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RESERVOIR CHARACTERIZATION OF POLE FIELD IN NIGER DELTA BASIN, USING WELL LOGGING

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ABSTRACT

Well log data of five (5) wells termed Pole Field located in the Niger Delta basin were used in the characterization of reservoir sands. Well log data used included sonic, gamma ray, matrix density and resistivity logs. A computer software (PETREL) was used and the wireline log data were studied to characterize the porosity, water saturation, and volume of shale of the pole field reservoir. The thickness of each sand unit in reservoir A, B and C varied between 225-279ft, 86001050ft, and 45-258ft respectively. The average water saturation (S_W) of reservoir A, B and C are 0.344%, 0.412 and 0.152% respectively. The effective porosity for reservoir A varied between 21-28 with an average effective porosity of 25. For reservoir B, the effective porosity varied between 21-25 with an average effective porosity of 13.6. While for reservoir C, the effective porosity also varied between 21-25 with an average effective porosity of 23.3. Hence, the 5 wells located in Pole field of Niger Delta basin have a favourable average net sand thickness, average effective porosity and hydrocarbon saturation which are indicators for high hydrocarbon accumulation.

Keywords: Characterization, Hydrocarbon, Niger Delta basin, Petrel, Well log.

INTRODUCTION

One of the most fundamental methods for reservoir characterization is the well logging. In oil and gas industry, it is an essential method for geoscientist to acquire more knowledge about the condition below the surface by using physical properties of rocks.

Well logging can be defined as a tabular or graphical portrayal of any drilling conditions or subsurface features encountered that relate to either the progress or evaluation of an individual well (Gatlin, 1960). The ultimate aim of the well log interpretation, however, is the evaluation of potential productivity of porous and permeable formations encountered by the drill (Djebbar and Erle, 2004).

This method is very useful to detect hydrocarbon bearing zone, calculate the hydrocarbon volume, and many others. In the formation of oil, it is believed that the formation is fully saturated with water before the oil migration and trapping in the formation. The less dense hydrocarbons migrate to positions of hydrostatic and dynamic equilibrium by displacing the initial water. Therefore, more than one fluid is normally present in oil reservoir (oil, gas, water, etc.) (Borai, 1987). Fluid saturation is the measure of the gross void space in a reservoir rock that is occupied by a fluid (such as water, oil, or gas) and often measured in routine core analysis.
In trying to saturate a reservoir, the properties of such reservoir are gathered using all available data from the well logs so as to be able to accurately predict the performance of such reservoir (Fatoke, 2010). The process of characterization can either be qualitative or quantitative. In qualitative reservoir characterization, the quality of the rock is evaluated to see if it can be a reservoir rock (Alamsyah, 2011). While in the quantitative, the process of numeral statements on some characteristics such as permeability, porosity, saturation, pressure and pore sizes are done. Saturation is one of the most important parameters in reservoir characterization. This work, therefore seeks to characterize the saturation parameters of a geologic formation using well log.

Well Logging

Well logging, also known as borehole logging is the practice of making a detailed record of the geologic formations penetrated by a borehole. The log may be based either on visual inspection of samples brought to the surface (*geological* logs) or on physical measurements made by instruments lowered into the hole (*geophysical* logs). Some types of geophysical well logs can be done during any phase of a well's history: drilling, completing, producing, or abandoning (Berg, 1985). Well logging is performed in boreholes drilled for the oil and gas, groundwater, mineral and geothermal exploration, as well as part of environmental and geotechnical studies.

Geology of Study Area

The Niger Delta Basin, also referred to as the Niger Delta province, is an extensional rift basin located in the Niger Delta and the Gulf of Guinea on the passive continental margin near the western coast of Nigeria (Tuttle *et al.*,2015), suspected or proven access to Cameroon, Equatorial Guinea and São Tomé and Príncipe (Fig.1).This basin is very complex, and it carries high economic value as it contains a very productive petroleum system.

