Incorporating spectral colour into impedance inversion

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ABSTRACT

Most seismic data processing flows try to shape seismic data into a white spectrum during deconvolution. This choice of white spectra is largely a statistical convenience and most natural occurring reflectivity sequences do not have white spectra. Shaping the seismic spectra to that seen in reflection coefficients computed from well logs is known as colouring. By colouring the seismic data we are potentially rewarded with a more realistic data set. A colouring operator can be devised by dividing a modeled trace spectrum with a modeled well reflectivity spectrum. We experimented with a variety of spectral models for both data and reflectivity. We choose to model the trace spectra using a 4th order polynomial fit to the log amplitude spectrum. Alternately, we model the well reflectivity log amplitude spectrum with a 4th order polynomial log frequency. The ratio of these spectral models is our colour operator which can then be applied to the seismic data. The coloured seismic data are then input into acoustic impedance inversion using the BLIMP (BandLimited IMPedance) algorithm. The 10Hz geophone dynamite Hussar data was used in this study. When the coloured operator was applied to the seismic data, 0.2 to 0.6 seconds was overwhelmed by noisy high frequencies. These high frequencies also carried over into the impedance inversion. It seems likely that the seismic data spectrum is nonstationary and our spectral models, based on stationary spectra, are not appropriate. Further work needs to be done to perfect this method to produce quality inversions for the entire section.

INTRODUCTION

When processing data with conventional deconvolution, we try to remove the wavelet in the data and shape the spectra to a white state. Many assumptions that we make during processing are based on this white spectra. In 1985, Walden and Hosken showed that most reflectivities from wells sourced all over the world do not have “white” spectra. Therefore when we are computing inversions better results should be achieved when colouring the reflectivity to the shape observed in local wells before computing an inversion.

To do this we chose to model both the trace spectra and the well reflectivity spectra. Ideally, spectral models should follow the general trend of the spectra but not the detail. Clearly, this requires a judgement call and we spent considerable time investigating possible spectral models. Once the models are determined, the trace is then coloured by dividing the trace spectra by the modeled trace spectra and multiplying the modeled well reflectivity spectra. We chose to apply this process to migrated, stacked data immediately before impedance inversion. Once this is done the trace is said to be coloured and further processing including inversion can proceed. For this paper we will colour the traces and then use the BLIMP (BandLimited IMPedance) algorithm (Ferguson and Margrave, 1996) to compute the inversions.

For this study we will be using the 10Hz geophone and dynamite source Hussar data set. This data has been conditioned as described in Lloyd and Margrave (2012). We apply our colouring process to the final migrated stack and then input the coloured data directly into impedance inversion.

Inversions can also be computed directly by modeling the trace spectra and the impedance spectra. The inversion can be applied by then dividing the trace spectra by the trace spectra model and multiplying by the impedance spectra model (Lancaster and Whitcombe, 2000). This method will not be used in this study but is something to be investigated at a later time.

METHOD

To produce a coloured inversion the traces, representing reflectivity, must be coloured. This is facilitated by modeling the trace spectra and the reflectivity spectra with mathematical functions. For the trace spectra, several methods were tried including Butterworth bandpass filters and Gaussian taper filters but the best results were found with a 4th order polynomial fitted to the log amplitude spectra. The fit of the spectra can be seen in Figure 1. Modelling the reflectivity from the well proved more difficult as the low frequencies contain a roll off but the higher frequencies maintain a nearly white spectrum. Various functions were attempted to fit this character but only one method came close. Walden and Hosken (1985) modeled the reflectivity using a linear function in log frequency. This method fitted a linear trend to the ramp of the spectra and ignored the low and high frequencies. Since the low frequencies are especially important we used a 4th order polynomial in log frequency to model the spectra, shown in Figure 2. The same spectra are shown in ordinary frequency in Figure 3. Once the models had been created the colour operator follows as the ratio of the spectral models. This was done by dividing the well reflectivity spectral model by the trace spectral model. This operator strongly boosts the high frequencies so to remove frequencies beyond the signal band a low pass [0 0 100 125] filter was applied to the colour operator. The colour operator boosts the low frequencies and mid frequencies but subdues the high frequencies as seen in Figure 4.

