How much well do you need in acoustic impedance inversion?

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Summary

An acoustic bandlimited impedance inversion study was done to determine an acceptable amount of well-derived low frequency information that is added to the bandlimited seismic data. For the first example, a 20-50 Hz bandlimited seismic trace was generated and then combined with a low pass filtered fluid substituted impedance log with varying cut-off values. The inverted impedances were very sensitive to the well log data for cut-off values of 2.5 Hz or greater. The experiment was repeated to include noise, providing results that were less sensitive to the fluid-substituted log for frequencies lower than 5 Hz. A third example was created that used a bandwidth that corresponded to the cut-off value. The inversions from this example were dominated by the well log with cut-off values higher than 5 Hz. When the cut-off value exceeds 5 Hz the reference log dominates the inversion, even for a small reservoir.

Introduction

This study will focus on the amount of well log low frequency information that is needed to calculate accurate impedance inversions. Seismic data can be used to see differences in the reservoir but impedance is a better indicator of changes (Pendrel, 2006) because it is a measurement of the actual properties of the layers where seismic data only indicates the contrast between layers at their boundaries. This allows a better interpretation of the subsurface, especially when detecting subtle fluid contacts. While there are more sophisticated methods of computing inversions (such as full waveform inversion) the quickest and simplest way is to compute an acoustic impedance inversion using the recursion formula, $I(t) = I_o e^{2\int_0^t r(\tau)}$, where I_o is the impedance at the surface and r is the reflectivity sequence (Waters,1978). For this method to work the reflectivity sequence must have low frequencies which the seismic data does not have as it is inherently missing them due to instrumentation errors and possible limitations of the source. Lindseth (1979) suggested that information from a nearby well log could be used to provide this missing low-frequency component.

Method

The BLIMP (BandLimited IMPedance inversion) method as described in Ferguson and Margrave (1996) will be used to incorporate the low frequencies from the well into the bandlimited seismic data. This method applies a bandlimited integration filter to the seismic trace and then exponentiates the result of the filter. The exponentiated filtered trace is then scaled to match the well impedance that has been filtered at a low pass cut-off frequency determined by the user in the frequency domain. These results are then added together and inverse Fourier transformed to produce the acoustic impedance inversion.

Selecting an appropriate low cut-off frequency is not always a simple task. Ideally, this frequency would be chosen to be the lowest trusted frequency in the seismic. If this frequency is too high then the well impedance information dominates the inversion. This study will examine what occurs when the cut-off is too low or too high.

Examples

We use data from Violet Grove in the Pembina Oil Field, located in the west-central plains of Alberta (McCrank, 2009). Well 102-07-11-048-09W5 and Well 102-08-14-048-09W5 were combined to form a single log containing well data from the surface to a depth of 2300 m. For the velocity log least squares linear gradient was applied as the overburden (0 to 308 m) and underburden (2220 to 2300 m) and a mean value was used for the density. To create the fluid-substituted logs, a method of Gassmann fluid substitution described in Smith et al. (2003) was calculated from the Cardium (1600m) to the lower Cardium (1639m). The original fluid was taken to be 50% oil and 50% brine and for the fluid substituted logs, 10% CO_2 was then injected such that the replacement fluid contained 45% oil 45% brine 10% CO_2 as it was assumed that the brine and oil would be displaced equally. The rock properties necessary to compute this fluid substitution were from Chen (2007). The logs in Figure 1 will be used in the following analysis. The baseline logs will be used to create the synthetic trace where as the fluid substituted log will be used as the well input. This is to emphasize the error associated with adding low frequency well information that does not match the seismic data.

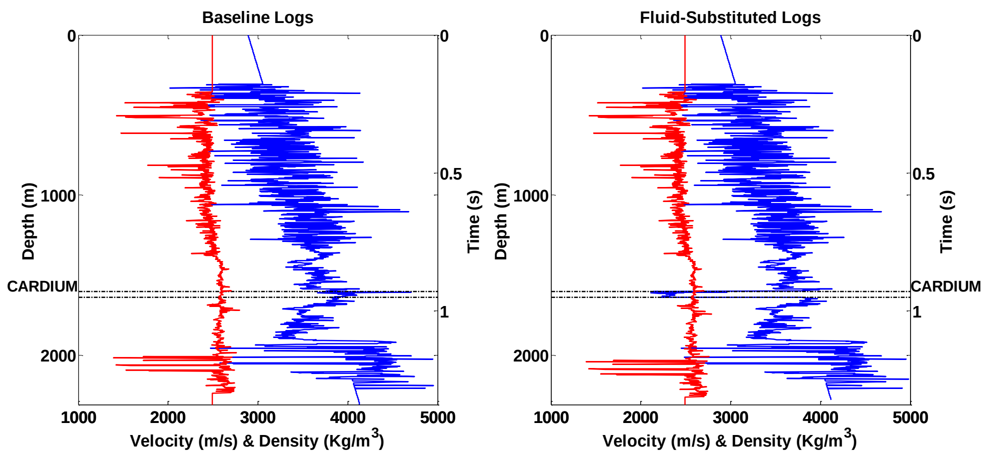

Figure 1: The Baseline logs are shown on the left with the density in red and the velocity in blue. The fluid-substituted logs are shown on the right with the velocity having a low velocity kick in the Cardium formation.