The Niger delta basin is one of the largest sub-aerial basins in Africa. From the Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the Niger delta at each stage of its development (Doust and Omatsola, 1990).These depobelts form one of the largest regressive deltas in the world with an area of about 300,000 km^2 (Kulke, 1995 and Chukwueke, 1997), a sediment volume of 500,000km^3, and a sediment thickness of about 12km in the basin depocenter.

It is composed of several different geologic formations that indicate how this basin could have formed, as well as the regional and large scale tectonics of the area. The Niger Delta Basin is an extensional basinsurrounded by many other basins in the area that all formed from similar processes. The Niger Delta Basin lies in the south part of a larger tectonic structure, the Benue Trough. The other side of the basin is bounded by the Cameroon Volcanic Line and the transform passive continental margin.

The lithologies of the area experience changes due to several factors. One factor would be the types of sediment coming through the delta, which could be influenced by sea level, *or maybe volcanic activity in the area.* The type of environment of deposition will also change the sediment type. The early Cretaceous sediments were thought to be from a tide dominated system that were deposited on a concave shoreline, and throughout time the shoreline has become convexed and it is currently a wave dominated system (Archie, 2002). Also closer to the coast you have Precambrian continental basement (Winsauer, 2015).

The Niger Delta province contains only one identified petroleum system (Akata-Agbada) Petroleum System (Kulke, 1995).The Akata Formation is Paleocene in age. It is composed of thick shales, turbidite sands, and small amounts of silt and clay. This formation is estimated to be up to 7000m thick (Gluyas and Richard, (2004).

There is a transition zone, and then there is a contraction zone, which lies in the deep sea part of the basin. Fatoke (2010).

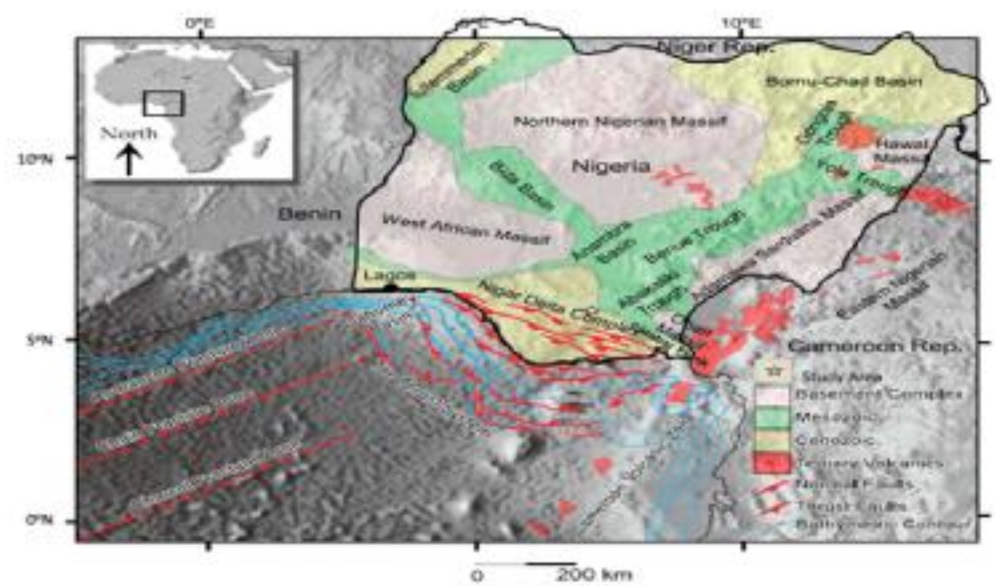

Figure 1: Location map of the Niger Delta region showing the main sedimentary basins and tetonic features. The delta is bounded by Cameroon volcanic zone, the Dahomey basin, and the 400m (13,000ft) bathymetric contour. The regional geology is modified from Onuoha (1999). Topography and bathymetry are shown as a shaded relief gray-scale image

Concept of Reservoir

In the study of Archie (2002), he observed the electrical parameters of core sample in different water saturation, and succeeded to calculate the water saturation by using electrical resistance logs and porosity derived from porosity logs, it also shows that electrical resistance of connate water and constant parameters of Archie equation are computed from laboratory core analysis.

