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Influence of color operator on Hussar seismic data

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Summary

The real seismic section, even after excellent data processing, is always very bandlimited, lacking both low and high frequencies. In this situation, recovering any of this bandwidth can be helpful. Especially, at the low frequencies, missing any of this information can effect remarkably the impedance estimation. Data that has been deconvolved will usually have a white spectrum whereas well logs show a roll off in spectral amplitude at the low frequencies that is called "color". Using a color operator can restore this spectral color. In this study, the effect of three different color operators on Hussar data has been investigated. The results also are compared with the Colored Inversion method which is a popular way to compute a bandlimited impedance inversion with spectral color. These results demonstrate that using the color operator can improve the impedance results significantly.

Introduction

Inversion of seismic data to Acoustic Impedance (AI) because of band-limited seismic data is always challenging. In case of broadband seismic data, the recursion formula (Oldenburg et. al., 1983) is working perfectly and can estimate the acoustic impedance with all frequencies. However, in the real world the recorded seismic data because of number of reasons such as bandlimited nature of source wavelet, noise contamination, attenuation, absorption and etc. the recorded data are always bandlimited. Thus, the calculated acoustic impedance from recursion formula in this case is very inaccurate, missing both low and high frequencies. Instead of using recursion formula to calculate the bandlimited acoustic impedance, another method was developed by Lancaster and Whitcombe (2000) which called Colored Inversion (CI). The CI method is a simple and fast technique to invert the band-limited seismic data to relative impedance and can be done by generating a single operator to match the average seismic spectrum to the shape of the well log impedance spectrum. From their observation, the AI spectra can be written as power law such as

$$S_{AI} \propto f^{\alpha} \ , \qquad (1($$

where f is frequency and the α term is a negative constant number. The α can be found for a field by curve-fitting to AI logs then the amplitude spectrum of the inversion operator is determined as being that which maps the seismic spectrum to a curve of form f^{α}. Once the inversion operator derived it should be applied to the deconvolved trace to create the acoustic impedance.

To use the conventional method for acoustic impedance calculation (recursion formula), it has been needed to take the missing frequency data from well log data. In 1996, Ferguson and Margrave created the BLIMP (BandLimited IMPedance) inversion algorithm which extracts the low frequency data from well log data and applies them to the bandlimited inverted impedance. On the other hand, the deconvolution operator assumes the reflectivity should has white spectrum while the real reflectivity has a color spectrum (Esmaeili and Margrave, 2014) and that means there is a spectral error between real reflectivity and estimated reflectivity (Figure 1a). To correct this spectral error, a specific operator needs to be designed to model the color trend of reflectivity without reproducing the specific characteristics of reflectivity that must be preserved in the seismic. Esmaeili and Margrave (2014) showed it is possible to derive the spectral shape of reflectivity and apply it to amplitude spectrum of deconvolved trace. The amplitude spectrum of color model is deriving via curve fitting of a specific function on the spectrum of reflectivity and because the operator needs to correct the error of minimum phase whitening deconvolution, that must be minimum phase. They developed two different model to represent the reflectivities spectral trend, arctan function and sigmoid function which represent arctan color operator and sigmoidal color operator (Figure 1b and 1c).

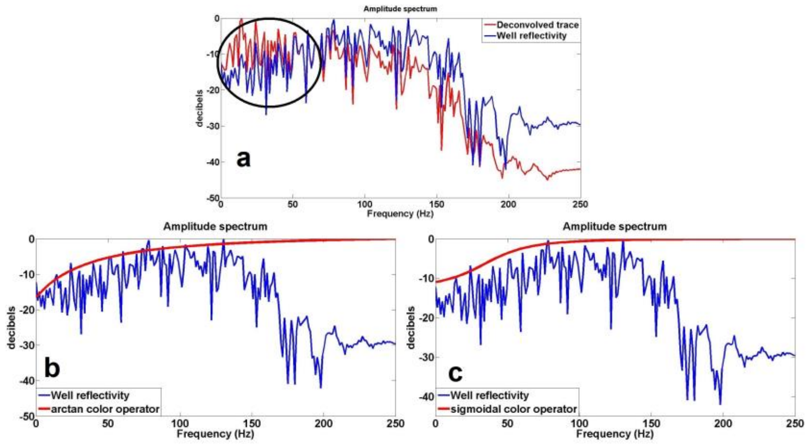

Figure 1. (a) the spectral error between well reflectivity and deconvolved trace, (b) designed arctan color operator and (c) sigmoidal color operator.

