Asian Journal of Geological Research

Volume 6, Issue 1, Page 12-23, 2023; Article no.AJOGER.97014

Estimation of Petrophysical Parameters Using 3-D Seismic Data from a Field in Niger Delta, Nigeria

J. I. Umoh [a*], G. T. Akpabio [b] and K. I. Udo [a]

[a] *Department of Physics, University of Uyo, Uyo, Akwa Ibom State, Nigeria.*
[b] *Department of Geosciences, University of Uyo, Uyo, Akwa Ibom Sate, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/97014

Original Research Article

Received: 22/12/2022
Accepted: 27/02/2023
Published: 29/03/2023

ABSTRACT

Estimation of petrophysical parameters have been carried out using seismic data in an Onshore Niger Delta field to assess the reservoir characteristics of the field. A pre stack seismic volume and a suite of well logs from two wells were used in the analysis. The petrophysical parameters evaluated include acoustic impedance, porosity, water saturation, hydrocarbon saturation, permeability, volume of shale, Poisson ratio and Vp/Vs ratio. An interval with low gamma ray, low volume of shale, high resistivity, low water saturation and low acoustic impedance was identified and mapped as a potential hydrocarbon reservoir with a thickness of 70ft. The extracted wavelet from the seismic data showed a zero phase, which implies that energy is concentrated at the peak. The well to seismic correlation result yielded a maximum zero lag coefficient and a high correlation coefficient of 0.815 which gives confidence that the results of this work are reliable. Seismic inversion was then performed with the seismic and log data as input using an initial model and the inversion volume showed a low acoustic impedance which confirms that the delineated interval is a hydrocarbon saturated sand. The results obtained also revealed that the reservoir sand has low volume of shale (13.88%), high porosity (31%), high permeability (67.5mD), low Vp/Vs ratio (1.35)

**Corresponding author: Email: justinumoh@gmail.com;*

and low Poisson ratio (0.19) which are characteristics of a typical hydrocarbon reservoir with high prospectivity and production potential. The analysis also revealed that water saturation is low in the reservoir with an average value of 0.1 and hydrocarbon saturation is high with an average value of 0.9. This results in general suggest that the reservoir sand of the study field contains probable accumulations of hydrocarbon with a significant economic value.

Keywords: Well logs; seismic data; seismic inversion; seismic slice; petrophysical parameters.

1. INTRODUCTION

The Niger Delta is one of the world's largest tertiary delta systems and extremely prolific hydrocarbon province. It is situated at the north-eastern margin of the Gulf of Guinea on the west coast of Africa and it covers an area of about 75000km2 forming a triple junction during the continental breakup in the cretaceous with at least 11km deep in its deepest parts [1].

The basin has preserved thick sedimentary deposits and prominent geological features favourable for petroleum generation, migration and entrapment from the onshore through the continental shelf and to the deep-water terrains. It is the largest basin in the West African continental margin and is noted among the major prolific deltaic oil and gas accumulation [2].

Hydrocarbons are largely trapped in sandstones and unconsolidated sands in the paraliclastic agbada formation which consists of multiple vertically stacked reservoir sequences [3]. However, the traps and structures pose great challenges in mapping because of their complexities largely in structural deformations. The identification and delineation of reservoir characteristics also form part of the major challenges faced by exploration geoscientists during field planning, appraisal and development, owing to the heterogeneous nature of the sub-surface [2]. The characterization of these reservoirs therefore involves the integration of different datasets for accurate building of reservoir models which can used to identify, delineate reservoirs for hydrocarbon accumulations and estimate petrophysical parameters of the reservoirs using seismic data for field development. This dataset is used to evaluate well properties using log data, evaluate well properties using seismic data, investigate the link between seismic and petrophysical parameters through theory and application.

This study seeks to estimate petrophysical parameters of a reservoir using well logs, estimate pertrophysical parameters using seismic data, establish the link between seismic and petrophysical parameters as well as establishing a workflow model and testing it's effectiveness as a viable tool for assisting hydrocarbon exploration, exploitation and production.

1.1 Location of Study Area

The Niger delta basin is a major geological feature of significant petroleum exploration and production in Nigeria and it is Africa's leading oil province [4,5]. The Niger Delta Basin accounts for the entire hydrocarbon production at present day Nigeria [6] and is situated on the continental margin of the Gulf of Guinea in equatorial West Africa between latitude 3^{o}N and 6^{o}N and longitude 5^{o}E and 8^{o}E [5].

1.2 Geology of Study Area

The Niger Delta is a low-lying region in the southwestern part of Nigeria that is densely populated and rich in oil and natural gas resources. The geology of the area is characterized by a complex layer of sedimentary rocks and soils that have been deposited over millions of years by the Niger River and its tributaries [8]. The sedimentary rocks in the Niger Delta include sandstones, shales, and limestones, which have been formed by the accumulation and compression of sediment.

The delta is formed primarily of recent sediments, including fluvial sands, silts and clays laid down in the last 30 million years. The subsurface geology is complex and includes deep coastal plain, estuarine and deltaic sands, clays and shales. The sediments are mostly of marine origin and were deposited in a series of deltaic cycles [9].

Oil and natural gas are found in the Niger Delta primarily in the sandstone and shale layers that make up the delta's subsurface geology. These hydrocarbons are trapped in the rock formations by overlying layers of clay and shale, which act as seals [10].

