Seismic Acoustic Impedance Inversion in Reservoir Characterization Utilizing gOcad
Boonsville Field – Central Texas
Data Made Public Thru
The Bureau of Economic Geology

- 5.5 sq. Miles of 3D seismic data
- Vertical seismic profile (VSP) near center of survey
- Digital well logs from 38 wells
- Well markers for the Bend Conglomerate Group
- Perforations, reservoir pressures, production and Petrophysical data for the 38 wells
Contributing Companies and Organizations to This Public Domain Dataset

Arch Petroleum

Enserch
Boonsville Field Location Map

Middle Pennsylvanian
Paleogeography map
Showing the Fort Worth Basin and the Boonsville project area

Modified from
Lahti and Huber (1982)

Modified from
Thompson (1982)
Stratigraphic Column

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>SERIES</th>
<th>GROUP OR FORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>UNDIVIDED</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>WOLFCAMPION</td>
<td>Cisco Group</td>
</tr>
<tr>
<td></td>
<td>VIRGILIAN</td>
<td>Canyon Group</td>
</tr>
<tr>
<td>UPPPER</td>
<td>MISSOURIAN</td>
<td>Strawn Group</td>
</tr>
<tr>
<td>MIDDLE</td>
<td>DES MOINESIAN</td>
<td>Atoka Group</td>
</tr>
<tr>
<td></td>
<td>ATOKAN</td>
<td>Marble Falls</td>
</tr>
<tr>
<td></td>
<td>MORROWAN</td>
<td>and Canyon Formation</td>
</tr>
<tr>
<td>MISSISSIPPIAN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gas from Bend Conglomerate Group
Type Log and Stratigraphic Nomenclature

BEG Sequence nomenclature to define Bend Conglomerate genetic sequences in Boonsville field
Example Seismic Line

- Caddo
- Davis
- Runaway Vineyard
- Marble Falls LS
- Ellenburger LS

2.75 miles

3500 ft
BEG’s Major Conclusions

• Karsting from Ellenburger carbonates cause collapse features compartmentalizing the reservoir.
  – Large range of compartment sizes
• Need 3D seismic to image the collapse features.
• Seismic attributes can sometimes predict the reservoir facies
  – Upper Caddo: Amplitude
  – Lower Caddo: Inst. Frequency
  – Lower Bend Conglomerate sequences not definitive
• Reservoirs often exist as stacked compartments of genetic sequences.
Overview of Reservoir Modeling

- Structural Framework
- Stratigraphic Gridding
- Lithology and Facies Mapping
- Pressure Field

- Rock Properties
- Fracture Network & Stress Field
- Reservoir Fluids & Dynamic Response
Motivation for Reservoir Modeling
- Technical -

- Integration of all relevant and available data.
- Merge data of different scales.
  - Cores.
  - Well logs.
  - Seismic.
  - Production.
- Dynamically update the model as new information becomes available.
- Measurement of errors and uncertainty as well as expected value.
- Specific workflows dependant on number and type of data available.
Motivation for Reservoir Modeling
- Business Case -

• Integration of different disciplines in team.

• Earth model serves as the focal point of interdisciplinary communication.

• Better assessment of risk:
  – Lowering of risk.
  – Proper risk assessment.

• Make better business decisions.
Rock Properties Workflow

**Input Data**
- Well Logs (sonic, density, RT, porosity)
- Seismic Amplitude Data
- Background AI
- Velocity Field

**Process**
- Seismic to Log Calibration
- Inversion to Acoustic Impedance
- Depth Conversion for Correlation to Logs

**Product**
- Rock Property Model of Reservoir in Depth Containing Detailed Seismic Information and Faulted Network
Seismic to Log Calibration

Final Seismic Wavelet
Average of 4 Well Ties

Time Domain Wavelet

Amplitude Spectrum (linear scale)

Avg. Phase 285° (or –75°)
Background AI Model From 4 Wells (Simple Gridding)
Model Based Inversion to Acoustic Impedance (AI)
Model Based Inversion to Acoustic Impedance (AI)

Zero-phase Seismic traces overlaid on AI

Note: Reflections are at layer boundaries.
Check on Inversion and Depth Conversion at Well: Yates 18D

Time Domain

Depth Domain

Caddo

Marble Falls LS

AI from Well Log
Well Log & Seismic AI
Cross-Section at well: Yates 18D
Correlation of Seismic Inverted AI to Log Properties (Simple Gridding Model)

- Log scale properties cross-plotted with lower resolution seismic AI: \((RT \times AI)\) CC=0.31

- Seismic resolution is a lowering of variance
  - Loss of 25\% of rock property variance.

- Necessitates that the well logs be smoothed to the common resolution scale of the seismic data
  - Smoothed logs over 20ft: \((RT \times AI)\) CC=0.41
  - Still low Correlation Coefficient from sub-optimal seismic inversion.
Logging Runs in Boonsville Project Area

Logging Runs

<table>
<thead>
<tr>
<th>Log Type</th>
<th># of this log type</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>36</td>
</tr>
<tr>
<td>SP</td>
<td>38</td>
</tr>
<tr>
<td>GR</td>
<td>18</td>
</tr>
<tr>
<td>NPHI</td>
<td>14</td>
</tr>
<tr>
<td>RHOB</td>
<td>17</td>
</tr>
<tr>
<td>PEF</td>
<td>7</td>
</tr>
<tr>
<td>DELT</td>
<td>4</td>
</tr>
</tbody>
</table>
Many Caddo penetrations gives good log data coverage. Fewer Vineyard penetrations needs seismic data to constrain modeling.
Build a Better Background
Impedance Model

AI Logs (only 4 wells)

RT Logs – many more wells
Build a Better Background
Impedance Model

Use RT as a proxy for AI

Variogram Model for RT Logs

Variogram Parameters
- Anisotropy Direction N45E
- UVW Space Transform
- Ranges = 0.6 & 0.4
- Sill = 0.8 (normalized)

CC = 0.72
(from well log data)
Co-Kriging the RT and AI Log Data

Log_{10}(RT) Kriged Model

Co-Kriged to AI

Filtered back to 0-20Hz

Subdued response due to far distance from well control
AI Model From Co-Located Co-Kriging of Well Log RT and AI Data (Filtered back to 0-20 Hz)

Map View with the 4 wells that have AI log data

Both Low and High AI areas captured by incorporating the RT logs in the modeling
2nd Iteration: Model Based Inversion to AI
Correlation of Seismic Inverted AI to Log Properties

AI vs. Gamma Ray

- Colored by Gamma Ray Log
  - (Red to Orange = Sand, Green to Blue = Shale)
- CC = -0.35

AI vs. Resistivity

- CC = 0.50

Smoothed Logs (20ft average)
Building a Gamma Ray Model w/ Co-Located CoKriging Seismic AI
Building a Resistivity Model w/ Co-Located CoKriging Seismic AI
Relationship of Porosity to RT

Smoothed Logs

CC = -0.80
Building a Porosity Model
CoKriging with $\log_{10}(RT)_{\text{Smth}}$ Model

Shales have porosity set = 0%
Sequential Gaussian Simulation (sGs) For Porosity Model
Conclusions

• Seismic inverted acoustic impedance (AI) improves the interwell reservoir modeling.

• Integration of all the well log data improves the seismic inversion.

• Rock property modeling provides a detailed 3D model of this heterogeneous reservoir.