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Continuous Wavelet Transform: A tool for detection of hydrocarbon

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Summary

The paper presents localization of hydrocarbon zone using Continuous Wavelet Transform (CWT) tool. Presence of low frequency shadow zone, which arises due to attenuation of high frequencies in the seismic spectrum, indicates the presence of hydrocarbon zone. Through detailed analysis of time-frequency plot of seismic traces obtained via wavelet transform method, it is possible to confirm presence of such shadow-zones in stacked seismic section. The results from the analysis of seismic section of F3 block in the Dutch sector of North Sea show the utility of the method.

Keywords: Continuous Wavelet Transform, hydrocarbon detection, seismic spectrum

Introduction

Detection of hydrocarbon bearing zones is of paramount interest in a seismic data analysis, and thus warrants the application of improved processing techniques to locate such zones. Bright spot, dim spot, low frequency shadows etc. are the most common hydrocarbon indicators. Wavelet transforms have been previously used to process the seismic data. (Chakraborty and Okaya 1995) and Shengjie et al. (2002) utilized the method to detect hydrocarbon. The hydrocarbon bearing strata, due to attenuation of seismic waves, appear as zones of low frequency shadows. Shenghong et al. (2009) used this local frequency as a direct hydrocarbon indicator.

The method of CWT serves as a major tool in analyzing the data in time-frequency domain. Sinha et al. (2003) followed the time frequency attribute using wavelet transform to detect the presence of hydrocarbon. In present study, low frequency shadows have been located in time-frequency plots and thus CWT is extended to process and interpret the seismic data for possible hydrocarbon-bearing zones. The time-frequency property of CWT is used to precisely mark the zone of hydrocarbons.

The Method

In general, the Fourier Transform is used for extracting spectral information from the seismic data, but due to inherent exponential basis ($e^{i\omega t}$, $e^{-i\omega t}$) and non-stationarity property of seismic data; Fourier transform fails to provide local spectral nature. Thus one needs to modify this exponential basis by using some operator which should result into an optimized basis for local spectral analysis. Continuous wavelet transform is very routinely applied for such spectral analysis. Time-frequency (T-F) plots of seismic traces are generated from CWT method and are analyzed for presence of hydrocarbons.

Many a times, one finds spectral information in particular localized part of seismic section. Fourier transform by its definition is unable to extract time localized information contained in the phase spectrum, (Liner, 2008). Even the Windowed Fourier transform (WFT) is unable to extract local spectral information due to its constant window length.

Wavelet transform $F(t)$ of a signal is defined as:

$$F(t) = \int_{-\infty}^{\infty} f(\tau) \frac{1}{|s|^p} \psi\left(\frac{\tau-t}{s}\right) d\tau \dots (1)$$



Where, $\psi(t)=g(t) \times \exp(i \omega t)$ and $g(t)$ is real and symmetric window, ω is central frequency of $\psi(t)$. $\psi(t)$ is called as the wavelet and 's' is the scale factor. Equation 1 shows that the wavelet transform is a convolution of given signal with scaled wavelet at different scale. This helps in measuring the similarity between the signal and the wavelet at different scales. For various scales, at a given time, CWT coefficients are computed and the scale for which maximum coefficient value occurs at given time that scale is pointed out. Since there is an inverse relationship between the scale and the frequency, the corresponding lower or higher frequencies can be pinpointed for further study. These frequencies eventually help to highlight the anomalous hydrocarbon zones that are typically difficult to retrieve from a seismic section. For our analysis, we use Morlet wavelet.

Synthetic Study

Fig-1 shows the synthetic seismic trace whose time-scale plot is generated by CWT method using Morlet wavelet. Sampling rate of synthetic trace is 4 ms. Numbers along the x-axis represents sample number. Synthetic trace comprises of wavelets with different time support at different time locations. In the time vs scale plot, it is obvious that more the time support lesser the frequency content. For example, at the time sample no. 1750 (Fig-1a), missing high frequencies makes the wavelet broader than other. This is also represented in time-scale plot (Fig-1b) as high scales are missing at sample number 1750. Thus CWT is one of the ways to understand and analyze the local spectral nature of seismic data.

