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The Choice of Mother Wavelet in the Application of Continuous Wavelet Transform Method of Spectral Decomposition in Field 'A' in Central Niger Delta

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ABSTRACT

Abstract: Spectral decomposition is an interpretation tool that transforms seismic data set in time domain into frequency domain. It can aid interpreters to understand the geology of the subsurface such as the stratigraphy and structures of the subsurface of interest which can lead to the drilling of producing wells. There are various methods of spectral decomposition, such as matching pursuit, S-Transform, Short Time Fourier Transform (STFT), and Continuous Wavelet Transform (CWT). CWT method was used in this research. The purpose of this research is to choose the best mother wavelet in the application of Continuous Wavelet Transform (CWT) to effectively enhance structural features that are difficult to delineate on a conventional 3D seismic data set. The effective implementation of CWT can be achieved when the best mother wavelet is chosen. The application of CWT using mother wavelets such as Gaussian mother wavelet, Mexican hat wavelet or Morlet mother wavelet is data depended, this is because a mother wavelet suitable for a particular seismic data, can give poor result when used for a different data set. It is observed from this research that of the three basic mother wavelets used in CWT, the Gaussian mother wavelet delineates faults better than the Mexican hat mother wavelet and the Morlet mother wavelet in the study area.

Keywords: Spectral Decomposition, Faults, Continuous Wavelet Transform (CWT), Short Time Fourier Transform (STFT), Wavelet.

1. INTRODUCTION

Spectral decomposition [SD] is an interpretation tool that transforms seismic data set in time domain into frequency domain. It can aid interpreters to understand the geology of the subsurface such as the stratigraphy and structures of the subsurface of interest which can lead to the drilling of producing wells. According to Castagna et al. [1], spectral decomposition can be used as a hydrocarbon indicator tool. The interpretation of faults in any seismic interpretation process has significant importance during the exploration stage or development stage. Faults are important in trapping hydrocarbon into accumulation for drilling; they also serve as a conduit through which hydrocarbons migrate after being generated in the 'kitchen zone'. The identifying and mapping of fault structures often help in the determination of the size, geometry and the level of compartmentalization of hydrocarbon reservoirs [2, 3].

In spectral decomposition, a seismic signal in time domain is decomposed into the frequency domain, so as to delineate geological features of interest. STFT method of SD is carried out by selecting a window function, where the signal is considered stationary. Performing Fourier Transform at that segment of the window function, provide the Fourier content of the signal at that time period, however in CWT, spectral decomposition is carried out by using a wavelet such as Gaussian wavelet, Mexican wavelet or Morlet. These wavelets are translated or scaled on the signal, in doing so, the signal in time domain can be decomposed into the frequency component where geological features of interest can be delineated.

The effectiveness of CWT is a function of the mother wavelet chosen. The terms mother wavelet and wavelet are often used interchangeably. The mother wavelet used in CWT is any of the following wavelets; the Morlet wavelet,

Mexican hat wavelet or the Gaussian mother wavelet. The delineation of geological features using CWT is limited by the choice of a mother wavelet.

The best wavelet to use in delineating geological features is data depended. According to Adison [4], the best wavelet for a particular application depends on the nature of the seismic signal. The mother wavelet which fits the input seismic data by way of better correlation of scaling and shifting, would yield superior results [5].

Chopra and Marfurt [5] in their research observed that, the Morlet wavelet is more robust and yields better results than the Gaussian and Mexican hat methods. However, they did not generalize their result as it is possible that another mother wavelet may have a better fit with the seismic data, but recommended that CWT should be applied on a test volume to select the best mother wavelet to be used in the application of spectral decomposition.

Okiongbo and Ombu [6] in their research observed that, Gaussian wavelet gave better resolution in delineating Stratigraphic features such as channels, and it was considered as the best mother wavelet for the data. The work carried out by Saeid et al. [7] shows that Morlet wavelet has good horizontal resolution, at low frequencies compared with Gaussian and Mexican hat wavelet. The Gaussian wavelet had relatively good resolution at low and medium frequencies but not as good as with a Morlet wavelet. On the other hand, the Morlet wavelet has poor vertical resolution compared with Gaussian and Mexican hat. The Mexican hat provides very good vertical resolution, especially at low frequencies, and the Gaussian wavelet has relatively good vertical resolution at medium to high frequencies.

This research focus on the best mother wavelet to use in the application of CWT in delineating structural features of interest to the interpreter in Field ‘A’ in Central Niger Delta.

