Stratigraphic Framework of the Wolfcamp – Spraberry of the Midland Basin

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Lowell Waite
Department of Geosciences
Permian Basin Research Lab
University of Texas at Dallas
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, 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*
• Confluence of Marathon-Ouachita fold and thrust belt and Ancestral Rockies basement-involved uplifts (Penn. – early Permian)
## Permain Basin Stratigraphy and Tectonic History

### System
- **Permian**
  - **Series**
    - Ochoan
    - Guadalupian
    - Leonardian
- **Pennsylvanian**
- **Mississippian**
- **Devonian**
- **Silurian**
- **Ordovician**
- **Cambrian**
- **Precambrian**

### Series and Formations
- **Delaware Basin Formations**
- **CBP & NW Shelf Formations**
- **Midland Basin Formations**

### Tectonic Phase
- **Post Orogenic Loading**
  - Rapid Subsidence;
  - Onset of HC Generation
  - (~ 50 million yrs. duration)

### Active Margin
- **Permian Basin Phase**
  - **Penn. – Early Permian Foreland Deformation**
  - **Tobosa Basin**
  - **(Middle Ordovician to Late Mississippian)**
  - **Moderate Subsidence**
  - (~ 150 million yrs. duration)

### Passive Margin
- **TOBOSA BASIN PHASE**
  - **Great American Carbonate Bank**
  - (Late Cambrian – Early Ordovician)
  - **Basement assembly and breakup of Rodinia supercontinent**
  - **Grenville Orogeny (~ 1.3 to 1.0 bya)**

### Time Scale
- **Ma**
  - 541
  - 485
  - 444
  - 419
  - 359
  - 323
  - 299
  - 252

(modified from Reed, unpub., 2016)
The Permian Basin

The Permian Basin is a large sedimentary basin located in the southwestern United States, covering parts of New Mexico, Texas, Oklahoma, and Kansas. It is one of the most important oil and natural gas producing areas in the United States, with significant deposits of Permian Basin rock formations, such as the Wolfcamp formation, which is a major source of hydrocarbons in the region.

The Permian Basin is characterized by a series of sedimentary basins and uplifted areas, including the Midland Basin, Delaware Basin, and Guadalupe Mountains. The basin is divided into several geologic provinces, each with its own unique geologic history and hydrocarbon potential.

The basin is also known for its rich paleontology, with numerous fossil sites and findings of dinosaurs, plants, and other ancient life forms.

The Permian Basin is an active area of geologic research and development, with ongoing exploration and production activities aimed at tapping into the basin's immense hydrocarbon resources.

(Courtesy of Mark George, PXD)
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)

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)
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**

**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

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

**Wolfcamp D:** Basinal cyclothems (starved basin)

**Lower Strawn:** shallow-water platform limestones

(modified from Hamlin and Baumgardner, 2012)
Lower Strawn Limestone and Wolfcamp D (Cline)
### Mid Continent / Anadarko Basin

<table>
<thead>
<tr>
<th>System</th>
<th>Series</th>
<th>Lithostratigraphic Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permian</td>
<td>Guadalupian</td>
<td>Whitehorse Group, El Reno Group</td>
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<tr>
<td></td>
<td>Leonardian</td>
<td>Summer Group, Enid Group, Hamnssey Group</td>
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<tr>
<td></td>
<td>Wolfcampian</td>
<td>Ghose Group, Council Grove Group, Admoer Group, Pontotoc Group</td>
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<td></td>
<td>Virgilian</td>
<td>Wabansiae Group, Shawnee Group, Atia Group</td>
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<td>Missourian</td>
<td>Kansas City Group, Hugser Group</td>
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<tr>
<td></td>
<td>Desmoinesian</td>
<td>Marmaton Group, Cherokee Group, Deesey Group</td>
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<td></td>
<td>Atonkan</td>
<td>Atoka Group, Formations, Springer Formations, Chester Group, Mayes Group</td>
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<tr>
<td></td>
<td>Morrowan</td>
<td>Osage Group, Osage Limestone</td>
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<tr>
<td></td>
<td>Mississippian</td>
<td>Kindershoek Group, Kinderhook Shale, Woodford Shale</td>
</tr>
<tr>
<td></td>
<td>Desmoinesian</td>
<td>Chautauquan, Mississippian, Lenêe sand, Hunton Group</td>
</tr>
<tr>
<td></td>
<td>Pennsylvanian</td>
<td>Cuygian, Niagra Group, Alexandrian, Sylvan Limestone, Maquoketa Shale, Viola Group, Formations, Spear Group, Arbuckle Group, Reagan Sandstone</td>
</tr>
<tr>
<td></td>
<td>Cambrian</td>
<td>Trampkealeuran, Fransonian</td>
</tr>
</tbody>
</table>

