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Application of Spectral Decomposition in Identification of Traps in *Edijalo* Field, Onshore Niger Delta, Nigeria.

Oladipo O.V., Ehinola O.A. and Ikhane, P.R

Abstract

Spectral decomposition is an imaging improvement that offers interpreters with high-resolution reservoir feature for imaging and mapping the seismic signature into its frequency constituents inside a time window of interpreted horizon of concern which can be applied to understanding the minor subtle faults, stratigraphy and channel features. Seismic reflection method generally reveals structure and geometry of the subsurface. It however fails to reveal many features that are below seismic resolution. These below seismic structures are of importance in understanding reservoir details. The capacity of spectral decomposition to reveal below seismic reservoir details makes it useful in seismic interpretation works. This research is aimed at applying spectral decomposition in understanding structural and stratigraphic features in *Edijalo* Field, Niger Delta.

The data used for the study include 3D seismic, three wells having essential logs like GR, sonic, density, etc and checkshot. The wells are correlated and calibrated with seismic to map horizons. In all, three horizons were mapped. The mapped horizons were then subjected to spectral decomposition at frequencies 28 Hz, 25 Hz and 21 Hz representing high (B), medium (G) and low (R) frequencies. The spectral decomposition algorithms used in this project were the Fast Fourier Transform (FFT) and the Continuous Wavelet Transform (CWT) algorithms. The fault mapping, horizon mapping and spectral decomposition were done using OpendTect software.

The FFT RGB blend at different time gates showed sand distribution pattern on the mapped horizons and thus revealed that the southern part has more sands. Also, the CWT (RGB blend) that showed hydrocarbon attenuation effect at low frequency revealed the probable area of hydrocarbon accumulation. Besides, spectral decomposition revealed very subtle faults in the field. These were faults that were below seismic resolution. The faults were important to our trapping system.

The study concluded that spectral decomposition can successfully be applied in understanding the structural and stratigraphic features (traps) that can aid hydrocarbon accumulation in the field.

Index Terms: Spectral decomposition, CWT, FFT, Seismic resolution, Checkshot

1 Introduction

As hydrocarbon reserves are being depleted and no major discovery is made, the onus lies on Petroleum Exploration and Production Companies to maximize the potentials of the field where they are operating. This may involve exploring for hydrocarbons that are localized in yet to be discovered reservoirs or by- passed sands or thin beds and other stratigraphic traps. Due to the limitations of conventional seismic interpretations, these situations could not be easily dealt with and with the rising cost of drilling; something must be done if companies must make profit I n the oil and gas business.

So, the concept of spectral decomposition has greatly improved exploration and discovery. This concept simply means decomposing seismic in time domain to time and frequency domain using mathematical tools. This is an over simplification!

- *Oladipo O.V. is a research student in the department of Geology, Olabisi Onabanjo University, Ago-Iwoye. E-mail: olajideoladipo11@gmail.com*
- *Ehinola O.A. is a Professor and Head, Department of Geology, University of Ibadan, Ibadan, Nigeria. E-mail: oa.ehinola@ui.edu.ng*
- *Ikhane P.R. is a Senior Lecturer and Ag. Head, Department of Earth Sciences, Olabisi Onabanjo University, Ago-Iwoye. E-mail: phillips.ikhane@gmail.com*

Spectral decomposition in this regards is an approach of decomposing the seismic signature into its spectral components within a time window of interpreted horizon of interest which can be utilized for understanding the minor subtle faults and channel features [1], [8].

According to [30], in his unpublished work titled Spectral Decomposition: A Powerful Tool for the Seismic Interpreter unpublished, Spectral decomposition is an imaging innovation that provides interpreters with high-resolution reservoir detail for imaging and mapping temporal bed thickness and geological discontinuities within 3D seismic surveys by breaking down the seismic signal into its component frequencies.

It unravels the seismic signal into its constituent frequencies [12]. The frequency domain representation of seismic data illustrates many features that are not apparent in time domain representation and hence, spectral decomposition serves as a useful tool for seismic interpreters since it as well reveals stratigraphic and structural details that are often obscured in the broadband data [36], [32]. The above makes spectral decomposition more useful in seismic data interpretation than the conventional horizon mapping and attribute extraction.

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Among the factors that control the spectral decomposition response of a reservoir are thickness, stratigraphy (i.e. reflectivity series), fluid type and effective attenuation. Thus, the most common application of spectral decomposition in seismic interpretation have been to delineate and visualize stratigraphic features and as a direct hydrocarbon indicator (DHI) and hydrocarbon typing tool [2].

Among the various geophysical techniques available for characterizing traps (the strati-structural features like faults and channels), 3D seismic attributes analysis and spectral decomposition have proven to be some of the most useful. Variation of seismic response due to geologic changes is expressed only in a certain spectral ranges, buried within the broadband data. Spectral decomposition in this regards is an approach of decomposing the seismic signature into its spectral components within a time window of interpreted horizon of interest which can be utilized for understanding the minor subtle faults and channel features [13]

Sun *et al* [31] have discussed low frequency shadows associated with hydrocarbons. Thus, based on the work of [13], when spectral decomposition is carried out on seismic data collected in hydrocarbon proven region, resultant frequency slices show frequency anomalies i.e. low frequency slices show higher amplitude than corresponding high frequency slices at hydrocarbon zones. Therefore, this technique may be utilized as DHI and can play a major role in minimizing dry well drilling. Partyka *et al*. [23] discussed spectral-decomposition analysis and interpretation of 3D seismic data. They showed how channel details and discontinuities could be imaged and mapped better with spectral-decomposition results. Both studies used a Fourier transform over short time windows, or short-time Fourier transform (STFT).
Castagna *et al*. [6] applied instantaneous spectral analysis to seismic data and obtain high-resolution spectral-decomposition images. They illustrated how spectral-decomposition results are used to detect low-frequency shadows beneath gas-sand reservoirs.
Related studies also show that spectral decomposition could be used to image hydrocarbon sands at certain frequency bands [5], [27].
Odebeatu *et al*. [19] applied S transform to seismic data and observed spectral anomaly attributed to gas bearing rocks. Sinha *et al*. [27] have developed a novel method of calculating time-frequency spectrum using CWT which they reported as TFCWT. Spectral decomposition with TFCWT is used to detect low frequency shadows caused by hydrocarbons and to identify subtle stratigraphic features for reservoir characterization [28].

Liu and Marfurt [14] showed that spectral decomposition can be used to map subtle changes in thickness of channels filled with porous rock and encased in a nonporous matrix. Oliveira *et al*. [20] used spectral decomposition to delineate gas hydrates concentration and to interpret free gas accumulations in Pelotas basin.
In this work, spectral decomposition is used in seismic data interpretation for traps detection (hydrocarbon detection, delineating channels if present, determination of stratigraphy, and identification of subtle faults) using the Fast Fourier Transform (FFT) and Continuous Wavelet Transform (CWT) methods.

