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Examples of Enhanced Spectral Processing in Direct Hydrocarbon Detection

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Summary

The Enhanced Spectral Processing (ESP) time-frequency spectral analysis technique eliminates the windowing problem in Fourier spectral analysis and has very high resolution in time and frequency. Synthetic studies show that the technique can be used to generate useful spectral attributes. Application to various gas reservoirs from the Gulf of Mexico indicates that these attributes can potentially be used for direct hydrocarbon detection. In our real data examples, reservoirs exhibit high attenuation of spectral amplitude at higher frequency. We also are able to detect the spectral amplitude anomaly which is caused by variations in tuning thickness caused by gas. The peak frequency extracted from ESP also enables us to delineate thin bed reservoirs.

Introduction

Traditional Fourier analysis provides a projection of the signal from the time domain to frequency domain. Every point from the time domain representation of the signal contributes to the frequency representation of the signal in the Fourier transformation, and vice versa. For non-stationary data, where the frequency content changes with time, the frequency representation after the Fourier transforms is an average representation of the frequency content change through all times. It can't reflect the instantaneous change of the frequency content with time. For those highly non-stationary data that have many local features, like seismic data, the Fourier transform may even provide misleading frequency features. Although the short window Fourier transform has been employed to provide the localization of the frequency content, windowing problems limit the resolution of this technique (Xia, 1999).

ESP time-frequency analysis directly extracts frequency content at each time location and eliminates windowing problems, thereby, allowing very high-resolution spectral analysis. In this paper, we perform synthetic and real data ESP case studies. Synthetic modeling demonstrates the high resolution of the technique by verifying the known frequency content at known time location. Three real data examples of gas reservoirs show the potential of this method for direct hydrocarbon indication.

Synthetic study

The technique was applied to a synthetic trace (Figure 1.a). As shown in Figure 1.a, the first event is created by adding a positive Ricker wavelet of 40 Hz at sample No. n=16. The second event is generated by adding two positive Rickers of 40 Hz and 10 Hz at n=81. The third event is generated by respectively adding Rickers of 30 Hz at n=130 and n=135. The fourth event is generated by respectively adding two Rickers of 30 Hz and 20 Hz at n=165 and n=172. The fifth event is generated by adding a positive Ricker of 30 Hz at n=220, a negative Ricker of 30 Hz at n=225 and a positive Ricker of 30 Hz at n=230. Figure 1.b shows the result of the ESP time-frequency analysis. Figure 1.c shows the result of short window furrier transform (STFT) time-frequency analysis which used 64 samples as window width. The frequency content is much better identified for each event by ESP than by STFT both in time domain and frequency domain, especially for the composite signals.

The high-resolution feature of this technique has many potential applications in seismic exploration. For example, the technique can potentially detect the change of the frequency content caused by high attenuation (Q=10-30) which generally indicate a gas reservoir (Sun, 2000). It has also been used to resolve the anomalas of frequency content caused by tuning and the change of the frequency content caused by velocity differences of brine and gas in the same formation.

Practical application

Based on the synthetic studies, we have applied the ESP techniques to three real data sets. The first example is a fractured carbonate gas reservoir. The reservoir is detected at around 1250ms by ESP analysis which shows a higher spectral amplitude attenuation at higher frequency. Figure 2 shows the seismic section from the fractured carbonate reservoir. Figure 3 shows the ESP spectral amplitude of this section at 40 Hz and figure 4 shows the ESP spectral amplitude of this section at 60 Hz. We can see that the spectral amplitude below the formation around 1250 ms is seriously attenuated on figure 4 relative to figure 3. This anomaly means that this formation has very high attenuation and suggests a thick gas reservoir. Figure 5 is the difference of figure 3 and 4 and more clearly shows the attenuation anomaly. We can see that the amplitude is canceled above the reservoir formation and the high attenuation starts at the reservoir. To confirm this conclusion, we apply ESP to another known thick gas reservoir in the second real data example. Figure 6 compares the spectral amplitude at 20 Hz and 30 Hz of this data set. The significant attenuation at higher frequency (30 Hz) starting from the reservoir top strongly supports our conclusion from example one: high attenuation at higher frequency suggests a thick gas reservoir. The third example is a thin gas reservoir. The target is at time 650 ms between CDP 280 to 380. Figure 7 shows the seismic section from this reservoir. Figure 8 shows the ESP spectral amplitude at frequency 20 Hz. It is not easy to see the attenuation anomaly of spectral amplitude at higher frequency because the reservoir is too thin. But the result from our ESP time-frequency analysis clearly shows the high amplitude anomaly (figure 9) of spectral amplitude caused by tuning preferential at a frequency of 70 Hz. The peak frequency technique (Partyka, etc., 1999; Marfurt and Kirlin, 2001) is used to extract the peak frequency from the ESP results. Figure 10 shows the peak frequency we extracted for this section. The target zone corresponds to a group of thin reservoir beds.

