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Comparism of Discrete Fourier Transform and Short Time Fourier Transform in Mapping Stratigraphic Features In TMB Field, Niger Delta

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Abstract
The research compares the Short Time Fourier Transform (STFT) and Discrete Fourier Transform (DFT) methods on seismic signal processing in mapping hidden stratigraphic features in the 3D seismic data. Seismic data volume, suites of well logs and checkshot data were used for this research. The software used for this research is MATLAB and Suffer-8 Software. An alternation of sand and shale lithology was delineated in the gamma ray logs. The reservoir window/interval ranging in depth from 6300ft – 6384ft, was converted to time using check shot and tied to the seismic data. The reservoir interval (sand - 2.440sec to 2.468sec) in the seismic data was then divided at an interval of 4ms and decomposed with the STFT and DFT. A total of 10 slices was obtained between the top of the sand interval (2.440 sec) and the base of the sand (2.468 sec). The original seismic magnitude and phase was plotted for the top sand (2.440 sec) and transformed using the DFT and STFT in MATHLAB Software determined the domain frequency in terms of seismic attributes, magnitude and frequency. The identified lithologies in the reservoir bandwidth across the field comprise sand and shale. The results revealed that the sands have low frequency while the shale has high frequency. It was observed that the amplitude decreased with depth which is an indication of changes in formation fluid and sequence boundary. From frequency maps (slices) at data sampling interval (4ms) over the reservoir window, the STFT approach gave a detailed lithology variation compared with DFT.

Keywords: *Short Time Fourier Transform (STFT), Discrete Fourier Transform (DFT), MATLAB, Stratigraphic features.*

Introduction

Seismic signal transformation helps to improve seismic data visibility through change of seismic data from amplitude measurement to another (transform) - frequency domain with the aid of some mathematical tools such as Fourier transform and Hilbert transform. This technique is used to separate fact from artefact and to extract rock-fluid information from the seismic data (Ofuyah et al, 2014). The Fourier transform is very important in seismic data analysis as It is used in almost all stages of seismic data processing. A seismic trace represents a seismic wave field recorded at a receiver location. The seismic data can be described completely as a discrete sum of a number of sinusoids — each with a unique peak amplitude, frequency, and a phase. The decomposition of a seismic trace into its components can be obtained by the forward Fourier transform. Fourier transform helps in understanding the components of the trace and does not normally allow scrutiny of local changes or differences (Tanner *et al*, 1979; Robertson and Nogami, 1984). 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 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, 1988). Traditional seismic data do not solve subtle geological attributes, as it is band- limited. In order to improve resolution, seismic source parameters such as wavelet type and frequency bandwidth defining detection and imaging capabilities should be considered (Okaya, 1995). Spectral decomposition techniques provide enhanced frequency resolution and 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 goal of stratigraphic exploration is to elucidate deep seated features associated with low frequencies. In this study, the spectral decomposition method using a Windowed or Short-Time Fourier Transform is used in analysing seismic data from the Niger Delta to delineate subsurface stratigraphy. Niger Delta is classified as one of the most prolific oil- producing Tertiary Deltas in the world, comparable to the North Slope of Alaska, the Mississippi, the Oronoco and the Mahakam (Reijers *et* *al*., 1997). The geology, structural geology, biostratigraphy, stratigraphy, sedimentology, petroleum geology and reservoir studies has been undertaken 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), Oyanyan and Ideozu (2016), Ideozu and Bassey (2017), Awe and Ideozu (2017), Iheaturu and Ideozu (2017), Ideozu *et al* (2018), Ejieh and Ideozu (2018), Awe *et al* (2018), Awolola and Ideozu (2019 and Ndokwu (2019) and many others. See Figures 1 – 2.

