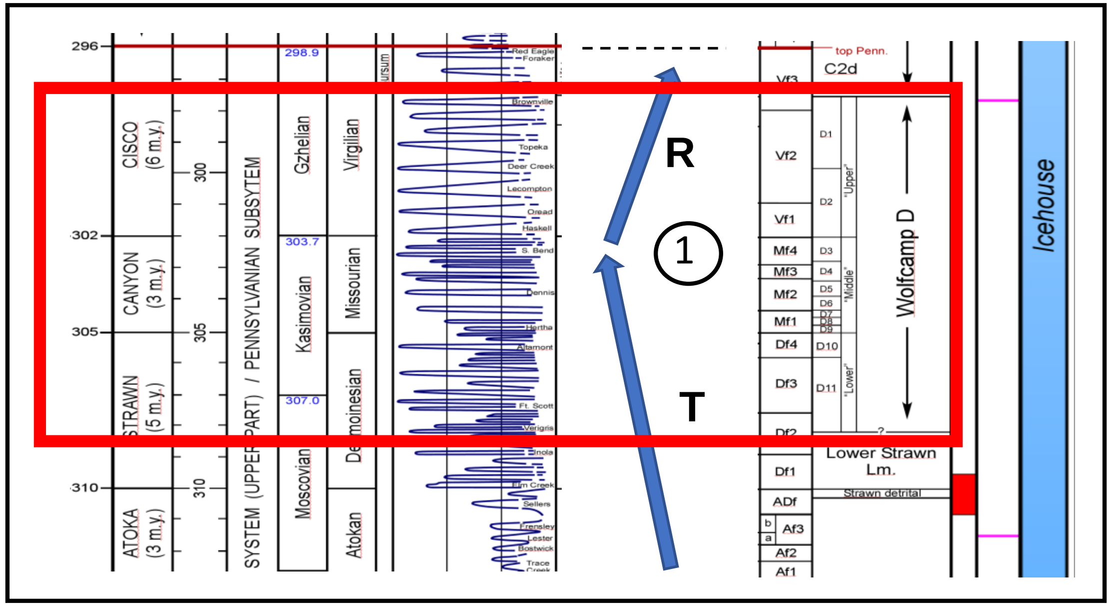


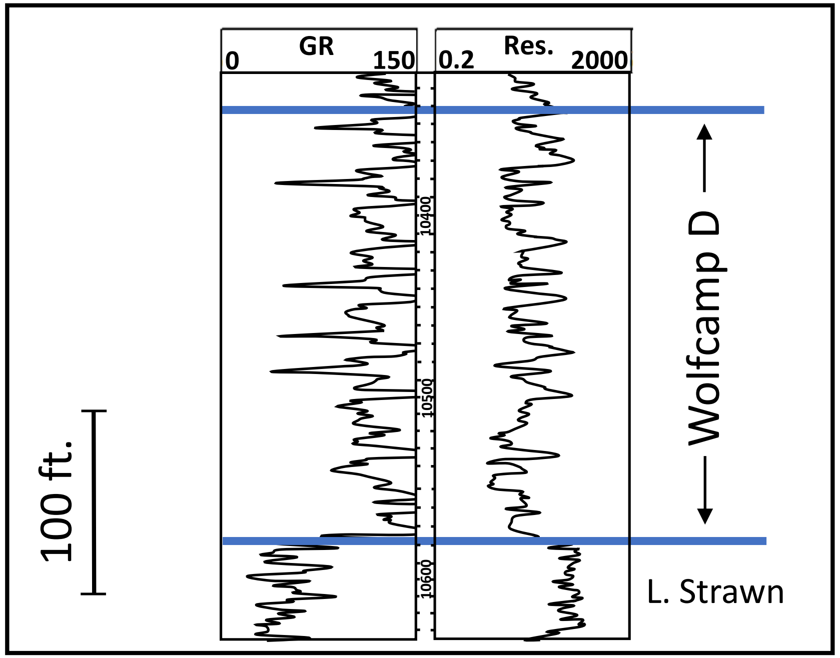
(Saller et al., 1999)

Organic-rich Wolfcamp D (Canyon – Cisco) black shales in core from the center of Midland Basin

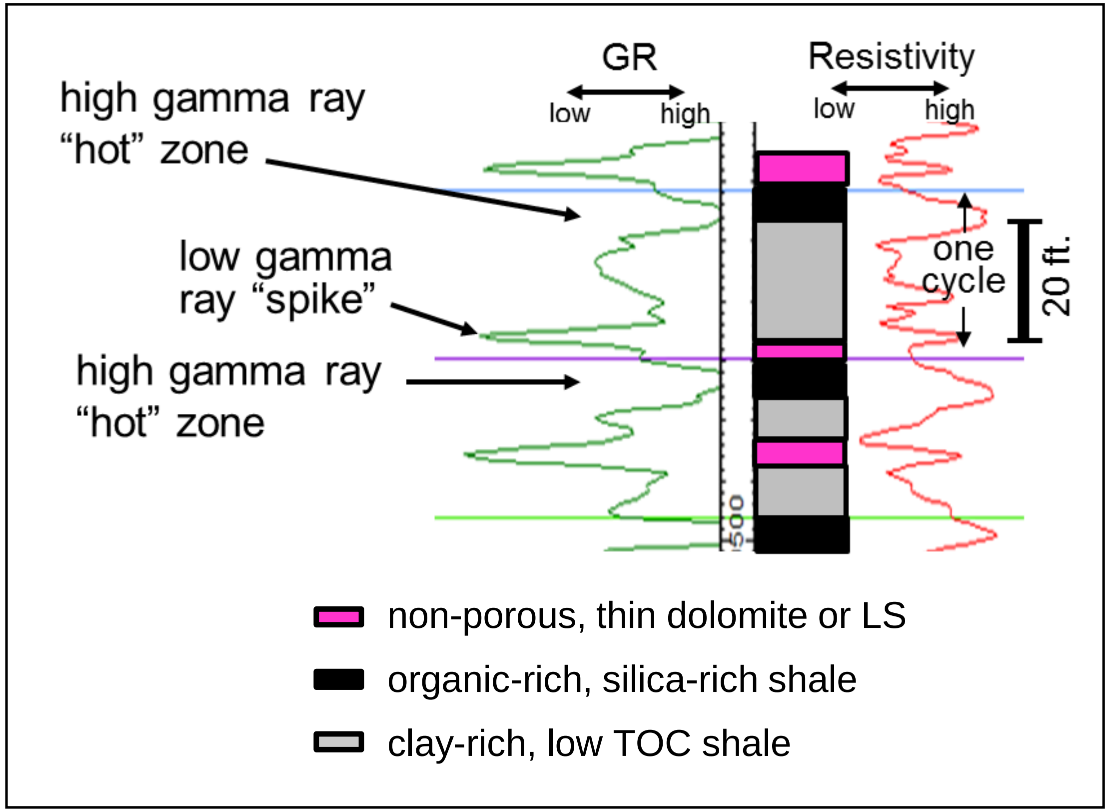


Wolfcamp D: Basinal cyclothems



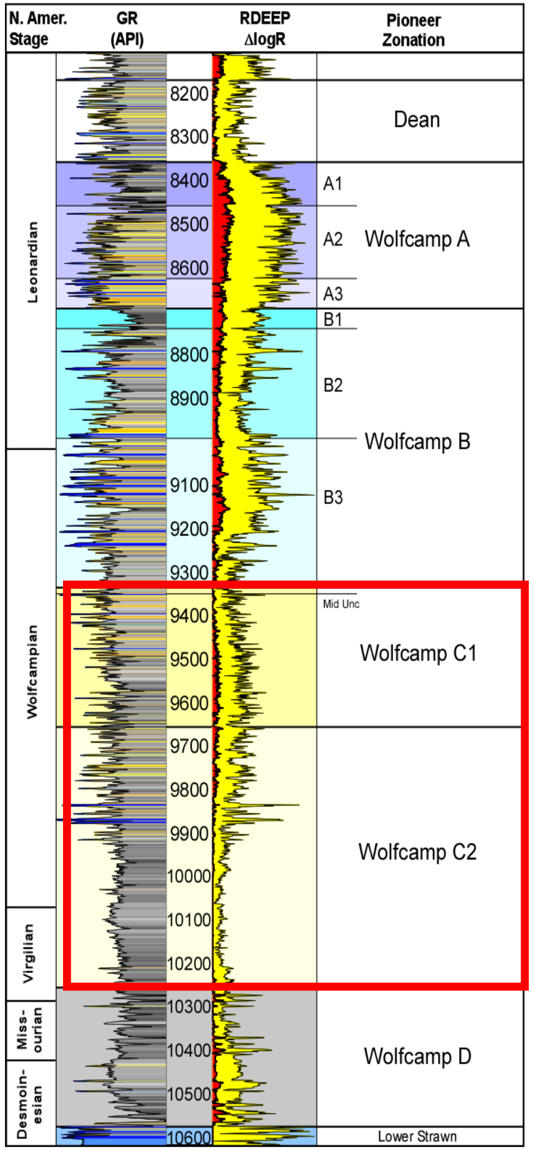


- Equivalent to classic “Penn. cyclothems” on shelves
- Silica – rich shales; relatively high clay content
- Each basinal cyclothem = 15 – 45 ft. thick; bounded by thin dolomite or LS; highly correlative basin-wide
- Organic content partitioned into multiple thin cycles
- High pore pressures due to depth, maturity

