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HYDROCARBON RESERVOIR CHARACTERIZATION OF KOLO CREEK FIELD, CENTRAL NIGER DELTA

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ABSTRACT
There are different stages of exploration and development of a prospective reservoir which its characterization is one of the most important stages. It is important though to integrate result obtained from the characterization with other analyses in order to prevent doubtfulness. Results of the analyses in this study; was achieved using well logs obtained from the Kolo Creek field. The petrophysical parameters calculated includes the porosity, permeability, volume of shale and the volume of hydrocarbon in place using Schlumberger Petrel and the Python programming language software. The methodology encompasses the delineation and correlation of reservoir units across the wells using the gamma ray, resistivity, density and neutron well log suites. The result obtained from this study indicates that the reservoir units found in the area are economically viable and the formations seen in the area include sand and shale formations. Results can be used for future hydrocarbon reservoir evaluations of fields in the central Niger Delta and its environs with similar tectonic settings.

INTRODUCTION
Well log analyses comprise of the use of different petrophysical tools to describe the properties such as saturation, porosity, permeability, etc. of prospective reservoir units. It gives detailed information about the well logs obtained in the field and the hydrocarbon production potential by evaluating the prospective reservoirs. Analyses of well logs are carried out in order to correlate different zones, isopach mapping of depth and thicknesses of different zones determination. Before now, the method of hydrocarbon reservoir characterization was carried out based on a quick look method of log interpretation as well as analyses of the reservoir units' physical properties. Today, to characterize the lithology along with its fluid-content requires the use of quantitative techniques of well log studies i.e. reservoir parameters interpretation is no longer based on qualitative but quantitative measurements.

LOCATION OF STUDY AREA
The Kolo Creek field is situated in the Central Niger Delta Region of the Niger Delta Basin which is located in the Gulf of Guinea on the west coast of Africa between 6˚00' – 6˚51' East of the Greenwich meridian and 4˚00'– 5˚45' North of the Equator, Figure 1,(Adejuwon, 2012).

Geological Settings of the Niger Delta
The Niger Delta is a large, accurate delta of the destructive, wave dominated type which covers an area of about 256,000 km^2. The Niger Delta is situated on the Gulf of Guinea continental margin between latitudes 30˚and 60˚N and longitudes 50˚ and 80˚E (Murat, 1970), (Weber, 1971), (Reijers, 1996)). Starting as depocentres, the Niger Delta has coalesced to form a single system since Miocene (Short & Staublee, 1967). Delta construction proceeded in discrete mini-basins ranging in tectonic configuration from extensional, through translational to compressional toe-thrust regions. The Akata formation, composed of mainly shales and of Palaeocene age (63Ma), is the oldest amongst the Niger Delta formations. The shales of this formation are the source of the hydrocarbon rocks of the Niger Delta. The Agbada formation of Eocene to Recent age in the middle overlying the Akata formation consists of paralic sequences of sandstones and shales. The sandstone units constitute the hydrocarbon reservoir while the shales form the seal.

The Benin formation has the unit of superficial quaternary deposits overlying it. These deposits are either a relatively uniform lithology or an alternating sequence of recent deltaic sand, silt, clay-peat or sand-silt-clay mixtures, the presence of clay and peat becoming increasingly predominant seaward (Allen, 1965), (Reyment, 1965), and (Tse & Akpokodje, 2010). Amongst the three formations, the Agbada formation constitutes the main reservoir for hydrocarbons in the Niger Delta (Short & Staublee, 1967).

