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Evaluation of Reservoir Sand using Petrophysical Analysis in 'Jat' Field, Niger Delta Basin Nigeria

A. O. Falade[1*], S. O. Ijato[1], A. A. Edema[1] and T. E. Oni[2]

[1]Department of Geological Sciences, Achievers University, Owo, Ondo State, Nigeria

[2]Department of Mining and Geological Engineering, Federal Polytechnic Ado Ekiti, Ekiti State, Nigeria

*E-mail: ayouseh2003@gmail.com

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ABSTRACT

The research aims at evaluating delineated reservoirs in 'Jat' Field, Niger Delta, Nigeria to know their quality by using their petrophysical properties through a mathematical relative indexing method. The work employed results from well log analysis to describe the reservoir properties of the delineated reservoir sands in the study area and relatively rank them. Three reservoirs, namely RES 1, RES 2 and RES 3 were delineated and correlated in the SW-NE direction across four wells. Their reservoir properties (lithology, gross thickness, net pay, net to gross (NTG), porosity, permeability, hydrocarbon saturation) were determined. The average determined porosity, permeability, NTG and water saturation with respect to each reservoir from RES 1 to RES 3 were 30%, 28%, 29%; 1082 md, 2110.75 md, 1205.75 md; 762%, 82%, 78%; and 48.25%, 54.25%, 51% respectively. The reservoir quality assessment and ranking were carried out by categorizing the reservoir properties as linear (those associated with thicknesses like gross thickness, net thickness and net pay) and non-linear (properties other than those associated with thickness like porosity, permeability, hydrocarbon saturation) using a mathematical relative indexing method while prioritizing the non-linear properties over the linear properties. Result shows that all the can be exploited for hydrocarbon production with RES 1 being the main target for production.

KEYWORDS: Well logs, Petrophysics; Niger Delta; Hydrocarbon; Reservoir properties

1. Introduction

Petroleum is a naturally occurring liquid found beneath the Earth's surface that can be refined into fuel. Petroleum is a fossil fuel that is formed from decomposed organic matter of over millions of years (Chen, 2021). Petroleum is used as fuel to power vehicles, heating units, and machines of all sorts, as well as being converted into plastics and other materials. Because of worldwide reliance on petroleum, the petroleum industry is extremely powerful and is a major influence on world politics and the global economy (Maugeri, 2006). The supply of the world's oil will last for about another 48 years with the present level of annual global consumption (Rapp, 2021). This makes the resource to be one of the most sort-after resources in the world and ways of enhancing recovery and improving production is be look into from time to time.

The life of a reservoir starts with exploration which leads to its discovery and then followed up by characterization which is continuous and spans to the last phases of hydrocarbon field development and production (Chopra and Marfurt, 2007; Akeze, 2009; Chambers and Yarus, 2010). Characterizing a reservoir involves assigning quantified properties of reservoir while also taking the geological and geophysical information of the area into consideration (Fowler et al., 1999; Falade et al., 2021). Well log is one of the tools used in evaluating the formations in the subsurface. One of its roles in petroleum exploration is to evaluate the subsurface formations in respect to its hydrocarbon content. Therefore, there is a need to identify hydrocarbon reservoirs and characterize them to reduce the risk involved in both oil exploration and exploitation.

Niger Delta basin is known to be characterized with geological features associated with hydrocarbon production. Several researchers (Aigbedion and Iyayi, (2007); Adaeze *et al.*, (2012); Adejumo (2013); Adewoye et al., (2013); Okumoko and Omoboriowo, (2014); Emujakpore and Faluyi, (2015); Emina et al., (2016); Alaminiokuma and Ofuyah, (2017); Osinowo *et al.*, (2017); Kafisanwo et al., (2019), among others) have worked on characterizing reservoirs in the Niger Delta basin using petrophysics. The act of differentiating the reservoir properties into linear and non linear properties to aid comparison and ranking of the delineated reservoirs to know the one with the best quality is the highlight of this research and could be employed in other researches.

2. Location and Geology of the Study Area

The study area "Jat field" is located in the eastern part of Niger Delta basin Nigeria as seen in figure 1. The Niger delta basin account for the entire hydrocarbon production at present day Nigeria and is situated on the continental margin of the gulf of guinea in equatorial west Africa between latitude 3^0 E and 6^0 N and longitude of 5^0 E and 8^0 E (Reijers, 1996). The basin is very complex, and it carries high economic value as it contains a very productive petroleum system. The Niger delta basin is one of the largest subaerial basins in Africa. It has a subaerial area of about 75000 km^2, a total area of about 300,000 km^2, and a sediment fill of 500,000 km^3 (Doust and Omatsola, 1990).

In its sedimentary succession, the Niger Delta comprises a lower unit of purely marine shales, the Akata Formation; a middle coastal unit consisting of paralic sequence of sand with intercalation of shales, the Agbada Formation; and an upper continental sequence of sands and the youngest of all the formation in the Niger Delta basin, the Benin Formation as shown in figure 2. Each of these units represents an enormous geologic age span, because of the advancement of the Niger Delta ocean ward. Ancient marine shales (Akata Formation) in the Niger Delta provide excellent source rocks for petroleum, whereas the sands (Agbada Formation) are the reservoirs where oil and gas accumulation took place; trapping is mostly along faults (Short and Stauble, 1967).