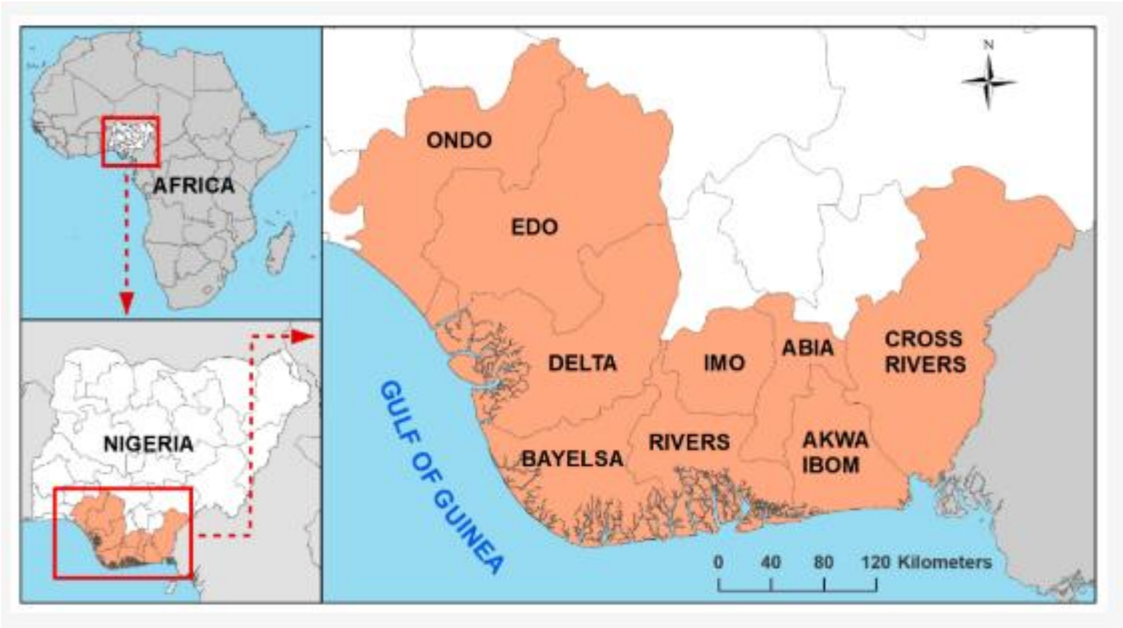


Fig. 1. Location of study area [7]

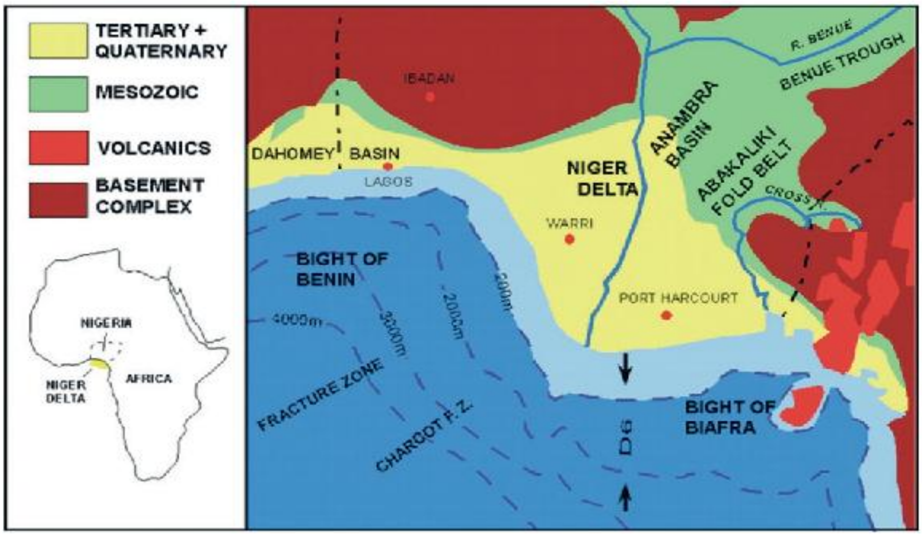


Fig. 2. Geology of the study area [11]

One of the most important geologic features of the Niger Delta is the presence of large salt dome which is subsurface features formed as a result of the movement of salt layers beneath the surface of the Earth. These salt domes have been known to trap hydrocarbons and are significant exploration targets [10].

2. METHODOLOGY

Two datasets were used, namely; 3D Pre-stack seismic data for analysis including attribute generation using a model-based inversion approach and well logs editing/modelling. The log suite includes caliper log, Resistivity log, Gamma ray log, and porosity logs, Sonic, and Density logs. The workflow chart below shows the methods adopted to achieve desired objectives. These datasets were provided by Shell Petroleum Development Company (SPDC), Port Harcourt, Nigeria. They were analyzed using Hampson Russell (HR) software.

The seismic data was acquired as checkshots, focused on obtaining more precise measurements of the speed of sound waves in the subsurface rock formations. The data (seismic and well logs) were imported and conditioned into the tool used for the analysis. Efforts were thus, made to carefully check for quality and completeness prior to its use in this petrophysical analysis.

The gamma ray (GR) log is particularly useful for defining shale beds, thus, used to indicate reservoir sands. The interval with low gamma ray, high resistivity, and low acoustic impedance was mapped as sand lithologies containing hydrocarbon.

The wavelet extraction method applied is model supported, using seismic and well information. Two wavelet extraction methods have been applied in this work; they are statistical wavelet extraction and wavelet extraction using the full log.

The well -to- seismic tie is a process manually stretches or squeezes the log in order to improve the time correlation between the target log and the seismic attributes [13].

A model-based deconvolution was used to invert the stacked sections to pseudo-velocity sections. The model-based inversion derives the impedance profile which best fits the modelled trace and the seismic trace in a least squares sense using an initial guess impedance.

From the seismic data, initial models were built for the acoustic impedance, porosity, water saturation, volume of shale, Vp/Vs ratio and Poisson ratio as shown in figures below.

