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Delineating Favorable Hydrocarbon Zones in X-Field

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***Abstract*: This study evaluated the X-Field within the Niger Delta basin for its potential to hold hydrocarbons. A synergistic approach combining seismic data analysis and well log interpretation was employed to pinpoint favorable reservoir zones. Seismic sections identified rollover anticlines, ideal structures for trapping oil and gas. Well logs from five locations (NEM-10 to NEM-4) pinpointed four potential reservoirs (A, B, C, and F). Reservoirs A and B displayed encouraging characteristics, with A in Well NEM-10 exhibiting the most promise based on porosity and permeability. A closer look at these key reservoirs using core data from Well-7 confirmed the interpretations from well logs, revealing high permeability and good to high porosity. By integrating various data sources, the study strengthens the case for hydrocarbon exploration in the X Field. This approach identified potential traps, porous rock for storage, and promising reservoir properties, particularly in Reservoir A of Well NEM-10.**

***Keywords*: hydrocarbon exploration, Niger delta basin, reservoir characterization, seismic data analysis, well log interpretation, porosity, permeability, reservoir zones, rollover anticlines, X-Field.**

1. Introduction

The Niger Delta basin in West Africa is renowned for its prolific hydrocarbon reserves, serving as a significant contributor to the global oil and gas landscape (Short & Stauble, 1967). However, meticulously evaluating the potential of specific reservoirs within this geologically complex basin necessitates a rigorous and integrated approach (Nwankwo et al., 2016). This study centers on X-Field, a promising area within the Niger Delta basin, and adopts a synergistic strategy that leverages well log and core data analysis to achieve a specific aim: to delineate favorable zones for hydrocarbon exploration and development. The overarching objective of this study is to unlock the hydrocarbon potential of X-Field by employing a multi-disciplinary approach. This approach entails a comprehensive evaluation of the geological, geophysical, and petrophysical characteristics of the reservoir zones within the field. By integrating various data sources and analytical techniques, the study strives to identify zones with the most favorable properties for hydrocarbon accumulation, such as porosity, permeability, and fluid saturation.

The importance of meticulous reservoir evaluation in the success of hydrocarbon exploration and production endeavors is paramount (Asquith & Gibson, 1982). It involves a thorough characterization of the subsurface rock formations to determine their capacity to store and transmit fluids, particularly oil and gas. Key reservoir properties, such as porosity, permeability, and fluid saturation, play a critical role in this assessment (Amaefule et al., 2004). Traditionally, well log data has been the primary source of information for reservoir evaluation (Ellis & Singer, 2007). Well logs provide continuous measurements of various rock and fluid properties at specific depths within a wellbore. When interpreted effectively, these measurements can reveal valuable insights into the lithology, porosity, permeability, and fluid content of the reservoir.

While well logs offer a wealth of information, their inherent limitation lies in the fact that they provide data only at specific points within the wellbore (Lucia, 2007). The characteristics of the reservoir between these points remain relatively unknown. To overcome this limitation and achieve a more comprehensive understanding of the reservoir, core data analysis is often integrated with well log interpretation (Ehrlich et al., 1978). Core data is obtained using software analysis of the well logs. In light of the Niger Delta basin's established hydrocarbon potential and the critical role of meticulous reservoir evaluation (Short& Stauble, 1967; Asquith & Gibson, 1982), this study focuses on X-Field. By employing a multi-disciplinary approach that leverages both well log and core data analysis, the study aims to delineate favorable zones for hydrocarbon exploration within the field. This comprehensive evaluation will not only contribute to the success of potential exploration activities in X-Field but also serve as a valuable model for future hydrocarbon exploration efforts in the Niger Delta basin.

2. Study Area

The study area is in Niger delta Basin in Nigeria.

Fig. 1. Map of Nigeria showing the Niger Delta Complex, the Anambra Basin & the Benue Trough (After Corredor et al, 2005)

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3. Methodology

A. Data Acquisition and Assessment

The cornerstone of our approach lies in the data utilized. We employ two primary data groups:

Well Data: A comprehensive suite of well data was acquired for reservoir characterization of X-Field. This includes:

Seismic Data: We utilize [Specify type, e.g., 3D seismic] data, acknowledging any limitations (e.g., fair to good quality, resolution diminishes at deeper levels).

Well Deviation Survey Data: This data, available for all wells penetrating X-Reservoir, is crucial for determining the true vertical thickness of the reservoir.

Checkshot Data: Essential for establishing seismic-to-well tie, checkshot data availability (mention well count) is noted.