Conclusion

From these examples, we conclude that the ESP time-frequency method can potentially be used to directly detect hydrocarbons using high frequency attenuation anomaly for thick gas reservoirs. The peak frequency extracted from ESP analysis can be used to delineate thin bed reservoirs and may be used to distinguish between gas zones and water zones with different fine thicknesses.

Acknowledgement

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References

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Figure 1. Synthetic modeling. a) The synthetic trace for modeling study. b) ESP time-frequency spectrum

c) STFT time-frequency spectrum

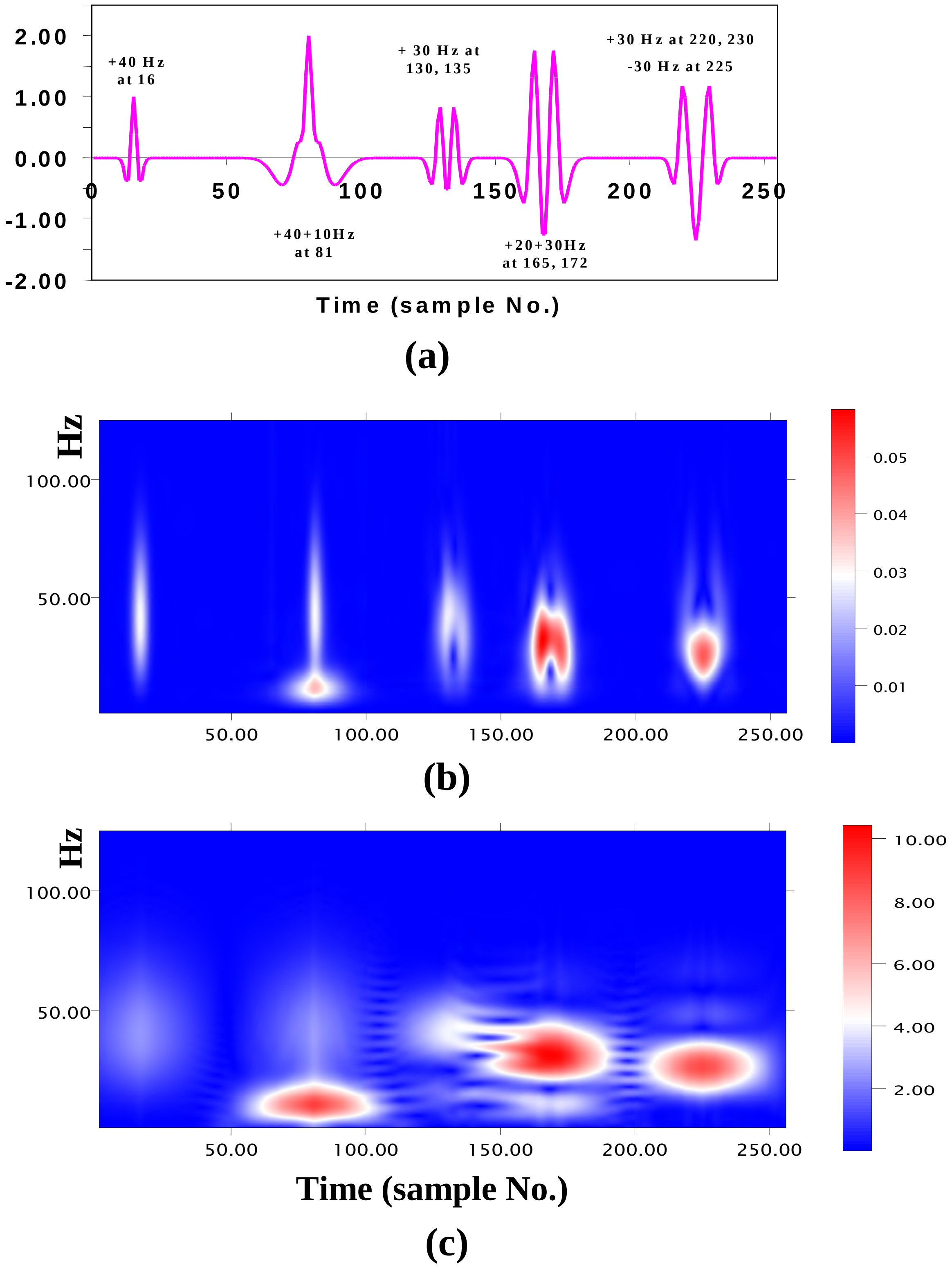


Figure 2. Seismic section from fractured carbonate reservoir.

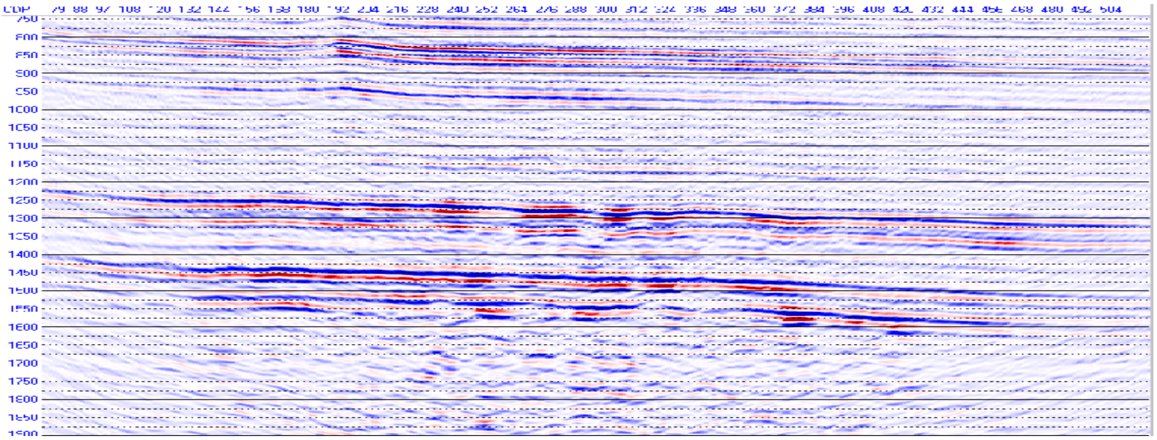


Figure 3. ESP spectral amplitude of fractured carbonate at 40 Hz.

