A CEPSTRAL TECHNIQUE FOR UNMASKING VITAL SUB-SEISMIC STRATIGRAPHIC DETAILS EMBEDDED IN DENSE 3D SEISMIC DATA FROM NIGER DELTA

Orji, O.M.*
Department of Petroleum Engineering and Geoscience, Petroleum Training Institute, Effurun, Nigeria,

Ugwu, S.A.
, Department of Geology, University of Port Harcourt, Nigeria, and

Ofuyah, W.N.,
, Department of Earth Sciences, Federal University of Petroleum Resources, Effurun, Nigeria.
Corresponding Author:

ABSTRACT: *Seismic visibility is enhanced through the change of the seismic data outlook from the standard amplitude measurement to a new domain in order separate fact from artifact in seismic processing and interpretation. 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. These methods operate on stacked and migrated data and without adequate calibration. Besides, final stacks are inadequately displayed, processing is coarse and in time domain. Actual hydrocarbon entrapments are rarely detailed well enough to permit reliable location of wells from these studies alone owing to noise. This paper presents the results of the application of Cepstral transform (CT) in the interpretation of the 3D seismic data in the Niger Delta. The aim of the study was to develop a robust technique for mapping subtle stratigraphic units which are usually masked during normal data interpretation using Cepstral algorithm. The Cepstrum is the Fourier transform of the log of the spectrum of the data. The transform filters the field data recorded in time domain, and recovers lost sub-seismic geologic information in quefrency domain. Cepstral domain analysis separates source and transmission path effects. The algorithm is based on fast Fourier transform technique and was developed within Matlab software. The results of the Cepstral decomposition yielded gamnitude, saphe and quefrency maps of the reservoir and revealed sub-seismic faults, differences in lithology and better reservoir delineation and delimitation.*

KEYWORDS: Cepstrum, Fourier transform, Gamnitude, Hilbert transform, Homomorphic, Kepstrum,Quefrency, Saphe,

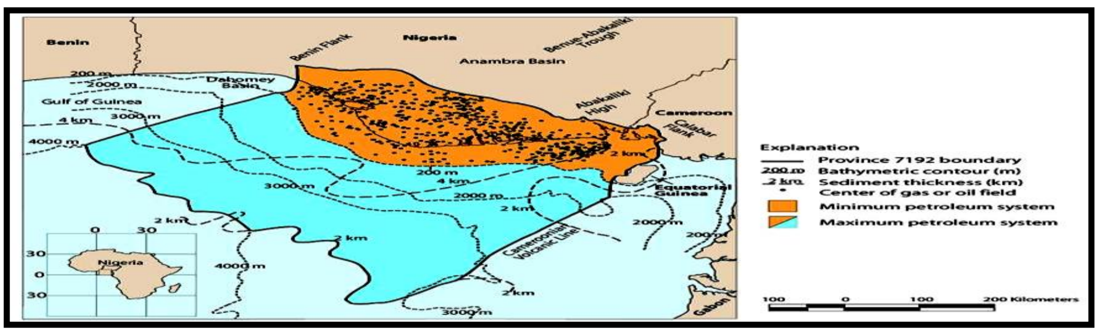
INTRODUCTION

The application of Cepstral transform for unmasking vital sub-seismic stratigraphic details embedded in dense 3D seismic data is an approach to understanding the geometry and character of stratigraphic features using horizontal seismic sections (time slices) of Cepstral transformed seismic amplitude data in order to identify subtle geologic features. 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 visibility is enhanced through the change of the seismic data outlook from the standard amplitude measurement to a new domain in order separate fact from artifact in seismic processing and interpretation. In frequency domain, the technique separates fact from artifact and better geologic picture emerges. This is necessary in hydrocarbon reservoir characterization since a clear knowledge of the reservoir facilitates enhanced recovery which impacts on production (Ofuyah et al, 2014). The high incidence of subtle trap accumulations in hydrocarbon province like Niger Delta, particularly in deep waters, and uncertainty in data from marginal fields due to their attendant complex geologic scenarios have led to the need for a high resolution interpretation scheme such as Spectral and Cepstral decompositions to facilitate the identification and characterization of these features. The variation of signal amplitude such as abrupt or gradual (approximating structural events) and subtle or gentle (approximating stratigraphic events), are generally among the most meaningful features for extracting the information content of signal. The discontinuities of image intensity for example, indicate the contours of the different objects constituting the image. 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). This paper presents the results of the application Cepstral transform (CT) in the interpretation of the 3D seismic data in the Niger Delta using time slices This is an approach to lithologic study in terms of spatial extension 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 aim of the study was to develop a robust and practical technique for mapping subtle stratigraphic units which are usually masked during normal data interpretation using a developed complex Cepstrum algorithm. The Cepstrum is the Fourier transform of the log of the spectrum of the data. The transform filters the field data recorded in time domain, and recovers lost sub-seismic geologic information in quefrency domain. Cepstral domain analysis separates source and transmission path effects. The algorithm is based on fast Fourier transform technique and was developed within Matlab software. The results of the Cepstral decomposition yielded gamnitude, saphe and quefrency maps of the reservoir and revealed sub-seismic events/faults, differences in lithology and better reservoir delineation and delimitation. These positively impact on production.

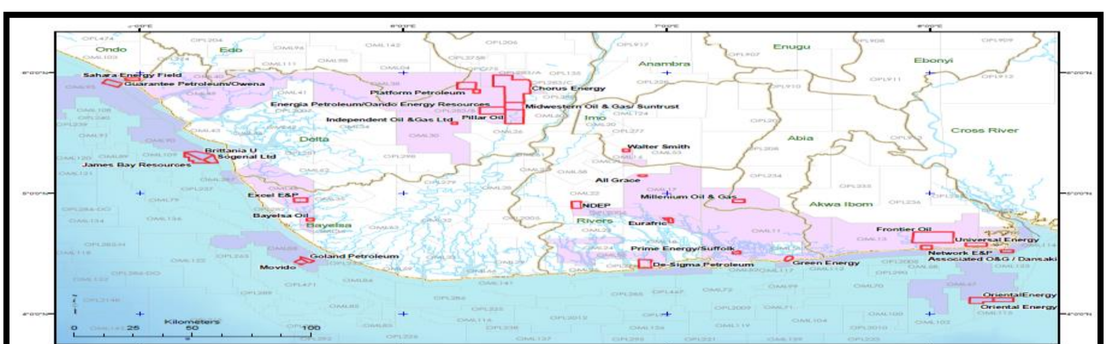
This paper is an attempt to describe aspect of innovative and unconventional methods and new technology developed for application in areas of uncertain data or complex geology such as in deep waters, marginal fields, etc. for the purpose of their development. Marginal field refers to an oil field that may not produce enough net income to make it worth developing at a given time. However; should technical or economic conditions change, such a field may become commercial. It is usually associated with small pockets of hydrocarbons that have a plateau of a few years. Marginal fields have several parameters that affect them. These include environmental concerns, political stability, access, remoteness and, of course, the price and price stability of the produced gas/liquids. The presentation outline is as follows: in section 2, the concepts of complex attributes such as Hilbert (used here in form of peudo-section for general understanding of the geology of the survey), before narrowing down to Cepstrum and its variants are discussed to facilitate understanding, while in section 3, the methodology adopted is presented. In section 4, the results and analysis are discussed and finally in section 5, the conclusions of this study are stated.

