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THE APPLICATION OF SHORT –TIME FOURIER TRANSFORM AND DISCRETE FOURIER TRANSFORM IN MAPPING STRATIGRAPHIC FEATURES IN TMB FIELD, NIGER DELTA.

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ABSTRACT

This research focuses on mapping hidden stratigraphic features on a 3D seismic data with approaches better than direct/commercial approach. Materials used in this research are seismic data, well logs, checkshot and base map of the study area. The approach used is the Short Time Fourier Transform (STFT) programmed into MATLAB and Suffer-8 Software and algorithm used is based on Fast Fourier Transform (FFT). A reservoir window/ sand interval identified on well logs in depth were converted to time (frequency) using checkshot at 4ms decomposed with STFT and Discrete Fourier Transform (DFT). Results showed sand interval extracted in time and seismic amplitude sliced at 4ms and 10 slices obtained – a time slice before the top sand interval (2.440sec) and below the base sand interval (2.468 sec). The original seismic magnitude and phase plotted for the top sand top (2.440 sec) was transformed using the DFT and STFT which determined the domain frequency in terms of seismic attributes, magnitude and frequency. Identified lithologies in the studied section across the wells are sand, sandy shale and shale. A subtle stratigraphic feature – Channels has been identified. The time slice interval of 2.436 – 2.472 sec, showed variations in amplitude properties with depth suggesting changes in formation fluid and sequence boundary. Resolving hidden stratigraphic features on seismic data require high frequency enabled tuning and has been achieved with the STFT and DFT. Frequency maps (slices), the reservoir window identified with the STFT approach gave localized stratigraphic feature, better results compared with DFT and time domain.

Key Words: Short Time Fourier Transform, Discrete Fourier Transform and Hidden stratigraphic features

INTRODUCTION

Seismic signal transformation is an approach to enhancing seismic visibility through change of seismic data outlook from standard amplitude measurement (seismic domain) to a new (transform) domain using seismic compatible and efficient mathematical transform, such as Fourier transform and Hilbert transform. This is to separate fact from artefact and accurately deduce vital rock-fluid information from the data (Ofuyah *et al*, 2014). Signals are transformed into their sinusoidal parts with the application of Fourier analysis based on the hypothesis that the frequency is stationary with time, (Robertson and Nogami, 1984). Fourier transform gives room for understanding average component of an acceptable degree of large section of trace and does not

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normally allows scrutiny of local changes or differences (Taner *et al*, 1979). This is because; the convolution of a source wavelet with an arbitrary geologic series of wide window engenders an amplitude spectrum that resembles the wavelet. A narrow window or Short Time Fourier Transform (STFT) can be used to obtain a wavelet overprint that reflects the local acoustic properties and thickness of the subsurface layers. The objectives of seismic processing include improved resolution, improved visualization of structural and stratigraphic characteristics, thin- bed reservoir thickness estimation, noise filtering or suppression and direct designation of hydrocarbons. (Ofuyah *et al*, 2014). The generally known seismic interpretation involves direct mapping of the fault and horizon, stratigraphic sequence, fundamental spectral analysis and seismic modelling to generate structural, stratigraphic and reservoir maps for the delineation, exploitation and generation of hydrocarbons in an oil and gas field. This results in interpretative ambiguities due to poor seismic data resolution, inadequate display of final stacks, rough processing and inadequate calibration (Ofuyah *et al,* 2014). The quality of the resolution and clarity of the attainable seismic traces depends on the presence of high frequencies and a fairly wide seismic signal bandwidth (Dobrin and Savit, 1988). Traditional seismic data does not solve subtle geological attributes, as it is band- limited. To improve resolution, seismic source parameters such as wavelet type and frequency bandwidth defining detection and imaging capabilities should be considered (Okaya, 1995).A typical geologic feature's wavelength bandwidth is 0 - 1000Hz or higher while the common seismic bandwidth is 15-65Hz in the vertical direction. Although field procedures and data processing can recover moderately high frequency components, low frequency information below 10Hz associated with stratigraphy and high frequencies greater than 100 Hz in well data are vital for detailed interpretation, are absent from the seismic trace. In some formations such as gas sands and oil reservoirs anomalies directly underneath them are associated with low frequencies (Sheriff, 1973). Spectral decomposition techniques provide enhanced frequency resolution; the concept behind spectral decomposition is that a reflection from a thin bed has characteristic expression in the frequency domain that is indicative of temporal bed thickness (Amplitude Spectra) (Partyka *et al*, 1999). In general, enhanced time transformation via calibration in time-domain recovers lost details in the standard seismic response, while in time- frequency transformation (spectral decomposition using Fast Fourier Transform convolution techniques) detects hidden stratigraphic information and subtle anomalies within a specific horizon that could be increased. The goals in stratigraphic exploration theory are deep seated features associated with low frequencies. Besides, there is also minimal research about the use of high-resolutionspectral methods to resolve seismic signal issues in Niger Delta Nigeria because ithas not been quite well discussed and publicized (Ofuyah *et al,* 2015). Though the current commercial interpretation methodologies and computer programs represented in the computer software of the oil and gas sector are still certainly good, they are dependable when geological conditions are advantageous and have to be strengthened for accurate delineation and characterization of the reservoir. This is particularly necessary to improve the success ratio of field appraisal and identify potential exploration projects. There is therefore the need for ahigh-resolution and innovative technique for rapid, accurate and optimal interpretation of 3-D seismic data. In this study, the spectral decomposition method using a Windowed or Short-Time and Discrete Fourier Transform is used in analysing seismic data from the Niger Delta in other to delineate subsurface stratigraphy. The geology, structural geology, biostratigraphy, stratigraphy, sedimentology, petroleum geology and reservoir studies of the Niger Delta has been carried out by Reijers *et al* (1997), Oomkens (1974), Burke (1972), Doust and Omatsola (1990), Short and Stauble (1967), Avbovbo (1978), Evamy *et al*(1978), Kulke (1995), Ejedawe *et al* (1984), Lehner and Ruiter, (1977), Ekweozor and Daukoru (1994), Omoboriowo *et al* (2012), Ideozu *et al* (2015), Raphael and Richmond (2016), Ideozu and Bassey(2017)**,** Awe and Ideozu (2017), Iheaturu and Ideozu (2017),Ideozu *et al* (2018), Ejieh and Ideozu (2018), Toba*et al* (2018) and Ndokwu*et al* (2019)(Figures 1 – 3). This research involves the transform of 3-D seismic data of Niger Delta, thereby enhancing the wavelet in other to map stratigraphic features. The aim of this research is to apply spectral decomposition (DFT and STFT) to mapping stratigraphic features in TMB Field, Niger Delta and d the objectives are as follows: Identify sand intervals in depth on the plotted well log with the aid of Gamma ray and Resistivity log, Convert depth interval into time interval with the aid of check shot, Extract time interval from the seismic data volume in the study area and transform the seismic signal from seismic (time) domain to transform (frequency) domain, Extract viable diagnostic attributes from the transform coefficients, which could be used to map subsurface stratigraphy, and estimate its variables such as lithology, fluid content, connectivity, etc. Use the extracted attributes to identify and map hydrocarbon reservoir by determining its most probable location and dimension of the stratigraphic features and analyse and interpret the constituent seismic facie maps and their local variations and areal association. The scope of this research is limited to Developing Discrete and Short-Time Fourier Transform algorithm for high-resolution of the 3-D seismic data volumes interpretation and the application of the developed transform technique to the seismic data analysis of TMB Field, Niger delta.

