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Evaluation of Petroleum Source Rock Using Well Logs in the Niger Delta Region of Nigeria

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ABSTRACT

Petroleum source rock potential evaluation was carried out on eight wells of the Niger Delta's Agbada Formation by assessing some source parameters from well logs, and through well logs analysis based on organic matter effect and relationship on and with well logs. Source rock determinant parameters such as volume of shale (Vsh), total organic content (TOC), amount of generated hydrocarbon (S2) was derived from well logs following established organic matter effects on well logs using Schlumberger's Techlog 2015 software, while hydrogen index (HI) was calculated using known values of TOC and S2 respectively. Well log data used for the analysis includes GR log, resistivity, sonic and Density logs. Apart from deriving source rock parameters, the well logs were also used to identify, quantify and somewhat determine mature zones of source rock intervals by correlation with TOC, S2, and HI source parameters respectively, Therefore, a source interval criterion composing of high GR log, high resistivity, high sonic and low-Density was developed alongside source rock parameters. Results of the analysis in the area show poor to fair source rock quality rating in terms of TOC, and insufficient source rock thickness fit for sustaining a world-class petroleum province like the ND petroleum province and further depicting that the Agbada FM may not be the principal source rock of the area. It is therefore, recommended that more elaborate studies covering greater depths of the Agbada FM be carried out in other to properly represent the true source quality of the area.

Keywords: Petroleum source rock, Niger Delta, Well logs, Source Evaluation, Niger delta source rock, Agbada Formation, Akata Formation, Log Interpretation.

1 INTRODUCTION

One of the most important aspects of the petroleum system is the source-rock, it holds a statutory relevance in the entire history of hydrocarbon formation. Hence, there is almost no petroleum system without a petroleum source rock presence, that holds the obligation of hydrocarbon generation. The source rock can be seen as a part, or component of the petroleum system composed of an efficient quantity of organic matter sufficient enough to yield and let-out hydrocarbon upon maturity.

According to Carol, (1999) a rock is qualified as a source rock if it has the capacity to yield or has yielded dischargeable quantities of hydrocarbon. Hence, considering the role of the source rock in a petroleum system it can therefore, be established that the quantity, quality, and type of hydrocarbon is directly proportional to the source rock composition and as such the conventional rule of source rock exploration holds that when a source rock has been identified, the quality must also be characterized in order to derisk uncertainties that may cloud expectations and estimations. Three very important factors and two vital processes have been outlined as components which qualify a source rock; the components include organic matter quality and quantity, and thermal maturity (Peters and Cassa, 1994), while the processes which influence the factors include; the depositional settings and disposition, structural and tectonic report of the area. The depositional setting and disposition influence the organic matter quantity and quality, while the structural and tectonic setting account of the area influences the thermal maturity (Filipo et al., 1999).

Evaluation of the organic matter quantity is resolved through the assessment of the TOC present in the source-rock while quality is assessed by substantiating and exerting present kerogen type in the source-rock and thermal maturity estimated using vitrinite reflectance analysis respectively.

The TOC of the source rock is a very relevant determinant composition that influences its organic-richness in terms of both quantity and quality of a given source interval. It can be assessed through geochemical analysis of rock samples such as cores and drill cuttings across formations intervals of interest. Researches on industrial practices have shown that this approach of TOC determination is appreciably limiting, considering its economic implications and consequent limited interval of analysis. Hence, this research work employs the pragmatic use of well logs approach in TOC determination, which effectively addresses the challenge of the limited interval of analysis in an economically and environmentally friendly approach.

The well log approach does not only solve the problem of limited interval of analysis, but also presents such economic packages as time conservation, timely result, and cost and result effectiveness.

The knowledge of play assessment begins with source rock evaluation which provides a detailed guide that unravels uncertainty issues that are associated with investments and development decisions.

The traditional method of source rock evaluation involves the use of geochemical techniques based on laboratory analysis carried out on core samples, and sidewall cuttings, while the new well logs technique simply utilizes well log data acquired during drilling which is at the same time used for petrophysical and fluid property analysis of the well. Hence, considering the cost of laboratory analysis and coring operations it is thus worthy to say that the geochemical method of source rock evaluation is cost-intensive and needs to be replaced by the less expensive well log technique. The well log technique for hydrocarbon source evaluation, proposes an economical and environmentally friendly approach that is timely and efficient.

In recent years we have witnessed the discrepancies between two schools of thought as it concerns the ideal source-Formation of the ND Petroleum province. The first school of thought premiered by Weber and Dakoru., (1975) holds that the source-FM of the Delta is the Akata FM. While the other school of thought by Ibe and Akionbare., (1984) asserts the ideal source-rock of the ND to be the paralic shale deposits of the Agbada FM. AS such this study seeks to enhance better understanding of the ND petroleum province.

1.1 LOCATION OF THE STUDY AREA

Well log data utilized for this study was acquired from eight exploratory wells of the "Koko" Field, offshore ND in the Agbada FM. It covers an area of 142sqkm and extends within Latitude 4^{0} 00' 47'' to 4^{0} 09' 11'' and longitude 7^{0} 28' 10'' to 7^{0} 36' 24''

2 LITERATURE REVIEW

2.1 Niger Delta Source-Rocks and Previous works

The actual source-rock in the ND has been an unresolved issue with diverse opinions and arguments amongst researchers as to exerting the actual source-rock responsible for the hydrocarbon yield in the region even though the Agbada FM is recently generally acceptable.

As stated by Ekweozor and Okoye, (1980) the Agbada FM constitutes intervals with sufficient organic matter qualified to be good source-rocks. But on the other hand, the intervals lack sufficient thicknesses required to support a global standard petroleum province like the ND and also suffer immaturity in several areas across the basin (Starcher, 1995).

In another consideration, the Akata shales holds sufficient thickness beneath the Agbada Formation efficient enough to support such a global standard oil province like the ND. Evamy et al., (1978) through alpha and beta hopanes and oleananes, carried out a fingerprinting on crude considering different sources within the shales of the Agbada FM, along the east of the delta, and the older marine Akata shales along the west of the delta. Ekweozor and Okoye, (1980) further restricted the hypothesis through geochemical immaturity scales which showed immaturity in younger rocks compared to the rocks of the deeply buried paralic sequence. (Michele L.W et al., 1999).