3. Materials and Methods

3.1 Materials

For this study, a composite well log suite comprising gamma ray, resistivity, density and neutron logs of four (4) wells were employed through the usage of Petrel™ software.

3.2 Methodology

Lithology Identification: The delineation of the lithologies in the area was carried out using the gamma ray log and a cut off line of 75 API was used. Gamma ray values below this cut off line of 75 delineate sand and above delineate shale.

Well Correlation: Lithologies were then correlated across all the wells with the help of resistivity log to show its consistency.

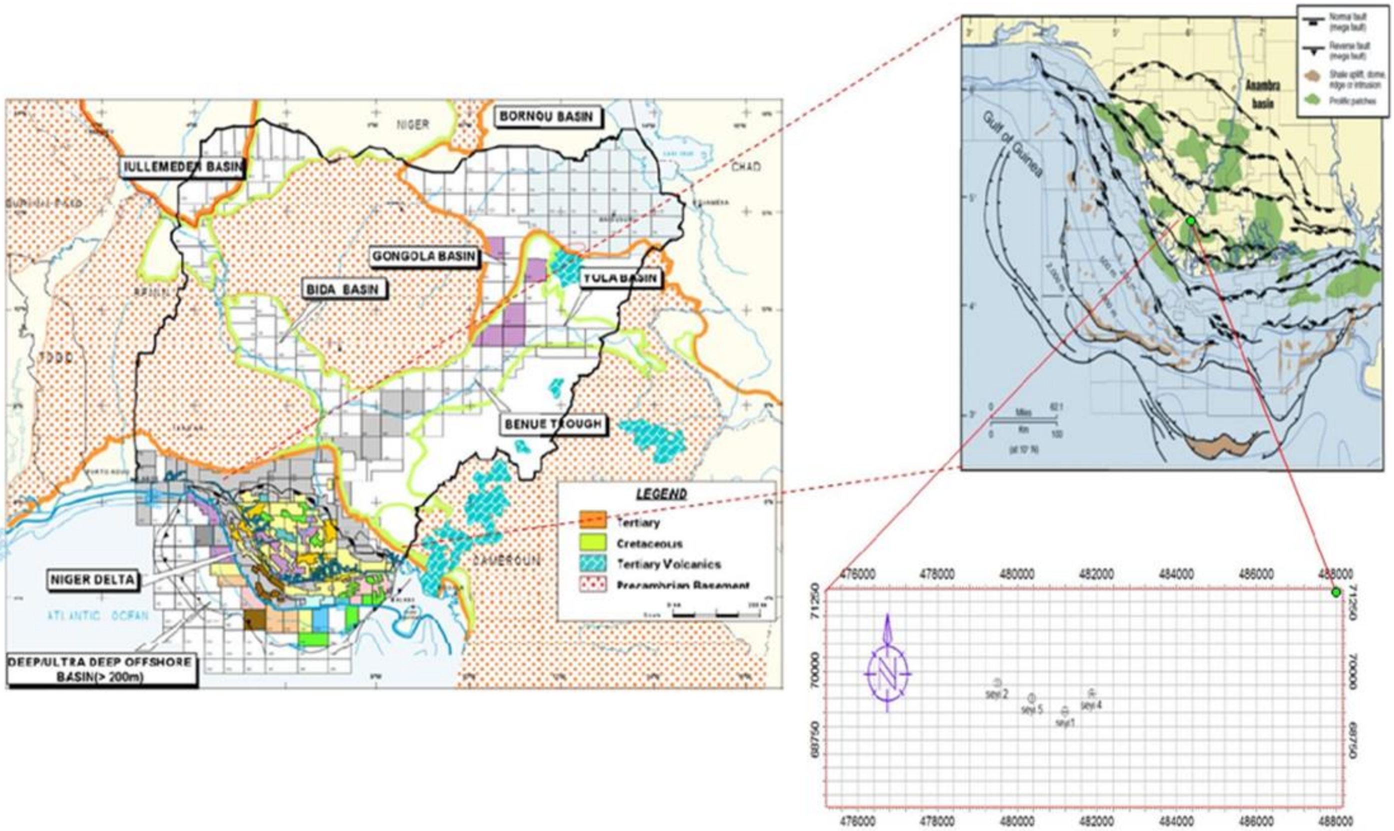


Figure 1: Base map of the study area

Reservoir Delineation: Reservoirs delineation was carried out by combining the lithologies and resistivity log; High resistivity logs revealed the portion of the sand bodies with hydrocarbon and low resistivity logs revealed the portion of the sand bodies with water. Neutron and density log were combined together show fluid discrimination in the reservoirs.

Formation Evaluation: Some empirical equations were used to evaluate the delineated reservoirs by importing readings from the well logs and characterize the reservoirs.

3.3 Petrophysical Properties

Petrophysical parameters were calculated for the identified reservoirs including Gross Thickness, Net Thickness, Net to Gross Thickness (NTG), Volume of Shale (Vsh), Porosity (ϕ), Permeability (k), Water Saturation (Sw), and Hydrocarbon Saturation (Sh).

Gross Thickness: The Gross thickness is the total thickness of the reservoir calculated by subtracting the depth value of the top of the reservoir from the base.

Gross Thickness = Base of Reservoir - Top of Reservoir

Net Thickness: The Net thickness is the thickness of sand units within a reservoir.