2. Theoretical Background

2.1. Wavelet

A wavelet is defined as a function with a zero mean, which is localized in both time and frequency [8]. Wavelet transform is a convolution of the wavelet function with the signal. This function (wavelet) is used to transform seismic signal under investigation into another representation, which presents the signal information in a more useful form, so that features of the original seismic signal are easier to study. The wavelet can be manipulated in two ways: it can be moved (translate) to various locations on the signal as shown in Fig. 1 and it can be stretched (dilation i.e. spreading out of the wavelet) or squeezed to transform the signal into another form which 'unfolds' it in time and scale [4] this is shown in Fig. 2. Mother wavelet and wavelet are used interchangeably, some examples of commonly used wavelets in CWT are shown in Fig. 3

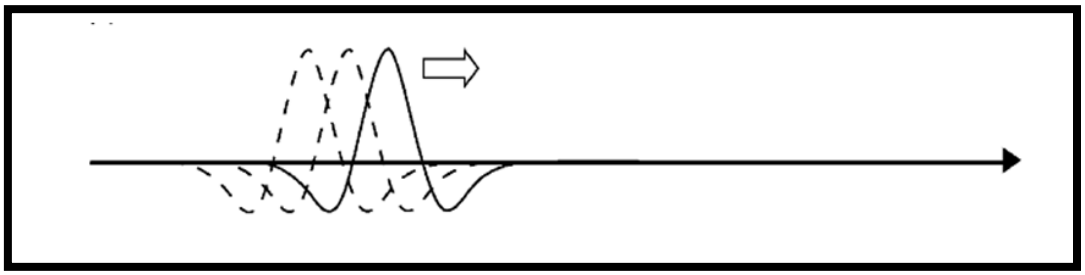

Fig. 1: Translation of the wave along the signal [4].

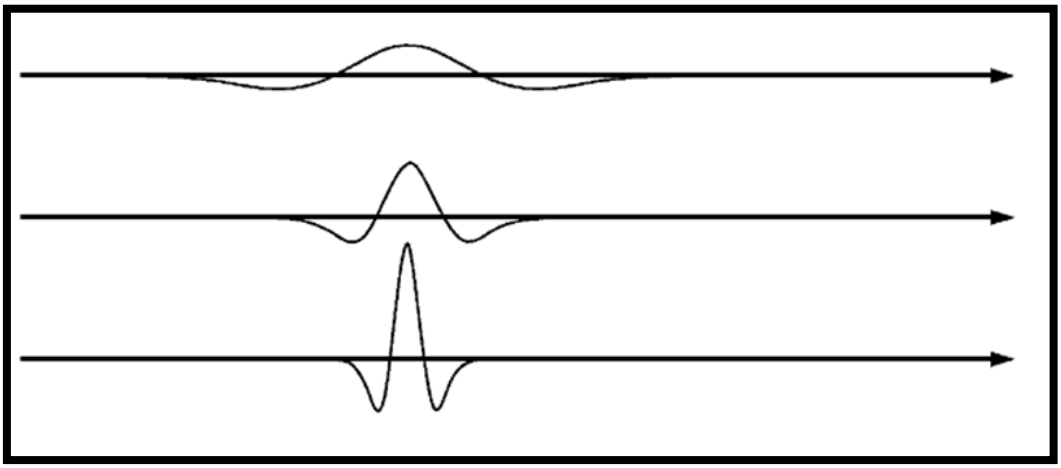

Fig. 2: Dilation and squeezing of a wavelet [4].

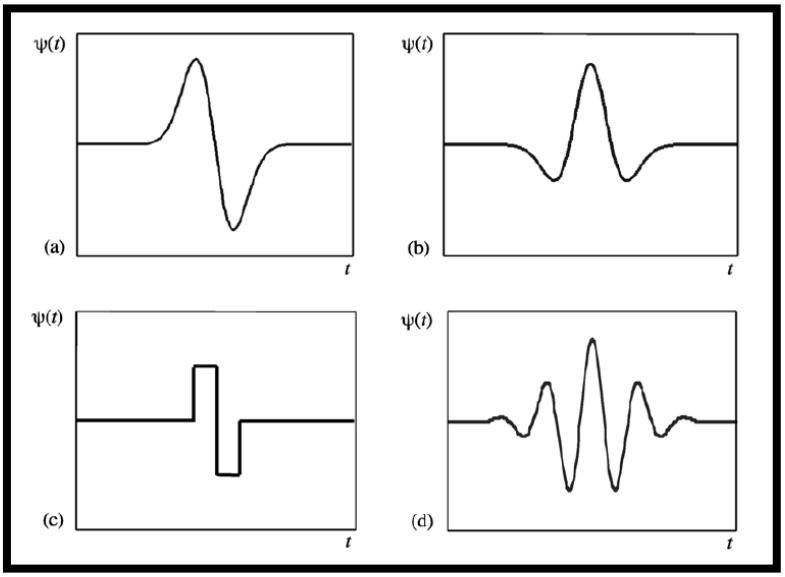

Fig. 3: Commonly used wavelets in CWT (a) Gaussian wavelet, (b) Mexican hat wavelet, (c) Haar wavelet, (d) Morlet wavelet [4].

The mathematical expression for the Gaussian wavelet, Mexican hat, and Morlet wavelet are shown in equations 1. 2, 3 respectively. These equations are used in generating the wavelets, from which dilation and translation are derived [4,9].

$$\varphi(t) = e^{jvt} e^{-t^2/2} \qquad (1)$$

$$\varphi(t) = (1 - t^2) e^{-t^2/2} \qquad (2)$$

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$$\varphi(t) = \frac{1}{4} e^{i2\pi f_0 t} e^{-t^2/2} \qquad (3)$$

2.2. Continuous Wavelet Transform method of spectral decomposition

Geological features of interest such as channels, point bars and faults are often hidden in the time domain, the transformation of a seismic signal from time domain into frequency domain delineate these geological features. According to Chakraborty and Okaya [9], frequency representation of a seismic data in time domain delineates many features that are difficult to visualize in the time domain.

