

Post-stack inversion of the Hussar low frequency seismic data

Patricia E. Gavotti*, University of Calgary, Alberta, Canada

pegavott@ucalgary.ca

and

Don C. Lawton, University of Calgary, Alberta, Canada

Gary F. Margrave, University of Calgary, Alberta, Canada

J. Helen Isaac, University of Calgary, Alberta, Canada

Summary

The Hussar experiment was carried out in September 2011 with the purpose of acquiring low frequency seismic data to be used in inversion methods. Three wells located close to the seismic line and a dynamite-source dataset, acquired with three-component 10 Hz geophones, were used for a post-stack inversion test using commercial software. Several low-frequency cut-off filters applied to the data were tested with the 3-5 Hz model being selected as the optimum. The resultant impedance reflects lateral changes that were not present in the initial model and therefore are derived from the seismic reflections. Impedance changes in the target zone shows the general trend and relative variations, which would allow changes in the reservoir as variations in the rock properties occur. A final inversion was performed to simulate traditional approaches when the low-frequency component is absent in the seismic data. Filtered seismic-data (10-15-60-85 Hz) and an initial model with a 10-15 Hz cut-off were used for this test. The results at the well locations show a good match but the lateral variation and character of the events resemble more the initial model character.

Introduction

Inversion of seismic data is a process to produce an estimate of earth's acoustic impedance. Impedance inversion was first accomplished and reported in Lindseth (1979). Different approaches have been used for post-stack inversion, including band-limited, sparse-spike and model-based, among others (Russell and Hampson, 1991).

The way in which the reflectivity can be extracted from the seismic is based on the convolutional model of the seismic trace according to the equation 1:

$$S = W * R + N, \quad (1)$$

where **S** is the seismic trace, **W** is the wavelet, **R** is the reflectivity and **N** is the noise and * denotes convolution. Noise is assumed to be random and uncorrelated with the signal.

Reflectivity is defined as the contrast in impedance between two interfaces (equation 2) where the impedance (Z) is simply the product between velocity and density:

$$R_i = \frac{Z_{i+1} - Z_i}{Z_{i+1} + Z_i}, \quad (2)$$

Band-limited impedance inversion commonly uses a recursive inversion algorithm, which ignores the effect of the seismic wavelet, and treats the trace as a set of reflection coefficients (Lindseth, 1979).

The inversion of seismic data is based in equation (3) from rearranging the terms of (2) to give the impedance series:

$$Z_{i+1} = Z_i \left(\frac{1+R_i}{1-R_i} \right), \quad (3)$$

The inversion requires the initial value of Z to be known but the limited seismic bandwidth constrains this technique. The low-frequency component missing in the seismic is added from sonic logs to assure a more realistic result (Lindseth, 1979).

The results shown here are based on the Hampson-Russell software model-based inversion approach to estimate impedance from the Hussar seismic data.

Theory and/or Method

Model-based inversion (Russell and Hampson, 1991) uses a generalized linear inversion algorithm which assumes that the seismic trace (S) and the wavelet (W) are known and attempts to modify the initial model until the resulting synthetic matches the seismic trace (Cooke and Schneider, 1983).

The basic approach is to minimize this function (Hampson-Russell software. STRATA manual):

$$J = weight_1 \times (S - W * r) + weight_2 \times (M - H * R), \quad (4)$$

Where S is the seismic trace, W the wavelet, R the final reflectivity, M the initial guess model impedance and H the integration operator, which convolves with the final reflectivity to produce the final impedance (* = convolution).

The initial background model (Figure 1) was formed by blocking an impedance log from a well. The final result is dependent on the initial model so the model must first be low-pass filtered to reduce this effect. Lloyd and Margrave (2011) produced a good inversion result in the well 12-27-25-21W4M location using a low cut-off of 3 Hz for the 4.5 Hz geophone data receivers and found that consistent low-frequency information is present in the dynamite data as low as 1 Hz. To identify an initial model low-frequency cut-off point, several band-pass filters were applied to the seismic data to best estimate which frequency range is missing (Figure 2). Based on the amplitude spectrum and the filter tests, it is difficult to identify any coherent signal below 4 Hz, suggesting that our low-frequency cut-off can be defined around this value.