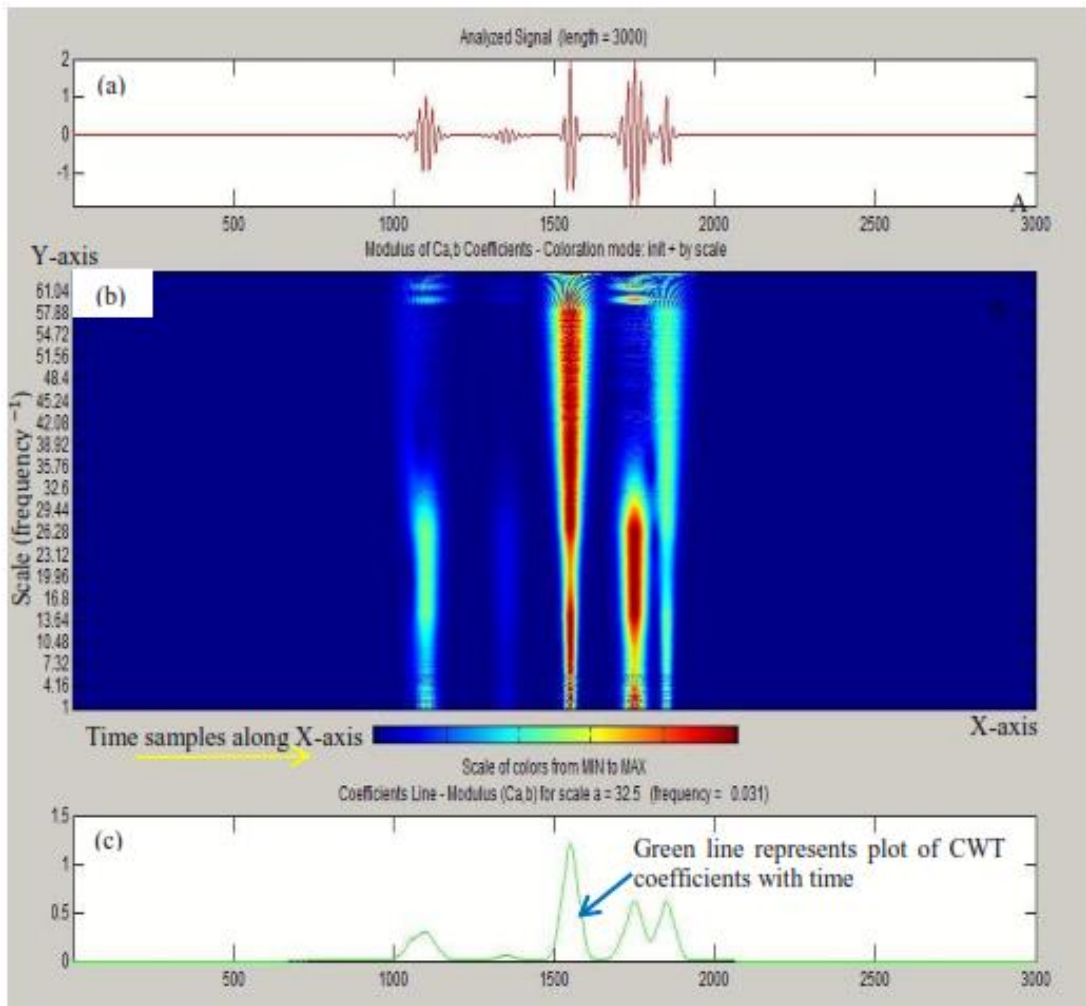


Figure 1: (a) Signal used for analysis (b) T-F plot using window of 2560 points (c) T-F plot using window of 256 points (d) T-F plot using window of 60 points (e) Time-Scale plot using wavelet transform

Real Data Study

One key assumption that low frequency shadow zone is because of hydrocarbon, is the base of the current study. The data used in the present work is provided by dGB Earth Sciences through its web portal. The data was acquired from F-3 block in the Dutch Sector of North Sea, Netherland. Seismic section along inline no. 1024 is shown with total 481 traces (Fig-2a). For time-frequency analysis of a seismic trace (marked as blue in seismic section in Fig2a) is analysed using Morlet wavelet.

