__Original Research Article__

VOLUMETRIC ANALYSIS OF SELECTED RESERVOIRS IN OGBENU FIELD, NIGER DELTA, NIGERIA USING 3D SEISMIC AND WELL LOG DATA

ABSTRACT

Volumetric analysis of selected reservoirs in the Ogbenu field in the Niger Delta, Nigeria was carried out using 3D seismic and well log data. The objective includes identifying and selecting appropriate reservoirs for volumetric analysis, correlating reservoirs across the field, producing synthetic seismograms and seismic-to-well ties, performing structural interpretation of faults and horizons, identifying potential prospects, and estimating hydrocarbon volume in place. Fault and horizon mapping established the structural framework, while key reservoir intervals identified during well log analysis were mapped throughout the field. Volumetric analysis of these selected reservoir intervals determined the amount of hydrocarbons present. Detailed analysis of seismic responses, synthetic seismograms and petrophysical properties from well logs led to the identification and correlation of eight reservoir intervals. These intervals are of varying quality, with a decline in reservoir quality towards the south and evidence of gas-water contacts in reservoir A with a similar trend in the other reservoir units. Petrophysical analysis confirmed the prospects of the deposits. Subsequent volumetric assessments identified two gas-bearing and six oil-bearing reservoirs. This comprehensive study provides valuable insights into the subsurface geology, structural features and reservoir properties of the Niger Delta region, contributing to a better understanding of hydrocarbon potential and assisting in more accurate resource assessments.

Keywords: Volumetric Analysis, Niger Delta Basin, Petrophysical Analysis, Structural Interpretation, Geophysics

INTRODUCTION

The Ogbenu field is located onshore, within the coastal swamp I depobelt, of the Niger Delta Basin. The Niger Delta Basin is one of Nigeria's main sedimentary basins renowned worldwide for its prolific hydrocarbon accumulations. The basin, a major petroliferous region, houses the Akata-Agbada petroleum system, having significant economic importance within the broader West African Continental Margin (Tuttle *et al.,* 1999; Aizebeokhai and Olayinka, 2011). The basin is characterized by common geological structures like fault blocks, synclines, and anticlines and its sedimentary sequence has been dated to span from the Cretaceous to Recent. It is organized into the Akata, Agbada, and Benin Formations, comprising diverse facies such as sandstones, shales, and claystones.

Hydrocarbon exploration and exploitation in the Niger Delta is integral to Nigeria's economy, and the major reservoir intervals come from the Agbada Formation, predominantly composed of loose or poorly consolidated shale and sandstone. The basin's complex stratigraphic framework, marked by alternating sedimentary sequences, holds significant implications for hydrocarbon reservoir distribution and characteristics. Thus, a thorough understanding of the structural and stratigraphic setting is crucial for the oil and gas industry, operating in the field necessitating a comprehensive volumetric analysis to evaluate hydrocarbon reserves accurately.

Volumetric analysis is a key method in assessing hydrocarbons-in-place prior to drilling, and involves geophysical and geological interpretations. The importance of structural and stratigraphic interpretations of seismic data in this process has been strongly emphasized by Allstair (2011) and Weber (2012). Integrating 3D seismic and well log analysis provides a comprehensive understanding of subsurface geology and geophysical properties, enabling accurately mapping and assessing hydrocarbon traps, delineate potential prospects, and calculate volumes in place.

The specific focus on the Ogbenu field within the coastal swamp I depobelt requires precise volumetric analysis through the integration of available 3D seismic and well log data. The study projects that interpreted data will not only contribute to understanding petrophysical properties, structural settings, and fluid contents of the reservoirs but will also guide decision-making processes related to economic feasibility, optimization, field development, and production (Okwoli *et al.*, 2015).

This research aims to identify potential prospects and estimate the volume of hydrocarbons initially in place in the Ogbenu field. The findings will be useful in optimizing hydrocarbon recovery in a cost-effective manner, benefiting stakeholders and developers alike.

GEOLOGY OF STUDY AREA

The Niger Delta is tectonically divided into six regions or structural provinces: The Northern delta, Greater Ugheli, Delta edge, Central swamp, Coastal swamp and offshore depobelts (Okpara *et al.,* 2021). Evidence indicate that the growth and development of these deposition belts was controlled by old fault belts or zones which formed in the Cretaceous, that progressively form a network of trenches and ridges in the deep Atlantic (Okpara *et al.*, 2021). The initiation of the Niger Delta has been traced to the late Jurassic and continued into the middle Cretaceous (Lehner, 1977). It is part of a rift system. Gravity induced shale tectonism has been the primary mechanism responsible for modifying the basin into its present-day structural style (Okpara *et al.,* 2021).

The Basin is situated near West Africa's continental edge (Figure 1). The tertiary portion of the delta has been stratigraphically separated into three formations. Facies variations allow for the identification of prograding facies, which make up the majority of these formations. The youngest formation, the Benin Formation, is primarily composed of continentally-derived sand facies with sporadic shale deposits or breaks (Figure 2). This formation moves laterally and vertically into the Agbada formation (Okpara *et al.,* 2021). The paralic deposit known as the Agbada Formation is typical. This formation transitions into the Akata Formation's marine shales offshore. The Akata Formation is a sequence of thick, massive shale with sporadic or non-existent sand deposits that are probably turbidites.

The study area is located on the west coast of Central Africa, close to the Gulf of Guinea, in the southern portion of Nigeria within the swamp and marshes of the Niger Delta. It is part of the Niger Delta, one of the world's biggest deltaic systems. The delta's structural and stratigraphic evolution have had a significant impact on the formation of hydrocarbon traps and seals. Structural traps make better exploration targets than stratigraphic traps within the basin.

