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Imaging Subsurface Channels within the Tertiary Niger Delta Basin using Spectral Decomposition Methods

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Abstract

Channels are hydrocarbon prospective areas which are often below the resolution of seismic data. This study was therefore conducted with the aim of using spectral decomposition methods for imaging of buried channels and associated structures in a 3D Post-Stack Depth Migrated (PSDM) volume acquired from a field in the Niger Delta Basin. Two commonly used spectral decomposition methods were used to enhance the resolution of seismic data for interpretation. The methods utilized included Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT). Petrel and Opendtect were the interpretational software tools utilized for the study. The seismic data was conditioned using structural smoothing, and a zone of interest was selected around -1000 to -3000ms. Three dominant frequencies were selected from the sub-volume generated around the zone of interest. The frequencies were 10Hz, 25Hz and 32Hz respectively. These frequencies were extracted from the seismic data using FFT and CWT decomposition methods. The results were colored using Red, Green and Blue (Red for 10Hz, Green for 25Hz and Blue for 32Hz). These frequencies were then blended together in a process called RGB blending. The resultant output was a mix of only these three dominant frequencies. Analysis of these results revealed the presence of several channels, crevasse splay deposits, flood-plains and faults on two time-slices obtained at -2020ms and -1800ms. The channels were meandering channels of low sinuosity, some of which were fault controlled. The crevasse splay deposits were significantly large and increased in number at the shallow time-slice. Some of the crevasse splay deposits were found bifurcating fault lines and being deposited on floodplains, indicating that they were younger than the faults. Channel flow direction was from East to West, while

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channel migration was from South to North of the study area. The increase in the number of channels from the base to the top of the seismic data suggested a multistory stacked channel system. It was established that channels and crevasse splays were best enhanced using the FFT decomposition method while major and minor faults were best enhanced using CWT method. Hence, this study has proven that the spectral decomposition method is very effective in imaging subsurface buried channels, thus delineating prospects and can be used for reservoir characterization.

Keywords: Spectral decomposition, Fast Fourier Transform (FFT), Continuous Wavelet Transform (CWT), Channels, Crevasse splays, Faults, Reservoir Characterization.

1. Introduction

Channels are generally visually close to or below seismic resolution (Caldwell *et al*., 1997; Tetyukhina *et al.*, 2010), so thin to their surrounding geometry that their subtleties are nearly invisible in traditional seismic data. Thus, delineating thin reservoir sands from conventional seismic data has always been a challenge. Recent innovations such as coherence technology (Marfurt *et al*., 1998) and other edge sensitive attributes (Luo *et al.*, 1996) are common methods employed in mapping boundaries of these geological subtle targets (channels). Although coherence images and edge sensitive attributes reveal channels edges, a key limitation in these techniques is that they cannot delineate the channel's thickness (Chopra and Murfurt, 2006). Spectral decomposition is a recent seismic interpretation technology that reveals otherwise hidden geological information and thus is being used extensively as an excellent tool for mapping buried channels (Partyka *et al.*, 1999). In spectral decomposition, reflection from a thin bed has a peculiar expression in the frequency domain that gives an indication of the temporal bed thickness. It is a powerful seismic imaging and mapping tool that provides the interpreter useful quantitative information for determining bed thickness (Partyka *et al.*, 1999), visualization of stratigraphy (Marfurt and Kirlin, 2001) and detection of hydrocarbon (Castagna *et al*., 2003; Sinha *et al*., 2005) to a level that was previously impossible. Spectral decomposition is also an effective tool in enhancing geohazard analysis as it is sensitive to wavelet, reflectivity, tuning and attenuation changes (Selvage *et al.*, 2012). In spectral decomposition, the seismic data is converted from the time domain to the frequency domain and decomposed into frequency components. Studying the individual frequency components and comparing their responses provides significant insight into the subsurface geology. The time-frequency mapping process is a non-unique process; as a result, there are several methods for carrying out time-frequency analysis of non-stationary signals. Popularly used spectral decomposition methods include Fast Fourier Transform (FFT), Continuous Wavelet Transform (CWT), S-transform (ST), and Matching Pursuit decomposition (MPD). It is important to note that each method has its strengths and weaknesses

(Chakaborty and Okaya, 1995; Leppart *et al.*, 2010). This study involved the use of two spectral decomposition approaches (FFT and CWT) in delineation/imaging of buried subsurface channels in an offshore prospect field within the tertiary Niger Delta Basin to aid in the reservoir characterization objectives.

In more recent times, the search for hydrocarbons is geared towards identifying geologically complex and subtle targets such as channels that the traditional seismic sections cannot display since they are very thin (visually sub-seismic) to their surrounding geometry. These geologically complex and subtle channels filled with porous rock enclosed in a non-porous matrix are important stratigraphic events useful in reservoir studies because they constitute hydrocarbon exploration plays; as such, a handful understanding of their stratigraphic geometry and characteristics is imperative. In this study, seismic spectral decomposition techniques such as Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) will be used to decompose a 3D seismic data acquired from the central swamp depobelt, offshore Niger Delta Basin from time to frequency domain to delineate stratigraphic channels as possible hydrocarbon traps. This research is aimed at applying spectral decomposition to detect (image) buried channels. The aim would be achieved through a set of objectives which includes;

i. 3D PSDM seismic volume tuning to zone of interest.
ii. Deploying spectral decomposition for analysis of amplitudes and phase slices.
iii. Using spectral decomposition for the selection of discrete frequency (Iso-frequency of amplitudes and phase).
iv. Using Spectral decomposition (FFT and CWT methods) for detection of channels using frequency amplitudes and faults on phase volumes.
v. Comparing the results obtained from both spectral decomposition methods, to find out which method achieves the best result for imaging channels and associated structures.

This research work on spectral decomposition is limited to the use of Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) for detection of buried channels and also faults. Gamma ray and resistivity logs will be used to identify the zone of interest. Synthetic seismograms will be generated and used to match and identify the zone of interest on seismic data for frequency extractions. The extracted frequencies will be used to identify buried channels and faults across the entire seismic volume. The delineation of subtle geological features such as channels has always been a challenge as previously stated. This is because channels are sub-seismic, so thin to their surrounding geometry that their subtleties are nearly invisible in traditional seismic data. But these geo bodies are important because they serve as hydrocarbon traps. The work therefore emphasizes the usefulness of the spectral decomposition methods (FFT and CWT) in the imaging of buried channels which are potential hydrocarbon traps and would enhance the reservoir characterization objectives in the prospect.

2. Location of the Study Area and Geological Settings

The study area is located within the shallow offshore of the Niger Delta Basin and bounded geographically by latitudes 5˚00ˈN to 8˚00ˈN and longitudes 4˚00ˈE to 6˚00ˈE (Figure 1). The field lies within the coastal swamp depobelt. The field is located within the Tertiary Niger Delta Sedimentary Basin. Short and Stauble (1967) recognized three stratigraphic sequences in the tertiary Niger Delta Basin. From oldest to youngest, they include; Akata, Agbada and Benin Formation. The Akata Formation is the oldest stratigraphic unit in the Delta. It is of marine origin and compositionally consists of uniform under-compacted shales, clays, and silts at the base of the delta with abnormally high-pressured sandstone lenses at the top of the formation (Avbovbo, 1978). The formation thickness ranges from 1,968 to 19,680ft (Whiteman, 1982). The marine shales are rich in both planktic and benthic forams and were deposited in shallow to deep marine environments (Short and Stauble, 1967). Avbovbo (1978) proposed an Eocene to Recent age for the formation. The Agbada Formation overlies the Akata Formation and is characterized by paralic sandstone and shale with a thickness that well exceeds 3000m. The top of Agbada Formation shows the first occurrence of shale with marine fauna that coincides with the base of the Benin formation (Adesida and Ehirim, 1988). The base of Agbada Formation is a significant sandstone body that coincides with the top of the Akata Formation (Short and Stauble 1967). The sand shale ratio is similar at the base of the formation and becomes sandier towards the top. Some of the shales of the Agbada Formation were thought to be the source rocks, however; Ejedawe *et al.*, (1984) deduced that the main source rocks of the Niger Delta are the shales of the Akata Formation. The paralic Agbada sequence is present in all depobelts, and ranges in age from Eocene to Pleistocene (Whiteman, 1982). The Benin Formation is the youngest unit in the Delta and overlies the Agbada formation. It is Miocene to Recent in age with a thickness > 6000 ft (Avbovbo, 1978). The formation is composed predominantly of continental/alluvial sands and sandstones with minor shale intercalations (Reyment, 1965). The upper part of the formation is composed almost entirely of alluvial sands which are coarse-grained, sub-angular, and well-rounded and are very poorly sorted. The formation is believed to have been deposited in an alluvial or upper coastal plain environment.

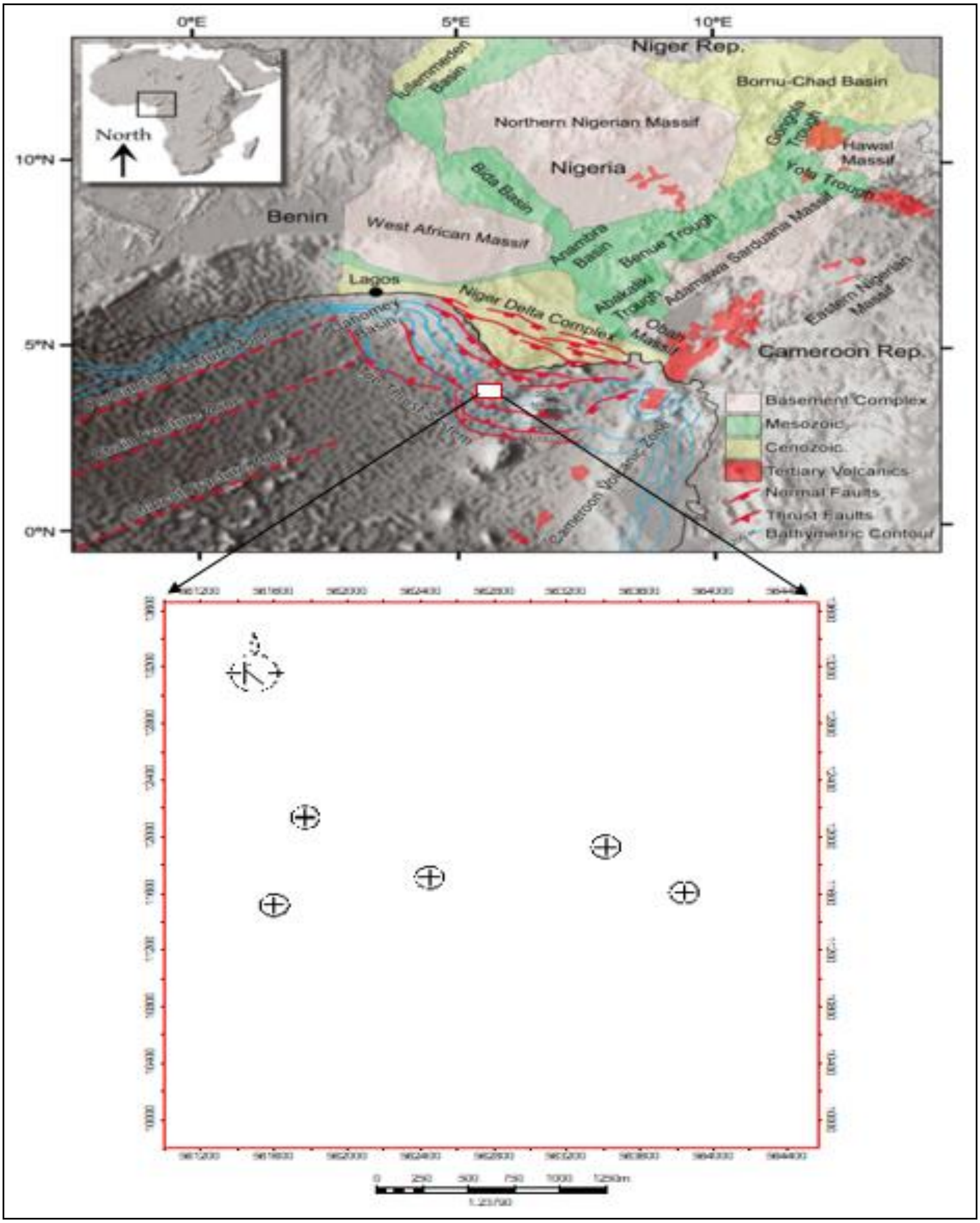

Figure 1: A map of Niger Delta Basin complex showing the location of the study area and wells distribution within the field.

