International Journal of Earth & Environmental Sciences
Vol. 7, No. 1, 2022, pp. 50-67

http://ijees.ielas.org
ISSN: 2545-4161

EVALUATION OF THE PETROPHYSICAL PROPERTIES OF THE K-FIELD, NIGER DELTA BASIN'S OFFSHORE DEPOBELT, NIGERIA

[1*] **Ekeahenhen Thaddeus A**, [2] **Ezeugwu Innocent O**
[1] Department of Geology, University of Benin, Benin City, Edo State, Nigeria.
[2] Department of Geology and Mining Enugu State University of Science and Technology.
*Corresponding author: thaddeusekeahenhen@gmail.com

Received: 2022-04-15 Accepted: 2022-06-28 Published online: 2022-07-10

Abstract

This study, titled "Petrophysical Evaluation of K-Field in the Niger Delta Basin's (NDB) Offshore Depobelt" assesses the potential of hydrocarbon (HC) generation and quality of reservoirs within the field. Petrophysical parameters evaluated include lithology, shale volume (Vsh), porosity (φ), permeability (Ka), hydrocarbon saturation (Sh), water saturation (Sw), and net-to-gross (NTG) ratio. Well log analyses of wells 6, 7, 10, and 11 were conducted for reservoir characterization. Lithology was delineated from the gamma ray log, while hydrocarbon-bearing zones were identified using resistivity and density logs. Porosity was derived from density log readings, shale volume from gamma ray data, and Sw using Archie's equation, with resistivity of the formation water (Rw) gotten from plotting Pickett's plot.
Two lithologies sand and shale were identified, comprising five reservoirs. Gross thickness ranges from 64–243 ft, net thickness 53–178 ft, and net-to-gross ratios 0.734–0.937. Porosity values range 23–30%, permeability 2,204–6,031 mD, and Sh 47–73%. Statistical evaluation ranked Reservoir E8000 as the most prolific and D8000 the least. The results confirm that reservoirs D5200, D7000, D8000, E8000, and F3000 are viable for HC production.

Keywords: Reservoir, Well log, Hydrocarbon, Lithology, Characterization.

1. INTRODUCTION

The NDB, which is situated along the margin of the West African continental plate, is most often referred to as one the world's of the most prolific HC provinces (Odesa *et al*., 2024, Ideozu *et al*., 2025; Mba-Otike *et al*., 2025; and Eyankware *et al*., 2025). Over the decades, exploration and exploitation activities have been predominantly concentrated in the onshore and shallow offshore areas. However, as geological understanding of the basin has advanced, exploration efforts have progressively shifted toward deeper offshore depobelts, where significant hydrocarbon accumulations are being discovered.

Petrophysical assessment plays a vital role in hydrocarbon exploration and field development. It provides quantitative evaluation of properties of reservoirs like lithology, V_{sh}, φ, K_a and fluid saturation (F_s), which are essential for reserve estimation and production planning. A precise petrophysical interpretation enhances the success rate of exploration wells and reduces uncertainty in reservoir characterization.

Well logging, also known as borehole logging, remains a fundamental technique for subsurface evaluation. It involves continuous recording of the physical and chemical properties of subsurface formations penetrated by drilling tools. The data acquired through tools such as gamma ray (GR), resistivity, sonic as well as density logs aid in identifying reservoir zones, delineating lithologies, and estimating S_h. These logs are obtained by lowering instruments (sondes) into the borehole, where they transmit or receive electrical, acoustic, or radioactive signals to infer formation characteristics (Mode and Anyiam, 2007).

In the course of this study, petrophysical analysis was conducted for the K-field, Offshore Depobelt of the NDB to evaluate the HC potential of reservoirs penetrated by wells 6, 7, 10, and 11. Logs were analyzed to determine lithology, Vsh, φ, Ka and F_s using established models such as the Archie equation and Pickett plot. The results revealed five distinct reservoirs (D5200, D7000, D8000, E8000, and F3000) characterized by high porosity (23–30%), excellent permeability (2,204–6,031 mD), and favorable S_h (47–73%). Statistical ranking identified Reservoir E8000 as the most prolific and D8000 as the least.

These findings underscore the effectiveness of integrated petrophysical evaluation in delineating productive zones and improving reservoir development strategies in offshore Niger Delta fields.

2. Materials and Methods

Area of Study

The NDB is located at the pinnacle of the Gulf of Guinea along the western coast of the African plate and represents one out of the world's most vital deltaic HC regions globally. The basin spans an estimated area circa 75,000 km² attaining a maximum thickness of sediments that is approximately 11 km in its deepest depocenters. Hydrocarbon production within the basin averages 2.1 million barrels of oil and 85,000 barrels of condensate per day (Haack et al., 2000). The present study focuses on the K-Field, located the within Oil Mining Lease (OML F) in the Depobelt's offshore segment termed the Eastern Coastal Swamp of the NDB (Figure 1). The aforementioned area is structurally controlled by growth faults and rollover anticlines typical of the basin's extensional tectonic regime. These structures form suitable traps for hydrocarbon accumulation, making the offshore depobelts a key focus of current exploration and production activities.