Lambert-Aikionbare and Ibe, (1984) proposed that the over-pressured Akata Formation will compose of a less than 12% migration efficiency, therefore, indicating its inefficiency to have released such amount of hydrocarbon as seen in the ND. Ejedawe et al., (1984) hold the opinion that oil was sourced from the Agbada shale while gas was sourced from the Akata shale in the central part of the delta using maturation models. They believe that oil is sourced by both shales in the other part of the delta. While Starcher, (1995) holds that the source rock with sufficient volume and oil window coherent depth of burial is the Akata Formation and thus uphold that it is the major source-rock of the ND.

Every petroleum system comprises a source rock, thus identification of source rock fosters efficient design exploration strategies (Abrakassa et al., 2015).

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2.1 The Well Log Concept

Over the year's laboratory of samples have been the traditional approach and technique for hydrocarbon source rock potential and thus have contributed significantly in the discovery of new hydrocarbon resource even though it is economically unfriendly. As such a new economy friendly method for which results are quite acceptable and effective has been developed and is known as the present-day well log technique.

According to Nwajide, (2013) 0rganic matter richness in the Niger Delta is a function of age, depth of occurrence and environment of deposition. Tissot and Welte, (1984) already established that the volume of hydrocarbon yield from a given source rock is proportional to the degree of organic-richness it contains. It is therefore worthy to note that a comprehensive assessment in terms of determining hydrocarbon generation potential requires not only TOC assessment but also requires S1and S2 evaluation, since TOC only evaluates source rock potential, considering the fact that organic materials of the same content possess varying hydrocarbon yields (Katz, 2006; Akande et al., 2011).

Dynmann et al. (1996) hold that the summation of S1 and S2 parameters make up the hydrocarbon yield potentiality of a source interval. The HI (hydrogen index) is another resourceful parameter employed in the classification of kerogen type present in the source-rock and can be assessed by the ratio of S2/TOC (Tissot et al., 1974).

The well log concept through studies and observations has shown that kerogen presence in a rock in terms of log response exhibits low density, low velocity, low conductivity, and high hydrogen content and radioactivity. Studies have also shown that kerogen type sourced from marine and continental environments is characterized by high gamma-ray activity, while those sourced from lacustrine environment show low gamma-ray activity as a result of the insufficient presence of uranium ions in the environment.

Density Log

The density log constitutes a very important parameter in generating the organic content of a rock. Studies have shown that the organic matter content contained in a rock holds an inverse relationship to the density of the rock, such that an increase in TOC causes a decrease in the density of the rock. This inverse relationship is therefore expressed in the equation below with respect to typical source rock components such as rock matrix, organic matter, and pore fluid.

$$TOC = \alpha[\frac{1}{\frac{\rho K[\frac{\rho_m \rho_b}{\rho_k} + \rho_m V_w - V_w - \rho_m]}{[\rho_b + \rho_m V_w - V_{w-}\rho_m]}}] \qquad (1)$$

ρ_m = Density of rock matrix

ρ_b = Bulk density

ρ_k = Kerogen density

V_w = Volume of Formation water

Sonic Log

The sonic log is another important parameter. Again, studies have shown that the sonic log holds a direct relationship with the organic matter content of the rock, such that a 10% increase in organic matter is proportional to 40 to 50µsec/ft in travel time.

$$TOC = \alpha[\frac{1}{1 - \rho_m - \frac{\rho_v V_w - V_w - \rho_m}{\Delta t - V_w \Delta t_w + V_w \Delta t_m - \Delta t_m}(\Delta t_k - \Delta t_{m))}}](2)$$

Where;

ρm = Density of rock matrix

ρ_v = Density of pore fluid

V_w = Formation water

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Δt = Compressional slowness

Δt_m = Compressional slowness of rock matrix

Δt_w = Compressional slowness of Formation water

Δt_k = Compressional slowness of Kerogen

Neutron Log

The neutron log is very useful in generating and assessing the hydrogen index of the rock, considering that the neutron log upon acquisition generates neutron into the formation in order to assess the degree of interaction between the neutron and hydrogen atom present in the formation, measured in terms of decay. Hence the mathematical equation that expresses this relationship considers only organic matter content and pore water present in the rock.

$$TOC = \alpha[\frac{1}{1-\rho_m-\left(1-\frac{1}{\rho_m}-\frac{1}{V_w}\right)\frac{\rho_m V_w HI_k}{\varphi_N - V_w}} \qquad (3)$$

Where;

ρm = Density of rock matrix

V_w = Volume of formation water

φN = Neutron porosity

HI_K = Hydrogen index of the kerogen

GR Log

The GR log is one of the best tools in the evaluation of source rock TOC. It functions with respect to the originally existing radioactivity of a rock and estimates the degree of organic materials present in the rock. According to MC Kelvey and Nelson, (1949); Leventhal, (1981)., the gamma-ray log holds a good direct relationship with organic matter content of a rock, considering its radioactivity due to uranium presence and the organic matter itself such that a 1% TOC increase is equivalent to 1.5 to 5 pounds per million increase in uranium (Mendelson, 1985).

Resistivity Log

The resistivity log is also a very important log, competent in the estimation of rock fluid saturation but holds very little influence in terms of TOC assessment, it is perhaps not the best tool for TOC determination but can as well make a degree of contribution in TOC assessment. The use of resistivity log in TOC follows the precedence that organic matters are deposited alongside the sediments that make up the rock and thus form part of the materials that reside in the rock pore spaces. Considering that resistivity log response is principally influenced pore fluid, it is therefore envisaged that the organic matter present in the rock may exert a slight influence on log response.

2.2 Source Rock Potential of the Niger Delta

According to Abrakassa et al, (2015) TOC values for a study carried out on river-Niger, river-Benue, and Niger Delta, Benue rivers and ND front showed higher TOC values for the river sediments with respect to the ND front, and was credited to the upward mixing process in the Delta front which causes organic-matter concentration in shallow depths where they undergo biodegradation by microorganisms. These, therefore, accounts for the low hydrocarbon yielding potentials of the ND source-rock in terms of organic matter content (Evamy et al., 1978) composing of fair to moderate total organic matter content which is recompensed for by sufficient thickness of the ND source interval.

