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Petrophysical Evaluation and Hydrocarbon Prospectivity Determination of Osaka Field, Niger Delta, Nigeria

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ABSTRACT

Petrophysical evaluation and hydrocarbon prospectivity of Osaka Field in Niger Delta Nigeria was carried out with the aim of identifying the reservoir and estimating the hydrocarbon-bearing potentials of the reservoirs. Composite suite of well logs comprising gamma ray, resistivity, neutron porosity, density porosity and sonic logs were acquired from an oil producing company. Four wells, Osaka well 001, well 002, well 003 and well 004 were used for the exercise. The logs were uploaded into the Petrel Workflow software. Three reservoirs R1, R2 and R3 were correlated and petrophysical parameters (porosity, permeability, water saturation, irreducible water saturation, and hydrocarbon saturation and formation factors) computed. Hydrocarbon discrimination was done using the overlay of the neutron and the density porosity logs. The petrophysical analysis result showed that the water saturation varies from 15% to 46% in well 1, 38% to 46% in well 2, 40% to 65% in well 3 and 26% to 40% in well 4. The irreducible water saturation also varies from 4% to 8% in well 1, 6% to 8% on well 2, 5% to 7% in well 3, 5% to 7% in well 4. Based on the results obtained from the hydrocarbon saturation which vary from 53% to 84% in well 1, 54% to 62% in well 2, 40 to 69% in well 3 and 60% to 74% in well 4. It is concluded from the study that reservoir rocks in the studied wells in Osaka field generally are prospective and could be exploited for exploration purposes.

1. INTRODUCTION

The primary aim of any hydrocarbon exploration is to identify and establish suitable reservoir formations with commercial accumulation of oil and gas and thereafter characterize the reservoir as accurate as possible. This is because this information is able to assist in the evaluation of the hydrocarbon reserve as well as help in the determination of the most effective way of recovering as much of the resource as possible. Reservoir characterization is a technique involving quantitative distribution of reservoir properties such as facies distribution, porosity, permeability and fluid saturation (Amigun, 2013). The knowledge of these petrophysical properties is an important factor in quantifying producible hydrocarbon (Schlumberger, 1989). This is because the petrophysical properties are hidden within well log data and they provide reliable downhole geological information useful for evaluating the

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hydrocarbon potential of rock formations (Asquith and Gibson, 1982). The evaluation of these parameters is a major key towards predicting hydrocarbon-bearing intervals, abnormally pressured zones, estimate hydrocarbon reserves and reservoir bed thickness and to distinguish between gas, oil and water bearing strata, by observing their electrical resistivity and relative permeability values (Hilchie, 1990; Schlumberger, 2005; Uguru *et al.*, 2002). Reservoir characterization gives a description of the petrophysical properties such as porosity, permeability, oil saturation, hydrocarbon pore fluid in place and thickness of productive net sand.

Traditionally, certain petrophysical properties are best identified from cores descriptions. However, while core data provide direct observations of these parameters, some other parameters cannot be easily predicted. As a result, predictions are carried out indirectly from wireline logs. Such parameters include the porosity of a formation and the permeability information which is best predicted from empirical relationship which uses porosity as a component. The main challenge is that core data are too costly to acquire and recovery is often less than 100% (Enikanselu and Ojo, 2014), as they seldom encompass the entire stratigraphic interval of interest (Chang *et al.*, 2000). Also, core description can be time consuming and dependent on geologist's extensive wealth of experience. Therefore, an alternative lower-cost method yet providing similar or improved accuracy and resolution is desirable. This is the reason why well logs have found usefulness in the prediction of reservoir parameters over the years.

