Abstract

The Lower Permian Wolfcamp deep-water basinal succession in the Midland Basin has recently become an important target for unconventional reservoirs. However, uncertainty remains for reservoir characterization of the Wolfcamp due to the complexity of lithofacies in this region. This study combines petrophysical observations from cores, thin sections, and scanning electron microscope cubes with chemostratigraphic data from X-ray fluorescence (XRF) and total organic matter content (TOC). Lithofacies investigation were made using 4 drilling cores from Counties Glasscock (180 ft), Sterling (110 ft), and Irion (80 ft and 60ft), Texas. Based on core analysis, microscopic observations and XRF data, four lithofacies were defined in the Glasscock core representing the Wolfcamp upper calcareous interval: (1) fusulinid bioclast packstone, (2) calcareous mudstone, (3) brecciated mudstone, and (4) laminated skeletal mudstone. While the Wolfcamp lower siliciclastic interval is reflected by 5 lithofacies identified in Sterling and Irion cores as (5) clean litharenite, (8) calcite cemented litharenite, (7) clay-coated litharenite, (9) silte stone, and (9) siliceous mudstone. The Wolfcamp succession reveals a complex diagenetic history, ranging from compaction, recrystallization, replacement, cementation, and dissolution. Primary pores are rarely preserved due to significant compaction showing concavo-convex grain contact and sedimentary rock fragments as pseudo matrix. Isopachous and blocky carbonate cements further occlude initial pore space, especially in the calcareous interval. However, chlorite coating in lithofacies 7 inhibits further quartz cementation of primary pore space, making it a potential reservoir target. Measured core plug porosity and permeability suggest moderate porosity up to 10.2%, and very low permeability ranging from 0.001 to 0.197md. The highest porosity and permeability are reported in lithofacies 1 and 7. Combining this result with XRF and TOC data, lithofacies 7 is expected to have the best reservoir quality since it is more organic-rich and laterally extensive across this region. Findings in this study demonstrate variations in lithofacies and complicated diagenesis in the Wolfcamp succession that controls reservoir quality. Future work will incorporate well log correlation for regional reservoir characterization across the Midland Basin.

References Cited


Tyler, N., W.E. Galloway, C.M. Garrett, Jr., and T.E. Ewing, 1984, Oil accumulation, production characteristics, and targets for additional recovery in major oil reservoirs of Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 84-2, 31 p.


Qilong Fu, Robert W. Baumgardner, Jr., and H. Scott Hamlin, Early Permian (Wolfcampian) succession in the Permian basin: icehouse platform, slope carbonates, and basinal mudrocks, in review.
Lithofacies, Diagenesis, and Reservoir Quality Evaluation of Wolfcamp Unconventional Succession in the Midland Basin, West Texas

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Introduction

The Permian Basin of west Texas and southeast New Mexico is one of the world's significant hydrocarbon-producing provinces, with mixed siliciclastic-carbonate reservoirs. Original estimation of oil in place regarding to conventional sandstone reservoirs was more than 16 BBD (Tyler and others, 1944). But with the advent of technology and understanding, the unconventional reservoirs have become an important target for petroleum exploration.

In the Midland Basin, the Wolfcampian succession was deposited in a deep-marine environment. The Wolfcamp basin sequence consists of complex subaqueous density-flow deposits alternating with more organic matter-rich hemipelagic sediments. Lithofacies compositions change rapidly within meter scale and show great lateral heterogeneity (Hamlin and Baumgardner, 2012). Thus there is still a significant amount of uncertainty in terms of the integrated description of lithofacies heterogeneity.

Methods

This study combined petrographic observations from cores, thin sections, and scanning electron microscope cubes with chemostratigraphic data from X-ray Fluorescence (XRF), X-ray Diffraction (XRD) and total organic matter content (TOC) in order to provide an integrated characterization for the Wolfcamp succession.

The SEM samples were cut into around 9mm cubes and milled by Argon-ion Miller. The milling process was conducted by Leica EM TXC120 Triple Ion-Beam Miller under current of 2.8 mA and 88kV accelerating voltage for 2-3 hours at 800 °C.