2 Study Area Location

The study area is located onshore Niger Delta. It is given a pseudo name EDIJALO in order to maintain the proprietary nature of the data. Therefore no coordinates are given. The field has five wells with associated well log suite. However, three of the wells have very important logs that are relevant to this study. The study area is as shown below in Figures 1 and 2:

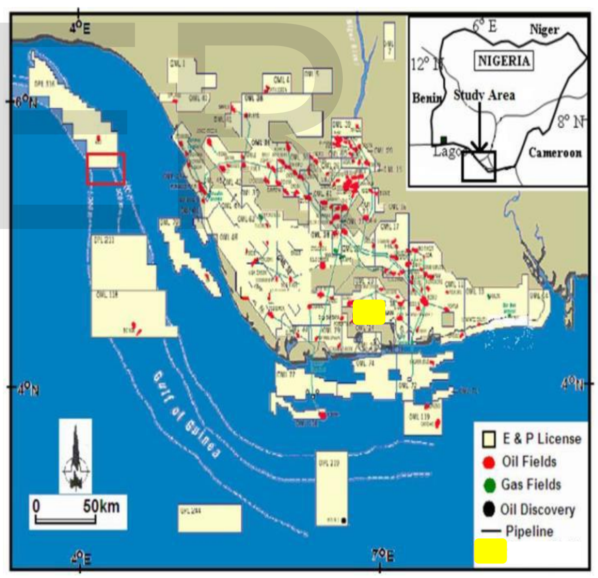

Figure 1: Concession map of Niger Delta showing study area (modified from [10])

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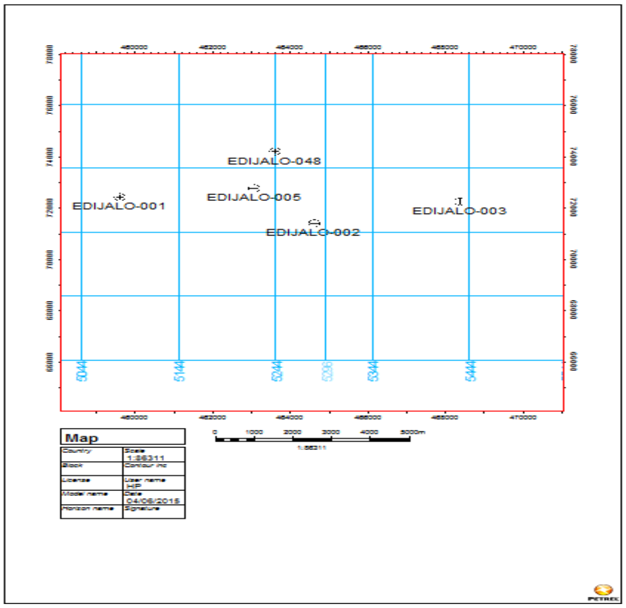

Figure 2: Base map showing well locations

3 Regional Geology

The Niger Delta Basin is a unique sedimentary basin located on the continental margin of the Gulf of Guinea in equatorial West Africa and lies between latitudes 4^0 and 7^0N and longitudes 3^0 and 9^0E [35]. It extends to the southern part of Nigeria and covers an area of about 75,000 km², with a 12 km thick clastic wedge overlying the lower part of the Benue Trough which has greatly influenced its formation. It is bounded in the south by the Gulf of Guinea (or the 4000 m bathymetric contour) and in the North by older (Cretaceous) tectonic elements which include the Anambra Basin, Abakaliki Uplift and the Afikpo Syncline [34], [4], [11], [35], [29], [24], [22] and [15].

Short and Stauble [26] described the stratigraphic evolution of the Tertiary Niger Delta and underlying Cretaceous strata. The depositional environment, sedimentation and physiography of the Niger Delta have also been described by [3] and [21]. The Niger Delta's sediments show an upward transition from marine pro-delta shales (Akata Formation) through paralic interval (Agbada Formation) to a continental sequence (Benin Formation). These three sedimentary environments, typical of most deltaic environments, extend across the whole delta and ranges in age from Early Tertiary to Recent.

3.1 Akata Formation

The Akata Formation is found at the base of the delta and is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep waters) and minor amount of clay and silt with thickness of over 4000 ft [17]. The Formation is of marine origin and forms the basal major time transgressive lithological unit in the Niger Delta. As concluded by [34], the Akata shale was deposited under anoxic conditions on the continental slope in front of the delta where the nutrient supply for planktonic organisms was abundant. The shale is undercompacted, prodeltaic, dark grey, fairly hard, sandy or silty, contains plant remains and some mica. The shale is rich in benthonic and planktic foraminifera [26].

3.2 Agbada Formation

The Agbada Formation overlies the Akata Formation .It occupies an interval of 5,760 ft (1755.6 m) to 9,500 ft (2895.6 m) below derrick-floor, and consists mainly of alternations of sands, sandstones and siltstones. The sandy parts of which constitute the main hydrocarbon reservoirs in the delta oilfields and occurs almost delta-wide beneath the Benin Formation. It becomes younger down-delta. It is of Eocene to Pliocene in age, and was laid-down under a variety of environmental conditions [7], [17].

Lithologically, the Agbada Formation consists of an alternating sequence of sandstones and shales of delta-front, distributary channel and deltaic plain origin. As shown by [33], the alternating sequence of sandstones of the Agbada Formation is said to be the cyclic sequence of marine and fluvial deposits. . Merki [16] indicated a maximum thickness of 4,500 m while [34] gave a range from 2,927- 4,268 m. The Formation is the thickest in the central and coastal swamp depobelts and is referred to as the zone of maximum subsidence and transition from continental to oceanic crust. Agbada Formation is rich in microfauna at the base decreasing upward and thus indicating an increasing rate of deposition in the delta front. Texturally, sandstones of this Formation range from coarse to fine grained. The coarsest and most poorly sorted sand are found within the high-energy fluvial sand estuarine channels while the fine-medium grained and moderately well sorted are found in the tidal channel sands. The sandstones are composed mainly of quartz with subordinate K-feldspar and minor plagioclase. Heavy minerals usually occur in trace amounts, bioclasts and carbonaceous debris are locally abundant. The age of the Agbada formation ranges from Eocene to Recent [1].

3.3 Benin Formation

The Benin Formation is the topmost lithostratigraphic units of the Niger Delta Basin. It has been described as "Coastal Plain Sands" which outcrop in Benin, Onitsha and Owerri

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provinces and somewhere else in the delta area [25]. It is made up of massive continental sands and gravels deposited in an upper deltaic plain environment either as point bars by braided streams or channel fills on natural levees following southward shift of deltaic deposition into new depobelts. The thickness of the Formation ranges from 0-2100 m [26].

