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Research Paper

Integration Of Core and Well Log Data for Petrophysical Analysis of Reservoirs in an X-Field in Niger Delta

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ABSTRACT
In this study an integrated core and well log data were used for petrophysical analysis of reservoirs in the X-Field in Niger Delta. These datasets were interpreted using RockDoc software to improve the understanding of reservoir characteristics. Three wells were examined and correlation of the composite logs, led to the identification of eight reservoir sand units (Sand 1–Sand 8).The analysis revealed total porosity values ranging from 0.24 to 0.30, while effective porosity ranged between 0.06 and 0.24. Permeability values of 1887–2892 mD indicating that the reservoir possesses excellent fluid flow potential. Shale volume varies from 0.14 to 0.81, reflecting differences in shale content across the reservoir intervals. The net-to-gross ratio ranges from 0.20 to 0.86, suggesting that reservoir quality varies from moderate to very good. Water saturation values lie between 0.057 and 0.433, whereas hydrocarbon saturation was found to be 0.943, confirming the presence of productive hydrocarbon-bearing zones. Comparison of porosity and permeability values obtained from core analysis with those estimated from well logs revealed only a weak relationship, demonstrating the importance of calibrating log-derived results with core measurements for a better dependable reservoir evaluation. In all, the reservoirs are predominantly sandstone with good to excellent reservoir quality, characterized by high porosity, high permeability and low water saturation. The integration of core and well log data provides a more accurate and reliable reservoir characterization, reduces uncertainty and enhances hydrocarbon evaluation and field development planning in the Niger Delta.

Keywords: ***Reservoir , Petrophysical Analysis, Core Data, Well Logs, Porosity, Permeability, Niger Delta, Hydrocarbon Saturation.***

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I. INTRODUCTION

Petrophysical analysis and reservoir characterization are fundamental concepts in petroleum geoscience used for evaluating hydrocarbon reservoirs. These concepts help in understanding the physical properties, fluid distribution, storage capacity and productivity potential of subsurface formations (Asquith & Krygowski, 2004; Tiab & Donaldson, 2015).

Petrophysical analysis involves the quantitative evaluation of rock and fluid properties such as porosity, permeability, water saturation, shale volume and lithology using subsurface data (Schlumberger, 1989). These parameters are commonly derived from core measurements and well log interpretations. Core data provide direct laboratory measurements of reservoir properties, while well logs offer continuous in-situ information along the borehole. The integration of these datasets improves the reliability and accuracy of reservoir evaluation (Rider & Kennedy, 2011; Tiab & Donaldson, 2015).

Reservoir characterization refers to the process of describing the geometry, heterogeneity and petrophysical behavior of reservoir rocks. It integrates geological, geophysical and petrophysical information to identify reservoir quality, fluid distribution and depositional environments (Dake, 1978). In heterogeneous reservoirs such as those found in the Niger Delta, reservoir characterization is important for identifying productive zones and minimizing uncertainties during hydrocarbon exploration and production (Weber & Daukoru, 1975; Doust &Omatsola, 1990).

The Niger Delta Basin is one of the most prolific hydrocarbon provinces in the world, characterized by complex depositional systems and varying reservoir properties (Doust &Omatsola, 1990). Due to the heterogeneity of reservoirs within the basin, integrated studies involving core and well log data have become increasingly important for accurate formation evaluation (Avbovbo, 1978). Therefore, the integration of petrophysical analysis and reservoir characterization techniques provides a comprehensive understanding of reservoir performance and enhances decision-making in field development (Rider & Kennedy, 2011).

This study focuses on the integration of core and well log data for the petrophysical analysis of a reservoir in an x-field Niger delta, using core and well log data.In the case of the X-Field in the Niger Delta, this integrated approach is particularly important due to the region's complex depositional environment, structural intricacies and variability in reservoir quality. By combining petrophysical analysis with reservoir characterization, a robust model of the X-Field can be developed, thereby informing strategic decision-making for exploration, development planning and enhanced hydrocarbon recovery (Asquith & Krygowski, 2004; Doust &Omatsola, 1990).

1.1 Area of the Study

The study was conducted in an X-Field located within the Niger Delta Basin, Nigeria. The Niger Delta occupies the apex of the Gulf of Guinea along the western margin of Africa and covers approximately 140,000 km². The basin contains sedimentary deposits exceeding 12 km in thickness and represents one of the most productive hydrocarbon provinces globally.

