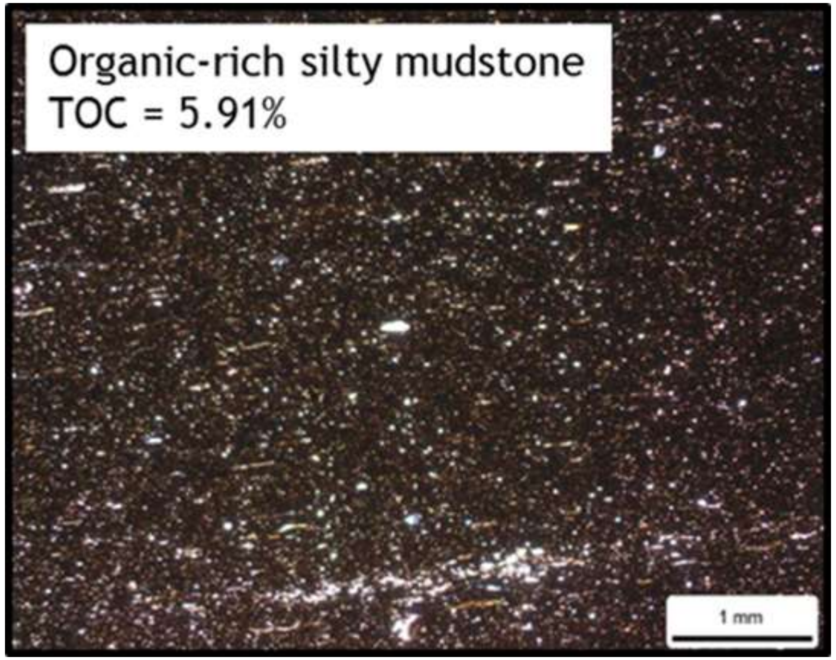
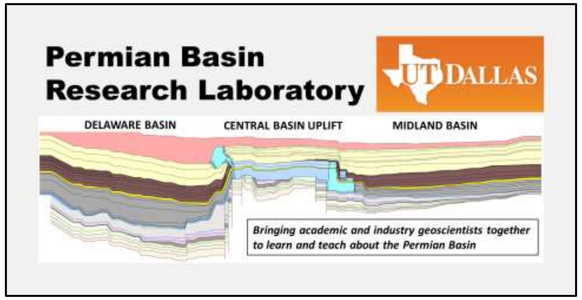
Stratigraphic Framework of the Wolfcamp – Spraberry of the Midland Basin

A presentation to Ovintiv

November 1, 2022





Lowell Waite

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Permian Basin Research Lab
University of Texas at Dallas

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

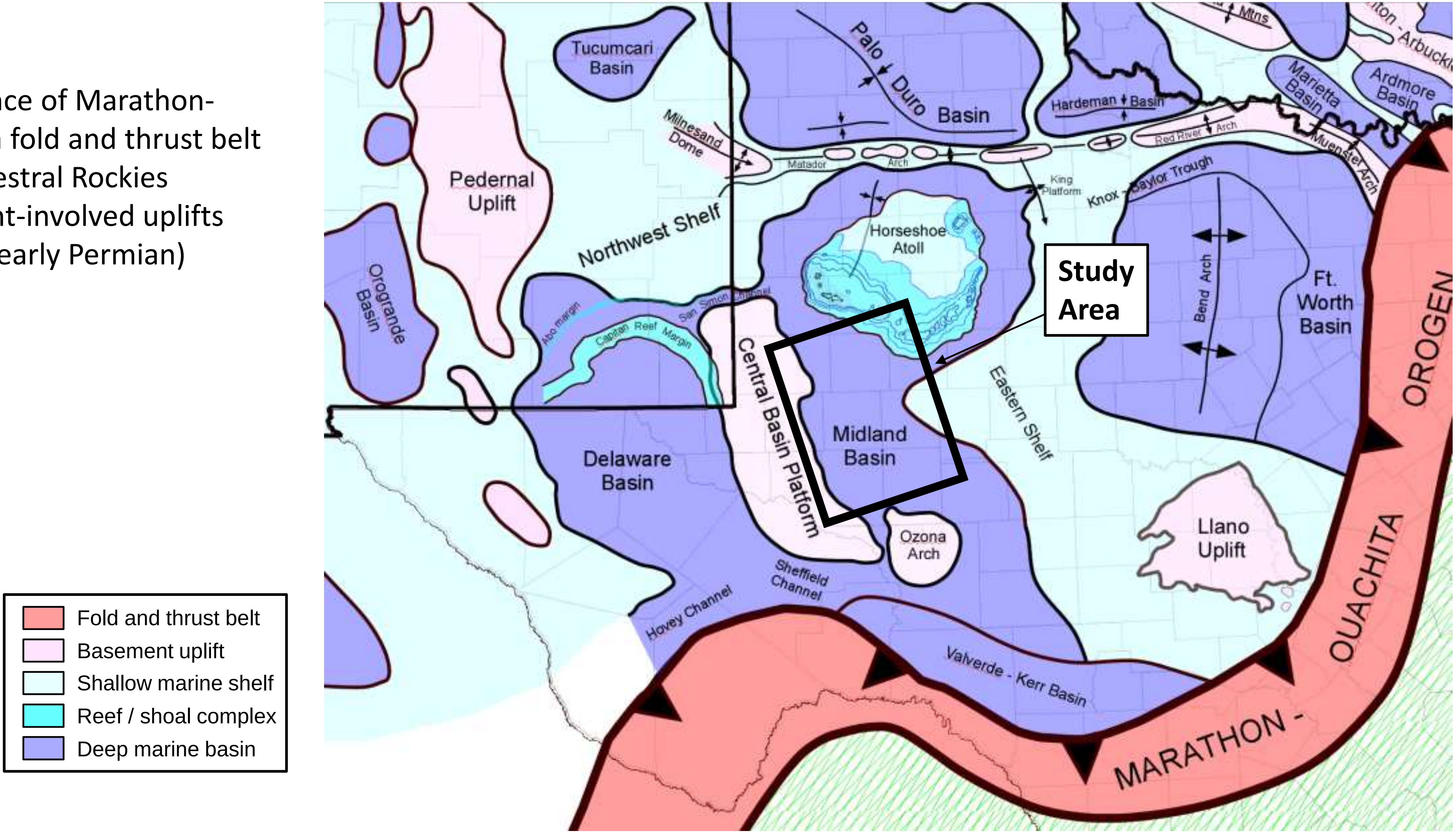
"Not all shales are created equal"

Notes: Although not specifically addressed, the framework outlined here is applicable to the Delaware Basin

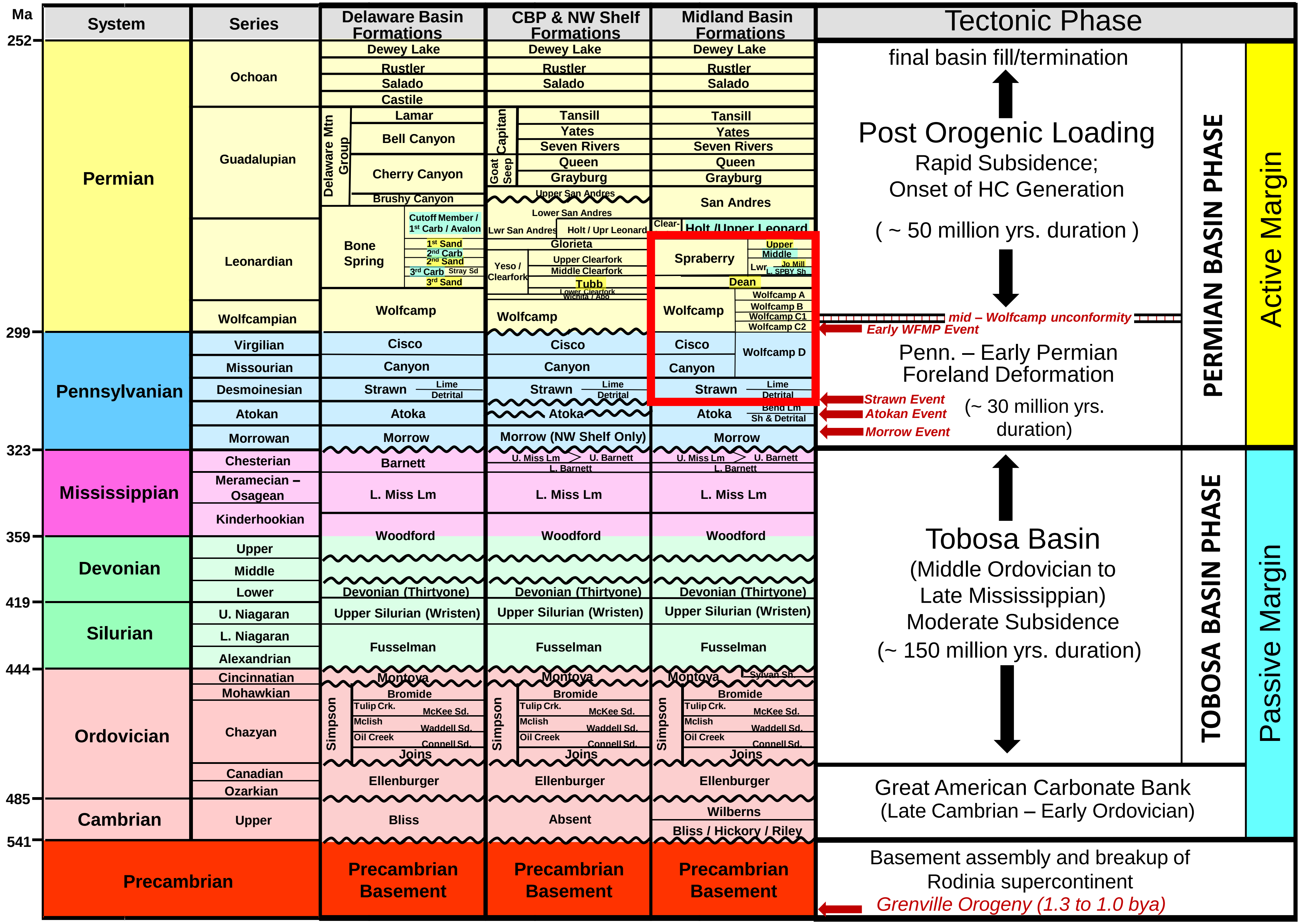
This talk focuses on geology and does not discuss engineering/completion topics

Greater Permian Basin Region of west Texas and SE New Mexico

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



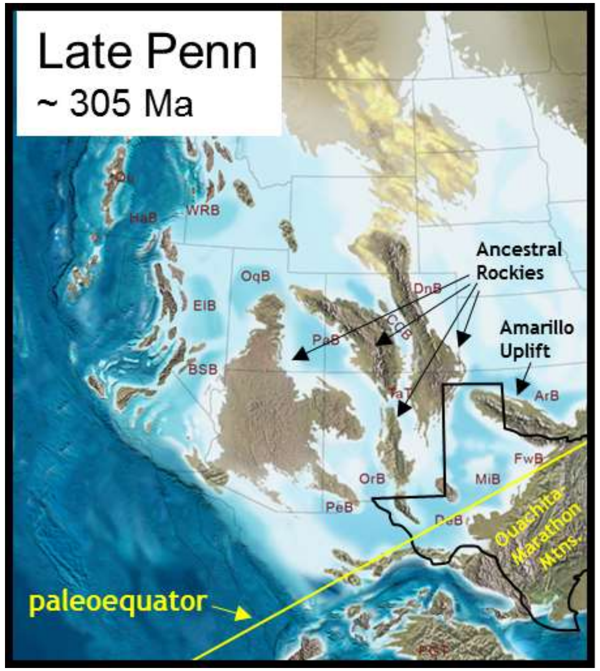
Permian Basin Stratigraphy and Tectonic History



UTD Permian Basin Research Lab

(modified from Reed, unpub., 2016)

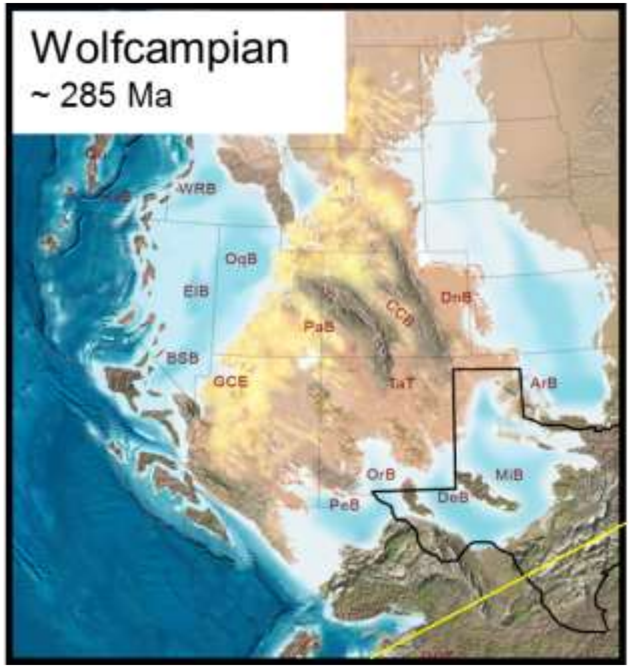
LATE PENNSYLVANIAN – EARLY PERMIAN EVOLUTION OF WESTERN PANGEA

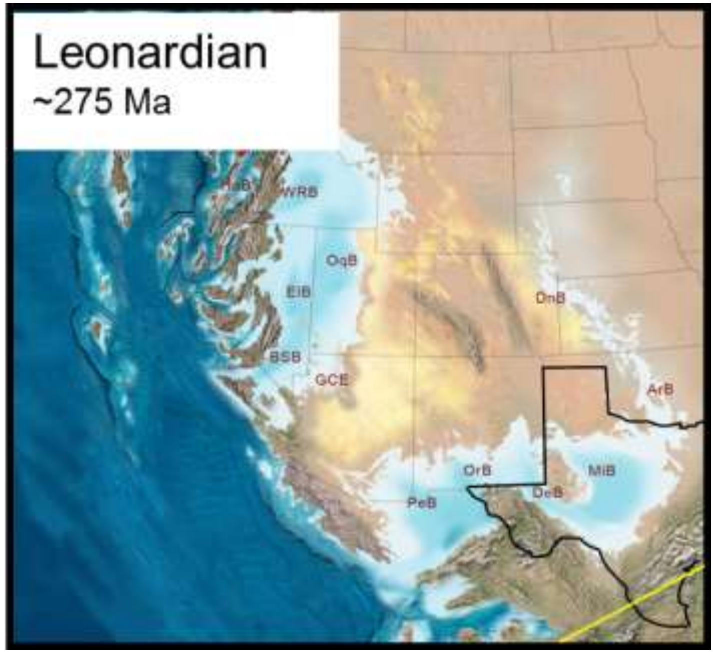


Late Pennsylvanian

- Icehouse climate; PB in humid-tropical setting (abundant rainfall)
- Numerous high-freq., high-amplitude short-term 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)

