Petrophysical Evaluation of Nwosa Field, Offshore Niger Delta, Nigeria; Implication for Depositional Environment

[1]Mba-Otike, M. N., [2]Ideozu, R. U., [1]Odiaka, N. I

[1]Department of Geology, Dennis Osadebay University, Asaba

[2]Department of Geology University of Port Harcourt

DOI: https://doi.org/10.51244/IJRSI.2025.12010076

Received: 07 January 2025; Accepted: 11 January 2025; Published: 22 February 2025

ABSTRACT

Well log data were studied to evaluate their petrophysical properties and to decipher the depositional environment of sediments in Nwosa Field, Offshore Niger Delta. The materials used for this study comprised well log data (detailed measurements from various geological formations) well header data (metadata of each well, as well as identification and operational details, deviation data (indicating the angles of deviation of each well from vertical) and the Petrel Software was employed for geological modeling and analysis. A reservoir bodies X was identified, with the environment of deposition for reservoir interpreted as a deltaic sequence occurring at a depth of 8510-8600ft. While below the deltaic sequence is a bar at a depth of 7940-800ft. The average petrophysical parameters were calculated for reservoir X and the properties obtained are porosity (21%), permeability (1533.7md), net-to-gross (0.608911), oil saturation (55%) and STOIIP (63.0111mmstb). This is an implication that the reservoir formation is porous and permeable with good interconnected pore spaces within the reservoir stratigraphic units.

Key Words: Petrophysical Evaluation, Depositional Environment, Offshore Niger Delta, Juxtaposition of Stratigraphic Units.

INTRODUCTION

Formation evaluation encompasses assessment of reservoir characteristics with the integration of diverse data sources, aimed at constructing reliable models that enhance reservoir performance and predictions. Odesa *et al* (2024) characterized mature petroleum systems in part of the Niger Delta where exploration and production strategies are closely intertwined, an understanding of the petrophysical properties within reservoir systems is essential for effective reservoir management (AAPG Bulletin, 2005). This study models the reservoir properties and their spatial distribution within the Nwosa Field, Niger Delta (Figure 1), by leveraging rock petrophysical properties to interpret depositional environment and reservoir performance. The objectives are to construct a well log model for geological and petrophysical evaluations, the identification of reservoir sand bodies, well log correlations, and the determination of depositional environments based on well log interpretations. These models facilitated computation of petrophysical properties of the interpreted reservoir and the identification of different depositional environments. The Niger Delta clastic sedimentary wedge is about 75, 000 km^2 area in southern Nigeria and the Gulf of Guinea offshore Nigeria. These deposits have been divided into three large-scale lithostratigraphic units: (1) the basal Paleocene to Recent pro-delta facies of the Akata Formation, (2) Eocene to Recent, paralic facies of the Agbada Formation and (3) Oligocene-Recent, fluvial facies of the Benin Formation (Table 1) (Evamy *et al.*, 1978; Short and Stauble, 1967; Whiteman, 1982). These formations become progressively younger farther into the basin, recording the long-term progradation of depositional environments of the Niger Delta onto the Atlantic Ocean passive margin. Three major depositional cycles have been identified within Tertiary Niger Delta deposits (Short and Stauble, 1967; Doust and Omatsola, 1990). The first two, are marine deposits which began during the middle Cretaceous marine incursion and ended in a major Paleocene marine transgression. The second of these two cycles, started in late Paleocene to Eocene time, and reflects the progradation of a true delta, having an arcuate, wave- and tide-dominated coastline. These sediments range in age from Eocene in the north to Quaternary in the south

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue I January 2025

(Doust and Omatsola, 1990). Deposits of the last depositional cycle have been divided into a series of six depobelts (Doust and Omatsola, 1990) also called depocenters or megasequences) are separated by major synsedimentary fault zones. These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta. Such depobelts changed position over time as local accommodation was filled and the locus of deposition shifted basinward (Doust and Omatsola, 1990).

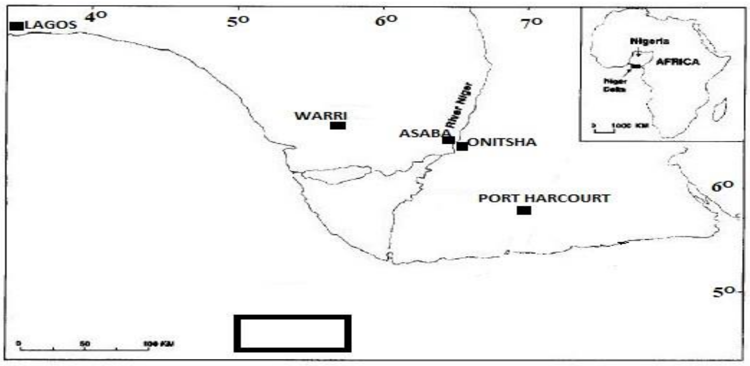

Fig 1: Map of the study location.

