INTERPRETATION OF WELL LOG MODELS FROM E-FIELD IN THE NIGER DELTA SEDIMENTARY BASIN

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Abstract. Interpretation of well log models in this research was achieved with the use of well log data from three (3) wells of an E-field in the Niger Delta sedimentary Basin. The well log data was processed with Petrel software (2010 version) which gives various well log signatures of the well logs resulting from the subsurface properties, in order to determine the subsurface lithology, the reservoir sand of interest, the hydrocarbon potential of the delineated reservoir, the petrophysical properties of the reservoir and the fluid contained in the reservoir. The logs used were the gamma ray, spontaneous potential, resistivity, density and neutron logs. The subsurface lithology of the formation of interest was identified as sand and shale, the reservoir was delineated as sand bodies. Although, there were several reservoirs with appreciable depth present across the wells, only two reservoirs (reservoir M and reservoir K) were chosen for detailed analysis, mapped and correlated across each of the wells. It was observed that reservoir (M) had a thickness of 50ft in OLJ 1, 50ft in OLJ4, 50ft in OLJ 5 and reservoir (K) had a thickness of 60ft in OLJ 1, 90ft in OLJ 4 and 70ft in OLJ 5. The petrophysical log used were the porosity log, permeability log, net to gross log and water saturation log. The average petrophysical properties of the reservoir (M) gave a porosity value of 0.23 (23%), permeability value of 1635mD, net to gross (NTG) value of 0.9, water saturation value of 38%, hydrocarbon saturation value of 62% and reservoir (K) gave a porosity of 0.23 (23%), permeability of 1442mD, net to gross (NTG) value of 1.0, water saturation 38% and hydrocarbon saturation of 62%, which indicates an excellent hydrocarbon reservoir system with much petroleum and gas prospect for hydrocarbons exploitation.
Keywords: *well log models, pay zones, porosity, permeability, Net to Gross (NTG), fluid saturation*

Introduction

Interpretation of well logs involves choosing the best model from the given data in order to obtain results which are true pictures of the subsurface geology. Well logging interpretations are often qualitative and quantitative. Qualitative interpretation of well log data involves the use of models which represents the characteristics log response to formation parameters in order to determine the hydrocarbon reservoir lithology. In qualitative interpretation, identification of lithology is achieved with the use of gamma ray log combined with spontaneous potential log in order to ascertain the lithology (sand and shale) in the various formations of different wells. Quantitative interpretation of well log data on the other hand, involves the use of mathematical models to determine petrophysical parameters of the hydrocarbon reservoir. Geophysical well logging has become a standard operation in the petroleum exploration as it has the ability to determining the depth of geological interfaces or beds that have a characteristics geophysical signature, to provide a means of correlating geophysical information between boreholes for the evaluation of possible productive reservoirs which is the principal objective (Telford et al, 1990). Geophysical well logging was first introduced to the Petroleum Industry by Marcel and Conrad Schlumberger in 1927. The main purpose of well logging is the identification and evaluation of the potential hydrocarbon bearing formations. The potential of a zone is measured by estimating its water saturation, hydrocarbon saturation and other petrophysical parameters (Ipek, 2002). The objective of interpretation of well log is to obtain parameters such as porosity, permeability, water saturation and hydrocarbon saturation from the composite log. The various wireline logs used in the E-field for appropriate modeling and estimation of petrophysical parameters were the gamma ray, resistivity, density, neutron and spontaneous potential logs.

The knowledge of reservoir dimension is an important factor in quantifying producible hydrocarbon (Özkanlı, 1990). Among the needed information includes the thickness and the area extent of the reservoir. Precise determination of reservoir thickness is best obtained on well logs, especially using the gamma ray log and resistivity log (Asquith et al., 2004). Because almost all oil and gas produced today comes from their accumulation in the pore spaces of lithologies like sandstone, limestone and dolomite. The aim of this research is to qualitatively interpret well log models from E-field within the Niger Delta sedimentary Basin in order to quantify producible hydrocarbons. The objectives of this research include to; determine the subsurface lithology, delineate the reservoir of interest, determine the hydrocarbon potential of the delineated reservoir, estimate the thickness of hydrocarbon bearing zones, determine the type of fluid contained in the reservoir and to estimate petrophysical properties of the reservoir sand. The scope of the research entails the application of well log data from three wells in E-field to qualitatively delineate the formation and characterize the hydrocarbon reservoir within the study area. This involves the use of gamma ray log combined with spontaneous potential log to identify the lithology and the use of resistivity, neutron and density logs to estimate the porosity and fluid content of the reservoir formation as well as to identify GOC and WOC across the wells. Empirical models would equally be deployed to estimate petrophysical parameters of the identified reservoirs of interest.

Qualitative interpretation of well log models is very essential in the exploration and production of hydrocarbons and is also fundamental to reservoir characterization. Understanding the lithology and fluid content of a reservoir is the foundation from which other petrophysical parameters are determined. Porosity, permeability, and water saturation are physical properties that make it possible to evaluate hydrocarbon reservoirs. However, these physical parameters can be determined accurately only when lithology and fluid content are determined accurately. The major challenge encountered in this work was related to lack of necessary data for confirmation and comparison of the results obtained from the petrophysical parameters calculated, a comparison of the well log data used in this research to other data is required for optimal result but these data were not available. The unavailable data were high resolution seismic data, check-shot data to carry out well to seismic tie and core data as well as production data.

