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Petro physical analysis of wells in explorer field, offshore Niger delta, Nigeria using well log and core data

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Abstract

Petro physical Analysis of Wells in Explorer Field Offshore Niger Delta, Nigeria is the focus of this research. Data used in this research well logs and core data that were integrated to evaluate the reservoir characteristics of Explorer Field. The objectives of this research is to determine lithology, shale volume (V_{sh}), porosity (Φ), permeability (K), fluid saturation and cross plotting of petro physical and core values at specific intervals to evaluate their level of correlation. Twelve hydrocarbon-bearing reservoirs from three wells were in this research. The average permeability value of the reservoirs is 20.0140md while porosity value ranges between 18%-39%. Fluid type defined in the reservoirs based on neutron/ density log signature indicates water, oil and gas, low water saturation values ranging from 2.9% to 46% in Explorer wells indicate high hydrocarbon saturation. The Pearson Correlation Coefficient and Regression Equation gave a significant relationship between petro physical derived data and core data. Scatter plot of petro physical gamma ray values versus core gamma ray values gave an approximate linear relationship with correlation coefficient values of 0.6642, 0.9831 and 0.3261. Cross plots of well log determined density values and core density values revealed that there is a strong linear relationship between the two sets of data set with correlation coefficient values of 0.7581, 0.9872 and 0.3557, and the regression equation confirmed the relationship between the two data sets. In addition, the scatter plot of well log derived porosity/density values versus core porosity/ density values revealed a strong linear relationship between the two data sets with correlation coefficient values of 0.7608 and 0.9849; the regression equation confirmed this also. Cross plots of well log derived porosity/density values versus core porosity/density values in Well 3 gave very weak correlation coefficient values of 0.3261 and 0.3557 with a negative slope. The petro physical properties of the reservoirs in Explorer Well showed that they contain hydrocarbon in commercial quantity and the cross plot of the petro physical and core values showed direct relationship in most of the wells.

Keywords: petro physics, correlation, regression, reservoirs, characterization, hydrocarbon and saturation

Introduction

Hydrocarbon accumulations have been found to occur in pore spaces of reservoir rocks. Petro physical parameters such as porosity, permeability, hydrocarbon saturation, and thickness can be inferred from various well logs [1]Explorer Field lies in the Gulf of Guinea 120 kilometers from the coast of Nigeria (Figure 1).The geology, the stratigraphic, structural framework, petroleum geology and petroleum systems of the Niger Delta is well established[2] Reijers, Kulke, Ekweozor & Daukoru,[3–7] Haack *et al.*[8,9] Whiteman,[10] In addition, the following have undertaken a lot of work on various aspects of Petro physics, sedimentology, structural geology and reservoir studies of the Niger Delta.

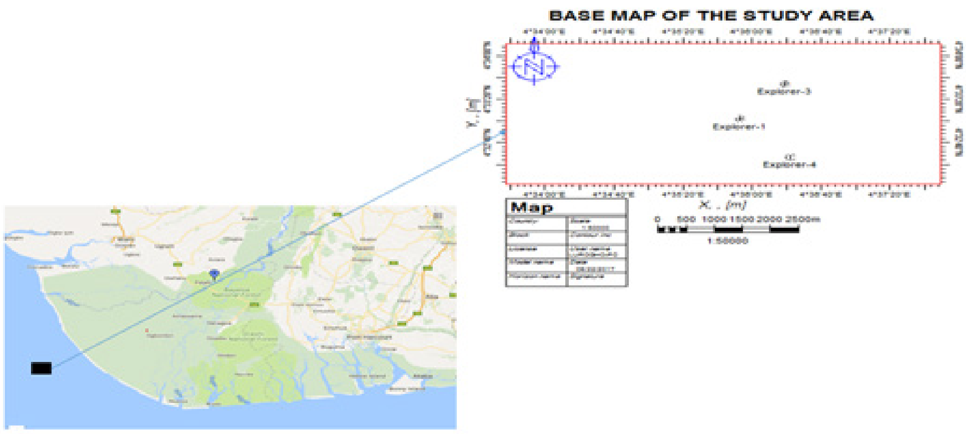

Figure 1 Location and base map of EXPLORER field showing location of the wells.

Materials and methods

Geophysical well log interpretation and core description has been carried out on the wells of Explorer Field, concise qualitative and quantitative evaluation were done on the well by first identifying the sand and shale using the gamma ray log, and next compare zones of sandstone with the corresponding resistivity log by identifying sandstone to be of high resistivity and shale to be of low resistivity, the porosity log was then used in identifying the fluid contact. By using empirical petro physical formula, the petro physical values were computed which enables in differentiating the oil-bearing reservoir from water bearing reservoir (Figure 3.1), the porosity log also confirms the nature of the reservoir. The core data in excel format were then compared with the computed petro physical values using excel software, at depth where all the core data corroborated with the petro physical values, Cross plots was done and comparison was done using statistical approach.