Formation Tops Data: Serving as a reference point for the reservoir interval, formation tops data availability and any exceptions encountered are documented.

Well Log Data: A full suite of digital well logs was acquired for most wells, with details regarding quality mentioned. Key logs for differentiating rock types include gamma ray, resistivity, compensated neutron porosity, and bulk density logs. Any limitations in log coverage across wells (missing logs or specific intervals) are highlighted.

Production Data (timeframe mentioned): Production data is used to understand the reservoir's behavior over time.

Bottom Hole Pressure (BHP) Data: BHP data provides insights into pressure support and reservoir continuity (mention implications).

PVT Data (source and purpose mentioned): Pressure-Volume-Temperature (PVT) data is used in the analysis.

B. Software and Tools Employed

The data processing and analysis employed software like Petrel® (Schlumberger software) for geological and geophysical interpretation, and Techlog software for petrophysical evaluation.

C. Subsurface Evaluation

The subsurface evaluation workflow for characterizing the reservoir involves the following steps:

Seismic Data Interpretation:

The process of loading and interpreting seismic data for structural understanding is described.Techniques used for enhancing seismic data quality (e.g., structural smoothing, trace AGC) are mentioned.

Fault identification and classification procedures are explained. The approach for establishing seismic-to-well tie using available data (checkshot or alternative methods) is discussed.

The process of reservoir horizon identification and mapping throughout the seismic volume is detailed.

D. Structural Interpretation and Mapping

A brief description of the interpreted structural configuration of the field (e.g., rollover anticline) is provided.

Reservoir Geology: The approach for analyzing and understanding the geological setting of the reservoir (sedimentary facies, depositional environment) is discussed.

Petrophysical Evaluation: The methodology for using well log data to estimate key reservoir properties (porosity, permeability, fluid saturation) is explained.

The specific log responses used for each property estimation (e.g., gamma ray for clay content, resistivity for formation fluids) are mentioned.

If core data is available, how it's integrated with well log interpretation for calibration and validation is described (e.g., core data can be used to refine porosity and permeability estimations derived from well logs).

Static Modeling: The process of building a geological model of the reservoir based on seismic and well data interpretation is briefly mentioned.

E. Integration of Well Log and Core Data

This subsection delves deeper into how well log and core data are integrated for a more robust characterization (applicable only if core data is available):

Explain how core data is used to calibrate porosity and permeability estimations derived from well logs.

Discuss how core observations on pore type distribution can be used to refine fluid saturation interpretations from well logs.

Types of Logs Used

- Gamma Log
- Neutron Log
- Resistivity Log

4. Results and Interpretations

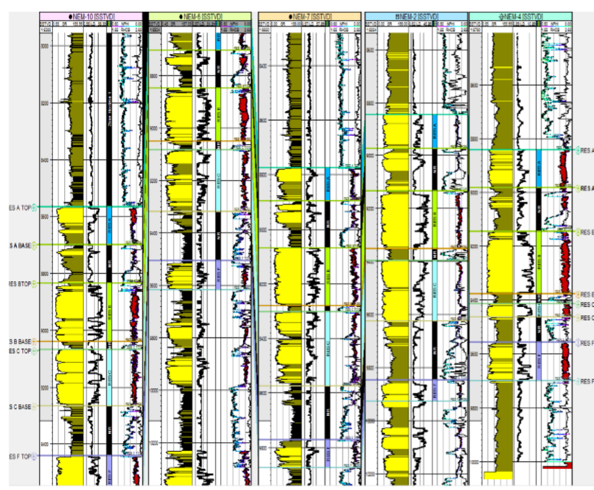

Fig. 2. Well log correlation of the four wells

The Figure 2 shows well correlation of the four wells, a comprehensive analysis of well logs from four wells (NEM-10, NEM-6, NEM-7, and NEM-2) in search of potential hydrocarbon reservoirs. The evaluation focused on Reservoirs A, B, C, and F within each well, utilizing Gamma Ray, Induction Lateral Deep (ILD - resistivity), and Neutron-Porosity/Density (NPHI/RHOB) logs (refer to Figure 4.7 for well log correlation).

