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Reliability of Mud Logging Data for Formation Characterization and Pore Pressure Prediction: A Comparative Analysis with Wireline Logging and Fluid Sampling in OSA Oilfield, Niger Delta

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Abstract
This study deals with the severe uncertainty of using real time mud logging data in the Niger Delta on the operational reliability of the data as an instrument of formation assessment and drilling security. It employed a comparative evaluation of the efficiency of mud logging versus wireline logging and fluid sampling data of the OSA oilfield. A direct comparative methodology was used to compare the data of gas chromatographic and drilling exponent using mud logs together with the petrophysical properties of the wires and the direct results of the fluid sample. The results of the analysis indicated that mud logging is a good predictive tool of pore pressure, which has a high correlation with data provided by wireline in critical wells. However, its ability to characterize its formation was not uniform, and gas ratio analyses did not effectively identify hydrocarbon zones in more than a third of cases, especially in lithologically complicated intervals. This study found that though invaluable in real-time pressure monitoring, the mud logging data has to be combined with the wireline and sampling data to enable reliable characterization of the formation.

Keywords: *Mud Logging Data, Formation Characterization, Pore Pressure Prediction, Wireline Logging, Fluid Sampling.*

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I. Introduction

The accurate description of subsurface structures and predictability of pressure in the pores are the fundamental area of petroleum geoscience to ensure safe, efficient, and cost-effective drilling processes (Ehsan et al., 2025). These are the parameters that establish the critical mud weight range, failure to get it right will cause disastrous well control accidents or expensive drilling hitches. Although wireline logging and formation fluid sampling offer high-fidelity, retrospective data, the industry strongly depends on mud logging because of the constant information acquisition throughout the drilling (Osaki, and Rorome, 2025; Laouini et al., 2025). Chaanda et al., (2025) opined that, the systematic data validation of mud logging records by these more conclusive measurements has not been well done so there is a large gap in reliability. The latest developments, such as machine learning models, show that the combination of mud logging and wireline data can considerably increase the accuracy of the prediction, but the environment and constraints of mud logging as a single biometric should be better defined.

This study will compare and contrast with an aim of assessing the credibility of mud logging data in characterization of formations as well as in predicting pore pressure. It compares the performance of mud logging to wireline logs and fluid sampling in the OSA field of the Niger Delta, a prolific but geological complex basin where such systematic validation is immediately needed. The results will offer a scientifically verified model of data interpretation, which will be directly linked to the enhanced safety of operations and the optimization of drilling plans in this and other hydrocarbon provinces.

A. Aim and Objectives

The aim of this study is to use a comparative analysis to evaluate the reliability and accuracy of mud logging data for formation characterization and pore pressure prediction in the OSA Oilfield, Niger Delta.
The objectives are to;

i. Evaluate the effectiveness of mud logging data in characterizing lithology and reservoir properties within the OSA Oilfield, Niger Delta;
ii. Determine early warning indicators of abnormal pressure zones during drilling;

iii. Measure similarities, differences, and accuracy levels between wireline logging data and formation characterization results from mud logging.

II. Geology of the Location

The OSA Oilfield is situated within the geologically complex and prolific Niger Delta Basin, a major hydrocarbon province in southern Nigeria. The field is specifically located in the basin's Coastal Swamp or Greater Ughelli depobelts, which are characterized by intricate networks of syn-sedimentary growth faults and associated roll-over anticlines that form the primary structural traps for hydrocarbons (Momta, 2019). Stratigraphically, the reservoir sands of OSA are part of the paralic (coastal) Agbada Formation, the delta's primary hydrocarbon-bearing unit. This formation consists of an interbedded sequence of sands and shales deposited in a fluvio-deltaic to shallow marine environment, overlain by the thick, sandy continental Benin Formation and underlain by the marine source rock shales of the Akata Formation (Madu et al., 2021). The reservoir sands, often deposited as barrier bars, channels, or shoreface systems, exhibit good porosity and permeability, forming high-quality reservoirs within a structural framework of fault-bounded closures. The petroleum system is sourced from the underlying Akata Formation shales, with geochemical fingerprinting confirming a terrestrial (Type III) organic matter input deposited under oxic conditions, generating both oil and gas. Recent studies highlight that the ongoing interaction between sea-level changes and depositional tectonics continues to influence hydrocarbon perspectivity in this region (Anyanwu and Ekpo, 2025).