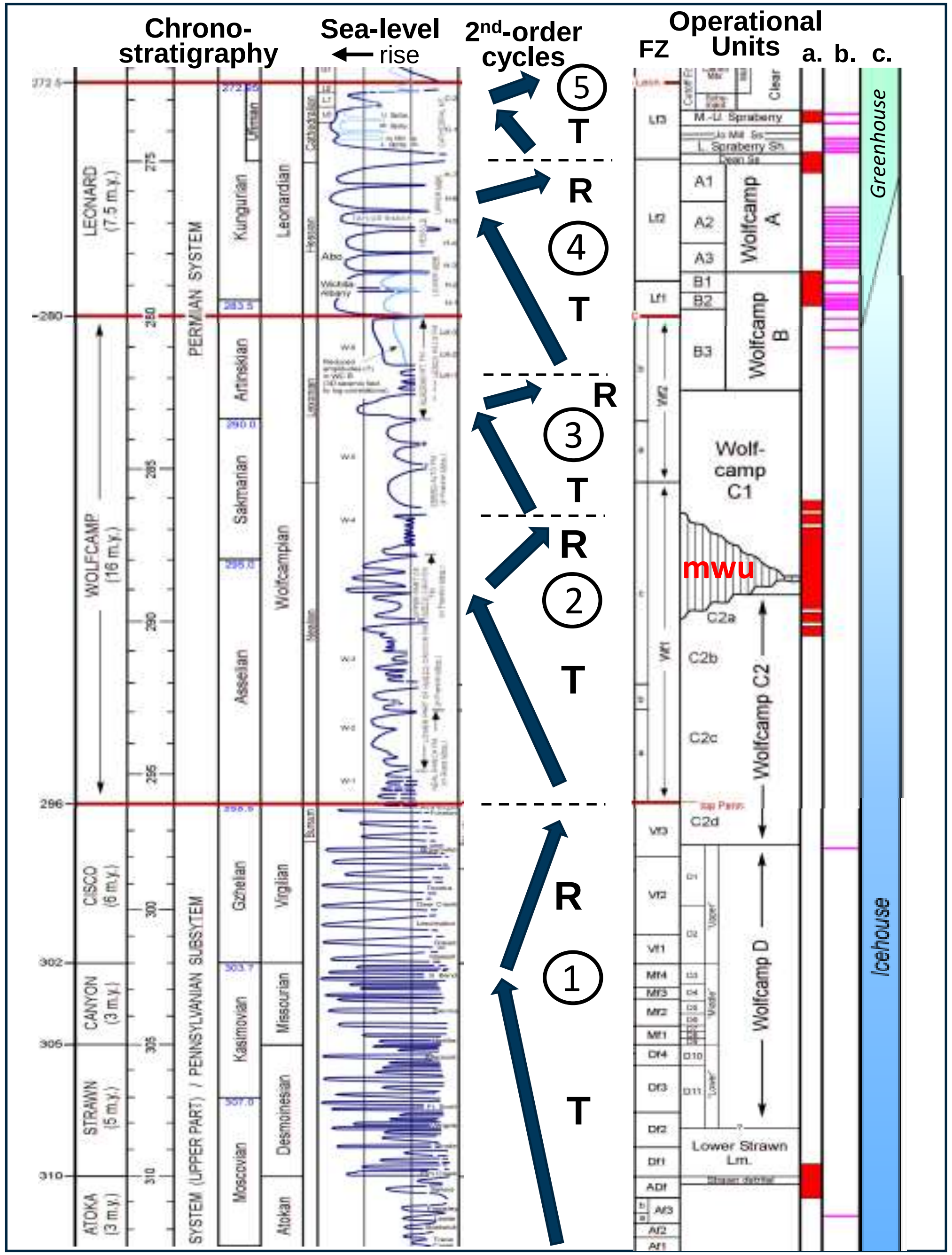
(maps: Ron Blakey, NAU/Colorado Plateau Geosystems)

Stratigraphic framework, Wolfcamp - Spraberry

(Waite et al., 2019, AAPG SW Section mtg)

Numerous 3rd- and higher-order cycles of sea-level change organized into larger 2nd-order cycles (supersequences; 5 – 10+ m.y. in duration) bounded by lowstands; these include:

- ⑤ **Dean – Spraberry**
- ④ **WC A - B**
- ③ **WC C1**
- ② **WC C2**
- ① **Atoka - WC D - lowermost WC C2**



FZ. Fusulinid zonation

a. Tectonic pulses

b. Ash beds

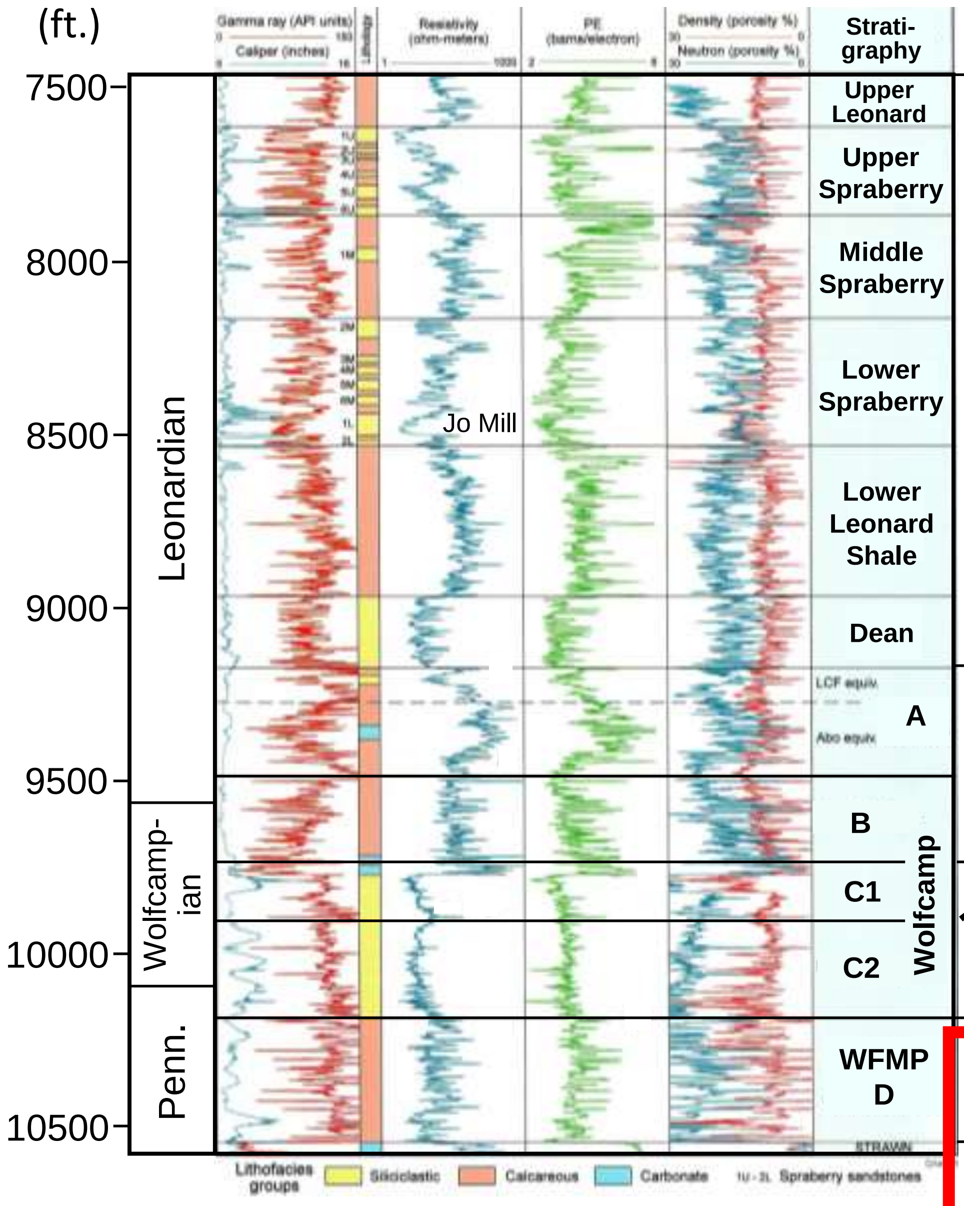
c. Climate phase

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

(Based on numerous core studies)

Super-
cycle

Spraberry – Dean:
silty mudstones and clay-rich siltstones punctuated by multiple deeper-water submarine fan complexes (incl. massive to laminated, fine-grained sandstones) — ⑤

Wolfcamp A – B:
silty- and calcareous organic-rich mudstones; carbonate percentage increases upward — ④

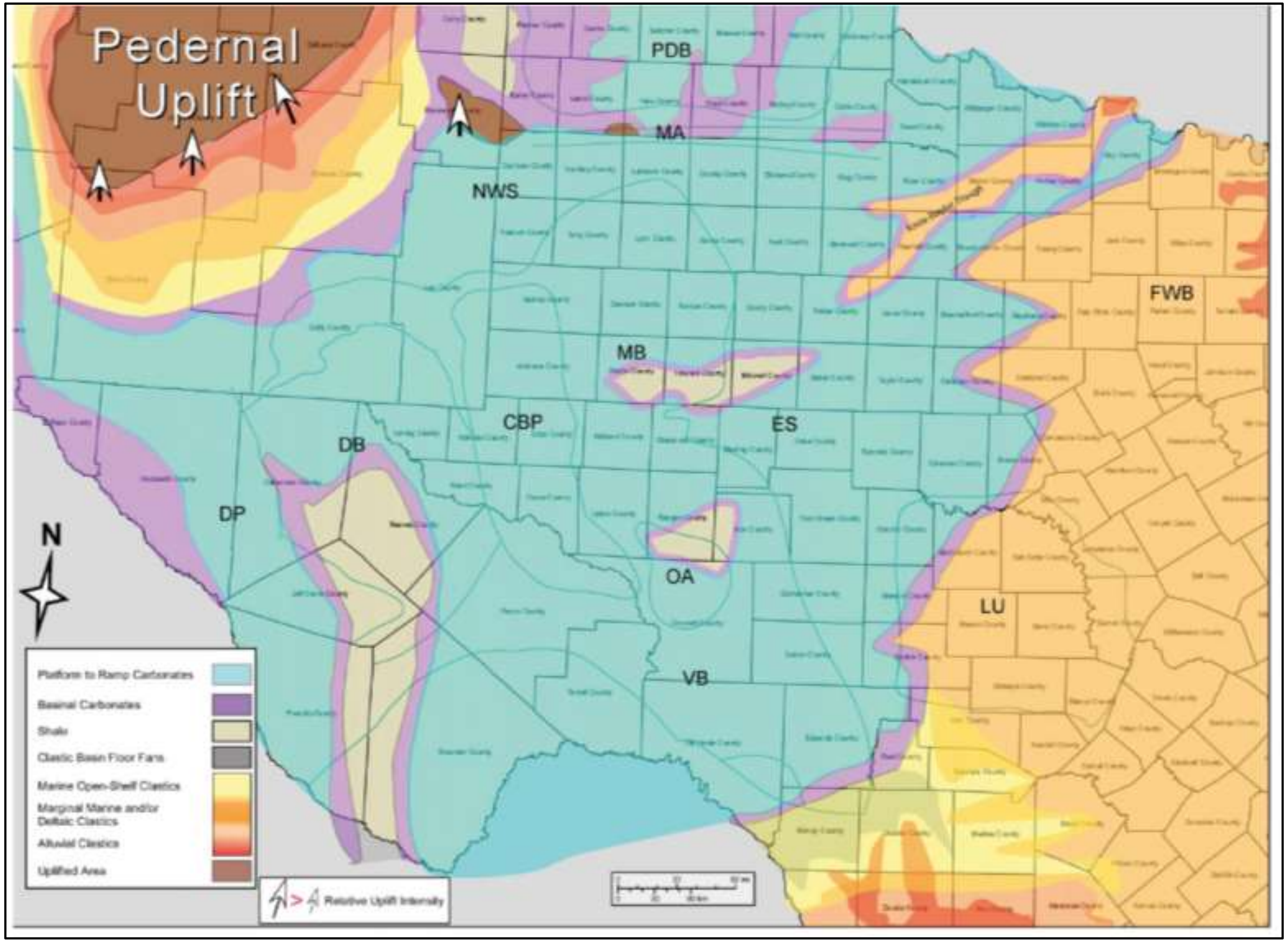
mid-WC unconformity

Wolfcamp C: Clay-rich shale (progradation of Eastern Shelf deltas & Glasscock Nose) — ③ ②

Wolfcamp D: Basinal cyclothems (starved basin)

Lower Strawn: shallow-water platform limestones — ①

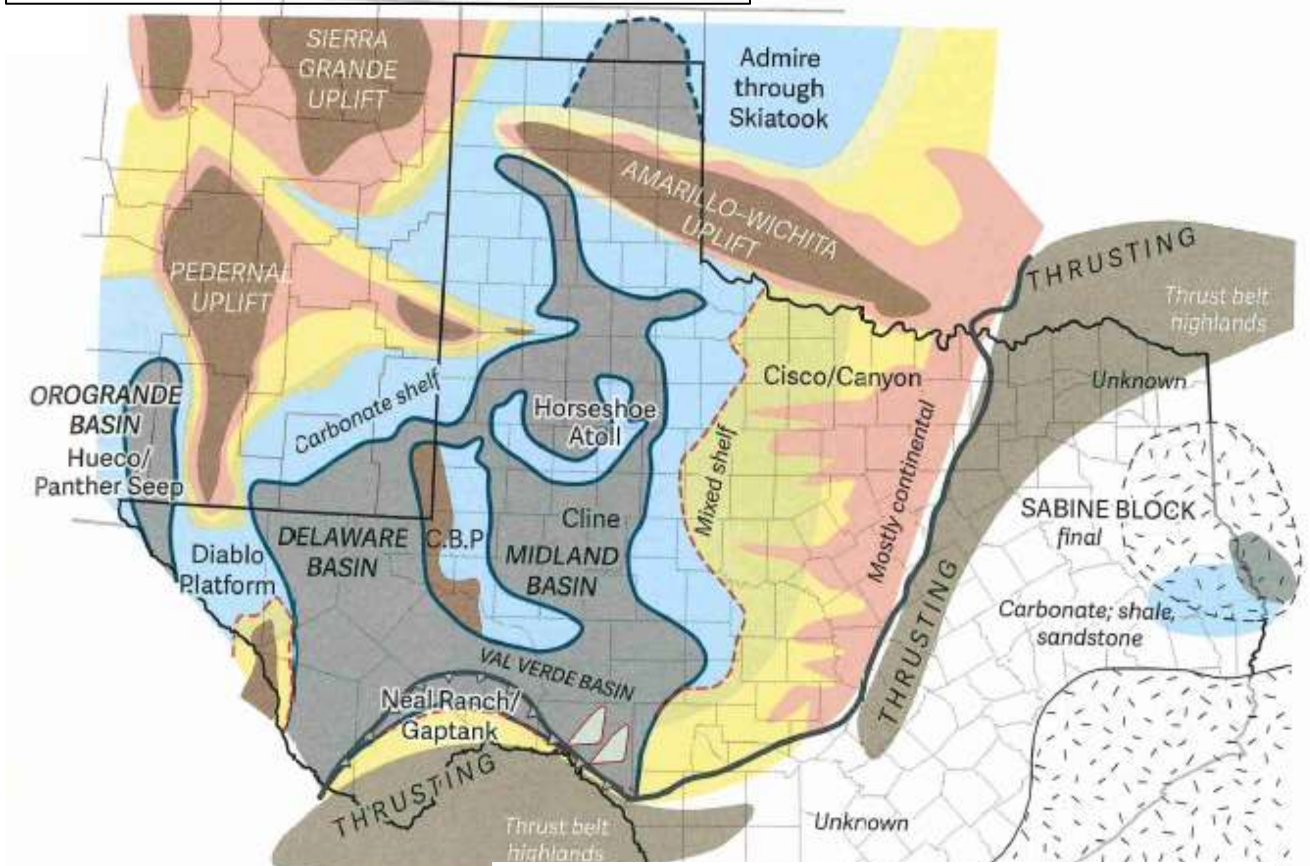
Lower Desmoinesian Facies (Lower Strawn Limestone)

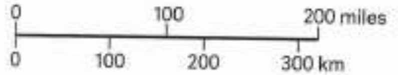


(Wright, 2011)

- Shallow water carbonate facies (Concho Platform) extend across entire Midland Basin and Eastern Shelf region; eastward-dipping into Ft. Worth Basin foredeep
- Lower Strawn Limestone is generally < 200 ft. thick in Midland Basin; good log / seismic marker
- Core analyses from center of Midland Basin indicates typical Penn shelf cyclothem deposits: burrowed skeletal wackestones grading upward into phylloid algal packstones and skeletal grainstones, capped by exposure surfaces
- Long-term sea-level lowstand; pre-dates drowning of Midland and Delaware basins

Upper Strawn to Canyon – Cisco

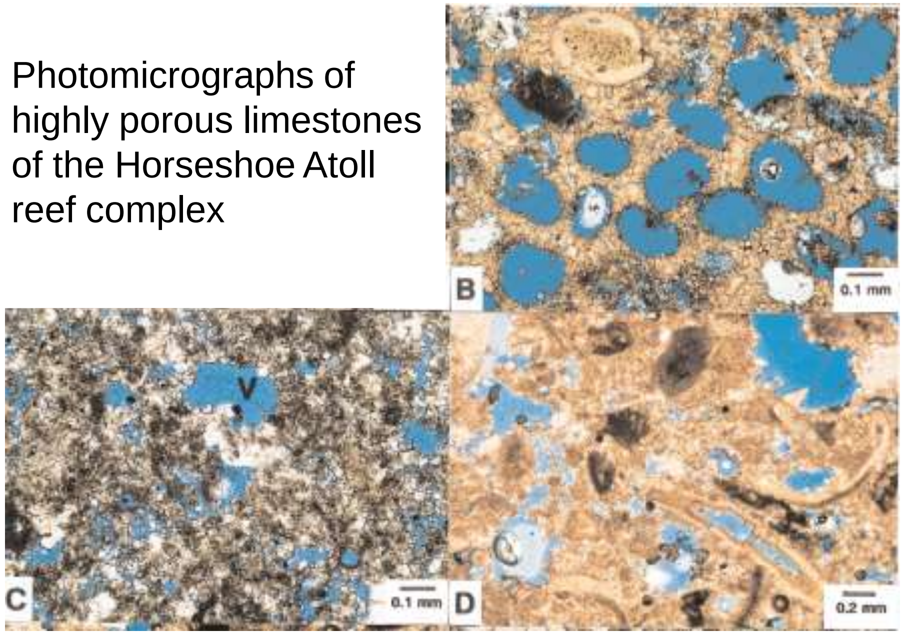




- Long-term eustatic rise (drowning of basins and backstepping of surrounding shelves)
- Starved Delaware and Midland basins

