GeoConvention 2016
Calgary • Canada • March 7-11
OPTIMIZING RESOURCES

Comparison of Spectral Enhancement Techniques and Application to Improved Well-to-Seismic Ties

*Pavel Jilinski and Tom Wooltorton**
GeoTeric

Summary

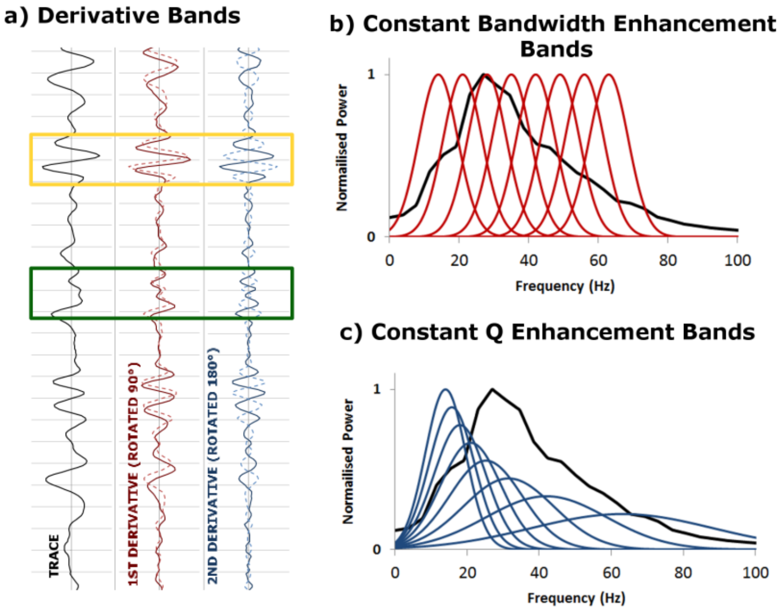
Spectral enhancement is a technique for selectively boosting portions of the seismic signal with distinguishable frequency content. It is often applied to seismic data in order to boost the high frequency content of the data, which can be masked by underlying low frequency signal. The practical application is to improve the vertical resolution of events thereby improving interpretability and in this case, well-to-seismic ties. Here we compare three different methods of spectral enhancement that are regularly applied to 3D post stack seismic data. We are particularly interested in the effectiveness of each technique in enhancing real signal in the data, as well as the efficiency of each process at this task. The most successful method was then used improve well-to-seismic tie correlation, compared to the original full-stack 3D seismic.

Introduction

The tying of well log information to seismic data is an essential part of the seismic interpretation workflow, when making geological interpretations and accurately delineating reservoir character. The difference in scale of geophysical measurements is however a widely known issue to the oil industry. Well tie workflows commonly relate centimeter scale of well logging tools to tens of meters resolution of seismic data. A common workflow for well to seismic ties is based on downscaling well log data. However, seismic data also typically contains frequency information that when exploited and appropriately enhanced, can increase the vertical resolution of the seismic and address the scale mis-match from the other direction. Applying spectral enhancement can reduce the attrition of log information during the tying process, extend the useful life of the seismic dataset, and impart knock-on benefits for all seismic interpretation and analysis steps.

Method

Here we compare three different approaches for isolating and enhancing frequency, with particular focus on wavelet methods with different time and frequency resolution (Fig. 1). Two of the methods are based on bandpass filtering the data through convolution of Gabor wavelets with different scales while the third method uses the trace derivative (curvature) to increase frequency content. To provide a comparison between different methods, spectra have been computed for each method at a key interval using fast Fourier transform (fft) averaged over a number of traces and statistical measures are computed from each spectrum (see Widess, 1982; Barnes, 1993 for spectral measurements). Measures of average frequency are based on the distribution of power and energy over the frequency spectrum and they include mean, median, mode and RMS frequency. Measures of bandwidth of the spectral distribution include standard deviation, interquartile range and spectral width at 50% peak power. Statistics based on spectral power can be erroneous if the fft spectrum is notched, whereas measurements based on energy may be misleading if there is inclusion of data below the noise floor, therefore comparison of multiple measurements is preferred.



a) sample trace (black), first derivative (dashed red), phase rotated first derivative (red), second derivative (dashed blue), phase rotated second derivative (blue). Events on the trace which are well resolved (highlighted yellow) are largely unchanged by the differential process whereas poorly resolved events (doublets highlighted green) are enhanced,

b) Constant bandwidth decomposition bands at uniform spacing and matched to a sample seismic spectrum.

c) Constant Q decomposition bands with increasing bandwidth and at exponential spacing, matched to a sample seismic spectrum.