The colour operator was applied to the average trace and compared with the average well in Figure 5. This shows that the coloured inversion still has the trace character but has more high frequencies in the data especially between 0.2 and 0.7 seconds. Figure 6 shows how the spectrum was modified. The left panel shows the original spectral shape of the trace where the right panel shows the spectral shape after colour correction. The high frequencies have been accentuated in the colour correction. The colour correction was then applied to the whole seismic section. Figure 7 shows the original seismic section where Figure 8 shows the colour corrected section. More detail can be seen in the colour corrected section; but it is also apparent that the time zone from .2 to .7 seconds seems over-whitened. It is likely that the signal band in this zone is less broad than in the target zone (.7 to 1.1 seconds) due to the data processing mute and the consequent lower fold in the shallower section. This suggests that the signal band is nonstationary and is not well modelled at all times by our stationary spectral model.

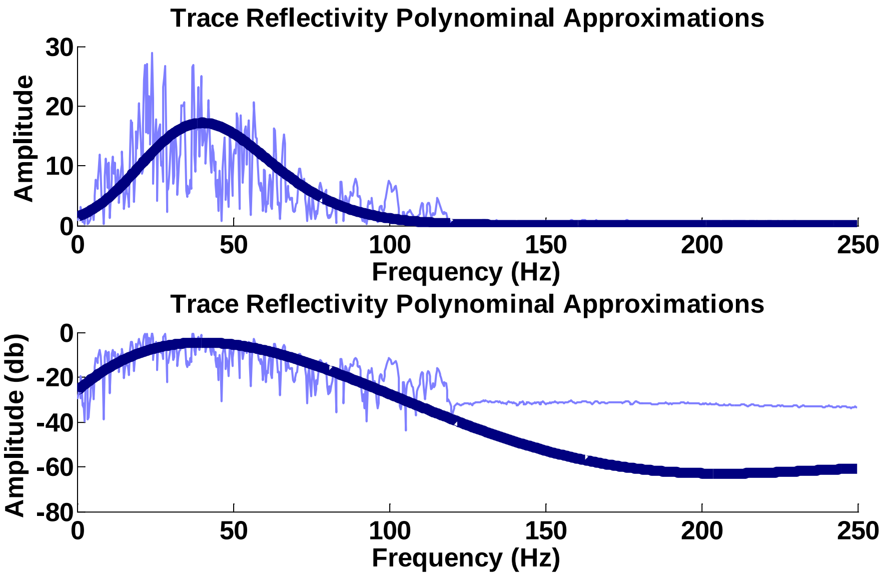

FIG 1: The amplitude spectra modeling for the trace using a 4th order polynomial fit to the decibels.

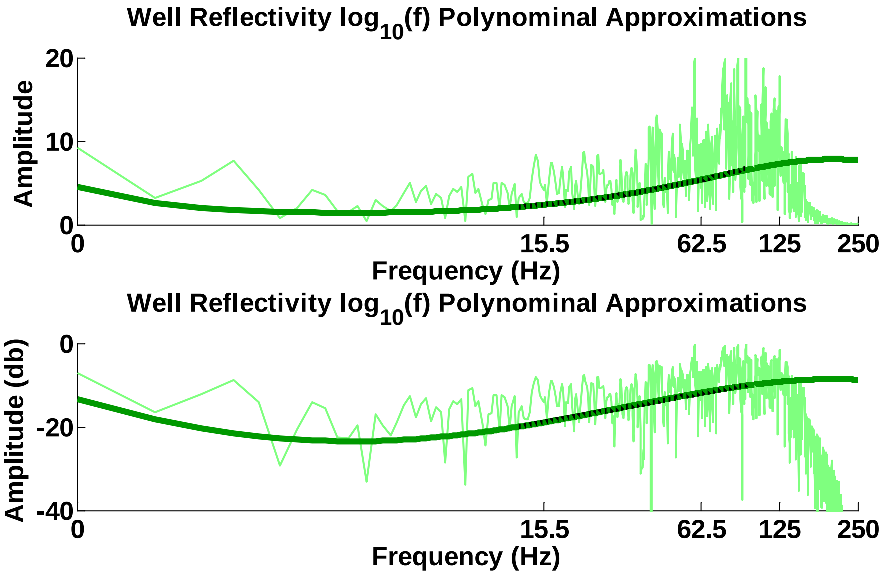

FIG 2: An amplitude spectra model for the well reflectivity using a fourth order polynomial fit to the decibels in $\log_{10}(f)$ from 0 to half-Nyquist. The Walden-Hosken linear trend is shown in black on the figure.