The extent at which these geological features can be delineated in the frequency domain depends on the spectral decomposition technique used. STFT and CWT are the major methods of SD used frequently. STFT has resolution problem, because of the application of moving window of the time domain signal, the type and the length of the selected window used [10]; it suffers from time-frequency resolution limitation [9].

Using STFT leaves one with better resolution in time and poor resolution in frequency, while better resolution in frequency leaves one with poor resolution in time. If the resolution in frequency is enhanced, the resolution in time is poor. In STFT, one can trade time resolution for frequency resolution or vice versa. This effect in physics is known as the Heisenberg uncertainty principle, expressed mathematically as,

$$\Delta t \Delta f \geq \frac{1}{4\pi} \qquad (4)$$

Where is the time-window length and Δf is the frequency window length.

CWT provides solution to the resolution limitation encountered with STFT method. CWT is a wavelet transforms that use wavelet to decompose a seismic signal into different frequency components [11].

Spectral decomposition carried out with the use of the continuous wavelet transform (CWT) requires the choice of a mother wavelet, the mother wavelet accounts for most part when using the CWT algorithm, selecting a good wavelet has a significant effect of the transform [12]. Unlike STFT, in CWT the window selected is not fixed it varies with the frequency i.e. shorter windows for high frequencies, and longer window for lower frequencies as shown in Fig. 4.

In using CWT for SD, it allows seismic signal to be examined in both time-frequency domains simultaneously. It has optimal time-frequency resolution property and has become a popular tool for the spectral analysis of 3D seismic data than the windowed Fourier transform methods [1, 8, 9, 13].

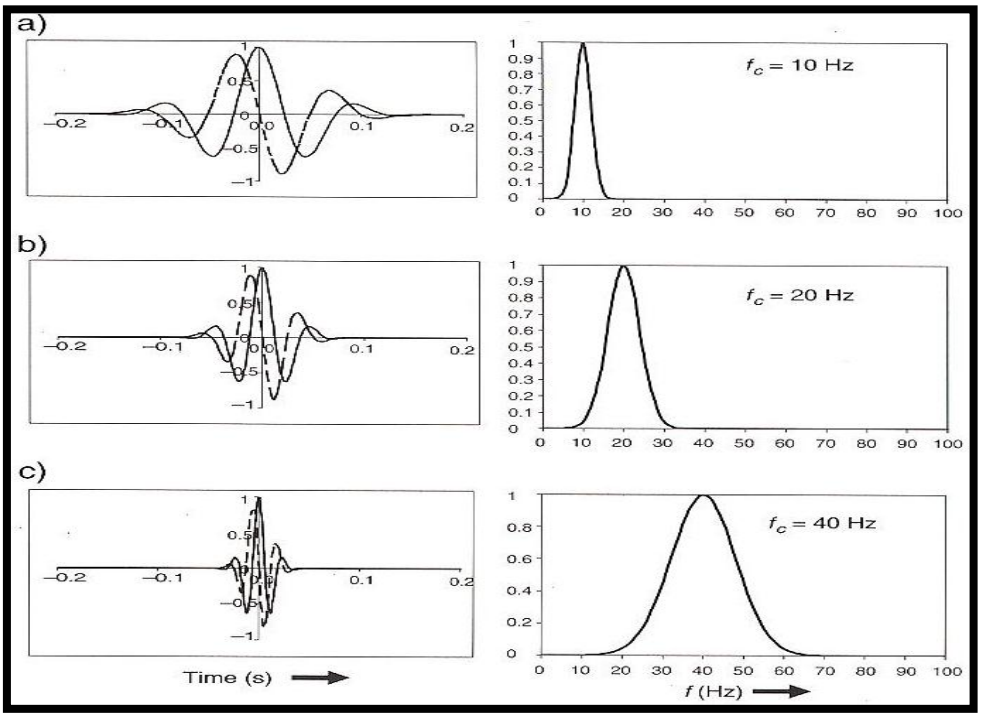

Fig. 4: Seismic wavelets and their corresponding frequency spectral for different frequency value [9].

CWT uses dilation and translation of a wavelet to produce a time-scale map called scalogram [8, 14]. Sinha et al. [8] defined the Continuous wavelet transform as the inner product of the family of wavelets with the seismic signal.

This can be expressed mathematically as,

$$F_W(\sigma,\tau) = \langle f(t), \varphi_{\sigma,\tau} \rangle = \int_{-x}^{x} f(t)\overline{\varphi}\left(\frac{t-\tau}{a}\right)dt \qquad (5)$$

where is the complex conjugate of and is the time- scale map (i.e. the scalogram).