Mineralogically, the sandstones consist dominantly of quartz and potash feldspar and minor amounts of plagioclase. The sandstones constitute 70 to 100 % of the formation. This Formation is partly marine, partly deltaic, partly estuarine and partly lagoonal or lay down in a continental upper deltaic environment [26], [25]. The Formation attains a maximum thickness of 1,970 metres at the Warri – Degema area, which coincides with that (i.e. depocentre) of the Agbada Formation. The formation thins basinward and ends near the shelf edge. The top of the Formation is the recent subaerially-exposed delta top surface and its base extends to a depth of 4600 feet. The base is defined by the youngest marine shale. Shallow parts of the Formation are composed entirely of non-marine sand deposited in alluvial or upper coastal plain environments during progradation of the delta [10]. The age of the formation varies from Oligocene (or earlier) to Recent.

4 METHODOLOGY

The data set used for this work contains the following:

- A composite log of six wells, namely: Edijalo 001, Edijalo 002, Edijalo 003, Edijalo 005, Edijalo 025 and Edijalo 048 including, Gamma ray, Resistivity, Sonic and density logs.
- A 3-D seismic survey.
- A checkshot data

Schlumberger's Petrel™ 2009 software and OpendTect 4.2.0 software were used in the interpretation of data in this field (Edijalo field). PETREL ™ software is designed to visualize the inputed well logs in a pictorial form, correlate wells with geology, perform seismic interpretation i.e. horizon and fault mapping, 3D reservoir modeling, etc. Well correlation was done using Petrel ™ 2009 software. This was carried out by importing well data which comprises of the coordinates of wells, depth and different log types in ASCII format. After displaying logs, well tops were inserted, and these tops are correlated from well to well across the field. The correlated tops are later called horizons when posted and mapped on 3D seismic.

Checkshots (that gives the time-depth relationship) were imported to calibrate the seismic to time in order to ascertain that the tops picked on wells are the actual seismic events mapped as horizon in time.

OpendTect 4.6.0 software is designed for seismic interpretation i.e. faults and horizons interpretations, to reveal the areas of probable accumulation of hydrocarbon, delineate channels and show subtle faults. The well data were imported into the software then the seismic data which was in the SEG-Y data format was imported into the software. Faults were mapped on the in-lines. The horizons interpretation was done first on coarse grids and then finer grids in order to minimize errors of mistie. These horizons were then subjected to spectral decomposition. Before the mapped horizons were subjected to spectral decomposition, the amplitude spectrum of each of the horizon was displayed so as to extract the high (blue), medium (green) and low (red) frequencies. These frequencies were used in the spectral decomposition analysis of the mapped horizons using Fast Fourier Transform (FFT) algorithm at different time gates. The time gate refers to how far below or above a mapped horizon do you want to view using the spectral decomposition tool. Another algorithm used is the Continuous Wavelet Transform using the Morlet wavelet.

5 RESULTS AND DISCUSSIONS

Three wells namely, Edijalo 003, Edijalo 005 and Edijalo 048 were correlated in the study area because these are the well containing essential logs (Gamma ray, resistivity, density, sonic, etc). Others that are not used are lacking in either one or more of these important logs. The correlation was done to establish the lateral relationships and continuity of the hydrocarbon reservoirs.

Three hydrocarbon reservoirs were correlated. Gamma ray logs (and SP log) and Resistivity logs were used to pick the hydrocarbon bearing reservoirs across. The gamma ray log was used to determine the sand and shale units while the resistivity log was used to establish the presence of hydrocarbon zone in the sand unit based on high resistivity reading. The correlated wells are shown in Figure 3.

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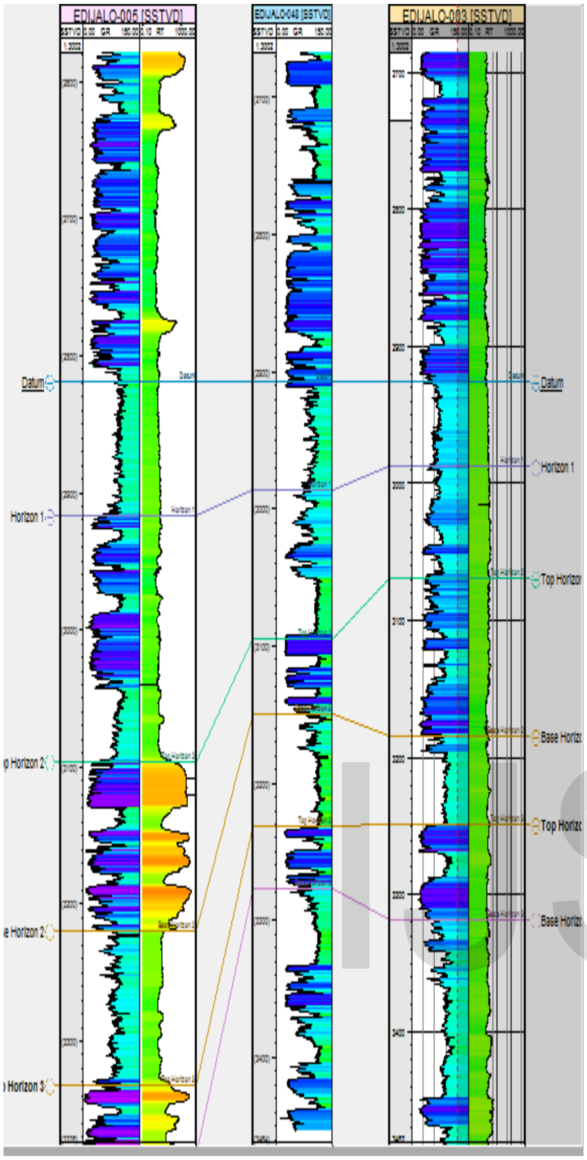

Figure 3: Well correlation panel for wells Edijalo 005, Edijalo 048 and Edijalo 003

Ten faults (Faults A-J) were mapped across the survey area. The faults were picked on coarse grids of every 20 lines on inlines, and later on every 5 lines (fine grid) to ensure the continuity of faults and to achieve good result. Some of the mapped faults are displayed on Figure 4.

Three horizons were mapped on the seismic section using OpendTect software. The first horizon is however too shallow and was therefore discarded and not used for spectral decomposition purposes. Horizons 2 and 3 (suspected hydrocarbon layers) were mapped. The practice employed for horizon mapping also follows the same pattern as that of fault mapping. These mapped horizons were subjected to spectral decomposition analysis.

5.1 Spectral Decomposition as a DHI tool

The results of the spectral decomposition on Horizon 2 using the FFT and the CWT are as shown below. Frequencies are extracted from the amplitude spectrum. These frequencies represent the frequency range of the seismic data used for this project. Also, the frequencies are important because they are used in the spectral decomposition analysis especially using the FFT algorithm. The frequencies used are 21Hz, 25Hz and 28Hz corresponding to low, medium and high respectively. Three horizons that represent top of reservoirs as seen from well correlation were mapped. However, the first Horizon (blue) appears to be too shallow and cannot be a suitable reservoir. It is therefore discarded and will not be discussed as far as spectral decomposition is concerned. The mapped horizons with some major faults are as shown in the Figure 4.

