Borehole log guided seismic spectral enhancement applied for well to seismic tie workflow

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Abstract

The difference in scale of geophysical measurements is 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. The main aim of downscaling is to filter out small scale variations leaving the significant lithological changes (from an interpreter's point of view). Common tools include smoothing and filtering operators, blocking and Backus averaging. Those steps remove minor (intra-layer) variation keeping major acoustic impedance contrasts to generate the synthetic seismic trace. The seismic wavelet width used to convolve the reflection coefficient series to produce the synthetic seismogram serves as a downscaling operator resolving only distinct major acoustic impedance contrasts. On the other hand the earth serves as a natural filter for the seismic signal travelling through it, attenuating higher frequencies.

As the exploration process moves toward development, the need for more precise well ties becomes more acute. In this paper an additional step in the methodology is discussed by upscaling seismic resolution using well log data as a guide. Well and seismic data from the Teapot Dome field were used in this work.

Introduction

Downscaling of well log data has become a common practice for oil and gas exploration well tie workflows (Backus, 1962; Halliburton, 2008; Schroeder, 2011; Schlumberger, 2014*).* Downscaling processes are aimed at focusing acoustic impedance contrasts at major lithological changes according to interpreter needs. Well log character is a characteristic of the medium influenced by local conditions rather than depth. Logging data is characterized by superposition of high frequency events over low frequency trends. Commonly lower frequency characteristics are used as markers of sequence boundaries (eletrofacies).

The attenuation of seismic energy with depth (time) is frequency dependent (Yanghua, 2008). The earth rock's acts as a filter downscaling seismic resolution and changing the amplitude balance from the original source spectrum. Therefore processing is requiring for harmonizing amplitudes over spectrum ranges to improve well ties and achieve a more realistic image subsurface.

One of the post-processing tools available for seismic resolution increment is spectral enhancement though frequency dependent amplitude balancing. Increasing the bandwidth of the spectrum and normalizing the power between higher and lower frequencies helps to increase seismic resolution. Spectral enhancement was applied to improve the resolution of higher frequency events in the seismic data achieving higher well to seismic tie correlation.

Method

In order to determine optimal frequency ranges for seismic enhancement, well logs were converted to time using averaged layer velocities from checkshot data and a series of low pass FFT filters were applied (Figure 1).

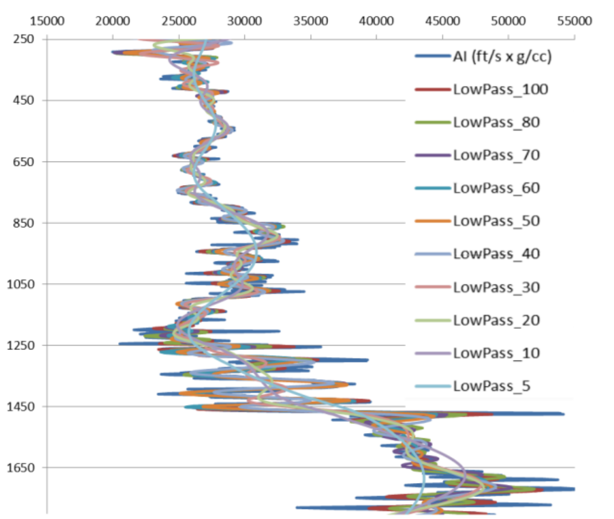

Figure 1. Acoustic impedance log (ft/s x g/cm^3) filtered using low pass filters of variable size from 0 to 100 Hz compared with original smoothed log.

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 (Figure 2). 60 Hz was chosen as the optimal compromise between seismic and log resolution.

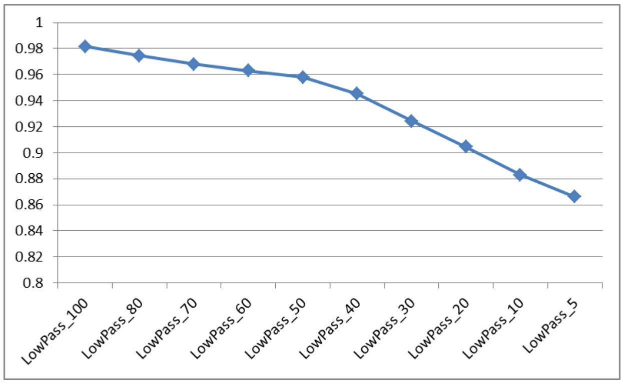

Figure 2. Correlation between smoothed log and filtered logs.