The effect of color operator on real seismic data

In September 2011, CREWES with cooperation of Husky Energy initiated a seismic experiment near Hussar in Alberta. The line was 4.5km long and intersected three wells 14-35, 14-27 and 12-27, shown in Figure 2 (Margrave et al, 2012). After the data collected at the field, the CGG Veritas implemented a specialized processing flow. Normally a high-pass filter is applied to the data to remove noise such as ground roll. This high-pass filter can be as high as 10 Hz. To keep the integrity of the low-frequencies, different noise attenuation was needed. Some of these methods were as follows: removing sinusoidal noise caused by power lines and pump-jacks, attenuating coherent noise and attenuating anomalous high amplitude frequencies. These noise attenuation procedures were repeated several times during the processing flow. Scaling was also specialized as common trace equalization, such as an AGC was undesired. Geometrical spreading gain recovery and surface consistent scaling was implemented instead.

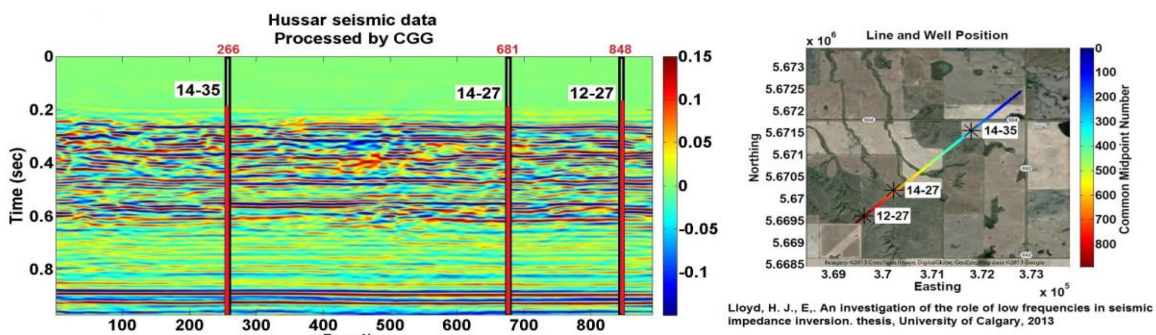

Figure 2. Fully processed Hussar seismic data and the position of three wells located in the seismic line.

To investigate the result of different color operator on Hussar seismic data, they should apply to the stacked seismic section. Using two different methods the color operators can be applied to the seismic section. We can average three color operators which created from three Hussar wells and then the averaged color operator can be applied into the entire seismic section or, by calculation the spatial interpolation of color operators between three wells, the color operator matrix can be computed for the whole section and then by convolving each seismic trace with its color operator, the colored seismic section can be computed. In this study two color operator types (arctan color operator and sigmoidal color operator) have been calculated for the whole seismic section using spatial interpolation method. Once it has been done, each trace of seismic section can be convolved with its related color operator. The result of applying minimum phase arctan and sigmoidal color operators to the seismic section are shown in the Figure 3. At each figure the right hand side figure is before applying color operator and the left hand side is after applying color operator respectively.

