Applications in Geochemistry, Geophysics and Petrophysics for the Exploration and Production of the Niobrara Formation in the Powder River Basin and Adjacent Areas

Cal Reppe and Vanja M. Stevanovic
Yates Petroleum Corporation

WGA/SPE January 30, 2015
Acknowledgements

- Yates Petroleum Corporation
- Ballard Petroleum Holdings, LLC
- TGS
- Schlumberger/Terra Tek
- Seitel
- NuTech
- Chemostrat
- Sirius
- Weatherford
Outline

▪ Well Data, DST's, Cores, Published Reports/Articles, Databases

▪ Reservoir Analysis, Depositional Models & Sequence Stratigraphy

▪ Structural & Geophysical Evaluations

▪ Modern Logging Applications

▪ Temperature Modeling, API Gravities, Gas-Oil Ratios (GOR)
Outline (continued)

- Organic & Inorganic Geochemical Analysis
- Timing and Migration of Hydrocarbons
- Identification of Sweet Spots
- Environmental Issues & Infrastructure
- South Dakota Exploration Play
Regional Map

(Wood MacKenzie, 2006)
- Well Data, DST’s, Cores, Published Reports/Articles, Databases
- Reservoir Analysis & Depositional Models
  - Structural & Geophysical Evaluations
  - Modern Logging Applications
  - Temperature Modeling, API Gravities, Gas-Oil Ratios (GOR)
  - Organic & Inorganic Geochemical Analysis
  - Timing and Migration of Hydrocarbons
  - Identification of Sweet Spots
  - Environmental Issues & Infrastructure
  - South Dakota Exploration Play
Upper Cretaceous Seaway
(Interpretation by Ron Blakey)
Stratigraphic Column

Niobrara Formation Characteristics

- Structural Deformation Episodes & Sweet Spots
- Maturation and Total Organic Carbon %
- Chalk and Clastic Benches Reservoir Characteristics
- Fractures associated with Structural Normal and Listric Normal Faulting, i.e. Horsts and Grabens, and Salt Dissolution/Collapse
- Regional East to West and North to South Niobrara Lithologic Correlations
- Mapping Lithologic Trends with Gamma Ray, Compensated Neutron Porosity, & Resistivity
Kauffman, 1977

Overview Niobrara Fm Depositional Trends

Schlumberger Intera - Cretaceous Niobrara Formation Study, 1992
Schlumberger
Intera - Cretaceous Niobrara Formation Study, 1992
Niobrara Structural Cross Section
Overview Niobrara Formation

Schlumberger
Intera - Cretaceous Niobrara Formation Study, 1992

Niobrara Formation Isopach

Overview Niobrara Formation
Tight Oil DST

Tennessee Gas
#1 USA Helen V. Smith
Sec. 8-T47N-R69W
API 4900505091
- Well Data, DST's, Cores, Published Reports/Articles, Databases
- Reservoir Analysis & Depositional Models
- **Structural & Geophysical Evaluations**
- Modern Logging Applications
- Temperature Modeling, API Gravities, Gas-Oil Ratios (GOR)
- Organic & Inorganic Geochemical Analysis
- Timing and Migration of Hydrocarbons
- Identification of Sweet Spots
- Environmental Issues & Infrastructure
- South Dakota Exploration Play
Structural Deformation Episodes

Precambrian Lineaments
Late Paleozoic Lineaments
Laramide Orogeny Lineaments

Schlumberger
Intera - Cretaceous Niobrara Formation Study, 1992
Schlumberger
Intera - Cretaceous
Niobrara Formation Study, 1992

Slack, 1981
3D Geophysical Salt dissolution map
Modern Logging Applications

• Triple or Quad Combo - Resistivity, Neutron-Density, Acoustic, and/or Cross-Dipole XMAC
• Nuclear Magnetic Resonance
• Dipmeter
• Formation Micro Imager (FMI)

