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EVALUATION OF PETROPHYSICAL PARAMETERS AND 3D SEISMIC ANALYSIS FOR RESERVOIR CHARACTERISATION AND PROSPECT IDENTIFICATION OF UZERE FIELD, NIGER DELTA, NIGERIA.

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Abstract
Evaluation of petrophysical parameters of Uzere oil field in Niger Delta region was performed to determine how these properties influence the reservoir's hydrocarbon potential and productivity of oil extraction in the area. Poor-quality 3-D seismic surveys are often reprocessed into modern 3-D seismic data of better quality to improve seismic data interpretation. The study used 3-D seismic data and well logs (Gamma-ray, resistivity, neutron and density logs, well deviation, and check shot data) to re-evaluate the hydrocarbon prospects in the field. Three lithostratigraphic units of the Niger Delta were analyzed: Akata, Agbada, and Benin formations. Five faults (F1 to F5) were identified from seismic structural interpretation, while three hydrocarbon-bearing sand intervals (Sand A – C reservoir) were delineated from correlation and petrophysical analysis. The sand intervals thin out basin wards, suggesting a prograding sequence. The effective porosity of the sand intervals ranged between 0.0760 and 0.3019, implying good to excellent porosity. The water saturation values ranged from 0.146 to 0.244 from top to bottom this indicated a prospective high accumulation of hydrocarbon. The Sand reservoirs had the most significant accumulation of hydrocarbon in-place with a hydrocarbon pore volume of 825301630 bbl and 635295302 ft3 of oil and gas, respectively, Stock Tank Oil-Initially-In-Place (STOIIP) of 515813511 barrels (bbl). Findings from the study revealed that the characterization of the reservoirs in the Niger Delta provided a better understanding of the subsurface structures of the area. This delineated reservoirs, predicted reservoir characteristics, and provided effective cost of extraction. The 3-D seismic interpretation revealed that the structural style is dominated by rollover anticlines, which is in line with the previous studies in the Niger Delta. The amplitude map generated showed that the drilled wells did not pass through the hydrocarbon accumulated (prospect) region. In conclusion, the results of the seismic interpretation and petrophysical analysis revealed that the reservoir under consideration has a good to excellent hydrocarbon (oil) prospect.
Keywords: Hydrocarbon, Reservoir, Niger Delta, Faults, Logs.

Introduction

The daunting challenge in the exploration and exploitation of oil and gas in the face of the world's continual rise in the demand for energy consumption is how to recover by-passed reserves with existing tools economically. Past exploration activities in the Uzere field had changed the area's geological conditions, making it difficult to predict the location and quantity of hydrocarbon reserves accurately. Due to these environmental changes, much oil and gas could have been bypassed. This raises awareness of the necessity of returning to these areas to look for additional reservoirs that could contain sizable hydrocarbon reserves utilizing current cutting-edge exploration techniques. The evaluation of hydrocarbon potential at the Uzere oil field in the Niger Delta Basin using a 3D seismic reflection survey is a geophysical exploration study aimed at assessing the oil and gas potential of a particular oil field in the Niger Delta region of Nigeria. The Niger Delta Basin is known to be one of the most prolific hydrocarbon basins in the world, with vast reserves of oil and gas. The Uzere oil field is located within this basin, and it is believed to have significant hydrocarbon potential. According to U.S Geological Survey World Energy Assessment, the Niger Delta Basin is ranked the twelfth richest in petroleum resources, with 2.2% and 1.4% of the world's discovered oil and gas basin (Tuttle et al., 2015). Considering the size and volume of hydrocarbon accumulation discovered in this basin, it is Nigeria's most prolific and economic sedimentary Basin. As a result of its economic potential, various exploration strategies have been used to recover the considerable oil and gas deposits. These comprise onshore hydrocarbon exploration, on the continental shelf, and deep offshore (Nton and Adesina, 2009).

Hydrocarbons are organic chemical compounds composed exclusively of hydrogen and carbon atoms. They originate from the buried organic remains of plants and animals, which have been subjected to high temperatures and pressure over a geologic period of time. They are mostly found deep underground in porous rock formations, such as sandstone, limestone, and shale. Hydrocarbon resources remain vital to the economy of several nations of the world but require high cost of exploitation and high level of accuracy for both interpretations of exploratory data and precision in hydrocarbon production (Laherrère and Bentley, 2022).

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Nigeria is a nation that is endowed with a vast accumulation of hydrocarbon. Hence, they are the Nation's primary revenue source. The recent increase in revenue demand for development in Nigeria has created awareness for more oil and gas discoveries. Consequently, the difficulty in finding new mature fields in the Niger Delta Basin has motivated explorations to re-visit old fields to search for bypassed oil and gas deposits to meet the Nation's hydrocarbon resource target (Okeke et al., 2018). The study re-evaluated the reservoir characteristics, structural geology, and stratigraphy of the Uzere oil field to determine the presence and distribution of hydrocarbon deposits. This will assist oil and gas companies make informed decisions regarding the development and exploitation of the Uzere oil field.

Study Area and Geology

The study area (fig 1) lies within latitude 5˚18" N and 5˚68" N and longitude 5˚33" E and 6˚40" E Mid-West of the Niger Delta region of Nigeria. The Niger Delta spans across the Gulf of Guinea and extends all through the Niger Delta Province. It is found in the southern region of Nigeria. It falls between longitude 4˚ – 9˚ East and latitude 4˚ – 6˚ North (Ogbe et al., 2020). Positioned at the West African continental margin, right at the apex of the Gulf of Guinea, it was the site of a triple junction during the continental break-up in the Cretaceous period (Bonne, 2014).

Since the Eocene epoch until now, the delta has advanced in a southwestward direction, creating depobelts that signify the most dynamic part of the delta's evolution at each stage (Doust and Omatsola, 1990). These depobelts constitute one of the world's largest regressive deltas, spanning approximately 300,000 square kilometres (Kulke, 1995), having a sediment volume of 500,000 cubic kilometres and a sediment thickness surpassing 10 kilometres in the central basin region (Michele et al., 1999). The Niger Delta Province comprises a single recognised petroleum system (Ekweozor and Okoye, 1980; Kulke, 1995) known as the Tertiary Niger Delta (Akata–Agbada) Petroleum System.

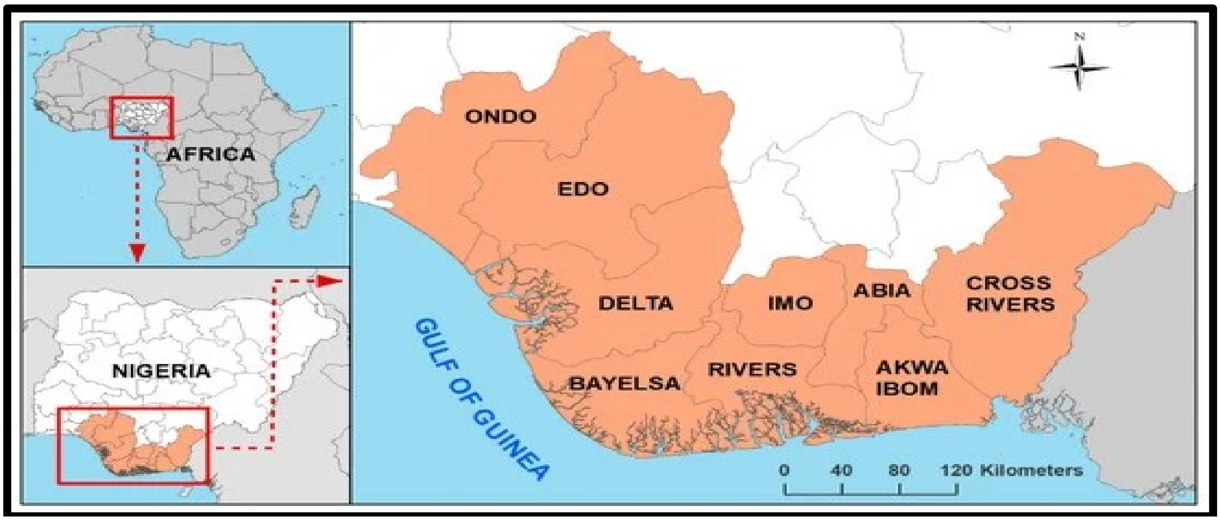

Fig. 1. The study area (Ebhuoma et al., 2020).