Fig.1 – Spectral Enhancement methods compared in this study

Derivative (trace curvature) method

The first and second derivatives of the seismic trace were computed in the trace direction. In order that the derivative function has the correct peak and trough alignment with the input reflectivity it is phase rotated (1st derivative by 90° and the 2nd derivative by 180°). The process of differentiation has the effect of fully resolving doublets, increasing the mean frequency of the data, thereby enhancing high frequencies and suppressing low frequencies. To ensure that the low frequency content is maintained the phase rotated derivative function is summed with the input reflectivity data.

Constant bandwidth narrow-band enhancement

This method involved decomposing the seismic signal into a number of narrow frequency bands through bandpass filtering with a Gabor wavelet. For the constant bandwidth enhancement the scale of the Gabor wavelet is varied to maintain uniform bandwidth of decomposition bands with increasing central frequency. A spectral enhanced reconstruction of the seismic signal can be made by summing the individual bands with modified weightings, thus manipulating the frequency-power distribution. The narrow bandwidth equates to a good frequency localisation, therefore it is useful for isolating discrete frequencies; for instance, acquisition noise or processing artefacts. For this reason the narrow bands are extremely useful for spectral whitening because they provide a lot of scope for spectral reshaping. It is usual for uniform frequency spacing to be used between bands in order that the resolution is maintained across the whole spectrum. The high frequency localisation comes at a cost to resolution in the time domain and this trade-off can be attributed to uncertainty principle. Reduced temporal resolution at higher frequency often manifests as 'ringing', which is multiple oscillations about peak or trough centre.

In extremes, ringing can cause unrealistic events to appear in the enhancement band in the location of side lobes in the original data and care must be taken to avoid these unwanted effects. In addition to the problem of multiple harmonic or ‘ringing’ events appearing, a small break in a single reflector (possibly noise) may manifest as multiple breaks in the high frequency – low bandwidth response, which could be misinterpreted as a fault or structural boundary. It is a good idea to minimise the risk of any noise related effects by improving reflector continuity through noise cancellation prior to enhancement. Ringing and aliasing are avoided by honouring the bandwidth and Nyquist limits of the input spectrum.

Constant Q variable bandwidth enhancement

This method is similar to the constant bandwidth method of enhancement in that a number of Gabor filters, convolved with the seismic data are used to produce decomposition responses that can be recombined with the original data in order to manipulate the shape of the spectral energy distribution. The key difference is that the scale of the decomposition wavelets is kept constant for different frequencies (the wavelet Q factor is proportional to the product of its power and bandwidth), which results in the bandwidth increasing with central frequency. The increased bandwidth results in decreasing frequency resolution at higher frequencies which, converse to the previous method, maintains resolution in the time domain. The use of variable window transforms for spectral enhancement is described in literature elsewhere, (e.g for bandwidth extension, Smith, 2008). When applying constant Q enhancement exponential spacing between frequency bands is sufficient to maintain frequency resolution. A consequence of decomposition using high bandwidth filters at high frequencies is that it is much more difficult to isolate frequency. The transform, being a convolution method, means that a given decomposition band will preferentially boost signal of higher power within that band. Practically this results in a limit to the amount of enhancement that can be applied through a Constant Q filter.

Application

In order to determine optimal frequency ranges for seismic enhancement and tying, well logs were converted to time using averaged layer velocities from checkshot data and a series of low pass FFT filters were applied. A trend of increasing correlation between original log data and FFT low pass filtered data is observed as higher frequencies are included. It was identified that after reaching 60 Hz (0.96) the rate of increase in correlation decreases. 60 Hz was chosen as the optimal compromise between seismic and log resolution. The spectrum of seismic data over the region of interest was analyzed. After reaching the peak frequency at 27 Hz the power of higher frequencies quickly decreases reaching the inflection point at 46 Hz and at 60 Hz only 20% of the power is present relative to the peak frequency. It was concluded that significant geological information could be revealed by enhancing higher frequencies of the seismic data up to 60 Hz, increasing its correlation with well log spectrum. In order to minimize the enhancement of noise in the seismic data, coherent and random noise was attenuated by running structurally oriented filters prior to the spectral enhancement.