Logging suites can be incorporated with cores and geochemistry which will assist with the interpretations of structure, fractures, sequence stratigraphy, and depositional models.
Petrophysical logs
Petrophysical Map: HCPV
Chemostratigraphic correlation
▪ Well Data, DST’s, Cores, Published Reports/Articles, Databases
▪ Reservoir Analysis & Depositional Models
▪ Structural & Geophysical Evaluations
▪ Modern Logging Applications
▪ **Temperature Modeling, API Gravities, Gas-Oil Ratios (GOR)**
▪ Organic & Inorganic Geochemical Analysis
▪ Timing and Migration of Hydrocarbons
▪ Identification of Sweet Spots
▪ Environmental Issues & Infrastructure
▪ South Dakota Exploration Play
Niobrara Oil API (gravity’s)

Niobrara Gas Oil Ratios (GOR’s)

Geologic Assessment of Undiscovered Oil and Gas in the Powder River Basin Province, Wyoming and Montana
Borehole Temperatures (BHT)

Note: These temperatures are not calibrated or normalized to the actual BHT. The BHT are taken from the well log header.
Gas - Oil Ratio (GOR) MAP

Note: The GOR’s were calculated using the cumulative oil and gas produced by a well. The oil and gas production was taken from the Wyoming Oil and Gas Conservation Commission’s (WOGCC) web site and normalized to the same date.
- Well Data, DST's, Cores, Published Reports/Articles, Databases
- Reservoir Analysis & Depositional Models
- Structural & Geophysical Evaluations
- Modern Logging Applications
- Temperature Modeling, API Gravities, Gas-Oil Ratios (GOR)
- **Organic & Inorganic Geochemical Analysis**
- Timing and Migration of Hydrocarbons
- Identification of Sweet Spots
- Environmental Issues & Infrastructure
- South Dakota Exploration Play
## Kinetics

<table>
<thead>
<tr>
<th>Depth</th>
<th>Formation</th>
<th>TOC</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>Tmax</th>
<th>Hi</th>
<th>Oi</th>
<th>PI</th>
<th>Mean Ea</th>
</tr>
</thead>
<tbody>
<tr>
<td>9620</td>
<td>Sharon Springs</td>
<td>1.64</td>
<td>0.07</td>
<td>2.41</td>
<td>0.37</td>
<td>441</td>
<td>147</td>
<td>23</td>
<td>0.03</td>
<td>A 55.74</td>
</tr>
<tr>
<td>9770</td>
<td>Niobrara</td>
<td>2.58</td>
<td>0.06</td>
<td>4.62</td>
<td>0.42</td>
<td>443</td>
<td>179</td>
<td>16</td>
<td>0.01</td>
<td>A 55.68</td>
</tr>
<tr>
<td>9980</td>
<td>Niobrara</td>
<td>2.79</td>
<td>0.06</td>
<td>4.64</td>
<td>0.58</td>
<td>447</td>
<td>166</td>
<td>21</td>
<td>0.01</td>
<td>B 56.01</td>
</tr>
<tr>
<td>10010</td>
<td>Carlile</td>
<td>2.54</td>
<td>0.07</td>
<td>3.47</td>
<td>0.58</td>
<td>447</td>
<td>137</td>
<td>23</td>
<td>0.02</td>
<td>B 55.93</td>
</tr>
</tbody>
</table>
## Organic Geochemistry

<table>
<thead>
<tr>
<th>#</th>
<th>Saturates</th>
<th>Aromatics</th>
<th>NSO’s</th>
<th>Asphaltenes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68.72</td>
<td>25.94</td>
<td>5.28</td>
<td>0.050</td>
</tr>
<tr>
<td>2</td>
<td>62.59</td>
<td>31.78</td>
<td>5.37</td>
<td>0.243</td>
</tr>
<tr>
<td>3</td>
<td>64.30</td>
<td>29.69</td>
<td>5.68</td>
<td>0.315</td>
</tr>
<tr>
<td>4</td>
<td>64.88</td>
<td>29.23</td>
<td>5.70</td>
<td>0.189</td>
</tr>
<tr>
<td>Depth</td>
<td>Quartz</td>
<td>Feldspar</td>
<td>Calcite</td>
<td>Dolomite</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>----------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>1902</td>
<td>29</td>
<td>8</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>1911</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>1914</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1917</td>
<td>26</td>
<td>7</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>1934</td>
<td>28</td>
<td>8</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>1935</td>
<td>17</td>
<td>4</td>
<td>20</td>
<td>5</td>
</tr>
</tbody>
</table>

