Seismic attributes of the Barnett and Bakken shales

Bode Omoboya

16th May, 2013

- Introduction
- Bakken Shale Case Study
- Barnett Shale Case Study
- Other Forward Modeling Projects
Most oil in the Bakken petroleum system resides in open fractures in the Middle Member (Pitman et al, 2001).

Source: USGS

<table>
<thead>
<tr>
<th>Geologic Age</th>
<th>Upper Devonian/Lower Miss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithology (Middle Member)</td>
<td>Sandstone/Siltstone/Dolomite</td>
</tr>
<tr>
<td>Total Area (sq mi)</td>
<td>200000</td>
</tr>
<tr>
<td>Total Gas (tcf)</td>
<td>945</td>
</tr>
<tr>
<td>Producible Gas (tcf)</td>
<td>20</td>
</tr>
<tr>
<td>Depth (feet)</td>
<td>10000</td>
</tr>
<tr>
<td>Thickness (feet)</td>
<td>150</td>
</tr>
<tr>
<td>Pressure (psi)</td>
<td>5600</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>5</td>
</tr>
<tr>
<td>Matrix Permeability (nD)</td>
<td>10000</td>
</tr>
<tr>
<td>Pressure Gradient (psi/ft)</td>
<td>0.5</td>
</tr>
<tr>
<td>Clay Content (Middle Member %)</td>
<td>5</td>
</tr>
<tr>
<td>Average Horz Well Cost ($M)</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Bakken Shale – Core Samples and Well Logs

Upper Shale

Middle Member

Lower Shale

Core Image from NDIC

Well: NELSON

MD= 9100 ft

Upper Bakken

Middle Member

Lower Bakken

MD= 9250 ft
Bakken Shale – Shale Volume

1000 ft. Interval 40% – 60% Vsh

200 ft. Interval 80% Vsh

\[ I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \]

\[ V_{sh} = \frac{I_{GR}}{3 - 2I_{GR}} \]

Steiber, 1970

Data Courtesy of Hess Corporation
Bakken Shale – Non-Hyperbolic Moveout

\[ V = 3000 \text{ ft/s} \]

\[ V = 16000 \text{ ft/s} \]

\[ X = 0 \text{ ft} \]

\[ X = 15000 \text{ ft} \]

<table>
<thead>
<tr>
<th>( C_{11} )</th>
<th>( C_{33} )</th>
<th>( C_{44} )</th>
<th>( C_{66} )</th>
<th>( C_{13} )</th>
<th>( \varepsilon )</th>
<th>( \gamma )</th>
<th>( \delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>343</td>
<td>227</td>
<td>54</td>
<td>106</td>
<td>107</td>
<td>0.255</td>
<td>0.481</td>
<td>-0.051</td>
</tr>
</tbody>
</table>

\( \eta \) from Core = 0.341

\( \eta \) from Seismic \( \approx \) 0.32

Jones and Wang, 1981
Physical modeling of anisotropic domains: Ultraasonic imaging of laser-etched fractures in glass

*(Geophysics, 2013)*

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Mark Willis

Samik Sil
Minimum Offset: 400m
Maximum Offset: 2000m
CMP Interval: 20m
Depth of Model: 800m (TWT to end of model = 350ms)
Average Velocity of Model: 5800m/s
Dominant Frequency/Wavelength: 120 Hz / 50m

Schematic of NMO eta scan experiments on glass models

Model C3
Model C10
Model C9 “BAKKEN MODEL”
Bakken Shale – Forward Modeling Project

- Model C3
  - Max $\eta = 0.0$
  - Blank Model

- Model C10
  - Max $\eta = 0.23$
  - VTI Model

- Model C9 Azimuth 0
  - Max $\eta = 0.14$
  - VTI+HTI+VTI

- Model C9 Azimuth 45
  - Max $\eta = 0.08$
  - VTI+HTI+VTI

- Model C9 Azimuth 90
  - Max $\eta = -0.06$
  - VTI+HTI+VTI

Max $\eta$

- Model C10 VTI Model
- Model C9 Azimuth 0
- Model C9 Azimuth 45
- Model C3 Blank Model
- Model C9 Azimuth 90
Barnett Shale Quick Facts

- **Geologic Age**: Mississipian
- **Lithology**: Dense Organic rich shale
- **Water Saturation (clay-bound)**: 20-30%
- **Gas Saturation**: 70-80%
- **Depth (feet)**: 4000 - 5000
- **Thickness (feet)**: 5-1000 ft
- **Pressure (psi)**: 5600
- **Porosity (%)**: 5
- **Natural fractures**: 100 to 120 deg
- **Natural fractures**: More common in limestone interbeds
- **Artificial fractures**: Oriented in the direction of minimal stress

N-S structural cross section through the Newark Field in the Fort Worth Basin. Modified after Burna and Smosna, 2011
Barnett Shale – CDP Gathers after Time Processing and Migration
Barnett Shale – Residual eta ($\eta$) Volume

$t = 0s$

$\eta = -0.2$

$t = 1.5s$

$\eta = 0.2$
Barnett Shale – Seismic to well tie

Well Y

TWT = 600 ms

TVD = 3300 feet

TWT = 800 ms

TVD = 4100 feet

TVD = 4300 feet

Sonic velocity log

Gamma ray log

Density log

Computed reflectivity log
P-Impedance Volume

t = 0.55ms

Base Marble Falls

Top Barnett

Top Ellenberger

t = 0.85ms
Density Volume

Base Marble Falls
Top Barnett
Top Ellenberger

$t = 0.55\text{ms}$

$t = 0.85\text{ms}$
Mu-Rho Volume

$t = 0.55\text{ms}$

$\text{Base Marble Falls}$

$\text{Top Barnett}$

$\text{Top Ellenberger}$

$t = 0.85\text{ms}$
Constituent Materials:

- Resin
- Plexiglass (polycarbonate)
- Copper tubes

Experimental study of the influence of fluids on seismic azimuthal anisotropy.  
(Geophysical Prospecting, 2013, submitted, under review)

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Barnett Shale – Forward Modeling Project

Min offset = 400m, Max offset = 2200m, Offset interval = 30m

All travel time and distance/offset measurements are scaled by a factor of 10,000

Gas saturated
Vnmo = 2131 m/s

Water saturated
Vnmo = 2372 m/s

NMO corrected gather at 30° azimuth at gas and water saturated conditions
Barnett Shale – Forward Modeling Project

Water Saturated

Glycerin Saturated

Stiffness Coefficient (GPa)
Model M3
Crack Density = 4.0 \%

Model M2
Crack Density = 4.5 \%

Shear wave anisotropy from aligned inclusions:
ultrasonic frequency dependence of velocity and attenuation

\( \varepsilon = \frac{N \pi r^2 h}{V} \)

Hudson, 1981
Forward Modeling Examples: Source Frequency VS Anisotropy
Forward Modeling Examples: Source Frequency VS Anisotropy

\[ \gamma' = \frac{1}{2} \left( \frac{V_{S1}^2}{V_{S2}^2} - 1 \right) \]

Thomsen, 1986
Acknowledgement

- Dr. Steve Peterson – Marathon Oil
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- Dr. Edip Baysal – Paradigm
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