Play styles like shallow or deep simple/faulted rollover, k-type structures, reversed footwall closure, back-to-back structures, and inversion structures are a few examples of play styles that have shown to be viable exploration targets.

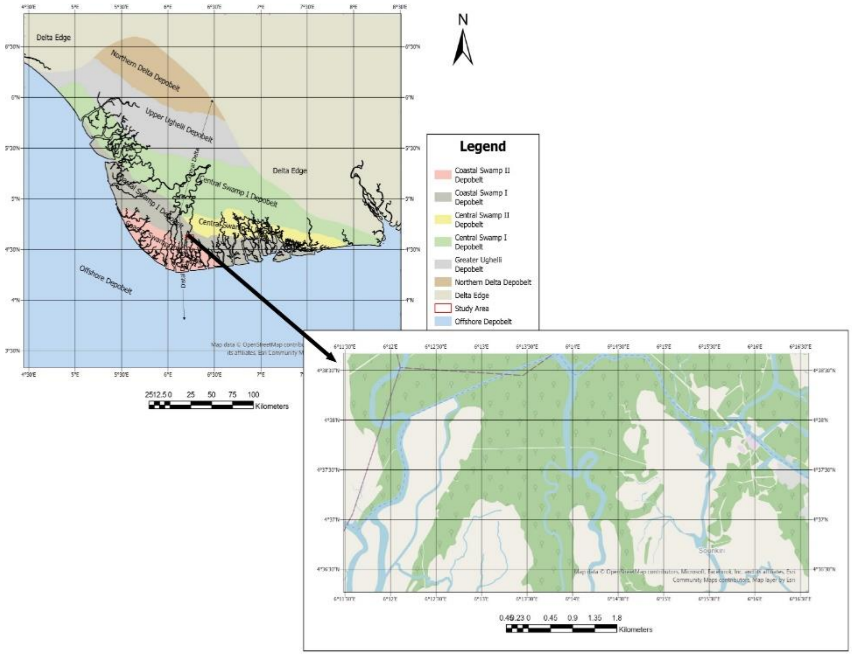

Figure 1: Location Map of the Study Area

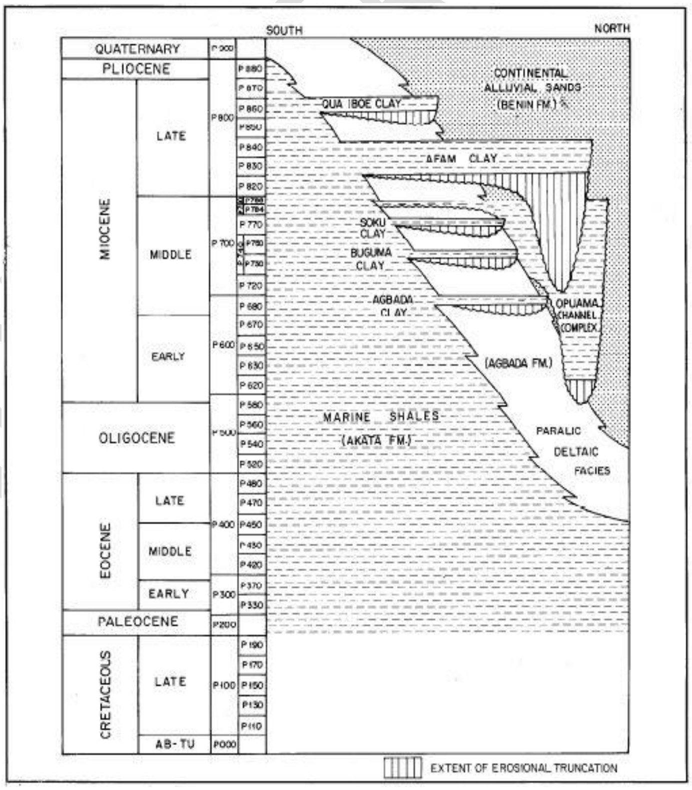

Figure 2: Schematic representation of Stratigraphic column of the Niger Delta and relationship of clay filled channels on the delta flanks (Doust and Omatsola, 1990).

MATERIALS AND METHODS

The data used for this study are 3D seismic and well logs data. The methodology involves identifying suitable reservoirs, delineating and correlating them, carrying out petrophysical assessment of the reservoirs generating synthetic seismograms, conducting structural interpretation and doing volumetric analysis. The study aimed to estimate the volume of hydrocarbons in place and identify prospects. The schematic below (Figure 3) gives a summary of the workflow indicating the various research parameters, procedures and steps taken to achieve the research aim. These procedures include data sourcing, data gathering, data loading into relevant software (Schlumberger Petrel and Techlog), data quality assurance and quality control, well logs conditioning (despiking and interpolation), well correlation, petrophysical evaluation of reservoirs, visualization and analysis of estimated petrophysical properties.