3. Theoretical Background

The background theories of the spectral decomposition method, with emphasis on the two methods deployed in the study, which includes the Fast Fourier Transform (FFT) and the Continuous Wavelet Transform (CWT), are briefly provided in this section of the paper.

3.1 Spectral Decomposition

Spectral decomposition is a relatively quick and effective method that gives a suitable definition to determine stratigraphic sequences and structural characteristics of a reservoir. Spectral decomposition unravels and decomposes the seismic signal into its constituent frequencies, thereby allowing interpreters to see phase and amplitude spectra to specific wavelengths. The frequency contents of seismic traces vary with time (and depth) due to the fact that the earth is a non-stationary medium. With this technique, it is possible to analyze independently each frequency, revealing features that were previously hidden and to see more clearly features which may not be seen from a fixed map view. Since time-frequency mapping is a non-unique process, there exist various time-frequency analysis methods which are available to improve the temporal and spectral resolutions and will be briefly discussed under the following sub-headings.

3.1.1 Fast Fourier Transform (FFT)

The Fast Fourier Transform (FFT) is a classical approach used in extracting and evaluating the frequency spectrum of a seismic data. It has the capability in detecting reservoir stratigraphic characteristics such as reef (carbonate reservoir), channel body (Saadati Nejad *et al.*, 2011) and other stratigraphic features (Partyka *et al.*, 1999). It uses the windowing concept of a seismic data as a function of its temporal resolution. Therefore, choosing appropriate time gate or window length in this method helps to reveal more geological features in the seismic data. That is, selecting an optimal window length is important as it is convolved with a Gaussian window. In this way, the Fourier Transform of the window can be determined. It is important to know that by preselecting a temporal window length or choosing a predetermined time gate, the time frequency resolution becomes fixed over the entire time-frequency space. Thus, resolution in seismic data analysis becomes dependent on user-specified window length. Furthermore, the theoretical basis of Fast Fourier Transform (FFT) is essentially built from the Short Time Fourier Transform (STFT) in which a time-frequency is produced by taking the Fourier Transform (FT) over a short time window. The basic idea is to divide the non-stationary signal into small segments (which are considered stationary parts) and then, calculating the Fourier Transform for each segment.

3.1.2 Continuous Wavelet Transform (CWT)

A wavelet transform (WT) is also a technique to decompose a signal to identify its frequency distribution through time. This technique differs from the Short Time window Fourier Transform (STFT) in that while an STFT uses a fixed size time window, a wavelet transform uses a variable window size. The continuous wavelet transform (CWT) is an example of the WT technique. It was first introduced in Morlet *et al*. (1982) and Goupillaud *et al*. (1984), but received full attention of the signal (seismic data) processing community when Daubechies (1988) and Mallat (1989) established connections of the WT to discrete signal processing. The main advantage of using a CWT over a STFT in addition to that mentioned previously is that the CWT has a good frequency resolution for low frequencies and a good time resolution for higher frequencies (Chakraborty and Okaya, 1995 and Castagna *et al*., 2003). In the CWT, wavelets dilate in such a way that the time support changes for different frequencies. A smaller time support increases the frequency support, which shifts toward higher frequencies. Similarly, a larger time support decreases the frequency support, which shifts toward lower frequencies. Thus, when the time resolution increases, the frequency resolution decreases, and vice versa. A wavelet is defined as a function $\psi(t) \in L^2(IR)$ with a zero mean, localized in both time and frequency. By dilating and translating this wavelet ψ(t), a family of wavelets is produced.

$$\psi_{\sigma,\tau}(t) = \frac{1}{\sqrt{\sigma}}\psi\left(\frac{t-\tau}{\sigma}\right) \tag{1}$$

Where $\sigma > 0$ is the dilation parameter or scale and $\tau \in IR$ is translation parameter. Note that the wavelet is normalized such that the $L^2 - norm|\psi|$ is equal to unity. The CWT is defined mathematically as the inner product of the family of wavelets $\psi\sigma, \tau$ with the signal s (t).

$$S_w(\sigma,\tau) = \int_{-\infty}^{\infty} s(t)\left(\frac{1}{\sqrt{\sigma}}\right)\overline{\psi}\left(\frac{t-\tau}{\sigma}\right)dt \tag{2}$$

Where $\overline{\psi}$ the complex conjugate of ψ and S_w is the time scale map (scalogram) (Sinha *et al*., 2005).

Note that CWT also suffers from some disadvantages in that the wavelets utilized must be orthogonal. Furthermore, experience has shown that a DFT with a Gaussian window of appropriate length produces almost the same result as a CWT with a Morlet wavelet (Farfour, 2013).

4. Materials and Methods

4.1 Materials

The materials deployed for this research includes; 3D post stack time migrated (PSTM) SEGY seismic data, Schlumberger Petrel and Opendtect geophysical software installed in a fully functional workstation for the data processing, analysis and interpretational aspects of the project.

4.1.1 Seismic Data Specification

The seismic volume utilized for this study was an offshore 3D post stack time migrated (PSTM) SEGY seismic data. The unit of the seismic data was in milliseconds (ms). The volume was a floating 32-bit format with a bulk value format of 8-bits. The seismic inlines were found between 1930 to 2980, while crosslines were found between 5100 to 6000. The total number of crosslines and inlines were 901 and 1051 respectively. Inlines interval increment and crossline interval increment were 1, corresponding to 25m on ground surface. The vertical geometry of the seismic data ranged from 0.0ms at the surface to -7000ms (7 seconds) in the subsurface. A total of 1751 samples were utilized in building each seismic trace. The seismic amplitudes range from -33024 to 32766.

4.1.2 Software Deployment

Schlumberger Petrel and Opendtect were utilized for this study. Schlumberger Petrel was used to tune the seismic volume to the zone of interest. Opendtect was preferred for spectral decomposition because of its ease in decomposing frequencies and combining them to form a blend easy for interpretation. Schlumberger Petrel has gained a wide acceptance in the Oil and Gas Industry as a means for visualizing and interpreting seismic data. The version of Petrel utilized for this study was 2014.2 edition while the Opendtect version was 6.2.1.

4.2 Methods (Processing Workflow)

Figure 2 show a detailed workflow utilized to achieve the focal objectives for the study. The process began with loading the 3D PSTM SEGY seismic data into Petrel and conditioning the seismic volume using structural smoothing to smoothen the edges of the reflectivity. The seismic data was carefully analyzed for likely presence of channels which defined the zone of interest. A sub-volume was generated covering only the zone of interest. This new volume was then exported from Petrel and imported into Opendtect for spectral decomposition. Two decomposition methods were employed; FFT and CWT methods. Three dominant frequencies were extracted from the seismic data using these methods independently. The frequencies were analyzed separately and combined together in a blend (co-blending). The blended frequency which was now a mix of three dominant frequencies was then analyzed for the presence of channels and other geologic structures enhanced by these attributes. Finally, the outcomes were then compared to determine which spectral decomposition method worked best in the study area for detecting buried channels.

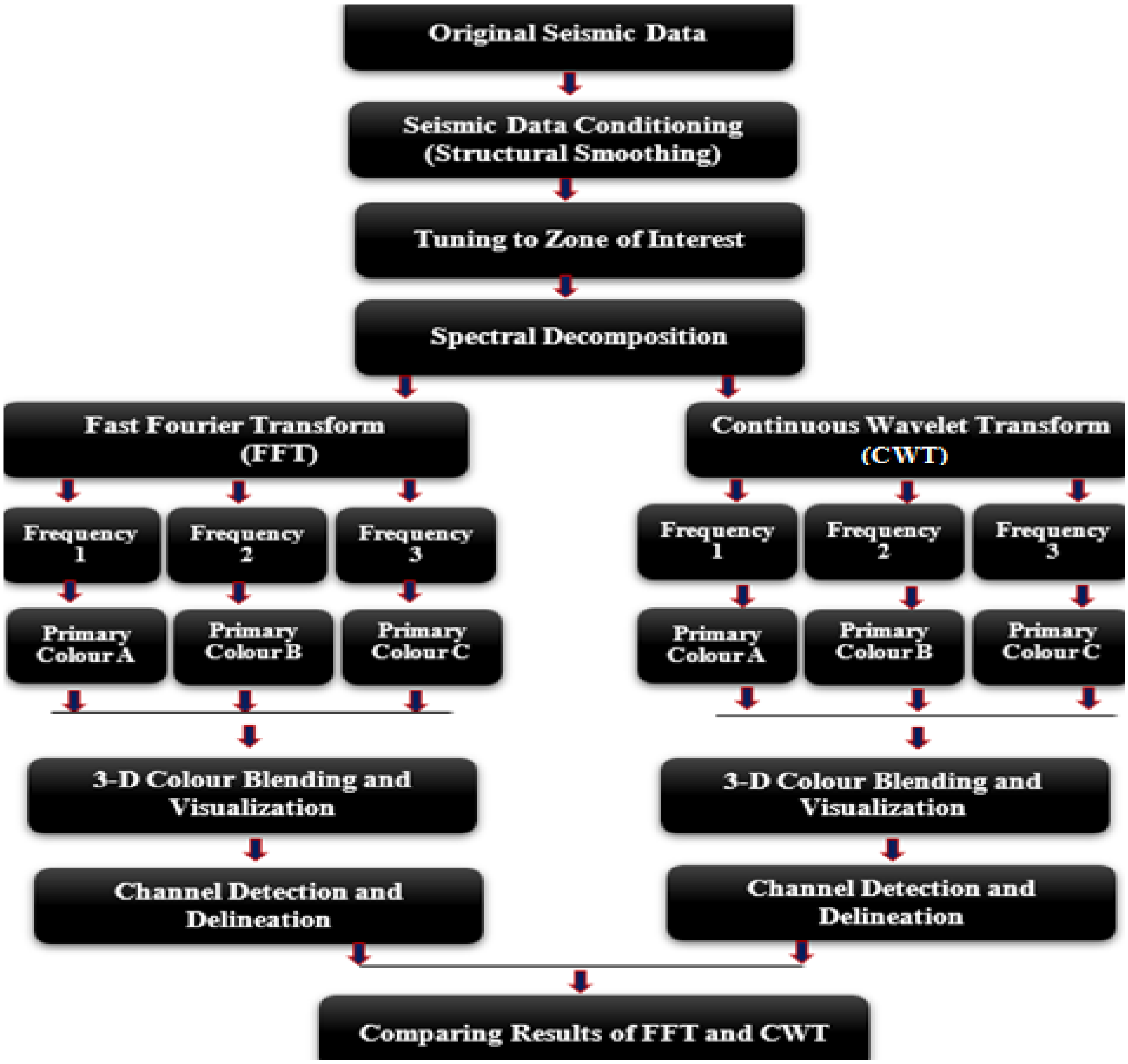

Figure 2: Adopted processing workflow used to achieve focal objective for the study.

