Facies, Environments, Diagenesis, Sequence Stratigraphy, Stress and an Oil Migration Model for the Bakken Petroleum System of the Williston Basin

PBS-SEPM
Luncheon Talk
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Presented by:
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Graham R Davies.
CDL who we are what we do

- Multi-Client Projects
- Information Products
- Geoscience Consulting
- Data & Software
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Resource Starfish
(Ophiura ophiura)

Source Rock Composition and Maturity
(In-situ, migration)

Geomechanical Properties
(Natural Fractures, Fracability)

Hydrodynamics
(Overpressuring, Aquifers)

Stress
(Minimum Principal Stress Gradient)

Reservoir Characterization
(Sequence Stratigraphy, Petrophysics)

From: Hillewaert, 2005
Outline/Key Points

• The five components of a successful resource play
• Reservoir and Facies
  – 10 Facies, 21 subfacies
  – Residual structure mapping and facies distribution
  – Facies Interpretations and depositional models
  – Porosity by facies depth - dolomite implications
• Hydrogeology, migration modeling
  – Source rock maturity from temperature data
  – Force vector modeling of water and oil
  – Hydrogeological play types
Outline/Key Points

• Petrophysical model
  – Confirmation of hydrogeological model

• Preliminary stress analysis
  – Minimum principal stress measurements from Fracs
  – The effects of stress on drilling and production

• Conclusions
Study Area

- 95 Cores
- 2916 Wells
- 151 Thin Sections
- 352 DST’s
- 30 SEM, TOC, XRD
Bakken Facies

10 Major Facies, 21 Subfacies

BF.9
‘Upper Shale’

BF.8
Silty Dolomudstone w/Chondrites

BF.7
Burrowed Argill. Dolosiltstone with Storm(?) Event Beds

BF.6
a, b
Graded Dolosiltstone Laminite

BF.5
Rippled Dolosandst w/ ‘Black Specks’

BF.4
a,b,c,d,e
Cross-Bedded Microbioclastic Sandy Ooid Grainstone/Oolitic Sandstone, var Tidal Subfacies

BF.3

BF.2

BF.1B
‘Lower Shale’

BF.1A
a,b,c,d
Basal Transgressive Facies

SE Saskatchewan
North Dakota

THREE FORKS / TORQUAY

“Pronghorn”
Bakken North Dakota: Log-Core Correlation
3rd Order Residual Structure Map of Three Forks

- Bakken Subcrop Edge
- Three Forks Unconformity Third-Order Structural Residual
- CI = 50 ft
- High: 420 ft
- Low: -1035 ft

Legend:
- Orange: Bakken Subcrop Edge
- Three Forks Unconformity Third-Order Structural Residual
- CI = 50 ft
- High: 420 ft
- Low: -1035 ft
Basal Transgressive Facies of Bakken – “Pronghorn Member”
Or Big Valley-Margin Facies?? (But Unconf. On Torquay)

BF.1A: Subfacies a, b, c, d
Stratified Basin Model for Bakken Black “Shales”

Oxidization of organic matter-high alkalinity, high pH: favorable to precip’tn of fine crystalline dolomite?
= Bakken BF.8, other.

Potential Chemo-Processes
- Sulphate reduction
- Oxidation of organic matter
- Early methanogenesis
- Precipitation of pyrite
- Precipitation of carbonate??
- Siderite diagenesis
  - Direct Precipitation?
    - of bacterially-mediated framboidal pyrite
  - OM
    - Organic matter:
      - phytoplanktonic and terrestrial? sources

Variables
- Tectonics-basin subsidence/ arch uplift
- Sea level cyclicity, glacioeustacy?
- Depth of chemocline
- Organic productivity, accumulation rate
- Siliciclastic supply
- Climatic factors
Bakken BF.1B “Lower Shale”
Bakken BF.2 “Lower Siltstone”
Selected Trends and Calcite Cement (N. Dakota)
(on Third-Order Residual Structure)

- Thins/pinches out onto ‘Eastern Shelf’
- Thickest in Northern “East Nesson” Subbasin
- Increased microbioclastic content (or preservation?) into ‘East Nesson’ Subbasin, off eastern shelf
  = Increased nodular/massive calcite cement (core data only)
  = Reduced poroperm

INJ: Sediment-infilled injection structures in BF 1B
Bakken Siltstone (BF 2/3) Isopach
Bakken Facies 3: Laminitie to Rippled Silt/Sand - Distribution & Subfacies Trends
Event Bed Deposition, Bakken Facies 7,8

Violet Olsen, 9,974.5 ft
BF 7, Base 8: Depositional Trends of Storm? Event Beds

Corrected to L. Dev - E. Miss paleotectonic/paleogeographic setting, Source from SE?
Internal Bakken Unconformities
RESERVOIR
Bakken Composition: BF.2 Siltstone

- Very high dolomite comp
- Very early diagenetic emplacement (pre-comp.) of auth. dolomite
- Some on detrital dolo. nuclei (= Montney)
- Some ≈ syndepositional – reworked into event beds
- Density, Pe impact
- Reduced compaction??