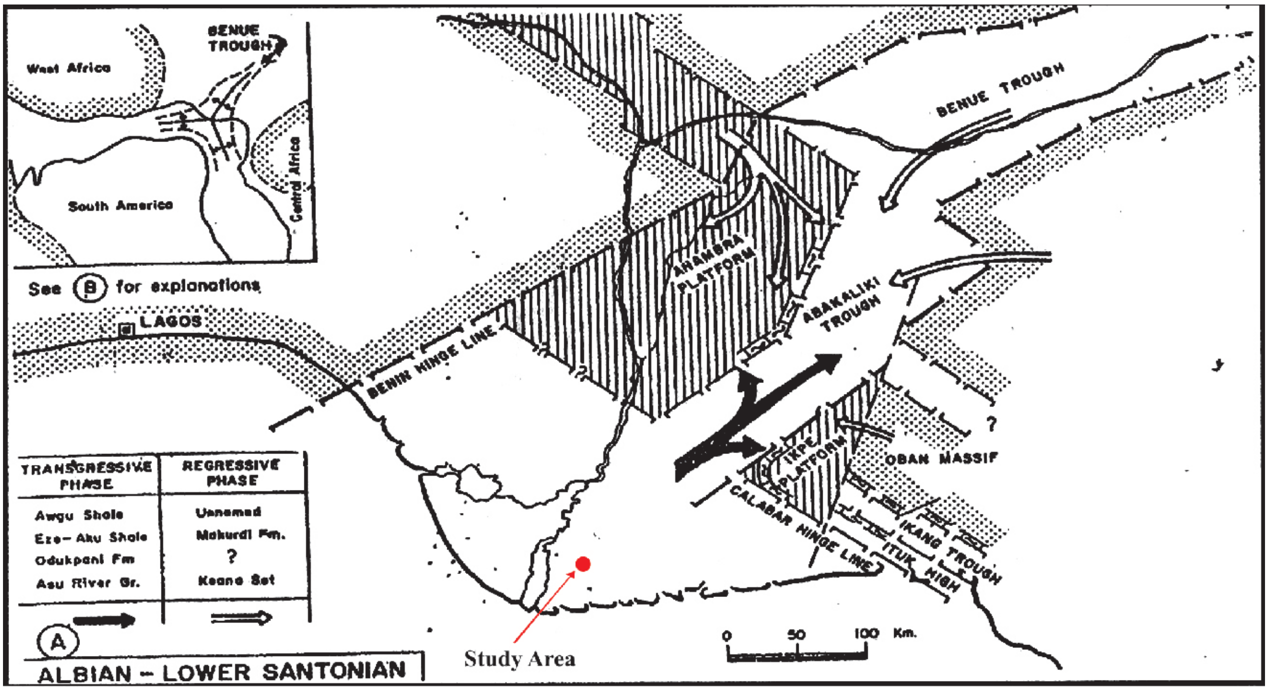

Fig. 1: Niger Delta Tectonic Map (Modified after Kogbe, 1989).

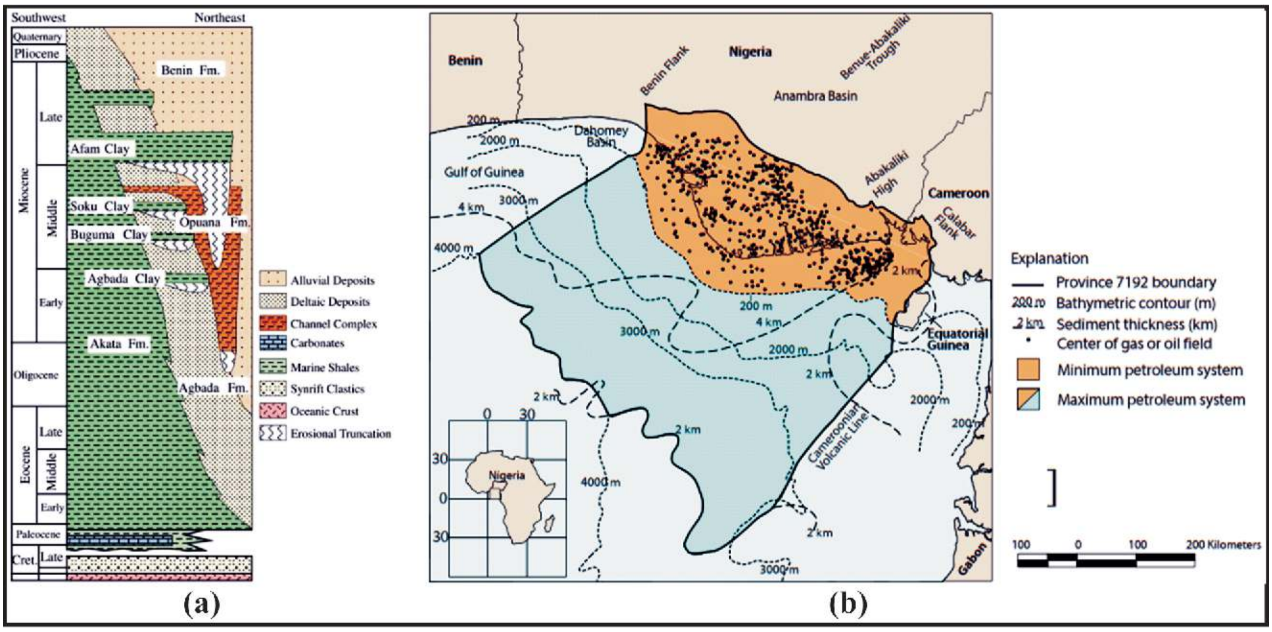

Fig. 2: (a) Stratigraphic column depicting the three Niger Delta formations (modified from Lawrence *et al*., 2002). (b) Cameroon and Nigeria Index Map. Niger Delta Map showing Province outline (petroleum system) and bounding structural features (Petroconsultants, 1996).