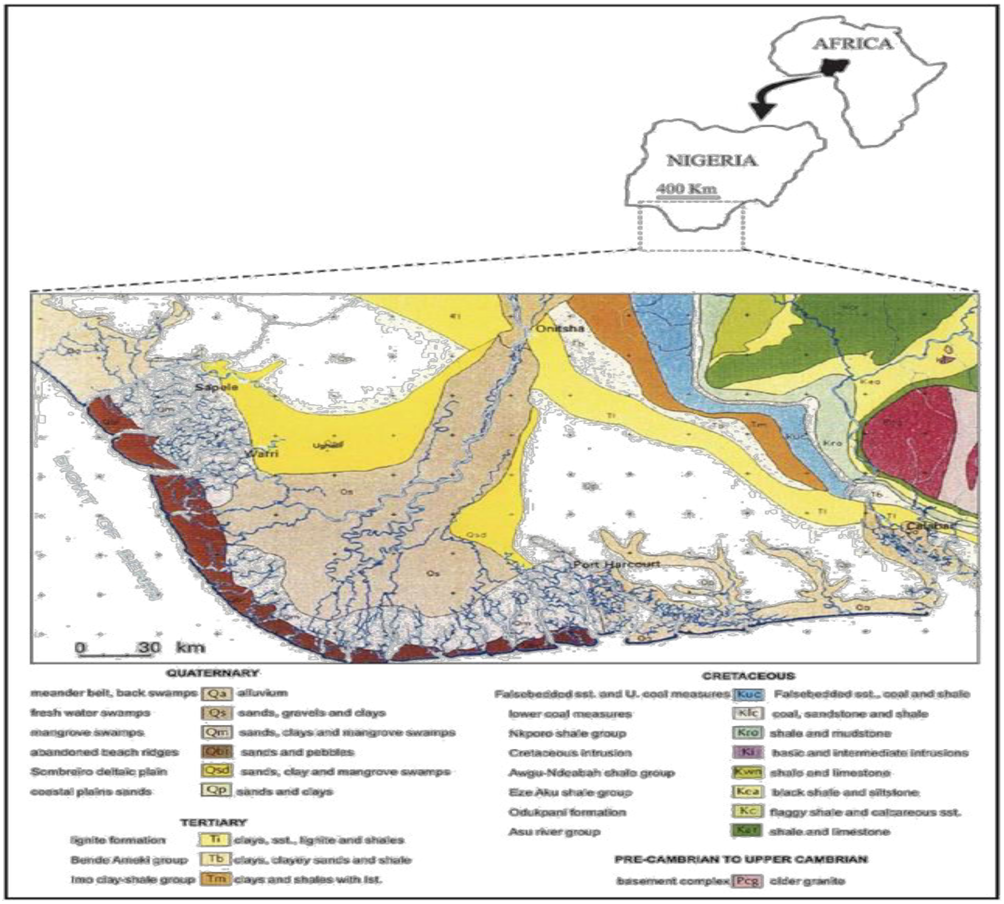

Figure 1.1. Geologic map showing the Niger Delta and parts of its contiguous basins (Reijers, 2011)

Data Acquisition

The dataset employed in this study is composed of the composite wireline log suites gotten from four wells (6, 7, 10, and 11) within the K-Field. The following log types were analyzed:

- GR Log: for the identification of lithology and for V_{sh} estimation.
- Resistivity Log: for discrimination type of fluid and for the determination of S_h.
- Density Log: for calculating φ and correcting lithology.
- Sonic Log: for φ estimation and lithologic support.
- Caliper Log: for borehole quality assessment and identification of washouts.
- Spontaneous Potential (SP) Log: for formation boundary identification and K_a.

These logs were provided in digital LAS format and imported into Techlog™ software (Schlumberger) for processing, analysis, and visualization.

Data Quality Control and Validation

Prior to analysis, quality control (QC) and data validation were performed to ensure data integrity and reliability. The caliper log was used to detect borehole enlargements (washouts) and mudcake buildup, which could adversely affect log readings. Spurious data points and non-physical spikes were filtered out to produce smoothed, continuous log curves. All log readings were cross-checked to ensure they conformed to Standard International (SI) units and standard industry scales. Borehole conditions were verified, and any sections affected by tool malfunctions or poor hole conditions were excluded from analysis. The processed log data were subsequently used for lithologic correlation and petrophysical evaluation.

Well Correlation and Lithologic Interpretation

Correlating the entire Field was done along both strike and also dip directions to establish lateral continuity of lithologic units across the wells. The GR log was primarily employed to distinguish sands and shales sequences, while integration with resistivity and density logs enhanced the discrimination between hydrocarbon-bearing and water-bearing sands. This correlation framework formed the basis for identifying equivalent stratigraphic horizons across wells within the K-field.

Petrophysical Analysis

Quantitative petrophysical evaluation was conducted using Techlog™ software to determine key reservoir parameters, including V_{sh}, φ, S_w, S_h, k_a, and NTG ratio. V_{sh} was computed from the GR log using the linear and Larionov equations, with a shale cutoff value of 0.5 applied to define net sand intervals. φ was derived from the density log, calibrated with sonic log data where necessary. S_w was estimated through the Archie's equation, with the R_w obtained from the Pickett plot. K_a was empirically calculated from φ and lithologic data correlations. NTG ratio was derived from the proportion of the reservoir's net thickness to that of the thickness of the gross interval.

Reservoir Delineation and Ranking

Five principal reservoirs; D5200, D7000, D8000, E8000, and F3000, were identified across the study wells. Computed petrophysical parameters for each reservoir were statistically analyzed and compared to evaluate reservoir quality and productivity potential. Ranking of the reservoirs was based on their average φ, K_a, S_h, and NTG ratio, leading to the identification of E8000 as the most prolific and D8000 as the least productive.

Software and Analytical Tools

All quantitative interpretations and graphical visualizations were performed using Techlog™ (v2021) for log analysis, Excel for data computation and statistical ranking, and CorelDRAW for final figure production and presentation formatting.

