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Hydrocarbon Indication Using Petrophysical Well Logs in the Niger Delta Basin: Insights from Zip Field

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Abstract-* *This study evaluates hydrocarbon potential in the onshore Niger Delta Basin through detailed petrophysical well log analysis of four wells (ZIP1–ZIP4) in the ZIP Field. Using gamma ray, resistivity, and density logs interpreted in RokDoc software, key reservoir properties are volume of shale (Vsh), porosity (ϕ), water saturation (Sw), hydrocarbon saturation (Sh), bulk volume of water (BVW), permeability (K), and net-to-gross ratio (NGR) were determined for three primary reservoir units (Z1000, Z2000, and Z3000). Crossplots and log correlations revealed lateral lithological variations and identified clean sand intervals with favourable hydrocarbon indicators. Z2000 emerged as the most promising reservoir, showing low shale content (<5%), high porosity (up to 42%), low water saturation (14–25%), and permeability values supporting fluid flow. Diagnostic plots effectively discriminated between hydrocarbon-bearing sands, wet sands, and shales. The results demonstrate the efficacy of integrated petrophysical evaluation for delineating productive zones and guiding exploration strategies in the Niger Delta Basin.

Index Terms-* *Petrophysical Analysis, Well Logs, Hydrocarbon Potential, Niger Delta Basin, Porosity, Water Saturation, Permeability, And Reservoir Characterization.

I. INTRODUCTION

Hydrocarbon (crude oil) has become one of the most substantial natural resources across the globe leaving Nigeria Niger Delta basin un-exempted. Due to this fact, well logging in the area is crucial for characterising subsurface formations, assessing hydrocarbon potential, reservoir characterization, integration with other data, guiding drilling operations and improved accuracy. In order to help identify prolific zones and maximise development plans, well log analysis offers broad details regarding lithology, reservoir characteristics, and fluid saturation. Well log is a continuous record of measurement made in bore hole respond to variation in some physical properties of rocks through which the bore hole is drilled (Shaltami, 2021). Open-hole, cased hole, and production logging are the three primary categories of geophysical well logging. The study of the physical-chemical characteristics of rocks and how they interact with the fluids around them is known as petrophysics (Ishwar and Bhardwaj, 2013).

Porosity is commonly estimated using acoustic well logs, which employ sound waves to assess the characteristics of rocks, particularly in clean sand, water-saturated sandstones. This is based on a finding by Wyllie *et al.,* (1956) that compressional-wave slowness (I/velocity) shows a strong correlation with porosity in clay-free, water-saturated sandstones under high confining pressure. Recently, there has been a lot of interest in using rock acoustics for "direct detection of hydrocarbons." In its most basic form, it has been noted that a high impedance contrast with the rock layer above is frequently produced by the low compressional velocity of gas reservoirs. As a result, there is a high reflection coefficient between the layers, which causes reflection seismograms to show a "bright spot" (huge amplitudes). Additionally, oil reservoirs with high concentrations of dissolved gas can produce bright spots by lowering the bulk modulus of the pore fluid (Batzle and Wang, 1992; Winkler and Murphy III, 1995). In reality, it is discovered that lithology contrasts, not pore fluid contrasts, are the origin of a large number of compressional wave brilliant spots. Finding comparable shear wave bright spots which are brought on by lithology contrasts but not by hydrocarbons is one method of differentiating between the two. Amplitude variation with offset, or

AVO, is a different method for locating bright spots associated with hydrocarbons when shear seismic data is not available. Numerous geophysical techniques for reservoir characterisation, from amplitude variation with offset (AVO) and seismic inversion to petrophysical analysis, have been used in the Niger Delta Basin in an effort to boost hydrocarbon production (Oyeyemi *et al.,* 2017, Omoja and Obiekezie, 2019 and Munyithya *et al.,* 2020). The aim of this study is to interpret gamma ray, resistivity, and density; evaluate key reservoir parameters; correlate reservoir intervals; use diagnostic crossplots for lithology and fluid discrimination within the identified reservoir units; and identify the most promising reservoir zones for future exploration and production based on petrophysical analysis results.

II. GEOLOGY OF THE STUDY AREA

ZIP Field (Figure 1) is located in the Niger Delta Basin on the top of the Gulf of Guinea, in the southern region of Nigeria, on the tropical West African continental margin. Latitudes 4°N to 7°N and longitudes 5°E to 8°E are its ranges, West Africa. The Niger Delta basin constitutes three major formations; the Benin formation (continental setting) has an estimated thickness of 1830 metres to 2000 metres, which is 1.83 km to 2 km, respectively. It is primarily composed of quartz (75-90%) and rock fragments (5-25%) (Ideozu and Solomon, 2018). A major component of the Agbada Formation (paralic setting) is fluviomarine deposits, which are mainly composed of alternating sandstones and shales. It is a thick unit that can get up to 4500 metres thick. Though it can vary by depth and region, the Agbada Formation's precise percentage composition of sandstones and shales is typically a mixture of sandstones, siltstones, and shales. Oil is produced from sandstone facies within the Agbada Formation. The primary source rock is the upper Akata Formation (marine setting), the marine-shale facies of the delta (Tuttle *et al.,* 1999).