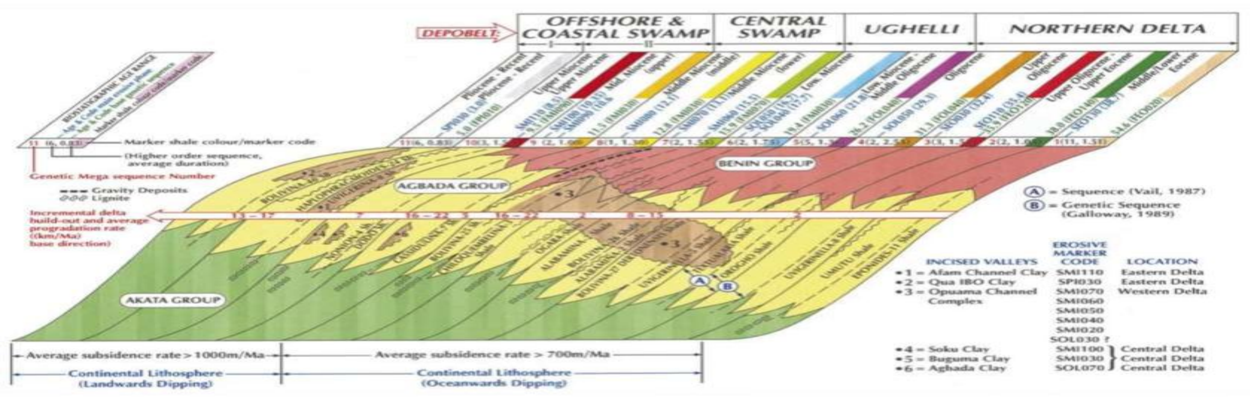

Figure 1 Diagrammatic reflection of the Niger Delta's stratigraphic development (After Reijers, 2011).

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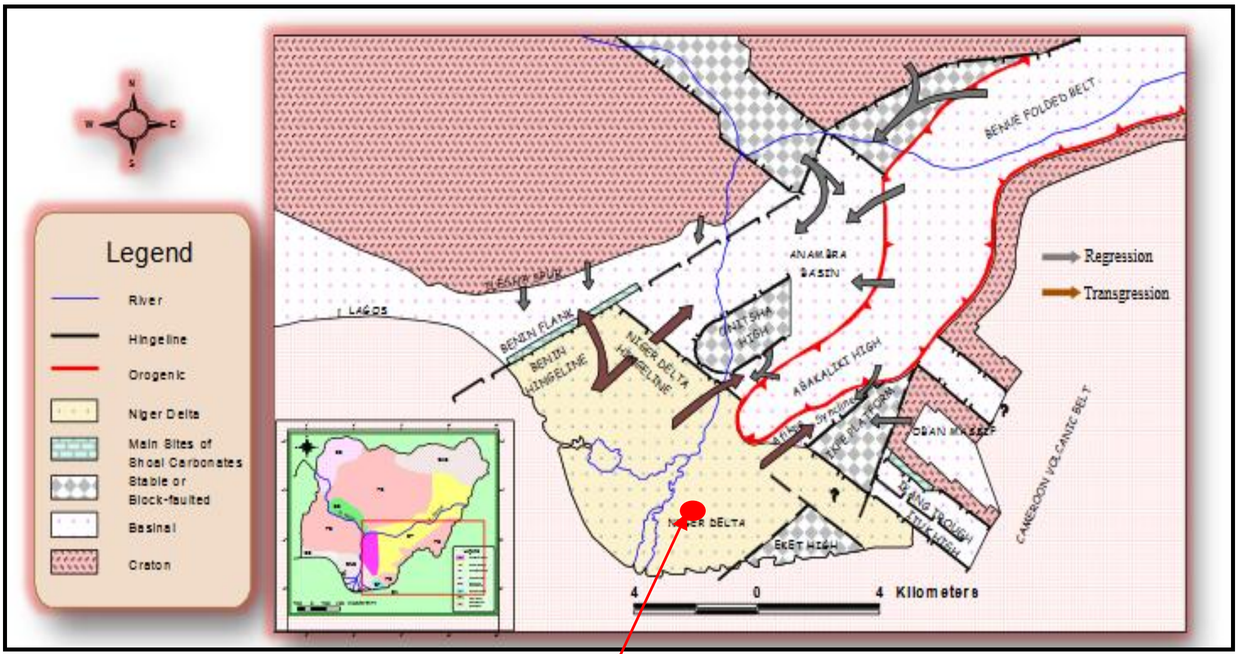
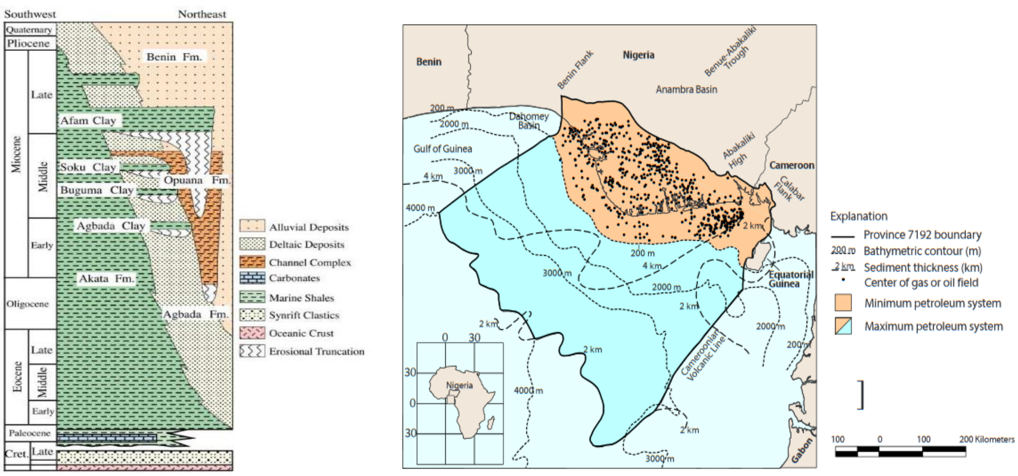


Figure 2 Niger Delta Tectonic Map (Modified after Kogbe, 1989).



(a) (b)

Figure 3 (a) Stratigraphic column depicting the three Niger Delta formations (modified from Lawrence *et al*., 2002).(b) Cameroon and Nigeria Index Map. Niger Delta Map showing Province outline (petroleum system) and bounding structural features (Petroconsultants, 1996).

MATERIALS AND METHODS

Materials

The materials used for this research comprises of the following: Seismic Amplitude Data, Well Log Suites, Base Map of Field and Check Shot Data. Workstation and MATLAB software was used for the analysis of the data used in this research.

Methods

The methods adopted in this research are;

Discrete Fourier Transform (DFT): The DFT technique is the digital correspondent of the continuous Fourier transform and is expressed as

$$f(w)= \sum_{t=-\infty}^{w-\infty} f(t)\exp(-iwt) \qquad 1$$

Where, w is the Dual Fourier of the variable't'. If 't' signifies time, then 'w' represents the angular temporal frequency 'f' (Yilmaz, 2001).

Also, f(w) comprises both real ($f_r(w)$) and imaginary ($f_i(w)$) components. Hence,

$$f(w) = f_r(w) + if_i(w) \qquad 2$$

$$A(w) = [f_r^2(w) + f_i^2(w)]^{1/2} \qquad 3$$

$$Ø(w)= \tan^{-1}[f_i(w)/f_r(w)] \qquad 4$$

Where A(w) and Ø(w) are the phase and amplitude spectra respectively (Yilmaz, 2001).

Short Time Fourier Transform (STFT): The STFT or Windowed Fourier transform is an analysis with fixed resolution. It maps to the 2-D frequency-time from a seismogram and is driven by the need for a spectral representation which integrates the time-varying characteristics of a non- stationary signal (Chakraborty and Okaya, 1995). Assuming that the signal f (t) in time-domain seismogram is stationary when viewed via a limited extent g (t) window, centred at the time (T), the STFT can be expressed as:

$$STFT(t, f) = \sum f(t)g*[t-F]\exp(e-jwt) \qquad 5$$

Where 'g(t)'is the function for window, and 'e^{-jwt}' represents Fourier kernel. A 2-D function in a time-frequency plane (t, f) is obtained when the signal is mapped by the transform. The choice of window g(t) is the critical factor for STFT analysis (Chakraborty and Okaya, 1995). The major disadvantage or shortfall of Discrete Fourier Transform is that it gives an average representation and scalar attributes of the frequency behaviour in an entire seismogram with no local concentrations of energy information. This can be enhanced by Short Time Fourier Transform (STFT) application. In practice, the movement of the windows is along the seismogram with an increase in time significantly smaller than the window width. This creates a more resolute F- T transform by finer sampling along the time axis. (Chakraborty and Okaya, 1995). This involves the adoption of convolution methods of Fast Fourier Transform, while the outcome of the seismic analysis will be displayed as seismic facies maps and cross- sections.

