Reservoir Characterization through the Application of Petrophysical Evaluation of Well Logs of Animaux Field, Niger Delta Basin, Nigeria

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ABSTRACT

Reservoir characterization through the application of petrophysical evaluation of well logs was carried out over Animaux Field in the Niger Delta Basin of Nigeria. A suite of well logs from three wells (Ani-1, Ani-2, and Ani-3) were evaluated and used for reservoir characterization. Five hydrocarbon reservoirs containing oil, in three levels and oil and gas in two levels were interpreted from the three wells. Petrophysical properties (net-to-gross, thicknesses, water saturation and porosity) were estimated over five reservoirs to characterize the quality as well determine fluid typing of the reservoirs. Well correlation was carried out to find out the connections between the three wells to determine connectivity and extent. The Petrophysical analysis produced an average porosity value of 28% for the Ani-1 well for the various zones and water saturation of 31%, 21% and 20% for the E, G, and H oil zones respectively. Reservoirs E, G, H, and L have an average net pay thickness of 3.05m, 7.62m, 3.05m and 6.59m for the oil zones respectively, while the net pay thickness for reservoirs G, H and H_1 gas zones are 11.28m, 8.99m and 9.91m respectively. The reservoir parameters obtained show that the reservoirs are good and of high quality.

Keywords: Reservoir, Characterization, Petrophysical properties, well log, Animaux

INTRODUCTION

The role of Oil and gas field evaluation in global energy sustainability and economic prosperity cannot be overemphasized. The economic worth of an oil and gas company depends on its hydrocarbon reserves which are used by shareholders and investors as the present and future strength of the company (Emujakporue, 2016). Therefore, there is need to be sure of the prospects of an oil field before embarking on the exploration of the oil field as it could be counterproductive and end up with a dry hole especially when all geological conditions such as source rock, reservoir rock, traps, seal and migration required for the field to be productive are not present.

Reservoir characterization refers to the process of unfolding all the features of the hydrocarbon-bearing reservoir, which necessitates the utilization of the most accurate measurements since considering all the characteristics of the reservoir are pertinent to its ability to store and facilitate fluid flow (Ganguli and Dimri, 2023). Log analysis is used to describe the porosity, lithology, and geometry of the pores, in addition to permeability and is often used to provide estimated interpretation on reservoir level of oil (Asquith and Krygowski, 2004).

The aim of this study is reservoir characterization through the application of petrophysical evaluation of well logs data of Animaux Field, Niger Delta Basin, Nigeria with the objectives of determining volume of shale, porosity, water saturation, hydrocarbon saturation, gross rock volume, net-to-gross ratio, net rock volume of hydrocarbon bearing reservoirs.

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Location and Geology setting of the Study Area

Animaux Field is located in the coastal fringe of the Niger Delta Basin and in swamp terrain (Figure 1). The Niger Delta swamp is a tropical rain forest with marshy land, brackish water and green vegetation in southern Nigeria. The field can be accessed through rivers, creeks and creeklets.

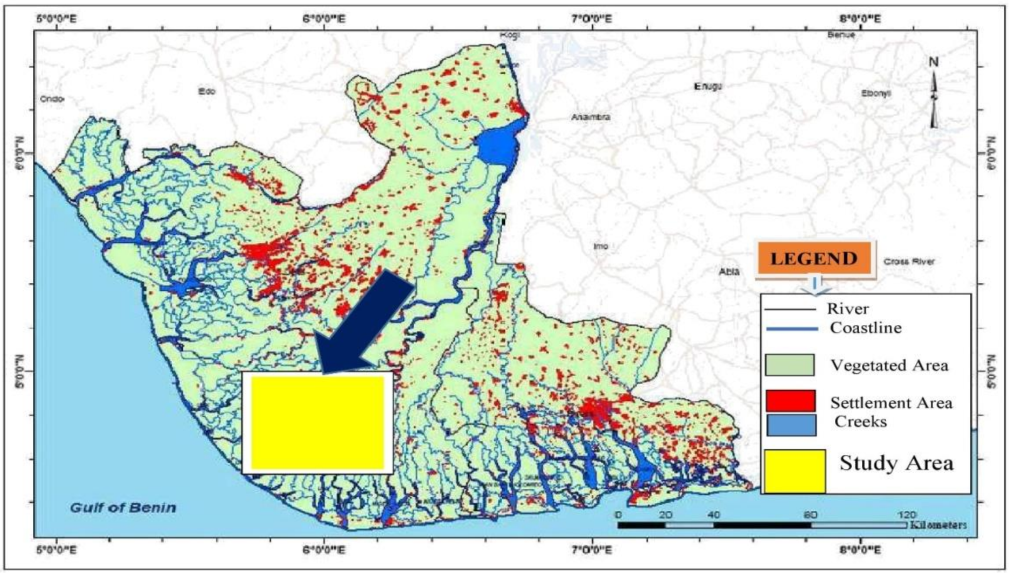

Figure 1: Map of the Niger Delta showing the location of the Study Area -Animaux Field (modified after Amangabara and Obenade, 2015)

Evolution of the Niger Delta is closely linked to the geodynamics related to the separation of the African and South American continents and the tectonics of the formation of the Benue Trough (Najime *et al*., 2017). Rifting in this basin started in the Late Jurassic and ended in the Mid Cretaceous (Lehner and De Ruiter, 1977). The stratigraphy of Niger Delta has been noted to be tripartite lithostratigraphic succession (Short and Stauble, 1967). These tripartite lithostratigraphic units are recognized in deep well sections as vertical subdivision of formation types. Figure 2 depicts the Stratigraphic column showing the three formations of the Niger Delta.