Net Thickness = Gross Thickness - Shale interval thickness

Net Pay: It is determined by using resistivity log to differentiate the portion of the delineated reservoirs filled with saline water and hydrocarbon. The portion filled with saline water is expected to be conductive while those of hydrocarbon will be resistive.

Net to Gross: It is a ratio used to determine the percentage of the delineated reservoir that contains economically recoverable hydrocarbons. It is determined by dividing the Net Pay by the Gross thickness.

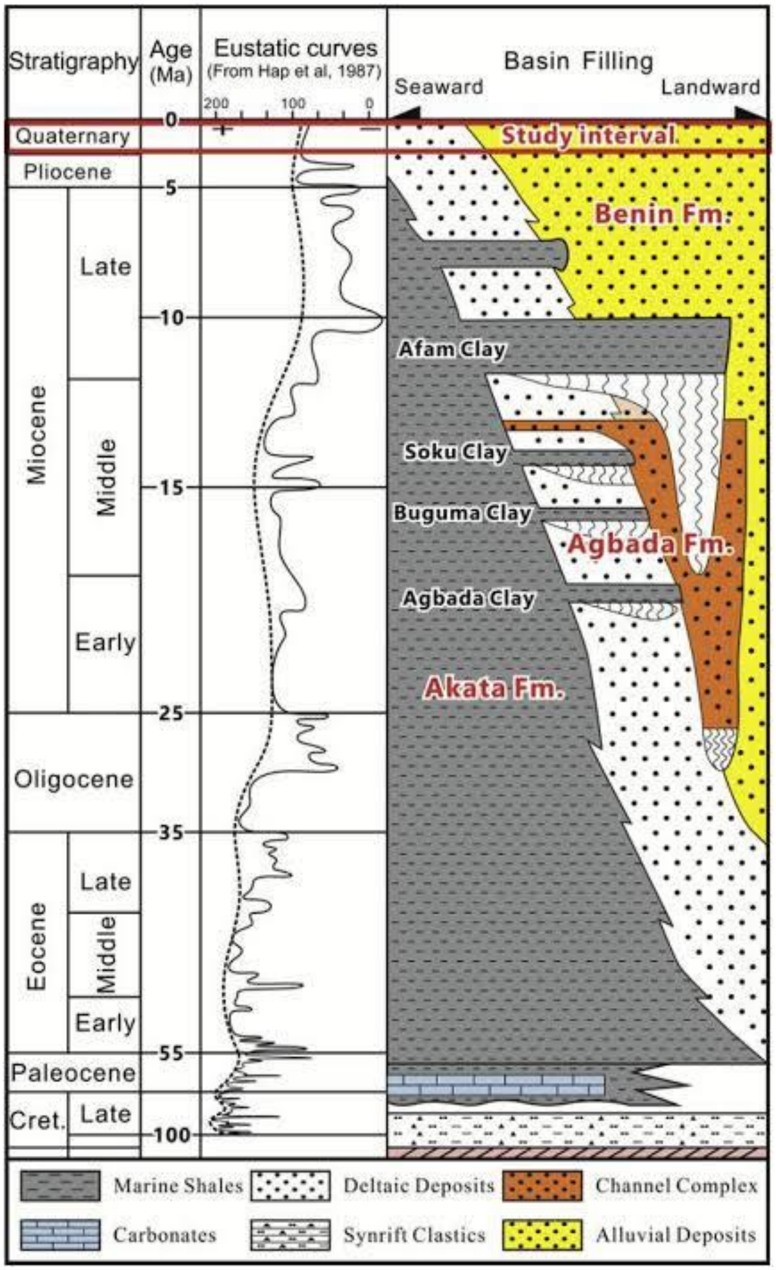


Figure 2: Stratigraphy of Niger Delta (Modified by Zhao et al., 2018 after Corredor et al., 2005).

Volume of shale: This is the volume of non reservoir sediment within the reservoir interval $V_{sh.}$

$V_{sh} = 0.083\ (2^{3.7\ \mathrm{x}IGR} - 1)$

Where IGR is gamma ray index.

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (Larionov, 1969) \qquad \textbf{(2)}$$

Where, GR_{max} is gamma ray maximum (shaly sand)

GR_{min} is gamma ray minimum from clean sand

GR_{log} is gamma ray log (shaly-sand)

Porosity (ϕ): This is used to determine the percentage of voids to the total volume of rock. Since porosity data are point data, average values are used to characterize reservoirs as excellent reservoir will have high porosity while poor reservoir will be characterized by low porosity. Porosity was calculated using matrix density, fluid density and observed log density.

$$\phi_{den} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$$

Where ρ_{fl} is the fluid density = 1.09 gm/cm^3 (fluid density with default brine),

ρ_b is the formation bulk density,

ρ_{ma} is the matrix density = 2.65 gm/cm^3 (sandstone)

Water Saturation (S_w): The water saturation for uninvaded zone was estimated using the following Archie's equations.

$$S_w{}^2 = \frac{F \times \mathrm{Rw}}{R_t}$$

$$\mathrm{F} = \frac{R_o}{R_w}$$

$$S_w{}^2 = \frac{R_o}{R_t}$$

Where S_w = water saturation of the uninvaded zone, R_o = resistivity of formation at 100% water saturation, F = Formation Factor and R_t = true formation resistivity

Hydrocarbon Saturation (S_H): This is the percentage of pore volume in a formation occupied by hydrocarbons. It is estimated by subtracting the value obtained for water saturation from 100%.

$$S_H = (100 - S_w)\ \%$$

Where, S_H= Hydrocarbon saturation, S_w = Water Saturation.