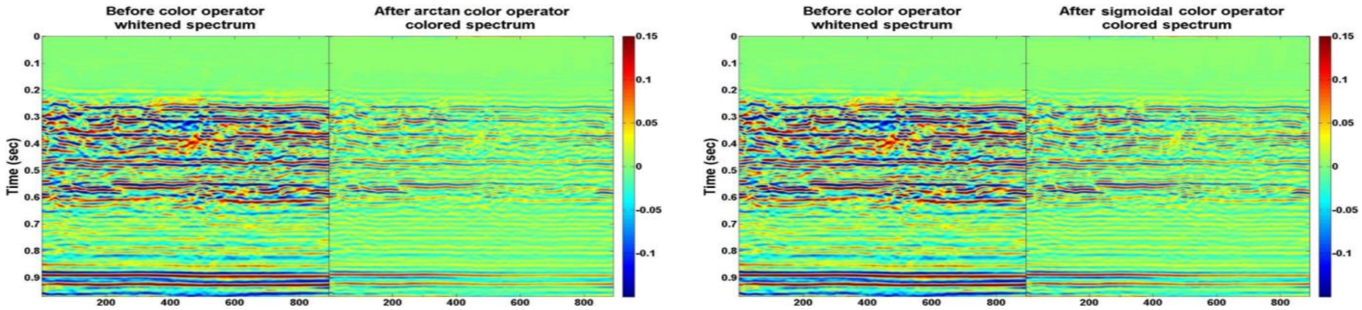

Figure 3. Effect of arctan (left) and sigmoidal (right) color operators on Hussar seismic data.

The results show that the seismic data after applying color operator are becoming dim which means their power of amplitude are decreasing. This can be seen from amplitude spectrum of arbitrarily trace from seismic section before and after applying color operator. For example, the amplitude spectrum of seismic trace near well 14-27 before and after applying color operator have been displayed in figure 5.

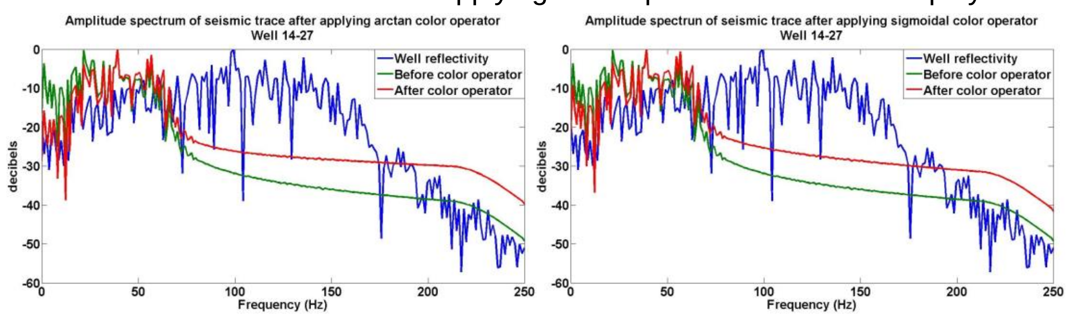

Figure 5. The amplitude spectrum of seismic trace located near well 14-27 before and after applying arctan (left) and sigmoidal (right) color operators.

The BLIMP algorithm has been used to calculate the acoustic impedance section. The low frequency value for BLIMP algorithm was chosen 5Hz and the frequencies higher than 70Hz were removed in impedance calculation.