Several literatures about the Niger Delta petrophysical parameters and hydrocarbon reservoir prospectivity abound and these have revealed a lot about the sedimentary basin as well as its abundant hydrocarbon potential. Most recent works include the works of Uguru, (2002) who carried out permeability modeling for reservoirs in the Niger Delta based on geological descriptions and core data, Emujakporue (2009) who evaluated the Hydrocarbon Prospect of Amu Field, Niger-Delta, Nigeria, Obaje (2005) who attempted to understudy the fairways and reservoir prospects of Plocene -Recent sands in the shallows offshore Niger delta, Aigbedion and Iyayi (2007) who carried out formation evaluation of Oshioka Field, using geophysical well logs and Alao *et al.*, (2013) who conducted subsurface and petrophysical studies of shaly-sand reservoir targets in Apete Field, Niger Delta, Ameloko *et. al.*, (2019) who carried out evaluation of seismic and petrophysical parameters for hydrocarbon prospectivity of G field, Niger Delta, Nigeria. This study is aimed at evaluating the petrophysical parameters of reservoir sand of wells in Osaka field, an oil field managed by the Nigeria National Petroleum Company. This was done by identifying the reservoirs and non-reservoirs, correlating the reservoirs, computing the petrophysical parameters, computing the hydrocarbon saturation and determining the hydrocarbon prospectivity of the reservoirs. Relevant reservoir petrophysical properties were determined to evaluate and the prospectivity of Osaka field in Niger Delta, Nigeria in order to appraise its hydrocarbon potential. The study established vertical as well as lateral lithologic distribution across available wells in the field, delineate potential fluid bearing formations, discriminate formation fluids, determine the petrophysical properties.

1.1 Location of Study Area

Osaka Field is located in the Niger Delta region of Nigeria, which is a prolific hydrocarbon producing area. The field is situated in the eastern part of the Niger Delta, approximately 40 kilometers northwest of Port Harcourt, the capital of Rivers State. The field is located approximately on the coordinate given by 4.8969° N, 6.7903° E. The field is situated within OML 18 (Oil Mining Lease 18), which is jointly operated and owned by the duo of Eroton Exploration and Production Company and the Nigerian National Petroleum Corporation (NNPC). The oil field is bordered by Bonny Field to the eastern part, Inda field to the south, Awoba and Elukama field to the west and finally Cawthorne Channel to the North and Alakiri field to the far North. The field covers an area of approximately 45 square kilometers, with multiple producing 2reservoirs at depths ranging from 3,000 to 12,000 feet. Osaka field of the eastern Niger Delta is separated from the large Channel field by a major antithetic (counter regional) normal fault.

The location of the Osaka Field is strategically important due to its proximity to several major oil and gas pipelines, export terminals, and refineries in the Niger Delta region. The field is also situated within a prolific hydrocarbon province, with numerous other oil and gas fields located nearby. The Osaka fields, with a STOIIP (stock tank oil initially in place) of about 78 x 106m^3 (492 million STB), is situated within the area jointly owned by Eroton Petroleum and Gas and the NNPC. It is located within Oil Mining Lease 18, in the coastal swamp of the eastern Niger Delta (Figure 1). The Niger Delta of southern Nigeria has been described as an arcuate shaped wave and tide-dominated prograding deltaic system and has been the subject of extensive study since the discovery of commercial hydrocarbons in the 1950's.

1.2 Regional and Local Geology of Niger Delta

The Tertiary Niger Delta is situated in the Gulf of Guinea off the coast of West Africa. The basin encompasses the entire Niger Delta with an area covering an expanse of about 1,200,000 square kilometers (km^2) (Klett *et al*., 1997).and it lies within the coordinates of latitudes, 3o to 6o N and longitudes, 5o to 8o E (Reijers *et al*., 1996). The basin is a product of sediments supply from rivers

in the present-day Niger River, Benue River, Cross River and their several distributaries all flowing into the Ocean. Sediments deposited by the rivers and distributaries consist of unlithified sands and shales which produced the different formations that makes up the basin (Idowu *et al*., 1993).

The Niger Delta sediments prograde southwest from Eocene to Recent had formed depobelts which are the most active portion of the delta at the stage of every growth (Doust and Omatsola, 1990). The Niger Delta depobelts formed one of the world's biggest regressive deltas within a region of some 300,000 square kilometres, a sediment volume of 500,000 cubic kilometres with a sediment thickness of over 10 kilometers (Hospers, 1965, Kulke, 1995, Kaplan *et al*, 1994).