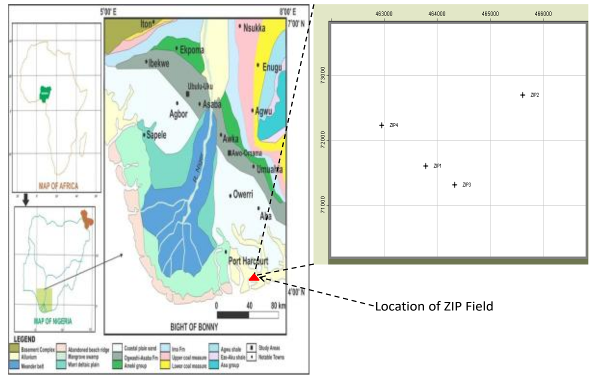

Figure 1. Map of Africa, Nigeria, Niger Delta Basin and Base Map of the study location showing the four (4) drilled in ZIP Field. Basin map modified from (Oyebanjo *et al.,* 2018).

III. PETROLEUM SYSTEM OF NIGER DELTA

There are three different petroleum systems in the Niger Delta Basin: Tertiary (deltaic), Upper Cretaceous-lower Paleocene (marine), and Lower Cretaceous (lacustrine). The tertiary deltaic system, especially the Akata-Agbada petroleum system, is the most important for the production of petrol and oil (Figure 2). In this system, the Agbada Formation serves as the main reservoir and the Akata Formation as the main source rock. Oil and gas are built up in the Agbada's structural traps (Haack *et al.,* 2000)

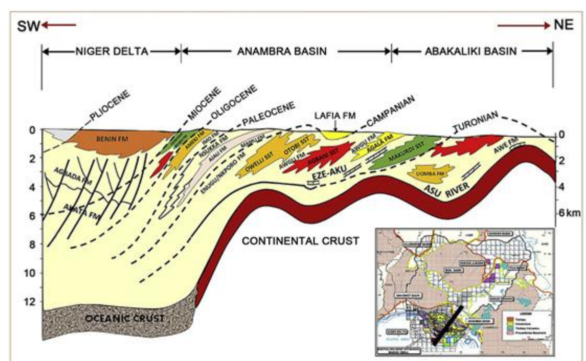

Figure 2. Cross section Niger Delta, Anambra and Abakaliliki Basins showing their lithosratigraphic unts Cross section Niger Delta. After Benkhelil (Nton and Adeyemi 2021).

Materials and Methods

The principal data used for this study was acquired from Shell via the assistance of the Nigeria Upstream Petroleum Regulatory Commission (NUPRC) and is well-log data interpreted with RokDoc geophysical software from four wells (ZIP1, ZIP2, ZIP3, and ZIP4) spread across the ZIP field (Figure 1). To avoid conflicts of interest, the field and wells used in this study were renamed for proprietary reasons. The well data are comprised of sonic (DT) log which is used to determine P wave and S wave or V_P and V_s, gamma ray (GR) log which is used to determine the lithology or the shale content, resistivity (DEP and OHM) log is used to determine hydrocarbon and water saturation, and density (RHOB) log is used to determine formation of porosity, lithology, fracture and gas. These data were acquired from ZIP field operating in the Niger Delta Basin.

The study was carried in three main steps. The first step was the petrophysical analysis of the well logs. In this step, reservoir evaluation and analysis were carried out using gamma ray, resistivity and crossplots of shallow (DEP) vs. deep (OHM) resistivity and density logs to identify and map reservoirs and characterize pore fluids. The mapped reservoir interval was evaluated to estimate reservoir properties such as volume of shale (Vsh), porosity (ϕ), hydrocarbon saturation and water saturation and subsequently correlated across all the five wells in the field to indicate the hydrocarbon potential area. The data used in the present study consists of a suite of well logs.

Petrophysical evaluation of the delineated reservoir units was carried out to establish hydrocarbon presence in field. This was achieved by the calculation of key reservoir parameters including volume of shale (Vsh), total porosity (Ø), and water saturation (Sw), using standard petrophysical equations. The empirical equations used in computing the reservoir properties are given below: Volume of shale (Vsh), which defines the percentage of shale contained in a sandstone or heterolithic reservoir, was calculated using the Larionov model for sediments of Tertiary age:

Volume of Shale ($\boldsymbol{V_{sh}}$)

Volume of shale is the proportion of the rock's volume that is occupied by shale. This is an important step in characterization of reservoirs as well as valuation of hydrocarbon potentials.

$$I_{GR} = \frac{GR - GR_{matrix}}{GR_{shale} - GR_{matrix}} \quad 1$$

$$V_{sh} = 0.083 \times (2^{(3.7 \times I_{GR})} - 1) \quad 2$$

Where GR_{log} (GR) is the value of the formation measured from log, GR_{matrix} (GR_{min}) is the GR minimum value of clean sand, GR_{shale} (G_{max}) is the GR maximum value of the shale beds and I_{GR} is the gamma ray index.