Nyantakyi et al., (2014) accomplished a research study to establish the source-rock quality of the Agbada FM within Southern ND. His study employed the use of core samples analyzed through Rock eval pyrolysis in order to estimate TOC, HI, OI, and thermal maturity. Van Krevelen diagram was used to isolate the kerogen type. The outcome of the analysis revealed that 50% of the samples correspond to type II kerogen, while other samples correspond to type III kerogen. Result of TOC plot against depth showed fair to good source rock quality in terms of TOC standards. TOC is used as a major parameter for assessing organic matter richness of source rock and is measured in wt %. TOC classification for hydrocarbon generation holds that the more abundant the

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TOC volume is, the higher the capacity of the source-rock to yield hydrocarbon. According to Peters and Cassa, (1994) classification, source-rocks with <0.5wt % TOC has a low generative hydrocarbon potential which is described as poor, 0.5 wt% to 1wt % have fair yield potential, 1wt % to 2wt % have good generative potential, 2wt % to 4wt % is considered to have remarkable yield potential and source rocks with greater than 4wt % are considered to have exceptional yield potential. Results of the TOC values of the studied samples fall within the range of 1wt % to 2wt % depicting a proportionately fair to good source quality.

Falebita et al., (2014) also did a study on the assessment of the organic richness of the Agbada Formation using well log data and petrophysical properties. The study explored six to seven wells of the "Neya field" ND. TOC assessment was carried out through quantification from well logs. The study identified six shale intervals, with petrophysical properties corresponding to typical shaly to shale zones features. The result of the study showed TOC concentrations ranging from 7.56% to 12.44% in the wells, exceeding the 0.5% standard for source-rocks hydrocarbon generation, corresponding with TOC results of previous research works in some parts of the Agbada Formation. The results of the study further proposed that the enrichment of the organic matter (TOC) holds no direct proportionality to the sediment column, shale volume, and porosity of a given area.

Another study carried out by Abiola et al., (2019) on the assessment of organic richness of the Niger Delta's Agbada Formation using well log data acquired within six exploratory wells in the "Charis field", of the ND. Organic richness was assessed by estimating the TOC present in the rock using computations of the density log alongside resistivity and porosity logs. Results of the study showed overlying resistivity and porosity log responses in areas of lean organic contents, while organic-rich intervals were characterized by the separation of the two logs. The study identified organic content-rich intervals with TOC values ranging from 1.7% to 6.20%, once again exceeding the 0.5% threshold for hydrocarbon generation in accordance with earlier reported TOC values in the onshore and offshore paralic sediments of the Agbada Formation. The study also showed that the central south-eastern part is composed of high TOC percentage concentrations, and therefore holds the proposition that the hydrocarbon within the study area may have been sourced from the Agbada Formation.

Akinbode, (2018) utilized Rock-Eval, resistivity and bulk density to analyze source potentiality within the northern depobelts of the Eocene deposits of the Niger Delta. TOC was derived from GR log, Rock eval was used to determine Eocene age, and further analysis was done using the density and resistivity logs. Ten sections were identified as good source rocks based on their thicknesses. Result of the study showed a decreasing trend of TOC values with depth. Agbada sections showed TOC values within 3.7% to 4.4% while deeper Akata sections showed TOC values within 3.8%-3.9%. According to Passey et al., (1990) non-source rocks are made up of basically two constituents, which include; the matrix and fluid occupying the pore spaces of the rock. While immature source rocks are composed of solid form organic-matter, rock matrix, and formation water occupying the rock pores. Upon maturation, a part of the organic matter is further transformed into fluid (hydrocarbon) displacing the FM water in the pore spaces.

Organic sediments of source rocks are classified as light and heavy components. The heavy component is composed of mineral organic matter, while the light constituent comprises of the FM fluids in the source rock. The total organic matter present forms part of the light component. Conventionally as diagenesis occurs and compaction set in, water is expelled therefore resulting in a relative increase in density. However, rocks rich in total organic matter content possess a higher quantity of the light fraction which is responsible for the source rock low density attribute expressed in the density log. Based on the aforestated precedence results of the study reported that bulk density trends and resistivity log response were unable to delineate source rocks in the Agbada sections, while trends in the Akata sections varies with depth and identified source rocks intervals where opposite log response trends of resistivity and bulk density characterized the source zones.

Abiodun et al., (2018) carried out another study using well logs, the study utilized the EXXON method in the analysis and establishment of source-rock TOC using well log data which include; GR, Resistivity, Sonic, Density, and Neutron logs respectively. The study was carried out to analyze source-rock in western ND.

The EXXON Mobil in a model published by Passey et al., (1990); and Heidanifard, (2011) provides the equation to calculate TOC contents from well logs, within a defined window. The equation is expressed as;

$$\Delta \log R = log10\,(R/\,Rns) + K * (P - Pns) \quad (4)$$

Where; $\Delta \log R$ denotes the log separation, R represents the measure formation resistivity, P is the porosity log value, R_{ns} and P_{ns} represents the values for both resistivity and porosity within fine-grained non-source rocks while K is a scale factor with respect to the porosity log unit.

TOC was thus calculated using the equation;

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$$\text{TOC} = \Delta\log R * 10^{(2.297-0.1688*\text{LOM})} \quad (5)$$

Given that; HI and S2 were thus calculated using the following equations;

$$\text{HI} = 0.2914 * \text{LOM}^4 - 11.6\text{LOM}^3 + 169.57\text{LOM}^2 - 1099\text{LOM} + 2863.2 \quad (6)$$

$$\text{HI} = \frac{100*\text{S2}}{\text{TOC\%}} \text{ (S2 was calculated from known values of HI and TOC\%)} \quad (7)$$

The study employed the use of well logs analysis for estimating and identifying TOC in the studied area. The method integrates the overlaying of porosity log (estimated from sonic) on the resistivity log track. The technique is built around then precedence or concept that organic clean rocks saturated with water possess resistivity log and porosity log responses parallel to each other, and thus can be overlain. While in organic-rich hydrocarbon saturated rocks, the two rocks are separated from each other. Studies have shown that these differences occur as a result of the fact that the porosity log response is a function of reduced density and velocity of kerogen, while the resistivity log functions as a result of Formation fluid type within the rock. Hence in immature organic-rich rock where hydrocarbon is yet to be generated, separation of the logs is primarily and only a function of the porosity log. While in mature organic-rich rock where hydrocarbon has been generated, separation of log response is a function of the resistivity log considering that resistivity log responses increases as a result of hydrocarbon presence in the rock. The degree of track separation of the two logs is therefore used to establish TOC and maturity of source-rock enabling a depth assessment of richness of organic matter. The analysis was done through the Goodview module of the Hampson Rusell software.

