The Application of Fourier Transform in the Interpretation of Subsurface Stratigraphy

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Abstract
General seismic data interpretation involves direct fault and horizon mapping, sequence stratigraphy and seismic modeling to produce structural, stratigraphic and reservoir maps for the delineation, exploration and production of hydrocarbon in oil fields. The first two methods operate on stacked and migrated data, while the third is done without adequate calibration, inadequate display of final stacks, coarse processing and in time domain. Actual hydrocarbon entrapments are rarely detailed well enough to permit reliable location of wells from these studies alone owing to inherent noise. This paper presents the results of the application of time-frequency transform on 3D seismic data over an oil field in Niger Delta. The aim of the study was to develop a robust technique for mapping subtle stratigraphic units which are usually masked after normal data interpretation using spectral algorithm. The discrete Fourier transform applied in the interpretation of the 3D seismic data filters the field data recorded in time, and recovers lost sub-seismic geologic information content in frequency. The algorithm is based on fast Fourier transform technique and was developed within Matlab software. The results of the spectral decomposition yielded frequency maps (slices) at data sampling interval (4ms) over the reservoir window. The maps revealed sub-seismic faults, differences in lithology and better reservoir delimitation. The results gave enhanced structural disposition of the reservoir bed and more detailed indication of the variation of reservoir character with depth.
Keywords: Fourier transform, Spectral decomposition

1. Introduction

Seismic data are usually contaminated by noise, even when the data has been migrated reasonably well and are multiple-free (Satinder et al. 2011). Seismic facies analysis is a key component of the seismic interpretation workflow as much information on depositional process, environment and ultimately reservoir potential can be determined from seismic data alone (i.e. in the absence of well data) (Satinder et al. 2011).

The application of Fourier transform in the interpretation of subsurface stratigraphy is an approach to understanding the geometry and character of stratigraphic features using horizontal seismic section (time slice) of Fourier transformed recorded, seismic data, in order to identify subtle geologic features. This is necessary in hydrocarbon reservoir characterization since a clear knowledge of the reservoir facilitates enhanced recovery which impacts on production. In frequency domain, the technique separates fact from artifact in seismic processing and interpretation and better geologic picture emerges.

Spectral decomposition techniques provide enhanced frequency resolution. The concept behind spectral decomposition is that a reflection from a thin bed has characteristics expression in the frequency domain that is indicative of temporal bed thickness (Amplitude Spectra). Amplitude spectra delineate thin bed variability via spectra notching patterns, which are related to local rock mass variability. Likewise phase spectra respond to lateral discontinuities via local phase instability. (Partyka, 1999).

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This paper presents the results of the application of time-frequency transform on 3D seismic data over an oil field in Niger Delta using the discrete Fourier transform (DFT) and its response amplitude. The aim of the study was to develop a robust technique for mapping subtle stratigraphic units which are usually masked after normal data interpretation using a spectral algorithm. This is an approach to lithologic study in terms of spatial extension or horizontal section in the interpretation of seismic data. Time slices verify the presence of a basin and a time slice at any one time value contains more than one horizon. (Dobrin, 1988).

The discrete Fourier transform applied in the interpretation of the 3D seismic data filters the noisy field data recorded in time, and recovers lost sub-seismic geologic information content in frequency. The algorithm is based on fast Fourier transform technique and was developed within Matlab software. The results of the spectral decomposition yielded frequency maps (slices) at data sampling interval (4ms) over the reservoir window. The maps revealed sub-seismic faults, differences in lithology and better reservoir delimitation. The results gave enhanced structural disposition of the reservoir bed and more detailed indication of the variation of reservoir character with depth.