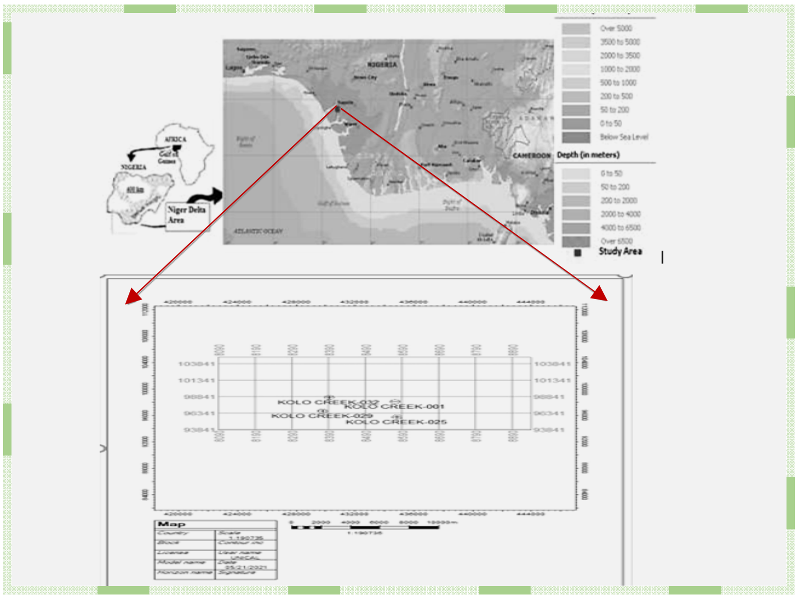

Figure 1: Map of Niger Delta showing the location of study area.

MATERIALS AND METHODS

The materials used for this characterization of hydrocarbon reservoir are:

i. Well logs data from three wells (KOCR-001, KOCR-025 and KOCR-029 in a field in the central Niger Delta. Consisting of CALI, GR, SP, LLD, and NPHI for KOCR-001 GR, SP, LLD, RHOB, and NPHI for KOCR-025, GR, SP, LLD, RHOB, NPHI and DT for KOCR-029.
ii. Schlumberger Petrel 2014 software
iii. Python Programming Language

The petrophysical parameters of the reservoir units were calculated using the following formula;(Dresser, 1979)formula for calculating porosity,

$$\phi = (\rho max - \rho b)/(\rho max - \rho f)$$

ρmax = 2.5, ρf = 1

Effective porosity of each reservoir unit

$$\phi eff = (1 - Vsh) * \phi$$

Hydrocarbon saturation

$$Sh = (1 - Sw) + Sg.$$

Vsh from gamma ray index (I_{GR})

$\{0.083 * (2^{3.71} * ^{(IGR)} - 1)\}$, (Asquit & Gibson, 1982) formular for:

Irreducible water saturation given as $Swirr = \sqrt{(F/2000}$

where $F = 0.62/\phi^{2.15}$

(Emudianughe& Utah, 2019) formular for permeability of the formation as

$$k = 307 + 26552\phi 2 - 3450(\phi Swirr)2 .$$

Table 1 shows the porosity and permeability classification according to Bayowa, 2019 where porosity is grouped into six classes based on the percentage of porosity and permeability grouped into six classes based on the amount in milliDarcy of permeability.

Table 1: Classification of Porosity (Modified from *(Bayowa, 2019)*).

Porosity (%)	**Interpretation**	**Permeability (mD)**	**Interpretation**
0 - 5	Negligible	<10.5	Poor
5 - 10	Poor	15 – 50	Moderate
15 - 20	Good	50 – 250	Good
20 - 30	Very Good	250 - 1000	Very Good
>30	Excellent	>1000	Excellent

The workflow adopted in this study is shown in the Figure 2.The first step of the method was to input the data into the Schlumberger Petrel 2014 software and quality check the relevant well logs needed for the analysis, display of the well logs was done and the hydrocarbon bearing zones were delineated as well as stratigraphic correlations across the wells and production of map of the study area with the aid of the Schlumberger Petrel. Calculation of the petrophysical parameters was achieved by applying the verified formula mentioned above. Fast quantification of the reservoir volumetric was achieved using the Python programming language software.