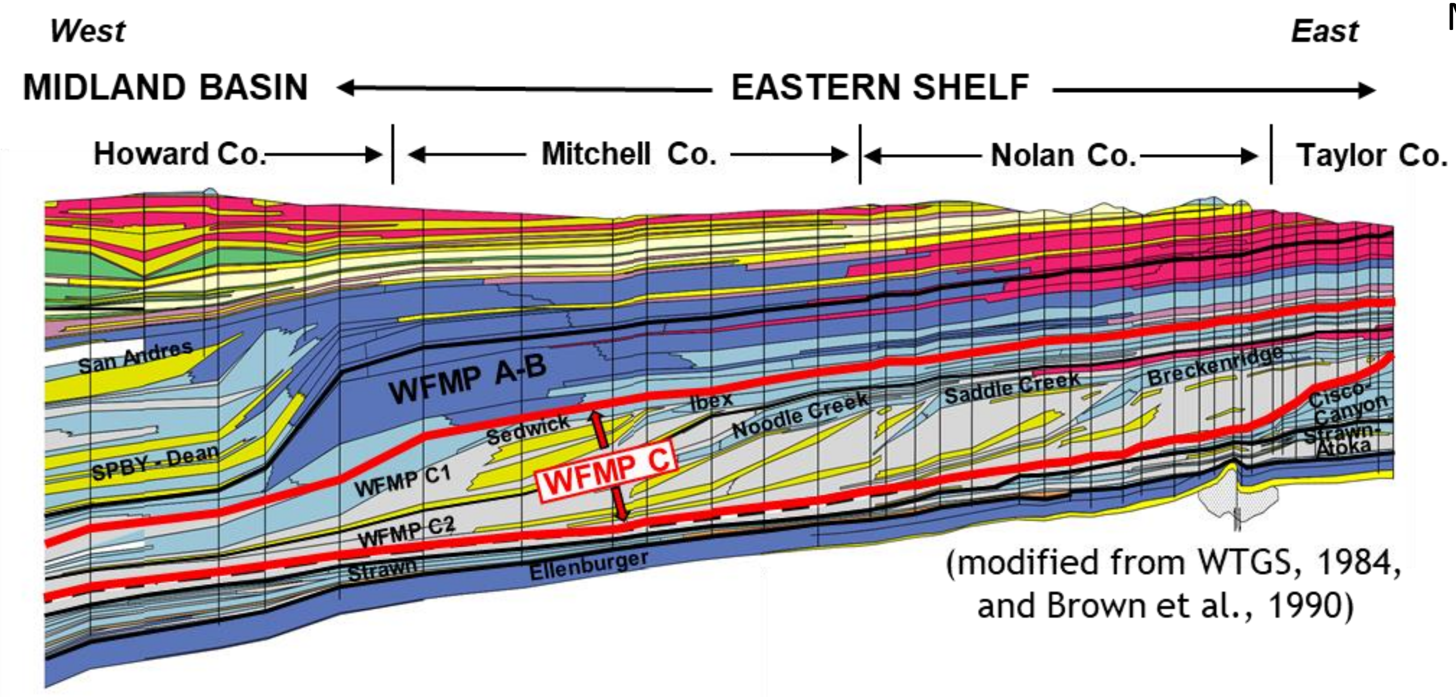


Wolfcamp C

Wolfcamp C

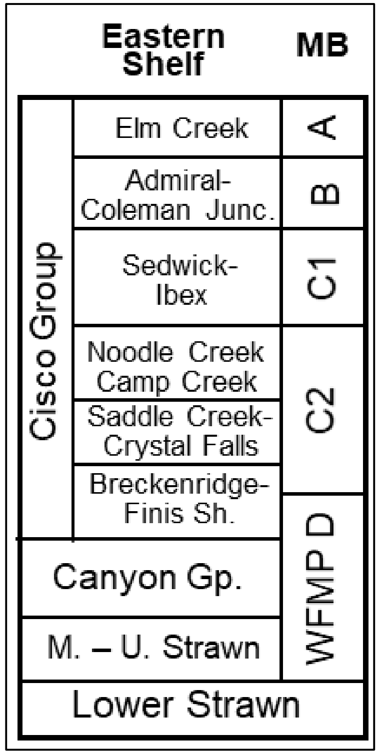


(Sinclair et al., 2018)



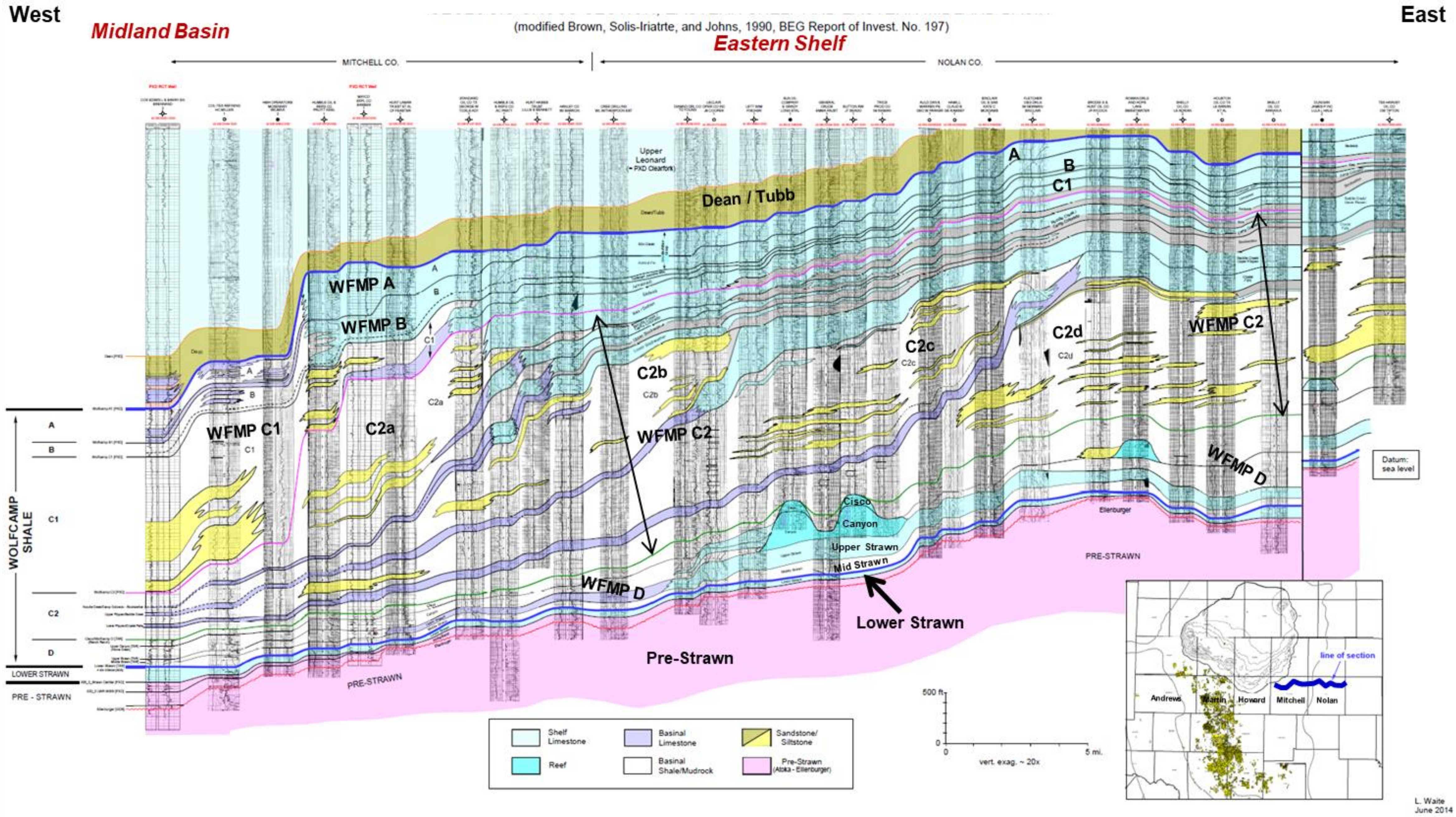
(modified from WTGS, 1984, and Brown et al., 1990)

Preliminary correlation of MB tops to Eastern Shelf

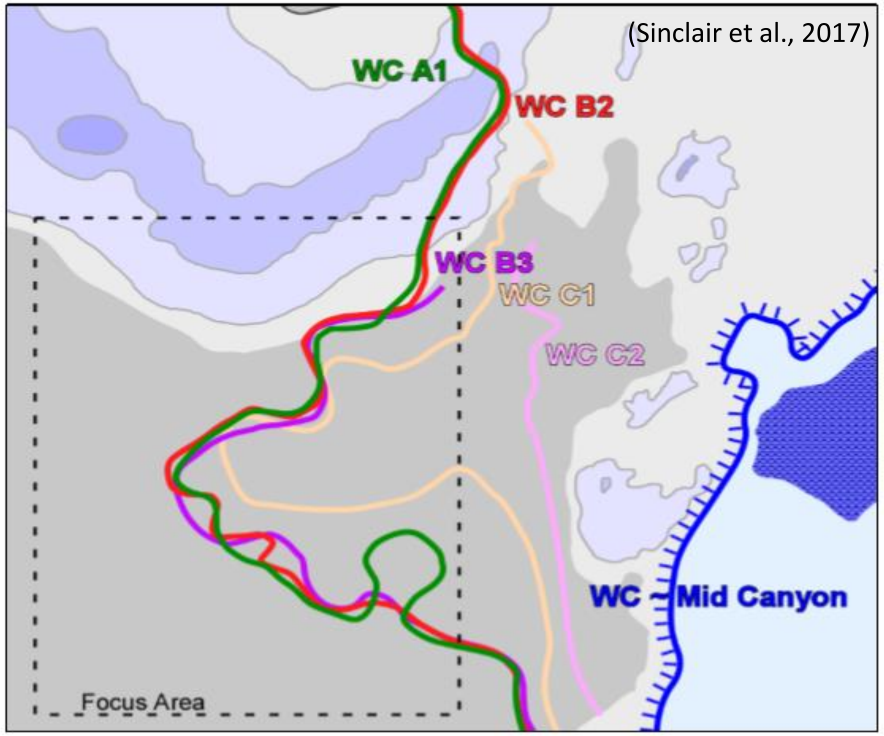


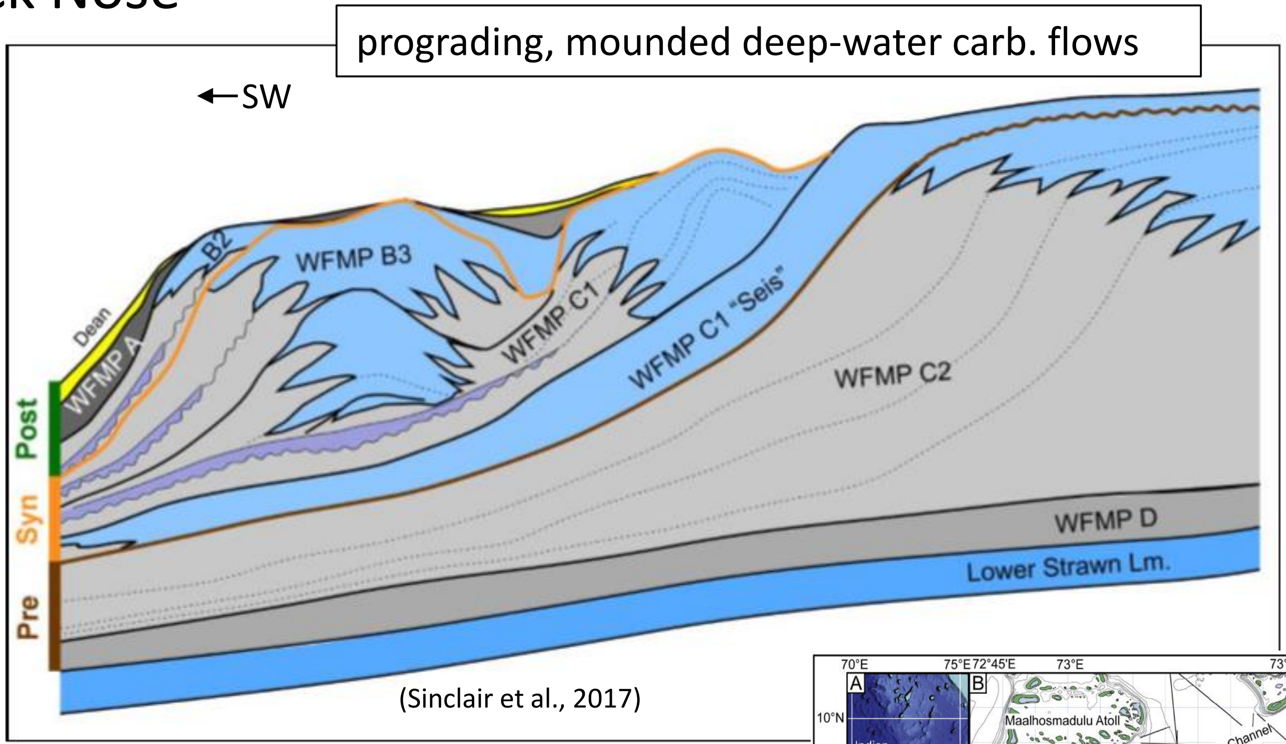
- Westward progradation of Eastern Shelf delta systems and platform margins (100 -150 km)
- Initial development of Glasscock Nose during WFMP C1 time
- Uplift of CBP structural blocks and development of mid-Wolfcamp unconformity