The structure and stratigraphy of the delta are closely intertwined, with the evolution of each dependent on the interaction between sediment influx and subsidence rates.

The thick wedge of the Niger Delta is considered to consist of three units Benin, Agbada, and Akata formations. (fig.2), the typical sections of these formations are described by Short and Stauble (1967) and summarised in various papers (Avbovbo, 1978; Doust and Omatsola, 1990; Kulke, 1995).

The figures below present the progradation and stratigraphic sequence of the delta.

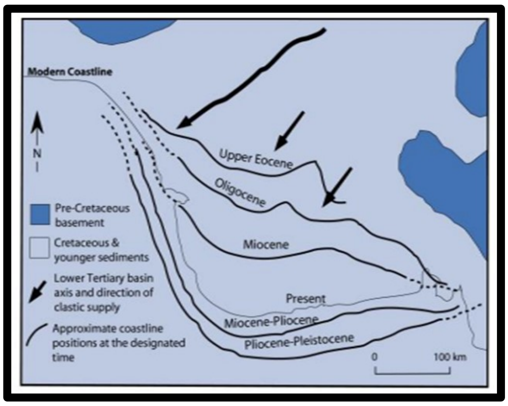

Fig. 2a.

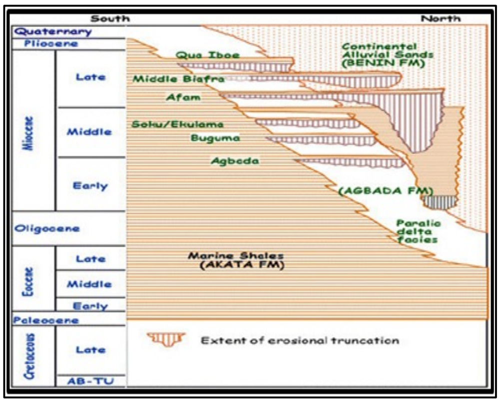

Fig. 2b.

Figures 2(a&b) showing progradation of the Niger Delta coastline since 55Ma (Adiele and Ofuyah, 2017). The Stratigraphic Column of the Niger Delta Basin indicates the Marine Akata, Paralic Agbada and Alluvial sands of Benin formations (Ozumba, 2013) respectively.

Literature Review

Review on use of 3D seismic surveys to assess hydrocarbon reservoirs within Niger Delta by the following authors are presented below.

Adaeze et al (2012) conducted analysis of petrophysical attributes of the Uzek well. The study examined various reservoir properties, including lithology, depositional environments, shale volume, porosity, and fluid saturation, utilizing data obtained from well logs and cores. The findings of the analysis revealed the presence of four hydrocarbon-bearing reservoirs within the Uzek well, permeability values of these reservoirs exceeded 100 millidarcies, while porosity values ranged from 20% to 30%, this indicated the presence of well-sorted coarse-grained sandstone reservoirs with minimal cementation, indicative of high reservoir quality .Further analysis on plotting of porosity values against permeability values unveiled robust linear relationships between these variables across all reservoirs. Such findings suggested that the reservoirs within the Uzek well are highly permeable, with pores exhibiting strong communication, the petrophysical properties elucidated in this study affirm the viability of hydrocarbon production within the Uzek well.

Abe and Olowokere (2013) conducted a reservoir characterisation and formation evaluation in selected regions of the Niger Delta, using 3D seismic data and well-log data. Utilising Petrel software, they analysed 3D seismic data, checkshot data, and a suite of well logs from three wells to delineate lithologies, identify reservoirs, perform well correlation, determine petrophysical parameters, map horizons and faults, and estimate reserves. Notably, one reservoir was mapped with petrophysical analysis, revealing porosity values ranging from 0.19 to 0.46 and permeability values from 14.53md to 496.61md. Additionally, Sw values ranged from 5.6% to 24%, while shale volume ranged from 0.02 to 0.07 across the reservoir. Structural mapping unveiled an anticlinal structure hosting the wells, with amplitude and interval average attributes highlighting bright spots indicative of hydrocarbon presence. The reserve estimate stood at 40.1 million barrels. This study underscores the efficacy of integrating attribute analysis with structural interpretation for comprehensive formation evaluation and reservoir characterisation, thereby enhancing hydrocarbon exploration and reserve estimation.

Adewoye et al (2013) conducted a comprehensive study on the 'Maiti' field in the Niger Delta, employing well logs and 3-D seismic data for petrophysical and structural analysis. The research was to delineate oil-bearing sand reservoirs, determine petrophysical parameters and analyse geological structures within the field. Through evaluation of well logs, check shot data, and 3-D seismic data, three hydrocarbon reservoirs labelled R1, R2, and R3 were identified. Results indicated that reservoir R1 exhibited the highest productivity, while R2 displayed the least. Structural analysis unveiled a fault-assisted anticlinal structure, serving as a significant structural trap within the 'Maiti' field in the Niger Delta, Nigeria. This study contributed valuable insights into reservoir characterisation and structural understanding, crucial for optimising exploration and production strategies in the region.

Amigun and Bakare (2013) conducted reservoir evaluation of the "Danna" field in the Niger Delta, employing petrophysical analysis and 3D seismic interpretation techniques. Their analysis of sand bodies revealed three hydrocarbon-bearing reservoirs within the field. Through the generation of time and depth structural maps from 34 seismic data sets, the subsurface structures acting as traps for hydrocarbons were studied, and the prospect areas of the reservoirs were estimated in acres. Integrating well and seismic data, the gas reserve was estimated at 225,997 barrels per cubic foot, while oil reserves for the three reservoirs were calculated as 6,566,089.09 barrels per acre, 14,006,716 barrels per acre, and 42,746,580 barrels per acre, respectively. This study significantly contributed to understanding the reservoir potential of the "Danna" field, crucial for effective resource management and exploration strategies in the region.

Amigun and Odole (2013) conducted reservoir characterization study of the SEYI oil field in the Niger Delta, utilizing petrophysical properties analysis. Their examination of various petrophysical parameters revealed the presence of hydrocarbons across all reservoirs. Porosity values ranged from 0.22 to 0.31, permeability varied from 881.58 md to 14,425.01 md, and average hydrocarbon saturations were found to be 41.44%, 20.29%, 30.82%, 37.92%, 51.20%, 91.97%, and 85.11% for reservoirs A through G respectively. Additionally, the determination of movable hydrocarbon index (MHI) values ranging from 0.05 to 0.75 further underscores the high hydrocarbon potential of the reservoir system. These findings collectively suggest a reservoir system with satisfactory performance for hydrocarbon production, highlighting the significance of petrophysical analysis in assessing reservoir viability and optimizing production strategies in the SEYI oil field.