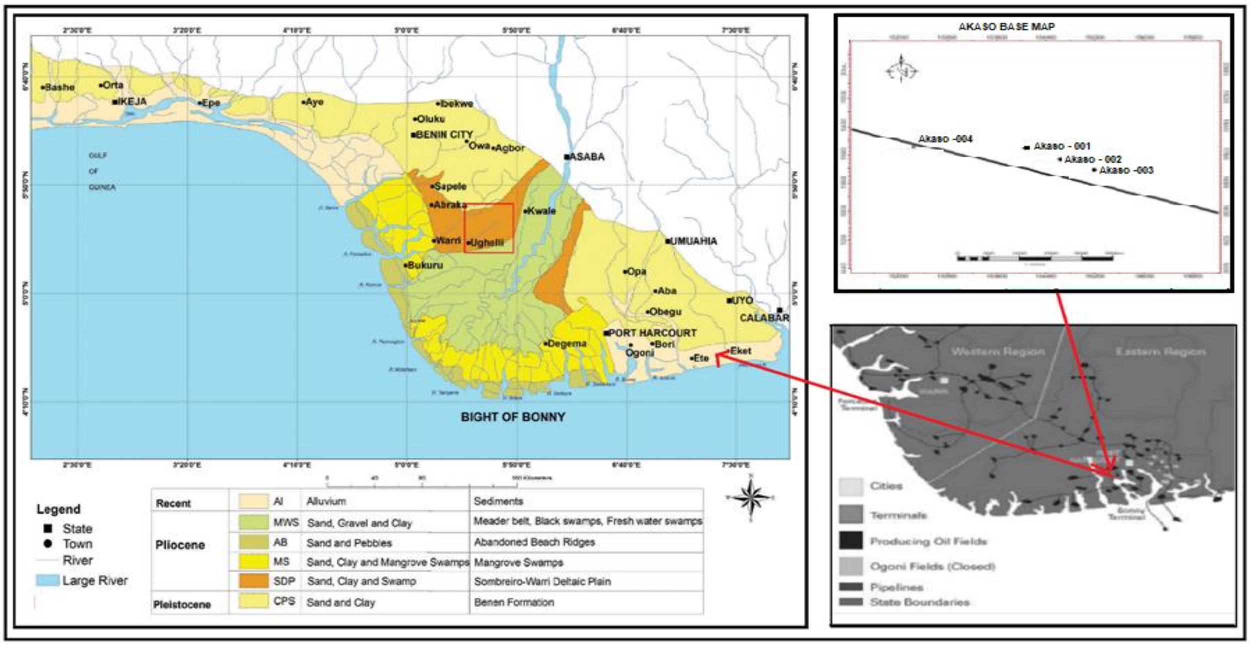

Figure 1: Basemap of Osaka Field showing the relative position of the wells within the field and their location in the Niger Delta sedimentary basin

The basin can be divided into three diachronous lithostratigraphic unit, the Akata, Agbada and Benin Formations from bottom (oldest) to the top (youngest) formation (Short and Stauble, 1967; Weber and Daukoru, 2002). The Akata Formation comprises of predominantly marine shales, with sandy and silty beds which occur as turbidites and continental slope channel fills. The Agbada Formation predominantly consists of shoreface and channel sands at the top and an intercalation of sands and shales of equal proportion in the bottom. The Benin Formation predominantly consists of about 90% of sands and gravels from the continent with little shale intercalations, which becomes more abundant towards the bottom. The Akata Formation is made up of marine sediments predominantly shales with sandstone intercalations. The formation has been recognized as the major source rock for Niger Delta (Evamy *et al*,1978). The basin is one of the most productive hydrocarbon provinces globally. The Akata and Agbada Formations (Tertiary) are the most prominent petroleum system in the basin (Kulke, 1995; Ekweozor and Daukoru, 1994). The petroleum system has hydrocarbon reserves of about 34.5 billion barrels of oil and 93.8 trillion cubic feet of gas which ranks 12th richest in hydrocarbon resources world over with 2.2% of oil and 1.4% of gas reserves.