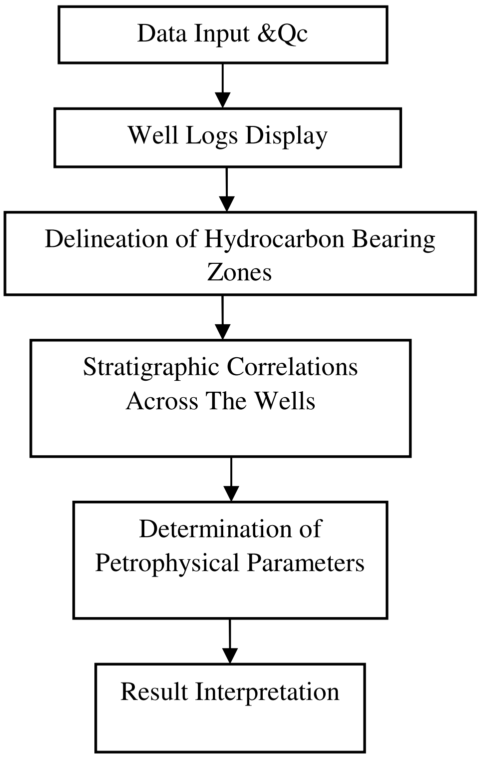

Figure 2: Reservoir characterization workflow.

RESULTS AND DISCUSSION

Reservoir fluid type and contacts

The gas fluid of the well “KOCR-029” occur at the 3585.00 – 3590.70m, 3601.40 – 3606.82m and 3611.66 – 3615.92m below the surface and oil fluid occur at the 3620.66 – 3622.40m below the surface. The balloon effects displayed by the density-neutron logs show that there are associated gas reservoirs. Fluid contacts can be gradational in mixed-fluid reservoirs but are typically horizontal or nearly so because of the difference in density between gas, oil and water (Figure 3).