Geologic Background

The source of our data is the 'Tomboy' Basin in Niger delta region (Figure 1). The region is a prolific hydrocarbon province formed during three depositional cycles from middle cretaceous to recent in Nigeria. It is located in Nigeria between latitudes 3^0N and 6^0N and longitudes 4^030^1 E and 9^0E and bounded in the west by the Benin flank, in the east by the Calabar flank and in the north by the older tectonic elements e.g. Anambra basin, Abakaliki uplift and the Afikpo syncline. The Niger delta basin is one of the largest subaerial basins in Africa. It has a subaerial area of about 75,000 km^2, a total area of 300,000 km^2, and a sediment fill of 500,000 km^3 (Tuttle, et al, 2015). The region is a large arcuate delta of the destructive wave dominated type and is divided into the continental, transitional and marine environments. In order of deposition, a sequence of under compacted marine shale (Akata formation, depth from about 11121 ft, and main source rock of the Niger delta), is overlain by paralic or sand/shale deposits (Agbada formation, depth from about 7180-11121ft, are present throughout. This is the major oil and natural gas bearing facies in the basin. The paralic interval is overlain by a varying thickness of continental sands (Benin formation, depth from 0-about 6000ft, contains no commercial hydrocarbons, although several minor oil and gas stringers are present) Avbovbo (1978), Merki(1972). Growth faults strongly influenced the sedimentation pattern and thickness distribution of sands and shales. Oil and gas are trapped by roll-over anticlines and growth faults (Weber, 1987). The ages of the formations become progressively younger in a down-dip direction and range from Paleocene to Recent (Merki, 1972). Hydrocarbon is trapped in many different trap configurations. The implication of this is that geological and geophysical analyses must be sophisticated, a departure from the conventional, in order to unmask hidden/by-passed reserves, usually stratigraphic and laden with huge hydrocarbon accumulation.



(a) Index Map of Nigeria and Cameroon: Map of the Niger Delta Showing Province Outline of Maximum
Petroleum System (After Petroconsultant, 2001).



(b) Map of Marginal Fields in Nigeria (The Department of Petroleum Resources, 2017)

Figure 1: (a) Index Map of Nigeria and Cameroon. Map of the Niger Delta Showing Province outline of Maximum Petroleum System. (b) Map of Marginal Fields in Nigeria

THEORY

Cepstral Transform (CT)

Cepstral decomposition is a new approach that extends the widely used process of spectral decomposition. This measures bed thickness even when the bed itself cannot be interpreted (Hall, 2006). While spectral decomposition maps are typically interpreted qualitatively using geomorphologic pattern recognition or semi quantitatively, to infer relative thickness variability Spectral decomposition is rigorous when analyzing subtle stratigraphic plays and fractured reservoirs. The Cepstrum processing technique gives a solution of other signals which have been convolved or multiplied in time domain because the operation of the nonlinear mapping can be processed by the generalized linear system (Homomorphic system). (Jeong.2009). Cepstral analysis is a special case of Homomorphic filtering. Homomorphic filtering is a generalized technique involving (a) a nonlinear mapping to a different domain where (b) linear filters are applied, followed by (c) mapping back to the original domain. The independent variable of the Cepstrum is nominally time though not in the sense of a signal in the time domain , and of a Cepstral graph is called the Quefrency but it is interpreted as a frequency since we are treating the log spectrum as a waveform. To emphasize this interchanging of domains, Bogert, Healy and Tukey (1960) coined the term Cepstrum by swapping the order of the letters in the word Spectrum. The name of the independent variable of the Cepstrum is known as a Quefrency, and the linear filtering operation is known as Liftering. The Cepstrum is useful because it separates source and filter and can be applied to detect local periodicity. There is a complex cepstrum (Oppenheim, 1965) and a real Cepstrum.. In the “real Cepstrum”, as opposed to the complex Cepstrum used here, only the log amplitude of a spectrum is used (Hall, 2006). Complex Cepstrum was introduced by Schafer (1969) by using the information of both the magnitude and phase spectra from the observed signal. The complex Cepstrum method is used to recover signals generated by a convolution process and has been called Homomorphic deconvolution (Oppenheim and Schafer, 1968). The applications can be found from seismic signal, speech and imaging processing. Kepstrum was named by Silvia and Robinson in 1978 and used for seismic signal analysis, although the literature on its application is limited. The Kepstrum and complex Cepstrum give almost same results for most purpose.
The Cepstrum can be defined as the Fourier transform of the log of the spectrum. Given a noise free trace in time (t) domain as x (t) obtained by convolution of a wavelet and reflectivity series r and assuming X (f), W (f) and R (f) are their frequency domain equivalents, then ,Since the Fourier transform is a linear operation, the Cepstrum is

$$F\,[\ln(\mathrm{mod}\ X)] = F\,[\ln(\mathrm{mod}\ W) + F[\ln(\mathrm{mod}\ R)] \qquad (1)$$

To distinguish this new domain from time, to which it is dimensionally equivalent, several new terms were coined. For instance, frequency is transformed to Quefrency, Magnitude to Gamnitude, Phase to Saphe, Filtering to Liftering, even Analysis to Alanysis. Only Cepstrum and Quefrency are in widespread today, though liftering is popular in some fields (Hall, 2006). Fourier analysis decomposes a signal into its sinusoidal components based on the assumption that the frequency is not changing with time (stationary). This contrasts with complex trace analysis which is based on the generalized assumption that a signal is changing with time (non-stationary) if it is expressed as a function of time and frequency. This enables instantaneous attributes to be computed (Robertson and Fishier, 1989). The measured seismic signal represents the real component of an analytic signal. While the Fourier transform (FT) represents the frequency and phase spectra of a signal, assumes stationarity and highlights the average properties of its dominant portion, assuming analytical, the Hilbert Transforms (HT) computes the imaginary part and assumes non-stationarity of the signal. The Hilbert transform, despite its good resolution capability was used in this study as a reconnaissance transform to highlight the instantaneous attribute sections of the sand interval studied in order to understand the geology of the survey.