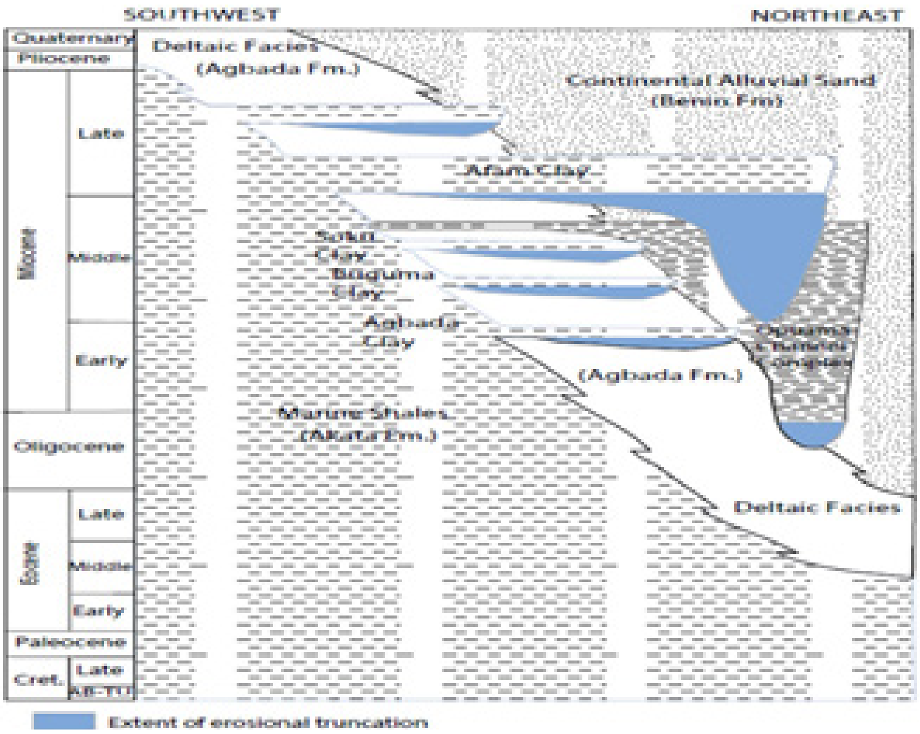

Figure 2 Stratigraphic Column showing the three Formations of the Niger Delta.[2]

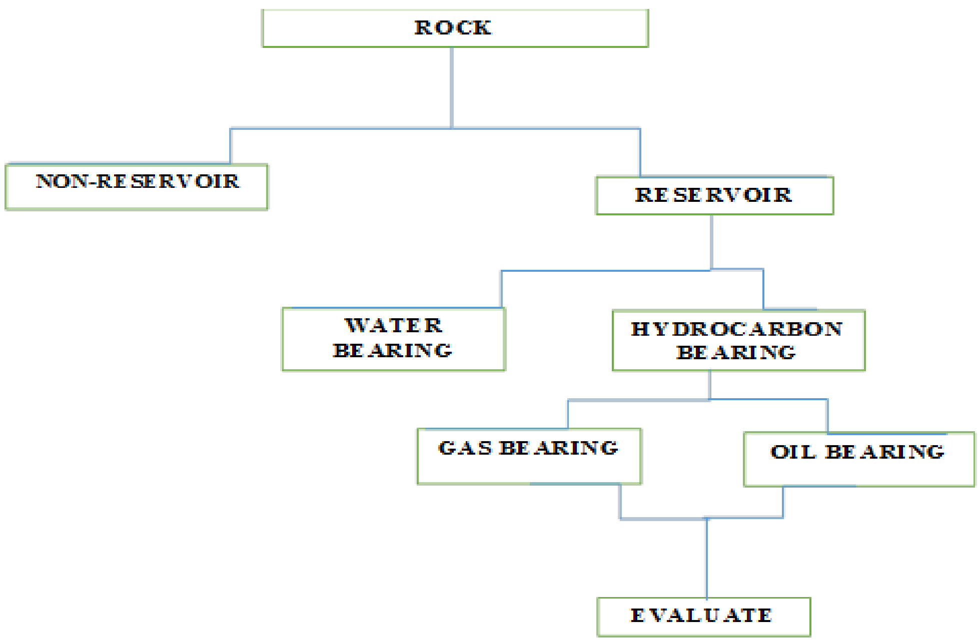

Figure 3 Workflow for petrophysics analysis.

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Shale volume estimation

Shale volume (Vsh) was calculated using the [8] formula in equation (1) which uses values from the gamma ray (GR) in equation (2)

$$V_{sh} = 0.083[2^{(3.17\times I}GR^{)} - 1.0 \quad 1$$

$$I_{GR} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}} \quad 2$$

In equation (2), I_{GR} is the gamma ray index, GR log is the picked log value while GR minimum and GR maximum indicate values picked in the sand and shale base lines respectively.

(Figure 3) Workflow for petro physics analysis

Determination of porosity

Porosity, ϕ_{DEN} is defined as the percentage of voids to the total volume of rock. According to[8] this parameter is determined by substituting the bulk density readings obtained from the formation density log within each reservoir into equation (3)

$$\phi_{DEN} = \left(\frac{pma - pb}{pma - pf}\right) \quad 3$$

Where ℓ_{ma}, ℓ_{b} and ℓ_{f} are matrix density, formation bulk density and fluid density respectively.

Calculation of water saturation

To calculate water saturation, S_w of un invaded zone, the method used requires a water resistivity Rwvalue at formation temperature calculated from the porosity and resistivity logs within clean water zone, using the Ro method given by the following equation

$$s_W = \left(F \times \frac{R_W}{R_t}\right)^{1/n}$$

Where; F: Formation Factor, R_w: Formation water resistivity at formation temperature, R_t: True formation resistivity, n: Saturation exponent. This was given to be 2. 0.

Determination of hydrocarbon saturation

Hydrocarbon Saturation, S_h is the percentage of pore volume in a formation occupied by hydrocarbon. It can be determined by subtracting the value obtained for water saturation from 100% i.e.

$$S_h = (100 - SW)\%$$

Calculation of permeability

Permeability, K is the property of a rock to transmit fluids. For each identified reservoir permeability, K is calculated using equation 6

$$k^{1/2} = \frac{250\times\phi^3}{s_w irr}$$

Where Swiris the irreducible water saturation [11]

Results and discussion

The results of this research are presented in (Figures 4–25) and (Tables 2–5).the petro physical parameters have computed based on well logs and core data for the reservoirs of interest (Reservoirs A–E). The parameters compute dare porosity, permeability, Net-to-Gross, volume of shale, hydrocarbon saturation, water saturation and irreducible water saturation, using empirical petro physical equations (Equations 1–6). The subsurface lithologies were mapped and interpreted using Gamma Ray log which indicate low values for sand and high for shale. Litho logy identification of the reservoir sands were marked throughout the wells and resistivity logs were used to indicate the fluid type in the reservoirs. Petro physical parameters such as porosity (ϕ), permeability (k), Volume of shale (V_{sh}), Water saturation (S_w), Hydrocarbon saturation (S_h), Irreducible water saturation (S_{wirr}) etc. were evaluated and the results presented in graphical format (Figures 13–25) and Tables (Tables 1–6). Based on the qualitative and quantitative interpretations, five (5) reservoirs sand were identified throughout four (4) wells. The depth (m) interval and thickness of the reservoirs range from 5.62–42.77m. See (Table 2).