Table 1. Data Available

FIELD	WELLS	LOGS						
		GR	SP	CAL	RT	DEN	NEU	DT
K- Field	6	✓	✓	✓	✓	✓	✓	✓
	7	✓	✓	✓	✓	✓	✓	None
	10	✓	✓	✓	✓	✓	✓	None
	11	✓	✓	✓	✓	✓	✓	None

2.1. Lithology/ Reservoir Identification

Sand and shale units in this study were delineated from the GR log and signatures. The identification of the sand bodies was from the left deflection of the GR log which is indicative of radioactive minerals’ having lower concentration in bodies of sand, while right deflection shows minerals that are radioactive high concentration thus signifying shale. In identifying reservoir, GR and resistivity was used, water bearing interval are characterized with low resistivity while hydrocarbon bearing interval are characterized with high resistivity. Therefore, decrease in gamma ray reading with a corresponding increase in resistivity indicates a reservoir.

2.2. Delineating fluid distribution

To establish fluid contacts in this study, an integrated approach was employed, due to the unavailability of reservoirs’ RFT data. The fluid contact idenified in the well logs were used as the reservoirs’ actual contacts. These contacts observed in the studied wells, have been indentified using both Density and Resistivity logs. Subsequently, log correlation was done to finalise the delineation in this study, while neutron and density log was used in identifying reservoire fluid

2.3. Porosity determination

Density log within the techlog software was employed to generate porosity logs. φ is expressed as shown below:

$DPHi = \frac{RHOMa - RHOB}{RHOMa - RHOF}$ (Eshimokhai and Akhirevbulu, 2012) ………………………………………………1

where: DPHi = φ derived from density, $RHOMa$ = matrix's density, $RHOB$ = formation's bulk density, RHOF= fluid's density (0.8 for oil, 1.0 for fresh mud as well as 1.1 for salty mud).

2.4. Permeability determinations

K_a is the rock property that deals with transitivity of the fluids within the rock. Somehow, it pertains to φ but is not entirely dependent on it. K_a is controlled mostly by parameters like rock grain sizes, shapes as well as their arrangement. Its unit of measurement is in millidarcies. K_a was obtained through the Thumur's equation. Given that phi is φ (effective) as well as irreducible S_w being the S_{wirr}. It is therefore expressed as seen below;

$K = a.\frac{Phi^b}{S_{wi}^c}$ ……………………………………………………………………………………………………2

Where: a is 8581, B is 4.4 and C is 2

2.5. Water Saturation

S_w estimation was achieved from the Archie model. The R_t for the water at the FWL, just after the OWC contact in the studied wells was gotten from resistivity log. The porosity was also taken at that same point. Subsequently, all obtained figures were then imported into the Archie model and R_w for the reservoirs was obtained after assuming S_w as 1. Also, the φ at the oil zone of the reservoir was retrieved together at that same point with the figure of the resistivity. Then all the values were then also imported into Archie equation, so that the S_w at that interest zone is then gotten. All these were carried out on the Techlog software and mathematically expressed as seen below:

$S_w = \sqrt[n]{\left(\frac{a}{\varphi^m}\frac{R_w}{R_t}\right)}$ ………………………………………………………………………3 (Archie, 1942)

2 Default values: a = 1, m = 2, n = 2

Where:

Sw is the water saturation of the unevaded zone;
Rw is the formation water's resistivity
Rt is the formation resistivity of the uninvaded zone

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ISSN: 2545-4161

φ is the porosity
a is the factor of tortuosity
m is the exponent of cementation
n is the exponent of saturation

2.6. Volume of shale

V_{sh} is the matrix (i.e. silt and mud) in addition to fluid (i.e bound water). V_{sh} is often shown as a decimal, a fraction or even a percentage. V_{sh} is gotten from GR log's non-linear kind of stretch occurring between the clean sand endpoint and the endpoint of shale being 0 and 150 respectively. V_{sh} also poses as an adequate estimation index for shale present in the reservoir unit, that has been used for the generation of the other logs, like S_w and NTG log in this study's petrophysical analytical procedure. The first step used was to calculate minimum and maximum gamma ray values using Gamma ray histogram as shown in figure. The second step in determination shale volume is the calculation of GR Index through equation 4. The non-linear relationship is the relationship that was employed while generating this from V_{sh} GR log.

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad \ldots\ldots 4$$

Given that:

I_{GR} is the GR index

GR_{log} is the GR reading of the formation

GR_{min} is the minimum GR (clean sand or carbonate)

GR_{max} is the maximum GR (shale)

All these above stated values were read off within each given reservoir. Having gotten the GR index, V_{sh} was then obtained through the usage of steiber equation (1970) shown in equation 5 below

$$V_{sh} = \frac{I_{GR}}{3 - 2 \times I_{GR}} \quad \ldots\ldots 5$$

2.7. Net-to-Gross (NTG)

An estimation was done for the gross thickness of the identified reservoir, and it was carried out from the top of the reservoir down to its base. The determination of net thickness, that is the thickness of the portion of the reservoir which is both porous as well as permeable. This was done by the removal of thickness value of the non - reservoir portion from the gross total thickness value. The gross reservoir thickness value too, was at this point used to divide the net reservoir thickness value to obtain the NTG. NTG thus can be gotten as follows:

Net reservoir is non-reservoir thickness value subtracted from Gross reservoir value 6

NTG is Gross reservoir divides Net reservoir (Amigun and Odole 2013) 7

3. Results and Discussion

Four well logs in this study have been evaluated for the determination of the Petrophysical properties of K-field. These analytical results are as shown in figure 2, 3,4, 5, 6, 7 and 8, and table 3, 4, 5, 6 and 7 below, while figure 9 and 10 show statistical analysis of all the reservoirs using average petrophysical parameters.