If V_{sh} is less than 10% it is clean sand indication and good reservoir potential, in between 10-35% of shale volume is an indication of shaly sand and if the shale volume is greater than 35% it is an indication of a non-reservoir zone, often interpreted as a shaly zone or non-clean sand. (Akpan et al., 2020 and Kamayou *et al.*, 2021)

Water Saturation ($\boldsymbol{S_w}$)

Water saturation is a parameter which helps in evaluating the volume of hydrocarbon in reservoirs. To calculate water saturation (S_w) for each reservoir, we used Archie's equation in equation 3 the most widely used method in clean (non-shaly) sandstone formations;

$$S_w = \frac{V_w}{V_P} = \frac{Water\ Volume}{Pore\ Volume}$$

$$S_w = \left(\frac{a \times R_w}{R_t \times \emptyset^m}\right)^{1/n} \quad 3$$

The simplified form of the Archie's equation is

$$S_w^n = \frac{a.R_w}{\emptyset^m.R_t} \quad 4$$

$$R_w = \frac{R_t.\emptyset^m}{a} \quad 5$$

$$F = \frac{a}{\phi^m} = \frac{062}{\phi^{2.15}} \quad 6$$

Where F is formation factor, R_t is the true formation resistivity (uninvaded zone from Resistivity log); R_w is water resistivity, n is the saturation exponent (usually 2.0), a is the tortuosity value (usually 0.62-1.0), m is the cementation factor (usually 1.8-2.0) (Archie, G. E. 1942; Asquith and Krygows 2004; Tiab and Donaldson 2015)

Bulk Volume of Water (BVW)

The Bulk volume of water is the fraction of the total volume that is occupied by formation water (the water naturally present in the reservoir's pore spaces). It gives a direct measure of how much water is in a unit volume of rock. It can be shown mathematically in equation 7 (Asquith and Krygows 2004).

$$BVM = \emptyset \times S_w \quad 7$$

Net-to-Gross Ratio (NGR)

Net-to-Gross Ratio is a key parameter used in petroleum geology, reservoir engineering, and mining to evaluate the quality and productivity of reservoir or mineral-bearing formation. By definition, it is the ratio of net reservoir rock (the portion that is porous and permeable enough to store and transmit fluids lie oil, gas, or water) to the total thickness (gross) of the geological formation being evaluated.

$$NGR = \frac{Net\ sand}{Gross\ sand} = \frac{Net\ Pay\ thickness}{Gross\ Thickness} \quad 8$$

Or Net-to-Gross can also be calculated in a situation where we have gotten volume of shale as show in equation 9 below (Egbele *et al.,* 2005);

$$\text{Net-to-Gross (N/G)} = 1 - V_{sh} \quad 9$$

Where: Net Thickness is the sum of thicknesses of intervals meeting all cutoffs, Gross Thickness is the total thickness of the reservoir interval (e.g., Z1000_base – Z1000_top gives the gross thickness).

Hydrocarbon Saturation (S_H)

Hydrocarbon Saturation is the percentage of pore volume occupied by hydrocarbon in a reservoir rock. It can be calculated using equation 10 below (Asquith and Krygows 2004; Tiab & Donaldson 2015).

$$S_H = 1 - S_w \quad 10$$

Permeability (K)

Permeability is the measure of a rock's ability to transmit fluids through its pore spaces and fractures.

$$K = \frac{0.136 \times \Phi^{4.4}}{S_{wi}^{\,2}} \quad 11$$

Where S_{wi} is the irreducible water saturation, given by Obimma *et al.,* 2021 as;

$$S_{wirr} = \sqrt{\frac{F}{2000}} \quad 12$$

Formation Porosity ($\emptyset$)

The formation porosity can be estimated from porosity log, density log, neutron log, sonic log and crossplot porosity but we estimated porosity from density log using equation 8 below; A measure of how porous a material is or the ratio of the volume of pores to the total volume.

$$\emptyset = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad 13$$

where ρ_b is the bulk density of the formation (Read it from density log), ρ_{ma} is the density of the rock matrix (ρ_{ma} for clean sand is 2.65 g/cc), and ρ_f is the density of the fluids occupying the pore spaces (ρ_f for water is 1.0 g/cc) (Okewu *et al.,* 2024).