Table 1: Formations of the Niger Delta Area and their relative age (After Short and Stauble, 1967)

SUBSURFACE			SURFACE OUTCROPS		
YOUNGEST KNOWN AGE	***FORMATION***	***OLDEST KNOWN AGE***	***YOUNGEST KNOWN AGE***	***FORMATION***	***OLDEST KNOWN AGE***
Recent (Short and Stuable, 1967)	**Benin Formation**	Oligocene (Obaje and Amajor, 2000)	Pleistocene (Ojo and Rahaman, 1989)	**Benin Formation**	Oligocene (Obaje and Amajor, 2000)
Pliocene (Adetola, 2014)	**Agbada Formation**	Eocene (Kogbe, 1978)	Miocene (Dixon, 1964)	**Ogwashi - Asaba Formation**	Oligocene (Nwajide, 1990)
			Middle Eocene (Obaje, 2009)	**Ameki Formation**	Early Eocene (Avbovbo,1978)
Miocene (Petters, 1982)	**Akata Formation**	Palaeocene (Wright, 1985)	Early Eocene (Kogbe 1976)	**Imo Shale**	Late Cretaceous (Wright, 1985)

Materials and Methods

This study utilized the following datasets and software comprising:

1. Well Log Data (Detailed measurements from various geological formations).
2. Well Header Data (Metadata of each well, as well as identification and operational details).
3. Deviation Data (indicating the angles of deviation of each well from vertical).
4. Petrel Software (Version 2010): employed for geological modeling and analysis.

The methodology adopted in this study involved the use of Petrel Software (version 2010.2.2) for interpretation and analysis of well log data. The initial step began with quality assessment of the dataset to ensure accuracy and consistency which involved verification of measured units in X and Y coordinates, as well as the types and quantities of logs present. Followed by the construction of well log models using the Petrel software to facilitate the interpretation of reservoir characteristics. The models assisted in determining the depth of reservoir sands, identifying lithologies with hydrocarbon storage, and interpreting their sequence stratigraphic attributes. Correlation between wells was based on geological and physical properties derived petrophysical properties such as porosity, permeability, water saturation (Sw), and oil saturation (So). The oil saturation was calculated using the saturation equation $S_o = 1 + S_w$, alongside other relevant parameters such as the net-to-gross ratio.

The methodological workflow adopted in this study can be outlined as follows:

1. Data Quality Assessment: Verification of critical items necessary for analysis, including depth units, coordinates (X and Y), well locations, and company affiliations.
2. Data Importation: Sequential importation into Petrel Software, beginning with well header data matched to corresponding file types.
3. Incorporation of Deviation Data: Importation of deviation data for four wells to account for non-vertical drilling angles.
4. Well Log Importation: Integration of well logs, check-shot data (travel time measurements), and seismic data formatted in SEG-Y.
5. Well Log Modeling: Development of models to analyze reservoir sand bodies.
6. Well Correlation: Establishing correlations among wells based on geological properties.
7. Petrophysical Analysis: Conducting analyses to derive porosity, permeability, water saturation, oil saturation, and net-to-gross ratios.
8. Qualitative Reservoir Assessment: Providing qualitative descriptions regarding reservoir quality.
9. Environmental Analysis: Determining depositional environments based on collected data.

RESULTS AND DISCUSSION

The results of this study is presented in Figs.2 – 8 and Tables 1 – 2. The results of the modeling illustrates changes in lithofacies units of the subsurface layers for wells NWO A, NWO B, and NWO C, respectively (Fig. 2 – 4). These models provide a view of the geological framework and highlight the variability in lithofacies across the study area. The well logs reveal distinct transitions between different rock types, which are critical for understanding reservoir behavior and fluid flow dynamics. This integration allows for a more robust interpretation of the subsurface geology which aided the identification of potential reservoir zones that may be productive. The visualization of these lithofacies changes helped in establishing correlations between wells and understanding the spatial distribution of reservoir properties.