The mapped Horizon 2 prior to spectral decomposition analysis, with little or no structure on it is shown in Figure 5. At the highest frequency (28 Hz), blue, the bright spot at the Southeastern part is beginning to appear but not very obvious. However, from the medium to low frequency, the bright spot can be seen well (Figures 6 to 10).

When the three colours are combined, we have the RGB blend (Figure 11). This can be observed on the two algorithms (FFT and CWT). This RGB will make the bright spot very clear especially on the CWT that shows hydrocarbon attenuation effect. This can be observed in the figures below.

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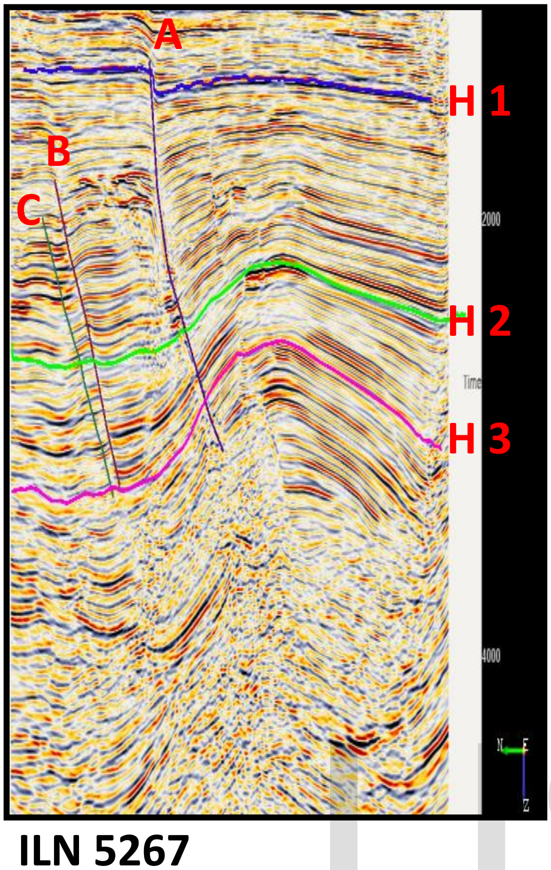

Figure 4: Seismic section showing mapped horizons and some interpreted faults. A,B,C are Faults A,B and C respectively while H1, H2 and H3 are Horizons 1, 2 and 3 respectively.

It is important to note that on the FFT RGB colour blend, the white colours indicate sands, whereas the dark colours indicate shale as we have it in the Niger Delta. Therefore the analysis shows the distribution of sand in the field. It is convenient to say that we have more sand distributed in the southeastern and central parts of the field than any other part.

As earlier explained, time gate is a measure of how far above and below your target horizon (reservoir) do you want to view? This is important and must be determined. Also, since most horizons represent formation tops the time gate should be defined mainly below the horizon.

Figures 12 and 13 show the effect of choosing a correct time gate. Note that for positive (+), one is viewing above the reservoir and negative (-) is for below the reservoir. Therefore +28-28 ms time gate simply means 28 ms above the reservoir and 28 ms below the reservoir respectively. The output is going to be the 'average' of geological features seen by the spectral decomposition analysis time gate of +28-28 ms.

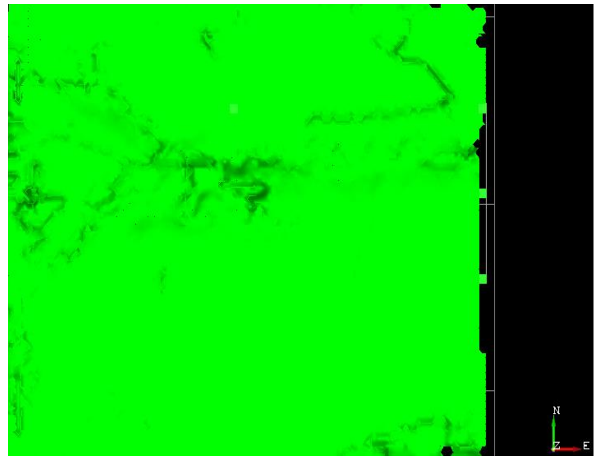

Figure 5: Mapped Horizon 2, with no structure shown on it prior to spectral decomposition analysis

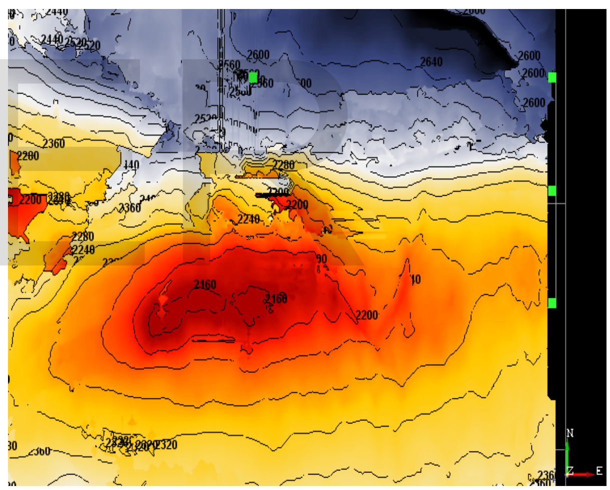

Figure 6: Structure map of Horizon 2 revealing the presence of a trap (closure)

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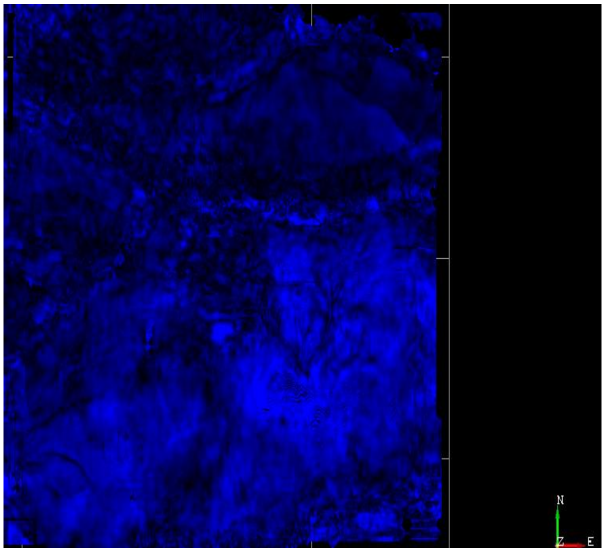

Figure 7: Spectral Decomposition Analysis map of Horizon 2 at high frequency 28 Hz