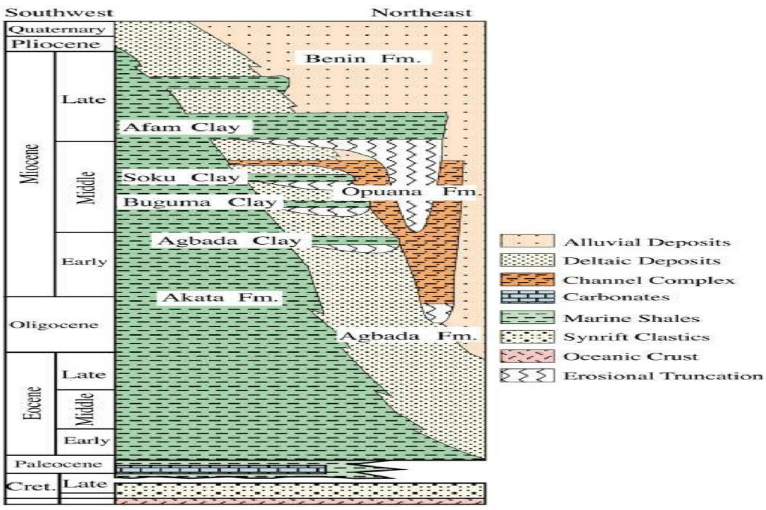

Figure 2: Stratigraphic-column-showing-the-three-formations-of-the-Niger-Delta (Lawrence *et al.*, 2002; Corridor *et al.*, 2005).

The three Formations are: the transgressive marine Akata shale, the petroliferous parallic Agbada Formation and the continental Benin sands. Shales are major cap rocks which act as seals while sands and/or sandstones are the reservoirs that entrap the hydrocarbon in the Niger Delta (Adagunodo and Akinlabi, 2024). The Agbada

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Formation is the major oil and natural gas-bearing facies in the basin. This sequence is over 4,000 m thick, but thicker at the central part showing that the depocentre is located in the central Niger delta (Evamy *et al.* 1978).

Data Availability and Quality

The available data for petrophysical evaluation includes a suite of well logs from Ani-1, Ani-2 and Ani-3, deviation survey data, formation well tops and checkshot data fromAni-1. The suite of logs contains gamma rays, spontaneous potential, density, neutron, and resistivity logs. There is no core data to aid formation evaluation. Table 1 shows the availability of petrophysical data or otherwise. Green indicates availability while red indicates the non-availability for a particular well log.

Table 1: Animaux Field well data availability

	LITHOLOGY			RESISTIVITY	POROSITY				
WELL NAME	SP	CAL	GR	RES	RHOB	NPHI	DT	Well log Header Information	DEV
Ani-1									
Ani-2									
Ani-3									
			Not Available					Available	

MATERIALS AND METHODS

Well Log Correlation

Well Log correlation was carried out across the wells using the available log suite from each of the wells. The correlation of wells was used to define trends of petrophysial data across the field and to determine connectivity and extent. Figure 3 shows the Well correlation panel for Ani-1, 2 and 3 showing the reservoirs.

The five reservoirs : E, G, H, K, and L were identified as hydrocarbon bearing (see table 2 and 3). The reservoirs are made up of mainly sandstones, shaly sand and sandstone with shale intercalation based on the log signature.