2.1 Equations Used for the Analyses

Permeability, $K^{1/2} = 250 \times \phi^3/S_{wirr}$ (1)

Thickness of Reservoir (h = H – h) (2)

Net/Gross = h/H (2.1)

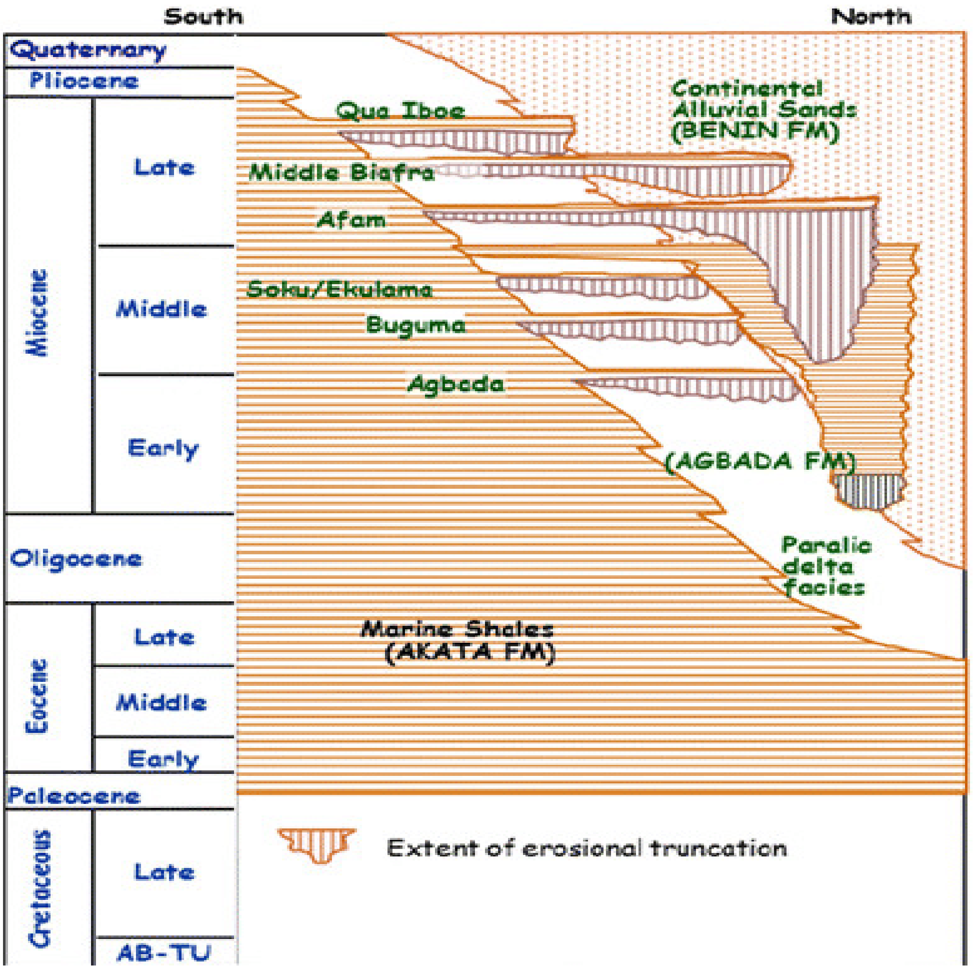


Fig. 3. Lithostratigraphic map of the study area [12]

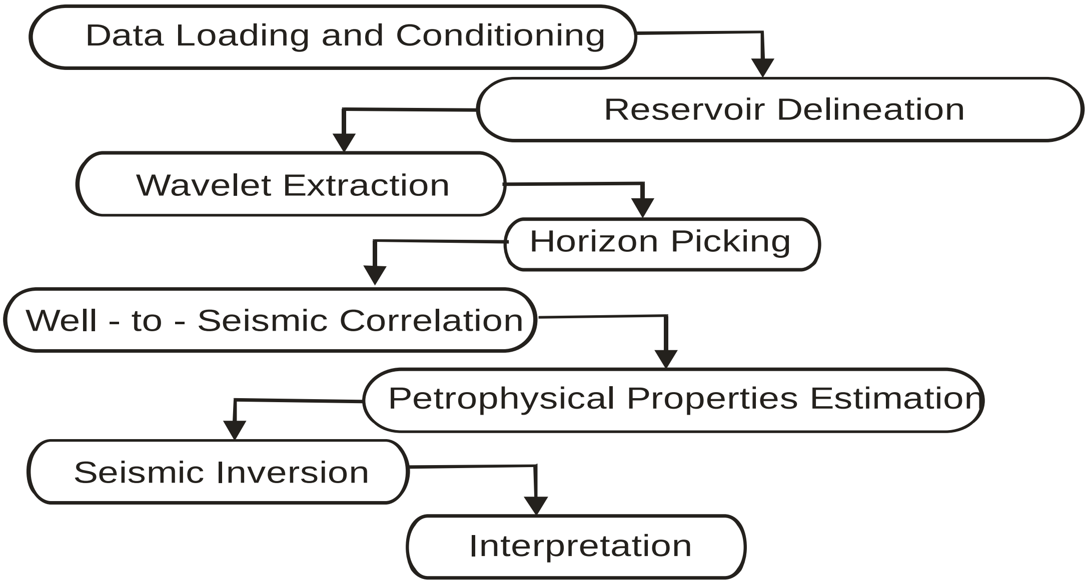


Fig. 4. Research workflow

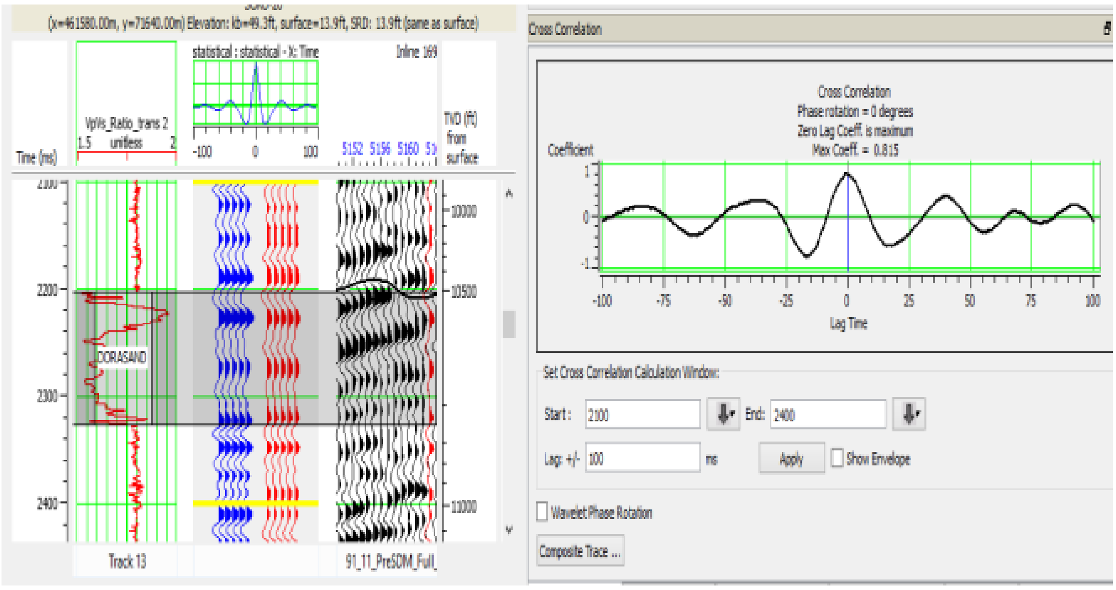


Fig. 5. Well -to- Seismic Correlation

Hydrocarbon Saturation, $S_{hc} = 1 – S_w$ (3)