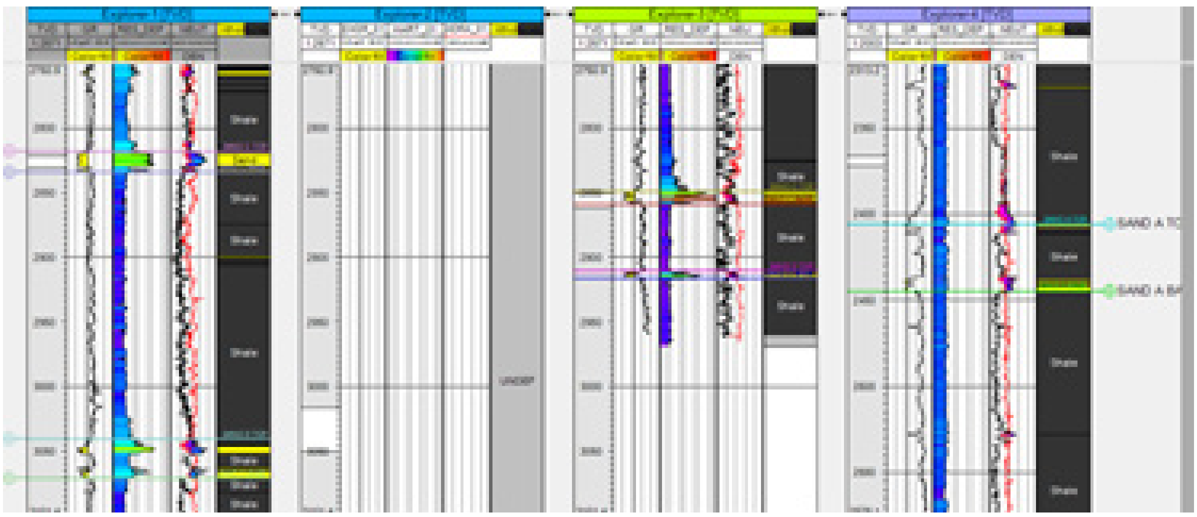

Figure 4 Log responses to the Explorer sandstone lithology.

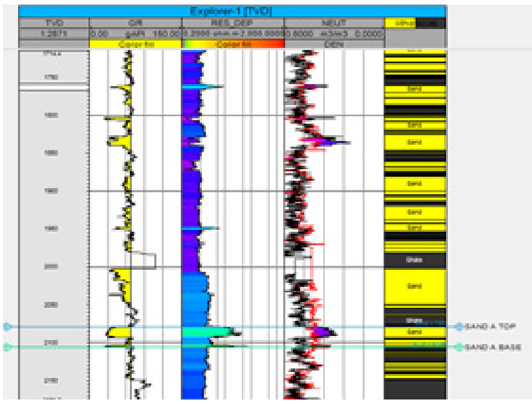

Figure 5 Well 1 reservoir A.

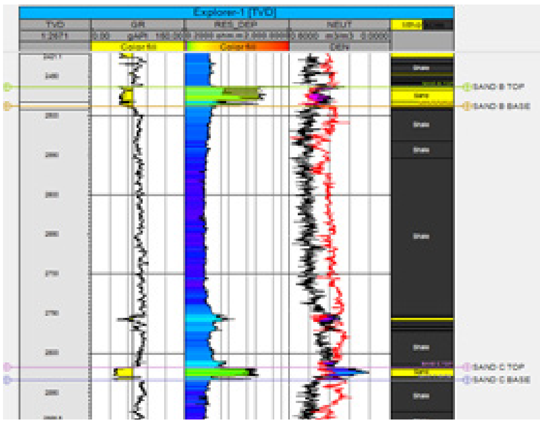

Figure 6 Well 1 reservoir B and C.

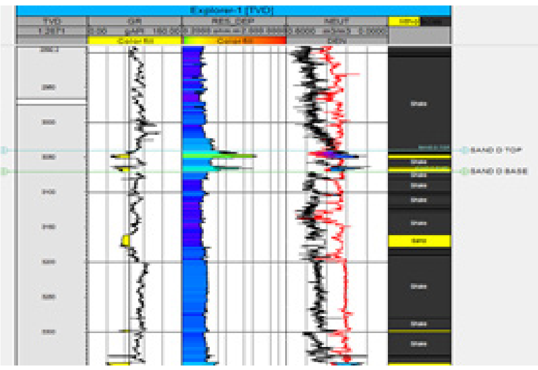

Figure 7 Well 1 reservoir D.

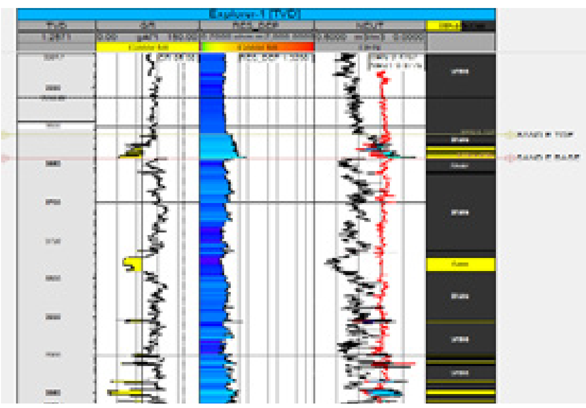

Figure 8 Well 1 reservoir E.