Previous studies within the Niger delta sedimentary basin

The Niger Delta Basin has been studied extensively by both individual geoscientist and corporate bodies (Multinational Oil and Gas Companies) due to its enormously high potential for oil and gas in the hydrocarbon reservoir systems of the Basin. In 2009, Ekine and Iyabe carried out study on Petrophysical logs interpretation for characterization of reservoir sands in the Niger Delta and found out that the characterization of the reservoir sands are very useful and an important tool for selecting, planning and implementing operationally sound supplementary schemes and also for the evaluation of reservoir rocks petrophysical properties in terms of their porosity, water saturation and permeability. Ohakwere-Eze and Adizua (2014) carried out a preliminary study of well log data over an offshore Niger Delta field in order to qualitatively delineate hydrocarbon bearing reservoirs. They succeeded in estimating the porosity and hydrocarbon saturation of the delineated reservoir and concluded that the reservoirs were good enough for potential commercial hydrocarbon accumulation which could be exploited. Ogungbemi and Tech (2014) used the ratio of compressional and shear wave velocities and their travel times to predict lithology of the "Benin River Field" located in the Niger Delta Basin in Nigeria. He used well logs to successfully predict lithology and pore fluid contents of hydrocarbon reservoirs. Due to the absence of gamma ray and spontaneous potential logs, velocity ratio was used to differentiate between sand and shale. However, velocity ratio cannot be used to effectively differentiate between carbonate and shale. Hence, the need for a comprehensive lithology prediction using well logs. Ekweozor and Okoye (1980) carried out petroleum source bed evaluation of the Tertiary Niger Delta. They established that the dominant sedimentary kerogen in the Niger Delta were the humic and mixed types. They also stated that habitats of the hydrocarbons are mainly the sandstone reservoirs in the paralic sequence of the Agbada Formation, where the hydrocarbons are characteristically trapped by growth faults at the crest of rollover anticlines. Omatsola (1982) concluded that reservoir sands of more than 15m thick in most places represent composite bodies, and may consist of two to three stacked channels. The sands according to his findings were poorly consolidated and have porosities as high as 40% in oil bearing reservoirs. Porosity reduction with depth was gradual and permeability in hydrocarbon reservoirs were commonly in the range of 1 to 2 Darcy.

Outline geology of the Niger delta sedimentary basin

The Niger Delta Basin is a prolific hydrocarbon belt in the world. The formation of the Niger Delta Basin was initiated in the early Tertiary time. The Niger Delta Basin is situated in the Gulf of Guinea and extends throughout the Niger Delta province. From the Eocene to the present, the Delta has prograded Southwest ward, forming depobelts that represent the most active portion of the Delta at each stage of its development (Doust et al., 1990). Deposition of the three formations occurred in each of the five off lapping siliciclastic sedimentation cycles that comprise the Niger Delta. These cycles (depobelts) are 30 - 60 kilometers wide, prograde southwestward 250 kilometers over oceanic coast into the gulf of guinea, and are defined by syn-sedimentary faulting that occurred in response to variable rates of subsidence and sediment supply (Doust et al., 1990). The interplay of subsidence and supply rates resulted in deposition of discrete depobelts when further crustal subsidence of the basin could no longer be accommodated, the focus of sediment deposition shifted seaward, forming a new depobelt. Each depobelt is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt (Doust et al., 1990). Five major depobelts are generally recognized, each with its own sedimentation, deformation and petroleum history. The sedimentary wedge of the Niger Delta contains a major submarine part (Reijers et al., 1997) which forms part of the complex continental margin intruding into the Gulf of Guinea. In the Niger delta province, the Tertiary Niger delta (Akata-Agbada) petroleum system has been identified. The Delta formed at the site of a rift triple junction related to the opening of the Southern Atlantic starting in the late Jurassic from inter-bedded marine shale of the lowermost Agbada formation and continuing into the cretaceous. The Delta proper began developing in the Eocene, accumulating sediments that now are over 10km thick. The primary source rock is the upper Akata Formation; the marine-shale facies of the Delta with possibly contribution from inter bedded marine shale of the lowermost Agbada formation. Oil is produced from sandstone facies within the Agbada Formation; however, turbidite sand in the upper Akata Formation is a potential target in deep water offshore and possibly beneath currently producing intervals onshore.

The study area falls within the southern margin of the depobelt of Niger Delta Basin. The fault pattern is NW-SE and the traps involved in this field are mainly structural in nature. The study area (E-field) is within the para-sequence set of Agbada formation. Hence, the local geology of the area is similar to that of the Niger Delta Basin. The Niger Delta area is situated in the Gulf of Guinea between longitudes 5˚ and 8˚E and latitude 3˚ and 6˚N (Klett et al., 1997). The Map of Niger Delta Basin showing the depobelts (*Figure 1*) is shown adapted from the work of Weber (1971). The geology of the Tertiary Niger Delta is divided into three formations, representing prograding depositional facies distinguished mostly on the basis of sand-shale ratio. They are Benin Formation, the Paralic Agbada Formation and Prodelta Marine Akata Formation (Doust et al., 1990) which constitutes the lithostratigraphical units of the Niger Delta Basin. The Benin Formation consists mainly of sands with thickness ranging from about 0 to 2,100 meters. The Agbada Formation which consists of paralic siliciclastics underlies the Benin Formation and it is the principal reservoir of the Niger Delta Basin and the thickness ranging from about 0 to 4500 meters. The Akata Formation is the major basal time transgressive lithologic unit in the Niger Delta Complex with approximate range of thickness ranging from about 0 to 7000 meters. The Formation is mainly shale but sandy or silty in the upper part where it grades into the Agbada Formation. The Akata Formation is the major source rock in the Niger Delta. *Figure 2* shows the Niger Delta lithostratigraphic cross section showing the Benin, Agbada and Akata Formations (Weber and Daukoru, 1975). The field under study is pseudo-named E-Field and it is situated in the onshore southern province of Niger Delta Basin, Nigeria. As a result of the current practices of Exploration and Production (E&P) companies in Nigeria, the exact location of the field would not be disclosed.