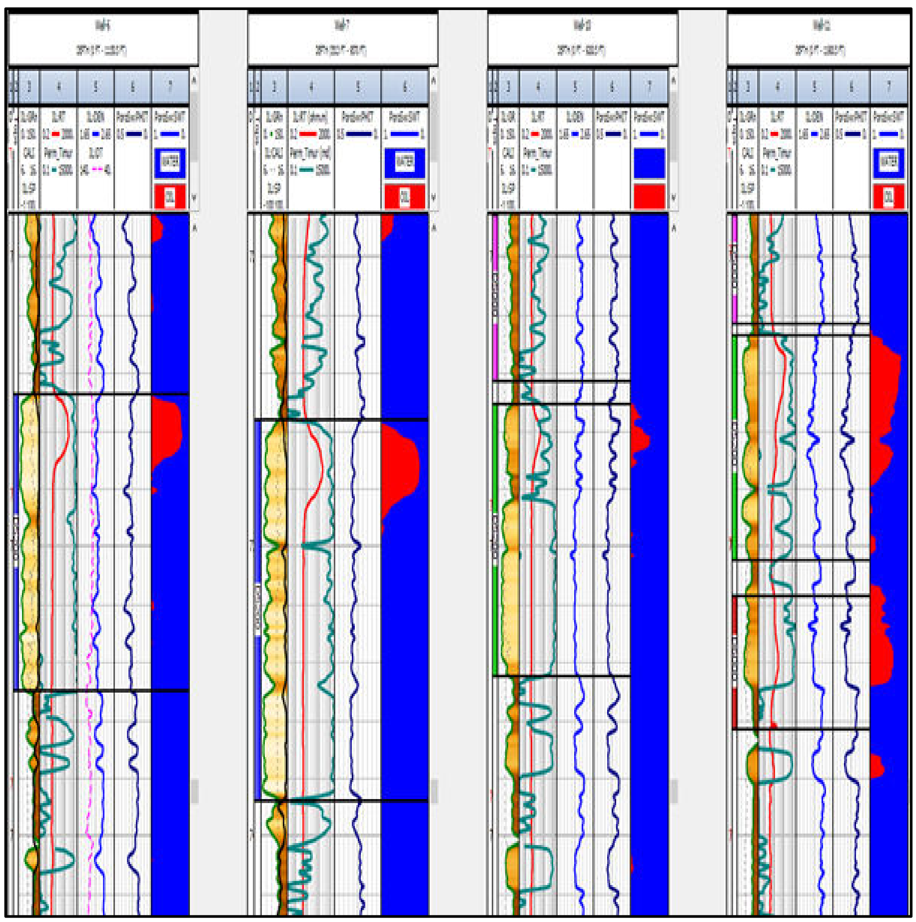

Figure 2. Identification of lithology and reservoirs of well 6, 10 and 11

Table 2. Fluid Contacts From Logs Summary Table

WELL STATUS	WELL-6	WELL-7	WELL-10	WELL-11
TOP	7386	7404	7384	7337
BASE	7488	7554	7484	7419
THICKNESS				
GUT				
GDT				
GOC				
OUT				
PERF1 TOP				
PERF1 BASE				
PERF2 TOP				
PERF2 BASE				
PERF3 TOP				
PERF3 BASE				
PERF4 TOP				
PERF4 BASE				
PERF5 TOP				
PERF5 BASE				
PERF6 TOP				
PERF6 BASE				
ODT			7430	7419
GWC				
OWC	7432	7436		
WUT			7436	