4.2.1 Processing Sequences and Outcomes

A. Data Loading Procedure

The seismic data was loaded into the Schlumberger Petrel in SEGY format. After loading the seismic data, the default amplitude seismic template was assigned to the seismic volume. On the original seismic, only inlines and crosslines were available. A time slice was then generated after realizing the seismic data (Figure 3). Realizing the seismic data was not only for the generation of the time slice, but also to reduce the size of the seismic data for spectral decomposition. The time-slice was relevant for this study because geologic structures such as channels are better visualized on time-slices.

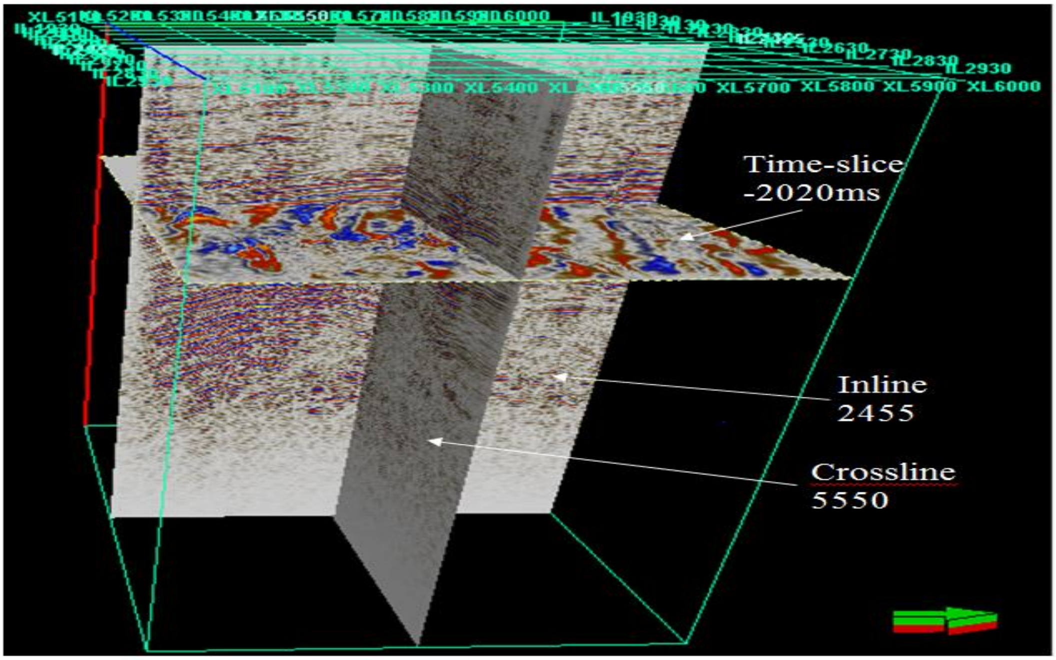

Figure 3: A 3D window showing the inline, crossline and time slice for seismic data loaded into Petrel visualization and interpretation tool.

B. Identification of Zones of Interest

After loading the seismic data into Petrel and realizing the volume, the seismic data was conditioned using structural smoothing and then tuned to the zone of interest. The zone of interest was selected after a careful evaluation of the entire seismic volume. On the seismic volume, two channel-like structures were found at a depth of -1500 ms and -2500 ms (Figure 4). These structures were the emphasis for this study. The seismic volume was then adjusted to generate a smaller volume mirroring the zone of interest as shown in Figure 5. The sub-volume was extracted from -1000 ms to -3000ms. The sub-volume was then exported from Petrel into Opendtect for spectral frequency decomposition and RGB colour blending.

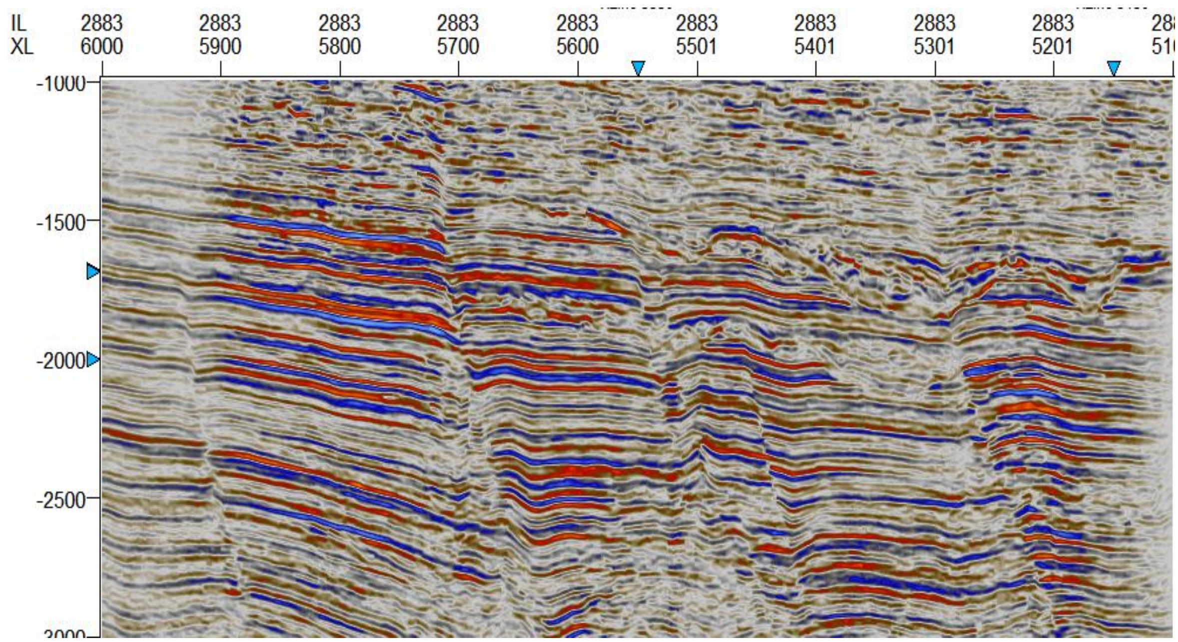

Figure 4: Seismic inline 2883, showing channel-like structures at -1500 ms and -2500 ms depths.

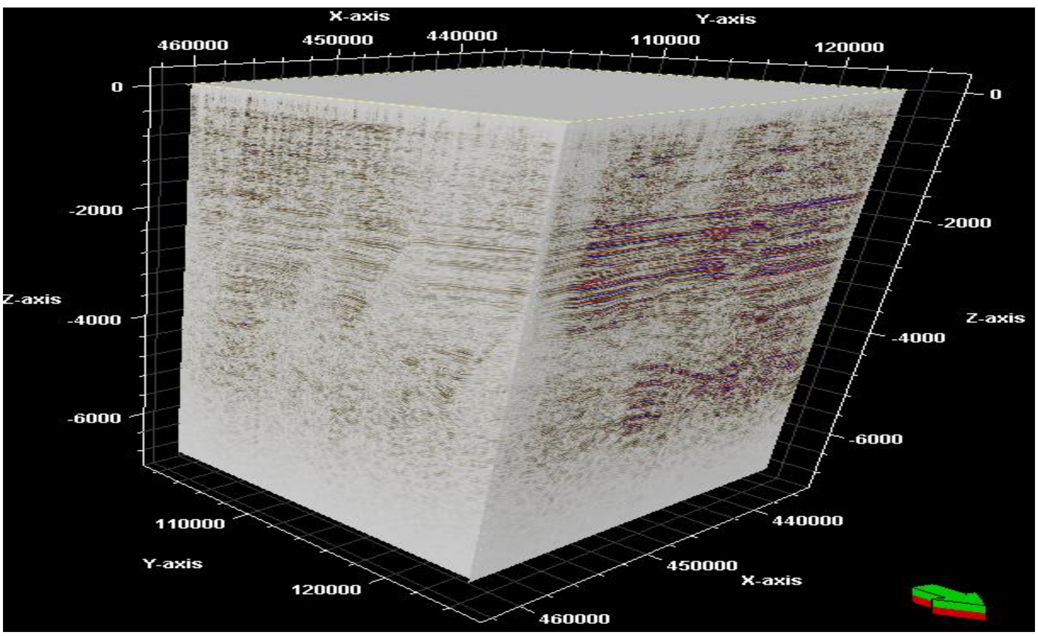

Figure 5: a) Original seismic volume (0 to -7000 ms).

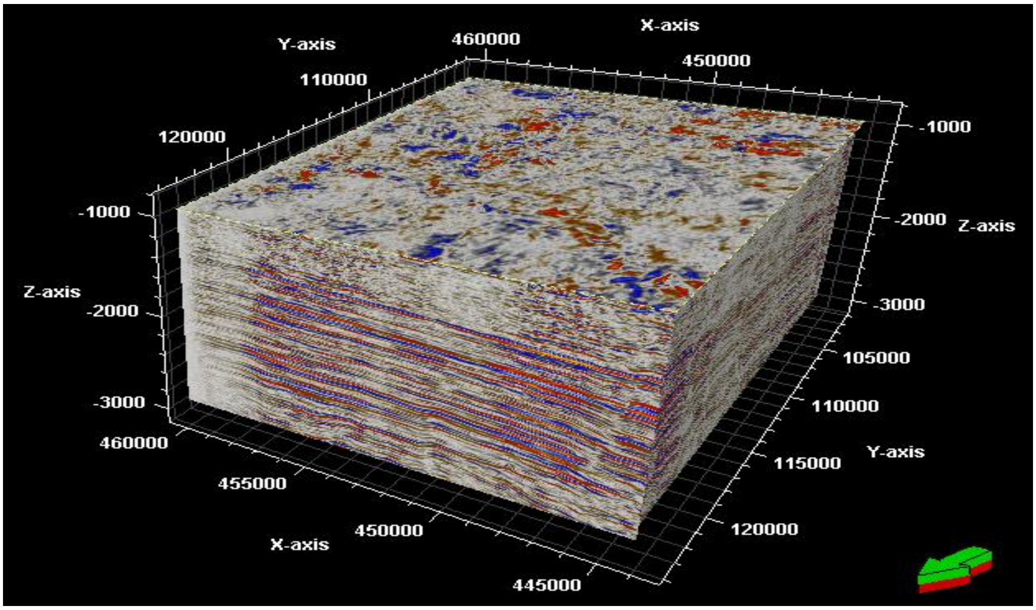

Figure 5: b) Seismic volume tuned to the zone of interest (-1000 to -3000 ms),

C. Spectral Decomposition Methods

Two methods were utilized in decomposing seismic frequencies for this study in the Opendtect processing platform; Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT). These methods have been introduced in section 3, where basic background theories of these methods were provided. A Fast Fourier Transform (FFT) is an algorithm that samples a signal over a period of time (or space) and divides it into its frequency components. The FFT method returns the amplitude spectrum while the CWT returns the wavelet coefficients. The theoretical basis of Fast Fourier Transform (FFT) is essentially built from the Short Time Fourier Transform (STFT) in which a time-frequency is produced by taking the Fourier Transform (FT) over a short time window. The basic idea is to divide the non-stationary signal into small segments (which are considered stationary parts) and calculate the Fourier Transform for each segment.

