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Research Paper

Reservoir Identification in Bornu Basin, Northeastern Nigeria Based on Well Log Analysis

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Abstract: The successful hydrocarbon exploration activities in Chadian and Nigerien sector of Chad basin has led to increase in exploration in Nigerian sector (Bornu basin). The geology of the Bornu basin is similar to that of the contiguous Termit basin in Niger and Chad Republics where commercial oil discoveries has been made. Major source and reservoir rocks in the Termit basin occur in continental Aptian to Cenomanian deposits of the Abu Gabra and Bentiu formations respectively which is correlated Bima Sandstone in the Bornu basin. Well log data was utilized to identify reservoir zones in Bornu basin, three reservoirs were identified in the study area (Bornu basin) with the aid of Gamma log (GR), Resistivity log (ILD), Density (RHOB) and Neutron Porosity log (NPHI). Petrophysical calculations were done employing the Archie's equation. Reservoir 2 across Kanadi well is at depth interval of 1010 – 1050 m, Volume of Shale of 0.140, Total Porosity (Φ_T) of 0.38, Formation Water Resistivity (R_w) of 0.26 Ωm, Permeability (K) of 0.55 and Hydrocarbon Saturation (S_h) of 72.2%. Reservoir 2 across Kinasar well is at interval of 950 -980 m, Volume of Shale (V_{shale}) of 0.280, Total Porosity (Φ_T) of 0.39, Formation Water Resistivity (R_w) of 0.28 Ωm, Permeability (K) of 0.67 and Hydrocarbon Saturation of 72%. Porosity and Resistivity cross-plot was generated for the wells showing hydrocarbon zone in the Kinasar well.

Keywords: Bornu Basin, Hydrocarbon, Lithology, Gamma Ray, Resistivity, Porosity, Density, Formation Factor, Petrophysics, Volume of Shale, Permeability.

1. Introduction

Nigeria joined the rank of oil producers in 1958 when Shell Group started production from the Oloibiri field, Niger Delta. Three decades after, researchers and scholars on petroleum exploration and production in Nigeria concentrated in the coastal (Niger Delta and Anambra) basins with little attention on the remote inland basins namely; Benue trough, Bornu basin (Nigeria's Sector of Chad Basin) and Gongola basin which are in the Northern part of Nigeria [1]. Commercial discoveries in the Chad and Niger Republics encouraged many multinational companies in Nigeria like Chevron Nigeria limited, Elf Nigeria Limited and Shell Nigeria Exploration and Production Company Limited to look northwards and acquire exploration leases in Nigeria's Gongola basin in the upper Benue trough in 1992 marking the start of exploration activities in Nigeria's inland Basins [2]. In search for more reserve, the Nigerian National Petroleum Corporation (NNPC) increased hydrocarbon prospection in the Bornu basin, but effort over the years has not yielded required result, despite that the geology of the Bornu basin is similar to that of the contiguous Termit basin in Niger and Chad Republics where commercial oil discoveries has been made [1]. Major source and reservoir rocks in the Termit basin occur in continental Aptian to Cenomanian deposits of the Abu Gabra and Bentiu formations respectively which can be correlated to Bima Sandstone in the Bornu basin [2]. In Niger Republic, hydrocarbon have also been discovered in Mesozoic to Cenozoic sediments in the east Niger graben [3]. The Nigerian National Petroleum Corporation (NNPC) acquired 33,642 km^2 of 2-D seismic data, and more recently a 3-D seismic data spanning the same area, and a total of 23 exploratory wells has also been drilled [4]. Most of the drilled wells did not encounter commercial hydrocarbon show but interpreted seismic data acquired continue to indicate promising stratigraphic, and structural features that usually form the basic elements of a petroleum systems [5]. The utilization of available well log data for petrophysical and cross plot analysis will enhance the hydrocarbon prospectivity of Bornu basin, identifying viable zones for further investigations.

1.1 The Study Area

Bornu Basin is one-tenth of the total areal extent of the Chad basin which extends to Chad Republic, Cameroun and Niger Republic. It is part of Western Central African Rift System (WCARS) that was formed as a result of mechanical separation of the African crustal block in the Cretaceous [6]. The area is covered by sand and lack basement outcrop. It is part of a regional tectonic setting with geological structures

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trending southwest to the Benue trough and northwest to the Air Mountains [7]. The current study area is within latitude 11.75^0 N and 13.00^0 N and longitudes 12.00^0 E and o 14.00^0E, with an area of 27,225 km^2 (See figure 1) .The area is bound to the north by Termit Basin (Niger Republic), to the south by Yola basin and the Benue trough (Nigeria), to the east by Bongor and Doba basins (Chad Republic) and to the west by Gongola basin (Nigeria). According to [8], the Bornu basin is divided into six formations based on the nature of sedimentary deposits within the depression. The divisions are namely; Bima Sand stone, Gonglia Formation, Fika shale, Gombe, Kierri-Kierri formation and Chad formation.

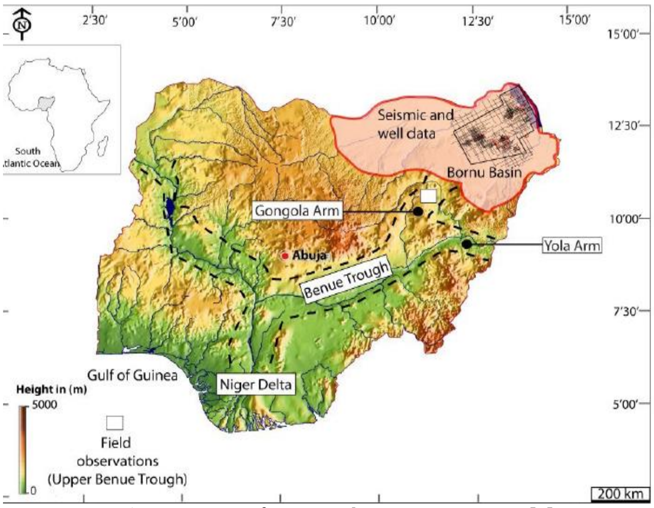

Figure 1. Map of Nigeria Showing Basin Basin [9]

2. Related Work

[10], showcased that the basin comprises significantly of interconnection of faults, horsts, grabens, folds and unconformity surfaces. With structural orientation mainly in the northeast-southwest trend which is similar to structural pattern observed in the adjacent Benue Trough. They showed faults in the basin to consist of both deep-lying (basement-involved faults) and detached faults. The folds as simple symmetrical structures, restricted to the deeper parts of the basin. The structural pattern is complicated further by the presence of intrusions that were presumed to be the subsurface extension of volcanic outcrops that terminated in the Southeastern part of the Nigeria Chad Basin. The consequence of a dominantly active tensional stress is crustal stretching and thinning, development of fractures / high angle normal faults, graben / rift valley, horst, magmatic intrusion and eventually reverse faults.

