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Optimizing Hydrocarbon Production Through Petrophysical Evaluation: A Case Study of the XY Creek-43 F2 Well in the Niger Delta

E. G. Maju-Oyovwikowhe*, J. H. Onobredefe and J. 0. Kinrin-Ola
Department of Geology, University of Benin, Benin City, Nigeria
*Corresponding Author: efetobore.maju@uniben.edu; +2348107040751

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Abstract

This study presents a comprehensive Petrophysical evaluation of the XY Creek-43 F2 well in the Niger Delta's Greater Ughelli Depobelt, aimed at identifying optimal production strategies based on subsurface characteristics. Using gamma ray, resistivity, porosity, and permeability logs, the analysis highlights the interval between 8740 and 8780 feet as the most promising for hydrocarbon extraction. This zone demonstrates excellent reservoir quality, with high porosity (0.32–0.33 v/v), high permeability (>180 mD), and hydrocarbon saturation, supported by low gamma ray and high resistivity values. The correlation between these logs confirms that this interval contains clean, hydrocarbon-bearing sands, with strong production potential. Based on these findings, the primary production strategy should focus on completing this interval without requiring additional stimulation techniques, as the natural permeability is sufficient to support efficient hydrocarbon flow. The study also recommends avoiding production from zones below 8800 feet, where higher water saturation and shale content limit hydrocarbon recovery. These insights provide a framework for maximizing the well's productivity while minimizing water production risks

1. Introduction

The Niger Delta basin is one of the most prolific hydrocarbon provinces in the world, contributing significantly to global oil and gas reserves. This basin, located in southern Nigeria, has developed over millions of years due to the interplay of fluvial, deltaic, and marine depositional environments. The basin contains several depobelts, which are regions of thick sedimentary deposits conducive to hydrocarbon accumulation. Among these, the Greater Ughelli Depobelt is particularly important due to its well-developed reservoir characteristics and proven oil and gas potential. The depobelt's sedimentary structures, composed of interbedded sandstones and shales, offer significant prospects for hydrocarbon exploration [1].

The XY Creek-43 F2 well is located within the Greater Ughelli Depobelt and represents an opportunity to assess the hydrocarbon potential of this part of the basin. To properly evaluate the reservoir characteristics of the well, petrophysical data from well logs such as gamma ray, resistivity, porosity, and permeability logs are crucial. These logs are indispensable in determining the lithological and fluid properties of subsurface formations. For instance, gamma ray logs are used to differentiate between sandstones and shales, with lower gamma ray readings typically indicating clean sands that can serve as reservoirs, while higher readings often suggest shale-rich, non-reservoir [2].

Resistivity logs provide essential information on fluid content within the formation. Higher resistivity values often indicate hydrocarbon-bearing zones, as hydrocarbons resist electrical current, whereas lower resistivity values suggest the presence of conductive fluids such as water [3]. Combining gamma ray and resistivity log data allows for the identification of potential hydrocarbon zones in the subsurface.

In addition to lithological and fluid content analysis, porosity and permeability are key factors in evaluating reservoir quality. Porosity refers to the proportion of void spaces within a rock that can store hydrocarbons, while permeability measures the ability of those fluids to flow through the rock. Effective reservoir rocks typically have high porosity and permeability, enabling significant volumes of hydrocarbons to be stored and produced [4]. The petrophysical evaluation of XY Creek-43 F2 will focus on identifying zones where these properties are favorable for hydrocarbon production.

The importance of a thorough petrophysical evaluation is highlighted by the complex depositional environments of the Niger Delta. The Agbada Formation, which dominates much of the basin, consists of alternating sandstones and shales deposited in a deltaic environment. The sandstones often form excellent reservoirs, while the shales act as both seals and hydrocarbon source rocks. In such a complex setting, accurate characterization of the reservoir through well log analysis is essential for determining the economic viability of a hydrocarbon field [5].

This study aims to conduct a comprehensive petrophysical evaluation of the XY Creek-43 F2 well, utilizing gamma ray, resistivity, porosity, and permeability logs to identify key reservoir properties. By integrating these well log data, the study seeks to pinpoint zones with favorable hydrocarbon potential, ensuring that exploration efforts are focused on the most productive intervals [6]

1.1. Study Location: XY Creek-43 F2 Well

The XY Creek-43 F2 well is located within the Greater Ughelli Depobelt of the Niger Delta basin, which spans approximately 75,000 square kilometers and is known for its significant hydrocarbon reserves. The Niger Delta basin is one of the most prolific hydrocarbon-producing regions globally and has developed over millions of years through fluvial, deltaic, and marine depositional processes [1]. The basin is divided into several Depobelt, including the Greater Ughelli Depobelt, where the XY Creek-43 F2 well is located (Figure 1). This region is known for thick sequences of clastic sediments conducive to hydrocarbon accumulation and has been extensively explored due to its productive oil and gas fields [2].

The Greater Ughelli Depobelt consists of interbedded sandstones and shales, which serve as reservoirs and seals, respectively. These alternating sand-shale sequences are key to hydrocarbon exploration, with the sands acting as productive reservoirs and the shales providing effective seals to trap hydrocarbons [6].