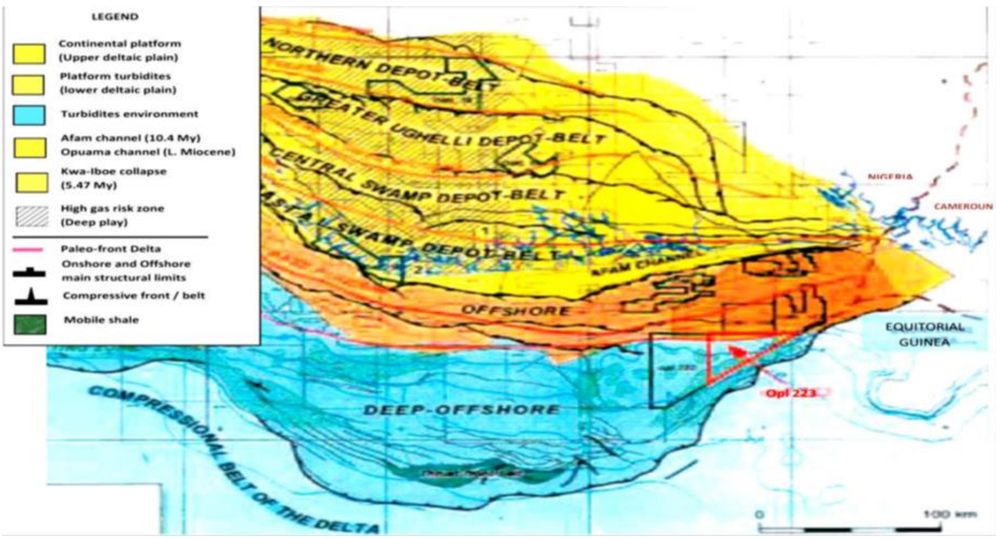

Figure 1. *Map of Niger Delta showing the depobelts (Weber, 1971).*

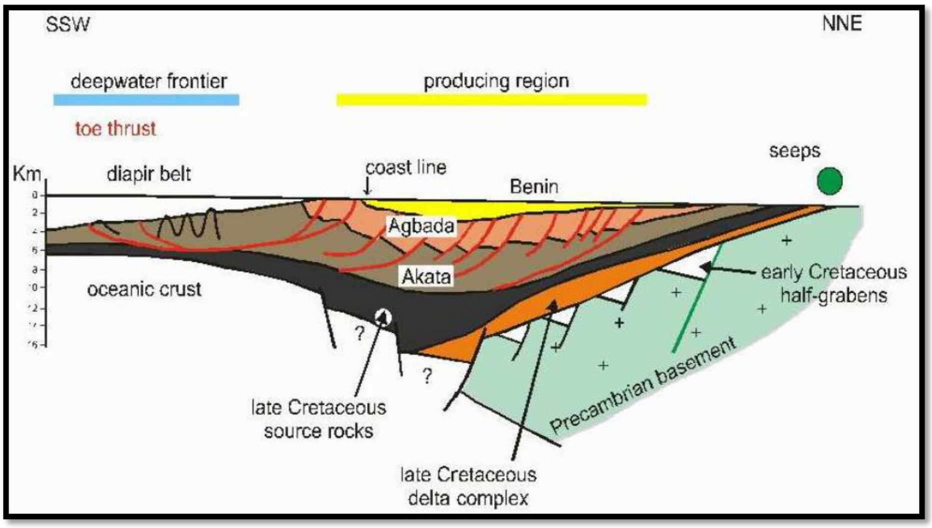

Figure 2. *The Niger Delta lithostratigraphic cross section showing the Benin, Agbada and Akata Formations (Weber and Daukoru, 1975).*

Materials and Methods

Dataset

The dataset deployed comprised of the base map of the study area, the well header, the well deviation and the geophysical well logs all procured from Nigerian Agip Oil Company (NAOC). Petrel 2010 Version was the software used for the well log modeling and analysis. Each of the well log suite consists of the Gamma ray (GR), Spontaneous potential (SP), resistivity (ILD), density (DEN) and neutron logs except for well OLJ 5 that does not contain the SP and resistivity log (ILD). *Figure 3* shows the base map of the study area. The various methods applied in this study are summarized in the work flow presented in *Figure 4*.

