Depositional Processes and Reservoir Quality of the Lower Permian Wolfcamp Formation in the Delaware Basin, West Texas*

Maria Reistroffer¹, McKenzie Mitsdarffer¹, Yulun Wang¹, G. Michael Grammer¹, Erik Kvale², and Christopher Bowie²

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Abstract

The Delaware Basin, located in southeast New Mexico and west Texas, is the westernmost sub-basin of the Permian Basin. With an estimated 24 BBL of recoverable oil, the lower Permian Wolfcamp Formation is one of the most productive unconventional petroleum systems in the United States and is characterized by significant lateral and vertical heterogeneity in a mixed carbonate-siliciclastic system. Understanding the depositional processes, sequence stratigraphic framework, and petrophysical parameters associated with the reservoir facies in the lower Permian Wolfcamp Formation has major implications to maximizing hydrocarbon production.

Wolfcamp lithologies vary from calcareous and non-calcareous organic-rich mudstones to grainstones, conglomerates, and breccias. Wolfcampian gravity-flow deposits are sourced from a semi-arid, mixed carbonate-siliciclastic shelf and were deposited in a slope to basinal setting. The deposits are comprised of non-cohesive turbidites, cohesive debris flows, and hybrid flow events. These deposits are likely driven by global sea-level fluctuations associated with the growth and ablation of continental ice during the Permian icehouse conditions. During these periods of eustatic fluctuation, increased siliciclastic deposition occurred during low-stands, and carbonate deposition dominated high-stands as carbonate detritus was shed off of the adjacent Central Basin Platform.

This study evaluates the reservoir quality of two Wolfcamp A cores from the north Texas portion of the Delaware Basin and how the reservoir quality in these cores varies on a sub-meter scale as a result of depositional processes and diagenetic alteration. Depositional analogs to sedimentation occurring in the Wolfcamp A (i.e. debris flows, turbidites, hybrid flow events) will help constrain the expected potential reservoir geometry and distribution. The integration of datasets, which include cores, thin sections, wireline logs, and laboratory measured petrophysical properties, will determine the reservoir quality of the Wolfcamp A. The pore system architecture will be analyzed using ion milled samples under the SEM and laboratory measured sonic velocity analysis. Additionally, rebound hardness will be analyzed and tied to facies, stratigraphic architecture and reservoir quality.
Selected References


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Abstract

The Delaware Basin, located in southeast New Mexico and west Texas, is the westernmost sub-basin of the Permian Basin. With an estimated 24 billion barrels of recoverable oil, the lower Permian Wolfcamp Formation is one of the most productive unconventional petroleum systems in the United States and is characterized by significant lateral and vertical heterogeneity in a mixed carbonate-siliciclastic system. Understanding the depositional processes and petrophysical parameters associated with the reservoir facies in the lower Permian Wolfcamp Formation has major implications for maximizing hydrocarbon production. This study evaluates the reservoir quality of Wolfcamp A cores from the north Texas and southeast New Mexico portion of the Delaware Basin and how the reservoir quality in these cores varies on a sub-meter scale as a result of depositional processes and diagenetic alteration. In addition, this study aims to test the value of rebound hardness (RHN) in reservoir characterization by comparing the RHN data with reservoir properties from core samples.

Geologic Background

- The Delaware Basin is located within the Permian Basin of west TX and southeast NM.
- Basin formation began in the Late Mississippian and continued into the Late Permian, coinciding with the formation of Pangea.

Depositional Environment

- Deposition of the upper Wolfcamp Formation occurred across a distally steepened ramp during a period of increased sedimentation and subsidence.
- Mass transport deposits (MTD) shed off from the inner ramp, or upper slope into the basin in various geometries based on flow processes, the amalgamation of sediments, and MTD types.
- Trigger mechanisms for these MTDs are likely due to highstand carbonate shedding, tectonic activity, and storm events.
- Facies vary depending on location of initiation from inner ramp to basin.

Mass Transport Deposits (MTD)

<table>
<thead>
<tr>
<th>Flow Type</th>
<th>Deposit Profile</th>
<th>Architectural Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debris Flow</td>
<td>Massive bedding; clasts may exhibit random and chaotic fabrics with variations in size, roundness, and composition; clasts and matrix may contain shelly and basin facies, internal deformational shearing, local inverse grading, and clast protrusion into underlying and/or overlying strata.</td>
<td></td>
</tr>
<tr>
<td>Grain Flow</td>
<td>Massive bedding; sharp upper and lower bed contacts; basal erosional features; local inverse grading; and sediment concentrations dominated by gravel-, sand-, and silt-sized grains.</td>
<td></td>
</tr>
<tr>
<td>Liquified Flow</td>
<td>Dewatering structures occurring at the base or top of individual depositional packages; collapse structures: slight to moderate grading; and basal load structures. Liquified flows exhibit greater runout distances compared to fluidized flows due to increased sediment concentrations of fine sand-sized grains within the flow body.</td>
<td></td>
</tr>
<tr>
<td>Fluidized Flow</td>
<td>Variable bed thicknesses (millimeters to meters); basal scour marks; dewatering structures occurring at the base or top of individual depositional packages; partial to complete bypass sequences; long travel distances (10s of kilometers); and cyclical stratigraphic occurrence (i.e., cyclical stacking of individual depositional packages).</td>
<td></td>
</tr>
<tr>
<td>Turbidity Current</td>
<td>Spoon-shaped external geometry; minimal internal deformation of bedding along central axis of flow body; moderate folding and microfolding are common.</td>
<td></td>
</tr>
</tbody>
</table>