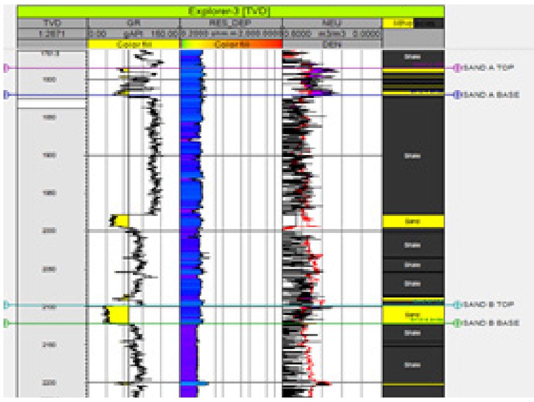

Figure 9 Well 3 reservoir A and B.

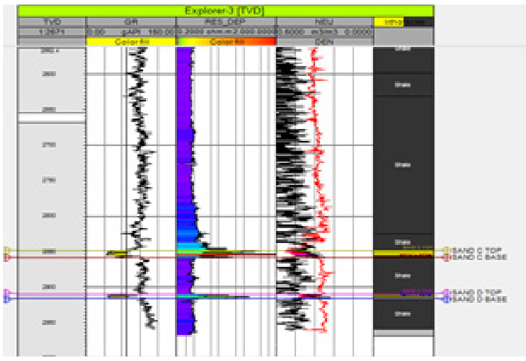

Figure 10 Well 3 reservoir C and D.

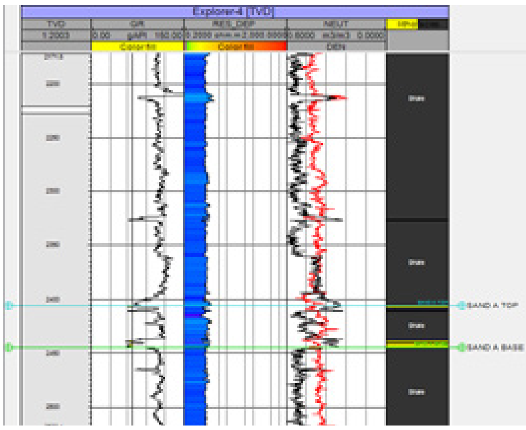

Figure 11 Well 4 reservoir A

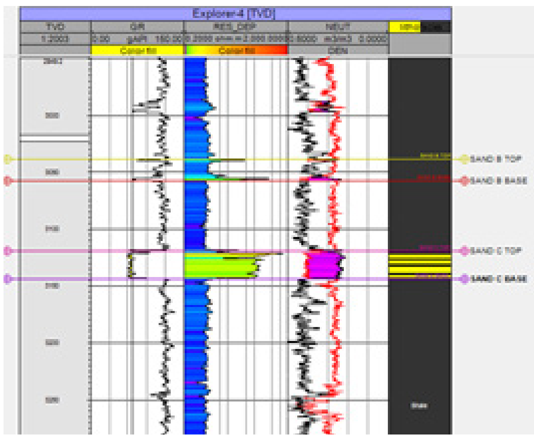

Figure 12 Well 4 reservoir B and C.

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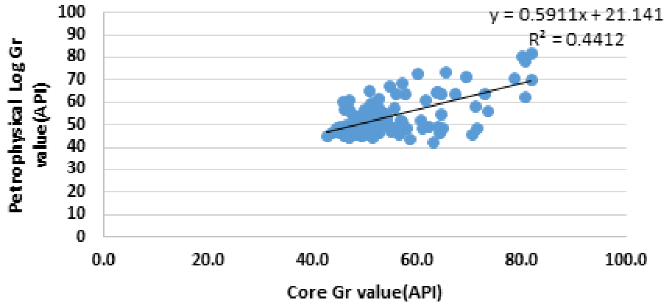

Figure 13 GR petrophysical log data versus GR core data for well 1 reservoir B.

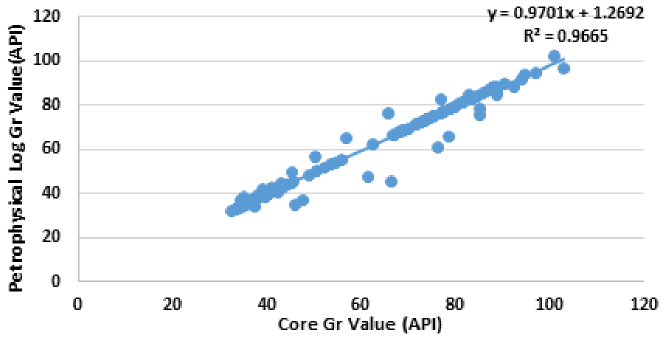

Figure 14 GR petro physical log data versus GR core data for well 3 reservoirs C and D.

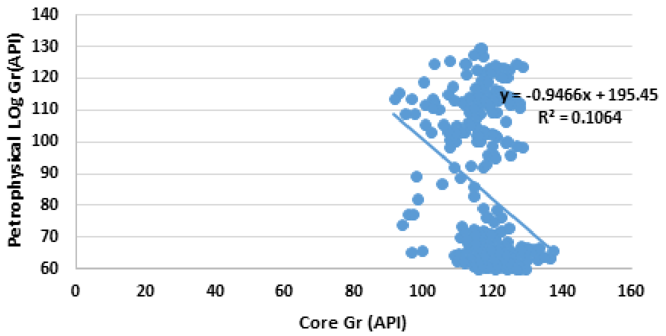

Figure 15 GR petro physical log data versus GR core data for well 4 reservoirs B and C.