Kamel and Mabrouk (2000), in their study of sandstone reservoirs, shows that carbonate reservoirs are much heterogeneous in their reservoir rock properties, which caused many changes in reservoir characteristic. The perceptions of this heterogeneity in reservoir properties are very important in petrophysical analysis. However, Archie equation is used as the basic equation for interpreting of logging data, this equation is applicable for extremely water-wet with clean inter-granular pore spaces.

Gamma rays attenuate according to the diameter of the borehole mainly because of the properties of the fluid filling the borehole, but because gamma logs are generally used in a qualitative way, amplitude corrections are usually not necessary (Ara*et al.*,2013 and Sethi, 2012).

The relative salinity of the mud and the formation water will determine which way the SP curve will deflect opposite a permeable formation. Generally, if the ionic concentration of the well bore fluid is less than the formation fluid then the SP reading will be more negative (usually plotted as a deflection to the left). If the formation fluid has an ionic concentration less than the well bore fluid, the voltage deflection will be positive (usually plotted as an excursion to the right). The amplitudes of the line made by the changing SP will vary from formation to formation and will not give a definitive answer to how permeable or the porosity of the formation that it is logging. The presence of hydrocarbons (e.g. oil, natural gas, condensate) will reduce the response on an SP log because the interstitial water contact with the well bore fluid is reduced. This phenomenon is called hydrocarbon suppression and can be used to diagnose rocks for commercial potential (Ara*et al.,* 2001). Positive deflections are observed for fresh water bearing formations (Winsauer, 2015).

MATERIALS AND METHOD

This study was carried out on five wells in the Niger Delta basin shown in Fig 2 below, from south to north (POLE 3, POLE 1, POLE 5, POLE 4 and POLE 2).

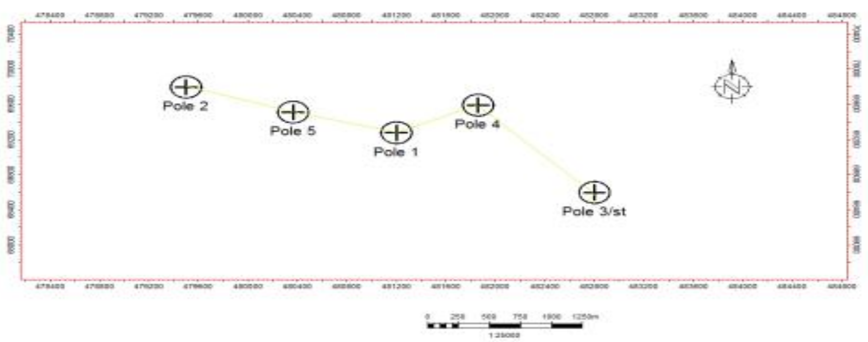

Figure 2: Base Map of the Field

Materials

WELL LOGS and SCHLUMBERGER SOFTWARE PETREL (2009) were used to carry out this research work. Petrel is a software platform used in the exploration and production sector of the petroleum industry. It allows the user to interpret seismic data, perform well correlation, build reservoir models, visualize reservoir simulation results, calculate volumes, produce maps and design development strategies to maximize reservoir exploitation. Risk and uncertainty can be assessed throughout the life of the reservoir. Petrel is developed and built by Schlumberger [Wikipedia, 2013].

Method

Lithologic correlation of equivalent strata across the six wells was done using the gamma ray log. Equally, identified potential hydrocarbon reservoirs in the various wells were correlated using the gamma ray and resistivity logs to know their lateral and vertical extent (Figure 3 and Figure 4).

The initial step in this log analysis is to identify the zones of interest i.e. clean sand with hydrocarbon. Gamma ray (GR) log which measures natural radioactivity in Formations (Figure 3), as used in the identification of sand/shale lithology in the study area.