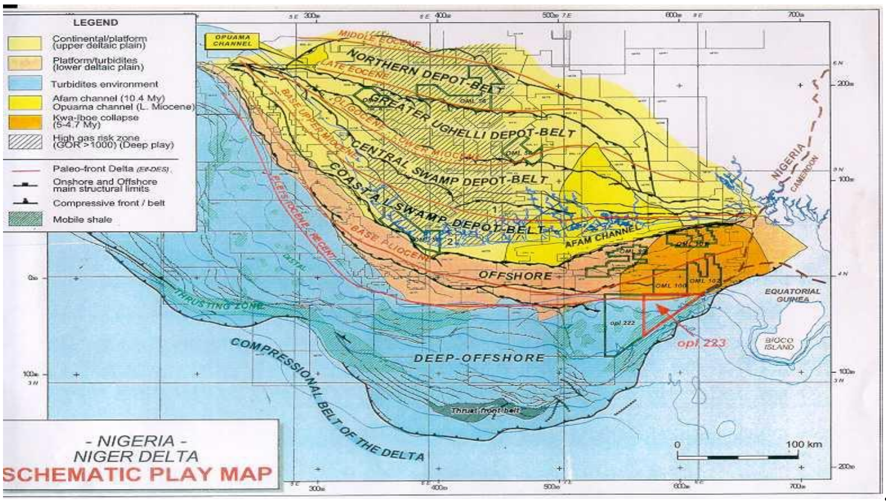

Figure 1: Map of the Niger Delta Basin and Location of XY Creek-43 F2 Well [7]. White arrow shows the study area

1.1.1 Geological Setting of the Niger Delta Basin

The Niger Delta basin is divided into three primary formations, which represent different depositional environments (Figure 2):

Akata Formation: The deepest unit, composed primarily of marine shales, which act as source rocks for hydrocarbons in the region.

Agbada Formation: A sequence of alternating sandstones and shales, deposited in fluvial and deltaic environments. The sandstones serve as excellent reservoirs due to their high porosity and permeability, while the shales act as seals. The XY Creek-43 F2 well targets this formation, which is known for its productivity [1].

Benin Formation: The youngest and shallowest of the three, consisting mainly of continental sands, which have limited potential for hydrocarbon storage.

The Agbada Formation is particularly important as it serves as the main reservoir unit in the Niger Delta. The sand-shale alternation provides ideal conditions for hydrocarbon entrapment. The XY Creek-43 F2 well, located within this formation, has significant potential for hydrocarbon production due to the favorable reservoir characteristics of its sandstones [5].

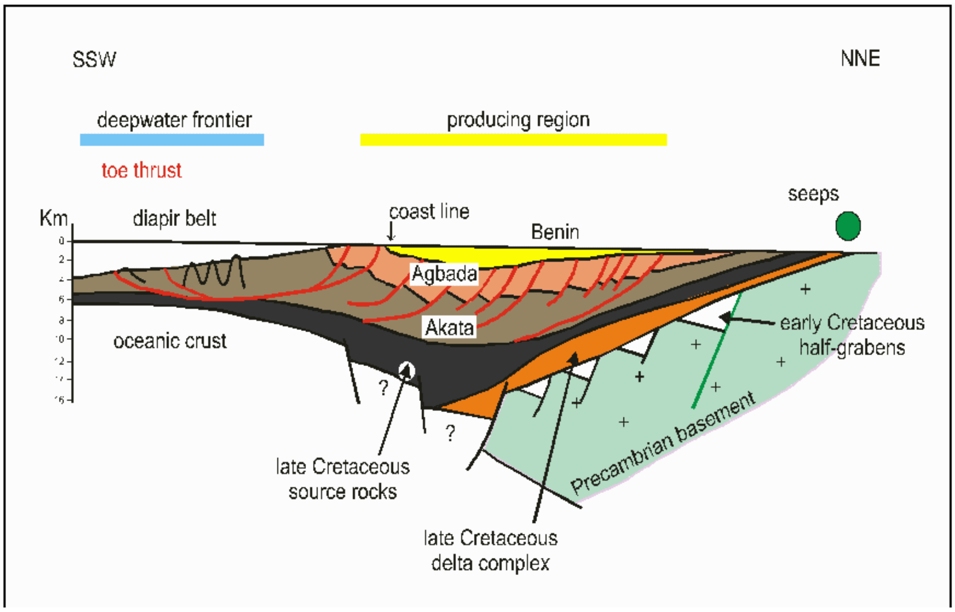

Figure 2: Structural and Stratigraphic configuration of the Niger Delta (Modified from [8])

1.1.2 Review of Related Studies on Hydrocarbon Production

A range of studies have investigated methods to optimize hydrocarbon production through petrophysical evaluation, especially in the Niger Delta Basin. [01] explored the stratigraphic evolution and hydrocarbon potential of the Greater Ughelli Depobelt in the Niger Delta Basin, utilizing petrophysical logs to assess reservoir properties. Their study highlights the importance of understanding depositional settings for accurate hydrocarbon potential estimation, which aligns with our approach in evaluating similar geological characteristics in the Niger Delta.

[2] conducted a petrophysical evaluation for developing a marginal oil field in the onshore Niger Delta, employing well logs to delineate reservoir boundaries and fluid contacts. Their results demonstrate the reliability of density and resistivity logs in delineating oil-water contacts, a technique also used in our study. Our work expands on this by applying these methods in a case study that involves more complex lithologies, providing further insights into the adaptability of these techniques across different Niger Delta formations.

In a similar vein, [3] applied well log data for hydrocarbon formation evaluation in the XYZ well within the Niger Delta. Their study underscores the significance of porosity and permeability measurements derived from petrophysical logs, which are critical parameters in reservoir characterization. Our research parallels their approach, yet differs in the application of additional cross-plot techniques to enhance the interpretation of reservoir quality in our case study.