Ihianle et al (2013) conducted structural interpretation of the 'X – Y' field in the Niger Delta, Nigeria, utilizing three-dimensional seismic data and well logs. Their analysis unveiled fault-assisted closures at the field's centre, corresponding to crest positions of rollover anticlines, serving as crucial trapping mechanisms. Estimation of hydrocarbon volumes within the interval ranging from 3,909.06m (12,825ft) to 4,053.84m (13,300ft) yielded a total of 289,227,007 barrels (37,281 acre-ft) of oil in place. The study highlights the efficacy of integrating borehole data with structural maps to delineate reservoir fluid boundaries, crucial for accurate volume calculations of hydrocarbons in situ. This research underscores the importance of structural interpretation techniques in enhancing reservoir charactersation and resource assessment in the Niger Delta region, offering valuable insights for efficient hydrocarbon exploration and production strategies.

Materials and Methods

The materials used in this study include Dell Inspiron 3541 with these features: 8 GB RAM, 500 hard discs, a 64-bit operating system, and an x64-based processor. 3-D processed seismic data, well logs, checkshot, and deviation data. Petrel 2017 version interpretation software was used for interpretation and reservoir model development.

The investigation and modelling of the subsurface have improved with the introduction of the 3D seismic reflection method, particularly in the search for hydrocarbons. The 3D seismic reflection survey is a powerful geophysical tool used to image the Earth's subsurface. It involves the generation of seismic waves, which are then reflected off subsurface structures and recorded by sensitive detectors. By analysing the seismic data, a detailed three-dimensional image of the subsurface is created to identify potential hydrocarbon reservoirs. Petroleum reserves are contained in three-dimensional traps, but the seismic method, in its attempt to image the subsurface, has traditionally taken a two-dimensional (2D) approach (Slatt, 2013). The use of 3D interpretation has been reported to yield better results; they have better resolution and have increased fault details as compared to the old 2D surveys (Wellmann and Caumon, 2018).

Reservoir characterisation typically involves identifying the total volume within the trap capable of containing hydrocarbons, as well as ensuring the accuracy of reservoir estimates, including thickness and other parameters. The petrophysical parameters of each reservoir play a crucial role in interpreting and estimating properties such as porosity, water saturation, and other factors from seismic and well-log data. During analysis, seismic data can be utilized to predict reservoir parameters quantitatively. One fundamental step in this process involves comparing the seismic volume at a well's location to the information obtained from the well, often facilitated by a synthetic seismogram—a modeled seismic track derived from sonic and density logs. During analysis, the focus is on estimating the physical properties of subsurface rock units, which are crucial in both hydrocarbon exploration and exploitation. Understanding reservoir characterisation and conducting volumetric analysis are vital factors in quantifying producible hydrocarbons (Okwoli et al., 2015). Reservoir characterisation stands as a crucial phase in both the exploration and development stages of a prospect. It integrates multidisciplinary analyses to mitigate risks and deepen comprehension of reservoirs. This process entails utilizing empirical formulas to estimate various reservoir parameters, including volume of shale, formation factor, porosity, water saturation, permeability, and hydrocarbon saturation, among others. Calculating these reservoir parameters aids in assessing the exploitability of a reservoir (Obiora et al., 2016; Stacy et al., 2010).

Available well logs and headers are summarized in the tables following.

Table 3. Available Well logs in the study area. Note: Y=Yes, N=No.

S/N	Field Name	Well ID	Gamma Ray	Resistivity	Sonic	Density	Neutron
1	Uzere	1	Y	Y	Y	Y	Y
2	Uzere	7	Y	Y	N	Y	Y

Table 4: Available well header information for Uzere Field.

S/N	**Field Name**	**Well Name**	**SURFACE X**	**SURFACE Y**	**TOTAL DEPTH**	**ELEVATION**	**ELEVATION TYPE**
1	Uzere	1	436181.13	96307.23	12050	39	KB
2	Uzere	7	431251.25	96211.83	11880	40	KB

An integrated approach employed in interpreting the available data for this study is summarized in the workflow below, see figure following.

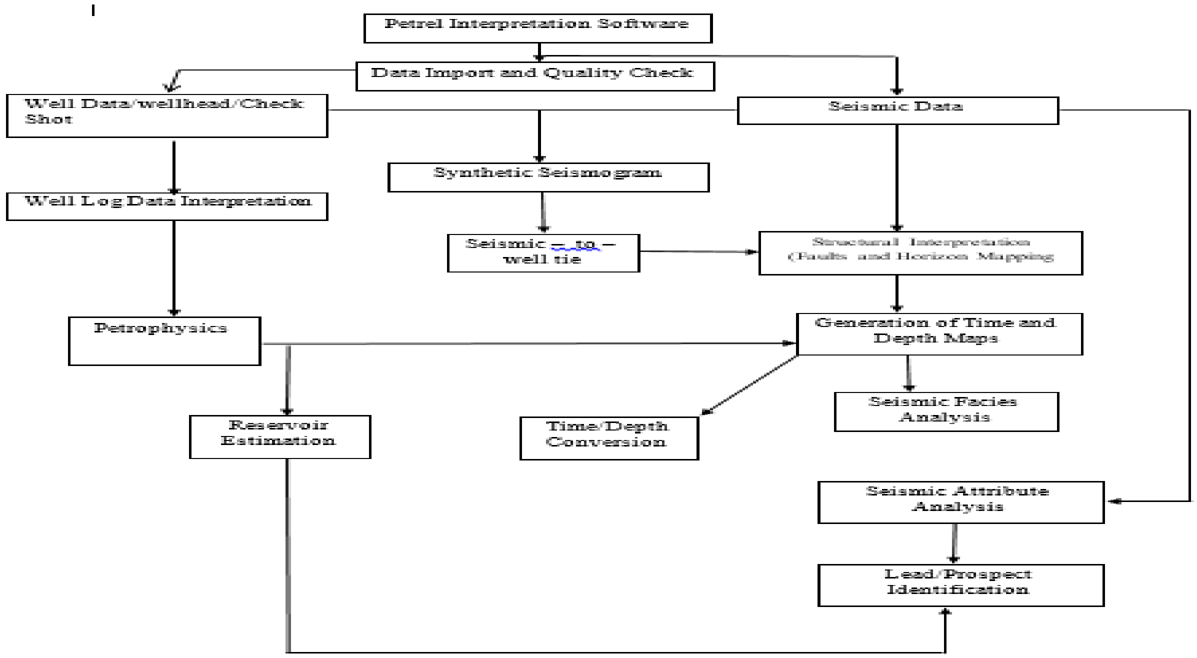

Fig. 3.1. Comprehensive and detailed workflow chart used in this research study.

Results and Discussion

Schlumberger's software was used for interpretation and the following results as were generated. Seismic faults, attributes and horizons can be clearly seen.

The figures following presents the attributes of the said faults.