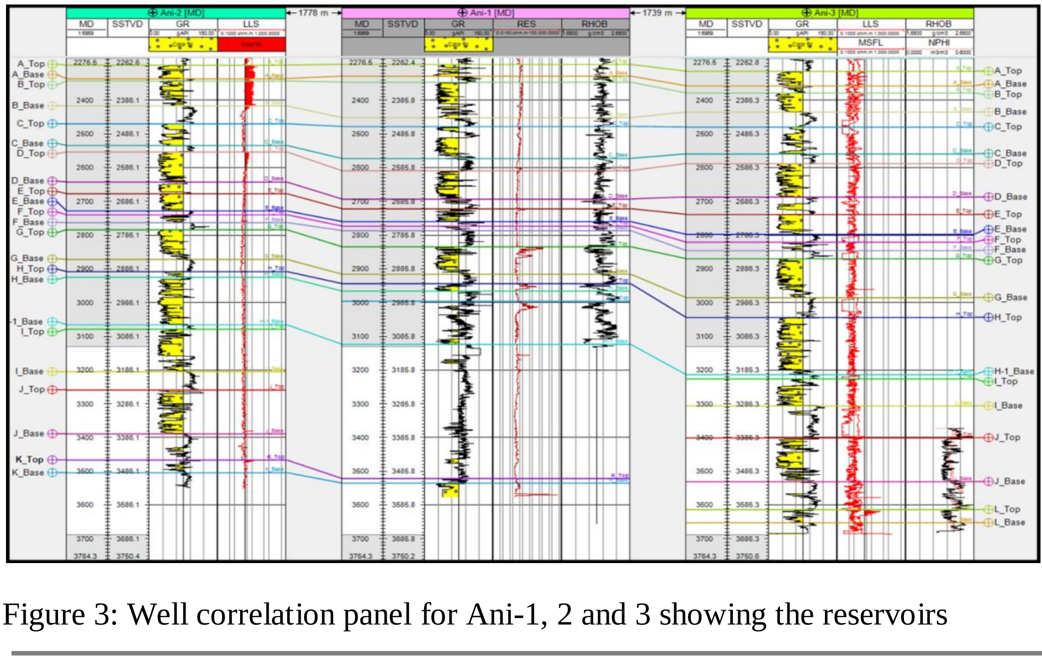

Figure 3: Well correlation panel for Ani-1, 2 and 3 showing the reservoirs

Petrophysical Evaluation Methodology

Using the available data in Table 1 above, the formation evaluation methodology in this study consisted of:

(1) Data Preparation and loading (LAS format) into Techlog.

(2) Logs QA/QC.

(3) Logs normalization.

(4) Fluid typing and Contacts assumptions.

(5) Vshale Evaluation/Net to Gross (NTG).

(6) Porosity Evaluation.

(7) Sw Evaluation.

(8) Pay Cut-off Analysis.

The well logs in LAS file format were loaded into Techlog software. The LAS (Lidar LASer) file format is a binary file format specifically designed for storing lidar point cloud data. It was developed and is maintained by the American Society for Photogrammetry and Remote Sensing (ASPRS) as a standardized format for lidar data exchange and interoperability (Iqbal, 2023). Histogram charts of the GR curves were plotted and found to be bimodal in the wells suggesting two predominant lithologies of sandstone and shale. Figure 4 shows a graphical representation of the petrophysical workflow.

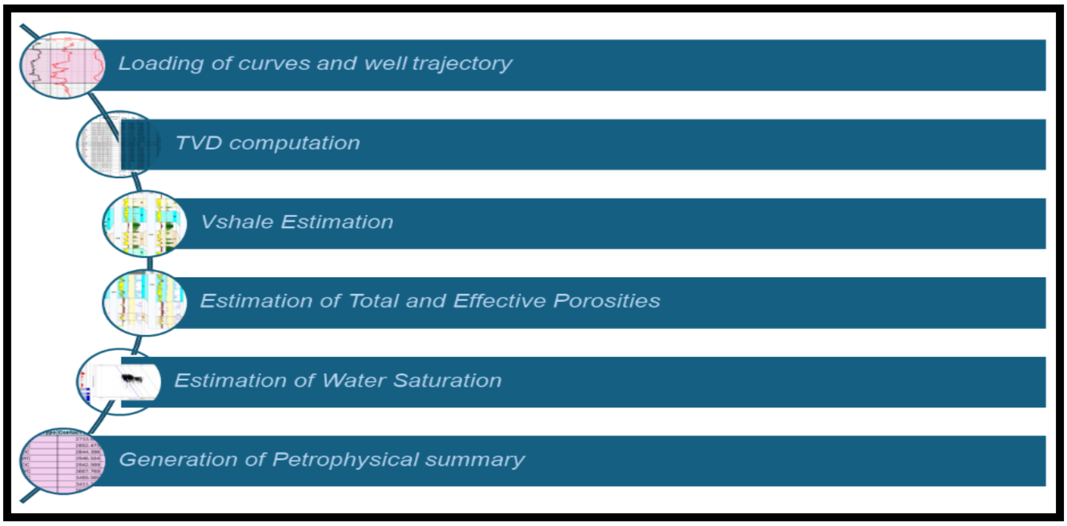

Figure 4: Graphical representation of Petrophysical workflow

Petrophysical properties Evaluation:

The petrophysical properties evaluauted in this work are discussed below:

Grain Density

Core data (conventional and sidewall Cores) were not available for this evaluation to carry out log-core calibration. Average grain density value of 2.65 g/cc, which is the value for quartz matrix, was used for the evaluation due to lack of core data. Andrea *et al*., (1997) opined that the value of the grain density taken depends upon the lithology of the interval under question. Tamunobereton-ari *et al.*, (2013) are of the view that, in the absence of core data, grain density from part of the Niger delta can be used in the estimation of petrophysical parameters such as acoustic velocity, compaction factor, porosity, permeability and fluid content.

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Determination of True Resistivity (Rt)

True resistivity is the value of deep resistivity reading from resistivity logs.

Water Resistivity Determination (Rw)

The formation water resistivities for the reservoirs were determined from the Pickett plot. 1.8 was used as the cementation factor (m) and saturation exponent (n). Pickett plots were generated to determine the formation water resistivity across clean water bearing zones. The water resistivity derived from Pickett plot in the water leg was used for Water Saturation evaluation in all the available wells.