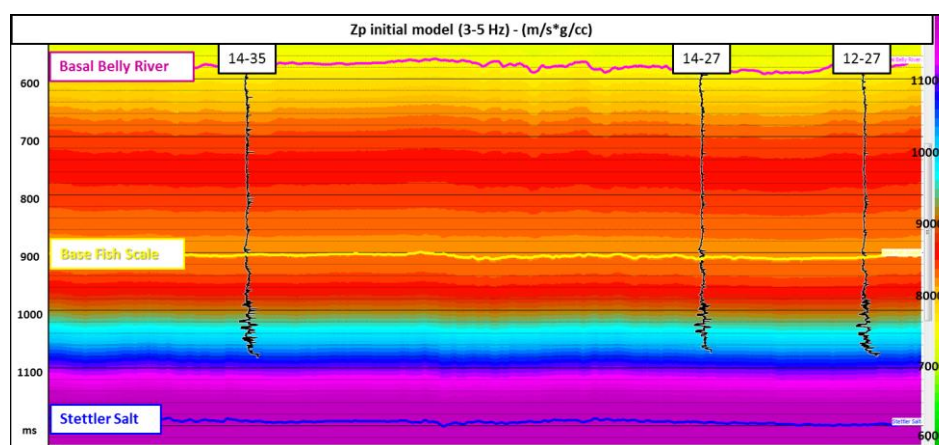


Figure 1: Initial low frequency P-impedance model (3-5 Hz).

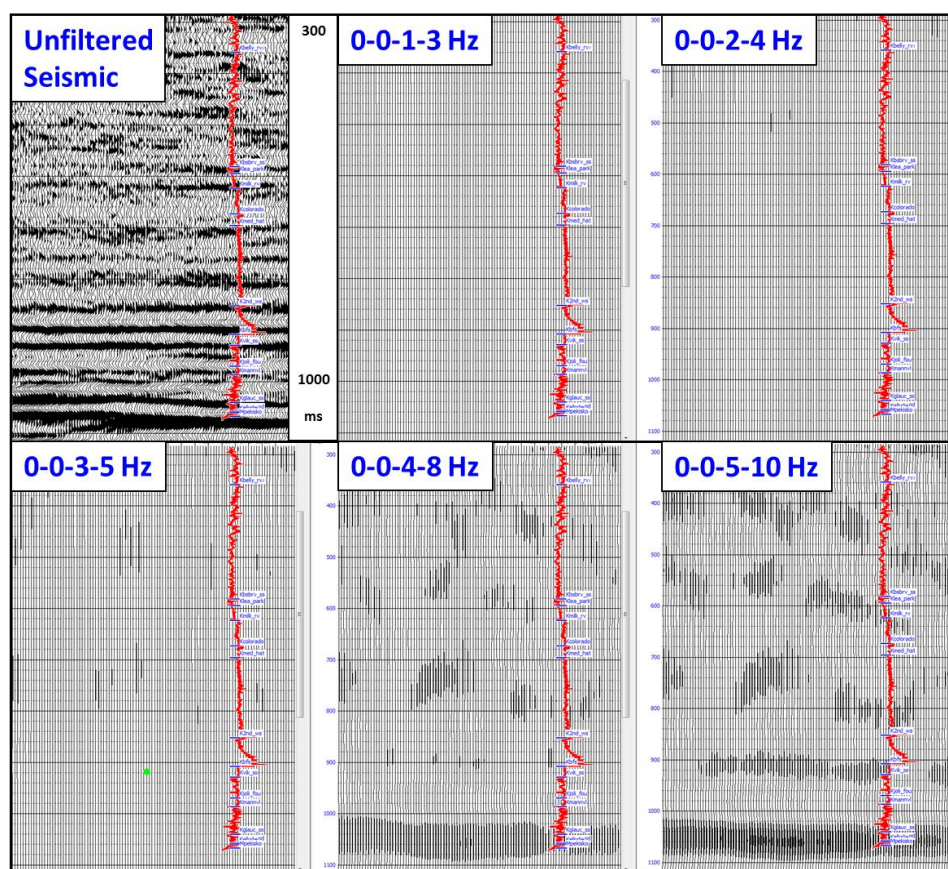


Figure 2: Filter panels assessing low frequency data present in the seismic data.
The unfiltered seismic data are displayed for reference.