Materials and Methods

The materials used for this research include: Seismic Amplitude Data, Well Log Suites, Base Map of Field and Check Shot Data. The research was carried out in a Workstation and MATLAB software environment. The procedures adopted involved lithology and reservoir identifications from well logs. The Discrete Fourier Transform (DFT) and Short Fourier analysis were carried out within the identified reservoir of interest. Discrete Fourier Transform (DFT). The Discrete Fourier Transform (DFT) technique is the digital correspondent of the continuous Fourier transform and is expressed as:

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

Where,
w = the Dual Fourier of the variable't'. If 't' signifies time, then 'w' represents the angular frequency which is akin to the temporal frequency 'f' (Yilmaz, 2001). Also, f(w) comprises of both real (Fr(w)) and imaginary (f_i(w)) components. Hence,

$$f(w) = f_r(w) + if_i(w) \quad \text{..(2)}$$
$$A(w) = [f_r^2(w) + f_i^2(w)]^{1/2} \quad \text{.......................................(3)}$$
$$Ø(w) = \tan^{-1}[f_i(w)/f_r(w)] \quad \text{..................................... (4)}$$

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

Short Time Fourier Transform (STFT) is an analysis with fixed resolution. It maps 1-D to 2-D frequency-time plane from a seismogram. It is driven by the need for a spectral representation that 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 is expressed as follows:

$$STFT(t, f) = \sum f(t) g * [t - F] \exp(-i2ft) \quad \text{....(5)}$$

were '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).

Results and Discussion

The results of this research is presented in Figures 3 – 10. The interpretation of the well log for well 06 shows that two major lithologies sand and shale are present in the studied section (Figure. 3-4). In sedimentary formations, high Gamma Ray log reading indicate shale while low Gamma Ray log readings indicate sand / sandstone. This is because of the presence of high radioactive elements in shale and clay. Formations with very low radioactivity are referred to as clean formations, unless it is contaminated with granite wash, volcanic ash or dissolved radioactive salts in the formation fluid. The sand interval used for this study occurs within 6300ft to 6384ft as indicated with a red rectangle across the well logs.See Figure 3. To have a clearer picture of the sand body, it was zoomed in for better examination. (See Figure 4). The established sand depth interval 6300ft – 6384ft was converted to time (ms) using check shot tied with 2.440sec to 2.468sec in the seismic data. The seismic data over the established sand interval (reservoir window) 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, between the top of sand (2.440sec) and base (2.468sec) of the sand interval. Figure 5 shows the horizontal sections of the time slice for 2.436sec, 2.452sec and 2.472 sec in to determine how the sand interval changes with depth. The frequency distribution of the sand body was transform with STFT at different bandwidth to obtain the Magnitude, Phase and frequency. (See Figures 5 to 10). The results of the transform, is based on 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. The time slice (amplitude) of the established 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 (Awolola and Ideozu, 2019). 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.

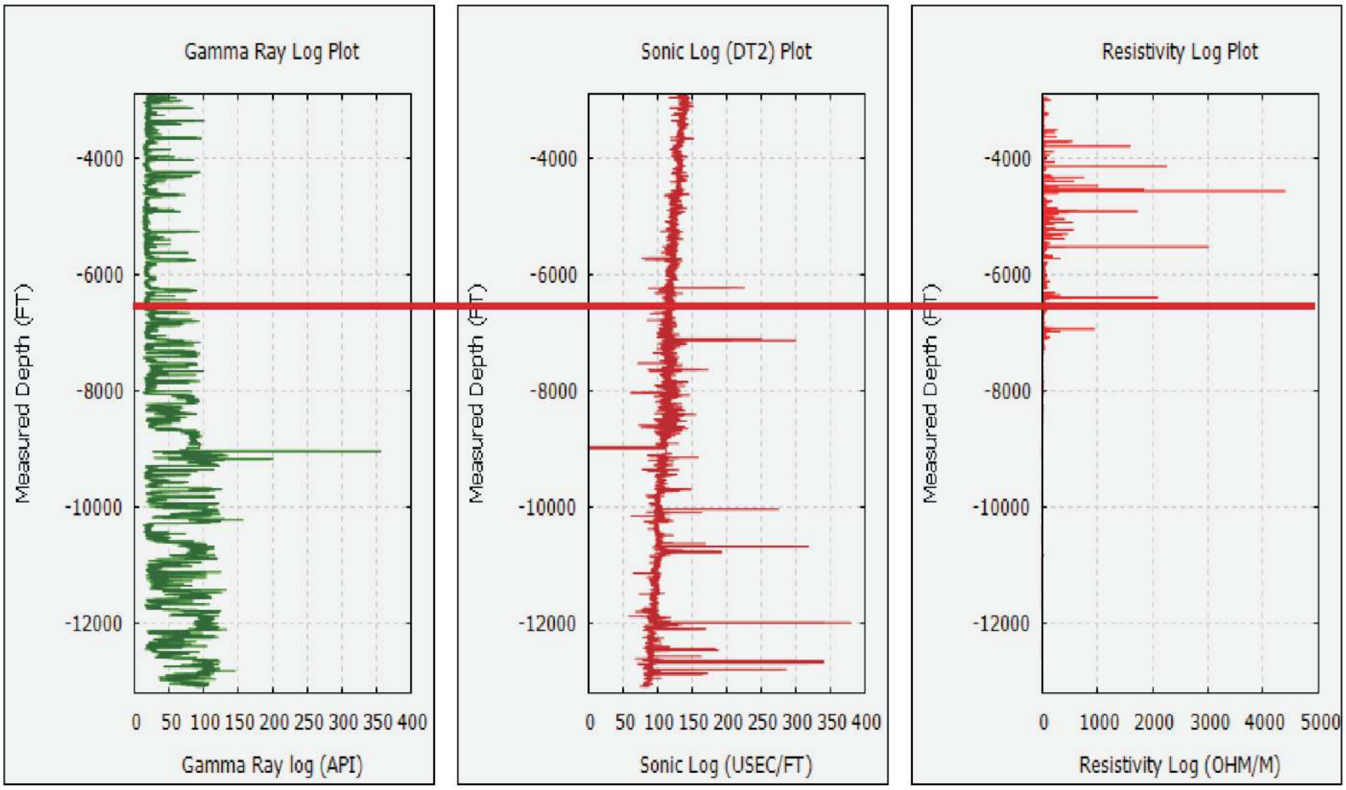

Fig. 3: Plot of whole Gamma Ray, Sonic, and Resistivity data respectively for Well 06 with red rectangle across showing the sand interval established.