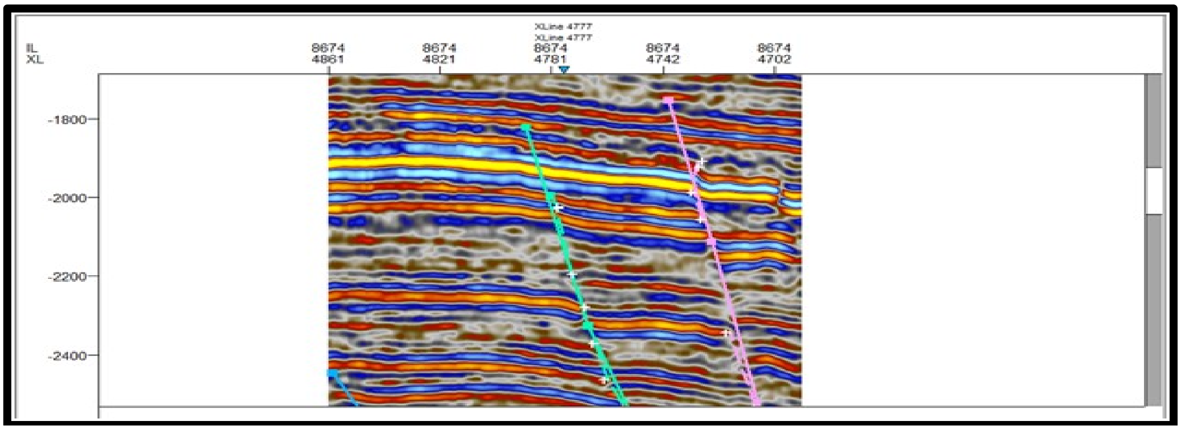

Fig. 4.1. Mapped seismic faults.

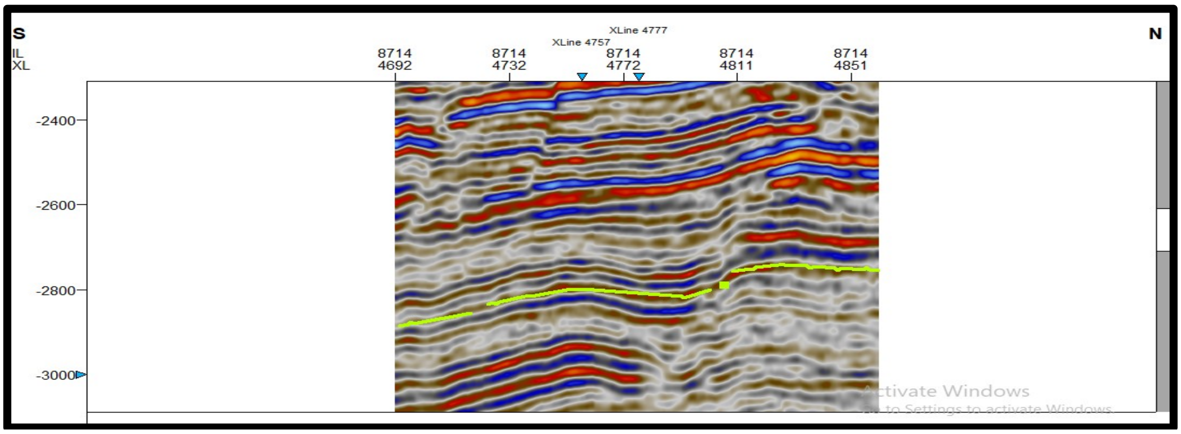

Fig.4. 2. Mapped seismic horizon.

Key features, including significant and minor faults, as well as horizons, were identified in the seismic interpretation section (Figures 4.1 and 4.2). These identified and interpreted faults occurred due to discontinuous reflection along the disorientation of reflectors (Wang et al., 2022).

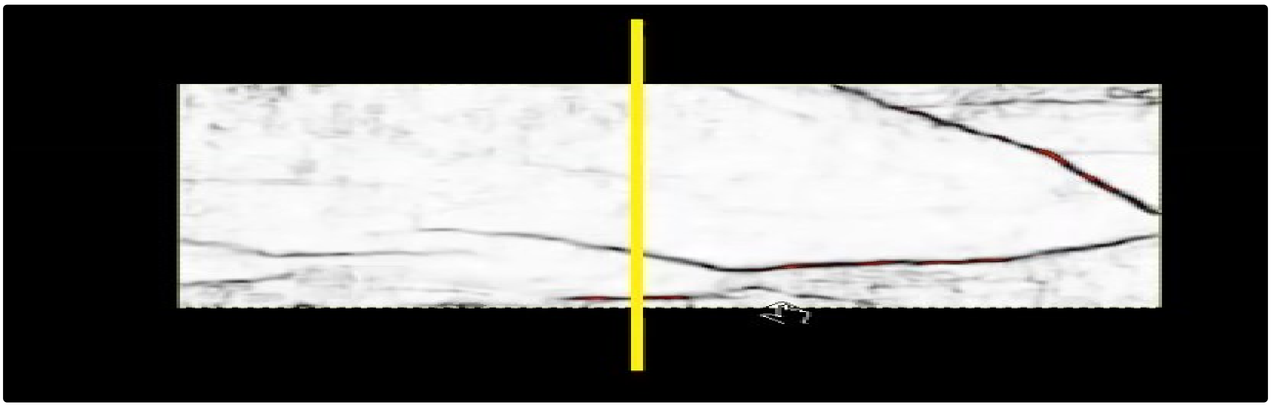

Fig.4.3. The generated seismic attribute.

Analysis of seismic attributes conducted within the study area identified prospective zones that were not penetrated by the drilled wells. RMS amplitude and variance edge attributes were chosen for this study due to their utility as Direct Hydrocarbon Indicators (see Fig. 4.3). By correlating these attributes with the structural closures observed on the depth structure maps (Fig. 4.17), it revealed the existence of potential zones within these regions. The anomalies were identified based on their seismic attribute response, which serves as an indicator to potential hydrocarbon accumulations. The variance edge method was used to enhance and identify edges and boundaries within the seismic data. Variations in the attributes were analyzed to identify areas of significant changes, revealing the boundaries of different geological formations. Elevated values of the root mean square (RMS) attribute in localized areas suggested porous lithology, typically associated with sands. Heightened values of the instantaneous frequency attribute further supported the indication of hydrocarbon presence. High values of variance edge attribute within the high amplitude zones of the envelope attribute are indicative of hydrocarbon-filled sand, and localized high values of root mean square attribute within the high amplitude zone are indicative of hydrocarbon accumulation. More of the seismic attributes and depth plot are shown in the figures following.