Examples

The model-based inversion of the seismic data was undertaken using the 3-5 Hz model and a wavelet extracted from the seismic-well tie process from well 14-27-25-21W4M and well 14-35-25-21W4M. The algorithm uses both the available wells and the seismic data near those wells. It extracts the wavelet by finding the operator which, when convolved with the reflectivity from the well, closely approximates the proximal seismic traces.

The inversion result (Figure 3) shows zones of low impedance (green-yellow) within the Colorado Group (Fish Scale Zone) and Upper Manville units (Glaucinitic and Medicine River Coal). Higher impedance values correspond to more shaly units. The P-Impedance log filtered with a high cut of 60/85 Hz was inserted for comparison with the inversion result.

The sub-units within the Manville Group are not as evident as those in the Colorado Group possibly because of resolution limitations. Most of these units have thicknesses below the seismic vertical resolution. However, the inverted impedance shows the general trend and relative variations. The coal section is identified along the Medicine River Coal marker with values closer to the actual ones. Around 1070 ms a low impedance anomaly is seen between wells 12-27-25-21W4M and 14-27-25-21W4M which can be related to a channel within the Eilerslie Formation which is overlain by high impedance rocks possibly related to the shale unit of the Ostracod Formation.

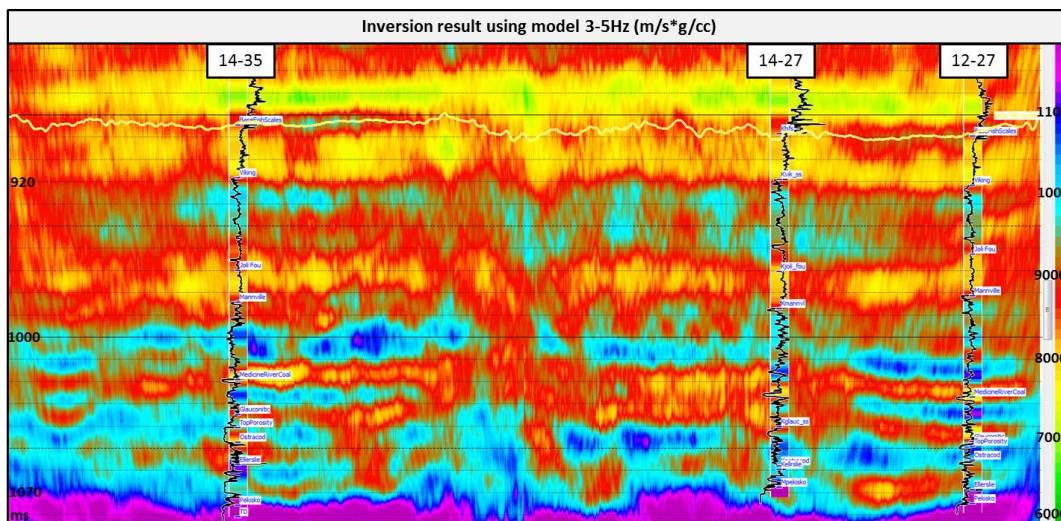


Figure 3: Inversion result of Hussar 10 Hz dynamite dataset showing the gamma ray curve in black and the impedance log with a high-cut filter 60/85 Hz in color at the well locations for comparison.

The result shows lateral variations in the impedances of the units that were not present in the initial model. The initial model showed a general trend of increasing the impedance but with no significant lateral variations. The changes observed in the resultant impedance reflect the character of the seismic reflections indicating that the inversion process was dominated by the seismic data.

