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Integrated Petrophysical Analysis of D1000 and E2000 Reservoirs in Niger Delta Basin

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***Abstract*: The Niger Delta basin is home to the D1000 and E2000 reservoirs, identified through a well log investigation of four wells. Lithological variations were discerned via gamma ray logs, distinguishing pure shale and clean sand. Resistivity logs within sand units indicated potential oil presence, complementing the identification of hydrocarbon-bearing intervals. Petrophysical analysis involved calculating key parameters such as Net-to-Gross ratios, porosity, water saturation, and permeability, facilitating volumetric investigations. Volumetric estimates, including Hydrocarbon Pore Volume (HCPV) and Stock Tank Oil Initially in Place (STOIIP), highlighted significant hydrocarbon potential in the reservoirs. The integration of well log data underscored the substantial hydrocarbon reserves present in the D1000 and E2000 reservoirs. Their high porosity and permeability suggest favourable conditions for hydrocarbon extraction, supporting the economic viability of the region. This comprehensive approach enhances understanding of reservoir characteristics, vital for successful exploration and development endeavours.**

***Keywords*: Niger Delta basin, reservoir characterization, well log analysis, hydrocarbon potential, petrophysical analysis, volumetric estimation, porosity, permeability, hydrocarbon extraction, exploration and development.**

1. Introduction

The Niger Delta basin, renowned for its prolific hydrocarbon reserves, presents unique challenges due to its complex geological makeup. Reservoirs within this basin are often characterized by alternating sand-shale sequences, posing significant hurdles for accurate reservoir characterization and production optimization (Avbovbo et al., 2015). The Niger Delta basin, a sprawling tapestry woven across 300,000 square kilometers of Nigerian soil, holds within its depths a treasure trove of hydrocarbons. Yet, this very bounty presents a unique challenge – its intricate geological makeup, characterized by a mesmerizing dance of sand and shale sequences, throws a veil of complexity over accurate reservoir characterization and optimal production strategies. Within this intricate tapestry lie the D1000 and E2000 reservoirs, beckoning with their whispers of vast hydrocarbon potential. However, their secrets remain hidden, guarded by the complex interplay of sand and shale formations. Unraveling these secrets requires a meticulous approach, one that delves beyond the surface and into the very heart of these formations, analyzing their fundamental properties. This study embarks on a mission to unlock the hidden wealth of the D1000 and E2000 reservoirs, wielding the combined power of well log data analysis and established petrophysical models. Our aim is threefold:

1. *Mapping the Landscape of Porosity and Permeability:* We delve deep to understand the spatial distribution of porosity and permeability within the sand-shale sequences. These parameters, akin to the reservoir's breathing and circulatory system, determine its ability to store and transmit fluids – crucial knowledge for maximizing production and optimizing reservoir management (Avbovbo, 1978).
2. *Evaluate Water Saturation:* By carefully analyzing the water saturation profile across the reservoirs, we aim to identify zones brimming with hydrocarbons. Water saturation, the unwelcome guest in the hydrocarbon party, directly impacts the recoverable volume and plays a pivotal role in estimating reserves and designing production strategies (Amaefule et al., 1993).
3. *Estimate Hydrocarbon Potential:* Integrating the secrets gleaned from porosity, permeability, and water saturation with the reservoir's geometry, we estimate the potential bounty of extractable hydrocarbons. This involves not only quantifying the volume of hydrocarbons in place but also evaluating the economic viability of their extraction, providing valuable insights for investment decisions and project planning (Short and Stauble, 1967).

The journey to unlock these secrets is paved with rigor and relies on established techniques and models. Well log data, meticulously collected from strategically chosen wells, forms the foundation of our petrophysical analysis (Archie, 1942). By employing well-respected equations such as the Wyllie-Archie and Timur models (Timur, 1968), we ensure robust and reliable results, even amidst the inherent complexities of these formations. This study is more than just an exploration of two specific reservoirs; it represents a holistic approach to understanding and maximizing the potential of complex formations within the Niger Delta basin. By unraveling their intricacies and quantifying their hydrocarbon resources, we contribute not only to the oil and gas industry but also to the advancement of geological knowledge and the sustainable development of these valuable resources. Ultimately, this study aims to unlock the hidden wealth of the D1000 and E2000

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reservoirs, contributing to a brighter future for the Niger Delta region and beyond.