Mathematically, STFT is the inner product of signal *u(t)* and a time shifted window $g(t-\tau)$ in time τ and the frequency ω as shown in Equation 3;

$$STFT_{(\tau,\omega)} = \left[u(t)g(t-\tau)e^{-i\omega t}\right] = \int_{-\infty}^{+\infty} u(t)\bar{g}(t-\tau)e^{-i\omega t}\,dt \qquad (3)$$

Where; $\bar{g}(t-\tau)$ is the complex conjugate of $g(t-\tau)$.

The FFT required a short window (time-gate) and a step-size between the analyzed frequencies. This step can be interpreted as the frequency resolution. The time-gate utilized for the FFT decomposition was -28 with a step-size of 5. These were the default settings programmed within the software tool. In mathematics, the continuous wavelet transform is a formal tool that provides an over complete representation of a signal by letting the translation and scale parameter of the wavelets vary continuously. The Continuous Wavelet Transform (CWT) is used to decompose a signal into wavelets.

The CWT was calculated in Opendtect as the sum over the signal multiplied by a scaled and shifted wavelet. The CWT was calculated based on the equation below;

$$F_w(\sigma,\tau) = \langle f(t), \Psi_{\sigma,\tau}(t)\rangle = \int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{\sigma}}\bar{\Psi}\left(\frac{t-\tau}{\sigma}\right)dt \tag{4}$$

Where; $\bar{\Psi}$ is the complex conjugate of Ψ. $F_w(\sigma,\tau)$ is the time-scale map (i.e., the scalogram).
Morlet wavelet was utilized for extracting the frequencies of interest.

The Morlet wavelet is defined by Torrence and Compo (1998) as;

$$\Psi_o(t) = \pi^{-1/4}e^{i\omega_o t}e^{-t^2/2} \tag{5}$$

Where; ω_o is the frequency and is taken as 2π to satisfy the admissibility condition. The center frequency of the Morlet wavelet being inversely proportional to the scale provides an easy interpretation from scale to frequency. The wavelet is shifted along the signal and at each position the correlation of the wavelet with the signal is calculated. The result is called a wavelet coefficient. The frequency to be extracted corresponds to the central wavelet frequency. A step of 5 was also utilized for CWT frequencies extraction. The step determines the output resolution, which is especially interesting when evaluating this attribute. Zabihi and Siahkoohi, (2006) suggests that there are several parameters that influence the result of spectral decomposition, which includes; the quality of seismic data, the selection of time window, the algorithm of spectral decomposition that are used, and the output frequency.

D. Frequency Extraction

The next processing step in spectral decomposition is the extraction of dominant frequencies. For this to be accomplished, a graphical plot of frequency (Hz) against Power (dB) was generated for the seismic volume in Opendtect. Of all the frequencies displayed on the frequency spectrum, three of the frequencies, representing the dominant frequencies (mode occurrence) that make up the entire seismic volume were selected and extracted from the seismic data. The frequency extraction process is usually slow and needs a high–end workstation with a good central processing unit. Even with a powerful workstation, it takes several hours to complete the extraction of any selected frequency. It is good practice to extract as many dominant frequencies as possible from the seismic data in order to evaluate which frequencies combination best reveals the structure of interest. But due to the slow rate of extracting these frequencies, only three dominant frequencies of interest were extracted and evaluated from the seismic data. These frequencies are 10Hz, 25Hz and 32Hz respectively as seen in Figure 6.

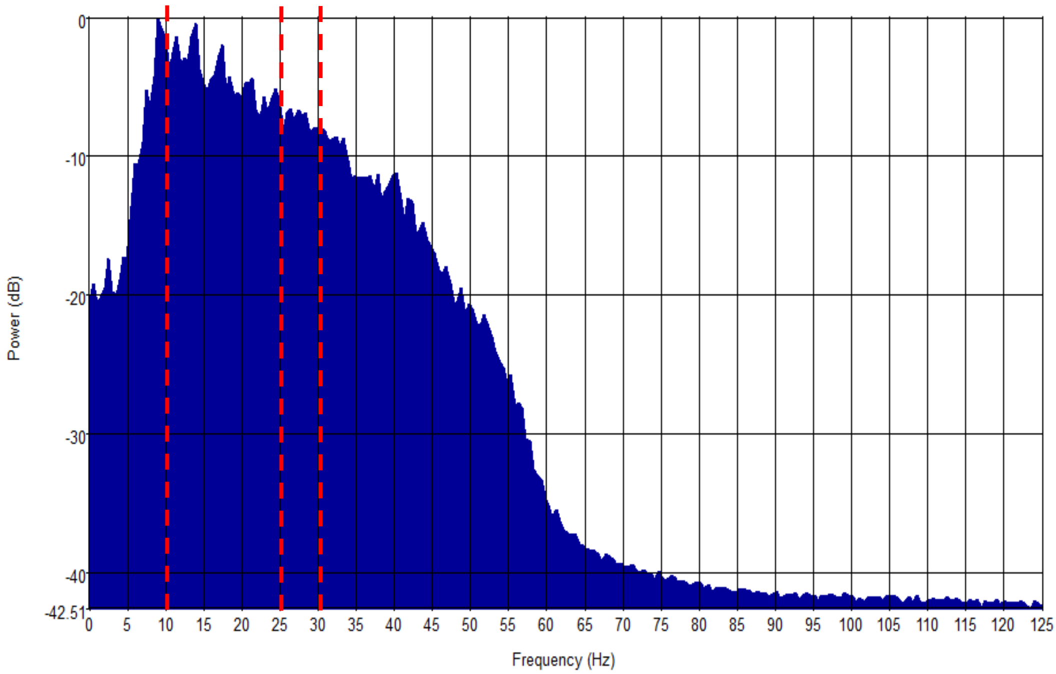

Figure 6: Frequency spectrum showing the dominant frequencies within the seismic volume for a 2000 ms analysis window.

E. Frequency Spectrum Analysis and RGB Frequency Blending

Once the seismic data has been decomposed into its relative components, the frequency response can be evaluated individually or in combination. The individual frequencies can be analyzed independently for the presence of structures such as channels, faults etc. This is usually best achieved using the seismic time-slice. Meanwhile, the selected frequencies can be combined to form a mixture through colour blending. A common method of combining multiple frequency responses is by colour blending, so that multiple frequency responses can be merged into a composite image. RGB colour blending as utilized in this study is a form of blending that uses Red, Green or Blue colour schemes for each frequency channel respectively. The resultant blend in Opendtect shows a variety of colours and contrast that reflects the complex interplay of frequencies and therefore variations in the phenomena that are the cause of the frequency dispersion. From the RGB blend in Opendtect, elements of geology and interactions between these elements could be seen in stark and vibrant details.

5. Results and Discussions

5.1 Results of Spectral Decomposition

The results of spectral decomposition using Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) decomposition methods are presented in Figures 7-13 respectively. The results of the dominant iso-frequencies extracted for 10 Hz, 25 Hz and 35 Hz at -1800ms depth as compared with the original seismic volume are presented in figures 7a, 7b, 7c and 7d using FFT method and figures 9a, 9b, 9c and 9d using CWT method. Similarly, for -2020ms depth, figures 11a, 11b, 11c and 11d shows the original seismic amplitude compared with the iso-frequencies which are 10 Hz, 25 Hz and 32 Hz generated using FFT method and Figures 13a, 13b, 13c and 13d using the CWT method. The dominant frequencies were assigned various primary colors. Red color was assigned to 10 Hz frequency for FFT and CWT, green to 25 Hz while blue color was assigned to 32 Hz frequency. These frequencies were then mixed in a color blend to enhance interpretation (Figures 8d, 10d, 12d and 14d). These results will be discussed in the subsequent sections of this paper.

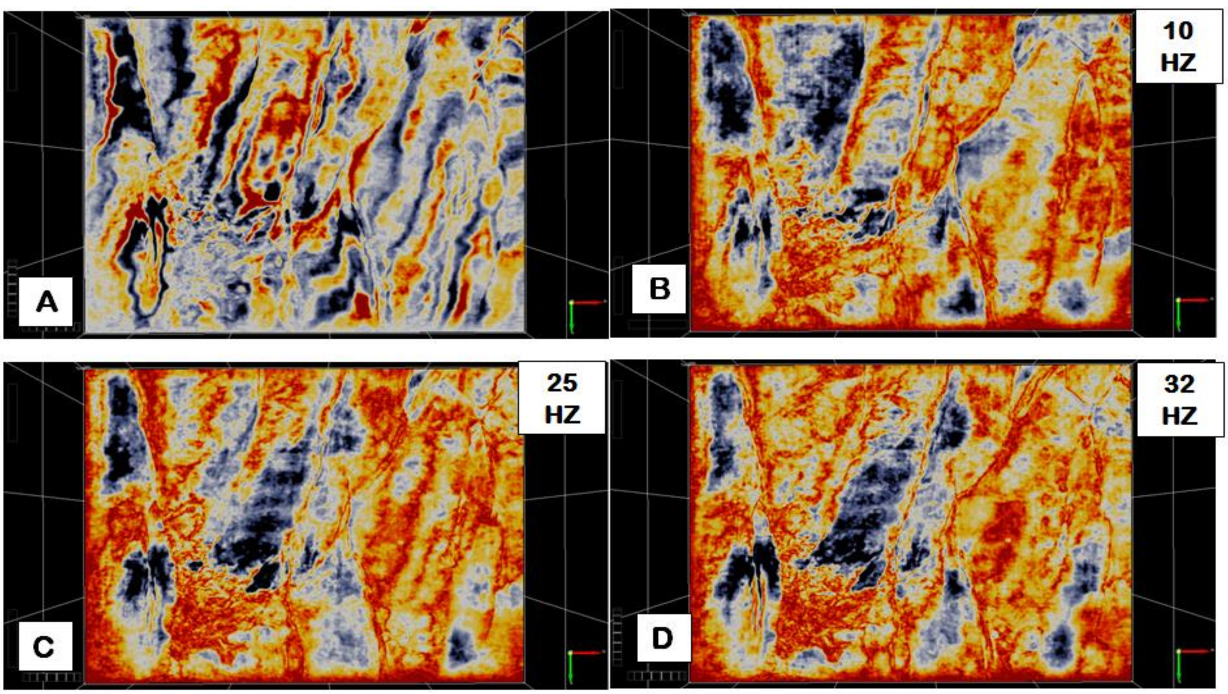

Figure 7: Seismic data display for -2020ms time slice. a) Original Seismic data. b) 10Hz frequency obtained using FFT method. c) 25Hz frequency obtained using FFT method. d) 32Hz frequency obtained using FFT method.

