3D seismic proves its value in Bakken geosteering

Angie Southcott
Outline

• **Introduction to the Williston Basin**

• Background and motivation for the talk

• 3D processing history

• Converting time to depth

• Conclusions
Williston Basin stratigraphic column

Modified from LeFever

- **Oil producer**
- **Gas producer**
- **Source rock**

**Modified from Peterson**

Not to scale
Williston Basin stratigraphic column

**BAKKEN**
- **TOP OF BAKKEN**
  - Upper Bakken Shale
- Middle Bakken
- Lower Bakken Shale
  - First Bench
  - Unit 5
  - Second Bench
- Third Bench
- Fourth Bench
- **TOP OF BIRDBEAR**

**THREE FORKS**

**GAMMA RAY**

**RESISTIVITY**

**Target zone for geosteering**

Middle Bakken target zone isochore from logs
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Shale strikes not just a WPX problem

175 sidetracks on map

5 # of sidetracks
Republic Plaza is 2 miles from where this photo was taken. Middle Bakken is about four stories thick (yellow bar).
How did we get the 90% reduction in geosteering errors?
Cycle of Learning

Data

Failure to transfer information

Seismic quality, interpretation, pipe tally, wireline stretch, errors in well tops, missing data, un-reprocessed data, incorrect data, etc.

Interpretation, type-log selection

Steering and type-log selection

Progs and surfaces

Time to depth conversion, gridding algorithms, interpretation, prog well selection

Action to address risk level

Estimation of risk

Lack of action, wrong action, ineffective application

Overconfidence, under-confidence

Communication gap

Communication gap
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3D processing history: Converting to depth for geosteering

Average Velocity ($V_{avg}$)

Time

$\frac{(V_{avg} \times \text{Time})}{2} = \text{Depth}$

10,000'

target zone

projected lateral
3D processing history: Processing progression - Post Stack

- Basic processing flow
- Spectral Whitening 6-84Hz
- Post Stack Spectral Balancing

Upper Bakken Thickness: 15-25’
Middle Bakken Thickness: 25-45’
Lower Bakken Thickness: 25-40’
First Bench Three Forks Thickness: 40-60’

62.525 Hz
3D processing history: Processing progression - Pre Stack Time Migration

- Spectral Whitening 6-84Hz
- PSTM Kirchhoff Migration
- Residual Velocity Analysis
- Radon Filter, Horizon Based
- Post Stack Spectral Balancing

Upper Bakken
Three Forks
Bakken

Upper Bakken Thickness: 15'-25'
Middle Bakken Thickness: 25'-45'
Lower Bakken Thickness: 25'-40'
First Bench Three Forks Thickness: 40'-60'

62.525 Hz
3D processing history: Gather panels

Before radon

After radon
Processing progression: Pre Stack Time Migration \( \text{High Frequency Extender} \)

- Spectral Whitening 6-84Hz
- PSTM Kirchhoff Migration
- Residual Velocity Analysis
- Radon Filter, Horizon Based
- High Frequency Enhancement

**Thicknesses:**
- Upper Bakken Thickness: 15'-25'
- Middle Bakken Thickness: 25'-45'
- Lower Bakken Thickness: 25'-40'
- First Bench Three Forks Thickness: 40'-60'
### Processing progression: Pre Stack Time Migration HFE

**Table:**

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<thead>
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<th>Time</th>
<th>Geo</th>
<th>FV</th>
<th>Voxel Size</th>
<th>Log Val (b)</th>
<th>Trace</th>
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<tbody>
<tr>
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<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>2:20</td>
<td>0.05</td>
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<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Diagram:**

- Upper Bakken
- Three Forks

**Note:**

- 125.025 Hz
3D processing history: refining HFE volume

Spectral Balancing with Radon

HFE version 1

HFE version 2
3D processing history: HFE

vertical well

Upper Bakken

Three Forks
• Well logs and core verify fault interpretation not seen until this HFE volume
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• Converting time to depth
  • PSDM workflow
  • Well tops and their accuracy
  • Depth calibration of CBL and MWD/LWD logs

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Converting time to depth: Isotropic Depth Conversion

Depth Domain

**START**

- **PSDM**
  - Tomography applied
  - Tops do not fit horizons
  - Bakken not imaged

- VelWell uses all horizons except Bakken

**PSDM**
- Tomography applied
- Fits everything except Bakken

**PSDM HFE**
- Bakken not in the right place
- Pick Bakken horizon

- VelWell uses all horizons including Bakken

New Velocity Field
- Modified by horizons including Upper Bakken picked in depth and fits tops

- **PSDM HFE with VelWell applied**
  - Fits Bakken

Time Domain

- **Velocity Field**
  - Modified by horizons picked in depth and fits tops

- **Velocity Field**
  - Modified by horizons picked in depth and fits tops

- **PSDM converted to time**
  - Using modified velocity field

- **Apply HFE**
  - To resolve the Bakken

*The major assumption to this workflow is the well tops are consistent and accurate*
Converting time to depth

- After the tomo passes have converged on an answer the PSDM volume is interpreted at key horizons

  - Interpret shallowest horizon
  - Adjust top consistency and fit with wavelet
  - Velocity perturbation

- Go to second shallowest surface and repeat process of comparison to tops
- And so on down to last surface
- Provide fixed tops and interpreted horizons to processor
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• **Converting time to depth**
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Well tops and their accuracy

Suggested seismic Greenhorn pick

Greenhorn

PSDM

GR

Pstm radon Wavelet synthetic

PSDM Trace

GR

Pstm radon Wavelet synthetic

PSDM Trace

GR

Pstm HFE Wavelet synthetic

Seismic pick

Original pick
Well tops and their accuracy

PSTM HFE

PSDM

Wpxenergy
Well tops and their accuracy

- Wells to north showed deepening
- Related to syncline at Charles Salt?

Upper Bakken Vavg original

Pseudo Upper Bakken top from lateral interpretation

Base Charles Salt

Upper Bakken

Three Forks

Vertical portion of well projected onto line
Well tops and their accuracy

- Error of 40 ft/sec is only 0.4%
- Puts the lateral in the Upper Bakken shale
Well tops and their accuracy

- Error of 40 ft/sec is only 0.4%
- Puts the lateral in the Upper Bakken shale
Well tops and their accuracy

Base of Rierdon TWT

Base of Rierdon Vavg original

Base of Rierdon Vavg revised
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Depth calibration of wireline/CBL and MWD/LWD logs

- MWD GR logs turned on in Lodgepole due to time and cost constraints
- CBL GR run from KOP to surface usually months later
Depth calibration of wireline/CBL and MWD/LWD logs

CBL has opportunity to be tied in with different markers at different depths

One choice was to shift MWD GR to CBL GR

Posting TVDSS depths of Upper Bakken top does not suggest that MWD should be shifted to CBL

Shift CBL GR to MWD GR and shift all shallow tops!
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Conclusions

Pre-drill

- 90.5°
- 89.2°

Projected lateral: 10,000’

Target zone: 130’

Post-drill

- 90.68°
- 90.0°
- 89.8°

Actual lateral: 10,000’

Target zone: Thinner than total Middle Bakken thickness – this is **not** a shale strike

• Post drill surfaces modified by lateral GR interpretation
Thank you

WPX Energy

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John Frame
Simon Cole

STERLING

Rus Kappius
Steve Saindon

CGG

Rick Trevino