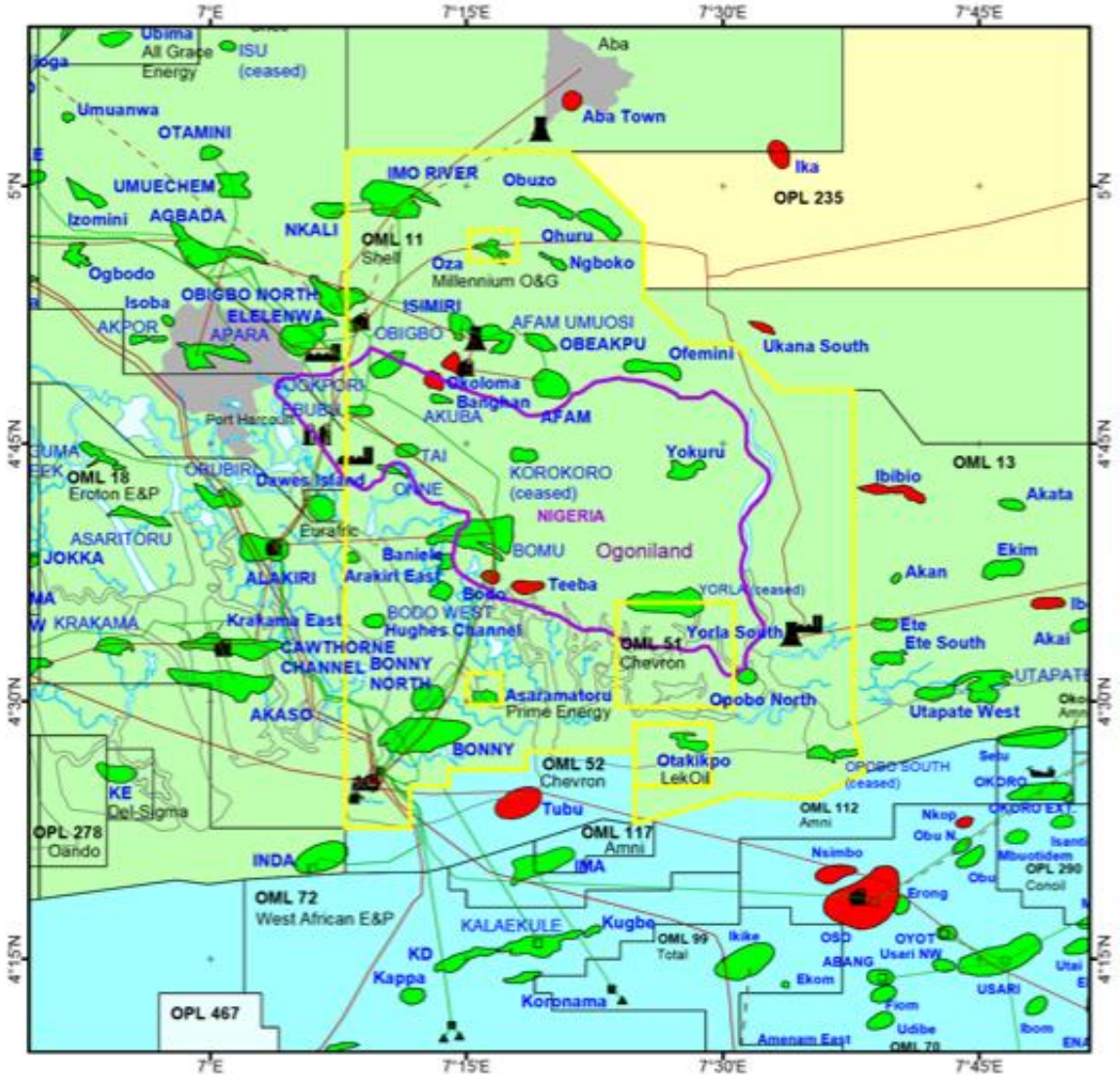

Fig. 1: OSA Oilfield Map Encompassing All the Reservoir Formations. Source: (Decklar, 2025).