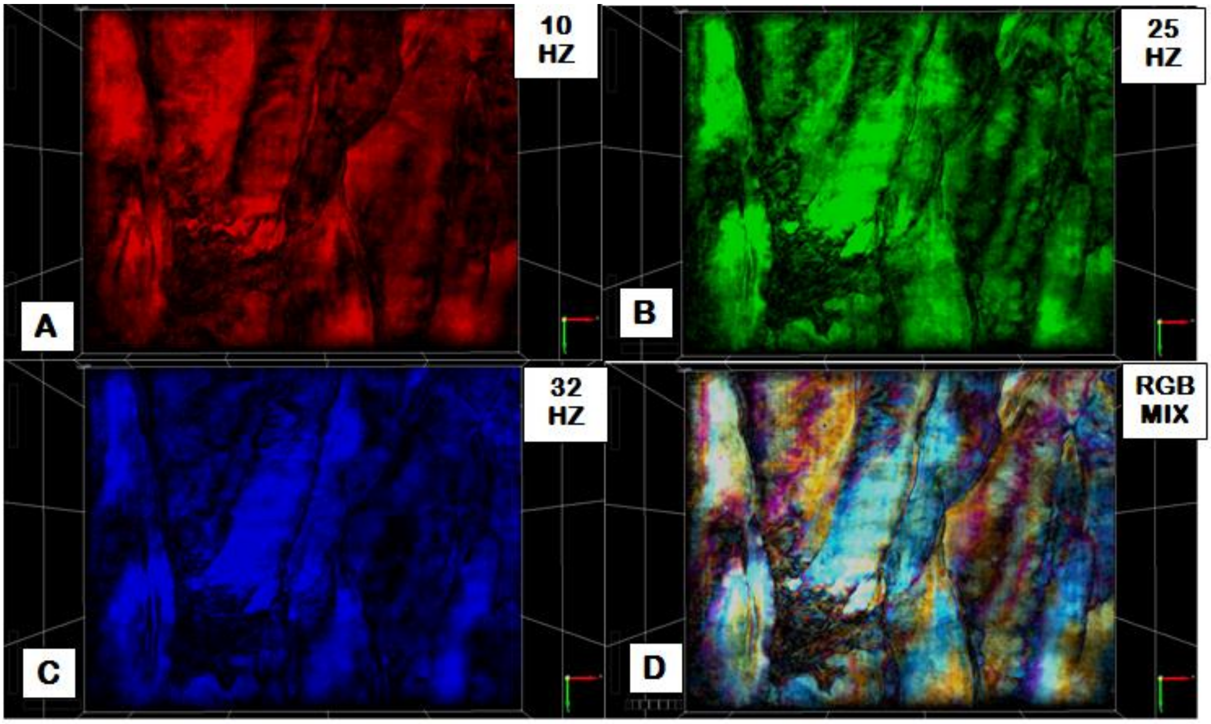

Figure 8: a) 10Hz frequency obtained from -2020ms time-slice using FFT method and colour coded Red. b) 25Hz frequency obtained using FFT method and colour coded Green. c) 32Hz frequency obtained using FFT method and colour coded Blue. d) RGB blended image showing a mix of all three dominant frequencies.

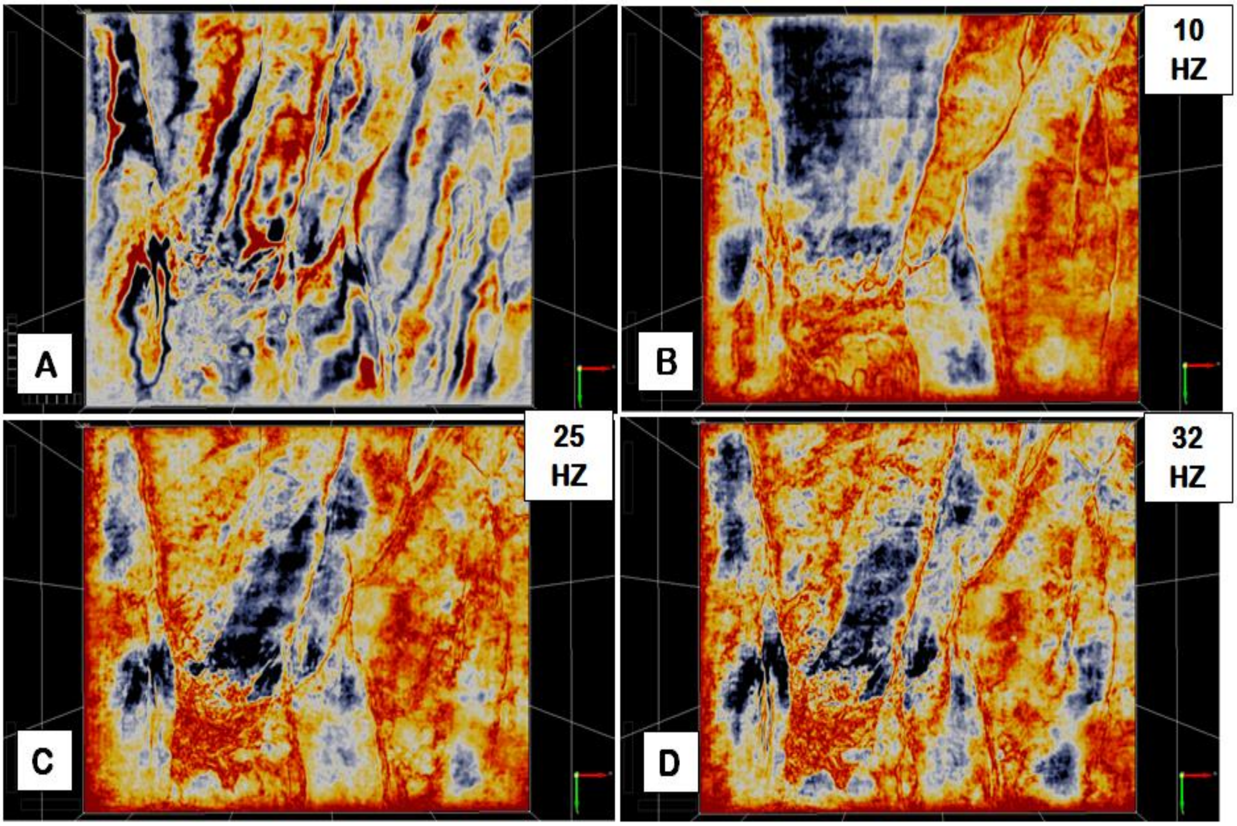

Figure 9: Seismic data display for -2020ms time slice. a) Original Seismic data. b) 10Hz frequency obtained using CWT method. c) 25Hz frequency obtained using CWT method. d) 32Hz frequency obtained using CWT method.

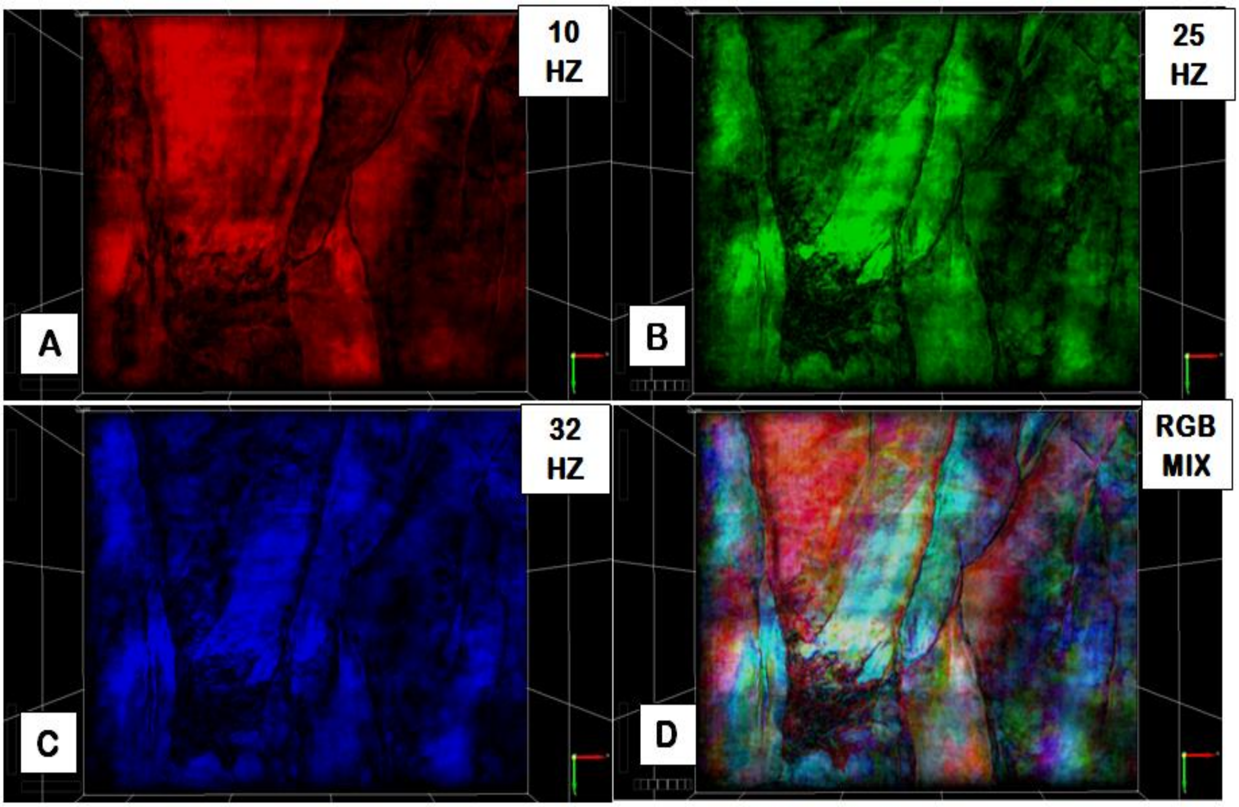

Figure 10: a) 10Hz frequency obtained from -2020ms time-slice using CWT method and colour coded Red. b) 25Hz frequency obtained using CWT method and colour coded Green. c) 32Hz frequency obtained using CWT method and colour coded Blue. d) RGB blended image showing a mix of all three dominant frequencies.