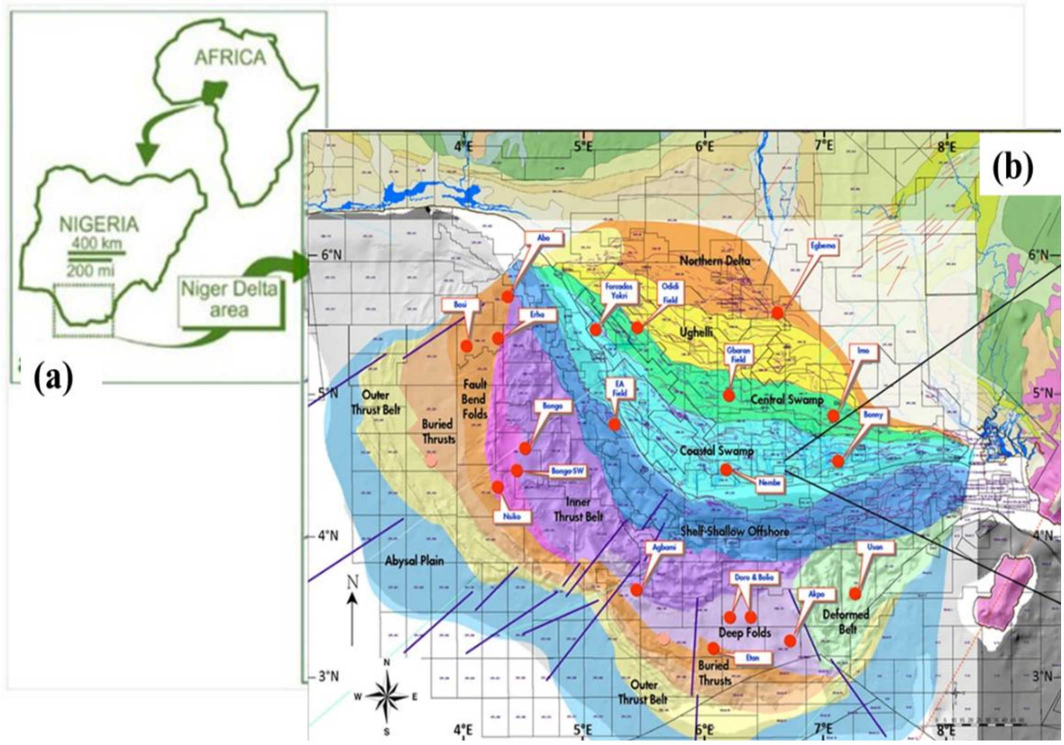

Figure 1.1 (a) Map of Africa, Nigeria and Niger Delta (b) Map of the Niger Delta and its depositional belts (after Adojoh*et al*., 2017)

Geologically, the Niger Delta comprises three major lithostratigraphic formations, the Akata formation, Agbada formation and Benin.

Akata Formation

The Akata Formation consists predominantly of marine shales with minor sandstone interbeds. It serves as the principal source rock for hydrocarbon generation within the basin.

Agbada Formation

The Agbada Formation is composed of alternating sandstone and shale sequences deposited in paralic environments. It constitutes the primary hydrocarbon-bearing reservoir interval in the Niger Delta.

Benin Formation

The Benin Formation consists mainly of continental sands and sandstones with minor shale intercalations. It represents the youngest stratigraphic unit in the basin.

The X-Field reservoirs evaluated in this study occur predominantly within the Agbada Formation, where stacked sandstone units provide favourable conditions for hydrocarbon accumulation and production.

II. MATERIALS AND METHOD

2.1 Materials

i. Well Log Data
ii. Core Data
iii. RokDoc software
iv. Ms. Excel

2.2 Method

2.2.1 Data Quality Control and Well Correlation

The well logs were imported into RokDoc software and subjected to quality control procedures. Depth matching was performed between core and well log datasets to ensure consistency. Reservoir correlation was carried out using Gamma Ray and Resistivity log signatures to identify reservoir continuity across the three wells.
Eight reservoir units designated as SAND 1 to SAND 8 were identified and correlated.