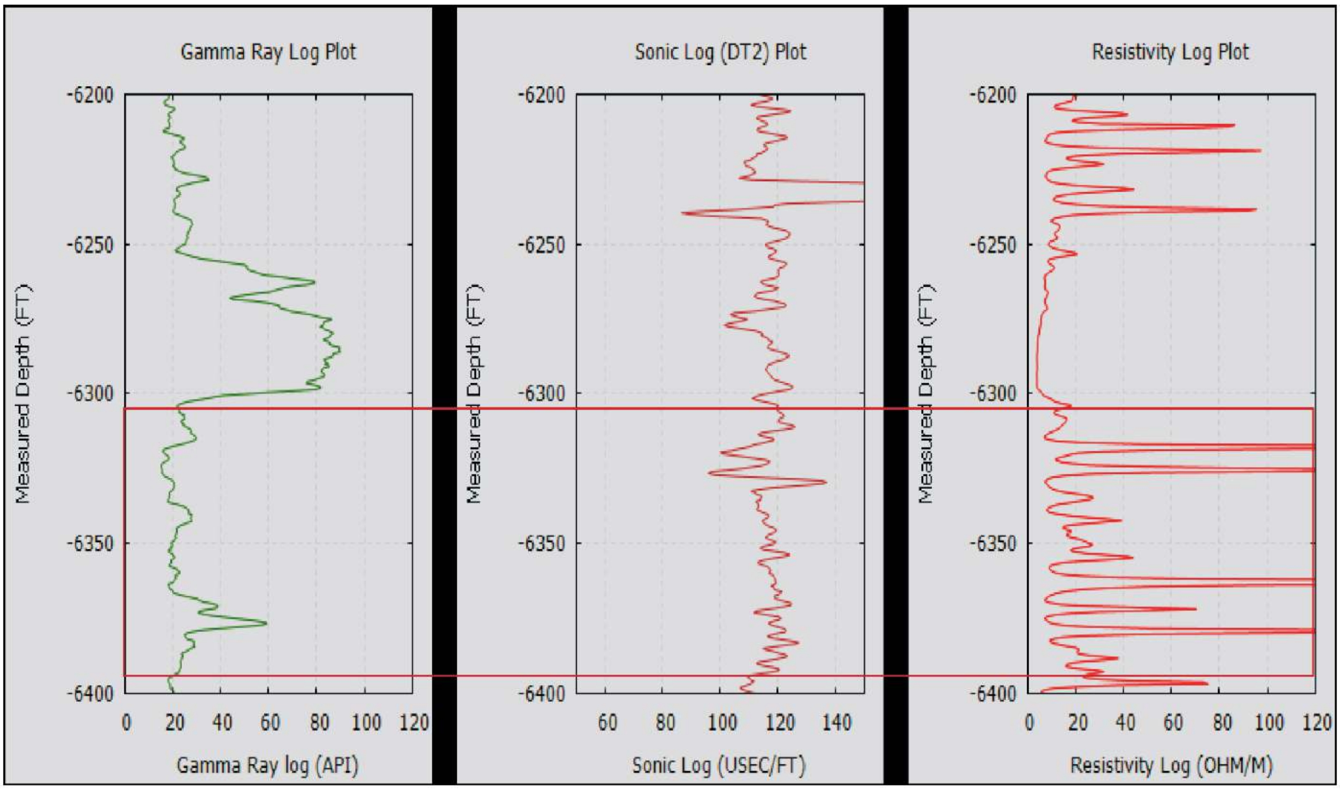

Fig. 4: Plot of Gamma Ray, Sonic and Resistivity data respectively plotted for some parts of the dataset for Well 06 with the red rectangle across showing the sand with depth interval 6300 – 6384ft.