[11], studied the depositional and structural styles in Bornu basin and revealed the basin to have combination of faults and folds. They presented the stages of development of structural features in the Chad Basin based on rifting model. Seismic reflection data also reveal distinguishable seismic sequences that correlate with the established stratigraphic sequence of the basin. These seismic determined structural features show that Bornu Basin is structurally fit as prospects for hydrocarbon plays in the Cretaceous rocks.

[12], carried out integrated well log and 2-D seismic data interpretation to image the subsurface stratigraphy and structures in North – eastern Bornu basin. They deployed well log suits gamma ray, resistivity, bulk density and sonic log to identify lithology and stratigraphic boundary of the subsurface formation. Four well log facies and environment of deposition were determined in their study. They showed that the main subsurface structural lineament in the area includes NW – SE, NE – SW and NNW – SSE trending faults which formed horst and graben features.

[13], studied the hydrocarbon potential of chad basin using wire-line log from well GUBIO 1, NGAMMA 1 and NGOR 1. They used gamma ray log, caliper, neutron, density, sonic and resistivity logs to identify the reservoir zones, lithology, fractured rock, porosity and estimated hydrocarbon saturation. The petrophysical calculation result showed that the chad basin could be a prospective gas province.

[14], studied the petroleum system elements and migration pattern of Basin. They employed the method of coupled structural analysis and petroleum system modelling to investigate the structural and hydrocarbon evolution of the basin in order to reassess the hydrocarbon potential and migration trends. The structural model showed that the basin has extended up to 2900 km since the late cretaceous. This extension was shown to be controlled by regional tectonic activities and has affected the West and Central African Rift System causing some localized tectonic perturbation in form of magmatic intrusion and igneous under-plating leading to regional uplift.

[15], worked on the integration of well logs and seismic data for prospect evaluation of X-field, onshore Niger Delta Nigeria. The work validated the relevance of integration of well log and seismic data in structural and stratigraphic mapping. The result of the qualitative interpretation of the gamma ray and the resistivity log showed some reservoir to contain hydrocarbon.

[16], researched on seismic attribute analysis as a precursor to hydrocarbon indicators: A case study of OK field, Niger Delta. The methodology used involves integration of well log with seismic data. Horizon and fault interpretation were carried out to produce surface attribute maps. Lithologic panels derived from well log data showed that the study area is characterized by sand-shale intercalations. They delineated two reservoir horizon and the seismic amplitude analysis was used to identify prospective hydrocarbon zones.

[17], confirmed the presence of the three fundamental structures (Source rock, Reservoir, and Seal) for hydrocarbon accumulation in Bornu basin. Their work revealed that shale of Bima, Gongila and Fika formation contains sufficient organic matter for hydrocarbon generation. They calculated the Total Organic Carbon (TOC) for most of the samples to range from 0.54 wt% - 1.25 wt%. The Hydrocarbon Index (HI) from 11 – 173.8 mg/g in the interval with maximum temperature range of 365 – 519 ^{0}C. They determined the kerogen content to be of type III with minor type II. This

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suggest that there may be presence of gas in the basin. Possible reservoir rocks occurs as sandstone beds within Bima, Gombe and Kierri- Kierri formation. They identified both stratigraphic and structural trapping systems in the basin.

[18], noted that the amplitude content within the seismic data effectively provides physical parameters about the subsurface such as acoustic impedance, reflection coefficient, velocities, and absorption effect which supply structural and stratigraphic details or act as Direct Hydrocarbon Indicators (DHI). While Frequency derived attributes are useful in stratigraphic events, fault interpretation. When frequency attributes is combined with amplitude-based attributes, they may help in interpretation of geologic layering. They pointed that for effective attribute study, several attributes should be correlated in other to validate the end result of the feature of interest.

[19], worked on the lithostratigraphic interpretation and analysis of depositional environment of the chad basin. Their seismic analysis showcased region of low amplitude discontinuous facies, high amplitude convergent facies, and continuous low amplitude facies across the seismic volume. Their study indicate that cretaceous basement features controlled the deposition of overlying formations in the basin

3. Theory and Calculation

Determination of Shale beds and Volume of Shale: The Gamma ray gives details about the lithology revealing sand zones and shale zones, it is quantitatively a direct indicator of shale [20]. The determination of the shale beds allowed the differentiation of the reservoirs from the non-reservoirs. There are different methods of determining Volume of Shale (Vsh) in a shaly formation. But in this work, the method described by [21] was adopted, the volume of shale (Vsh) was estimated in a shaly porous and permeable zone from the deflections of the GR log. The gamma ray activity associated with the zone of interest (GR_{log}) was read, a clean shale-free zone is selected and read as the gamma ray clean (GR_{clean}), and a 100% shale zone was also read as the gamma ray shale (GR_{shale}). The volume of shale was then calculated for all the zones of interest using [21] linear response formula in equation (1)

$$I_{GR} = \frac{GR_{log} - GR_{clean}}{GR_{shale} - GR_{clear}} \quad (1)$$

The [22] model for older rocks was used as nonlinear estimator as given by equation (2)

$$V_{shale} = 0.33[2^{2I_{GR}} - 1] \quad (2)$$

Porosity determination: The porosity of the reservoir rocks were determined using the density and neutron log (porosity logs) since they respond differently to matric, fluid, and pore types. This was done by adopting the methods and formula described by [23] as equation (3). The density porosity (Φ_D) was calculated as the ratio of the difference between the matrix density (ρ_{ma}) and bulk density (ρ_b) to that of the difference between the matrix density (ρ_{ma}) and the fluid density (ρ_{fl}).