XRD Analysis
Proppant embedment test
Van Krevelen Diagram showing the primary composition of the different types of kerogen and the changes as a function of heating (maturation) during progressive burial (from Bjorlykke, 2010)

S1 = @ 300°C measure the oil and gas that has already been generated in the source rock
S2 = @ 400-460°C represents the amount of HC generated from the kerogen in the sample
S3 = from C. 300-550°C CO₂ is generated, collected and measured (from Bjorlykke, 2010)
• Well Data, DST's, Cores, Published Reports/Articles, Databases
• Reservoir Analysis & Depositional Models
• Structural & Geophysical Evaluations
• Modern Logging Applications
• Temperature Modeling, API Gravities, Gas-Oil Ratios (GOR)
• Organic & Inorganic Geochemical Analysis
• Timing and Migration of Hydrocarbons
• Identification of Sweet Spots
• Environmental Issues & Infrastructure
• South Dakota Exploration Play
Timing and Migration of Hydrocarbons
Identification of Sweet Spots

EXPLANATION
- Lineament
- Niobrara production
- Niobrara depth > 8,000 feet
- Potential sweet spots
- Province 5033 boundary

Geologic Assessment of Undiscovered Oil and Gas in the Powder River Basin Province, Wyoming and Montana
Environmental and Infrastructure Considerations

Environmental and Infrastructure issues need to be addressed. If your evaluations indicate hydrocarbon potential but the environmental and infrastructure indicate you wouldn’t be able to drill and/or produce the hydrocarbons. Than….it’s not a drillable prospect…..at this time.
- Well Data, DST's, Cores, Published Reports/Articles, Databases
- Reservoir Analysis & Depositional Models
- Structural & Geophysical Evaluations
- Modern Logging Applications
- Temperature Modeling, API Gravities, Gas-Oil Ratios (GOR)
- Organic & Inorganic Geochemical Analysis
- Timing and Migration of Hydrocarbons
- Identification of Sweet Spots
- Environmental Issues & Infrastructure
- South Dakota Exploration Play
South Dakota Exploration Play

Potential oil Migration pathways
Contour Interval = 10 °C
Niobrara N850 Interval

Schlumberger
Intera - Cretaceous
Niobrara Formation
Study, 1992

Niobrara Basal Chalk – N850
Schlumberger – Intera Study

Effects of Paleohighs on N850 Interval Chalks
Niobrara N900 Interval

Schlumberger
Intera - Cretaceous
Niobrara Formation
Study, 1992
Oil and Gas shows were associated with water production during production tests and drill stem tests (DSTs). As a result, a strong hydrodynamic influence is present. Therefore, hydrodynamic stratigraphic and structure traps will need to be considered.

Oil and Gas shows were taken SDGS, Circular 41, 1970 and SDGS Open File Report 2-BAS, 1981

Colorado Lineament

Gas Shows

Oil Shows

A Geology of South Dakota, Part 1, The Surface, E. P. Rothrock, 1943
Preliminary PreCambrian Structure Map, 1961
Closing Statement

As geologists, we have to incorporate existing & new data from geology, geochemistry, and geophysics into our exploration & production reservoir characterization & analysis.

This is only part of our industry’s strategy in developing resource plays. The reservoir characterization needs to be incorporated into the Completion Engineers development of a completion model/strategy. This completion program needs to be optimized to provide the best Rate of Return/Investment (ROR/ROI) and/or the best Net Present Value (NPV). In order to achieve this, the geologist and engineers must work together as a TEAM.

Quoting Mike Vincent: “Neither the Geologists or Completion Engineers should fall into the trap of becoming Xerox Geologists or Engineers. If we do, we should be indicted for Geology and/or Engineering Malpractice”.

As professionals, we need to plan for success.
America's Cup, San Francisco, CA September 2014
USA's Oracle was down 8 to 1 to New Zealand's Emirates
Oracle's shipper was quoted as saying "it will be one hell of a comeback".
Oracle won 9 to 8