A. Well NEM-10 Analysis

The well log data for NEM-10 revealed several promising zones for hydrocarbon accumulation. From a depth of 7980 meters to the base at 9475 meters, fine sand to shale formations were observed, acting as top and bottom seals for potential reservoirs. Within this well, specific attention was given to Reservoirs A, B, C, and F. The first significant sand body, identified as Reservoir A (8580-8640 meters), displayed a favorable thickness (60 meters) and encouraging characteristics for hydrocarbon entrapment. This zone exhibited high ILD values in the upper section, supported by a gas balloon signature on the NPHI/RHOB logs, indicating potential fluid movement and hydrocarbon presence. A marginal sand body separated Reservoir A from B, with good ILD responses and NPHI/RHOB signatures, further suggesting hydrocarbon potential.

Reservoir B (8845-9040 meters) displayed a massive sand body (195 meters) with strong evidence for hydrocarbons. This zone exhibited high ILD kicks and characteristic gas balloon structures on the NPHI/RHOB logs, along with top and bottom seal rocks for potential entrapment.

Reservoir C (9030-9230 meters) boasted an even greater thickness (200 meters) compared to A and B. Similar to the previous reservoirs, it displayed high ILD kicks and NPHI/RHOB gas balloon signatures, indicating the presence of hydrocarbons and bound by top and bottom seals.

Unfortunately, the evaluation of Reservoir F in NEM-10 was inconclusive due to an incomplete log, hindering the estimation of its thickness. However, the available data suggested the presence of attributes indicative of hydrocarbons.

B. Findings from Well NEM-6

Similar to NEM-10, an evaluation of Reservoirs A, B, C, and F was conducted for Well NEM-6, covering a depth range of 8720 meters to 10280 meters. Reservoir B (8820-9025 meters) displayed exceptional promise, with high ILD kicks and prominent gas balloon structures throughout the NPHI/RHOB logs from top to bottom, signifying the presence of hydrocarbons.

Reservoir C (9040-9260 meters) also exhibited encouraging signs. Based on the ILD, NPHI/RHOB signatures, and the presence of top and bottom seal rocks, optimal recovery zones were identified within the depths of 9040-9070 meters and 9180-9260 meters.

Well NEM-6's Reservoir F (9460-9610 meters) presented a unique characteristic - a serrated sand body. Despite this, it possessed a good thickness (150 meters) with top and bottom seals, gas balloons, and high ILD kicks towards the base, suggesting potential hydrocarbon entrapment. Interestingly, the log data hinted at the possibility of additional hydrocarbon-bearing formations below Reservoir F.

C. Well NEM-7 Evaluation

The analysis of Well NEM-7, ranging from depths of 8460 to 9870 meters, focused on Reservoirs A, B, C, and F. The well's upper section (8460-8788 meters) comprised fine sand to shale formations, potentially acting as a top seal for the reservoir section below.

Reservoir A (8788-8824 meters) displayed a good sand body thickness with encouraging ILD kicks and gas balloon signatures on the NPHI/RHOB logs. However, a separate sand body found below lacked the necessary parameters indicative of hydrocarbons. Another potential reservoir zone was identified within depths of 8855 (top) and 8890 meters (base), exhibiting a gas balloon signature and positive ILD and NPHI/RHOB responses.

Moving on to Reservoir B (9035-9240 meters), a massive sand body with a thickness of 205 meters was observed. This zone displayed high ILD values but limited to discontinuous gas balloon signatures throughout the reservoir. Nonetheless, the presence of top and bottom seals remained favorable.

Reservoir C (9250-9587 meters) covered a significant thickness of 337 meters and displayed a serrated rise and fall pattern in its sand body. This zone exhibited ideal gas balloon signatures concentrated in the upper to middle sections, suggesting potential hydrocarbon accumulation. The presence of top and bottom seals further strengthens the case for this reservoir.

D. Well NEM-2 Analysis

Well NEM-2 spanned depths from 8570 to 10220 meters. Similar to other wells, the focus was on Reservoirs A, B, C, and F. The initial section (8570-8820 meters) consisted of a combination of fine sand, shale, and sand formations.

Reservoir A (8820-8988 meters) displayed a minor crossover gas balloon signature and a small ILD kick, suggesting a lower potential for hydrocarbons compared to other reservoirs.

Reservoir B (9168-9385 meters) presented a more promising picture with a thickness of 217 meters. This zone exhibited high ILD and NPHI/RHOB log responses, along with top and bottom shale seals, indicating a good chance of hydrocarbon entrapment.

Reservoir C (9400-9610 meters) boasted a thickness of 190 meters and displayed a weak gas balloon structure along with positive ILD log responses, suggesting some potential for hydrocarbons.

The evaluation of Reservoir F in Well NEM-2 revealed a promising zone with depths ranging from 9830 meters (top) to 9850 meters (base). This zone exhibited good crossover structures on the gas balloon and hinted at the presence of additional sand bodies below that could potentially hold hydrocarbons.