2. Geologic Background

The Niger delta is one of the most prolific oil producing areas in the world. It is located in southern Nigeria between latitudes 3^0N and 6^0N and longitudes $4^0 30^1$ E and 9^0E. The delta covers an area of about 105,000km^2. The Niger delta is a large arcuate delta of the destructive wave dominated type and is divided into the continental, transitional and marine environments. A sequence of under compacted marine shale (Akata formation, depth from 11121 ft.) is overlain by paralic or sand/shale deposits (Agbada formation, depth from 7180-11121ft) are present throughout. Growth faults strongly influenced the sedimentation pattern and thickness distribution of sands and shales. The paralic interval is overlain by a varying thickness of continental sands (Benin formation, depth from 0-6000ft).Hydrocarbon is trapped in many different trap configurations. Oil and gas are trapped by roll-over anticlines and growth faults (Weber, 1987). Merki (1972) noted that the age of the formations become progressively younger in a down-dip direction and ranges from Paleocene to Recent.

The seismic data used in this study are digital and real. The recorded data sets (3D) were obtained over 'X' field by Chevron Corporation Nigeria. The field data comprises a base map, a suite of logs from six (6) wells, and four hundred (400) seismic lines and 220 crosslines. Some of the log types provided are Gamma-ray (GR), self-potential, resistivity density, sonic, water saturation.

3. Theory

Fourier analysis is extremely useful for data analysis, as it breaks down a signal into constituent sinusoids of different frequencies. It is particularly useful in areas such as signal and image processing, where its uses range from filtering, convolution, and frequency analysis to power spectrum estimation. Spectral decomposition techniques provide enhanced frequency resolution. The concept behind spectral decomposition is that a reflection from a thin bed has characteristics expression in the frequency domain that is indicative of temporal bed thickness (Amplitude Spectra) (Partyka, 1999). Amplitude spectra delineate thin bed variability via spectra notching patterns, which are related to local rock mass variability. Likewise phase spectra respond to lateral discontinuities via local phase instability. (Partyka, 1999).

Spectral techniques include discrete Fourier transform (DFT), short time Fourier transform (STFT), Hilbert transform (HT), maximum entropy method (MEM) etc. The DFT was adopted in this study to overcome the limitation of time domain interpretation arising from inherent noise.

3.1 Discrete Fourier Transform (DFT)

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

$$f\,(w) = \sum_{t=-\infty}^{w-\infty} f(t)e^{-i\omega t} \qquad (1)$$

where, w is the Fourier dual of the variable 't'. If 't' signifies time, then 'w' is the angular frequency which is related to the linear (temporal frequency) 'f' (Yilmaz,2001).A key limitation of discrete Fourier transform is that it gives scalar attributes and an average representation of the frequency behavior of a whole seismogram without information as to the local concentrations of energy. This can be improved by the application of Short Time Former Transform (STFT). (Chakraborty and Okaya, 1995).

3. Method

The lithologic log (Gamma-ray) and resistivity log provided were first plotted to identify the sand (reservoir interval) unit of interest. Here, we established general lithology of well using a combination of logs including Gamma Ray (GR), spontaneous potential (SP), and resistivity logs. Various cross-plots such of Resistivity/GR, SP/Resistivity and density/ acoustic impedance were obtained to establish different relationships in time domain. Following time-depth conversion, seismic data over the log defined thin sand (reservoir) window was extracted in time and transformed into frequency using the discrete Fourier transform within Matlab software. Afterwards, both data types (seismic amplitude and seismic spectral (response) amplitude) were each sliced at the data sampling interval of 4ms over the reservoir window and compared. In order to obtain a gross picture of the sampling, we have in this report displayed the horizontal sections (time and frequency slices) a sample before the top of reservoir (sand), two samples at the middle of the reservoir and a sample after the base of reservoir. The reservoir interval is from 2752-2768ms.The slices displayed are at 2748ms and 2752ms (top), 2756ms and 276ms (middle) and 2768ms and 2772ms (base).

4. Discussion of Results

The base map of the study area is shown in Figure 1. Figure 2 shows an interpreted **a**rbitrary seismic line indicating two major faults, F1, F2 bounding the wells at the reservoir level under analysis (2.752-2.768 secs, arrowed).The well locations are indicated above the seismic section

Figure 3 shows Logs of (a) Gamma Ray, (b) SP and (c) resistivity respectively plotted for the entire data set in well 5, a representative well in view of its good data quality. The arrow on the seismic section and log shows the thin sand interval of interest. This sand interval in well 5) is (11127.5-11200ft) corresponding to is (2.752-2.768sec).