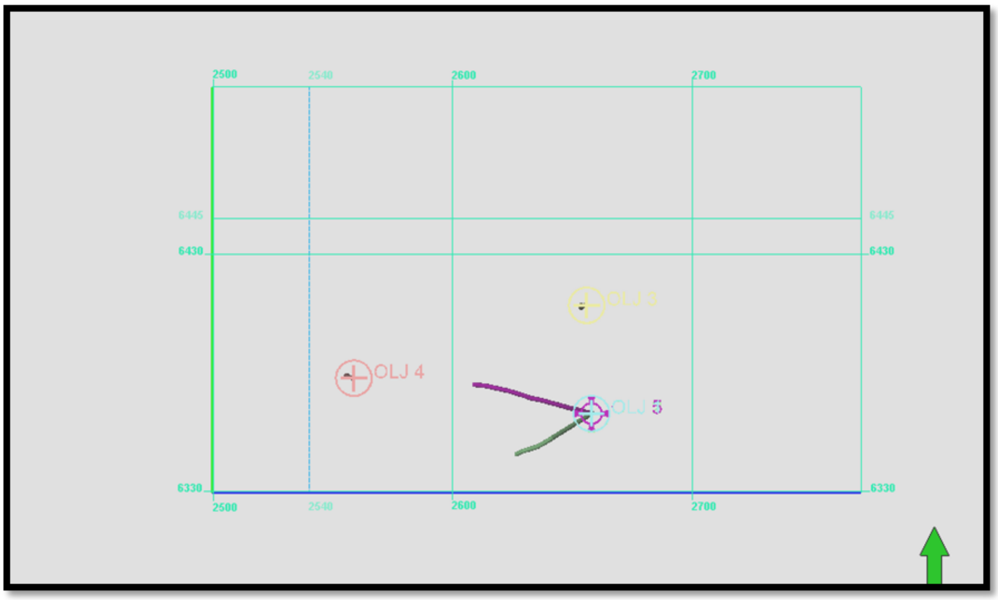

Figure 3. *Base map of the study area.*

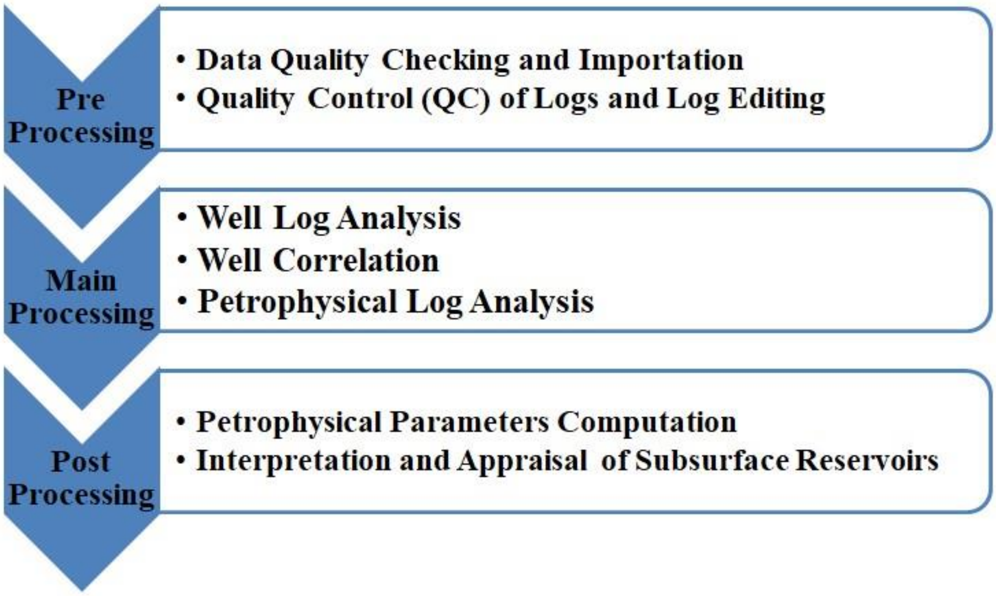

Figure 4. *Work flow showing processing and interpretational workflow adopted for the study.*

Data quality checking and importation

This involves inputting the well log data accordingly into the software (Petrel 2010 Version) from the well headers through the well deviations (a data that shows that the wells are not completely vertical) and to the logs.

Well log analysis

This involves using the well log models across the three (3) wells from the gamma ray log signatures to delineate the reservoir sand bodies.

Well correlation

This involves the matching of the reservoir sands of interest across the three (3) wells in order to know the depth and shape of each reservoir. This was achieved by picking the top and bottom of each reservoir sand across the wells and matching them.

Petrophysical log analysis

This involves analyzing the petrophysical properties of the wells with respect to the depth. It is done by selecting the petrophysical properties of interest you wish to visualize and the signature is displayed on the section.

Petrophysical computation

This involves computing the petrophysical properties of the identified reservoirs after the petrophysical log analysis has been carried out. It is done by inputting the mathematical formulae for each petrophysical properties and the values are displayed.

Interpretation and appraisal of the subsurface reservoirs

This was carried out after all the necessary steps listed on the methodology workflow were achieved. From the log responses of the wells, we could describe where there was an increase in porosity, permeability, net to gross and a decrease in water saturation by quick look approach.

Determination of lithology, reservoir and petrophysical properties

In lithology, the gamma ray (GR) log was used for the identification of the various lithologies on the well bore (sand, shale, and sand/shale intercalations). The grey colouration from the log responses represents shale while the yellow colouration represents reservoir sand bodies. For reservoir, the reservoirs in the subsurface were delineated using the GR and resistivity logs by taking note that the sand formation with low gamma ray reading and high resistivity indicates hydrocarbon saturated zones. As a result of faulted zones on the subsurface, delineated reservoirs across the wells were not all at the same depth and thickness so there was a need for well correlation to understand and better visualize the lateral configurations of the identified reservoirs. Meanwhile, an accurate well correlation should be able to tie similar reservoirs across the wells. It was easy to determine similar reservoir by picking the top and bottom of the reservoir thereby building a well fence. This gives insights to the reservoir thickness across the wells. Different petrophysical properties such as porosity, permeability, water saturation, net to gross (NTG) ratio and hydrocarbon saturation were determined. Although the quality of any good reservoir is highly dependent on porosity and permeability, it was pertinent to determine other petrophysical properties. The interpretation templates for porosity and permeability by Rider (1986) were adapted for the study. These templates are presented in *Table 1* and *Table 2* for porosity and permeability respectively.

Table 1. *Criteria for qualitative description of porosity of reservoirs.*

Percentage porosity (%)	Qualitative description
0-5	Negligible
5-10	Poor
15-20	Good
20-30	Very good
>30	Excellent

Source: Rider (1986)

Table 2. *Criteria for qualitative description of permeability of reservoirs.*

Average K value (mD)	Qualitative description
<10.5	Poor to Fair
15 – 50	Moderate
50 – 250	Good
250 -1000	Very good
>1000	Excellent

Source: Rider (1986)

Results and Discussion

Interpretation of the well log models

The qualitative interpretation of the well log models (results obtained after processing) involved analysing the log response from the models in order to get a better understanding of the subsurface characteristics.