Osaka Field is a part of the larger Niger Delta region, which is located in Nigeria. It is situated within the Coastal Swamp Depobelt, which is part of the Niger Delta Basin. The Osaka Field is characterized by a deltaic depositional environment. Over time, as rivers carried sediment downstream, the sediments settled and accumulated in a marine environment. The deposition of sediments, including sand, silt, and clay, resulted in the formation of thick sedimentary sequences. (Asquith 2004). The Osaka Field is underlain by the

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Akata Formation, which is an important source rock for hydrocarbons. The Akata Formation consists of organic-rich shales and mudstones that have undergone significant burial and thermal maturation, leading to the generation and migration of hydrocarbons. The Agbada Formation, which overlies the Akata Formation, is the primary reservoir rock in the Osaka Field. It consists of interbedded sandstones, siltstones, and shales that have good porosity and permeability, allowing for the accumulation and storage of hydrocarbons. The Osaka Field is influenced by various structural features, including fault systems, folds, and anticlines, which have resulted from tectonic forces in the region. These structural features play a crucial role in trapping and preserving hydrocarbons within the reservoirs. The hydrocarbons generated from the source rocks in the Akata Formation migrate through the porous and permeable sandstone reservoirs of the Agbada Formation. The presence of structural traps, such as fault closures and anticlines, can act as barriers, preventing the upward migration of hydrocarbons and allowing for their accumulation in commercial quantities.

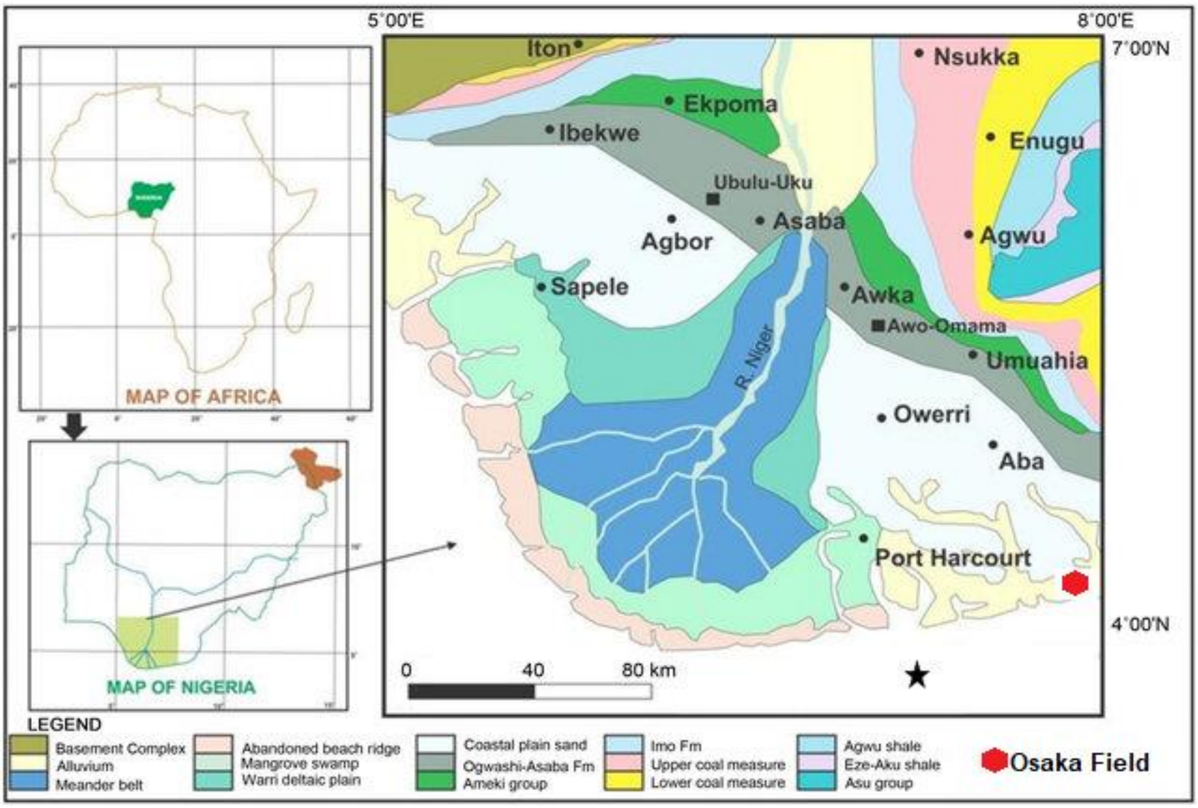

Figure 2: Geologic Map of the Niger Delta (Nwajide, 2013)