2.2.2 Volume of Shale (Vsh) Determination

The Gamma Ray Index (IGR) was first calculated using:

$$\text{IGR} = \frac{(GRlog\ -\ GRmin)}{(GRmax\ -\ GRmin)} \qquad (1)$$

Larionov Equation:

$$\text{Vsh} = 0.083(2^{(3.71GR)}) \qquad (2)$$

2.2.3 Total Porosity Determination

$$\emptyset_t = \frac{(\rho\text{ma} - \rho\text{b})}{(\rho\text{ma} - \rho\text{f})} \qquad (3)$$

2.2.4 Effective Porosity Determination

$$\emptyset_e = \emptyset_t(1 - \text{Vsh}) \qquad (4)$$

2.2.5 Water Saturation Determination

$$S_w = \left[\frac{a \times R_w}{R_t \times \emptyset_t^m}\right]^{1/n} \qquad (5)$$

2.2.6 Hydrocarbon Saturation Determination

$$S_h = 1 - S_w \qquad (6)$$

2.2.7 Net-to-Gross Ratio Determination

$$\text{NTG} = \frac{\text{Net Reservoir Thickness}}{\text{Gross Reservoir Thickness}} \qquad (7)$$

2.2.8 Permeability Estimation

$$K = \frac{0.136\emptyset^{4.4}}{\text{S}_{wirr}^2} \qquad (8)$$

Table 1: Niger Delta reservoir quality evaluation using cut-off values Avbovbo, (1978).

Parameter	Cut-off value	Interpretation
Volume of shale	≤ 0.5	Clean reservoir
Porosity	≥ 10%	Productive reservoir
Water saturation	≤ 0.6	Hydrocarbon-bearing zone
Permeability	≥ 10 Md	Good reservoir flow

2.2.9 Core and Log Integration

Core porosity and permeability measurements were cross-plotted against log-derived values to evaluate the reliability of the petrophysical interpretations.

2.2.10 Reservoir Quality Assessment

Reservoir quality was assessed using porosity, permeability, water saturation, hydrocarbon saturation, and net-to-gross ratio.

Table 2:Reservoir quality classification

Reservoir Quality	Porosity (%)	Permeability (mD)
Excellent	>25	>1000
Very Good	20–25	500–1000
Good	15–20	100–500
Fair	10–15	10–100
Poor	<10	<10

III. RESULTS AND DISCUSSION

3.1 Result

The result obtains from integrated petrophysical Analysis of areservoir in an x-field Niger Delta, using core and well log datain are presented below. The results of the study carried out are presented in figures 2-5 showing the relevant activities, while table3-5 present the data acquired from the study as stated.