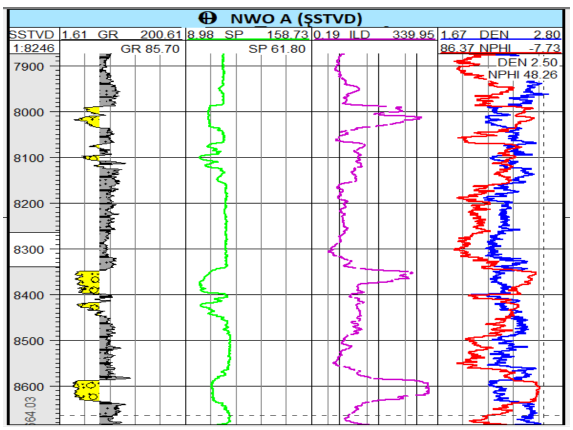

Fig 2. Well log model showing changes in lithofacies unit of the subsurface layers of well NWO A (Source: Petrel 2010.2.2 version).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue I January 2025

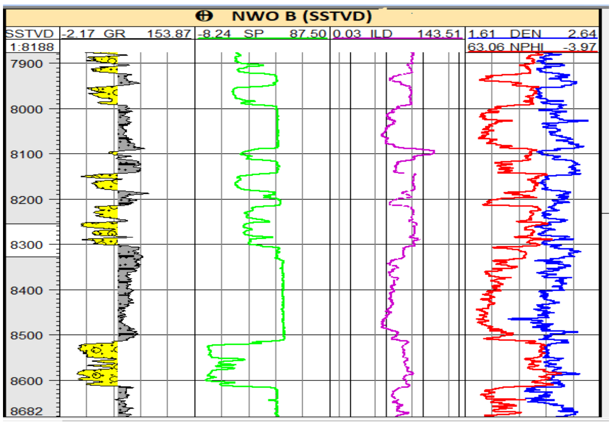

Fig. 3. Well log model showing changes in lithofacies unit of the subsurface layers of well NWO B (Source: Petrel 2010.2.2 version).

The well correlations in Fig. 6 - 7 enhanced our understanding of the subsurface architecture highlighting the continuity of geological features enabled assessment of reservoir connectivity. This correlation helped enhance reservoir performance and optimizing hydrocarbon recovery strategies. Such correlations are essential for delineating reservoir boundaries and understanding how variations in lithology may impact fluid movement within the reservoir. This study identified reservoir X and including their tops and base at 7985 and 8035 feet (NWO A), 7948 and 7995 feet (NWO B) and 7950 and 8010 feet (NWO C) respectively. (See Table 2). The average values for the petrophysical parameters calculated above for Reservoir X is presented in Table 3, and they indicate a favorable hydrocarbon accumulation. The porosity of 21% suggests a substantial volume of void space available for hydrocarbon storage, while a permeability of 1533.7 md indicates that fluids can migrate effectively through the reservoir rock. The net-to-gross ratio of 0.608911 signifies that approximately 61% of the reservoir unit comprises productive sand layers (Table 2), enhancing its potential for hydrocarbon extraction. The oil saturation of 55% supports the viability of Reservoir X as a productive asset, indicating a predominance of hydrocarbons over water within the pore spaces. Additionally, the STOIIP reflects a considerable volume of hydrocarbon pore fluid available for extraction, reinforcing the conclusion that this reservoir holds significant economic potential. Figure 8 presents a juxtaposition of stratigraphically correlated reservoir units from wells NWO B and NWO C alongside a log motif adapted from Rider (1999). This figure is instrumental in interpreting the depositional environment across the field. The Gamma Ray log signatures depicted in this figure facilitate a nuanced understanding of lithological variations; deflections towards the right indicate shale formations characterized by increasing gamma ray readings due to radioactive materials commonly found in clays (e.g., Uranium, Thorium, Potassium-40). Conversely, deflections to the left signify sand formations with lower or negligible radioactive content. These gamma ray signatures suggest coarsening upward sequences (funnel shape) in sandy intervals and fining upward sequences (bell shape) in shaly intervals. Based on this interpretation, it is hypothesized that Reservoir Y represents a deltaic sedimentation sequence occurring at depths between 8510 and 8600 feet, while Reservoir X exhibits characteristics consistent with a stream bar environment at depths ranging from 7940 to 8000 feet.

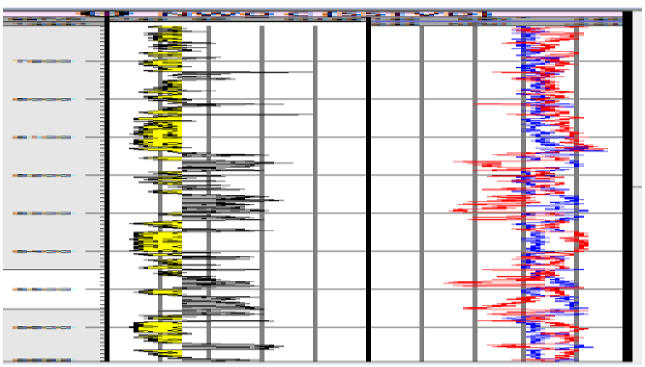

Fig. 4. Well log model showing changes in lithofacies unit of the subsurface layers of well NWO C (Source: Petrel 2010.2.2 version).