RESULTS

The results for this research are displayed in Figures 4 - 12. The data of well log (Gamma Ray, Sonic and Resistivity Logs) of Well 06 of the TMB Oil Field were plotted using Gnuplot (Figure 4). Based on Table 1, a sand interval was identified from depth 6300ft to 6384ft

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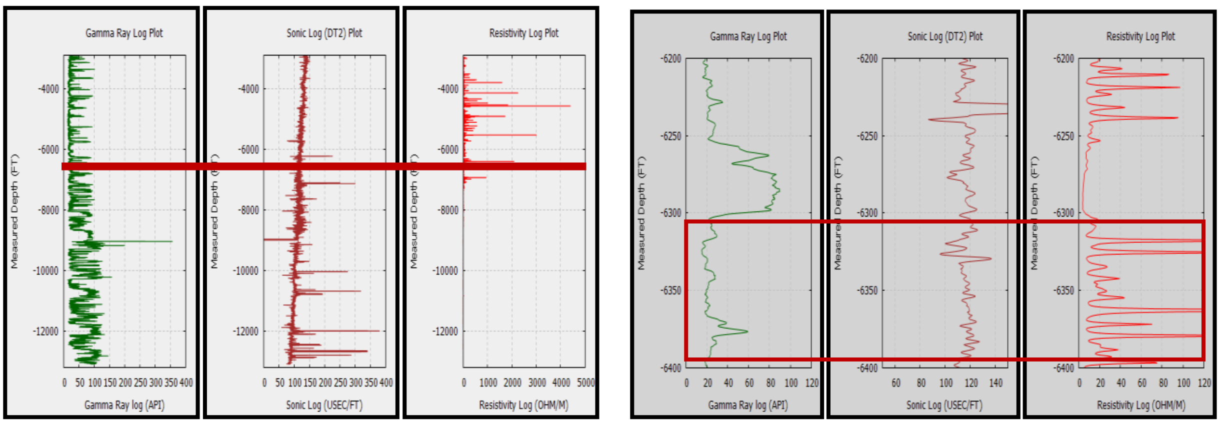
Table 4.1: Summary table of responses by GR and Resistivity logs (Ashish, 1999).

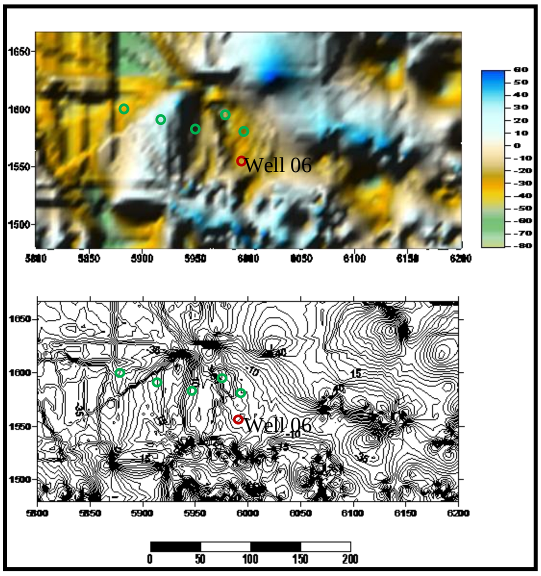
Log Type	Sand	Shaly Sand	Sandy Shale	Shale	Comments
Gamma	Low	Medium	Medium	High	<40 Sand, 40 – 75 Shaly Sand, 75 - 100 Sandy Shale and >100 Shale.
Resistivity	High	Medium	Medium	Low	Dependents on the type of fluid and measure of the fluid resistivity.

hightliighted with a red rectangle across the well logs (Figure 4) and then zoomed in for better examination (Figure 5). The established sand depth interval 6300ft – 6384ft from well log was converted to time (ms) using check shot (Figure 6) which tied in with 2.440sec to 2.468sec. Based on the depth to time conversion, seismic data over the established sand interval (reservoir window) was extracted in time and the seismic amplitude was sliced at a data sampling interval of 4ms. A total of ten (10) time slices were obtained, a time slice before the top of sand interval (2.440sec) and below the base of the sand interval (2.468sec). The time slices are 2.436sec, 2.440sec, 2.444sec, 2.448sec, 2.452sec, 2.456sec, 2.460sec, 2.464sec, 2.468sec and 2.472sec. The horizontal sections of the time slices are displayed to show the sand interval changing with depth (Figure 7). The original seismic magnitude and phase were plot graphically for the sand top (2.440sec) (Figure 4) and then transformed using Discrete Fourier Transform and Short Time Fourier Transform within MATLAB software to determine the dominant frequency (Figure 5). The decomposed data are presented in Figure 6 - 7 and Figure 12 for both DFT and STFT respectively and will be discussed based on the three (3) seismic attributes used in this research - magnitude, phase and frequency. The magnitude shows sequence boundary over the window, phase shows discontinuity/continuity while frequency indicates lithology with low frequency indicating sand and high frequency indicating shale.

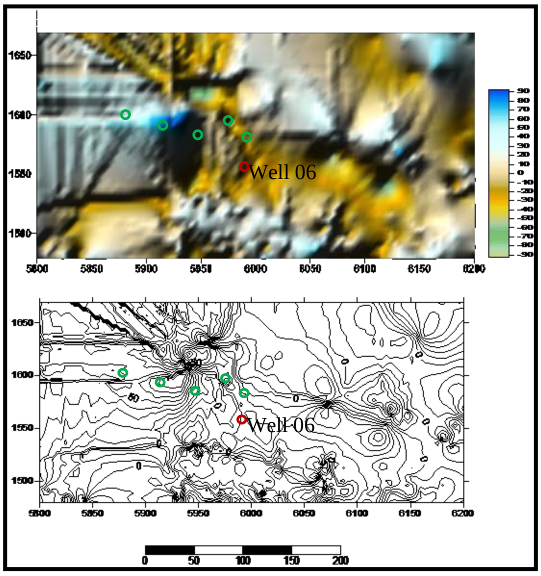


a b

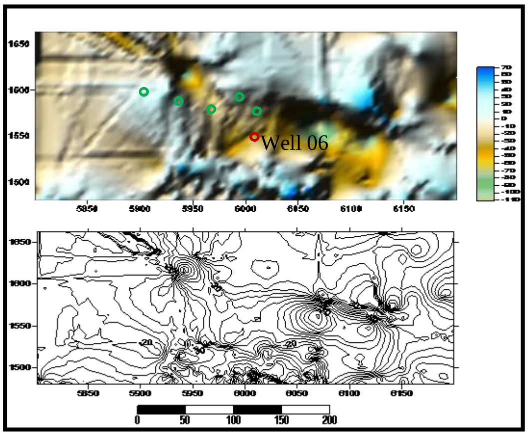
Figure 4 (a) Plot of whole Gamma Ray, Sonic, and Resistivity data respectively for Well 06 with red rectangle across showing the sand interval established. (b) Plot of Gamma Ray, Sonic and Resistivity data respectivelyplotted for some parts of the dataset for Well 06 with the red rectangle across showing the sand with depth interval 6300 – 6384ft.



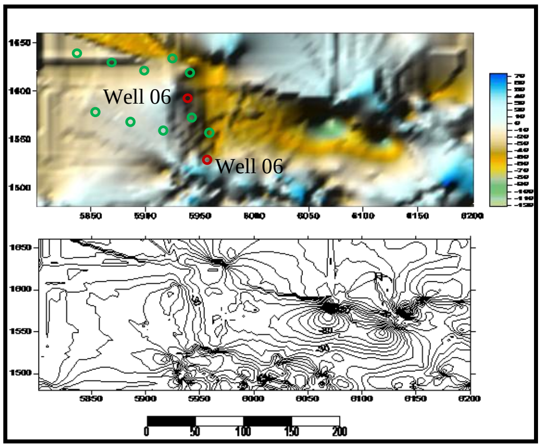
(a) Time Slice (Amplitude) at 2.436sec.



