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Hydrocarbon Resource Evaluation using 3D Seismic Attributes and Petrophysical Analysis- A Case Study of Pearl Field, Offshore Niger Delta, Nigeria.

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Abstract

Identification of the hydrocarbon-bearing zone and estimation of the recoverable hydrocarbon in Pearl Field, Offshore Niger Delta, was determined using calculated petrophysical parameters and volumetric assessment. Seismic interpretation and petrophysical analysis of borehole logs from five wells were carried out to obtain subsurface characterization and hydrocarbon resource evaluation of the Pearl field. The volume attributes generated extracted basic features associated with hydrocarbon presence detection. Processed 3-D seismic data and well logs (Gamma-ray, resistivity, neutron and density, well deviation, and checkshot data) were analyzed using the Petrel 2017 software module. A total of thirty faults were mapped within the field: three major faults (F1-F3) appeared to be regional, and 27 minor faults. Structural interpretations from time and depth maps revealed the presence of syn-sedimentary dominant growth and synthetic faults, which served as pathways for the upward migration of hydrocarbon generated within the field. Two prospects and four hydrocarbon-bearing reservoirs were interpreted. The results of petrophysical analysis conducted on four hydrocarbon-bearing reservoirs (H1-H4) show average porosity (0.3215, 0.2805), average net to gross (0.795, 0.616), average water saturation (0.243, 0.1325) and average shale volume (0.3175, 0.3795) for prospect 1, 2 respectively. The result of volumetric estimation carried out on prospects 1 and 2 revealed Stock Tank of Oil initially in Place (STOIIP) values of 108.51 MMbbl and 44.052 MMbbl, respectively. Results showed that the hydrocarbon-bearing reservoirs in the field are viable for oil exploitation.

Keywords: Hydrocarbon, Niger Delta, Faults, Reservoir, Seismic Interpretation.

Introduction

Reservoir Characterization primarily assesses the total volume within a geological trap capable of containing hydrocarbons, alongside ensuring precise estimates of reservoir attributes such as thickness. Vital to this process are the petrophysical parameters of each reservoir, pivotal for interpreting and estimating properties like porosity, water saturation, and additional parameters derived from seismic and well-log. Seismic data analysis can quantitatively forecast reservoir parameters; a fundamental approach involves comparing the seismic volume at a well's location to the well's data, typically facilitated by a synthetic seismogram (a simulated seismic track created from sonic and density logs). The analysis concentrates on estimating the subsurface physical properties of rock units, crucial for both hydrocarbon exploration and exploitation endeavors. Understanding reservoir characterization and volumetric analysis is pivotal in quantifying producible hydrocarbons (Okwoli et al., 2015). Reservoir characterization stands as a critical phase during both exploration and development stages of a prospect. It combines multi-disciplinary results of different analyses to reduce risk and enhance understanding of reservoirs. This process entails employing empirical formulas to gauge various reservoir parameters including volume of shale, formation factor, porosity, water saturation, permeability, hydrocarbon saturation, and more. Such calculations of reservoir parameters are instrumental in assessing the exploitability of a reservoir (Obiora et al., 2016; Stacy et al., 2010). Correct determination of reservoir characteristics and properties through structural analysis of the subsurface geology and delineation of the quantity and economic worth of hydrocarbon in prospect are some of the significant challenges facing oilproducing industries. These problems span across the issue of types of closure, reservoir units, reservoir stratigraphy, sedimentology, and reservoir volumetric (Oluwajana and Owoeye, 2023). Seismic attributes analysis has been commonly used within the petroleum industry to define reservoir architecture and heterogeneity. Various successful case studies used seismic attributes for reservoir characterization (Hardage et al., 2009; Almoqbel, 2012), mapping geological structure e.g., fault;(Neves et al., 2004), and identifying gas chimney (Meldahl et al., 2001).

Furthermore, to obtain more detailed reservoir parameters and geological structure (e.g., fault). 3D seismic is a geophysical method used to interpret subsurface geology, and it is a valuable tool in allocating potential drilling targets. As a field progresses from its initial discovery through development, a significant amount of well, seismic, and production data accumulates. With the integration of these datasets, the accuracy of the subsurface interpretation is improved over time. 3D seismic datasets give a more accurate interpretation of structural and stratigraphic details of the subsurface than 2D due to its dense grid of lines (Saeland and Simpson, 1982). Over the years, it has been observed that hydrocarbon exploration is highly dependent on the presence of structural traps. The anticlinal theory, the rollover anticlines in the Niger Delta, for instance, has been a successful exploration strategy. The combination of seismic and well data makes it possible to map subsurface structural elements with a high degree of accuracy. This combined approach will no doubt be a practical exploration tool to delineate structural features such as faults, stratigraphic features such as anticlines, lithofacies, sequences, depositional environment, and hydrocarbon reservoirs. By integrating log-derived reservoir properties with seismic data and structural interpretation, interpretation teams can quantify subsurface hydrocarbon accumulations, identify prospects and leads, classify petroleum resources, assess the probability of success, rank resources, plan future wells, mitigate exploration and drilling risks, and enhance the success rate for drillable prospects. Studies have demonstrated that integrating 3D seismic data with well log data yields a potent tool for delineating the structural framework and estimating reserves within a field. (Futalan et al., 2012 and Amigun et al., 2013). The Niger Delta area is one of the most productive basins in Africa, typified by six depobelts (OPEC, 2017). This hydrocarbon-rich basin is ranked eighth among the world's hydrocarbon provinces, with further auspicious reserves not yet discovered as the search for petroleum proceeds deeper offshore. The Niger Delta hydrocarbon province boasts verified recoverable reserves of approximately 37,452 million barrels (mmbbl) of oil (OPEC, 2017) and 5.1 trillion cubic meters of gas resources. Recent significant oil discoveries in the deep-water zones of the Delta indicated that the province will remain a key focal point for exploration efforts (Corredor et al., 2005). 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 to meet the Nation's hydrocarbon resource target (Okeke et al., 2018). This study interpreted the stratigraphy of the structure by utilizing petrophysical parameters and conducting seismic sequence and attribute analysis. The goal is to identify the presence and distribution of hydrocarbon deposits in the field using specialized software designed to enhance the imaging of complex seismic attributes of subsurface structures.