(Ewing, 2016)

Photomicrographs of highly porous limestones of the Horseshoe Atoll reef complex

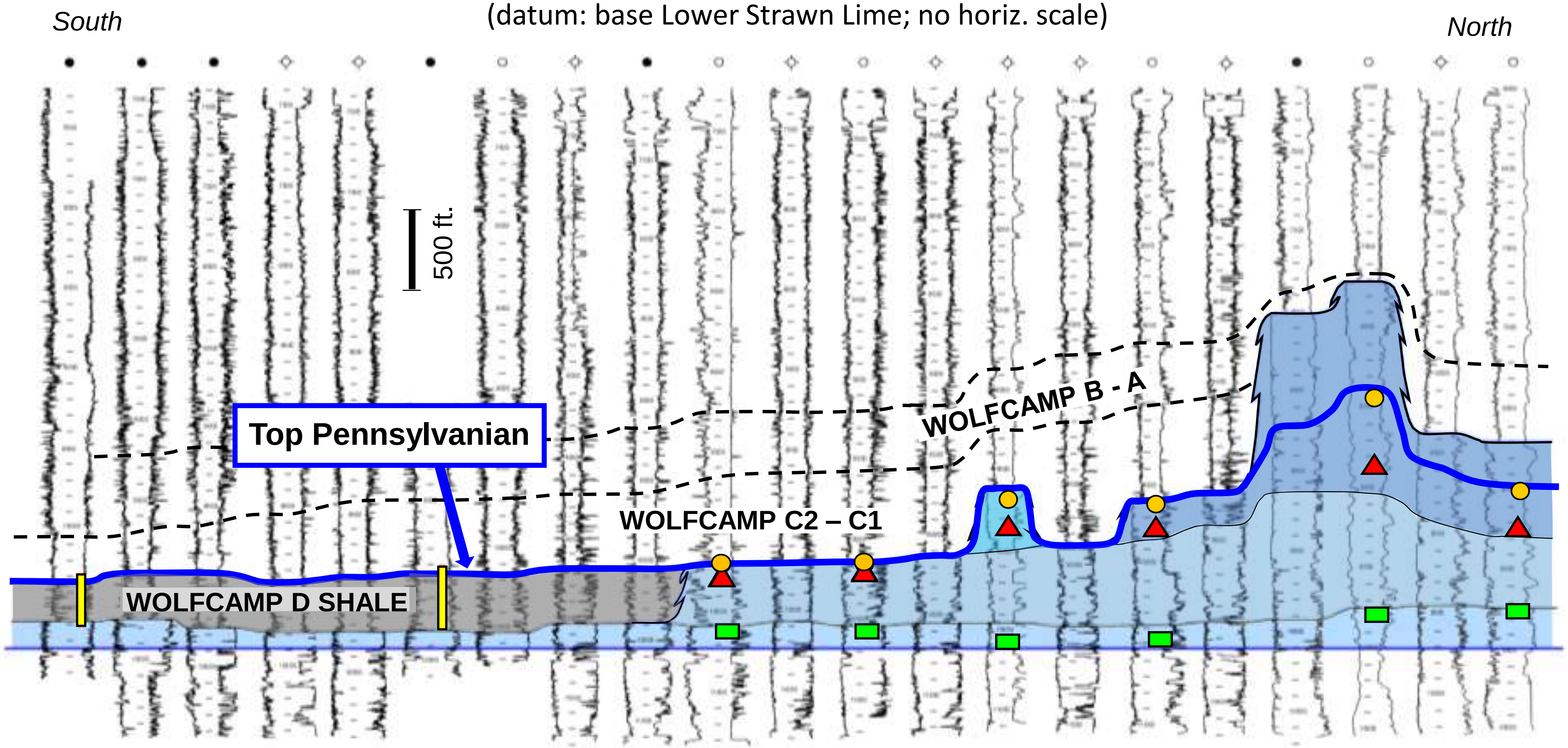


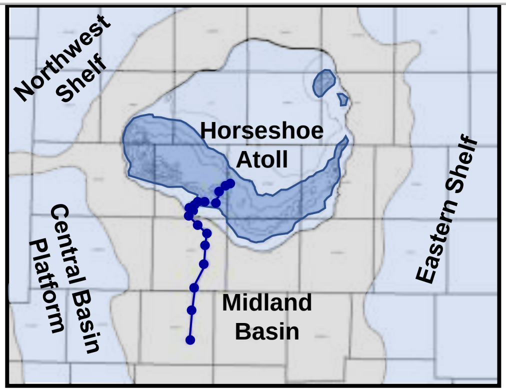
(Saller et al., 1999)

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

Wire-line log correlation from Midland Basin to Horseshoe Atoll

(datum: base Lower Strawn Lime; no horiz. scale)





Paleo control

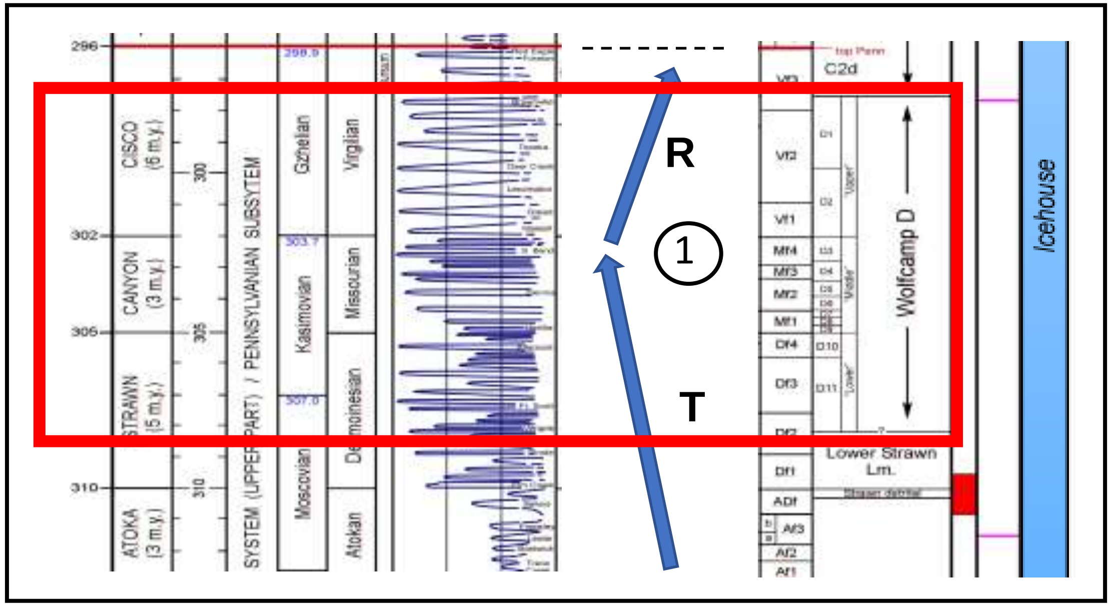
- Cisco fusulinids
- Canyon fusulinids
- Lower Strawn fusulinids
- **cored interval**

Observations:

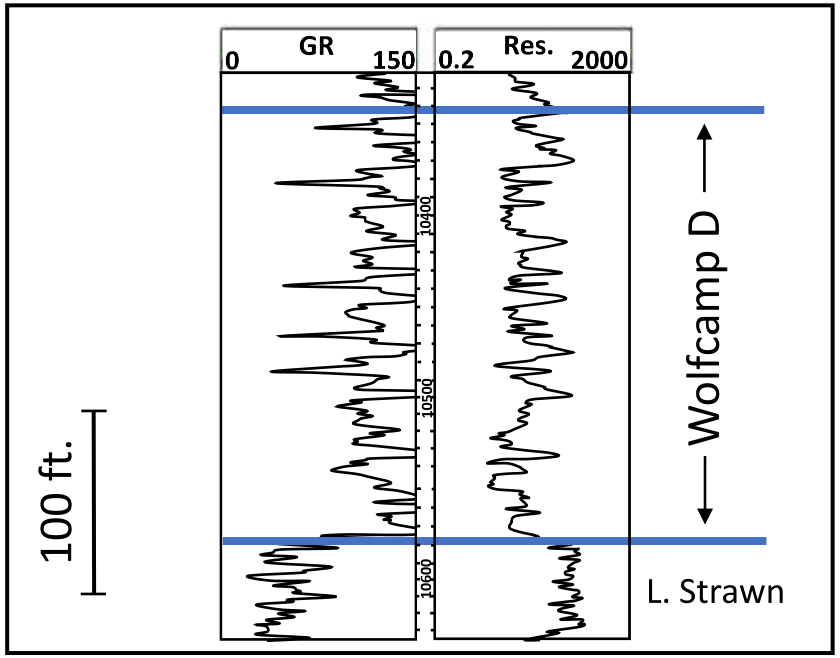
- Shale facies (basin) transition abruptly into carbonate reef facies (Atoll)
- Wolfcamp D shale is Penn. age (correlation to fusulinid-bearing LS)

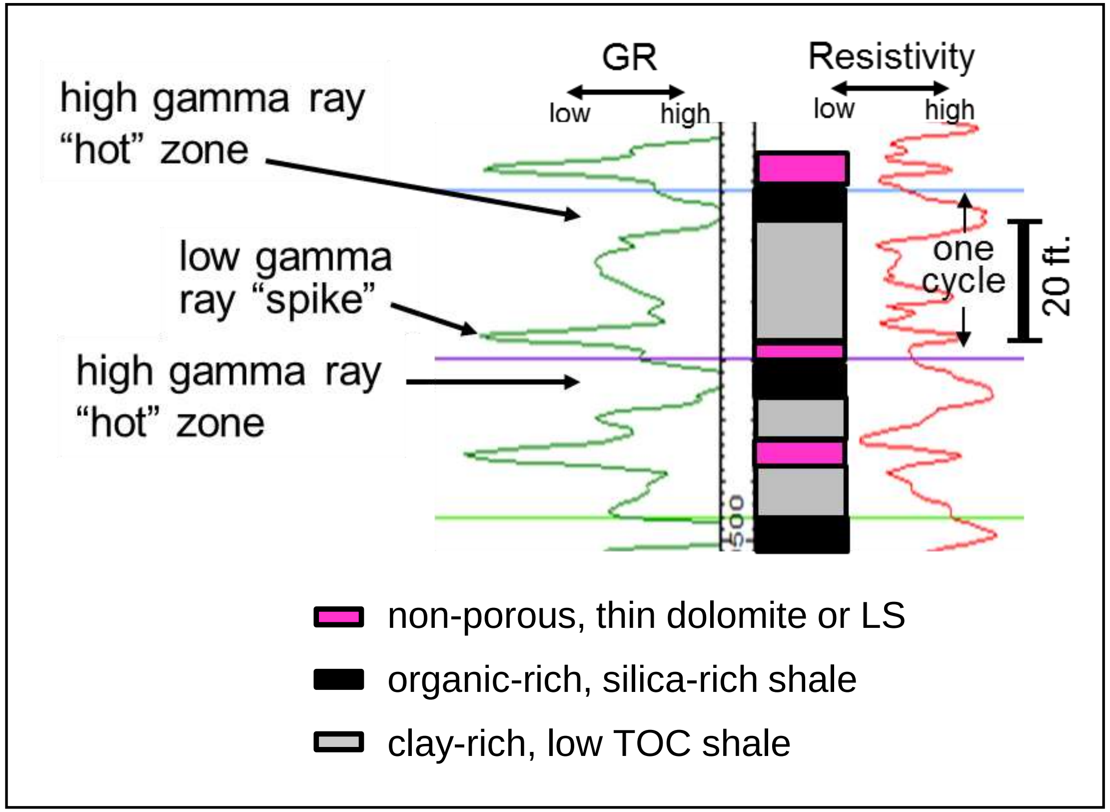
(L. Waite, unpublished, 2015)

Wolfcamp D: Basinal cyclothems

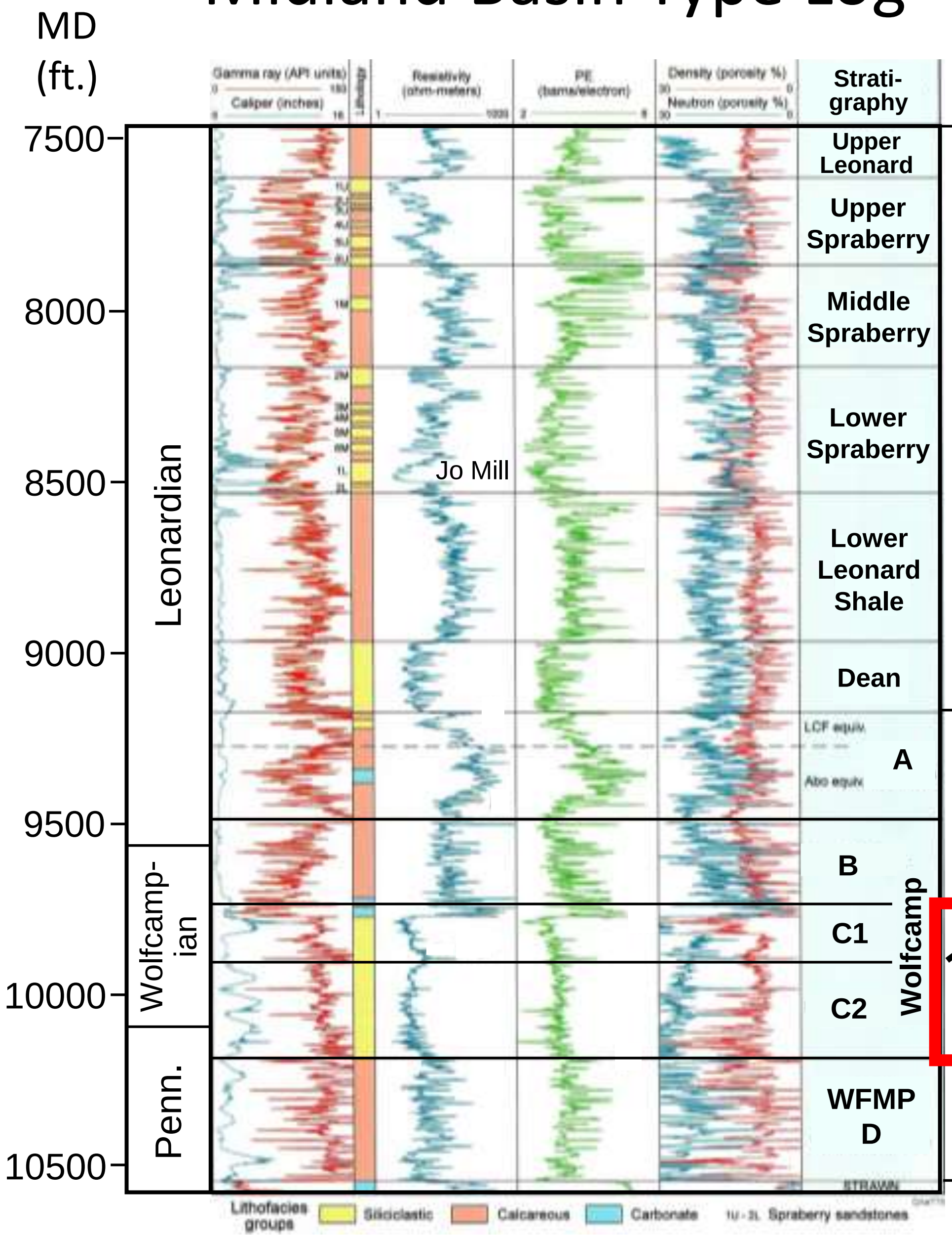


- Equivalent to classic "Penn. cyclothems" on shelves
- Silica – rich shales; relatively high clay content
- Each basinal cyclothem = 15 – 45 ft. thick; bounded by thin dolomite or LS; highly correlative basin-wide
- Organic content partitioned into multiple thin cycles
- High pore pressures due to depth,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