Progradation of Wolfcamp C shelf delta systems across the Eastern Shelf



Sequential development of the Glasscock Nose





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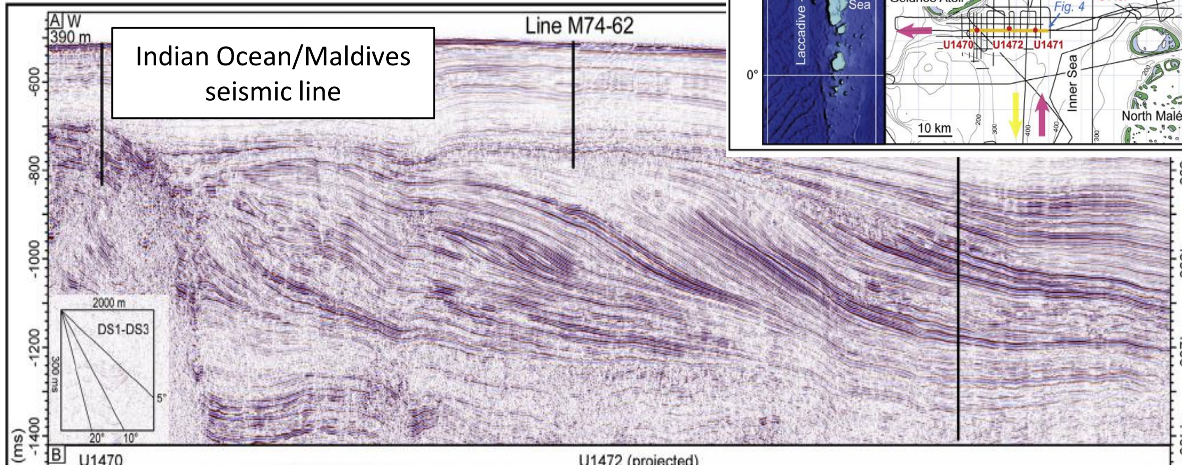
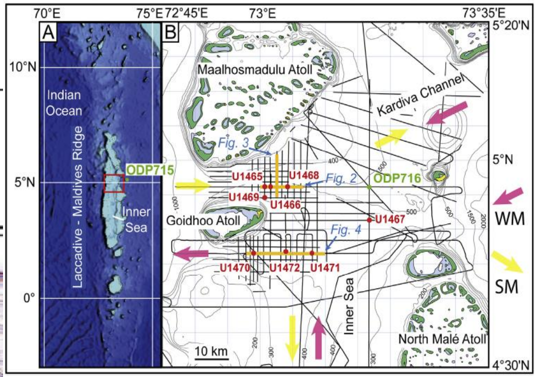
Carbonate delta drift: A new sediment drift type

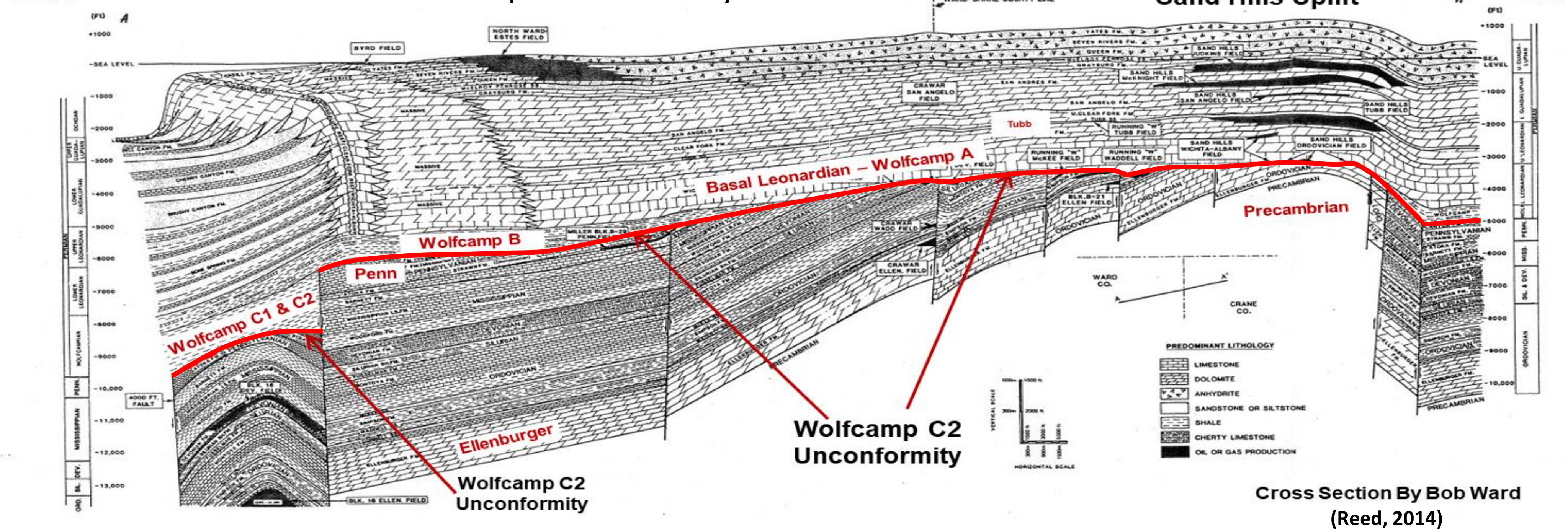
Thomas Lüdmann[a,*], Christian Betzler[a], Gregor P. Eberli[b], Jesús Reolid[a], John J.G. Reijmer[c], Craig R. Sloss[d], Or M. Bialik[e], Carlos A. Alvarez-Zarikian[f], Montserrat Alonso-García[g,h], Clara L. Blättler[i], Junhua Adam Guo[j], Sébastien Haffen[k], Senay Horozal[l], Mayuri Inoue[m], Luigi Jovane[n], Dick Kroon[o], Luca Lanci[p], Juan Carlos Laya[q], Anna Ling Hui Mee[b], Masatoshi Nakakuni[r], B. Nagender Nath[s], Kaoru Niino[t], Loren M. Petruny[u], Santi D. Pratiwi[v], Angela L. Slagle[w], Xiang Su[x], Peter K. Swart[b], James D. Wright[y], Zhengquan Yao[z,aa], Jeremy R. Young[ab]

Possible analog: carbonate delta drift

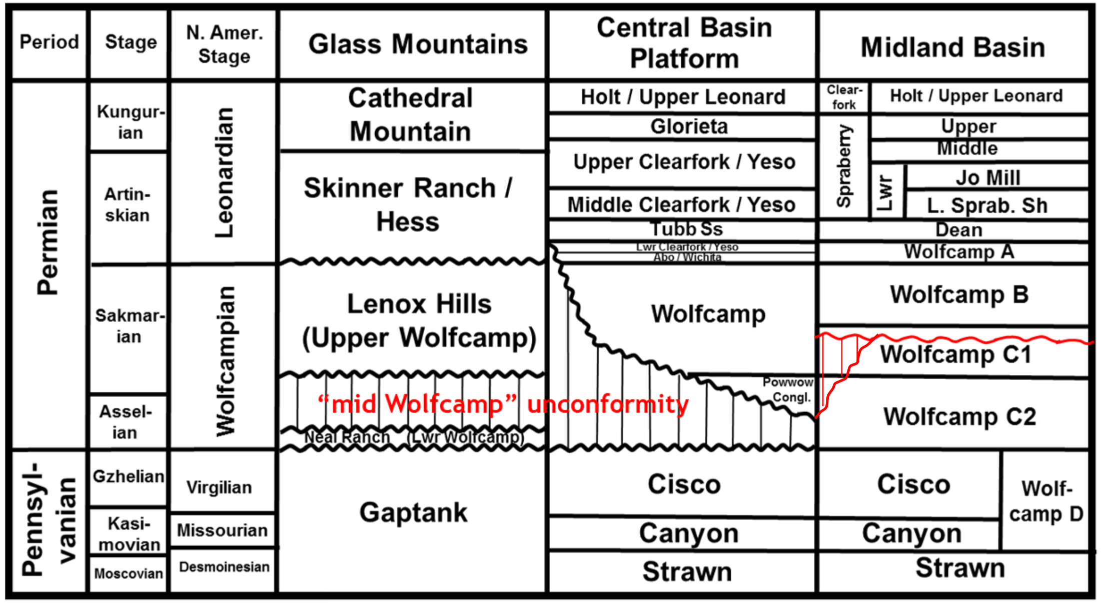




mid-Wolfcamp unconformity on the CBP



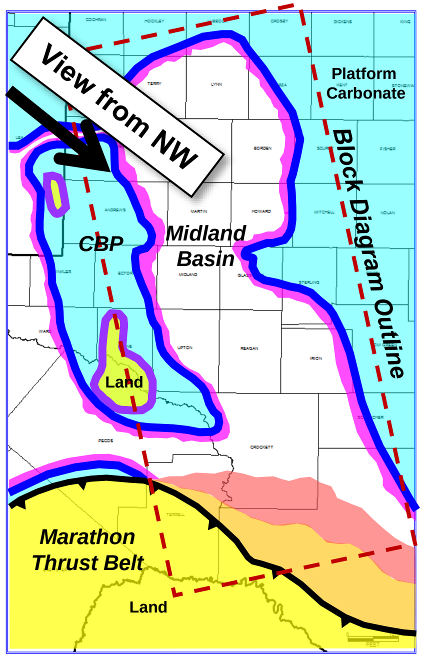
Cross Section By Bob Ward
(Reed, 2014)



- last major tectonic pulse prior to middle – late Permian subsidence phase
- note diachronous nature of unconformity across Permian Basin region