The wavelet used in CWT is multiplied with the seismic trace after which it is slide along the seismic trace and the product is an output of decomposition related to the scale of the wavelet as a function of time. As the wavelet is sliding along the seismic trace, if it matches the shape of the seismic trace perfectly at a specific scale and location as shown in Fig.5, a large transform value is obtained. In a situation where the wavelet and the seismic signal do not match, low value of the transform is obtained. The transform value is then located in the two-dimensional transform plane shown in Fig.5 (indicated by the black dot). The transform is computed at various locations of the signal and for various scales of the wavelet, thereby filling up the transform plane [4].

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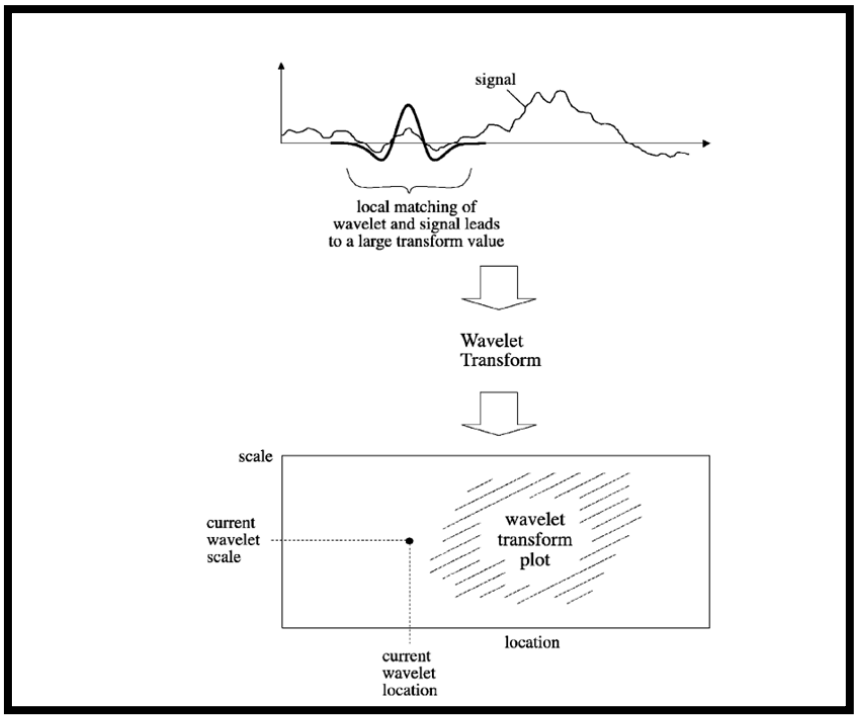


Fig. 5: The matching of the wavelet with the signal and the wavelet transform plot [4].

3. Materials and Methods

3D seismic data was used in this research; SD was applied on the data using Opendtect software. In the application of SD on seismic data, three different frequencies known as iso-frequencies are usually chosen based on the frequency content of the seismic data. The choices of these frequencies are chosen such that they represent the low, middle and high frequencies of the seismic bandwidth around the horizon or time slice of interest. These iso-frequencies are stacked together into a single display to produce a better image of the geological feature of interest. The stacking of these iso-frequencies is called RGB blending.

RGB displays show features with greater clarity and increased details when compared to standard displays [15]. RGB stands for Red, Blue and Green Channel. The low frequency is displayed as the Red Channel, the middle frequency is displayed as the Green Channel, while the High frequency is displayed as the Blue Channel. Figure 6 is the frequency spectrum of the Land seismic data, from the frequency display of the data, three frequencies were selected that delineate the geological features of interest from the data.

The three frequencies are blended together to achieve optimal results. The selected frequencies are 10 Hz, 20 Hz, and 30 Hz, as shown in Fig. 6. After the selection of the iso-frequencies, the various wavelets (Gaussian, Mexican and Morlet) were individually applied on the data, the best wavelet was chosen as the main wavelet to use in this research.