METHOD

The 3D seismic and well data used in this study were obtained over 'Tomboy' 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 Inlines and 220 Crosslines. Some of the log types provided are Gamma-Ray (GR), Self-Potential (SP), Resistivity, Density, Sonic, etc. Lithologic logs of Gamma-Ray and Self Potential were fist plotted to identify the sand (hydrocarbon) unit of interest (5490-5553 ft) and then correlated with Resistivity logs .This Interval corresponds to (2.440-2.468 seconds) using time-depth conversion. It is important to state that rather than use measured seismic line near the well (TMB 01) under examination for seismic-to-well tie, as is traditionally done, a line(arbitrary) connecting the entire wells was constructed to enhance the seismic data quality for the tie since it integrates the general geologic information in the survey. Complex trace analysis by Hilbert transform of the arbitrary line was used to examine major variations in the data over a wider time gate of 2.200 to 3.250 seconds. However, data extracted at reservoir top (2.440second) covering the entire survey were used to compute the Cepstral maps and interpreted. The displays start from extracted section to its pseudo-sections, through well log analysis, comparative display of line plots of Spectrum and Cepstrum of top of reservoir interval with standard plots, and end at Cepstral reservoir maps. The circled spot on the arbitrary section indicating fault and original seismic amplitude map serves as reference for interpretation. Other inferences can be drawn.

RESULTS AND ANALYSIS

Figure 1 shows map of the Niger Delta indicating province outline of maximum petroleum system and map of Marginal Fields in Nigeria. Tomboy Field, Niger delta and the base map of the study area are shown in Figure 2. Figure 3 shows an **a**rbitrary seismic line connecting the wells after interpretation and its Hilbert transform attributes. The well under study (TMB 01), a representative well in the survey used for the analysis (in view of its good data quality) is located at coordinates inline 5950 and crossline 1600. Two major faults, F1, F2 are shown bounding the well (TMB 01) at the reservoir interval under analysis 5490-5553 ft (2.440-2.468 seconds). The log plots are shown in Figure 4. The sand interval under consideration lies between depths 5490-5559ft corresponding to 2.440-2.468 two-way time in seconds and identified by a low on Gamma-ray log, a low on self potential log (lithologic logs) and correlated with a high on resistivity log. Recall that the computed instantaneous attributes for the pseudo -section assume non-stationarity of the signal in order to obtain a general but useful view of the geology of the survey, while for the same reason, complex Cepstral attributes were computed for the top slices of the reservoir. The pseudo-sections and maps were interpreted as described below.

Print ISSN: 2397-7728, Online ISSN: 2397-7736

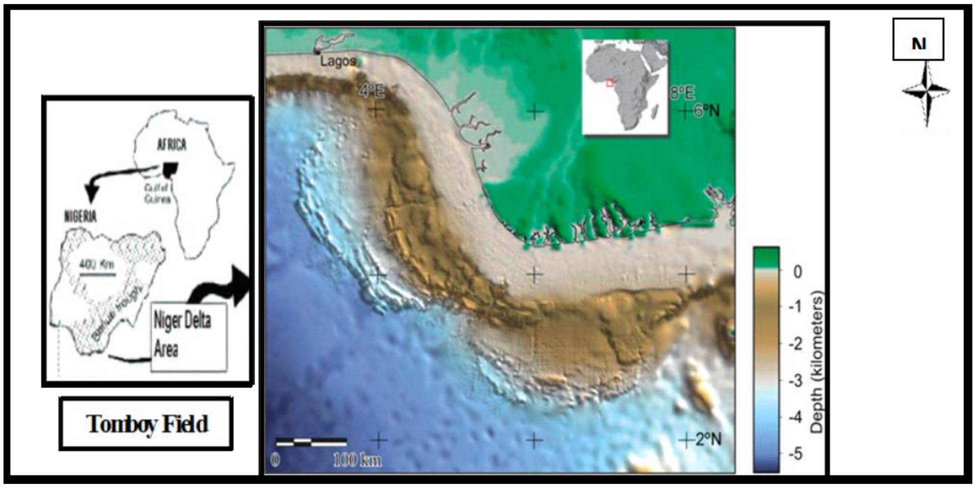
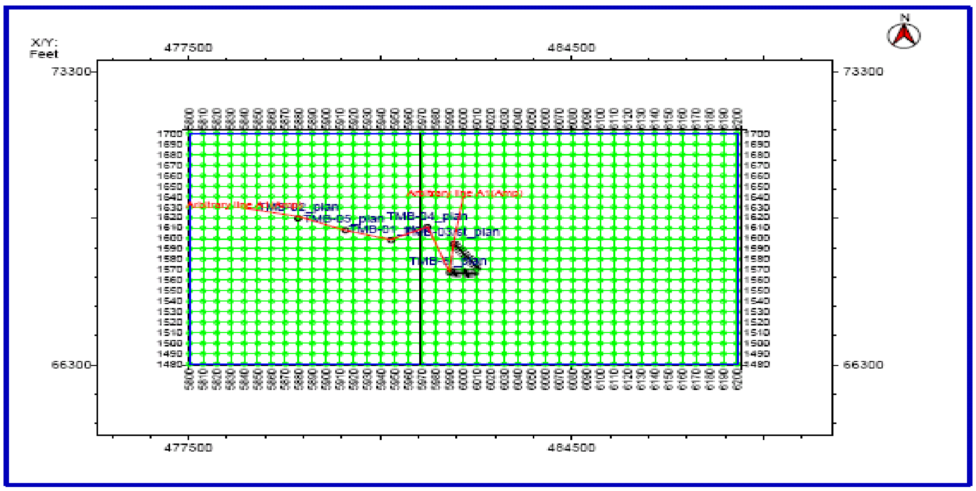


Figure 2: Tomboy Field, Niger Delta: (a) Bathymetric Sea-floor image of the Niger Delta obtained from a dense grid of two-dimensional seismic reflection profiles and the global bathymetric database showing the location of the Study Area **(b)** Base map of survey area showing the Arbitrary line(in Red). The Arbitrary line connects the entire six wells (black dots). The well under consideration is TMB 01 Crossline 5950, Inline 1600, left of the vertical line.

(a) Tomboy Field, Niger Delta (Smith and Sandwell, 1997, as cited in Corredor *et al*,, 2005).