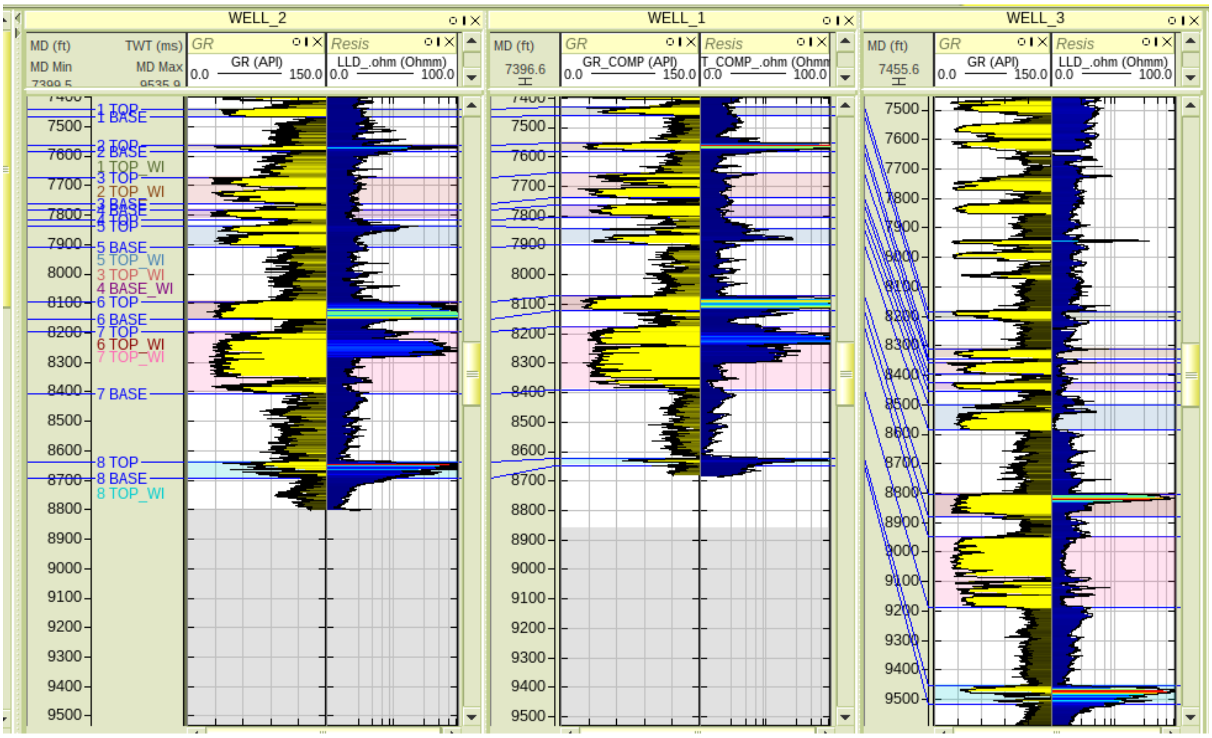

Fig. 2: Well Log Correlation of the Three Wells

Table 3: Summary of Reservoir Depths and Gross Thicknesses of the Well

Well	Reservoir	Top Depth (ft)	Bottom Depth (ft)	Gross Thick (ft)
WELL_1	SAND 1	7432.33	7461.04	28.72
	SAND 2	7551.89	7582.15	30.25
	SAND 3	7655.55	7738.72	83.17
	SAND 4	7764.32	7806.54	42.23
	SAND 5	7844.93	7897.39	52.46
	SAND 6	8072.70	8122.57	49.87
	SAND 7	8178.19	8389.16	210.98
	SAND 8	8625.07	8646.17	21.10
WELL_2	SAND 1	7440.34	7468.61	28.27
	SAND 2	7563.20	7584.15	20.94
	SAND 3	7673.27	7761.95	88.67

	SAND 4	7782.64	7815.15	32.51
	SAND 5	7835.84	7907.77	71.92
	SAND 6	8092.96	8153.97	61.01
	SAND 7	8195.30	8405.89	210.59
	SAND 8	8638.13	8693.24	55.11
WELL_3	SAND 1	8183.22	8213.06	29.85
	SAND 2	8309.08	8342.77	33.69
	SAND 3	8355.97	8397.40	41.43
	SAND 4	8425.63	8453.85	28.23
	SAND 5	8500.73	8586.75	86.02
	SAND 6	8803.51	8881.92	78.41
	SAND 7	8948.26	9187.50	239.24
	SAND 8	9452.87	9515.19	62.32

