Department of Employment, Economic Development and Innovation
Geological Survey of Queensland

Creating a synthetic seismic trace
with Microsoft Excel

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Introduction

A synthetic seismic is a simulated seismic trace (or wiggle) created using sonic log data. The synthetic seismic closely resembles a real seismic section in the vicinity of the well that the sonic log was obtained from. By comparing the synthetic seismic with real seismic data acquired through or close to the well, features from the actual seismic trace can be tied to the well log data and well core. The production of synthetic seismic was undertaken as part of a technical collaboration between the Energy and CGI Groups from the Geological Survey of Queensland (GSQ). A manual method was undertaken using Microsoft Excel and the Seismic Unix software produced by the Colorado School of Mines as an alternative to using standard industry software as it better emphasised the steps and theory required. The general method used to produce a synthetic seismic is presented and applied to identify the top of the newly identified Millungera Basin using sonic log data from two wells drilled in 2011, as part of the GSQ Coastal Geothermal Energy Initiative.

1. Wave reflection theory:

A seismic section is constructed by summing the amplitudes of pressure (sound) waves reflected off different stratigraphic boundaries which arrive at a geophone (microphone) located on the surface. The proportion of the wave's energy that is reflected at each boundary is dependent on the impedance of the rocks above and below the boundary.

Impedance:
The ratio of the pressure produced by the wave moving through a medium to the velocity of the wave.

$Z=pv$ Z = Rock impedance, p = Rock density, v = Wave velocity in rock

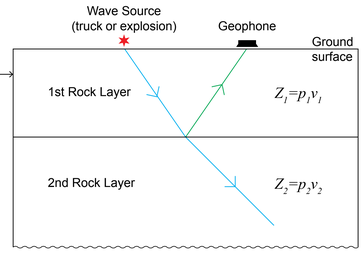
- A pressure wave encountering a boundary between different rock types is partially reflected and partially transmitted. The proportion of the energy of the wave that is reflected is the reflection coefficient and is dependent on the difference in the values of the impedances of the two rock types.

- The Reflection Coefficient (R) is given by:

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{p_2 v_2 - p_1 v_1}{p_2 v_2 + p_1 v_1}$$

Z_i = Impedance of first and second rock types
p_i = Density of first and second rock types
v_i = Velocity of wave in first and second rock types

- Example:
If R=0.6, 60% of the incident wave is reflected
If R=-0.6, 60% of the incident wave is reflected but the reflected wave undergoes a 180° phase change (peaks become troughs and visa-versa).

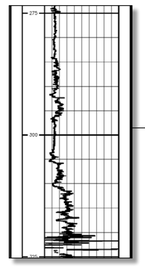


A pressure wave being partially reflected and transmitted at the boundary of two stratigraphic layers.

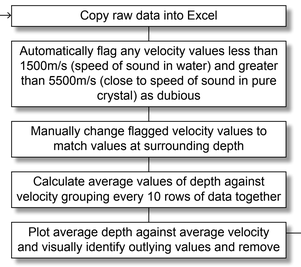
2. Editing velocity data:

The sonic log is examined and edited to remove spurious and incorrect values possibly caused by the sonic log instrument mis-picking the first occurrence of a reading at a particular depth. The sonic log provides the velocity of a pressure wave as a function of depth enabling the reflection coefficients at each stratigraphic boundary to be calculated using the equation for R. (As density values down the well were not logged, the densities of the different stratigraphic units are assumed to be constant).

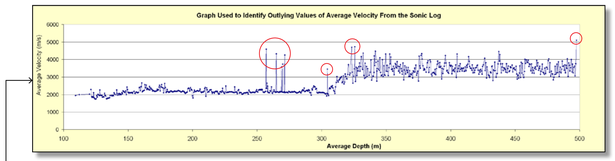
The Sonic Log



Flow process used to edit the sonic log



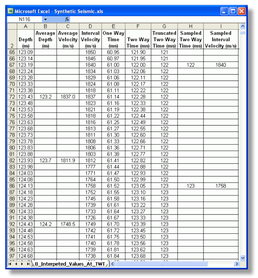
- Outlying values circled in red are visually identified and removed



3. Converting velocity data into two way time (TWT) and calculation of the reflection coefficients:

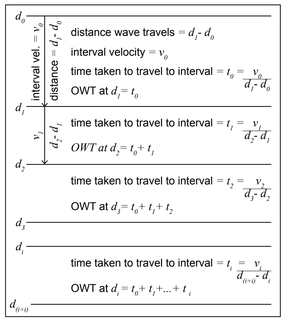
(TWT is the time taken for a wave to travel from the source on the surface to a particular depth and back to the surface again.)

Converting velocity at depth to velocity at TWT in Excel



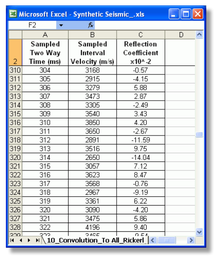
- Column A: The actual depth values from the sonic log
- Column B and C: The average depth and velocity values calculated in step 2
- Column D: The velocity of the wave as it travels through each interval of depth (1 row in Excel). Calculated by interpolating between the average values in column C using the depth values in Column A for weighting.
- Column E: One Way Time (OWT), the time taken for a wave to travel from the source to a particular depth.
- Column F: Twice the OWT of column E
- Column G: The TWT from column F rounded down to the nearest integer
- Column H: The first occurrence of a truncated TWT value from Column G
- Column I: The value of the interval velocity from column D if a value exists in column H

Calculating One Way Time (OWT)



Calculating the reflection coefficients at TWT

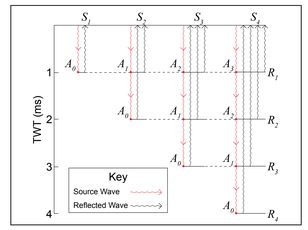
The above equation for R is used. (Density assumed constant for all layers)



4. Producing the synthetic seismic:

Following the calculation of the reflection coefficients, a suitable test wave can be simulated to pass across the different TWT boundaries and the theoretical values of the reflected amplitudes at sequential values of 1ms TWT summed and calculated. This process is called convolution and results in a synthetic seismic trace being produced.