[4] investigated the correlation between porosity and permeability using well log data, focusing on Niger Delta reservoirs. Their study found a strong correlation that could improve the accuracy of hydrocarbon volume estimations. While our study also utilizes porosity and permeability data for reservoir evaluation, we integrate a comparative analysis of different well log types to address the heterogeneity in sedimentary facies specific to the XY Creek-43 F2 well.

[9] evaluated reservoir petrophysical parameters in the Niger Delta, providing valuable insights into the use of wireline logs for hydrocarbon exploration. Their findings suggest that wireline log data can reliably identify hydrocarbon-bearing zones and estimate reservoir properties. Our study similarly employs wireline logs but adds to the literature by examining these parameters in the context of a specific well in the Niger Delta, thereby demonstrating the efficacy of conventional log interpretations in local field studies.

These studies collectively provide a comparative framework for our work, underscoring the value of petrophysical evaluation in hydrocarbon production optimization. Our study, as outlined in Section ___, contributes to this body of research by applying these well-established petrophysical techniques within the challenging geological setting of the Niger Delta. Our findings underscore both the strengths and limitations of traditional log-based techniques in optimizing hydrocarbon production, particularly in complex sedimentary environments, offering practical insights for similar fields worldwide.

2. Materials and Methods

The Petrophysical evaluation of the XY Creek-43 F2 well involved a detailed analysis of multiple well logs to assess reservoir quality and hydrocarbon potential within the subsurface formations. The depth interval analyzed ranged from 8700 to 8900 feet, covering key stratigraphic layers expected to contain hydrocarbons. This section outlines the data acquisition, log interpretation methods, and data processing techniques employed in this study.

2.1 Well Logs and Data Acquisition

The data presented in Table 1, titled "Well Log Data for Jones Creek-43 F2 Well," was generated from the composite well log displayed in Figure 3. The well log data, which includes gamma ray, resistivity, porosity, and permeability measurements at various depths, was collected via wireline logging. Wireline logging involved lowering a suite of measurement tools into the wellbore to capture continuous data about the subsurface formations in real time.
Each type of measurement in Table 1 was derived as follows:

Gamma Ray (GR): Measured using a gamma ray logging tool, the GR log captures natural gamma radiation emitted by subsurface formations. Higher gamma readings generally indicate shale-rich zones, while lower readings correspond to sandstone or cleaner reservoir sections. For example, at a depth of 8800 ft, a gamma reading of 60 API (from the well log) indicates moderate shale content.

Resistivity (ohm-m): Resistivity was measured using dual induction resistivity tools, capturing deep and shallow resistivity to assess hydrocarbon presence. High resistivity values (e.g., 1200 ohm-m at 8775 ft) suggest hydrocarbon-bearing zones, whereas lower values typically indicate water saturation. This differentiation allows for better identification of productive intervals.

Porosity (v/v): Neutron and density logging tools were used to estimate porosity. Neutron logs, sensitive to hydrogen atoms, provide porosity data based on fluid saturation, while density logs offer bulk density estimates, allowing porosity calculations when matrix density is known. For instance, the 0.33 porosity reading at 8775 ft indicates a highly porous zone likely capable of storing hydrocarbons.

Permeability (mD): Although permeability cannot be directly measured via wireline logging, it was estimated using empirical correlations based on porosity and resistivity data, with adjustments from core analysis where available. The value of 250 mD at 8775 ft signifies a highly permeable layer conducive to fluid flow, making it a prime target for hydrocarbon extraction.

Table 1 consolidates these measurements at key depth intervals, facilitating a structured overview of the well's petrophysical properties. The composite log in Figure 3 illustrates the full data set from which these values were derived, enabling cross-referencing between the table and the graphical log data.

Table 1: Well Log Data for Jones Creek-43 F2 Well

Depth (ft)	Gamma Ray (GAPI)	Resistivity (ohm-m)	Porosity (v/v)	Permeability (mD)
8700	50	550	0.25	100
8725	45	480	0.28	150
8750	40	1000	0.32	200
8775	35	1200	0.33	250
8800	60	850	0.30	180
8825	80	600	0.22	120