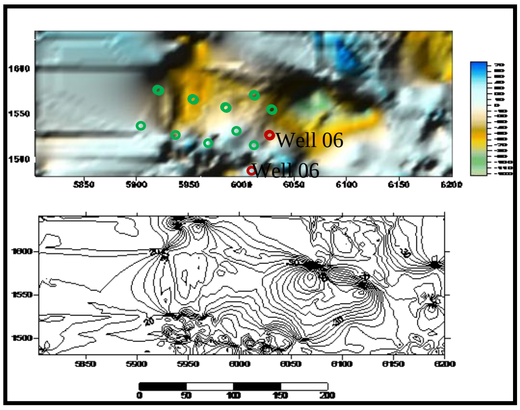
(b) Time Slice (Amplitude) at 2.440sec.



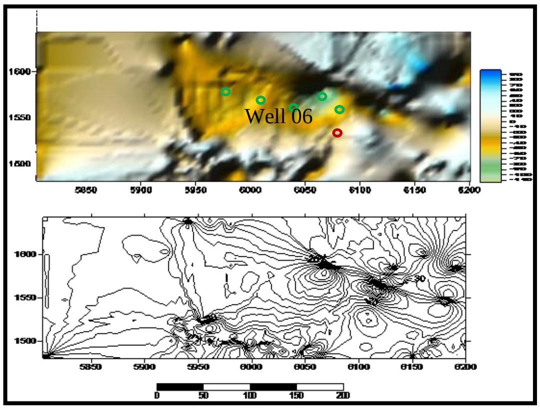
(c) Time Slice (Amplitude) at 2.444sec.



(d) Time Slice (Amplitude) at 2.448sec.



(e) Time Slice (Amplitude) at 2.452sec.



(f) Time Slice (Amplitude) at 2.456s

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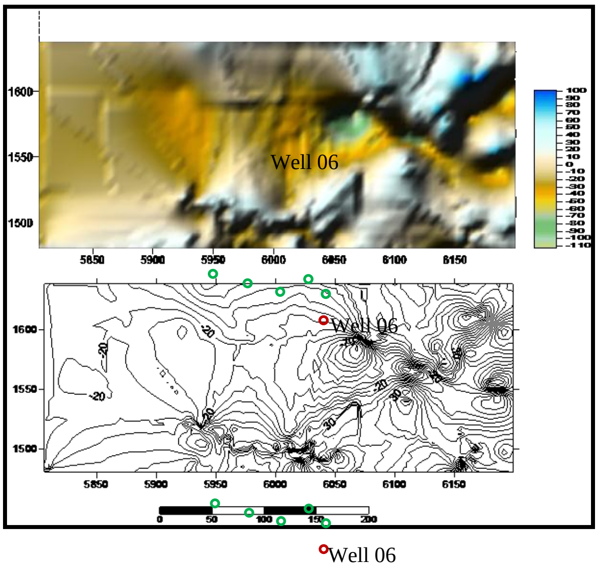
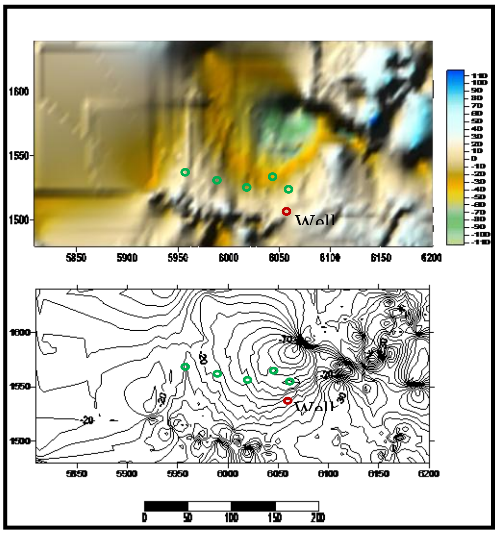
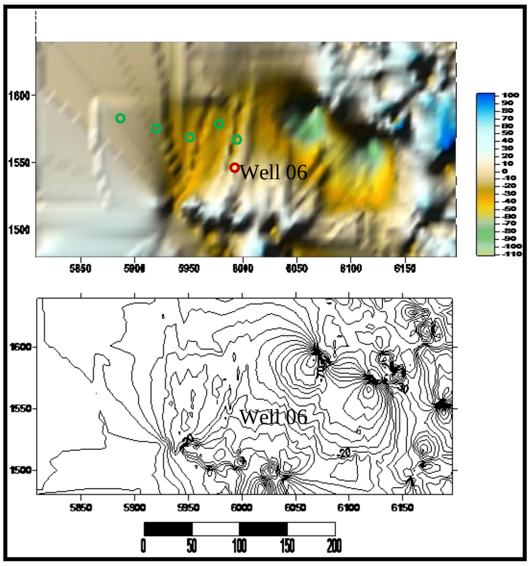
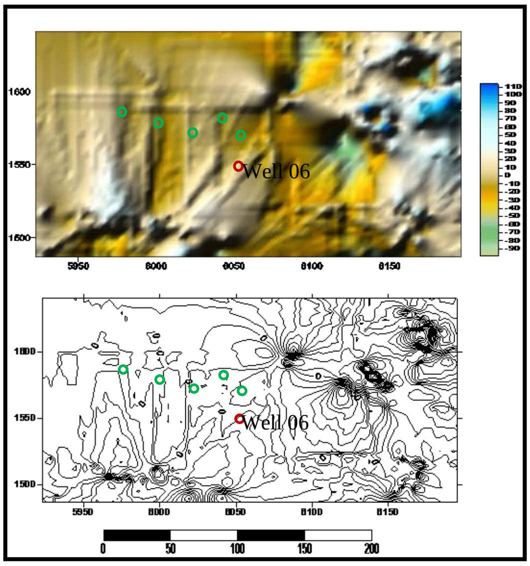


(g)Time Slice (Amplitude) at 2.460sec.



(h) Time Slice (Amplitude) at 2.464sec.





(i) Time Slice (Amplitude) at 2.468sec. (j) Time Slice (Amplitude) at 2.472sec.

Figure 5 Time slices at 4ms sample interval across the selected sand interval showing variation of reservoir character with TWT and red ring signifying well in use.