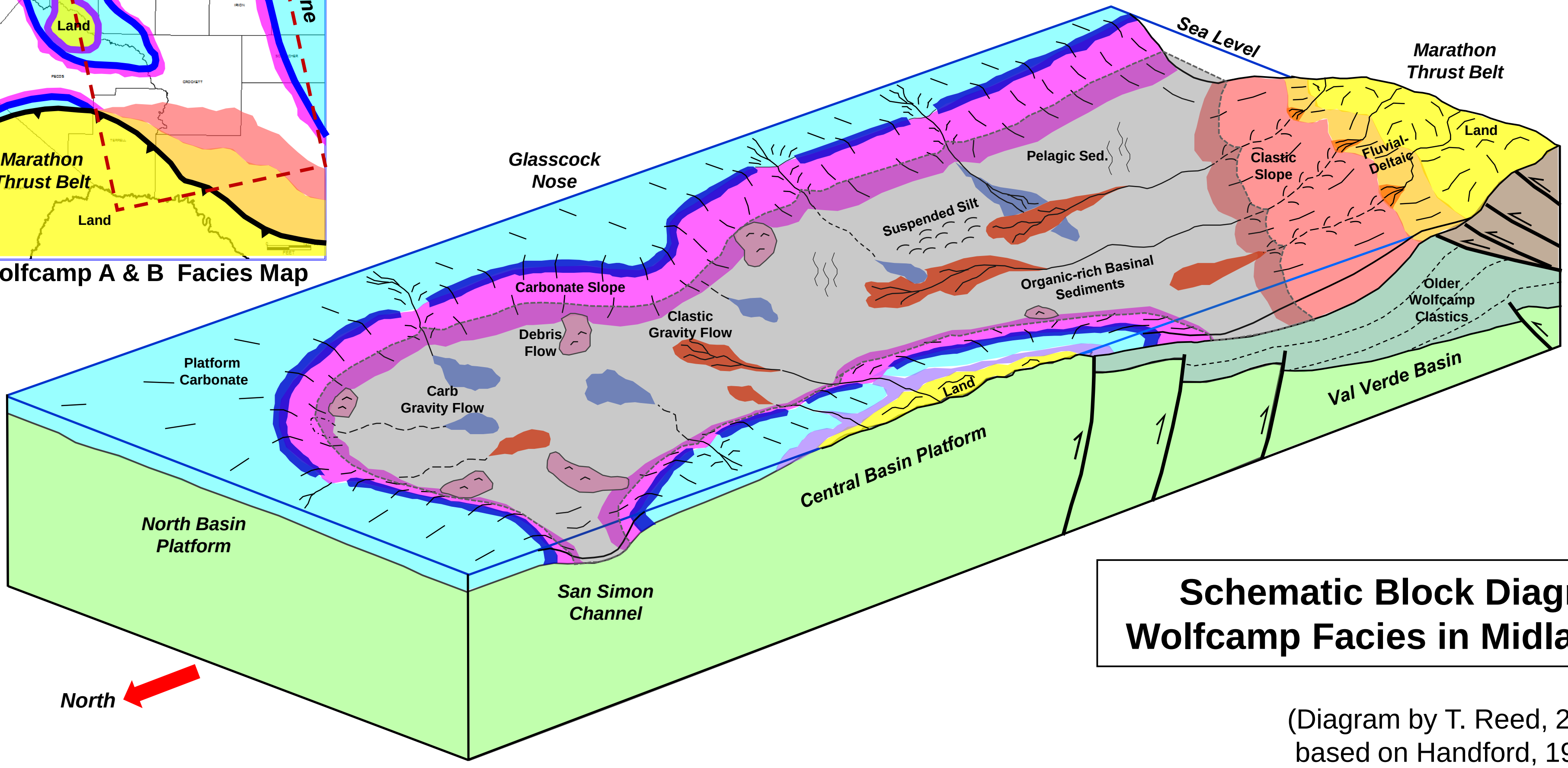
Wolfcamp A - B

Wolfcamp A and B Facies & Depositional Model



Wolfcamp A & B Facies Map

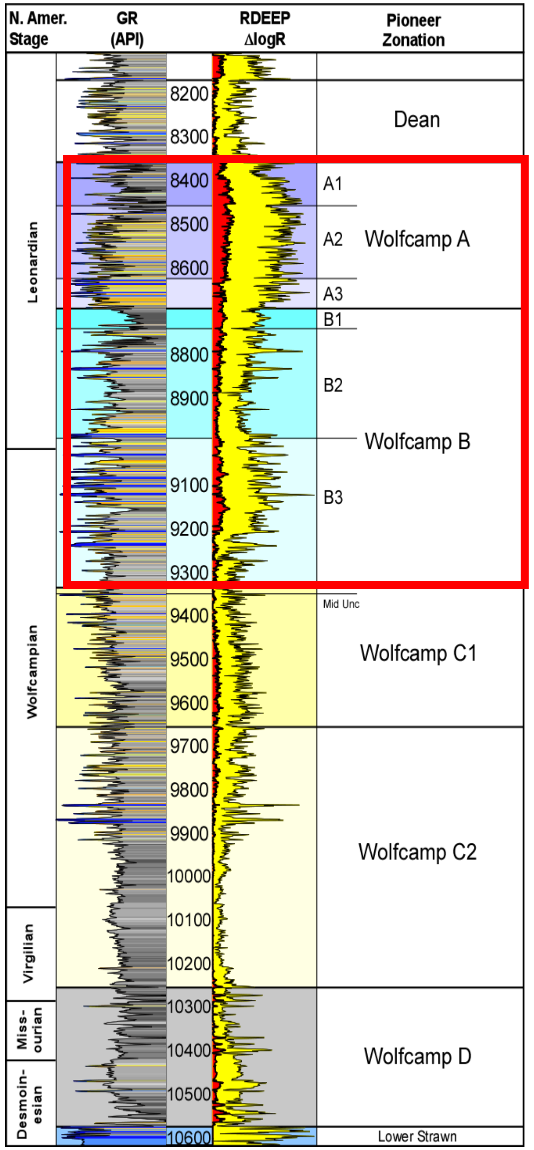
- Platform Carbonate
- Shelf Edge Carbonate
- Slope Sediments & Reef Talus
- Carbonate Debris Flows
- Carbonate Gravity Flows
- Basinal Sediments
- Land
- Clastic Detrital
- Fluvial - Deltaic
- Delta
- Clastic Slope Sediments
- Clastic Gravity Flows
- Pelagic Sediments
- Silt Cloud in Suspension
- Anaerobic Zone (Organic-rich Sediments)



Schematic Block Diagram of Wolfcamp Facies in Midland Basin

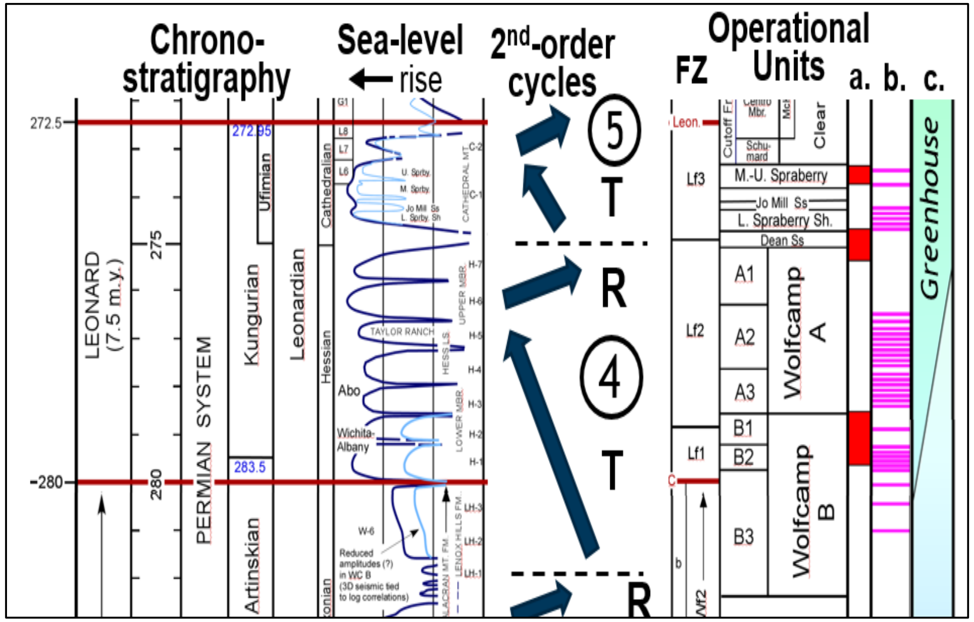
(Diagram by T. Reed, 2013, based on Handford, 1981)

Wolfcamp A - B

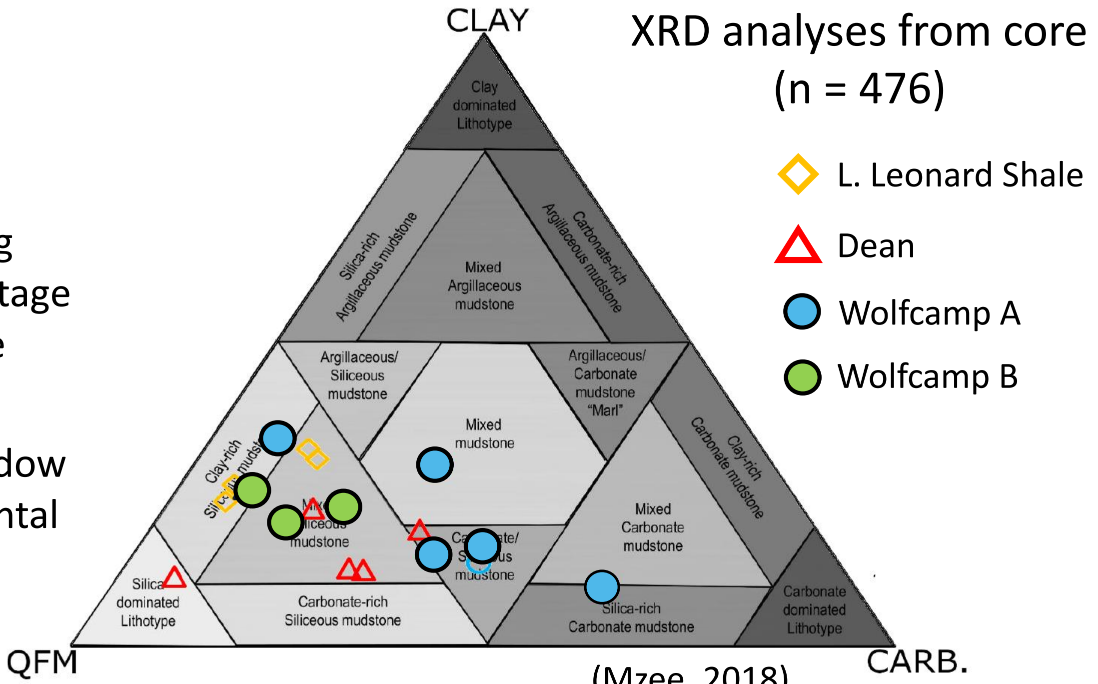


(Sinclair et al., 2018)