Location of Study Area and Geology

The study area lies within latitude 4˚48" N and 5˚11" N and longitude 5˚47" E and 6˚08" E Mid-West of the Niger Delta region of Nigeria (see fig 1)

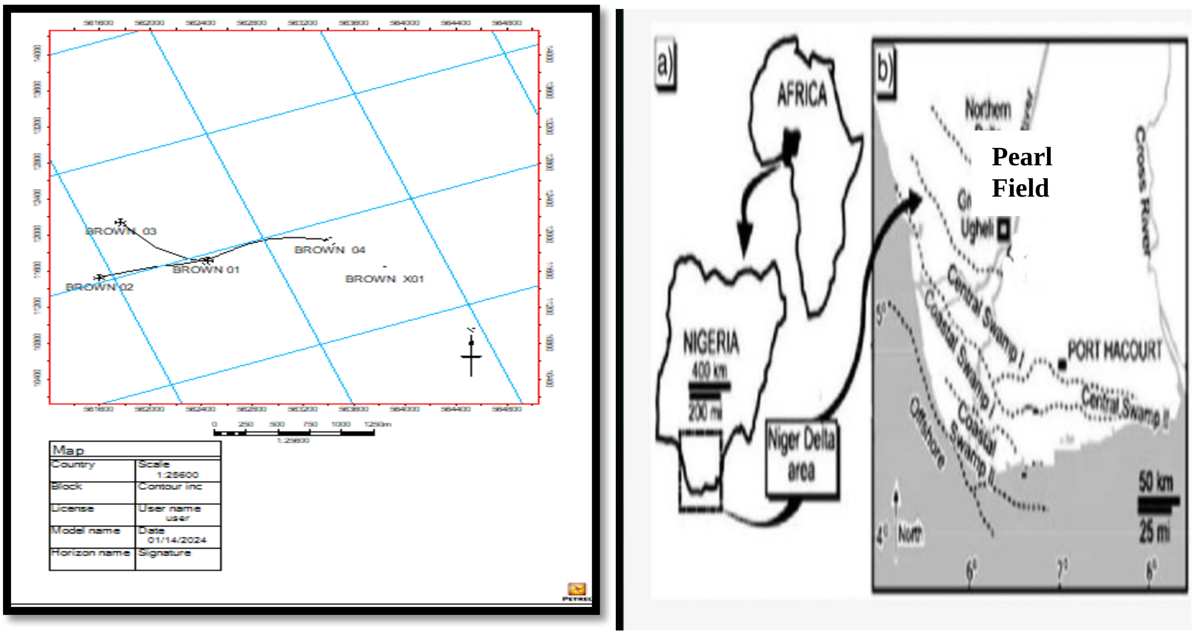


Fig. 1a. Map of the study area (Doust and Omatsola, 1990). **b.** Generated base map of the study area.

From the Eocene onward, the delta has extended southwestward, forming depobelts signifying its most active segments at different developmental stages (Doust and Omatsola, 1990). These depobelts constitute one of the world's largest regressive deltas, spanning approximately 300,000km² (Kulke, 1995), with a sediment volume of 500,000 km³ and a thickness exceeding 10 km in the basin depocenter (Michele et al., 1999). The Niger Delta Province harbours a single identified petroleum system, termed the Tertiary Niger Delta (Akata–Agbada) Petroleum System (Ekweozor and Okoye, 1980; Kulke, 1995), extensively confirmed by Tuttle et al. (2015). Beginning in the late Jurassic and continuing into the Cretaceous, the delta's formation was linked to the opening of the southern Atlantic at a triple junction (Tuttle et al., 2015). Initially developing in the Eocene with sediment accumulation around 10 kilometres thick (Ekweozor and Daukoru, 1994; Tuttle et al., 2015), the delta has been nourished by the Niger, Benue, and Cross Rivers, draining an expanse exceeding 106 km² of continental lowland savannah. Presently, it exhibits a wave-dominated morphology with a coastline smoothly seaward-convex, traversed by distributary channels (Doust and Omatsola, 1990). From apex to coast, the sub-aerial portion stretches over 300km, covering 75,000 KM². Below the Gulf of Guinea, two large lobes protrude a further 250 km into deep waters (Ekweozor and Daukoru, 1994). The delta sequence consists of a tertiary clastic deposit that progressively coarsens upwards, reaching a thickness of up to 12 km. This deposit is informally divided into three main lithofacies (Klett et al., 1997). Delta structure and stratigraphy closely interrelate, influenced by sediment supply and subsidence rates, dominated by sync- and post-sedimentary lithic normal faults (Doust and Omatsola, 1990). Major growth-fault trends divide the delta from Northwest to Southeast into several structural and stratigraphic belts called depobelts, which age progressively southward (Doust and Omatsola, 1990) (fig 2) . These depobelts represent successive phases in the delta's history. The Niger Delta consists of three units: Benin, Agbada, and Akata formations, strongly diachronous and characterized by S-shaped crosssections (Short and Stauble, 1967; Avbovbo, 1978; Doust and Omatsola, 1990; Kulke, 1995).

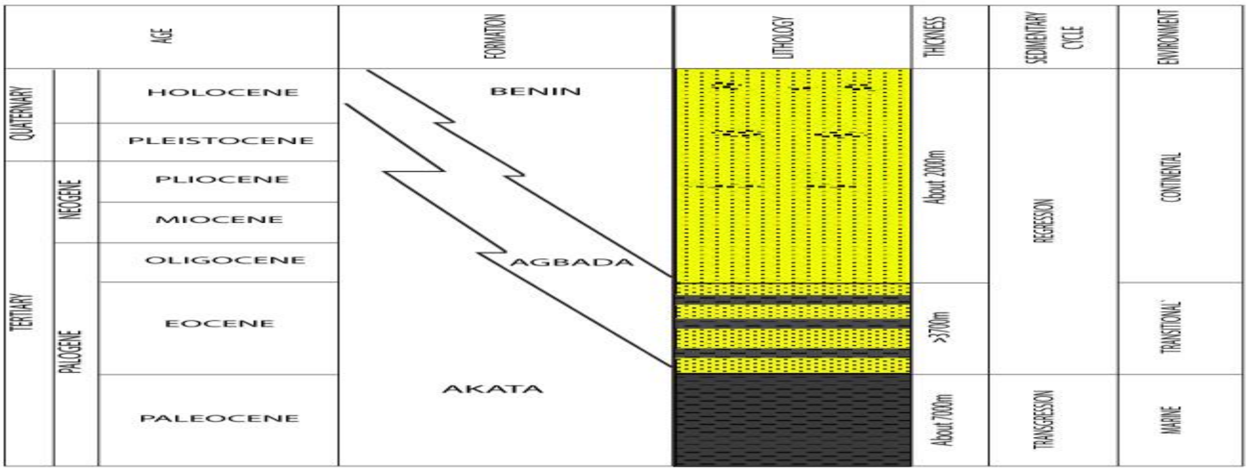


Fig. 2. Stratigraphic column of Niger Delta Basin (Doust and Omatsola 1990).