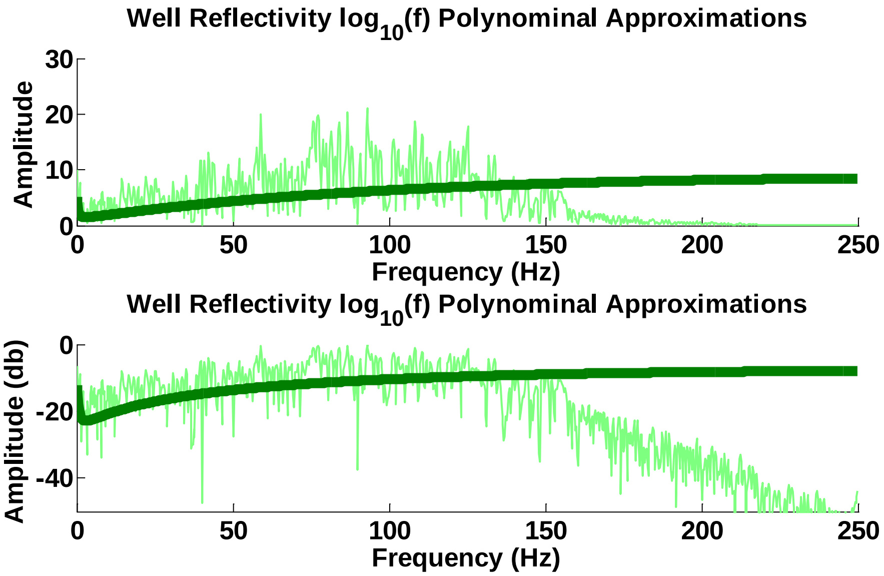

FIG 3: An amplitude spectra model for the well reflectivity using a fourth order polynomial fit to the decibels in $\log_{10}(f)$ from 0 to half-Nyquist.

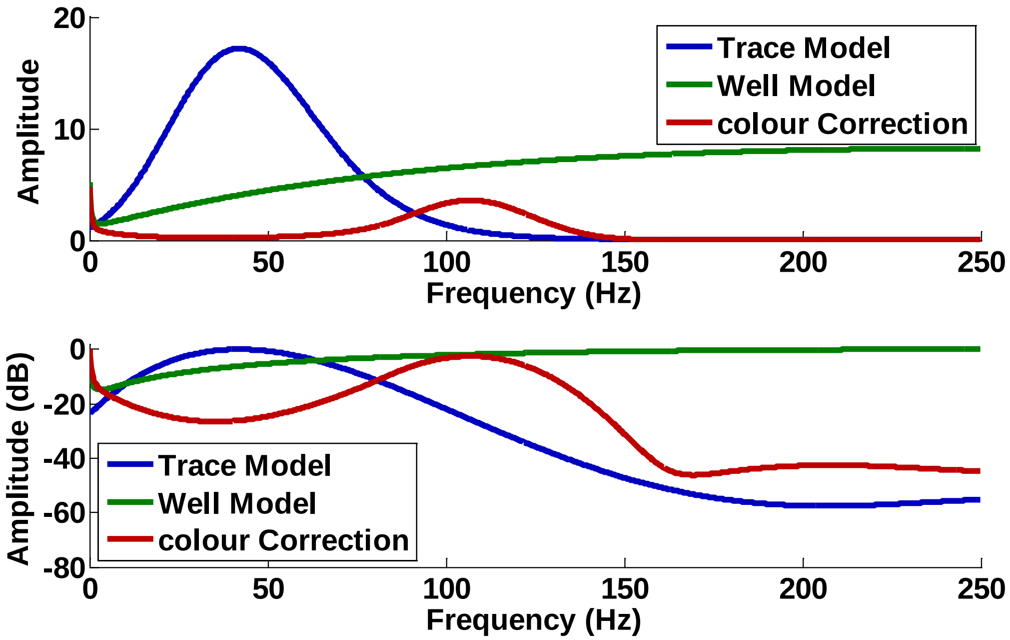

FIG 4: A comparison of the trace model, reflectivity model, and the colour correction operator.