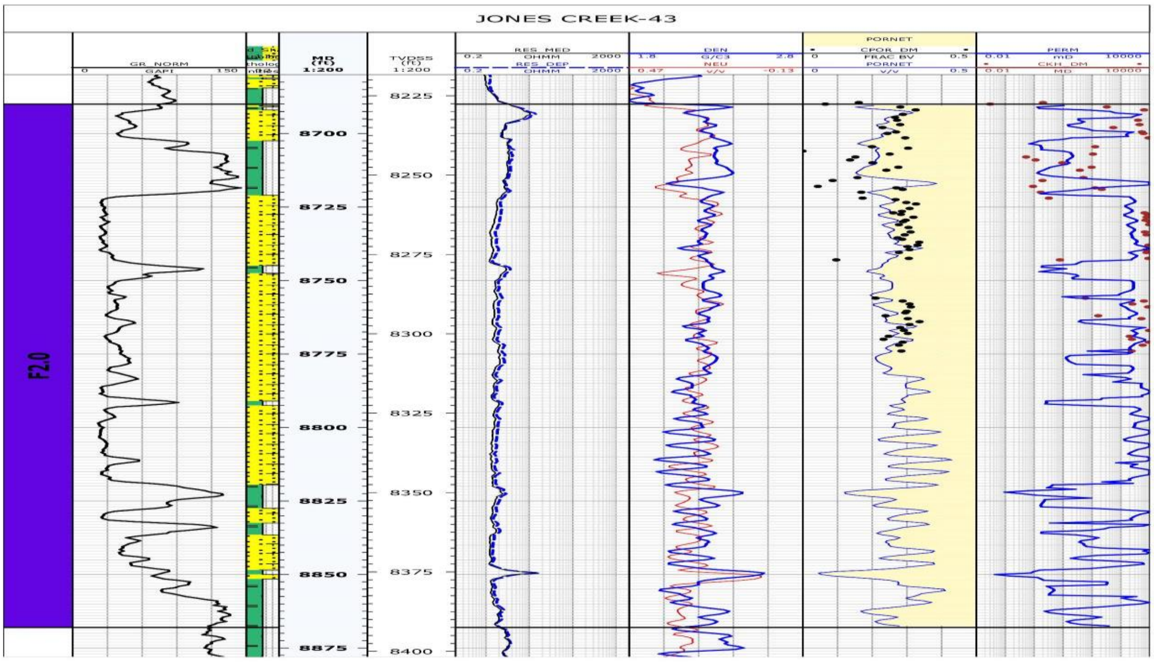

Figure 3: Composite Well Log for XY Creek-43

Gamma Ray (GR) Log: **The gamma ray (GR) log is used to measure the natural gamma radiation emitted by rocks, which primarily comes from potassium, uranium, and thorium isotopes. In well logging, the GR log is an essential tool for differentiating between shale-rich and cleaner, sand-dominated formations. Shale-rich formations typically emit higher levels of gamma radiation due to their clay content, while clean sandstones exhibit lower gamma ray readings. This differentiation enables geologists to distinguish between sand and shale layers, which is crucial in identifying potential reservoir zones.**

In this study, the GR log was employed to analyze lithological variations across the subsurface formations in the XY Creek-43 F2 well. By recording gamma ray readings at various depths, the GR log provided insights into the lithology of the well, identifying intervals where sand-rich formations might act as potential hydrocarbon reservoirs. The tool used was calibrated to ensure accurate measurement of gamma ray intensity, recorded in American Petroleum Institute (API) units

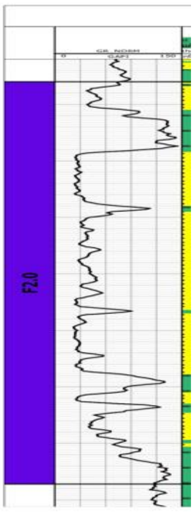

Figure 4: Gamma Ray Log for XY Creek-43 F2 Well

Resistivity Logs (Deep and Shallow): **Resistivity logs are used to measure the electrical resistance of subsurface formations, providing valuable insights into the types of fluids present within the pore spaces. These measurements are crucial in distinguishing between hydrocarbon-bearing and water-saturated zones, as**

hydrocarbons (oil and gas) generally have higher resistivity values due to their insulating properties, while saline formation water conducts electricity, resulting in lower resistivity readings.

In this study, both deep and shallow resistivity logs were employed to assess fluid saturation and distribution within the XY Creek-43 F2 well. The deep resistivity log provides information on the formation's undisturbed zone, while the shallow resistivity log helps identify mud-filtrate invasion from the drilling process. Together, these measurements aid in distinguishing between hydrocarbons and water and in delineating potential reservoir zones. The resistivity tools used were calibrated for the specific formation characteristics of the Niger Delta region, ensuring reliable readings across various depths.

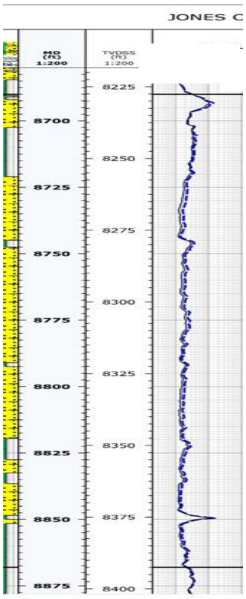

Figure 5: Resistivity Log for XY Creek-43 F2 Well

Neutron and Density Porosity Logs: **The neutron and density porosity logs were used to estimate the porosity of the formation, representing the amount of void space available to store hydrocarbons. The neutron log measures hydrogen content, which correlates with fluid-filled pores, while the density log provides an estimate of the rock's bulk density. Combined, these logs yielded effective porosity values. The highest porosity values, ranging from 0.32 to 0.33 v/v, were observed between 8740 ft and 8775 ft, indicating good hydrocarbon storage potential (Figure 6) [4].**

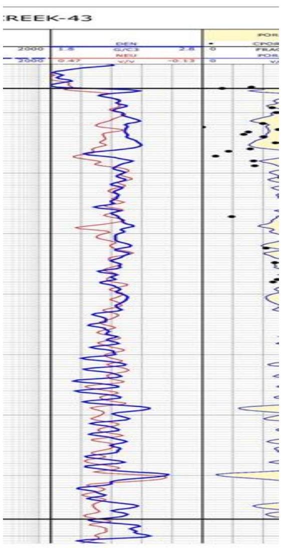

Figure 6: Porosity Log for XY Creek-43 F2 Well

Permeability Logs: **Permeability is a key property that determines the ability of the rock to transmit fluids. Higher permeability allows for easier extraction of oil or gas, which is critical for production. Permeability was estimated using empirical relationships between porosity and permeability. The logs indicated permeability values exceeding 180 mD between 8740 ft and 8780 ft, suggesting that this zone has favorable conditions for hydrocarbon flow (Figure 7) [5].**

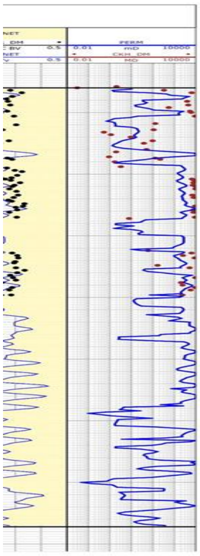

Figure 7: Permeability Log for XY Creek-43 F2 Well

The data acquisition was carried out with precise calibration to ensure accuracy. Each log was processed to correct for borehole effects and environmental conditions that could skew the results

2.2 Data Processing and Interpretation

The well log data was processed using Petrel Software, a widely used geoscience and reservoir engineering application developed by Schlumberger. Petrel enables detailed petrophysical analysis by integrating well log data, seismic data, and geological modeling tools to visualize and interpret subsurface formations accurately. The software is commonly used in the oil and gas industry for reservoir characterization, well planning, and geological modeling.