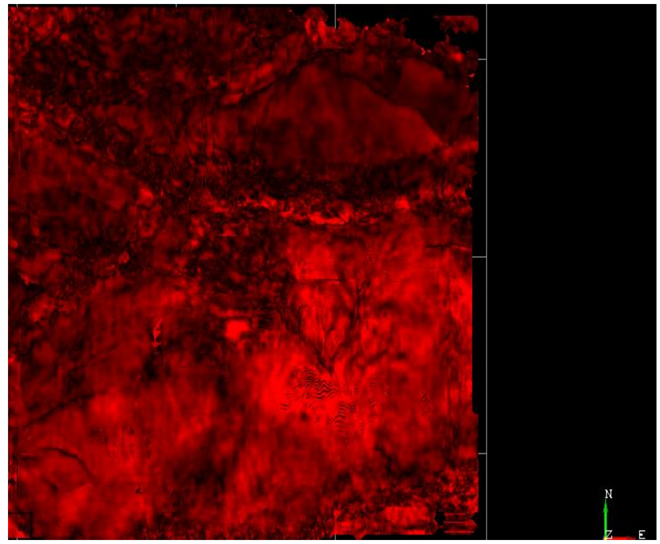

Figure 9: Spectral Decomposition analysis map of Horizon 2 at low frequency 21 Hz

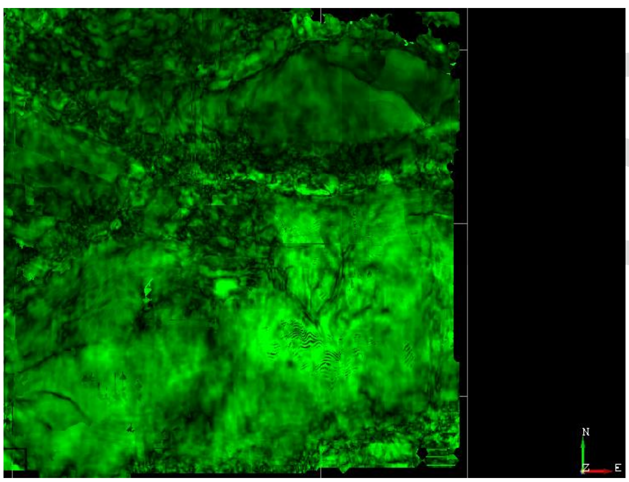

Figure 8: Spectral Decomposition Analysis map of Horizon 2 at mid frequency 25 Hz

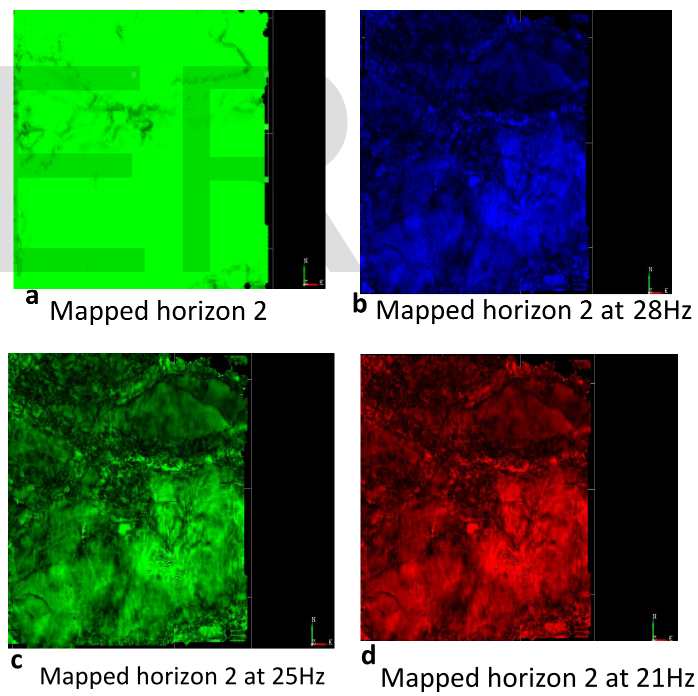

Figure 10: Combining the three frequencies of the Spectral Decomposition Analysis. (a) shows the mapped horizon prior to spectral decomposition, (b)–(d) show responses after spectral decomposition at 28 Hz, 25 Hz and 21 Hz

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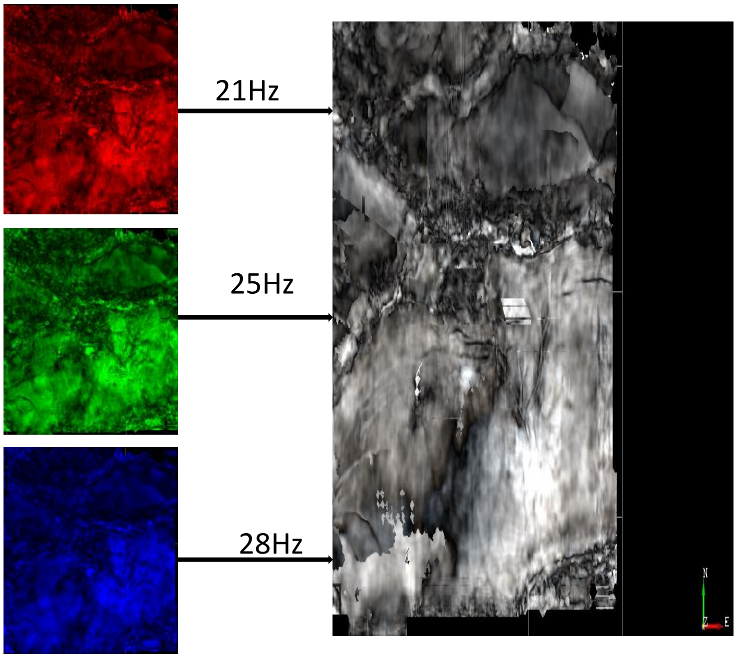

Figure 11: RGB blend of the three frequencies at -28+5ms time gate using FFT of the Spectral Decomposition Analysis. A bright response is represented by white. The colours are additively combined to produce the full-spectrum image shown.