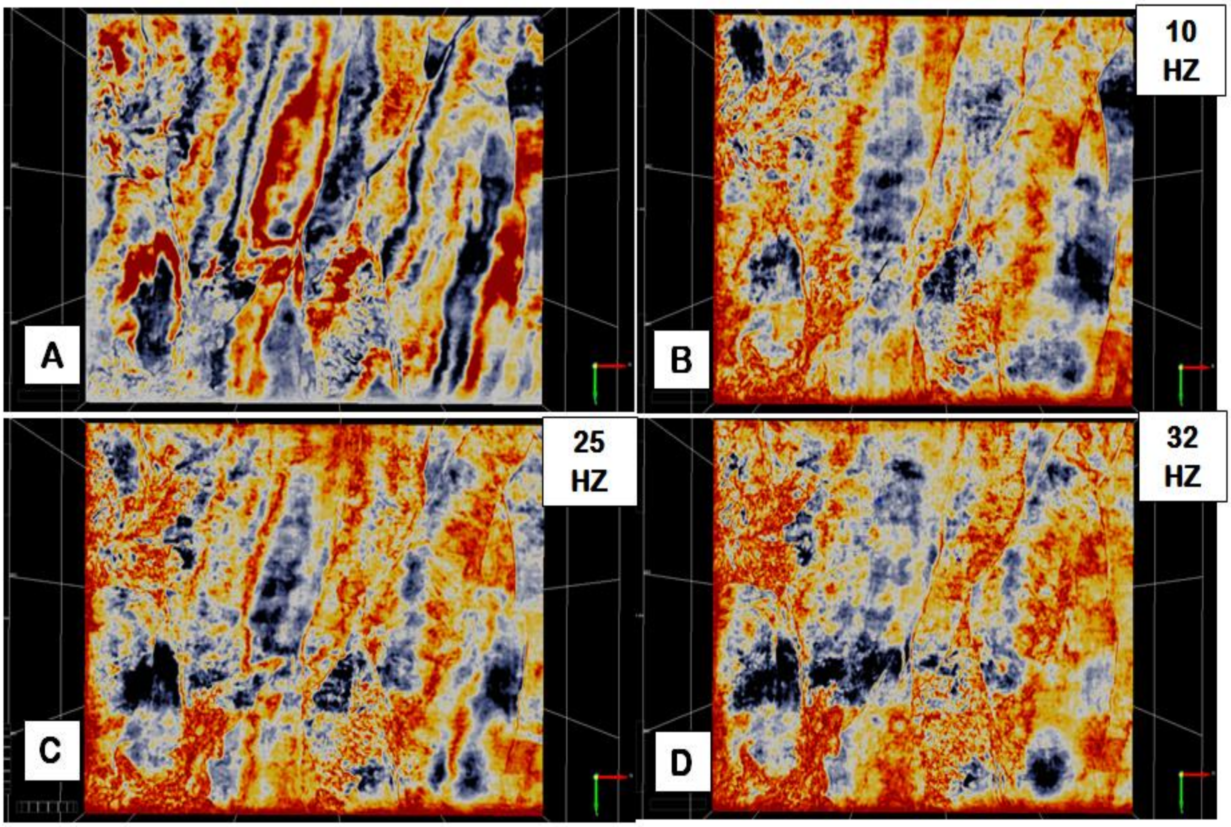

Figure 11: Seismic data display for -1800ms time slice. a) Original Seismic data, b) 10Hz frequency obtained using FFT method, c) 25Hz frequency obtained using FFT method, and d) 32Hz frequency obtained using FFT method.

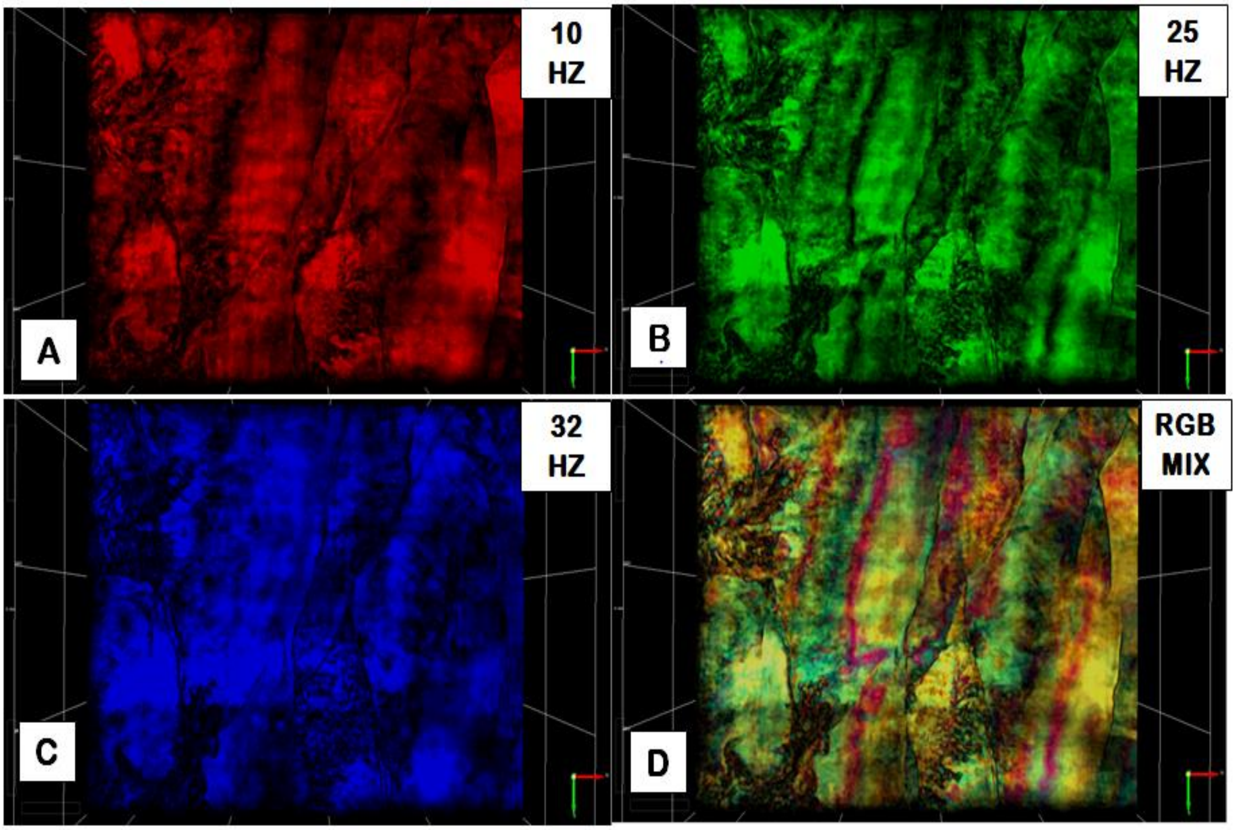

Figure 12: a) 10Hz frequency obtained from -1800ms time-slice using FFT method and colour coded Red, b) 25Hz frequency obtained using FFT method and colour coded Green, c) 32Hz frequency obtained using FFT method and colour coded Blue, and d) RGB blended image showing a mix of all three dominant frequencies.

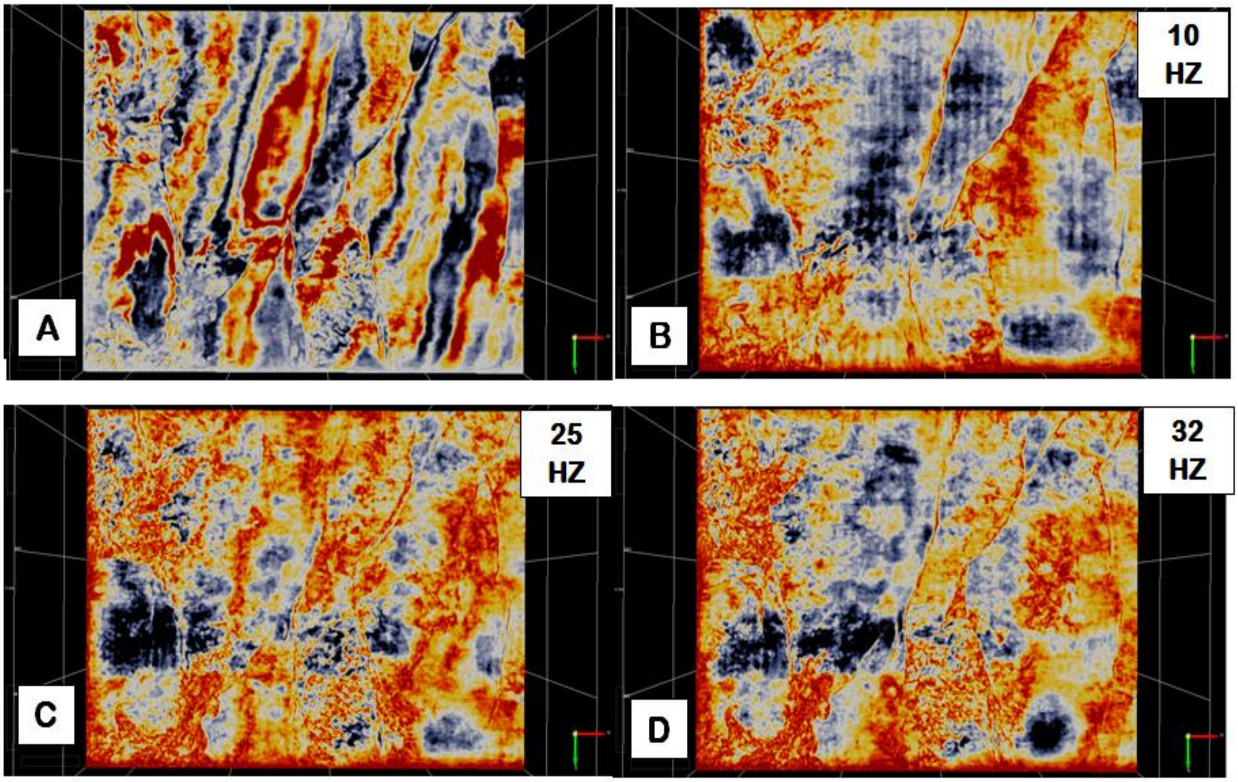

Figure 13: Seismic data display for -1800ms time slice. a) Original seismic data, b) 10Hz frequency obtained using CWT method, c) 25Hz frequency obtained using CWT method, and d) 32Hz frequency obtained using CWT method.