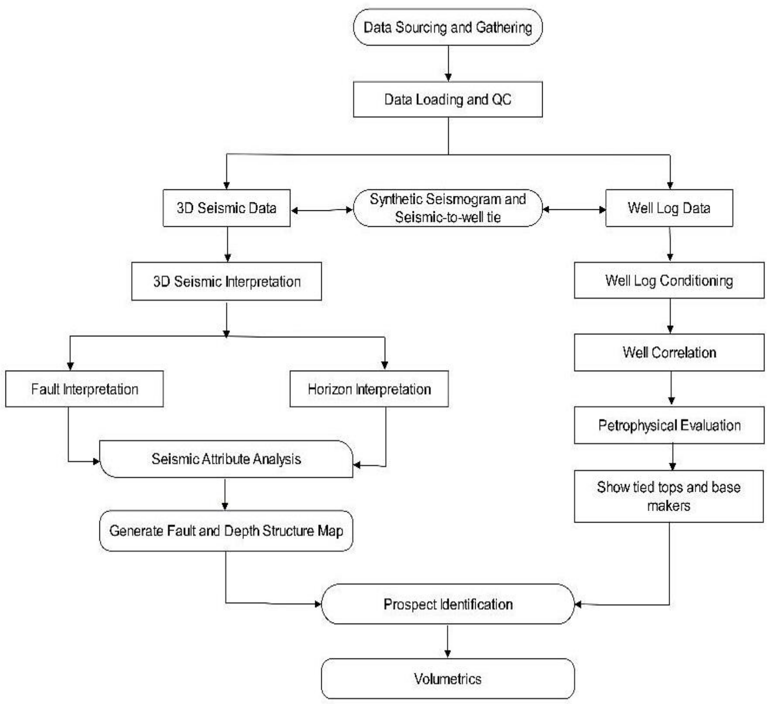

Figure 3: Illustration of the Research Flow Chart

STRUCTURAL INTERPRETATION

The Ogbenu field lies within an extensional province, characterized by a faulted rollover anticline. The geometry of this anticline has been notably influenced by lateral or horizontal fault block movements, contributing to a complex structural style in plain view. The primary feature is an east-west boundary fault which transition into a decollement plane in section view at the top of the Akata or base of the Agbada Formation (Figure 5). This fault has played a key role in the formation of a northeast-southwest trending rollover anticline, a typical structure within the Niger Delta basin. Visual inspection of the dip of beds from the seismic section indicates a steep plunge towards the south and gentler northwards toward the controlling boundary fault. Additionally, other detached minor conjugate faults have significantly influenced the anticline's geometry, demonstrating a synthetic sense of strike and dip (southwards) to the major boundary fault. There are other numerous detached minor faults striking in the northwest-southeast with an opposite sense of dip (antithetic) which may have possibly formed accommodation zones enabling the horizontal or lateral movement of fault blocks.

In plain view, the faults exhibit a narrow and cuspate geometry along their strike, partitioning the field into five distinct fault blocks (Figure 4), making precise boundary delineation challenging. Examination of the seismic section reveals lateral transitions from areas of low signal strength to regions of continuous reflections, particularly in the lower portions of the seismic volume, occurring at shallow depths beneath the footwall of the fault block adjacent to the major boundary fault in comparison to the down-thrown fault block. The boundaries of the low-amplitude, discontinuous zone vary, appearing sharp in some areas and gradual and diffuse in others. These boundaries shifts suggest fracturing of deposits due to overpressure, resulting in displacement from the buoyancy of the underlying strata.

On the seismic sections, following the dip of depositional sequences, reflections within anticlines appear generally horizontal and parallel to the fold axis. Additionally, since flooding surfaces are interpreted as relatively flat depositional planes, often seen as strong reflectors with regional extent across the field, a top structure map was selected to traverse all the key structures within the field. This was utilized to establish broad displacement patterns across faults and deformation of fault blocks within the stratigraphic interval (Figure 6).

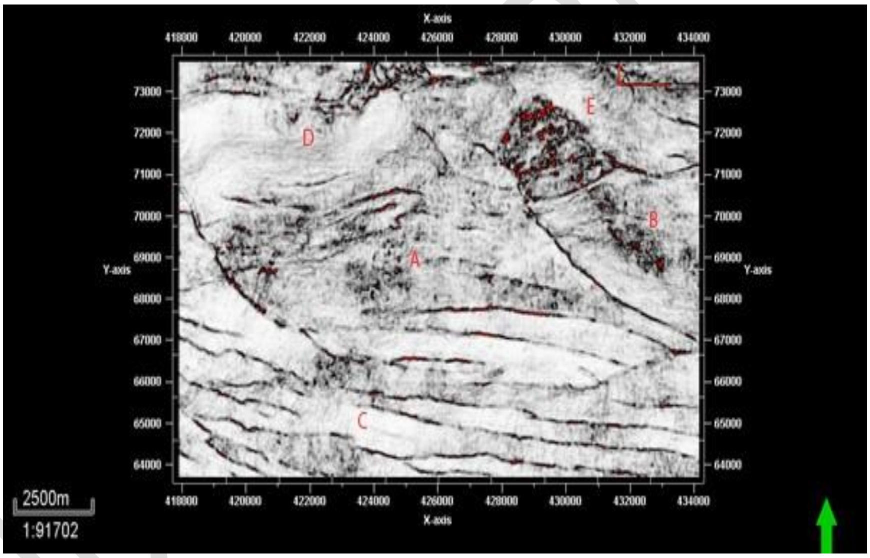

Figure 4: Time slice of Variance Edge Volume taken at 2496ms corresponding to Agbada Formation and showing the structures.