III. Literature Review

One-to-one comparative analysis in the Niger Delta Basin showed a lot of discrepancies. Although the mud logging predictions of pore pressure (based on the D-exponent model) were equal to the wireline predictions in two of three wells, the likelihood of the model to characterize the formation fluid was poor. According to Chaanda et al., (2025) in about 37.5 percent of instances, especially in reservoirs with complicated lithologies or with low gas indications, gas ratio analysis (based on the Pixler Model) was not successful in differentiating hydrocarbon zones. This highlights an acute limitation mud logging offers great real-time drilling safety information but may not be a reliable independent method of identifying the fluid type and saturation. In contrast, Ekop et al., (2025) wireline logging is always more fidelity rich in its data used in measuring petrophysical characteristics such as porosity, permeability, and saturation of hydrocarbons. Although very sparse, and costly, core and fluid sampling data are the ground-truth reference point of the validation of both mud logging and wireline interpretations. This creates a definite pyramid of data reliability.

Theoretically, prediction of pore pressure using mud logging is based on empirical models (e.g. Eatons procedure) which interrelates parameters of the drilling such as rate of penetration with formation pressure. Yet, these models usually do not work in complicated geological conditions (Osaki, 2025; Liang et al., 2025). The most recent theoretical change incorporates machine learning (ML) to supersede these limitations. According to advanced research, hybrid models of mud logging and wireline data have a considerable positive influence on the accuracy of the prediction (Osaki, & Opara, 2018; Ehsan et al., 2025). Ogbu et al., (2024) gave an example of a Gradient Boosting Regressor (GBR) model, which had a R2 score of 0.91 and an integrated backpropagation neural network, which increased the accuracy by more than 8 percent. Such methods acquire complicated, non-linear interactions that the conventional empirical models overlook.

IV. Methodology

B. The Effectiveness of Mud Logging Data in Characterizing Lithology and Reservoir Properties

During drilling operations, mud logging offers continuous, real-time drilling data, such as gas compositions and descriptions of cuttings, which can reveal lithological changes and possible reservoirs (Anifowose et al., 2022). Abass et al., (2020) noted that, it improves early decision-making and drilling safety by identifying sandstone versus shale intervals and hydrocarbon shows that correlate with reservoir zones. However, compared to wireline logs, mud logging is qualitative and less accurate in measuring reservoir characteristics like porosity and saturation (Shakirov et al., 2023).