Permeability (K): Permeability is the measure of a formation to transmit fluids. It is controlled by the size of the connecting passages between the pores. The permeability was calculated for the reservoirs using the Tixier (1961) relationship.

$$K^{0.5} = \frac{250 \times \phi^3}{S_{wirr}}$$

Where, S_{wirr} is the irreducible water saturation

Reservoir Ranking: Petrophysical properties were categorized as linear and non linear. Petrophysical properties measured as linear measurements (gross thickness, net pay and net sand) were categorized as linear properties while others in form of ratios and/or percentages {NTG, hydrocarbon saturation (Sh), porosity, permeability} as non-linear properties. The estimated values for all non-linear reservoir properties are rated with other reservoirs' by relating them with the highest estimated value. When considering a particular property across the delineated reservoirs, the highest value for the property will be used to divide all estimated values making the reservoir with the highest value (best in that category) to have a maximum value rating of 1 while others have value ratings less than 1. These values ranging from 0 - 1 will be plotted against the corresponding reservoirs in a chart to show their variation. This will be done for all the non-linear properties while real values of linear properties will be plotted. Reservoirs will be ranked based on the charts while prioritizing the non-linear properties over the linear properties. The methodology employed in this study is summarized in workflow shown in figure 3.

4. Results and Discussions

4.1 Presentation of Results

The results of this study were grouped into log interpretation and reservoir ranking. The results are presented as well log panels, charts and tables.

4.2 Discussion of Results

4.2.1 Lithologic Interpretation

Lithologies were identified within the field using gamma ray logs as shown in Figure 4. Two major lithologies (sand and shale) were delineated in the studied field and are discussed below:

1. Sand: This display as low values away from cut-off, they are yellow in colour indicating porous and permeable and capable of holding large number of hydrocarbons.

2. Shale: This displays as high values away from the cut-off (i.e. above 75 API). They are grey in colour and interpreted as shale because of high radioactive contents indicating porous but impermeable rocks, forming the petroleum elements, possibly; source rocks, trap and seals.

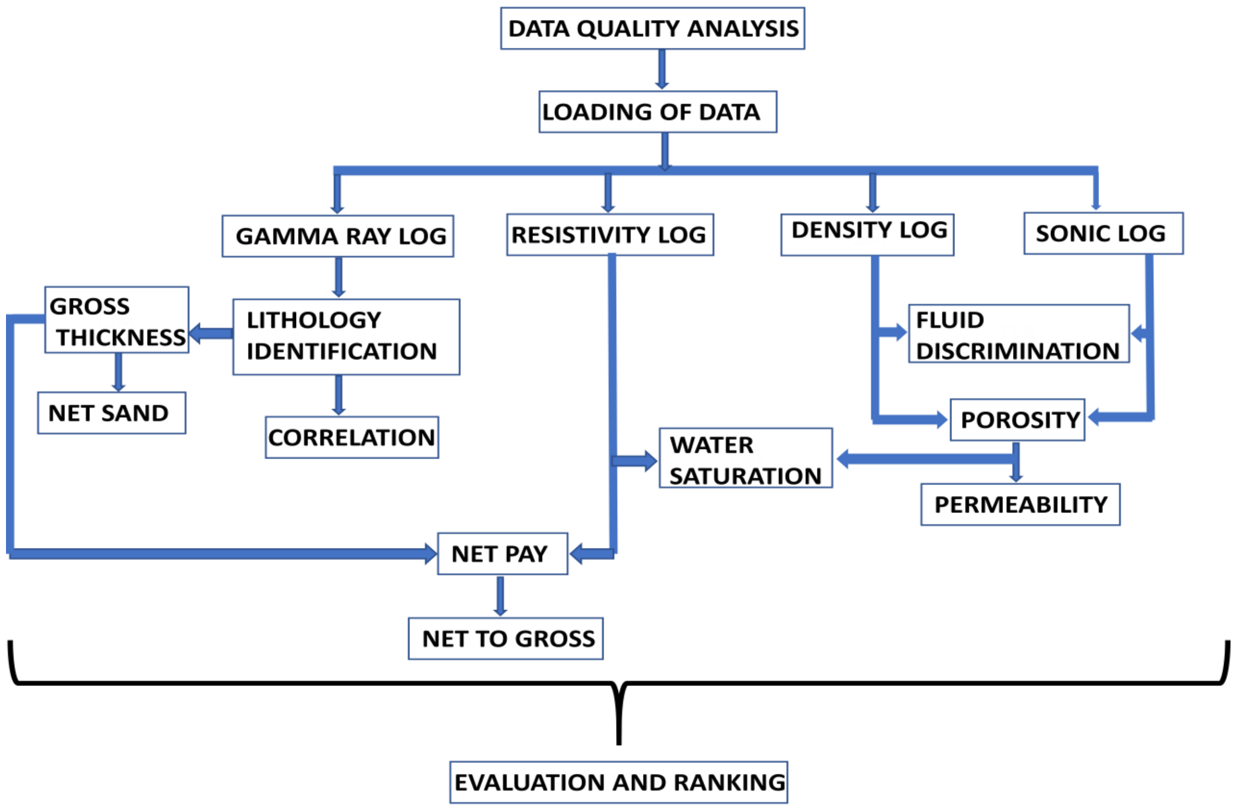


Figure 3: Workflow of the Research Work.

