Blueback Workflows for Seismic Reservoir Characterization

written and presented by Patrick Connolly and supported by Cegal

This course will provide participants with the skills needed to design and implement workflows for seismic reservoir characterization based on the Cegal Blueback suite of QI applications. The course covers both the theory and practice of coloured inversion, AVO including elastic and extended elastic impedance, DHIs, seismic net pay and inversion including the new stochastic application ODiSI.

This is a classroom based course using examples, laptop based exercises and discussion plus the opportunity to allow participants to immediately apply the theory to real data examples within the Petrel environment using the Blueback Seismic Reservoir Characterization, ODiSI, Rock Physics and Investigator plug-ins. The course can also include a workshop session to discuss your own projects and data.

The core components of the course form an integrated workflow and hence we recommend a minimum of three days to cover the key elements with five days required for a full development of all the elements.

The course will be delivered at an intermediate level. Participants should have a basic knowledge of the seismic method, including acquisition and processing with a minimum of three years working with seismic data. However, the subject matter of this course, AVO and inversion, is covered from basic principles. A complete copy of the slides is provided to each participant.
Summary

The primary objective of the course is to help make your seismic more like geology. This is achieved through a number of conceptually simple steps;

1. Transforming from reflectivity to relative impedance and improving resolution (Coloured Inversion)
2. Coordinate rotating intercept and gradient data to optimize correlation with desired reservoir properties (Extended Elastic Impedance)
3. Removing tuning effects and calibrating amplitudes (Seismic Net Pay), or
4. Inverting optimized relative impedances to reservoir properties.

This last step will be illustrated using the new stochastic inversion application ODiSI that performs the inversion by matching the seismic data to very large numbers of pseudo-wells.

The key message is that, rather than putting the seismic data into one complicated application, it is better to proceed through a series of simpler, comprehendible steps. The user can then develop an intuitive feel for the relationship between the input and output and thereby optimize the results from each component of the workflow. This leads to an appreciation of the level of confidence that can be placed in the final results.

Judgment by eye is critical. There is no way to calculate optimum parameters and there is no way to measure the uncertainty of the final results; there are always too many unknowns. For this reason it is always best to apply transformations to the seismic rather than, say, analysing cross-plots of extracted seismic measurements where context is lost. Staying within the seismic domain provides broader geological context allowing the user to best exercise judgement.

This course provides the theory behind each step of the workflow, reinforced with Excel exercises, and discusses practical aspects of implementation with participants able to apply ideas to real data within the Petrel environment using Cegal plug-ins.
Coloured Inversion

- The theory behind the characteristic form of impedance and reflectivity spectra based on the statistics of bed thickness distributions.
- The advantages of relative impedance over reflectivity.
- Maximizing bandwidth and optimizing wavelets; practical aspects of Coloured Inversion and Blueing.
- Stabilizing the low frequencies though frequency slice filtering and structurally conformable filtering.
- Controls on resolution; stratigraphic filtering, Q and ghosts.

Exercises

- Excel: 1D geological modelling with different bed-thickness distributions
- Excel: Wavelet modelling
- Petrel: Dynamically design a CI operator and run the CI processes
- Petrel: Frequency Spectra Analysis
AVO

- AVO theory; Zoeppritz equations and linearizations; Aki & Richards, Wiggins, Fatti, etc.
- Measuring AVO, measurement errors, what can be reliably measured and what are the implications of errors.
- Intercept-gradient cross-plots, coordinate rotations and the relationship with elastic moduli. Fluid and lithology projections.
- AVO in the impedance domain; Elastic Impedance and Extended Elastic Impedance
- Cross-plot domains and rock physics templates
- Optimizing the correlation of seismic with reservoir properties

Exercises

- Excel: Half-space modelling with Wiggins, Dong, Fatti and Rüger equations
- Excel: AVO measurements and associated uncertainties.
- Excel: Intercept-gradient coordinate rotations
- Excel: Optimizing chi-angle stacks for different scenarios
- Petrel: Dynamic EEI analysis of well data
- Petrel: Dynamic EEI analysis of seismic data
- Petrel: AIGI Cross plotting
- Petrel: Designing rock physics templates
Seismic Net Pay

- Bandwidth and the causes and nature of impedance and reflectivity tuning
- Detuning and calibration and the meaning of seismic net-to-gross.
- Understanding the assumptions, uncertainties and practical aspects of the SNP method
- Examples of application to conventional and unconventional reservoirs
- Well ties, wavelet estimation and the limits of seismic calibration