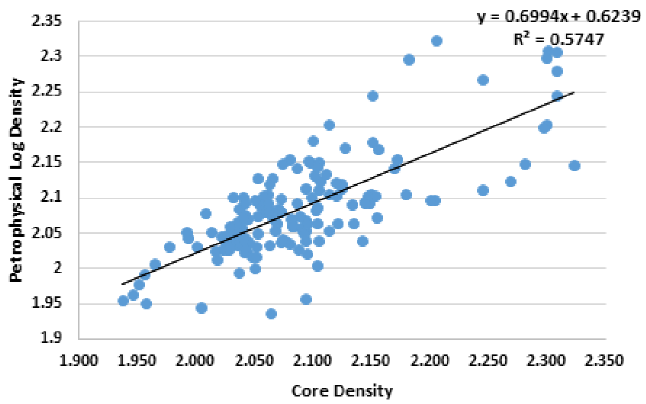

Figure 16 Density petrophysical log data versus Density core data for well 1 reservoir B.

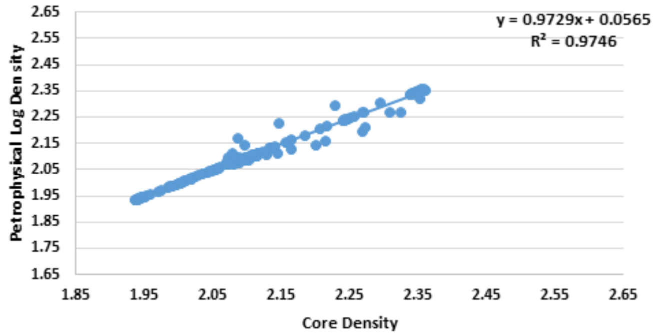

Figure 17 Density petrophysical log data versus density core data for well 3 reservoirs C and D.

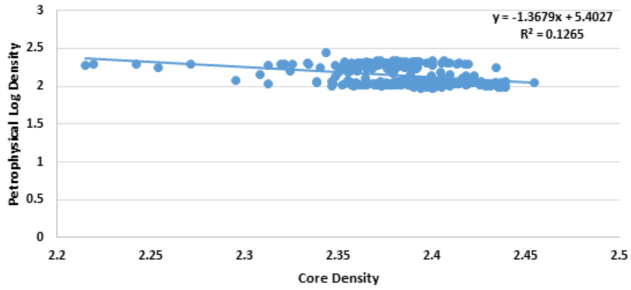

Figure 18 Porosity-Density Petrophysical log data versus Porosity-DensityCore data for well 4 reservoirs B and C

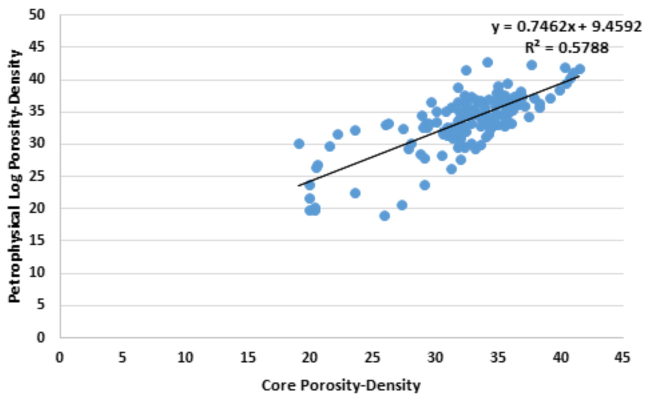

Figure 19 Porosity-Density Petrophysical log data versus Porosity-Density Core data for well 1 reservoir B.

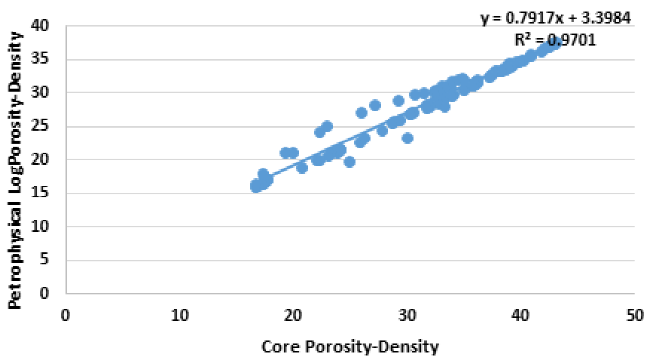

Figure 20 Porosity-Density Petro physical log data versus Porosity-Density Core data for well 3 reservoirs C and D.

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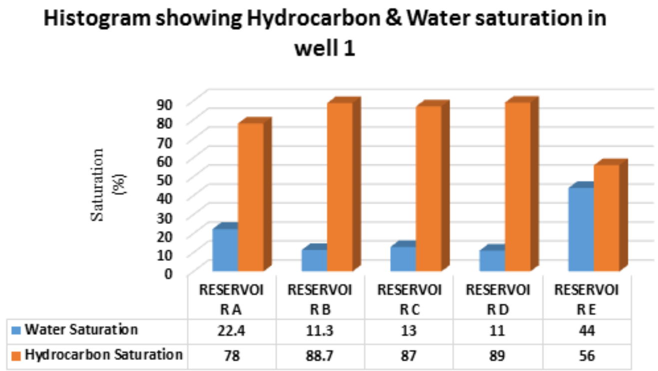

Figure 21 Histogram showing hydrocarbon and water saturation in well 1.

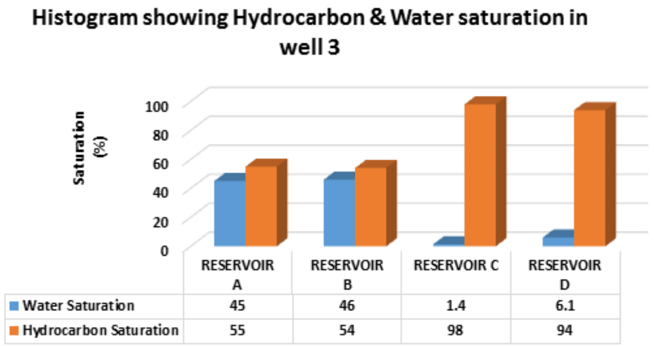

Figure 22 Histogram showing hydrocarbon and water saturation in well 3.