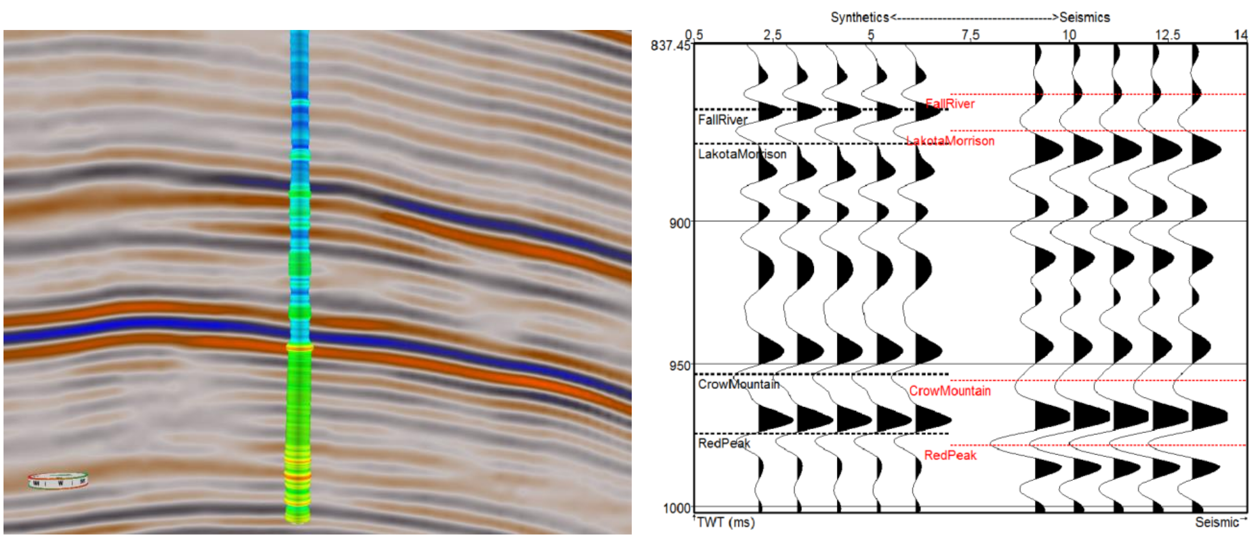


Fig. 2 – Enhanced seismic and acoustic impedance log (left) and plot tying synthetic to seismic (right).

The resulting seismic volume kept its dominant frequency but the bandwidth of the spectrum was widened to 60 Hz toward higher frequencies (compared with 22 Hz of the original data). Also the mean frequency was shifted toward higher frequencies. Further increase of the higher frequencies was unviable due to very small power of the original seismic data. The spectrally enhanced seismic data shows the reflections corresponding to major inter and intra-layer changes allowing more reliable well to seismic ties and horizon interpretation. Figure 2 shows the well tie implication of the spectral enhancement. Increasing the bandwidth toward the higher frequencies and balancing amplitudes allowed smaller scale features to be resolved, and correlation between synthetic seismic and seismic trace increased from 0.67 to 0.87 after spectral enhancement.

Conclusions

The constant bandwidth method, through the utilization of narrow bands is very good at isolating frequency, which it makes it very useful for targeting events with a discrete frequency and when noise cancellation filters are applied to each band they can be used to target frequency specific noise. The narrowness of the filters employed, allows for the most manipulation of the spectrum; this can however result in ringing, so care must be taken when optimizing the filters and band weightings. Constant Q enhancement also increases the time resolution, but it is difficult to isolate frequency specific noise and signal, especially at higher frequencies. It is difficult to over enhance using constant Q filters and therefore such an enhancement requires minimal QC of the input bandwidth threshold and noise floor. The poor frequency resolution means that it not useful for manipulating the spectrum to a specific shape. The derivative method is not useful for enhancement of low frequencies but is fast, relatively parameter-less and it is difficult to over-enhance or to produce artefacts.

On the basis of the above, constant bandwidth spectral enhancement was chosen as the most appropriate technique to improve the baseline 3D seismic survey to increase well-to-seismic tie correlation. Analyzing the spectrum of the well log data at the interval of interest provided the constraints for the optimal bandwidth increase. Increasing the spectral bandwidth of the original seismic data resulted in a narrowing of the original seismic wavelet, separating interfering seismic reflectors and constructing a more reliable well tie synthetic correlation by mapping separated layers on the spectrally enhanced seismic data. Following these processes, an increase in the correlation between well log and seismic was observed and measured.

Acknowledgements

The contributions of Nick McArdle are acknowledged and appreciated, for undertaking much of the research described above.

References

McArdle, NJ and Paton, G. [2014] Comparison of Spectral Enhancement Techniques Applied to Post Stack Data, EAGE Conference and Exhibition 2014 Amsterdam, poster presentation.

Barnes, A.E. [1993]. Instantaneous spectral bandwidth and dominant frequency with applications to seismic reflection data. *Geophysics*, 58(3), 419-428.

Smith, M., Perry G., Stein, J., Bertrand, A. and Yu, G. [2008]. Extending seismic bandwidth using the continuous wavelet transform. *First Break,* 26, 97-102.

Widess, M.B. [1982]. Quantifying resolving power of seismic systems. *Geophysics,* 47(8), 1160-1173.

Backus, G. E., [1962], Long-wave elastic anisotropy produced by horizontal layering: J. Geophys. Res., 67, 4427-4440.

Partyka, G., Gridley, J. and Lopez, J., [1999], Interpretational application of spectral decomposition in reservoir characterization: The Leading Edge, 353-360.

Wang, Yanghua, [2008], Seismic inverse Q filtering. Blackwell Pub. ISBN 978-1-4051-8540-0.