Classification of MTD based upon: 1) rheology, 2) dominant sediment support mechanism, 3) initial flow mechanism, 4) concentration, 5) size, and 6) type of material transported.

Methods

- Core description tied to wireline and borehole image logs.
- Thin section petrography.
- Scanning electron microscopy (SEM) using ion-milled samples.
- Rebound hardness: a proxy for rock strength
  - Tested using Equotip (a handheld device; shown above).
  - Acquired from all 6 cores with an overall frequency of 0.1 to 2 feet.
  - Cross-plotted against φ (from crushed samples) and XRD mineralogy.

Integrated Reservoir Characterization

- Core & Wireline Logs
- Pore Architecture
- Thin Sections, SEM
- Analogs
- Petrophysics
- Grain size
- Clay
- Ion-milled samples
- Cross-plotted against φ (from crushed samples) and XRD mineralogy.
Core Description, Logs, and Borehole Image Logs

**Modern Slope Analog**

- Side view color bathymetry/image taken across Great Bahama Bank.
- Loose sediment and failure along the middle to lower slope has a 2°-8° slope angle, which is analogous to the 5°-7° slope angles in the Delaware Basin.
- Slope failure initiating on lower slope is capable of transporting sediment 100s of km downslope, into the basin.

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**Ablation & Provenance**

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Less preserved skeletal packstones, ripples, and geometries</td>
</tr>
<tr>
<td>C</td>
<td>Erosive basal bedding contacts</td>
</tr>
<tr>
<td>Debris Flow</td>
<td>Dominated by coarse skeletal intraclast packstones</td>
</tr>
<tr>
<td>Turbidites</td>
<td>Greater volume of siliciclastic mudstone</td>
</tr>
</tbody>
</table>

**Allochems & Provenance**

<table>
<thead>
<tr>
<th>Grain Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Skeletal Fragments</td>
</tr>
<tr>
<td>C</td>
<td>Phylloid Algae</td>
</tr>
<tr>
<td>D</td>
<td>Foraminifera</td>
</tr>
<tr>
<td>E</td>
<td>Crinoids</td>
</tr>
<tr>
<td>F</td>
<td>Bivalves</td>
</tr>
<tr>
<td>G</td>
<td>Fusulinids</td>
</tr>
<tr>
<td>H</td>
<td>Bryozoans</td>
</tr>
</tbody>
</table>

**Sedimentary Structures**

- Planar laminations
- Ripple cross laminations
- Slumped bedding
- Bioturbation
- Normal grading

**Core Description Profile**

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Gamma-ray (API)</th>
<th>Resistivity (medium)</th>
<th>Sonic phi (%; limestone)</th>
<th>Neutron phi (%; limestone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10611.85</td>
<td>0 150</td>
<td>0.0 12.5 25.0</td>
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<tr>
<td>10610.95</td>
<td>0 150</td>
<td>0.0 12.5 25.0</td>
<td>0 25</td>
<td>0.0 25</td>
</tr>
</tbody>
</table>

**Turbidites**

- Debris Flow (10809.16'-10797')
- Debris Flow (10809.16'-10797')
- Debris Flow (10809.16'-10797')

**Explanation:**

- Faintly Laminated
- Normal grading
- Ripple cross laminations
- Planar laminaed
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**Pore Systems**

- Cross plot of porosity (%) and permeability (mD) from one of the southern wells.
- Average porosity: 7-14%
- Average permeability: <.01 mD
- Porosity is highly variable, but permeability is consistently very low.

**Key Points**

1.) The upper Wolfcamp is a laterally heterogeneous formation composed of a mixture of carbonate and siliciclastic MTDs deposited across an upper ramp to basinal setting.
2.) Each MTD has distinct (but variable) associated facies, pore types, and pore architectures that affect petrophysical parameters of the rock. Various allochems may contribute to microporosity.
3.) MTDs can be recognized using borehole image logs tied to core analysis.
4.) Reservoir quality within the upper Wolfcamp Formation is dependent on the various types of MTDs and their associated diagenetic alterations.
5.) Rebound hardness may provide a first-order estimation of reservoir quality, rock strength, and relative abundance of bulk clay content in a faster, cheaper, and sample-conservative way as compared to lab analyses.

**Acknowledgments**