Formation water resistivity (Rw) was determined from a Pickett plot of porosity against resistivity over clean water leg and wet zones. Shale resistivity was read from logs above and below reservoir intervals. Figure 5 shows the Formation Water Resistivity from Picket (Ani-1).

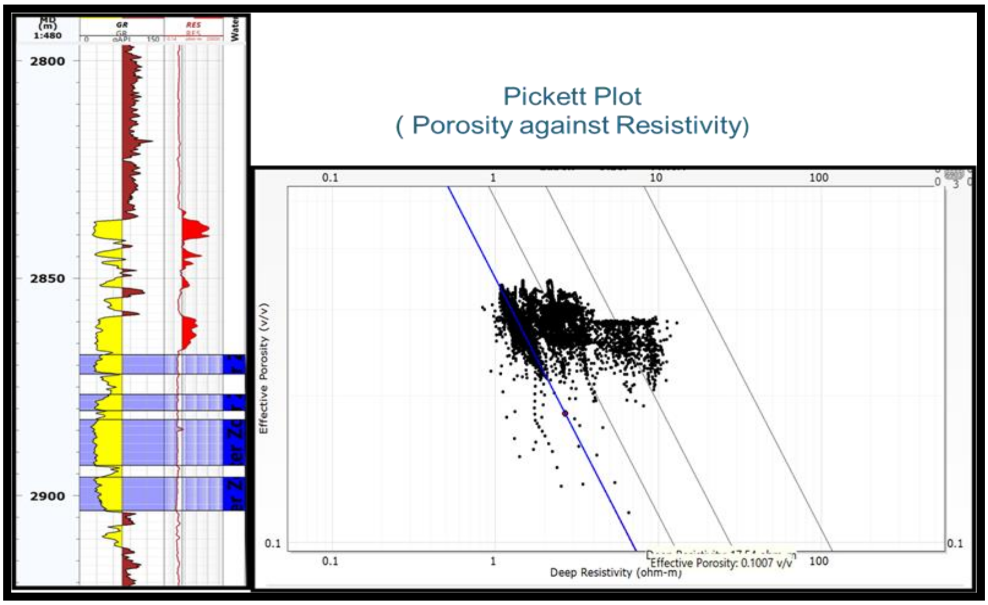

Figure 5: Formation Water Resistivity from Picket (Ani-1)

Rock Property Determination

Volume of Shale

Gamma ray logs were used to determine the volume of shale using the normalized gamma ray log. The Larionov’s method for tertiary rocks with the equation shown below was used for estimating the volume of shale.

Gamma Ray Method (Larionov for Tertiary rocks)

$$V_{Sh} = 0.083 * (2^{(3.7*GR_{index})} - 1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$GR_{index} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Volumes of shale were calculated from gamma ray log after determining GR minimum and GR maximum values for each zone in each well from a GR against frequency histogram plot and log display within, above and below the reservoir intervals using the Gamma Ray index linear equation. Figure 6 shows Volume of Shale estimated using Gamma Ray.

The sand and shale values were taken from the most representative intervals of well and an average volume of shale cut-off 0.1 is adopted as reservoir.

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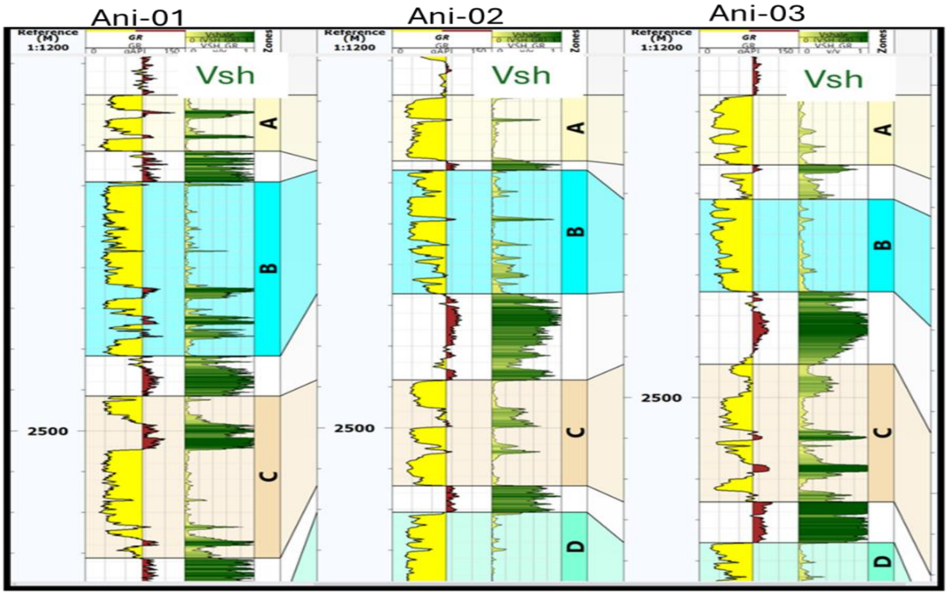

Figure 6: Volume of Shale estimated using Gamma Ray

Porosity

Porosity was determined from the density logs, Neutron and Sonic logs. Density of Matrix (RhoM) - 2.65g/cm^3, water -1g/cm^3, oil- 0.85 g/cm^3 and gas- 0.75 g/cm^3 were used as constants for density of water, oil and gas respectively.