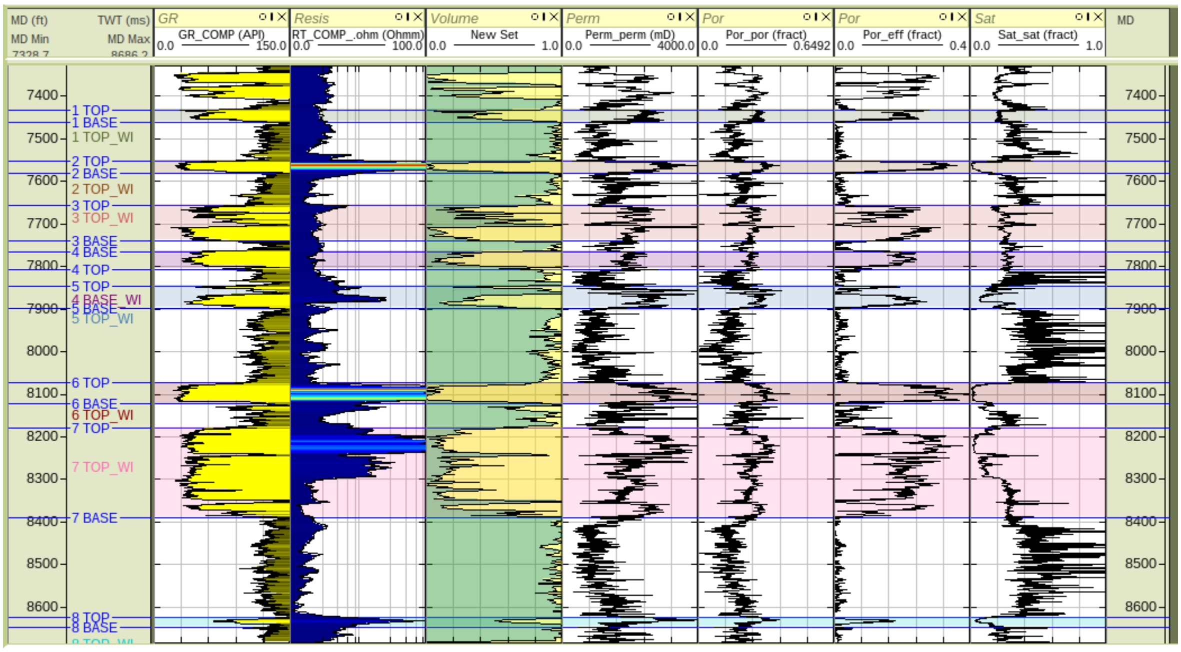

Fig. 3:Composite well log display for WELL 1

Table 4: Reservoir parameters estimated from the well logs of **WELL_1**, Shale Volume (V_{sh}), Total Porosity (Φ_t), Effective Porosity (Φ_e), Permeability (k), and Water Saturation (S_w).

Well	Reservoir	Top Depth (ft)	Bottom Depth (ft)	Gross Thick (ft)	Net Thickness (ft)	Net-to-Gross (NTG)	Shale volume	Total porosity	Effective Porosity	Permeability (mD)	Water Sat	HC Sat	Fluid Type
WELL 1	SAND 1	7432.33	7461.04	28.72	16.85	0.587	0.413	0.2597	0.1596	2168.75	0.241	0.759	Oil
WELL 1	SAND 2	7551.89	7582.15	30.25	20.75	0.686	0.314	0.2697	0.2057	2422.57	0.079	0.921	HC
WELL 1	SAND 3	7655.55	7738.72	83.17	50.64	0.609	0.391	0.2503	0.1583	2021.63	0.252	0.748	Oil
WELL 1	SAND 4	7764.32	7806.54	42.23	29.06	0.688	0.312	0.2441	0.1677	1886.81	0.272	0.728	Oil
WELL 1	SAND 5	7844.93	7897.39	52.46	21.24	0.405	0.595	0.2513	0.1127	2083.08	0.196	0.804	Water
WELL 1	SAND 6	8072.70	8122.57	49.87	38.85	0.779	0.221	0.2905	0.2403	2630.95	0.077	0.923	Gas/Oil
WELL 1	SAND 7	8178.19	8389.16	210.98	154.85	0.734	0.266	0.2633	0.1978	2201.04	0.173	0.827	Oil
WELL 1	SAND 8	8625.07	8646.17	21.10	4.11	0.195	0.805	0.2719	0.0575	2345.35	0.102	0.898	Water

The petrophysical workflow illustrated for WELL1 was similarly applied to WELL2 and WELL3. The same procedures involving reservoir identification, lithology interpretation, shale volume estimation, porosity determination, permeability estimation and fluid saturation evaluation were performed for all wells.