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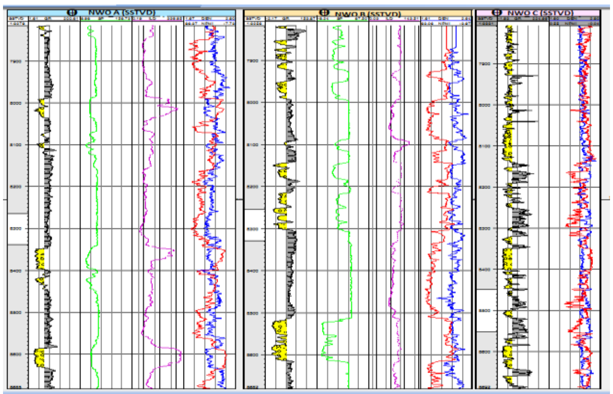

Fig. 5. Well log model showing changes in lithofacies unit of the subsurface layers of well NWO A, NWO B and NWO C (Source: Petrel 2010.2.2 version).

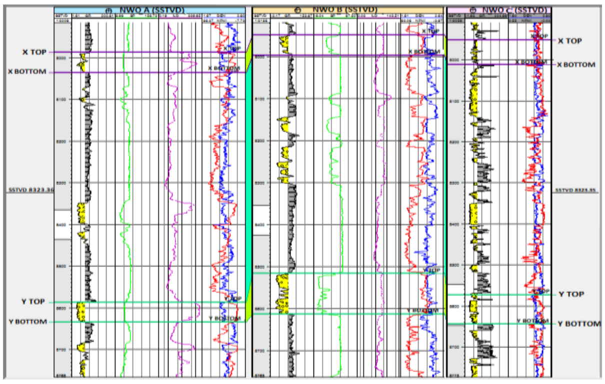

Fig. 6. Stratigraphic well correlation of the lithofacies unit of the subsurface layers of well NWO A, NWO B and NWO C (Source: Petrel 2010.2.2 version).

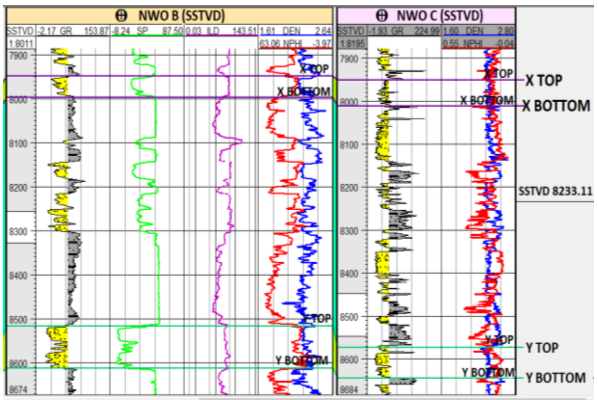

Fig. 7. Stratigraphic well correlation of the lithofacies unit of the subsurface layers of well NWO B and NWO C (Source: Petrel 2010.2.2 version).

CONCLUSION

The study revealed key petrophysical parameters for Reservoir X, such as porosity of 21%, permeability of 1533.7 millidarcies (md), a net-to-gross ratio of 0.608911, oil saturation of 55%, and STOIIP of 63.0111 (mmstb) and the interpretation of depositional environments indicated that Reservoir X is characterized by a deltaic sequence occurring between 8510 and 8600 feet, in addition, it is associated with a stream bar environment at depths ranging from 7940 to 8000 feet. The petrophysical parameters combined with lithofacies modeling and stratigraphic correlation, provided valuable insights into the reservoir quality and depositional environments. The integration of well log data of multiple wells enhanced understanding of the geology and future exploration strategies aimed at optimizing hydrocarbon recovery

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Table 2: Petrophysical Parameters Ranges of Reservoir X.