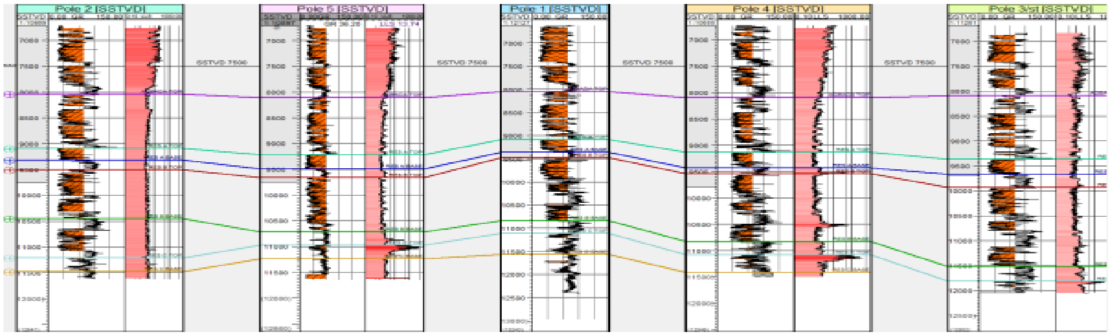

Figure 3: NW-SE Reservoir correlation across POLE Field with GR and Deep Resistivity

The deep laterolog (LLD) represented in track-2 (Figure 3) in combination with the GR log were used to differentiate between hydrocarbon and non-hydrocarbon bearing zones. Consequently, the zones of interest for the petrophysical interpretation were defined in terms of clean zones with hydrocarbon saturation (low GR and high resistivity). The formation density and neutron logs were used for the differentiation of the various fluid types. The gas zones are interpreted from crossover of the porosity logs i.e. formation density and neutron logs, oil zones are based on high resistivity values and water zones corresponds to very low resistivities (Figure 4).

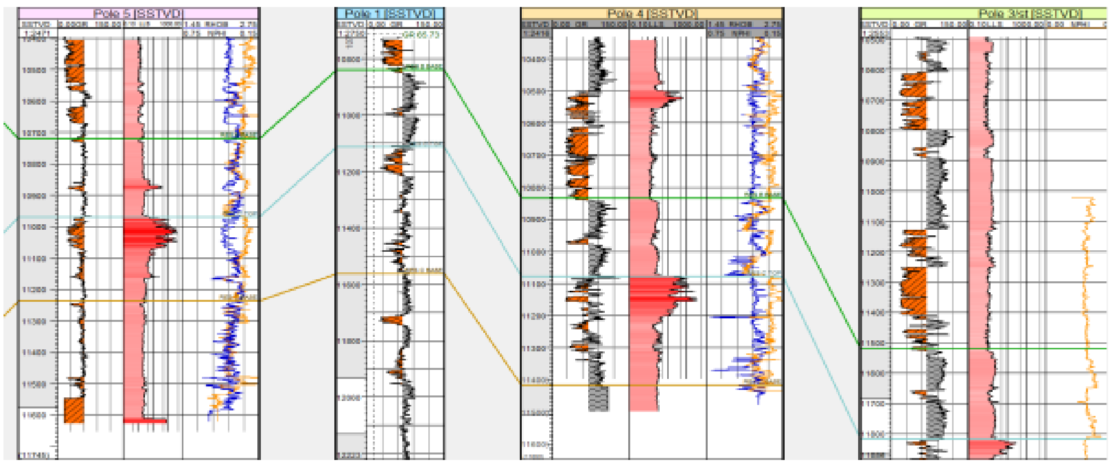

Figure 4: Reservoir correlation showing balloon feature in reservoir A and B in well 5 and 6

The next step is shale volume estimation; shale volume (Vsh) was calculated using the Dresser Atlas, 1979 formula in equation (1) which uses values from the gamma ray (GR) in equation (2)

$$V_{sh}=0.083^{(2(3.7xIGR)} \quad (1)$$

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

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

Porosity, f_D was determined (DresserAtlas, 1979) by substituting the bulk density readings obtained from the formation density log within each reservoir into the equation (3).

$$f_D = \frac{?_{ma}-?_b}{?_{ma}-?_f} \text{ -vsh}\frac{?_{ma}-?_b}{?_{ma}-?_f} \quad (3)$$

And where, $\rho_{ma,}\rho_{b,}?f$and are matrix density, formation bulk density and fluid density respectively. To calculate water saturation, S_w the method used in this study requires a water resistivity R_w value at formation temperature calculated from the porosity and resistivity logs within clean water zone, using the Ro method given by the following equation:

$$R_w=\frac{?^m-R_0}{a} \quad (4)$$

R_w is the water resistivity at formation temperature, φ and R_o are the total porosity and deep resistivity values in the water zone respectively. Tortuosity factor is represented as "a" and m is the cementation exponent usually 2 for sands (Asquith and Krygowski, 2004). In the water zone, saturation should be equal to 1, as water resistivity R_w at formation temperature is equal to R_{wa}.