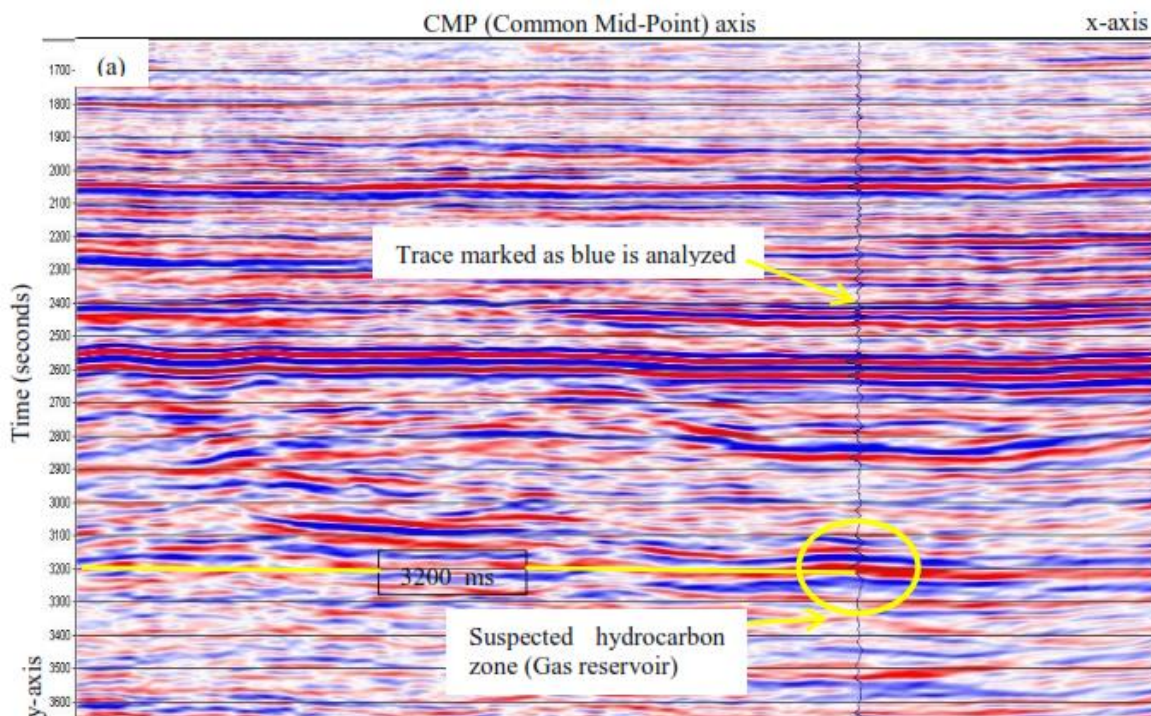
Time-frequency plot of trace is shown in Fig-2c. The data under consideration is sampled with sampling rate of 4 milliseconds. Along the time axis (x-axis), sample numbers have been shown. In seismic section a bright spot anomaly is present at 3200 ms (Fig-2a), which corresponds to time sample no. 800 in Fig-2b. In time-scale plot also, one can see the high amplitude anomaly with some finite scale range (marked in red oval) followed by still higher scales (marked in yellow oval).

Since there is an inverse relationship between scale and frequency, this higher scale range corresponds to lower frequency which may be due to seismic attenuation in hydrocarbon zone. This might be a hydrocarbon zone.

Some bright anomalies also stand out at low scale (i.e. high frequency) at and around time sample no. 600 (shown within the white oval). In seismic section one can easily mark these zones as relatively thinner beds (compared to bed nearby sample no. 800). It is not very pronounced but can be keenly observed that wavelet transform infers presence of thin beds.

Conclusions

Through this work hydrocarbon zone is being detected through the presence of low frequency shadow zone, just below the bright spot anomaly. Since this low frequency shadow is likely to be due to gas pocket above, hence this zone may be inferred to be a gas reservoir.