Volume of Shale, $V_{sh} = 0.083\ (2^{3.7IGR} – 1)$ (4)

Acoustic Impedance, $I_p = v_p\ \rho$ (5)

Poisson Ratio (Anderson Method) $v = 0.125 \times Vsh + 0.27$ (6)

3. RESULTS AND DISCUSSION

Table 1 shows the summary of the average estimated petrophysical parameters obtained from which the reservoir was characterized as a hydrocarbon-bearing zone.

The wavelet extracted from the seismic data showed a zero phase, which implies that the data quality is good and that energy is concentrated at the peak. The well to seismic correlation result yielded a maximum zero lag coefficient and a high correlation coefficient of 0.815 which gives confidence that the results of this work are reliable. Table 1 show the thickness of the delineated reservoir at 70ft, which falls within the range of reservoirs that have economic value

(Opara, 2010), as obtained using equations 2 and 2.1. The inversion volume which is derived from seismic and well data using an initial model showed low acoustic impedance, a characteristic of hydrocarbon saturated sand.

Fig. 6 show the acoustic impedance gotten from seismic inversion and the acoustic impedance slice obtained. Acoustic impedance was obtained using equation 5 and was found to be low with an average value of 17519.15 (ft/ss) * (g/cc), an indication that the reservoir is rich in hydrocarbon. Fig. 7 show the inverted porosity with the well curve and the porosity slice respectively. The reservoir average porosity was 31% indicating an excellent reservoir quality and reflecting probably well sorted coarse grained sandstone reservoirs with minimal cementation. Rider [14] stated that a reservoir with porosity value between the range 20% to 30% is of very good quality while reservoirs with porosity value greater than 30% has an excellent quality.

The permeability of the reservoir units' range was 67.5mD which falls within the category of good reservoir quality according to Rider [14]. Permeability was determined using equation 1.

Fig. 8 shows the inverted Vp/Vs ratio and Vp/Vs slice. From the figures, the Vp/Vs for the reservoir is low with an average value of 1.35 as shown in Table 1. Low Vp/Vs ratio is a characteristic of typical hydrocarbon reservoir as espoused by Castagna et'al. [15].

Table 1 show the average value of water saturation of the reservoir to be 0.1 as obtained using equation 3, meaning that hydrocarbon saturation of the reservoir is 0.9. This is indicating that the proportion of void spaces occupied by water is low with high hydrocarbon saturation as seen in Fig. 9. The volume of shale in the delineated reservoir is 13.88% as shown in Table 1. Niger Delta formation is known to consist of a sand/shale sequence. Fig. 10 show the volume of shale from inverted seismic and slice respectively. As shown in the figure, volume of shale values near the well location are low which is good for a reservoir as espoused by Dresser-Atlas (1982) using equation 4. Poisson ratio in the location is low with an average value of 0.19 as shown in Table 1, which is as expected of a hydrocarbon reservoir. Hydrocarbon reservoirs are characterized by low Poisson ratios which ranges from 0 to 0.5 obtained using Anderson's method seen in equation 4 [16].