The results of the analysis showed that estimated TOC values from well logs amounted to about 6.64wt % and occurs in an increasing trend with level organic maturity and vitrinite reflectance. A comparison between well log generated TOC geochemical log generated TOC showed an average of 9wt% and 3wt% respectively within the defined window. Statistical tools such as mean, mode, median, and standard deviation were employed to calculate the deviation of the results. A standard deviation value of 3.14 for well log generated TOC was determined while that of geochemical log generated TOC resulted in a standard deviation value of 1.2. irrespective of the marginal difference between the two approaches the methods still arrived at the same conclusion, predicting that the hydrocarbon yield from the study area is gas prone.

3 MATERIALS AND METHOD

The well log approach of determining hydrocarbon source potential is an economy friendly approach, with several advantages such as result efficiency and timeliness alongside environmentally sustainable processes and practices. It involves the use of well logs in generating parameters necessary for hydrocarbon source evaluation.
This study utilized well log data acquired from eight exploratory wells within the offshore ND.

Data Collection

The well log data obtained for eight exploratory wells of the "Koko" field in offshore ND region include;

Table 1. Data Collection

Wells	Wells Logs					
	GR	CAL	LLD	RHOB	NPHI	DT
Zorian_1	√	√	√	√	√	√
Zorian_2	√	X	√	√	√	√
Zorian_3	√	√	√	√	√	√
Zorian_4	√	√	√	√	√	√
Zorian_5	√	√	√	√	√	√
Zorian 6	√	√	√	√	√	√
Zorian 8	√	√	√	√	√	√
Zorian 9	√	√	√	√	√	√

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3.1 Analytical Software

This study was carried out using Schlumberger's Techlog 2015 software. Well log data were imported into the software and required parameters and plots were generated respectively.

3.2 Method of Data Analysis

The study employed the well log method. The process comprises of well measurement of necessary parameters through a continuous depth profile. The measured parameters involve important rock properties required for hydrocarbon source evaluation. TOC and S2 were generated through the analytical software using empirical relationships with respect to Δlog approach premiered by Passey et al, (1990). The method was applied using an overlay of resistivity log with neutron, density and sonic logs to estimate TOC wt%.

3.3 General Workflow

This study holds the primary objective of assessing the hydrocarbon potentiality of the shale zones of the Agbada FM present in the exploratory wells of the “Koko” field, offshore ND. Previous chapters have showed a clear pathway to achieving this primary objective using the well log approach. Hence statutory parameters necessary for hydrocarbon source potential evaluation such as the TOC, S2, and Kerogen volume will be derived from well log data. The TOC indicates the volume presence of organic matter in the zone which therefore, determines its hydrocarbon generative potential, while S2 expresses generated hydrocarbon amount by the source-rock. Considering that resistivity logs measure and identifies hydrocarbon presence in the formation, it is therefore correlated against high S2 plot and high transit time intervals to efficiently validate hydrocarbon generation when it occurs in shale intervals and hydrocarbon presence that have migrated into surrounding reservoirs when found in sands respectively. The inflection points of resistivity and sonic are further used to support the inference of hydrocarbon presence in the formation intervals where they occur. Plots of TOC and S2 will provide determinant information necessary to establish the EOD and characterize type and abundance of kerogen present in the flagged source intervals including their hydrocarbon generative potential.

3.4 Mathematical Expressions of Generated Analytical Source-Rock Parameters

The $\Delta\log R$ method is based on the precedence that parallel log tracks become overlain in organic pure rocks while a separation between the two log tracks takes place in high organic content rocks. Hence, this separation is known as $\Delta\log R$ and is therefore used to compute TOC.

The baseline points of the RHOB, NPHI, ΔT, and LLD were estimated in non-source rocks when two tracks overlay each other while their separations were interpreted as organic-rich zones. The following are mathematical expressions used to calculate $\Delta\log R$ for TOC computation, S2, HI, and Vsh.

TOC

TOC was derived using Passey’s equation

$$TOC = \Delta\log R * 10^{(2.297-0.1688*LOM)} \quad (8)$$

Given that;

$$LOM = 0.0989*VR*5 - 2.1587*VR*4+12.392*VR*3 - 29.032*VR*2+32.53*VR - 3.0338 \quad (9)$$

Δlog*R* = Track separation which is derived through the following expressions;

$$\Delta\log R\_Sonic = \log 10\ (RT/RT\_Baseline) + 0.02*(\Delta T - \Delta T\ Baseline) \quad (10)$$

$$\Delta\log R\_Density = \log 10\ (RT/RT\_Baseline) - 2.5*(RHOB - RHOB\_Baseline) \quad (11)$$

$$\Delta\log R\_Neutron = \log 10\ (RT/RT\_Baseline) + 4*(NEUT - NEUT\_Baseline) \quad (12)$$

Given that;

$\Delta\log R$ = Track separation
RT = True Resistivity in ohm-m
ΔT = Compressional slowness µsec/ft
NEUT = Neutron porosity in fraction
RHOB = Density in g/cm3
RT_Baseline = Resistivity with respect to ΔT baseline, NEUT baseline, and RHOB baseline.
NOTE: The values 0.02, 4.00 and 2.50 are ratios between resistivity scales and sonic, neutron and density respectively.