2. RESEARCH METHODOLOGY

Four wells, Osaka well 001, well 002, well 003 and well 004 were selected for the study. Composite suite of logs used include the lithologic log such as gamma ray log, electrical logs such as the resistivity log, porosity log such as the neutron and the density log. These logs were imported into the Petrel Workflow tools while the reservoir and non-reservoir rocks in the field were delineated using the gamma ray (GR) logs. Correlatable reservoirs showing similarity in log signals were selected across the four wells and correlated from one well to another. The depths at which these reservoirs occur were noted. Petrophysical parameters such as porosity, permeability, water saturation, hydrocarbon saturation, formation factor and irreducible water saturation were computed using relevant petrophysical expressions.

Porosity was computed using the density-porosity equation given by

$$\acute{\emptyset}_{DEN} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_i}$$

(1)

where $\emptyset_{DEN}$ = density derived porosity, ρ_m, density of matrix (2.65 g/cm^3 for sandstone) ρ_b is bulk density, ρ_f is fluid density (0.85 g/cm^3 fluid density). However, permeability was computed using the Coates expression given by

$$K^{\frac{1}{2}} = 100\frac{\emptyset^2(1 - S_{wirr})}{S_{wirr}}$$

(2)

where K= permeability, Ø = porosity and S_{wirr} = irreducible water saturation. Permeability assessment was done using the Table 1.

Table 1: Permeability Classification table.

Permeability Value (mD)	Classification
<10	Fair
10 – 100	High
100 – 1000	Very High
>1000	Exceptional

The water saturation was calculated using the Modified Archie expression given by

$$S_w = \{\frac{a.R_w}{\emptyset^m.R_t}\}^{\frac{1}{n}}$$

(3)

where S_w= formation water saturation, R_w = Formation water resistivity, Ø = Porosity, a = cementation factor, m = cementation exponent and n = saturation exponent. The formation factor was computed using the Humble‘s formula for tertiary rocks (since Niger Delta formation is a Tertiary sediment) and it is given by

$$\text{F} = \frac{0.62}{\emptyset^{2.15}}$$

(4)

where F = formation factor and (ϕ) = porosity. The irreducible water saturation in this work was computed using the Asquith and Gibson (1982) given by

$$S_{wirr} = \frac{\sqrt{F}}{2000}$$

(5)

where S_{wirr} = Irreducible water saturation and F= formation factor. Hydrocarbon saturation was computed using the expression given by

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

(6)

$$S_h = 1 - S_w$$

(7)

where S_h = hydrocarbon saturation; S_w = water saturation

3. RESULTS AND DISCUSSION

3.1 Reservoir Correlation

The gamma ray log was used in the identification of reservoir rock based on the fact that the sandstone reservoir exhibits very low radioactivity because of the low content of radioactive elements. It is very important to identify the reservoir interval and the type of fluid in the reservoir rock because reservoirs may contain hydrocarbon (oil and gas), non-hydrocarbon fluid (water), or both. For a reservoir to contain hydrocarbons, the interval should be porous with resistivity values higher than those of water-bearing zones. In this research, reservoir rocks were identified using the interpretation of the available gamma log data which discriminates the reservoir rocks from non-reservoir rocks. Resistivity logs were also used to predict the fluid content in the reservoirs. This is based on the knowledge of the fact that reservoir exhibit relatively higher resistivity values than non-reservoir zones. Based on neutron and density logs, oil-bearing interval was discriminated from gas-bearing interval due to the gas-bearing loop produced when neutron log is superimposed on the density to produce a cross over. Figures 3 represents the workflow followed during the data analyses and interpretation. Figure 4 is the lithologic identification panel of Osaka 001, Osaka 002, Osaka 003 and Osaka 004 wells using gamma ray logs while Figure 5 is the correlation panel of well logs Osaka 001, Osaka 002, Osaka 003 and Osaka 004 in Osaka Field. The reservoirs are located within the depth range of 6,603 - 6,636 m in the studied wells and designated as R1, R2, R3. The general lithology revealed an alternation of sand and shale units. The sand units decrease in thickness with depth and the shale units increase in thickness correspondingly. This stratigraphy is typical of Agbada formation of the Nigeria Niger Delta. In well 1, three reservoirs as R1, R2 and R3 were delineated at depths between 6,603 and 6,939 m. while in well 2, the same reservoirs were delineated at depths between 7,549 and 7,757 m. Same reservoirs were delineated between depths of 6,544 and 7,198 m respectively in well 3.