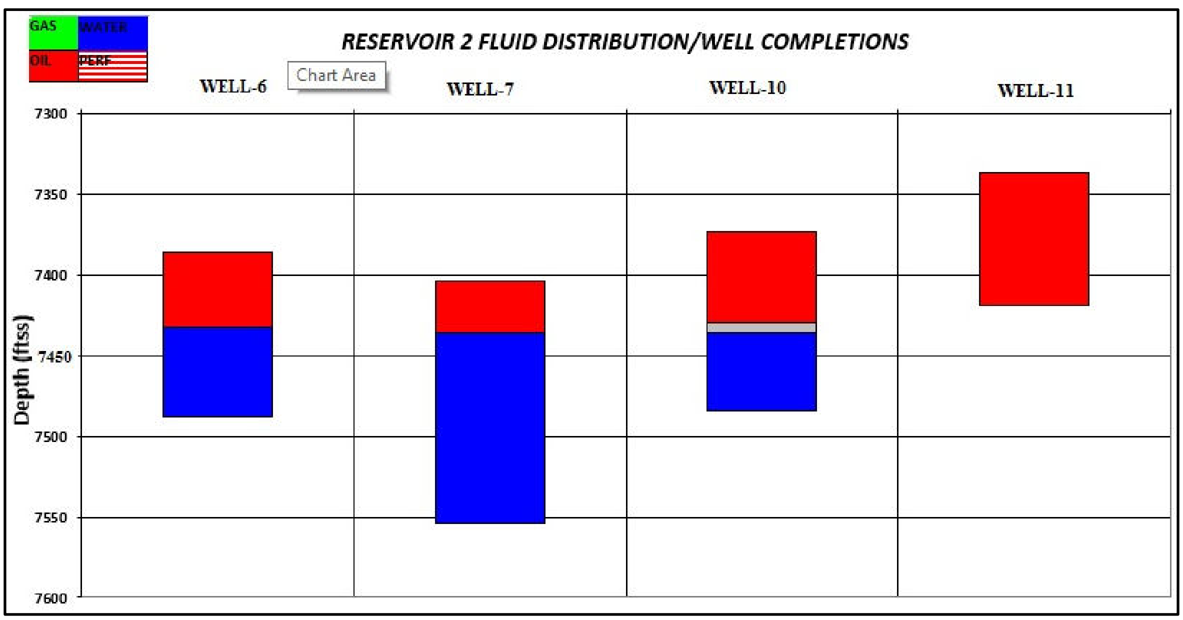

Figure 3. Fluid distribution plot across the wells

Figure 4. Porosity cross plot

Figure 5. Permeability cross plot

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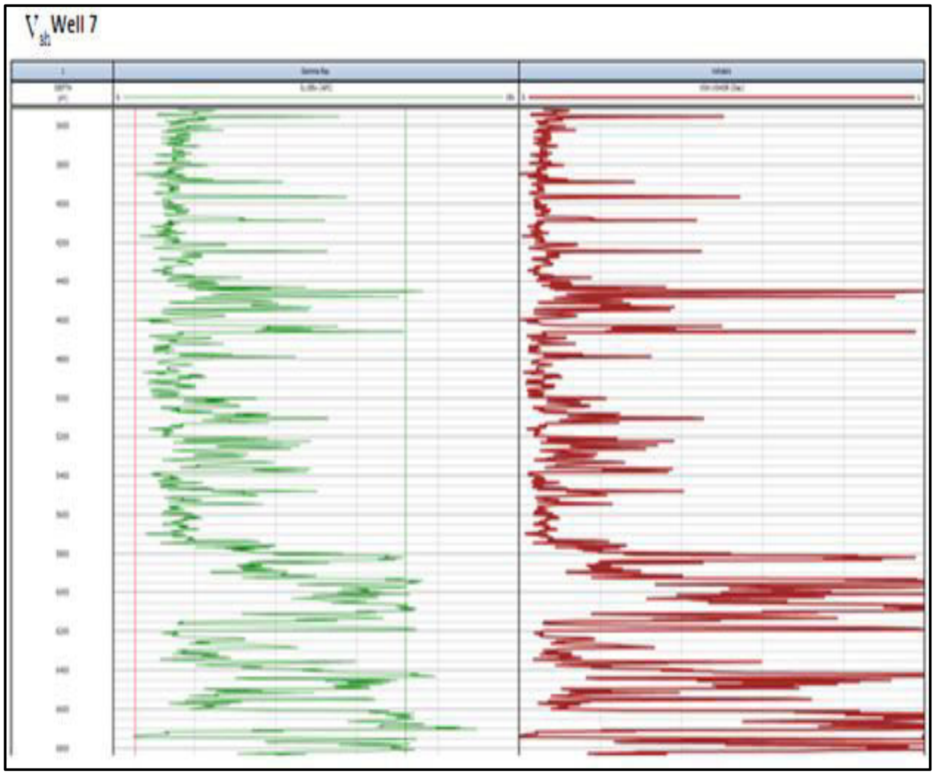
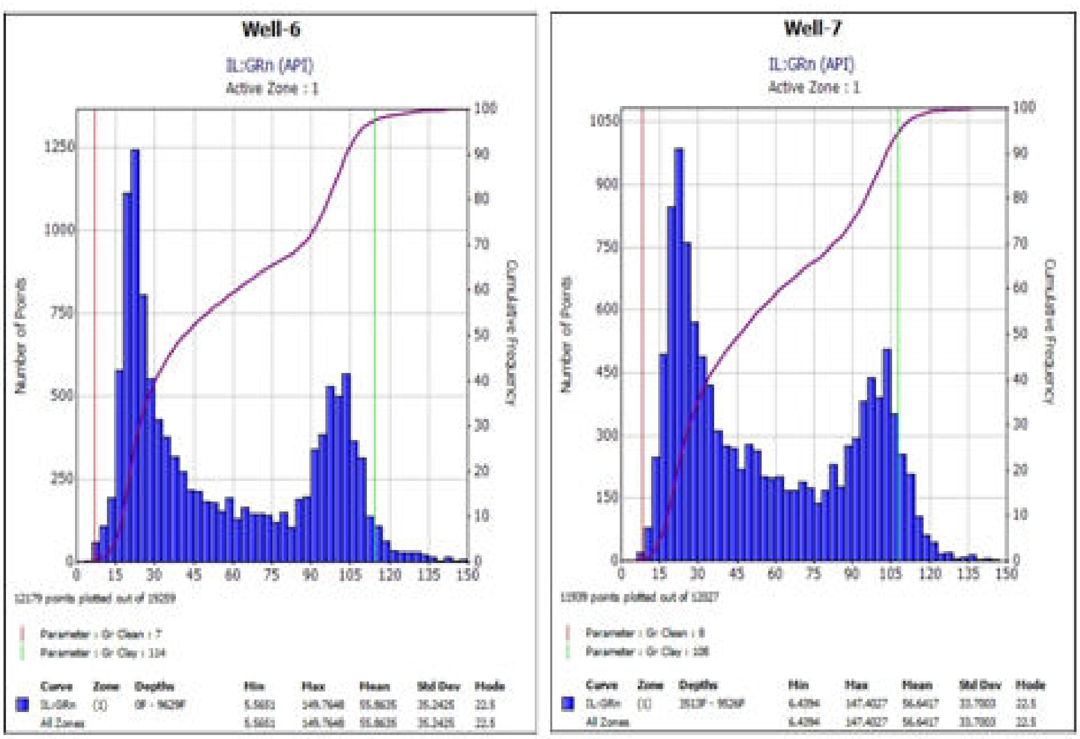