Figure 4a shows the top time slices of amplitude data in time domain and in frequency domain between 2.748 and 2.752s. The different slices have their respective legend at the top. The red ring represents well 5 under examination with coordinate (5914, 1607).

The middle amplitude slices in time and frequency domains between time 2.756 and 2.760s are displayed as Figure 4b. Figure 4c shows the bottom slices in both domains between time 2.768 and 2.772s. Within this interval, the seismic amplitude (in spectral domain) shows distinct bright spot that varies with depth due to variation in fluid and formation properties. There is also a gradual transition from mainly sand at top of the reservoir to shale at bottom .In addition, it can be seen that the well location indicating sand /hydrocarbon zone (green/orange) is clearer on the frequency map than on the time map. This is true on all the maps. Also, the location of the well is synclinal as the contours crowd together with increasing time or depth. This suggests that the deposits are along a paleo-channel. This is indicative that the reservoir is a channel fill and that the structural disposition of the reservoir bed is synclinal.

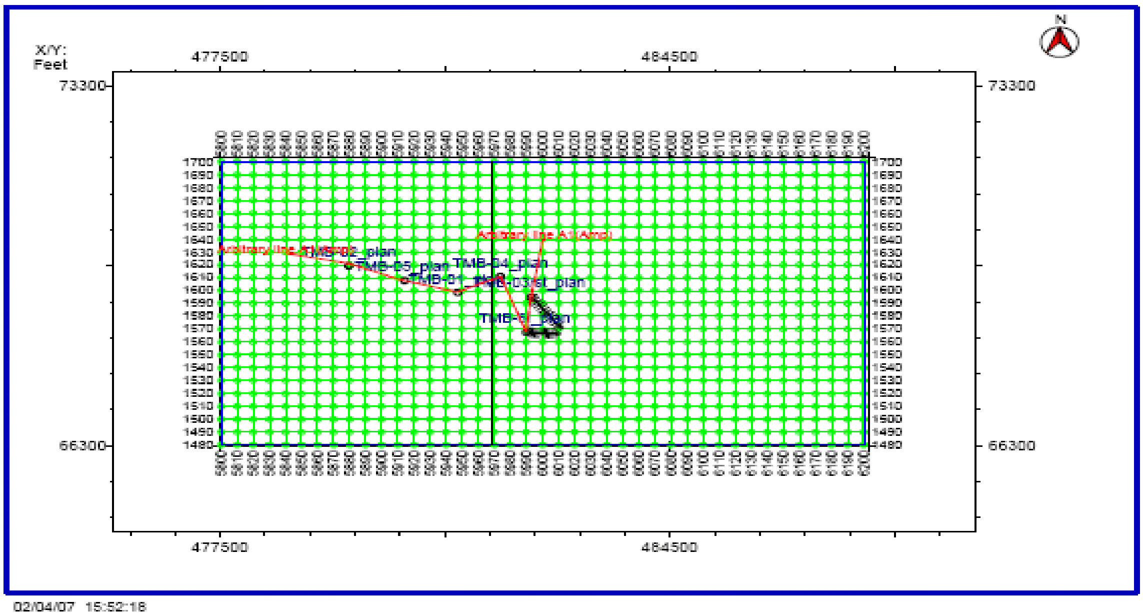


Figure 1. Base map of 3-D seismic showing all wells. Well 5 is shown as TMB 05 plan with coordinate (5914, 1607). Courtesy: Chevron; modified).