3.2 Petrophysical Analysis Osaka Field

The complete summary of the reservoir properties evaluation of wells, 1, 2, 3 and 4 is presented as Tables 1. Reservoir 1 occur at a depth of 6.603 m to 6,636 m, a thickness of 33 m in Osaka well 001. This extends laterally to Osaka well 002 where the thickness is 34 m, in well 0003 to 27 m and finally 43 m in Osaka well 4. The signature of the resistivity log shows that the reservoir under investigation is hydrocarbon bearing. However, the signature of the density log-neutron log overlay shows that the reservoir contains oil. This is exemplified by the lower density log at the same interval. The porosity ranges from as low as 26% in Osaka well 2 to as high as 25% in Osaka well 3, an average of 22%. However, the permeability K varies from as low as 21.90 mdarcy in well 002 to as high as 28.78 mdarcy in well 003, and an average of 25.38 mdarcy. Based on the permeability estimate (25.38 mdarcy) in this reservoir, K value in R1 can best be described and classified as good. Also, the water saturation (Sw) in reservoir 1 vary from 15% to 49%, an average of 21%. Hence, the hydrocarbon saturation (Sh) was found to vary between from 53% to 84%. This indicates that the reservoir possesses high hydrocarbon potential.

Reservoir R2 on the other hand occurred at a depth of 6,658 to 6,739 m in well 0001, 7600 to 7612 in well 002, 7227 to 7264 m in well 0003 and depth of 6628 to 6642 in

Table 1: Summary of the Petrophysical Properties Obtained from Osaka 001, Osaka 002, Osaka 003 and Osaka 004 wells

		Depth (m)	**Thickness (m)**	**ØD**	K	**Sw**	**Sw_{irr}**	**Sh**	F
Osaka 001	R1	T= 6,603 - B= 6,636	33	*0.21*	23.07	0.46	0.008	0.53	16.42
	R2	T= 6,658 - B= 6,739	81	0.26	35.99	0.23	0.006	0.77	13.21
	R3	T= 6,754 - B= 6,939	185	0.32	52.36	0.15	0.004	0.84	8.98
Osaka 002	R1	T= 7,549 - B= 7,583	34	0.20	21.98	0.46	0.008	0.54	17.09
	R2	T= 7,600 - B= 7,612	12	0.26	37.04	0.38	0.006	0.62	12.82
	R3	T= 7,644 - B= 7,757	113	0.24	30.72	0.46	0.007	0.54	13.50
Osaka 003	R1	T= 7,182 - B= 7,209	27	0.25	28.78	0.40	0.007	0.60	12.4
	R2	T= 7,227 - B= 7,264	37	0.32	33.46	0.65	0.005	0.40	7.18
	R3	T= 7,307 - B= 7,390	83	0.30	43.83	0.60	0.006	0.69	8.12
Osaka 004	R1	T= 6,544- B= 6,587	43	0.22	27.59	0.40	0.007	0.60	14.52
	R2	T= 6,628- B= 6,642	14	0.29	42.15	0.26	0.005	0.74	10.11
	R3	T= 6,661- B= 7,198	537	0.28	41.17	0.26	0.005	0.74	10.69

Note: K- Permeability; F- Formation factor; S_w - Water saturation; Sw_{irr} - Irreducible Water Saturation; S_h - Hydrocarbon Saturation; ǾD – Density Porosity Expression