Total porosity (PHIT) and Effective porosity (PHIE) were estimated from Neutron and Density and Sonic (Wyllie's method). Logs used for each well were determined by availability; Density in Ani-1, Sonic in Ani-2 and Neutron-Density in Ani-3. A correction was applied on PHIE in Ani-1 to reduce overestimation of porosity in gas zones. The estimated porosity porosity log across Animaux Field is shown in figure 7

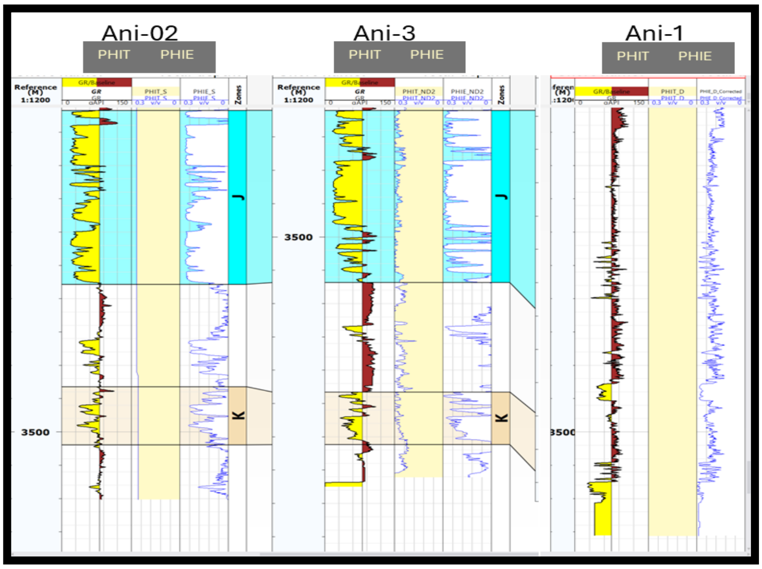

Figure 7: Estimated porosity log across Animaux Field

Water Saturation

Water saturation was estimated using Archie's method, effective porosity was the porosity used

$$Sw = \left(\frac{R_W}{\varphi^m R_t}\right)^{\frac{1}{n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Figure 8 shows the estimated water saturation across Animaux Field.

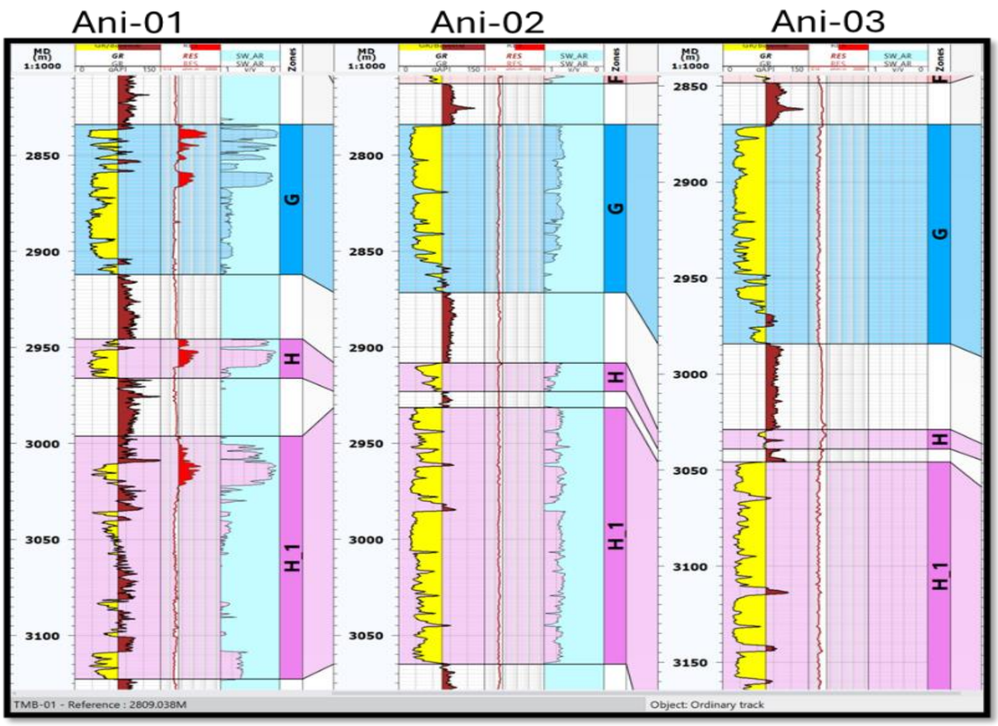

Figure 8: Estimated water saturation across Animaux Field

Fluid Distribution

A combination of gamma ray, resistivity and porosity logs (neutron density) were used to distinguish reservoir rocks from non-reservoir rocks. The reservoirs are made up of mainly sandstones, shale and sandstone with shale intercalations based on log signatures interpretation.