Water saturation, S_w can then be calculated using Archie's method, given by

$$S_W = \left(\frac{R_W}{R_{wa}}\right)^{1/n} \quad (5)$$

where n is the saturation exponent and $R_{wa}$is water resistivity in the zone of interest, calculated in the same manner as R_W at formation temperature (Archie, 2002). Hydrocarbon Saturation, S_h is the percentage of pore volume in a formation occupied by hydrocarbons. It can be determined by subtracting the value obtained for water saturation from 100% i.e.

$$S_h = (100 - S_W)\ \% \quad (6)$$

The productivity of each delineated reservoir rock at the zone of interest are estimated by evaluating results of their calculated petrophysical parameters using equations (1-6).

RESULTS AND DISCUSSION

Available well log data was used in interpreting various parameters, attribute maps extracted on top of key horizons were used for better visualization and interpreting the morphological and reflectivity characteristics of the reservoir (Figure5).

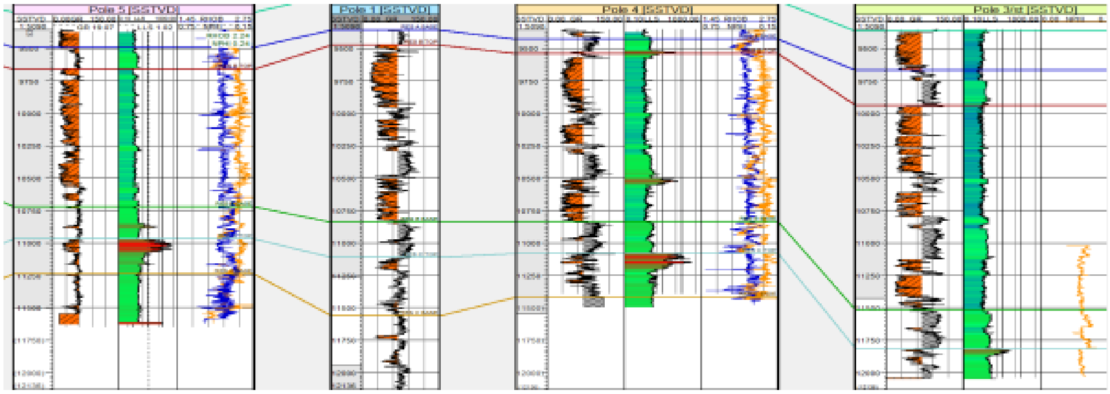

Figure 5: Validation of fluid Nature in reservoir zone (Red = Gas, Green= Oil, Blue = water)

The results of the interpreted well logs for Reservoir A (Table 1) revealed that the hydrocarbon range in the areas occur between the depth range of 9070-9650ft. Reservoir A has Gross thickness range of between 248-292ft and average Gross thickness of 268.6ft, Net thickness range of between 225-279ft and Average Net thickness of 251ft. The gamma ray and the resistivity logs show True Porosity range (poro T) of the reservoir sand between 28-38 and Average True Porosity of 32.33, it shows us an Effective Porosity (poro E) range of between 21-28 with Average Effective Porosity of 25. The water saturation of Reservoir A range between 0.33-0.75 and average of 0.344 per well. It gave us a hydrocarbon saturation of range of 0.62 – 0.91 with pole 2 and pole 3 having no hydrocarbon at all. The above data gives Reservoir A as a productive reservoir with pole 5 being the most productive well having a Net to Gross (NTG) thickness reservoir sand of 0.91. The results when compared with (Eshimokhai and Akhirevbulu, 2012) are indicative of very good hydrocarbon potentials.