$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \quad (3)$$

The matrix density of 2.65 was used for this study since the area of study is dominated by clastic reservoir, while the fluid densities of 1 for water, 0.9 for oil, and 0.81 for gas was adopted.
The total porosity, which includes all the available pore spaces within the reservoir, was calculated by summing the density and neutron porosity, and dividing by two as presented by [20] in equation (4).

$$\Phi T = \frac{\Phi_D + \Phi_N}{2} \quad (4)$$

The effective porosity, which is the percentage of the pore spaces that are interconnected, was further determined by equation (5), after [20].

$$\Phi E = \Phi_T - (V_{sh} \times \Phi_T) \quad (5)$$

Determination of Formation water Resistivity (R_W): Formation water, sometimes called connate water or interstitial water, is the water uncontaminated by drilling mud that saturates the porous formation rock. It is an important interpretation parameter which was utilized for the calculation of percentage saturation of water. There are several methods to derive the quantitative information of formation water resistivity, these include water catalogs, chemical analyses, the spontaneous potential (SP) curve, and various resistivity-porosity computations and cross plots [20]. However, the formation water resistivity for the area of study was computed from the apparent water resistivity using [24] equation (6).

$$R_{wa} = \frac{R_t}{F} \quad (6)$$

Where Rt is true formation resistivity gotten from a deep-investigation resistivity log (ILD), and **F** is the formation factor which is a measure of tortuosity of the conductive paths (pore space) in the rock. It can be estimated from the following relationship described by [24] as equation (7);

$$F = \frac{a}{\Phi^m} \quad (7)$$

Where "**a**" is Tortuosity, **m** is the Cementation factor, and **ϕ** is porosity. Tortuosity is the ratio of actual flow path length to the straight distance between the ends of the flow path. Cementation factor indicates the reduction in the number and size of pore space, it models how much the pore network increases the resistivity, and rocks are assumed to be non-conductive [24]. Typical values of a = 1.0, m= 2.0. For clean, water-bearing zones, $R_t = R_o = FR_w$, and the R_w is equal to the R_{wa} that is calculated from equation (6)

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Water saturation (S_w) and Hydrocarbon saturation (S_h): Determining water and hydrocarbon saturation is one of the basic objectives of well logging [25]. Water saturation is the fraction (or percentage) of the pore volume of the reservoir rock that is filled with water. It is generally assumed, unless otherwise state that the pore volume not filled with water is filled with hydrocarbons.

The water saturation was determined using [24] water saturation equation (8).

$$S_w = \left[\frac{(a * R_w)}{\Phi^m * R_t}\right]^{\frac{1}{n}} \quad (8)$$

Where, n = saturation exponent.

Hydrocarbon saturation (S_h) is the percentage of pore volume in a formation occupied by hydrocarbon. It was determined by subtracting the value obtained for water saturation from 100 as shown in equation (9).

$$S_h = (100 - S_w)\% \quad (9)$$

Permeability Estimation: Permeability is the ability of a reservoir rock to transmit fluid. Permeability values determines whether a zone is attractive for hydrocarbon exploitation. Permeability values were computed using the petrel calculator. [26], equation (10) was imputed into the calculator in order to compute the permeability ($_{Ktim}$).

$$K_{tim} = 0.136\left[\frac{\Phi^{4.4}}{S_{wirr}^2}\right] \quad (10)$$

Where $\mathbf{S_{wirr}}$ is irreducible water saturation, and Φ is porosity.

A formation is at its irreducible water saturation when its Bulk water volume (B_{vm}) is constant [27].

Irreducible water saturation refers to water saturation at which all the water present within a formation adhere on the grains within the formation [28]. A formation at irreducible water saturation will produce water free hydrocarbon. The irreducible water saturation was calculated using equation (11), after [29].

$$S_{wirr} = \left(\frac{F}{2000}\right)^{\frac{1}{2}} \quad (11)$$

F is the formation factor.

The relationship between porosity and reservoir's flow units is very effective for explaining reservoirs' geological attributes such as grain size, shale content, and consolidation of rock, pore size and interconnectivity among others [21]. The predictability of the occurrence of hydrocarbon in the reservoirs and recoverability of hydrocarbon from the reservoirs are dependent on these attributes: Free Fluid Index (FFI) Permeability (K) Reservoir Quality Index (RQI) and Flow Zone Indicator (FZI) [29] and the parameters are directly or indirectly dependent upon porosity and on one another and could be calculated using the following equations (12, 13, 14, 15) respectively as stated by [29]:

$$FFI = \Phi - 0.02 \quad (12)$$

$$Permeability(K_{mtx})^{0.5} = \frac{11180\Phi^4}{0.894} \quad (13)$$

$$RQI = \frac{315\Phi^4}{0.894\Phi^{0.5}} \quad (14)$$

$$FZI = \frac{315\Phi^4}{(0.894\Phi^{0.5})\Phi_r} \quad (15)$$

Φ_r = ratio of the derived porosity to the difference in maximum derivable value (100%) of porosity and the derived porosity.

4. Procedure

The data utilized for this work is available well logs in *LAS* file format, and check shot data the field map showing the location of each well. The logs includes Gamma ray (GR), resistivity (LLD), Porosity (Φ) and density (RHOB). The seismic and well log files were gotten from Nigerian National Petroleum Corporation (NNPC) through the Department of Petroleum Resources (DPR), in line with the Federal government of Nigeria's policy on education. *Petrel ® E&P* software platform 2017, was used for the 3D seismic interpretation and attribute visualization, and well logs data display. The well logs were imported into the petrel environment and displayed in various windows such as interpretation window, well section window and 3D window for data quality check (Data QC). The procedures adopted herein are; lithology description, reservoir identification with gamma ray log and resistivity log, qualitative petrophysics, quantitative petrophysics and porosity-resistivity cross plot.