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S2 = generated hydrocarbon by thermal cracking (mg/g)

S2 was also derived using Passey's equation which is given as;

S2 = HI*TOC

Give that HI = Hydrogen index

HI = Hydrogen index

$HI = \frac{100*S2}{TOC\%}$ (S2 was calculated from known values of HI and TOC%)

Shale Percentage (Vsh) Using Gamma-ray log

Vsh was derived through the Larionov method for tertiary rocks, considering the age of the ND basin.

$$Vsh = 0.083 * (2^{(3.7*GR_{index} - 1)}) \quad (13)$$

Given that;

$$GR_{Index} = \frac{GR - GR_{matrix}}{GR_{shale} - GR_{matrix}}$$

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WORKFLOW DIAGRAM

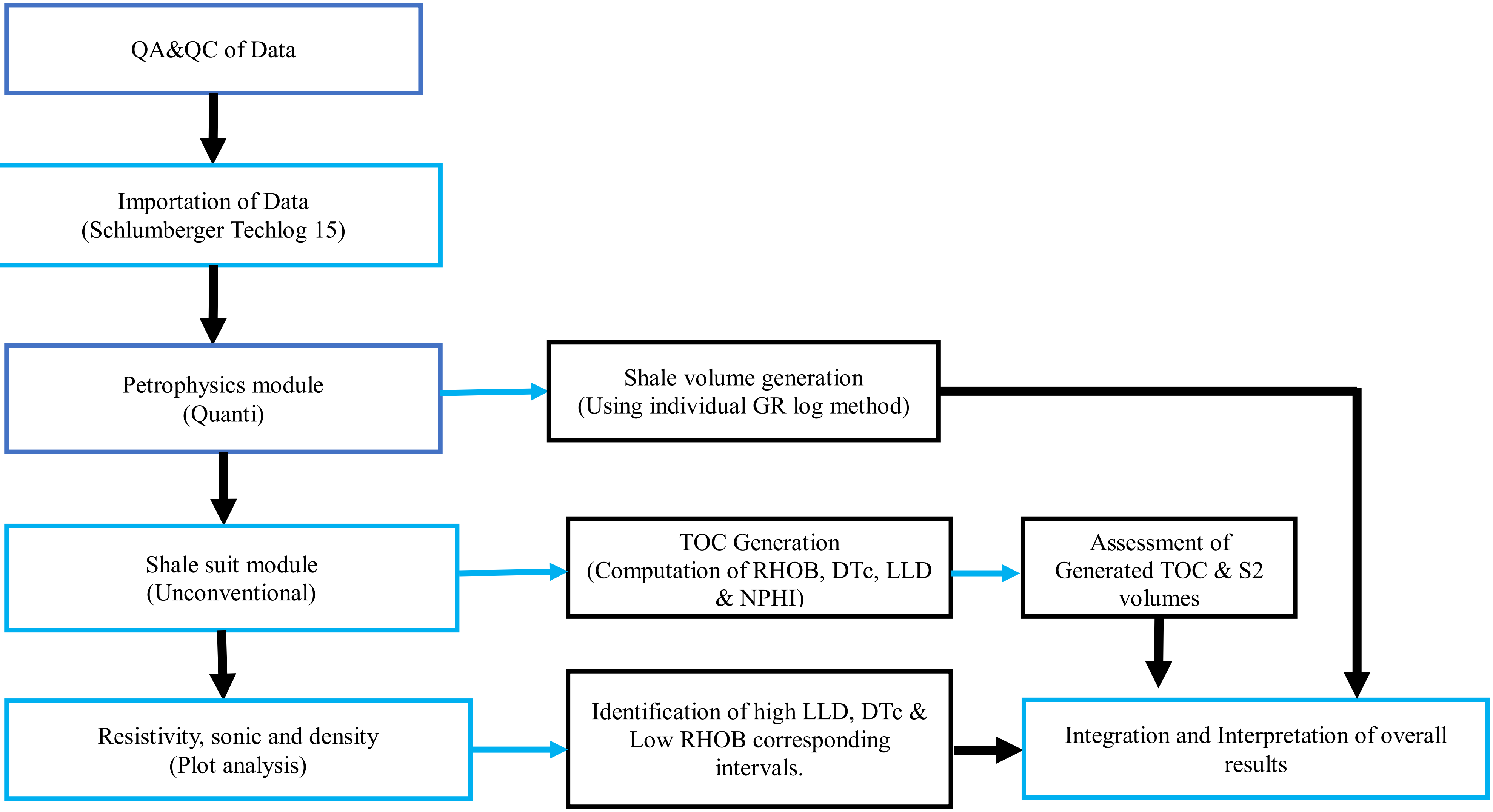

Figure 1. Workflow Diagram

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4 RESULTS AND DICUSSION/INTERPRETATION

4.1 Source Potential Identification

The GR log and the derived shale volume was first used to interpret lithology in order to establish possible organic-rich intervals (Fig.3). The well log technique employs the use of resistivity, density and sonic logs in the flagging of organic-rich rocks establishing both mature and immature intervals. Considering the varying effects of the source composition on resistivity, sonic and density logs respectively noting that organic-rich source-rocks are basically made up of the rock matrix, pore fluids and solid form organic matter (Passey et al., 1990). Immature source-intervals comprise of solid form organic matter, rock matrix and FM water occupying pore space, thus as the immature source-rock approaches maturity, part of the organic matter is reformed into liquid or gaseous hydrocarbon displacing present formation pore water and thus occupying the pore spaces.

According to Meyer and Nederlof (1984), sediments are considered to be composed of high- and low-density fractions. Where the high-density fractions form the minerals and the low-density fractions form the FM fluids. In source rocks, the organic matter forms part of the low-density fraction. Throughout the diagenetic phase, sediments undergo compaction and dewatering processes that consequently amount to an increase in density. Hence considering the presence of organic matter which is member of the light fraction, source-rocks, especially excellent quality source-rocks take on a higher quantity of low-density fractions compared to non-source rocks and is thus evident in density log characterizing source rocks with relative low-density log response. the above-stated concept is also responsible for the high and low sonic transit time expressed in source and non-source intervals.

Hence intervals with high and low sonic and density log responses are used to identify organic-rich source intervals, while the resistivity log is used as a maturity indicator to identify intervals where hydrocarbon have been generated which are characterized by high resistivity log response. as such the factor points as to determining the hydrocarbon generative potential of a source rocks include; high resistivity and sonic logs, and low-density logs.

4.2 Source Potential Criterion Using Well Log

Usually, the organic-richness of an interval is determined based on its TOC, they occur in dark coloured and highly radioactive rich shales owing to the presence of organic material. These organic-rich shales are responsible for the generation of hydrocarbon upon maturation given to certain conditions. They are thus characterized by high TOC values and high GR values accounted for by the presence of organic radioactive materials, high resistivity values are given to the fact that they are nonconductive, high sonic transit time, high S2 and Hydrogen index values, and low-density values. The study, therefore, employed the above-stated criterion in the qualifying of source intervals using primary and derived well logs (Table 4).