4.2.2 Well Log Correlation

Well-log correlation was performed to delineate the geometry and continuity of sand bodies within the field. Three hydrocarbon-bearing reservoirs (RES 1, RES 2 and RES 3) were correlated across the four wells using gamma ray and resistivity logs as shown in figure 4. The reservoirs correlated were based on the high resistivity readings and continuity across the sand beds (indicating the presence of hydrocarbon) across the wells. The relative formation density and neutron logs separation revealed their fluid discrimination (figure 5). The sand units are generally dirty having some interbeddings of thin sands. The delineated sands also decrease in thickness with depth. This sequence of sand with shale intercalation typifies the stratigraphy of the Niger-Delta basin.

4.2.3 Petrophysical Analysis

Petrophysical properties were determined for all delineated reservoirs (RES 1, RES 2 and RES 3) to define hydrocarbon storage capacity, deliverability and hydrocarbon saturation of the reservoir. The computed petrophysical parameters of the studied reservoirs are shown in table 1 and 2. Computed petrophysical parameters of interest include: gross thickness, net thickness, volume of shale, porosity, effective porosity, permeability, water saturation and hydrocarbon saturation.

Reservoir RES-1: Reservoir "RES 1" is being penetrated by all the four wells (JAT-01, JAT-02, JAT-03 and JAT-04). RES 1 has an average net thickness of 68 ft, net pay of 54.5 ft, net-to-gross ratio of 0.69, porosity of 0.30, effective porosity of 0.21, permeability of 1082 mD, water saturation of 48.25 and hydrocarbon saturation of 51.75 as shown in table 1 and 2. The hydrocarbon contained in this unit is oil and gas based on the neutron-density cross plot balloon shape (figure 5) and details in table 3.