Interpretation of OLJ 1 well log model

The major lithologies delineated from the GR log response (*Figure 5*) was sand and shale. The sand lithology was associated with low GR reading while the shale lithology had the maximum GR reading. The gamma ray log signature deflects to the right as a result of radioactive materials present in shale and deflects to the left as sand (potential reservoirs) which are free from radioactive materials. The SP log signature response showed a low SP log reading indicating a sand zone as a result of the low potential difference of sand while the shale zones showed a high potential difference reading. Furthermore, from the resistivity log (ILD) it can be deduced that the zones with high resistivity reading (i.e. a deflection to the right) indicates the presence of hydrocarbons while the zones with low resistivity reading depicts water bearing formations. From the density (DEN) and neutron (NPHI) log response, it was deduced that the fluid contained in the reservoir sand were gas, oil and water with regards to the fluid and the hydrogen ion concentrations in the formation. The combination of the density and neutron log signature gave a gas balloon structure which was used to delineate the Gas-Oil contact (GOC) and Oil-Water contact (OWC) in the reservoir sand.

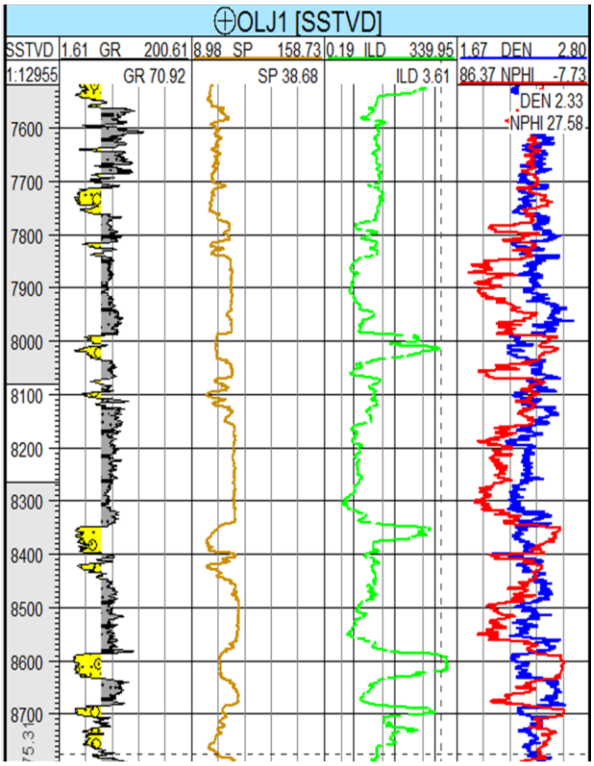

Figure 5. *Well log responses of GR, SP, ILD and NPHI/DEN for Well OLJ 1.*

Interpretation of OLJ 4 well log model

The major lithologies delineated from the GR log response (*Figure 6*) was sand and shale. The sand lithology was associated with low GR reading while the shale lithology had the maximum GR reading. The gamma ray log signature deflects to the right as a result of radioactive materials present in shale and deflects to the left as sand (potential reservoir) which is free from radioactive materials. The SP log signature response showed a low SP log reading indicating a sand zone as a result of the low potential difference of sand while the shale zones showed a high potential difference reading. Furthermore, from the resistivity log (ILD) it was deduced that the zones with high resistivity reading (i.e. a deflection to the right) indicates the presence of hydrocarbons while the zones with low resistivity reading depicts water saturated formations. From the density and neutron log response, it was deduced that the fluids present in the well contains oil, water and gas with regards to the density and hydrogen ion concentration of the fluids. The combination of the density and neutron log yielded a gas balloon structure which indicates that there is a contact between oil, water and gas.

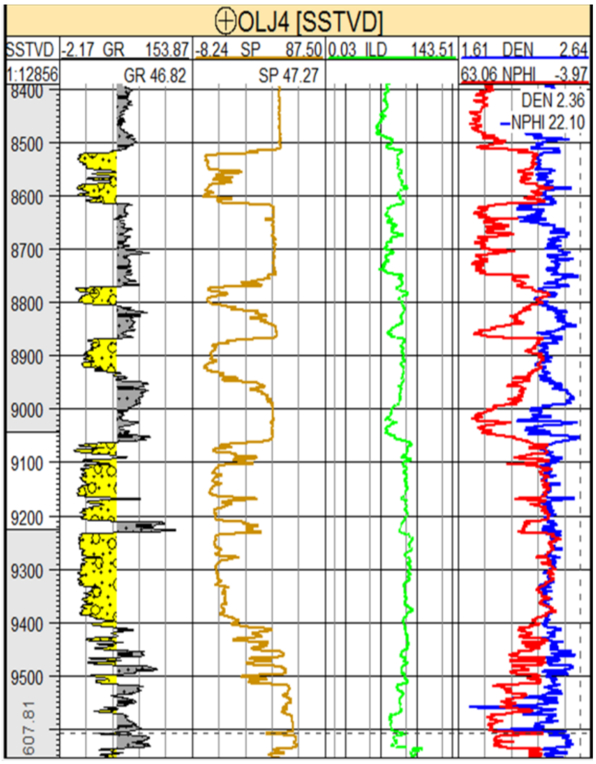

Figure 6. *Well log responses of GR, SP, ILD and NPHI/DEN for Well OLJ 4.*

Interpretation of OLJ 5 well log model

The Well OLJ 5 (*Figure 7*) shows the gamma ray GR log response, the density log response and the neutron log response. The same interpretation as applied to OLJ 1 and OLJ 4 is equally applicable here. The SP and resistivity log response was not displayed on the model and this implies that the SP and resistivity logging tool was not used in OLJ 5 and the reason for this is best known to the company that acquired the well log data.