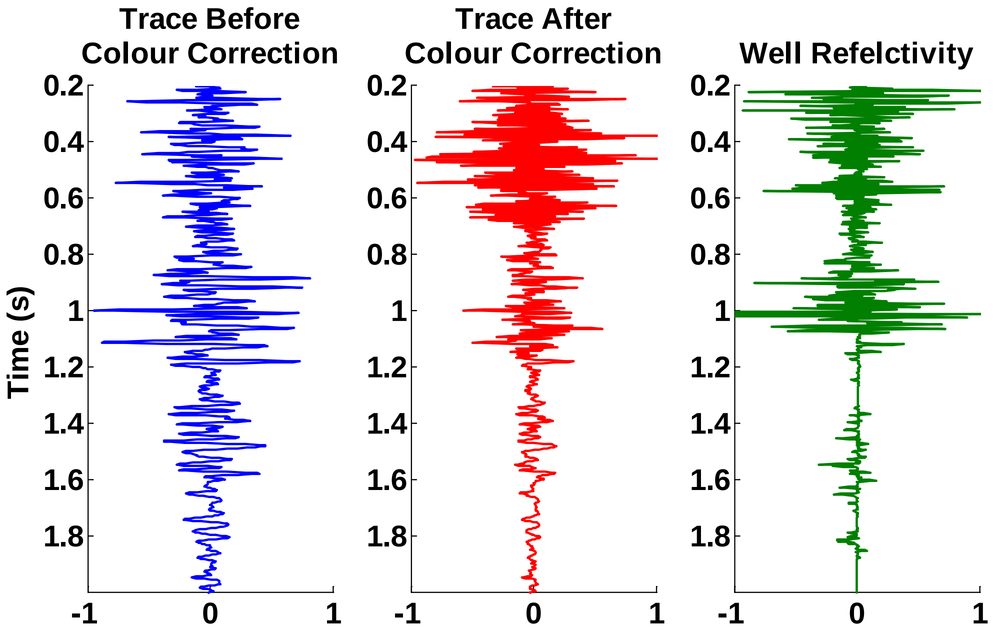

FIG 5: The average-trace in blue, the average-well reflectivity in green and the coloured trace in red.

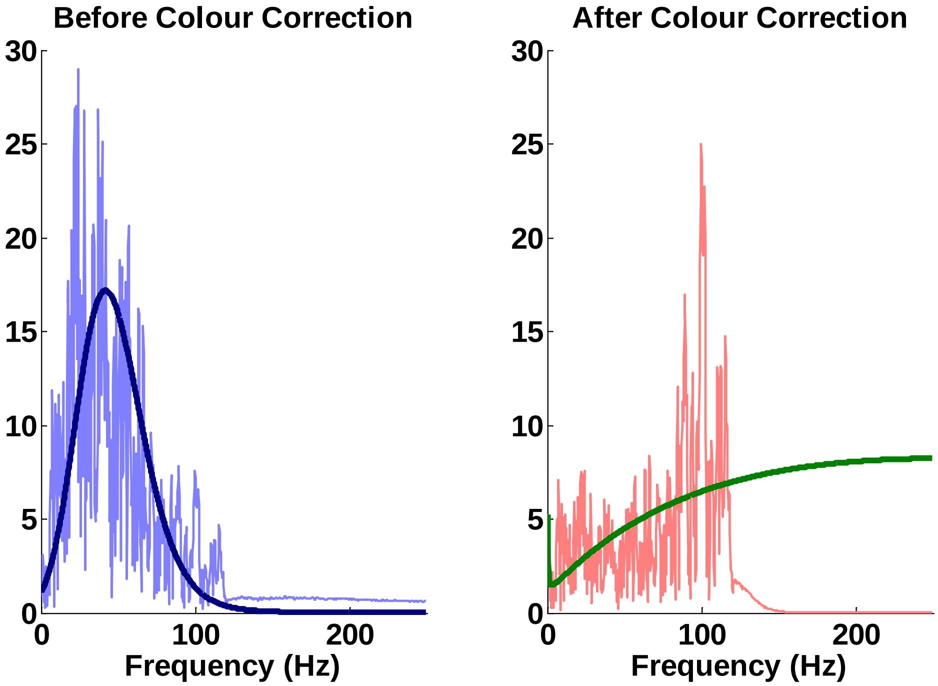

FIG 6: The trace amplitude spectra before colour correction in blue and after colour correction in red. The dark blue curve is the estimated shape of the trace spectrum and the green curve is the estimated shape of the reflectivity.