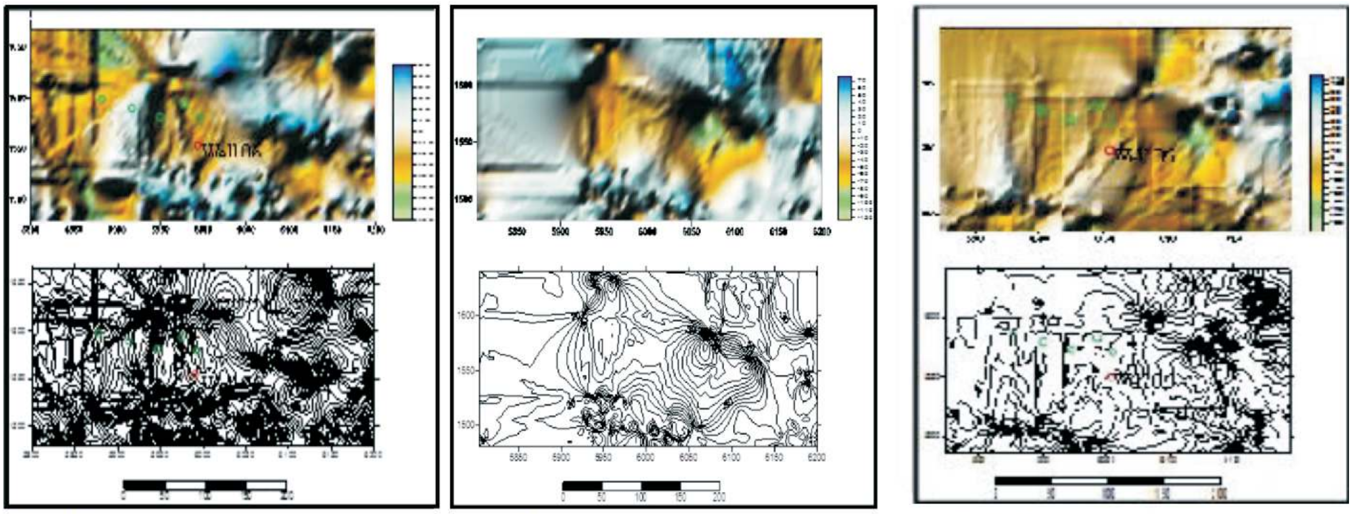

Fig. 5: Time slices Amplitude at 2.436sec, 2.452sec and 2.472sec selected sand interval showing variation of reservoir character with TWT and red ring signifying well in use.

Figure 6 is the map of the full bandwidth short time Fourier transform of top of the 2.440sec with no distinct stratigraphic features due to combination of all the frequency. The 0-5Hz frequency map of the sand top (2.440sec) slice presented in Figure 8, suggests that the magnitude values are similar in Well 01, Well 02 and Well 05 that is same sequence boundary 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). The variation could be due to difference in fluid content or lithology (Ofuyah *et al*, 2014; Awolola and Ideozu, 2019). The bandwidth of 45-55 Hz shows the same lithology type in the various wells as bandwidth 0-5Hz and 0-15 Hz. Figure 5, shows that the amplitude decreases with depth. The magnitude is low and almost uniform which is an indication that the sequence boundary could not be established. The phase decreases towards the eastern region. The frequency increases from west to east which is an indication that the western region contains sand while the eastern portion is shaly. The magnitude of the STFT is moderate and almost uniform within the top surface of the sand body. The phase is high in the western portion and moderate in the east. The frequency is high in the east and low in the west which is an indication of shale to sand (Partyka *et al*, 1999; Awolola and Ideozu, 2019). The magnitude, phase and frequency analysis of the STFT for various frequency bandwidth of the top sand body shows that for frequency map of STFT within frequency range of 0-5Hz shows that the phase ranges between -5 to 55 and it increases eastward. The frequency decreases westward and indication that it is shaly in the western region - frequency ranges from 0.2 to 4.8Hz. The frequency map for the STFT for frequency range between 0-15Hz shows that the frequency increases towards the east which is also shows that the west is shaly than the eastern part. The STFT map is moderate in the east and west but high in the middle. The magnitude is low and uniform in the whole surface. The frequency map for STFT for frequency interval between 45-55Hz shows that the frequency ranges from 4.5 to 55 Hz and it increases towards the east from west - the phase ranges from -100 to 0. The phase is high in the west and low in the east and the magnitude ranges from -2 to 22.

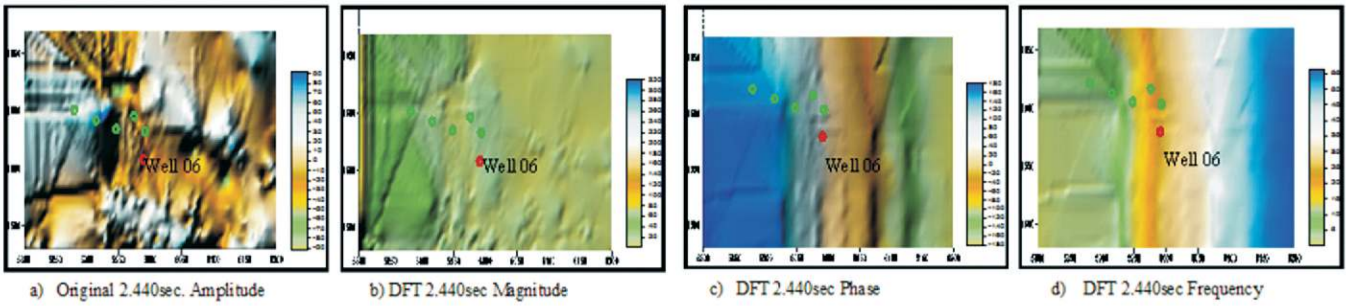

Fig. 6: Discrete Fourier Transform of the established Sand Top (2.440sec).

