

## Use of spectral decomposition technique for mapping geologic features of ‘Reigh’ field, Onshore Niger Delta

O. K. Olaleye<sup>†</sup>, P. A. Enikanselu, M. A. Ayuk

Department of Applied Geophysics, The Federal University of Technology, Akure, Nigeria

<sup>†</sup>Corresponding Author’s Email: [kolaleyeolomo@gmail.com](mailto:kolaleyeolomo@gmail.com)

**Abstract:** Spectral Decomposition Technique based on Short-Window Discrete Fourier Transform (SWDFT) was applied to three-dimensional (3D) seismic data obtained from ‘Reigh’ field, onshore Niger Delta with a view to enhancing stratigraphic interpretation for geological features which are beyond seismic resolution. Two sands units from the study area were studied to produce spectrally decomposed surfaces. The result of the study revealed thin bed layer at the centre of the field on sand unit ‘A’. Sand-filled meandering channel was detected and highlighted in the northern part of sand unit ‘B’ based on Red-Green-Blue frequency modulation of spectral decomposition. The study has enhanced geologic understanding of the field by improving thin bed resolution, highlighting geologic features and displaying bed thickness variation of studied sand units in the study area.

**Keywords:** geologic features, Niger Delta, seismic data, spectral decomposition

### 1. INTRODUCTION

Exploration geophysical methods utilize the science of natural forces and phenomenon of the earth in evaluating the physical processes and properties of the subsurface, particularly as they are applied to a wide range of investigation for societal and human needs [1], [2]. In hydrocarbon exploration, potential (gravity and magnetic), seismic and electromagnetic methods are mainly employed [3]. Magnetic, gravity and seismic methods measure the variations in the magnetic, density and acoustic properties of a geologic medium respectively. These variations measurement enables the mapping of gross geologic and stratigraphic features that are associated with the petroleum system of a basin, with the motive to studying its geologic history and likelihood of hydrocarbon generation and accumulation on a large scale basis [3], [4]. In addition, the reflection data of seismic method provides subsurface reflections, directly correlating to the physical properties of geologic strata at depth that reflects their local subsurface geology [2], therefore helps in characterizing distribution and physical properties of a reservoir on a field scale basis [5]. Electromagnetic methods are useful for detecting and monitoring hydrocarbon by measuring resistivity changes over geologic features already delineated by seismic surveys [6], [7]. Seismic survey is therefore apparently the most important technique in all stages of hydrocarbon production and development [8], [9].

Seismic data comprised of overprinted wavelet, resulting from frequent spanning of several subsurface layers during acquisition, therefore generating a complex tuned seismic reflection data. This varying frequency content in time makes seismic data non-stationary in nature [10]. The tuning effects of seismic data, together with subsurface lateral and vertical heterogeneity of sand distribution, affect the interpretation of some geologic features using conventional form of seismic structural interpretation. Geologic character responds differently to different frequency ranges of the

seismic signal, depending on the mode and frequency at which the geologic features were deposited. Therefore, certain geologic features are more visible and interpretable at some specific frequencies or frequency range. Spectral decomposition technique aims to delineate these subtle geologic features, by characterizing the time-dependent frequency response of the subsurface rocks [10], discretizing the complexly tuned reflection and boosting the higher frequency content from the seismic data.

Spectral decomposition has been used over the years as a way of qualitatively interpreting seismic data [11], [12], [13], [14], [15], [10]. Spectral decomposition is used in detecting stratigraphic features, such as channels, and thin beds beyond seismic resolution. Mapping geologic features require the specification of the geometry, facies changes in terms of bedding thickness and physical properties of the geologic formations. According to [15], spectral attributes are applicable beyond the detection of thin beds but also in delineation of internal architecture of reservoir sands by higher signal resolution, to highlight hidden geologic features and their geometry for the possibility of hydrocarbon prediction [14]. More so, stratigraphy resonates at wavelengths dependent on the bedding thickness [10], bedding thickness could also be predicted quantitatively using spectral decomposition.

This research was carried out in order to improve geological understanding in the Reigh Field in delineating stratigraphic features that requires higher seismic resolution and interpretation, which could serve as pathfinder for potential hydrocarbon reservoir within the field of study.