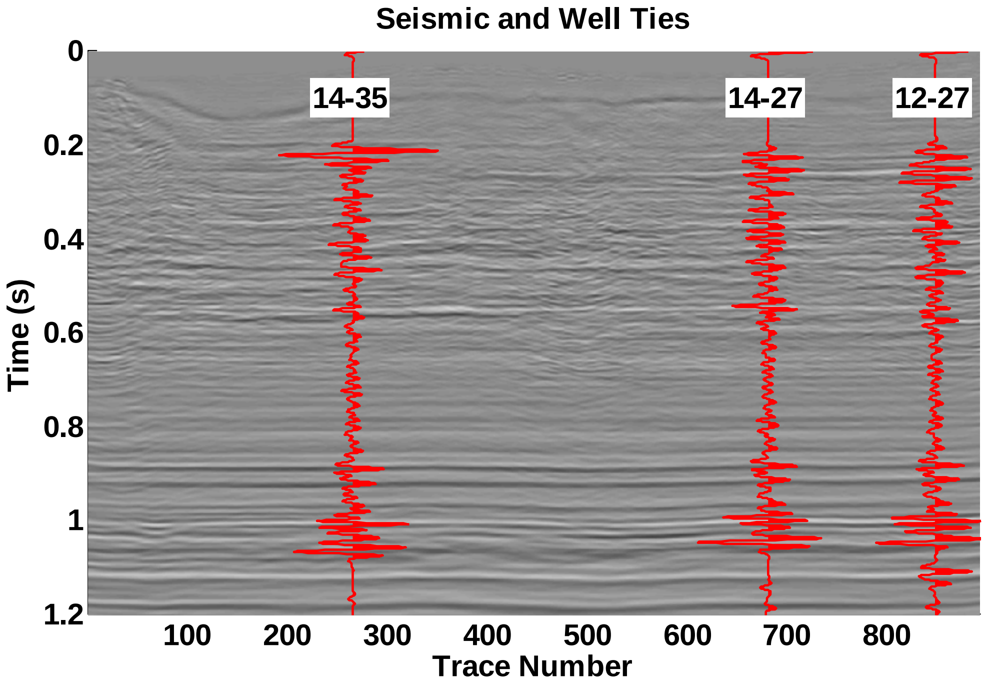

FIG 7: The balanced seismic data and well ties without colour correction

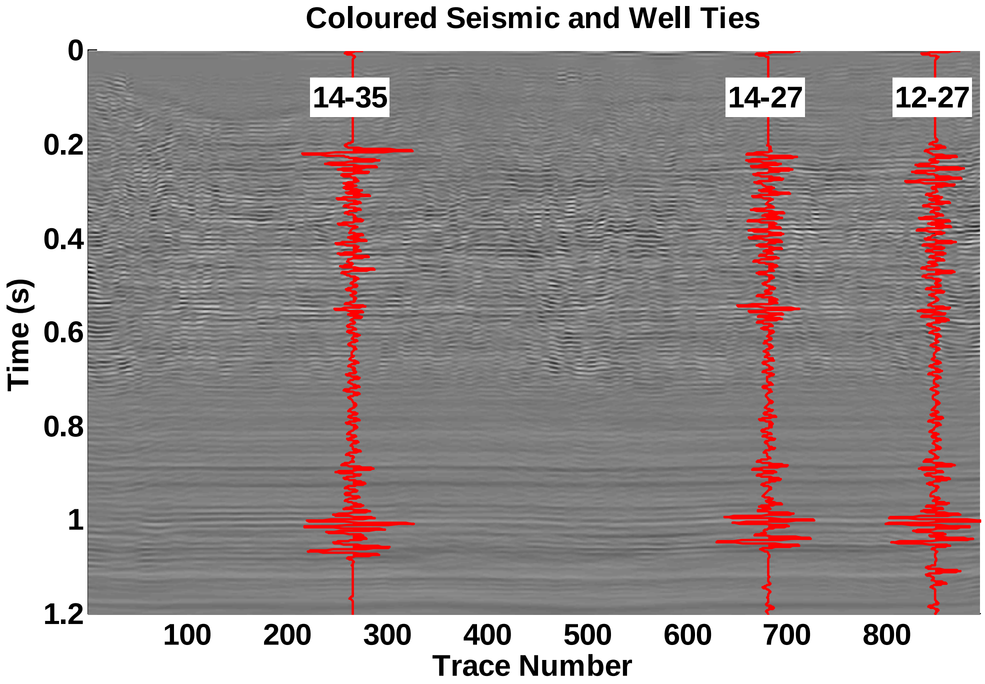

FIG 8: the balanced seismic and well ties after colour correction.

