Seismic calibration and low frequency modeling

The key to quantitative reservoir characterization

P.R. Mesdag, D. Marquez, L. de Groot*, V. Aubin*

*GDF-SUEZ, Netherlands
Overview

Seismic inversion

- What is it?
- How to QC lateral variations in wavelet amplitude

Modeling the low frequencies

- Inclusion of bodies
- Estimation by sidelobes
Wireline Logs
- Gamma Ray
- Spontaneous Potential
- Neutron
- Density ($\rho$)
- Resistivity (x5)
- Acoustic Sonic ($V_p$)
- Dipole Sonic ($V_s$)

Elastic parameters
- P-impedance ($AI$) = $V_p\rho$
- S-impedance ($SI$) = $V_s\rho$
- $V_p/V_s$
- Poisson Ratio ($\sigma$) = $(V_p^2-2V_s^2)/(2(V_p^2-V_s^2))$
- Lambda Rho ($\lambda\rho$) = $(AI^2 - 2SI^2)$
- Mu Rho ($\mu\rho$) = $SI^2$

Seismic Data
- P-impedance ($AI$)
- S-impedance ($SI$)
- $V_p/V_s$
- Poisson Ratio ($\sigma$)
- Lambda Rho ($\lambda\rho$)
- Mu Rho ($\mu\rho$)

Lithology
- $\phi$ - Porosity
- Fluid Type
- Reservoir Geometry
- Reservoir Connectivity

• Link between logs and seismic
• Different resolution
Inversion integrates data from all disciplines

Petrophysical Data
- Understanding of the formations, the geology & the rock properties

Geological Data
- Structural models, property maps, reservoir size and shape

Geophysical Data
- Rock properties as seen by seismic data

Engineering data
- Property maps, fluid contacts, reservoir connectivity, flow simulation
### Generating properties - key components

<table>
<thead>
<tr>
<th>Workflow</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative impedance</td>
<td>• Relative layer properties</td>
</tr>
<tr>
<td></td>
<td>• Qualitative interpretation</td>
</tr>
<tr>
<td>Absolute impedance</td>
<td>• Absolute layer properties</td>
</tr>
<tr>
<td></td>
<td>• Qualitative and quantitative interpretation</td>
</tr>
<tr>
<td></td>
<td>• Reduction of tuning</td>
</tr>
<tr>
<td></td>
<td>Full stack</td>
</tr>
<tr>
<td>----------------------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Seismic Detail</strong></td>
<td></td>
</tr>
<tr>
<td>→ <strong>Deterministic</strong></td>
<td><img src="Ip.png" alt="Ip" /></td>
</tr>
<tr>
<td></td>
<td>(CSSI)</td>
</tr>
<tr>
<td><strong>Log Detail</strong></td>
<td><img src="Ip.png" alt="Ip, Litho" /></td>
</tr>
<tr>
<td>→ <strong>Geostatistical</strong></td>
<td><img src="Ip.png" alt="Ip, Litho" /></td>
</tr>
<tr>
<td></td>
<td>(MCMC)</td>
</tr>
</tbody>
</table>
Key Features of an Inversion Workflow

- Low frequency modeling
  - sophisticated interpolation: user-defined weighting functions, Multi-Attributes Well Interpolation

- Stable and accurate wavelet estimation
  - Both in full stack and partial stack mode
  - Changes in reflectivity with offset/angle are properly handled
  - Multi-well estimation

- Flexible QC options for selecting the best inversion parameters
  - QC parameter individually or by group
  - Systematically scan or optimization

- Advanced options in simultaneous inversion
  - Laterally-varying wavelets
  - Vertically-varying wavelets: Q- and Scale-factors
  - NMO stretch
Laterally varying seismic amplitude and phase

- Due to overburden effects
  - Gas cloud
  - Salt or shale diapir
  - Chalk

- Varies with position and offset

- Needs to be compensated with laterally varying wavelets

- Careful QC to avoid false amplitude or AVO
Use inversion to QC laterally varying wavelets

Seismic with dimmed zone

Laterally varying wavelets

Inversion results

Inverted reflectivity

Calculate Normal incidence reflectivity ($R_p$) & Shear reflectivity ($R_s$) using a weighted stacking formula

Compare map for QC

Yes

Finish

No
Normal incidence reflectivity RMS map

Normal Incidence reflectivity from seismic

Normal Incidence reflectivity from Inversion

Dimmed zone

Dimmed zone has been compensated
Shear reflectivity RMS map

**Shear reflectivity from seismic**

**Shear reflectivity from Inversion**

Dimmed zone has been compensated
Modeling the low frequencies: How?

- Well interpolation
  - Interpolation concurrent to deposition and structure
  - Preferential location of wells causes bias
  - Over-imprint of good reservoir

- Iterative modeling using body capturing from first pass inversion

- Iterative modeling using the side lobes from a first pass inversion
Full bandwidth inversion is quantitative

Except far below tuning

Black = Input
Red = Inverted
What if layer is not included in low frequency?