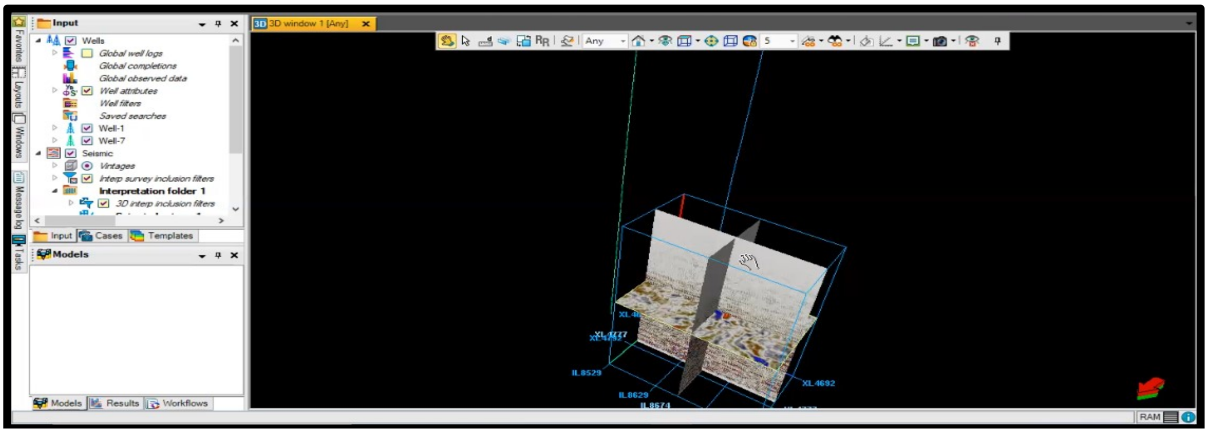

Fig.4.4. Xline and Inline of the imported seismic data.

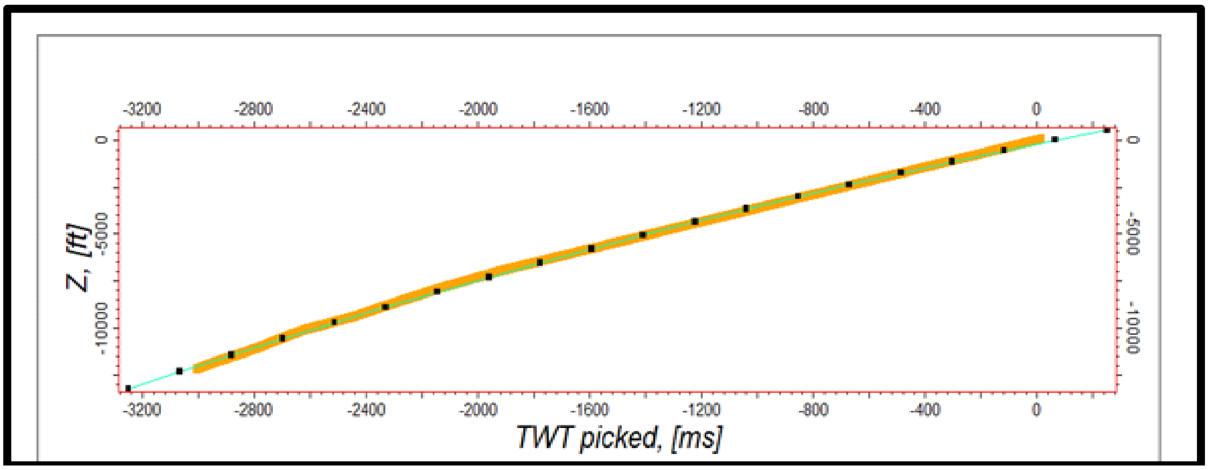

Fig.4.5. Two-way travel time against depth.

The checkshot data was plotted in two-way time against depth to convert the time structural map to the depth structural map as shown in (fig 4.5) above. The checkshot data was utilized for obtaining the relationship between the seismic (In time) and logs (In depth). It was majorly used during the time-depth conversion. The spatial extent of the reservoir was delineated using the depth structural maps.

Following well orientation outline and reservoir correlations.

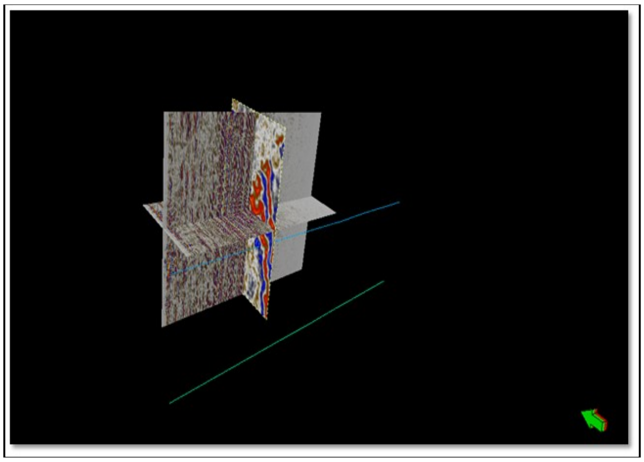

Fig.4.6. The wells orientation on the seismic sections.

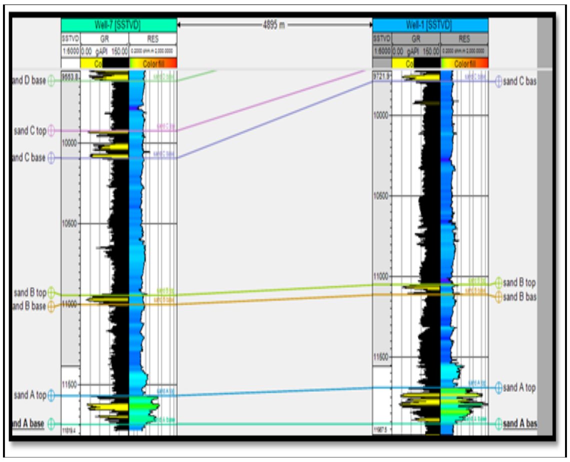

Fig.4.7. The reservoir correlations.

Findings from the well log interpretation indicated that the lithologies encountered consist of sand and sand-shale intercalations from the Benin Formation and Agbada Formation, respectively (Fig. 4.7). The lithologies of the area are dominantly sandstones, siltstones, and shale. These lithologies were shown to be gradational. See figure following.

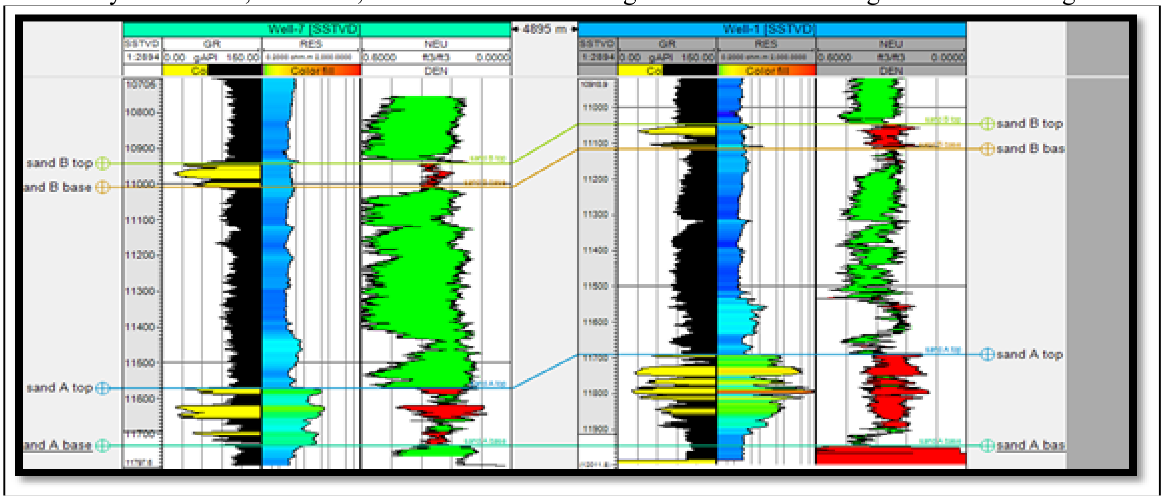

Fig. 4.8. Reservoir correlation across the fluid contents.