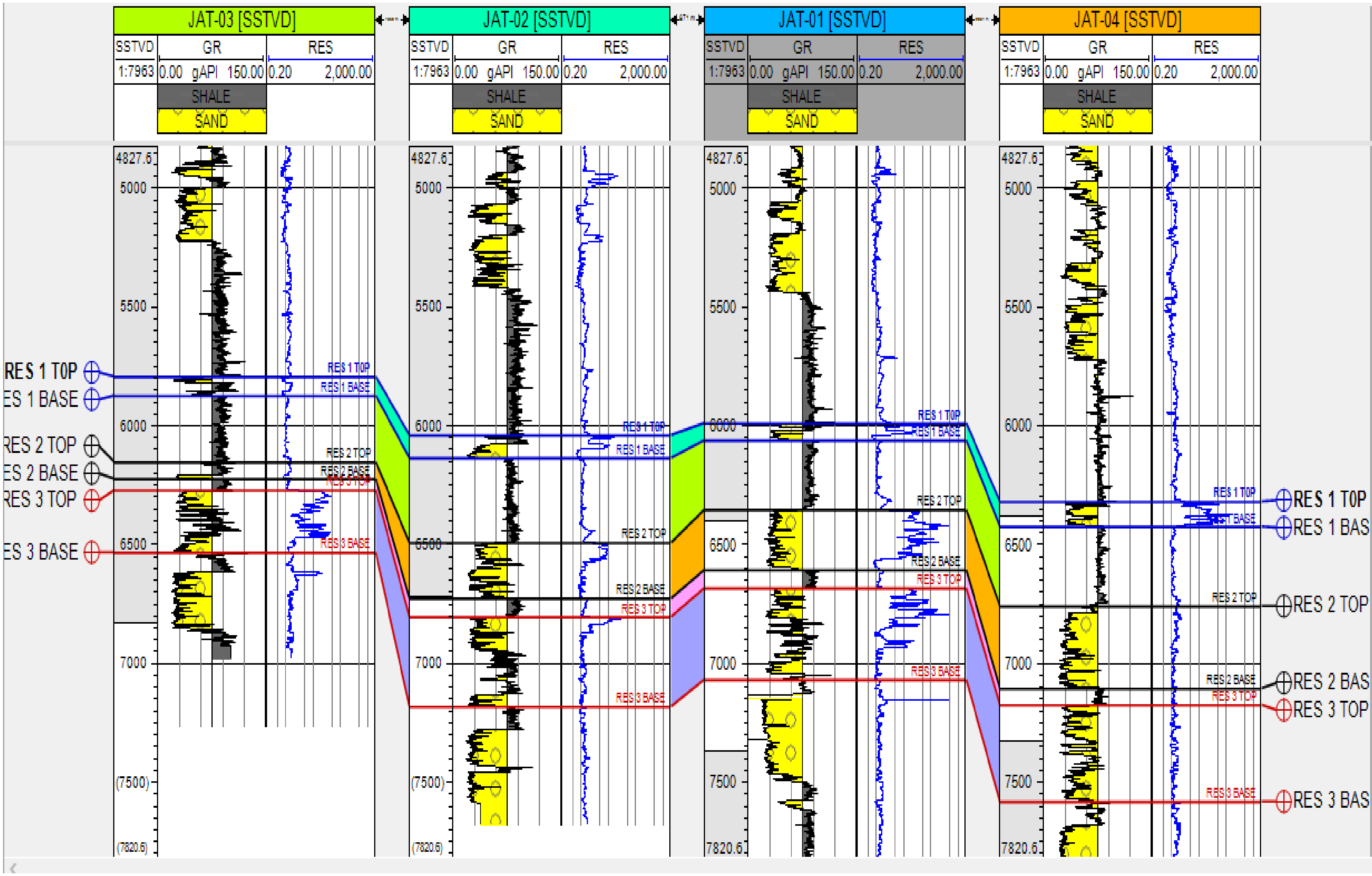


Figure 4: Interpreted Correlation Panel of Wells in the Study Area

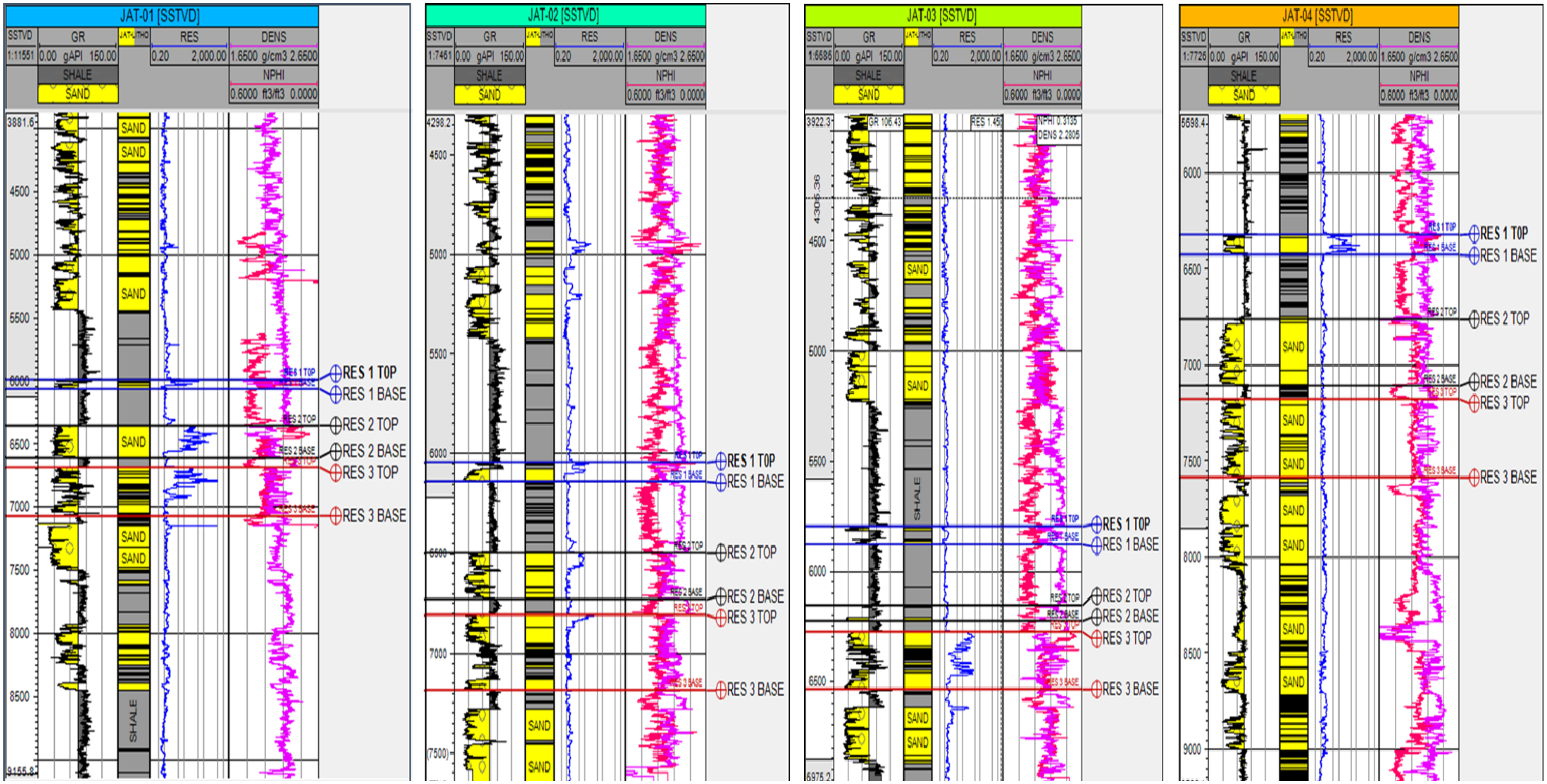


Figure 5: Log Panel Showing the Types of Hydrocarbon

Table 1: Formation Evaluation of the Delineated Reservoirs

	RES 1				RES 2				RES 3			
Well Number / Reservoir Parameters	**JAT-01**	**JAT-02**	**JAT-03**	**JAT-04**	**JAT-01**	**JAT-02**	**JAT-03**	**JAT-04**	**JAT-01**	**JAT-02**	**JAT-03**	**JAT-04**
Top (ft.)	5985	6040	5794	6310	6354	6493	6154	6766	6684	6805	6272	7176
Base (ft.)	6069	6137	5874	6425	6607	6725	6225	7107	7069	7182	6534	7583
Gross Thickness (ft.)	84	95	80	115	253	232	71	341	385	377	272	407
Net Thickness (ft.)	73	78	35	86	253	217	24	341	298	251	193	394
Net Pay (ft.)	73	59	0	86	234	102	0	0	204	87	146	0
NTG	1.00	0.76	0.00	1.00	0.92	0.47	0.00	0.00	0.69	0.35	0.76	0.00
I_{GR}	0.44	0.26	0.38	0.33	0.32	0.19	0.48	0.24	0.28	0.26	0.27	0.29
V_{sh}	0.39	0.20	0.33	0.27	0.26	0.12	0.43	0.18	0.22	0.20	0.21	0.23
Porosity (ϕ_{avg})	0.36	0.31	0.24	0.30	0.34	0.31	0.18	0.28	0.30	0.28	0.28	0.31
Effective porosity (ϕ_{eff})	0.22	0.25	0.16	0.22	0.25	0.27	0.10	0.23	0.23	0.22	0.22	0.24
Permeability (mD)	882	2499	66	882	2499	4679	1	1267	1267	882	882	1792
S_w (%)	39	54	78	22	20	30	74	93	26	70	20	88
S_h (%)	61	46	22	78	80	70	24	7	74	30	80	12

Reservoir RES-2: Reservoir "RES-2" is being penetrated by all the four wells (JAT-01, JAT-02, JAT-03 and JAT-04). RES 2 has an average net thickness of 208.75 ft, net pay of 84 ft, net-to-gross ratio of 0.35, porosity of 0.28, effective porosity of 0.21, permeability of 2110.75 mD, water saturation of 54.25 and hydrocarbon saturation of 45.25. The hydrocarbon contained in this unit is oil based on the neutron-density cross plot balloon shape (figure 5) and details in table 3.