Midland Basin Type Log



(modified from Hamlin and Baumgardner, 2012)

GENERAL DESCRIPTION / DEPOSITIONAL FACIES

(Based on numerous core studies)

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

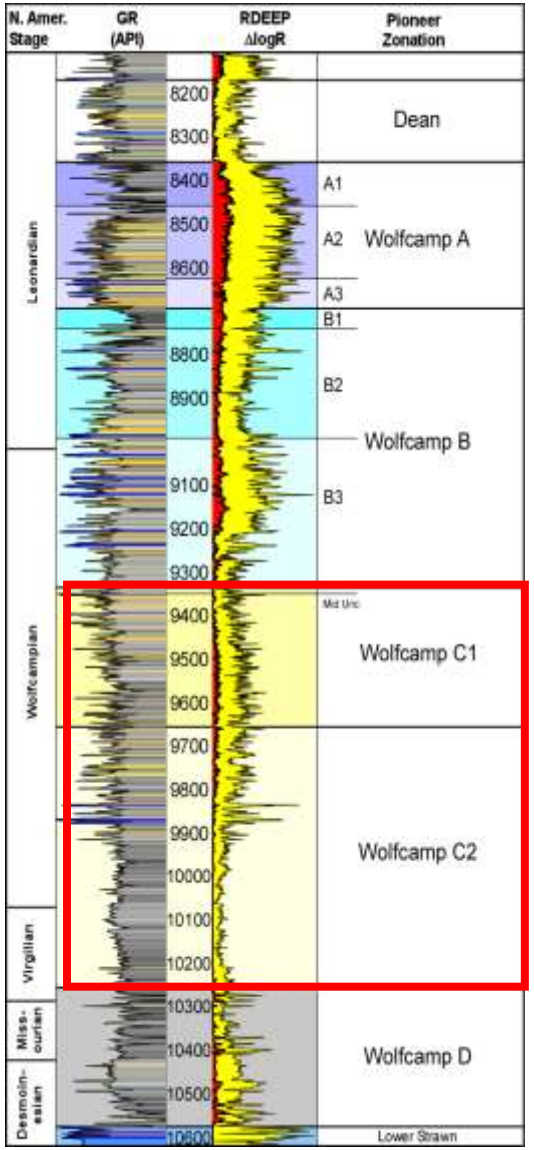
mid-WC unconformity

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

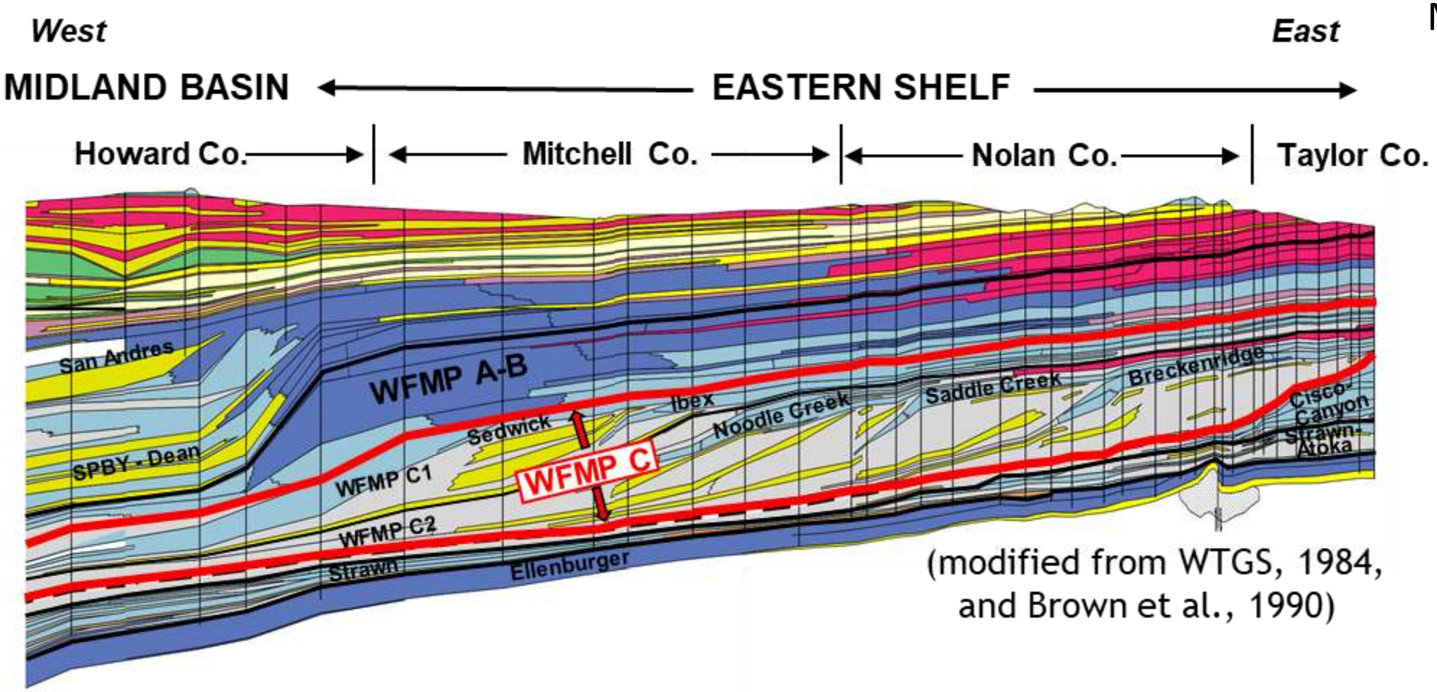
Wolfcamp D: Basinal cyclothems (starved basin)

Lower Strawn: shallow-water platform limestones

Wolfcamp C

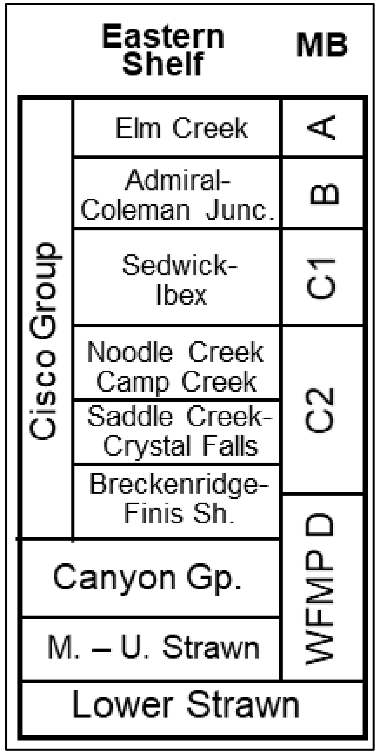


(Sinclair et al., 2018)



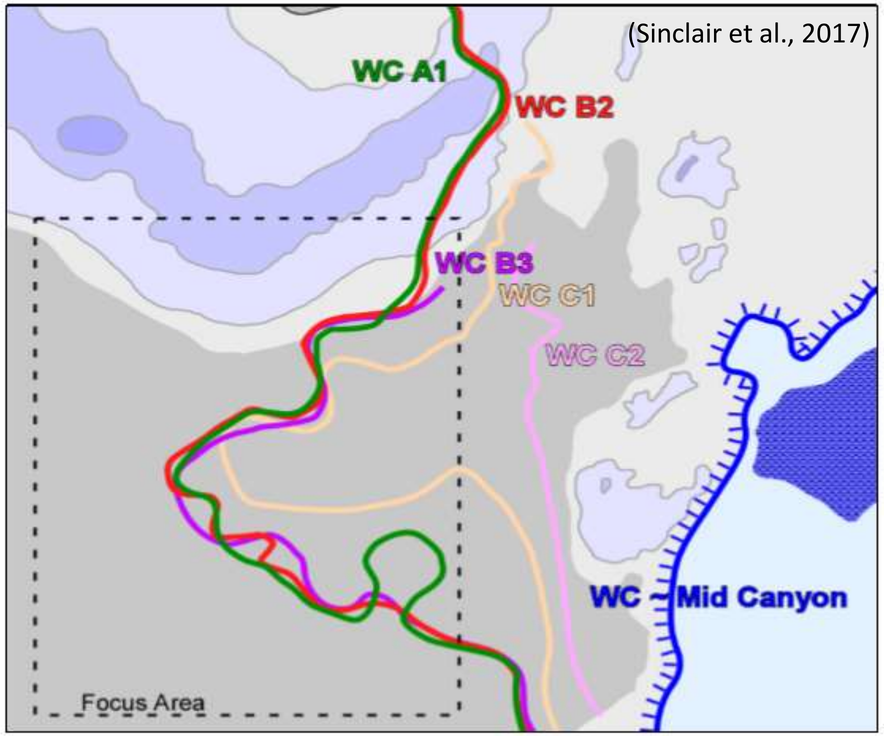
(modified from WTGS, 1984, and Brown et al., 1990)

Preliminary correlation of MB tops to Eastern Shelf

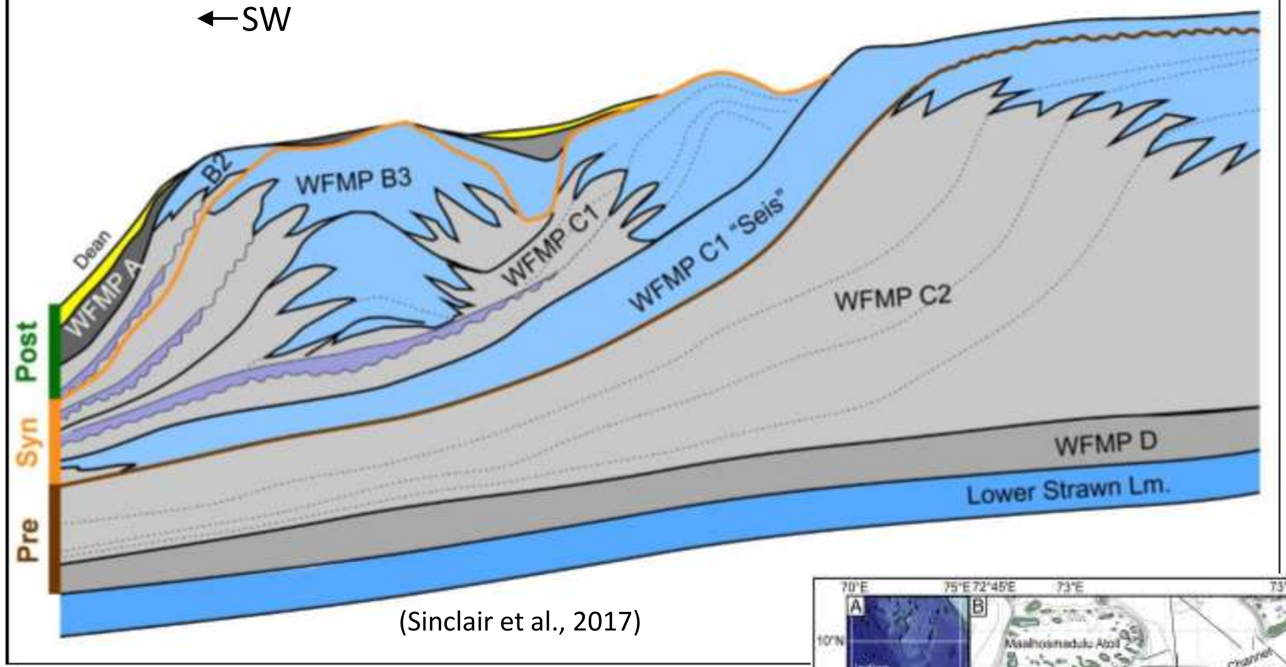


- Westward progradation of Eastern Shelf delta systems and platform margins (100 -150 km)
- C2 basinal shales are largely clay-rich, organic-poor
- Initial development of Glasscock Nose during WFMP C1 time
- Uplift of CBP structural blocks and development of mid-Wolfcamp unconformity

Sequential development of the Glasscock Nose



prograding, mounded deep-water carb. flows



Marine Geology 401 (2018) 98–111

Contents lists available at ScienceDirect

Marine Geology

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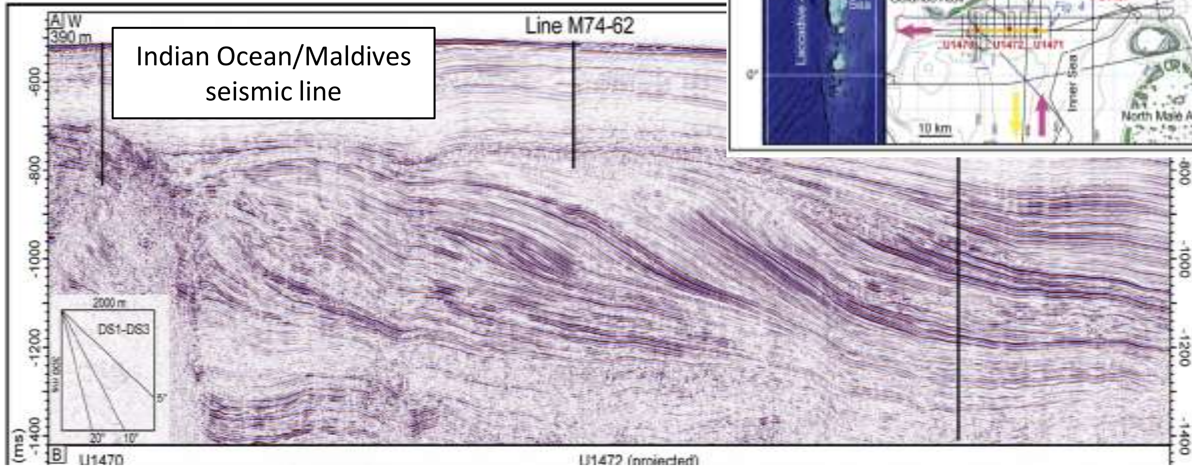
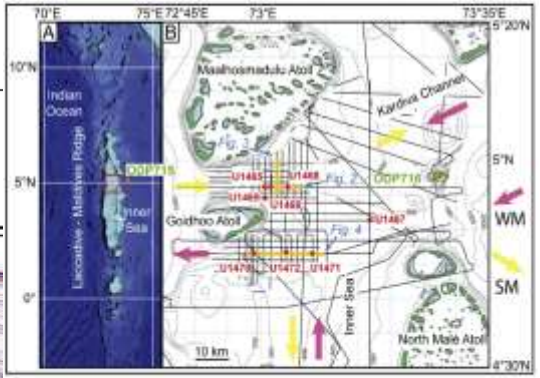
Carbonate delta drift: A new sediment drift type

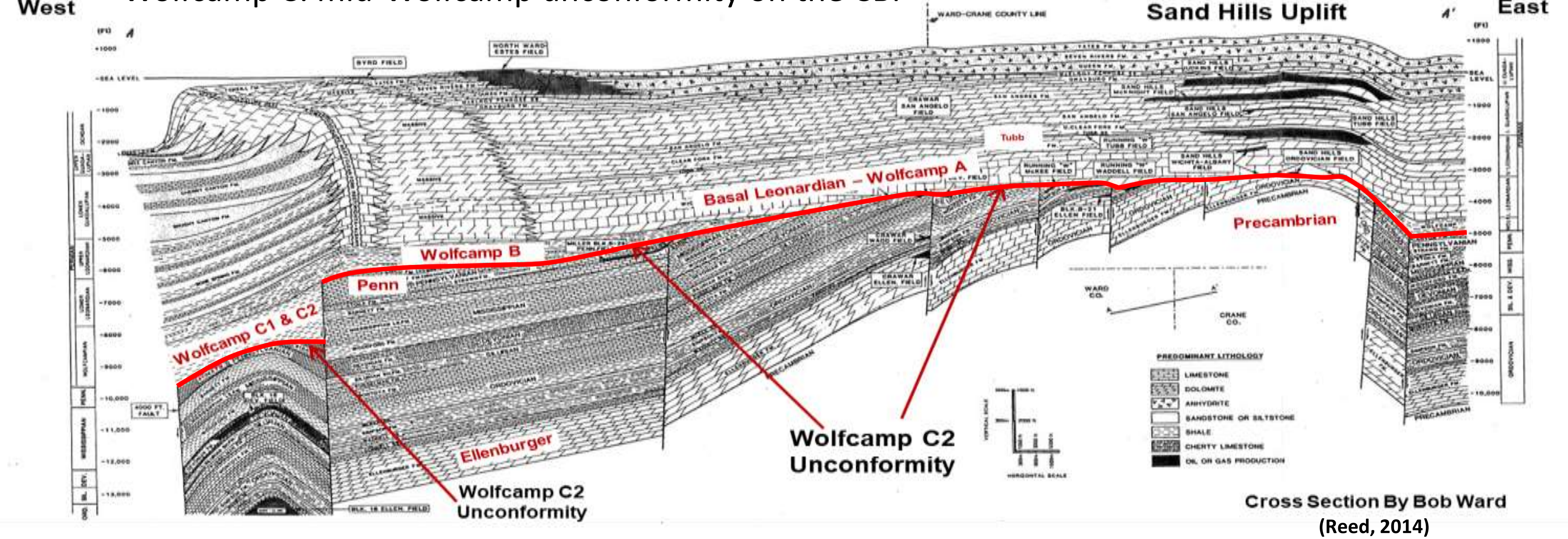
Thomas Lüdmann[a,*], Christian Betzler[a], Gregor P. Eberli[b], Jesús Reolid[a], John J.G. Reijmer[c], Craig R. Sloss[d], Or M. Bialik[e], Carlos A. Alvarez-Zarikian[f], Montserrat Alonso-García[g,h], Clara L. Blättler[i], Junhua Adam Guo[j], Sébastien Haffen[k], Senay Horozal[l], Mayuri Inoue[m], Luigi 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]