E. Well NEM-4 Findings

The final well, NEM-4, covered depths from 8500 to 10040 meters. Reservoirs A, B, C, and F were evaluated here as well.

Reservoir A (8820-8985 meters) displayed a medium range of ILD values but a good gas balloon signature throughout the reservoir, suggesting potential hydrocarbon presence.

Reservoir B (9170-9390 meters) exhibited a thickness of 220 meters with high ILD log and NPHI/RHOB log responses indicative of hydrocarbons.

Reservoir C (9408-9415 meters) was a relatively thin zone (27 meters) but displayed encouraging ILD log and NPHI/RHOB log responses, suggesting potential hydrocarbon entrapment.

Finally, Reservoir F (9580-9650 meters) displayed a thickness of 70 meters with high ILD log and NPHI/RHOB log responses, suggesting a good chance of containing hydrocarbons.

The analysis focused on Gamma Ray (rock type), resistivity (ILD), porosity (PHIT, NPHI/RHOB), revealing key features for NEM 10 (Figure 3).

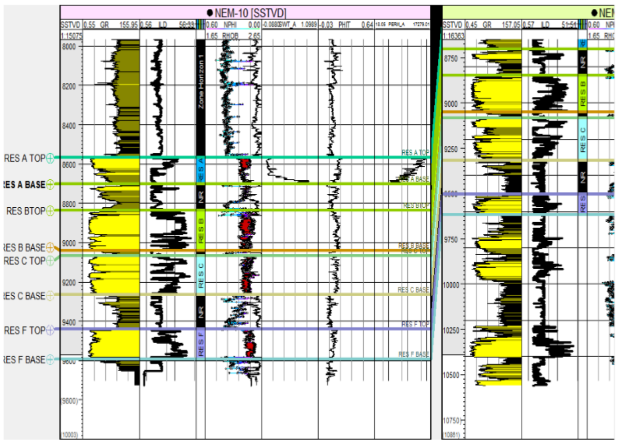

Fig. 3. Well showing correlation of NEM 10

Reservoir A (8680-8700 SSTVD): Deep analysis suggests high permeability and porosity, ideal for hydrocarbon flow and storage. Funnel-like shape (coarsening upwards) and "gas balloon" signature on NPHI/RHOB log hint at potential hydrocarbons.

Reservoir B (8820-9020 SSTVD): A thick sand body (200 SSTVD) with a "gas balloon" marker on NPHI/RHOB log again suggests potential hydrocarbons.

Reservoir C (9030-9250 SSTVD): Another thick sand body with increasing "gas balloon" signatures towards the base, indicating a possible increase in hydrocarbons with depth.

Reservoir F (9430-9600 SSTVD): A massive sand body encased by shale layers (top and bottom), with high ILD and NPHI/RHOB readings potentially indicating trapped hydrocarbons.

The improve seismic section (Figure 4) showing horizon of A Top and B Top and figure 5 showing the resolution of structural feature were smooth with improve and clear horizon (Figure 6) and fault plan well delineated, as red and blue horizons were used to trace the fault marker within XL 1600 and 1541 SSTVDs from north to southern part of the seismic section. The major faults were cited on both the original and improved resolution seismic section and structural smooth attributes, but the minor faults were defined in the structural smooth attribute within the depths of 2400 to 300 SSTVDs and 1640 XL. While the structural pattern were interpreted in terms of anticlinal and fault structures. Six faults were delineated on this seismic section at membered as F1, F2, F3, F4, F5 and F6. The roll over anticlines were developed within the fault closures of F2 and F3, F6 and F1 and F3 and F6 that shows the major anticlinal structures on the seismic section.while Variance Edge of a seismic attribute (Figure 7) that helps for the structural orientation of the faults and their geometry. They give you a better picture of the structures across the field.