Literature Review

Ameloko et al. (2019) conducted an extensive investigation focusing on the Evaluation of seismic and petrophysical parameters for hydrocarbon prospecting in the G-field, Niger Delta, Nigeria. Reservoir quality assessment revealed average values including thickness (72 m), porosity (0.31), net-to-gross ratio (0.75), V-shale (0.25), and water saturation (0.19). The study highlighted lateral and horizontal variations in reservoir properties, identified potential sweet-spot zones for future hydrocarbon recovery and Seismic attribute analysis predicted lithofacies variation within the sandstone body. Fajana et al. (2019) conducted a thorough investigation on Seismic interpretation and petrophysical analysis in the 'Pennay' field, Niger Delta. Integrated seismic interpretation and petrophysical assessments from seven wells, four hydrocarbon-bearing sands (Pennay 1-4) were delineated from borehole logs, time and depth structural maps were generated using checkshot data. The structural analysis identified three major faults (F2, F3, F5) and two antithetic faults (F1, F4). Petrophysical analysis indicated excellent reservoir quality, with hydrocarbon saturation ranging from 56 to 72%, shale volume between 7 and 20%, and porosity levels ranging from 25 to 31%. Reservoirs Pennay 2 and 3 demonstrated particularly superior characteristics. Estimated reserves totaled 53.005MMBO (1P/P90), 59.013MMBO (2P/P50), and 65.898MMBO (3P/P10). Reservoir C contained 7737MMscf (1P), 8893.2MMscf (2P), and 10185.2MMscf (3P) of gas. Combined, oil and gas reserves reached 137.30MMBOE (1P/P90), 154.9MMBOE (2P), and 171.515MMBOE (3P). Reservoirs B and D held the highest recoverable oil. And Emujakporue et al. (2012) conducted an integrated study combining well logs and seismic data to assess prospects in the X field, onshore Niger Delta, Nigeria. They evaluated the hydrocarbon maturation level of the Oben-1 well in the northern Niger Delta sedimentary basin using the Lopatin Time-Temperature Index (TTI). Results indicated both oil and gas potential, with the oil window spanning depths of 2.5 to 3.5 km and hydrocarbon generation occurring from 36 million years ago onward. Maturation levels were analyzed for seven horizons (A-G), revealing that horizons A-D (age < 36 Ma) were non-productive, while E-G (age > 36 Ma) exhibited oil and gas potential. This finding aligned with Vitrinite reflectance values. The study suggested extending exploratory wells beyond 3.5 kilometers depth, indicating high hydrocarbon prospects in the northern Niger Delta.

Materials and Method

The materials used in this study include; Hp Elite Book 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 log, table 1((including Density, Gamma-Ray, Sonic, Resistivity and Neutron), check shot and deviation data. Petrel 2017 version interpretation software was used for interpretation and reservoir model development. An integrated approach employed in interpreting the available data for this study is summarized in the workflow (Fig 3).

Table 1. Available Well logs in the study area. Note: Y=Yes, N=No.

Well Name	GR	RES	NPHI	DEN	SONIC	CHECKSHOT	DEVIATION
BF 01	Y	Y	Y	Y	Y	Y	Y
BF 02	Y	Y	Y	Y	Y	Y	Y
BF 03	Y	Y	Y	Y	Y	N	Y
BF 04	Y	Y	Y	Y	Y	Y	Y
BF X01	Y	Y	Y	Y	Y	Y	Y

Table 3.2. Available well header

Well name	Surface X	Surface Y	MD (ft)	Elevation(ft)	Elevation Type
BF 01	562448.16	11722.29173	9315.02	78.5	KB
BF 02	562445.094	11720.76975	7793.99805	66	KB
BF 03	562445.462	11721.87489	7878	79	KB
BF 04	562447.737	11721.08716	8315	79	KB
BF X01	563839.6535	11615.85574	9441.000001	66.00000101	KB