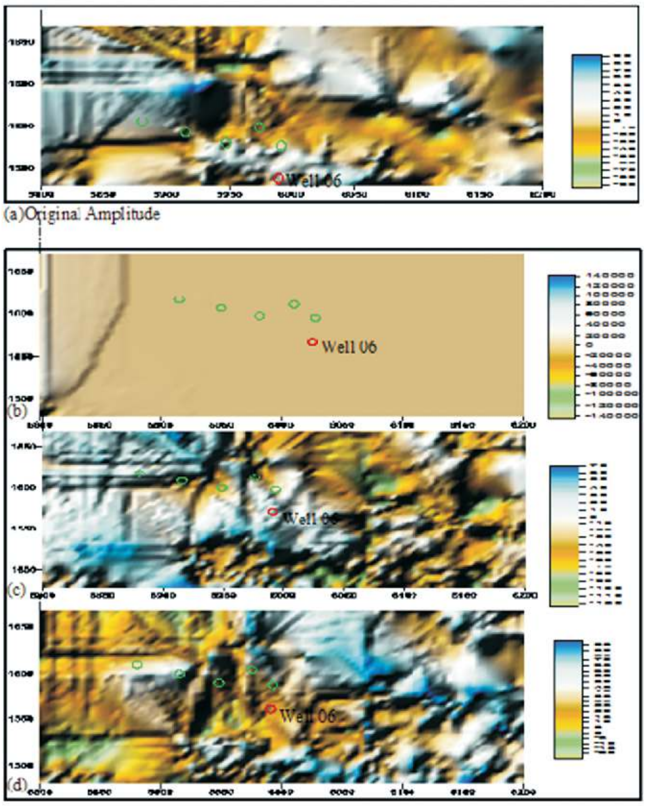

Fig. 7: Original and full bandwidth STFT attributes; from top (a) Original amplitude (b) Magnitude (c) Phase and (d) Frequency.

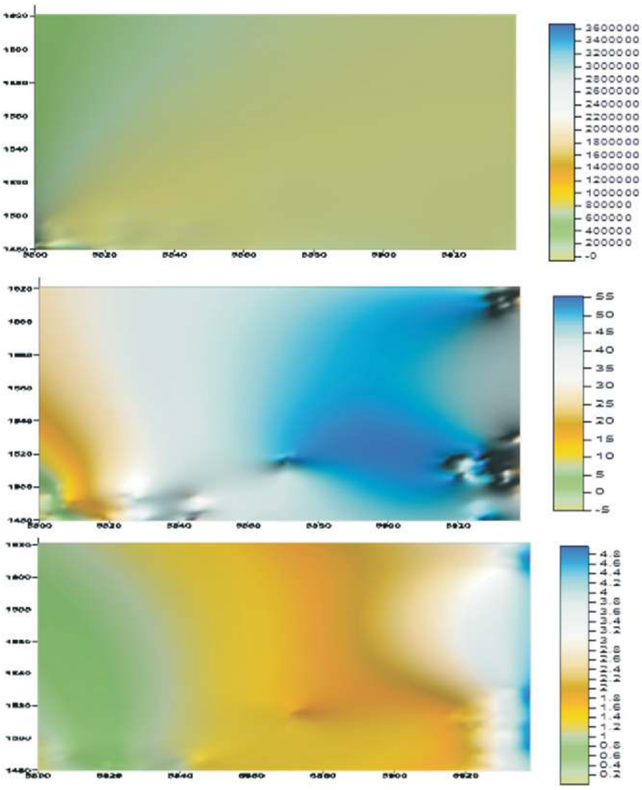

Fig. 8: Frequency maps; bandwidth STFT (0-5Hz). (a) Magnitude (b) Phase and (c) Frequency.

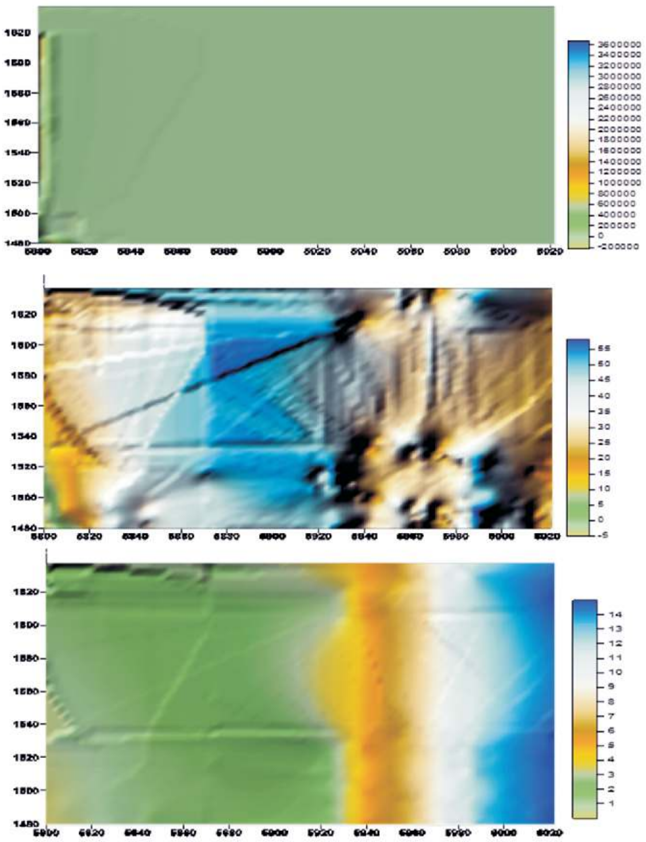

Fig. 9: Frequency maps; bandwidth STFT (0-15Hz) (a) Magnitude (b) Phase and (c) Frequency.