### 2. GEOLOGICAL FRAMEWORK

The study area is an onshore oil field in the Niger Delta Basin, located in the south-western part of Nigeria (Figure 1). The Niger Delta is located between Latitudes 4<sup>0</sup> and 6<sup>0</sup>N

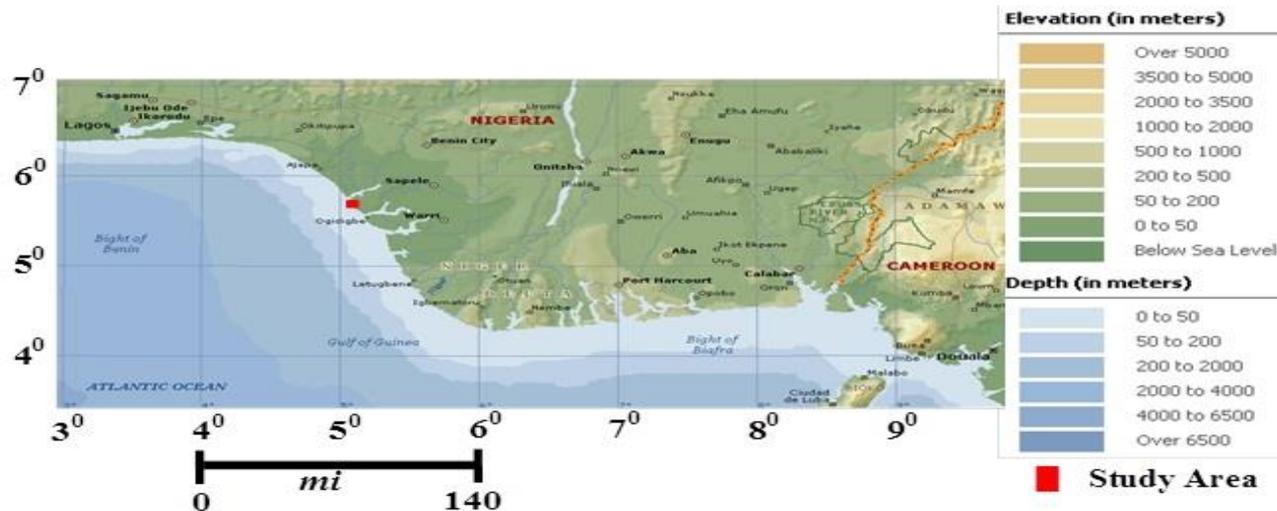


Fig. 1. Map of Niger Delta showing the study area (after [22])

and between Longitude 3<sup>0</sup> and 9<sup>0</sup>E [16]. It is situated at the apex of the Gulf of Guinea on the West Coast of Africa. The Niger Delta Basin is one of the most prolific deltaic hydrocarbons provinces in the World. The Niger Delta comprises of time-equivalent, proximal to distal, prograding facies units of Benin, Agbada, and Akata Formations, which are represented by a typical offlap sequence, distinguished mostly based on their sand-shale ratios [17]. The deep-marine pro-delta Akata Formation [18] composed of thick shale sequences, which is the potential source rock of the Niger Delta. Overlain by Akata Formation represents the actual deltaic portion, which has been the target for hydrocarbon reservoirs in the Niger Delta Basin. Finally, overlain by the delta-top Benin Formation, which consists of alluvial and upper coastal plain sands. The Niger Delta

structural trapping elements include those associated with simple rollover structures, structures with multiple growth faults, structures with antithetic faults, and collapsed crest structures [19]. On the flanks of the delta, stratigraphic traps are likely as important as structural traps [20]. Most of the turbidite oilfields also have some degree of stratigraphic control, either by reservoir pinchout, crestal accumulations below erosional surfaces and/or partial mud-filled channels.

### 3. THEORY

The use of short window discrete Fourier transform (SWDFT), also known as transform using constant size windows, to generate spectral balancing for the purpose of seismic interpretation was first demonstrated by [11], creating Morlet wavelets. The Morlet wavelets are good approximation to real seismic wavelets. Also, the first demonstration of spectral decomposition using SWDFT in interpreting 3D seismic data volumes to generate common frequency cubes was done by [12].