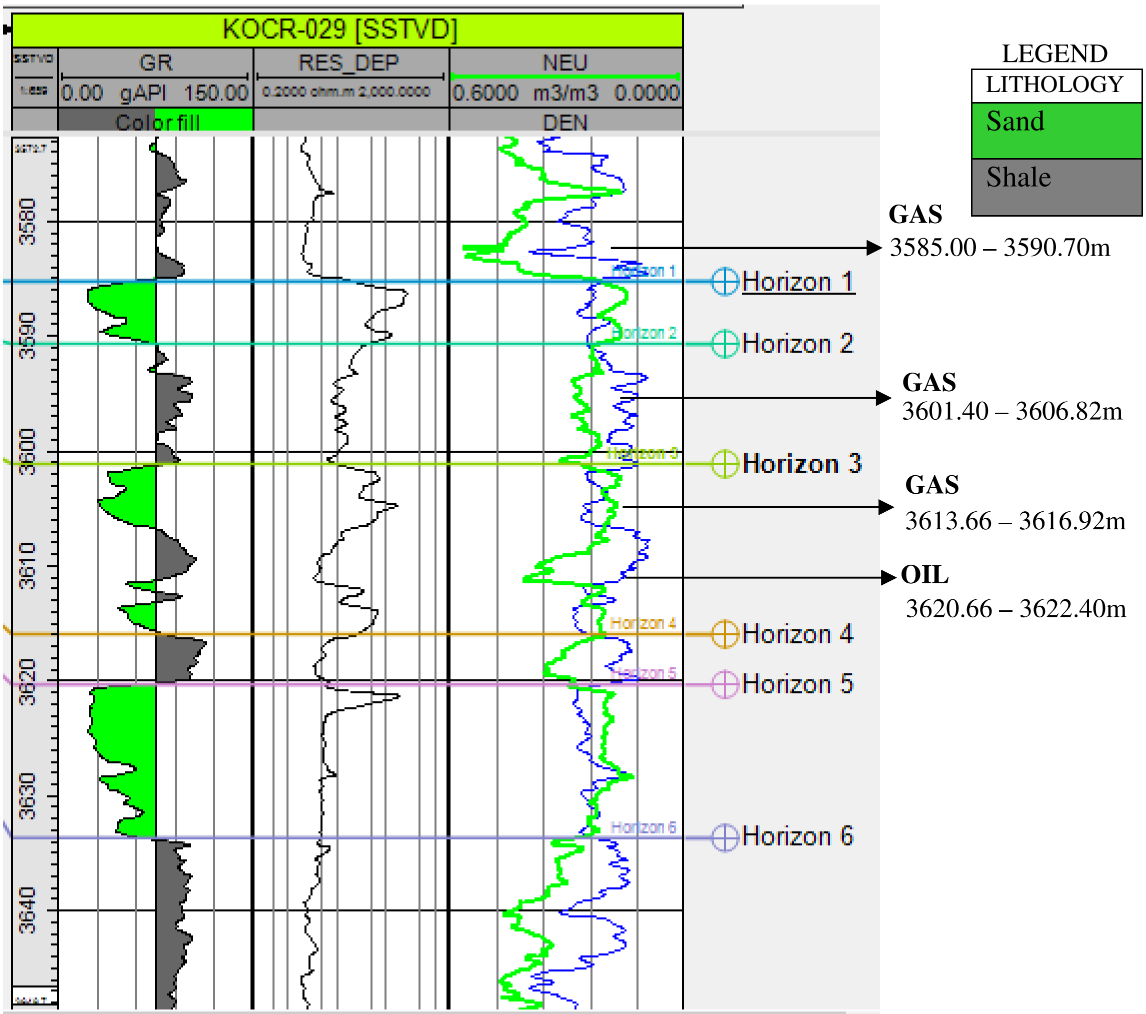

Figure 3: Fluids types present in the reservoirs.

Figures 4 and 5 shows the sands top and base correlation across the wells and the identification of reservoirs top and bottom respectively using the gamma ray and resistivity logs. The two lithologies seen in the study area are sand and shale respectively. Among the three sands mapped in the area, Sand 1 is the shallowest reservoir which located at a depth of 3,490m in KOCR-001, 3,566m in KOCR-025 and 3,585m in KOCR-029 below the surface with thicknesses of 5m, 3m and 5m in the respective wells. Sand 2 is located at 3,500m, 3,568m and 3,603m with thicknesses of 45m, 16m and 14m in the respective wells. Sand 3 which is the deepest amongst the three sands identified in the area is located at depth of 3,590m and 3,620m below the surface in KOCR-025 and KOCR-029 with thicknesses of 3m and 14m respectively in each of the wells. These three sand units extends through the field and are identified as the reservoir units which are hydrocarbon bearing