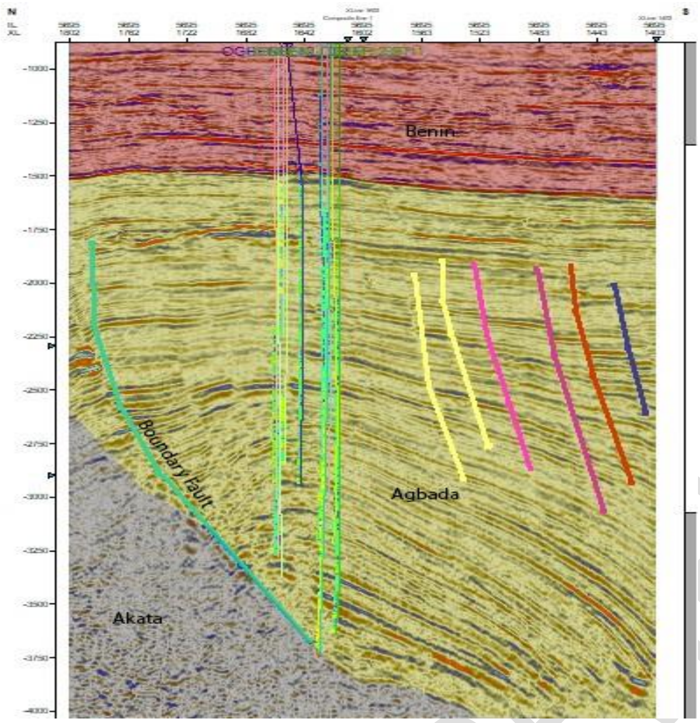

Figure 5: Seismic section of Akata, Agbada and Benin intervals and the structures (major boundary and minor faults)

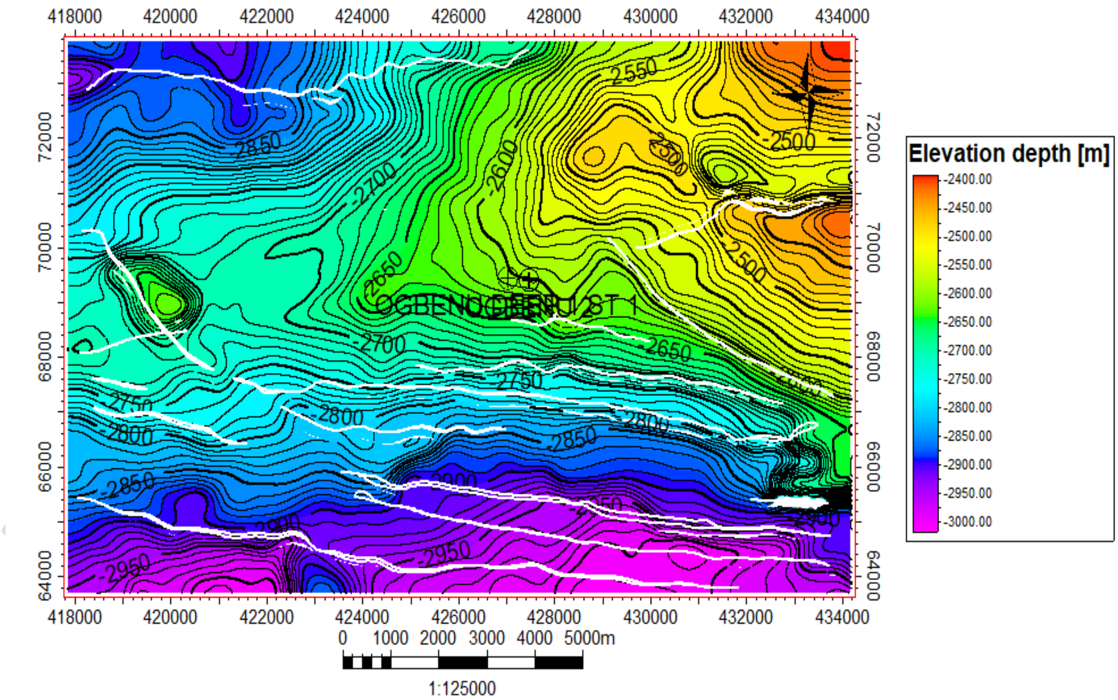

Figure 6: Depth structure map used to define broad structural deformation and style of the field.

RESERVOIR DELINEATION AND CORRELATION

Utilizing the unique characteristics and properties of the gamma ray, resistivity, neutron and density logs, eight reservoir intervals or units were identified and labelled A, B, C, D, E, F, G and H within well Ogbenu 2. These reservoirs were subsequently correlated to well Ogbenu deep 2 ST 1 (Figure 7a to 7d). Evaluation of the electrical resistivity and gamma ray logs reveals a decrease in reservoir quality moving southwards from well Ogbenu 2 to Ogbenu deep 2 St 1. Additionally, there is a corresponding decrease in the strength of the electrical resistivity log in the same directional trend.

This observation aligns with the mapping of the reservoir unit across the field on the seismic section, indicating a southward dip of the reservoir bed unit. Well Ogbenu 2 represents the updip section of the reservoir, while well Ogbenu deep 2 St 1 signifies the downdip portion (Figure 8). Furthermore, the reservoir appears not to be filled to its natural spill point which represents the lowest part along the plunge of the roll-over anticline southward. Additionally, there appears to be a gas - water contact somewhere at the base of the reservoir interval within well Ogbenu deep 2 St 1. Analysis of other reservoir intervals shows similar pattern or trend.