Spectral Decomposition requires the transformation of each individual 1D seismic trace,  $[s(t)]$  into a 2D time-frequency representation,  $[s(\tau, \omega)]$ . The equation for the short window discrete Fourier transform (SWDFT) is given in eq. 1 [21].

$$U_{SWDFT}(\tau, f) = \frac{1}{\sqrt{2\pi}} \int u(t)W(t - \tau)e^{-j2\pi ft} dt \quad (1)$$

where  $u(t) = \sum_j a_j \cdot w(t - t_j, f_j, \phi_j) + Noise$  is the seismic data time trace ( $a_j, t_j, f_j$  and  $\phi_j$  represent the amplitude, centre time, peak frequency, and phase of the  $j^{th}$  wavelet  $w$ , respectively),  $\tau$  is the centre time of the window function  $W(t)$

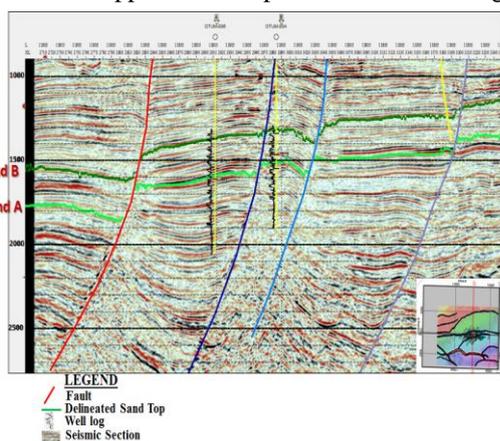


Fig. 2. Seismic section showing the positions of faults and map horizons of delineated sand units of the study area

$-\tau$ ),  $f$  is the frequency, and  $U_{\text{SWDFT}}(\tau, f)$  is the time-frequency function. The window function  $W(t - \tau)$  can be either a tapered or untapered rectangular window (boxcar), Gaussian window, Hamming window, or Hanning window.

#### 4. MATERIALS AND METHODS

A post stacked, migrated, zero phased and spectrally balanced three-dimensional (3D) seismic volume with bandwidth of 0 - 125 Hz was used as input data for the study. The 3D seismic data volume consists of 700 Inlines and 550 Crosslines with 25m line spacing. Mapped horizons of two sand units delineated from borehole logs of the field (Figure 2) were also used as input.

Matching pursuit spectral decomposition algorithm [23] was used. Brute force scans over all times and frequencies were done to generate spectral frequency distribution of the seismic data amplitude over the study area. Short-Window Discrete Fourier Transform (SWDFT) was used to generate discrete frequency cubes by transforming the time-domain seismic data to frequency domain. This replaces the single seismic input trace with a gather of traces corresponding to the Spectral Decomposition of the input data (seismic volume). The application of the SWDFT was used, on a trace by trace basis, to create spectral decomposition volumes. Seven discrete frequency cubes were generated within frequency range of 8 to 64 Hz, each one representing a different frequency band. The input horizons of the two delineated sand units were extracted from the output tuning cubes of the discretized seismic volumes to generate decomposed common frequency horizons of the sand units. The decomposed common frequency horizons of the sand units were viewed to identify textures and geological patterns. Horizon maps of the generated seven discrete frequencies were animated through and three of the maps with spatial patterns corresponding to reasonable geological models were chosen for further analysis. The chosen three discrete frequencies of spectrally decomposed surfaces were blended by plotting them against red, green, blue (RGB) colour scheme to interpret seismic facies distribution of the sand units based on frequency variations. RGB blending gives an effective use of colour in encoding information for detailed and highly intuitive visualization. In the RGB display, each input discrete spectral volume is mapped individually to the red, green and blue monochromatic components of RGB space. The intensity of each colour represents the contribution of the assigned spectral frequency band in the sand unit [24], [25]. Using the RGB blend, geological features, thin beds and thickness variations were interpreted through spatial pattern recognition. The period ( $T$ ) of a wave is increased within a thick medium. At high frequency, the period ( $T$ ) as well as the wavelength ( $\lambda$ ) of the seismic wave is small (Eqs. 2 and 3), therefore causing an increase in the vertical resolution and as such, highlighting thin reservoir layers.

$$f = 1/T \quad (2)$$

$$f = v/\lambda \quad (3)$$

Where  $v$  is the seismic wave velocity (m/s);  $\lambda$  is the wavelength (m) and  $T$  (Period) is time taken for one complete cycle (sec).

#### 5. RESULTS AND DISCUSSION

Figure 3 shows the extracted spectral frequency distribution of the seismic data amplitude over the study area. Figure 3 isolates the tuning effects of the spectral frequency relating to the geology of the field from that of the input seismic wavelet. Observation on Figure 3 shows that the seismic data have a seismic frequency range of 8 to 64 Hz relating to the geology of the field while frequency due to background/noise effect is from 64 Hz up to 125 Hz. The magnitude of reflection within the seismic frequency range (Figure 3) revealed that the geology of the area is characterized mainly by low frequency deposition.