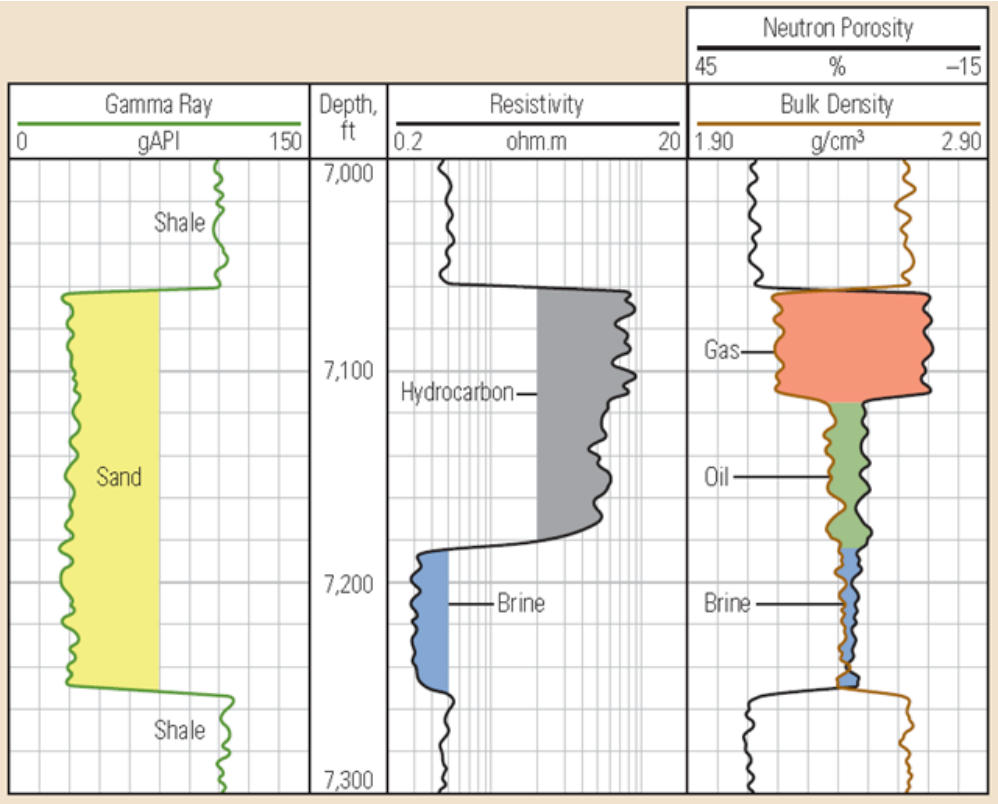

Fig. 2: Gas Compositions and Cuttings Descriptions Indicating Lithological Changes and Potential Reservoirs During Drilling Operations

C. Early Warning Indicators of Abnormal Pressure Zones During Drilling

Early warnings of impending abnormal pressure zones during drilling are provided by mud logging indicators like rising connection gas, decreased corrected d-exponent, and changes in drilling parameters. Prior to a kick, these signals correlate with overpressure transition zones, enabling proactive mud weight adjustments (Huszar et al., 2022). According to Zhang et al., (2025) when compared to traditional mud data alone, machine-learning integration of mud logging and well log parameters has recently demonstrated >96% accuracy in pore pressure prediction, improving early detection reliability.

Table I: Indicators of Abnormal Pressure Zones During Drilling Source: (Huszar et al., 2022)

Indicator	Reliability
Gas increase	Medium-gigh
D-exponent drop	Moderate
Drill mechanics	Supporting

D. Similarities, Differences, and Accuracy Levels Between Wireline Logging Data and Mud Logging

Mud logging and wireline logging are both intended to define the subsurface formations but the two vary in terms of data resolution and precision. According to Gietz et al., (2024) mud logging offers real-time and qualitative data like gas shows, cuttings lithology and drill-rate trends that tend to correlate with lithologic richness areas defined by wireline logs e.g., gamma ray or resistivity, but not depth data and quantitative petrophysical data. Meanwhile, Alkalbani and Chala, (2024) noted that, wireline logs provide detailed, numerical profiles of porosity, lithology and fluid content that would be useful in checking mud logging interpretations as a benchmark. As a mere comparison reveals, although the trends of mud logging e.g., gas increase have a tendency that is often directionally correlated with the wireline indicators of reservoir facies, the exact depth and magnitude of both are different owing to the drilling lag and contamination of the sample (Adamu et al., 2025).
The differences between mud logging data and wireline logging data is summarized in table II.

Table II: The Differences Between Mud Logging and Wireline Logging During Drilling

Depth (m)	Mud Gas (%)	Wireline (API)
1000	120	75
1050	200	65

V. Results

E. The Effectiveness of Mud Logging Data in Characterizing Lithology and Reservoir Properties Within the OSA Oilfield, Niger Delta

From the findings of this study, mud logging in the OSA Oilfield successfully highlighted reservoir intervals and identified significant lithologic changes. Qualitative lithology interpretation is supported by correlations between mud gas peaks, ROP (Rate of Penetration) changes, as presented in figure 3, and cuttings descriptions that match sandstone and shale intervals observed in calibrated wireline logs. In contrast to quantitative wireline measurements, mud logging underestimated fluid saturation and porosity. The comparisons in the methodology revealed similar lithological trends, but lag time caused differences in depth placement. Mud logging was generally helpful for early reservoir indication and real-time trend detection, but it was less accurate for precise quantification of reservoir properties without integration with wireline data.