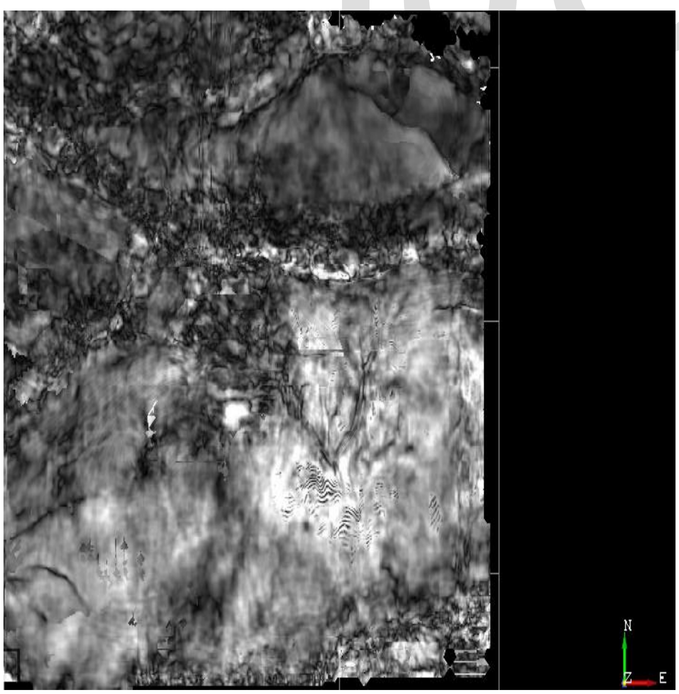

Figure 12: Spectral Decomposition Analysis map using FFT at -28+28ms time gate

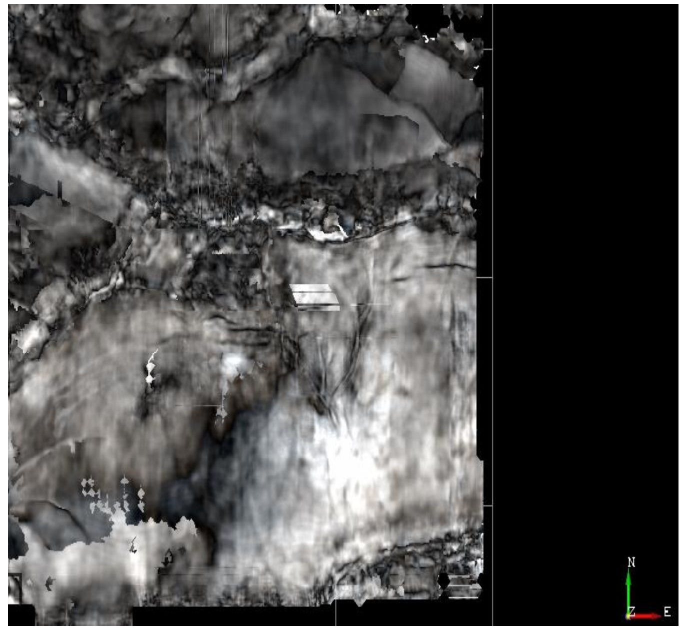

Figure 13: Spectral Decomposition Analysis map using FFT at -28+5ms time gate

The time gate used in figure 13, reveals more features than the one in figure 12. This is an importance of having the right time gate.

The CWT algorithm, being a wavelet based method, does not use time gate. Instead, it uses a specified wavelet. The Morlet wavelet was used in this case. This is because Morlet wavelet approximates the wavelet of the seismic.

It is used to determine hydrocarbon attenuation effects. Sometimes, seismic data analysts observe low frequency shadows in association with hydrocarbon reservoirs. The shadow is probably caused by attenuation of high-frequency energy in the reservoir itself [9], [18], such that the local dominant frequency moves toward the low-frequency range. Thus, anomalous low frequency energy is concentrated at or beneath the reservoir level [28]. Noting this, on the CWT RGB, the bright colour indicates the hydrocarbon accumulation.
The RGB blend of CWT is also presented in Figure 14 below.

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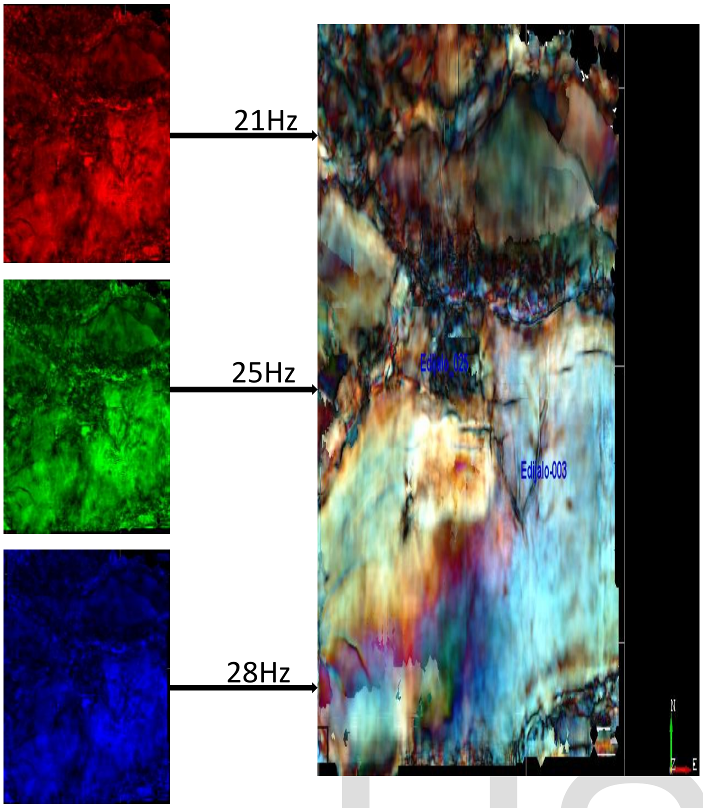

Figure 14: RGB blend of the three frequencies using CWT of the Spectral Decomposition Analysis. A bright response is represented by white. The colours are additively combined to produce the full-spectrum image shown.

Figure 15 gives a very vivid picture of the importance and use of the CWT.

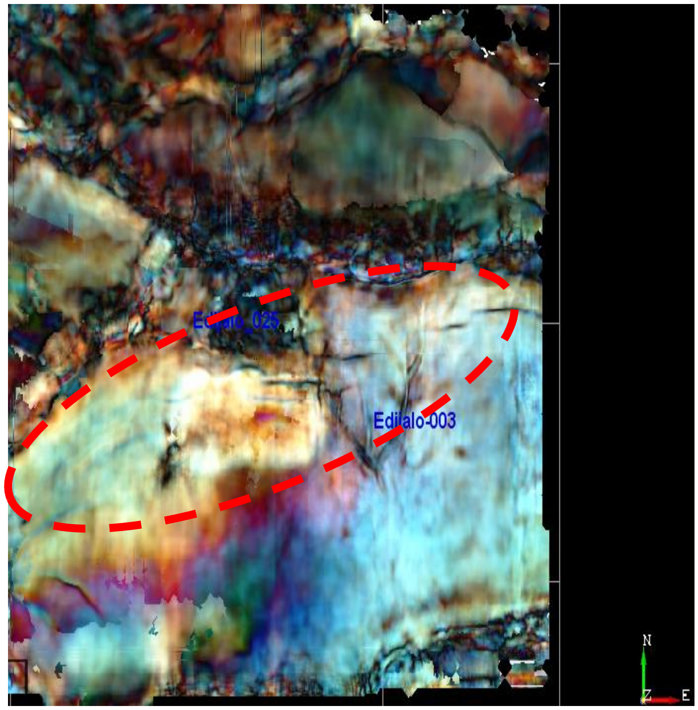

Figure 15: Spectral Decomposition Analysis map using CWT (Morlet wavelet). Red oval indicating a bright spot

Note that the wells did not exactly fall on the predicted hydrocarbon accumulation areas. Much comment cannot be made on how productive these wells are because no data was given on this regard. So, with this research, the wells would have been better placed for optimal production.