Table 1: Petrophysical Results for reservoir A

WELL	Top (Ft)	Base (Ft)	Gross Thickness (Ft)	Net Thickness (Ft)	Poro T	Poro E	SW	NTG	S^HC
Pole 2	9070	9318	248	225	36	28	Nil	0.93	Nil
Pole 5	9223	9490	267	258	30	25	0.33	0.97	0.91
Pole1	9076	9325	249	233	28	21	0.26	0.94	0.74
Pole 4	9136	9423	287	260	38	27	0.38	0.91	0.62
Pole 3	9358	9650	292	279	33	24	0.75	0.96	Nil

For Reservoir B (Table 2), the results revealed that the hydrocarbon potential range in the areas occur between the depth range of 9454-11505ft. Reservoir B has Gross thickness range of between 945 – 1580ft and average Gross thickness of 1243ft, Net thickness range of between 860-1050ft and Average Net thickness of 928ft.

The gamma ray and the resistivity logs shows pole 2 and 3 to have 0 porosity, water and hydrocarbon saturation. The remaining fields of Reservoir B gives True Porosity range (poro T) of the reservoir sand between 29-39 and Average True Porosity of 19.6, it shows us an Effective Porosity (poro E) range of between 21-25 with Average Effective Porosity of 13.6. The water saturation of Reservoir B range between 0.60-0.75 and average of 0.412 per well.

Table 2: Petrophysical Results for reservoir B

WELL	Top (Ft)	Base (Ft)	Gross Thickness (Ft)	Net Thickness (Ft)	Poro T	Poro E	SW	NTG	S^HC
Pole 2	9492	1043	945	860	Nil	Nil	Nil	Nil	
Pole 5	9655	10702	1047	950	29	21	0.75	0.91	
Pole 1	9454	10814	1360	900	30	22	0.60	0.66	
Pole 4	9542	10825	1283	880	39	25	0.71	0.69	
Pole 3	9925	11505	1580	1050	Nil	Nil	Nil	Nil	

While, Reservoir C (Table 3) revealed that the possible hydrocarbon range in the areas occur between the depth range of 10968-11554ft with pole 3 showing no depth which made it impossible getting data about its thickness, porosity, water and hydrocarbon saturation. For the remaining wells it shows a Gross thickness range of between 249-462ft and average Gross thickness of 327.75ft, Net thickness range of between 45-258ft and Average Net thickness of 167.5ft.

The gamma ray and the resistivity logs shows pole 2 also to have zero(0) porosity, water and hydrocarbon saturation. The remaining fields of Reservoir C gives True Porosity range (poro T) of the reservoir sand between 29-32 and Average True Porosity of 30.3, it shows us an Effective Porosity (poro E) range of between 21-25 with Average Effective Porosity of 23.33. With pole 2, 3 and 5 showing no water saturation Reservoir C only gives the water saturation of pole 1 and 4.

Table 3: Petrophysical Results for reservoir C

WELL	Top (Ft)	Base (Ft)	Gross Thickness (Ft)	Net Thickness (Ft)	Poro T	Poro E	SW	NTG	S^HC
Pole 2	11208	11457	249	45	Nil	Nil	Nil		
Pole 5	10968	11235	267	258	30	24	Nil		
Pole 1	11092	11554	462	109	29	21	0.23		
Pole 4	11070	11403	333	258	32	25	0.38		
Pole 3	11831	No data							

CONCLUSION

The log analysis performed in this study shows that the reservoir sand units of ‘Pole field’ contain significant accumulations of hydrocarbon. The delineated zones of interest (five in number) have a favourable average net sand thickness, average effective porosity and hydrocarbon saturation, S_h ranging from 0.002 to 0.22 which are favorable indicators for commercial hydrocarbon accumulation. In summary, Reservoir A is a productive reservoir with pole 5 being the most productive well.

RECOMMENDATION

Further calibration of the log analysis parameters with core and production data is necessary to verify the calculated values, as the permeabilities for some of the reservoir sand units are extremely high.

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