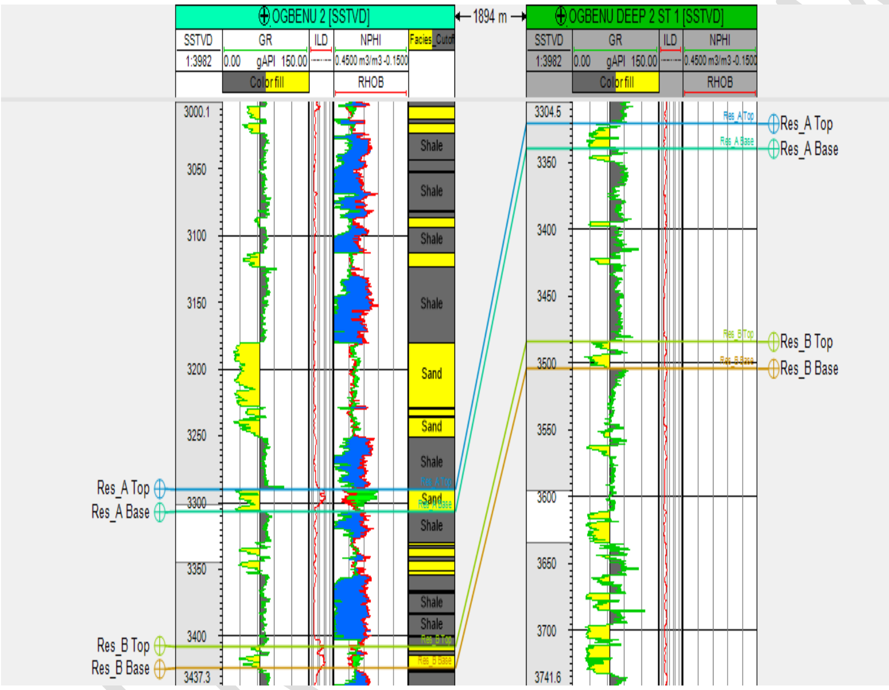

Figure 7: Well section through Ogbenu 2 to Ogbenu deep 2 st 1 displaying the reservoirs A and B intervals zones.

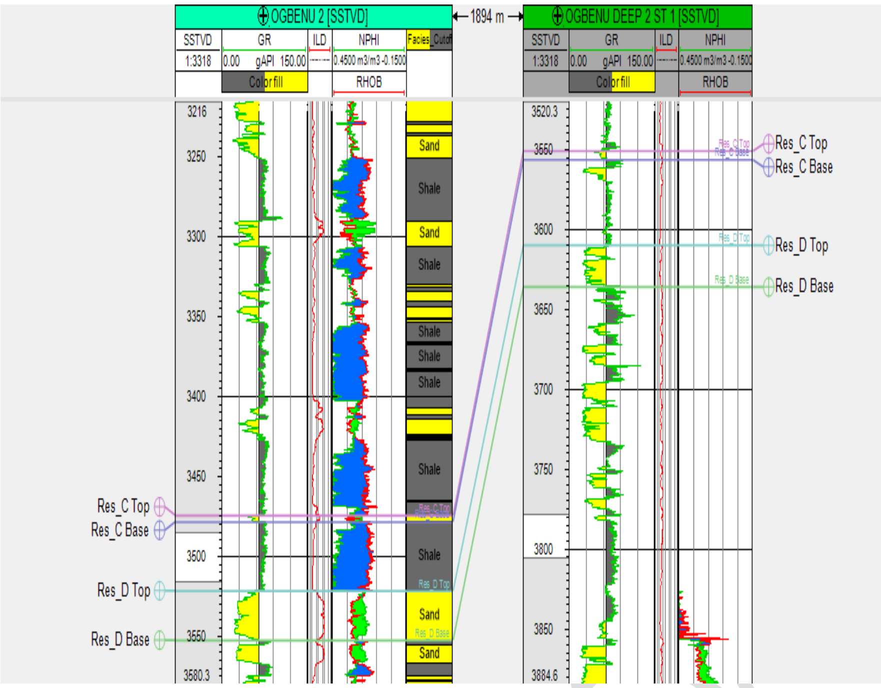

Figure 7b: Well section through Ogbenu 2 to Ogbenu deep 2 st 1 displaying the reservoirs C and D intervals zones.

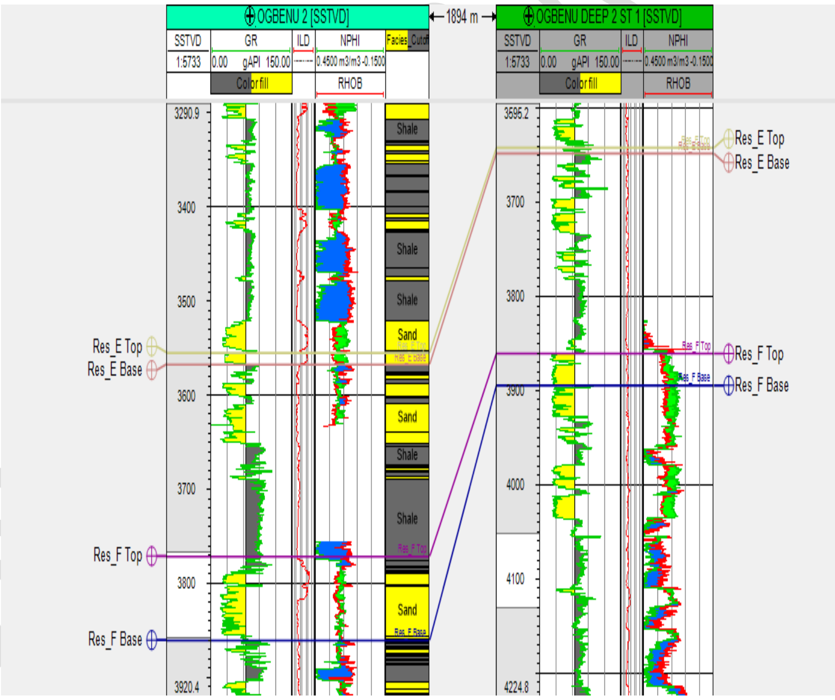

Figure 7c: Well section through Ogbenu 2 to Ogbenu deep 2 st 1 displaying the reservoirs E and F intervals zones.