IV. RESULTS AND DISCUSSION

The correlation encompassed four (4) wells namely ZIP1, ZIP2, ZIP3 and ZIP4 (Figure 3 and Figure 4). The signature of the well logs has GR (black), Resis (red), and Rho (green) in (Figure 3). Horizon lines were represented with the same colour blue for both top and base. The petrophysical analysis was conducted on well log data from the earlier listed wells on ZIP Field to evaluate the reservoir properties, including, porosity, permeability, water saturation, and net-to-gross ratio. The analysis was performed using RokDoc and the results are summarized below.

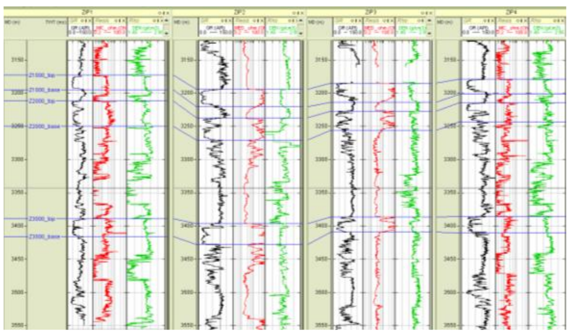

Figure 3. interpretation window showing four (4) well logs displaying the following log attributes; gamma ray, resistivity and density log signatures.

Petrophysical Evaluation

The tables 1-3 show the summary of the petrophysical data obtained from the selected well logs on the study area. The Z1000 reservoir shows mixed performance across the wells. ZIP2 and ZIP3 stand out with low volume of shale (4% and 3%), good porosity (28% and 19%), and low water saturation (17% and 10%), indicating the presence of oil in ZIP2 and gas in ZIP3. ZIP1 and ZIP4, however, have high water saturation (69% and 58%) despite reasonable porosity (~27%), suggesting predominantly water-bearing sands or flushed zones. Permeability is generally low across the wells, except for ZIP2 (0.081 md), which shows moderate flow potential. The high bulk volume of water (BVW) in ZIP1 (0.186) supports the interpretation of poor hydrocarbon productivity in that interval.

Z2000 exhibits the most favorable reservoir properties in the field. Shale content is uniformly low (3% in all wells), porosity is high (19–42%), and water saturation is relatively low, particularly in ZIP2 (22%) and ZIP3 (25%). These two wells also show the best hydrocarbon potential, with oil/gas indications and higher permeability (ZIP2: 0.553 md, ZIP3: 0.029 md). ZIP4, while clean in terms of shale volume, has low permeability (0.007 md) and moderate water saturation (30%), suggesting tight sands or poor connectivity. ZIP1's high porosity (42%) but high Sw (61%) points to a likely water-bearing zone despite good storage capacity.

The Z3000 reservoir is more variable and generally less productive. Although shale volume remains low (3% across wells), water saturation is high in ZIP1 (89%) and ZIP4 (74%), indicating wet sands. ZIP2 is the most promising in this interval, with low water saturation (14%), high porosity (33%), and moderate permeability (0.224 md), suggesting an oil-bearing zone. ZIP3 shows potential gas presence (Sw 25%) but has very low permeability (0.003 md), limiting producibility. The elevated BVW in ZIP1 (0.222) and ZIP4 (0.215) reinforces the predominance of water in these intervals.

Tables 1–3 collectively highlight Z2000 as the best candidate for development, offering consistently clean sands, favourable porosity, and acceptable water saturation levels in most wells. Z1000 and Z3000 contain localized hydrocarbon-bearing zones but are more affected by high water saturation and low permeability, making them less attractive for immediate development without enhanced recovery techniques. These findings emphasize the need for targeted drilling and testing in the most promising zones while considering reservoir heterogeneity in field planning.

Table 1. Petrophysical properties of Z1000 reservoir sand across the selected wells

Wells	Reservoir Thickness (ft)	Net-to-gross ratio	Volume of Shale V_{sh} (%)	Porosity ϕ (%)	Water Saturation S_W (%)	Bulk Volume of water (BVW)	Permeability K, (md)	Predominant Type of Hydrocarbon

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ZIP1	22.08	0.79	21.00	27.00	69.00	0.186	0.062	Water (S_w too high)
ZIP2	26.10	0.96	04.00	28.00	17.00	0.047	0.081	Oil (low $S_w, decent\ K$)
ZIP3	28.65	0.97	03.00	19.00	10.00	0.019	0.007	Gas (very low $S_w, low\ K$)
ZIP4	21.42	0.96	04.00	27.00	58.00	0.156	0.062	Water or Oil (S_w a bit high)

Table 2. Petrophysical properties of Z2000 reservoir sand across the selected wells