Using Petrel, we performed a series of data processing steps to interpret the petrophysical properties of the subsurface formations in the XY Creek-43 F2 well. These steps included data cleaning, depth matching, lithology identification, and fluid saturation analysis. The advanced visualization and analytical tools in Petrel facilitated an in-depth understanding of the reservoir's characteristics, enabling us to identify potential hydrocarbon-bearing zones effectively.

The well log data was processed to analyze lithology, fluid content, porosity, permeability, water and hydrocarbon saturation, and the net-to-gross ratio of the formations. The following methods were applied to interpret each petrophysical parameter:

Lithology Identification: **The gamma ray log was used as the primary tool to differentiate between sand and shale formations. Low gamma ray readings typically indicate clean sands, while higher readings suggest shale-dominated intervals. This method allows for a clear distinction between reservoir-quality sand formations and non-reservoir shale formations.**

Fluid Content and Hydrocarbon Zones: **The resistivity logs (deep and shallow) were analyzed to determine fluid saturation levels within the formations. Zones with higher resistivity values were interpreted as potential hydrocarbon-bearing intervals, as hydrocarbons resist electrical current. Lower resistivity values, in contrast,**

were indicative of water-saturated zones. By comparing deep and shallow resistivity measurements, potential hydrocarbon zones were identified while accounting for mud-filtrate invasion.

Porosity and Permeability Estimation: **Neutron and density logs were combined to estimate the effective porosity of the formations. The neutron log provided information on hydrogen content, indicating fluid-filled pore spaces, while the density log measured bulk density, allowing for porosity calculations when combined with known matrix density values. Permeability was subsequently estimated using empirical correlations with porosity data, which provided insights into the formation's capacity to allow fluid flow.**

Water and Hydrocarbon Saturation: **Water saturation was calculated using Archie's equation, which relates formation resistivity, porosity, and formation water resistivity to estimate the water content in the pore space. Hydrocarbon saturation was then derived as the inverse of water saturation, indicating zones that may contain hydrocarbons rather than water.**

Net-to-Gross Ratio (NTG): **The net-to-gross ratio was calculated to assess the proportion of reservoir-quality rock (clean sand) to the total rock thickness for each depth interval. This parameter helped to quantify the extent of reservoir rock within the formation, which is essential for evaluating the overall quality and productivity potential of the reservoir.**

3. Results and Discussion

3.1 Gamma Ray Log Interpretation

The gamma ray (GR) log (Figure 4) provides a detailed lithological profile of the analyzed depth interval. The clean sand formations between 8725 ft and 8775 ft are characterized by consistently low gamma ray readings, with values ranging from 35 to 45 GAPI. These readings suggest a low clay content, which indicates that this interval is dominated by clean sandstone, an ideal condition for hydrocarbon reservoirs [2]. In contrast, the gamma ray readings increase progressively below 8800 ft, reaching values between 60 and 80 GAPI, signaling a transition to more shale-rich formations, which are less favorable for hydrocarbon storage.

Reservoir Zones (Figure 4): Clean sand formations, indicated by gamma ray values consistently below 50 GAPI, are found between 8725 and 8775 feet (Table 2). These sands have minimal clay content, making them ideal for hydrocarbon storage.

Non-Reservoir Zones (Figure 4): The interval below 8800 feet shows higher gamma ray readings, indicating increased shale content, which is not conducive to hydrocarbon storage.

Table 2: Gamma Ray Data for XY Creek-43 F2 Well

Depth (ft)	Gamma Ray (GAPI)
8700	50
8725	45
8750	40
8775	35
8800	60
8825	80

3.2 Resistivity Log Analysis

The resistivity log (Figure 5) reveals key hydrocarbon-bearing zones in the well. The interval from 8750 to 8800 feet shows deep resistivity values exceeding 1000 ohm-m, which are indicative of hydrocarbons in the pore spaces [3], The high resistivity, combined with the low gamma ray readings, suggests the presence of oil or gas in clean sand formations. Below 8800 feet, resistivity

values drop sharply, falling below 500 ohm-m, which aligns with the increased gamma ray readings, indicating that the formation is likely water-saturated or dominated by shale.
Hydrocarbon Zones (Figure 5): The interval from 8750 to 8800 feet exhibits deep resistivity values above 1000 ohm-m, indicating hydrocarbon presence (Table 3). This high resistivity is strongly correlated with the clean sand formations identified in the gamma ray log.

Water Zones (Figure 5): In subsurface formations, resistivity values are often used as indicators of fluid types, with specific thresholds distinguishing between hydrocarbon- and water-bearing zones. Industry standards generally suggest that low resistivity values (often below approximately 500 ohm-m in sandstone formations) are indicative of water saturation, as water with dissolved salts conducts electricity, resulting in lower resistivity readings. In this study, we interpreted resistivity values below 500 ohm-m as water-bearing zones, consistent with common petrophysical interpretations in sandstone reservoirs.