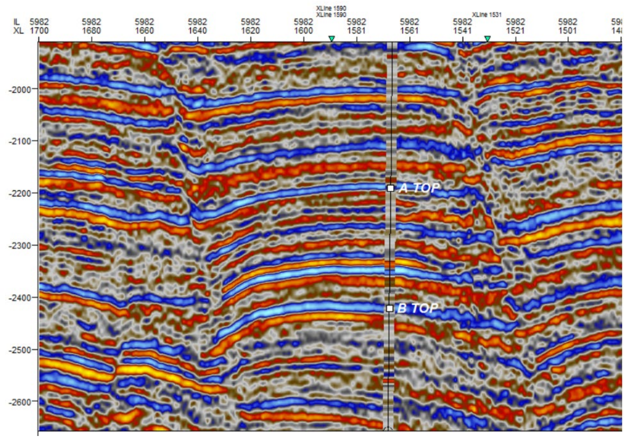

Fig. 4. Seismic section showing horizon of A Top and B Top

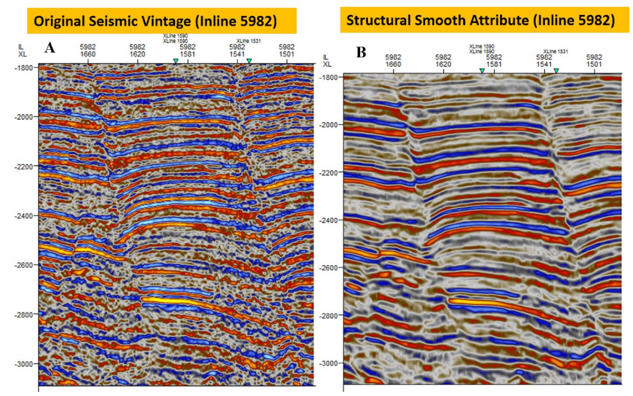

Fig. 5. Improved seismic resolution of (A) as seen on structural smoothing attribute used for faults and horizons marker in (B)

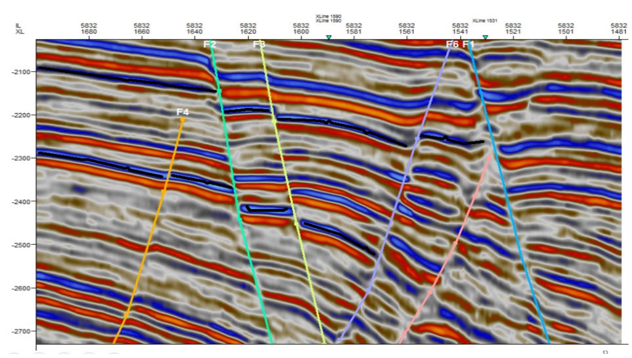

Fig. 6. Fault plans interpretation of structural smooth attribute on line 5832

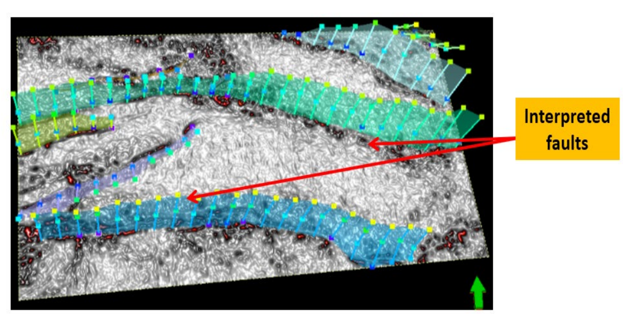

Fig. 7. Variance edge (Z - line 2360) attribute showing fault traces and the interpreted fault

Table 1
Average reservoir properties for Reservoirs A and B.

	2	4	6	7	10		2	4	6	7	10
NTG	0.88113	0.81090	0.87629	0.96352	0.78726	**NTG**	0.96347	0.82635	0.93663	0.98151	0.92920
SW	0.29991	0.29998	0.20101	0.12981	0.21012	**SW**		0.33636	0.21192	0.21829	0.31187
So	0.60091	0.60221	0.70001	0.62811	0.79182	**So**		0.63762	0.50021	0.71920	0.62263
PERM	2116.43	2871.00	8881.11	1221.99	2118.11	**PERM**	3211.10	3002.11	2001.91	3998.32	4222.22
PORO	0.26518	0.24411	0.27155	0.22711	0.25171	**PORO**	0.20017	0.25119	0.19918	0.26118	0.20111
RESERVOIR A						RESERVOIR B					

Table 2
Core petrophysical properties for NEM – 7

Porosity (fract.)	**Permeability (fract.)**	**Sw (fract.)**	**So (fract.)**
0.27219	3912.99	0.3101	0.6989

All the petrophysical and core results were generated in petrel from logs using these algorithms Equations for properties were show below;

$$IGR=(GR-10)/(110-10) \quad (1)$$

$$VSH=0.083*(Pow(2,(3.7*IGR))-1) \quad (2)$$

$$Poro=(2.65-RHOB)/(2.65-1) \quad (3)$$

$$Sw\_ud=0.082/Poro \text{……Udegbunam} \quad (4)$$

$$NTG=If(Poro<=0.2 \text{ And } VSH>=0.2,0,1) \quad (5)$$

$$PermX=307+26552*(Pow(Poro,2))-34540*Pow((Poro*Sw\_ud),2) \quad (6)$$

5. Discussion

A geological analysis of well logs from the Niger Delta basin, specifically focusing on Reservoirs A, B, C, and F in Well NEM-4.