Reservoir Identification: With the help of gamma and resistivity log, the lithology and potential reservoirs zones in Bornu Basin were identified and mapped across the wells. The well section window is populated with well logs; logs to be displayed are selected from the global well log. Well tops are displayed by toggling on the checkbox in front of the well top folder. The available gamma-ray and resistivity logs from the oil wells in the field were grouped and used for lithologies and reservoirs delineation. Logs were colour filled for better visualization and then followed by interactive facies interpretation using the discrete log class tool available in Petrel 2017 interpretation software. The deflections of the gamma ray signature to the left (low values) indicate sandstone while the deflection to the right (high values) signifies shale. High resistivity values corresponding with sandstone zone is interpreted as a reservoir while low resistivity values represent shale or reservoir containing saltwater [19]. In order to obtain proper litho stratigraphic correlation, the well section was flattened on one of the horizons. Petroleum systems are characterized by the presence of element of reservoir rock, source rock and seal [25]. Reservoir rocks which are essentially sandstone or carbonate were identified with the aide of combination of gamma and resistivity log, sandstones were marked at zones of low gamma activity and when it correspond with high resistivity value, indicates a potential hydrocarbon reservoir. The seal rocks are usually shale and were marked at zones of

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high gamma activity and relatively lower resistivity values. Rock units of the same properties in time and in space were correlated across the wells. This helped in revealing the lateral continuity and/or variations of the rock units across the wells. The correlation was achieved in the Petrel environment by identification of log signals that are of the same signatures from well to well in order to establish the lateral lithofacies changes as well as to classify the geology of the study area.

Petrophysics of Study Area: Petrophysical analysis involves the study of physical and chemical properties of the reservoir rocks and their interactions with fluids. Qualitative and quantitative petrophysical analysis of reservoirs in Bornu Basin was done with the help of Petrel interpretation software using sets equation described in subsequent paragraphs. The qualitative interpretation assesses reservoir properties and fluid types from log pattern, while the quantitative interpretation involves the numerical computation of the reservoir properties. The key rock properties that were studied in this work includes the lithology, volume of shale, porosity, permeability, and water saturation. These reservoir properties were estimated with the use of the available well logs. Standard formation evaluation techniques were used to derive lithology and volume of shale (Vsh), porosity, and water saturation. The reservoir rocks was separated from the non-reservoir rock using the gamma ray log. The resistivity log is used to identify the reservoirs that are hydrocarbon bearing. In hydrocarbon bearing zones, the deep induction log resistivity curve will read a high resistivity because hydrocarbons are more resistant than saltwater in the formation. Fluid type is determined by co-tracking Neutron (NPHI) and Density (RHOB) log and checking for crossovers [21]. Very good crossover indicates the presence of Gas, smaller crossovers indicates oil, while a tracking together of the logs indicate the presence of water within the reservoir. The quantitative petrophysical calculation carried out with the aid of a scientific calculator and the petrel software includes; calculation of volume of shale fraction, calculation of effective porosity and calculation of permeability of mapped reservoir zone.

5. Results and Discussion

Lithologic Description: The lithologic description of the study area was done using the Gamma ray log motifs. Two distinct lithologies were identified; Sand lithology, and Shale lithology in agreement with [19]. The sand lithologies were associated with the lower Gamma ray readings, while the shale lithologies were associated with the higher Gamma ray reading (See figure 2).

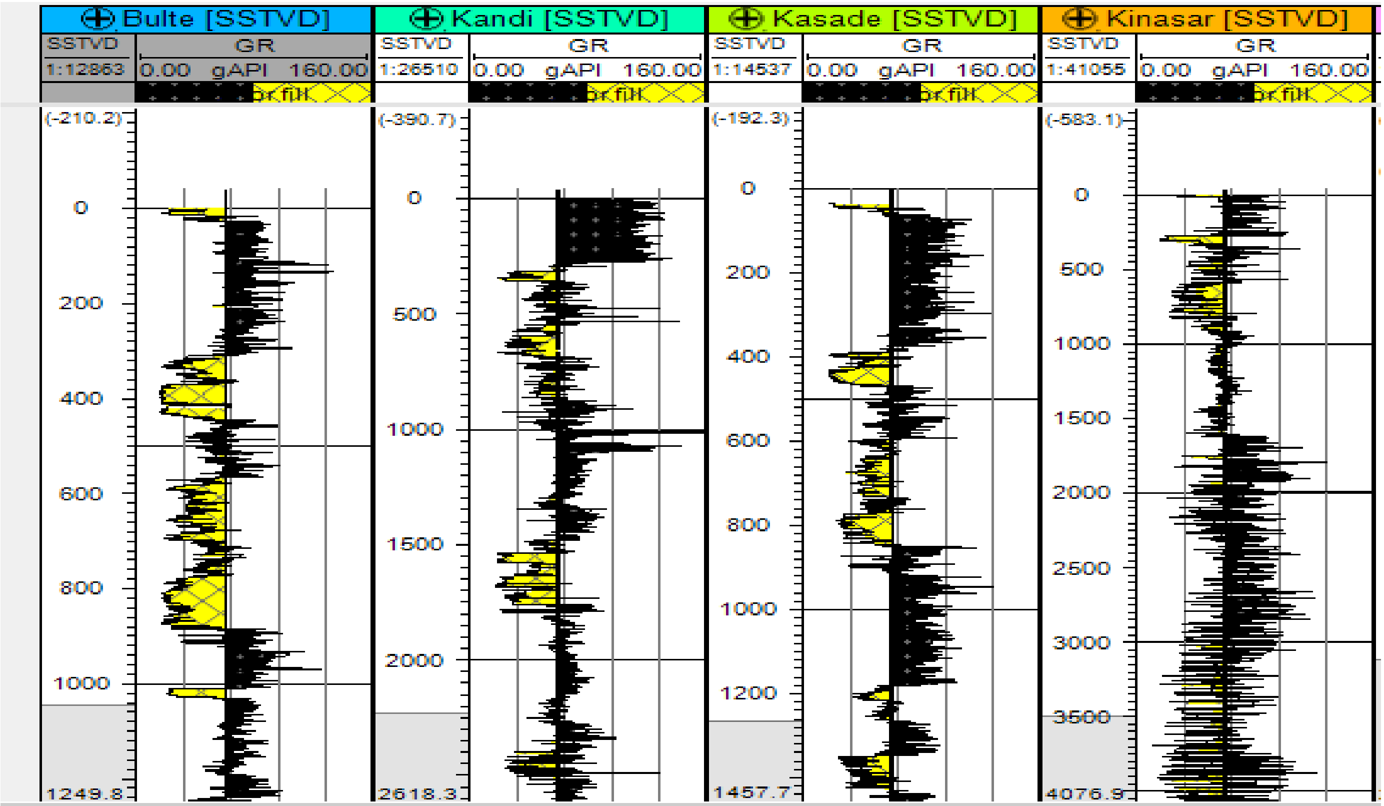

Figure 2. Lithology of Study Area

Reservoir Identification: Three reservoirs were observed and correlated across the oil wells in the field, the three reservoirs are marked as Res 1, Res 2 and Res 3 as shown in Figure 3. They were identified and marked in zones of low Gamma signature (sand zones) with high resistivity values trapped between zones of high gamma signature (Shale) with relatively low resistivity values. The interval colored yellow is sand, while the interval colored black is shale.