Figure 4 is the seven generated spectral decomposition surfaces at different frequency ranges of sand unit 'A'. In this display, Figure 4a - g are individual spectral components range. In a frequency spectrum, peak frequency slightly increases as the layer thickness decreases [26]. Also, tuning thickness is inversely proportional to the peak spectral frequency of a broadband spectral response [27]. Therefore, geological features are expected to be thicker at lower frequency range. The display on Figure 4a revealed that most of the geology of sand unit 'A' is beyond 16 Hz. The northeast part of Figure 4a (zone 'A'), have geologic feature with frequencies below 10 Hz. This part is the thickest part of sand unit 'A'. Figure 4b revealed that the centre part of sand 'A' (zone 'B') is characterized by spectral frequency

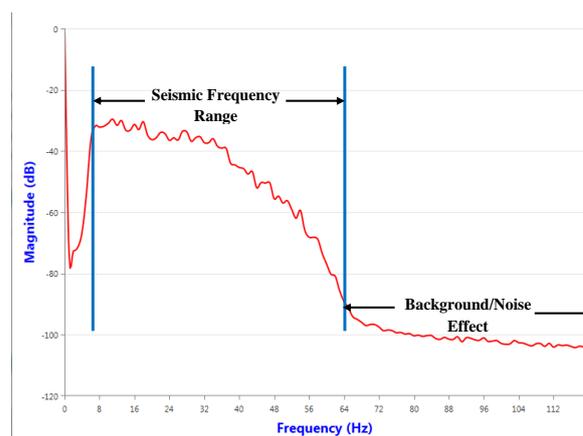


Fig. 3. Spectral frequency distribution of the seismic data amplitude over the study area.

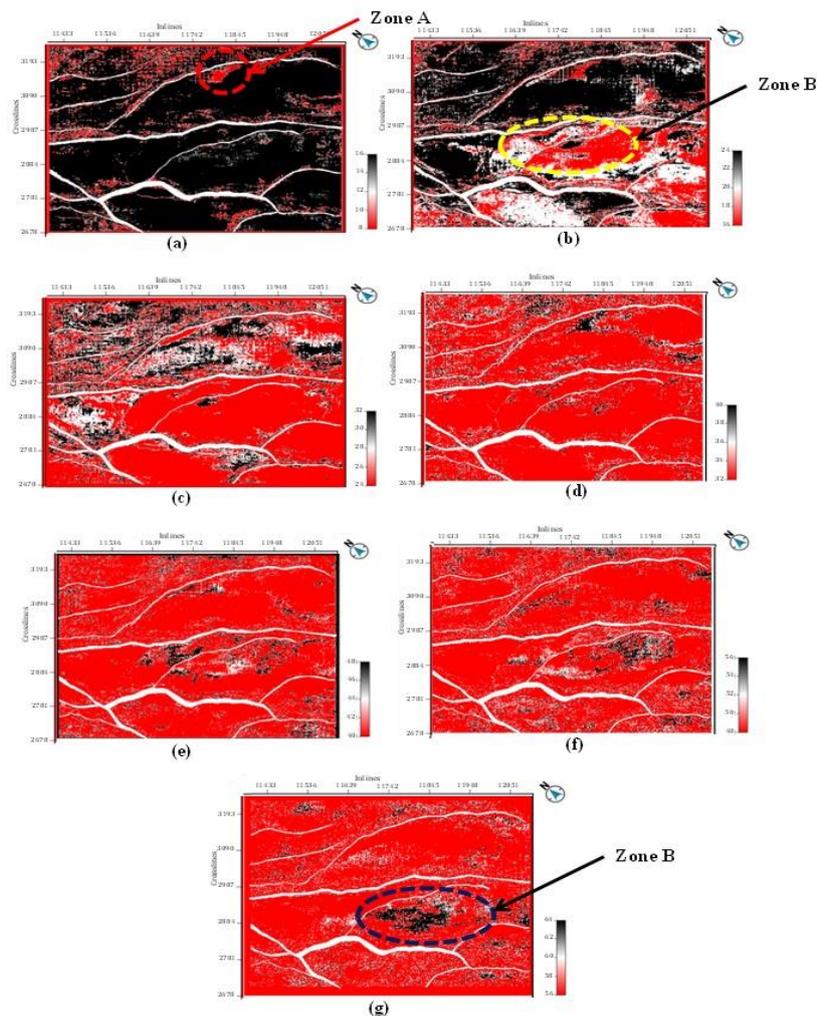


Fig. 4. Spectral Decomposition for Sand A, (a) Dominant Frequency 8-16Hz; (b) 16-24Hz; (c) 24-32Hz; (d) 32-40Hz; (e) 40-48Hz; (f) 48-56Hz; (g) 56-64Hz.