### AAPG COSUNA chart (1985)

#### Midland Basin Fusulinid zonation

- **Wolfcampian**
  - Wolfcamp Formation
  - Admiral Fm.
  - Putnam Fm.
  - Moran Fm.
  - Pueblo Fm.
- **Missourian**
  - Cisco – Canyon Group
  - Cisco Fm.
  - Canyon Fm.
- **Desmoinesian**
  - Strawn Group
  - Strawn Fm.
  - Scully Reef
  - Bend Fm.

- **Pennsylvanian**
  - Atoka Group
  - Bend Fm.
  - Lower Cherokee
  - Upper Cherokee
  - Marmaton
  - Early Late Strawn
  - Middle Late Strawn
  - Late Late Strawn
- **Mississippian**
  - Barnett Shale
  - Mississippian Limestone
  - Mississippian Limestone

(Gianoutsos et al, USGS, 2014)

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)

- 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

(Wright, 2011)
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 cyclothsems

- Equivalent to classic “Penn. cyclothsems” 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

![Diagram of Wolfcamp D with GR and Resistivity logs](image)

- High gamma ray “hot” zone: non-porous, thin dolomite or LS
- Low gamma ray “spike”: organic-rich, silica-rich shale
- High gamma ray “hot” zone: clay-rich, low TOC shale

![Graph showing GR and Resistivity values](image)
Wolfcamp C
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

(modified Brown, Soils-Institute, and Johns, 1990, BGR Report of Invest. No. 197)
Sequential development of the Glasscock Nose

(Sinclair et al., 2017)

prograding, mounded deep-water carb. flows

Possible analog: carbonate delta drift

Indian Ocean/Maldives seismic line

Marine Geology

Carbonate delta drift: A new sediment drift type

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
Wolfcamp A - B
Wolfcamp A and B Facies & Depositional Model

Schematic Block Diagram of Wolfcamp Facies in Midland Basin

(Diagram by T. Reed, 2013, based on Handford, 1981)
• 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 • B1
  - A2 • B2
  - A3 • 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

(L. Leonard Shale
Dean
Wolfcamp B
Wolfcamp A
XRD analyses from core (n = 476)

Mzee, 2018)
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 debris 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
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(modified from Hamlin and Baumgardner, 2012)
Dean – Spraberry units of the Midland Basin

- **Dean**
  - 1st major incursion of submarine fans
  - Equivalent to 3rd Bone Spring Sh.
  - Organic-rich siliceous shales

- **Lower Leonard Sh.**
  - 2nd major incursion of submarine fans
  - Equivalent to 2nd Bone Spring Shs
  - Silty, shales; minor fan complex

- **Spraberry**
  - 2 major submarine fan complexes (Floyd and Driver fans)
  - Equivalent to 1st Bone Spring Shs

- **Dean Ss (Mzee, 2018)**
  - Whole-rock mineralogy:
    - Qtz 45%
    - Clay 22%
    - Dolomite 17%
    - K-Feldspar 2%
    - Plagioclase 11%
    - Pyrite 2%
    - Siderite 1%

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Main facies:
- Massive f.g. sandstones ("Bouma A")
- Laminated siltstones / shales
- Burrowed siltstones / shales ($O_2$)
- Black shale (thin caps)

Depositional model?
- 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)
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 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 cannibalized 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

“Not all shales are created equal” (Hamlin and Baumgardner, 2012)