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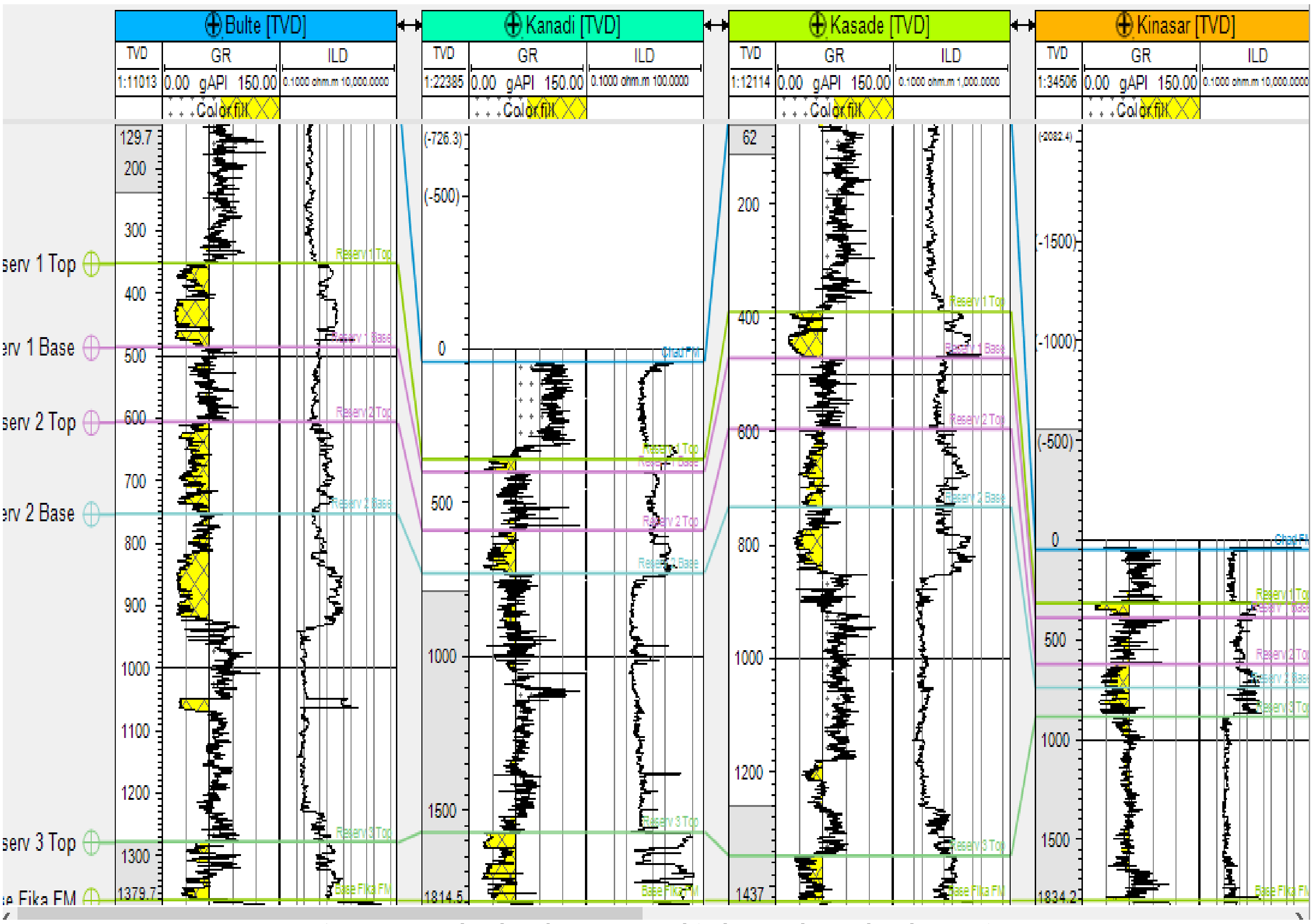

Figure 3. Potential Hydrocarbon Bearing sand (Bulte, Kanadi, Kasade and Kimasar)

Qualitative Petrophysics: For the qualitative interpretation, the reservoir rocks were separated from the non-reservoir rock using the gamma ray log. The resistivity log was used to identify the reservoirs that are hydrocarbon bearing. In hydrocarbon bearing zones, the deep induction log resistivity curve will read a high resistivity because hydrocarbons are more resistant than saltwater in the formation. The fluid type was determined by doing a Neutron and Density crossover. Very good crossover indicates the presence of Gas, smaller crossovers indicates Oil, while a tracking together of the logs indicate the presence of water within the reservoir [25]. The result of the qualitative petrophysical analysis is shown in figure 4. The rule of thumb is usually to map shaly zones where Density (RHOB) tracks to the right of Neutron Porosity (NPHI) but if Neutron Porosity tracks to the right of Density, then that zone is marked as Sand zone. For this reservoir 1 across Bulte well, it is observed to be characterized by moderately low resistivity trend, Neutron porosity (which is the magenta colour) is tracking right of Density (which is the brown colour) confirming the low gamma ray indication of sand reservoir zone. Reservoir 1 across Bulte is saturated with water. Reservoir 1 for Kanadi well registered low gamma ray and moderately high resistivity and the Neutron Porosity log also track to the right of the density and reasonable separation between the density and neutron porosity suggest this zone could contain hydrocarbon. Reservoir 1 across Kinasar registered a low gamma signature, moderately low but non uniform deep resistivity (ILD) value and the NPHI log also tracks to the right of the RHOB.