Well correlation delineating top sand reservoirs

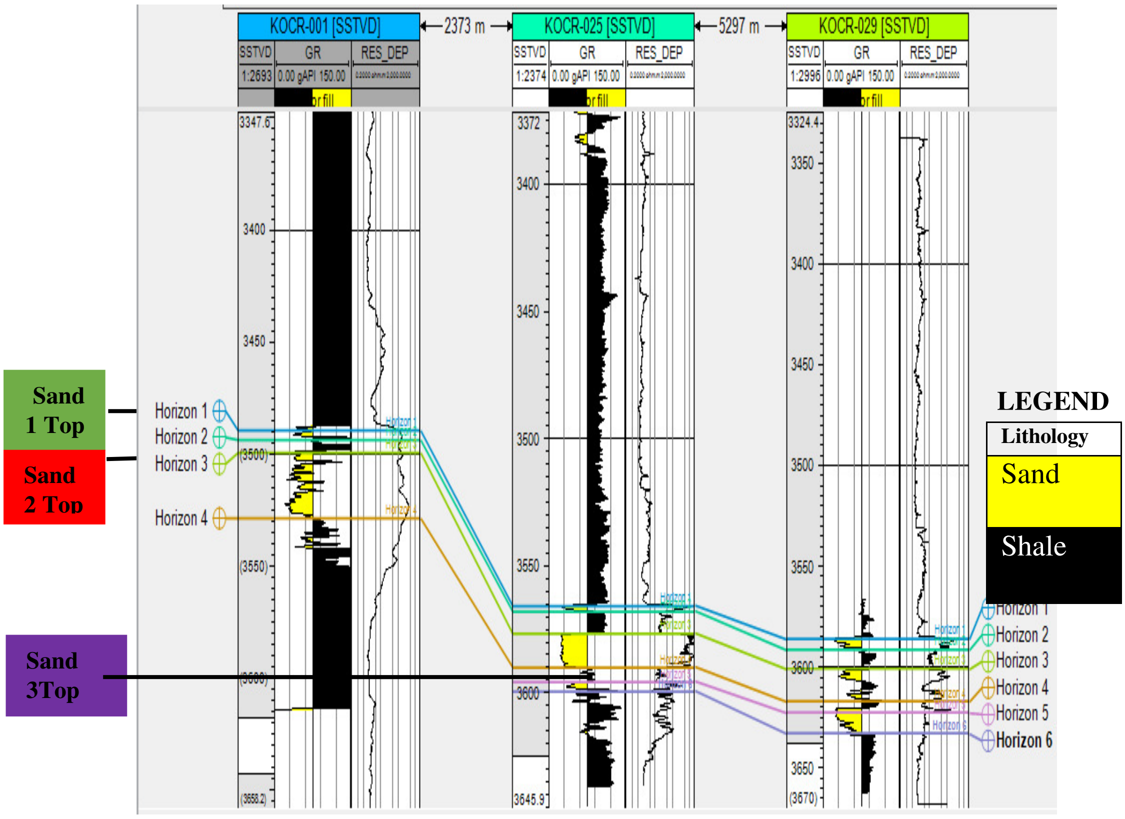

Figure 3: Well correlation of the reservoir sands in the well section.

Well Delineation

The lithologies delineated across the field are sand and shale with some abrupt sand/shale intercalations at some of the intervals.