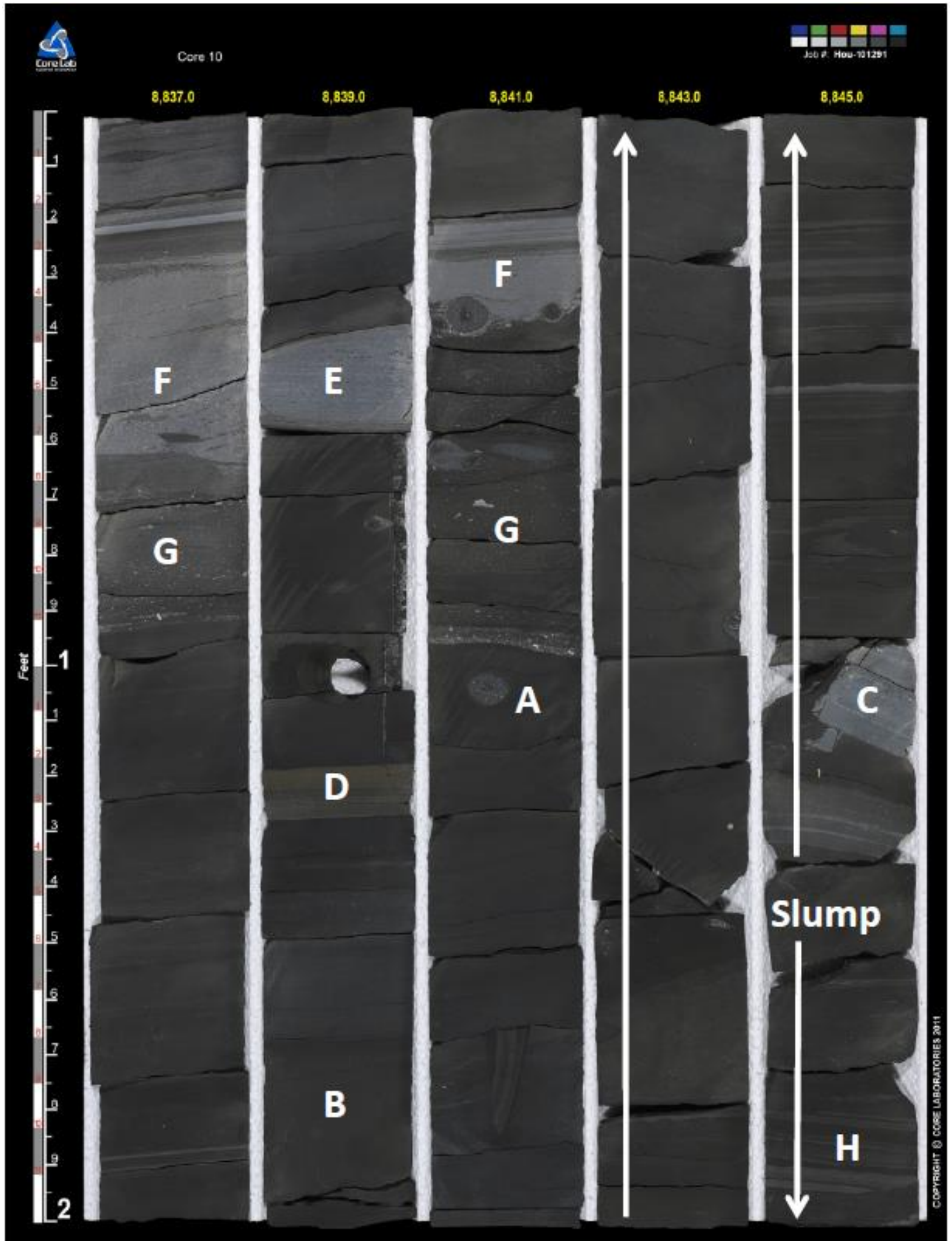
- 700+ ft. of organic-rich, silica- and calcareous-rich mudstone punctuated by numerous density flows (carb. turbidites and debris flows)
- Six operational sub-units:
  - A1
  - A2
  - A3
  - B1
  - B2
  - B3
- WC B are predominantly siliceous mudstones
- WC A are mixed carb-silica mudstones
- Aggradation of carbonate margins during second-order highstand increase percentage of $CaCO_3$ into basin during WFMP A time
- Interval currently resides in peak oil window in Midland Basin; remains a main horizontal drilling target



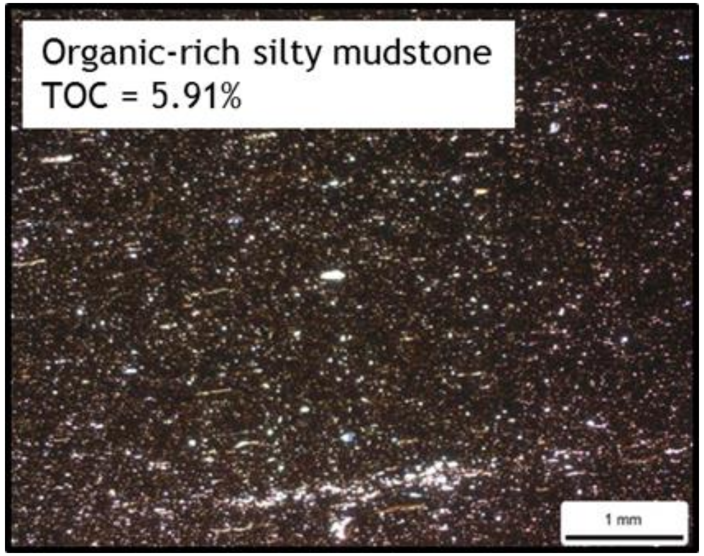
XRD analyses from core (n = 476)



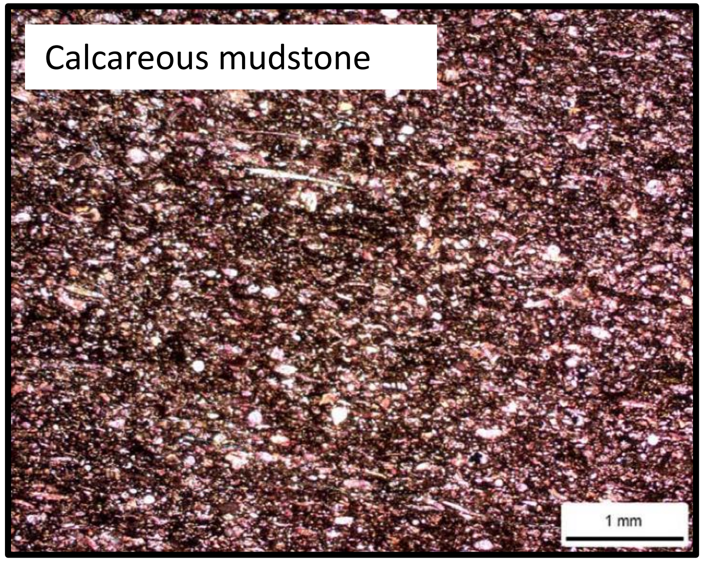
(Mzee, 2018)



Wolfcamp B2



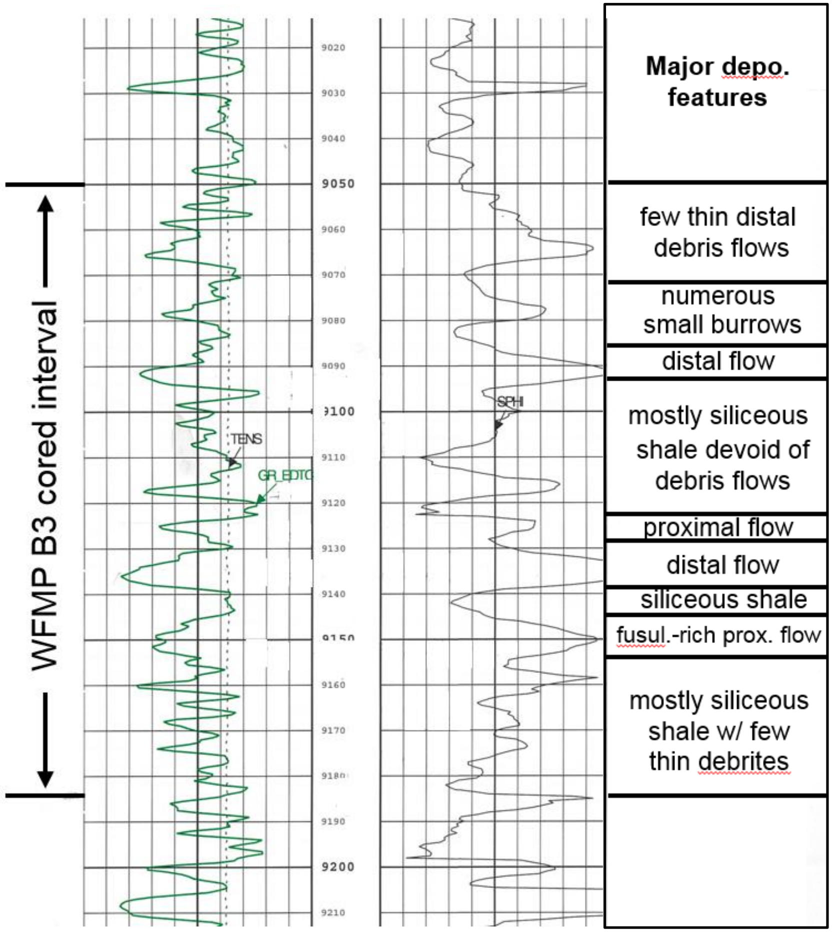
Wolfcamp A3



Photograph of core, **Wolfcamp B2**, depth 8837-8847 feet. (A) Structureless silty mudstone with phosphatic concretion. (B) Calcareous silty mudstone. (C) Carbonate lithoclast. (D) Ash bed. (E) Carbonate concretion. (F) Skeletal grainstone with erosive base and reworked concretions. (G) Thin, muddy debrite with deformed mudclast. (H) Sheared and rotated package of thin beds at the bottom of a slumped interval, 8847-8843 ft.

(Murphy, 2105)

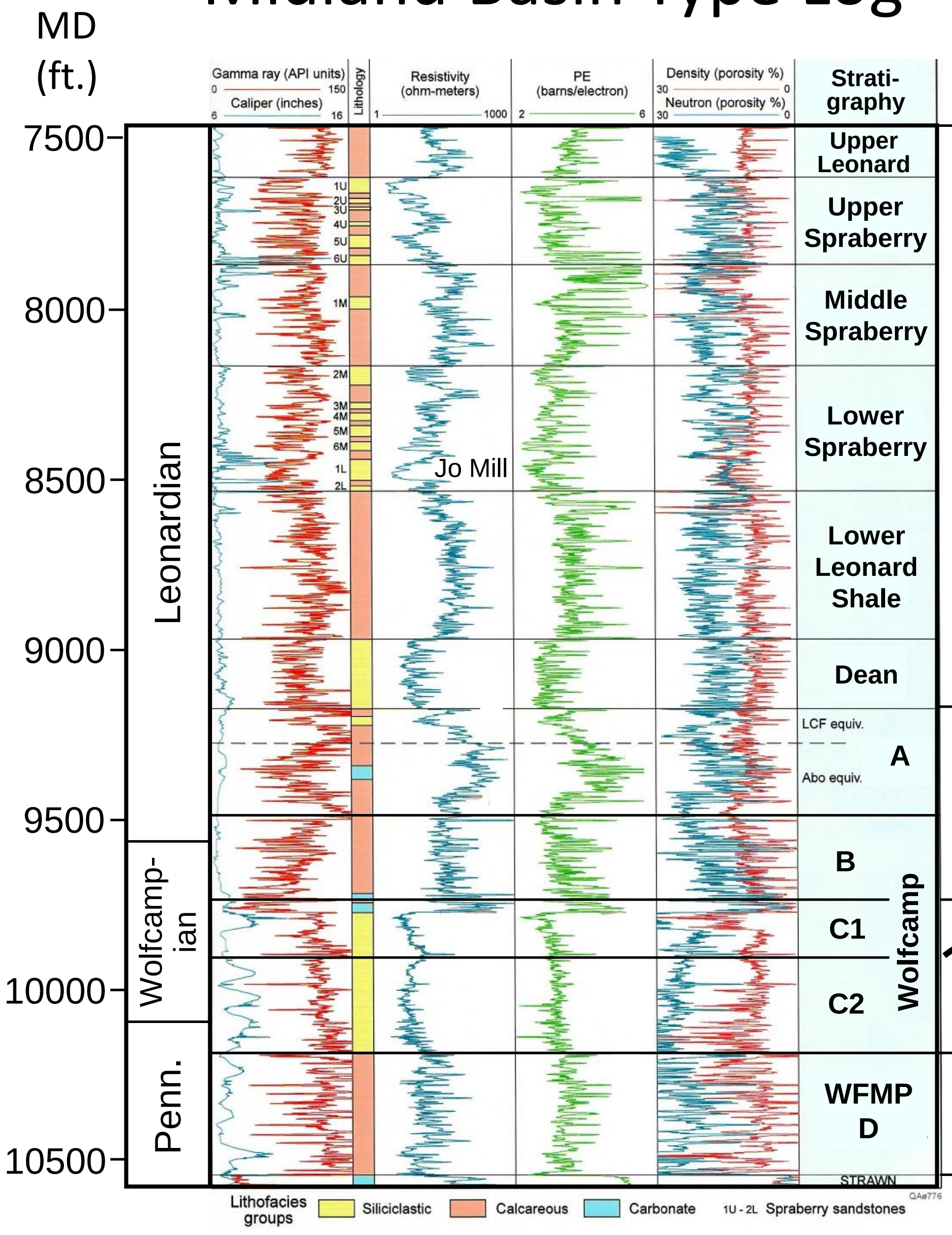
Wolfcamp carbonate debris flows



- Flows are thickest and coarsest near the shelf margins; distal portions of flows are thinner and finer grained
- Geometries include sheet-like fans and highly channelized flows