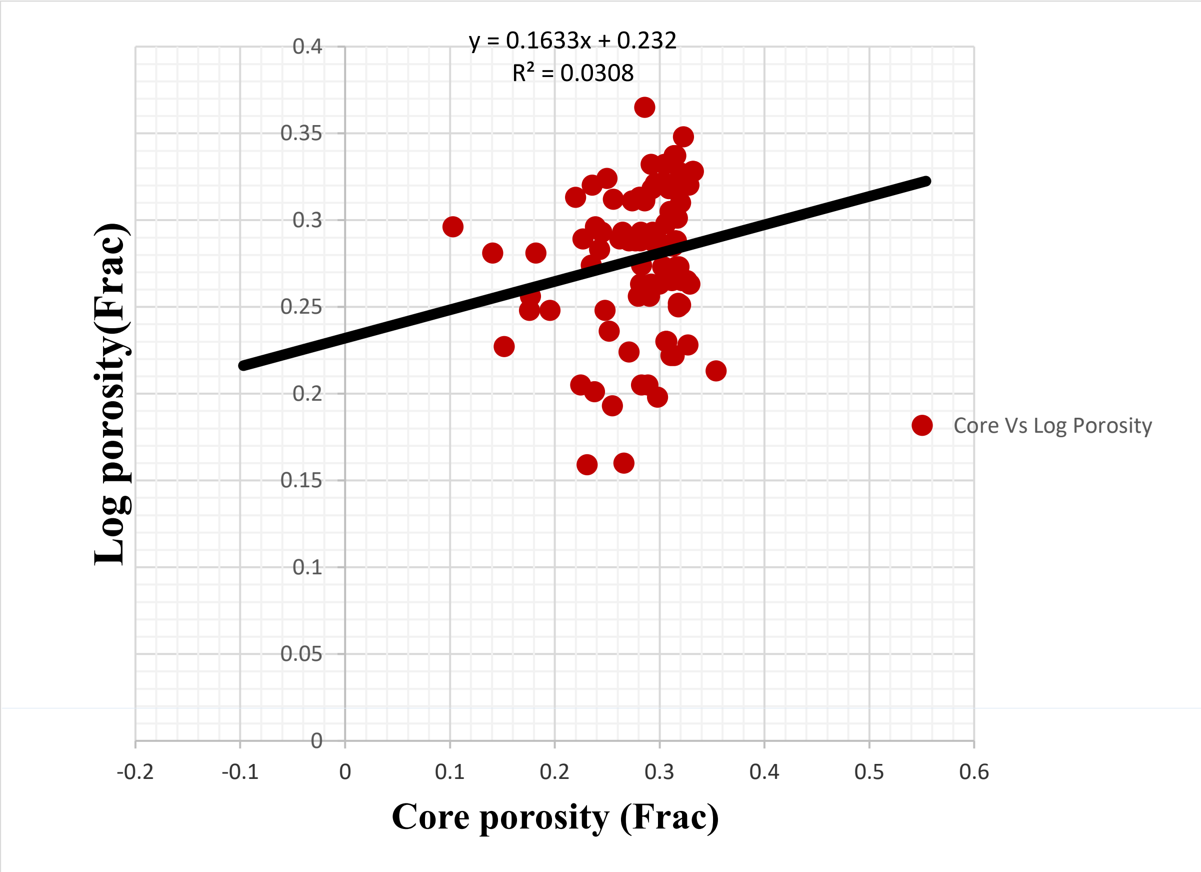

Fig. 4.3: Crossplot of core porosity against log-derived porosity for well 1

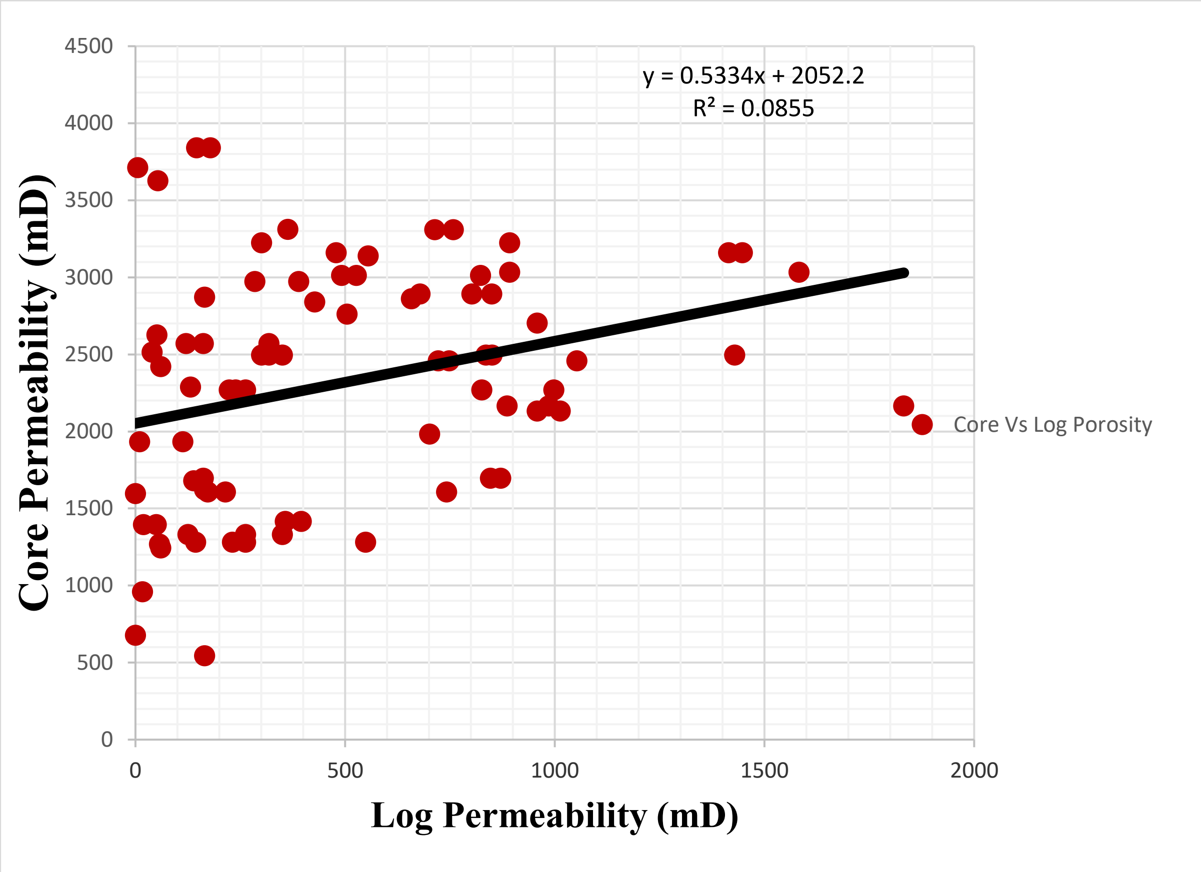

Fig. 4: Crossplot of core Permeability against log-derived Permeability for well 1

Similar crossplot relationships were observed for the remaining wells, indicating consistency between core-derived and log-derived petrophysical parameters across the field. Therefore, only representative crossplots are presented.

Table 5: Summary of the Reservoir Parameters

Reservoirs parameters	WELL 1	WELL 2	WELL 3
No. of Reservoir Sands layers	8	8	8
Depth Range (ft)	7432 – 8646	7440 – 8693	8183 – 9515
Reservoirs Depth Range (ft)	7432 – 8646	7440 – 8693	8183 – 9515
Total Porosity ($\emptyset_t$)	0.24 – 0.29	0.24 – 0.28	0.25 – 0.30
Effective Porosity ($\emptyset_e$)	0.06 – 0.24	0.10 – 0.23	0.11 – 0.20
Permeability (mD)	1887 – 2631	1914 – 2434	1990 – 2892
Shale Volume (V_{sh})	0.22 – 0.81	0.14 – 0.63	0.22 – 0.67
Net-to-Gross (NTG)	0.20 – 0.78	0.37 – 0.86	0.33 – 0.78
Dominant Reservoir Quality	Good	Good – Excellent	Good – Excellent
Good Reservoir Sands	Sand 3, Sand 5, Sand 7	Sand 4, Sand 6, Sand 7	Sand 1, Sand 2, Sand 3, Sand 7