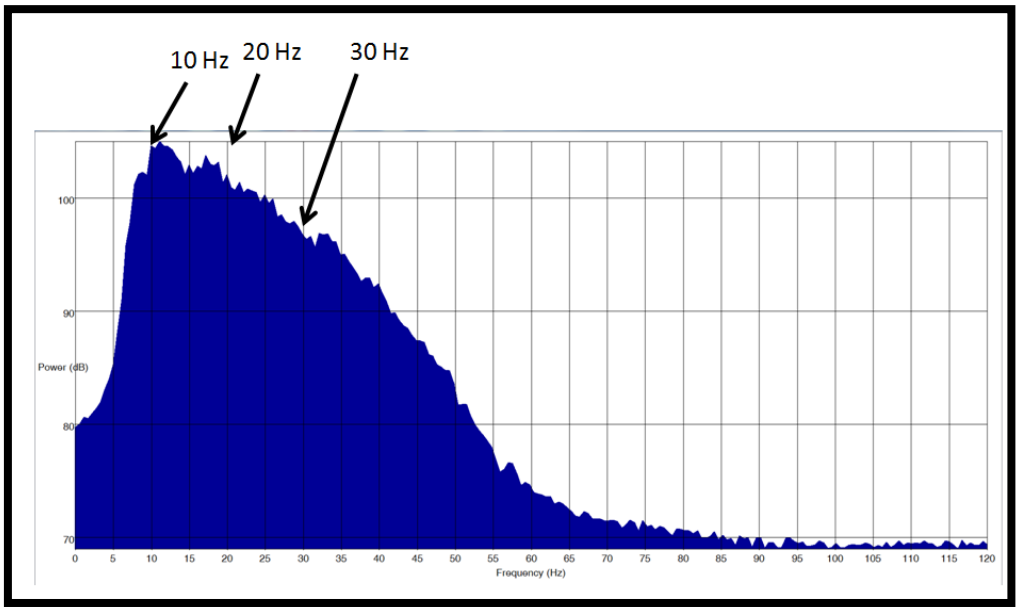
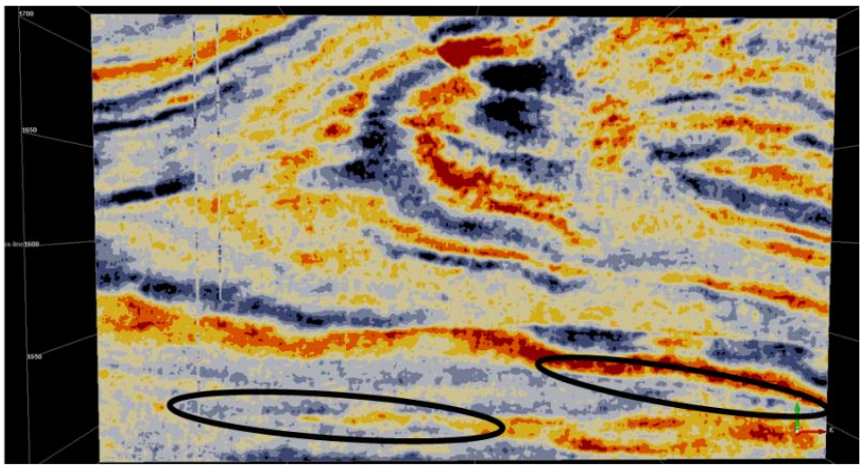


Fig. 6: Frequency spectrum of the seismic data.

4. Results and Discussion

Figure 7a shows the time slice of the data at 2.5s, the structural features in the black loop cannot be seen, applying Gaussian wavelet, the structures are well seen in the black loop, this is shown in Fig. 7b. Applying Mexican hat wavelet and Morlet wavelet, the structures were not clearly seen as compared to the application of Gaussian wavelet in Fig. 7b. Fig. 7c and 7d shows the application of Mexican hat and Morlet wavelet on the time slice at 2.5s respectively. Figure 8 shows inline 5714 and the application of SD, looking at the red rectangular loop and red arrow in Fig. 8a, the faults are not clearly seen. When Gaussian wavelet was used as the mother wavelet in Fig. 8b, the faults in the rectangular loop and red arrow are seen clearly. Applying Mexican hat wavelet and Morlet wavelet, the structures were not clearly seen as compared to the application of Gaussian wavelet in Fig. 8b. Figure 8c and 8d shows the application of Mexican hat and Morlet wavelet on inline 5714 respectively.