Spraberry - Dean

Midland Basin Type Log



(modified from Hamlin and Baumgardner, 2012)

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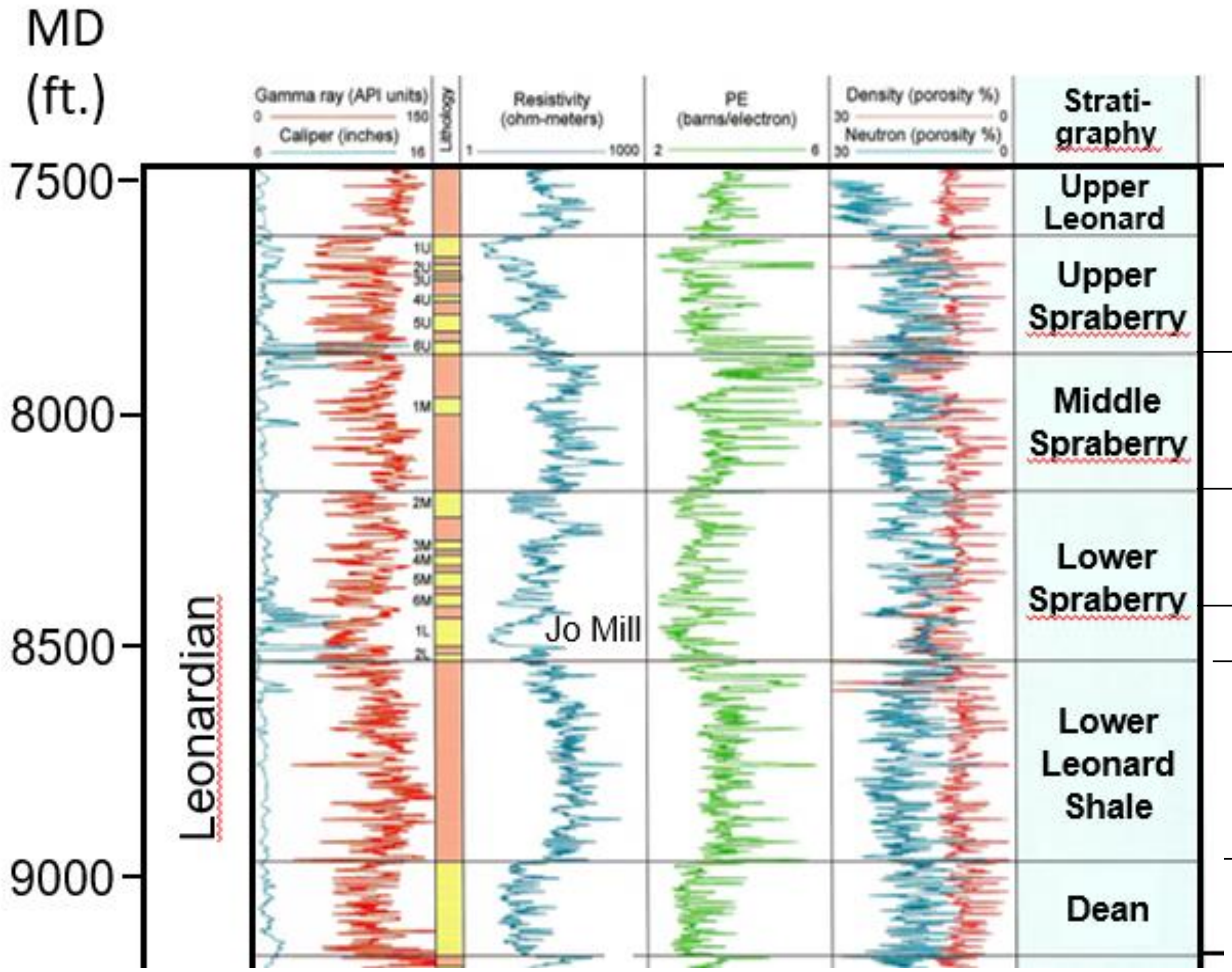
mid-WC unconformity

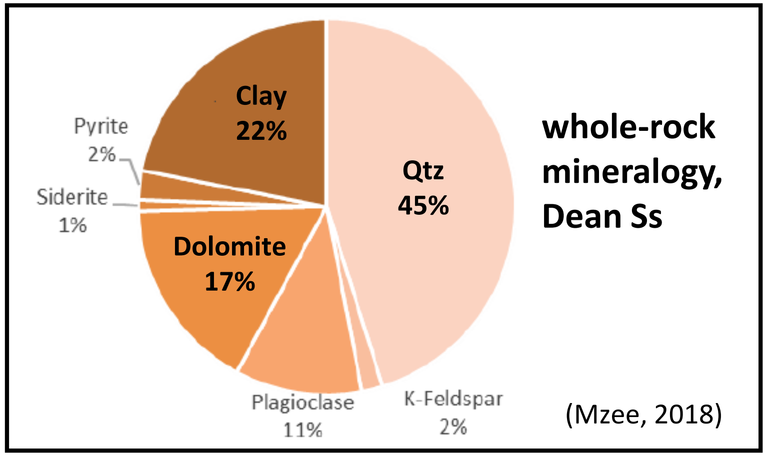
Wolfcamp C: Clay-rich shale (progradation of Eastern Shelf deltas & Glasscock Nose)

Wolfcamp D: Basinal cyclothems (starved basin)

Lower Strawn: shallow-water platform limestones

Dean – Spraberry units of the Midland Basin





U. Spraberry
- 2 major submarine fan complexes (Floyd and Driver fans)
- Equivalent to 1st Bone Spring Ss

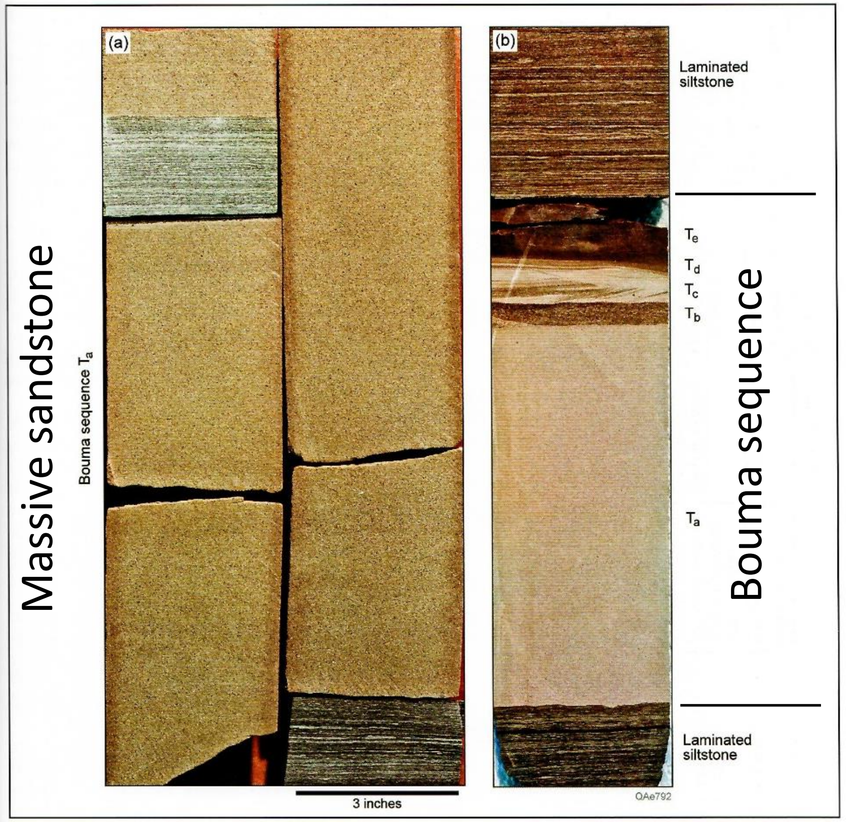
M. Spraberry
- silty, shales; minor fan complex

L. Spraberry
- siliceous shales, minor fans

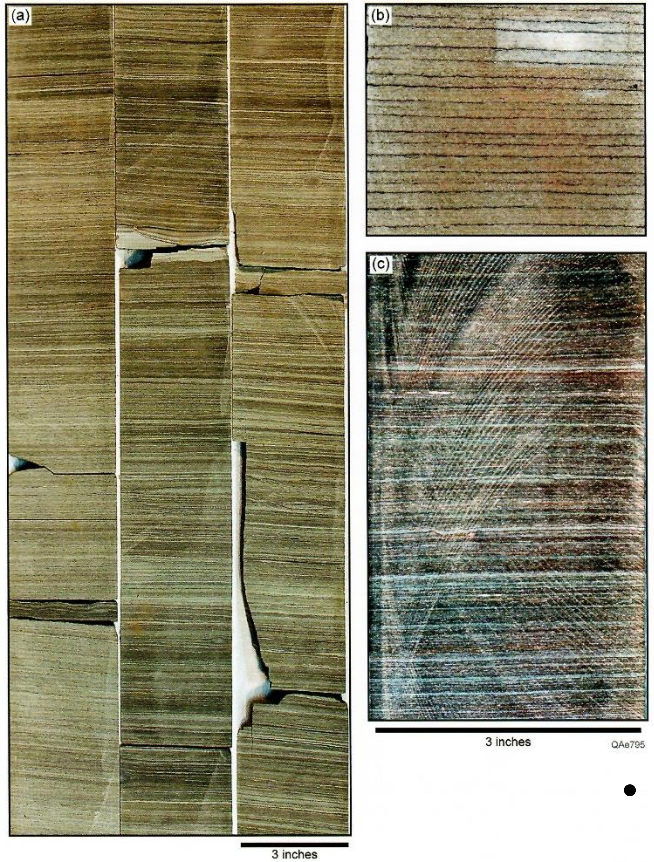
Jo Mill
- 2nd major incursion of submarine fans
- Equivalent to 2nd Bone Spring Ss