**Ave. by Point Count % * (Excluding burrows)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Count</th>
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<tbody>
<tr>
<td>Quartz</td>
<td>43</td>
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<tr>
<td>Feldspar</td>
<td>7</td>
</tr>
<tr>
<td>Musc. Mica</td>
<td>1</td>
</tr>
<tr>
<td>Heavies</td>
<td>1</td>
</tr>
<tr>
<td>Clay/Mx</td>
<td>0</td>
</tr>
<tr>
<td>Dolomite (Detr/Auth)</td>
<td>46</td>
</tr>
<tr>
<td>Pyrite</td>
<td>2</td>
</tr>
<tr>
<td>Macro-Porosity</td>
<td>28</td>
</tr>
</tbody>
</table>

*n=4

* Contrex Consulting

1-2-7-11W2
1,711.1m
Bakken:
Porosity-Perm by Facies: 1
Bakken:
Porosity-Perm by Facies: 2
Bakken: Porosity vs Depth, BF.2b

For described core with analysed BF.2b (n > 3)

Average • Range

BK Trend vs WCSB Poro-Depth

From Ehrenberg & Nadeau, 2005
HYDROGEOLOGY AND MIGRATION MODELING
Geothermal Gradient Map
Mature Source Rock Map
Fresh Water Head Map
Bakken Salinity Map
Three Forks Structure Map
Water Impelling Force Vector Calculation

\[ F_w^* = -\nabla h + [(D_{pw} - D_{fw})/D_{fw}] \nabla E_b \]

- \( D_{pw} \) = point water density
- \( D_{fw} \) = freshwater density
- \( h \) = freshwater head
- \( \nabla \) = gradient operator
- \( E_b \) = elevation of confining surface
- \( \bullet \) = grid node
Water Migration Map
Bakken Play Types
PETROPHYSICS
Petrophysical Answer Log
SW Map Bakken Sandstone (BF4/5) Facies
PRELIMINARY STRESS ANALYSIS
• Minimum Principal Stress can be derived from ISIP
• Fracture closure pressure is a fraction of the ISIP
• Variable but usually 0.8-0.9 of ISIP
• Fracture closure pressure is equivalent to the Minimum Principal Stress
The Well Completions & Frac Database, brought to you by Canadian Discovery Ltd. and engineering partner Introspec Energy Group Inc., provides industry with a frac and completions data set that is:

**Searchable** - predefined and custom queries
**Reliable** - engineering QA/QC, source documents
**Comprehensive** - resource plays across Western Canada
**Analysis Ready** - reports, lists, graphs, exportable

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Parshall Bakken 12 Month Cum Oil vs Number of Stages

- **12 Month Cumulative Oil (MMSTB)**
- **Number of Stages (N=17)**

The graph shows the relationship between the number of stages and cumulative oil production over 12 months.
Parshall Bakken 12 Month Cum. Oil vs Wellbore Length

Horizontal Wellbore Length (feet)

12 Month Cumulative Oil (MSTB)

N=17
Parshall Bakken IP Oil vs Avg. MPS Gradient
Parshall Bakken IP Oil/Stage vs Avg. MPS Gradient
Parshall Bakken 12 Month Cum. Oil vs Avg. MPS Gradient
Parshall Bakken 12 Month Cumulative Oil/Stage vs Avg. MPS Gradient

![Graph showing the relationship between 12 Month Cumulative Oil/Stage (MSTB) and Average MPS Gradient (kPa/m).](image)

- **Y-axis**: 12 Month Cumulative Oil/Stage (MSTB)
- **X-axis**: Average MPS Gradient (kPa/m)
- **Data Points**: Represented by blue diamonds
- **Trend Line**: Red line indicating a negative correlation
- **Sample Size (N)**: 17
Parshall Bakken 12 Month Cum. Oil/Stage vs Avg. MPS Gradient

12 Month Cumulative Oil/Stage (MSTB)

Average MPS Gradient (kPa/m)

N=17
Parshall Bakken First 12 Month Avg. Rate/Well vs MPS Gradient
Conclusions

• There are five key components to a resource play that should be addressed.
• The Bakken has complex facies trends and a diagenetic overprint reflecting tectono-eustatic controls.
• Bakken reservoir quality is a function of facies variations and depth.
• Geochemistry, hydrogeology and migration modeling can be used to identify three play types.
  – A highly overpressured oil rich resource play.
  – An overpressured less oil rich resource play.
  – A normally pressured conventional (migrated) play.
• Petrophysics confirms the migration model.
• Stress regimes, derived from frac data, appear to have a significant impact on productivity in the Parshall area.
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