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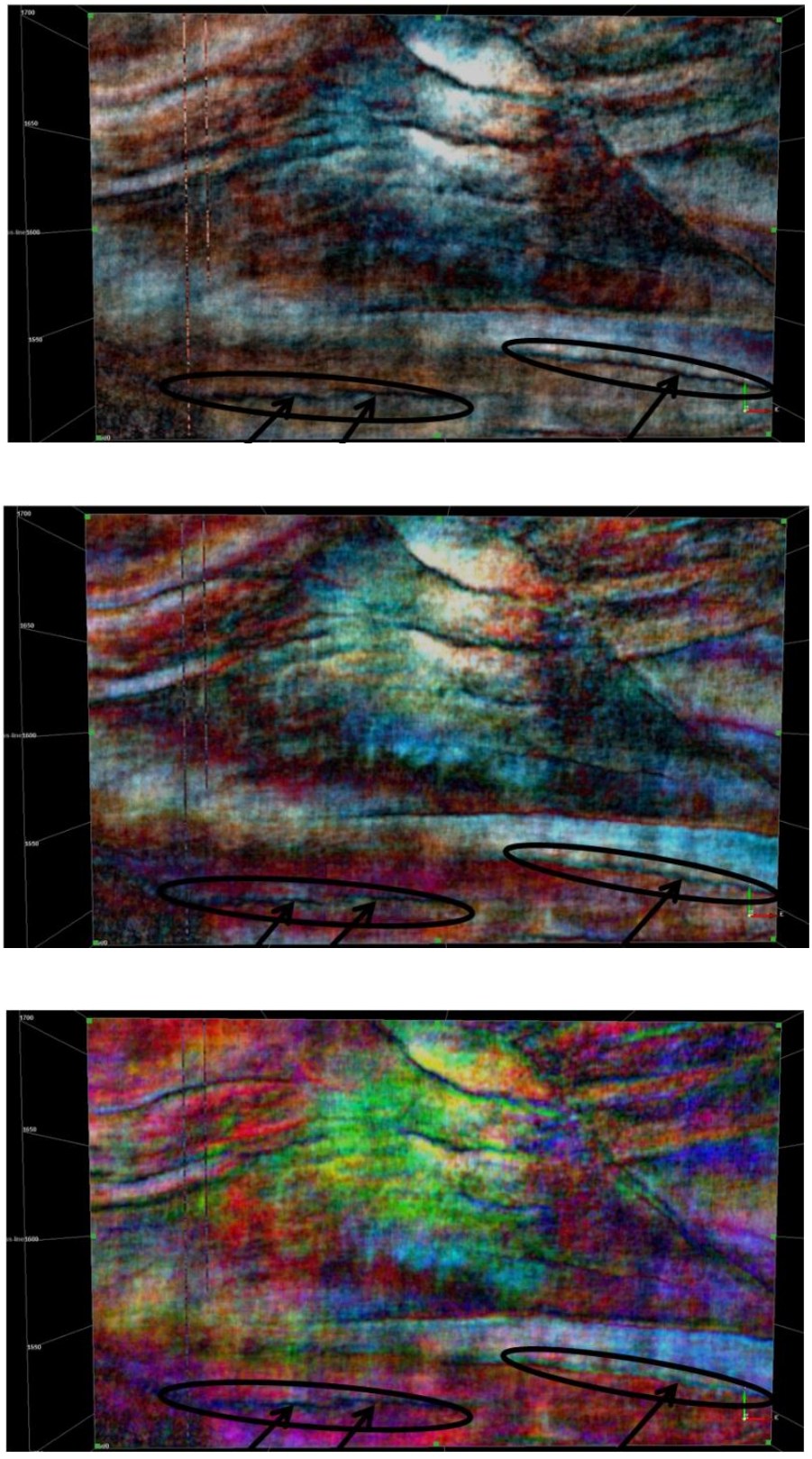

Fig. 7: Application of SD on time slice at 2.5s. (a) Time slice at 2.5s, (b) application of Gaussian wavelet, (c) application of Mexican hat wavelet, (d) application of Morlet wavelet

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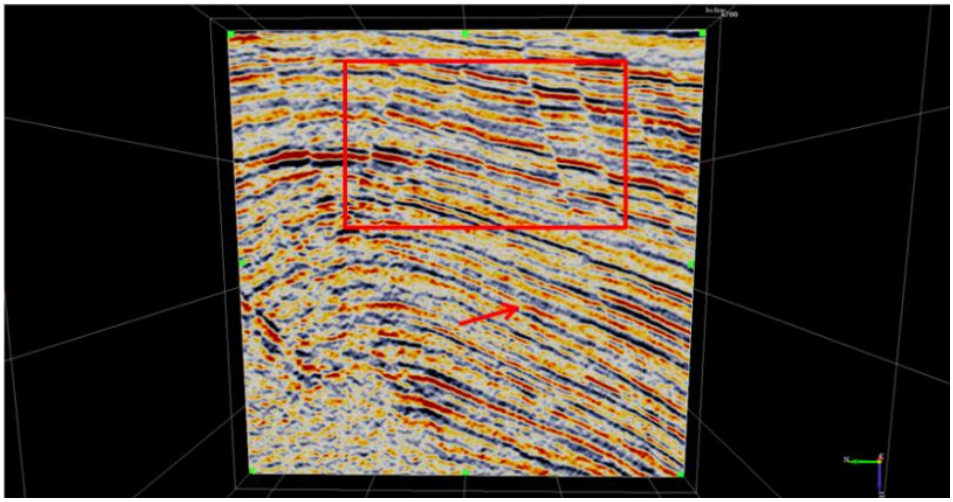