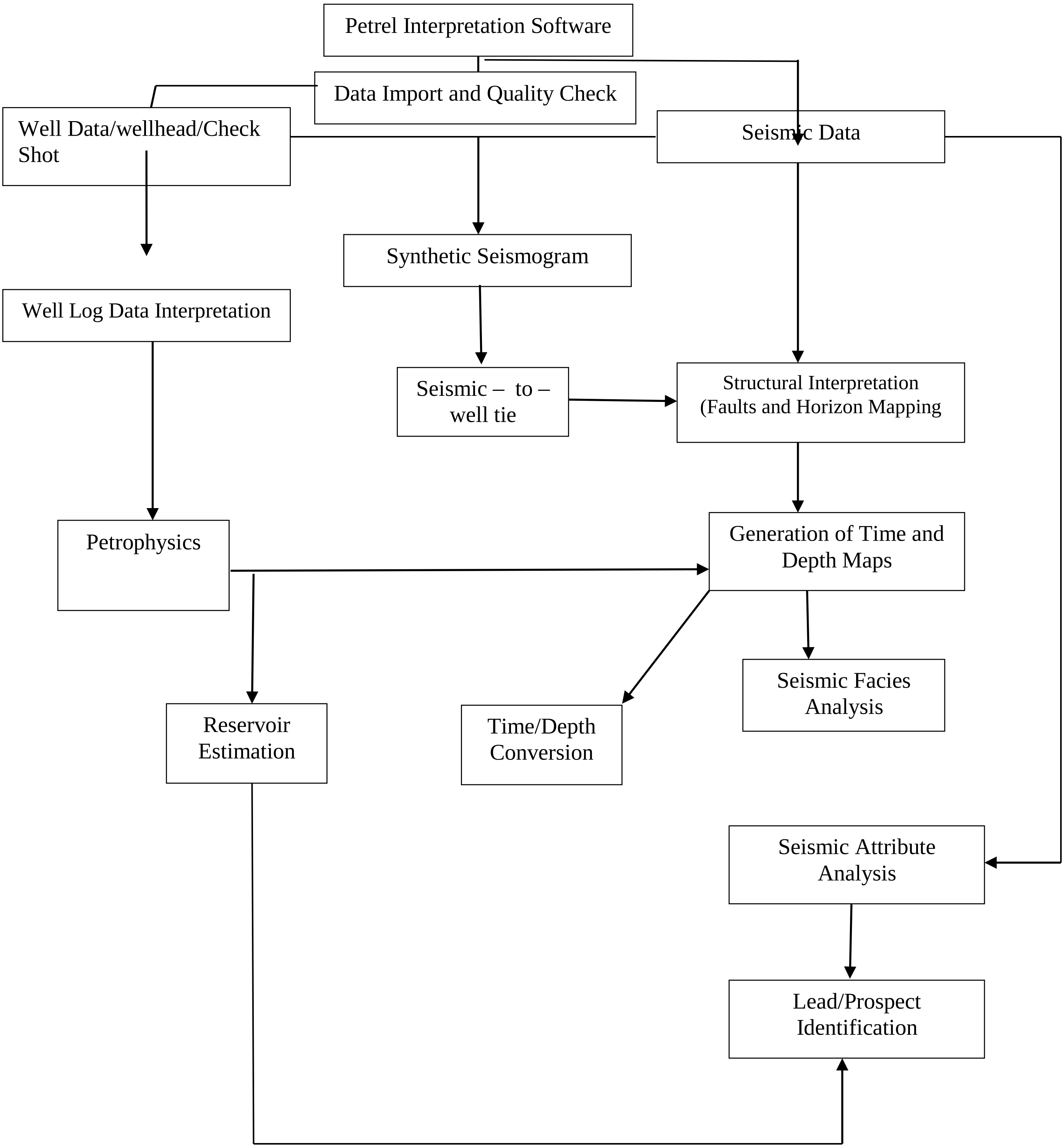

Petrel Interpretation Software
Data Import and Quality Check
Well Data/wellhead/Check Shot
Seismic Data
Synthetic Seismogram
Well Log Data Interpretation
Seismic – to – well tie
Structural Interpretation (Faults and Horizon Mapping
Petrophysics
Generation of Time and Depth Maps
Seismic Facies Analysis
Reservoir Estimation
Time/Depth Conversion
Seismic Attribute Analysis
Lead/Prospect Identification

Fig. 3. Comprehensive and detailed workflow chart used in this research study.

Results and Discussion

Interpretations were performed using Schlumberger Tech Log software and these results were generated. Significant features such as major and minor faults and horizons were identified in the seismic section's interpretation (Fig. 4.1 and Fig 4.2). The Faults were mapped in the crossline direction; results showed that thirty faults were mapped (F1-F30), three (3) significant faults (F1-F3), appeared to be regional and extended through the field while twenty-seven (27) are minor faults.

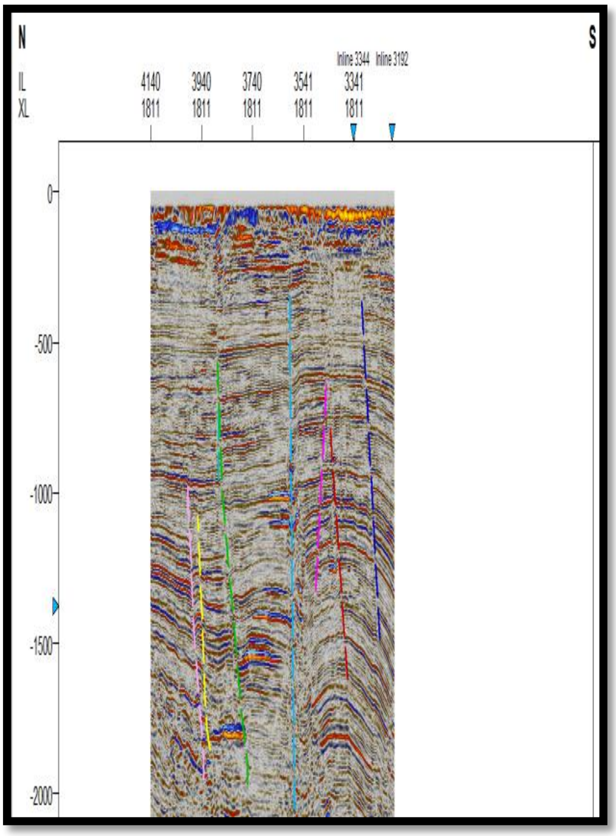


Fig. 4.1: Mapped faults on the seismic section.

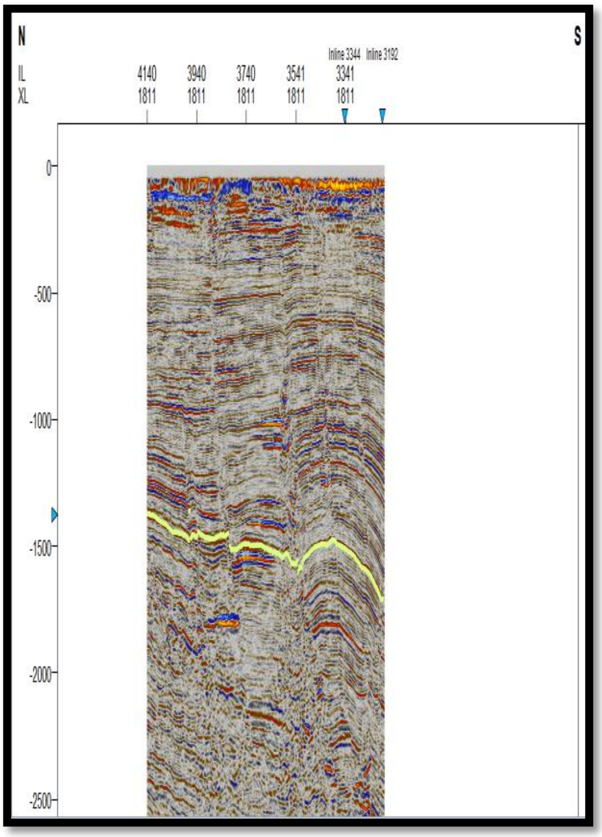
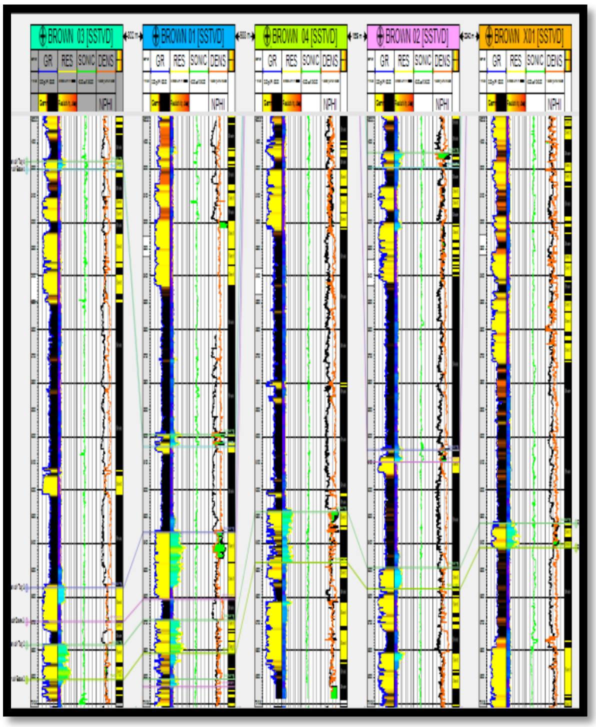