2. Location and Geology of the Study Area

The study area is situated in the Niger Delta Region of Nigeria, specifically in the Ughelli North and South Local Government Areas. It falls between 5◦54'0" E and 6◦4'0" E in longitude and between 5◦28'0" N and 5°32'0" N in latitude.

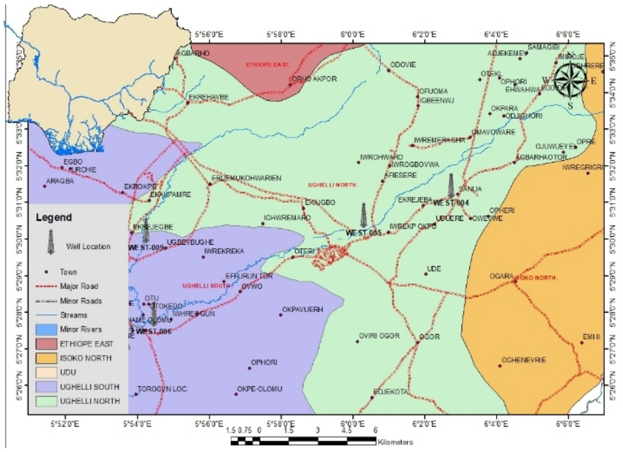

Fig. 1. Map of the study area showing sample point

3. Methodology

Four wells penetrating the D1000 and E2000 reservoirs were selected for this study. Extensive analysis was conducted on the well log data obtained, including gamma ray, neutron, density, and resistivity logs. These logs provide crucial information about the reservoir properties and were meticulously scrutinized. To quantify key petrophysical parameters such as porosity, permeability, and water saturation, well-established models were utilized. These include the Wyllie-Archie equation and Timur's equation, cited from authoritative sources (Archie, 1942; Timur, 1968). The equations used for calculations are as follows:

Porosity Calculation (Wyllie-Archie equation):

$$\phi=\Delta t_{f}-\Delta t_{ma}/\Delta t_{sl}-\Delta t_{ma} \quad (1)$$

Where:

- ϕ is porosity from sonic log (fraction)
- Δt_{sl} is acoustic transit time measured by sonic log (µsec/ft)
- Δt_{ma} is acoustic transit time of rock matrix measured in laboratory (µsec/ft)
- Δt_{f} is acoustic transit time of saturating fluid measured in laboratory (µsec/ft)

Permeability Calculation (Darcy's Law):

$$qf=kA\frac{\mu f}{\partial p}\partial l \quad (2)$$

Where:

- qf is flow rate of the saturating fluid (bbl/day)
- k is absolute permeability of the medium (md)
- A is cross-sectional area (ft²)
- $\partial fl\partial p$ is pressure gradient (psi/ft) is pressure gradient (psi/ft)

Water Saturation Calculation (Timur's equation):

$$Sw=f(\phi,k,\mu f,\rho f) \quad (3)$$

Where:

- Sw is water saturation
- ϕ is porosity
- k is permeability
- μf is fluid viscosity
- ρf is fluid density

These equations provide a robust framework for evaluating reservoir properties essential for further analysis and decision-making in reservoir management.

4. Results and Discussion

A. Lithology and Sand-Shale Distribution

Well log analysis of Fig. 2, revealed distinct lithological variations within both reservoirs. The gamma ray log, a sensitive indicator of shale content, effectively identified alternating sand and shale intervals. The sand units exhibited lower gamma ray readings, while shale intervals displayed higher values. This analysis confirmed the presence of a complex sand-shale sequence within both D1000 and E2000 reservoirs.

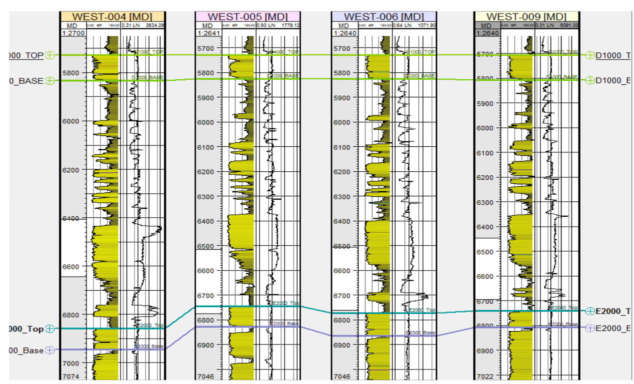

Fig. 2. Well log data

B. Porosity and Permeability Variations

Porosity analysis, utilizing neutron and density logs, revealed significant variations within the sand-shale sequence. Table 1 and Table 2 shows porosity and Permeability across the four wells and the reservoirs identified. Sand intervals displayed higher porosities, typically ranging from 0.20 to 0.30, while shale intervals exhibited lower porosities, generally below 0.10. Permeability calculations, based on porosity and resistivity data, indicated higher permeability values in sand units, ranging from 1000 to 5000 md, compared to negligible permeability in shale intervals. These findings align with established geological principles, highlighting the crucial role of sand bodies in