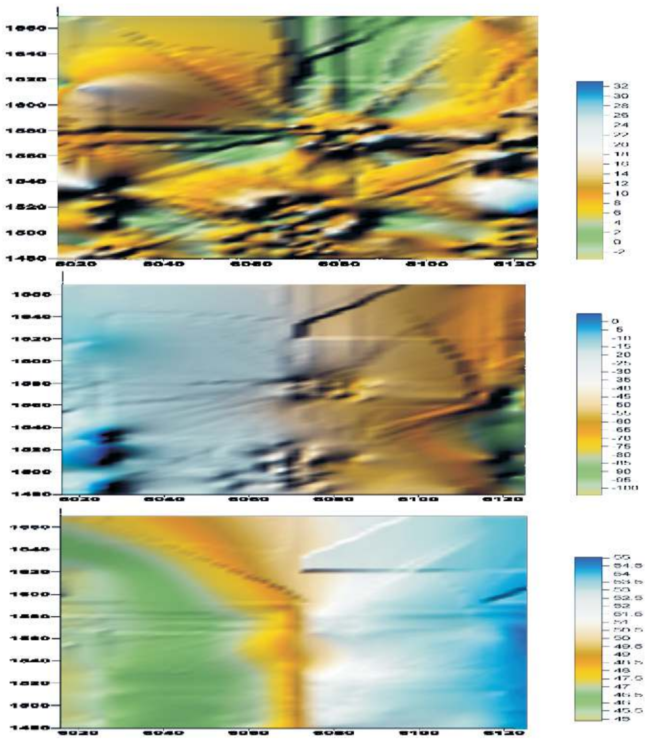

Fig. 10: Frequency maps; bandwidth STFT (45-55Hz) (a) Magnitude (b) Phase and (c) Frequency.

Conclusion

This research has demonstrated that the STFT technique helped in enhancing seismic data for stratigraphic feature delineation. The results of this research has demonstrated better understating of reservoir lithofacies from one time to another with depth as time (amplitude) data is spurious and 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.

References

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

Awolola, K.O. and Ideozu, R.U. (2019). The Application of Short-Time Fourier Transform and Discrete Fourier Transform in Mapping Stratigraphic Features in TMB Field, Niger Delta. Scientia Africana Volume 18 (1), Pp 92 – 109.

Burke, K. (1972). "Longshore Drift, Submarine Canyons and Submarine Fans in Development of Niger Delta," American Association of Petroleum Geologists Bulletin, 56, Pp. 1975 – 1983.

Chakraborty, A. and Okaya, D. (1995). Frequency-Time Decomposition of Seismic Data Using Wavelet-Based Methods. Geophysics, 1995, vol. 60 No 6, Nov-Dec, Pp. 1906-1916.

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

Doust, H. and Omatsola, E. (1990). Niger Delta. In: Edwares J.I. and Santogross P.A. (Eds) "Divergent / Passive Margin Basin" American Association of Petroleum Geologists Memoirs (48, 201 – 238), 1990.

Ejedawe, J.E., Coker, S.J.L., Lambert-Aikhionbare, D.O., Alofe, K.B. and Adoh, F.O. (1984). Evolution of Oil-Generative Window and Oil and Gas Occurrence in Tertiary Niger Delta Basin: American Association of Petroleum Geologists, Vol. 68, Pp.1744 -1751.

Ekweozor, C.M. and Daukoru, E.M. (1994). Northern Delta Depobelt Portion of the Akata-Agbada Petroleum System, Niger Delta, Nigeria, in, Magoon, L.B., and Dow, W.G., eds., The Petroleum System—From Source to Trap, AAPG Memoir 60: Tulsa, American Association of Petroleum Geologists, Pp. 599-614.

Evamy, B.D., Haremboure, J., Kamerling, P., Knapp, W.A., Molloy, F.A. and Rowlands, P.H. (1978). "Hydrocarbon Habitat of Tertiary Niger Delta," American Association of Petroleum Geologist Bulletin, 62, (1 – 39).