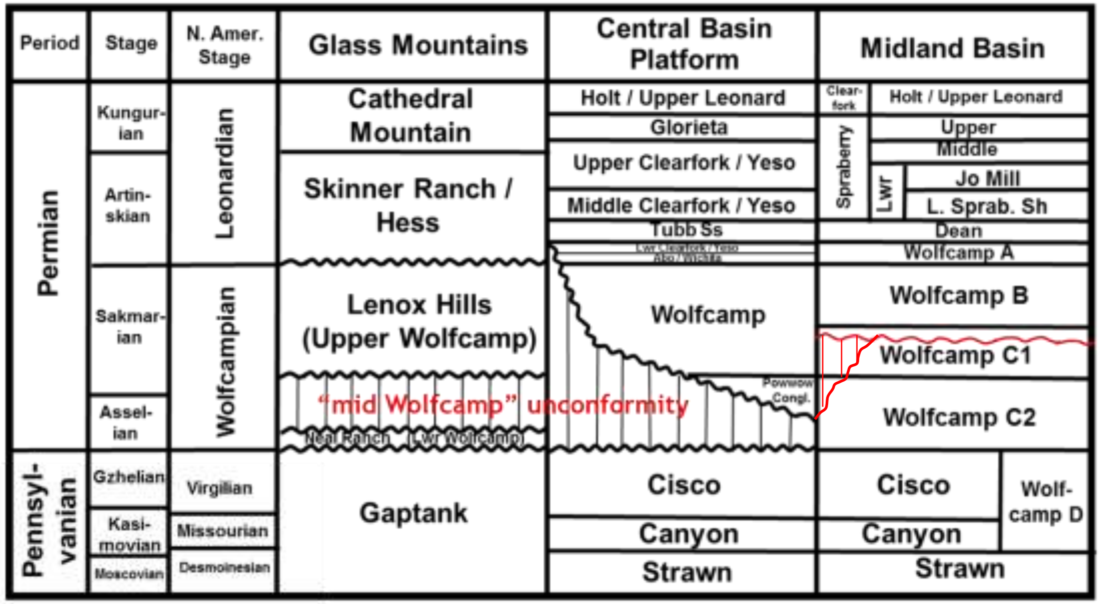
Possible analog: carbonate delta drift





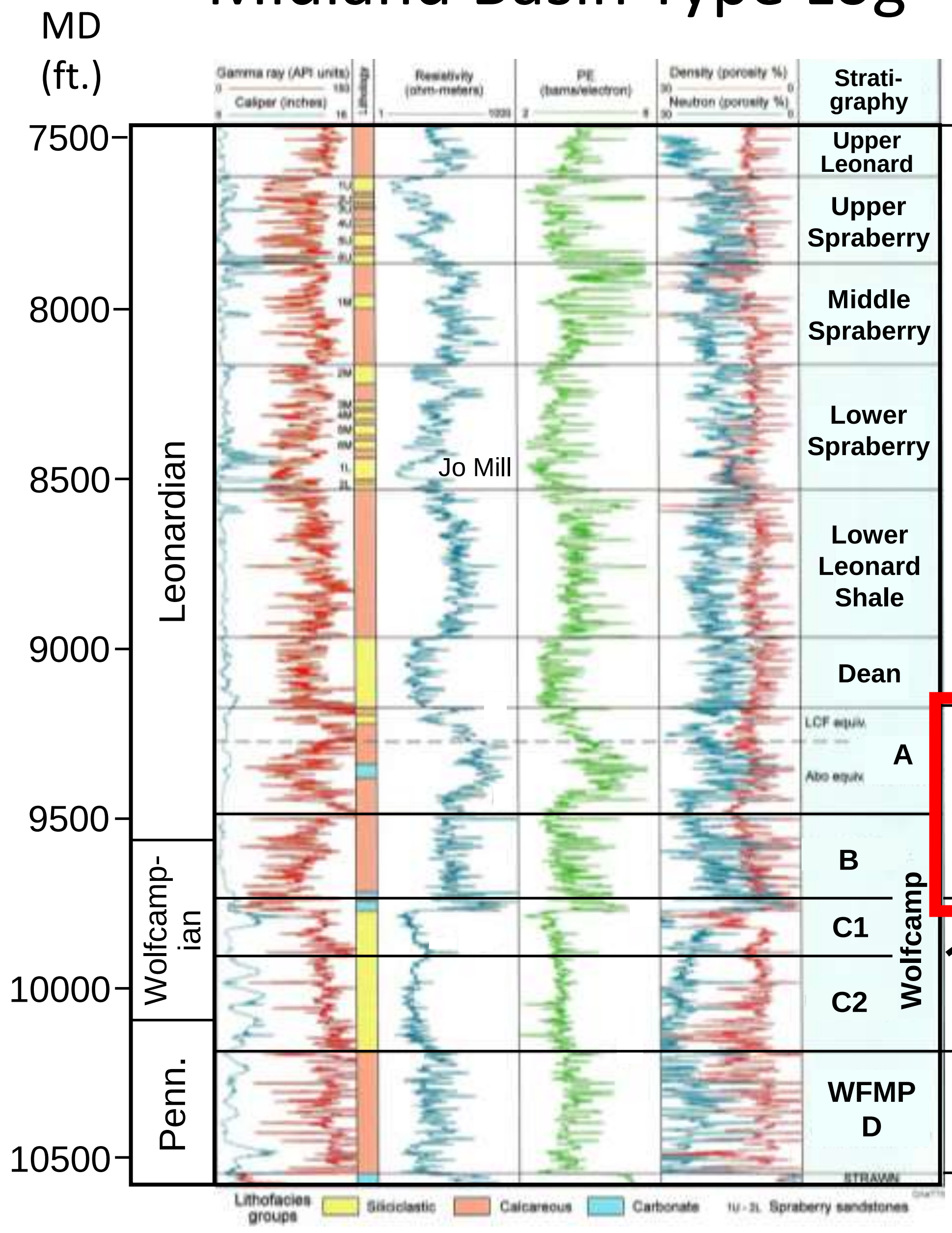
Wolfcamp C: mid-Wolfcamp unconformity on the CBP





- last major tectonic pulse prior to middle – late Permian subsidence phase
- note diachronous nature of unconformity across Permian Basin region
- Center of Midland Basin: angular unconf. identified on regional 3D seismic

Midland Basin Type Log



(modified from Hamlin and Baumgardner, 2012)

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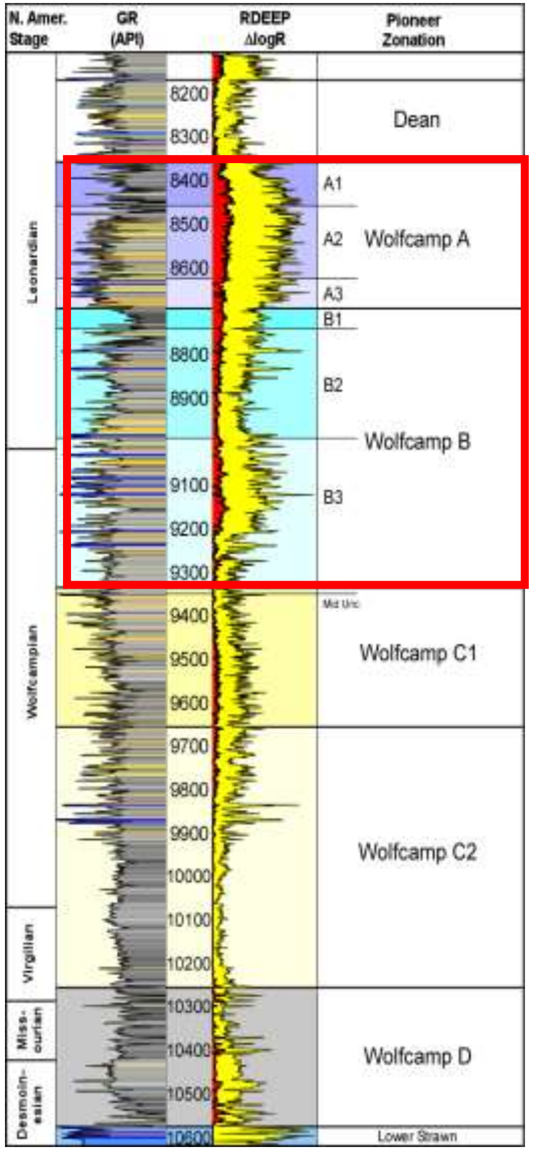
Wolfcamp D: Basinal cyclothems (starved basin)

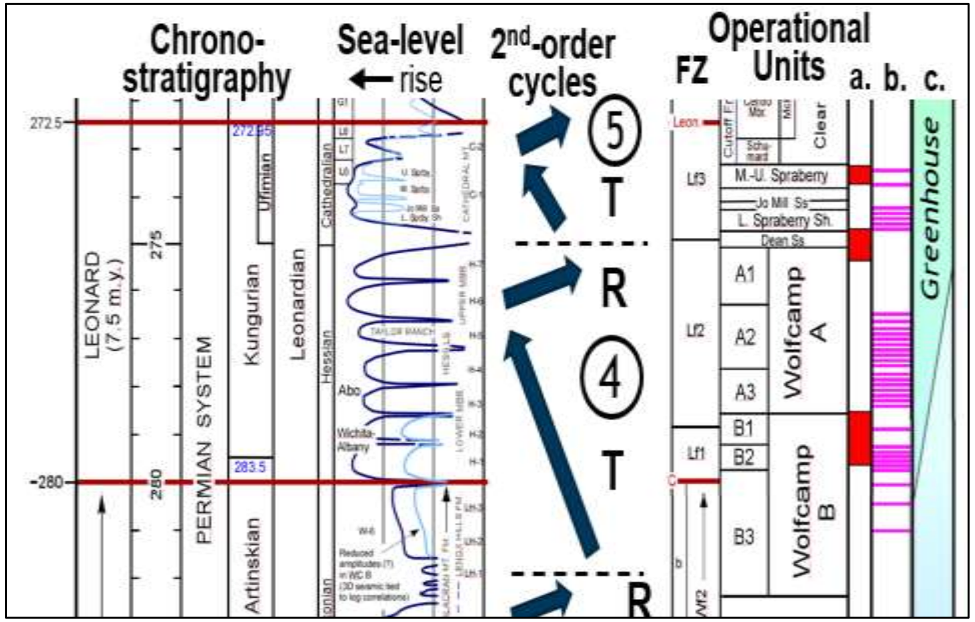
Lower Strawn: shallow-water platform limestones

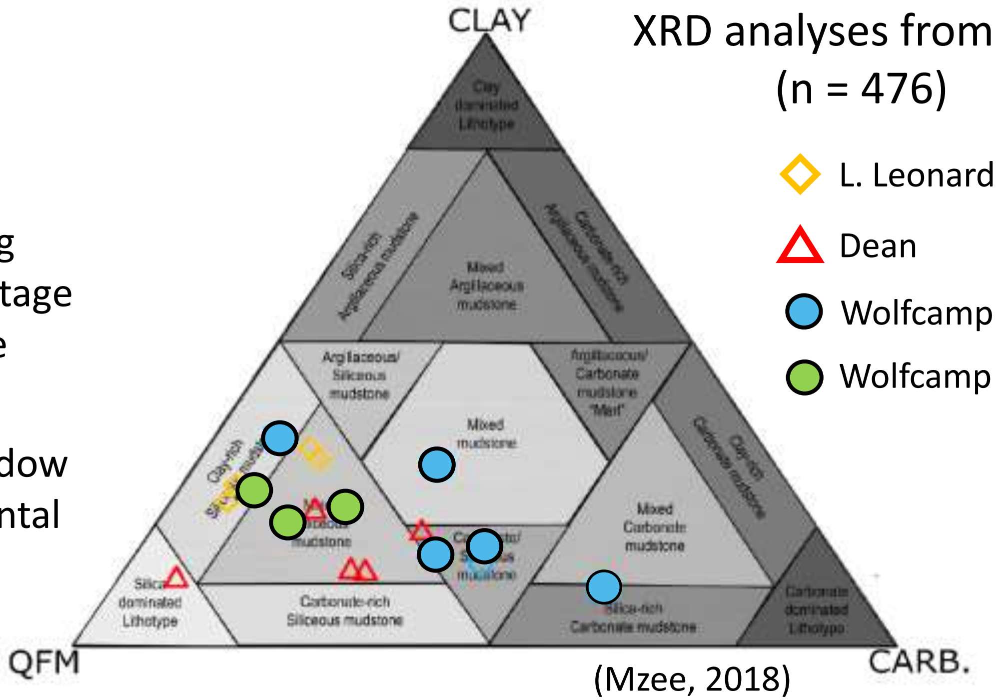
Wolfcamp A - B



(Sinclair et al., 2018)

- 700+ ft. of organic-rich, silica- and calcareous-rich mudstone punctuated by numerous density flows (carb. turbidites and carb. 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