Fig. 4.2: Mapped Horizons

The lithologies of the area are dominantly sandstones, siltstones, and shale of the Benin Formation and Agbada Formation, Fig. 4.3. The result obtained from the petrophysical analysis revealed that each of the sand units extended through the field and varied in thickness (i.e., possibly evidence of faulting). Permeable zones (sands) were distinguished from impermeable zones through the analysis of Gamma-ray, Resistivity, Neutron, and Density logs. Using this data, the boundaries of the Reservoir sands were identified and correlated across the wells. Additionally, Neutron and Density logs were intersected to determine the fluid composition within the identified reservoirs.



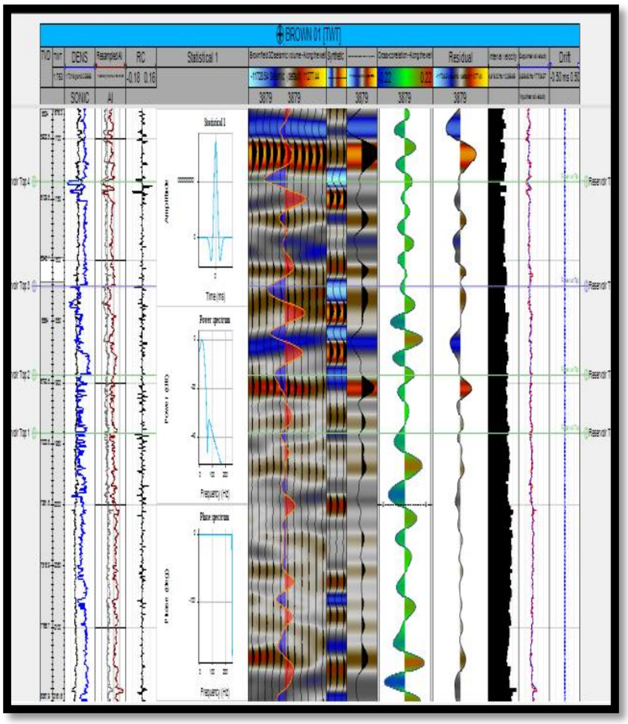


Fig.4.3: Lithostratigraphic correlation. **Fig. 4.4**: Generated Synthetic Seismogram.

A synthetic seismogram was generated using well 1 (Fig 4.4). Seismic attributes analysis was done using variance edge, the attribute were selected and used in this study to interpret fault (Fig 4.5).

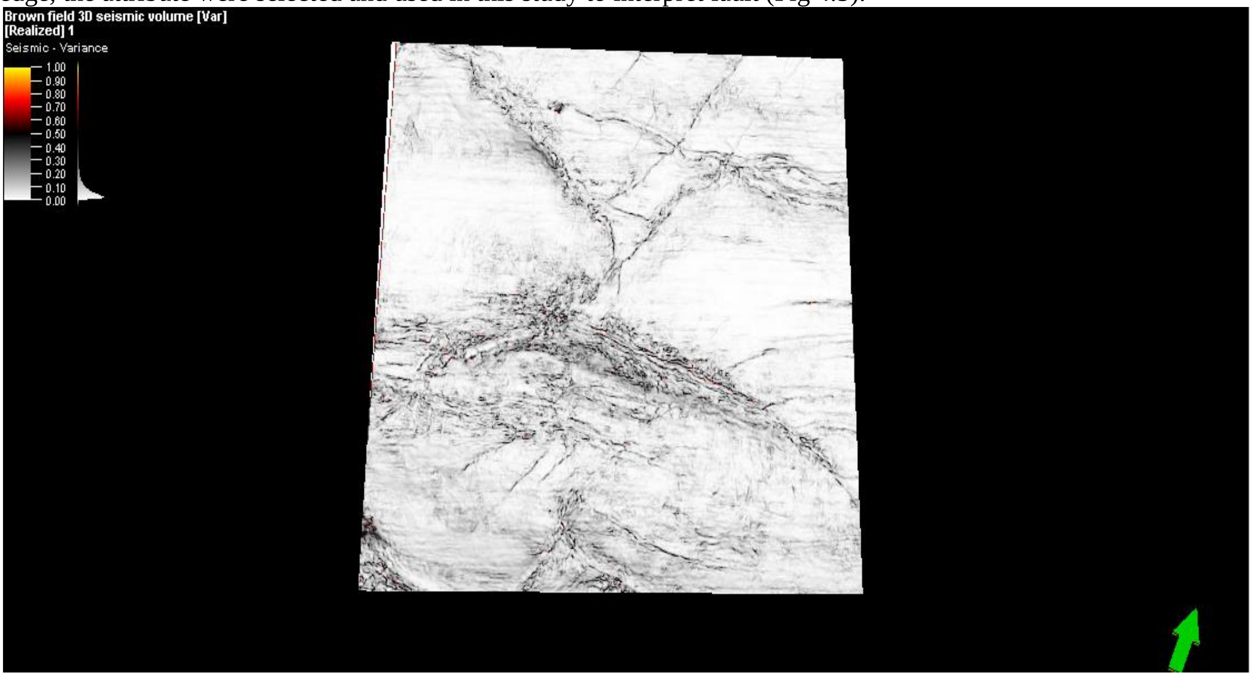
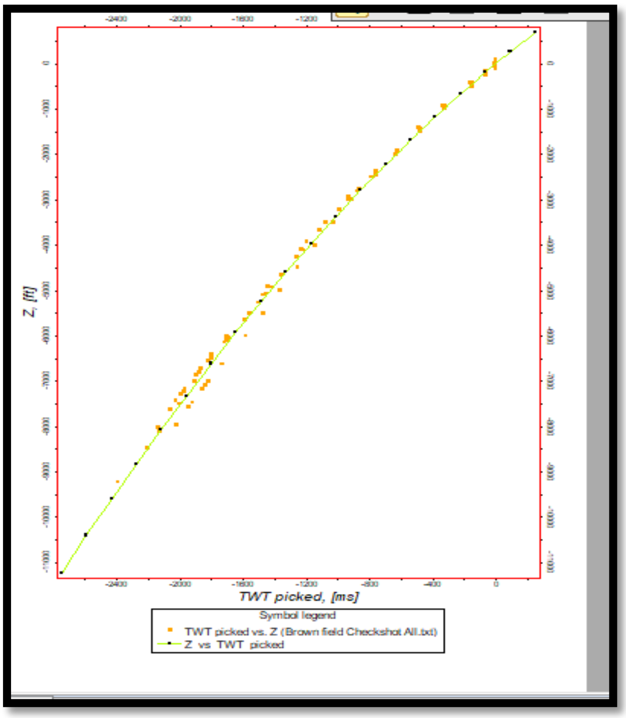


