Understanding the Middle Bakken*

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Abstract

Since the initial Bakken discovery well in 1957, over 8000 Bakken and 1600 Three Forks wells have been drilled across North Dakota, Montana, and Saskatchewan. Over the past decade we have seen a rapid uptick in the geologic understanding of the Bakken and Three Forks, coupled with increasingly effective, and efficient, customization of drilling and completions. We illustrate how the emergence of geologic data coverage has driven industry understanding of play nuances. Regional structural, thickness, and geochemistry maps highlight early play characterization and identification of the eastern "line of death" and unique characteristics of the Sanish and Parshall fields. Lithofacies classification of vertical well log suites illustrate the insights gained from delineation wells that framed interpretation of the complex play stratigraphy. More recently, sufficient well coverage has emerged to consistently map oil saturation/water cut across the basin; supported by more detailed depth and character mapping using the extensive gamma-ray coverage. Keeping pace with burgeoning geologic understanding, well completion techniques have been tested and tuned - from single to 40 and 50 stages - with sand volumes ranging well above 10 million pounds and accompanying fluids beyond 150,000 barrels. Currently, multi-lateral co-development of Bakken and two-to-four Three Forks formations are becoming standard operating procedure. "Frac hits" have emerged as the key development optimization focus as well spacings approach 500 feet in common formations and 250 feet in staggered multi-level patterns. While overlapping zones of stimulation can have beneficial effects, delayed infills are proving to be very problematic with unclear economic tradeoffs of increased, though contested well production, often offset with dramatic production decline in adjacent, active wells. Oilfield analytics provide a unique perspective of the ongoing efforts to "right size" drilling and completions engineering for rock and fluid characteristics in the Bakken and Three Forks reservoirs. Dynamic well spacing,
vertical and lateral geometry, drilling and completions parameters, and geologic character can all be quantified; providing a common basis for using analytic techniques to predict well performance. The results of these analyses are improved understanding of geologic prospectivity, independent of engineering, as well as indications of optimized engineering techniques for different geologic scenarios.
Paleo – Bakken/Three Forks

Late Devonian

Dr. Ron Blakey, Professor Emeritus NAU Geology
Study Objectives

• Identify key geologic drivers of Middle Bakken production and the degree to which they impact performance
  – Depth
  – Thickness
  – Thermal Maturity
  – TMAX
  – Water Cut

• Benchmark engineering impact on performance for variable geology
Middle Bakken Depth vs. 3 Month Oil/ft
Middle Bakken Depth vs. 3 Month Oil/ft
Middle Bakken Depth vs. 3 Month Oil/ft

3 Month Oil (bbl) per FT per Well vs. Regional Middle Bakken Depth (ft)
Middle Bakken Depth vs. 3 Month Oil/ft
Middle Bakken to Three Forks Thickness vs. 3 Month Oil/ft
Middle Bakken to Three Forks Thickness vs. 3 Month Oil/ft
Middle Bakken to Three Forks Thickness vs. 3 Month Oil/ft

3 Month Oil (bbl) per FT per Well vs. Regional Middle Bakken to Three Forks Thickness (ft)
Middle Bakken to Three Forks Thickness vs. 3 Month Oil/ft

3 Month Oil (bbl) per FT per Well vs. Regional Middle Bakken to Three Forks Thickness (ft)
Regional Middle Bakken Water Cut vs. 3 Month Oil/ft
Regional Middle Bakken Water Cut vs. 3 Month Oil/ft
Regional Middle Bakken 3 to 6 Month Water Cut vs. 3 Month Oil/ft
Lower Bakken TOC vs. 3 Month Oil/ft
Lower Bakken TOC vs. 3 Month Oil/ft
Lower Bakken TOC vs. 3 Month Oil/ft

3 Month Oil (bbl) per FT per Well vs. Regional Lower Bakken TOC

Regression line: $r^2 = 0.008$
Lower Bakken TOC vs. 3 Month Oil/ft

3 Month Oil (bbl) per FT per Well vs. Regional Lower Bakken TOC

Regional Lower Bakken TOC (10 bins)
Lower Bakken TMax vs. 3 Month Oil/ft
Lower Bakken TMax vs. 3 Month Oil/ft
Line of Death
TMax < 420
Middle Bakken Depth vs. Middle Bakken to Three Forks Thickness by 3 Month Oil/ft

Regional Middle Bakken to Three Forks Thickness (ft) vs...

Regional Middle Bakken to Three Forks Thickness (ft) (10 bins) vs...