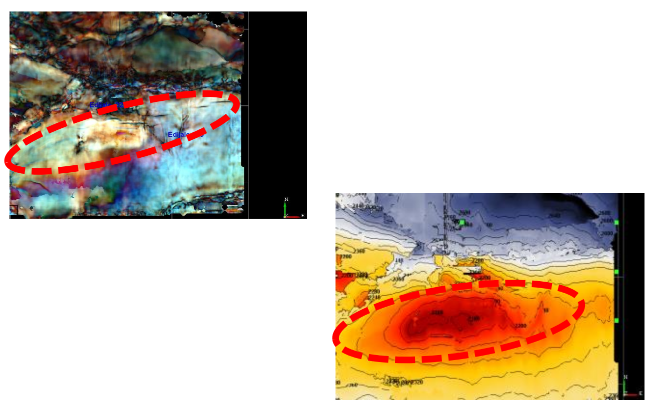

Figure 16: Comparing trap on structure map with trap identified from spectral decomposition analysis

The figure 16 above compares the position of the bright spot detected by spectral decomposition to the structural closure

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on the mapped horizon. And expectedly, as the closure shows the presence of trap, the bright spot shows the presence of fluid.

Clearly, from figure 16, the area filled by fluid in the corresponding structure can be viewed with ease. The import of this is that, the area in the trap containing more hydrocarbon is already isolated. This isolated area could now be targeted by drillers and wells will be optimally placed for maximum recovery. In this case, spectral decomposition serves as a well planning tool.

The third horizon also shows what have been discussed using Horizon 2. It must be stressed here as observed in the course of this work that due to relative positions of Horizons 2 and 3 on the seismic, Horizon 3 shows similar features compared to Horizon 2 while extracting above Horizon 3 (using positive time gate). These similarities in features however disappear while viewing below the Horizon 3 (on negative time gate). This claim is as shown in the Figures 17 to 21.

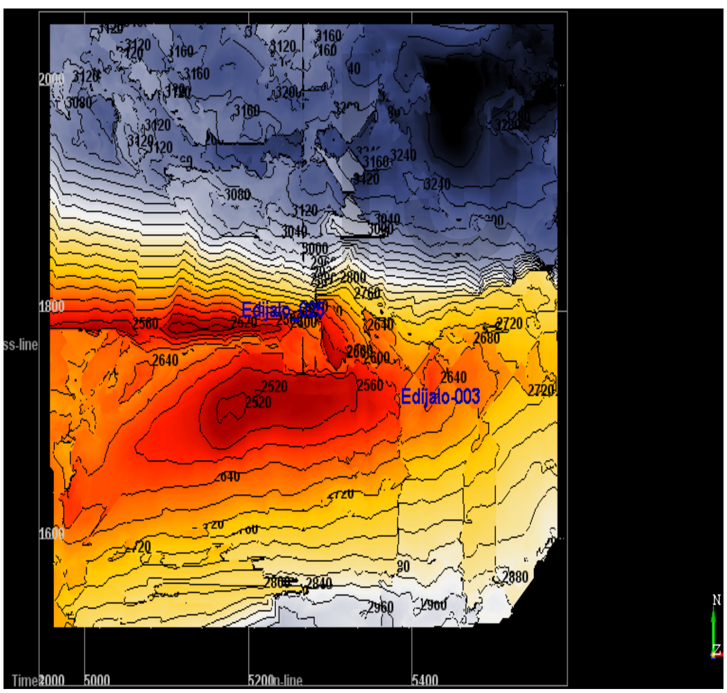

Figure 17: Structure map of horizon 3 revealing the presence of a trap (closure)

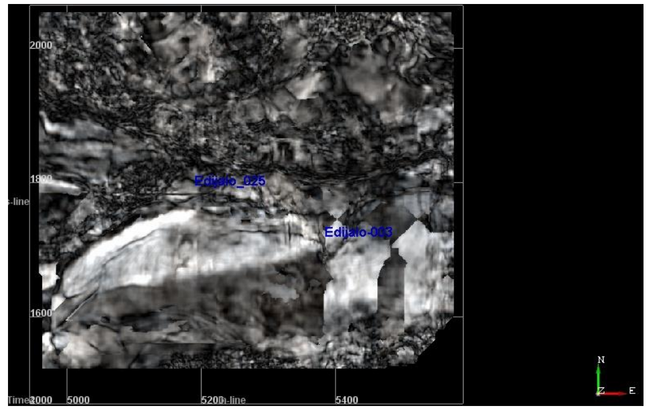

Figure 18: Horizon 3 using the FFT at -5+28 time gate. This clearly shows the structure and agrees with the structural map in figure 17.

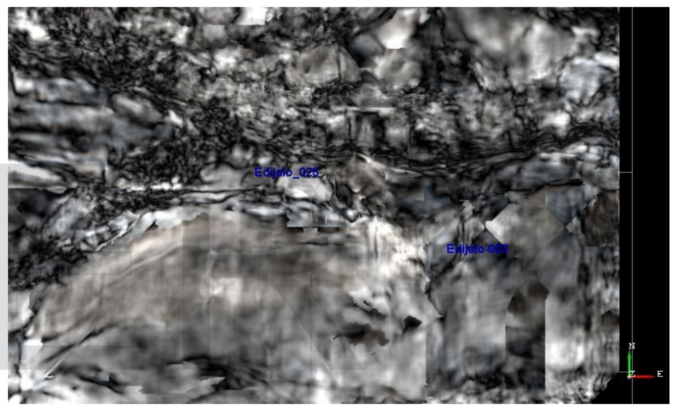

Figure 19: Horizon 3 using the FFT at -28+5 ms time gate. The structure almost disappears at 28ms below Horizon 3

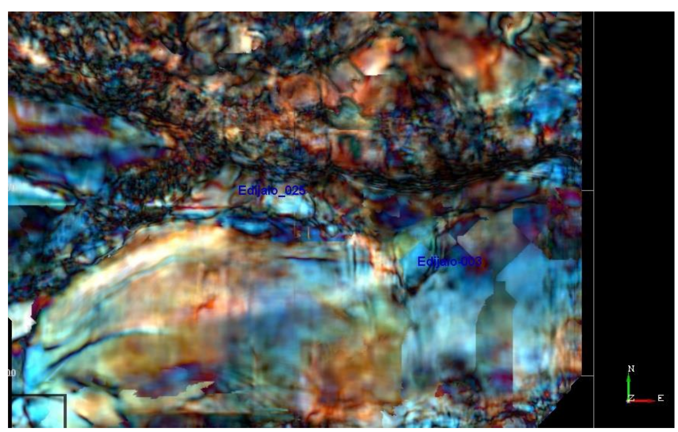

Figure 20: Horizon 3 using CWT. Bright spot conforming with structure. This is indicative of hydrocarbon attenuation on Horizon 3.