For Reservoir 2, looking at the combinatorial track of Neutron Porosity (NPHI) and Density (RHOB), it is observed that for Kanadi and Kinasar, neutron porosity tracks right of the density which is an indicative of sandstone but the corresponding close to uniform low resistivity absolutely confirms a water saturated reservoir. Whereas for Bulte, there is a sharp rise in resistivity along with neutron porosity tracking to the right of density which is indicative of hydrocarbon. The deep zone starts from the depth of 1400 m, it is characterized with low and uniform resistivity value and density tracking to the right of Neutron porosity, and this indicate multiple shale intercalation. The rule of thumb is usually to map shaly zones where Density (RHOB) tracks to the right of Neutron Porosity (NPHI).The result of the qualitative petrophysics indicate the Reservoir 1 and 2 contains both water and hydrocarbon zones.

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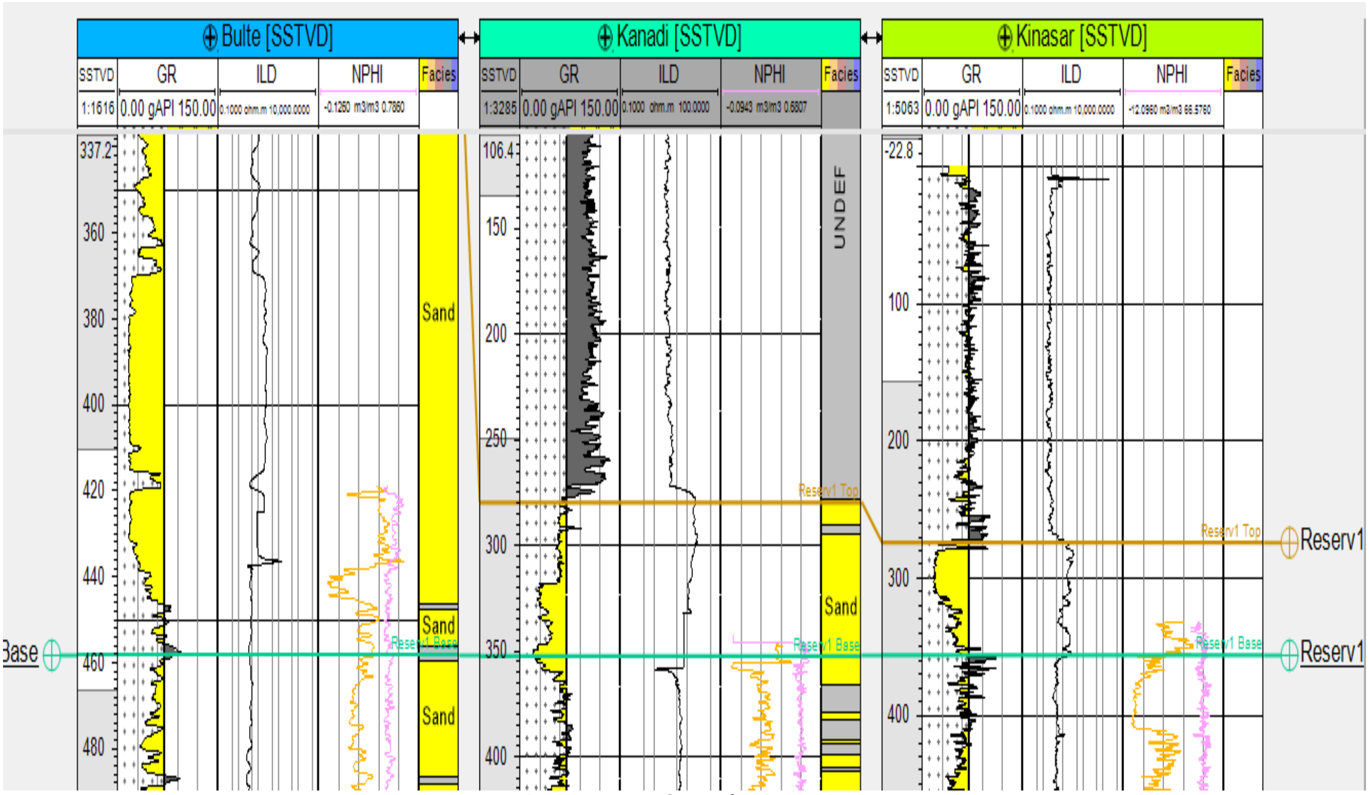