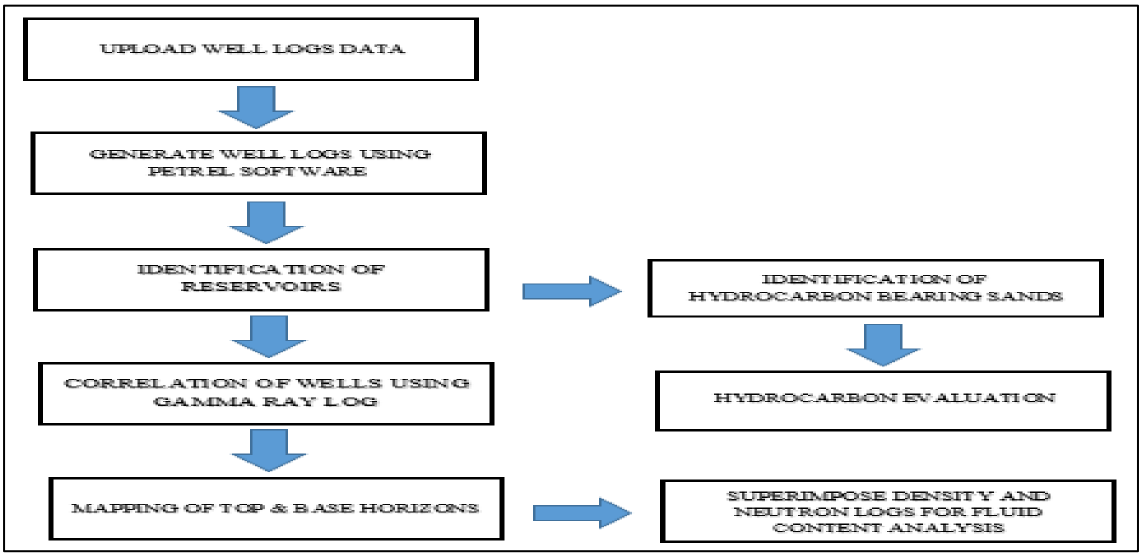

Figure 3: The workflow of the data analyses and interpretation

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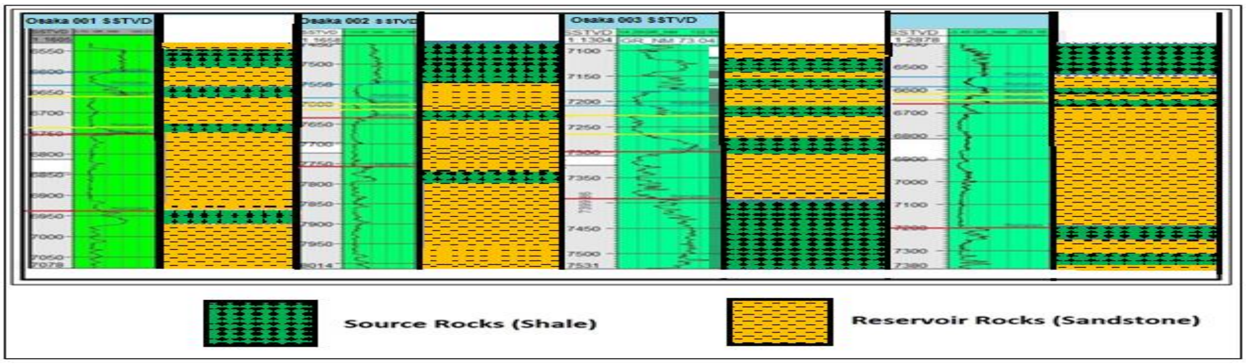

Figure 4: Lithologic Identification Panel from Osaka 001, Osaka 002, Osaka 003 and Osaka 004 Wells using Gamma ray logs.