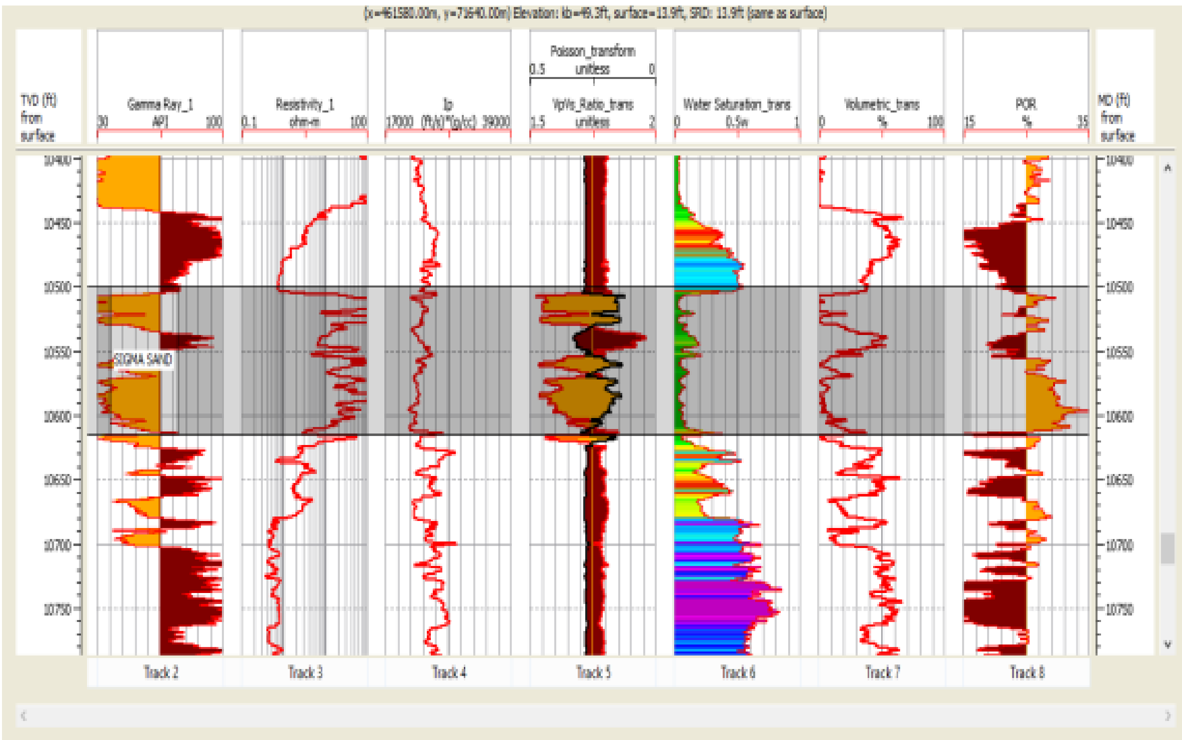


Fig. 6. Well log suite of the petrophysical parameters

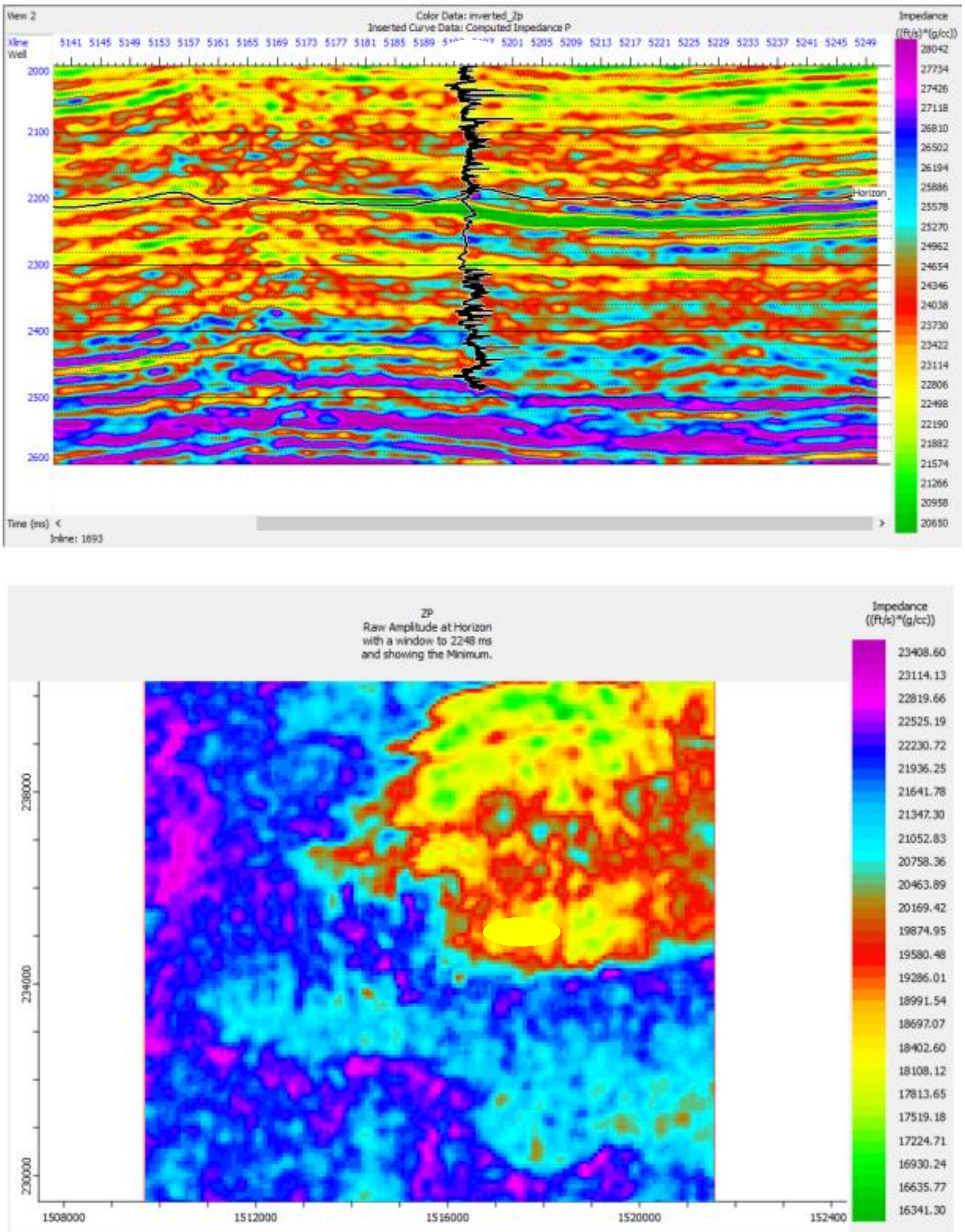


Fig. 7. Inverted acoustic impedance (I_p) and slice

Table 1. Showing the summary of estimated petrophysical parameters

Petrophysical parameters	Value	Remarks
Reservoir thickness (ft)	70.00	Adequate
Volume of Shale (%)	13.88	Low
Porosity (%)	31.00	High
Water Saturation, Sw (frac)	0.10	Low
Hydrocaron Saturation Sh (frac)	0.90	High
Permeability K (mD)	67.50	Adequate
Poisson Ratio	0.19	Low
Vp/Vs Ratio	1.35	Low
Acoustic Impedance (ft/s)*(g/cc)	17519.15	Low