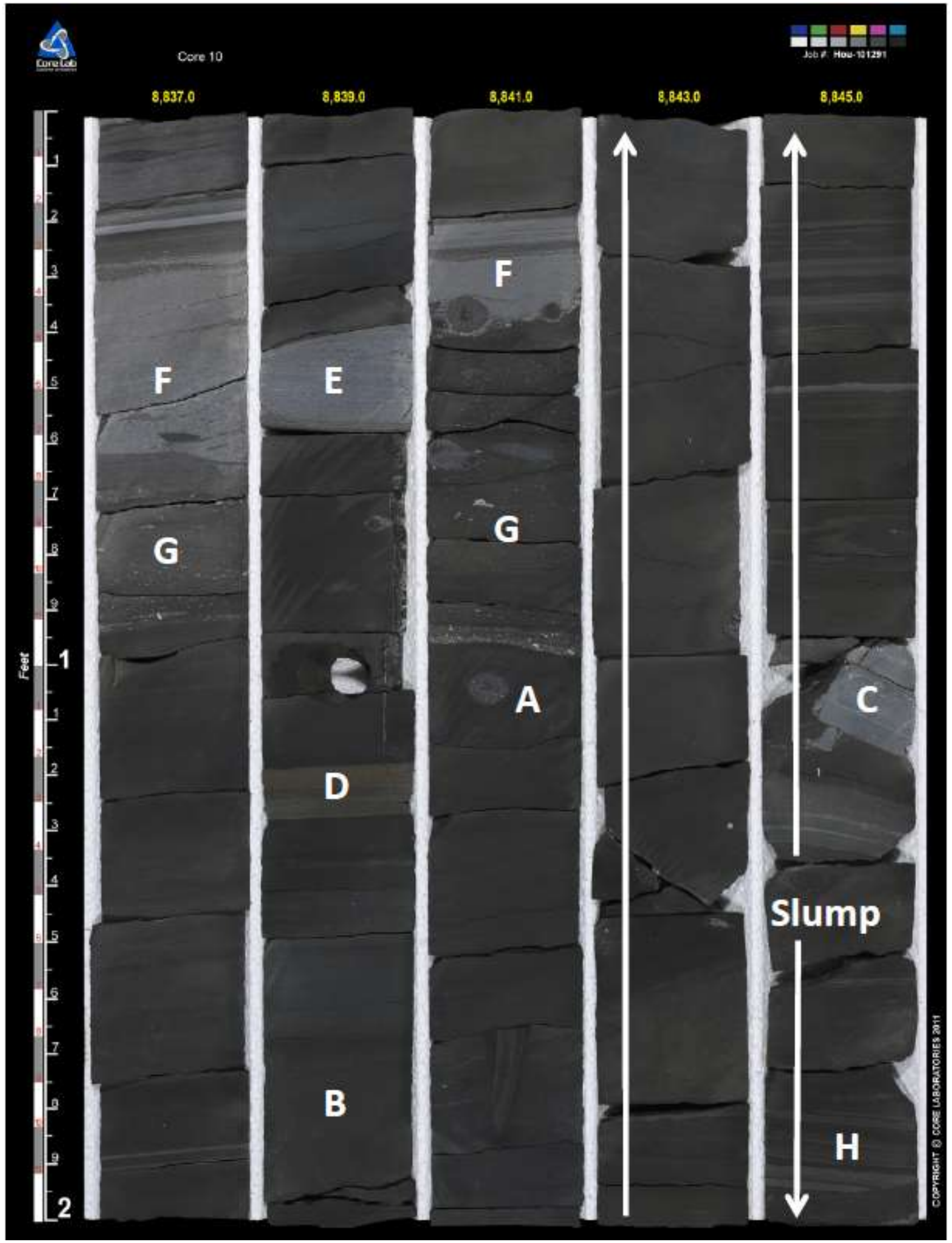




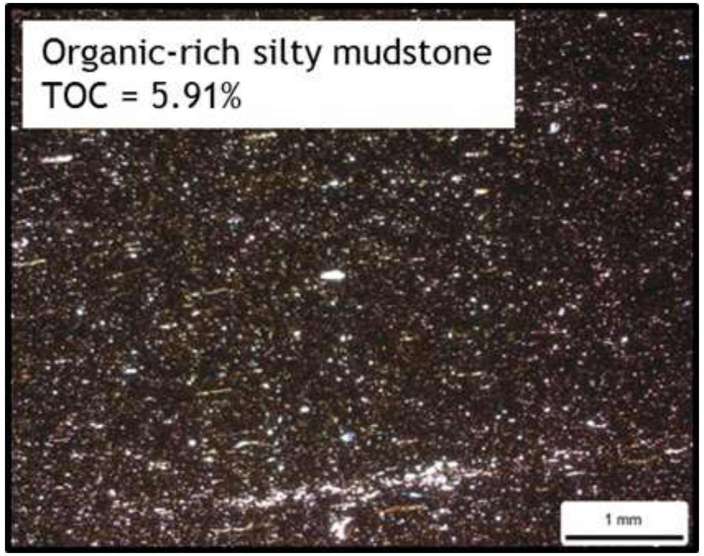
XRD analyses from core (n = 476)

- L. Leonard Shale
- Dean
- Wolfcamp A
- Wolfcamp B

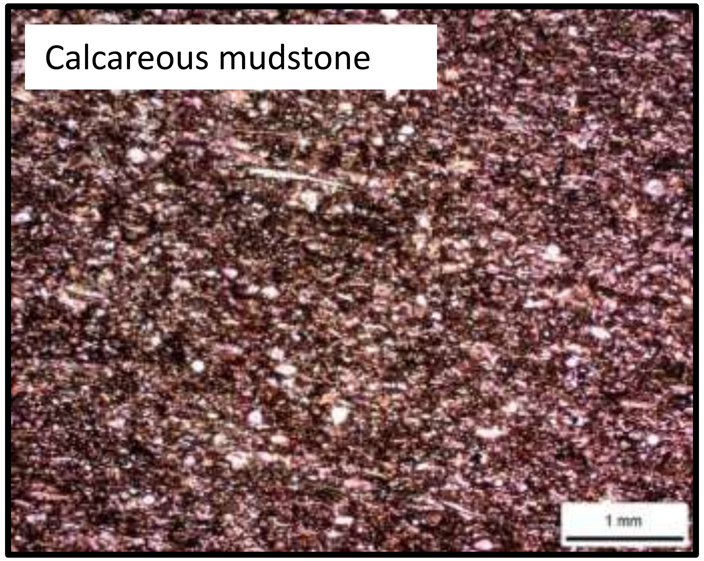
(Mzee, 2018)



Wolfcamp B2

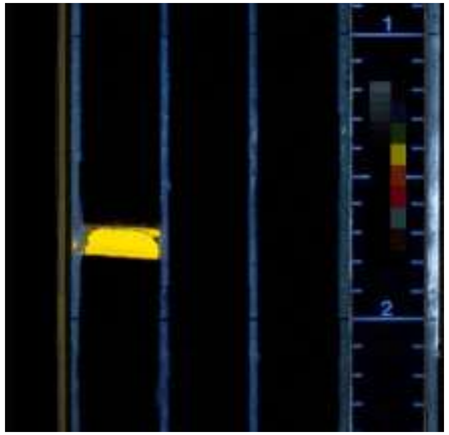


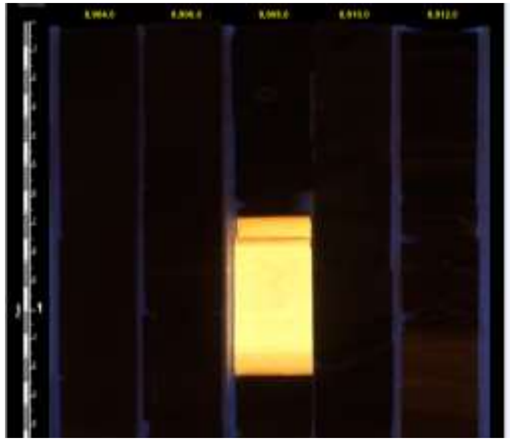
Wolfcamp A3



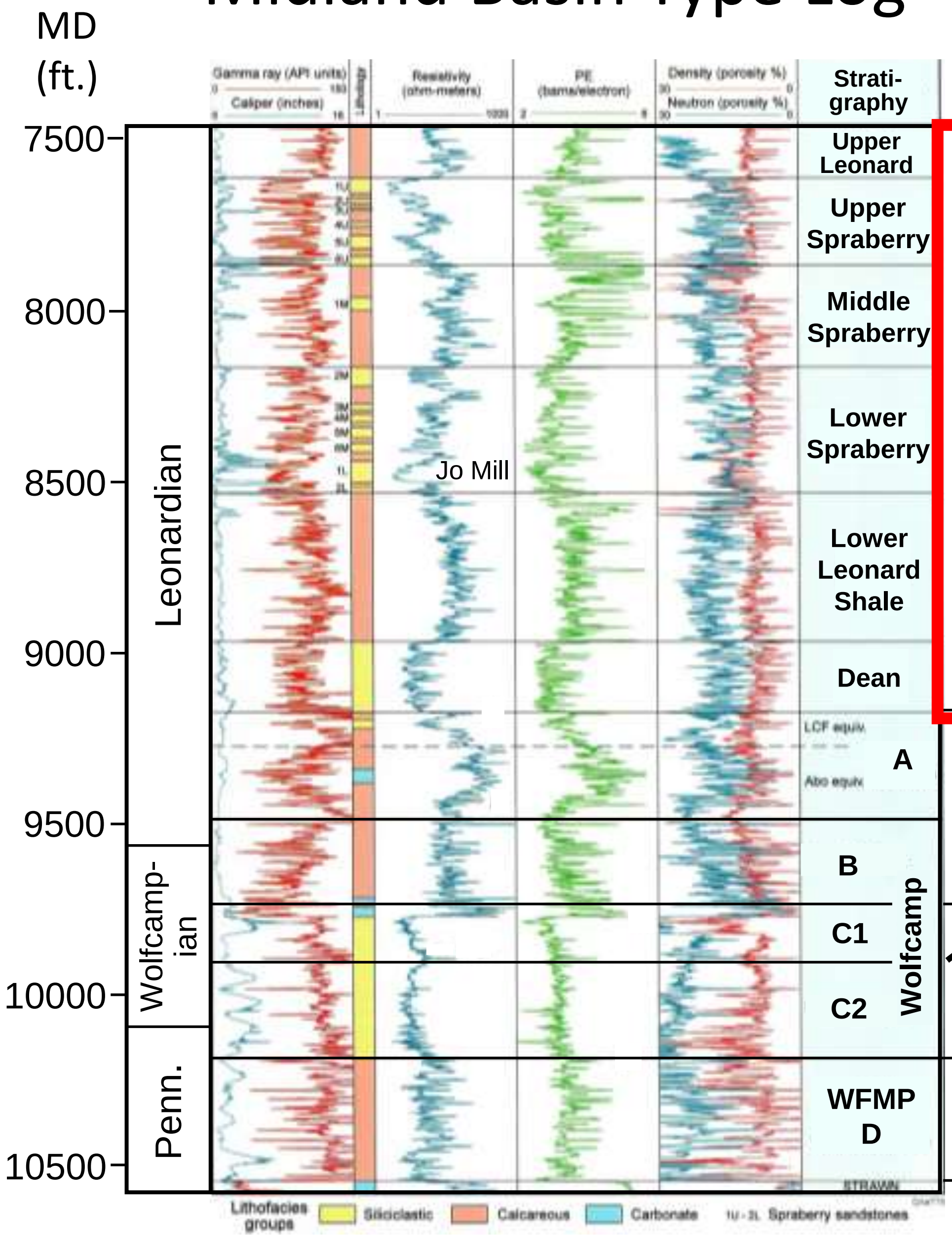
Photograph of core, **Wolfcamp B2**, depth 8837-8847 feet. (A) Structureless silty mudstone with phosphatic concretion. (B) Calcareous silty mudstone. (C) Carbonate lithoclast. (D) Ash bed. (E) Carbonate concretion. (F) Skeletal grainstone with erosive base and reworked concretions. (G) Thin, muddy debrite with deformed mudclast. (H) Sheared and rotated package of thin beds at the bottom of a slumped interval, 8847-8843 ft. (Murphy, 2105)

Ash beds in UV light; initiation of volcanic arc in Wolfcamp B time





Midland Basin Type Log



(modified from Hamlin and Baumgardner, 2012)

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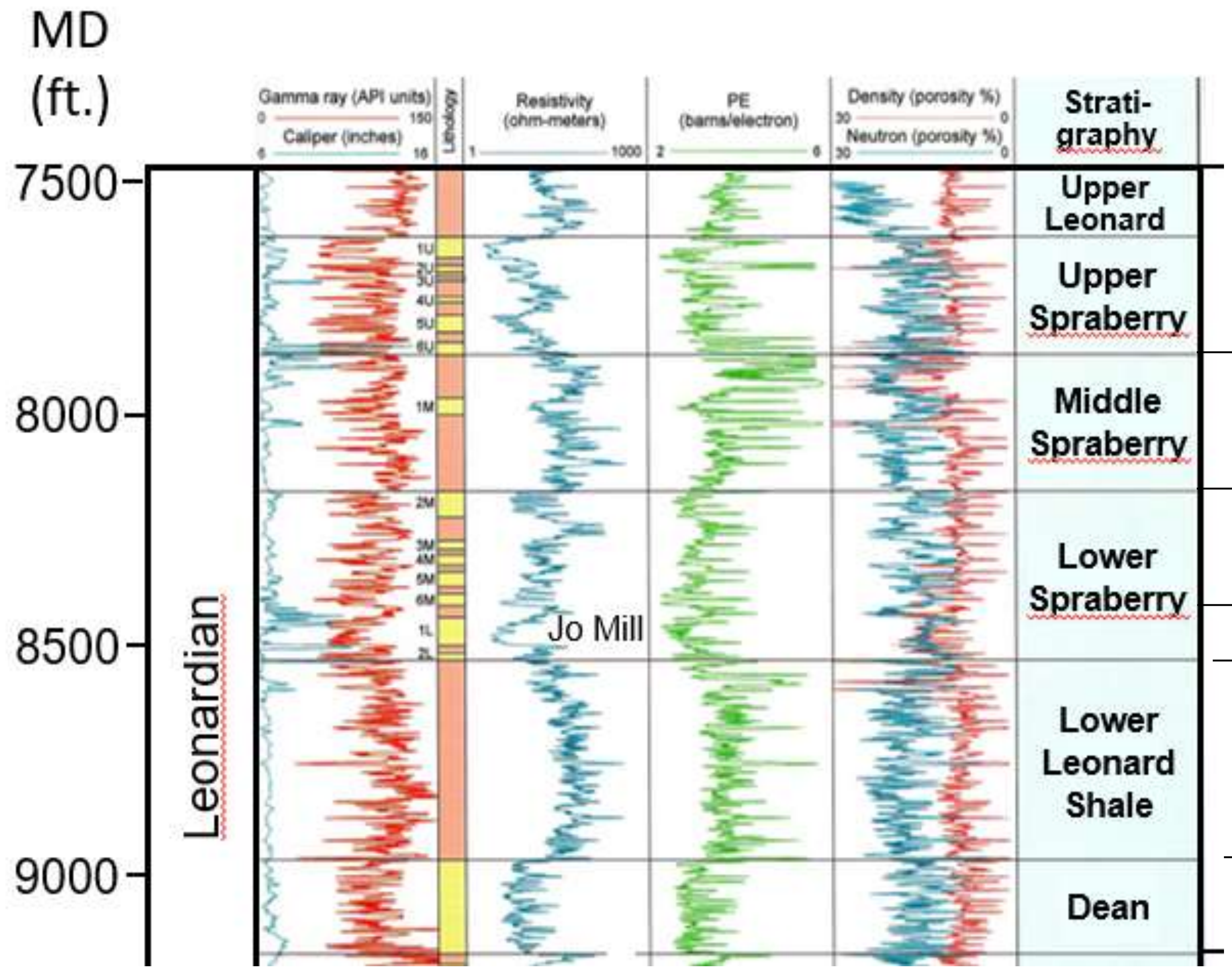
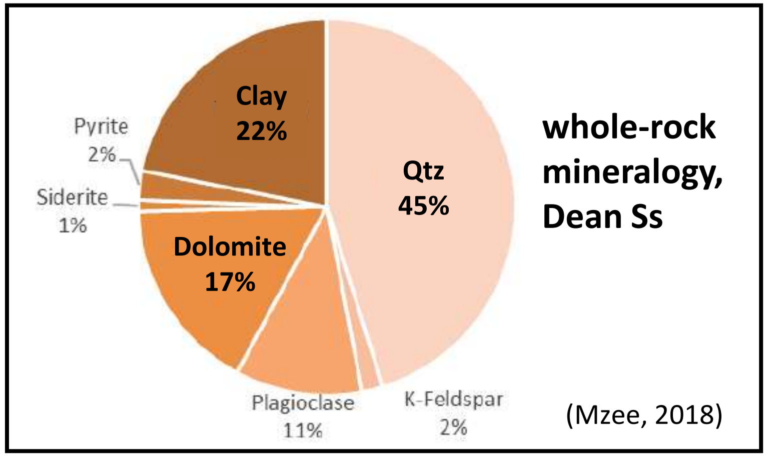
Wolfcamp C: Clay-rich shale (progradation of Eastern Shelf deltas & Glasscock Nose)

Wolfcamp D: Basinal cyclothems (starved basin)