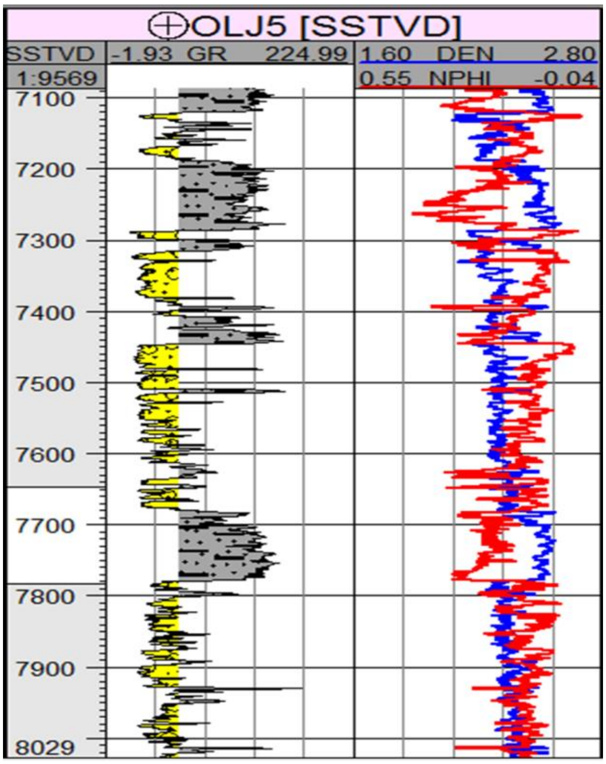

Figure 7. *Well log responses of GR, SP, ILD and NPHI/DEN for Well OLJ 5.*

Interpretation of the reservoir sand bodies correlated across OLJ 1, OLJ 4 and OLJ 5 wells

Several reservoir sand units within the three wells of E-field have been identified from the log models (*Figure 8*), but only two remarkable reservoir sand bodies were delineated for each of the wells and were tagged as reservoir M and reservoir K (*Figure 9*). The first reservoir mapped was M and had its top marked as M-Top and M-Base at the base of the reservoir. The second reservoir mapped was K and the thickness of this reservoir is the vertical distance between the top (K-Top) and its base (K-Base).

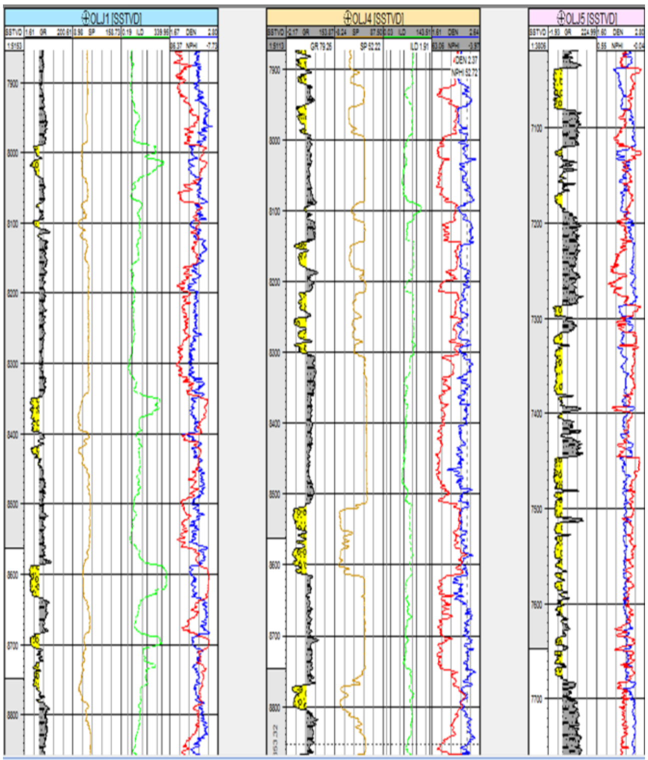

Figure 8. *Well log responses for OLJ 1, OLJ 4 and OLJ 5 with respect to their subsurface depths.*

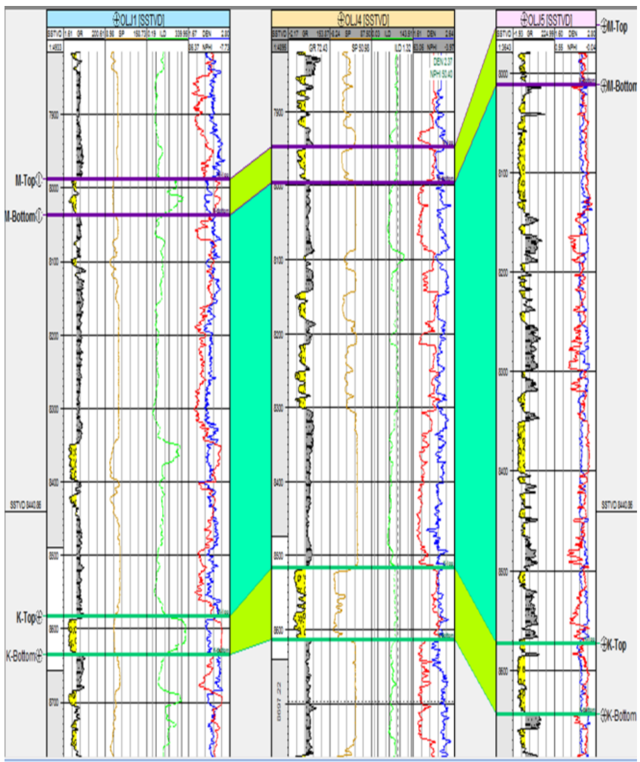

Figure 9. *Well correlation of the reservoir sand bodies across OLJ 1, OLJ 4 & OLJ5.*