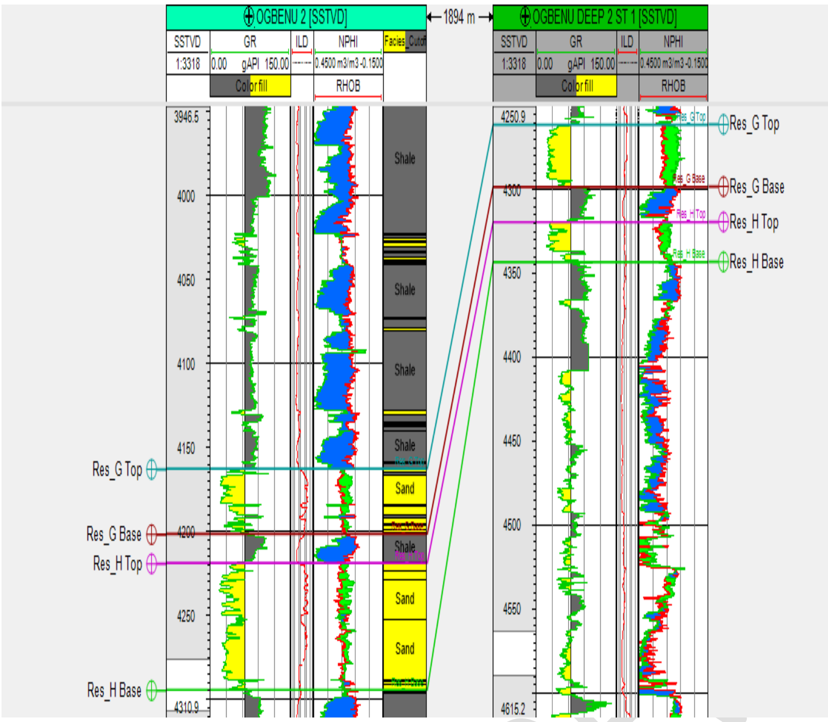

Figure 7d: Well section through Ogbenu 2 to Ogbenu deep 2 st 1 displaying the reservoirs G and H intervals zones.

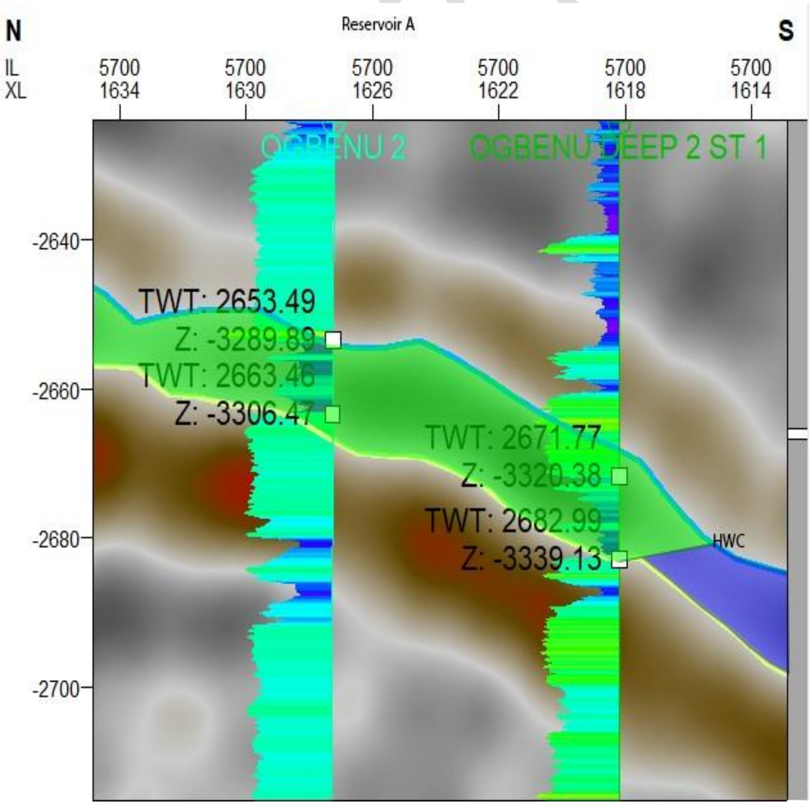

Figure 8: Seismic section through wells Ogbenu 2 and Ogbenu deep 2 st 1 showing the reservoir A interval. The beds can be seen to deep southwards.

PETROPHYSICAL ANALYSIS

Single well analysis revealed eight key reservoir intervals (A, B, C, D, E, F, G and H) for well Ogbenu 2 (Figure 9a to 9f) which was correlated to well Ogbenu deep 2 St 1. From the gamma ray and facies logs in the two wells, the reservoirs showed varying qualities and appear to decrease in quality southwards away from the structure controlling fault. Vertical variation in gamma ray and facies log also indicate the high heterogeneity within each reservoir interval. Petrophysical analysis confirmed that the reservoirs have the properties to make good prospects. The Table 1 is a summary of the results of the petrophysical analysis.

Table 1: The Petrophysical Properties of Reservoirs A-H.

