Synthetic seismograms, Synthetic sonic logs, Synthetic Core

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Consortium for Heavy Oil Research by University Scientists
Synthetic Seismograms

• Synthetic seismograms range from 1-D model seismograms that are least general but most economical to the most general and expensive methods such as viscoelastic 3-D finite difference modeling.
• The 1-D synthetic seismogram derived from sonic and density logs initiates seismic interpretation and is still the workhorse of the industry.
1D- Synthetic Seismograms

• 1-D Synthetic seismograms utilize sonic and density logs to simulate seismic reflection responses from a layered medium. See example below from Watson (2004).
Synthetic Sonic Logs (Lindseth, 1979)

• While 1-D synthetic seismograms, use sonic and density logs to simulate seismic data through:

\[ c_k = \frac{\rho_{k+1}V_{K+1} - \rho_K V_K}{\rho_{k+1}V_{K+1} + \rho_K V_K} \]

• Computing synthetic sonic logs (Lindseth, 1979) used seismic data, with log information for missing frequency bands, to simulate acoustical impedance logs.

\[ \rho_{K+1}V_{K+1} = \frac{\rho_K V_K(1 + c_K)}{(1 - c_K)} \]
Synthetic sonic logs

- These impedance plots from Watson (2002) show:
  - Upper left: impedance model built from interpolation of well logs
  - Upper right: Low pass filter (0-10Hz) of upper left model
  - Lower left: Bandlimited inversion of seismic data only
  - Lower right: Full inversion from combining upper right and lower left.
Synthetic Core

- The concept of “synthetic core” was discussed by Alam (2012 MSc thesis, U of Calgary) who interpreting data from a heavy oil field in Saskatchewan (designated here as P-field).
- Logs and cores were available in a neighbouring field.
- Logs were available, but no cores were available in P-field.
- The depositional environment of the region was known from logs, cores and seismic data in the area.
- Alam synthesized core for wells that had logs but no core.
Synthetic Core Methodology

• The first step involved the computation of shale volumes from gamma ray, density and neutron density logs using shale volume formulae in “The Geological Interpretation of Well Logs” by Rider and Kennedy (2011).

Empirical relationships that use gamma ray, neutron and density logs

\[ I_{sh} = \frac{\gamma_{\text{log}} - \gamma_{\text{Min}}}{\gamma_{\text{Max}} - \gamma_{\text{Min}}} \]

\[ V_{sh1} = 0.083 \left( 2^{3.7(I_{sh})} - 1 \right) \]

(For Tertiary and younger)

\[ V_{SH2} = \frac{\phi_D - \phi_N}{(\phi_D)_{SH} - (\phi_N)_{SH}} \]

\[ V_{SH} = (V_{sh1} + V_{SH2}) / 2 \]

Here, \( I_{sh} \) = Initial Shale Volume Factor
\( V_{sh1} \) = Shale volume Factor from Gamma log
\( V_{SH2} \) = Shale volume Factor from Porosity logs
\( V_{SH} \) = Average Shale volume Factor

(After Thomas and Steiber, 1975)
Facies Templates for Depositional Settings

• Templates were established that corresponded to different depositional environments in the area.
• Each of the templates has different shale and sand volumes ranging from “A” grade (pure sand) to “G” (pure shale)
• There were core samples in the neighboring fields corresponding to these seven different templates.
• Using well logs to establish templates will allow these core samples to serve as “surrogate core” for wells without real core.
Methods: Core Analysis and Facies Distribution

SBED Facies Templates

Facies

A1 = G
A2 = F
B1 = C
B2 = A
B3 = B
C1 = D
C2 = E

Facies A1: Laminated Shale
Facies A2: Bioturbated Shale
Facies B1: Planner bedded Sand
Facies B2: Tabular / Massive Sand
Facies B3: Trough Cross-bedded Sand
Facies C1: High Angle ripple Sand (less shaley Silt)
Facies C2: Low Angle ripple (more shaley Silt) with parallel bedding Shale

Sedimentary structures have been put in SBED templates for the reservoir modeling.
Methods: Core Analysis and Facies Distribution