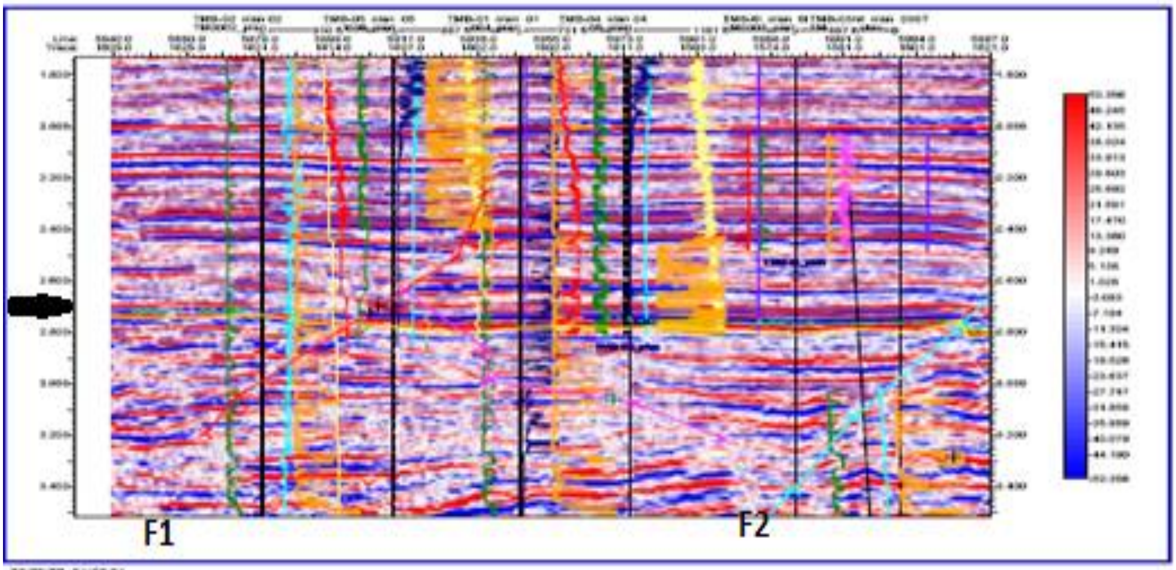


Figure 2. Arbitrary line after interpretation: Two major faults, F1, F2 are shown bounding the wells at the reservoir interval under analysis (2.752-2.768 secs, arrowed).The well locations are indicated above the seismic section