Reservoir RES-3: Reservoir "RES-3" is being penetrated by all the four wells (JAT-01, JAT-02, JAT-03 and JAT-04). RES 3 has an average net thickness of 284 ft, net pay of 109.25 ft, net-to-gross ratio of 0.45, porosity of 0.29, effective porosity of 0.28, permeability of 1205.75 mD, water saturation of 51 and hydrocarbon saturation of 49. The hydrocarbon contained in this unit is oil based on the neutron-density cross plot balloon shape (figure 5) and details in table 3.

4.2.4 Reservoir Quality Assessment and Ranking

Reservoir quality assessment was carried out from the formation evaluation as the estimated reservoir properties have been grouped as linear and non-linear (figure 6) as highlighted in the methodology and the reservoirs were ranked according to their quality in each group. Firstly, considering the non-linear physical attributes {NTG, hydrocarbon saturation (Sh), porosity, permeability}, all delineated reservoirs are good but RES 1 is relatively of higher quality than other reservoirs as those properties complement each other as shown in figure 6a.

Table 2: Average Petrophysical Parameters of the Reservoirs

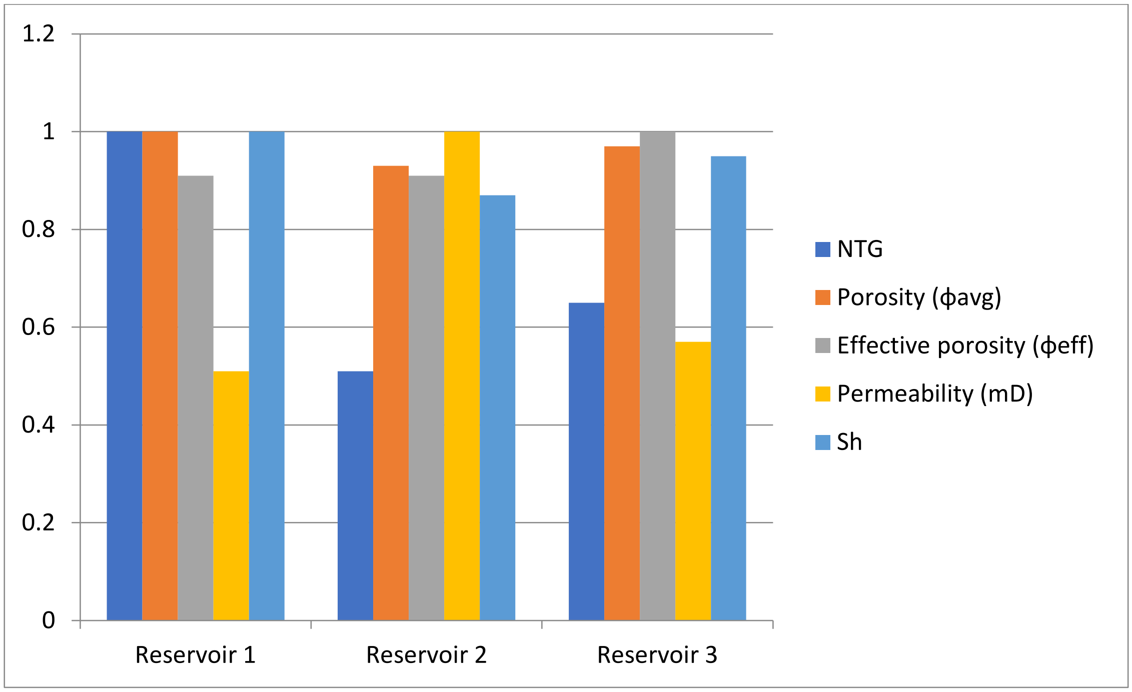
Petrophysical Parameters	RES 1	RES 2	RES 3
Gross Thickness (ft.)	93.5	224.25	360.25
Net Thickness (ft.)	68	208.75	284
Net Pay (ft.)	54.5	84	109.25
NTG	0.69	0.35	0.45
I_{GR}	0.35	0.31	0.28
V_{sh}	0.29	0.28	0.22
Porosity (ϕ_{avg})	0.30	0.28	0.29
Effective porosity (ϕ_{eff})	0.21	0.21	0.23
Permeability (mD)	1082	2110.75	1205.75
S_w (%)	48.25	54.25	51
S_h (%)	51.75	45.25	49