Fig. 4.5: Generated Seismic Attributes

The check shot data was plotted in two-way time against depth for converting the time structural map to the depth structural map, as shown in (fig 4.6) below. The seismic to-well tie was done using well 1, which is our prospect well (fig 4.7). The calibration of the sonic log was conducted to mitigate dispersion effects and enhance logging precision. Creating the surface map entails analyzing the structural interpretation of the subsurface based on observed 3-dimensional seismic survey data. Utilizing the mapped horizons, the surface map is generated. The contour map resulting from this procedure indicates that the prospective region is situated within the fault zone. The amplitude map generated (see fig. 4.8) illustrates the prevalent structure type within the field, with the rollover anticline structure observed to dip downwards. The resulting surface map illustrates that the prospect falls within the contour value of 5100, as depicted in (fig. 4.13).



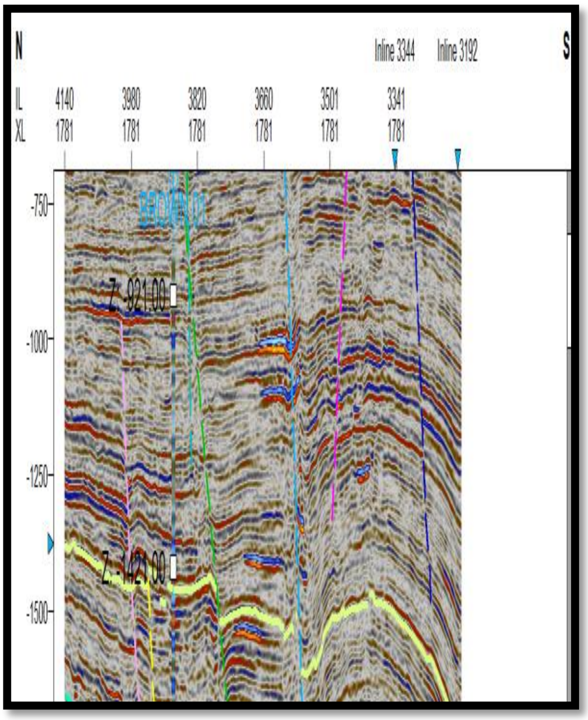


Fig.4.6: Two Way Travel Time against Depth. **Fig 4.7.** Seismic to well tie for Well 1.

The calculated petrophysical parameters were done for the reservoirs across well 1 using Techlog G and G software. These parameters were calculated: reservoir thickness, net-to-gross (NTG), effective porosity (POROE), volume of shale (Vsh), water saturation (Sw), and hydrocarbon saturation (Sh). The average petrophysical properties of the reservoir within the study area are shown in (table 4.1). The prospect well (well 1) is very porous and permeable and, as such, meets the basic requirement of being a reservoir rock.

The values of the volumetric analysis obtained in well 1 (table 4.2) revealed that the delineated reservoir contains huge barrels of hydrocarbon, which shows excellent potential for considerable size. The analysis showed that well one is viable and good prospect for hydrocarbon exploration and production. These computed petrophysical and volumetric values obtained are in consistent with what some authors have reported for the Niger Delta. Below are Prospects surface maps, the properties and features of the reservoirs and wells.