4.3 Source Intervals

Possible source intervals were first flagged off using Gamma-ray and subsequently validated using the derived Volume of shale ratio. As evaluation and assessment progressed analysis considering the aforementioned criterion, further showed that not all the shale intervals previously flagged were rich in organic matter, while some intervals were identified with fare organic richness and possible source potential respectively (Fig. 3). The analytic procedure involved the selection of source intervals with high shale volume and Gamma-ray values, high resistivity and sonic values, and low-density values corresponding with the presence of TOC and S2 values respectively.

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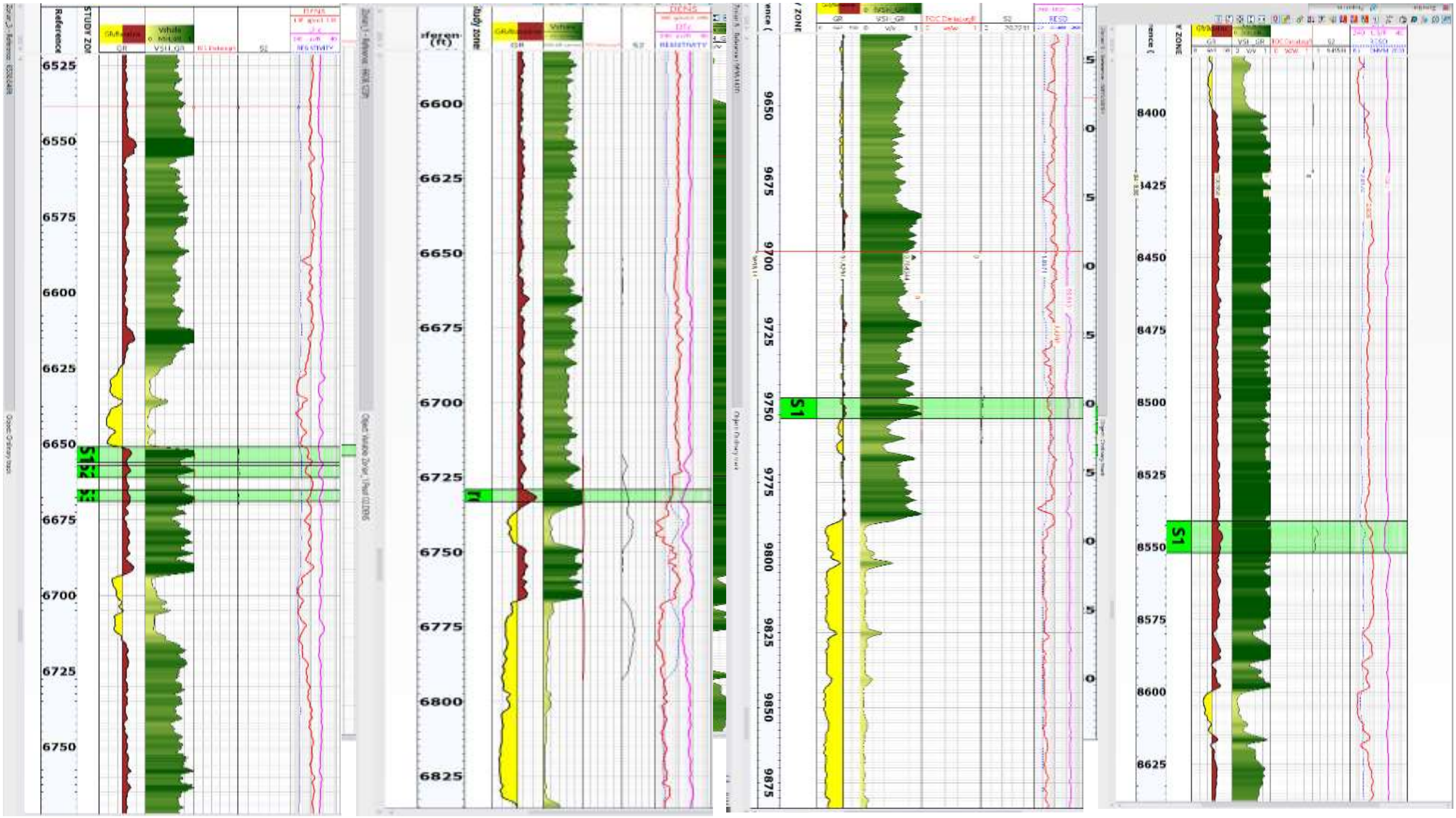

Figure, 2: Showing representative flagged source intervals across wells of the koko field at specific depths

Flagged Source intervals

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4.4 General Description

The studied wells of the koko field are generally composed of varying discrete to non-discrete shale intervals with a few bands showing 90% to 100% shale volume. varying TOC and S2 values are observed in both areas of discrete and non-discrete bands sparsely distributed across depth intervals. The wells are also composed of reservoir sands, well pronounced in some wells and sparsely distributed in some wells with corresponding qualifying parameters that indicate hydrocarbon presence as seen in Figure:3.

4.5 Discussion

The identification of source intervals was carried out considering intervals with high shale volume and Gamma-ray values, high resistivity and sonic values, and low-density values corresponding with the presence of TOC and S2 values respectively forming the source interval flagging criterion for this study (Table 4).