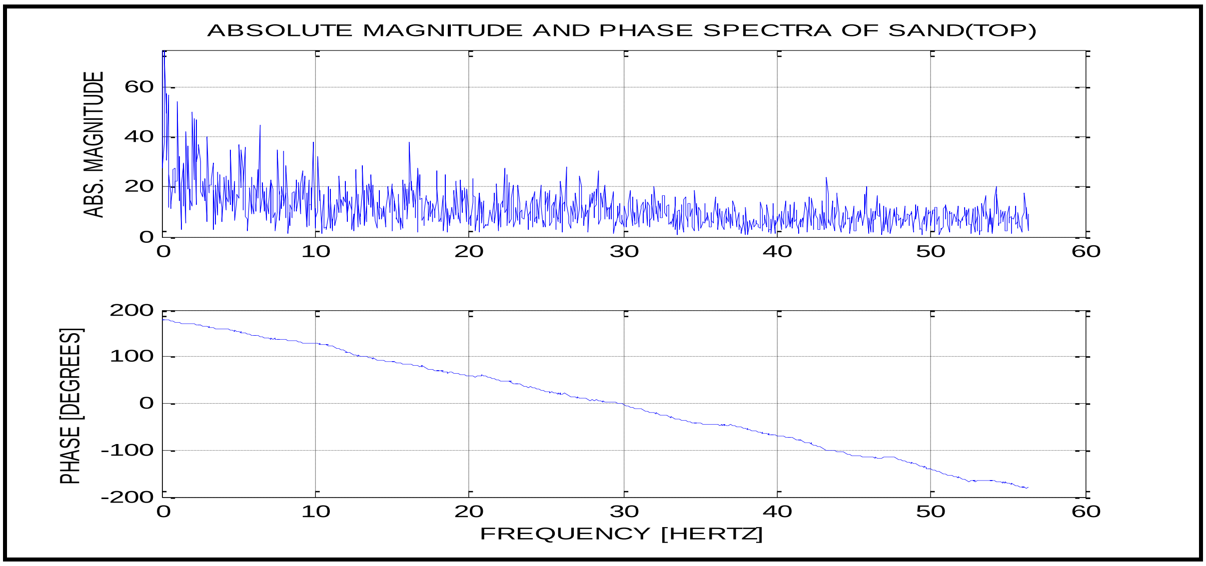
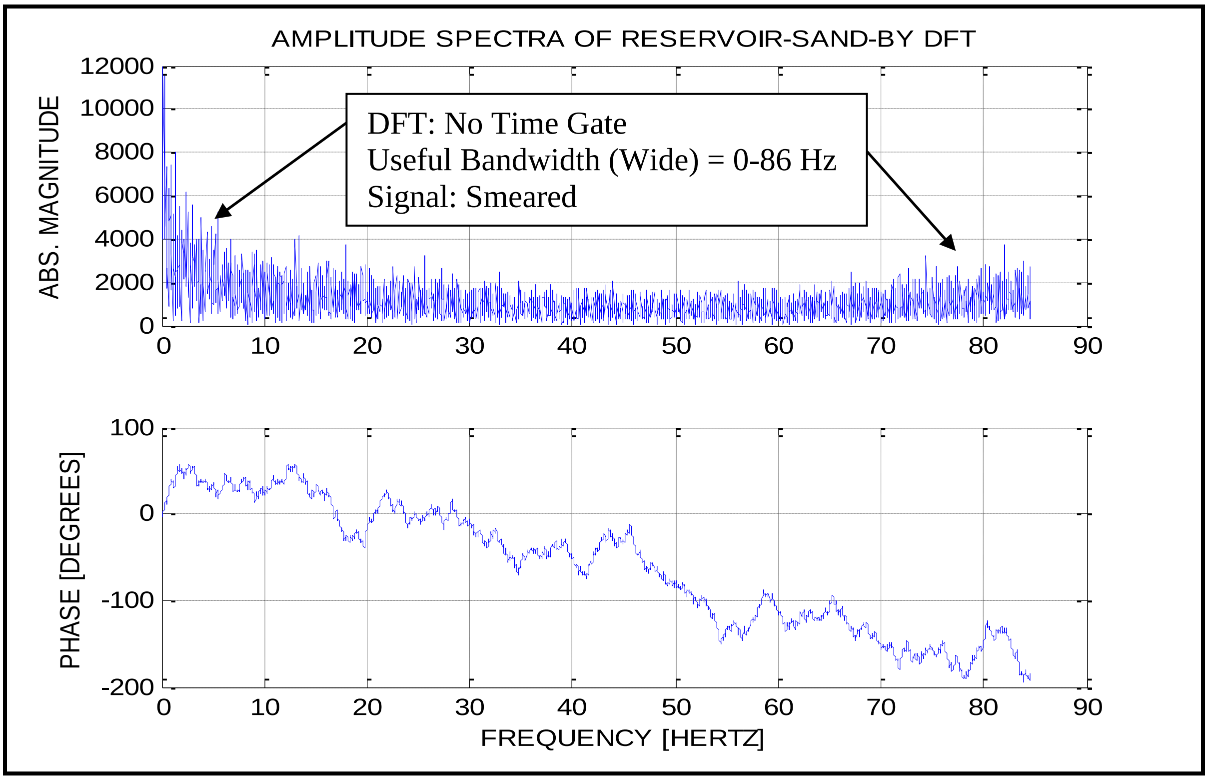


Figure 6 Absolute magnitude and phase spectra of Sand Top (2.440sec)



(a) Amplitude and Phase Spectra at Sand top, 2.440sec by DFT

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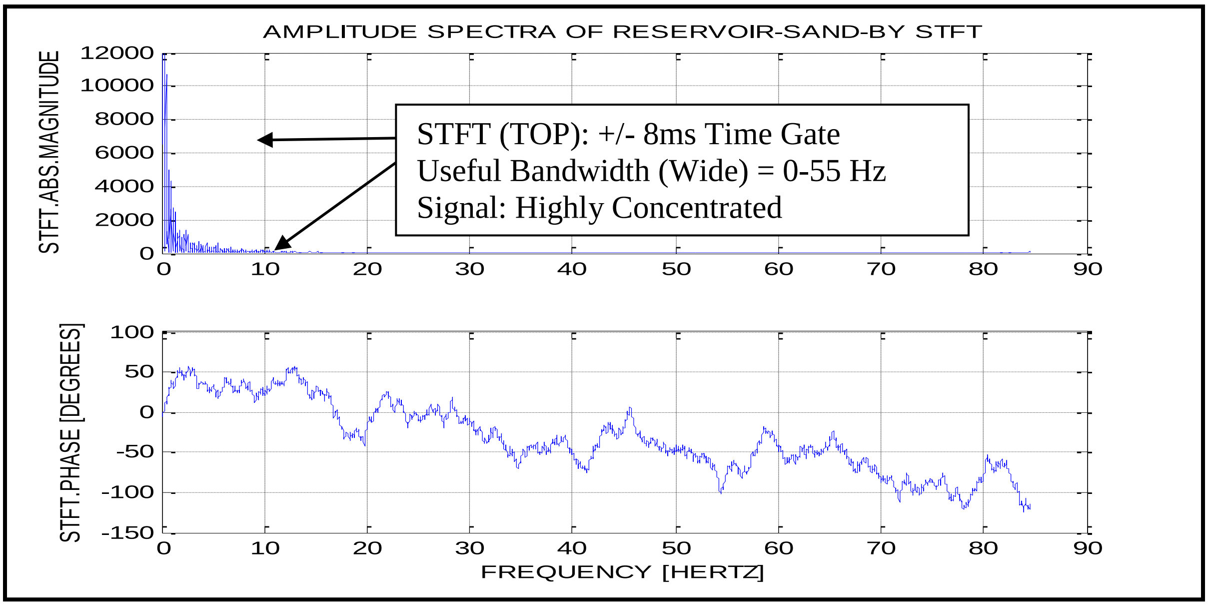
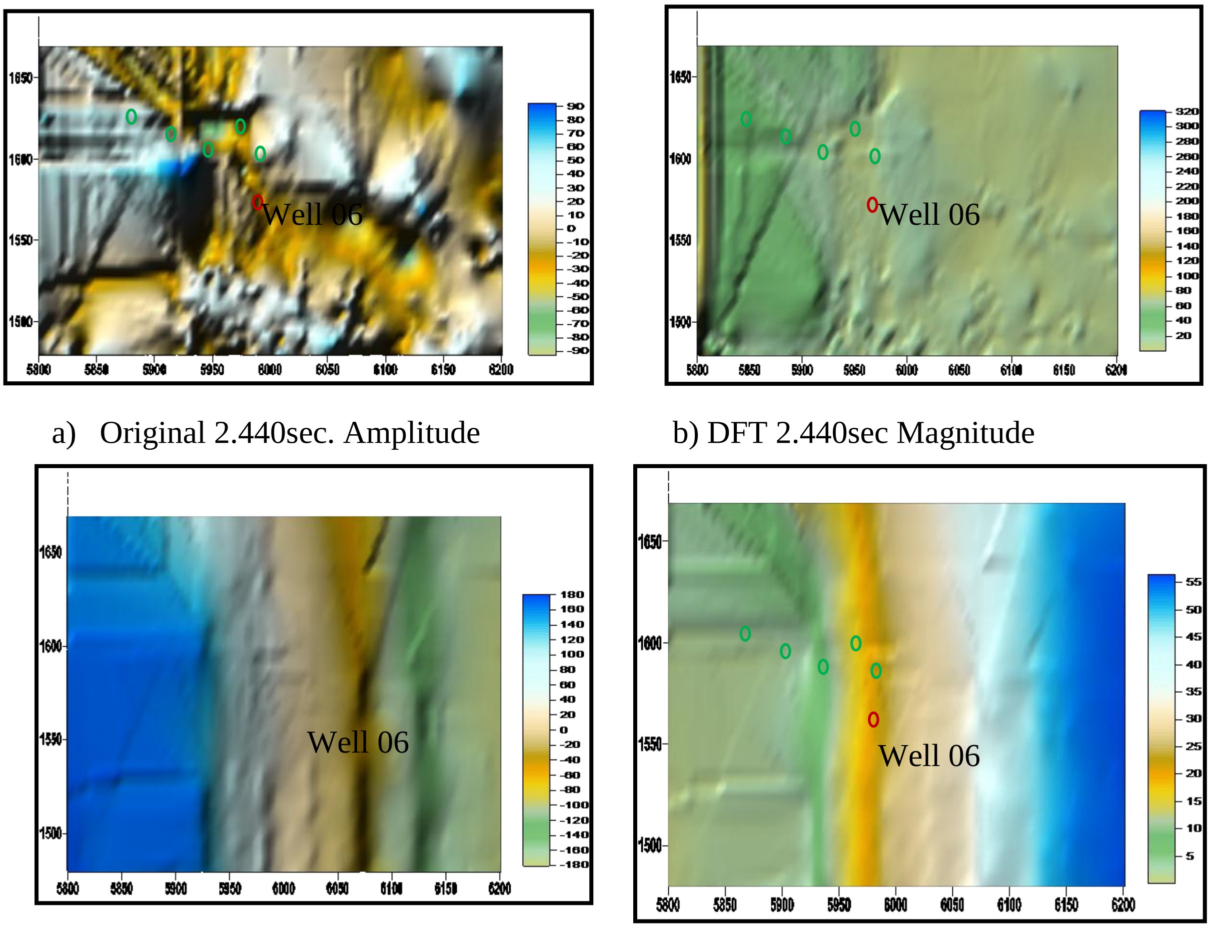