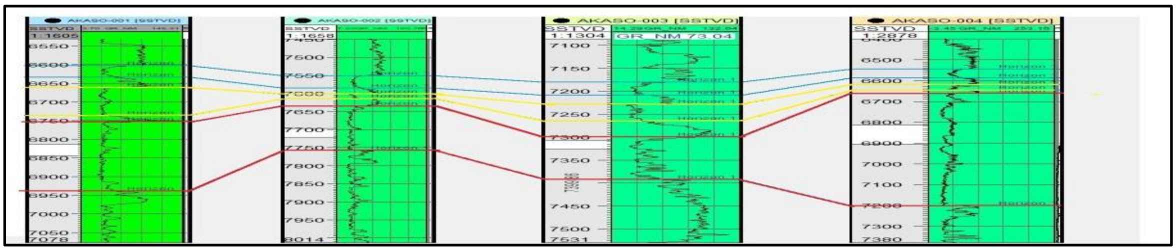

Fig 5: Correlation Panel of Well logs of Osaka Field using Osaka 1, Osaka 2, Osaka 3 and Osaka 4.

well 004. This indicates that R1 is 81, 12 m, 37 m and 14 m thick respectively. The porosity ranges from 26%, in well 0001, 26% in well 002, 32% in well 0003 and 29% in well 0004, an average of 28.25%; this indicates a good reservoir characteristic. Permeability varies from 35.99 mdarcy in well 001, to 37.04 mdarcy in well 002, 33.40 mdarcy in well 003 and 42.15 mdarcy in well 004. The water saturation (Sw) ranges from 23% in well 1, 38.9% in well 002, 65% in well 3 and 26% in well 4. In this reservoir, the irreducible water saturation was also observed to be far less than unity. This brings the hydrocarbon saturation (Sh) to range from 77%, 62%, 40% and 74% in wells 001, 002,003, and well 004 respectively, an average of 81.75%, an indication that the reservoir potential for hydrocarbon is very high.

Reservoir R3 is the thickest of all the reservoirs selected. It was found to occur at depths of 6754 to 6939 meters in well 001 (thickness of 185), depth of 7644 to 7757 meters in well 002 (thickness of 113 meters), 7,307 to 7,390 in well 0003 and 6,661 to 7,198 m in well 004. Generally, the porosity values are low and the values in reservoir R3 range from as low as 24% in well 002 to as high as 32% in well 001. However, the permeability ranges from 30.72 mdarcy in well 002 to 52.36 mdarcy well 001. The values can best be described as moderate permeability. The water saturation varies from 0.15 in well 001 to 0.60 in well 4 while the irreducible water saturation varies from 0.004 in ell 001 to 0.007 in well 2. The formation factor F was estimated to be 8.98 in well 001, 13.50 in well 002, 8.12 in well 003 and

10.69 in well 004. The hydrocarbon saturation also was observed to be about 84% in well 001, 54% in well 002, 69% in well 003 and 74% in well 004. Generally, the hydrocarbon saturation is averagely high and hence the reservoirs are prospective.

4. CONCLUSION

This work involves petrophysical evaluation and reservoir prospectivity of Osaka field, Niger Delta, Nigeria. The aim of the work is to investigate the hydrocarbon potential with the reservoir sands in the study area. A suite of well logs comprising of Gamma ray logs, resistivity log. Density log and neutron logs were acquired from an oil and gas company.

The logs were uploaded into petrel workflow tools and the top and bottom of selected reservoirs are correlated. Petrophysical parameters evaluated include porosity (using the density tool), permeability (using the Timur 1968 expression), water saturation (using the modified Archie's equation), formation factor (using the Humble formula for Tertiary rocks), hydrocarbon saturation and the irreducible water saturation.

The result showed that the Osaka Field is an oil rich field from the signature of density-neutron overlay. Petrophysical analysis result showed that the water saturation varies from 15% to 46% in well 1, 38% to 46% in well 2, 40% to 65% in well 3 and 26% to 40% in well 4. The irreducible water saturation also varies from 4% to 8% in well 1, 6% to 8% on well 2, 5% to 7% in well 3, 5% to 7% in well 4. Based on the results obtained from the hydrocarbon saturation which vary from 53% to 84% in well 1, 54% to 62% in well 2, 40 to 69% in well 3 and 60% to 74% in well 4. It was concluded that reservoir rocks in the studied wells in Osaka Field generally are prospective.

Future work on the subject matter in the study area should be tailored towards volumetric analysis of the reservoirs so as to know the volume of hydrocarbon that would be contained in each of the reservoirs. Also, a combination of the seismic data of the study area with well log data will be useful in this research.

Acknowledgement

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