Wells	Reservoir Thickness (ft)	Net-to-gross ratio	Volume of Shale V_{sh} (%)	Porosity ϕ (%)	Water Saturation S_W (%)	Bulk Volume of water (BVW)	Permeability K, (md)	Predominant Type of Hydrocarbon
ZIP1	38.15	0.97	03.00	42.00	61.00	0.256	1.065	Water or Oil (borderline high S_w)
ZIP2	33.47	0.97	03.00	38.00	22.00	0.084	0.553	Oil
ZIP3	28.77	0.97	03.00	24.00	25.00	0.060	0.029	Oil/Gas ($S_w\ low, but\ K\ low$)
ZIP4	28.78	0.97	03.00	19.00	30.00	0.057	0.007	Gas (low S_w & very low K)

Table 3. Petrophysical properties of Z3000 reservoir sand across the selected wells

Wells	Reservoir Thickness (ft)	Net-to-gross ratio	Volume of Shale V_{sh} (%)	Porosity ϕ	Water Saturation S_W (%)	Bulk Volume of water (BVW)	Permeability K, (md)	Predominant Type of Hydrocarbon
ZIP1	26.77	0.97	03.00	25.00	89.00	0.222	0.039	Water
ZIP2	31.45	0.97	03.00	33.00	14.00	0.046	0.224	Oil
ZIP3	23.42	0.97	03.00	17.00	25.00	0.043	0.003	Gas (low S_w & $very\ low$ K)
ZIP4	24.76	0.97	03.00	29.00	74.00	0.215	0.098	Water or Oil

The correlation (Figure 4) suggests a relatively continuous stratigraphic sequence across the wells, with identifiable shale and sandstone layers. The panels display data from multiple wells (ZIP1-ZIP4) across a depth range (approximately 3140 m to 3420 m). Each panel includes several log curves, such as Gamma Ray (GR), Resistivity (Resis), and Density (Rho), with depth on the y-axis and log values on the x-axis. The goal of correlation is to match similar geological features across wells to understand stratigraphy and reservoir continuity. There is horizons alignment in the reservoirs i.e., Z1000, Z2000, Z3000 that are consistent across the wells. The GR log (API) shows variation in radioactivity, typically higher in shales and lower in sandstone. Similar GR patterns (e.g., peaks and troughs) are observed across ZIP1-ZIP4, indicating potential conductivity of shale and sandstone layers, a prominent GR peak around 3200-3220 m aligns across all wells, suggesting a consistent shale layer.

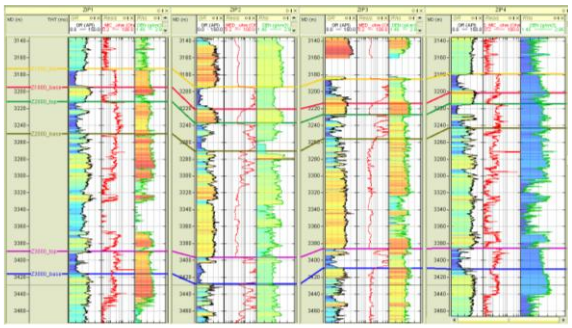

Figure 4. Correlation of ZIP Field well logs panel showing reservoir sand bodies. Z1000, Z2000, and Z3000 are the three main reservoir sand units identified in the study area.

The resistivity log (Ohm-m) shows higher values n hydrocarbon-bearing zones or tight formations and lower values in water-saturated zones. The resistivity spikes (e.g., around 3220-3240 m in ZIP1 and ZIP4) correlate with similar features in other wells, hinting at potential reservoir zones. The resistivity detailed near-wellbore variations.

Density log (Rho) in g/cm3 unit reflect lithology, with lower values indicating porous sandstones and higher values indicating denser shales or carbonates. The density curves show a general alignment, with a noticeable decrease around 3220-3240 m across wells, suggesting a porous zone that correlates with resistivity highs, possibly a hydrocarbon-bearing sandstones.

Reservoir Evaluation

From the combined gamma ray cutoff table across ZIP1 to ZIP4, we can deduce that variability of cutoff across ZIPs, each ZIP has different gamma ray cutoffs even for the same reservoir (Z1000, Z2000, Z3000). This implies lithological heterogeneity or different depositional environments across the ZIPs. Therefore, Z1000 reservoir in ZIP3 well appears to be cleaner (more sandy-prone) than in other ZIPs. Reservoir cleanliness ranking by cutoff (lower = sandier), Z2000 generally has the lowest cutoffs across ZIPs (≈30 API or less), suggesting that it is cleaner and more sand-rich in most ZIPs, especially in ZIP2 and ZIP3. Z1000 shows moderate variation which appears sandier in ZIP3 but shadier in ZIP4. Increasing shaliness from ZIP1 to ZIP4 shows that there is a progressive increase in cutoff values from ZIP1 to ZIP4, especially in Z3000. Reservoir with consistent cleanliness i.e. Z2000 across ZIP1, ZIP2, and ZIP3, Z2000 maintains low cutoff values (~30 API), indicating it's generally a sand-dominated reservoir, possibly a target zone for hydrocarbon exploration.

