The Pronghorn Member of the Bakken Formation, Williston Basin, USA
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ABSTRACT

The Bakken Formation is present in the Williston Basin of North Dakota, Montana, Saskatchewan and Manitoba. The organic-rich upper and lower shale charge the unconventional, Late Devonian-Early Mississippian Bakken Petroleum System. While the middle member of this formation, sandwiched between the two shales, has proven to be a prolific producer, recent drilling has expanded to focus on the upper Three Forks Formation and the irregularly occurring interval of variable lithology above the Three Forks and below the lower Bakken Shale. Nomenclature has evolved from 1954 to present. This interval has in previous studies been referred to as the Sanish sand, the Lower Bakken Silt, the Grassy Butte Member, and the Lower Bakken bench. It has recently been renamed the Pronghorn Member and placed within the Bakken Formation. This interval corresponds with the Big Valley Formation of Canada, which lies between the Torquay and Bakken Formations in south Saskatchewan.

While previous work has described locally occurring lithologies in various plays in the Williston Basin, the purpose of this study is to develop a basin-wide sequence stratigraphic framework for the facies by identifying related lithofacies and attempting to recognize the most significant sequence boundaries. The focus area of this study is the Pronghorn Member in the Williston Basin of northeastern Montana in comparison to the facies of the Pronghorn Member in the North Dakota portion of the basin.

Reservoir properties of the variable lithologies will be compared throughout the basin in order to determine the most economic facies. Preliminary work, including core description, well-log analysis, X-ray diffraction, and petrographic thin-section analysis have indicated a transgressive surface of erosion and a significant sequence boundary between the underlying Three Forks Formation and the Pronghorn Member. In Montana, this lag is made up of fragmented brachiopods, echinoderms, stromatoporoid, coral, dolomite clasts, and v. fine to fine-grained sandstone, within mud, clay, microcrystalline quartz, or peloidal dolomite matrix. An additional erosional surface is also present in some cores between the Pronghorn Member and the overlying lower shale member of the Bakken Formation. A silty shale to siltstone facies present in Montana may be an up-dip equivalent of the lower shale member, but the relationship between the silty facies and the shale facies in North Dakota has not yet been determined. Porosity and permeability appear to be highly variable, with the best reservoir quality expected in the sandiest facies. In comparison to the prolific Sanish sand facies of North Dakota, the facies in Montana have much higher illite/mica content, finer grain sizes, and therefore greatly reduced porosity.

Difficulties in correlation among the various lithofacies that may belong in Pronghorn Member of the Bakken Formation exist due to limited thickness and distribution throughout the basin. Further work will investigate the reason for isolated deposition and variable thickness. Proposed causes include accommodation space created by Prairie Salt dissolution or deposition within paleo-graben areas.
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Pronghorn Member facies of North Dakota

The proposed Pronghorn Member includes the lower Bakken silt and the facies of the Bakken bench (LeFever, 2011).

Bakken bench lithofacies:
- Fossiliferous wackstone-packstone facies
- Burrowed dolostone, mudstone, or limestone facies
- Burrowed sandstone and siltstone facies (aka the Sanish)

Lower Bakken silt lithofacies:
- Brown to black mudstone with thin laminae of silt to very fine-grained sandstone
- Equivalent to the Big Valley Formation of southeastern Saskatchewan

Proposed Pronghorn Member facies of Montana

The lithofacies recognized in the Montana core include equivalents to the lower Bakken silt facies and Bakken bench facies, but appear to be finer grained overall, more clay-rich, and more dolomitic.

Bakken bench equivalent lithofacies:
- Fossiliferous lime wackstone-packstone facies
- Burrowed dolostone, claystone, or limestone facies
- Burrowed siltstone facies

Lower Bakken silt equivalent lithofacies:
- Brown to black claystone with thin laminae of silt to very fine-grained sandstone and thin layers of fragmented fossils in peloidal dolomite, silica, or clay matrix

Figure 5: Bakken bench type log and core photos, Modified from LeFever et al., 2011.

Figure 6: Lower Bakken silt type log and core photos, modified from LeFever et al., 2011.

Figure 7: Petrographic thin-section Jackson Rowdy 3-8 at 7665', plane light Pronghorn dolomitic siltstone.

Figure 8: Crossed polarized light, 7665'.

Figure 9: Reflected light, 7665'.

Figure 10: Well log and core photo from the Jackson Rowdy 3-8, Elm Coulee Field, Richland County, Montana. Produced oil from the Middle Bakken.

Figure 11: XRD data for the Jackson Rowdy 3-8.

Figure 12: Petrographic thin-section at 7664', Lower Bakken siliceous claystone with siltstone lamination. Quartz grains are interpreted as eolian sediments derived from the craton to the northeast.

Figure 13: Petrographic thin-section at 7666', silty dolomite facies. The Pronghorn becomes increasingly quartz rich upwards, transitioning to a dolomitic siltstone.
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Figure 14: West to East cross section including available cores from Richland and Roosevelt Counties, Montana to Divide and Burke Counties, North Dakota.