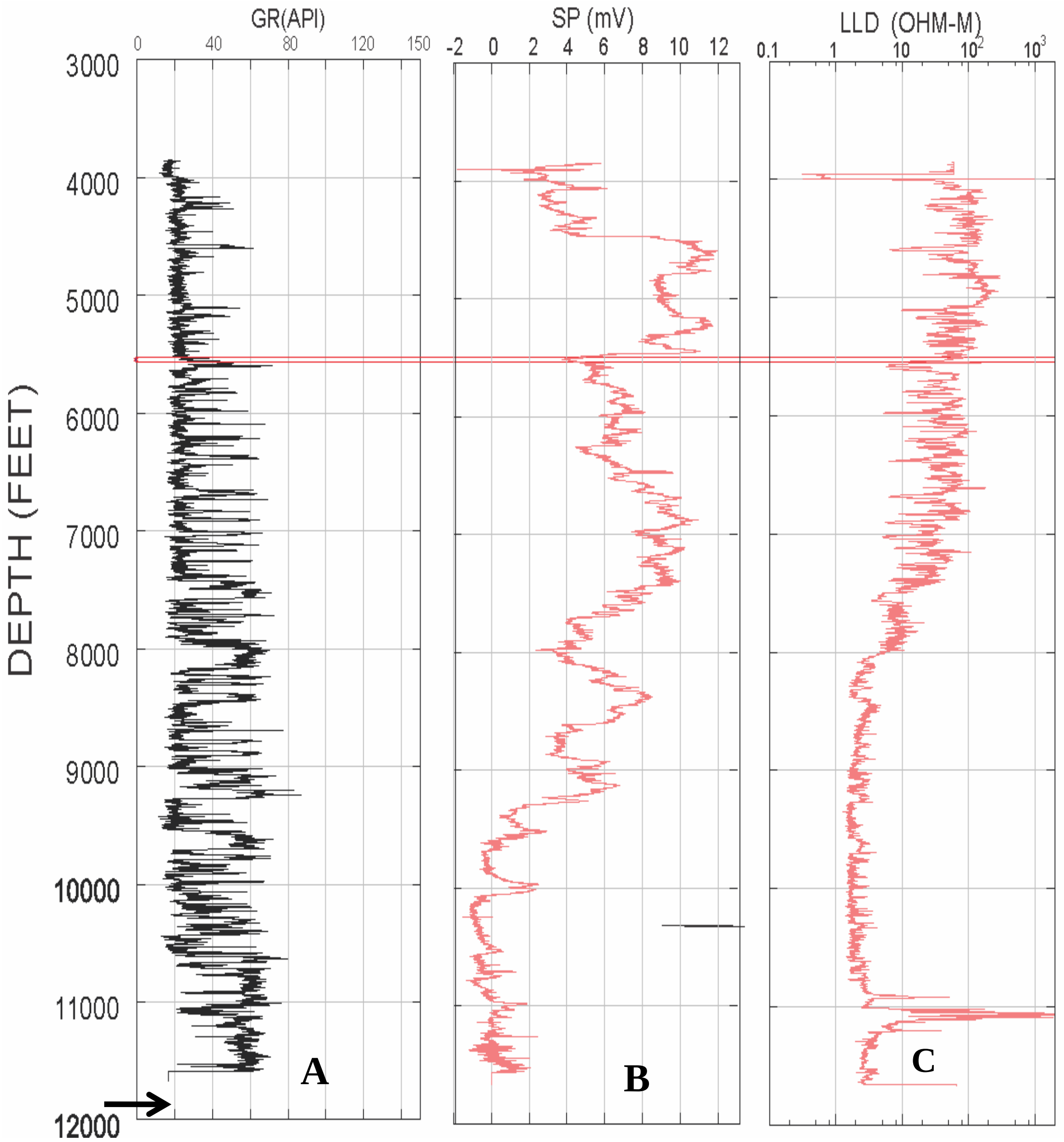
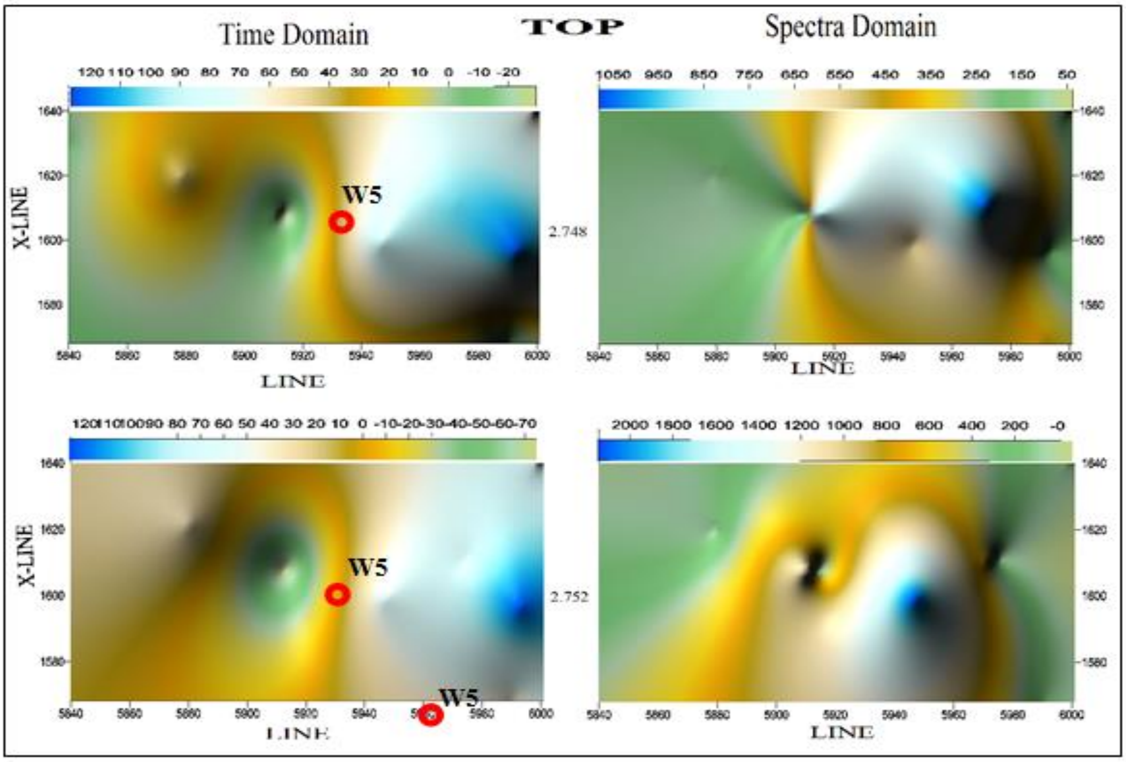