Best Reservoir Interval	**Sand 7** (largest thickness ~210.98 ft with good porosity and hydrocarbon saturation)	**Sand 6** (V_{sh} = 0.136, $\emptyset_e$ = 0.232, NTG = 0.864, S_w = 0.057)	**Sand 2** (highest porosity $\emptyset_t$ = 0.301 and permeability ~2808 mD)
Thickest Reservoir Sand	**Sand 7** (~210.98 ft)	**Sand 7** (~210.59 ft)	**Sand 7** (~239.24 ft)
Poor Reservoir Sands	Sand 1, Sand 8	Sand 8	Sand 5
Non-Reservoir Sands	None clearly defined	None clearly defined	None clearly defined
Most Prospective Targets	Sand 3, Sand 5, Sand 7	Sand 4, Sand 6, Sand 7	Sand 2, Sand 3, Sand 7

IV. DISCUSSION

4.1 Reservoir Correlation and Continuity

Eight reservoir units (SAND 1–SAND 8) were identified and correlated across the three wells. The correlation demonstrated substantial lateral continuity of the sandstone bodies, indicating favorable reservoir connectivity throughout the field.Among the identified reservoirs, SAND 7 exhibited the greatest thickness and lateral extent. Gross thickness exceeded 210 ft in WELL_1 and WELL_2 and reached approximately 239 ft in WELL_3. Such thickness and continuity suggest that SAND 7 represents the most significant hydrocarbon-bearing interval within the field.The successful correlation of reservoir units confirms the effectiveness of integrating Gamma Ray and Resistivity logs for reservoir delineation in clastic depositional environments.