Figure 15: Type log, core photo and petrographic thin-section photo for the Pronghorn burrowed sandstone facies (Sanish sand) from the Duncan Rose #1, in the Sanish Field of McKenzie County, North Dakota. Cum Oil: 187825 BBLS, Cum Gas: 257849, Cum Water: 4588 BBLS. Thin section above shows fine-grained sandstone, plane light. Inset thin-section shows pyrite nodules in reflected light.
Table 1: Facies recognized in the Enerplus cores from Elm Coulee Field, Montana.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Description</th>
<th>Bioturbation</th>
<th>Fossils</th>
<th>Well(s)</th>
<th>Core Depths</th>
<th>Well Depths</th>
<th>Erosional Surface(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siliceous Claystone</td>
<td>Mica/illite &gt;20-30% Quartz 20-30% Pyrite and Dolomite &gt;10%</td>
<td>heavily burrowed bioturbated</td>
<td>fragmented brachiopods, crinoids, fish bones, serpulid</td>
<td>Jackson-Rowdy 3-8</td>
<td>7664-7665.5</td>
<td>7665-7666.5</td>
<td>gradational 3F to PH, linear contact at 7664 with pyrite blebs in LBS</td>
</tr>
<tr>
<td>Dolomitic Siltstone</td>
<td>Quartz ~30%, Dolomite &gt;20%, Mica/illite ~20%, Pyrite &gt;10%</td>
<td>some burrows</td>
<td>none</td>
<td>Jackson-Rowdy 3-8</td>
<td>7665.5-7666.9</td>
<td>7666.5-7666.9</td>
<td>linear contact above and below, with mud drapes at 7665.5 and pyrite blebs at 7665.9</td>
</tr>
<tr>
<td>Siliceous Dolomite</td>
<td>Dolomite 60%, Quartz &lt;20%, Pyrite 10%, no clay</td>
<td>heavily burrowed below in 3F directly below lag</td>
<td>fragmented brachiopods, crinoids, increasing upwards</td>
<td>Foghorn-Ervin</td>
<td>10534.9-10535.2</td>
<td>10534.9-10535.2</td>
<td>PH lag cuts into 3F, gradational into LBS</td>
</tr>
<tr>
<td>Lime Packstone</td>
<td>Limestone &gt;78%, Quartz &lt;10%, Pyrite and Chlorite &lt;5%</td>
<td>heavily burrowed</td>
<td>abundant brachiopods, crinoids</td>
<td>Brutus East Lewis</td>
<td>10419.75-10422</td>
<td>10425.75-10428</td>
<td>PH cuts into 3F, 3F is ripped up, bioturbated, linear contact with LBS</td>
</tr>
</tbody>
</table>

Figure 16: Due to the disruption of the laminated Upper Three Forks at the contact with the Pronghorn, the presence of poorly sorted fossil fragments and dolomite clasts, the dolomitic siltstone is interpreted as a transgressive lag deposit in an overall upward deepening sequence.

Figure 17: Well log, XRD data, core and petrographic thin-section photos from the Brutus East-Lewis, Elm Coulee Field, Richland County Montana. Lithofacies identified include a lime packstone above a siliceous dolostone. The Upper Three forks green laminated dolostone facies is eroded and bioturbated at the contact with the Pronghorn siliceous dolostone. The siliceous dolostone facies contains brachiopods and crinoids, pyrite blebs, sparse pyrite and organic material. The lime packstone facies cuts into the dolostone. The packstone lag facies must have been less permeable than the overlying lower Bakken and the underlying siliceous dolostone in order to preserve the limestone.
Figure 18: The Oryx Energy Big Sky #1, Roosevelt County, Montana. Core photo showing gradational change from clay rich siltstone to siltstone with fossiliferous lag to Lower Bakken shale facies. Petrographic thin-sections (from top to bottom) show siltstone to wackstone lag at 9926’ depth, plane light; 9926’ depth, crossed polarized light; heavily burrowed clay-rich siltstone at 9929’ depth.

REFERENCES:
Christopher, J. E., 1961, Transitional Devonian Mississippian formations of southern Saskatchewan: Saskatchewan Department of Mineral Resources Report 52, Regina, Saskatchewan, 103 p.

CONCLUSION
This study attempts to understand the various facies, irregular thicknesses, and localized deposition of the Pronghorns in order to form an accurate sequence stratigraphic model and determine the reservoir quality of the various facies. Having done so, it will be possible to resolve and locate potentially productive zones within the Pronghorn Member of the Bakken Formation.

Siltstone to fine-grained sandstone facies are interpreted as shoreface to subtidal deposits. Siliceous dolomite facies are interpreted as subtidal to open marine deposits. The lime packstone facies is interpreted as a lag deposit in a subtidal environment, presumably above storm wave base. As a whole, the facies of the Pronghorn Member of the Bakken Formation in Montana are interpreted as subtidal deepening to open marine deposits. A significant surface is present at the contact with the intertidal Upper Three Forks facies and the subtidal Pronghorn facies. A lag deposit or erosion surface is present in some cores at the contact with the subtidal to open marine Pronghorn facies and the open marine Lower Bakken shale or claystone. These surfaces are interpreted as transgressive surfaces of erosion.

Figure 19: Idealized transgressive arid tidal flat sequence for the Late Devonian of the Williston Basin. Modified and ripped from Humphrey, 1988 “Idealized Regressive Arid Tidal Flat Sequence.”

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