The works of Peters, (1986) outlined an interpretable connection between source-rock potential and TOC wt% as well as Hydrogen index. his outline upholds the following;

Table 2. Source quality and TOC (Peters, 1986)

TOC (wt%)	Source rock Potential
<0.5	*Poor/ Non source rock*
0.5 – 1	*Fair*
1 – 2	*Good*
2 – 4	*Very good*
>4	*Excellent*

Table 3. Source Potential and HI (Peters, 1986)

HI (mg HC/gC_{Org})	Source Potential
0 – 150	*Gas*
150 – 300	*Mixed (Oil and Gas)*
300+	*Oil*

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Table 4. Showing Value Range for Source Criterion Parameters of flagged intervals with Source Potential and Quality Interpretation

Wells	Vsh (%)	ResD (Ohm.m)	DTc	RHOB	S2	TOC (wt%)	Source quality	HI	Source Potential
Zorian_1	60 - 100	2.48 – 2.45	125 - 146	2.19	2.5352 – 4.5807	0.0152 – 0.0276	<0.5 Poor	166.2	Oil and Gas zone
Zorian_2	60 - 87	1.70 – 2.36	115 - 119	2.20 - 2.25	0.6803 – 0.9595	0.0041 – 0.0064	<0.5 Poor	156.1	Oil and Gas zone
Zorian_3	100	1.62 – 1.74	122 - 125	2.26 – 2.29	1.0292 – 1.2393	0.0062 – 0.0074	<0.5 Poor	166.8	Oil and Gas zone
Zorian_4	62 - 72	1.19 - 1.60	135 - 140	2.21 – 2.23	2.2521 - 2.2565	0.0146 – 0.0147	<0.5 Poor	153.8	Oil and Gas zone
Zorian_5	63 - 82	2.30 – 3.92	112 - 121	2.23 – 2.27	0.5674 - 2.6452	0.0034 – 0.0159	<0.5 Poor	166.4	Oil and Gas zone
Zorian 6	60 - 65	1.80 - 1.85	120 - 122	2.14 – 2.34	1.0494 – 1.2495	0.0064 – 0.0084	<0.5 Poor	155.3	Oil and Gas zone
Zorian 8	90	5.06	101	2.29	1.3075	0.0078	<0.5 Poor	167.6	Oil and Gas zone
Zorian 9	100	2.40	119	2.34	1.4925	0.0090	<0.5 Poor	165.8	Oil and Gas zone

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After proper analysis and evaluation, the result showed that the organic matter quality and quantity of generated hydrocarbon in the study area ranged within values considered to be poor and fair according to the standard values outlined by Peters, (1986), (Table 4). Hence, the afforestated outcome of the analysis further corresponds with the outcome of previous research studies in the area which holds that TOC values in the Niger Delta range from poor to fair, while the Hydrogen Index varies from low to moderate. Irrespective of the poor-quality rating of TOC in the area, the Delta still produces a significant amount of hydrocarbon that meets world-class standard petroleum province. This is because the poor source quality of the area is compensated by significant source sediment thickness that accounts for its efficiency to produce such significant volume of hydrocarbon (Bustin, 1989). Irrespective of the poor source quality in terms of low TOC values, the presence of S2 values, even though they are low further shows that the shales must have generated hydrocarbon considering the mixed zone (oil and gas) corresponding values of Hydrogen index (HI) across the wells and high resistivity values present in the reservoir sands further suggesting a possible expulsion of hydrocarbon into the reservoir sands.

The log analysis and response of the wells in the study area show consistent character across the field displaying alternating sequences of sand and shale in relation to depth intervals that doubtlessly depict and characterize the Agbada Formation. Results showed that zones of notable and significant shale thickness across the wells were characterized by zero TOC and S2 values, thus accounting for zero organic matter presence and generated hydrocarbon while zones of thin or insignificant shale thickness relative to zones of significant thickness were characterized by presence of TOC and S2 values accounting for organic matter presence and generated hydrocarbon alongside other aforestated source interval criterion.

Hence, irrespective of the presence of TOC and S2 values alongside other defining parameters present in the flagged source intervals, the relatively low thickness of the intervals is opposed to the assertion by Bustin, (1989) which states that the poor organic-richness rating of in the ND as a matter of quality is compensated by significant and sufficient thickness of source sediments in the ND source rock. Thus, this imperatively explains that the encountered source intervals identified in the wells lack the sufficient thickness that accounts for the volume of hydrocarbon produced in the ND, as such suggesting that the Agbada FM, with respect to the facts outlined in this study may not be the principal source-FM of the ND petroleum province until the Akata Formation is explored and evaluated but is emphatically the reservoir rock of the province.

5 SUMMARY AND RECOMMENDATION

5.1 Summary

The well log technique was used to identify possible source intervals furnished with relatively distinguished organic richness. The effect of organic matter interaction with well log parameters was used to analyze and establish the source interval criterion for the study. Source interval criterion includes high GR, resistivity, sonic, and low density alongside TOC and S2 values respectively. Research has it that a non-conductive relationship exists between organic matter and resistivity, which, therefore, accounts for high resistivity values within organic-rich intervals. Organic matter, which is also expressed in TOC (wt%) forms part of the light fraction components of sediments which therefore account for high transit time and low-density values within organic-rich zones.

Possible source intervals identified after appropriate analysis and evaluation using the aforestated technique in the study area, showed very low to low TOC and low to intermediate S2 values which imperatively defines the studied formation to be of poor to fair source rock quality rating. The presence of S2 values is indicative of a prior or even present hydrocarbon generation by the identified possible source intervals further validated by the presence of parameters that are indicative of hydrocarbon presence in the surrounding reservoir sands, suggesting possible expulsion from the identified source intervals. Resulting Hydrogen index (HI) values all across the well indisputably show that the studied area corresponds to a mixed (oil and gas) zone. Further interpretation derived from the result imperatively suggest that the Agbada Formation may not be the principal or key source-rock of the ND petroleum province until thorough evaluation and analysis is carried out on the Akata Formation as well. This imperative interpretation is due to the lack of sufficient source interval thickness amidst a poor to fair source quality rating encountered in the study area. This, therefore, doesn't support the significant hydrocarbon volume production witnessed in the delta.

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5.2 Recommendation

The result of the study has revealed that the identified source intervals which are composite members of the paralic shales of the Agbada Formation possess a range of poor to fair source quality rating and therefore, form low hydrocarbon generative potential. We thus, endorse that further and elaborate studies be launched-out across the Agbada Formation, the study should comprise of deeper depths of the Formation so as to aid critical assessment of the organic-richness of the deeper shale members of the Formation since this study may have been limited by well total vertical depth suggesting that the studied interval might have only corresponded to the upper to intermediate zones of the Formation. The study should also be validated through other geochemical techniques.

REFERENCES

[1] Abiola, O., Abe, S. J., and Balogun, O., (2019). Estimation of source rock organic richness from wireline logs over "Charis" Field, onshore Niger Delta, Nigeria. Centre for research and development. 10(1), 77 – 85.