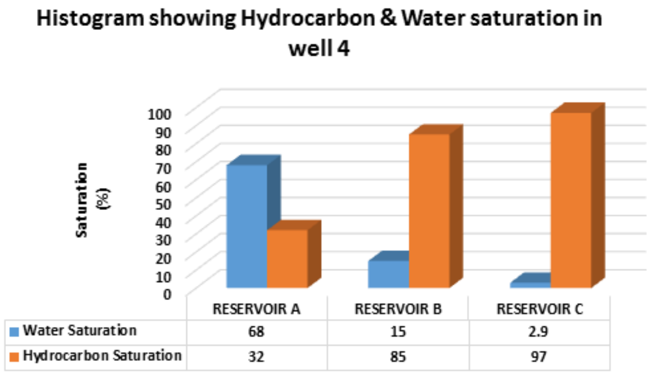

Figure 23 Histogram showing hydrocarbon and water saturation in well 4.

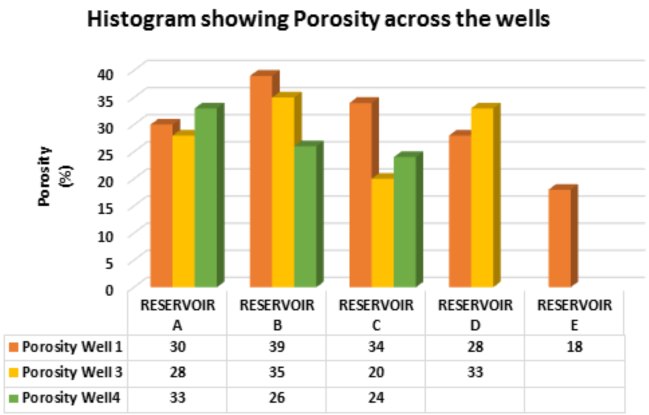

Figure 24 Histogram showing porosity across well 1, 3 and 4.

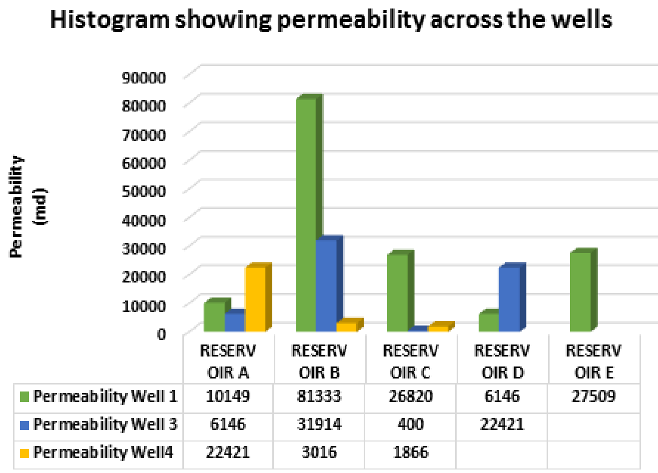

Figure 25 Histogram showing permeability across well 1, 3 and 4.

Table 1 Porosity and Permeability values for Reservoirs Qualitative Description (Adapted from Rider, (1986)

Qualitative evaluation of porosity	
Percentage porosity(%)	**Qualitative description**
0.5	Negligible
5-10	Poor
15-20	Good
20-30	Very Good
>30	Excellent
Qualitative evaluation of permeability	
Average km value(md)	**Qualitative description**
<10.5	Poor to fair
15-50	Moderate
50-250	Good
250-1000	Very Good
>1000	Excellent

Table 2 Depth intervals (m) – range and average depths in backets

Well	Sand a(m)	Sand b(m)	Sand c(m)	Sand d(m)	Sand e(m)
EXPLORER 1	2077.14-2104.94	2462.78-2487.52	2817.80-2834.75	3040.39-3070.78	3611.20-3641.62
	-27.8	-24.71	-16.95	-30.39	-30.42
EXPLORER 3	1784.47-1820.52	2098.20-2122.14	2845.78-2858.01	2909.94-2915.56	
	-36.05	-23.94	-12.23	-5.62	
EXPLORER 4	2401.83-2444.60	3038.59-3057.11	3118.41-3143.54		
	-42.77	-18.52	-25.13		

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Table 3 Computed petrophysical parameters for well 1

Explorer 1					
Parameters	Reservoirs				
	sand a	sand b	sand c	sand d	sand e
NET/GROSS (%)	100	96.9	82	71	76.1
IGR	0.147	0.29	0.15	0.12	0.17
Vsh (%)	2	9	3	2.9	4.6
Sw (%)	22.4	11.3	13	11	44
Sh (%)	78	88.7	87	89	56
ϕ (%)	30	39	34	28	18
K(md)	10,149.80	8,333.30	26820.6	6,146.56	27,509

Table 4 Computed petrophysical parameteor well 3

Explorer 3				
Parameters	Reservoirs			
	sand a	sand b	sand c	sand d
NET/GROSS (%)	58	87	92	70
IGR	0.214	0.637	0.04	0.22
Vsh (%)	6	3.4	9	6.1
Sw (%)	45	46	1.4	6.1
Sh (%)	55	54	98	94
ϕ (%)	28	35	20	33
K(md)	6,146.56	31,914.30	400	22,421.30

Table 5 Computed petrophysical parameter for well 4

Explorer 4			
Parameters	Reservoirs		
	sand a	sand b	sand c
NET/GROSS (%)	35	21	95
IGR	0.95	0.065	0.15
Vsh (%)	86	1.5	4
Sw (%)	68	15	2.9
Sh (%)	32	85	97
ϕ (%)	33	26	24
K(md)	22,421.30	3,016.80	1,866.24

Well 1 reservoir A

Reservoir A Well 1 (Figure 5) is a hydrocarbon reservoir. The reservoir is within 2077.14m to 2104.94m (Table 2) with NTG of 100% and volume of shale (V_{sh}) value of 2%, while the hydrocarbon saturation (S_h) is 78% with porosity (ϕ) value of 30% which indicate that the reservoir is excellent, an absolute permeability (K) of 10,149.8md. These petro physical parameters computed indicate that the reservoir contains only oil.