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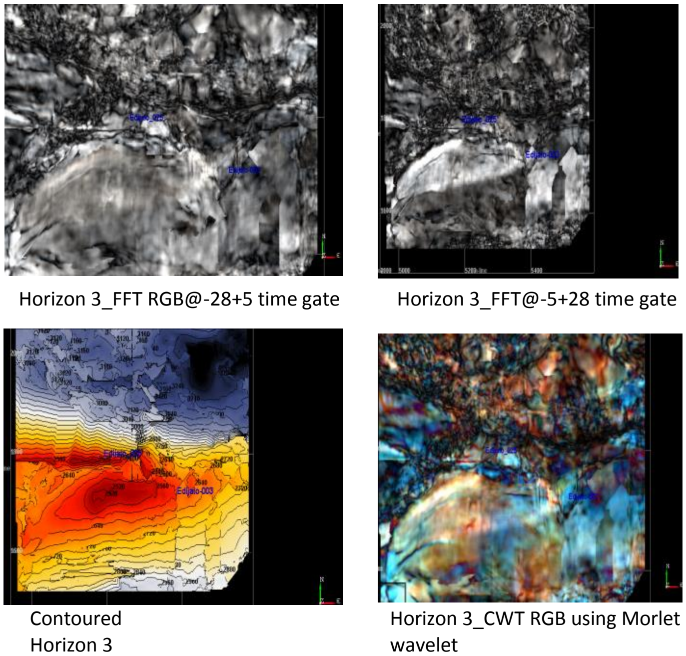

Figure 21: Obtained maps from horizon 3 for ease of comparison. These maps compare very well with those of horizon 2 previously shown.

5.2 Spectral Decomposition as a Fault Detection Tool

It is a common practice by seismic interpreters to accurately map the extent and orientation of structures like faults in a 3D broadband seismic data. These faults serve as traps or seals on both local and regional basis.

However, some faults are so subtle and may be of low angle, and so may be below seismic resolution. These possess serious problems in petroleum exploration, development and production. Example of such problems is reservoir compartmentalization. Thus, it is very important to know the trends and relationships of faults in a field.

In the study area, series of faults are mapped. Faults A, B and C (Figure 22) are examples of the mapped faults. Some are local whereas few are regional. However, some cannot even be picked due to data quality while others are below resolution (Figures 23 and 24). But when spectral decomposition is applied, even the much 'hidden' faults became very obvious. So, these 'unseen' faults are shown in the Figure 24.

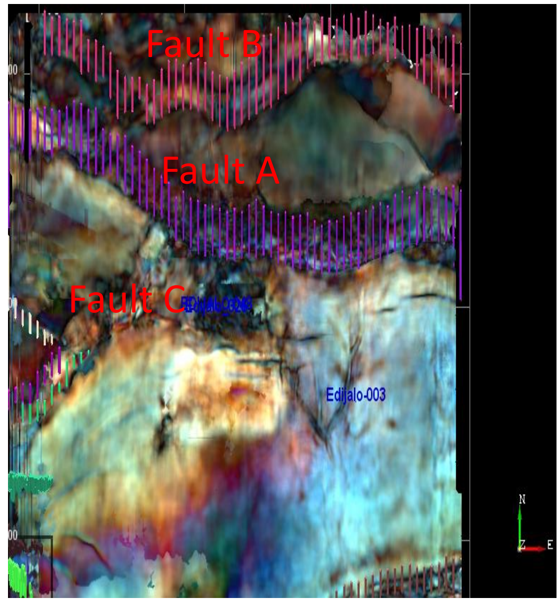

Figure 22: Mapped faults as seen on seismic. Faults A,B and C are major faults

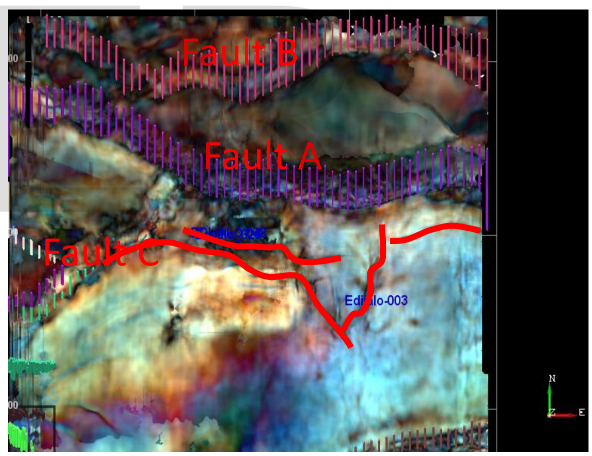

Figure 23: Mapped faults and unmapped faults. Red lines are very subtle faults not seen on seismic but picked by spectral decomposition.

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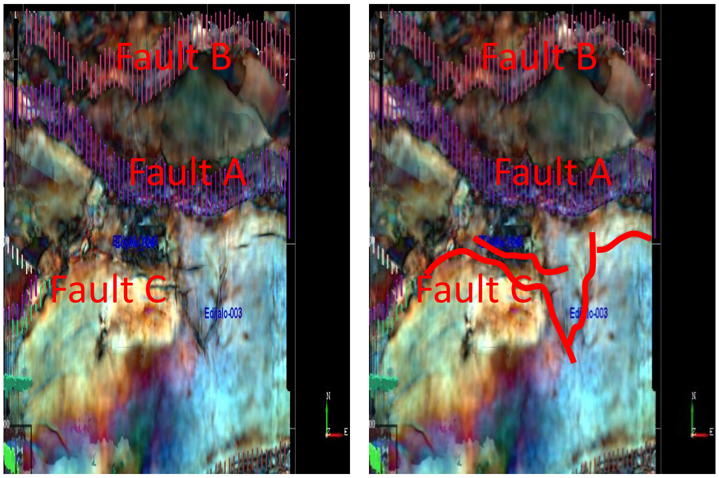

Figure 24: Fault detection use of Spectral Decomposition. The picture on the left shows faults mapped on seismic while the one on the right shows detected fault by spectral decomposition

6 Conclusions

As earlier said, spectral decomposition is an imaging innovation that provides interpreters with high-resolution reservoir detail for imaging and mapping temporal bed thickness and geological discontinuities within 3D seismic surveys by breaking down the seismic signal into its component frequencies. This study on the use of spectral decomposition of seismic in identifying traps data has yielded some results. Two horizons are mapped in probable hydrocarbon prone areas. The horizons are subjected to spectral decomposition algorithms of FFT and CWT.

The results show spectral decomposition analysis can be used

i. as a DHI tool to recognize where hydrocarbon is accumulated in a particular horizon
ii. to predict the sand distribution. The overall import of this is for optimum well planning for maximum recovery.
iii. in imaging structures such as faults and (channels if present) that are below seismic resolution.
iv. to further understand reservoir fluid distribution.

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