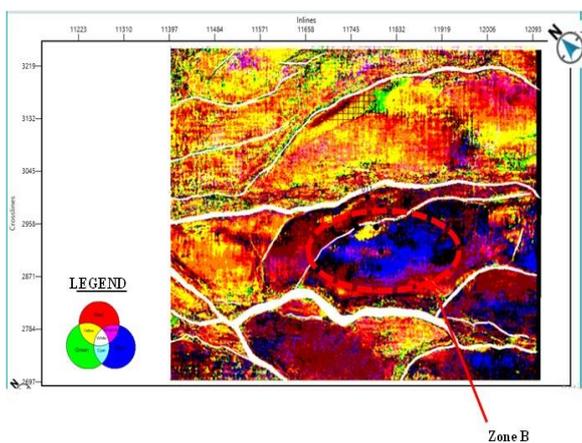


Fig. 5 . RGB Blend of Spectral Decomposition 8-16 Hz (Red), 24 Hz (Green) and 56-64 Hz (Blue) for Sand A

below 20 Hz indicating that this area is thick compared to the other parts with frequency beyond 24 Hz. The delineated thick portions within Figure 4a and b indicate thick geologic features which could harbour hydrocarbon, if structurally conformable and with high amplitude anomaly. Other significant areas on sand unit ‘A’ are the areas with thin beds as represented by black colour on Figures 4e, f and g. Special consideration is in the centre part of Figure 4g, which displays spectral frequency beyond 64 Hz, a thin bed within the sand unit. From Figure 4, the three geological significant amplitude surfaces are frequency range 8 to 16 Hz (Figure 4a), 16 to 24 Hz (Figure 4b) and 56 to 64 Hz (Figure 4g). These three quantities are combined to give a single image (Figure 5).

Figure 5 is an RGB blend of the three geological significant frequency surfaces and it reveals that thickest area of sand unit ‘A’ appears as brown/orange, the less thick as green/yellow and the thin areas as blue. Observation on

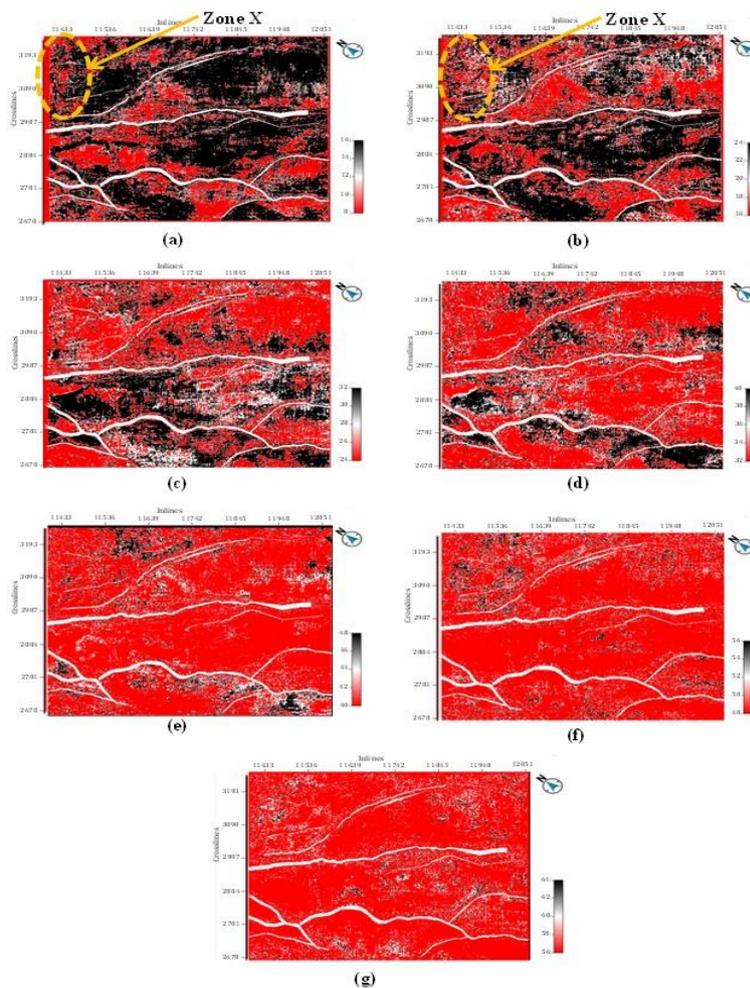


Fig. 6. Spectral Decomposition for Sand B, (a) Dominant Frequency 8-16Hz; (b) 16-24Hz; (c) 24-32Hz; (d) 32-40Hz; (e) 40-48Hz; (f) 48-56Hz; (g) 56-64Hz.