Figure 4a: Petrophysics for Reservoir 1

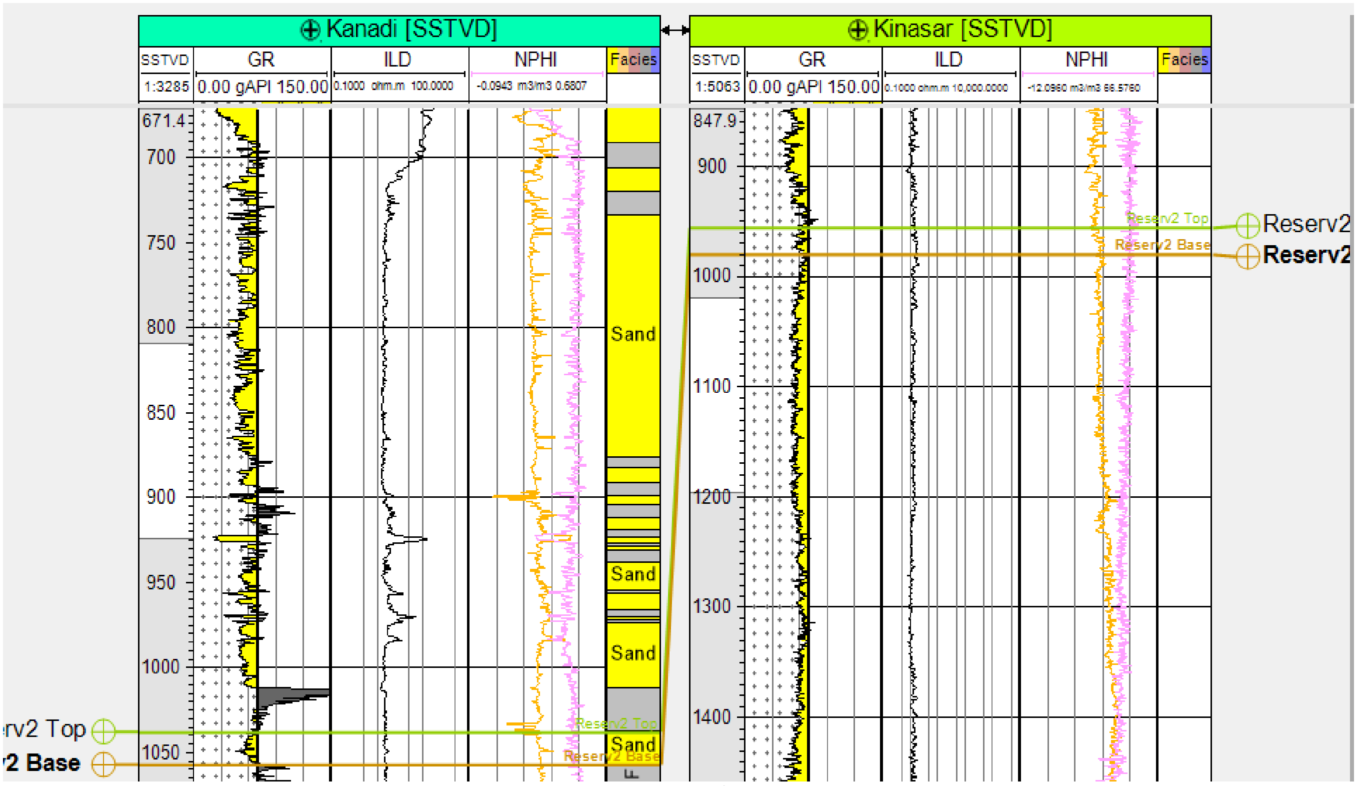

Figure 4b Petrophysics for Reservoir 2

Quantitative Petrophysics: The quantitative interpretation of the reservoirs of the study area was carried out using the methodology described by [21] (i.e. the determination of volume of shale, determination of effective porosity, determination of water saturation etc.), and the results of some computed petrophysical parameters of the study area are presented in table 1.

Table 1. Petrophysical Calculation for Two Reservoirs Marked Across Bulte, Kanadi and Kinasar

	Bulte									
	Interval (m)	V_{shale}	ϕ_e	**ILD (Ωm)**	**F**	R_{wa}**(Ωm)**	S_w **%**	S_h **%**	**K**	**RQI**
1	230-460	0.016	0.49	22.43	4.16	5.39	90.1	9.8	2.72	28.6
2	950-990	0.008	0.35	34.73	8.16	4.26	95.1	4.9	0.33	8.9
	Kanadi									
1	280-350	0.039	0.36	19.51	7.72	2.53	85.5	14.5	0.39	9.7
2	1010-1050	0.140	0.38	1.78	6.93	0.26	27.8	72.2	0.55	11.9
	Kinasar									
1	290-350	0.017	0.38	29.44	6.93	4.25	86.1	13.9	0.55	11.9
2	950-980	0.280	0.39	1.87	6.57	0.28	26.7	72.3	0.67	12.9

The result of the petrophysical calculation for Reservoir 1 and Reservoir 2 across three wells namely Bulte, Kanadi and Kinasar give quantitative information about the hydrocarbon saturation level for the reservoirs. It can be noticed that the volume of shale is low for the three wells across the two reservoir zones, this enabled the application of the [24] equations for the calculation of the reservoir parameters shown above. The column labelled K is the calculated Permeability. RQI is the Reservoir Quality Index. F is the Formation Factor R_{wa} is the resistivity of the water zone, S_w is the percentage of water saturation while S_h is the percentage hydrocarbon saturation. Water saturation (S_h) for reservoir interval 1 across Bulte, Kanadi and Kinasar wells are (90.1, 85.5 and 86.1) respectively, with effective porosity (**ϕ_e**) of 0.49, 0.36 and 0.38. For reservoir Interval 2, the percentage water saturation across Bulte, Kanadi and Kinasar wells are (95.1, 27.8 and 26.7) respectively with Effective Porosity of 0.35, 0.38 and 0.39.

Porosity – Resistivity Cross plot: Porosity – Resistivity cross plot for all the wells (Bulte, Kanadi, Kasade and Kinasar) was utilize to identify patterns in the well log data, these patterns have geophysical meanings [30]. Porosity was plotted against resistivity and coloured with gamma ray log, this is a graphical representation of [24] equation. The scatter of points helped to identify water bearing sand from hydrocarbon bearing sand [31]. The Hydrocarbon bearing sand plotted away from the water bearing sand as shown in figure 5. The result validates the petrophysical calculation that Kinasar well has zones of hydrocarbon saturation.