High-resolution energy dispersive XRF data were generated by a Bruker Tracer III (T3S2270) for major elements and a Bruker FEI Nova NanoSEM 430 for SEM cube observation.

Results --- Lithofacies

Petrographic observations show that upper Wolfcamp (Wolfcamp B) is more calcareous, dominated by calcareous mudstone with carbonate rock intervals, while lower Wolfcamp (Wolfcamp C) is a more siliciclastic interval, which is dominated by medium- fine-grained turbidity sandstone, siltstone with interbedded siliceous mudstone. In total, nine lithofacies and facies associations were defined.

Wolfcamp B Examples

Four lithofacies were defined in the Glasscock core representing the upper Wolfcamp calcareous interval: (1) fusulinid bioclastic packstone, (2) calcareous mudstone, (3) brecciated mudstone, and (4) laminated calcareous mudstone.

Wolfcamp C Examples

Wolfcamp C interval is dominated with sandstone with interbedded siltstone/mudstone. Incomplete Bouma sequence is commonly observed.
Lower Wolfcamp siliciclastic interval is reflected by 5 lithofacies and facies associations identified in bending and Irion cores as: (1) clean litharenite, (2) calcite cemented litharenite, (3) clay-coated litharenite, (4) siltstone, and (5) siliceous mudstone.

### Results --- Mineral contents and TOC

#### Wolfcamp B (Hardwood Trust #2 core)

<table>
<thead>
<tr>
<th>Quartz</th>
<th>Clay Minerals</th>
<th>Carbonate</th>
<th>Dolomite</th>
<th>Pyrite/Sedite</th>
<th>Redox</th>
<th>Organic Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Si</td>
<td>% Al</td>
<td>% K</td>
<td>% Ti</td>
<td>% Ca</td>
<td>% Mg</td>
<td>% Fe</td>
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<tr>
<td>35.7</td>
<td>42.6</td>
<td>3.2</td>
<td>22.2</td>
<td>3.5</td>
<td>5.0</td>
<td>0.92</td>
</tr>
<tr>
<td>30.7</td>
<td>46.6</td>
<td>3.2</td>
<td>22.2</td>
<td>3.5</td>
<td>5.0</td>
<td>0.92</td>
</tr>
</tbody>
</table>

#### Wolfcamp C (Noekle #38 core)

<table>
<thead>
<tr>
<th>Quartz</th>
<th>Clay Minerals</th>
<th>Carbonate</th>
<th>Dolomite</th>
<th>Pyrite/Sedite</th>
<th>Redox</th>
<th>Organic Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Si</td>
<td>% Al</td>
<td>% K</td>
<td>% Ti</td>
<td>% Ca</td>
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<td>0.92</td>
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</tbody>
</table>

Data: 30 XRD samples from calcareous mudstone
* F=Feldspar; P=Pyrite; S=Siderite

Data: 20 XRD samples from siliceous mudstone
* F=Feldspar; P=Pyrite; S=Siderite

### Results --- Mudstone Facies Associations Stacking from XRF

#### Wolfcamp B (Hardwood Trust #2 core)

- Clean litharenite
- Clay-coated litharenite
- Siltstone
- Siliceous mudstone
- Siliceous mudstone under SEM/EDS

#### Wolfcamp C (Noekle #38 core)

- Redox Organic Matter
- Calcareous mudstone
- Dolomitic calcareous mudstone
- Siliceous calcareous mudstone
- Siliceous mudstone under SEM/EDS

Data: 30 XRD samples from calcareous mudstone
* F=Feldspar; P=Pyrite; S=Siderite

Data: 20 XRD samples from siliceous mudstone
* F=Feldspar; P=Pyrite; S=Siderite
Results --- Diagenesis

**Calcereous Diagenesis**
- Dissolution pores
- Isopachous calcite (red circle) followed by blocky calcite precipitation in fusulinid bioclastic packstone
- Detrital cement filling micro-pores in fusulinid bioclastic packstone

**Siltstone/ Mudstone Diagenesis**
- Calcite cement filled in interparticle pores
- Pyrite cement in siltstone
- Clay coating in bioclastic mudstone

**Sandstone Diagenesis**
- Disseminated authigenic silica
- Quartz overgrowth and calcite cementation in litharenite
- Clay coating in litharenite (chlorite and illite)