Now that the seismic data have been coloured, the inversion can be computed. In Lloyd and Margrave (2012b) using the average well log for inversion was found to produce the least amount of error, so for this study the average well log will also be used. Since the low-frequencies were modified during the colouring process a new low-frequency cut-off needs to be chosen. Low-frequency cut offs between 0.5 and 10 Hz were compared in Figure 10. The difference between adjacent inversions were computed and plotted on the same figure in white. From this we can see that the inversion starts to stabilize at about 2 Hz. For reference the filtered average impedance log is plotted in the very right and left column of Figure 10. The filter that was applied can be seen in Figure 9.

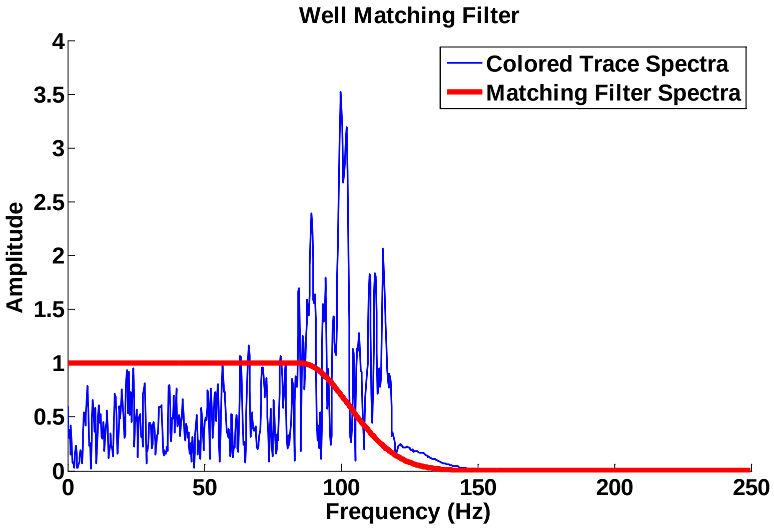

FIG 9: The matching filter used to attenuate the high frequencies in the well reflectivity.

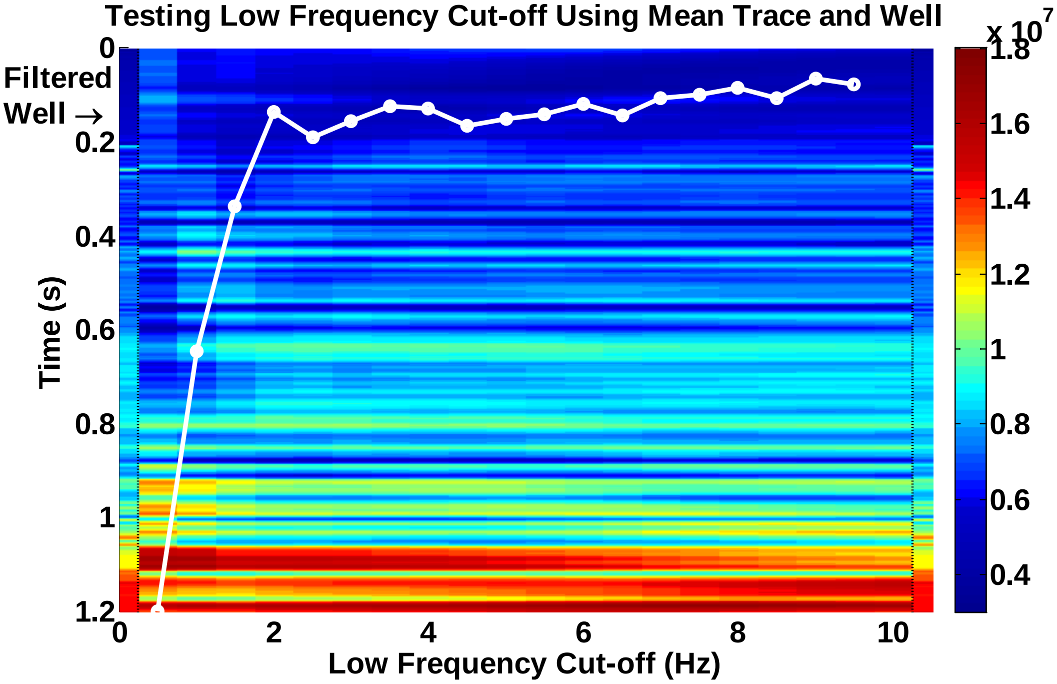

FIG 10: Frequency test to determine the best low frequency cut-off when using the impedance log from the average well. For comparison the filter impedance from the average well is shown at the very right and left of the section. The white curve shows the normalized difference between adjacent inversions.