For further validation, the gamma ray log was analyzed alongside the resistivity data to assess lithology. Increased gamma ray values in these intervals indicated a higher shale content, supporting the interpretation of poor reservoir quality in these water-bearing zones. This interpretation approach aligns with established petrophysical principles, such as those outlined by Rider and Kennedy (2011) in The Geological Interpretation of Well Logs, which provides standard resistivity and gamma ray profiles used in identifying water-saturated and shale-rich formations.

Table 3: Resistivity Data for XY Creek-43 F2 Well

Depth (ft)	Resistivity (ohm-m)
8700	550
8725	480
8750	1000
8775	1200
8800	850
8825	600

3.3 Porosity Analysis

The neutron and density porosity logs (Figure 6) show significant porosity variations across the analyzed interval. The best porosity values, ranging from 0.32 to 0.33 v/v, were observed between 8740 and 8775 feet. These high porosity values indicate that these formations have a large amount of pore space available for hydrocarbon storage (Ben et al., 2020). Below 8800 feet, porosity values decrease to around 0.22 v/v, suggesting reduced storage capacity due to the increased shale content in these intervals.

Key Observations:
High Porosity Zones (Figure 6): The interval from 8740 to 8775 feet exhibits porosity values between 0.32 and 0.33 v/v, confirming excellent hydrocarbon storage potential (Table 4). This high porosity is consistent with the clean sands identified in the gamma ray and resistivity logs.
Decreased Porosity Zones (Figure 6): Below 8800 feet, porosity values drop to around 0.22 v/v, indicating reduced storage capacity. This reduction is likely due to the increase in shale content, as shown by the gamma ray log.

Table 4: Porosity Data for XY Creek-43 F2 Well

Depth (ft)	Porosity (v/v)
8700	0.25
8725	0.28
8750	0.32
8775	0.33
8800	0.30
8825	0.22

3.4 Permeability Estimation

Permeability is crucial for determining how easily hydrocarbons can flow through the rock. The permeability log (Figure 7) shows that the interval between 8740 and 8780 feet has permeability values exceeding 180 mD. These values suggest excellent fluid flow potential, meaning that hydrocarbons can move efficiently within the reservoir (Mark et al., 2022). Below 8800 feet, permeability decreases significantly, with values dropping below 120 mD, indicating reduced fluid flow potential and the need for enhanced recovery techniques.

Key Observations:

High Permeability Zones (Figure 7): The interval from 8740 to 8780 feet has permeability values greater than 180 mD, confirming excellent reservoir quality (Table 5). This high permeability aligns with the high porosity observed in the same interval, making it a prime target for production.

Low Permeability Zones (Figure 7): Permeability values below 8800 feet drop below 120 mD, indicating poor fluid flow potential. In these zones, stimulation techniques such as hydraulic fracturing may be required to enhance production.

Table 5: Permeability Data for XY Creek-43 F2 Well

Depth (ft)	Permeability (mD)
8700	100
8725	150
8750	200
8775	250
8800	180
8825	120

3.5 Water and Hydrocarbon Saturation

Water saturation was calculated using Archie's equation, and hydrocarbon saturation was derived as the inverse of water saturation. The interval from 8740 to 8780 feet shows water saturation levels consistently below 30%, indicating that the majority of pore spaces are filled with hydrocarbons [6]. This low water saturation, combined with high porosity and permeability, confirms that this is a prime interval for hydrocarbon production. Conversely, intervals below 8800 feet exhibit water saturation exceeding 50%, indicating water-filled pore spaces and minimal hydrocarbon presence.

Key Observations:
Hydrocarbon-Rich Zones (Figure 7): Water saturation in the interval from 8740 to 8780 feet is consistently below 30%, meaning that hydrocarbons fill over 70% of the pore space. This interval shows excellent potential for hydrocarbon extraction.
Water-Dominated Zones (Figure 7): Below 8800 feet, water saturation exceeds 50%, suggesting that water occupies the majority of pore space, reducing the likelihood of hydrocarbon production.

3.6 Net-to-Gross Ratio (NTG)

The net-to-gross ratio was calculated to assess the proportion of reservoir-quality rock (sandstone) relative to the total rock volume in each interval. The interval from 8740 to 8780 feet shows a net-to-gross ratio of 0.8, meaning that 80% of the rock is composed of clean sands, making it a prime reservoir zone. Below 8800 feet, the net-to-gross ratio drops to 0.5, reflecting a higher proportion of shale and non-reservoir rock.

Key Observations:
High NTG Zones (Figure 4, Figure 7): The interval from 8740 to 8780 feet has an NTG ratio of 0.8, indicating that the majority of the formation consists of reservoir-quality rock. This high NTG, combined with high porosity and permeability, makes this interval a prime target for production.

Lower NTG Zones (Figure 4, Figure 7): Below 8800 feet, the NTG drops to 0.5, suggesting a lower proportion of clean reservoir rock. This interval is less favorable for hydrocarbon production due to increased shale content and lower reservoir quality.

3.7 Hydrocarbon Extraction Potential

The Petrophysical analysis identifies the interval between 8740 and 8780 feet as the most promising zone for hydrocarbon extraction. This interval exhibits:

- Low gamma ray values (35–45 GAPI), indicating clean sands (Figure 4).
- High resistivity values (above 1000 ohm-m), confirming hydrocarbon presence (Figure 5).
- Excellent porosity (0.32–0.33 v/v), providing substantial pore space for hydrocarbon storage (Figure 6).
- High permeability (above 180 mD), ensuring efficient fluid flow for production (Figure 7).
- Low water saturation (below 30%), indicating a high hydrocarbon content (Figure 7).