Vsh (%) Cut-off to the Sedimentary Bed-forms and the Facies

Shale Volume (Vsh) in Relation to Sedimentary Current Structures

The relationship of the Sedimentary facies to the Shale Volume factors.
Shale Volume Factor ($V_{SH}$) and the sedimentary facies for an individual well (1110617) is at the left side and an example of SBED controls is shown at the right side.
Methods: Core Analysis and Facies Distribution

### Facies Stacking (The well 1110617)

<table>
<thead>
<tr>
<th>Depth Interval</th>
<th>Facies Type</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>749.0 – 750.00</td>
<td>Facies A2</td>
<td>Bioturbated / organic Shale</td>
</tr>
<tr>
<td>750.0 – 751.50</td>
<td>Facies C2</td>
<td>Silty sand (more sandy)</td>
</tr>
<tr>
<td>751.5 – 752.00</td>
<td>Facies C1</td>
<td>Silty sand (more silty)</td>
</tr>
<tr>
<td>752.0 – 754.00</td>
<td>Facies C2</td>
<td>Silty sand (more sandy)</td>
</tr>
<tr>
<td>754.0 – 756.00</td>
<td>Facies A1</td>
<td>Massive shale</td>
</tr>
<tr>
<td>756.0 – 758.00</td>
<td>Facies B2</td>
<td>Massive sand</td>
</tr>
<tr>
<td>758.0 – 759.00</td>
<td>Facies C1</td>
<td>Silty sand (more silty)</td>
</tr>
<tr>
<td>759.0 – 760.00</td>
<td>Facies C2</td>
<td>Silty sand (more sandy)</td>
</tr>
<tr>
<td>760.0 – 760.7</td>
<td>Facies C1</td>
<td>Silty sand (more silty)</td>
</tr>
<tr>
<td>760.7 – 763.0</td>
<td>Facies B2</td>
<td>Massive sand</td>
</tr>
<tr>
<td>763.0 – 765.0</td>
<td>Facies B3</td>
<td>Sand (low angled lamina- more shaley)</td>
</tr>
<tr>
<td>765.0 – 767.0</td>
<td>Facies B1</td>
<td>Sand (high angled lamina – less shaley)</td>
</tr>
<tr>
<td>765.0 – 767.0</td>
<td>Facies B1</td>
<td>Sand (high angled lamina – less shaley)</td>
</tr>
<tr>
<td>767.0 – 768.0</td>
<td>Facies B1</td>
<td>Sand (high angled lamina – less shaley)</td>
</tr>
<tr>
<td>768.0 – 769.0</td>
<td>Facies C3</td>
<td>Silty sand (more sandy)</td>
</tr>
<tr>
<td>769.0 – 770.0</td>
<td>Facies A1</td>
<td>Massive shale</td>
</tr>
</tbody>
</table>

Sedimentary facies have been translated from the Vsh curve to the well that has no core data, i.e., well 1110617.
Reservoir property, i.e., Porosity Distribution in the 3D geo-cellular Model

Reservoir properties in the 3D Model: Porosity Distribution.
Self-Validation Tests

- Self-validation tests have been conducted.
- That is, we chose a well where core exists, and pretend we don’t know the core.
- Use this method to synthesize core.
- Compare synthetic core to the actual core.
Self-validation test: Comparison of Synthetic Core to Real Core

Core: 07-22

Litho-facies from Fine Particle Volume

Synthetic Core

Facies Templates

Sand Silty Sand Sandy Silt Mud

Fine Particle Volume (%)
Channels and shale volumes can be imaged effectively with 3-D seismic.

- Time slice of 3D seismic amplitude, showing point bars in the McMurray Formation (Source: Fustic et al, 2007) shown in PhD thesis of Xu (2012)
Developing geological templates corresponding to the seismic images

The point bar system (shown in map view and cross-section (Xu, 2012 PhD thesis) would have a distinct set of depositional templates.
Future Directions

• Self-validation tests have been encouraging. Do more testing.
• Use 3-D seismic data to aid in shale volumes. This should improve our description of $V_{\text{shale}}$. 
Acknowledgements

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