Mowry Shale - Outcrop to Production*

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Abstract

The increase in commodity prices and development of technology in the late 2000s created opportunity to exploit previously uneconomic drilling targets, including a number of oil-generating shales. Two important source-rock shales in the Northern Rocky Mountains are the Mowry and Niobrara shales. Although both shales have been drilled using current completion techniques, the Niobrara has been targeted much more than the Mowry in the Powder River Basin. Momper and Williams (1984) estimated that the Mowry Shale has generated 11.9 billion barrels of oil and expelled 7% or approximately 830 million barrels of oil in the southern Powder River Basin. This illustrates the importance of the Mowry Shale to oil production in eastern Wyoming. A small number of vertical and horizontal wells in the Powder River Basin produce oil from the Mowry but few of these have been economic. The keys to drilling, completing, and economically producing the Mowry have yet to be discovered. The Mowry Shale is a siliceous shale, which makes it very brittle. It is interbedded with bentonites and other clay minerals. Although the carbonate-based Niobrara Shale has interbedded bentonites and other clays, the Mowry has some different issues with respect to drilling and completing than the Niobrara. This presentation will review geologic aspects of the Mowry and review historic and recent development.

References Cited


Mowry Shale
Outcrop to Production

American Association of Petroleum Geologists
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October 3, 2016

Andrew Finley
Outline

Location and Activity
Powder River Basin Stratigraphic Column
Lithology and Facies Distribution
Outcrop and Core
Hydrocarbon Potential
Drilling and Completions Performance
Observations
Conclusions
### Powder River Basin Stratigraphic Column

<table>
<thead>
<tr>
<th>Upper Cretaceous</th>
<th>Lower Cretaceous</th>
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<tbody>
<tr>
<td><strong>Cody Sh.</strong></td>
<td><strong>Inyan Kara Gp.</strong></td>
</tr>
<tr>
<td><strong>Sussex SS. Mbr.</strong></td>
<td><strong>Fall River FM. (Dakota)</strong></td>
</tr>
<tr>
<td><strong>Shannon SS. Mbr.</strong></td>
<td><strong>Lakota FM.</strong></td>
</tr>
<tr>
<td><strong>Steele Sh.</strong></td>
<td><strong>Morrison FM.</strong></td>
</tr>
<tr>
<td><strong>Nobrara Mbr.</strong></td>
<td><strong>Mowry Sh.</strong></td>
</tr>
<tr>
<td><strong>Sage Breaks Mbr.</strong></td>
<td><strong>Mowry Sh.</strong></td>
</tr>
<tr>
<td><strong>Carlile Shale</strong></td>
<td><strong>Mowry Sh.</strong></td>
</tr>
<tr>
<td><strong>Belle Fourche Mbr.</strong></td>
<td><strong>Mowry Sh.</strong></td>
</tr>
<tr>
<td><strong>Wall Creek Mbr.</strong></td>
<td><strong>Mowry Sh.</strong></td>
</tr>
<tr>
<td><strong>2nd Wall Creek Sand</strong></td>
<td><strong>Mowry Sh.</strong></td>
</tr>
<tr>
<td><strong>Belle Fourche Mbr.</strong></td>
<td><strong>Mowry Sh.</strong></td>
</tr>
<tr>
<td><strong>Muddy SS.</strong></td>
<td><strong>Newcastle SS.</strong></td>
</tr>
<tr>
<td><strong>Thermopolis Sh.</strong></td>
<td><strong>Skull Creek Sh.</strong></td>
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<td><strong>Falls River FM. (Dakota)</strong></td>
<td><strong>Mowry Sh.</strong></td>
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<td><strong>Lakota FM.</strong></td>
<td><strong>Mowry Sh.</strong></td>
</tr>
<tr>
<td><strong>Morrison FM.</strong></td>
<td><strong>Mowry Sh.</strong></td>
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</table>

**Notes:**
- **Falls River FM. (Dakota)**
- **Lakota FM.**
Type Logs

West - BigHorn Basin

- Mowry Shell Creek Muddy
- High TOC
- Siliceous/Brittle

East - Powder River Basin

- Bentonites
- High TOC
- Siliceous/Brittle
Lithology

Medium to dark gray organic-rich siliceous shale
Silty shale
Bioturbated sandstone
Bentonite
Silica is thought to be dominantly biogenic
Figure 15. Regional distribution of total organic carbon (TOC) in the Mowry Shale. Note that most areas of anomalously low TOC values coincide with the deeper portions of Laramide structural basins.
Facies Distribution

Facies

Davis, 1970

Kaolinite

FIG. 5.—Distribution of montmorillonite in upper half and lower half of Mowry Shale in Wyoming.