Reservoir	Thickness	NTG	Porosity	VSH	Sw
A	17.53	0.70	0.22	0.24	0.32
B	20.15	0.82	0.15	0.41	0.27
C	4.02	0.81	0.12	0.42	0.48
D	30.07	0.86	0.18	0.21	0.18
E	10.65	1.00	0.19	0.17	0.24
F	86.33	0.35	0.16	0.19	0.12
G	40.48	0.89	0.12	0.28	0.20
H	76.7	0.85	0.16	0.28	0.23

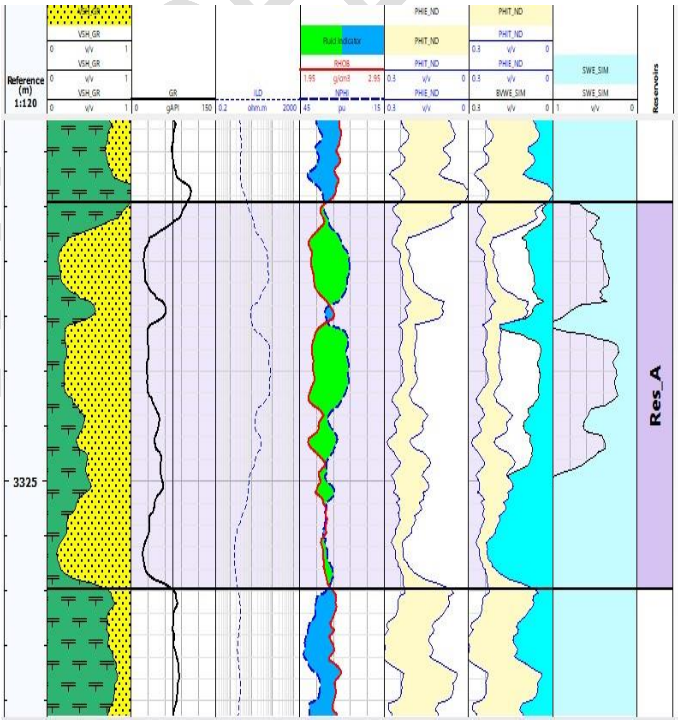

Figure 9a: Well section of Ogbenu 2 displaying the Petrophysical logs for Reservoir A.

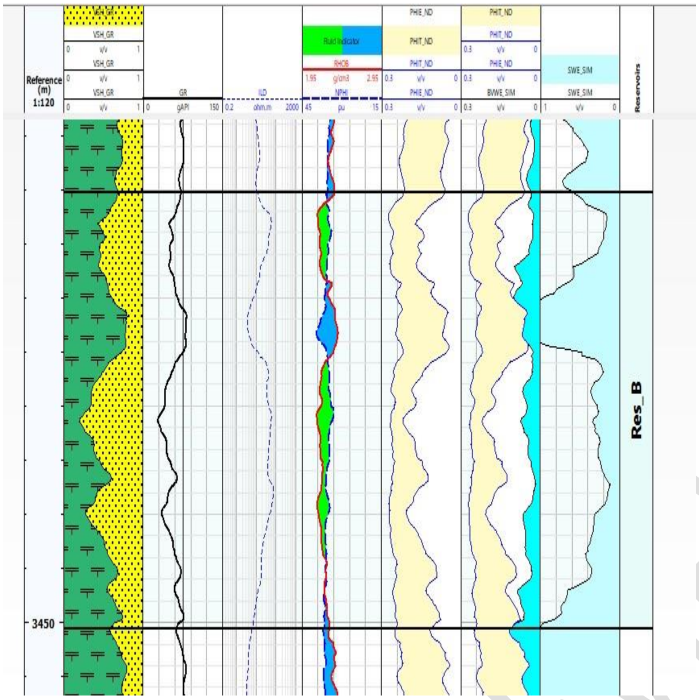

Figure 9b: Well section of Ogbenu 2 displaying the petRophysical logs for Reservoir B.

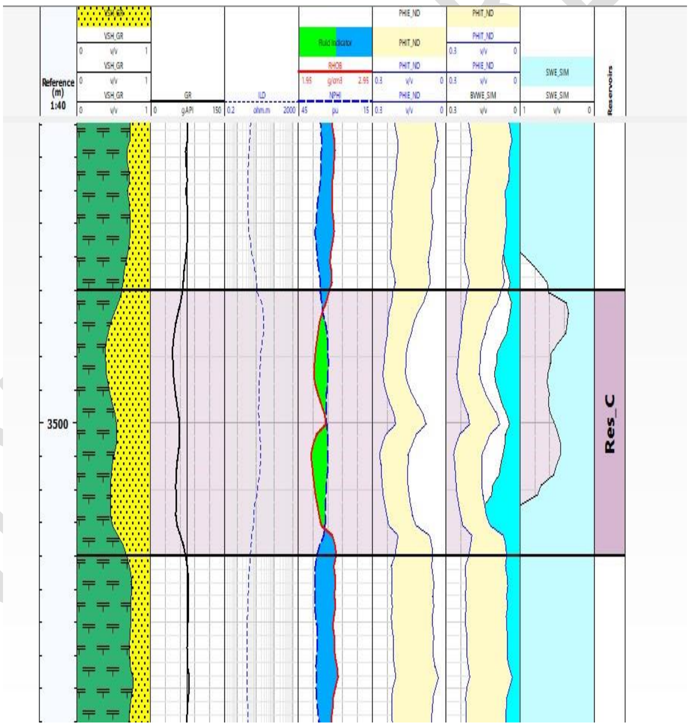

Figure 9c: Well section of Ogbenu 2 displaying the Petrophysical logs for Reservoir C

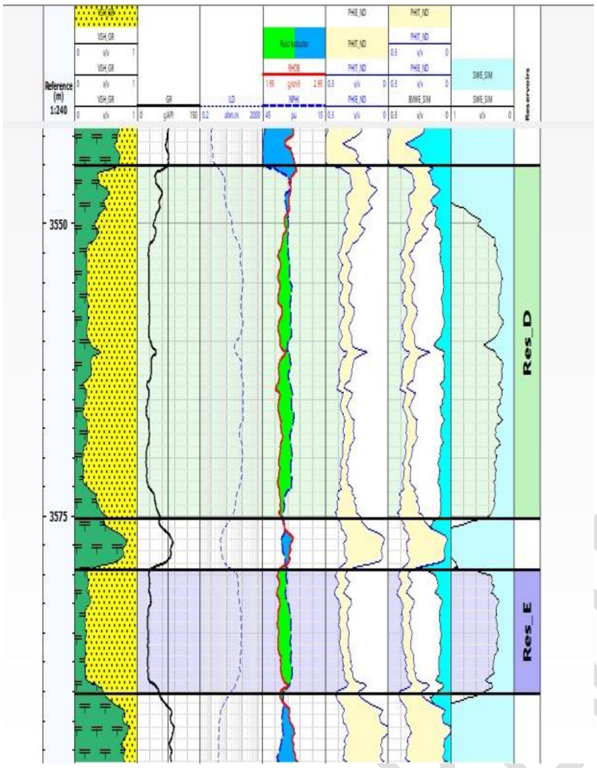

Figure 9d: Well section of Ogbenu 2 displaying the Petrophysical logs for Reservoir D and E.