Reflected waves at different TWT



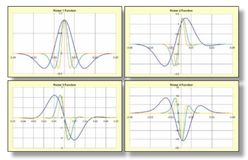
S_i=The signal. The signal is the sum of all reflected waves that reach the geophone at a particular TWT of "i" milliseconds.
A_i=The Amplitude. The amplitude is the value of the amplitude of the source (Ricker) wave at time "i" milliseconds.
R_i=The Reflection Coefficient at TWT depth of "i" milliseconds

- The value of the synthetic seismic at 1ms TWT S_1, is the result of the wave reflected at R_1. The value at 2ms S_2, is the sum of the waves that reach the geophone at TWT 2ms reflected from R_1 and R_2. This procedure is repeated for subsequent values of TWT.
- This can be represented mathematically as:

$$S_1 = A_0 \times R_1$$
$$S_2 = A_0 \times R_2 + A_1 \times R_1$$
$$S_3 = A_0 \times R_3 + A_1 \times R_2 + A_2 \times R_1$$
$$S_4 = A_0 \times R_4 + A_1 \times R_3 + A_2 \times R_2 + A_3 \times R_1$$
$$S_i = A_0 \times R_i + A_1 \times R_{i-1} + A_2 \times R_{i-2} + \cdots + A_i \times R_1$$
$$S_i = \sum_{i=0}^{i=t_{max}} A_i \times R_{t_{max}-i}$$

- This process is called convolution.

- The wave source used for convolution is a Ricker Wave. There are four types of Ricker Waves which together cover the general shape of real source waves. The graph to the right shows each Ricker Wave at three different frequencies. In the diagram to the left, the Ricker wave amplitudes are represented by A_i.

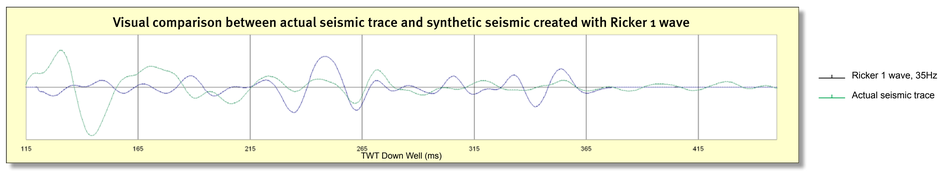


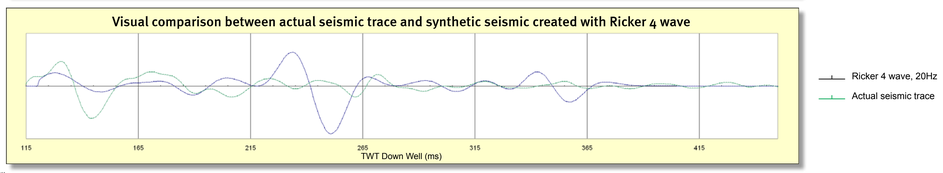
- In Excel, convolution, is achieved using the SUMPRODUCT worksheet function. The SUMPRODUCT function multiplies corresponding components in two arrays and returns the sum of the product.

$$SUMPRODUCT_{t=4ms} \begin{bmatrix} A_0 \\ A_1 \\ A_2 \\ A_3 \end{bmatrix} \begin{bmatrix} R_4 \\ R_3 \\ R_2 \\ R_1 \end{bmatrix} = A_0 \times R_4 + A_1 \times R_3 + A_2 \times R_2 + A_3 \times R_1 = S_4$$

5. Visual inspection of synthetic traces:

Synthetic traces were produced for 12 test frequencies for each Ricker Wave. Each trace was visually compared to the actual seismic data and the best matches chosen to create the final synthetic trace.





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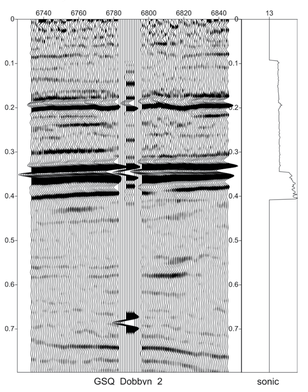
6. Synthetic seismic for GSQ Well Dobbyn 2

- The method described above was applied to tie the seismic line 07GA-IG01 to the newly drilled GSQ Well Dobbyn 2. The aim was to identify the top of the newly discovered Millungera Basin on the seismic section.
- The figure to the right is the synthetic seismic showing five copies of the synthetic trace nested between common depth points 6780 and 6800 of seismic line 07GA-IG01.
- The Ricker Wave used is shown in the bottom half of the synthetic and the original sonic log is placed on the right-hand side.
- The top of the Millungera basin was identified from the synthetic at a TWT depth of 0.35s which corresponded to an actual depth of 350m.



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