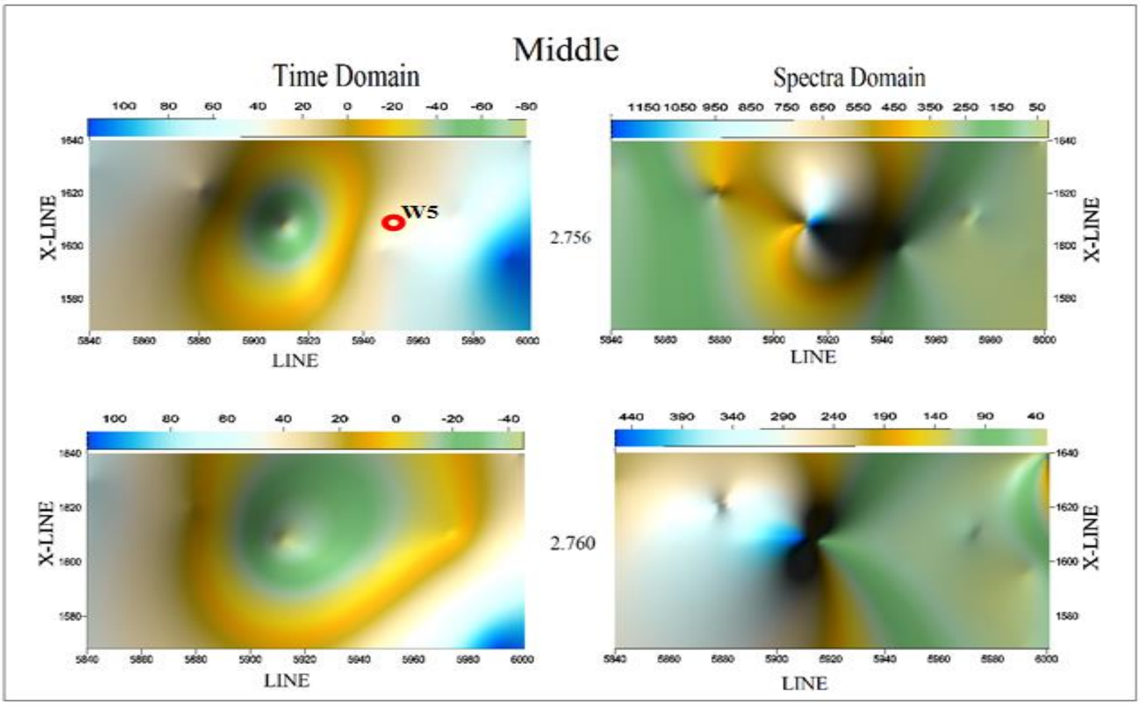