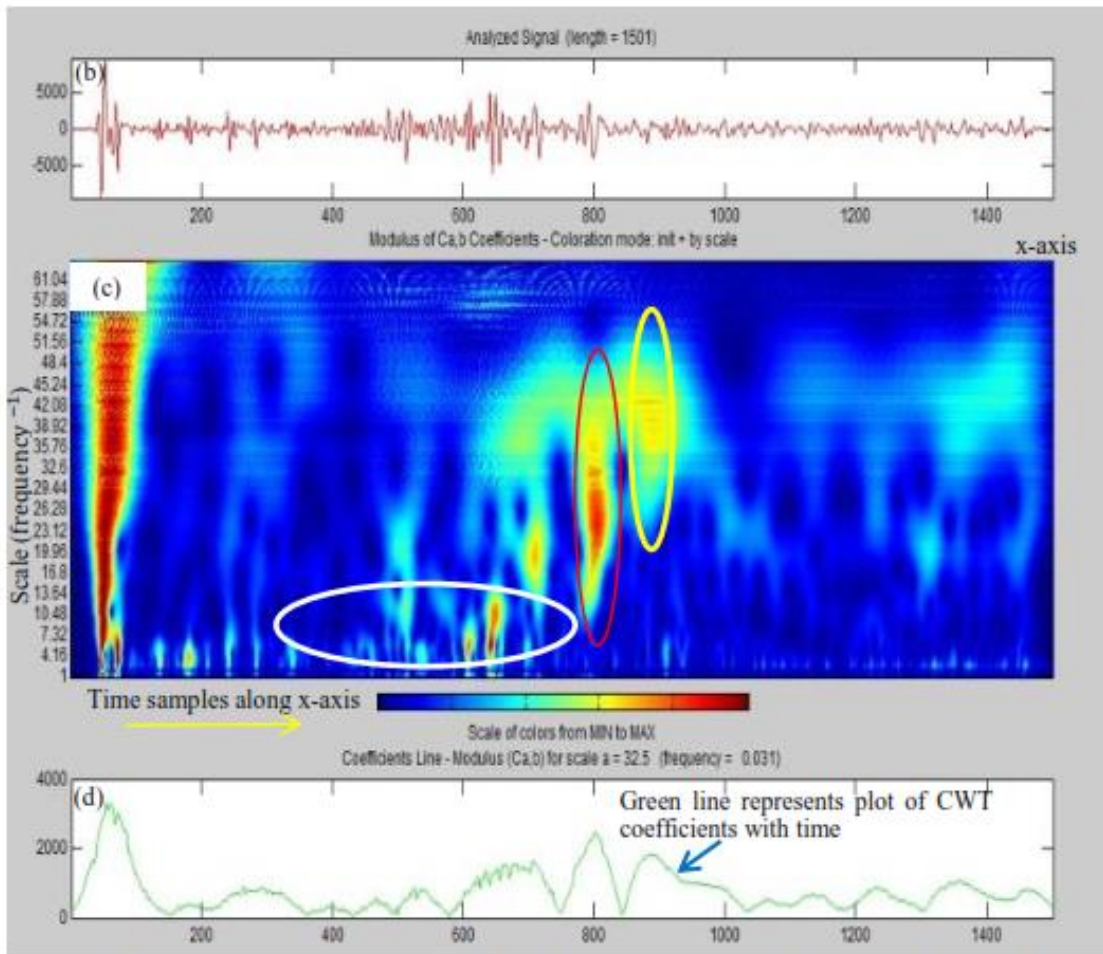


Figure 2: (a) Seismic section used in analysis. Blue wiggle is trace under analysis (b) seismic trace (c) Time-scale plot, highlighting the scale anomaly (marked in red oval) followed by still higher anomaly (marked in yellow oval), this yellow circled anomaly represents low frequency shadow zone (d) plot of CWT coefficients with time

Thus, Wavelet transform helps in detection of hydrocarbon zone. Since, such zones may arise due fractured brittle rock, one need to crosscheck these results with other methods. Along with this, wavelet transform helps us to detect silent features of thin beds.

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