Ideozu, R.U**.** and Bassey, U.B**.** (2017). Depositional Environment and Reservoir Flow Unit Characterization of Okogbe Field, Onshore Niger Delta, Nigeria. *Scientia Africana, An International Journal of Pure and Applied Sciences. Published by Faculty of Science, University of Port Harcourt. Volume 16, Number 2.*

Ideozu, R.U., Iheaturu, T.C. and Ugwueze, C.U. (2018). Reservoir Properties and Sealing Potentials of the Akani Oil Field Structures, Eastern Niger Delta, Nigeria. *Journal of Oil, Gas and Petroleum Science. Volume 1 (2), Pages 56 – 65.*

Ideozu, R.U., Uche-Peters, A. and Utuedor, E. (2015). Reservoir Characterization of the T20 Sand 'TANGO' Field, Niger Delta, Nigeria. *International Journal of Science Inventions Today, Volume 4 (6), 600-609.*

Ideozu, R.U., Utuedor, E. and Uche-Peters, A. (2015). Depositional Environment of 'XY' Reservoir Sands, PAMMA, Field Niger Delta, *Nigeria. International Journal of Science Inventions Today, Volume 4 (6), 610-621.*

Iheaturu, C.T. and Ideozu, R.U. (2017). The Effects of Structural Control on Reservoir Properties of Akani Field, Coastal Swamp, Eastern Niger Delta. *Journal of American Academic Research - JAAR. Volume 5 Issue 5.*

Kogbe, C.A. (1989). The Cretaceous Paleocene Sediments of Southern Nigeria. In C.A. Kogbe (Ed.), Geology of Nigeria (pp. 320–325). Jos: Rock View Ltd.

Kulke, H. (1995). Nigeria, *in* Kulke, H., ed., Regional Petroleum Geology of the World. Part II: Africa, America, Australia and Antarctica: Berlin, Gebrüder Borntraeger, Pp. 143-172.

Lawrence, S.R., Munday, S. and Bray, R. (2002). Regional Geology and Geophysics of the Eastern Gulf of Guinea (Niger Delta to Rio Muni). The Leading Edge, 21:1112–1117.

Lehner, P. and De Ruiter P.A.C. (1977). Structural History of Atlantic Margin of Africa. American Association of Petroleum Geologists Bulletin, 61:961-981.

Ndokwu, C., Okowi, V., Agbejule, A., Arnaud, D., Olagundoye, O., Umoren N., Ideozu R.U. and Acra, E.J. (2019). Complementary Structural Analysis of Channelized Deep-water Turbidites in Offshore Niger Delta. American Association Petroleum Geologist Datapages, Search and Discovery Article No. 42352. Pages 1 – 18.

Ofuyah, W.N., Alao, O. A., and Olorunniwo, M. (2014). The Application of Complex Seismic Attributes in Thin Bed Reservoir Analysis. Journal of Environmental and Earth Science, Vol. 4, No. 18, ISSN 2224-3216 (Paper),

Ofuyah, W.N., Alao, O.A., Duke, P. and Asadu, A.N. (2014). The Application of Fourier Transform in the Interpretation of Subsurface Stratigraphy. Journal of Environment and Earth Science, Vol.4, No.18, 2014, Pp. 68-75.

Ofuyah, W.N., Alao, O.A., Idoko, R. and Oladapo, F. (2014). Well Log Segmentation in Spectral Domain Journal of Energy Technologies and Policy, Vol.4, No.9, 2014, Pp. 15-21.

Ofuyah, W.N., Omafume, O. and Stanley, E. (2015). The Application of Spectral Decomposition to 3-D Seismic Data Over 'X'-Oil Field, Niger Delta, *Geosciences*, Vol. 5 No. 3, 2015, Pp. 86-99.

Okaya, D.A. (1995). Spectral Properties of the Earth's Contribution to Seismic Resolution Geophysics, Vol. 60, No. 1, Pp. 241-251.

Oomkens E. (1974) "Lithofacies Relations in Late Quaternary Niger Delta Complex, Sedimentology," Pp. 21 195 – 222.

Oyanyan, R.O. and Ideozu, R.U. (2016). Sedimentological Control on Permeability Anisotropy and Heterogeneity in Shoreface Reservoir, Niger Delta, Nigeria. *International Journal of Science and Technology, Volume 6 (1).*

Partyka, G., Gridley, J. and Lopez, J. (1999). Interpretational Applications of Spectral Decomposition in Reservoir Characterization, the Leading Edge, March, pp. 353-360. Processing Magazine Pp. 14-38.

Petroconsultants (1996). Petroleum Exploration and Production Database: Houston, Texas, Petroconsultants, Inc., [database available from Petroconsultants, Inc., P.O. Box 740619, Houston, TX 77274-0619].

Reijers T.J.A., Peters, S.W. and Nwajide, C.S. (1997). "The Niger Delta Basin in African Basins" Sedimentary Basins of the World, Vol. 3, Pp. 151 – 172.

Robertson, D. and Nogami, H.H. (1984). Complex Seismic Trace Analysis of Thin Beds, J Geophysics, Vol. 49, pp. 344 – 353.

Sheriff, R.E. (1973). Factors Affecting Amplitudes – A Review of Physical Principles in Lithology and Direct Detection of Hydrocarbons Using Geophysical Methods. Symposium of the Geophysical Society of Houston, PP. 3-16. See also Geophysical Prospecting, Vol. 23, 1975, Pp. 125-138.

Short K.C. and Stauble A.J. (1967) "Outline of Geology of Niger Delta," American Association of Petroleum Geologist Bulletin (51, 761 – 779).

Taner, M.T., Koehler, F. and Sheriff, R.E. (1979). Complex Seismic Trace Analysis, Geophysics, Volume, 44, No 6, Pp. 1041-1063.