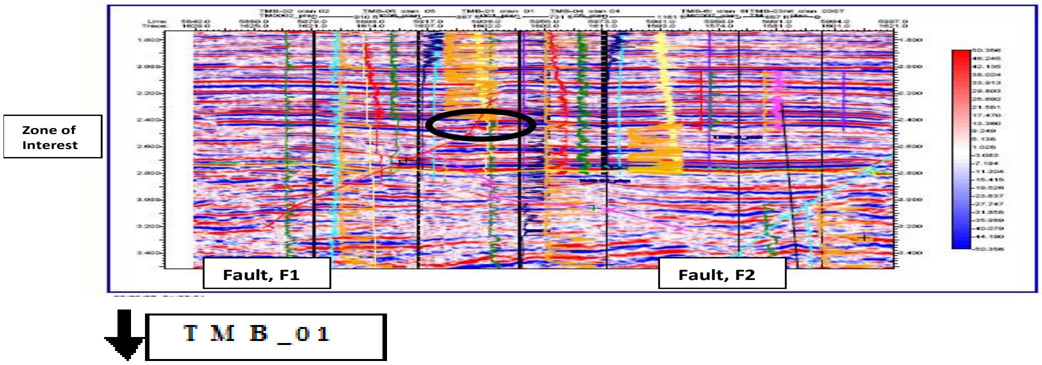


(b) Tomboy Field, Niger Delta: Base map of survey area showing the Arbitrary line (Red) in the field.

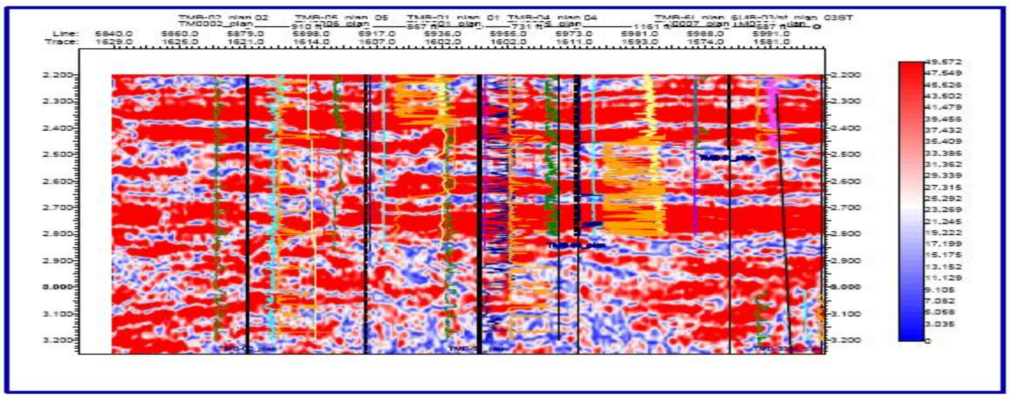
In seismic attribute analysis, amplitude or magnitude, or envelope indicates local concentration of energy, bright spots, gas accumulation, sequence boundaries, unconformities, major changes in lithology, thin bed tuning effects, etc; phase measures lateral continuity/discontinuity or faulting, shows detailed visualization of bedding configuration and has no amplitude information. In the case of the phase attribute, there is a flip owing to sign reversal (Jenkins and Watts (1968). The frequency attribute reflects attenuation spots, indicates hydrocarbon presence by its low frequency anomaly, shows edges of low impedance thin beds, fracture zone indication-appears as low frequency zones, and also indicates bed thickness.. Higher frequencies indicate sharp interfaces or thin shale bedding, lower frequencies indicate sand rich bedding, sand/shale ratio indicator (Subrahmanyam and Rao, 2008). In Cepstral domain, the Gamnitude, Saphe and Quefrency are interpreted in a similar manner to Magnitude, Phase and Frequency in the Spectral domain. In Figure 5(a) Cepstrum and Spectrum plots are compared with those of original data and log of magnitude of its spectrum while in 5(b) similar behavior of Cepstrum and Spectrum of seismic amplitude data at 2.440 seconds are presented. The Cepstral transform (CT) attributes map**s** are shown in Figure 6. In the Figure 6(a) Original Amplitude (b) Gamnitude (c) Saphe (d) Quefrency are presented. Gamnitude

Print ISSN: 2397-7728, Online ISSN: 2397-7736

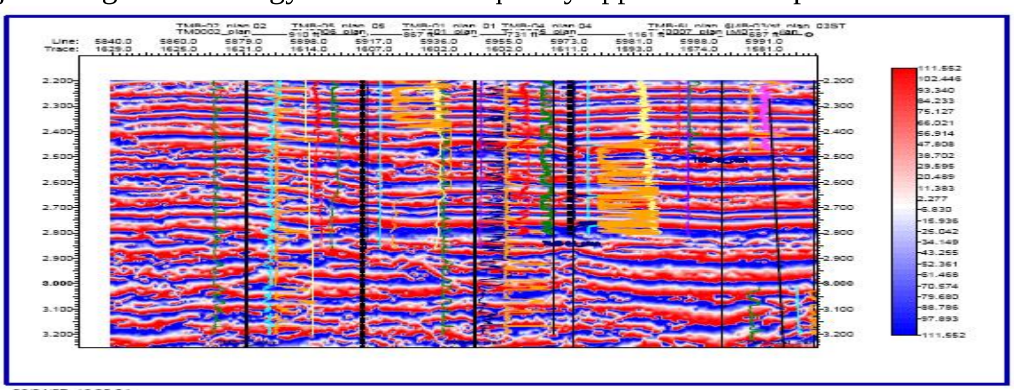
shows the sequence boundaries .Saphe highlights discontinuity and lithologic changes, while Quefrency (d) indicates fracture zone, hydrocarbon presence by its low values.



(a)Original Seismic Amplitude data interpreted



(b) HT Envelope of (a). This highlights discontinuities, faulting, and changes in deposition and major changes in lithology. It has low frequency appearance and positive values



(c)HT Instantaneous Phase of (a). Note the continuity/discontinuity of reflection events as compared to the original. It shows bedding configuration**.** The fault trace circled above is clearer