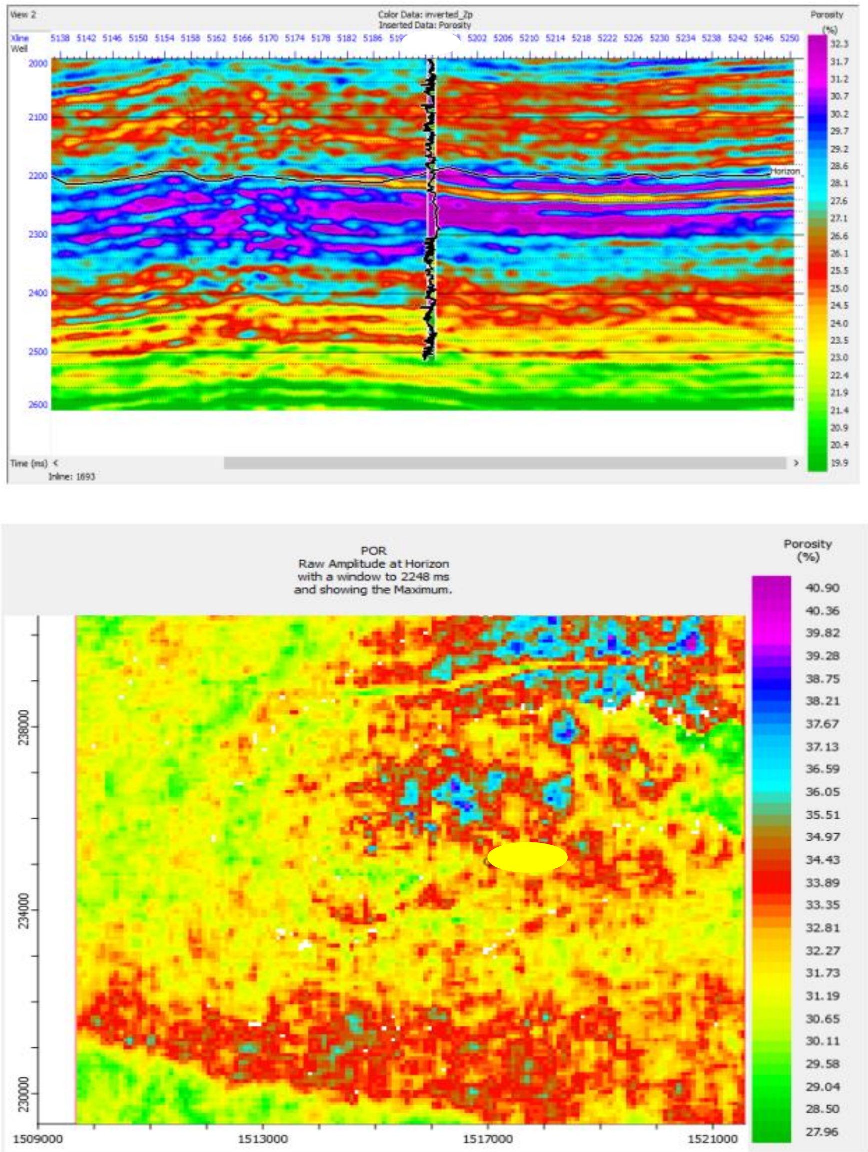
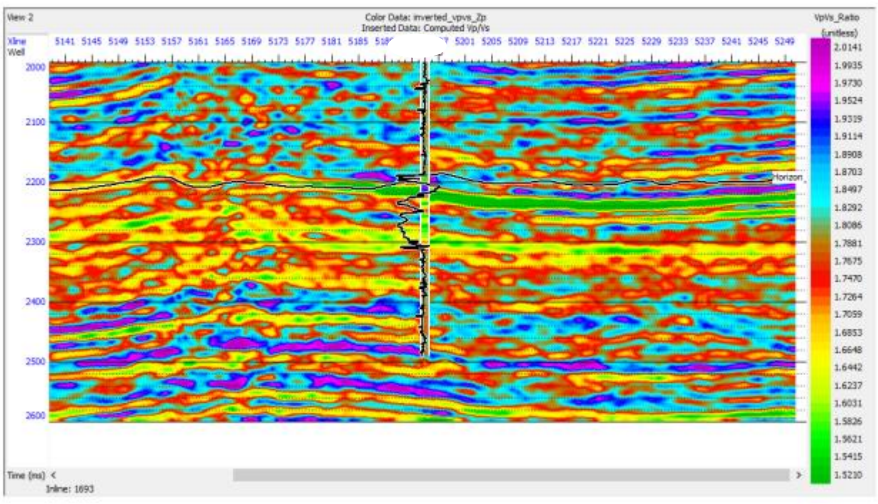