Colors:
- Max
- Average
- Min

3 Month Oil (bbl) per FT per Well
Middle Bakken Depth vs. Lower Bakken Tmax by 3 Month Oil/ft
Lower Bakken TMax vs. Lower Bakken TOC by 3 Month Oil/ft

Regional Lower Bakken TOC vs. Regional Lower Bakken TMax

Regional Lower Bakken TOC (10 bins) vs. Regional Lower Bakken TMax

Data points are color-coded by 3 Month Oil (bbl) per FT per Well.
Lower Bakken TOC vs. Middle Bakken 3 to 6 Month Water Cut by 3 Month Oil/ft
WHERE ARE THE SWEETSPOTS?
Middle Bakken Sweetspot Indicator
Middle Bakken Sweetspot Indicator
RIGHT SIZING ENGINEERING FOR GEOLOGY
Middle Bakken Sweetspot Indicator vs. Proppant/ft by 3 Month Oil/ft

- Average Proppant per Length (lbs/ft) vs. Middle Bakken
- Average Proppant per Length (lbs/ft) vs. Middle Bakken Cum...

Colors:
- Max
- Average
- Min
Middle Bakken Sweetspot Indicator vs. 3 Month Oil/ft by Proppant/ft

3 Month Oil (bbl) per FT per Well vs. Middle Bakken Cum 3 Month Oil Sweetspot Map (bbl)

Average Proppant per Length...
- $x \leq 250.00$
- $250.00 < x \leq 500.00$
- $500.00 < x \leq 750.00$
- $750.00 < x$

Middle Bakken Cum 3 Month Oil Sweetspot Map (bbl)
WELL SPACING IMPACT
Well Spacing Analysis Example
Well Spacing Analysis Example

How many prospective well locations are there?
1200ft Middle Bakken to Middle Bakken Spacing

New Locations = 1179
New Middle Bakken = 517
New Three Forks = 662

Estimated Total D&C Cost ($8M/well) = $9.4B
500ft Middle Bakken to Middle Bakken Spacing

New Locations
= 3379
New Middle Bakken
= 1596
New Three Forks
= 1783

Estimated Total D&C Cost ($8M/well)
= $27.0B
Decreasing well spacing drastically increases the number of available locations, but how viable are those locations?
Middle Bakken Sweetspot Indicator vs. Time-Dependent Well Spacing by 3 Month Oil/ft

Average Well Spacing to Time-Dependent Nearest Neighbor...

Middle Bakken Cum 3 Month Oil Sweetspot Map (bbl)...

- Max
- Average
- Min

3 Month Oil (bbl) per LBS...

- P90.00 (0.0267)
- P70.00 (0.0171)
- P50.00 (0.0127)
- P30.00 (0.0094)
- P10.00 (0.0058)

3 Month Oil (bbl) per LBS...

- ≥ 0.1857
- ≤ 0.0002

Average Well Spacing to Time-Dependent Nearest Neighbor...

Middle Bakken Cum 3 Month Oil Sweetspot Map (bbl)...

- Max
- Average
- Min

3 Month Oil (bbl) per LBS per Well...
Middle Bakken Sweetspot Indicator vs. 3 Month Oil/lbs by Well Spacing

Average Well Spacing to...
- $x \leq 1.20k$
- $1.20k < x \leq 2.20k$
Core Area: Same Formation Spacing vs. Different Formation Spacing by 3 Month Oil/ft

<table>
<thead>
<tr>
<th>Average Well Spacing to Time-Dependent Nearest Nei...</th>
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<tbody>
<tr>
<td>3 Month Oil (bbl)...</td>
</tr>
<tr>
<td>P50.00 (11.643035)</td>
</tr>
<tr>
<td>P70.00 (7.5758809)</td>
</tr>
<tr>
<td>P50.00 (5.69146591)</td>
</tr>
<tr>
<td>P30.00 (4.3039152)</td>
</tr>
<tr>
<td>P10.00 (2.6238376)</td>
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<td>≤ 0.0066020003...</td>
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<table>
<thead>
<tr>
<th>Spacing Attribute Comparison Heat Map</th>
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<tr>
<td>Average Well Spacing to Time-Dependent Nearest Nei...</td>
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<tr>
<td>x ≤ 1.00k</td>
</tr>
<tr>
<td>1.00k &lt; x ≤ 2.00k</td>
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<tr>
<td>x ≤ 1.00k</td>
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</tbody>
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Different Formation Spacing

Same Formation Spacing

Different Formation Spacing

Same Formation Spacing
Conclusions

• Oil Sweetspot defined by:
  – Middle Bakken Depth (>7,000’)
  – Middle Bakken to Three Forks Thickness (>70’)
  – Tmax (>420)
  – TOC (>18)
  – Water Cut (<40%)

• Wells with > 750lbs of proppant/ft show better performance in all ranges of geologic quality

• Decreasing same formation to less than 1,000’ spacing can result in a ~33% decrease in production

• Three Forks wells next to Middle Bakken might have negative impact on Middle Bakken well production in core region