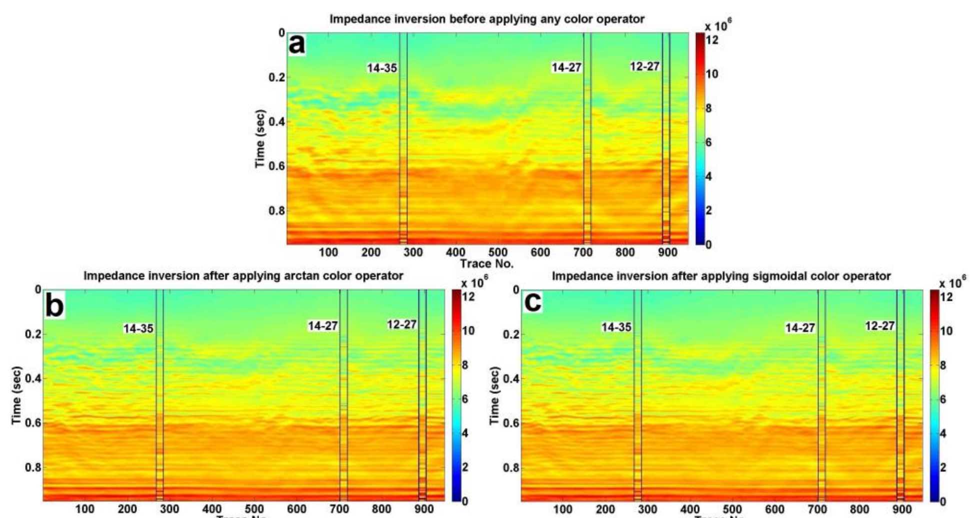

Figure 6. The result of applying color operators on acoustic impedance calculation of Hussar seismic data.

The impedance section also can be calculated via colored inversion method which introduced by Lancaster and Whitcombe (2000). The inversion operator was designed as described before (Figure 7a) and then applied to the whole seismic section to calculate the bandlimited acoustic impedance section (Figure 7b). As we can see, the computed impedance in this case is only showing the variation of impedance from its trend not its real value. Also, the results showed the computed impedance is proportional to -90 degree phase rotation of seismic data.

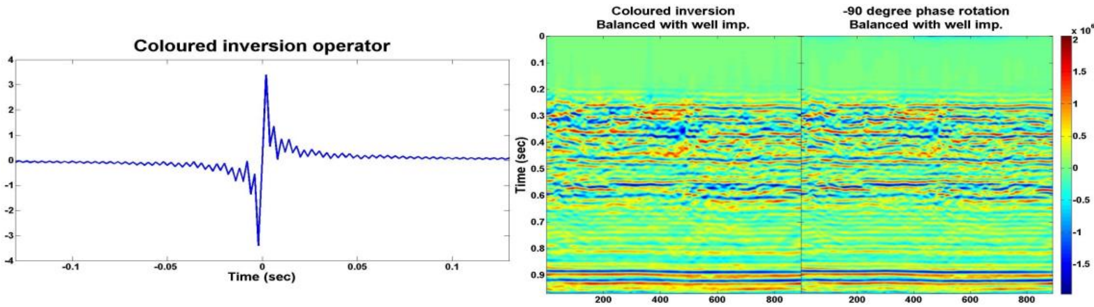

Figure 7. Designed colored inversion operator (left) and comparing the data after applying this operator and -90 degree phase rotation.

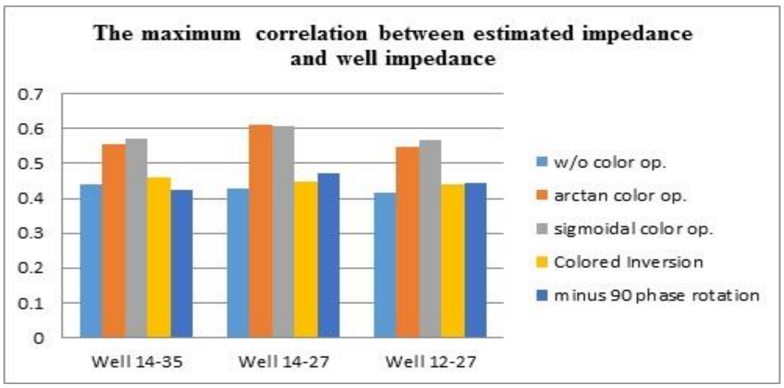

Chart 1. The chart shows the maximum correlation between estimated impedance using different methods and Hussar well impedance at the well locations. The frequency range for correlation calculation has been chosen between 10Hz and 60Hz.

Conclusions

As it has been seen, accurate acoustic impedance estimation requires the low frequencies from well logs. Furthermore, the results showed that a deconvolved trace shaped to a white spectrum can be corrected by applying a minimum phase color operator after deconvolution which improved the acoustic impedance results significantly. The results also demonstrate using the colored inversion method is a fast and robust technique to calculate the bandlimited acoustic impedance but comparing with the impedance results with color operator shows using the color operators gives us more accurate impedance results.

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