A trace hwith a 20-50 Hz bandwidth will be synthesized and various low frequency cut-off values applied to it, to see how a gap in the low frequencies between the well contribution and the seismic data contribution affects the inversion. The synthetic trace was created by convolving the reflectivity of the baseline log with a [15 20 50 60] zero phase Ormsby wavelet. Impedance inversions were calculated by using increasing amounts of low frequencies from the fluid-substituted log (Figure 2A). This frequency gap causes the inversions with a cut-off greater than 2.5 Hz to be dominated by the fluid-substituted log. Figure 3A shows the inversion results using a low frequency cut-off of 5Hz in detail. This gap shows a loss of detail in the impedance inversions especially at the lower cut-off values.

We wanted to investigate what occurs when there is noise present in an inversion. The above situation was modified to incorporate additive random noise with a signal to noise ratio of 6 calculated by the mean power in the time domain, Figure2B. This creates a significant problem as the noise dominates in the frequency gap, Figure 3B. If the noise spectrum is similar to the reflectivity spectrum this works in the inversion's favor however noise cannot be counted on and causes significant error in the inversions when it is dissimilar. The error between the baseline log and the inversion results were calculated for the frequency gap example and the noisy example. This example was not as consistently accurate than the non-noisy example showing that the introduction of noise in the frequencies causes sporadic results.

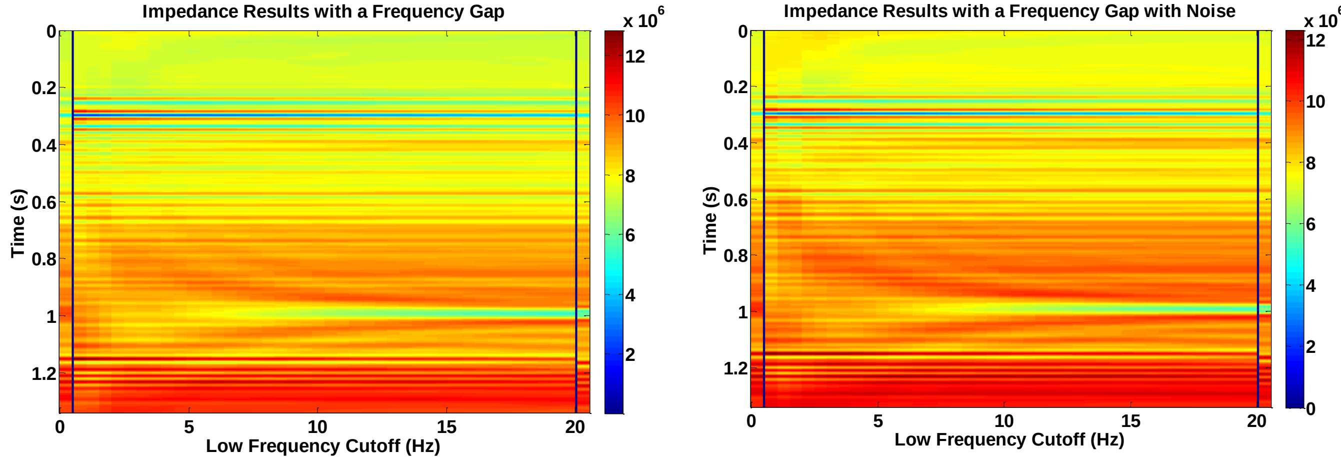

Figure 2: Impedance results when a there is gap between the low frequency well component and the seismic trace (A) and without noise added (B). The Baseline log is shown at the far left with the fluid-substituted log on the far right. The inversions were computed using low frequency cut-offs from .5Hz to 20Hz. Note that the inversions are similar to the baseline log only until 5Hz where the fluid substituted log begins to dominate the inversions.