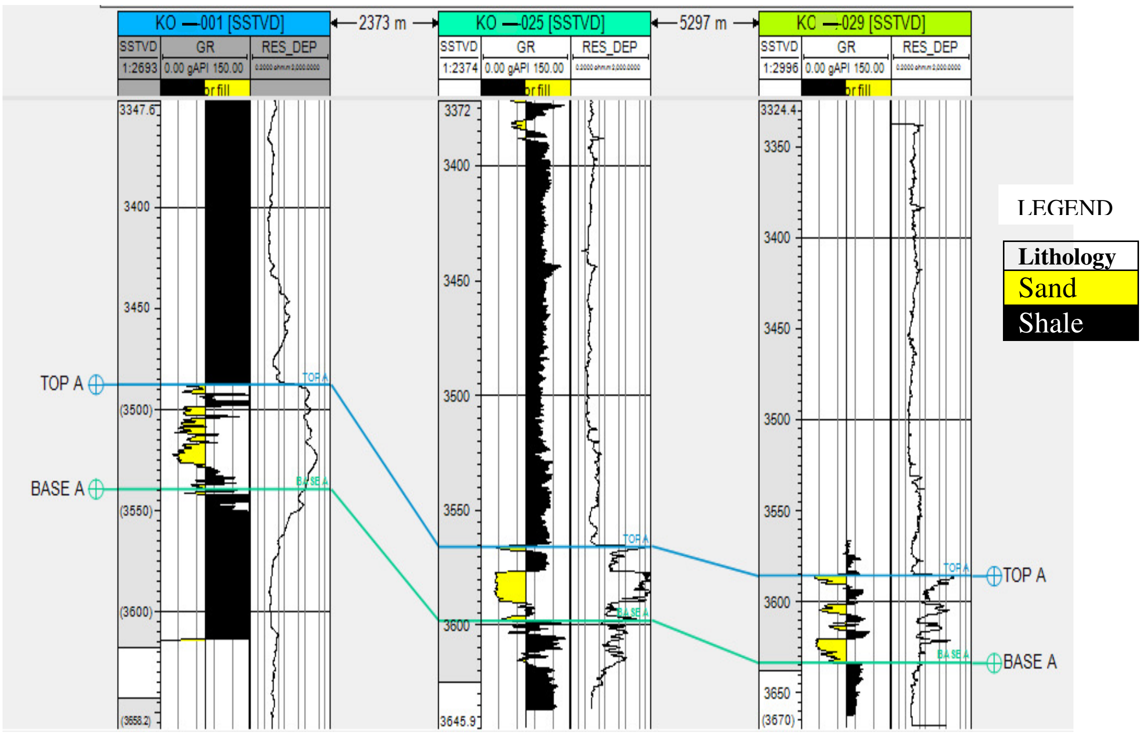

Figure 4: Delineation of reservoir tops on the well section.

Reservoir Thickness

Table 2:Reservoirs 1, 2& 3 thicknesses across wells KOCR – 001, KOCR – 025 & KOCR – 029.

S/N	Reservoir	Quantitative Interpretation (M)
1	1	95.40
2	2	83.25
3	3	81.34

From analyses of the data, the reservoir rock types in the formations are sand and shale which according to the porosity and permeability rankings of the sand units are termed very good reservoirs in the field.

Reservoir 1

From Tables 3, 4 and 5, reservoir 1 is seen across wells KOCR – 001, KOCR – 025 and KOCR – 029 at depths 305.49m to 3600.89m, the volume of shale ranges from 0.22 to 0.048 which is 22% to 48%. The porosity in reservoir 1 is good - very good with value 22 – 26%. The interconnected pore spaces ranges approximately from 0.17 to 0.13 which is obviously low. With the low water saturation, it is evident that the reservoir hydrocarbon saturation is high. The permeability is an excellent one which is >1000mD across the wells, this allows the fluids to flow freely.

Reservoir 2

From Tables 3, 4 and 5, it is evident that reservoir 2 was penetrated at depths 3,523m, 3590.97m and 3606.25m with a low volume of shale ranging from 2 – 36%. The porosity is between 11 – 19% which is classified as fair to good porosity. Its water saturation of 13 – 44% indicates high saturation of hydrocarbon in the reservoir. The reservoir permeability is 600 – 1239mD which is good to excellent permeability for a reservoir.

Reservoir 3

Tables 3, 4 and 5show that reservoir 3 was penetrated at 3534.39m – 3615.73m, with its volume of shale ranging from 30% - 50% indicating a fairly high shale volume in wells KOCR – 025 and KOCR – 029. Its porosity is 2% - 26% which is negligible to very good porosity for a reservoir. Reservoir 3 is 11% - 52% saturated with water which makes it moderately saturated with hydrocarbon. Its permeability is greater than 1000mD which is excellent for a reservoir permeability.

Table 3: Result for computed petrophysical parameter for well KOCR-001.

Well	Start MD (m)	Vsh (%)	Φ (%)	Φeff (%)	Sw (%)	ff	Swirr H (%)	k (mD)	NTG (%)
R1	3505.49	22.21	21.86	17.28	13.889	115.680	17.49	1571	77.79
R2	3523	35.87	10.64	6.78	12.492	488.019	41.37	600	64.13

Table 4: Result for computed petrophysical parameter for well "KOCR-025"

Well	Start MD (m)	Vsh (%)	Φ (%)	Φeff (%)	Sw (%)	ff	Swirr H (%)	k (mD)	NTG (%)
R1	3588.79	47.33	2.55	13.18	11.601	19.173	9.76	2031	52.67
R2	3590.97	2.11	18.75	18.33	31.458	45.454	14.79	1239	97.89
R3	3599.69	50.34	2.22	9.65	16.296	46.083	13.42	1613	49.66

Table 5: Result for computed petrophysical parameters for well "KOCR-029"