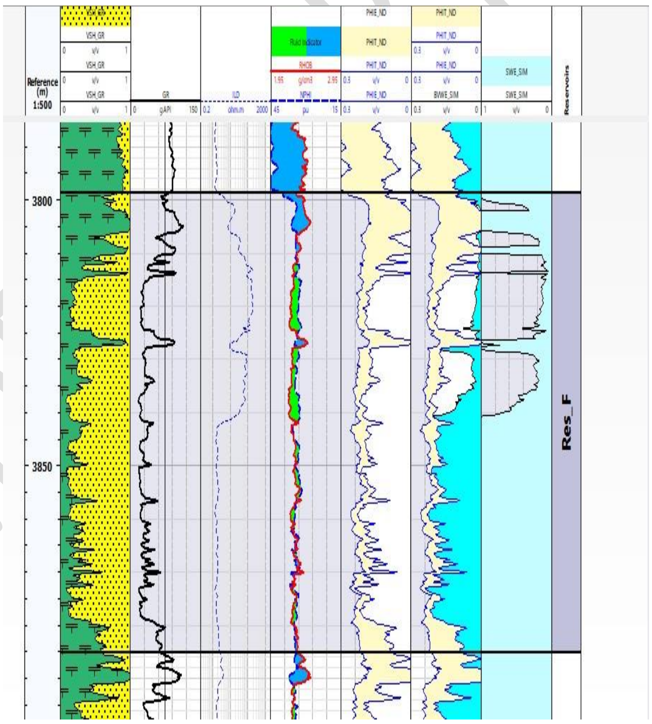

Figure 9e: Well section of Ogbenu 2 displaying the Petrophysical logs for Reservoir F.

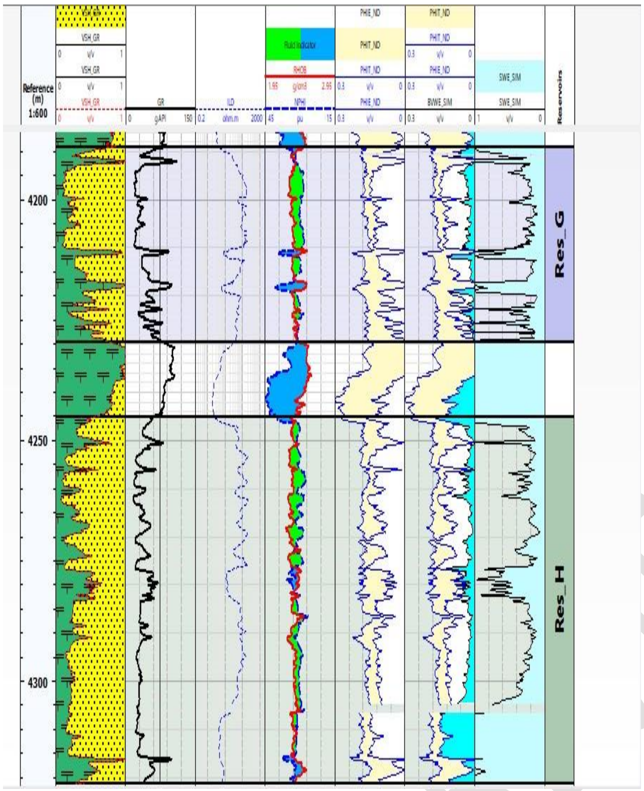

Figure 9f: Well section of Ogbenu 2 displaying the Petrophysical logs for Reservoir G and H.

VOLUMETRIC ANALYSIS

The reservoir properties used for volumetric analysis or assessment of the eight reservoirs utilized reservoirs properties such as porosity, water saturation and NTG, acquired through petrophysical analysis. The rock volumes were derived by taking the product of the surface area of each reservoir interval's top horizon and the average reservoirs thickness from the wells. With the petrel software, polygons were used to artificially enclose the structures in relation to the spill points. The analysis identified two gas bearing reservoirs and six oil bearing reservoirs. Table 2 presents the results of the volumetric analysis.

Table 2: Reservoirs and the Volumes of Hydrocarbons in place

Reservoir	Fluid Type	OIIP (MSTB)	GIIP (MMBOE)
A	Gas		29025.57
B	Oil	23.95775	
C	Gas		2776.374
D	Oil	48.19219	
E	Oil	16.69835	
F	Oil	131.984	
G	Oil	42.19574	
H	Oil	102.6037	

CONCLUSION

The comprehensive analysis of subsurface units, structural features, and reservoir intervals provides critical insights for hydrocarbon exploration in the Niger Delta, specifically in the Ogbenu field. The identification of distinct reservoir intervals and their varying qualities aids in resource assessment. The structural analysis enhances the understanding of the geological complexities, which is crucial for reservoir management strategies. The findings of this study contribute significantly to the knowledge base for effective exploration and production activities in the region.

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