Table 1
Petrophysical Parameters across the wells

Petrophysical Parameters	**WEST-004**	**WEST-005**	**WEST-006**	**WEST-009**
Permeability (md)	9824.16	10335.44	7494.12	6342.10
Porosity (frac.)	0.2461	0.2255	0.2593	0.2112
Water Saturation (frac.)	0.3661	0.2817	0.3772	0.4213
Net-to-Gross (frac.)	0.8942	0.9011	0.9604	0.8825
Pay Thickness (ft)	170	188	95	152

Table 2
Average petrophysical parameters and STOIIP for reservoirs D1000 and E2000

Reservoir	**Area (Acre)**	**Pay Thickness (ft)**	**Permeability (frac)**	**Porocity (frac)**	**Water saturation (frac)**	**Net to Gross (frac)**	**Oil Volumetric Factor, Bo (frac)**	**STOIIP (mmstb)**
D1000	5362	183	8272.10	0.2561	0.3124	0.9514	1.7	68.71
E2000	4986	162	9215.40	0.2631	0.3926	0.9881	1.8	60.87

providing storage and flow pathways for hydrocarbons within the reservoirs.

C. Water Saturation and Hydrocarbon Potential

Water saturation analysis, employing resistivity logs, revealed variations across the reservoirs. Sand units generally exhibited lower water saturation values, ranging from 0.20 to 0.40, indicating the presence of hydrocarbons. Conversely, shale intervals displayed higher water saturation, exceeding 0.60, suggesting limited hydrocarbon potential. Integrating porosity, permeability, and water saturation data with reservoir geometry enabled the estimation of hydrocarbon volumes and potential production rates. The results as captured in Fig. 3. suggest promising hydrocarbon potential within specific sand intervals, particularly in the D1000 reservoir, which exhibited higher porosity and permeability compared to E2000. The D1000 reservoir's shallower depth than the E2000 reservoir is a major plus. Drilling and producing from shallow reservoirs is often simpler, less costly, and more accessible. As a consequence, exploration and production have less operational risks and expenses. The map's northeastern area shows a thicker oil zone, as shown by the area's greater oil-water contact (OWC) elevation. This increases the allure of visiting the northeast. Because of the increased potential for oil production in this area, there is a higher chance of finding significant reserves.

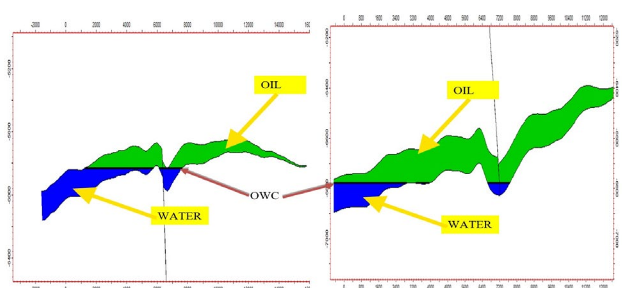

Fig. 3. Cross section of D1000 and E2000 showing OWC

5. Challenges and Limitations

This study acknowledges limitations inherent in relying solely on well log data. The absence of core data restricts direct measurements of porosity and permeability, potentially introducing uncertainties into the calculated values. Additionally, the complex sand-shale sequence presents challenges in accurately delineating reservoir boundaries and estimating hydrocarbon volumes.

6. Conclusion

This integrated petrophysical analysis of the D1000 and E2000 reservoirs in the Niger Delta basin highlights the significance of evaluating porosity, permeability, and water saturation variations within complex sand-shale sequences. By meticulously analysing well log data and employing established petrophysical models, we were able to:

- Identify alternating sand-shale intervals within the reservoirs.
- Quantify variations in porosity and permeability, highlighting the crucial role of sand units in hydrocarbon storage and flow.
- Evaluate water saturation, identifying potential hydrocarbon-bearing zones.

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