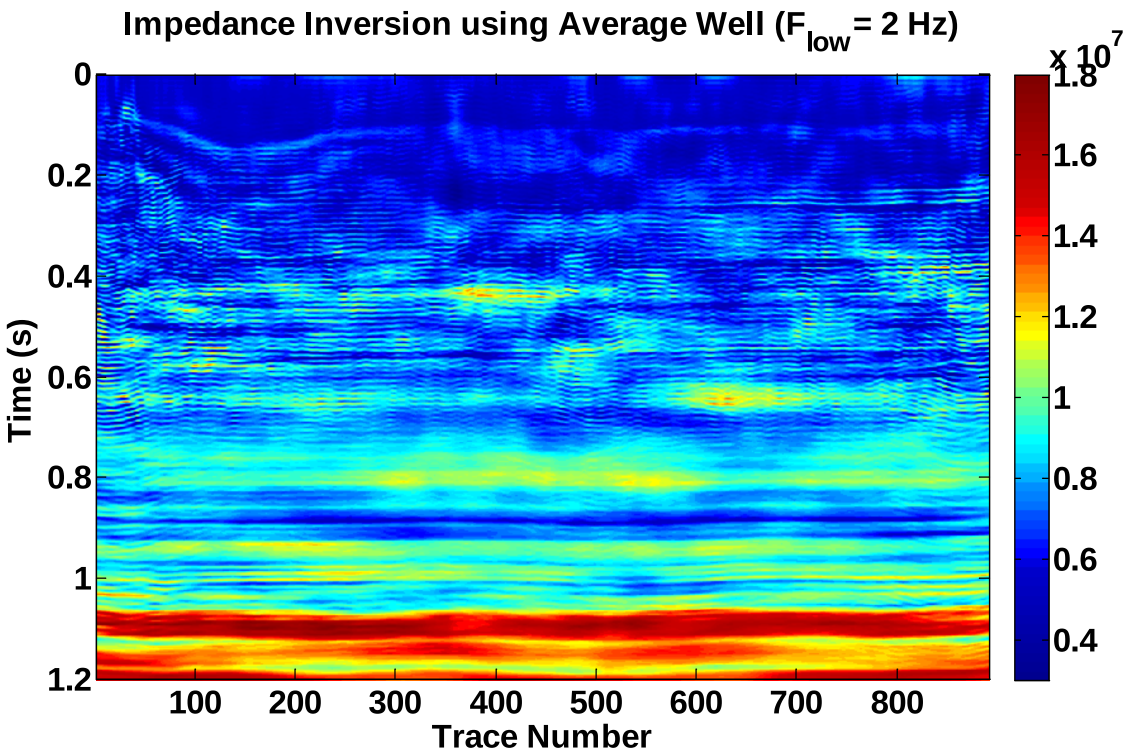

FIG 11: Coloured inversion section using the average well impedance and a low-frequency cut off of 2 Hz.