Analysis of all well sections uncovered that each sand unit traversed the field, exhibiting variable thicknesses, with certain units found at greater depths, potentially indicating faulting. Shale layers were noted to escalate in depth, accompanied by a decrease in sand layers. Permeable zones (sands) were differentiated from non-permeable zones using Gamma-ray, Resistivity, Neutron, and Density logs. Based on this, the tops and bases of Reservoir sands were delineated and correlated in both wells. Neutron and density logs were crossed, which gives the type of fluid content present in the identified reservoirs. Figures (4.8, 4.9, 4.10, 4.11) illustrated areas marked with red symbols denoting oil-saturated zones and those with green symbols indicating gas-saturated zones.

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These features can be observed in the figures following.

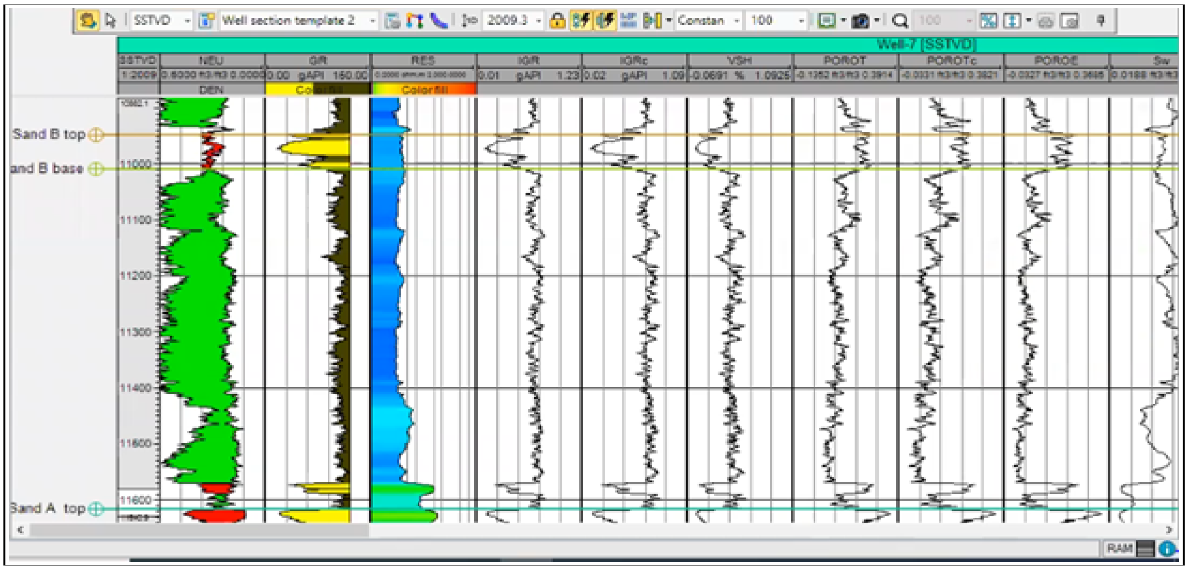
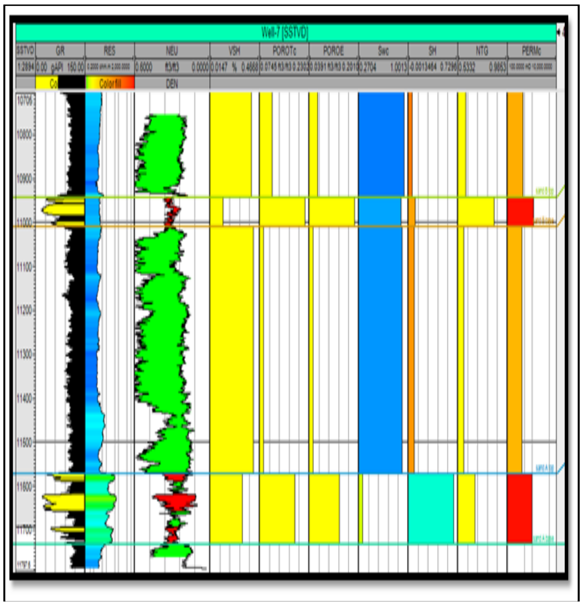


Fig. 4.9. The Petrophysical logs align with the correlations.



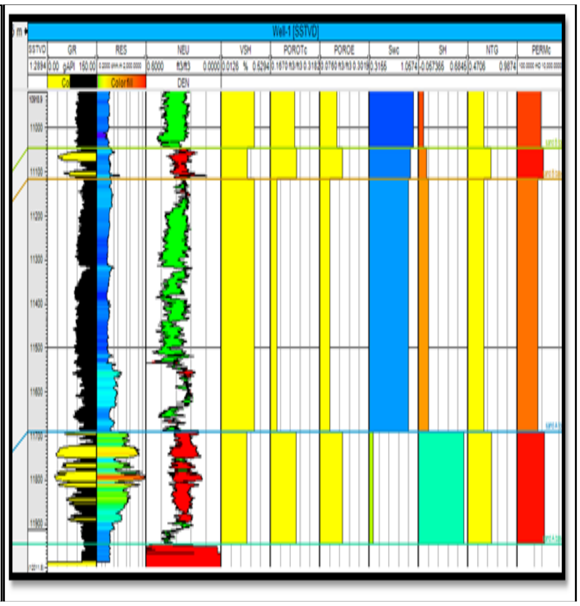


Fig.4.10. The modeled petrophysical logs for well   Fig.411. petrophysical log for well 1

Petrophysical parameters were computed for all reservoirs in both wells, namely well-1 and well-7. Petrophysical parameters were determined for all reservoirs within the two wells, designated as well-1 and well-7. The determined reservoir parameters include reservoir thickness, net-to-gross (NTG) ratio, effective porosity (POROE), volume of shale (Vsh), water saturation (Sw), and saturation of hydrocarbon (Sh). The average petrophysical properties of the reservoir within the study area are shown in (fig.4.10) and (fig.4.10 b) above. These parameters were calculated using some petrophysical formulas such as Archie’s equation. Generally, the obtained values indicated the presence of viable and excellent reservoir.

See the figure following

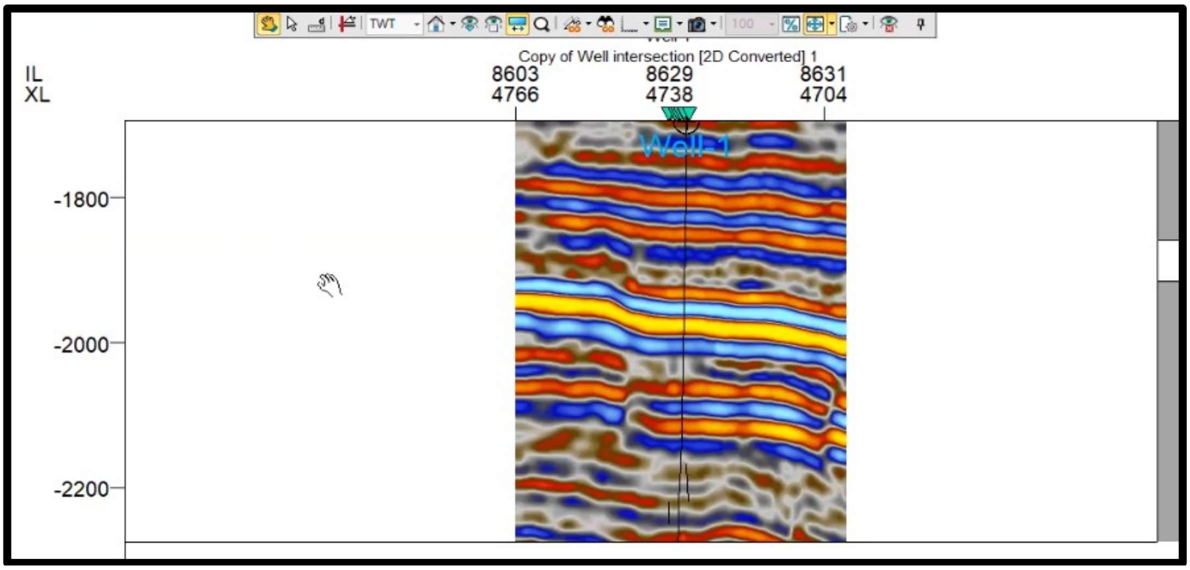


Fig. 4.12. Seismic to well tie of well 1.