A. Reservoir Characteristics

- The reservoirs consist of medium to high porosity and permeability sandstones with good Net to Gross ratio, especially in the upper zones.
- There is an increase in VSH (clay volume) and SWT (water saturation) from top to bottom of the reservoirs.
- Gas signatures were identified using logs like ILD and NPHI/RHOB.

B. Factors Affecting Properties

- Unconsolidated nature of the Niger Delta sediments is attributed to minimal compaction and diagenetic processes, leading to high porosity.
- Lateral variations in porosity are suggested to be caused by changes in depositional environment.

C. Well Specific Observations

- Well NEM-10: A Top and A Base show a funnel-shaped coarsening upward sequence with good sand thickness.
- Well NEM-7 Reservoir B: Analysis indicates good sand body thickness, high porosity and permeability, and low water saturation.
- Well NEM-2 Reservoir A: Gamma Ray log suggests fine sand layers and shales acting as seals between sand units.

D. Permeability and Porosity Values

- The entire mapped area shows good to very good porosity values.
- Permeability ranges from moderate to very high (2116 md to 8881 md) across different wells for Reservoir A.
- A core analysis confirms the log-derived permeability values.

Overall, promising reservoir characteristics in Well NEM-4 and surrounding areas within the Niger Delta basin. The unconsolidated nature of the formation seems to be a key factor contributing to good porosity and permeability.

6. Summary

A promising exploration opportunity is revealed in the X Field through analysis of seismic data and well logs. Seismic sections identified rollover anticlines, ideal structures for trapping oil and gas. These sections also showed well placements and six key faults, highlighting the complex geology. Well logs from five locations (NEM-10 to NEM-4) pinpointed four potential reservoirs (A, B, C, and F).

Reservoirs A and B were particularly interesting, with A in Well NEM-10 showing the best potential based on porosity and permeability. Positive signs were found elsewhere too, with Reservoirs B in other wells (NEM-6, NEM-7, NEM-2) exhibiting good thickness, porosity, and permeability. Well NEM-4 also showed promise across all its reservoirs.

To confirm these initial findings, a closer look was taken at Reservoirs A and B. This analysis, which included core data from Well NEM-7, examined properties like water saturation and porosity. It confirmed the well log interpretations, revealing high permeability and good to high porosity in these key reservoirs across multiple wells.

By combining data from seismic sections, well logs, and the closer look at key reservoirs, the study strengthens the case for hydrocarbon exploration in the X Field. This approach identified potential traps, porous rock for storage, and promising reservoir properties, particularly in Reservoir A of Well NEM-10.

7. Conclusion

Analysis of the X-Field for oil and gas reserves is promising. Seismic data revealed potential traps and well logs identified four zones (A, B, C, and F) with hydrocarbon potential. Reservoir A in well NEM-10 was particularly interesting, showing excellent porosity and permeability. Further evaluation confirmed these positive signs in Reservoirs A and B across multiple wells.

To capitalize on these findings, further exploration is recommended. This includes:

- Fossil Analysis: Studying fossils within the reservoirs to understand their age and predict reservoir continuity, aiding production planning.
- Core Data: The availability and importance of core data for direct measurement of reservoir properties like porosity and permeability are discussed.
- Incomplete log suites in some wells.
- Targeted Drilling: Focusing on the most promising areas, especially Reservoir A in NEM-10, to define reservoir size and continuity for resource estimation and development.
- Advanced Reservoir Studies: Utilizing advanced techniques to understand fluid flow behavior and optimize production strategies.
- High-Resolution Seismic: Acquiring clearer seismic data to improve visualization of underground features and well placement.

Additionally, an economic evaluation is crucial to assess the commercial viability of development. An environmental impact assessment is also necessary to mitigate potential risks associated with exploration and production.

This study significantly advances our knowledge of hydrocarbon exploration in the Niger Delta by:

- Identifying promising reservoir zones.
- Providing a quantitative analysis of these zones.
- Highlighting the exceptional properties of Reservoir A in NEM-10.

Overall, this research lays the groundwork for potentially discovering valuable hydrocarbon resources in the X-Field and the Niger Delta.

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