(b) Amplitude and Phase Spectra at Sand top, 2.440sec by STFT with 8ms window, and Gaussian function.

Figure 7 Amplitude and phase spectra of reservoir top by DFT and window by STFT



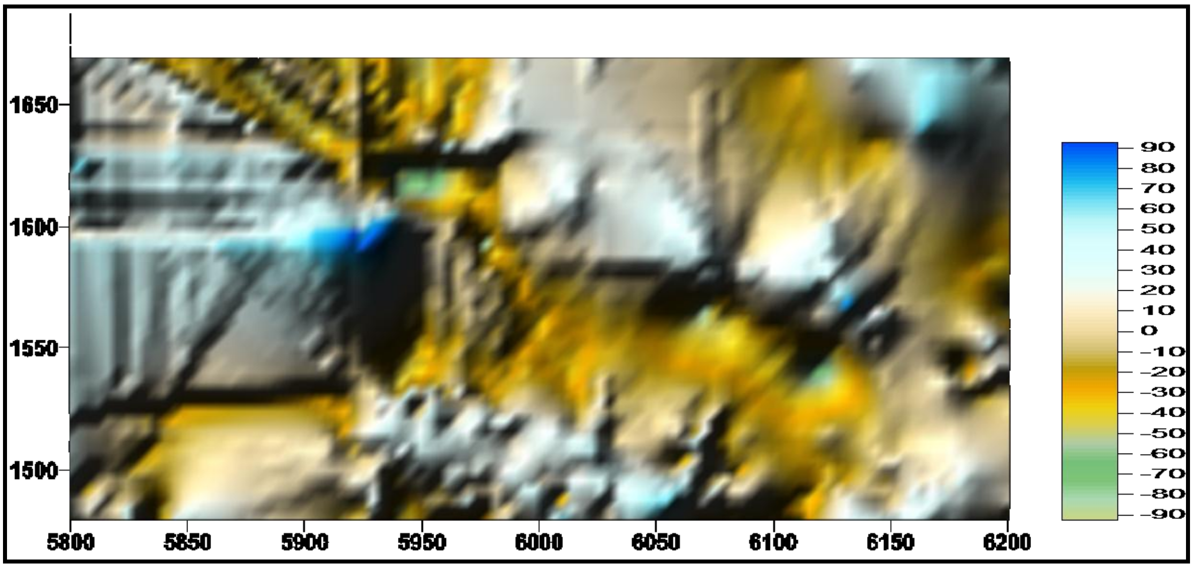
a) Original 2.440sec. Amplitude

b) DFT 2.440sec Magnitude

c)DFT2.440sec Phase

d) DFT 2.440sec Frequency

Figure 8 Discrete Fourier Transform of the established Sand Top (2.440sec).



(a) Original Amplitude

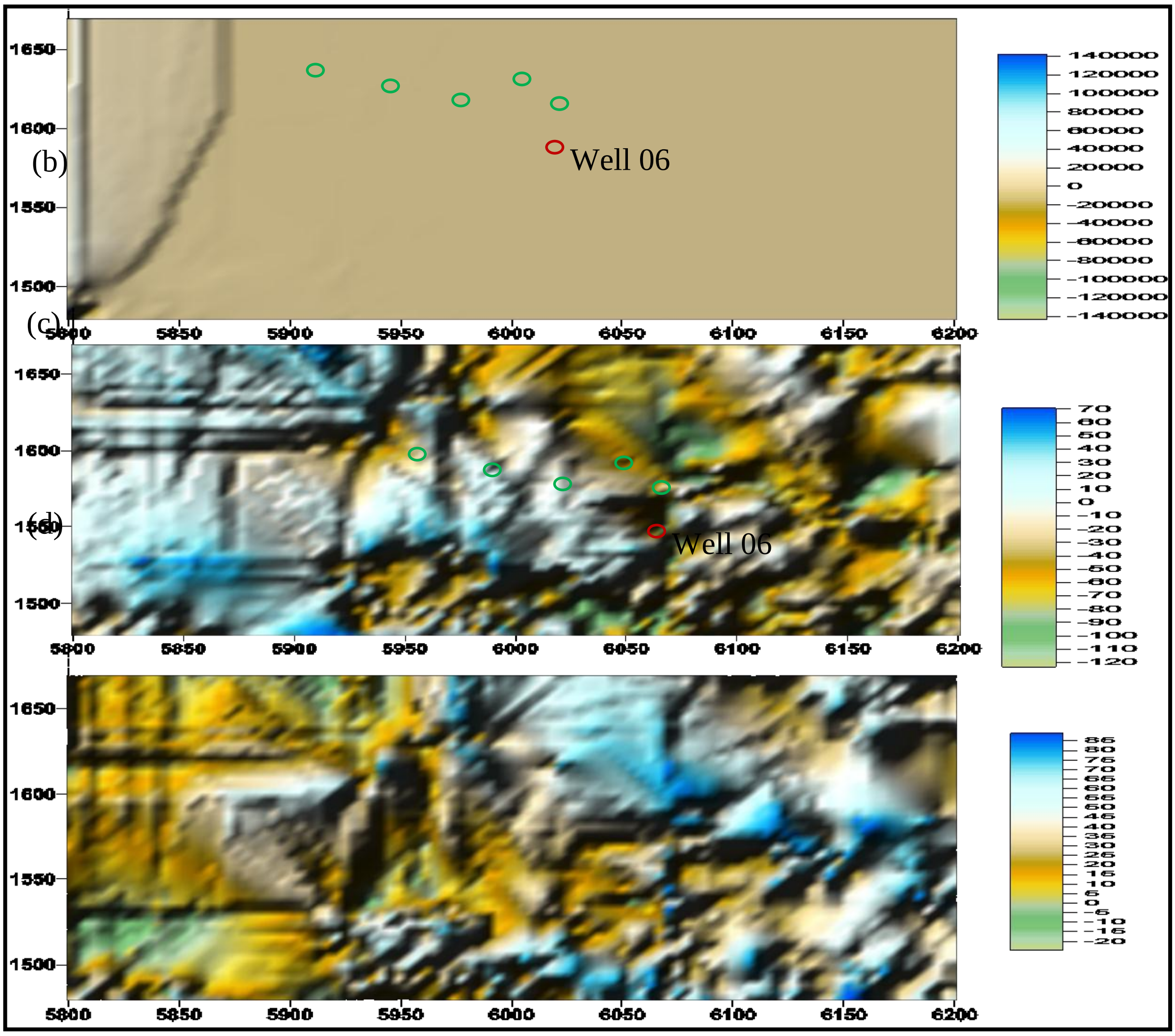


Figure 9 Original and full bandwidth STFT attributes; from top (a) Original amplitude (b) Magnitude (c) Phase and (d) Frequency.