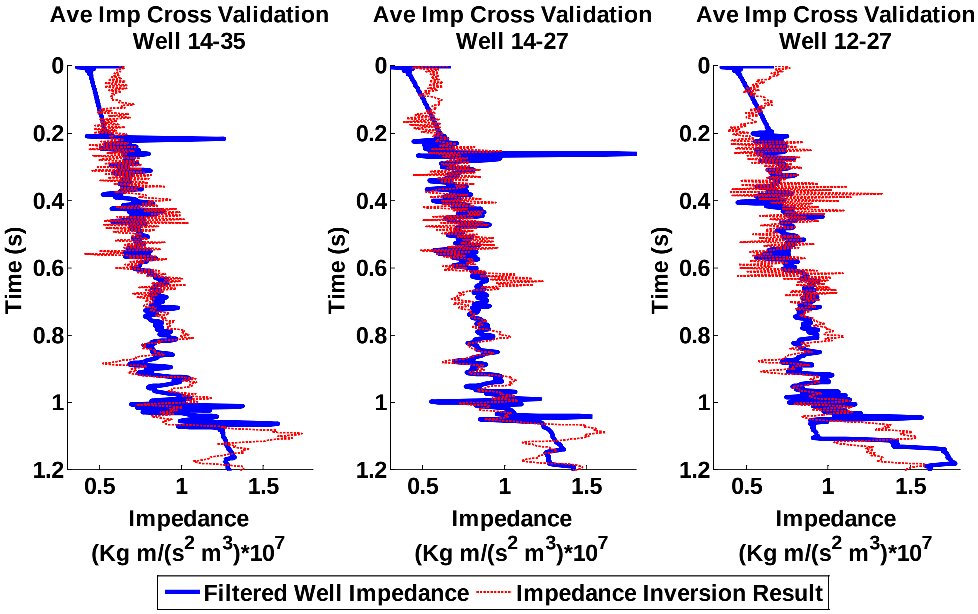

FIG 12: Cross Validation tests between the filtered well impedance and the impedance inversion at the well location.

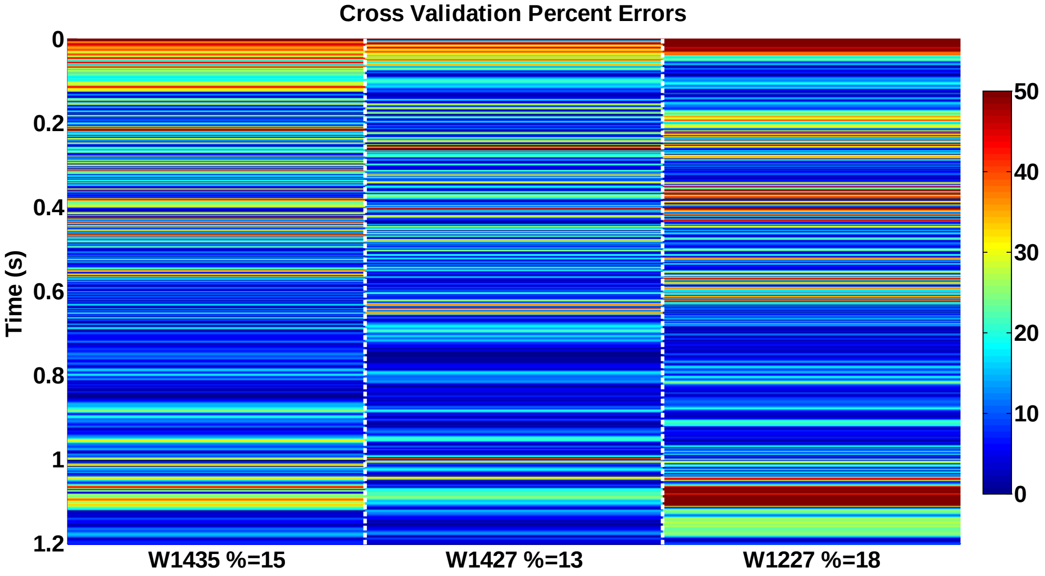

FIG 13: The percent error between the filtered well impedance and the impedance inversions at the well location. The mean error over the interval of 0 to 1.2 seconds is shown below.

Now that we have an appropriate cut-off value we can calculate the impedance section using BLIMP. The average well was used for the low-frequency component and the impedance section is shown in Figure 11. The high frequencies present in the inversion are evident but they do not seem to add any interpretable detail to the inversion. Figure 12 shows cross validation tests. There is good alignment with the wells after 0.8 seconds but before that there is too much noise to get a good impedance match. The cross validation errors are shown in Figure 13 where high frequency errors can be seen in the upper section. For the 14-35 cross validation test the mean percent error from 0 to 1.2 seconds was 15%, for the 14-27 cross validation test the mean error was 13% and for 12-27 cross validation test the error was 18%. These errors are not ideal.

CONCLUSIONS

This study shows that coloured inversion is very sensitive to high frequency amplification. It is also likely that our trace spectral model needs to be nonstationary due to the time-variant fold of a typical seismic image. More tests need to be done to find the perfect balance of amplifying the frequencies and attenuating the noise found in the high frequencies. There seems to be some improvement in the reservoir interval with coloured inversion compared with white inversion but more testing needs to be done. Investigating other methods of coloured inversion and comparing it to this method must also be done.

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