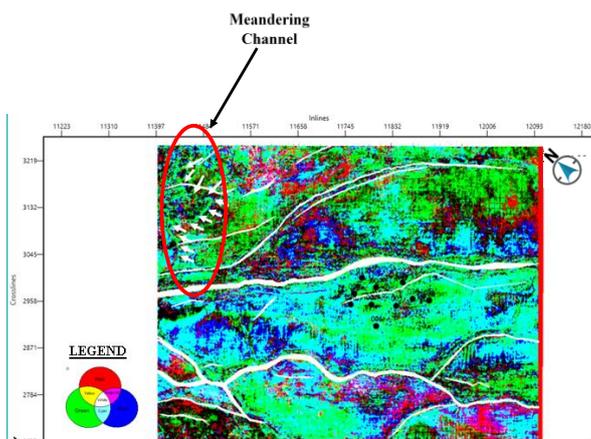


Fig. 7. RGB Blend of Spectral Decomposition Dominant Frequency for Sand B, Frequencies 8-16 Hz (Red), 16-24 Hz (Green) and 24-32Hz (Blue).

Figure 5 shows that the centre of the field is thick, with some patches of thin layer to the west. This was interpreted on the basis of brown spectral appearance at the centre, overlain by blue to the south-western part of the field. The presence of the thin layer of frequency 56-64 Hz indicates that the sand unit is stacked, with a thin sand layer at the top. The thin layer at the centre, if geologically conformable with high amplitude anomaly, may be significant for hydrocarbon accumulation and production in the field.

Figure 6 is the generated spectral decomposition surfaces at different frequency ranges of sand unit 'B'. Here, there is no thin layer beyond the seismic resolution as observed on Figure 6g. This is because black colour spectral patched, which are expected to characterize thin layer beyond 64Hz frequency, is not evident on the sand unit (Figure 6g). The zone labelled 'X' in the northern part of Figure 6a shows a narrow band of low frequency seismic amplitude to the west. This narrow band widens on Figure 6b, which latter

disappears on Figure 6c. The observation on zone 'X' is an indication of a geologic feature. Modulation of frequency ranges through the RGB blending (Figure 7) gave a better interpretation of the sand unit 'B' and the geological feature within zone 'X' was better revealed. Figure 7 is the RGB colour blend of the three most geological significant frequency ranges (Figure 6a-c) of sand unit 'B'. The northern corner of Figure 7 (zone 'X') provides more information on the stratigraphy of sand unit 'B' by mapping out a channel/levee deposit by the characteristic low frequency values along the channel deposit. There is a strong correlation between channel thickness and spectral amplitude [28], which makes the channel easy to map on spectral amplitude map on the bases of thickness variation and spatial patterns corresponding to the geological feature. This deposit continues towards the western side of the field indicating NE channel axis. This channel is a meandering type inferring geology interpretation of a low energy meandering depositional process around the area.

## 6. CONCLUSION

Short-Window Discrete Fourier Transform (SWDFT) was applied to three-dimensional (3D) seismic data obtained from 'Reigh' field, Onshore Niger Delta to produce spectrally decomposed surfaces of the field. Two sand units were interpreted using the spectral decomposition technique. The isolation of the tuning effects of the 3D seismic data revealed that the geology of the area is characterized mainly by low frequency deposition, indicating thick sands. Individual spectral decomposition surfaces generated for each sand unit revealed different geologic features and varying thicknesses at different frequency between 8 and 64 Hz.

The result obtained from the RGB blend revealed, through spatial pattern recognition and thickness variation, that the centre part of sand 'A' is characterized by thick sand deposit/geologic feature overlain by thin bed, which was interpreted as stacked sand unit within the field. A channel/levee deposit was delineated at the northern corner of sand unit 'B' distinguished mainly by characteristic low frequency along the channel deposit. The channel was interpreted to be thick with its channel axis toward NE direction of the field. The delineated geologic features on both sand units 'A' and 'B' may be significant for hydrocarbon accumulation and production in the field, if geologically conformable with high amplitude anomaly [15].

The analysis of seismic amplitude response at different frequencies and its RGB blend prove to be adequate in enhancing stratigraphic interpretation for geological features and characterizing sand units based on thickness variation.

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