In comparison, a band-pass filter was applied to the input data to remove the low-frequency components, in order to simulate traditional cases when the low-frequency component is missing in conventional seismic data. A post-stack inversion section was generated using the same parameters except for the initial model. In this case, the seismic bandwidth was 10-15-60-85 Hz and the initial model has a 10-15 Hz cut-off. Figure 4 shows the inversion result; interesting differences can be seen compared to the results shown in Figure 3. At the well locations there are good impedance matches, but the lateral variation and intensity of some events seems to be diminished and, in general, resembles more the initial model response.

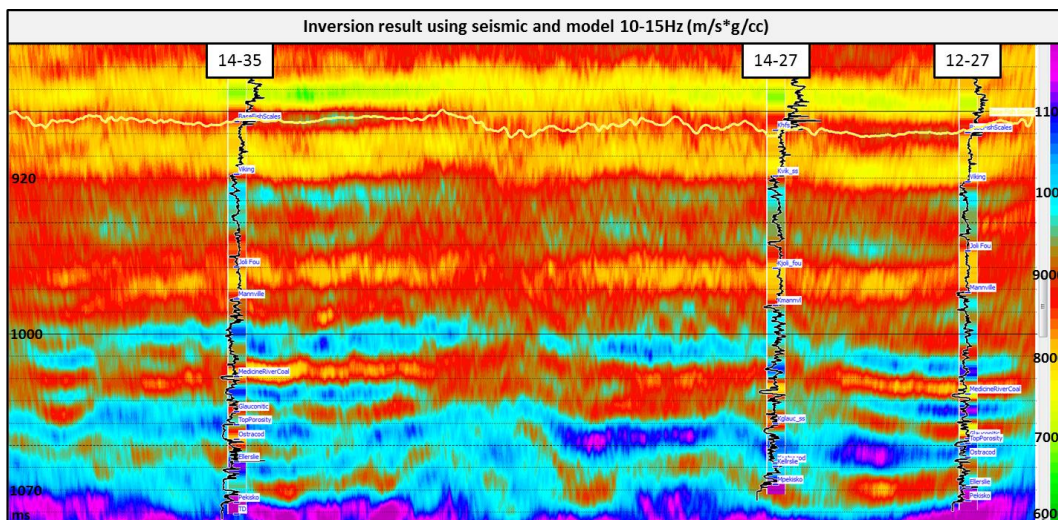


Figure 4: Inversion result of Hussar 10 Hz dynamite dataset with a band-pass filter of 10-15-60-85 Hz showing the gamma ray curve in black and the impedance log with a high-cut filter 60/85 Hz in color at the well locations for comparison. Note the differences in continuity and character of the events with respect to the results on Figure 2.

Conclusions

A model-based post-stack inversion study was undertaken using low-frequency seismic data from the Hussar experiment acquired with 3C 10 Hz geophones and 2 kg dynamite charges. The objective was to evaluate if the inversion result improves when there is low dependence on the initial model that sometimes strongly influences the inversion result.

Four initial inversion models were tested with different low-frequency cut-offs. These all had similar results but the 3-5 Hz model was chosen to invert the seismic data since this model does not result in too much overlap between the low frequencies within the seismic with those from the model. The initial model and the inversion were undertaken with the control of the well 14-35-25-21W4M while wells 12-27-25-21W4M and 14-27-25-21W4M were used as blind tests.

The impedance determined from the inversion reflects the changes due to the seismic reflection data more than the influence of the initial model. Impedance changes in the target zone are not as detailed as was expected, possibly due to limitations with seismic resolution; however, the inverted impedance shows the general trend and relative variations which might allow monitoring changes in the reservoir to be identified when variations in the rock properties occur.

A final inversion was calculated to verify results. A band-pass filter of 10-15-60-85 Hz was applied to the seismic data to remove the low-frequency component gained during the Hussar experiment. An inversion initial model was built with a 10-15 Hz cut-off to invert this seismic data and the results at the well locations showed a good match but the lateral variation and intensity of the events were subtle and resembled more the initial model character. This is observed when the low-frequency component is missing in conventional seismic data.

Acknowledgements

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