Reservoir M

This reservoir was qualitatively delineated based on the log responses from the three (3) wells. The GR log responses suggested that the reservoir was sand. Also from the SP log response of OLJ 1 and OLJ 4, there was a decrease in the log excursions, implying that the potential difference of the delineated sand reservoir is low which is in agreement with literature. From the resistivity log response of OLJ 1 reservoir sand body, it was deduced that there is an increase in the log excursion which deflects to the right and an intermediate log signature response implying that there is oil, water and gas contained in the reservoir. From the neutron and density log signature which gave a gas balloon structure, the GOC and OWC could be easily deduced. In well OLJ 4, the reservoir sand was delineated from the GR log response; the SP log response yielded a low potential difference reading. The resistivity log response showed an increase in resistivity which implies that hydrocarbons are present in the reservoir. The combination of the DEN log and NPHI log gave a good balloon structure that separates the fluid in the reservoir as oil, water and gas. In OLJ 5, the reservoir sand was thick and had an appreciable depth with a neutron and density log response that depicts the presence of hydrocarbons in the reservoir.

Reservoir K

In OLJ 1 well, the reservoir sand was appreciably thick with a decrease in SP log response indicating that the reservoir is predominantly sand lithology and the potential difference of the reservoir sand was low. The resistivity log response showed a high log signature indicating the presence of fluids (i.e. sufficient oil, gas and little water) in the reservoir. The density and the neutron log also showed that oil, gas and water were present in the reservoir and the contact could be deduced from the gas balloon structure that was displayed on the reservoir. Average reservoir thicknesses for reservoirs M and K in feets across the 3 wells is shown in *Table 3*.

***Table 3**. Average thickness of correlated reservoirs (M and K) across the three (3) wells.*

Wells	Reservoir M (ft)	Reservoir K (ft)
OLJ 1	50	60
OLJ 4	50	90
OLJ 5	50	70

Interpretation of petrophysical logs of OLJ 1, OLJ 4 and OLJ 5 well

This entailed the interpretation of the petrophysical log properties like porosity, permeability, water saturation, hydrocarbon saturation and net to gross (NTG) from the log response of the models. For well OLJ 1 delineated reservoirs M and K (*Figure 10*), it was deduced from the GR log response that the reservoirs were sand. From the porosity log signature, it was observed that porosity of the reservoir was appreciably good when compared with the Riders (1986) template which implies that the reservoir is very porous and sufficient amounts of hydrocarbons could be accommodated in the pore spaces of these reservoirs. From the permeability log signature, it was observed that there is a high reading from the log excursions which implies that the reservoirs are permeable and hydrocarbons can easily flow to the reservoir where it will be accommodated. The water saturation was low (*Table 4*) which consequently implies that the hydrocarbon saturated is high since both parameters have an inverse relationship. From the net to gross (NTG) signature on the model, it was observed that the ratio increases towards the right implying that the NTG is high for the two delineated reservoirs. It was observed that the net thickness of the prolific sand reservoirs and the thickness of the entire formation were appreciable. For OLJ 4 delineated reservoirs M and K, it was observed that the GR log response, the porosity, the permeability and the NTG was almost the same as that obtained in OLJ 1 except for the water saturation (*Figure 11*). For OLJ 5 (*Figure 12*), the gamma ray log response was almost the same as those obtained for OLJ 1 and OLJ 4, the porosity, permeability, NTG and water saturation was however intermediate (*Figure 13*).

Table 4. *Average petrophysical properties of delineated reservoirs.*

Reservoir	Φ (Frac)	K (mD)	NTG	Sw (%)	Sh (%)
M	0.23	1635	0.9	38	62
K	0.22	1442	1.0	38	62