Figure 6. Transposed volume of shale cross plot



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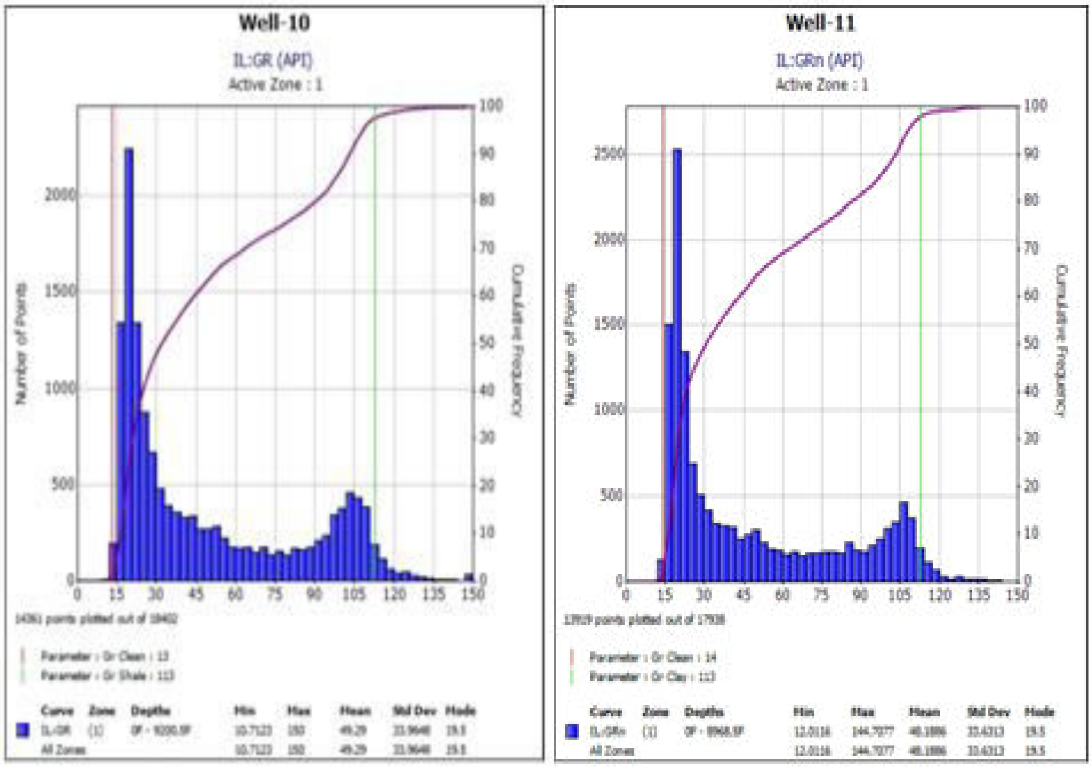

Figure 7. Shale volume Histogram cross plot of well 6, 7, 10 and 11

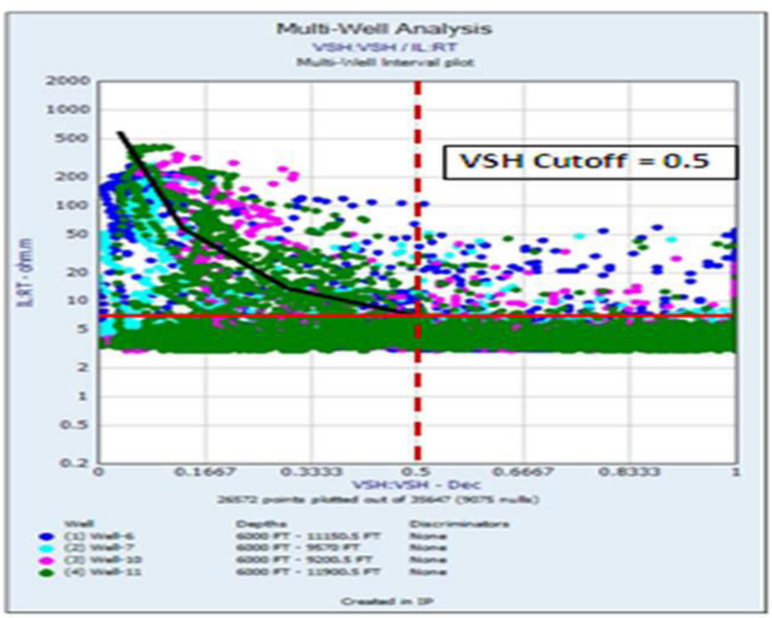

Figure 8. Net to gross determination plot

3.1 Well 6

In Table 3, the outcome of the calculation of some Petrophysical parameters for identified reservoir D5200, D7000 and E8000 which cut across K-field well 6 are shown. The reservoirs were penetrated at depths of 7244-7350m for D5200, 7468-7570m for D7000, 8841-9079m for E8000. It poses a gross thickness that ranges from 106,101 through to 238. Net thickness then ranges from 102,91 and 170, the NTG are 0.969, 0.897 and 0.716. The reservoirs also have an average porosities value ranges from 28, 34, 18 with permeability values ranges 7958, 4547, 840md. The S_w is as follows; 30, 3, 28% and S_h have values of 70, 72 and 97% respectively. The φ value obtained from reservoir 1 spanning through the two wells shows rating of good till excellent, while the K_a value being high is an indication of an excellent condition that can permit the fluid's flowing freely in reservoirs. The S_h points towards a quite high HC proportion in juxtaposition to S_w within the studied reservoir. That is to say that all the reservoirs are HC saturated reservoirs.