Vol.8, No.1, pp.45-58, 2021

Print ISSN: 2397-7728, Online ISSN: 2397-7736

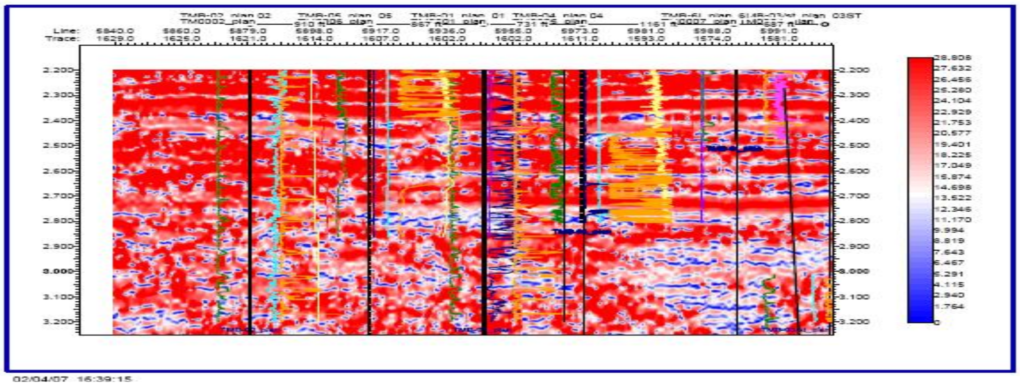
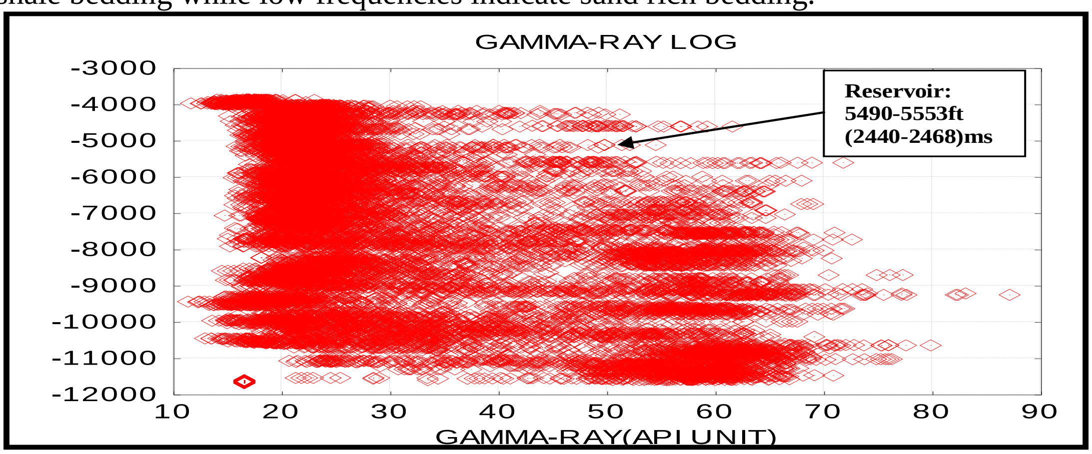
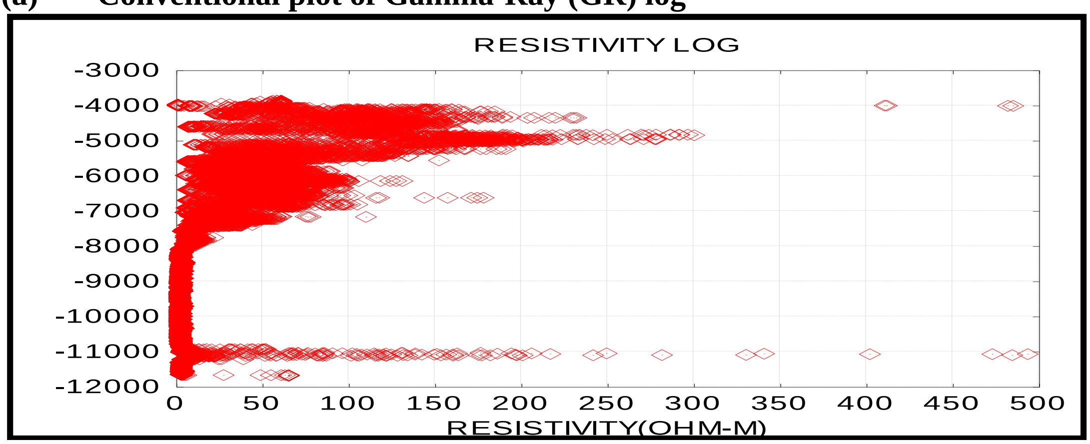


Figure 3:Tomboy Field, Niger elta. (a)Arbitrary line (original) after interpretation (b) HT Envelope of (a) (c)HT Instantaneous Phase of (a) (d)HT Instantaneous Frequency of (a):Two major faults,F1,F2 are shown bounding the wells at the reservoir interval under analysis 5490-5553 ft (2.440-2.468 seconds) .

(d) HT Instantaneous Frequency of (a). This attribute like phase is also independent of amplitude information. It indicates lithologic parameters. High frequencies indicate sharp interfaces or thin shale bedding while low frequencies indicate sand rich bedding.

