The Shear Difference: Insightful Perspectives and a Proposal

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Figure 5. Rock physics modeling can predict the amount of P-wave acoustic impedance change that CO₂ will introduce into a reservoir. Rarely do the predicted changes of S-waves match reality.

Figure 6. Weyburn Field (RCP’s study area) showing acoustic impedance changes in a 30-m thick reservoir at 1450 m after a year of injection from four twin-leg horizontal wells.

Figure 7. S-wave amplitude changes from S-wave data at Weyburn Field. The largest changes occur on the S22 component, indicating anisotropic changes in the horizontal stress field due to a rise in fluid pressure associated with the formation of the tertiary flood bank. A noise threshold has been applied, and the changes shown are only those that exceed one standard deviation.

T. Davis, The Leading Edge, Jan., 2010
Objectives

Study S-wave data quality issues in a Postle-like setting.

Assess the ability of time-lapse seismic to image the CO₂ flood.

To understand discrepancies between S-wave and P-wave images.
Project Activities

Build a 3D earth model with geology similar to Postle field.

Calculate full-waveform synthetic seismic data in the model.

Process the data using the best ideas for producing high quality images.
The hard parts

Build a 3D earth model with geology similar to Postle field.

Calculate full-waveform synthetic seismic data in the model.

Process the data using the best ideas for producing high quality images.
Data quality issues
240 ms S-wave statics

Baseline survey
Source residual statics

Monitor survey
Source residual statics

From Robert Windels, October, 2009
Data quality issues
S-wave polarization direction changes

Baseline and Time Lapse Survey - PHI - direction of fast Shear Waves

Base Line Survey

Time Lapse Survey
Data quality issues

40ms S-wave splitting in near surface

Baseline and Time Lapse Survey - LAG S1 - S2

Base Line Survey

Time Lapse Survey
Data quality issues
Surface wave scattering
Geologic influences on seismic data quality

Near Surface

Propagation Medium

Target
Slope and Basin Consortium
Brushy Canyon Model
(subjected to mild abuse)
Geologic influences on seismic data quality

Near Surface

Propagation Medium

Target
Dry Rock: Sample 6164 ft

![Graph showing P-wave and S-wave velocity vs differential pressure](image)

**Experimental Setup**

- **Pressure Vessel**
- **Tubing for Fluid**
- **Transducer**
- **Core Sample**
- **Strain Gauge**
- **S2-crystal**
- **S1-crystal**
- **P-crystal**

Borrowed from A. Wandler, 2009
Incident S-Wave AVO for A-Sand and Model

Notes on A-Sand:
Vp ~3900 m/s
Vs ~2350 m/s
Rho ~2.42 g/cc

Notes on Overburden:
Vp ~3322 m/s
Vs ~1524 m/s
Rho ~2.58 g/cc

Model Channel Sand
Postle survey to real-world scale

Postle survey size with geographic compression
Radial and Transverse Gather

Borrowed from Singh and Melvin, 2009
Conclusion 1

Readily available digital information enables rapid construction of useful models.

Next Issue

Is the calculation practical?
## Desired Model

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Dimensions</td>
<td>20 x 20 x 2.5 km</td>
</tr>
<tr>
<td>Upper Frequency</td>
<td>40 Hz</td>
</tr>
<tr>
<td>Velocity Range</td>
<td>500 – 5030 m/s</td>
</tr>
<tr>
<td>Grid Spacing</td>
<td>4-1/6 m</td>
</tr>
<tr>
<td>X,Y Offsets</td>
<td>+/- 4 km</td>
</tr>
<tr>
<td>Record Length</td>
<td>4 seconds</td>
</tr>
<tr>
<td>Symmetry</td>
<td>Heterogeneous HTI</td>
</tr>
<tr>
<td>Target run time</td>
<td>100 host-hrs/shot</td>
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</tbody>
</table>
Acquisition Parameters

Borrowed from Singh and Melvin, 2009
The Test Code

Algorithm: 1987 (J.T. Etgen, SEP Report 56-3)
Implemented: 2003 ('Modern' version of Etgen SEPLIB code)
Ownership: BP
RCP Access: 2004 (Restricted to Allied Geo hardware)

Run Time Estimate

For 5760 shots in an RCP-sized survey
105 days on modern 512 host cluster
(220 host-hours per shot)
Speeding the Calculation

Employ Regone's Method:
Only calculate what you need to conduct your tests

RCP-sized == small

Reduce submodel widths from 8 to 6 km ~ 2x

Consider reducing frequency content ~16x
  VSP data with 40 Hz vs. surface data with 20 Hz

Frequency reduction 40 -> 34 Hz ~2x

Use model-specific code ??
Conclusion 2

Calculating an RCP-sized 9-C survey in an anisotropic 3D elastic model is practical.

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With compromise.

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An industrial-sized calculation, but smaller than many being routinely undertaken today.
References


Borrowed Material


Wandler, A., 2009, Effects of stress from confining pressure and pore pressure on elastic-wave velocities: Presented at the Reservoir Characterization Project Fall Sponsors Meeting, p. 54-55.

Windels, R., 2009, S-wave direct mode processing highlights: Presented at the Reservoir Characterization Project Fall Sponsors Meeting, p. 75, 84.

Acknowledgments
Proposal

To engage RCP sponsors in a collaborative calculation of synthetic shear data.
Timing

Summer 2010
Allied Geo prepares models and executables for distribution to sponsor computing centers.

Fall 2010 through 2011
Sponsors perform calculation in 'white space' and retrun data to RCP.

2011 and beyond
Data are used to advance understanding of S-wave data quality issues.
Models to Calculate

Heterogeneous HTI without near-surface complexity (elastic)

Introduce near-surface complexity (elastic)

Introduce time-lapse component (elastic)

Introduce attenuation (anelastic)
Next steps

Get help! Your help.

Find ways to do the calculation
  Code contributions from anywhere
  White space in consortium member systems

Evaluate cost/value trade offs
  Make sure valuable features aren't needlessly omitted
  Find more ways to reduce run time

Continue testing model parameters
  Relative amplitudes between near surface and target
  Ability to separate noise from signal