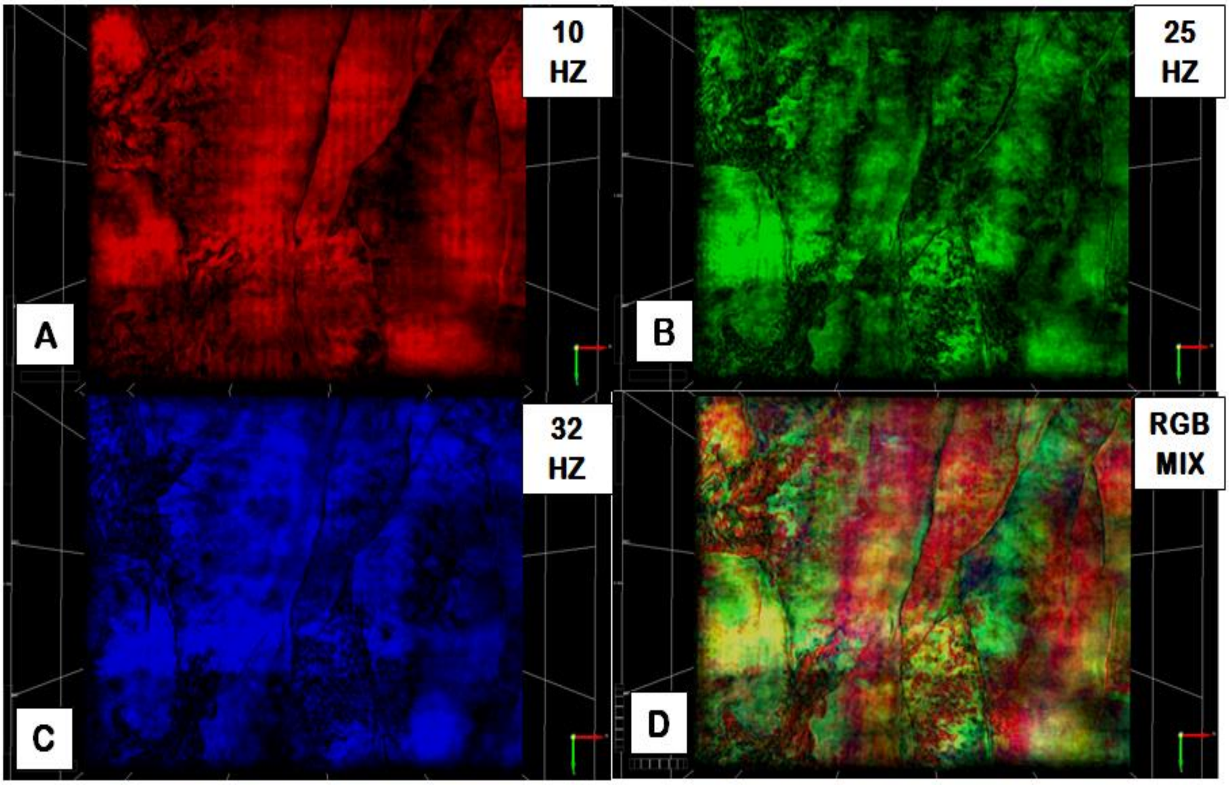

Figure 14: a) 10Hz frequency obtained from -2020ms time-slice using CWT method and colour coded Red, b) 25Hz frequency obtained using CWT method and colour coded Green, c) 32Hz frequency obtained using CWT method and colour coded Blue, and d) RGB blended image showing a mix of all three dominant frequencies.

5.2 Frequency Spectrum Analysis

Each of the extracted dominant iso-frequency enhanced a certain part of the seismic data; it became imperative therefore to visualize them in combination, this was achieved through RGB blending. The low frequency enhanced more of the channel geometry (10Hz), the higher frequency (32Hz) enhanced highlands while the median frequency (25Hz) enhanced a little of both aspects of the upper and lower frequency. The combined frequencies were able to reveal faults, channel geometry and channel sediment source areas within the prospect. The results of the combined frequency spectrum (frequency blending) revealed that the Fast Fourier Transform (FFT) decomposition method was a better method at resolving structural and stratigraphic features than the Continuous Wavelet Transformation (CWT) method in the field.

5.3 Imaging of the Buried Subsurface Channels

Figures 15 and 16 are enlarged images of the time-slices extracted from -1800ms and -2020ms for detecting buried channels. Geologically, deposition of sedimentary rocks occurs from the base upwards, hence, the time-slices were evaluated from the lower depth (older time) to shallower depth (recent time). Several low sinuous channels (meandering channels) were found on the -2020ms time slice along with a crevasse splay (Figure 15). A crevasse splay is a sedimentary fluvial deposit which forms when a stream breaks its natural or artificial levees and deposits sediments on a flood plain. Once the levee has been breached, the water flows out of its channel. As the water spreads onto the floodplain, sediments will start to fall out of suspension as the water loses energy. Crevasse splay deposits can create a graded depositional trend. Crevasse splay is most commonly associated with meandering channels. The channels were identified as the low frequency events on the seismic data which were more enhanced with 10Hz frequency. Many of the channels in Figure 15 were controlled by major faults as seen on the time-slice. The channels have their provenance in the eastern part which is outside the survey area, and channel flow direction is from the east to the west of the area (Figure 15). The crevasse splay which is well formed at the south-eastern part of the seismic data has a source area to the east that is outside the survey area. The crevasse splay has several major and minor distributary channels. Two of the major distributary channels that take their origin from the crevasse splay extended for long distances across the entire survey area (Figure 15). Flood plains were identified as the area between two river channels. Several floodplains were recognized on the time-slice. The crevasse splay deposits were found on the flood plain. Although the Continuous Wavelet Transform decomposition method was able to identify the crevasse splay deposit (Figure 16), all other channels were poorly resolved and could not be easily identified using this method.

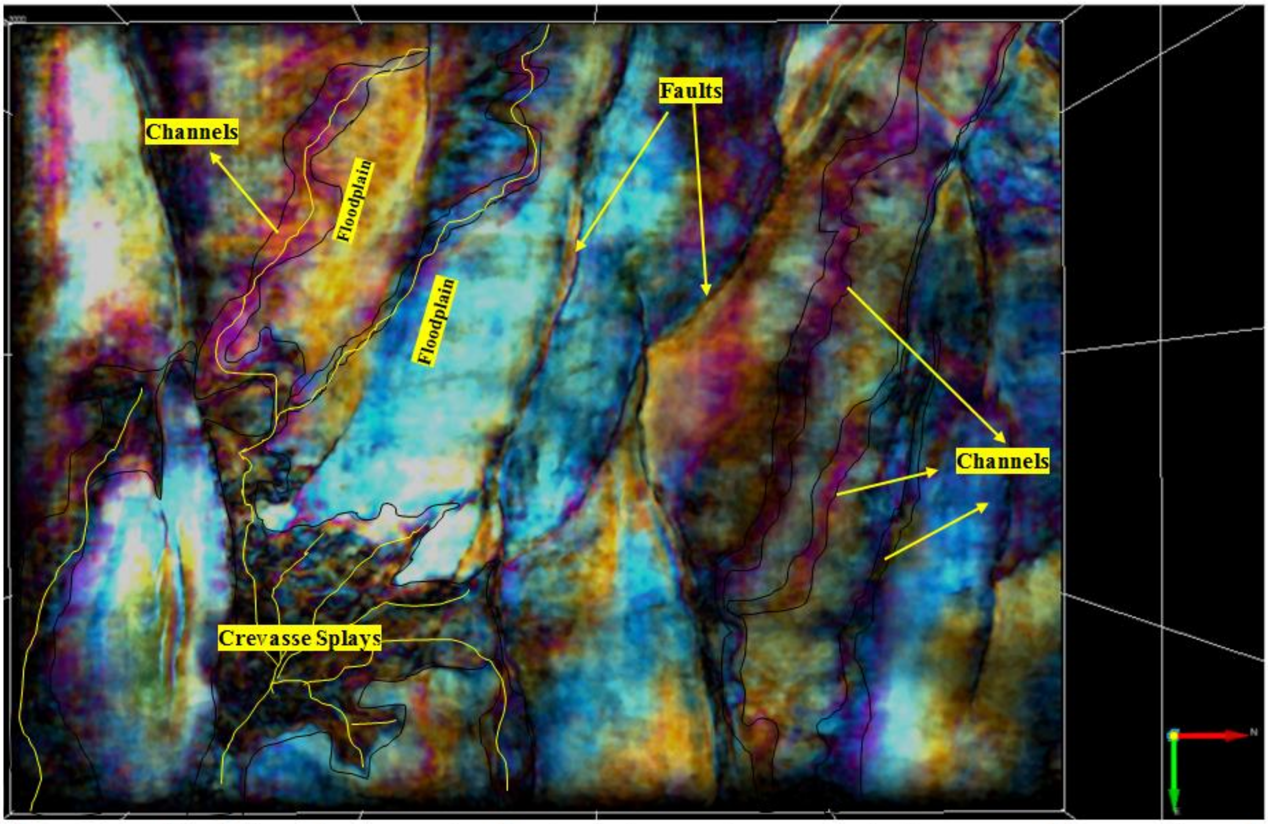

Figure 15: RGB blended image for -2020ms time-slice showing interpreted structures using the FFT spectral decomposition method.

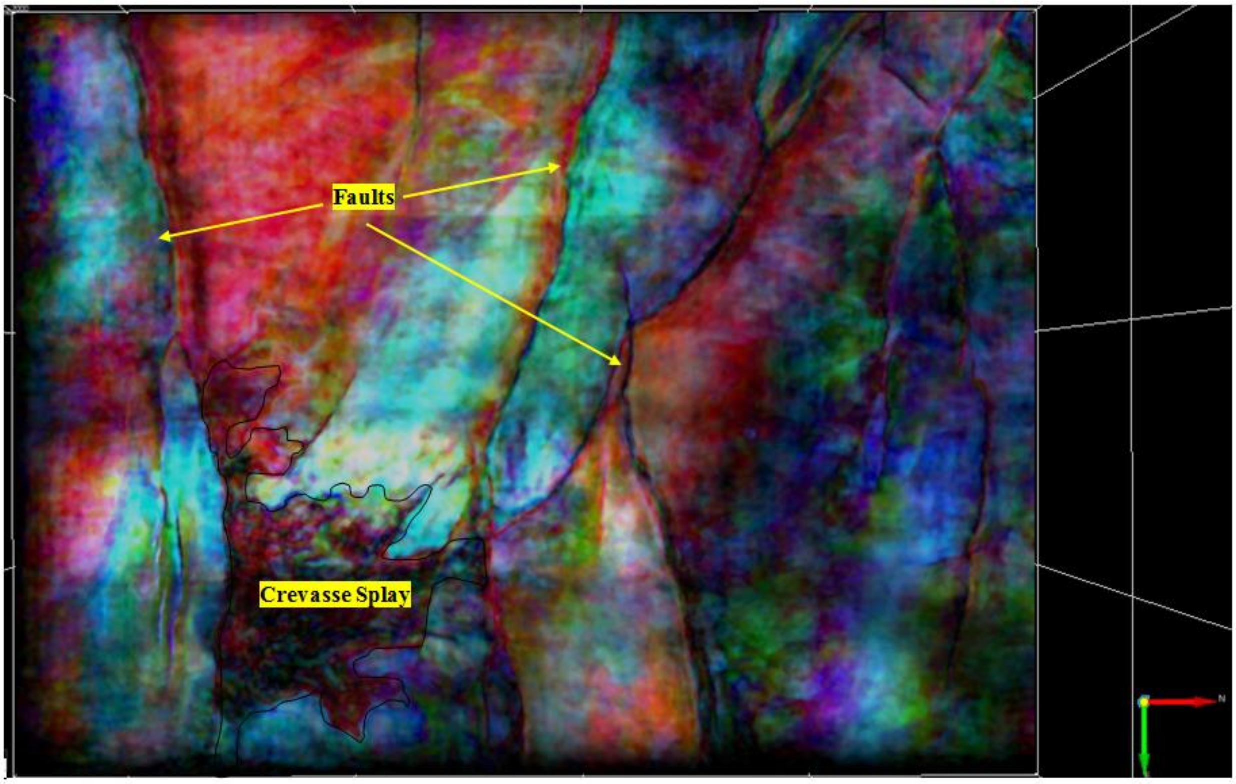

Figure 16: RGB blended image for -2020ms time-slice showing interpreted structures using the CWT spectral decomposition method.