Fig. 8. Inverted Porosity and slice



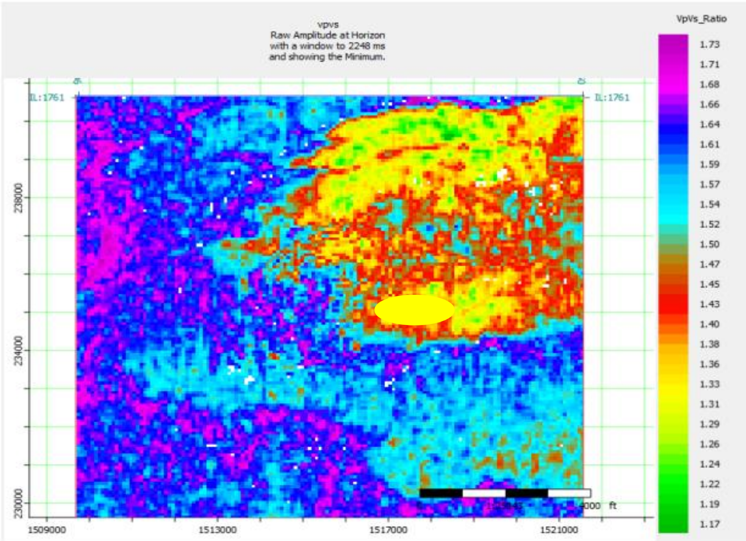


Fig. 9. Inverted Vp/Vs Ratio and slice

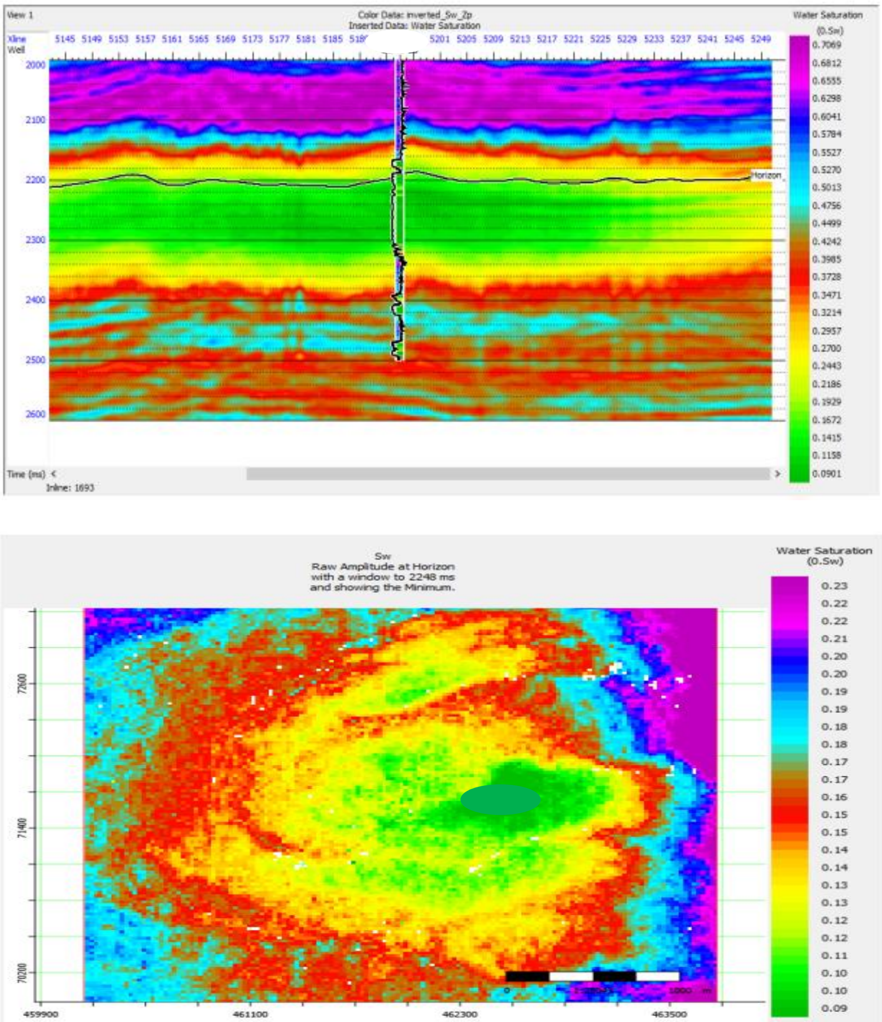


Fig. 10. Inverted water saturation model and slice

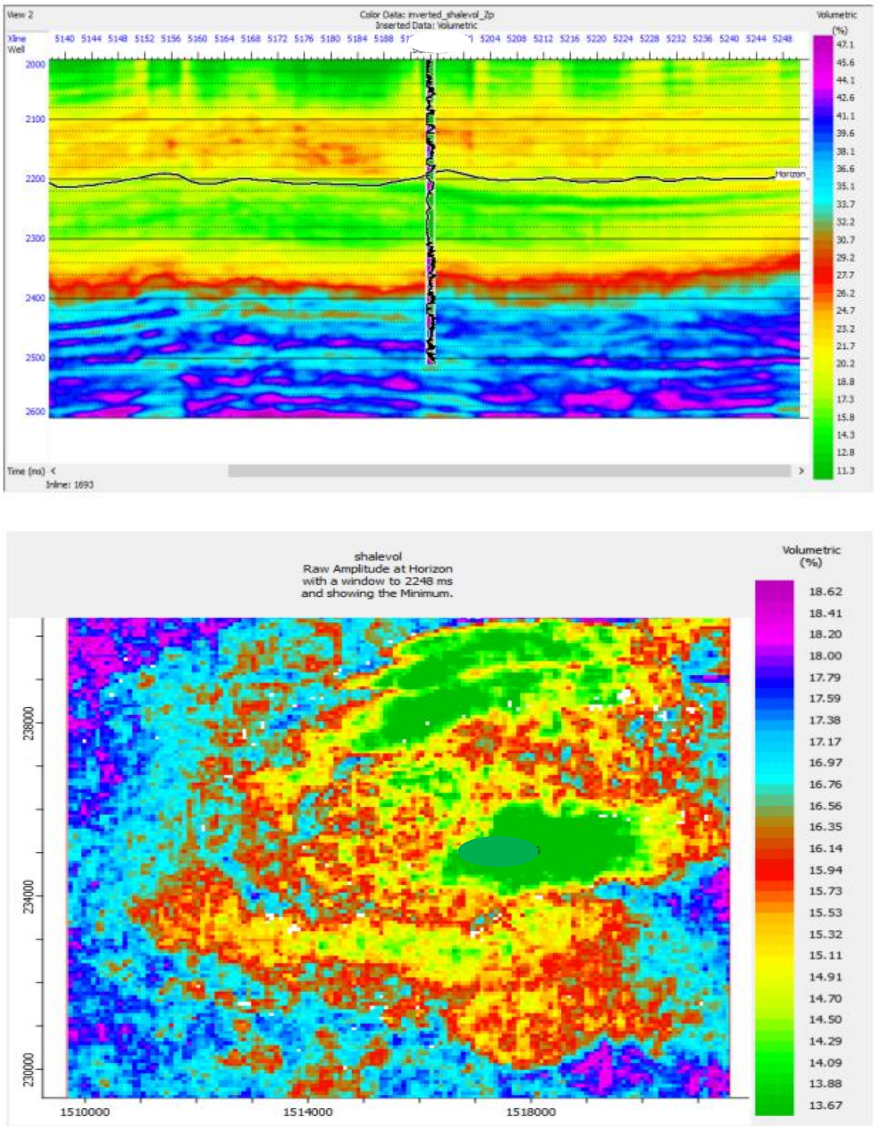
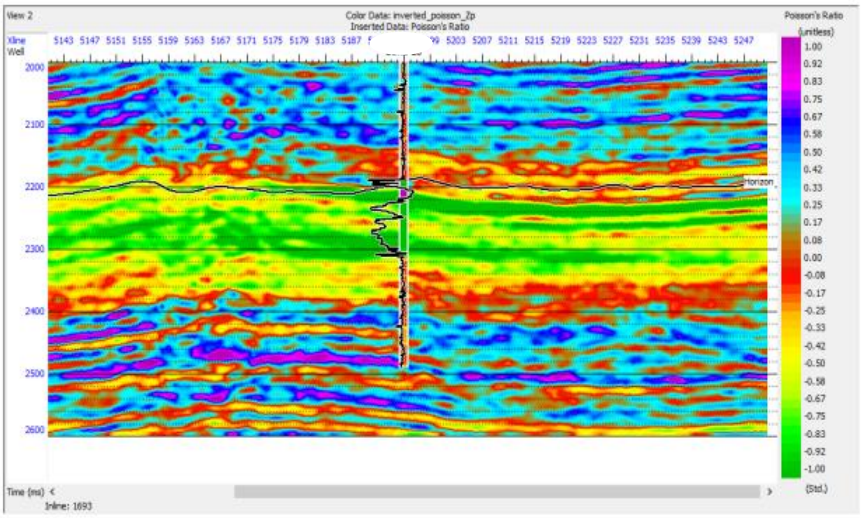