However, the interval below 8800 feet shows less favorable conditions, with increased shale content, reduced porosity, lower permeability, and higher water saturation. This interval may require advanced stimulation techniques, such as hydraulic fracturing, to improve hydrocarbon recovery.

3.8 Correlation Analysis for Enhanced Reservoir Understanding

The integration of gamma ray, resistivity, porosity, and permeability logs is essential for characterizing the reservoir and identifying the best zones for hydrocarbon production. By correlating these logs, we can confirm the presence of hydrocarbons, assess the quality of the reservoir rock, and estimate the flow potential for hydrocarbons within the subsurface formations.

3.8.1 Gamma Ray and Resistivity Correlation

The gamma ray and resistivity logs together provide a powerful tool for identifying hydrocarbon-bearing zones. The gamma ray log indicates lithology, particularly differentiating clean sands from shales, while the resistivity log helps identify fluid types within those lithologies.

Low Gamma Ray and High Resistivity (8750–8800 feet):

The gamma ray log shows low values (35–45 GAPI) between 8750 and 8800 feet, indicating clean sands with minimal shale content. Corresponding to this, the resistivity log shows high values (above 1000 ohm-m), which strongly indicates the presence of hydrocarbons in these clean sands. Hydrocarbons resist electrical current more than water, hence the higher resistivity.
The strong correlation between low gamma ray and high resistivity confirms that this interval contains hydrocarbon-bearing sands and is a key target for production [2].

3.8.2 Porosity and Permeability Correlation

Porosity and permeability are critical for assessing both the storage capacity of the reservoir and its ability to transmit fluids. High porosity indicates a good volume of space available to store hydrocarbons, while high permeability suggests efficient fluid flow through the reservoir.

High Porosity and High Permeability (8740–8780 feet):
The neutron porosity and density porosity logs show high values (0.32–0.33 v/v) between 8740 and 8780 feet, indicating that the sands in this interval have a good capacity for storing hydrocarbons.
The permeability log also shows high values (above 180 mD) in this interval, confirming that hydrocarbons can flow freely through these sands, making this zone highly productive.
Conclusion: The high porosity and high permeability correlation suggests that the interval from 8740 to 8780 feet is a prime production zone with both good storage capacity and flow potential [4].

3.8.3 Hydrocarbon Saturation and Permeability Correlation

Hydrocarbon saturation, derived from resistivity and porosity logs, is crucial for determining the amount of producible hydrocarbons in the reservoir. By correlating hydrocarbon saturation with permeability, we can assess the efficiency of hydrocarbon extraction.

High Hydrocarbon Saturation and High Permeability (8740–8780 feet):
The resistivity log suggests high hydrocarbon saturation in the interval between 8740 and 8780 feet, with resistivity values above 1000 ohm-m.
The permeability log confirms that the sands in this interval have high permeability, which allows for efficient hydrocarbon flow through the reservoir rock.
The correlation between high hydrocarbon saturation and high permeability in this interval confirms that hydrocarbons can be extracted efficiently from the reservoir [6].

3.8.4 Net Pay Thickness and Production Potential

Net pay is the thickness of the reservoir rock that contains producible hydrocarbons, and it’s often derived from a combination of gamma ray, resistivity, porosity, and permeability logs.

High Net-to-Gross Ratio (8740–8780 feet):
The net-to-gross ratio is high in the interval between 8740 and 8780 feet, as confirmed by the combination of low gamma ray, high resistivity, and high porosity/permeability.
This interval is dominated by clean, hydrocarbon-bearing sands, and it has minimal shale content.
The high net pay thickness indicates that a large portion of this zone is capable of producing hydrocarbons.
The interval from 8740 to 8780 feet represents a significant net pay zone, making it one of the best intervals for hydrocarbon extraction [5].

Summary of Key Correlations:
The correlation between gamma ray, resistivity, porosity, and permeability logs provides a comprehensive understanding of the reservoir's characteristics, based on accepted petrophysical standards for evaluating sandstone reservoirs.

Gamma Ray and Resistivity: Gamma ray values below 50 API are typically interpreted as clean sands, while values above 60 API indicate shale-dominated formations. In addition, resistivity values greater than 500 ohm-m are generally associated with hydrocarbon-bearing sands, while lower values suggest water saturation, as outlined in petrophysical standards for sandstone formations (e.g., Asquith & Krygowski, Basic Well Log Analysis). These thresholds confirm the presence of hydrocarbon-bearing sands between 8750 and 8800 feet.

Porosity and Permeability: Effective porosity values above 0.25 v/v are commonly considered indicative of high-quality reservoir rock, while permeability values exceeding 100 mD suggest excellent fluid flow potential (Rider & Kennedy, The Geological Interpretation of Well Logs). In this study, the interval from 8740 to 8780 feet exhibits both high porosity and permeability, suggesting excellent reservoir quality and production potential.

Hydrocarbon Saturation and Permeability: Hydrocarbon saturation, calculated using Archie's equation, provides an estimate of the proportion of hydrocarbons within the pore spaces. Zones with hydrocarbon saturation above 70% are typically regarded as having significant hydrocarbon content, supporting efficient hydrocarbon flow and extraction potential. When correlated with permeability values above 150 mD, these zones are considered highly productive and capable of sustained flow rates.

Net Pay Thickness: Net pay thickness is calculated by summing the intervals with high-quality reservoir characteristics (e.g., effective porosity above 0.20 v/v and permeability above 100 mD) and hydrocarbon saturation exceeding 60%. According to industry standards, a thick hydrocarbon-bearing interval with these characteristics can support long-term production and is essential for estimating the overall reserves and production potential of the field.