On the upper part of the seismic sequence (-1800ms time slice), several channels and crevasse splay deposits were found (Figures 17 and 18). Again, these channels were better enhanced using the FFT decomposition method (Figure 17). The channels were fault controlled in many cases. The interaction between the channels and the crevasse splay is a strong indication that they were possibly formed as a result of levee breaching. On top of the crevasse splays, there were several other minor distributary channels which act as conduits for the creation of new river systems. Because of the high number of channels and crevasse splay deposits on the southern part of the survey area in both the deeper and shallow intervals, it is most likely that channels migration is towards the north of the area. The crevasse splays at the southern end of the survey area shows fault breaching, indicative that the deposits are younger than the faults. Geologically, events that cut across other events are younger than the events they cross-cut. This is known as the law of cross-cutting relationship.

5.4 Identification of Faults

Faults are structural discontinuities that can aid in hydrocarbon accumulation. Figures 17 and 18 shows clearly the shape and extent of faults across the time slices. These results indicate that spectral decomposition is not only a good tool for resolving channels but also for detecting faults. Each of the frequencies extracted from the seismic data enhanced a certain portion of the fault (tips, edges and curves). Combined through blending, they clearly displayed various faults with good resolution. Figures 17 and 18 have clearly shown that the distribution of channels is controlled by the presence of faults. Although both FFT and CWT were very good for resolving faults, the CWT method was preferred because of its ability to resolve even the smaller faults not easily seen when using the FFT method.

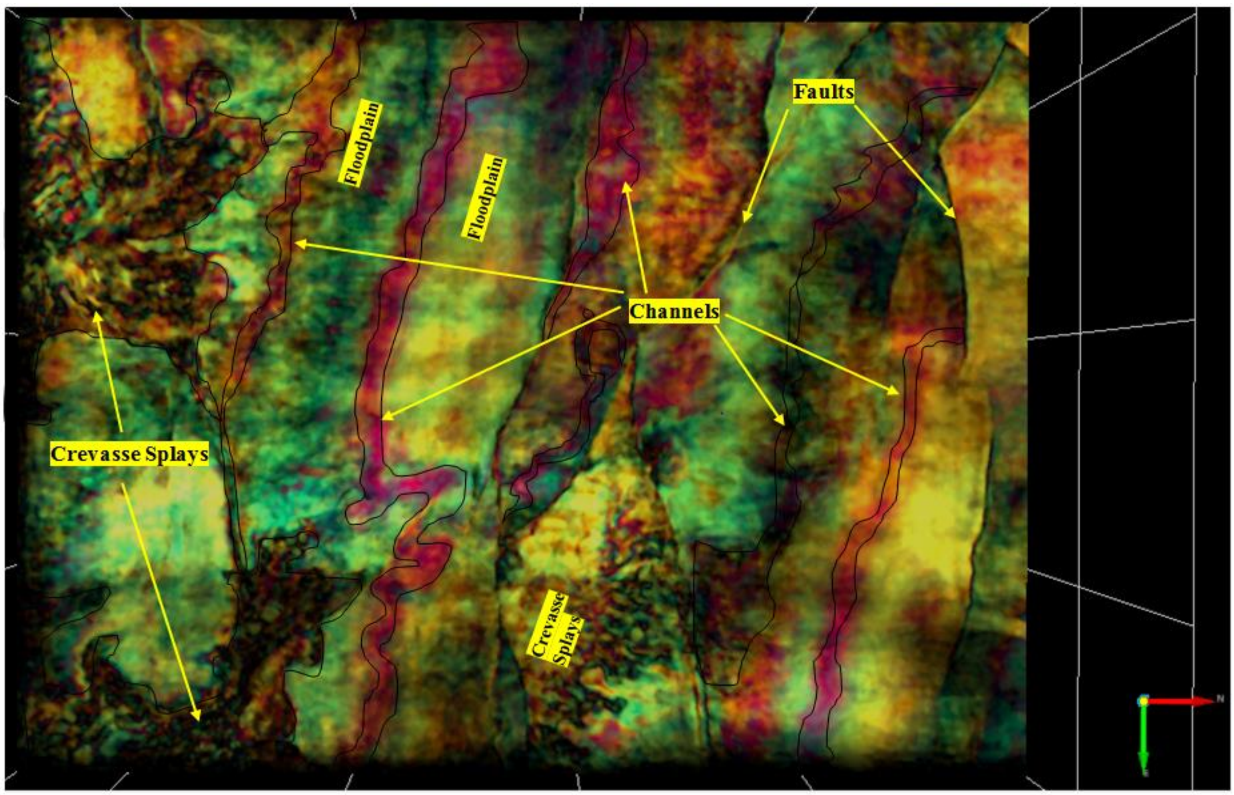

Figure 17: RGB blended image for -1800ms time-slice showing interpreted structures using the FFT spectral decomposition method.

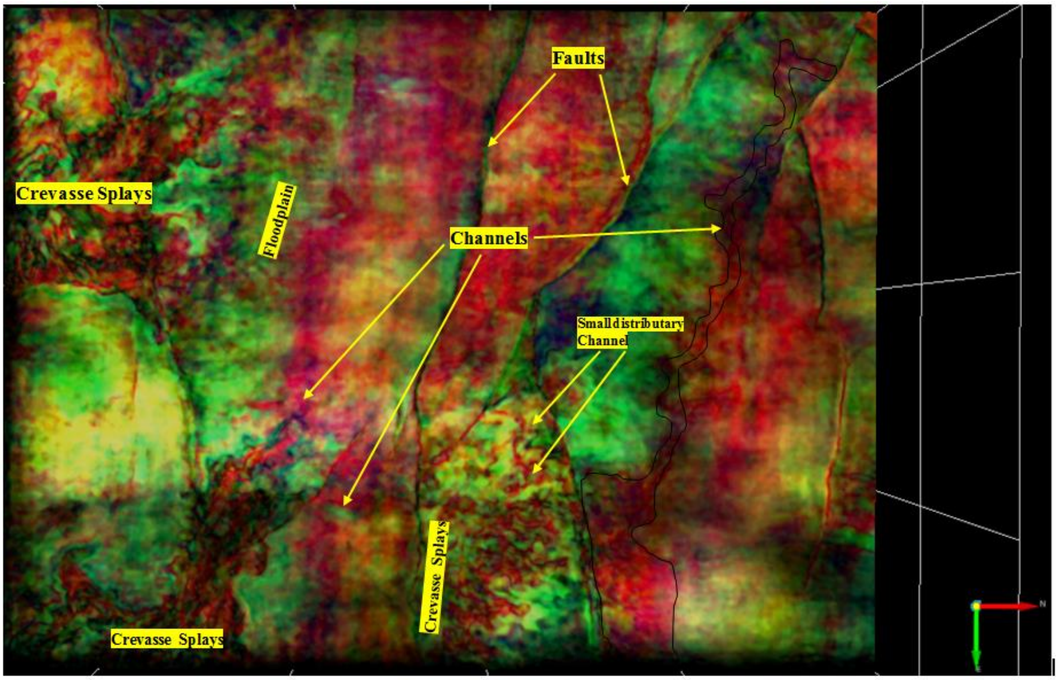

Figure 18: RGB blended image for -1800ms time-slice showing interpreted structures using the CWT spectral decomposition method.

5.5 Discussion of Results

To produce from a field, the geologist, geophysicist, petrophysicist and the engineering crew plan the best location to drill and perforate. Research has shown that channels are amongst the best environments of deposition that favors accumulation of hydrocarbons. Channel deposits are predominantly porous and permeable sands. They are often sought out for because they have good reservoir potentials. Well logs are useful tools for detecting channels using gamma ray log motif trends, whereas on seismic data, channels are not easily detectable because most channels are below the vertical resolution of seismic data. Hence, to determine the presence of these structures that hold great promise as hydrocarbon prospective areas on seismic data, other methods are often employed.

Spectral decomposition is one of the best methods utilized by oil and gas industries to detect and delineate channel geometries from seismic data. Several decomposition methods exist, but two commonly used methods are the Fast Fourier Transform (FFT) and the Continuous Wavelet Transform (CWT). These two methods were the emphasis of this study. After carefully extracting three dominant frequencies (10Hz, 25Hz, 32Hz) and co-blending them, they were analyzed to determine if they are effective for resolving these channels in the prospect offshore field. The results showed that both FFT and CWT methods were not only good at resolving channel geometries, but also discontinuities (faults) as well. Several channels were revealed from the lower (-2020ms) and upper (-1800ms) part of the field. The channels had low sinuosity and many of these channels were fault controlled. Also found in association with the channels were crevasse splay deposits. These deposits were formed as a result of levee breaching by the channel and subsequent deposition on adjacent floodplains. This behavior was clearly observed on the seismic data as levees were found truncating faults and deposited on the other side of the fault block as the channel current waned off to form crevasse splay deposits. At the top of the crevasse splays, several minor and major distributary channels were found. Some of these major distributary channels found in this study act as conduits for further river growth and development along flood plains. The high density of channels on the lower and upper seismic intervals is suggestive of a multistory channel system (stacked channels). The channels were flowing from the east to the west, while channel migration was most probably from the south to the north of the area. Crevasse splays are also known to be very good reservoir prospects because of their high sediment budget, porosity and permeability. The FFT and CWT spectral decomposition methods also revealed a good number of faults along with the channels and crevasse splay deposits. Generally, the FFT method is best and most preferred for channel geometry delineation while the CWT method is best for detecting the presence and continuity of fault.

6. Research Findings and Conclusion

6.1 Research Findings

This study entailed deploying two commonly used spectral decomposition methods for channel detection. These methods were the Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT). The following points are the key highlights that summarize the outcomes of this research;

i. Several channels were identified on two seismic time slices (-2020ms and -1800ms). The channels were identified as meandering channels of low sinuosity and were fault controlled. The channels were best resolved (better imaged) using the FFT method than the CWT method.
ii. Crevasse splay deposits were also found in association with the channel deposits. The channels were found to bifurcate faults and deposit their river load on the resulting flood plains creating crevasse splay deposits. Several minor and major distributary channels were found in association at the top of the crevasse splay deposits. The crevasse splay deposits were found using both FFT and CWT methods, but were more enhanced using the FFT method.
iii. The channel flow was from the east to the western part of the area while the channel migration direction was from the south to the north. This was determined from the increasing number of channels in the southern direction from the lower section to the upper section of the survey area. The high number of overlying channels over time slices is indicative of a multistory channel system.

iv. Several faults were found within the seismic volume. These faults were found on the different extracted dominant frequencies (10Hz, 25Hz and 32Hz) and on the co-blended time slice. The co-blended time slices revealed several faults much better than the individual frequencies in isolation. Generally, both FFT and CWT were able to resolve faults on these time-slices, but the CWT method offered the best resolution because it was able to resolve even smaller faults with good accuracy.

v. The presence of several channels, crevasse splay deposits and several associated faults are indicative of good hydrocarbon prospects. Crevasse splays and channels are known to carry sandy sediments with good porosity and high permeability values. The high density of faults is indicative of good trapping systems in the field.

7. Conclusion

Spectral decomposition methods are very effective tools for imaging buried channels and minor faults which are beyond the resolution of seismic data. The Fast Fourier Transform (FFT) based spectral decomposition method is better for crevasse splay and channel geometry detection and delineation (imaging) while Continuous Wavelet Transform (CWT) method is better for detecting minor faults geometry and their lateral extent. Hence FFT and CWT spectral decomposition methods when combined are powerful and effective tools for enhanced prospect evaluation and reservoir characterization.

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