Seismic to well tie was done using well 1, being the prospect well. This quantitative approach was used for visual comparison between synthetics and seismic data by analyzing the wavelet. Different wavelet characteristics were generated such as Ricker, Isis frequency, and Isis time, using different algorithms such as deterministic and statistical. Isis frequency was adopted as it best interprets our line of correlation, as shown in (fig. 4.14). Gardners equation was used in power, phase, and frequency spectrum generation because of its high level of accuracy and shows the systematic relationship between seismic velocity and density of the different rock units. The sonic log was calibrated (fig. 4.13) to stabilize dispersion effects and to improve the logging accuracy. See figures following.

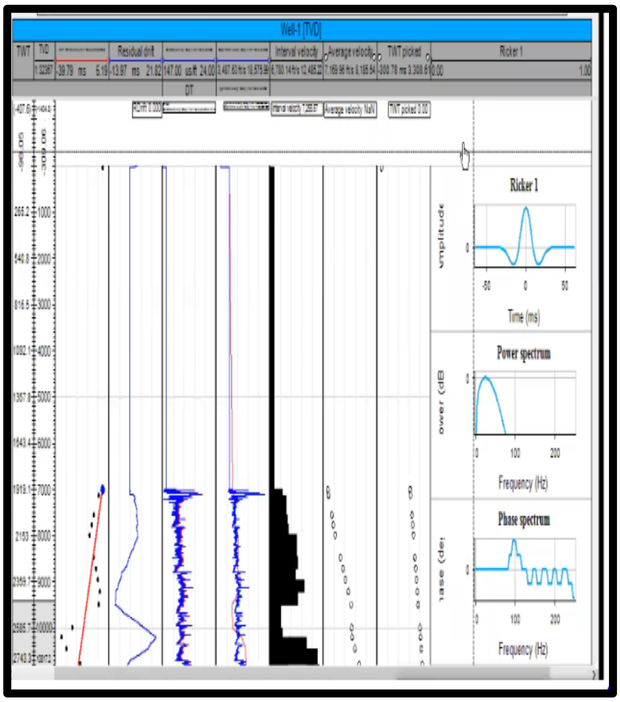


Fig.4.13. Sonic calibration of well 1.

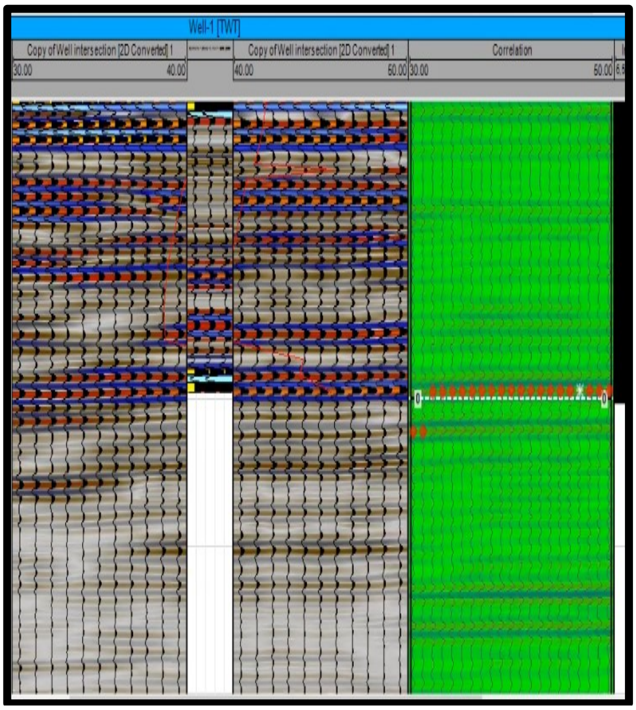


Fig.4.14. Synthetic seismogram of well 1

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A synthetic seismogram was generated using WELL 1. The synthetic seismogram produced (Fig. 4.14) exhibited an excellent match with over a 90% confidence level of agreement between the generated synthetics and the original seismic data. Reservoir tops were characterized by positive amplitudes, depicted as peaks, whereas reservoir bases were identified by negative amplitudes, illustrated as troughs. The calibrated sonic log (CSL) was used as the input log to generate a synthetic seismogram instead of the original sonic log (OSL) since the sonic and the surface seismic are measured at different frequencies due to the dispersion effect. See figures following:

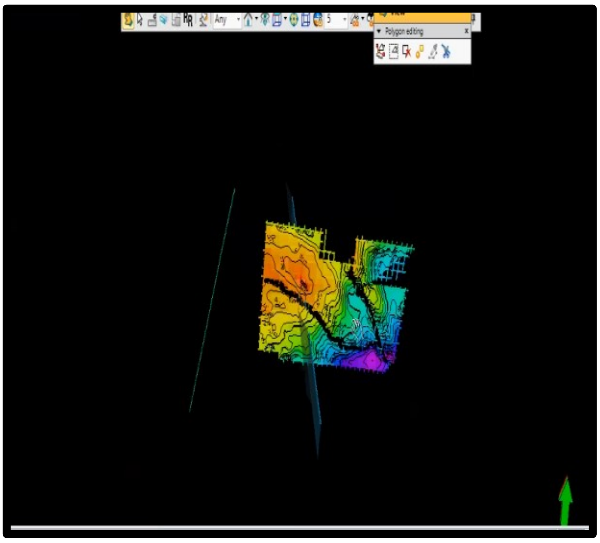

Fig. 4.15. Well 1 across the prospect region.