4.2 Petrophysical Parameters

The petrophysical evaluation parameters as shown in figure 4.2a to 4.2b indicates that the reservoirs possess good to excellent porosity and permeability, which is typical of productive Niger Delta reservoirs, as stated by Etu-Efeotor and Akpokodje (1990). The porosity values obtained in this study fall within the range of 0.20–0.35, which is consistent with the standard for high-quality sandstone reservoirs as described by Asquith and Krygowski (2004).

Porosity Distribution: Total porosity values range from 24% to 30%, indicating substantial pore space available for hydrocarbon storage. Effective porosity values range from 6% to 24%, suggesting that a significant portion of the pore network contributes to fluid flow.

The highest porosity values were observed within SAND 2 of WELL_3, indicating superior storage capacity.

Permeability Distribution: Permeability values range from approximately 1887 mD to 2892 mD. These values are considerably higher than the minimum threshold for productive reservoirs and indicate excellent fluid transmissibility.

High permeability reflects well-connected pore networks and favorable reservoir quality.

Shale Volume Distribution: Shale volume varies from 0.14 to 0.81 across the reservoir units. Lower shale content corresponds to cleaner sandstone intervals with enhanced reservoir quality, whereas higher shale content indicates increased heterogeneity and reduced flow efficiency.

Water and Hydrocarbon Saturation: Water saturation ranges between 5.7% and 43.3%, while hydrocarbon saturation reaches values as high as 94.3%. The relatively low water saturation and high hydrocarbon saturation observed in several reservoir units confirm the presence of commercially viable hydrocarbon accumulations.

4.3 Core and Log Data Relationship

The crossplots of core versus log-derived porosity and permeability as shown in Figures 4.3a to 4.3c show poor correlation indicating the need to calibrate core data with well log data for petrophysical analysis. The observed discrepancies between core and log data is attributed to shale effects, fluid variations and depth mismatch, which agrees with the findings of Odiegwu Chukwukelu *et al*. (2024), as emphasized in their analysis, highlighting the importance of calibration in integrated petrophysical studies.

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4.4 Reservoir Quality and Heterogeneity

Based on established reservoir quality classifications, most of the reservoir units fall within the excellent category due to their high porosity and permeability values.Although shale interbeds introduce some degree of heterogeneity, the reservoirs generally exhibit favorable petrophysical characteristics. The presence of thick, laterally continuous sandstone bodies further enhances reservoir performance and production potential.The integrated analysis indicates that reservoir quality is controlled primarily by sandstone cleanliness, pore connectivity, and fluid saturation distribution.

4.5 Hydrocarbon Potential

The combined petrophysical evidence confirms that the X-Field possesses significant hydrocarbon potential. High hydrocarbon saturation, low water saturation, excellent permeability, and substantial reservoir thicknesses suggest favorable production performance.SAND 7 is identified as the most prospective reservoir due to its exceptional thickness, continuity and favorable petrophysical properties. The field therefore presents strong opportunities for future hydrocarbon development and exploitation.

V. CONCLUSION

The results in this study has obliviously shown that integrated core and well log data application provides accurate result that are in line with previous works carried out in the Niger Delta and confirm that the X-field contains high-quality, laterally continuous reservoirs with significant hydrocarbon potentials, which reduces uncertainty and enhances hydrocarbon evaluation and field development planning in the Niger delta.

VI. RECOMMENDATIONS

1. Further calibration of log-derived petrophysical parameters with core data should be carried out to minimize discrepancies and improve accuracy in reservoir evaluation.
2. Large quantities of core samples and advanced logging tools should be acquired to enhance the reliability of petrophysical analysis and reduce uncertainty.

3. Further studies should incorporated using advanced techniques such as rock physics modeling, seismic inversion and machine learning to improve reservoir property prediction.
4. Detailed facies analysis should be conducted to better understand reservoir heterogeneity and depositional environments.

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