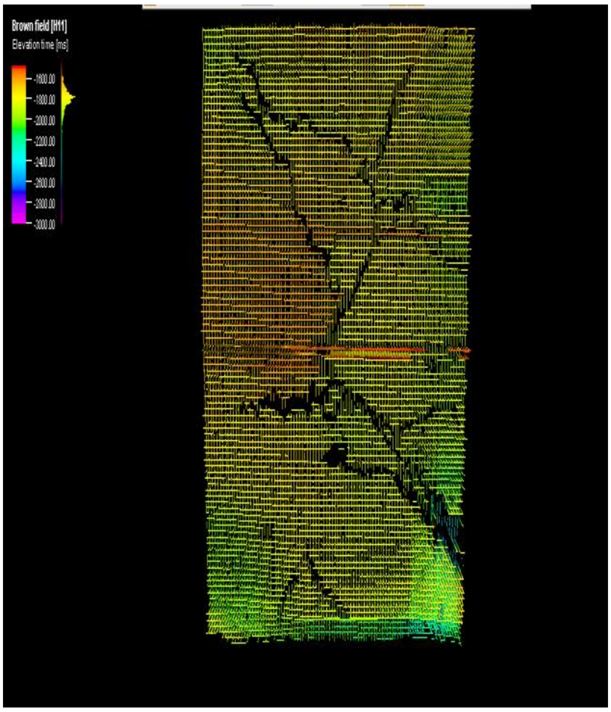


Fig. 4.8. Interpreted Horizon grid

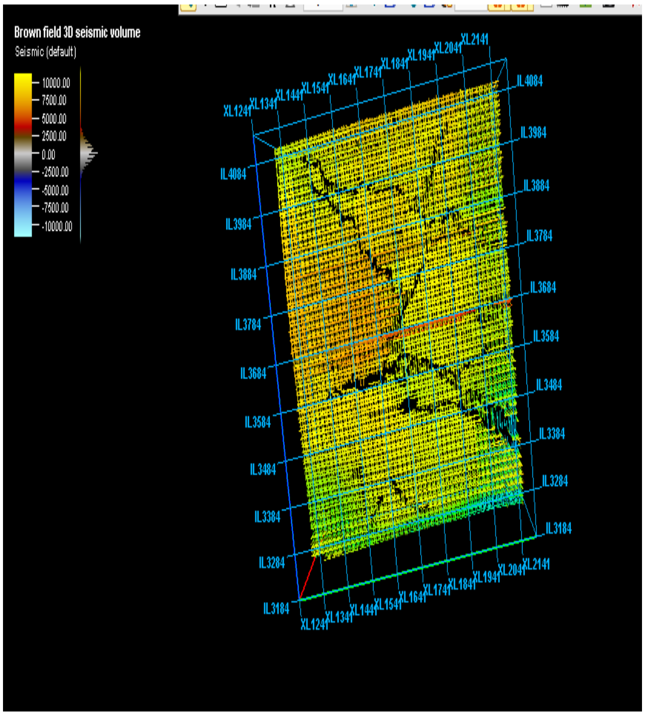


Fig. 4.9. Interpreted Horizons with x-line and in-line

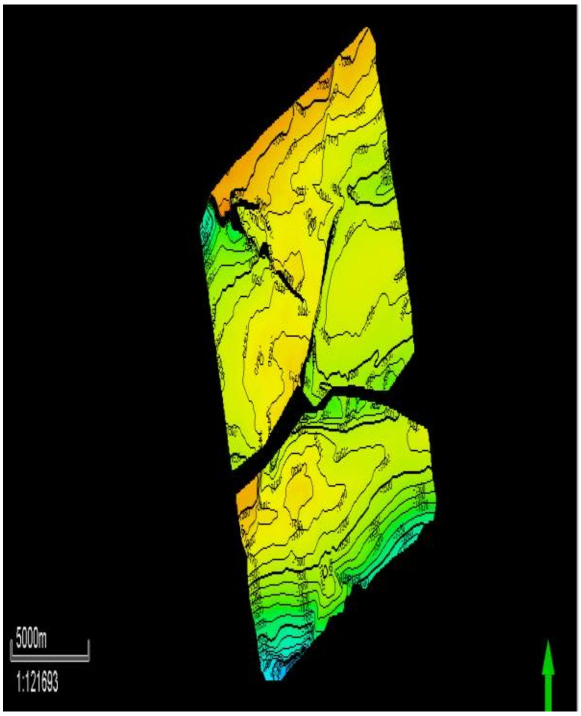


Fig 4.10: Time Surface Map

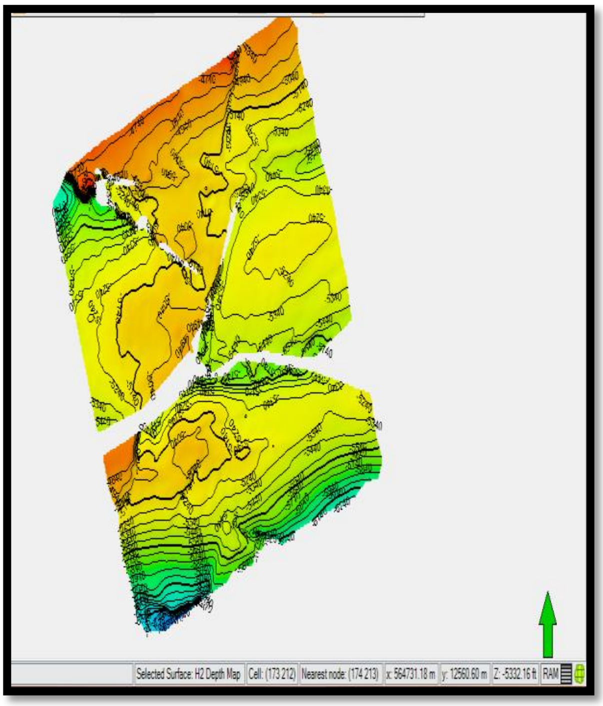


Fig. 4.11: Depth Surface Map.

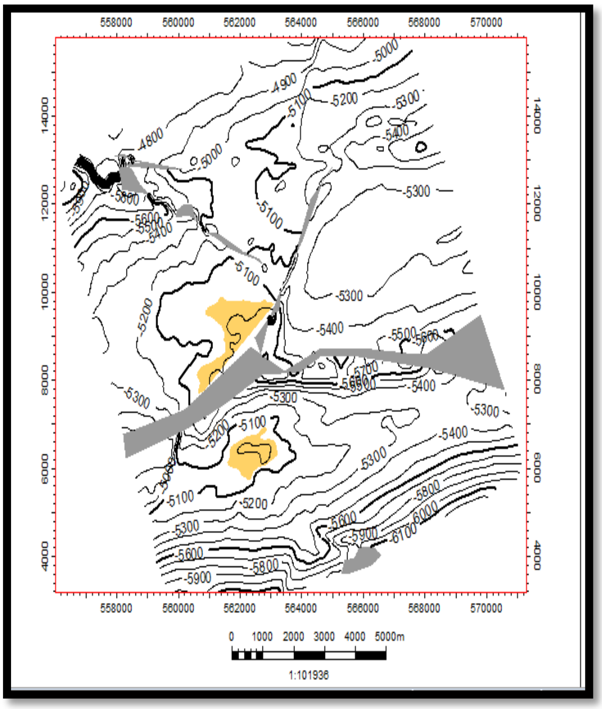


Fig. 4.12. Identified Prospect on Surface Map,

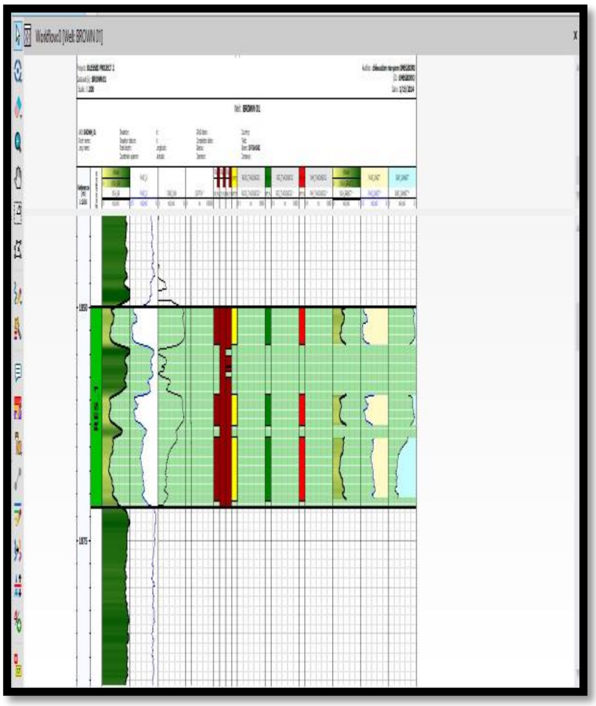


Fig. 4.13. Petrophysical Properties Reservoir 1.