Depth Range	PORO Range	SW Range	NTG	K Range
8900 - 8901.5	0.1066-0.1093	0.7504-0.7692	0	376.51-391.80
8902 - 8904.5	0.1153-0.1289	0.6361-0.7110	0	427.94-515.98
8905 - 8906.5	0.1049-0.1148	0.7140-0.7816	0	366.98-424.98
8907 - 8908	0.1108-0.1357	0.6043-0.7397	0	401.01-563.67
8908.5 - 8910	0.1554-0.1726	0.4751-0.5277	0	715.91-865.81
8910.5 - 8912	0.1648-0.1697	0.4832-0.4976	0	795.77-839.37
8912.5 - 8914.5	0.1862-0.2557	0.3207-0.4403	0	995.74-1810.75
8915 - 8916.5	0.3278-0.3906	0.2099-0.2502	1	2927.10-4125.87
8917 - 8920.5	0.3466-0.3851	0.2124-0.2366	1	3264.60-4012.28
8921 - 8923.5	0.2986-0.3333	0.2460-0.2746	1	2442.28-3024.98
8924 - 8926.5	0.2949-0.3122	0.2626-0.2781	1	2384.02-2663.45
8927 - 8930.5	0.2965-0.3124	0.2625-0.2765	1	2409.71-2666.46
8931 - 8934.5	0.2875-0.3038	0.2700-0.2853	1	2268.75-2524.67
8935 - 8937.5	0.2738-0.2855	0.2872-0.2995	1	2065.53-2239.24
8938 - 8941.5	0.2619-0.2970	0.2671-0.3130	1	1896.55-2577.75
8942 - 8944.5	0.2649-0.3056	0.2673-0.3095	1	1938.09-2554.09
8945 - 8947.5	0.2432-0.2689	0.3049-0.3434	1	1588.74-1994.78
8948 - 8951.5	0.2406-0.2555	0.3210-0.3408	1	1611.88-1807.46
8952 - 8954.5	0.2341-0.2488	0.3296-0.3503	1	1529.39-1718.20
8955 - 8958.5	0.1805-0.2457	0.3337-0.4543	1	939.68-1677.62
8959 - 8961.5	0.2484-0.2621	0.3155-0.3379	1	1638.32-1898.23
8962 - 8964.5	0.2573-0.2643	0.3103-0.3187	1	1833.04-1929.57
8965 - 8968.5	0.2510-0.2576	0.3183-0.3267	1	1747.15-1837.18
8969 - 8971.5	0.2670-0.2709	0.2995-0.3151	1	1967.19-2065.53
8972 - 8974.5	0.2632-0.2692	0.3046-0.3115	1	1914.29-1999.11
8975 - 8977	0.1301-0.2548	0.4862-0.6305	0-1	523.90-1798.43

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Table 3: Average Petrophysical Parameters of Reservoir X.

RESERVOIR	AREA (acre)	PAY THICKNESS(ft)	ϕ (frac)	K (md)	NTG (frac)	S_W (frac)	STOIIP (mmstb)
X	3510	148	0.218554	1533.7	0.608911	0.458428	63.0111

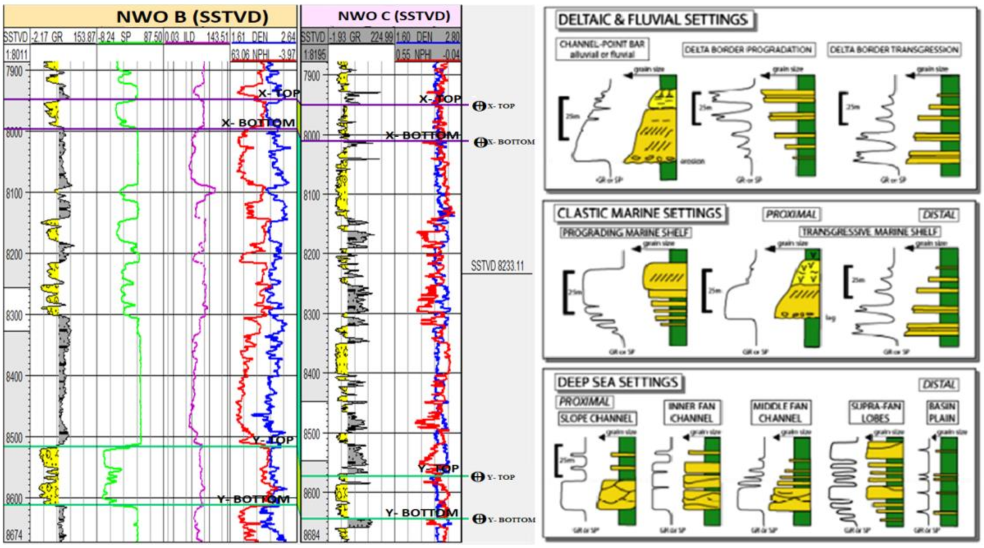

Fig. 8. Juxtaposition of Stratigraphic well correlated reservoir units of wells NWO B and NWO C and log motif (Source: Petrel 2010.2.2 version and the log motif was adapted from Rider, 1999).

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