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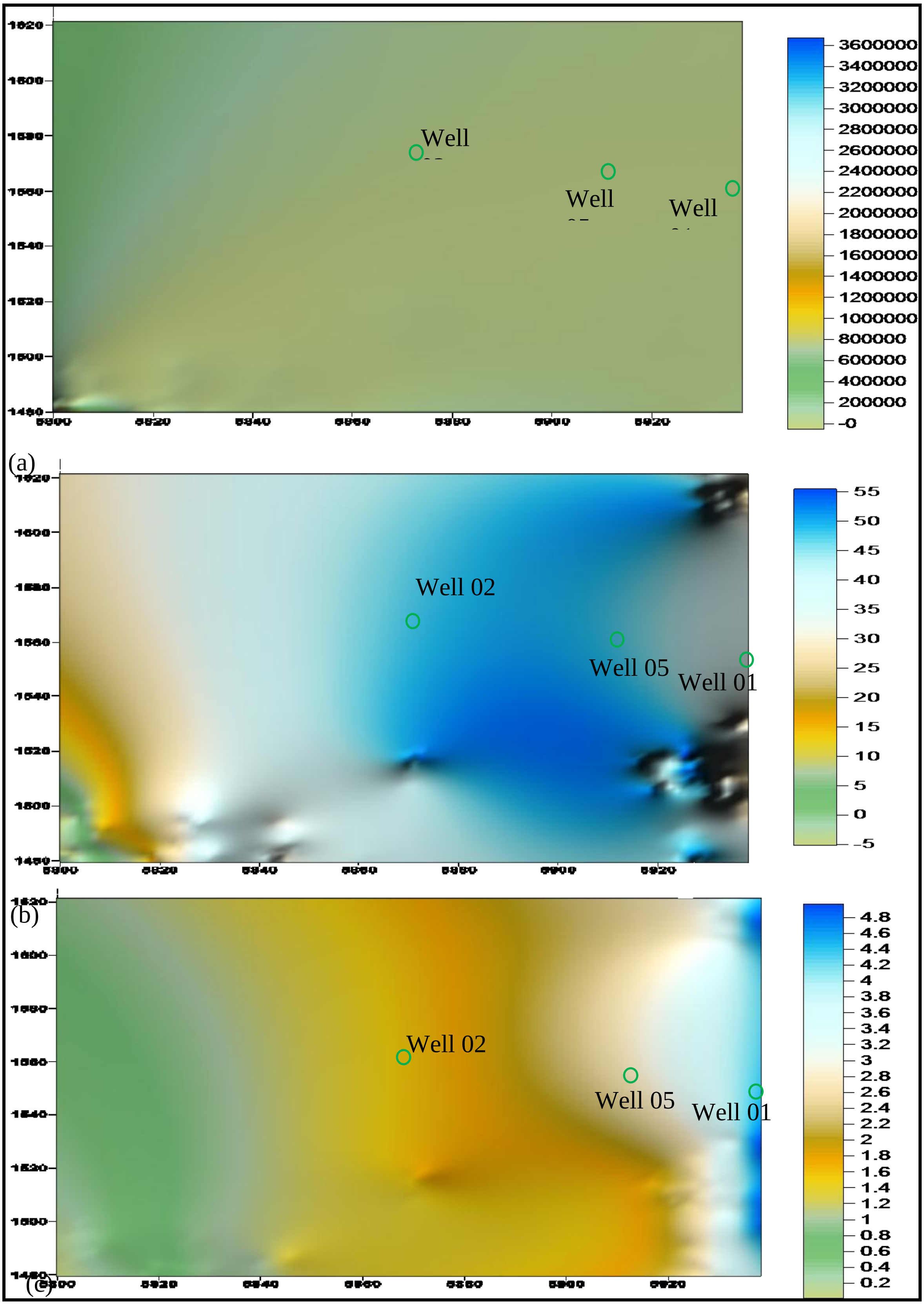

Figure 10 Frequency maps; bandwidth STFT (0-5Hz): (a) Magnitude (b) Phase and (c) Frequency.

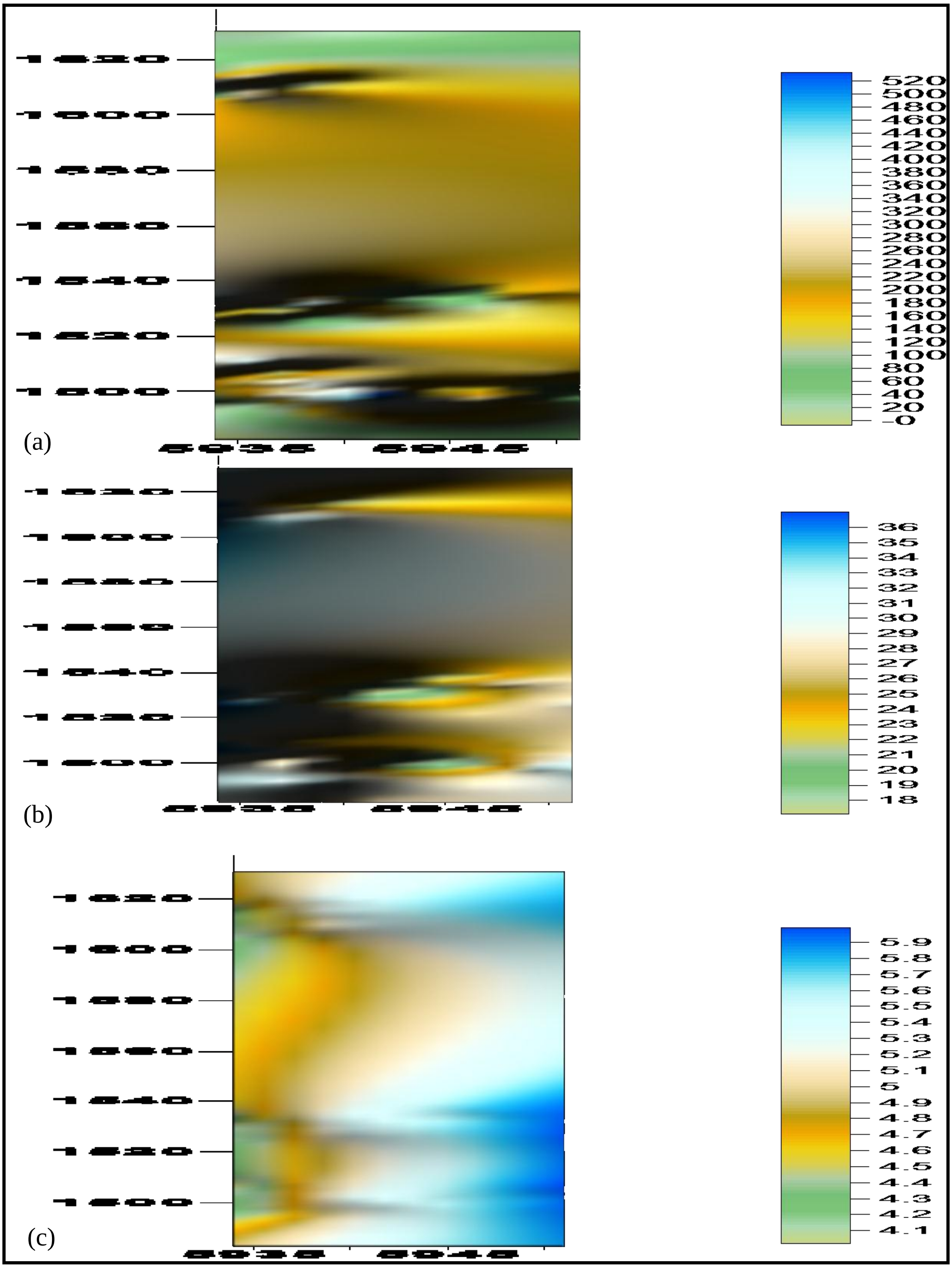

Figure 11 Frequency maps; bandwidth STFT (4-6Hz/mean 5Hz) (a) Magnitude (b) Phase and (c) Frequency.