Lower Leonard Sh.
- organic-rich siliceous shales

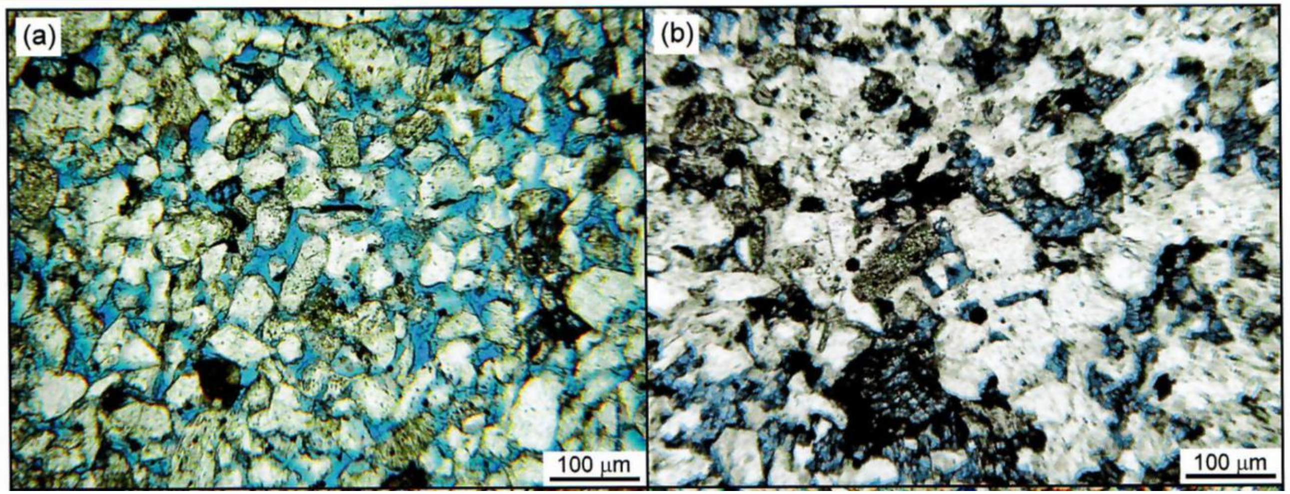
Dean
- 1st major incursion of submarine fans
- Equivalent to 3rd Bone Spring Ss



(Hamlin and Baumgardner, 2012)



Laminated siltstones

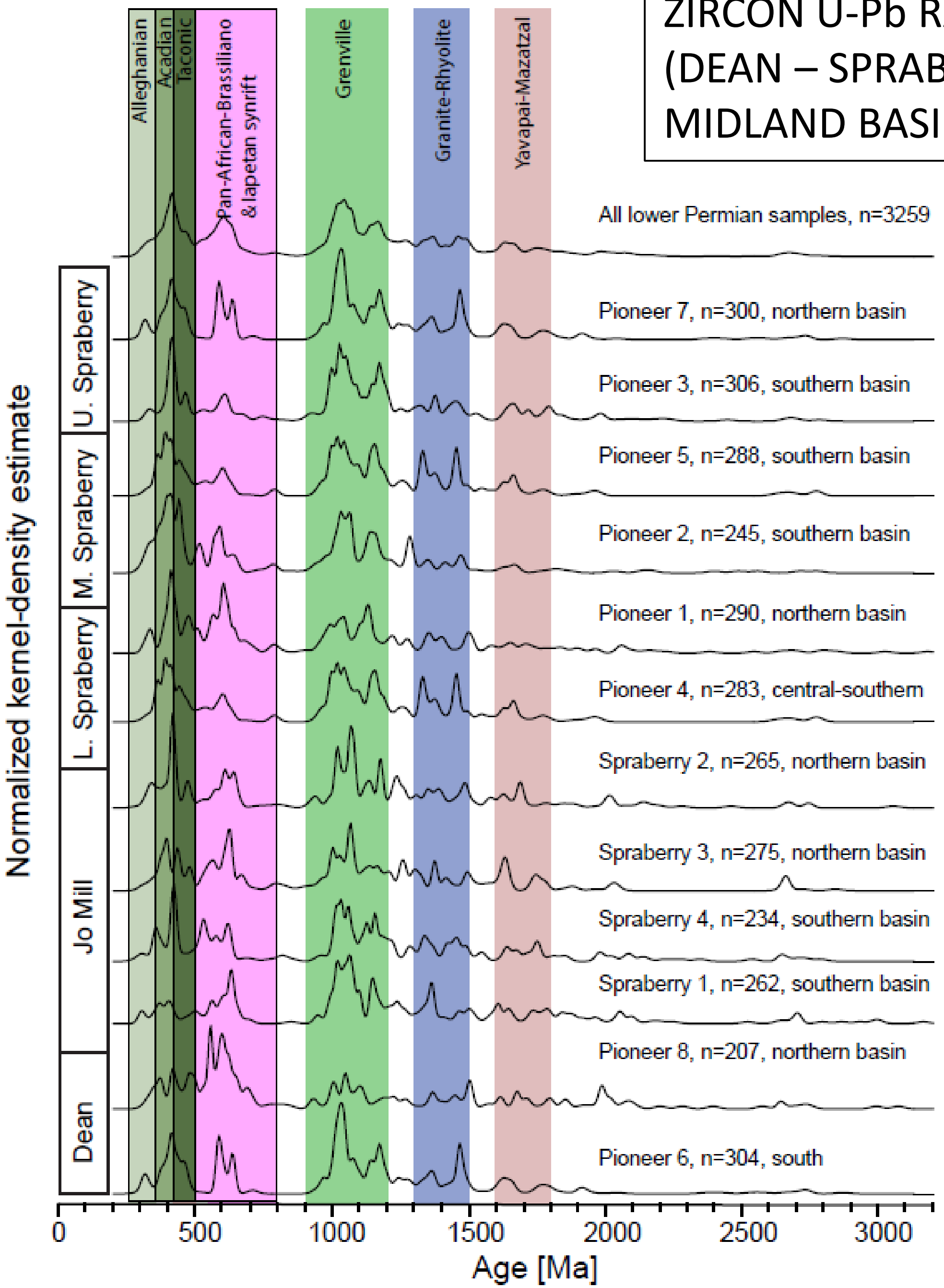


(a) Porous sandstone

(b) Sandstone cemented w/ ferroan dolomite

- All fans (Dean, Jo Mill, Middle & Upper Spraberry) are similar in appearance
- Main facies:
  - Massive f.g. sandstones (“Bouma A”)
  - Laminated siltstones / shales
  - Burrowed siltstones / shales (O_2)
  - Black shale (thin caps)
- Provenance? (north vs. south) Depositional model ?

ZIRCON U-Pb RADIOMETRIC AGE SPECTRA (DEAN – SPRABERRY, CENTRAL & SOUTHERN MIDLAND BASIN)



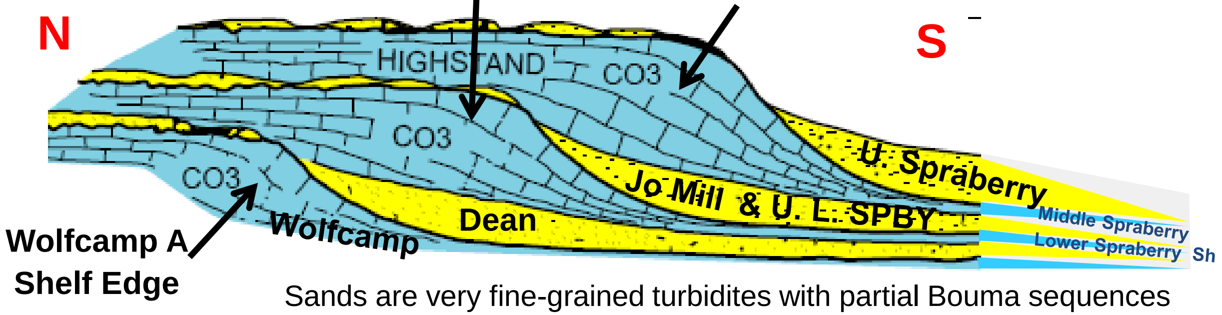
- Strong age signal ("peaks")
  - Grenville province (1100 Ma)
  - Gondwana (600 Ma)
  - Appalachia (400 Ma)
- Intermediate signal
  - Granite-Rhyolite province (1400 Ma)
- Weak signal
  - Yavapai – Mazatzal province (1700 Ma)

Strong age signals are from southern-located provinces, indicating a southern source land for Dean – Spraberry sands in central & southern Midland Basin (currently accepted view: all sands were from a northern source)

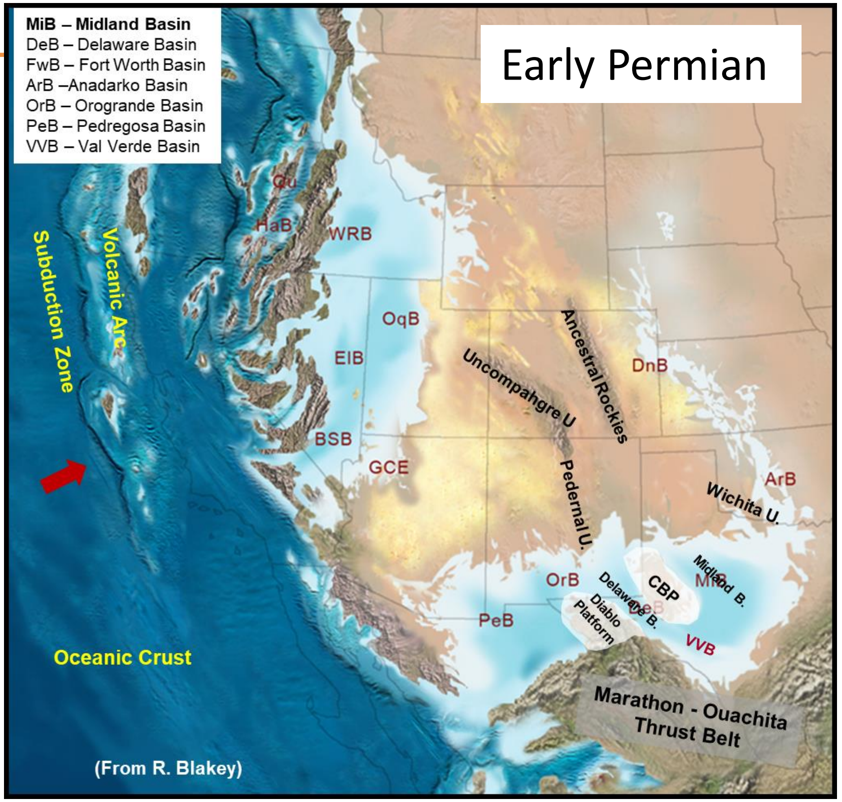
(Waite et al., in press)

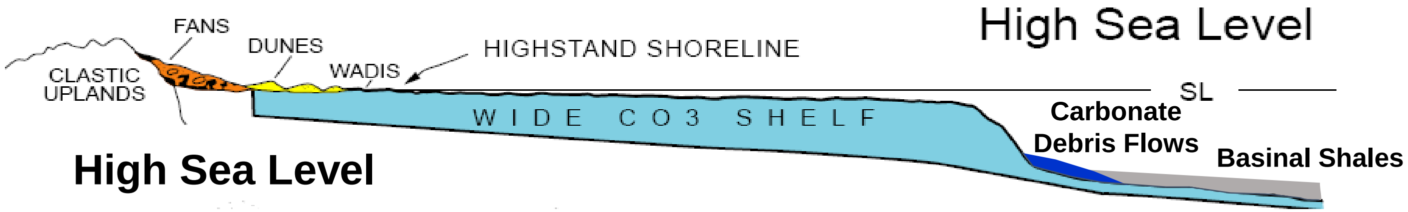
Spraberry & Dean (Bone Spring) Depositional Model (based on Hanford, 1981)

Spraberry and shelf equivalents are alternating sand-rich and organic shale/carbonate-rich packages deposited during alternating high and low sea levels.