Well 1 reservoir B

Reservoir B Well 1 (Figure 6) is a hydrocarbon reservoir. The reservoir is within 462.78m to 2487.52m (Table 2) with NTG of 96.9% and volume of shale (V_{sh}) value of 9%, while the hydrocarbon saturation (S_h) is 88.7% with porosity (ϕ) value of 39% which indicate the reservoir is excellent with an absolute permeability (K) of 8.333.3md. All the petro physical parameters computed and also the cross plot of the neutron density log indicate that the reservoir is oil.

Well 1 reservoir C

Reservoir C Well 1 (Figure 6) is a hydrocarbon reservoir. The reservoir is within depths of 2817.80m to 2834.75m (Table 2) with NTG of 82% and volume of shale (V_{sh}) value of 3%, while the hydrocarbon saturation (S_h) is 87% with porosity (ϕ) value of 34% which indicate the reservoir is excellent with an absolute permeability (K) of 26,820.6md. All the petro physical parameters computed indicate that the reservoir contains only oil and thus is prolific.

Well 1 reservoir D

Reservoir D Well 1 (Figure 7) is hydrocarbon reservoir. The reservoir is within depths of 3040.39m to 3070.78m (Table 2) with NTG of 71% and volume of shale (V_{sh}) value of 2.9%, while the hydrocarbon saturation (S_h) is 89% with porosity (ϕ) value of 28% which indicate that the reservoir is excellent with an absolute permeability (K) of 6,146.56md. All the petro physical parameters computed indicate that the reservoir contains only oil.

Well 1 reservoir E

Reservoir E for well 1(Figure 8) is hydrocarbon bearing reservoir. The reservoir is within depths of 3611.20m to 3641.62m (Table 2) with NTG of 76.1% and volume of shale (V_{sh}) value of 4.6%, while the hydrocarbon saturation (S_h) is 56% with porosity (ϕ) value of 18% which indicate excellent reservoir with an absolute permeability (K) of 27,509md.

Well 3 reservoirs A

Reservoir A for well 3 (Figure 9) is hydrocarbon reservoir. The reservoir is within depths of 1784.47m to 1820.52m (Table 2) with NTG of 58% and volume of shale (V_{sh}) value of 6.1%, while the hydrocarbon saturation (S_h) is 55% with porosity (ϕ) value of 28% which indicate the reservoir is excellent with an absolute permeability (K) of 6146.56md. All the petro physical parameters computed indicate that the reservoir is water bearing.

Well 3 reservoirs B

Reservoir B Well 3 (Figure 9) is hydrocarbon reservoir. The reservoir is within depths of 2081.79m to 2122.14m (Table 2) with NTG of 87% and volume of shale (V_{sh}) value of 34%, while the hydrocarbon saturation (S_h) is 54% with porosity (ϕ) value of 35% which indicate the reservoir is excellent with an absolute permeability (K) of 31914md. All the petro physical parameters computed indicate that the reservoir contains both oil and water, and the oil is not prolific.

Well 3 reservoirs C

Reservoir C Well 3 (Figure 10) is hydrocarbon reservoir. The reservoir is within depths of 2845.78m to 2858.01m (Table 2 with NTG of 92% and volume of shale (V_{sh}) value of 0.9%, while the hydrocarbon saturation (S_h) is 98% with porosity (ϕ) value of 20% which indicate the reservoir is excellent with an absolute permeability (K) of 400 md. All the petro physical parameters computed indicate that the reservoir contains only oil and is prolific, thus the reservoir can be put into production.

Well 3 reservoirs D

Reservoir D for well 3 (Figure 10) is hydrocarbon reservoir. The reservoir is within depths of 2909.94m to 2915.56m (Table 2) with NTG of 70% and volume of shale (V_{sh}) value of 6.1%, while the hydrocarbon saturation (S_h) is 94% with porosity (ϕ) value of 33% which indicate the reservoir is excellent with an absolute permeability (K) - 22421.3md. All the petro physical parameters computed indicate that the reservoir contains only oil and is prolific.

Well 4 reservoirs A

Reservoir A for well 4 (Figure 11) is hydrocarbon reservoir. The reservoir is within depths of 2401.83m to 2444.60m (Table 2) with NTG of 35% and volume of shale (V_{sh}) value of 86%, while the hydrocarbon saturation (S_h) is 32% with porosity (ϕ) value of 33% which indicate the reservoir is excellent with an absolute permeability (K) of 21.3md is gotten. All the petro physical parameters computed indicate that the reservoir contains water as the hydrocarbon saturation is very low.

Well 4 reservoirs B

Reservoir B for well 4 (Figure 12) is hydrocarbon reservoir. The reservoir is within depths of 3038.59m to 3057.11m (Table 2) with NTG of 21% and volume of shale (V_{sh}) value of 1.5%, while the hydrocarbon saturation (S_h) is 85% with porosity (ϕ) value of 26% which indicate the reservoir is excellent with an absolute permeability (K) of 3016.8md is gotten. All the petro physical parameters computed indicate that the reservoir contains only oil in small quantity.

Well 4 reservoirs C

Reservoir C for well 4 (Figure 12) is hydrocarbon reservoir. The reservoir is within depths of 3118.41m to 3143.54m (Table 2) with NTG of 95% and volume of shale (V_{sh}) value of 4%, while the hydrocarbon saturation (S_h) is 97% with porosity (ϕ) value of 24% which indicate the reservoir is excellent with an absolute permeability (K) of 1866.24md is gotten. All the petro physical parameters computed indicate that the reservoir contains gas only and also the Cross plots of the neutron-density curve give vivid evidence, as excellent porosity and permeability value also confirm this, thus it is recommended that the reservoir is put on production.