Fluid interpretation was based on the resistivity logs while hydrocarbon typing was based on the combination of neutron density logs. Fluid distribution plots were generated for all hydrocarbon-bearing reservoirs and are presented in Figures 9-11.

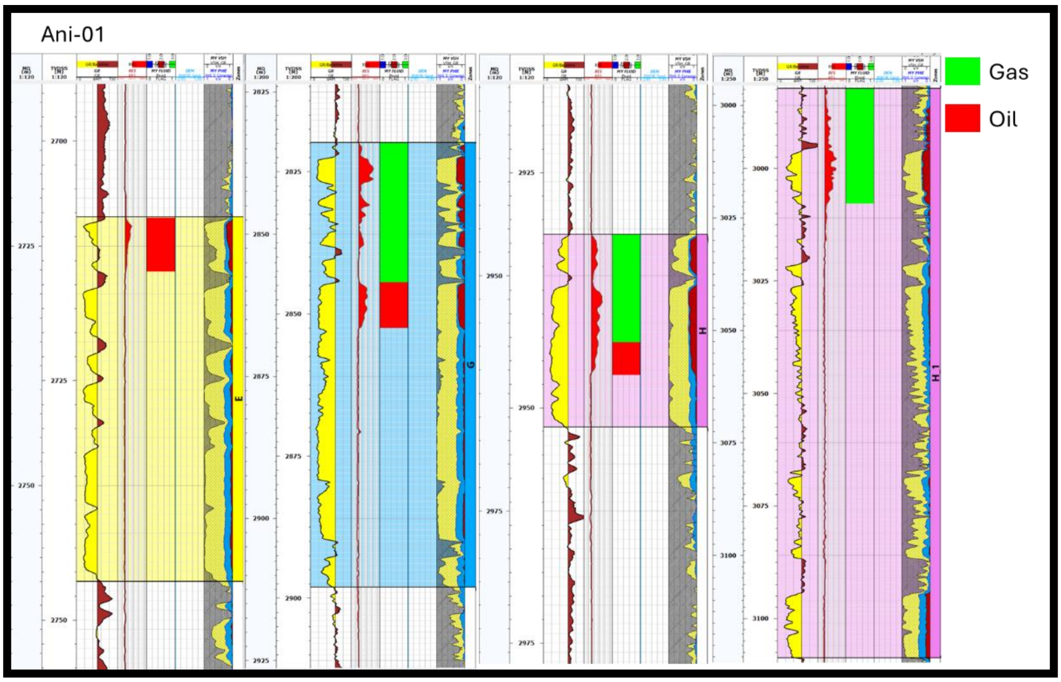

Figure 9: Ani-1 Hydrocarbon Bearing (E, G, H- reservoir)

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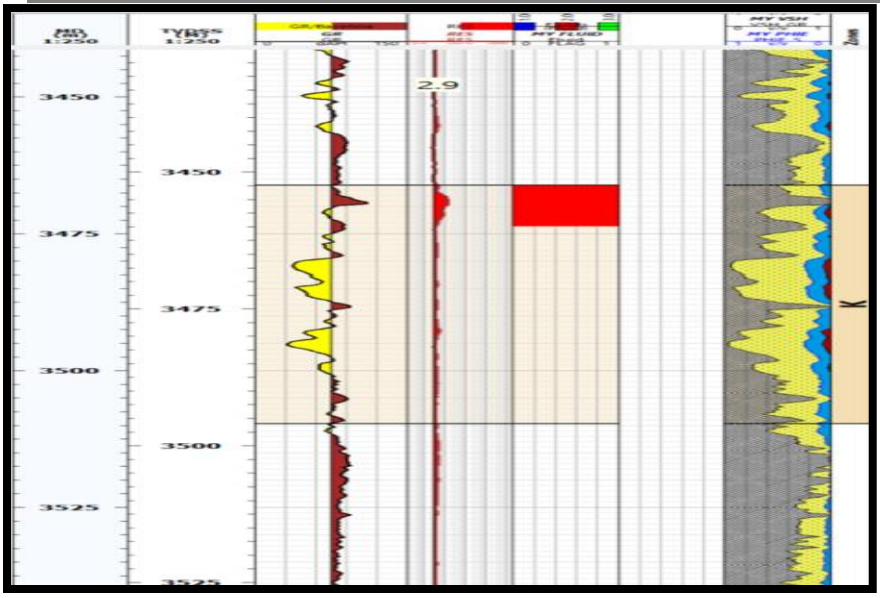

Figure 10: Ani-2 Hydrocarbon Bearing zones (K-reservoir)