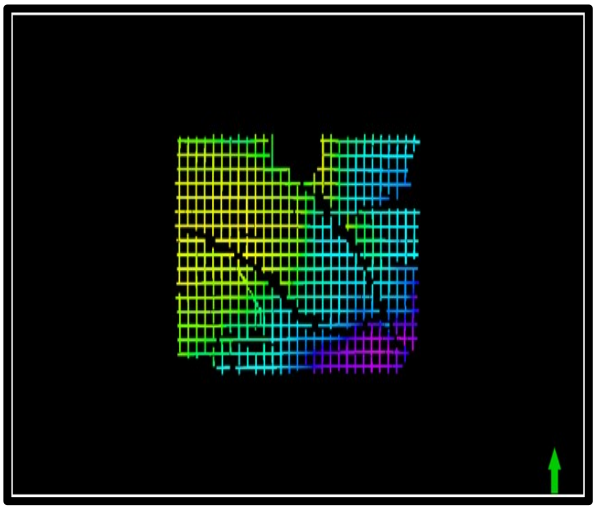

Fig.4.16. Mapped seismic horizon

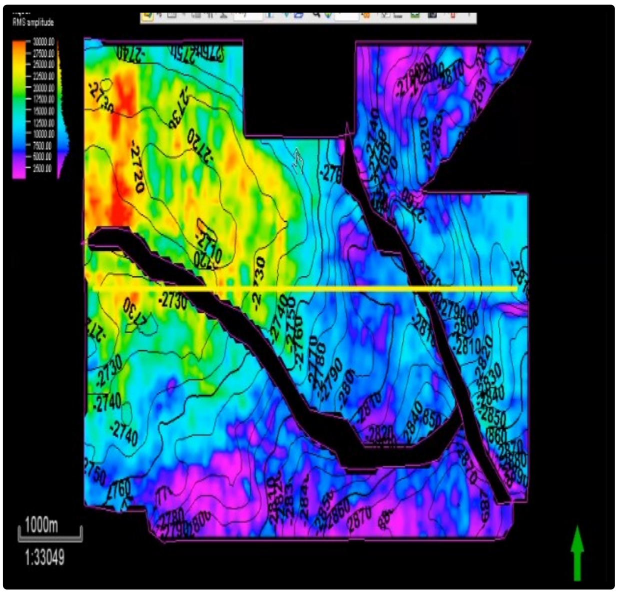

Fig.4.17. The generated RMS amplitude map.

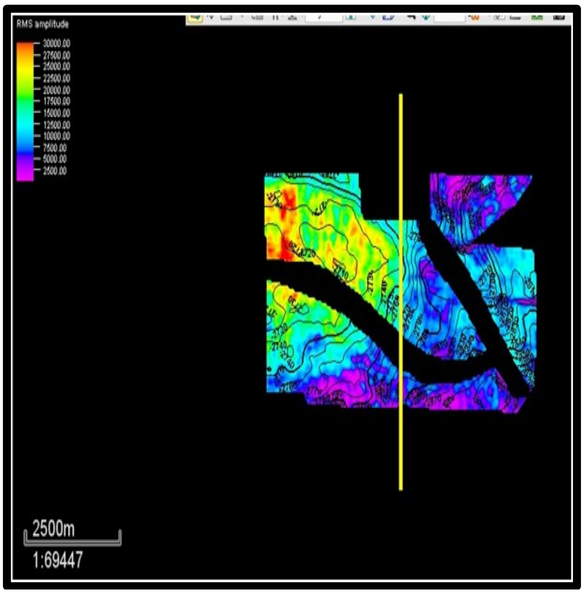

Fig.4.18. Generated surface map.

Structural seismic interpretation of the subsurface from the observed 3-dimensional seismic survey data was performed; the surface map generation was done using the mapped horizons, the contour map generated through this process showed that the prospect is a reservoir of 30 meters in thickness, as shown in (fig 4.17). The generated amplitude map (fig 4.17) showed that the type of structure in the field is a rollover anticline. The hydrocarbon accumulated region lies at the flank of the anticline structure. The time map generated showed that the drilled wells did not pass through the hydrocarbon accumulated region.

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The deep-seated fault is in excellent condition for hydrocarbon migration and accumulation as shown in the figure following

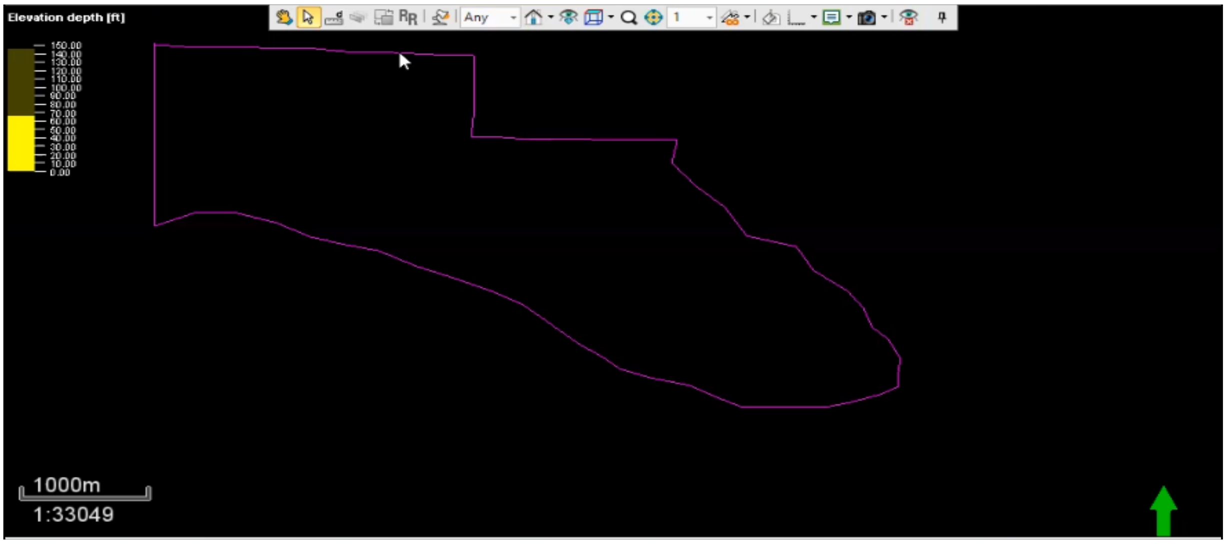

Fig.4.19. Polygon model of the surface map.

The subsurface structural feature in this study was modeled using fault polygons, producing horizon architecture. The fault modeling method was used to obtain accurate measurements of the fault boundaries, orientation distribution, and connectivity of hydrocarbon-bearing formations in the seismic section.

Table 4. Showing Petrophysical Parameters of Well 1

Volume of shale	Effective porosity	Water saturation	Hydrocarbon saturation	Net-To-Gross	Permeability
12.6%-29.4%	7.6%-30.19%	14.4%-24.6%	75.4%-85.6%	74.6%-96.74%	15.22md-25.85md

Petrophysical parameters were calculated for well 1, being the prospect well. The results are presented in Table 4 above. The range of values of the volume of shale suggested that a relatively small fraction of the rock is composed of shale. The range of the effective porosity showed a relatively more significant portion of the pore space is available for fluid movement. Also, the range of values obtained for the water saturation suggested that a significant portion of the pore space is available for hydrocarbon storage. This is desirable for efficient hydrocarbon extraction and production. The effective porosity values suggested it has a relatively good capacity to store and transmit fluids. Higher net gross values imply that a higher proportion of the rock is suitable for reservoir and hydrocarbon storage.

Conclusion

The study revealed that the characterisation of the reservoirs in the Niger Delta provided a better understanding of the subsurface structures of the area. The delineated reservoirs, predicted reservoir characteristics, and provided effective cost of extraction. The 3-D seismic interpretation revealed that the structural style is dominated by rollover anticlines, which is in line with the previous studies in the Niger Delta. The amplitude map generated showed that the drilled wells did not pass through the hydrocarbon accumulated (prospect) region. In conclusion, the results of the seismic interpretation and petrophysical analysis revealed that the reservoir under consideration has a good to excellent hydrocarbon (oil) prospect.

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