Table 5: Hydrocarbon Type within Reservoirs

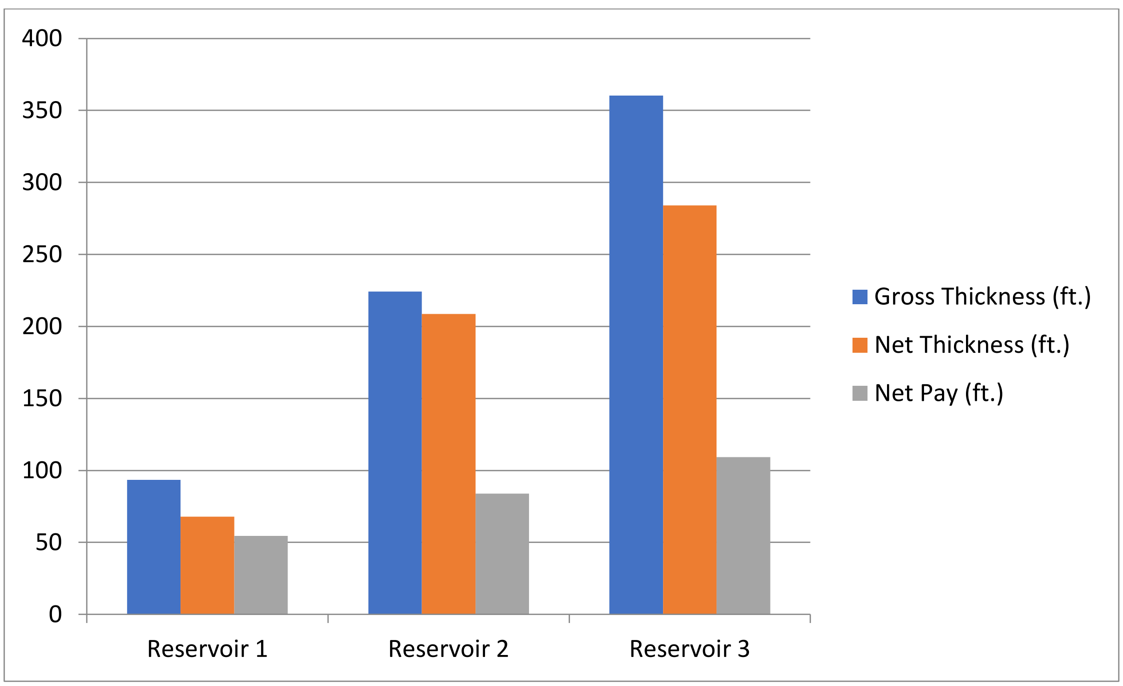
Wells / Reservoir	JAT-01	JAT-02	JAT-03	JAT-04
RES 1	Gas and Oil	Gas and Oil	Wet	Gas and Oil
RES 2	Gas and Oil	Oil	Wet	Wet
RES 3	Oil	Oil	Gas and Oil	Wet

The ranking based on the linear physical attributes in terms of the properties that deal with thickness variation (gross thickness, net pay and net sand) is revealed in figure 6b. RES 2 and 3 shows a moderately high distribution of gross thickness and net sand but low net pay as opposed to RES 1 which have all the properties complementing each other. Though RES 2 and 3 have higher gross and net thicknesses than Res 1, the fact that these properties are not complementing each other makes Res 1 to be preferred in this category.

All reservoirs delineated in this study area are of good quality by integrating both linear and non-linear attributes. However, RES 1 is of the best quality with gross thickness being the only advantage that other reservoirs have over it. Hence RES 1 is the best quality in the field and should be targeted for production followed by RES 3. It is to be noted that the non-linear attributes as categorized in this research are to be given priority over the linear attributes when dealing with the quality of a reservoir.



(a)



(b)

Figure 6: Comparison of reservoirs using (a) Non-linear properties (b) Linear Properties

5. Conclusions

Geophysical wireline logs data has been used to evaluate the hydrocarbon potential of the reservoir sands in 'Jat' field, Niger Delta basin. Petrophysical analysis was carried out to understand the properties of the reservoir sands. The reservoir properties were further grouped into linear and non linear properties. The estimated reservoir properties were used in ranking the reservoirs using a mathematical relative indexing method while prioritizing the non-linear properties over the linear properties. Three hydrocarbon bearing reservoirs (RES 1, RES 2 and RES 3) were ranked and the petrophysical parameters obtained from the study show that "Jat" field is characterized by high porosity, high permeability, high to moderately low hydrocarbon saturations, low percentage of shale volume and moderate to high NTG. From the reservoir ranking results, all the reservoirs can be exploited for hydrocarbon production with RES 1 being the priority. The mathematical relative indexing used in this study has shown its relevance and application in reservoir ranking as shown in this research.

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