Well	Start MD (m)	Vsh (%)	Φ (%)	Φeff (%)	Sw (%)	ff	Swirr_Den (%)	k (mD)	NTG (%)
R1	3600.89	48.95	24.6	12.54	17.88	21.350	10.27	1911	51.05
R2	3606.25	7.69	16.64	15.28	43.64	64.875	17.47	1040	92.31
R3	3615.73	31.94	2.19	13.92	51.51	42.545	13.34	1579	68.06

Tables 6, 7 and 8are the comparative volumetric analysis of the hydrocarbon in place of the reservoirs 1, 2 and 3 in the different wells KOCR-001, KOCR-025 and KOCR-029. From the results, it is seen that the volume of hydrocarbon in place are high, with the highest quantity (Mbbl) in reservoir 2 and the least (Mbbl) in reservoir 3. It is evident that hydrocarbon in the three reservoirs in three wells are economically viable. In the case of reservoir 3, the wells KOCR-025 and KOCR-029 are the only two wells which the reservoir cuts across.

Table 6: Comparative volume of hydrocarbon in place for reservoir 1.

Volumetric (Mbbl)	**Well KOCR-1 Quantitative**	**Well KOCR-25 Quantitative**	**Well KOCR-29 Quantitative**
Bulk Volumes	229561.475	86157.833	260208.221
Net Volumes	178575.871	45379.331	132836.297
Pore Volumes	30857.911	1157.173	32677.729
Hydrocarbon Pore Volumes	26571.747	1022.941	26834.951
Volume of Hydrocarbon Initially in Place	351887613.768		

Table 7: Comparative volume of hydrocarbon in place for reservoir 2.

Volumetric	**Well KOCR-1 Quantitative**	**Well KOCR-25 Quantitative**	**Well KOCR-29 Quantitative**
Bulk Volumes	2493951.233	786985.307	478204.885
Net Volumes	1599370.926	770379.917	441430.930
Pore Volumes	170173.067	144446.234	73454.107
Hydrocarbon Pore Volumes	152066.652	99003.449	99003.449
Volume of Hydrocarbon Initially in Place	1890811023.709		

Table 8: Comparative volume of hydrocarbon in place for reservoir 3

Volumetric	**Well KOCR-25 Quantitative**	**Well KOCR-29 Quantitative**
Bulk Volumes	234765.639	159016.135
Net Volumes	116584.616	108226.381
Pore Volumes	2588.179	2370.158
Hydrocarbon Pore Volumes	2166.305	1149.290
Volume of Hydrocarbon Initially in Place	21435320.919	

CONCLUSION

This study has proven that the analyses of petrophysical parameters using Schlumberger Petrel and Python programming language make easy the characterization of hydrocarbon reservoirs of an area and the overall evaluation of the quality of the reservoirs based on the quantity of exploitable hydrocarbons found. Analyses carried out using well logs provide details of well logs of the study area as well as evaluate the hydrocarbon reservoir production potentials. Well logs obtained from Kolo Creek field in the central Niger Delta using the Schlumberger Petrel and Python programming language were used to determine the hydrocarbon reservoir potential in the area. The porosity, permeability, comparative volume of hydrocarbon in place etc. indicates that reservoirs in the field are economically viable. From the data analysed, the rock types found in the study area are sand and shale which were continuous across the wells varying in thicknesses with some units which occur at depths greater than the adjacent units. The porosity and permeability are fair to very good and very good to excellent for a reservoir. Their volumetric analyses indicate that hydrocarbon in the reservoir units are economically viable. From the analysis using the Schlumberger Petrel three hydrocarbon reservoir units were delineated and discriminated from other formations at the top and bottom of the reservoirs at depth interval of 3489.15 – 3632.38m across the wells. The three reservoir units identified in the field were classified based on the volumetric study of the hydrocarbon in place, reservoir 2 is found to be the most prolific while reservoir 3 is the least prolific within the field. From the results obtained, it is evident that Kolo Creek field has potential hydrocarbon that is exploitable.

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