The spectrum of seismic data over the region of interest was analyzed (Figure 3). 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 for 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. The noise cancelled seismic data was decomposed (Partyka et al., 1999) using frequency bands of fixed size (Figure 3) and the resulting volumes were recombined giving higher weights to higher frequency values as shown in Figure 4 (Henning and Paton, 2012; Marfut and de Matos, 2014).

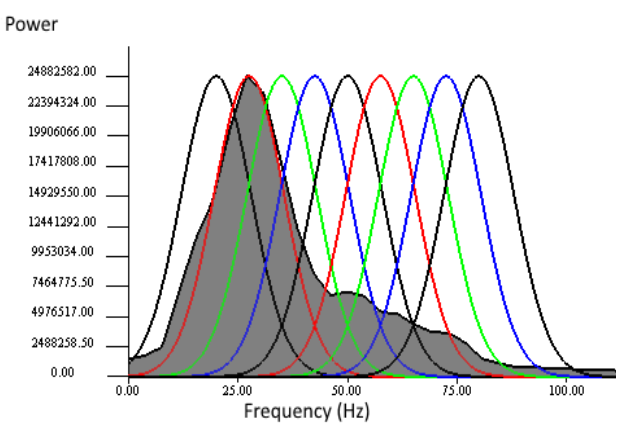

Figure 3. Frequency bands used to filter the original seismic. Seismic spectrum shown in light grey.

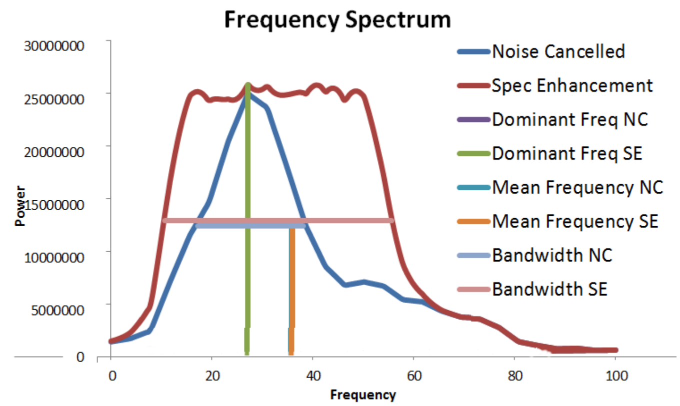

Figure 4. Noise cancelled and spectrally enhanced seismic spectrum. Main statistical parameters are shown.

Results

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 (Figures 5 and 6). Observe the enhanced resolution and increased continuity of reflectors at Figure 6.

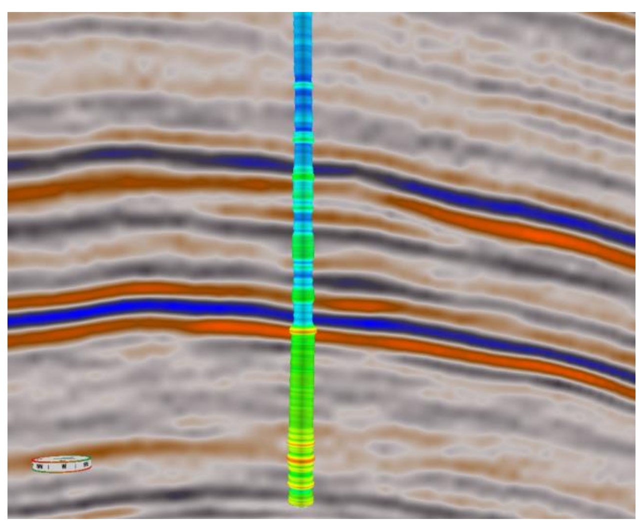

Figure 5. Original seismic (Acoustinc impedance log displayed).