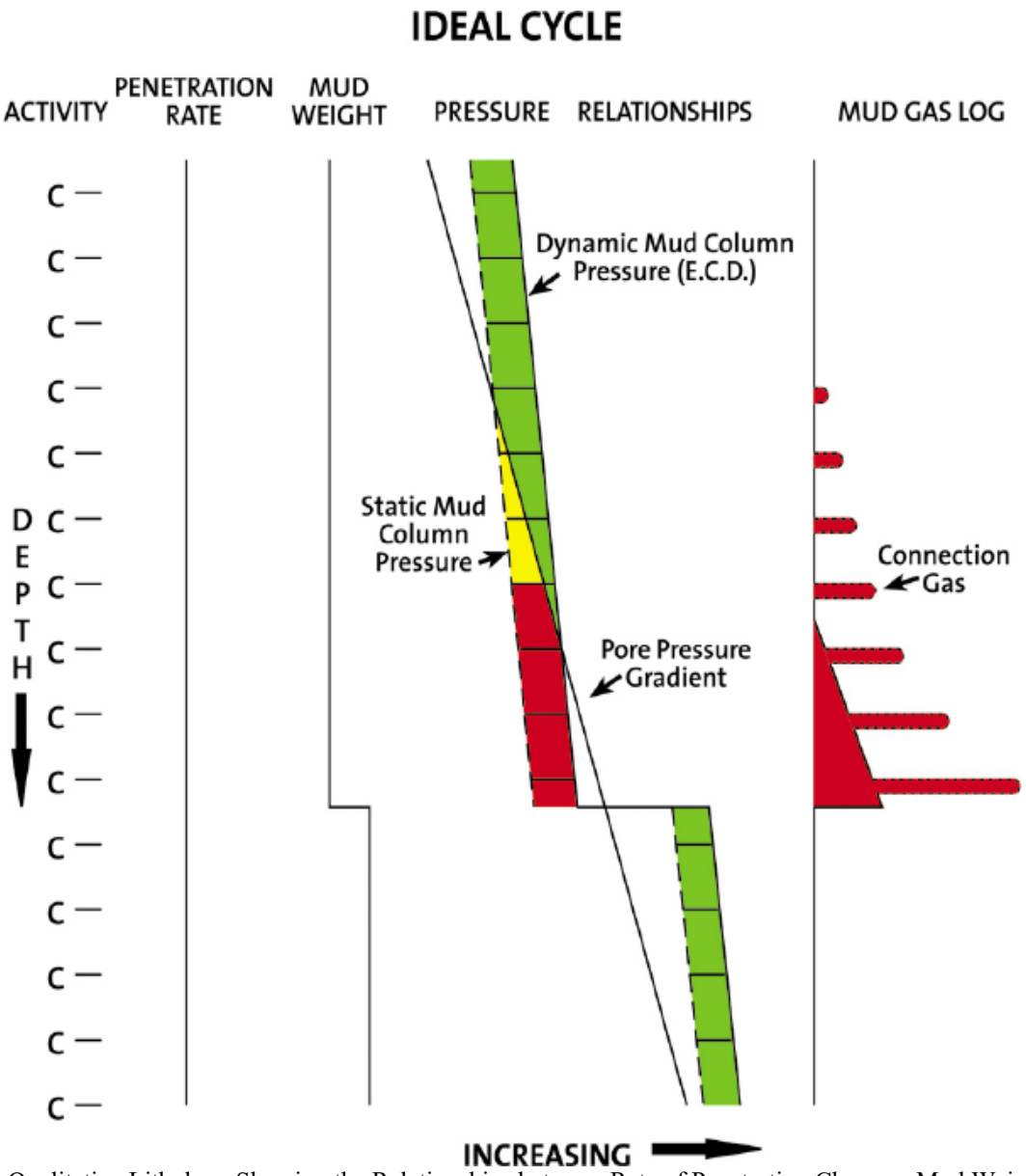

Fig. 3: Qualitative Lithology Showing the Relationships between Rate of Penetration Changes, Mud Weight and Mud Gas Log in OSA Oilfield.