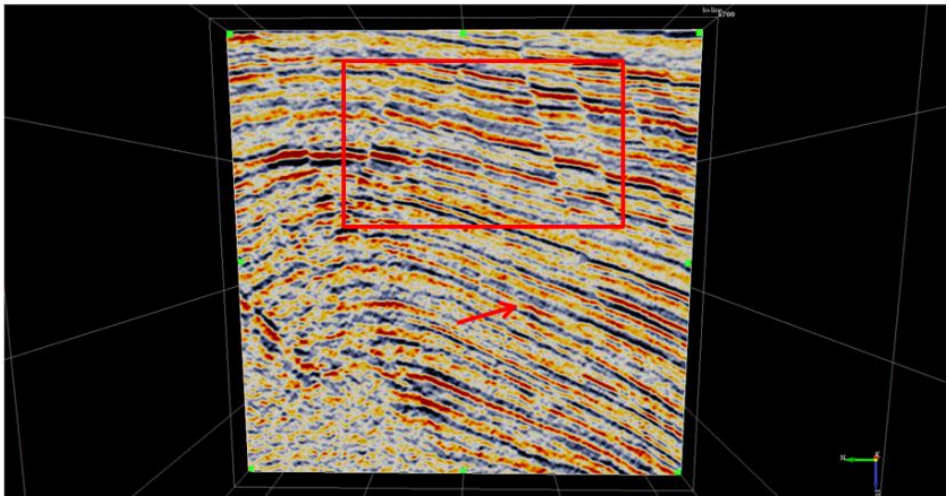

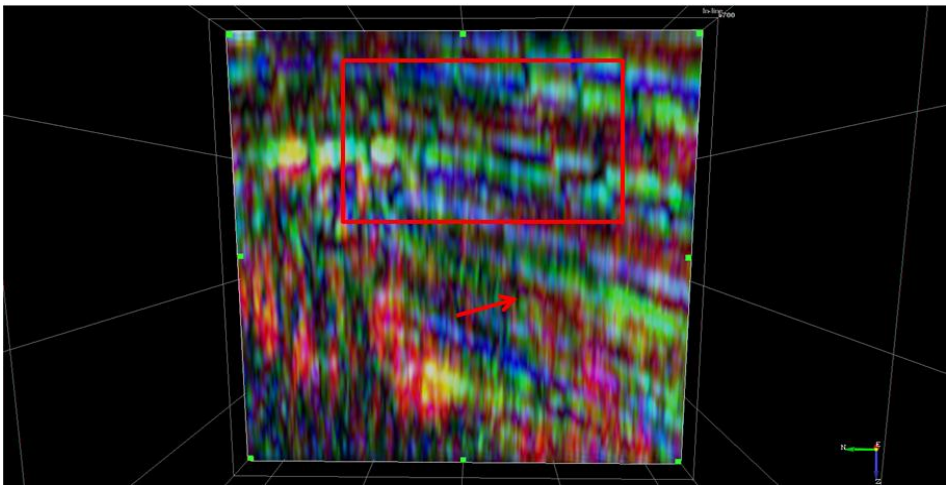

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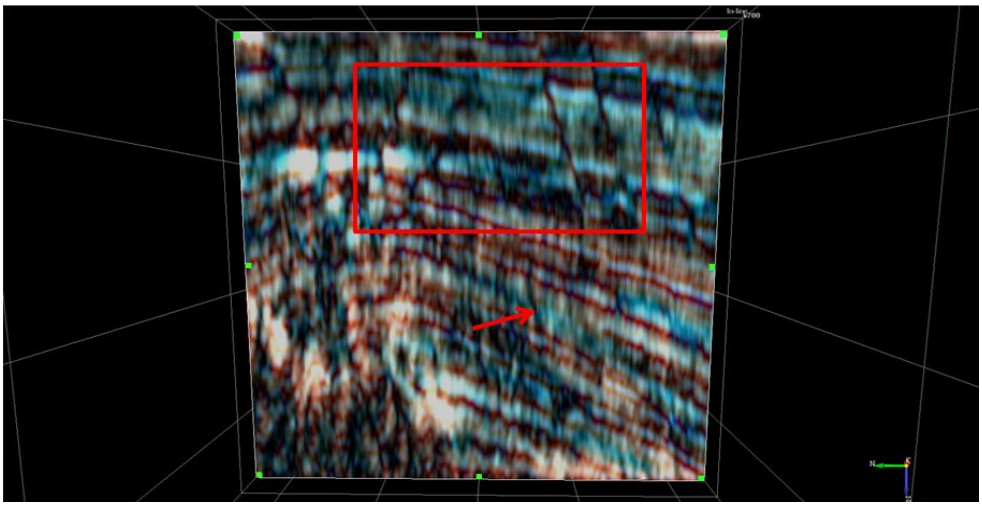
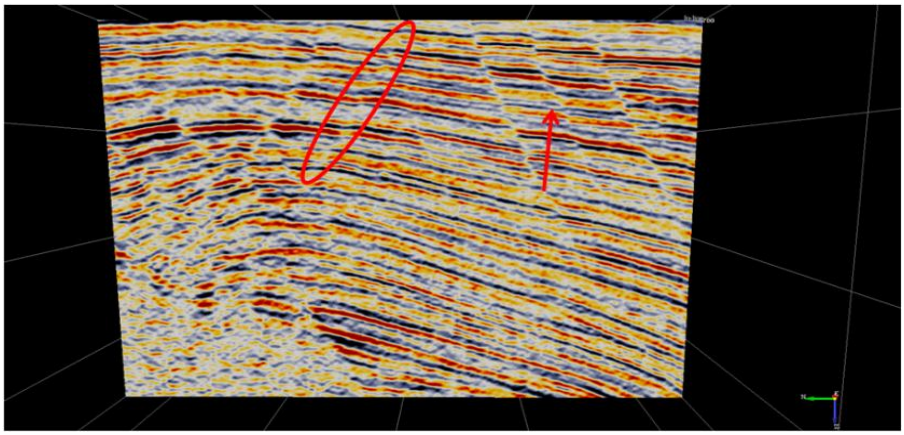
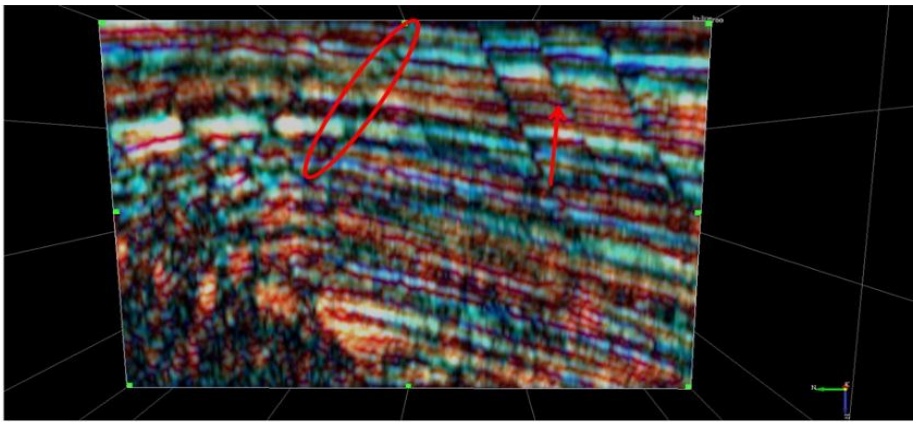