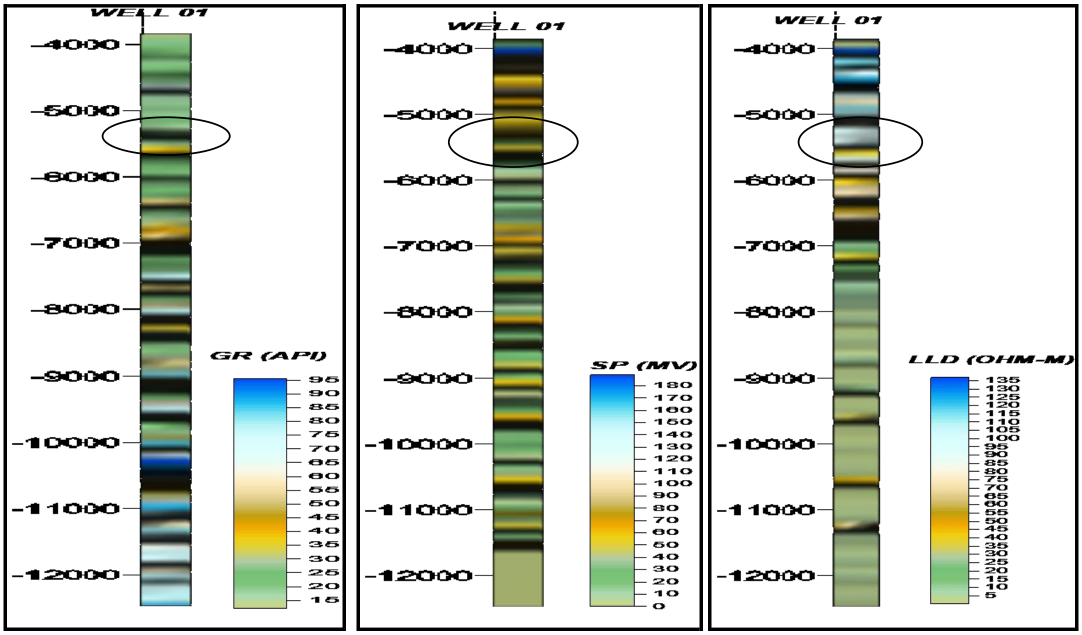


(a) Conventional plot of Gamma-Ray (GR) log



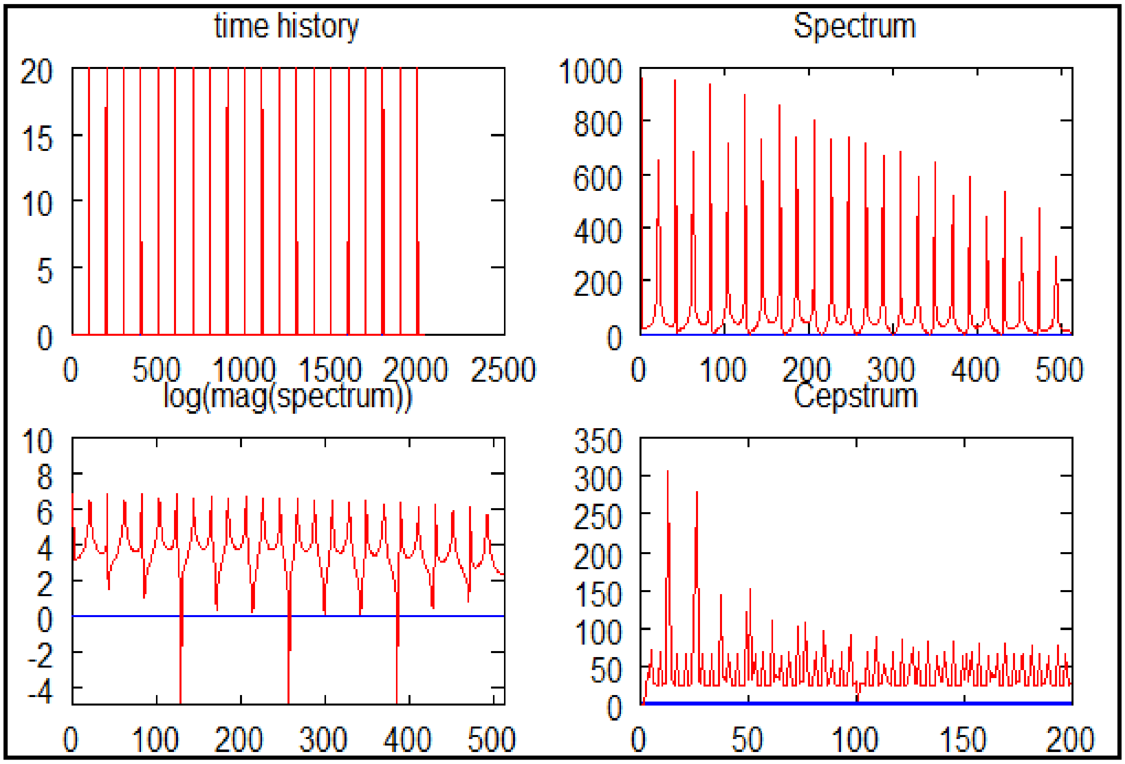
(b) Conventional plot of Resistivity (RES) log .

Print ISSN: 2397-7728, Online ISSN: 2397-7736

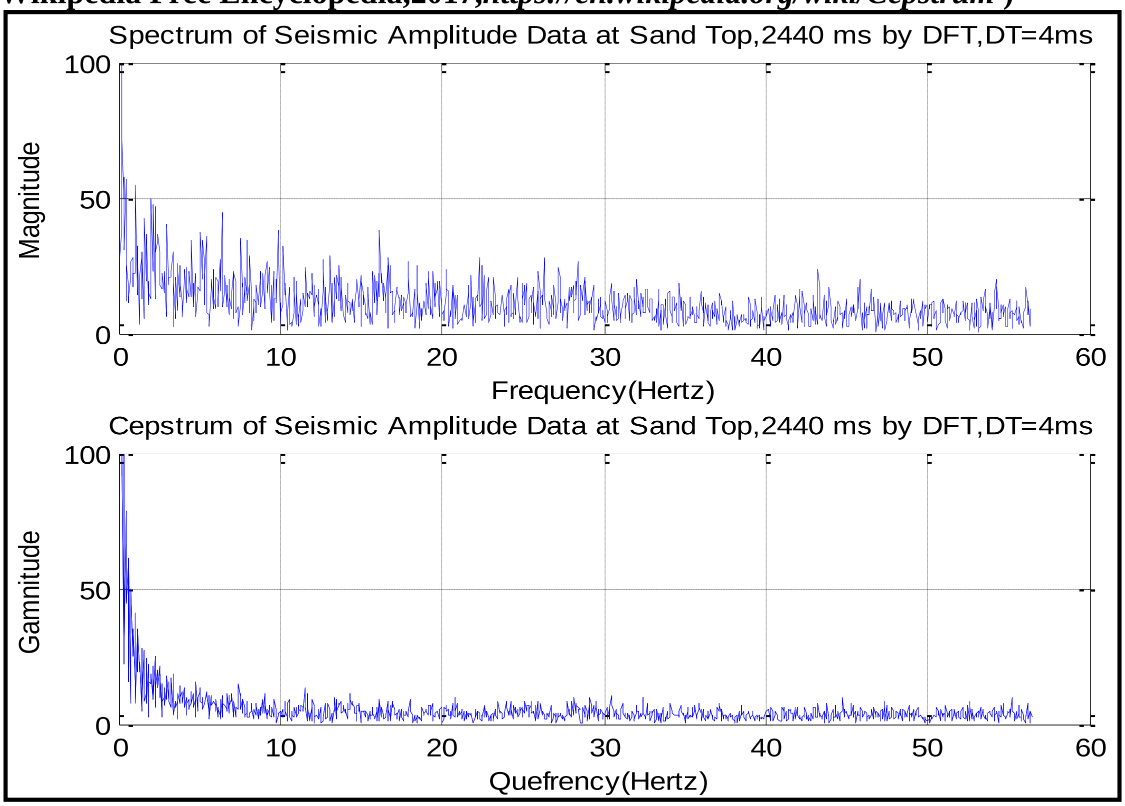


(c) Combination of Gamma Ray (GR), Self potential (SP) and Resistivity logs plotted in bands over same depth interval.

Figure 4: Tomboy Field, Niger Delta: Conventional plots of (a) GR log and (b) Resistivity log (c) Combination of Gamma Ray (GR), Self potential (SP) and Resistivity logs.The dark bands in (c) are indicative of noise, while low GR (green), low SP(green) and high Resistivity (RES/LLD, blue) are indicative of sand. The reverse is the case for shale.