F. Early Warning Indicators of Abnormal Pressure Zones During Drilling Operation

Increased total and connection gas readings, decreased corrected d-exponent trends, and sudden changes in rate of penetration (ROP) found in mud logging data, such as an increase in gas counts as formation pressure rises are typical early warning signs of abnormal pressure zones during drilling. In order to maintain wellbore stability and avoid kicks or blowouts, changes in drilling parameters like ROP spikes and drilling breaks may also signal the approach of higher-pressure zones and prompt mud weight adjustments.

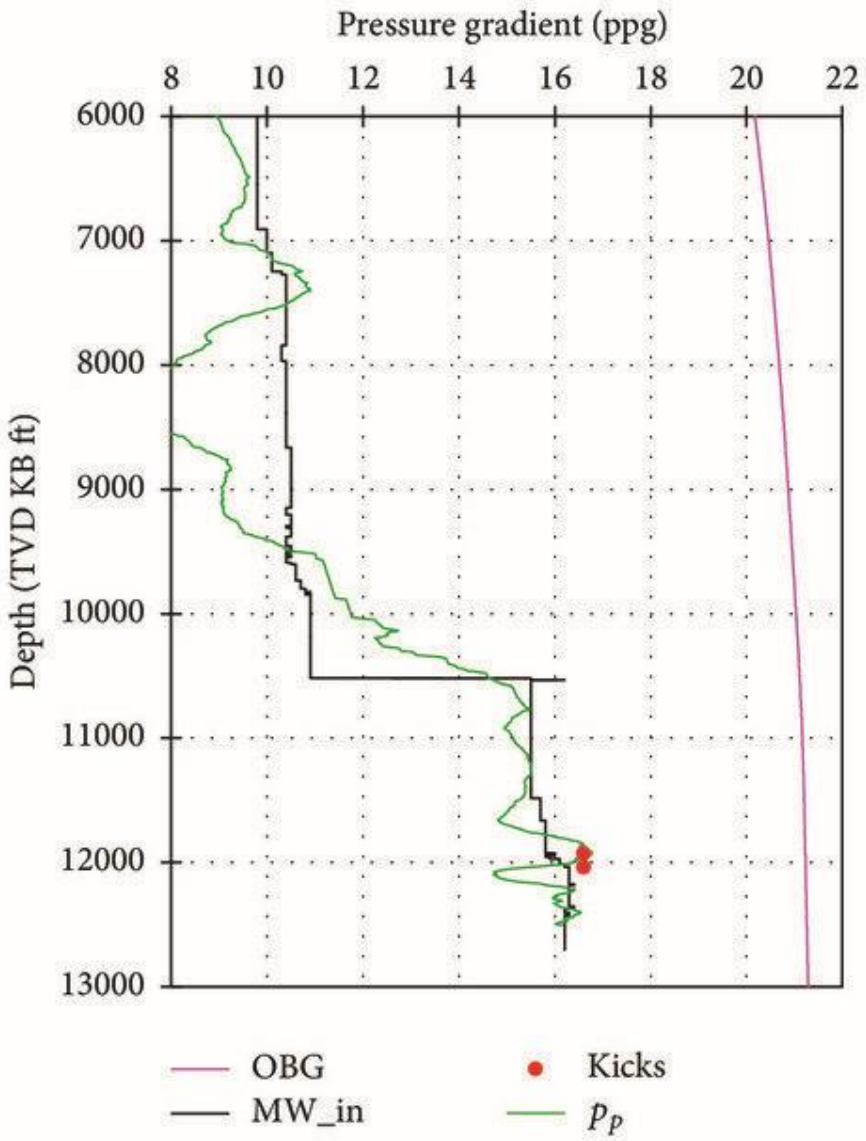

Fig. 4: Graph Showing Increase in Pressure Gradient in Proportion to the Reservoir Depth During Drilling

G. Similarities, Differences, And Accuracy Levels Between Wireline Logging Data and Formation Characterization Results from Mud Logging

The study findings indicate that there is a high relationship in the lithological patterns of the data of the mud logging and wireline logging across the OSA Oilfield. Description of mud logging cuttings, gas shows and trend of rate of penetration selected the major sandstone-shale alternations that were subsequently matched with the gamma ray and resistivity log response. The high mud gas and breaks in drilling intervals were interpreted as sand-filled formations congruent with the readings of low gamma ray and high resistivity on the wireline logs, proving similar trend in the formation.