[2] Abrakasa, S., Ukaegbu, V., Onojake, M., (2015). The source kitchen of Niger Delta oils: case study of Nembe Creek E1.0 and the Kolo Creek E2.0 reservoirs. Journal of Petroleum exploration and production technology. 6(3), pp 331 – 341.

[3] Akande, O. S., Ojo, O. J., Adekeye, O. S., Egbenhoff, S. O., Obaje, N. J., and Erdtmann, B. D., (2011): Stratigraphic Evolution and petroleum potential of middle cretaceous sediments in the lower middle Benue Trough, Nigeria: Insight from New Source Rock Facie Evolution. Petroleum Technology Development Journal, (1.1) ISSN: 1595 – 9104.

[4] Bustin, R. M., (1998). Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta, Origin of Source Rocks in Deltaic Environment. AAPG Bulletin. 72(3), 227 – 298.

[5] Carol, L. W., (1999). Treatise of petroleum geology/ Handbook of petroleum geology, Exploration of oil and gas traps. 6, 6 – 41.

[6] Dymann, T. S., Palacos, J. G., Perry, W. J., Pawlewicz, M. J., (1996). Source Rock Potential of Middle Cretaceous Rocks in South Western Montana. AAPG Bulletin. 80, 1977 – 1184.

[7] Ejedawe, J. E., Coker, S. J. L., Lambert-Aikhionbare, D. O., Alofe, K. B., and Adoh, F. O., (1984). Evolution of oil generative window and oil and gas occurrence in the Tertiary Niger Delta Basin. AAPG. 68, 1744 – 1751.

[8] Ekweozor, C. M., and Okoye, N. V., (1980). Petroleum Source Bed Evaluation of Tertiary Niger Delta. AAPG. 64, 1251 – 1259.

[9] Evamy, B. D., Haremboure, J., Kamerling, p., Knap, W. A., Molloy, F. A., and Rowlamds, P. B., (1978). Hydrocarbon Habitat of Tertiary Niger Delta. AAPG Bulletin. 62, 277 – 298.

[10] Falebita, D. E., Ayeni, O. Z., Bayowa, O. G., Anukwu, G. C., (2015). A study of the organic richness and petrophysical of selected shales from the analysis of wireline logs: a case study of Neya field, Niger Delta. Ife Journal of Science. 17, 1.

[11] Filippo, P., Ian, G., Main, Giammaria, Z., (1999). The thermal evolution of sedimentary basins and its effects on the maturation of hydrocarbons. Geophysical Journal International. 139, (1): 248 – 260.

[12] Heidarrifard, M., (2011). TOC prediction from well logs using Δlog R method and neural network technique in the northern Dezful Embayment. Zagros, Iran, The 2nd South Asian Geoscience

[13] Katz, B. J., (2006). Significance of ODP results on Deep Water Hydrocarbon Exploration- Eastern Equatorial Atlantic Region. Journ. African Earth Sciences. 46, 331 – 345.

[14] Lambert-Aikhionbare, D. O. and Ibe, A. C., (1984). Petroleum Source Bed evaluation of the Tertiary Niger Delta: Discussion. AAPG Bulletin. 68, 387 – 394.

[15] Levethal, J. S., (1981). Pyrolysis Gas Chromatography-Mass Spectrometry to characterize organic matter and its relationship to Uranium Content of Appalachian Devonian Black Shales, Geochem. And Cosmochem. 45, 883 – 889.

[16] McKelvey, V. E., and Nelson, J. M., (1945). Characteristics of marine uranium bearing sedimentary rocks. Econ, Geol. 35 – 53.

[17] Mendelson, J. D., (1985). Petroleum source rock logging, Earth laboratory, Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology Cambridge. MA 02139.

DOI: 10.31695/IJASRE.2022.8.5.7

[18] Meyer, B.L and Nederlof, M. H., (1984). Identification of Source rocks on wireline logs by Density/Resistivity and Sonic Transit Time/Resistivity Cross plots. AAPG Bulletin. 168, 121 – 129.
[19] Michele, L. W., Tuttle, I., Ronald, R., Charpentier, I., and Michael, E., (1999). The Niger Delta Petroleum System: Niger Delta province, Nigeria, Cameroon, and Equatorial Guinea, Africa. United States Geological Survey Report. 99 – 50.
[20] Nwajide, C. S., (2013). Geology of Nigeria's sedimentary Basins. Geoscan Technical services Ltd. Akwa, 565P.
[21] Nyantakyi, E. K., Hue, W. S., Borkloe, J. K., Qin, G., Cheng Han, M., (2013). Structural and Stratigraphic Mapping of Delta field, Agbada Formation, Offshore Niger Delta, Nigeria. American Journal of Engineering Research. 2,(11): 204 – 215.
[22] Passey, Q. R., Creaney, S., Kulla, J. B., Moretti, F. J., Stroud, J. D., (1990). A practical model for organic richness from porosity and resistivity logs. AAPG Bulletin. 74, (12): 1777 – 1794.
[23] Peters, K. E., (1986). Guidelines for evaluating Petroleum source rock using programmed pyrolysis. AAPG Bulletin. 70, (3): 318 – 329.
[24] Peters, K. E., Cassa, M. R., (1994). Applied source rock geochemistry, petroleum system from source to trap magoon. AAPG Bulletin. 60, 93 – 117.
[25] Stacher, P., (1995). Present understanding of the Niger Delta hydrocarbon habitat. In M. N. Oti and G. Postma (eds), Geology of Delta's; A. A. Balkema, Rotterdam. 257 – 267.
[26] Tissot, B., Durand, B., Espitalie, J., C0mbaz, A., (1974). Influence of nature and diagenesis of organic matter in formation/ AAPG Bulletin. 58,(3): 499 – 506.
[27] Tissot, B. P., Welte, D. H., (1984). Petroleum formation and occurrence (2nd edition) Springer, 699.

LIST OF ABREVIATIONS

ND: Niger Delta

GR: Gamma-ray log

S1: Amount of hydrocarbon in the source rock

S2: Amount of generated hydrocarbon

TOC: Total organic carbon

HI: Hydrogen index

OI: Oxygen index

Vsh: Volume of shale

LOM: Level organic matter

EOD: Environment of deposition

FM: Formation

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