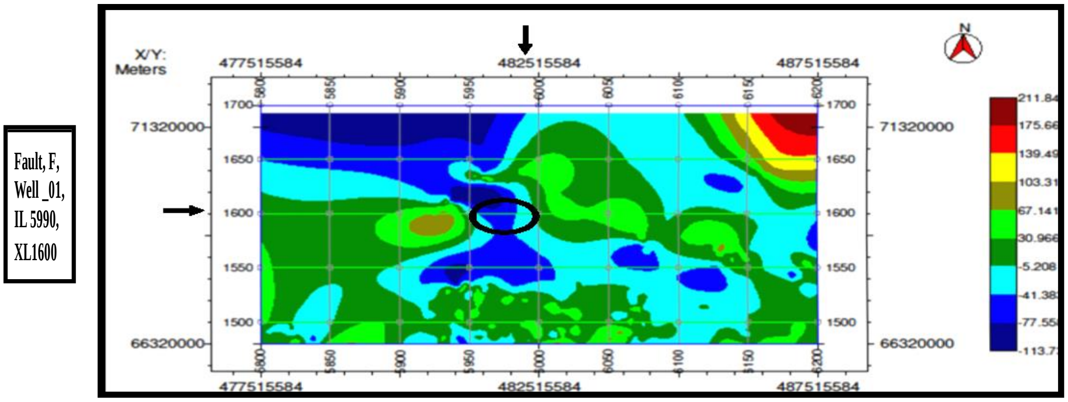
(a) Cepstrm and Spectrum compared with original data and log of magnitude of its spectrum (Source: Wikipedia Free Encyclopedia,2017,*https://en.wikipedia.org/wiki/Cepstrum*)



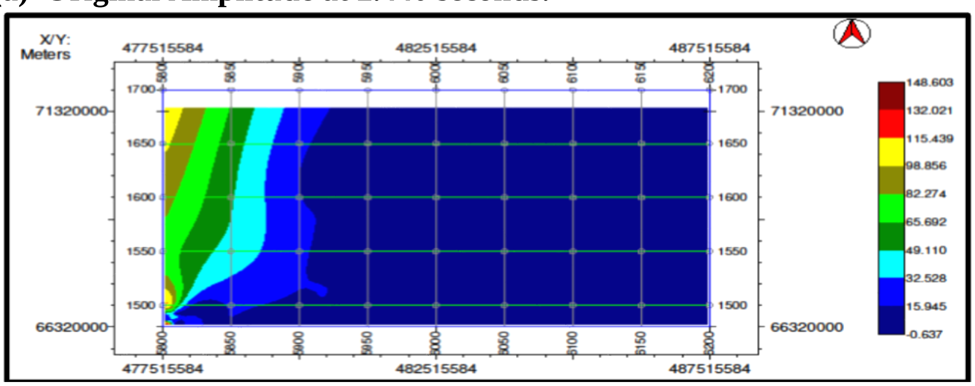
(b) Cepstrum and Spectrum of seismic amplitude data at 2.440 seconds

Print ISSN: 2397-7728, Online ISSN: 2397-7736

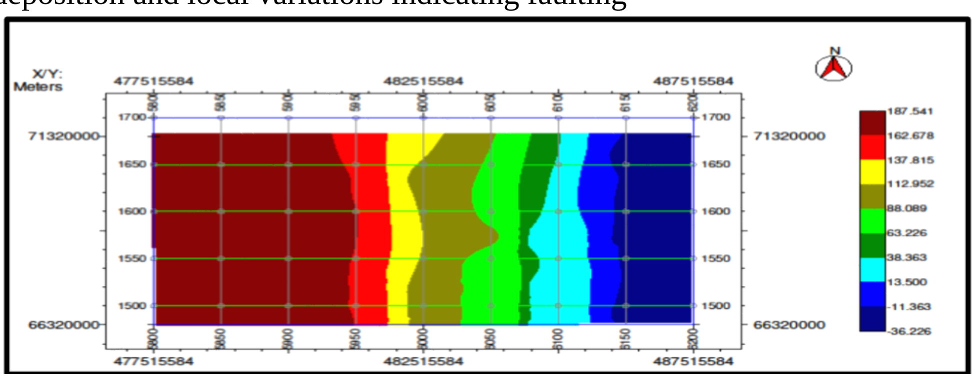
Figure 5: (a) Cepstrum and Spectrum compared with original data and log of magnitude of its spectrum (b)Cepstrum and Spectrum of seismic amplitude data at 2.440 seconds. Observe that lower (subtle/stratigraphic variations) amplitude values are recovered in Cepstrum domain over the same intervals.



(a) Original Amplitude at 2.440 seconds.



(b)Cepstral Transform (CT) Gamnitude of (a). Highlights discontinuities, changes in deposition and local variations indicating faulting



(c)Cepstral Transform (CT) Saphe of (a). The precise discontinuity and lithologic changes reflected here when compared to the original are evident

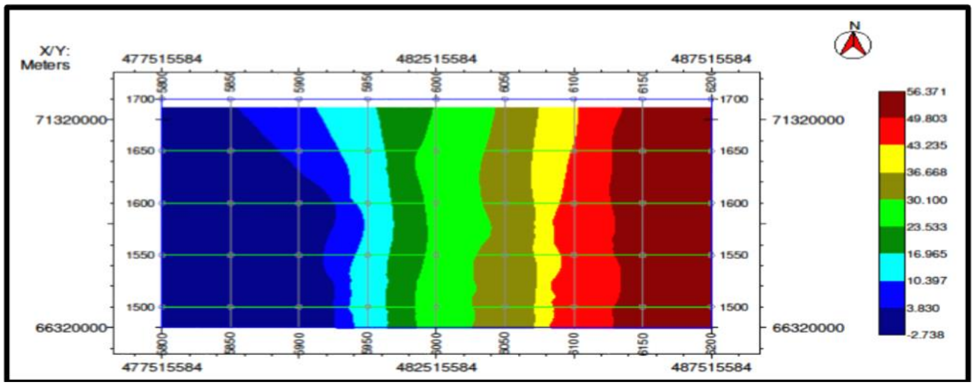


Figure 6: Tomboy Field, Niger Delta: Cepstral transform (CT) attributes.(a) Original Amplitude (b) Gamnitude (c) Saphe (d) Quefrency. Gamnitude shows the sequence boundaries .Saphe highlights discontinuity and lithologic changes while Quefrency(d) indicates fracture zone, hydrocarbon presence by its low values.