Comparison of core values with wire line values

Petro physical analysis results values were compared with core data using Pearson correlation coefficient and regression equation. The core analysis Gamma Ray values and the petro physical well log Gamma Ray values of wells in the Explorer Field showed significant similarity in Gamma Ray values. They show approximate linear relationship between the two variables. See (Figures 13-15). Though Well 4 gives an inverse relationship between the two data sets. The correlation coefficient r values of 0.6642, 0.9831 and 0.3261 were obtained for well 1 (reservoir B), well 3 (reservoirs C and D) and well 4 (reservoirs B and C) respectively, for well 1 a fairly strong linear relationship was observed, while Well 3 give very strong linear relationship, well 4 indicate a very weak relationship. A linear regression equation of y= 0.5911x + 21.141, y= 0.9701x + 1.2692 and y= -0.9466x + 195.45 were also computed for the petro physical log gamma ray values and core analysis gamma ray value in well 1 (reservoir B), well 3 (reservoir C and D) and well 4 (reservoir B and C) respectively, and were used to fit a regression line to the set of points (Figures 13, 14 and 15). The inverse relationship between the two data set for Well 4 account for the negative slope, which also leads to the weak correlation coefficient.

Comparison of petro physical density data and core density data

The core analysis density values and the petro physical log density values of the Explorer Wells studied revealed significant similarity in the density values determined from well log (density log) and core density data (See Figures 16 – 18). They showed approximate linear relationship between the two variables except for Well 4 which cut across reservoirs B and C having an inverse relationship. The correlation coefficient r values of 0.7581, 0.9872 and 0.3557 were obtained for Well 1 (reservoir B), Well 3 (reservoirs C and D) showed very strong correlation coefficient whereas Well 4 (reservoirs B and C) has a weak correlation coefficient respectively. The linear regression equations y= 0.6994x + 0.6239, y= 0.9729x + 0.0565 and y= -1.3679x + 5.0427 were also computed for the petro physical log density values and core analysis density value in Well 1 (reservoir B), Well 3 (reservoirs C and D) and well 4 (reservoirs B and C) respectively, and used to fit a regression line to the set of points (Figures 16- 18). The negative slope obtained from the Well 4 is as a result of the inverse relationship between the data set may account for the weak correlation coefficient.

The petro physical log porosity density values and the core analysis porosity density values of the reservoirs in Explorer well were plotted as a scatter diagram (Figures 19–20) show approximate linear relationships between the two variables. The correlation coefficient r values of 0.7608 and 0.9849 obtained for Well 1 (reservoir B) and Well 3 (reservoirs C and D) indicate a strong linear relationship. The linear regression equation of y= 0.7462x + 9.4592 and y= 0.7917x + 3.3984 computed for the petro physical log porosity density values and core analysis porosity density value in well 1 (reservoir B) and Well 3 (Reservoirs C and D) were used to fit a regression line to the set of points in (Figures 19 and 20).

Analysis of petro physical parameter estimation

Net/gross ratio has been used to define the proportion of the intervals considered reservoirs of interest aided in the understanding of the formation; this ratio reflects overall quality of the particular zone in question not minding its thickness. These intervals indicated areas/units where sand deposition is concentrated, and where better reservoir quality may be found with variations in the quality of sand. In attempting to distinguish net reservoirs and net pay intervals in the reservoirs of Explorer Field wells, cut-offs has been used, porous and permeable zones easily identified. Gamma ray, resistivity, neutron and density logs were used as indirect indicators of permeability Explorer Field reservoirs because core data are generally limited in extent and may not be relied on to define all net reservoir zones, hence, reliance was placed on the wire line log data indicate the presence of fluid invasion by mud filtrate. Low gamma ray reading indicated low shale content and higher permeability, while high neutron density porosity indicated high permeability. The average water saturation revealed the proportion of void space occupied by water in the Explorer Field reservoirs based on the calculations made, and showed that water saturation of the reservoirs are low except for Sand A Well 4 which is 68% thus, high hydrocarbon saturation and high hydrocarbon production.

Analysis of cross plots

Cross plots were carried out to show the relationship between log calculated values against those derived from core analysis data. The gamma ray log values were plotted against the core gamma ray values and this gives a direct relationship between the two data set except for the reservoir in well 4 which gives an inverse relationship between the two data, the inverse relationship is inferred based on the results of the core gamma ray data which might have loss its physical and chemical properties during analysis in the laboratory. The density log values were plotted against density core values, this plot shows that there is a consistent, straight line relationship between the two, except for the reservoirs in well 4 where both data sets show an inverse relationship which may be due to laboratory analysis of the core data. Each log shows the volume of shale in its own way. Though the straight line region, changes in porosity data which typically changes in shale volume content. However, in the very clean sandstones there are variations in porosity which may not be due to shale content and the relationship between the two log changes. The sands in the Explorer well reservoirs is oil filled, except for a particular reservoir in well 4 (reservoir C) which is gas filled.

Conclusion

Average k value of the reservoir is 20, 0140md while ϕ value ranges between 18% - 39%. Fluid type defined was basically water, oil and gas, low S_w indicates high Sh. The Pearson Correlation Coefficient and Regression Equation gave a significant relationship between petro physical derived data and core data.[11–15] Scatter plot of petro physical gamma ray values versus core gamma ray values gave an approximate linear relationship with correlation coefficient values of 0.6642. Cross plots of petro physical density values and core density values revealed that there is a strong linear relationship between the two data set with correlation coefficient values of 0.7581. Scatter plot of petro physical porosity density values versus core porosity density values revealed a strong linear relationship between the two data set with correlation coefficient values of 0.7608. These result reveals that the reservoir formation in has the capacity to produce economically when place on production, although some of the reservoir formations in the field, will be more prolific than others.

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Conflicts of interest

The authors declare that there is no conflict of interest

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