Nevertheless, depth precision and property resolution of the reservoir were significantly different. When using mud logging, cuttings lag, cavings and contamination of the mud influenced the interpretation of mud logging displaying depth differences of several meters with wire line logs. Although mud logging was used to determine the presence of porosity and fluids qualitatively, wireline logs were used to give quantitative measurements of porosity, saturation and density at a higher vertical resolution.

The accuracy assessment shows that mud logging was a good measure of first-order lithological changes but a moderate measure of the property of the reservoir. Wireline logging was regarded as the standard of detailed characterization of formation, and mud logging was the best example of the real-time supportive evaluation tool.

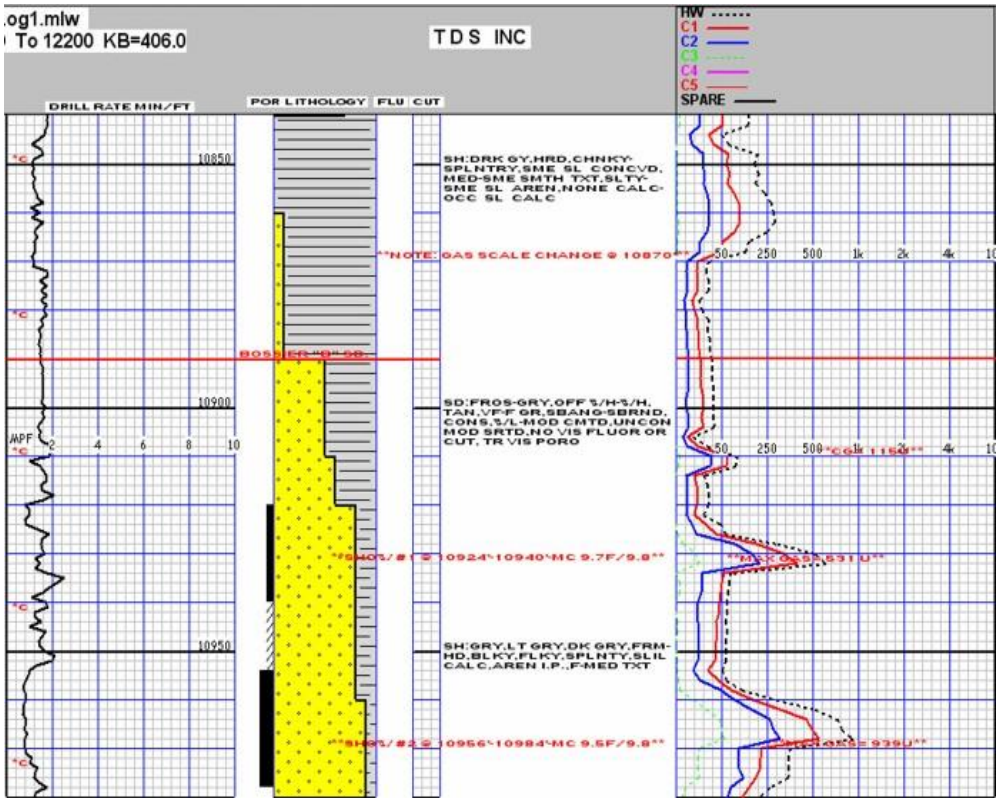

Fig. 5: Formation Characterization Results from Mud Logging Showing the Drill Rate and Lithology