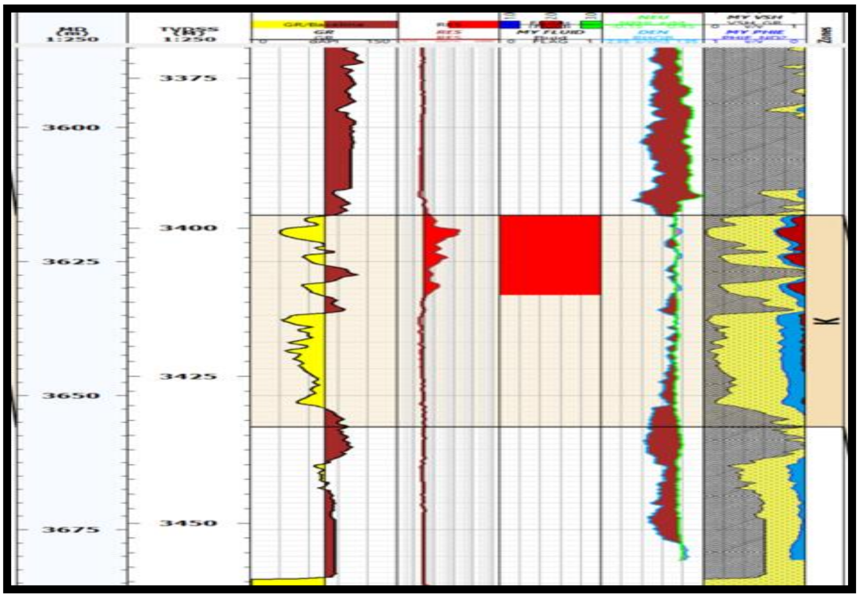

Figure 11: Ani-3 Hydrocarbon Bearing zone (L-reservoir**)**

RESULTS AND DISCUSSIONS

The results of the reservoir characterization through the application of petrophysical evaluation of well logs data of Animaux Field, Niger Delta Basin Nigeria are summarized in Tables 2 and 3.

Five reservoirs were identified as hydrocarbon-bearing and Fluid typing is based on combining information. The sums and averages are presented in Table 2 and 3.

Table 2: Sums and Averages in MD

Well	Zone	Fluid	Top	Bottom	Gross Res	Contact Type	Contact Depth	Gross Pay	Net Pay	NTGpay	Avg Shale	AvgPor	AvgSw
Ani-1	E	Oil	2721.93	2760.01	38.08	OWC	2727.80	5.639	3.048	0.541	0.125	0.28	0.319
Ani-1	G	Oil	2833.88	2912.05	78.17	OWC	2866.64	8.077	7.62	0.943	0.036	0.279	0.206

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

Ani-1	G	Gas	2833.88	2912.05	78.17	GOC	2858.56	24.536	11.278	0.46	0.094	0.285	0.203
Ani-1	H	Oil	2945.59	2966.06	20.46	OWC	2960.67	3.505	3.048	0.87	0.013	0.281	0.262
Ani-1	H	Gas	2945.59	2966.06	20.46	GOC	2957.16	11.43	8.992	0.787	0.1	0.289	0.192
Ani-1	H_1	Gas	2996.18	3122.76	126.58	GWC	3021.93	25.603	9.906	0.387	0.128	0.284	0.161
Ani-2	K	Oil	3466.08	3509.67	43.58	OWC	3473.80	7.62	0	0	0	0	0
Ani-3	L	Oil	3616.36	3655.86	39.49	OWC	3631.26	14.903	7.315	0.491	0.159	0.242	0.272

Table 3: Sums and Averages in TVDSS

Well	**Zone**	**Fluid**	**Top**	**Bottom**	**Gross Res**	**Contact Type**	**Contact Depth**	**Gross Pay**	**Net Pay**	**NTGpay**	**Avg Shale**	**AvgPor**	**AvgSw**
Ani-1	E	Oil	2707.89	2745.97	38.08	OWC	2713.63	5.63	3.048	0.541	0.125	0.28	0.319
Ani-1	G	Oil	2819.85	2898.02	78.17	OWC	2852.47	8.07	7.62	0.943	0.036	0.279	0.206
Ani-1	G	Gas	2819.85	2898.02	78.17	GOC	2844.39	24.53	11.278	0.46	0.094	0.285	0.203
Ani-1	H	Oil	2931.56	2952.03	20.47	OWC	2946.50	3.50	3.048	0.87	0.013	0.281	0.262
Ani-1	H	Gas	2931.56	2952.03	20.47	GOC	2942.99	11.4	8.992	0.787	0.1	0.289	0.192
Ani-1	H_1	Gas	2982.15	3108.74	126.58	GWC	3007.76	25.60	9.906	0.387	0.128	0.284	0.161
Ani-2	K	Oil	3452.35	3495.9	43.59	OWC	3459.90	7.55	0	0	0	0	0
Ani-3	L	Oil	3600.41	3638.61	35.71	OWC	3617.75	13.42	6.586	0.491	0.159	0.242	0.272

E Reservoir

The E reservoir penetrated by Ani-1, -2 and -3. The reservoir is oil bearing only in Ani-1 penetrating the structure at a depth of -2707.89m (TVDSS) with oil water contact at -2713.63m (TVDSS). E-reservoir has an average gross thickness of 5.63m, a net thickness of 3.05m, an average net-to-gross ratio of 0.54; average porosity of 28% and average water saturation of 32%.