First pass inversion without the wedge (red)

Black = Input
Red = First pass inversion

Residual side lobes
Tuning
Dimming
What if layer is not included in low frequency?

Interpret and add to the EarthModel in a second pass

Black = Input
Red = First pass inversion
What if layer is not included in low frequency?

Add new low frequency information

Red = First pass inversion
Blue = Low frequency trend
What if layer is not included in low frequency?

Add new low frequency information

Red = First pass inversion
Black = Second pass inversion
Blue = Low frequency trend
Sand channels in a shale background

A synthetic model based on real data:

- Two channel sands in a shale
LF modeling workflow

- Run an inversion with a simple trend model
- Capture the lithology based on the first pass inversion results
- Update the low frequency model based on
  - Captured bodies and trend or
  - Captured bodies and rock physics information
- Run a new inversion with the updated trend model
Simple trend model

A simple trend model:

- Shale trend used for first pass inversion
Shale trend is used for first pass inversion
Potential sands are captured from first pass inversion results.
LF model for the second pass of inversion

- Composed of Shale trend and constant values for captured sands
Second pass inversion results
Inversion using correct low frequency trend
Inversion using correct LF trend band-pass results

<table>
<thead>
<tr>
<th>P-impedance [kg/m^3 m/s]</th>
<th>Vp/Vs [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1e+06</td>
<td>0.08</td>
</tr>
<tr>
<td>-600000</td>
<td>0.04</td>
</tr>
<tr>
<td>-1e+08</td>
<td>-0.02</td>
</tr>
<tr>
<td>-500000</td>
<td>-0.08</td>
</tr>
<tr>
<td>-1e+06</td>
<td>Undefined</td>
</tr>
</tbody>
</table>

P-impedance – Band-passed

Vp/Vs – Band-passed

Inversion with exact LFM

True model
Conclusions

- Low frequency model can be updated within reservoirs using a sand trend model.
- For thicker packages manual interpretation is required to map sand bodies.
- Side lobe effects are highly reduced using updated low frequency model.
- Sand trends may be adjusted for various fluid scenarios.
- Concept relatively simple and fast to implement.
Example with time lapse signal*

\[ \Delta l_p \text{ monitor minus base} \]

No change assumed in low frequency model

Low frequency model updated for time-lapse

*From Girassol 2004 study by Fugro-Jason
A typical Zechstein problem

- High lateral variability of contrast between Zechstein and Rotliegend
- Well coverage is not sufficient to capture the lateral variability of the high contrast layer in the low frequency model

Predicted average P-Impedance in Rotliegend reservoir too low
What value to use as a trend between the wells?

Black = input model
Red = too soft
Green = correct
Blue = too hard
What value to use as a trend between the wells?

Black = input model
Red = too soft
Green = correct
Blue = too hard

Contrast is independent of actual value
Two-pass inversion

1. First-pass P-impedance inversion
2. Re-interpret of top and base of high contrast layer on first pass inversion
3. Extract Contrast and Update LFM
4. Re-run P-impedance inversion
Updated LFM

First-pass P-impedance inversion

Re-interpret of top and base of high contrast layer on first pass inversion

Extract Contrast and Update LFM

Re-run P-impedance inversion
Step 1: Calculate the bandlimited P-Impedance contrast over the Top Rotliegend

The minimum P-Impedance directly below the interpreted horizon is subtracted from the maximum P-Impedance directly above the interpreted horizon.

Upper panel: Bandpass P-Impedance section with P-Impedance logs in overlay.
Lower panel: P-Impedance contrast over the Top Rotliegend interpretation.

20 ms below
Updating the low frequency model

Step 2: Extract the average P-Impedance from Rotliegend in the original LFM

Upper panel: P-Impedance trend model
Lower panel: mean P-Impedance extracted from the Rotliegend in the top panel
Updating the low frequency model

Step 3: Add the P-Impedance contrast to the LFM Rotliegend P-Impedance

New input horizon
Updating the low frequency model

Step 4: Replace the new Zechstein P-Impedance in the original LFM

Top: original FT LFM. Middle: updated LFM. Bottom: difference.
Inversion results and QC

Extracted mean P-Impedance from Upper Slochteren sandstone

Upper panel: Original RockTrace P-Impedance; Middle panel: Newly merged P-impedance; Lower panel: mean P-Impedance. Original is in black.
Inversion results and QC

P-impedance (pseudo) logs

Blue = well data; Black = from original inversion; Red = from newly merged model
Map of average P-Impedance of the upper Slochteren sandstone

Mean P-impedance extracted from 5 to 50 ms below the Top Rotliegend horizon. Left panel: from newly merged P-impedance. Right panel: from the original inversion. The contours are from the Top Rotliegend time representation.
Conclusions

- Imprecise information in the LFM about high contrast layers causes residual sidelobes in neighboring layers.
- Adding contrast information to the LFM helps alleviating sidelobe effects.
Thanks to co-authors and GdF Suez Production Netherlands BV