Table 4 Combine Gamma Ray Table

ZIP	RESERVOIR	GR_{min}	GR_{max}	CUT-OFF	ROCK TYPE	Seal/Cap or Reservoir
ZIP1	Z1000	26.95	41.96	34.46	Moderate sandy	Reservoir
ZIP1	Z2000	24.21	42.05	33.13	Sandy	Reservoir
ZIP1	Z3000	36.25	50.76	43.49	Slightly shaly	Seal/Cap
ZIP2	Z1000	27.45	56.06	43.49	Slightly shaly	Seal/Cap
ZIP2	Z2000	27.76	33.07	30.42	Sandy	Reservoir
ZIP2	Z3000	18.13	31.95	25.04	Very clean sand	Reservoir
ZIP3	Z1000	18.28	40.62	29.45	Clean sand	Reservoir
ZIP3	Z2000	23.74	36.69	30.22	Sandy	Reservoir
ZIP3	Z3000	37.96	57.51	42.74	Shaly	Seal/Cap
ZIP4	Z1000	34.08	55.06	44.57	Shaly	Seal/Cap
ZIP4	Z2000	29.05	76.23	52.64	Highly shaly	Seal/Cap

ZIP4	30000	22.13	108.57	70.35	Very highly shaly	Seal/Cap

Diagnostic Cross plots

These plots figure 5-6 compare Gamma Ray (GR) with Density (Rho) and Resistivity, with colour coding. Each plot helps distinguish lithology and fluid types. There is a clear trend of low GR values in (a) which shows blue cluster at lower density ~2.0 – 2.2g/cm3, this is likely clean sandstones. Higher GR values show green to red occur at higher density ranges from ~2.3 – 3.6 g/cm3 which is typical of shales. This cross-plot effectively separates shale (high GR, high density) from sand (low GR, low density). In (Figure 5b), there is low GR (blue, sand) is associated with a wide range of resistivity values. Higher resistivity (right side) with low GR indicates clean hydrocarbon-bearing sands. Low resistivity with low GR may point to water resistivity, typical of shales. Figure 5c has similar trend to (a) it has high GR and density for shale volume and low GR and density for sand volume. Slight overlap between sand and shale may suggest heterogeneous zones in ZIP2. In figure 5d, it is similar to (figure 5b), high resistivity plus low GR equals hydrocarbon-bearing sands. There low resistivity plus low GR which is an indication of wet sands. And high GR plus low resistivity that is showing the presence of shale. There is low GR (blue) aligns with lower density values (~2.0 – 2.2 g/cm3) figure 6(e) which likely clean sands. High GR (red) corresponds with higher density (~2.4-2.6g/cm3), it indicates shale. Very distinct separation, suggesting good lithological contrast. The plot supports strong sand-shale discrimination. Most low points cluster at high resistivity in figure 6 (f) which is an indication of hydrocarbon-bearing sands. High GR values are mostly at low resistivity and this is a typical of shale. The extreme resistivity range may be due to tight sands or gas zones. This plot is very effective for fluid type discrimination (hydrocarbon vs water vs shale).

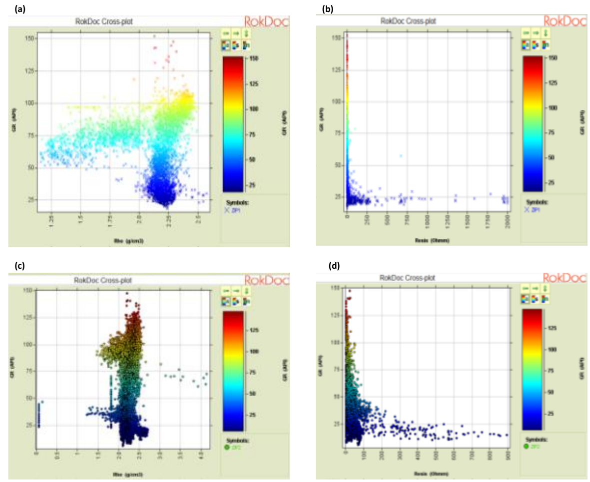

Figure 5. Diagnostic plots of Z1000-Z3000 with superimposed heuristic sands models in each well: (a) ZIP1 (GR vs Rho); (b) ZIP1 (GR vs Resis); (c) ZIP2 (GR vs Rho); (d) ZIP2 (GR vs Resis)