**Clay-coated litharenite**
- Clay coating in litharenite
- Clay coating is a mixture of chlorite and illite

Results --- Generalized Paragenesis

<table>
<thead>
<tr>
<th>Diagenetic Phase</th>
<th>Early Burial</th>
<th>Late Burial</th>
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</thead>
<tbody>
<tr>
<td>Mechanical compaction</td>
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<tr>
<td>Chemical compaction</td>
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<tr>
<td>Grain dissolution</td>
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<td>Feldspar kaolization</td>
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<tr>
<td>Silica cement precipitation</td>
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<tr>
<td>Pyrite cement</td>
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<tr>
<td>Clay coating</td>
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<tr>
<td>Calcite cement precipitation</td>
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</tr>
<tr>
<td>Mechanical compaction</td>
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<tr>
<td>Fossil grain dissolution</td>
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<tr>
<td>Isopachous calcite cement</td>
<td></td>
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<tr>
<td>Blocky calcite cement</td>
<td></td>
<td></td>
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<tr>
<td>Mosaic calcite cement</td>
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<tr>
<td>Dolomite cement</td>
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</tbody>
</table>

Litharenite Porosity-Permeability Test Result

- 27 core plugs in total
  - Average porosity: 8.2%
  - Average permeability: 0.1 md
- 26 core plugs in total
  - Average porosity: 7.6%
  - Average permeability: 0.1 md

Results --- Pore System and Reservoir Quality

**Silicieous Mudstone**
- Meso intergranular pores
- No organic pore

**Packstone/ Calcareous Mudstone**
- Intragranular pores in fossiliferous matrix
- Intragranular pores in intraclasts from clay minerals
- Intragranular pores in a clay matrix
- Organic pores are rare

Conclusion

Based on the integration of petrographic observation and geochemical data analysis, 4 lithofacies and 5 mudstone facies associations were defined in the upper Wolfcamp (Wolfcamp C) calcareous interval. The lower Wolfcamp (Wolfcamp C) siliciclastic interval is reflected by 5 lithofacies with litharenite facies association and 4 mudstone facies associations. The Wolfcamp succession represents a complex diagenetic history, ranging from compaction, pyrite, calcite, dolomite and silica cementation, to dissolution.

Primary pores in litharenite and packstone are rarely preserved due to significant compaction and later cementation. However, chlorite-illite-coated litharenite inhibits further quartz cementation of primary pore space.

Sedimentation in the Wolfcamp succession is highly controlled by density flow current, probably turbidity flow. The turbidity current brings both calcareous and siliciclastic sediments from the Eastern Shelf to the basin, thus increasing the lithology heterogeneity thus increases heterogeneity in reservoir quality.

Clay-coated litharenite is considered to have the best reservoir potential since it shows good porosity and permeability value, and is regionally continuous. It is usually present at the base of incomplete Bouma sequence identified cores.

Acknowledgment

We are grateful to State of Texas Advanced Oil and Gas Resource Recovery (STARR) project 30 for funding this research. We appreciate the Bureau of Economic Geology, Jackson School of Geoscience at the University of Texas at Austin for providing the cores and facilities to complete the research.

References

- Tyler, N., Galloway, W. E., Garrett, C. M., Jr., and Ewing, T. E., 1984, Oil accumulation, production characteristics, and targets for additional recovery in major oil reservoirs of Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 84-2, 31 p.
- Poole, F. G., W. J. Perry, Jr., P. Madrid, ... synthesis of the Ouachita-Marathon-Sonora orogenic margin of southern Laurentia: stratigraphic and structural implications for timing of deformational events and plate tectonic model: Geological Society of America Special Paper 393, p. 543-596.
- Qilong Fu, Robert W. Baumgardner, Jr., and H. Scott Hamlin, Early permian (wolfcampian) succession in the permian basin: icehouse platform, slope carbonates, and basinal mudrocks, in review.
- Intergranular pores and intragranular pores
- Isopachous calcite cement along cleavage planes and intragranular pores
- Clay coating is a mixture of chlorite and illite
- Calcite cement precipitation in fusulinid bioclastic packstone
- Organic pores are rare