(d) Cepstral Transform (CT) Quefrency of (a). The low frequency values represent the sand zones while high frequency vales represent thin shale bedding. The intermediate frequencies are the sand/shale regimes. The implication of this result is that for field development, drilling direction should be to the west. Most of the drilled wells of good quality are between yellow and light blue zones. Deep blue zone is undeveloped. The wells of poor data quality (or dry) are in the red and brown zones (extreme right).

CONCLUSIONS

In this study, an application of Cepstral transform for unmasking vital sub-seismic stratigraphic details embedded in dense 3D seismic data from Niger Delta has been undertaken. The study investigated a practical approach to seismic data interpretation in Quefrency domain. The aim of the study was to develop a robust technique for mapping subtle stratigraphic units which are usually masked during normal data interpretation using a developed complex Cepstrum algorithm 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, character and epicenter in order to facilitate the drilling of wells with improved confidence. The results obtained show the resolution capability of the complex Cepstrum in separating source and filter and the detection of local periodicity which are critical geological parameters in understanding stratigraphic details and hydrocarbon fairways which impact on enhanced recovery. This study is applicable in areas of uncertainty in data and time such as in complex geologic environments as in deep waters, marginal fields, etc. Several of such marginal fields (undeveloped) located onshore and in the shallow waters exist in Nigeria.

Acknowledgements

The authors thank Chevron Corporation, Nigeria for making the seismic and well data available for use. We are indebted to Shell Nigeria for the use of the Kingdom Suite Software at its work station at Department of Geology, Obafemi Awolowo University (O.A.U.), Ile-Ife, Nigeria,University of Port Harcourt, Nigeria, Petroleum Training Institue, Effurun, Nigeria and the Federal University of Petroleum Resources, Effurun, Nigeria for the use of their laboratories.

References

Avbovbo, A. A. (1978). Tertiary lithostratigraphy of Niger Delta. American Association of Association of Petroleum Geologists, Tulsa, Oklahoma, pp. 96-200.

Bogert,B.P. Healy, M. J. R. and Tukey,: J. W. "The Quefrency Alanysis [*sic*] of Time Series for Echoes: Cepstrum, Pseudo Autocovariance, Cross-Cepstrum and Saphe Cracking". *Proceedings of the*

Symposium on Time Series Analysis (M. Rosenblatt, Ed) Chapter 15, pp.209-243. New York: Wiley, 1963

Corredor, F., Shaw, J. H., and Bilotti, F.,(2005). Structural styles in the deepwater fold and thrust belts of the Niger Delta: American Association of Petroleum Geologist Bulletin, v. 89, no. 6, pp. 753– 780.

Dobrin, M.B.and Savit, C.H. (1988): Introduction to Geophysical Prospecting, 4tth edition, New York, Mc Graw-Hill. PP. 286-387

Doust, H. and Omatsola, O. (1990). Niger Delta, In: Edwards J. D. and Santoyiossi, P. A. (eds.), Divergent and Passive margin basin. American Association of Petroleum Geologists,Memoir48,pp.201-238

Hall, M. (2006): Predicting Stratigraphy with Cepstral decomposition. The leading Edge 25 (2), February (Special issue on spectral decomposition). doi:10.1190/1.2172313

Jenkins, G.M and Watts. D.G. (1968).Spectral analysis and its applications, Published by Boca Raton, Fl.: Emerson-Adams Press 525P, http://trove.nla.gov.au/version/39694417.

Jeong,J (2009):Kepstrum Analysis and Real-Time Application to Noise Cancellation, Proceedings of the 8th WSEAS International Conference on Signal Processing, Robotics and Automation pp. 149-154 issn:1790, isbn: 978-960-474-054-3

Marginal Field (Oil and Gas) *https://www.slideshare.net/karim3691/marginal-oil-fields-final* Mar 14, 2014

Marginal Fields in Nigeria, The Department of Petroleum Resources, 2017

Marginal-Field-Oil-and-Gas: *https://definitions.uslegal.com/m/marginal-field-oil-and-gas/* , 1997-2016 US Legal, Inc.

Merki, P. J. (1972).: Structural Geology of the Cenozoic Niger Delta. In: Dessauvagie, T. F. J. and Whiteman, A. J. (eds), African Geology, University of Ibadan Press, Nigeria. pp. 635-646.

Ofuyah, W.N.**,**Alao,O.A., and Olorunniwo, M.A.(2014): The Application of Complex Seismic Attributes in Thin Bed Reservoir Analysis,Journal of Environment and Earth Science, Vol.4, No.18, 2014 ,PP. 1-12

Partyka, G., Gridley, J. and Lopez, J. (1999): Interpretational Applications of Spectral Decomposition in Reservoir Characterization, The Leading Edge, March, PP. 353-360

Oppenheim,A.V (1965): "Superposition in a Class of Nonlinear Systems" Ph.D. diss., Res. Lab. Electronics, M.I.T.

Oppenheim, A.V and Schafer, R. W.(1968). "Homomorphic Analysis of Speech", IEEE Trans.Audio Electro acoust, Vol. AU-16, pp. 221-226, R.W. Schafer, Echo Removal by Discrete Generalized Linear Filtering:Res. Lab. Electron.MIT,Tech.Rep.,466,1969.

Oppenheim ,A.V.and Schafer R. W(1975); "Digital Signal Processing", (Prentice Hall)

Petroconsultants Inc. , (2001): Petroleum Exploration and Production Database: Houston, Texas,

Robinson, E.A.(1954) MIT Report; "Predictive Decomposition of Time Series with Applications to Seismic Exploration", Geophysics 1967 vol.32, pp.418-484;

Robertson, J.D. and Fisher, D.A. (1989): Complex Seismic Trace Attributes, In: A.R. Brown, (Editor), Seismic Interpretation Series, Society of Exploration Geophysicists Vol. 1, PP. 49 – 53.

Satinder, C., Marfurt, K. J., Misra, S., (2011). Seismic Attributes on Frequency-Enhanced Seismic Data; Recovery-2011

Silvia, M.T. and.Robinson, E.A 1978: "Use of the Kepstrum in Signal Analysis" Geoexploration, Volume 16, Issues 1-2, April 1978, PP. 55-73.

Stacher, P. (1995). Present Understanding of the Niger Delta Hydrocarbon Habitat; In:M.N. Oti and G.Postma (eds), Geology of Deltas; A.A.Balkema, Rotterdam;pp.257– 267.

Tuttle, Michele; Charpentier, Ronald; Brownfield, Michael. "The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa". United States Geologic Survey. United States Geologic Survey. 2015.

Weber, K. J. (1987). Hydrocarbon Distribution patterns in Nigeria Growth Fault Structure Controlled by Structural Style and Stratigraphy, Journal of Petroleum Sciences and Engineering, Vol. 1, PP. 91-104.