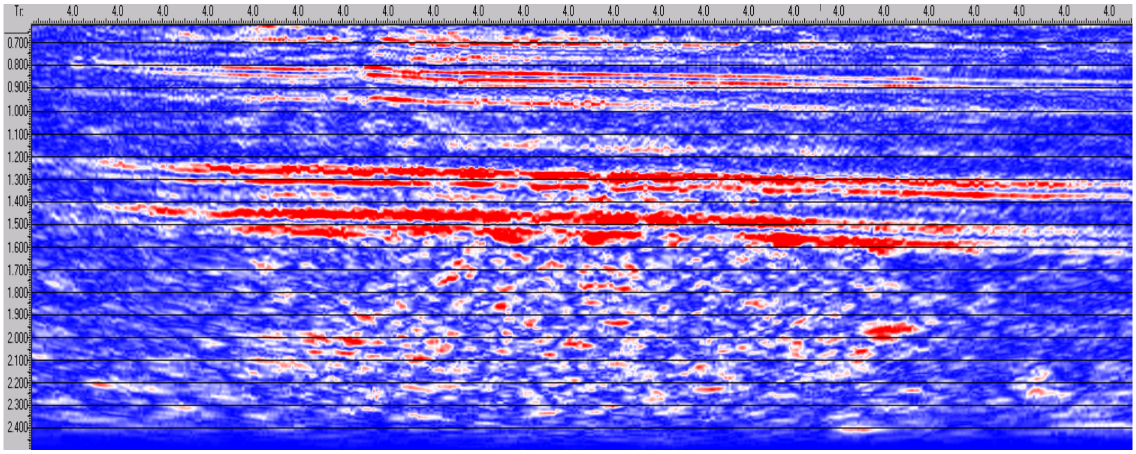


Figure 4. ESP spectral amplitude of fractured carbonate at 60 Hz.

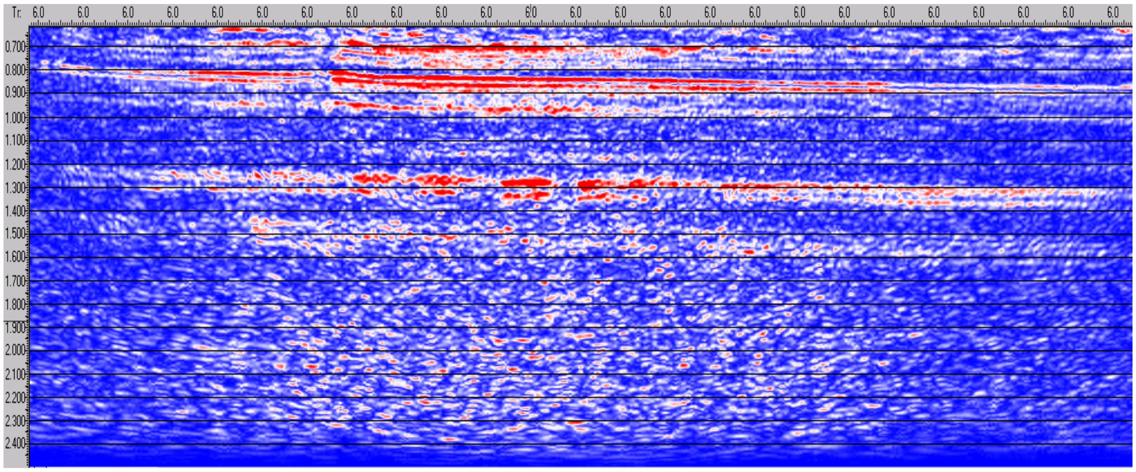


Figure 5. ESP Amplitude difference of fractured carbonate between 40 Hz and 60Hz.