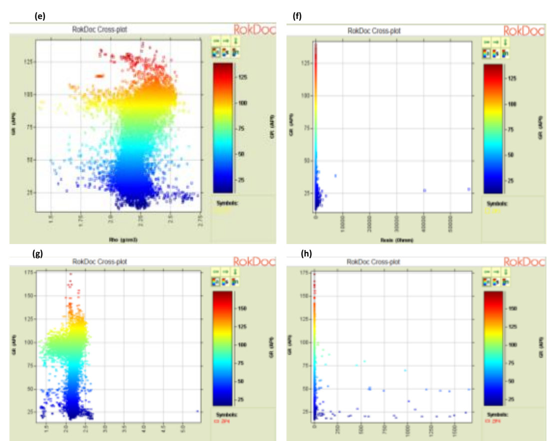

Figure 6. Diagnostic plots of Z1000-Z3000 with superimposed heuristic sands models in each well: (e) ZIP3 (GR versus Rho); (f) ZIP3 (GR vs Resis); (g) ZIP4 (GR vs Rho); (g) ZIP4 (GR vs Resis)

The low GR zones (blue) centered around lower densities in figure 6 (g), this shows clean sands. High GR zones (red) occur at higher densities which is an indication of shales. The pattern not as sharply separated as ZIP3 is possibly more mixed lithology or silty sands. In figure 6 (h), similar signature appears in ZIP3 which shows low GR plus high resistivity which is indication of hydrocarbon sands. Low GR plus low resistivity is indicating wet sands. Th combination of high GR and low resistivity gives shales. However, the spread is tighter and resistivity is lower than in ZIP3 which indicate poorer reservoir quality or water-bearing sands.

V. DISCUSSION

The petrophysical evaluation of the ZIP Field reveals laterally continuous but lithologically variable reservoir units (Z1000, Z2000, and Z3000) across four wells, with Z2000 emerging as the most promising due to its consistently low shale content (≤3–4%), high porosity (up to 42%), low water saturation (14–30%), and favourable permeability, particularly in ZIP2. In contrast, Z1000 and Z3000 exhibit localized hydrocarbon accumulations, with some wells (e.g., ZIP1 and ZIP4) showing high water saturation and bulk volume of water, indicating predominantly wet sands. Crossplot analysis (GR vs. Density and GR vs. Resistivity) effectively distinguished lithologies and fluid types, confirming hydrocarbon-bearing sands where low GR aligned with high resistivity, while high GR with high density indicated shales. The observed variations in reservoir quality are attributed to depositional heterogeneity, diagenetic effects, and potential structural influences, underscoring the importance of integrated well log analysis in identifying and prioritizing productive zones for exploration and development in the Niger Delta Basin.

VI. CONCLUSION

The petrophysical well log analysis of four wells (ZIP1–ZIP4) in the onshore Niger Delta Basin has provided valuable insights into reservoir characteristics and hydrocarbon potential within the ZIP Field. The integrated interpretation of gamma ray, resistivity, and density logs, combined with calculated parameters such as volume of shale, porosity, water saturation, bulk volume of water, and permeability, revealed significant lithological and fluid distribution variations across the studied reservoirs. Among the three main reservoir units, Z2000 emerged as the most promising, characterized by low shale content, high porosity, favourable permeability, and low water saturation in most wells particularly ZIP2 indicating good hydrocarbon storage and producibility. Z1000 and Z3000 showed localized hydrocarbon accumulations but were generally more affected by higher water saturation and lithological heterogeneity. Crossplot diagnostics proved effective in discriminating between hydrocarbon-bearing sands, wet sands, and shale intervals, confirming the reliability of the petrophysical interpretations. The results demonstrate that detailed well log analysis is a powerful tool for reservoir evaluation, enabling the identification of productive zones, optimization of drilling targets, and improved exploration success rates.

Future work should integrate seismic attribute analysis, core data, and production testing to refine reservoir models and validate hydrocarbon potential, ensuring that development plans for the ZIP Field are both efficient and economically viable.

VII. RECOMMENDATION

It is recommended that future exploration and development activities in the ZIP Field prioritize the Z2000 reservoir, particularly in wells with low water saturation and high porosity such as ZIP2, as these zones demonstrate the best potential for commercial hydrocarbon production. To enhance reservoir characterization and reduce exploration risk, this petrophysical analysis should be complemented with seismic attribute interpretation, core sample analysis, and production testing. Furthermore, implementing 3D reservoir modelling and dynamic simulation will improve understanding of fluid distribution, guide optimal well placement, and support efficient field development planning in the Niger Delta Basin.

REFERENCES

[1] Shaltami, O.R. (2021). Wireline Log Interpretation. Department of Earth Sciences Faculty of Science, Benghazi University, Libya. Pp 3. https://www.researchgate.net/publication/352478695

[2] Ishwar, N.B. and Bhardwa, A. (2013). Petrophysical Well Log Analysis for Hydrocarbon exploration in parts of Assam Arakan Basin, India. 10th Biennial International Conference & Exposition. Pp 153.

[3] Wyllie, M.R.J., Gregory, A.R. and Gardner, L.W. (1956). Elastic wave velocities in heterogeneous and porous media, Geophysics, 22, 4.