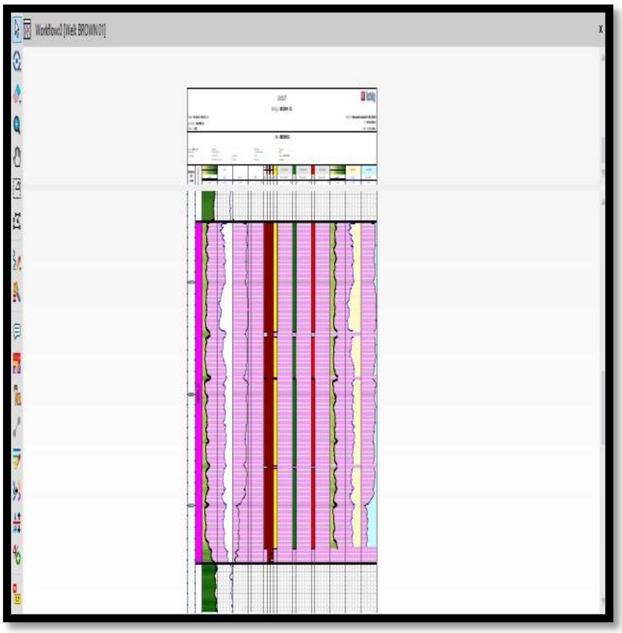


Fig4.14. Petrophysical features of Reservoir 2.

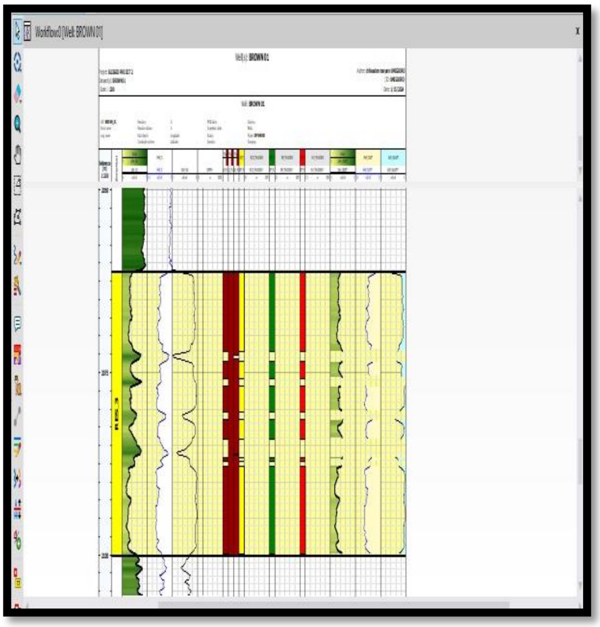
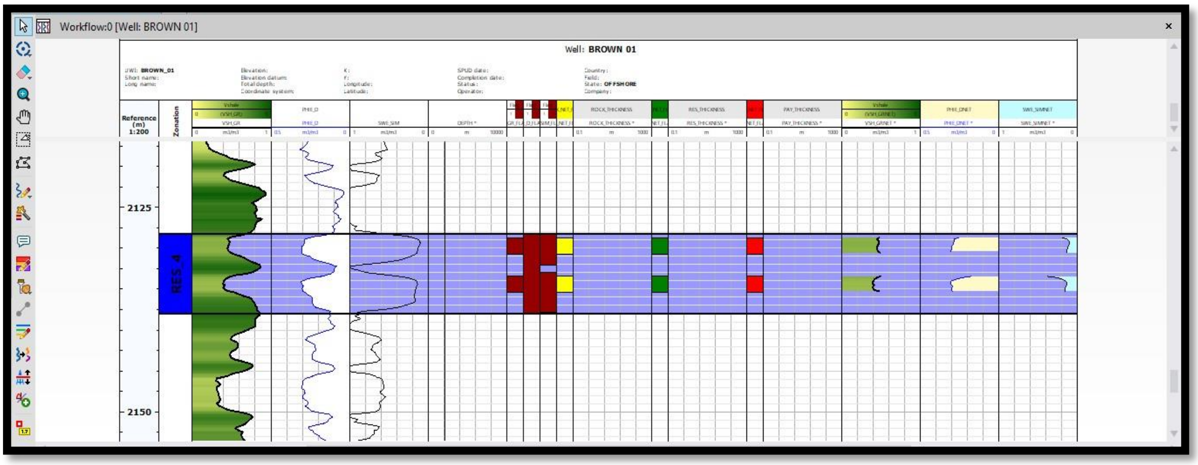


Fig. 4.15: Petrophysical features Reservoir 3.



4.16: Petrophysical Properties of Well 1 in Reservoir 4.

The tables below present the petrophysical and volumetric analysis of well I

Table 4.1: Petrophysical Parameters of Well 1

S\N	Well	Zones	Top	Bottom	Gross	Net	Net to Gross	Shale Volume	Porosity	Water Saturation
1	BROWN 01	RES_1	1849.92	1871.39	21.469	14.173	0.66	0.337	0.347	0.303
2	BROWN 01	RES_2	1961.363	2038.059	76.696	71.323	0.93	0.298	0.296	0.183
3	BROWN 01	RES_3	2061.151	2100.135	38.984	32.156	0.825	0.318	0.273	0.117
4	BROWN 01	RES_4	2128.243	2137.989	9.746	3.962	0.407	0.441	0.288	0.148

Table 4.2: Results of Volumetric Analysis of Well 1

Prospect	Levels	Depth to Prospects	Gross Rock volumes	Prospect properties			Barrels of Oil Equivalent mm(boe)
			Low	Porosity	Net Thickness	SWT	
Prospect 1	H1	4943	13803.8	0.3215	49.083	0.243	108.51
Prospect 2	H1	5000	6434.75	0.2805	24.365	0.1325	44.052

CONCLUSION

3D seismic interpretation was carried out on the Pearl Field using well logs and Seismic data volume. Five wells used in this study were correlated, and four reservoirs were interpreted using their gamma-ray logs and resistivity logs. The primary lithology comprises sandstones, siltstones, and shales. Thirty faults were interpreted from the seismic lines. Horizons were mapped on both inline and line within the study area. Structures such as rollover anticlines were interpreted to be part of the geology of the study area. The structural maps showed that the hydrocarbon accumulations are associated with anticlines. The petrophysical values which include the porosity, Net to Gross, and Water saturation values are all in agreement with the previous studies done in Niger Delta Basin. In conclusion, the results obtained from our interpretation showed that the field is prolific and viable for exploitation.

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