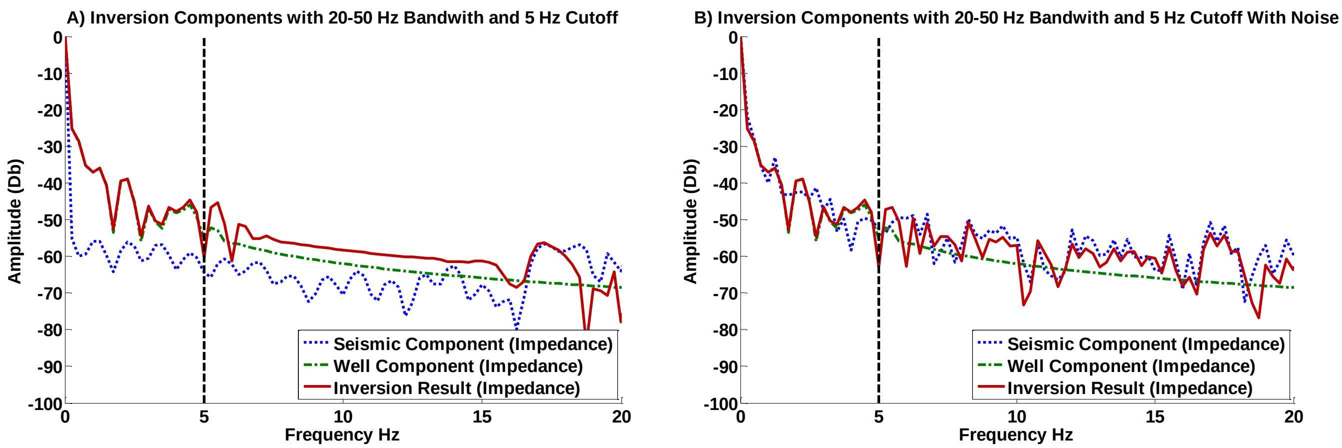

Figure 3: These figures represent both the frequency contributions from the well component and the seismic component using a cut-off value of 5 Hz. A) This plot shows the flat frequency gap (6-15 Hz) where as in B) the gap is filled with noise.

Table 1: The mean absolute percent error between the inversion and the baseline log for the frequency gap example, the frequency gap with noise example and the continuous example from the interval 0.95 – 1.05 seconds.

Frequency Cut-off	Frequency Gap Inversion (%)	Frequency Gap Inversion with Noise (%)	Continuous Inversion (%)	Frequency Cut-off	Frequency Gap Inversion (%)	Frequency Gap Inversion with Noise (%)	Continuous Inversion (%)
0.5	5.5505	6.6763	1.4418	8	14.6778	14.6792	14.5566
1	6.2030	6.7865	3.6985	10	15.7661	15.8536	15.3423
1.5	7.8422	8.2279	5.3806	12	16.4696	16.5618	16.0923
2	9.6996	10.4782	7.1038	14	16.8589	16.9184	16.7331
4	10.8772	10.8296	10.1753	16	16.8782	16.9369	16.8657
5	11.9450	11.7983	12.2374	18	16.8750	16.9239	16.8689
6	12.9501	12.8904	13.3442	20	16.8837	16.9358	16.8837

If it were possible to record down to the very low frequencies, less information would be needed from the well. In this next example synthetic traces are constructed with a [cutoff-cutoff*.25, cutoff 50 60] zero phase Ormsby wavelet. Using this data set the inversions, will have contributions from the well from 0 Hz to the cutoff frequency and the seismic will contribute frequency data from the cut-off value to 60 Hz. In this method there will be no low frequency gap so the spectrum will be appropriately filled. Figure 4 shows these results. Note that frequencies lower than 5 Hz produce reasonable inversions where cut-off values higher than 5Hz produce inversions that are dominated by the fluid substituted log. Table 1 shows the errors for the interval 0.95 seconds to 1.05 seconds, the error for this continuous example is less than the frequency gap examples for lower than 5Hz.

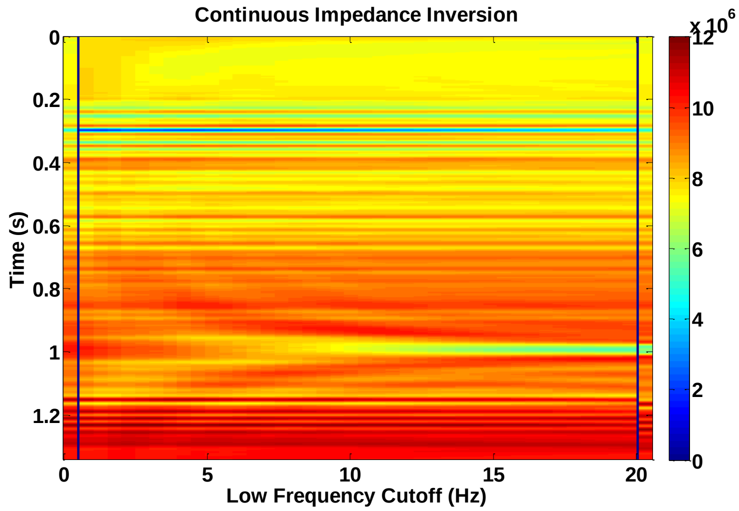

Figure 4: Impedance results when the low frequency well component and the seismic trace are continuous at the cut-off value. The baseline log is shown at the far left with the fluid-substituted log on the far right. The inversions were computed using low frequency cut-offs from .5Hz to 20Hz. Note that the inversions are similar to the baseline log only until 5Hz where the fluid substituted log begins to dominate the inversions.

Conclusions

This study showed that when there is a gap in the frequency spectrum the inversion results are more influenced by the well log even when compared to data that has noise in the signal. For these results using a cut-off value of less than 5 Hz is advisable as higher cut-off values produce inversions that are dominated by the well.

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