Table 3. Summary table containing computed petrophysical parameters gotten for well 6

Well	Zone	Top	Bottom	Gross	Net	NTG	Porosity (%)	SW (%)	Permeability (Md)	Sh	Vsh
6	D5200	7244	7350	106	102	0.969	28	30	7958	70	0.093
	D7000	7468	7570	101	91	0.897	34	3	4547	97	0.24
	E8000	8841	9079	238	170	0.716	18	28	840	72	0.193

3.2 Well 7

The Petrophysical parameters for reservoir D5200, D7000, E8000 and F3000 well 7 are displayed in Table 4. The reservoirs were penetrated at the following depths; 7256-7388, 7493-7643, 8880-9128 and 9363-9500m respectively. It has gross thickness ranges 131, 150, 248, and 137m, net thickness ranges 127, 139,186, and 109m, net to gross ranges from 0.97, 0.924, 0.752 and 0.799, φ ranges from 30, 29, 28 and 28. The Sw are as follows; 32, 52, 27 and 53, and Sh ranges from 68, 48, 73, and47% respectively with V_{sh} of 0.096, 0.18, 0.193 and 0.177. The φ values obtained across well 7 in the reservoirs indicates quite good values. Furthermore, the K_a showed some values deemed to be excellent. The HC ratio to the S_w indicates that this particular reservoir poses quantities of both water and HC, with HC slightly of a higher quantity than the S_w.

Table 4. Summary table containing petrophysical parameters gotten for well 7

Well	Zone	Top	Bottom	Gross	Net	NTG	Porosity (%)	SW (%)	Permeability (Md)	Sh	Vsh
7	D5200	7256	7388	131	127	0.97	30	32	7020	68	0.096
	D7000	7493	7643	150	139	0.924	29	52	4947	48	0.18
	E8000	8880	9128	248	186	0.752	28	27	3568	73	0.193
	F3000	9363	9500	137	109	0.799	28	53	3590	47	0.177

3.3 Well 10

Table 5 shows petrophysical parameters for well 10, reservoir D5200, D7000 and D8000. The reservoirs were penetrated at 7251-7345, 7460-7571, and7592-7664m respectively with gross thickness ranges 94, 111 and 72m, the net thickness are 85, 86 and 62m, N/G ranges 0.91, 0.776, and 0.868. Reservoirs have porosity of 29, 29, 30 and permeability values ranges 5076, 2459, 3701md respectively. S_w values are 60, 26, and 76%, while the S_h values are 40, 74 and 24%. The V_{sh} for the three reservoirs are 0.14, 0.249, and 0.185. The φ values are good to very good indicating a porous unit of sandstone and the K_a value reveals quite good interconnectivity existing between the pore spaces. The S_w and S_h revealing that quantities of both HC and water are existing in the studies reservoirs with HC being of a lower ratio in reservoirs D5200 and D8000.

Table 5. Summary table for the computed Petrophysical parameters gotten for well 10

Well	Zone	Top	Bottom	Gross	Net	NTG	Porosity (%)	SW (%)	Permeability (Md)	Sh	Vsh
10	D5200	7251	7345	94	85	0.91	29	60	5076	40	0.14
	D7000	7460	7571	111	86	0.776	29	26	2459	74	0.249
	D8000	7592	7664	72	62	0.868	30	76	3701	24	0.185

3.4 Well 11

Table 6 holds the result for some Petrophysical parameters that have been computed for reservoir D5200, D7000 and D8000 which cut across K-field well 11. The reservoirs were penetrated at depths of 7227-7306m for D5200, 7460-7571m for D7000, 7551-7608m for D8000. It poses gross thickness values of 79, 82 and 57. Net thickness values of 71, 71 and 45, the NTG thickness are 0.902, 0.861 and 0.803. The reservoirs also have an average porosities value ranges from 30, 28, 27 with permeability values ranges 4073, 1640, 1008md. The S_w is as follows; 38, 41, 64% and S_h values of 62, 59, and 46% respectively. The φ value gotten within reservoirs spanning across the two wells show a rating deemed to be good or excellent, while the high K_a value obtained indicates excellent values that permit fluid's free flow within the reservoirs except reservoir D7000 and D8000 which is fairly good. The S_h indicates high proportions of HC to the water quantity in reservoir D5200 and D7000. Therefore, all the reservoirs are HC saturated reservoirs.

Table 6. Summary table containing the petrophysical parameters computed for well 11.

Well	Zone	Top	Bottom	Gross	Net	NTG	Porosity (%)	SW (%)	Permeability (Md)	Sh	Vsh
11	D5200	7227	7306	79	71	0.902	30	38	4073	62	0.229
	D7000	7437	7519	82	71	0.861	28	41	1640	59	0.311
	D800O	7551	7608	57	45	0.803	27	64	1008	36	0.321

The summary of Petrophysical parameter averages of the respective reservoirs are as presented in Table 7.

Table 7. Average Petrophysical parameters for reservoirs

Zone	Top	Bottom	Gross	Net	NTG	Porosity (%)	SW (%)	Sh (%)	Permeability (Md)	Vsh
D5200	7244	7347	102	96	0.937	29	40	60	6031	0.139
D7000	7464	7575	111	96	0.864	30	30	70	3398	0.245
D8000	7571	7636	64	53	0.835	28	70	30	2354	0.253
E8000	8860	9103	243	178	0.734	23	27	73	2204	0.193
F3000	9363	9500	137	109	0.799	28	53	47	3390	0.177

3.5 Reservoir classification

Table 7 presents the average result summary of the pivotal petrophysical parameters that have been made use of as variables in this study to determine the quality of encountered reservoirs. These parameters were then taken through varying statistical analytical methods by taking their obtained values into consideration in all the reservoirs identified across the four studied wells within the studied area and in turn were then used for ranking of the delineated reservoirs. The five reservoirs were then classified or ranked as shown in Figure 9 using the petrophysical parameter average results. It is on this premise that reservoir E8000 is ranked as the most promising or prolific, while D8000 is ranked the least promising in the K-field. Similarly, ranking reservoir statistically using average permeability shows in figure 10 that reservoir 5200 is the most permeable, while reservoir E800 is the least permeable.