[4] Batzle, M. and Wang, Z. (1992). Seismic properties' of pore fluids, Geophysics, 57.

[5] Winkler, K.W. and Murphy III, M.F. (1995). Schlumberger-Doll research, Old Quarry Road, Ridgefield, CT 06877-4108.

[6] Oyeyemi KD, Olowokere MT, Aizebeokhai AP (2017) Evaluation of optimal reservoir prospectivity using acoustic impedance model inversion: a case study of an offshore field, Western Niger Delta, Nigeria. NRIANG J Astron Geophys 6:300–310.

[7] Omoja UC, Obiekezie TN (2019) Application of 3D seismic attribute analyses for hydrocarbon prospectivity in Uzot-field. Int J Geophys, Onshore Niger Delta Basin, Nigeria. https ://doi. org/10.1115/2019/17064 16.

[8] Munyithya JM, Ehirim CN, Dagogo T (2020) Reflectivity and spectral attribute-based reservoir characterization: a case study from "MUN" onshore Niger Delta field. J Pet Explor Prod Technol, Nigeria. https ://doi.org/10.1007/s1320 2-020-00922-4.

[9] Ideozu, R.U and Solomon, E. (2018). Sedimentological Charateristics Of The Ajali And Benin Formations Around Arochukwu – Odoro Ikpe Axis Southeast Nigeria. Scientia Africana, Vol. 16 (No. 2), December 2017. Pp 291-313.

[10] Oyebanjo, O.M, Ekosse, G.E and Odiyo, J.O. (2018). Mineral Constituents and Kaolinite Crystallinity of the < 2 µm Fraction of Cretaceous-Paleogene/Neogene Kaolins from Eastern Dahomey and Niger Delta Basins, Nigeria. Open Geosciences. 10(1):157-166.

[11] Michele, L. W. Tuttle, Michael E. Brownfield, and Ronald R. Charpentie (1999). The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa. U. S. Geological Survey Open File Report 99-50H.

[12] Haack, R. C, Sundararaman, P, Diedjomahor J.O, Xiao H, Gant, N. J, May E.D, and Kelsch, K. (2000). Niger Delta Petroleum Systems, Nigeria. American Association of Petroleum Geologists. https://doi.org/10.1306/M73705C16

[13] Kamayou, V. Ehirim, C. and Ikiensikimama, S. (2021). Estimating Volume of Shale in a Clastic Niger Delta Reservoir from Well Logs: A Comparative Study. *International Journal of Geosciences*, 12, 949-959. doi: 10.4236/ijg.2021.1210049.

[14] Akpan, A.S, Okeke, F.N, Obiora, D.N, Ibuot, J.C. (2020). Fluid substitution modelling and derived rock attribute-based discriminations of hydrocarbon and lithology: a case study of arcuate Niger Delta Depobelt, Nigeria. Springer Nature (NS Applied Sciences). https://doi.org/10.1007/s42452-020-03855-z

[15] Kenechi Junior Obimma1, Daniel N. Obiora, Andrew I. Oha, Johnson C. Ibuot1,

[16] John A. Yakubu (2021). Seismic and Petrophysical Characterization of Reservoirs in Kjoe Field, On-Shore Niger Delta, Nigeria. Petroleum and Coal.

63(1): 50-62 ISSN 1337-7027

[17] Egbele, C., Osokogwu, U., and Isibor, A. (2005). Net-To-Gross Ratios: Implications in Integrated Reservoir Management Studies. SPE Nigeria Annual International Conference and Exhibition. Society of Petroleum Engineers. DOI: 10.2118/94290-MS

[18] Asquith, G.B., and Krygowski, D. (2004). Basic Well Log Analysis (2nd Edition). AAPG Methods in Exploration Series. ISBB

[19] Tiab, D., and Donaldson, E.C. (2015). Petrophysics: Theory and Practice of Measuring Reservoir Rock and Fluid Transport Properties (4th Ed.). Elsevier. ISBN: 9780128031880

[20] Archie, Gus E. (1942). The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics. Transactions of the AIME, Vol. 146, pp. 54-62

[21] Okewu, G. O., Ugbor, D. O., Johnson Ibuot, Yakubu, J. A., Okoro, M. E., & Kentsa T. S. (2024). *Seismic Attributes Analysis and Petrophysical Evaluation of Reservoir Sand Units in "Mars" Field, Onshore Niger Delta Basin, Nigeria.* Petroleum and Coal.

[22] Pet Coal (2024); 66(4): 1320-1336 ISSN 1337-7027 an open access journal.

[23] Nton, M. E., & Adeyemi, M. O. (2021). Evaluation of Hydrocarbon Reservoir in AD Field, Offshore Niger. Open Journal of Geology Vol.11 No.5