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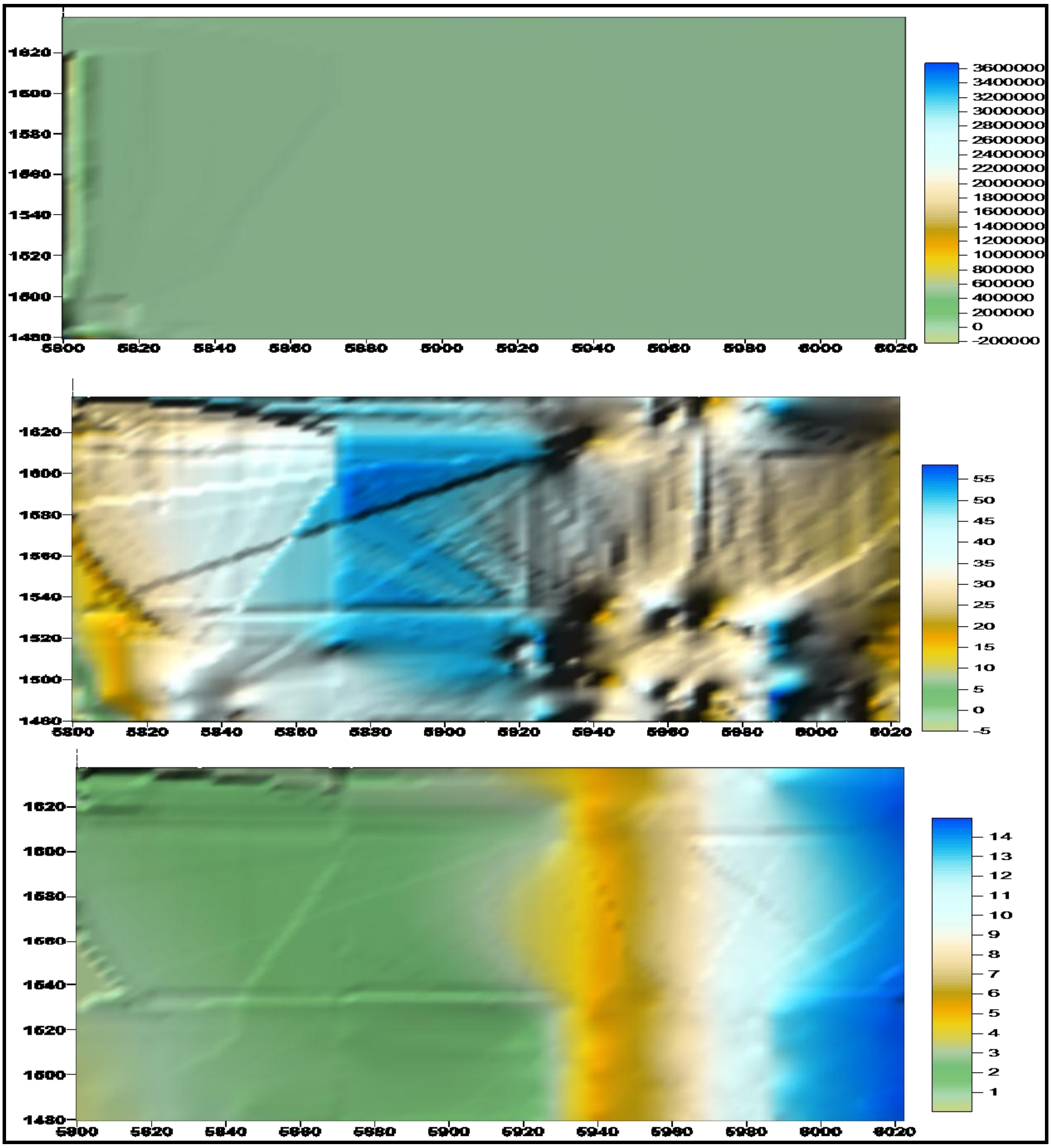

Figure 12 Frequency maps; bandwidth STFT (0-15Hz) (a) Magnitude (b) Phase and (c) Frequency.

DISCUSSION

The time slice (amplitude) of the established sand interval (2.436 sec to 2.472 sec) indicates variation in amplitude properties with depth which suggests changes in formation and fluid properties within the interval (Figure 4). The plot of the absolute magnitude and phase against the frequency before decomposition shows spurious signal as well as difficulty in dominant frequency determination (Figure 5). The plot of the absolute magnitude and phase against the frequency after decomposition with DFT shows a smearing signal with useful bandwidth between 0-86 Hz and indicates a dominant frequency of 43 Hz (Robertson and Nogami, 1984) The plot of the absolute magnitude and phase against frequency when decomposed with STFT shows a localized signal with useful bandwidth between 0-55Hz with dominant frequency of 43 Hz (Figure 5). The DFT is an average representation and scalar attributes of the frequency behaviour in the entire seismogram of 2.440sec established sand top and based on the 3 seismic attributes of the DFT maps of the established sand top (2.440 sec), the well 6 magnitude shows no distinct change in sequence boundary from other wells on the field except with well 5. The DFT phase map of 2.440 sec shows that there is continuity from well 06, 04 to 03 with slightly similar value but well 02 and 05 showing a discontinuity from other 3 wells. The DFT frequency map of 2.440 sec indicates that well 06 has similar lithology with well 03 and 04 i.e. shale and well 02 and 05 indicates a sandy formation (Figure 6) (Taner *et al.*, 1979). The map of the full bandwidth short time Fourier transform of top of the 2.440sec shows no distinct stratigraphic features due to combination of all the frequency (see Figure 7). The 0-5Hz frequency map of the sand top (2.440sec) slice suggests that the magnitude values are similar in Well 01, Well 02 and Well 05 that is they have similar sequence boundaries while the phase shows discontinuity as you move from left to right and the frequency indicates the Well 02 has a lower frequency (Sand) than Well 05 and Well 01 (Sandy shale), see Figure 8. The variation could be due to difference in fluid content or lithology (Ofuyah *et al*, 2014). A 4-6Hz (mean 5Hz) frequency map for the sand top (2.440sec) slice shows what could be a meandering channel (Figure 8). The meandering channel is not that visible on the 0-15Hz frequency map due to turning effect (Figure 10) but shows similar lithology as 0-5 Hz with Well 03, 04 and 6 having higher frequency (shale) and the wells have same sequence boundary. A mono-frequency map of the sand top (2.440sec) - Figure 9 also indicates subtle stratigraphic feature (Channel) similar to Figure 10. The bandwidth of 25-45 Hz and 45-55 Hz shows the same lithology type in the various wells as bandwidth 0-5Hz and 0-15 Hz but no visible channel (Figure 11- 12) (Partyka *et al*, 1999; Sinha *et al*., 2005).

This research has demonstrated that the STFT technique enhanced the seismic data used for stratigraphic feature delineation. This research established that STFT gives detailed and clear information about stratigraphic features than DFT and DFT, better than original data as well as established the presence of channels which is typical of many Niger Delta reservoirs. STFT has a more flexible domain (frequency), which gives a better resolution than DFT which is based on average frequency and gave a localized stratigraphic feature. In addition, the results have shown better understating of reservoir lithofacies from one time to another with depth as time (amplitude) data is spurious. The frequency data gave better resolution of geological maps. This better understanding of the reservoir can aid drilling operation confidence as well as proffer pay zone target.

This work is an extract from a MSc. Dissertation by Awolola, O. K titled ‘‘The Application of Short –Time Fourier Transform and Discrete Fourier Transform in Mapping Stratigraphic Features in

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TMBField, Niger Delta'' and supervised by R. U. Ideozu (PhD). The Department of Petroleum Resources (DPR) and Chevron Nigeria Limited (CNL) are acknowledged for data used in this research.

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