Geology of the Permian Basin

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

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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)
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 throughout 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 bafflesstones)
  - **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
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

Simpson paleogeography

Simpson isopach

(Harrington, 2019)

Simpson production mainly limited to CBU

(Harrington, 2019)
Upper Ordovician
Montoya Group
Middle – Late Ordovician: Biologic, Climatic, & Tectonic Trends / Events

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**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.)

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1. Harland et al., 1989
2. Finney & Berry, 2010
3. Haq and Schutter, 2008
4. Servais et al., 2009
5. Frakes et al., 1992
7. Huff et al., 1992
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)

(Harrington and Ruppel, 2019)

(Pope, 2004)
Montoya lithologies

- 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).
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
Two producing trends:
- Structures on CBP
- Strat traps on erosional subcrop

Cumulative oil production > 355 million barrels

Woodford shale (seal)

Oil accumulation trapped at pinch-out (associated with uplift/truncation during Early Devonian); reservoir porosity created/enhanced immediately below unconformity

(Dutton et al., 2005)
Late Silurian to Earliest Devonian (Wenlockian to Lochkovian)

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

Fasken Isopach

Frame Isopach

Wink Isopach

Water Depth ~1200 to 1300 ft

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 margins in central Andrews County.

(From Ruppel, Undated BEG Wristen Draft Report)
Wristen Group Facies

- 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.

(Ruppel et al., 2020)

(Dutton et al., 2004)
Lower Devonian Thirtyone Formation

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

**DOLLARHIDE 46-5D**

**WOODFORD SHALE**

**UPPER DOLOMITE**

**MIDDLE BIOClastic LIMESTONE**

**LAMINATED MICROPorous Chert**

**BURRORED CHERT**

**CARBONATE-CHERT MUDSTONE**

**THIRTYONE FORMATION**

![Diagram](Saller et al., 1991)

**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.

![Diagram](Ruppel et al., 2020)
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
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
Sea-level fall during Mid Devonian time led to exposure of the Tobosa Basin; exposed Wristen Thirtyone carls 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)
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.

(Ruppel et al., 2020)
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
Woodford Thermal Maturity

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)
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*
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.
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.

Deep-water mud mound

Crinoidal grainstones at ramp margin

(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
Mississippian stratigraphy of the Tobosa Basin: Summary

- **Woodford Shale**
- **downslope reef (Waulsortian mud mound)**
- **Barnettford play (?)**

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- **onset of icehouse climate (cyclothems)**

**Barnett**
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

- Lower Sil. – Mid. 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)
Horseshoe Atoll

Tectonic history – Part 1 (Big Picture)

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

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

Tobosa Basin stratigraphy (Mid Ord. – Mississippian)

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

Lower Permian (Wolfcamp – Spraberry)

Middle and Upper Permian / Permian Basin petroleum system