FIG. 6.—Distribution of kaolinite through upper, middle, and lower parts of Mowry Shale in Wyoming.
## XRD Comparison of SW VS SE PRB

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>SE</th>
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<tbody>
<tr>
<td>Quartz</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Chlorite</td>
<td>1%</td>
<td>10%</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>2%</td>
<td>5%</td>
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<tr>
<td>Illite</td>
<td>7%</td>
<td>9%</td>
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<tr>
<td>Mixed Illite/Smectite</td>
<td>22%</td>
<td>12%</td>
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</table>
Hydrocarbon Potential

Momper and Williams, 1984
- 3% Average TOC
- 160 BBOOIP
- 11.9 BBO expelled (7% efficiency)
- Predominantly Type II Kerogen

Modica and Lapierre, 2012
- Mowry maturation results in development of up to 2.5 to 3.3% kerogen porosity
- Kerogen porosity model hypothesizes that dominant storage capacity in source rocks is in kerogen porosity with little to no storage in mineral pores.
- This idea seems to be supported by recent work in FIB-SEM studies.

Is Mowry a mineral porosity, kerogen porosity, natural fracture play or combination?
PRB Maturity

Modica and Lapierre, 2012
TOC Perm and Targets

Highest oil saturation and TOC in Middle Mowry

Low permeability in Middle Mowry (30-35nd)

Figure modified from Hollon, 2014

Sociamnu, Kaszuba and Gustason, 2015
Mowry in Outcrop

Frontier/Belle Fourche

Fractures

Mowry Forms Ridges

Tree Roots Exploiting Orthogonal Fractures
Mowry in Core

- Open Fracture 12,000’+
- Expulsion Fractures
- Natural Fractures
- Bentonite
Drilling and Completions
2006-2010

Brigham, Baytex
4,000’ horizontals
3-11 Stages
½ Million # Sand
Slick water/linear gel

EOG
4,000’ horizontal
15 Stages
2½ Million # Sand
XL

2012-2014

EOG, Devon, Peak
4,000’ – 9,000’ horizontals
15 – 45 Stages
2 – 14 Million # Sand
XL, Hybrid (350-450 MMBF)
Performance

Mowry Hz EUR Range Distribution
Powder River Basin
Normalized to a 9,000' Hz

<table>
<thead>
<tr>
<th></th>
<th>Oil</th>
<th>Oil</th>
<th>Gas</th>
<th>Gas</th>
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</thead>
<tbody>
<tr>
<td>$P_{90}$</td>
<td>241,900</td>
<td>171,800</td>
<td>1.60</td>
<td>0.33</td>
</tr>
<tr>
<td>$P_{nn}$</td>
<td>336,100</td>
<td>289,300</td>
<td>4.68</td>
<td>3.20</td>
</tr>
<tr>
<td>$P_{10}$</td>
<td>444,500</td>
<td>434,100</td>
<td>9.14</td>
<td>8.20</td>
</tr>
</tbody>
</table>

Log Normal Mean Match Fit
Performance

Cum: 51 MBO, 69 MMCFG, 3 MBW
Performance

Cum: 127 MBO, 2,484 MMCFG, 136 MBW
Cum: 86 MBO, 578 MMCFG, 137 MBW
Observations - Bentonite Sealing Fault
Observations

What is the play?
Kerogen porosity, mineral porosity or natural fracture play?

What is the target?
Highest TOC is in Middle Mowry?
Highest silica content is at top of Mowry?
Summary

What is the nature of the Mowry play?
  Kerogen porosity?  Macro porosity?
  Hydraulic fractures?  Natural fractures?

Damage during drilling and completion?

Downhole fluid compatibility?

Are high EUR/high GOR wells due to effective perm created during completion or is the inherent perm system inhibiting oil production?

Do we know the right questions?
Acknowledgements

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