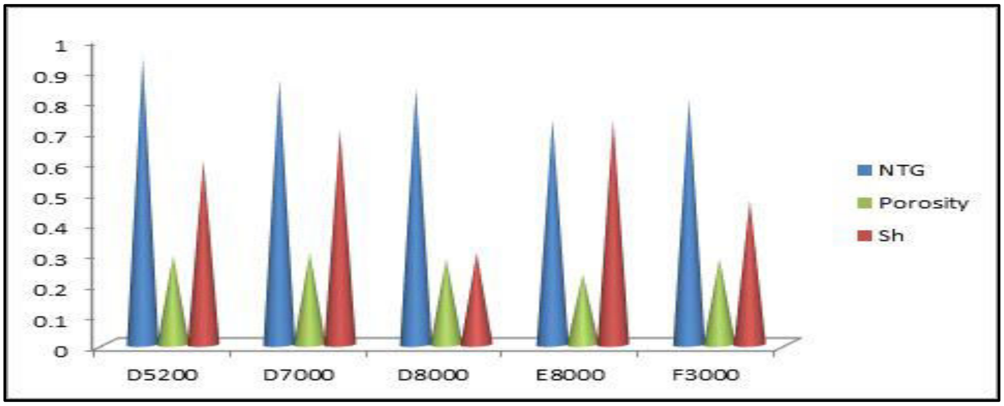

Figure 9: Statistical analysis of reservoir ranking using average Petrophysical parameters

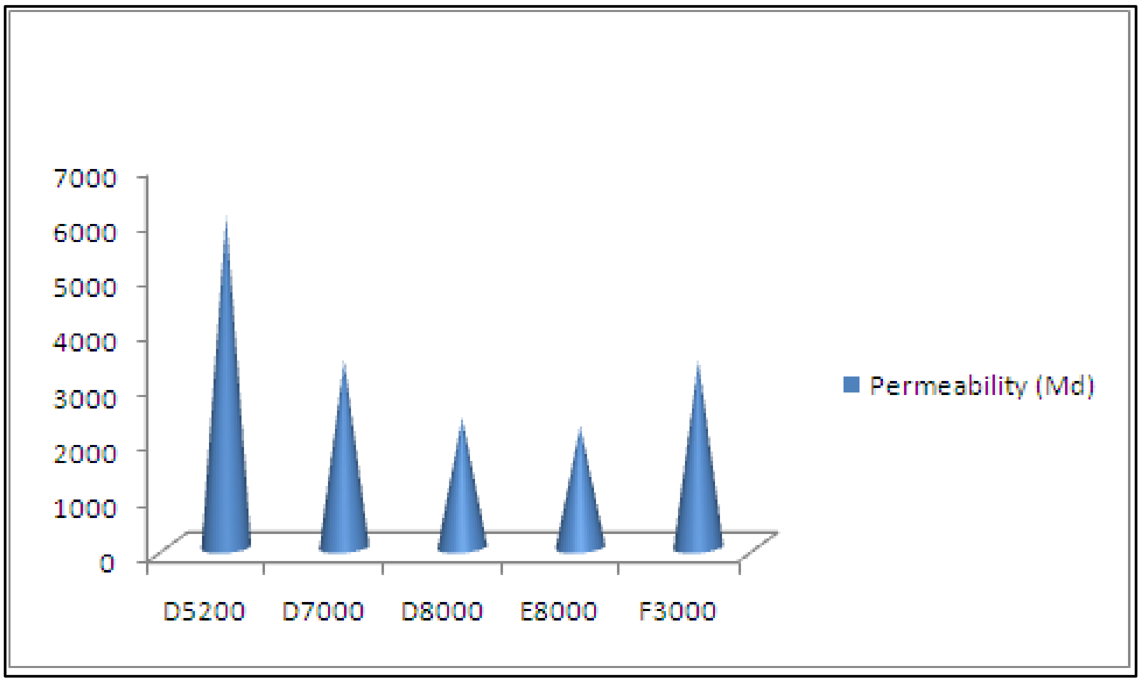

Figure 10: Statistical analysis using average permeability

CONCLUSION

The reservoir characterization of K-field, NDB has been done in this study. Five HC reservoirs from the studied wells were then identified. Also, the lithologies that were deciphered through the use of the GR log were two in number; sand and shale. Each sand unit from the analysis is shown to extend throughout the span of the field, nonetheless having variable thickness, with some of the units are occurring at some depth that is greater than their contiguous units. The layers of shale in the wells were also observed to increase notably with increasing depth alongside corresponding decreases recorded in

the units of sand in D7000 and D8000. Particularly from resistivity log in the analytical suite, all of the five delineated reservoirs then were identified to be HC bearing units throughout the span of the four studied wells, i.e well 6, 7, 10 and 11. Reservoir parameters such as φ, gross thickness, S_h, K_a, NTG and S_w on an average were derived from the analysis of petrophysical parameters. The five reservoirs aforementioned were then ranked from the average results gotten for these same petrophysical parameters. E8000 is then deemed on this premise to be most promising, then D8000 on the same premise is ranked the least prolific within K-field. From these above stated results, therefore we can then posit that K-field poses the potential for exploitable HC.

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