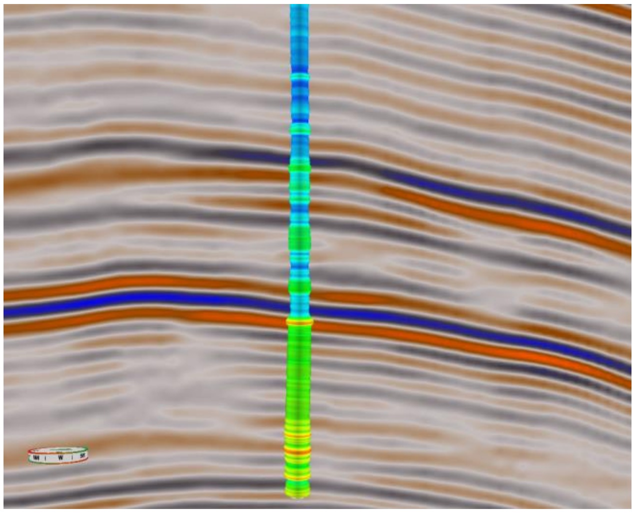

Figure 6. Spectrally enhanced (Acoustic impedance log displayed).

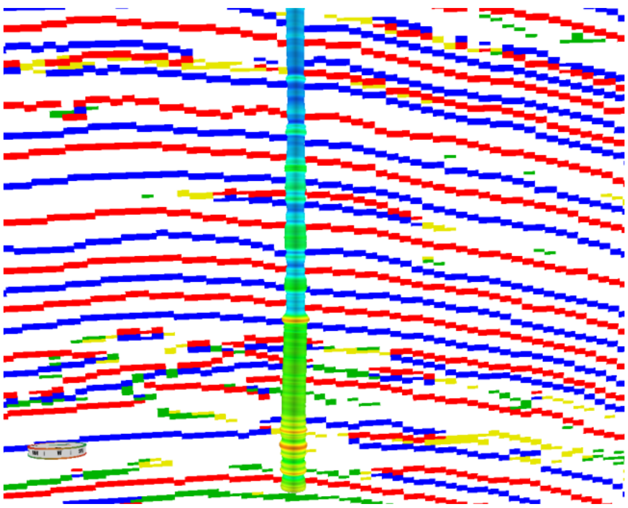

Figure 7. Bedform attribute mapping peaks and troughs on original data.

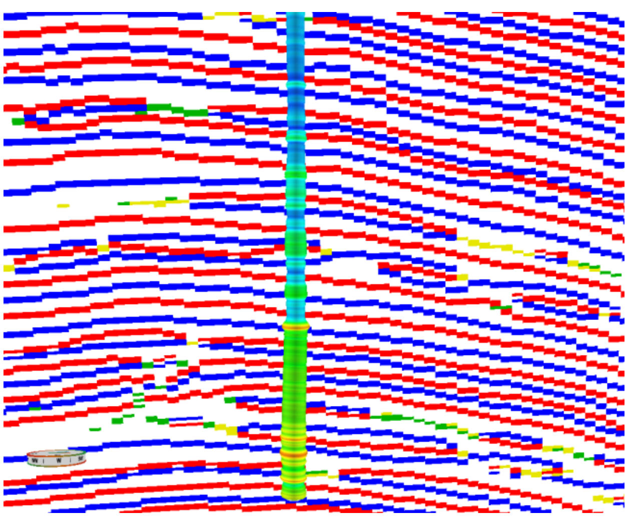

Figure 8. Bedform attribute showing position of the peaks and troughs on spectrally enhanced data.

A Bedform attribute mapping peaks and troughs was used to assess the increase in vertical resolution (Figures 7 and 8). On Figures 7 and 8 red and blue represent peak and troughs respectively; and green and yellow doublets for positive and negative values.

Figures 9 and 10 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. Note the increased resolution and correlation between original and spectrally enhanced seismic with the synthetic trace. Correlation between synthetic seismic and seismic trace increased from 0.67 to 0.87 after spectral enhancement.