G Reservoir

G reservoir penetrated by Ani-1, -2 and -3. The reservoir is both oil and gas bearing in Ani-1. For the oil, Ani-1 has a penetrating depth -2819.85m (TVDSS) with a GOC at -2844.39m (TVDSS) and OWC at -2852.47m (TVDSS). G-reservoir has an average gross thickness of 8.07m, a net thickness of 7.62m, an average net-to-gross ratio of 0.94, average porosity of 28% and average water saturation of 21% in the oil zone and an average gross thickness of 24.53m, a net thickness of 11.28m, average net-to-gross ratio of 0.46, average porosity of 29% and average water saturation of 20% for the gas zone.

H Reservoir

H reservoir penetrated by Ani-1, -2 and -3. The H reservoir has one oil zone and two gas bearing zone in Ani-1 denoted as H and H_1 For the oil Ani-1 has a penetrating of depth -2931.56m (TVDSS)with oil water contact at -2946.50m (TVDSS). H-reservoir for oil has an average gross thickness of 3.50m, a net thickness of 3.05m, an average net-to-gross ratio of 0.87, average porosity of 28% and average water saturation of 26%.Ani-1 penetrates gas in zones H and H_1 at depths of -2931.56m (TVDSS) and 2982.15m (TVDSS) respectively and with gas oil contact at -2942.99m(TVDSS) for H gas zone and gas water contact of -3007.76m (TVDSS) for the H_1 zone. H and H_1 reservoirs for gas have an average gross thickness of 11.4m and 25.60m, net thicknesses of 8.99m and 9.91m , an average net-to-gross ratios of 0.79 and 0.39; average porosities of 29% and 28% and average water saturations of 19% and 16% respectively.

K-Reservoir

The K reservoir is basically oil bearing only at Ani-2 well. The reservoir penetrates the structure at a depth of -3452.35m(TVDSS)with oil water contact at -3459.90m(TVDSS). K-reservoir has an average gross thickness of 7.55m.

L-Reservoir

The L reservoir penetrated by Ani-2 and -3. The reservoir is oil bearing only in Ani-3 penetrating the structure at a depth of -3600.41m (TVDSS) with oil water contact at -3617.75m (TVDSS). L-reservoir has an average gross thickness of 13.42m, a net thickness of 6.59m, an average net-to-gross ratio of 0.49; average porosity of 24% and average water saturation of 27%.

Ani-1 penetrated most of the hydrocarbon bearing reservoirs in the field, three oil zones (E, G and H) and three gas zones (G, H and H_1).

Comparing Results with other works in the Niger Delta

The average porosity of 28% in the Animaux Field compares favourably with the porosity range for the Niger Delta basin as reported by Opara (2010) in eight reservoirs of USSO Field Onshore Niger Delta Basin –who had 27% porosity. Tamunosiki *et al*., (2014) in the south-east Niger Delta Basin had porosity values that ranged from 15% to 31% and Oluwajana and Owoeye (2023) reported an average porosity of 27% for the XYZ Field in the Niger Delta Basin. These show that the estimated grain density of 2.65g/cc was within a geological plausible range. This has taken away data gaps which are usually associated with lack of core data and bridged any element of uncertainty which could have resulted from estimated grain density.

The reservoirs of Animaux Field are made up of mainly sandstones, shaly sand and sandstone with shale intercalation based on the log signature which is typical of the Agbada Formation of the Niger Delta as reported by Reijers *et al*., 1997; Doust and Omatsola, 1990 and which is consistent with the work of Emujakporue, (2016) in Amu Field of the Niger Delta who delineated sand and shale as the two major lithologies from well logs. Generally, the identification of five reservoirs E, G, H, K, and L as hydrocarbon bearing in theAnimaux Field, goes to support the works of Oyeyemi *et al*. (2018) within an exploration Field, Shallow Offshore Depobelt, Western Niger Delta, Nigeria; and Ola and Alabere, (2018) in the OVU Field, onshore Niger Delta and James(2021) in Honyx Field, Niger Delta; that the application of Petrophysical evaluation of well logs can be used in reservoir characterization.

CONCLUSION

The reservoir characterization through the application of petrophysical evaluation of well logs data was carried out in Animaux Field, Niger Delta basin Nigeria using data from three wells. Checkshot data from Ani-1 well and a suite of well logs from three wells (Ani-1, Ani-2, and Ani-3) were used for the evaluation. The

Petrophysical analysis produced an average porosity value of 28% for the Ani-1 well for the various zones and water saturation of 31%, 21% and 20% for the E,G,and H oil zones respectively. Reservoirs E, G, H, and L have an average net pay thickness of 3.05m, 7.62m, 3.05m and 6.59m for the oil zones respectively, while the net pay thickness for reservoirs G, H and H_1 gas zones are 11.28m, 8.99m and 9.91m respectively

Five hydrocarbon reservoirs containing oil, in three levels and oil and gas in two levels were interpreted from the three wells and evaluated for their respective petrophysical properties (net-to-gross, thicknesses, water saturation and porosity). The results generally show that five reservoirs E, G, H, K, and L were identified as hydrocarbon bearing. The reservoirs are made up of mainly sandstones, shaly sand and sandstone with shale intercalation based on the log signature. The reservoir parameters obtained show that the reservoirs are good and of high quality.

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