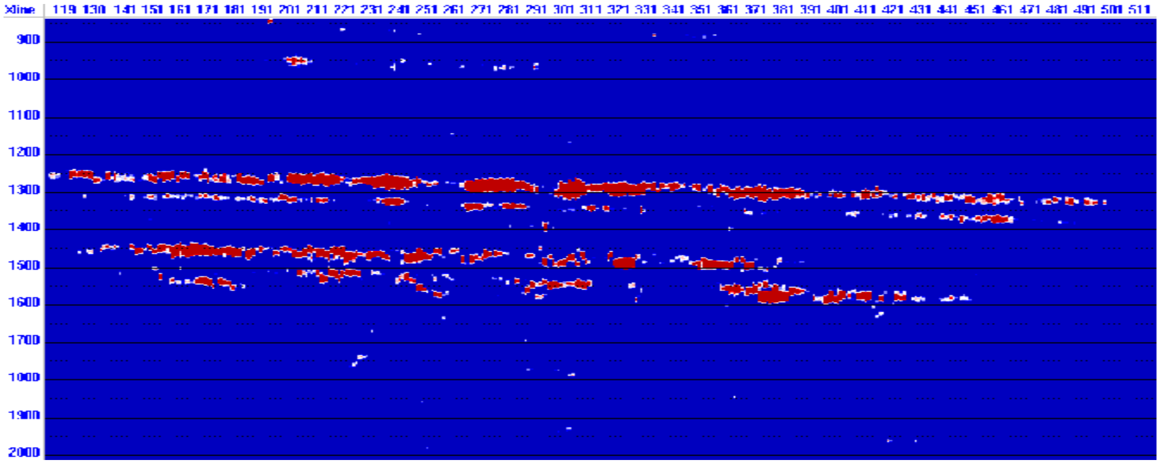
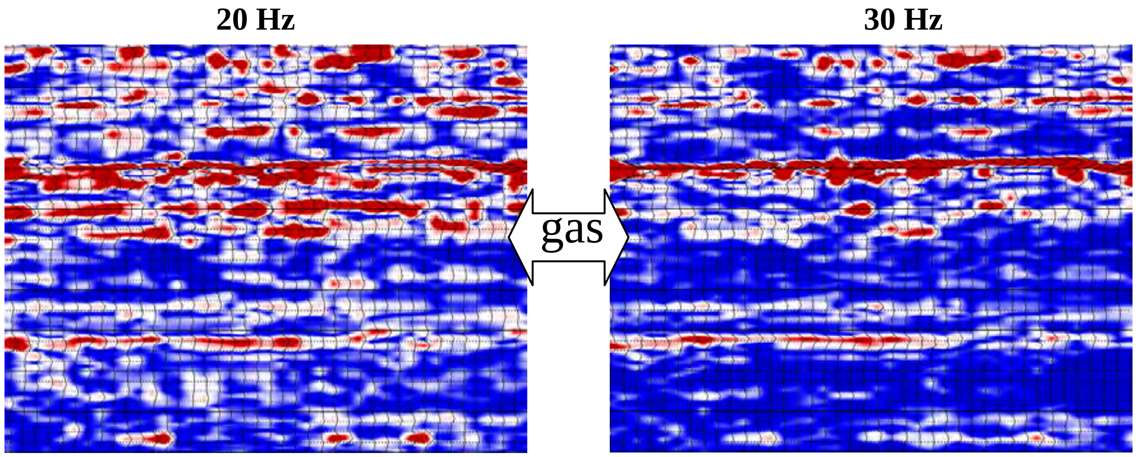


Figure 6. ESP spectra comparison of a thick gas reservoir between 20 and 30 Hz


20 Hz

30 Hz

Figure 7. Seismic section from a thin gas reservoir.

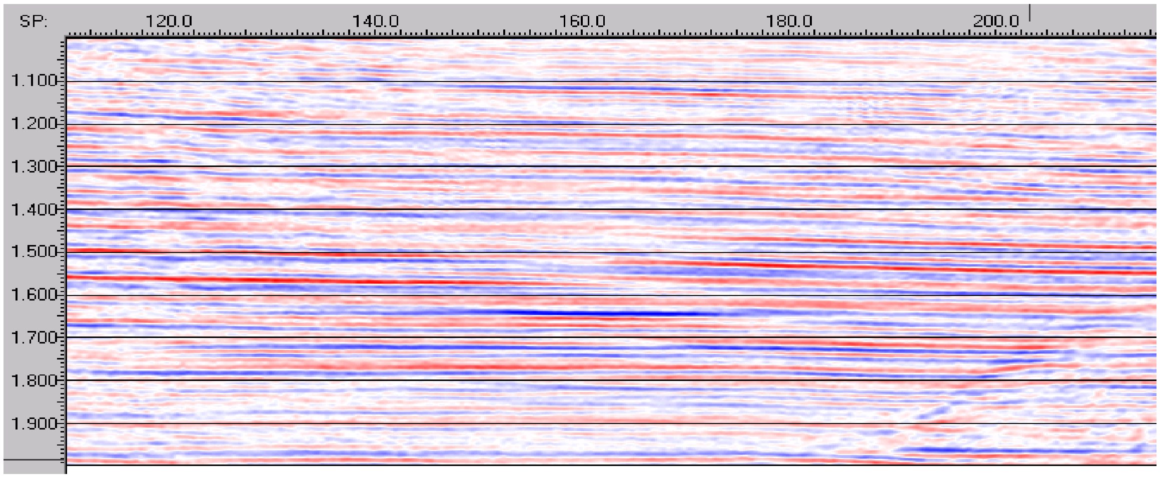


Figure 8. ESP spectral amplitude of the seismic section of figure 7 at 30 Hz.