Figure 11 shows the comparison between wavelets extracted from the original and spectrally enhanced seismic. Narrowing of the wavelet allows thinner layers to be resolved.

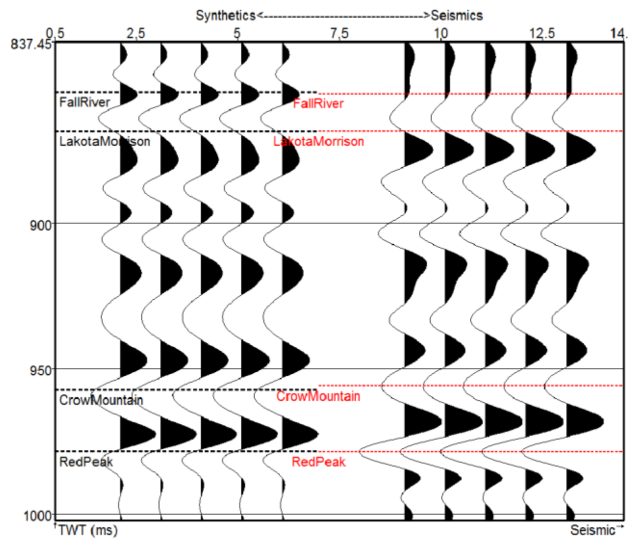

Figure 9. Synthetic seismic trace and original seismic data.

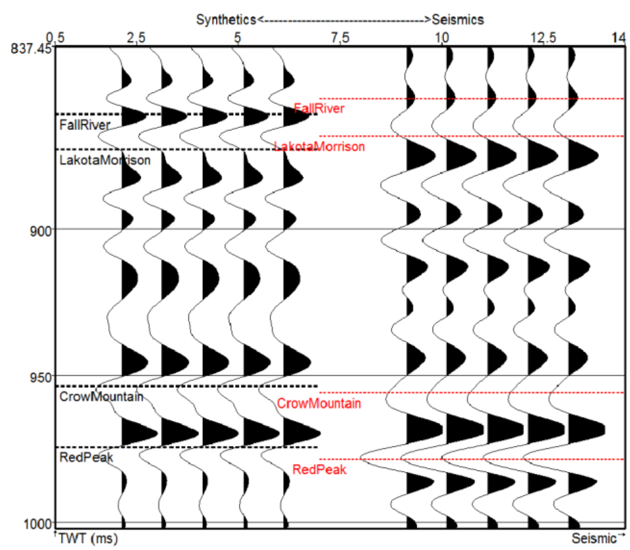

Figure 10. Synthetic seismic trace and spectrally enhanced seismic.

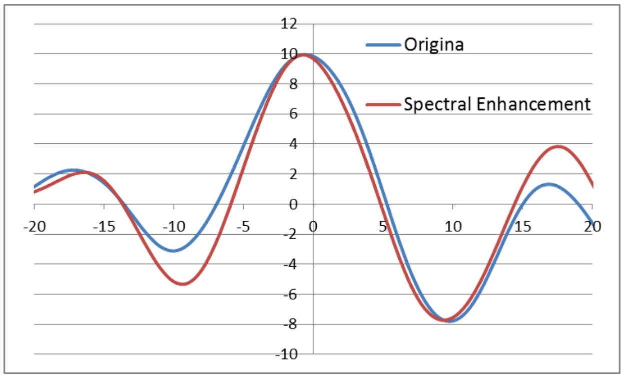

Figure 11. Comparison between wavelets extracted from original and spectrally enhanced seismic data.

Conclusions

Analyzing the spectrum of the well log data 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.

Spectral enhancement is a post-processing workflow that can be implemented by the interpreter and guided by well log data and local geology. Significant benefit can be obtained by applying methods that can improve the resolution of existing seismic data sets and that can be used with new data sets acquired with existing systems.

Acknowledgment

The author would like to thank RMOTC and the U.S. Department of Energy for providing the data set used in this presentation.

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