By applying these standards to interpret the well log data, this correlation analysis provides a more integrated understanding of the reservoir’s quality and potential. This approach enables optimized decision-making for hydrocarbon extraction and future field development, ensuring that production efforts focus on the most promising zones.

3.9. Discussion

The petrophysical evaluation of the XY Creek-43 F2 well has identified high-quality reservoir sands with significant hydrocarbon-bearing potential. Several studies, such as those by [9] and [10], reinforce the importance of sedimentological and petrographic analysis in understanding depositional environments and reservoir quality. These evaluations are essential for optimizing hydrocarbon recovery in the Niger Delta Basin, where depositional environments significantly influence reservoir characteristics. Additionally, the works of [11] and [2] support the utility of well log analysis in marginal oil field development.

3.9.1 Reservoir Quality and Hydrocarbon Potential

The well log data confirms the presence of clean sand formations with minimal shale content, supported by [9[, who emphasize the significance of petrographic analysis in identifying high-quality reservoirs. The resistivity values exceeding 1000 ohm-m in the 8750 to 8800 feet interval suggest hydrocarbon saturation, aligning with the findings of [12], who demonstrated that resistivity logs are crucial for estimating volumetric reserves and assessing reservoir geometry in offshore fields. Furthermore, studies like [13] and [14] have highlighted the importance of integrating well log data with 3D reservoir models to improve characterization and reduce uncertainties, as observed in the XY Creek-43 F2 well.

3.9.2 Production Potential of the XY Creek-43 F2 Well

The interval from 8740 to 8780 feet exhibits excellent production potential, with permeability values exceeding 180 mD. This finding is supported by [10], who found that rock properties derived from side wall samples are vital for accurate reservoir evaluation. Their research reinforces that interval with high porosity and permeability, such as those in the XY Creek-43 F2 well, are prime candidates for hydrocarbon extraction. Similarly, [5] and [15] have documented similar characteristics in reservoirs across the Niger Delta, where high permeability and porosity correlate strongly with production potential. Additionally, [16] noted that intervals with low water saturation, such as the XY Creek-43 F2 interval, offer excellent opportunities for efficient hydrocarbon recovery.

Net Pay and Reservoir Thickness: The net-to-gross ratio in this interval is high, indicating that the majority of the rock volume consists of reservoir-quality sands. This thick, hydrocarbon-bearing section can support long-term production, making it an ideal candidate for development.

Flow Characteristics: The high permeability in this zone ensures that hydrocarbons can be produced at a commercial rate. The combination of high hydrocarbon saturation and low water saturation further supports the viability of this zone for sustained production.

3.9.3 Implications for Field Development

The findings from this study, supported by [12], underscore the importance of accurate volumetric reserve estimation for field development. The high net-to-gross ratio of 0.8, combined with low gamma ray values, confirms the predominance of clean sands in the XY Creek-43 F2 well, making it a strong candidate for commercial production. The application of sedimentological and petrographic analyses, as suggested by [9], can further enhance reservoir characterization and lead to more optimized hydrocarbon recovery strategies. Studies such as [17] and [18] have shown that detailed Petrophysical analysis is critical for effective reservoir management and the maximization of recoverable hydrocarbon volumes.

The successful integration of well log data with sedimentological, petrographic, and 3D modeling approaches has been highlighted in several works, including [13] and [2]. This integrated approach, as applied in the XY Creek-43 F2 well, serves as a model for future field development in the Niger Delta Basin, where accurate reservoir evaluation and understanding of depositional environments are key to unlocking significant hydrocarbon reserves.

Hydrocarbon Zone Identification: The resistivity log has identified a significant hydrocarbon-bearing zone, and this interval should be prioritized for well completion. The zone between 8750 and 8800 feet provides the best opportunity for immediate hydrocarbon extraction.

Water Production Considerations: Below 8800 feet, the resistivity decreases, and the gamma ray values increase, suggesting a higher water saturation and shale content. This zone is less favorable for hydrocarbon extraction and may result in increased water production if targeted.

4. Conclusion and Recommendations

The Petrophysical analysis of the XY Creek-43 F2 well has identified the interval between 8740 and 8780 feet as the most promising for hydrocarbon extraction. The correlation between the gamma ray, resistivity, porosity, and permeability logs confirms that this interval consists of clean, hydrocarbon-bearing sands with excellent reservoir quality and flow potential.

The Gamma Ray and Resistivity correlation indicates the presence of hydrocarbon-bearing sands between 8750 and 8800 feet, with minimal shale content and high resistivity confirming hydrocarbon saturation.
Porosity and Permeability correlation suggests that the interval between 8740 and 8780 feet is highly productive, with high porosity values (0.32–0.33 v/v) and permeability exceeding 180 mD, making it ideal for production.

Hydrocarbon Saturation and Permeability: The correlation further confirms that hydrocarbons dominate the pore spaces in this interval, ensuring efficient flow and extraction potential.
Net Pay: The high net-to-gross ratio in the interval from 8740 to 8780 feet suggests that a significant portion of this zone is capable of producing hydrocarbons.

4.1 Recommendations

Completion Strategy: Focus completion efforts on the interval between 8740 and 8780 feet to maximize hydrocarbon production. Given the natural high permeability, additional stimulation techniques may not be necessary.
Water Management: Avoid targeting the interval below 8800 feet for production due to the increased water saturation and shale content, which may lead to higher water production and lower hydrocarbon recovery.
Future Well Planning: Use the findings from this well as a model for future drilling in the area. The strong correlation between the logs in this well can guide further development and optimize hydrocarbon recovery in nearby wells

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