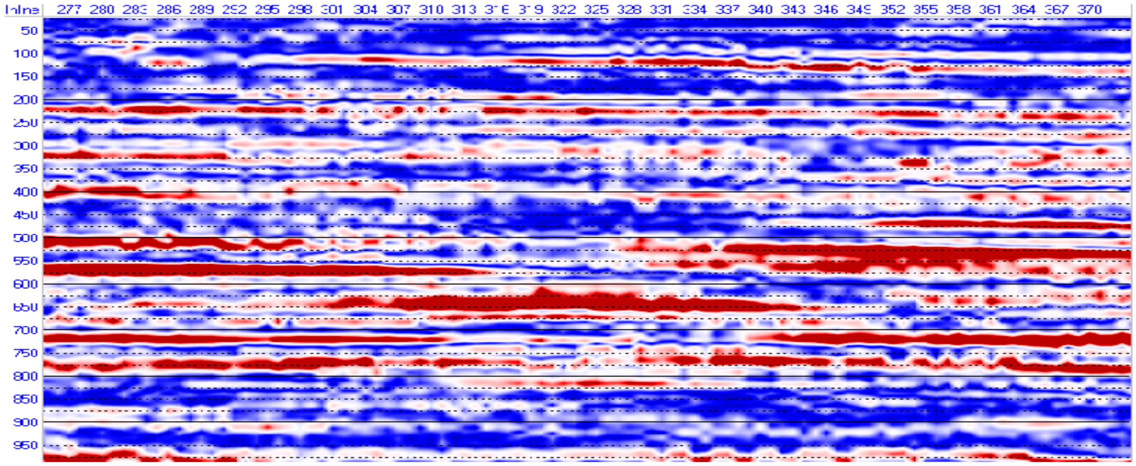


Figure 9. ESP spectral amplitude of the seismic section of figure 7 at 70 Hz.

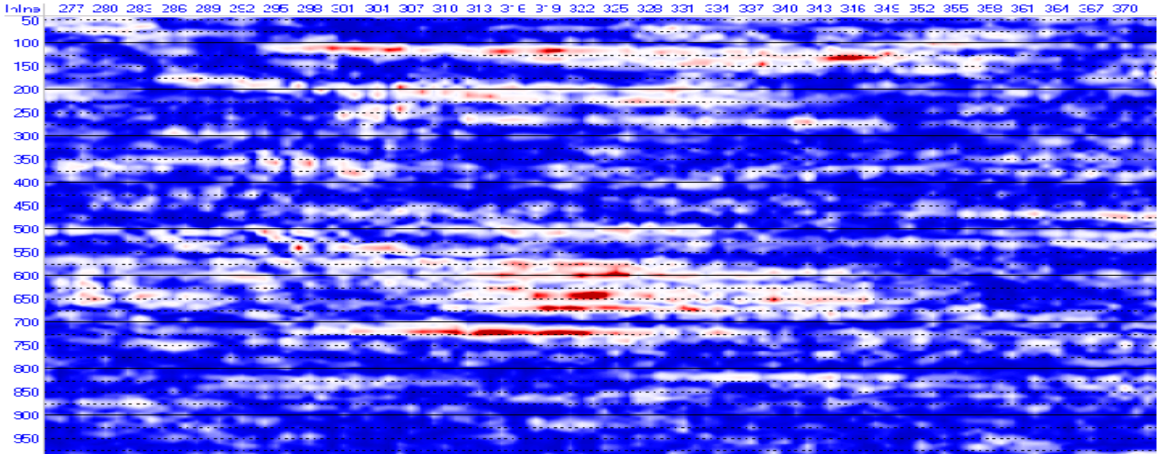


Figure 10. ESP Peak frequency of the seismic section of figure 7.