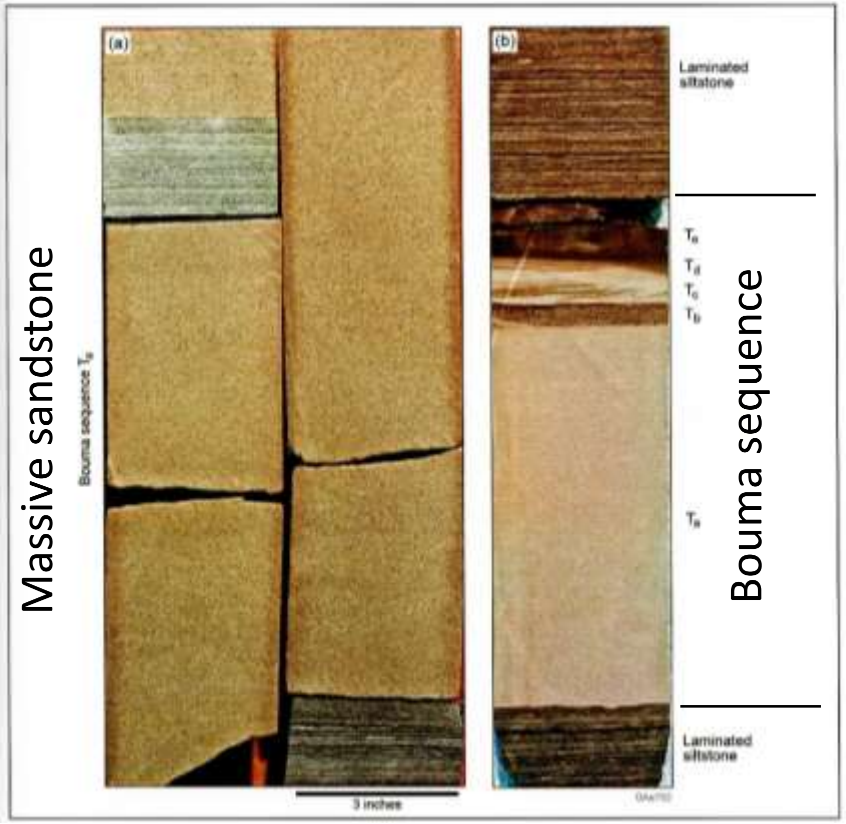
Lower Strawn: shallow-water platform limestones

Dean – Spraberry units of the Midland Basin

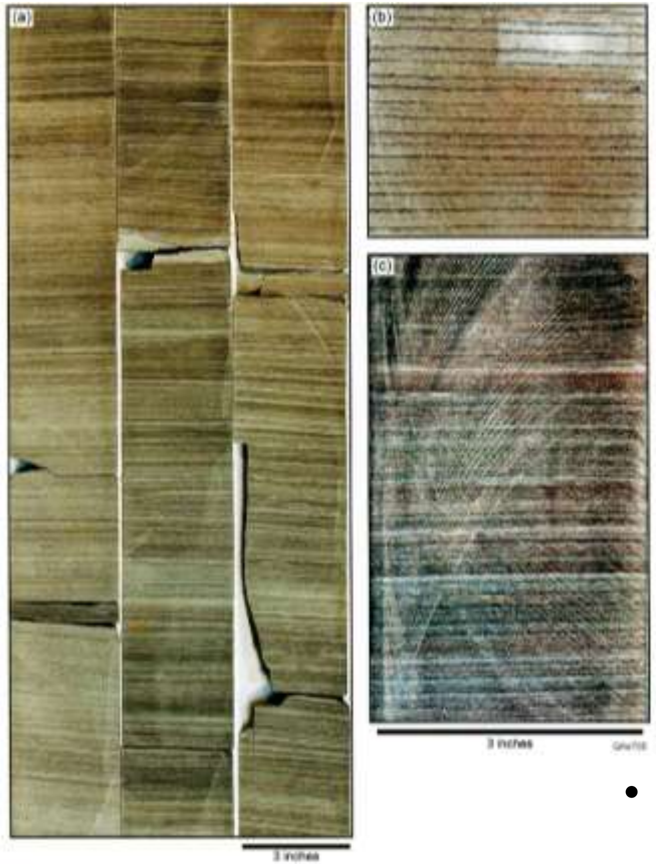




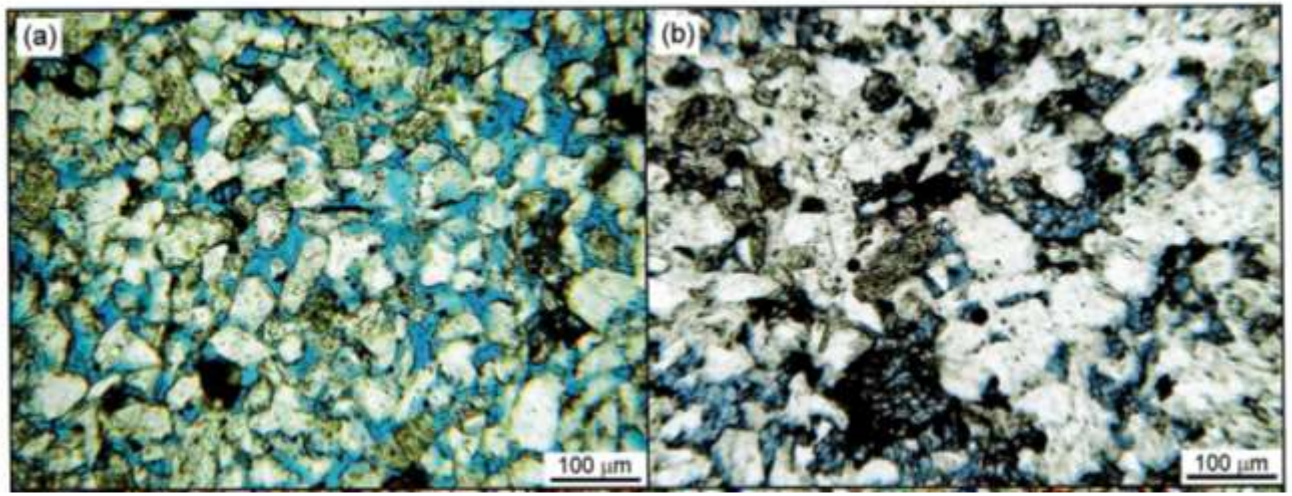
U. Spraberry	• 2 major submarine fan complexes (Floyd and Driver fans) • Equivalent to 1st Bone Spring Ss
M. Spraberry	• silty, shales; minor fan complex
L. Spraberry	• siliceous shales, minor fans
Jo Mill	• 2nd major incursion of submarine fans • Equivalent to 2nd Bone Spring Ss
Lower Leonard Sh.	• organic-rich siliceous mudrocks similar to Wolfcamp A-B
Dean	• 1st major incursion of submarine fans • Equivalent to 3rd Bone Spring Ss



(Hamlin and Baumgardner, 2012)



Laminated siltstones



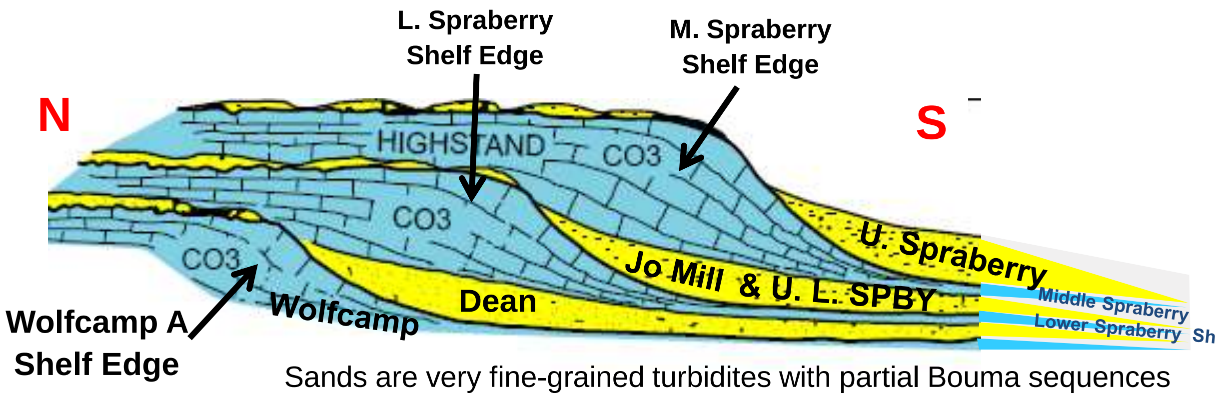
(a) Porous and permeable sandstone

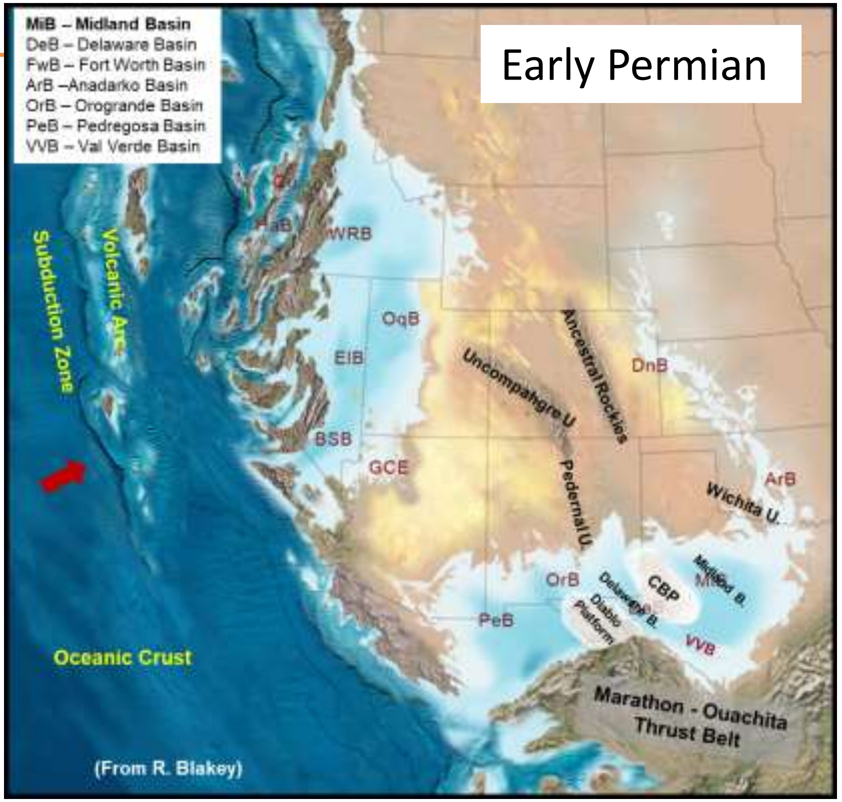
(b) Sandstone cemented w/ ferroan dolomite

- 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)
- Depositional model ?
- Provenance? (north vs. south)

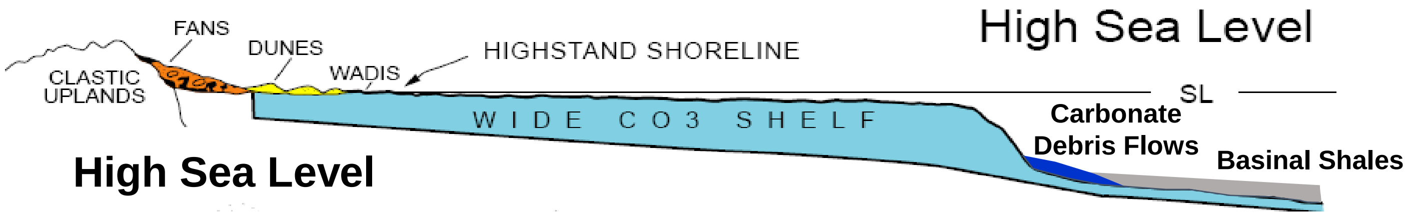
Spraberry & Dean (Bone Spring) Depositional Model (based on Hanford, 1981)

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

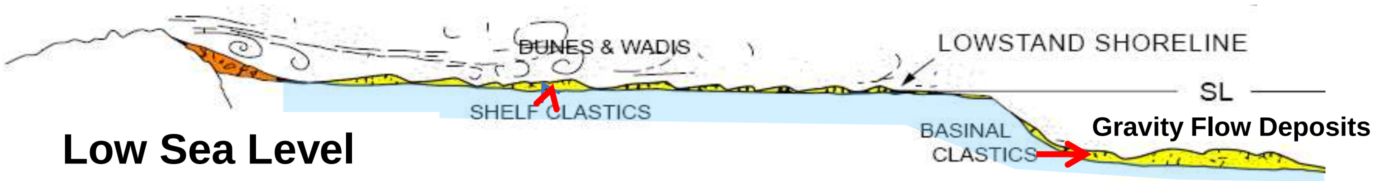




Sands are very fine-grained turbidites with partial Bouma sequences
Organic-rich shales highly laminated and not bioturbated; Organic-poor shales bioturbated
Thin dolomitic hard grounds observed in sands and shales

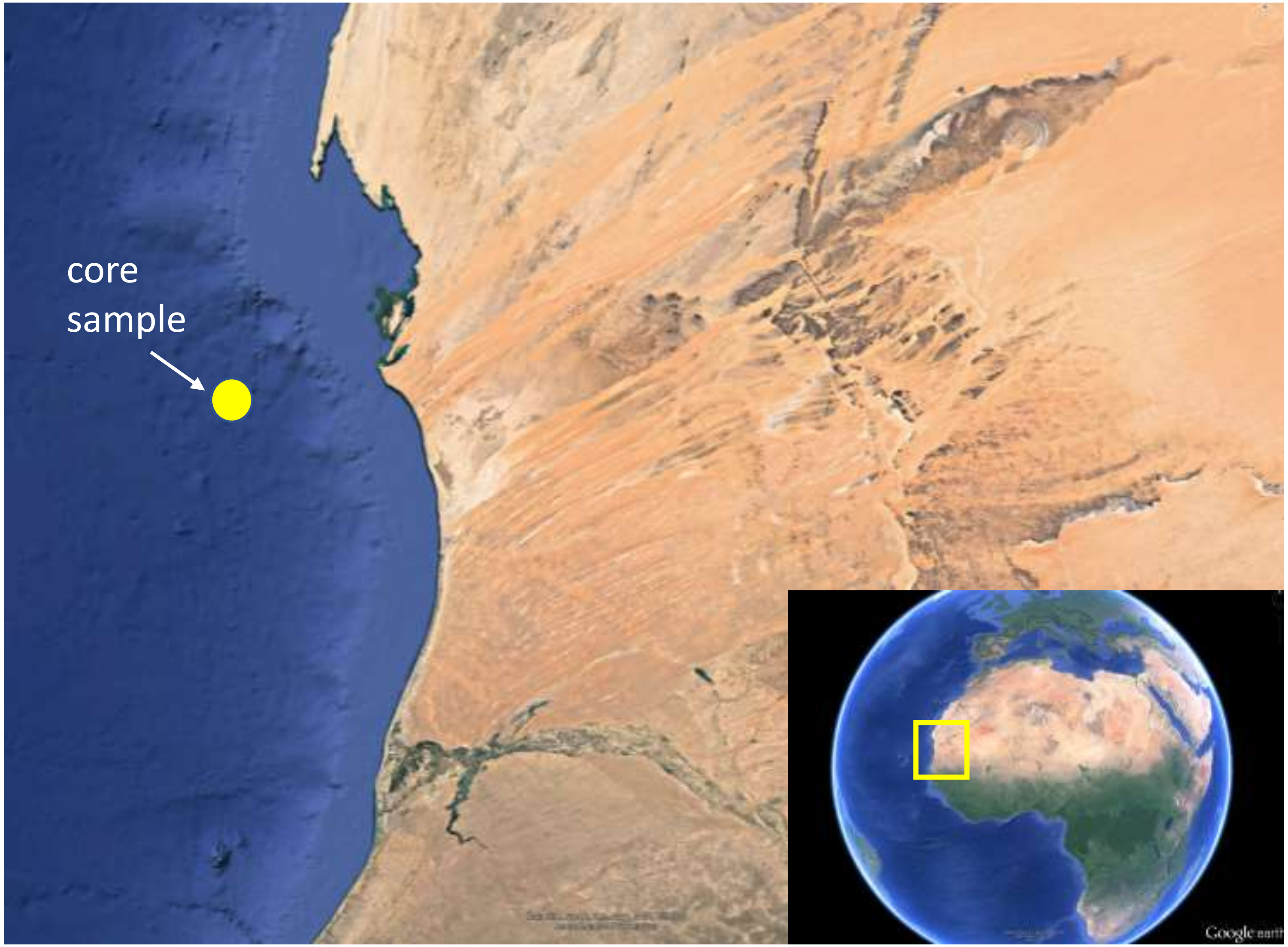


Highstand –
- Shelf submerged
- Carbonates on shelf
- Carbonate gravity flow deposits and organic-rich shales in basin