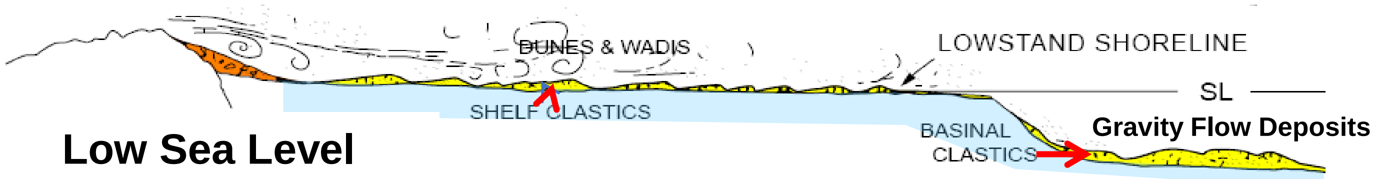


Sands are very fine-grained turbidites with partial Bouma sequences
Organic-rich shales highly laminated and not bioturbated; Organic-poor shales bioturbated
Thin dolomitic hard grounds observed in sands and shales



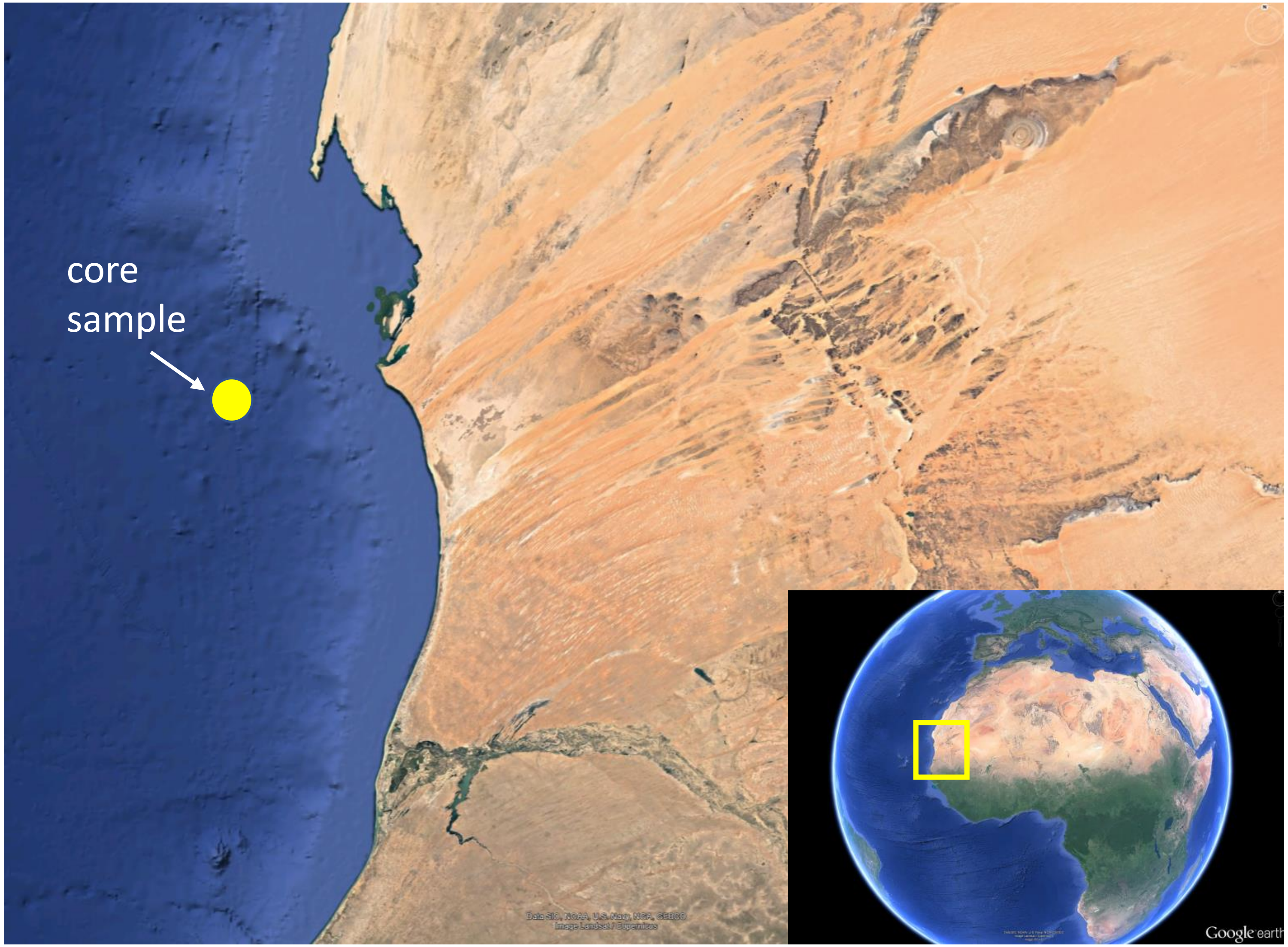


Highstand –
- Shelf submerged
- Carbonates on shelf
- Carbonate gravity flow deposits and organic-rich shales in basin

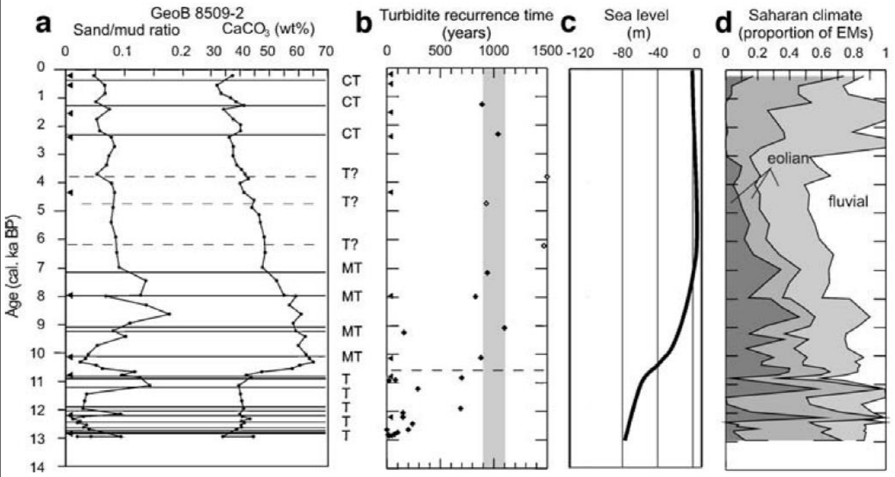


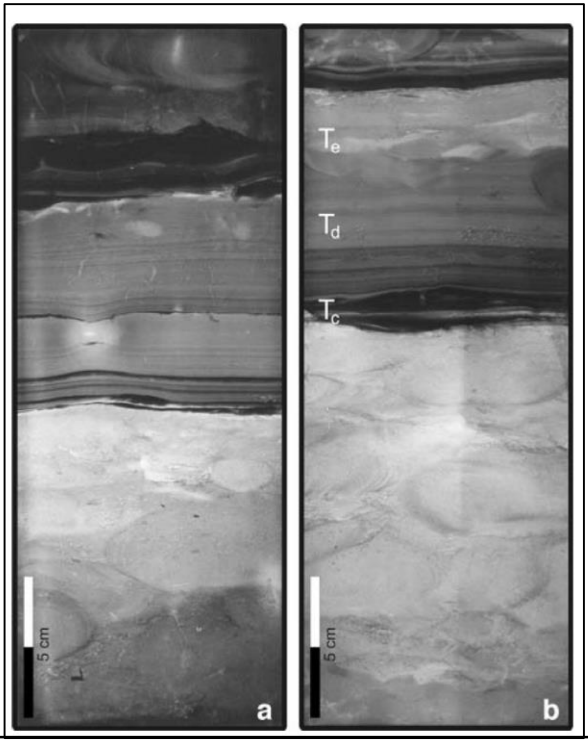
Lowstand and ensuing transgression–
- Shelf exposed
- Clastics move across shelf via wind and in wadis
- Clastic gravity flow deposits bypass shelf during lowstand and are cannabalized during early transgression

Possible modern analog for Dean - Spraberry: Offshore Mauritania, African Sahara



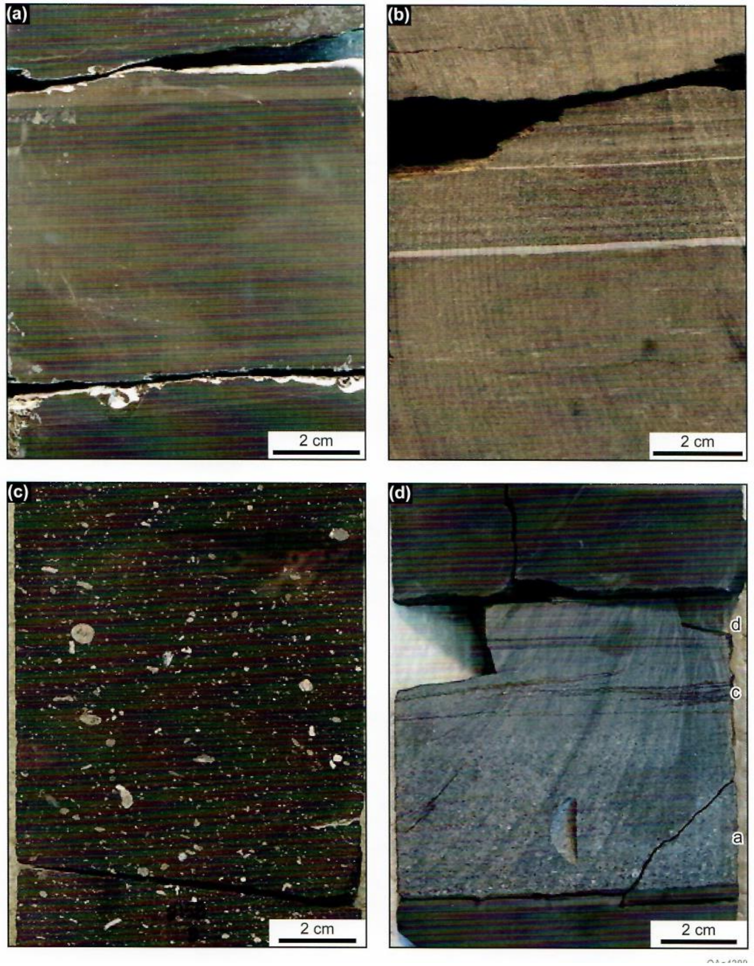
Core data (Zuhlsdorff et al., 2008)





Summary and Conclusions

- The Wolfcamp – Spraberry interval of the Midland Basin consists of a series of lithologically- and mineralogically-complex facies; each interval is unique
  - Wolfcamp D: basinal cyclothems
  - Wolfcamp C: clay-rich shales
  - Wolfcamp A - B: Silty, calcareous terrigenous shales; carbonate % increases upward
  - Dean - Spraberry: Argillaceous siltstones, punctuated by numerous submarine-fan complexes (massive & laminated sandstones)
- Complexity of these rocks reflects changing/evolving geologic conditions (eustasy, climate, tectonics, sediment supply, biota, etc.) along the SW margin of western Pangea during Late Pennsylvanian – early Permian time
- Geologists must work closely with drilling, completion, and reservoir engineers to fully communicate the complexity and uniqueness of each unit / horizontal zone



(Hamlin and Baumgardner, 2012)

"Not all shales are created equal"