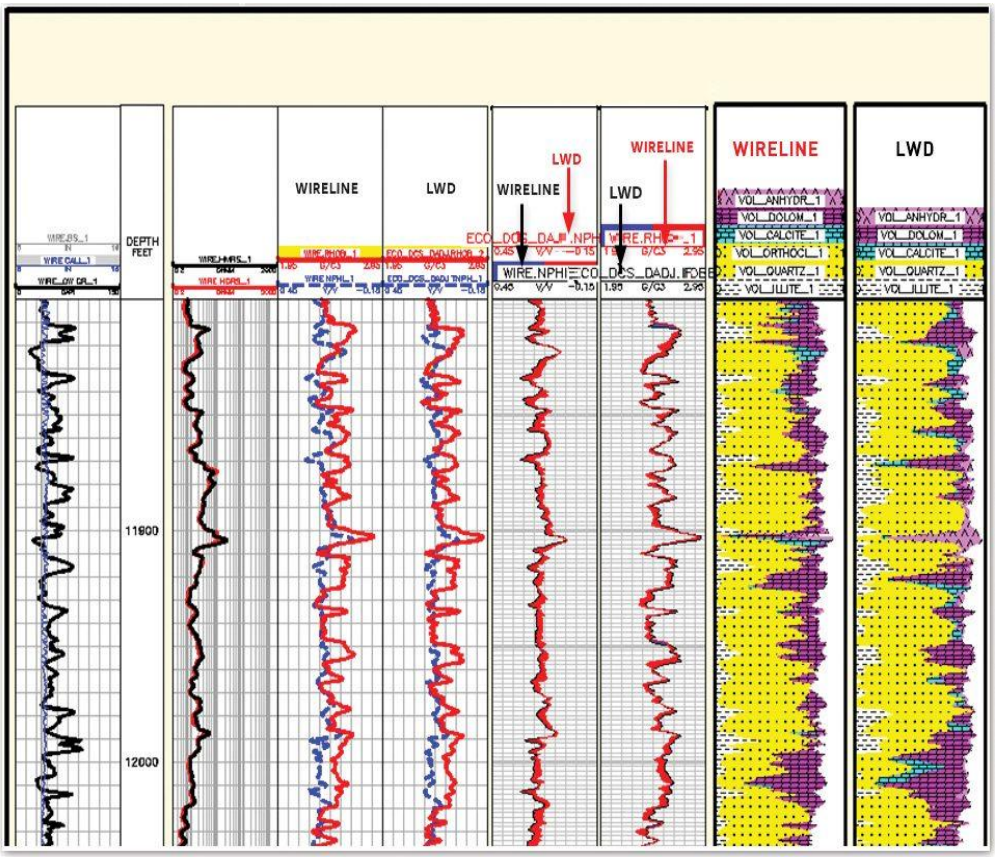

Fig. 6: Wireline Logging Data Analysis Showing the Depth Feet and the Wireline Results

VI. Discussions

This study gave a subtle perspective on the credibility of mud logging. The comparison of mud logging and wireline logging data revealed that, mud logging was a useful tool available in real time prediction of the pore pressure where the D-exponent model results were found to be close to wireline pressure data. The study by Chaanda et al., (2025) indicated that there are big inconsistencies with gas ratio analysis not being reliable in distinguishing hydrocarbon bearing zones in about 37.5% of cases especially when dealing with complex lithologies and low-gas reservoirs. This means that even though mud logging is a valuable source of real-time, up-to-date pressure information to use during drilling safety; it must be combined with wireline logs and direct fluid samples to make a complete and accurate evaluation of the formation.

VII. Conclusion

This study revealed that the mud logging data is a powerful and useful tool of the real-time formation characterization and early pore pressure identification in the OSA Oilfield, Niger Delta, but its application is context-dependent. Mud logging was effective in recognizing key lithological variations and intervals that fluctuate hydrocarbons, which lead to timely information that are used during a well-drilling process and well safety. Presence of signs of early warning, like gas displays, drilling interruptions, and d-exponent tendencies, were helpful in predicting the presence of abnormal pressures. It was, however, found that comparative analysis showed that mud logging interpretations are mainly qualitative and subjected to uncertainties with regards to cuttings lag, mud contamination and drilling dynamic. Wireline logging was better in-depth control and quantitative assessment of property of the reservoir and fluid sampling gave ultimate pressure and fluid confirmation. Mud logging is not appropriate by itself in determining the detailed evaluation of the reservoirs or the exact quantification of the pore pressure. It is advisable that an integrated solution of mud logging, wireline logging and fluid sampling be used to increase reliability, minimize the risk associated with drilling and optimize characterization of the reservoir associated with complex environments in the Niger Delta.

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