Fig. 11. Inverted shale volume and slice



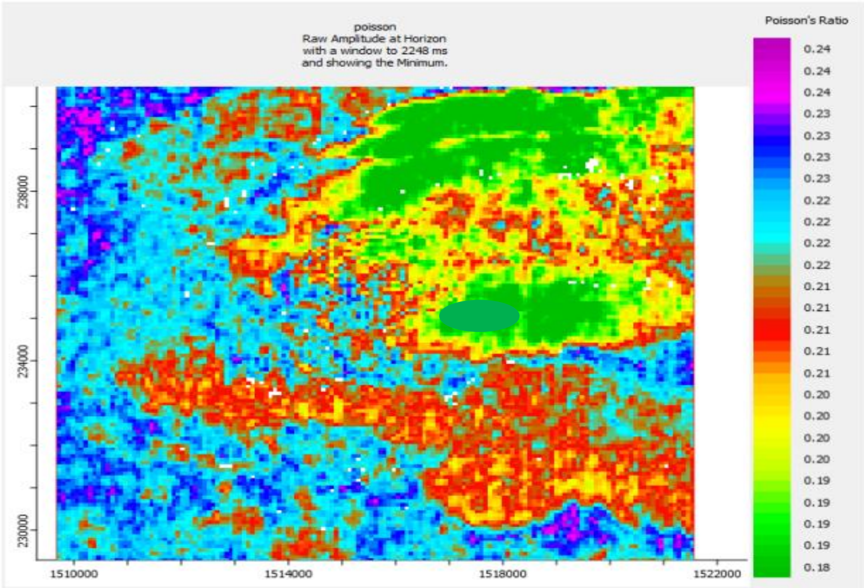


Fig. 12. Inverted poisson ratio and slice

4. CONCLUSION

This study showed that an interval with low gamma ray, low volume of shale, high resistivity, low water saturation and low acoustic impedance was identified and mapped as probable hydrocarbon reservoir. The petrophysical parameters calculated include acoustic impedance, porosity, water saturation, hydrocarbon saturation, permeability, volume of shale, Poisson ratio and Vp/Vs ratio. The inversion volume derived from seismic and well data using an initial model showed low acoustic impedance, as espoused by Opara, (2010) that low acoustic impedance can be a clear indication of hydrocarbon saturated sand. The results obtained also revealed that the reservoir sand has low volume of shale, high porosity, low water saturation, high permeability, high hydrocarbon saturation, low Vp/Vs ratio and low Poisson ratio which are characteristics of a typical hydrocarbon reservoir with high prospectivity for exploration and production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Omoja UC, Obiekezie TN. Application of 3D seismic attribute analyses for hydrocarbon prospectivity in Uzot field, onshore Niger Delta Basin, Nigeria. International Journal of Geophysics. 2019;20(19):1-11.
2. Ofurum GC. 3D Seismic interpretation and reservoir characterization of 'DIBA' field, Niger Delta, Nigeria. M.Sc. Project, Department of Geology, Federal University of Technology, Owerri); 2015.
3. Udo KI, Akpabio IO, Umoren EB. Derived rock attributes analysis for enhanced reservoir fluid and lithology discrimination. IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG). 2017;5(2):95-105.
4. Whiteman AJ. Nigeria: Its petroleum geology, resources and potentials. Graham and Trotman, London. 1982;394.
5. Reijers TA. Selected chapters in geology. SPDC coporate geographic service, Warri, Nigeria. 1996;194.
6. Obekiezie TN. Hydrocarbon exploration in Odo field in the Niger Delta Basin, Nigeria, using 3-D seismic reflection survey. Academic Journals. 2014;9(17):778-784.
7. Ebhuoma EE, Simatele MD, Leonard L, Ebhuoma OO, Donkor FK, Tantoh HB. Theorizing indigenous farmers' utilisation of climate services: Lessons from the oil-rich Niger Delta. Sustainability. 2020; 12:7349.
8. Madu UN. The social and environmental impact of oil exploration and exploitation in Niger Delta, Nigeria. Journal of Geology and Economics of Oil and Gas. 2017;4(2):15-21.

9. Bassey N. The political ecology of oil in the Niger Delta, Nigeria. Journal of Scientific Research. 2007;12(4):114-124.
10. Olorunfemi MA. The Niger Delta: An economic perspective. Journal of Scientific Research. 2015;24 (4):16-24.
11. Ekiti A. Petrophysical evaluation of reservoirs in 'y' prospect Niger delta. Journal of Geosciences. 2015;21:11-23.
12. Ozumba B. Geology of the Niger Delta: An Overview for Geophysics Processors. An SPDC presentation for geologists in Nigeria; 2013.
13. White RE, Hu T. How accurate can a well tie be? The Leading Edge. 1998;18 (8):1065–1071.
14. Rider MH. The geological interpretation of well logs. 1st ed. Halsted Press: New York, NY; 1986.
15. Castagna JP, Batzle ML, Eastwood RL. Relationships between compression wave and shear-wave velocities in clastic silicate rocks Geophysics. 1985;50:571-581.
16. Oweikeye E. GIS based mapping and analysis of oil pollution in Niger Delta Coastal Environment; 2017.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/97014