Fig. 8: Application of SD on inline 5714. (a) Inline 5714, (b) application of Gaussian wavelet on inline 5714, (c) application of Mexican hat wavelet on inline 5714, (d) application of Morlet wavelet on inline 5714.

Figure 9 shows inline 5696 and the application of SD, looking at the red loop and the red arrow in Fig. 9a, the faults are not clearly seen. When Gaussian wavelet was used as the mother wavelet in Fig. 9b, the faults in the loop and red arrow are seen clearly. Applying Mexican hat wavelet and Morlet wavelet, the structures were not clearly seen as compared to the application of Gaussian wavelet in Fig. 9b. Figure 9c and 9d shows the application of Mexican hat and Morlet wavelet on inline 5714 respectively.





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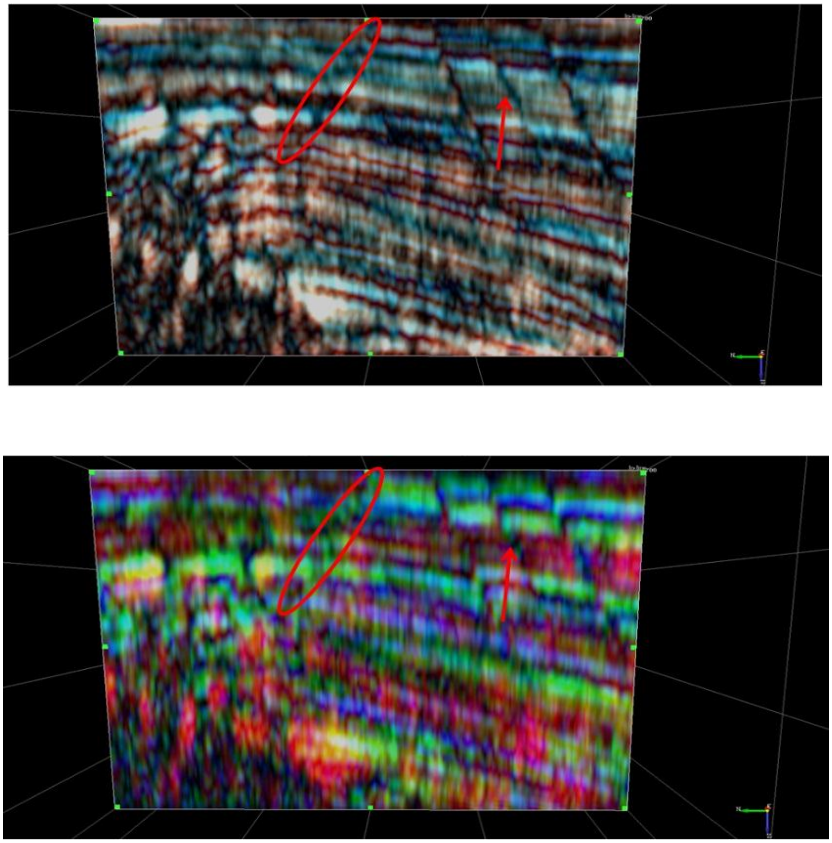

Fig. 9: Application of SD on inline 5696. (a) Inline 5696, (b) application of Gaussian wavelet on inline 5696, (c) application of Mexican hat wavelet on inline 5696, (d) application of Morlet wavelet on inline 5696.

5. Conclusion

This research has shown that the CWT method of spectral decomposition is an effective tool in the delineation of faults. Faults that could not be delineated on time slice at 2.5s and on amplitude data are easily delineated using the best mother wavelet. The choice of mother wavelets in the application of CWT is important in delineating geological features of interest. Three different mother wavelets namely, the Gaussian wavelet, Mexican hat and Morlet wavelet were analyzed to determine the best mother wavelet to use. It is observed in this research that, the Gaussian mother wavelet shows geological structures better than the Mexican hat wavelet and the Morlet wavelet.

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