Figure 3. Log of (A) Gamma Ray, (B) SP and (C) resistivity respectively plotted for the entire data set. The small rectangle that runs across shows the interval of thin sand that is herein closely examined quantitatively. The sand interval in well 5 is (2.752-2.768:11127.5-11200ft).



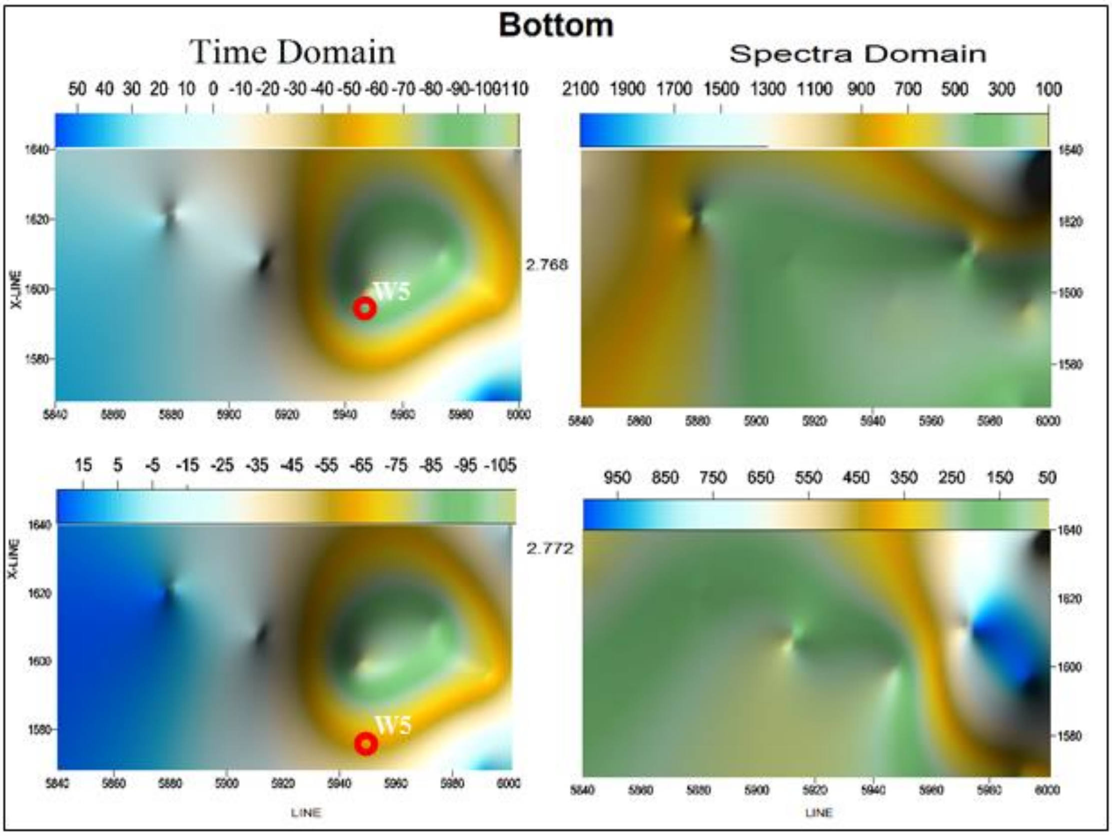
(top row:2.748secs) (bottom row:2.752 secs)

Figure 4a. TOP SLICES: Time slices of amplitude data in time and frequency domains at 2.748s and 2.752s. The different slices have their respective legend at the top. The red ring represents well 5 under examination, with coordinate (5914, 1607, orange).The bright spots and other depositional features are clearer on the frequency than on time slices at corresponding locations. Wells can be drilled with precession on the frequency slices.



(top row: 2.756secs) (bottom row: 2.760secs)

Figure 4b. MIDDLE SLICES: Time slices of amplitude data in time and frequency domains at 2.756s and 2.760s .The different slices have their respective legend at the top. The red ring represents well 5 under examination with coordinate (5914, 1607). Better geologic image is revealed on the frequency slices.



(top row: 2.768secs) (bottom row: 2.772secs)

Figure 4c. BOTTOM SLICES: Time slices of amplitude data in time and frequency domains at 2.768s and 2.772s. The different slices have their respective legend at the top. The red ring represents well 5 under examination with coordinate (5914, 1607).The channel is evident on the frequency slices here.

Conclusions

In this study, an application of Fourier transform in understanding subsurface stratigraphy with example taken from Niger Delta has been undertaken. The study investigated a practical approach to seismic data interpretation using efficient time-frequency horizontal sections.

The aim of the study was to develop a more resolving technique than conventional practice for mapping stratigraphy which is usually masked after normal data interpretation with a view to characterizing hydrocarbon reservoir. The overall objective was to provide a more accurate solution to the geologic problems of uncertain determination of reservoir geometry and character in order to facilitate the drilling of wells with improved confidence.

The results obtained show improved understanding of changes in reservoir lithofacies from one time (depth) level to another As time (amplitude) data is noisy, better geological maps were obtained with the frequency data. The results indicate that the reservoir is a channel fill and that the structural disposition of the reservoir is synclinal.

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