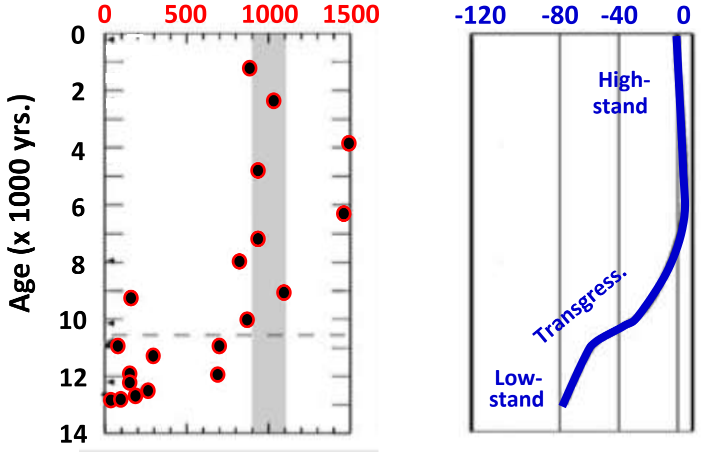


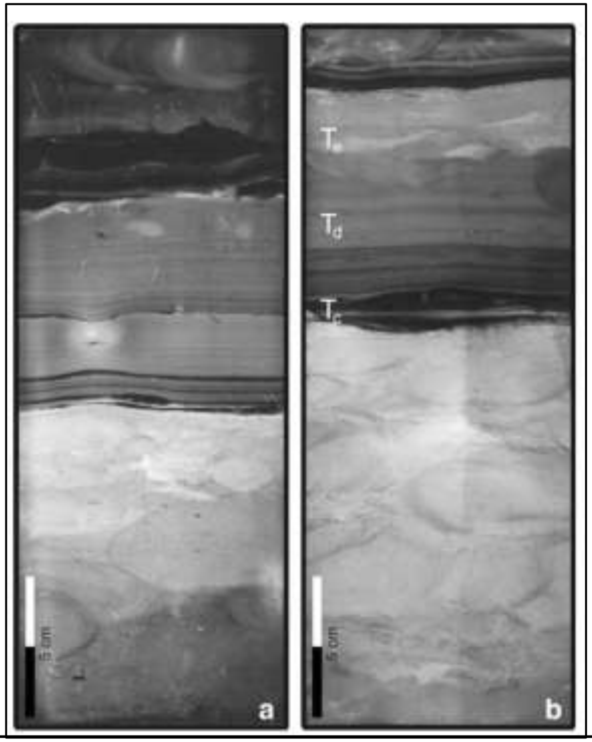
Lowstand and ensuing transgression–
- Shelf exposed
- Clastics move across shelf via wind and in wadis
- Clastic gravity flow deposits bypass shelf during lowstand and are cannabalized during early transgression

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



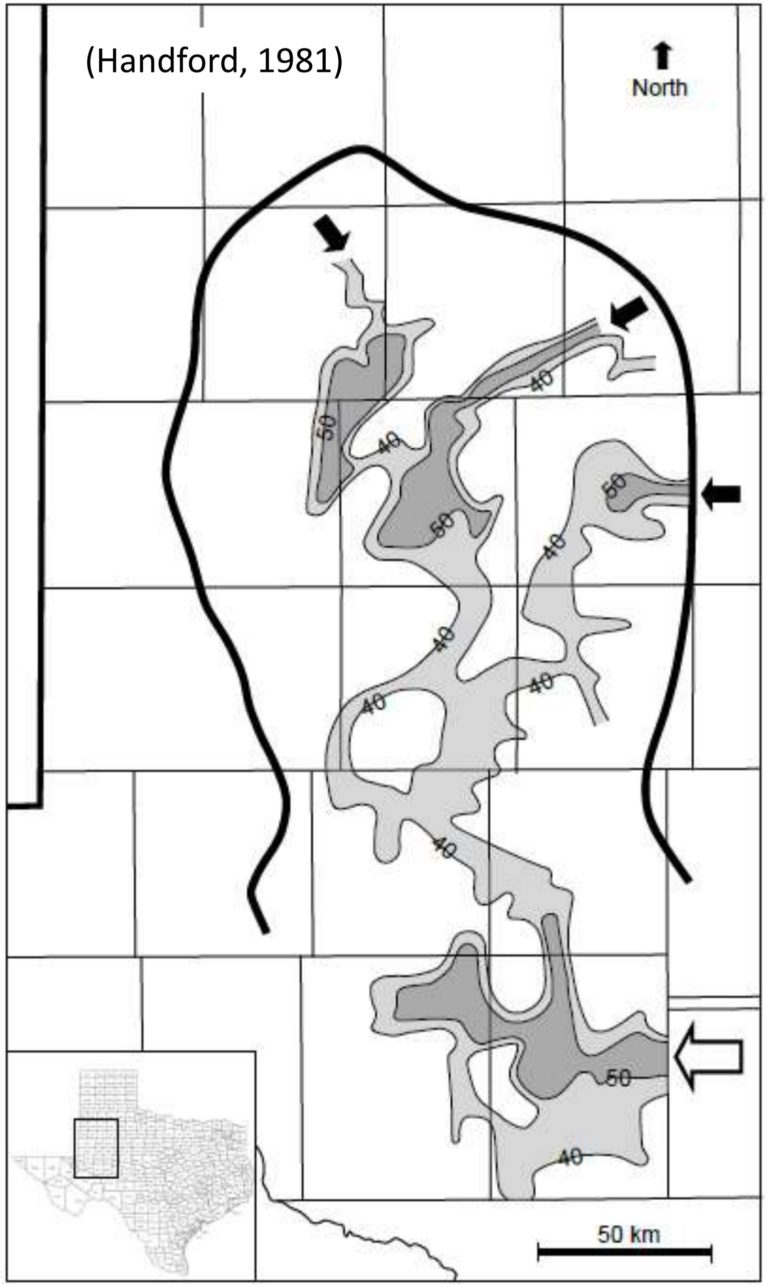
Core data (Zuhlsdorff et al., 2008)

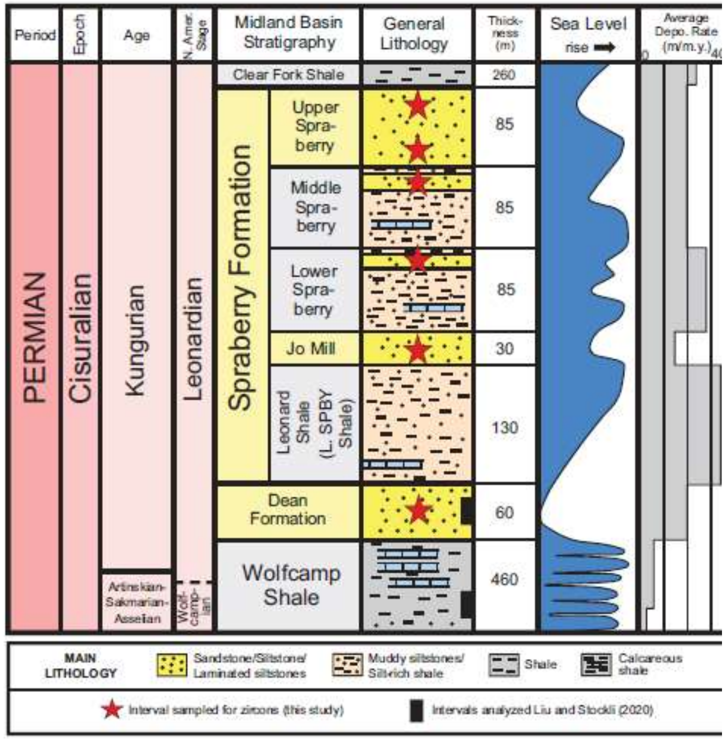


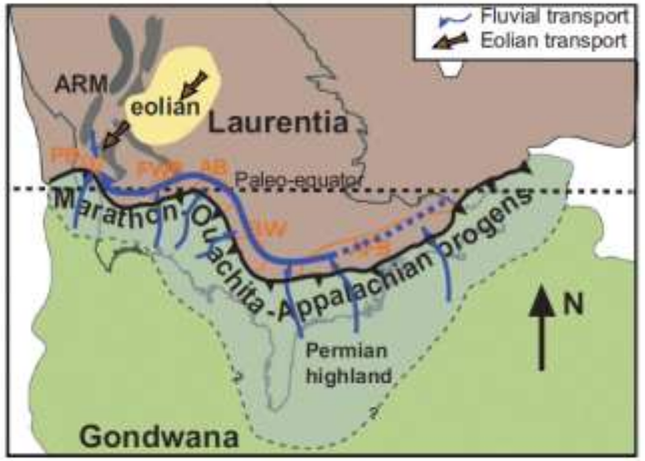


Spraberry

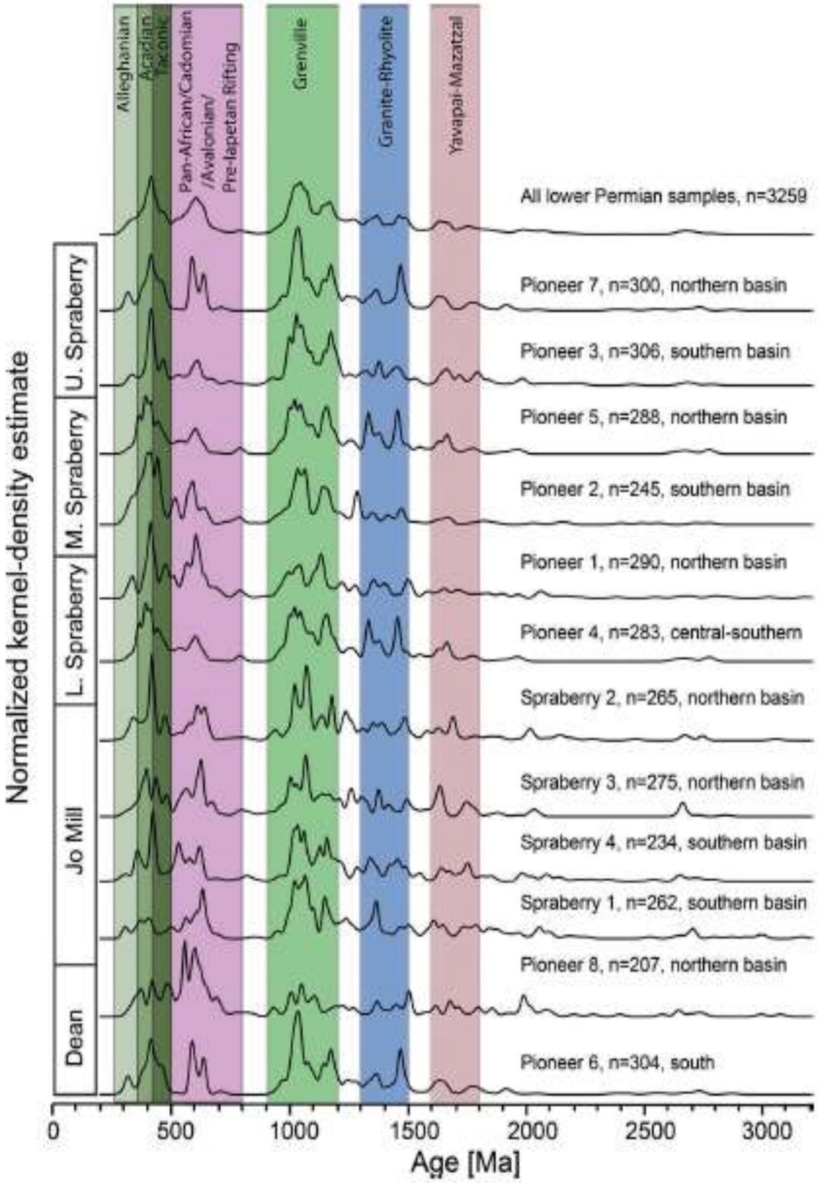
Sediment provenance of the Dean - Spraberry







Detrital zircon ages

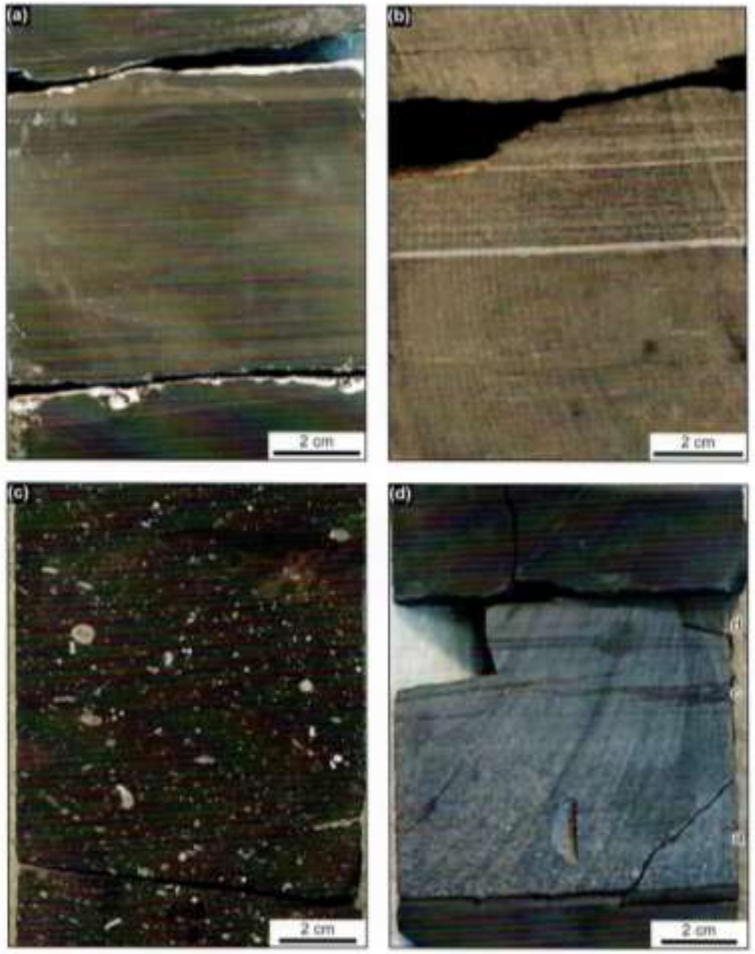


(Waite et al., 2020)

Summary and Conclusions

"Not all shales are created equal"

- 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; organics partitioned into thin, isolated intervals
  - Wolfcamp C: lower portion (C2) consists of clay-rich shales; increasing organics in C1; Glasscock Nose and mid-WC unconformity
  - Wolfcamp A - B: Thick, organic-rich, calcareous silty mudrocks; carbonate % increases upward; zone currently resides in peak oil window in Midland Basin
  - Dean - Spraberry: Argillaceous mudstones, punctuated by numerous submarine-fan complexes (massive & laminated sandstones)
- Complexity of these rocks reflects dynamic/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 uniqueness and complexity of each unit / horizontal target zone

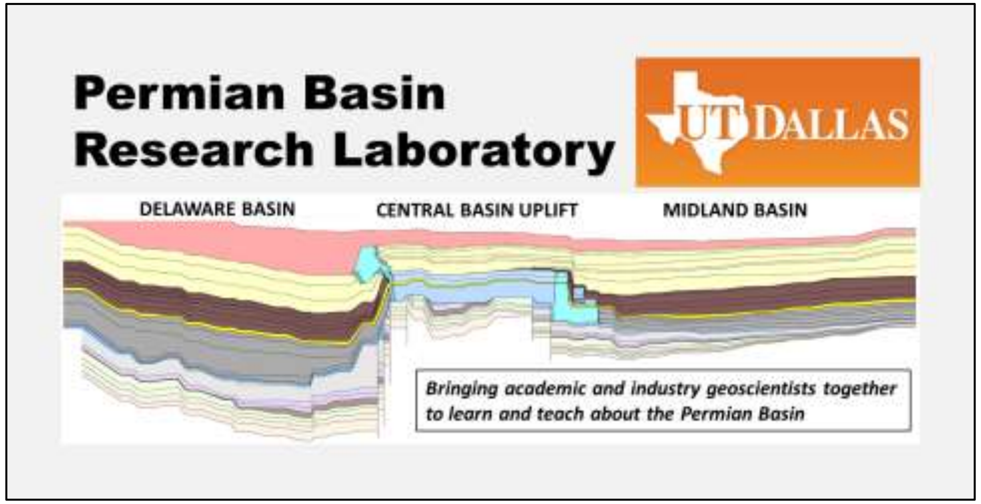


(Hamlin and Baumgardner, 2012)

Permian Basin Research Lab at UT Dallas

Dr. Robert J. Stern and Mr. Lowell Waite, Co-Directors

-- established January 2019 --



Goals:

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

- Educate and provide skills to students interested in careers in industry (experience w/ subsurface data sets)
  - Graduate courses offered:
    - Geology of the Permian Basin
    - Petroleum Geoscience
    - Paleo Earth Systems: Global Themes
    - Carbonate Sedimentology
    - Clastic Sedimentology/Sequence strat (Dr. Harper)

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