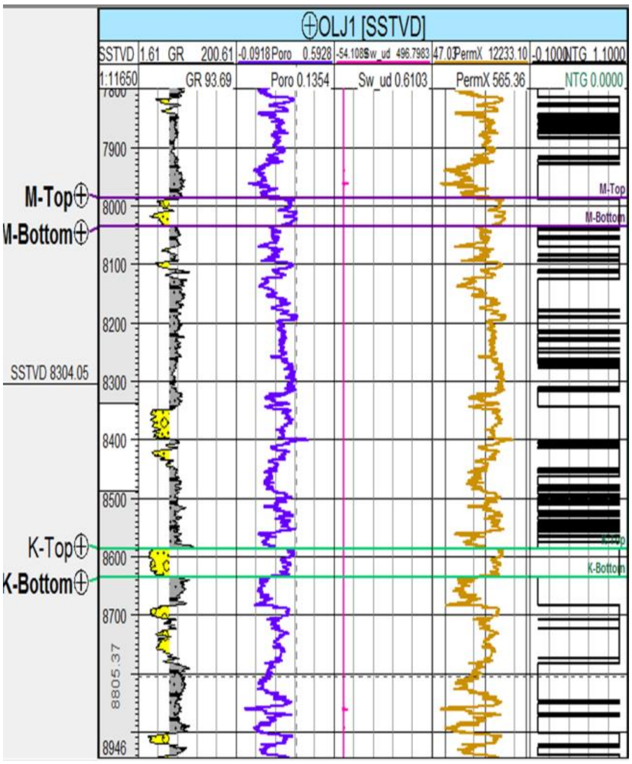

Figure 10. *Petrophysical logs of OLJ1 with respect to subsurface depth.*

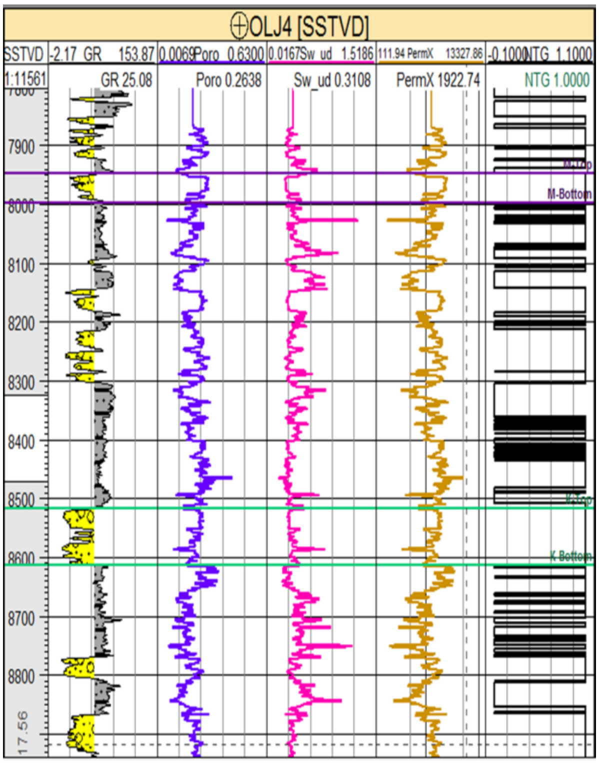

Figure 11. *Petrophysical logs of OLJ 4 with respect to subsurface depth.*

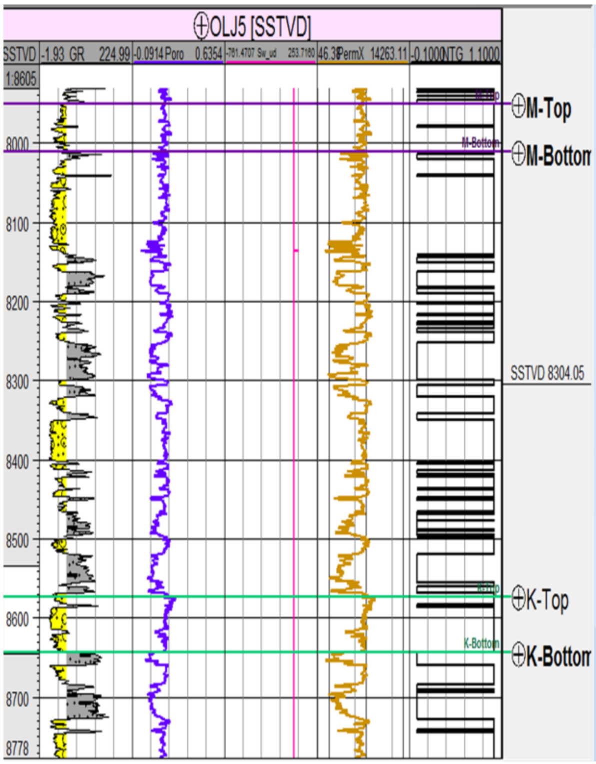

Figure 12. *Petrophysical logs of OLJ 5 with respect to subsurface depth.*

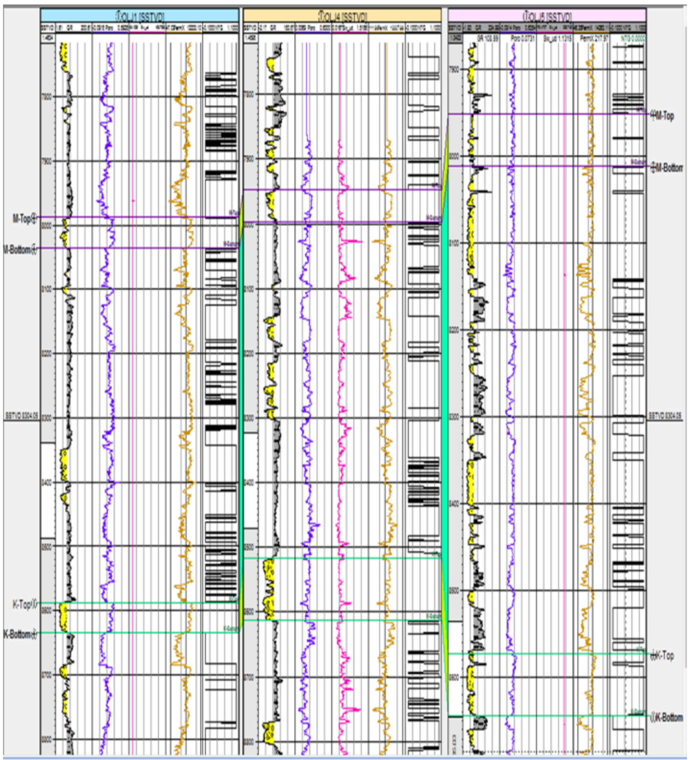

Figure 13. *Well correlation of the reservoir sand with respect to their petrophysical properties.*

Conclusion

The interpretation of well log models from an E-field in the Niger Delta Basin has been achieved. The results obtained reveals that the reservoir quality is strongly influenced by presence of sand bodies. As a result of the appreciably high values of porosity, permeability, net to gross and low values of water saturation in the delineated reservoirs, it was observed that the average value of porosity of reservoir M was (0.23 or 23%) while that of reservoir K was (0.22 or 22%). The average value of permeability of reservoir M was 1635 mD while that of reservoir K was 1442 mD. These permeability values according to Riders are within the range of excellent reservoir permeability. The average value of net to gross (NTG) of reservoir M was 0.9 while that of reservoir K was 1.0 and an average value of hydrocarbon saturation of 62% and 62% respectively for reservoirs M and K. We conclude that the reservoirs (M and K) have high potentials for hydrocarbon accumulation in commercial quantity and are producible and should therefore be exploited. Based on the result from the study, it is therefore recommended that 3D seismic data be incorporated to allow for a detailed and complimentary reservoir characterization study of the E-field. This will present an opportunity for the generation and analysis of 3D images that will show more graphic and revealing details of the geometry of the geologic features and also the area extent with which volumetric reservoir estimations can be computed to evaluate the reservoir economics of the field.

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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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