Exercises

- Excel: Impedance and reflectivity tuning
- Excel: The effects and limitations of bandwidth on detuning
- Petrel: Seismic Net Pay Exercise
Seismic Inversion

- DHI’s, exploration risking and Bayes theorem
- The risks of using statistically driven attribute relationships for reservoir characterisation
- Deterministic and stochastic inversion. The risk of bias from ignoring uncertainties (especially from low frequencies models)
- Bayes theorem with probability density functions.
- Sources of uncertainty, two-step inversion and partial stochastic methods.
- Seismic uncertainty and the limits of formal approaches.
- Inversion methods; optimizing and sampling algorithms. Spatial correlation.
- Inversion landscape; categorising inversion applications. A review of published methods. Criteria for selecting the appropriate method
- One Dimensional Stochastic Inversion; ODiSI. Theory and practice.
- Workflows for Seismic Reservoir Characterisation.

Exercises

- Excel: Spurious correlation from multi-attributes
- Excel: Uncertainty and How to Find the Answer to Anything
- Excel: The limits of optimisation algorithms; inversion by spreadsheet
- Petrel: full parameterisation and execution of ODiSI plug-in for Petrel.
Image Gallery: Coloured Inversion

Optimise wavelets to improve resolution

Petrel: Dynamically design and apply a coloured inversion operator
Petrel: Analyse the frequency spectra
Half-space and gather modelling to understand the controls on AVO response and errors in measurement

AI/GI coordinate rotation to optimise impedance contrasts

\[ EEI(y) = A_1 (AI/AI)_{brine}^{\text{brine-oil point}}, (GI/GI)_{shale-oil}^{\text{brine-oil}} \]

Exercise:
1. What is the chi angle of the fluid projection?
2. What is the chi angle of the lithology projection?

This worksheet demonstrates the effect of changing chi using slider bar. Ai and Gi values of oil, brine and shale can also be adjusted.

A noise ellipse can be specified to allow calculation of signal to noise.
Scenario modelling for selecting $\chi$ angles

<table>
<thead>
<tr>
<th>$V_p$</th>
<th>$V_s$</th>
<th>$\rho_0$</th>
<th>$K$</th>
<th>$\ln AI$</th>
<th>$\ln GI$</th>
<th>$EEI$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2953</td>
<td>1779</td>
<td>2.04</td>
<td>2.04</td>
<td>6012</td>
<td>3697</td>
<td>8.72</td>
</tr>
<tr>
<td>2869</td>
<td>1719</td>
<td>2.00</td>
<td>2.00</td>
<td>5448</td>
<td>3570</td>
<td>8.18</td>
</tr>
<tr>
<td>2869</td>
<td>1719</td>
<td>2.00</td>
<td>2.00</td>
<td>5448</td>
<td>3570</td>
<td>8.18</td>
</tr>
<tr>
<td>2869</td>
<td>1719</td>
<td>2.00</td>
<td>2.00</td>
<td>5448</td>
<td>3570</td>
<td>8.18</td>
</tr>
</tbody>
</table>

This worksheet contains 4 datasets illustrating different systems (data 1-3 courtesy Rock Physics Associates Ltd.). Each dataset is plotted with linked points on an AIGI crossplot.

You should first identify the location of each facies on the crossplot. Then, using the slider bar, investigate optimum $\chi$ angles to separate the various facies.

Copyright Patrick Connolly Associates Ltd. 2015
Designing rock physics templates
Image Gallery: Seismic Net Pay

Modelling tuning effects and calculating the detuning correction

<table>
<thead>
<tr>
<th>Table: Band-Limited Impedance Tuning</th>
<th>Graph: Detuning Correction</th>
<th>Graph: Seismic Net-to-Gross</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average amplitude, Seismic normalised amplitude, apparent thickness, true thickness (ms)</td>
<td>Average amplitude, Seismic normalised amplitude, apparent thickness, true thickness (ms)</td>
<td>Average amplitude, Seismic normalised amplitude, apparent thickness, true thickness (ms)</td>
</tr>
</tbody>
</table>

Petrel: Seismic Net Pay exercise
Petrel: SNP mapping exercise
Model spurious correlations from random ‘attributes’

Inversion algorithms
Petrel: ODiSI parameterisation

Petrel: ODiSI testing
Petrel: ODiSI application