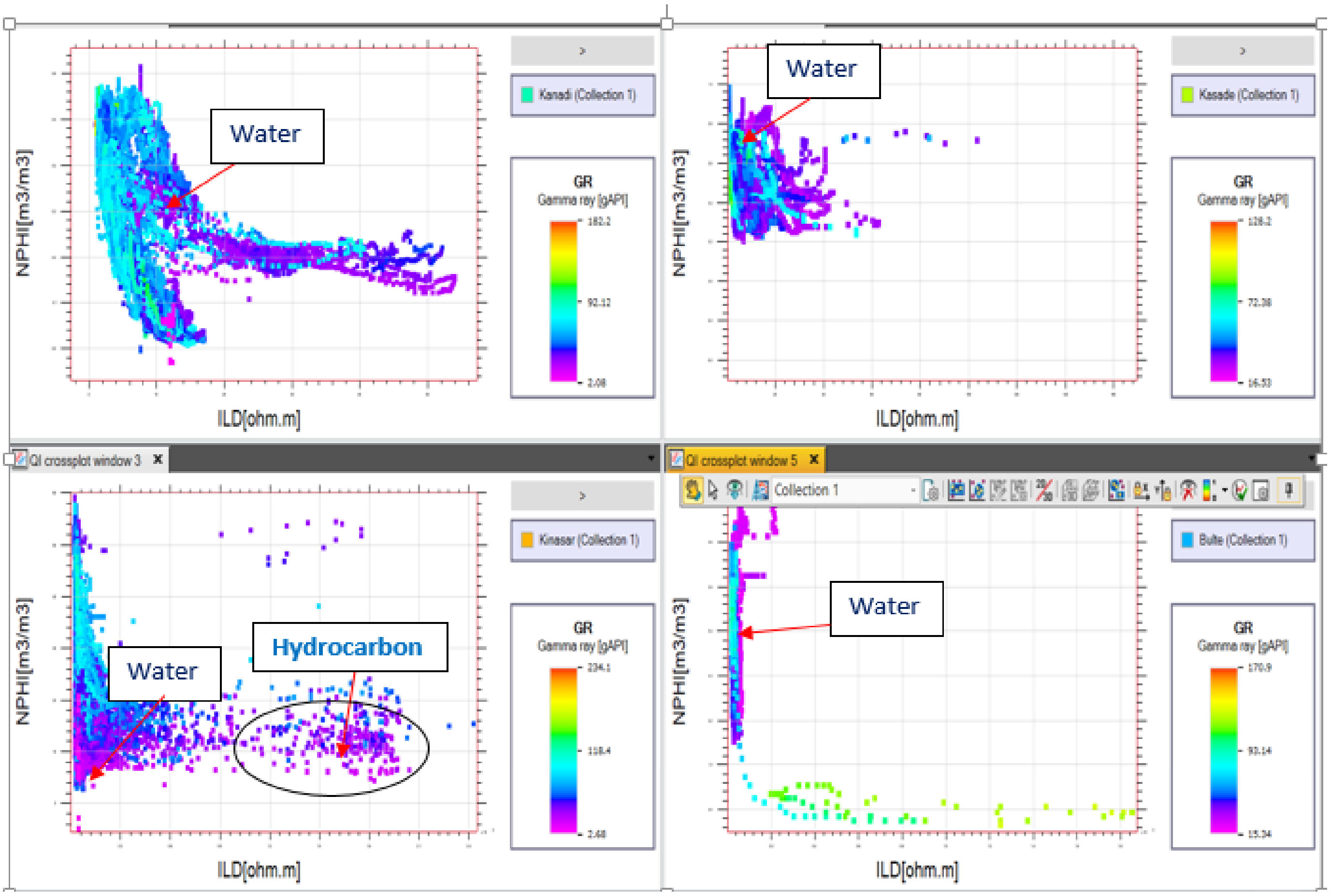

Figure 5. Porosity – Resistivity Crossplot

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6. Conclusion and Future Scope

From the well log data, sand and shale lithology were observed in the study area in sequence that form essential element of hydrocarbon systems. Three reservoirs were identified with the aid of gamma ray log, resistivity log, density and Neutron porosity log. Qualitative petrophysical analysis was done by identifying Neutron and Density log crossovers, quantitative Petrophysical calculations were done employing the Archie's equation. Reservoir 1 across the Bulte well is at depth interval of 230 -460 m. the calculated volume of Shale is 0.016, total porosity (Φ_T), Formation Water Resistivity (R_w) of 5.39 Ωm, Permeability (K) of 2.72 and Hydrocarbon Saturation (S_h) of 9.8%. Reservoir 2 across Kanadi well is at depth interval of 1010 – 1050 m, Volume of Shale of 0.140, Total Porosity (Φ_T) of 0.38, Formation Water Resistivity (R_w) of 0.26 Ωm, Permeability (K) of 0.55 and Hydrocarbon Saturation (S_h) of 72.2%. Reservoir 2 across Kinasar well is at interval of 950 -980 m, Volume of Shale (V_{shale}) of 0.280, Total Porosity (Φ_T) of 0.39, Formation Water Resistivity (R_w) of 0.28 Ωm, Permeability (K) of 0.67 and Hydrocarbon Saturation of 72%. Porosity and Resistivity cross-plot was generated for the wells which discriminate fluids using Scatter plot. Based on the interpretation results in the foregoing; the following conclusion are hereby drawn from the research:

1. The interpretation of gamma ray log showed that the study area is of sand and shale lithology.
2. Qualitative and quantitative petrophysics revealed that that some reservoir zones are saturated with water while some zones are saturated with hydrocarbon. Petrophysical calculation for reservoir 2 across Kanadi and Kinasar well got hydrocarbon saturation to be about 72% for both well which is a significant value.
3. The Porosity – Resistivity cross plot revealed zone of hydrocarbon saturation beneath Kinasar well.

Having gotten some valuable result in line with the aim and objectives, the following recommendations will be useful for future survey; more wells should be drilled in the study area with check-shot data together with seismic survey using angle gather for AVO analysis which is crucial for fluid substitution modelling

Data Availability
None

Conflict of Interest
Authors did not encounter any conflict of interest regarding this research paper.

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All stages of this research were conducted the authors in combined effort

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References

[1] N. G. Obaje, H. Wehner, and G. Scheeder, "Hydrocarbon prospectivity of Nigeria's inland basins: From the viewpoint of organic geochemistry and organic petrology", AAPG Bulletin, 2004, 87: 325–353, 2004.
[2] I. Hamza, and I. Hamidu, "Hydrocarbon resource potential of the Bornu basin northeastern Nigeria", *Global Journal of Geological Sciences*, 10(1), 2012.
[3] A. B. Aderoju, S. B. Ojo, A. A. Adepelumi, And F. Edino, "A Reassessment of Hydrocarbon Prospectivity of the Chad Basin, Nigeria, Using Magnetic Hydrocarbon Indicators from High Resolution Aeromagnetic Imaging", *Ife Journal of Science*, 18(2): 503-520, 2016.
[4] Y. B. Mohammed, and B. Tela, "Assessment of Tertiary sediments of Bornu basin for possible hydrocarbon reservoir", *Research Journal in Engineering and Applied Sciences*, 1(4): 251-257, 2012.
[5] F. E. Okpikoro, and M. A. Olorunniwo, "Seismic Sequence Architecture and structural analysis of North Eastern Nigeria Chad (Bornu) Basin", *Cont. Journal of Earth Science,* 5(2): 1- 9, 2010.
[6] G. J. Genik, "Regional framework structure and petroleum aspects of the rift basins in Niger, Chad and Central African Republic (C.A.R.)", *Tectonophysics*, 213:169–185, 1992.
[7] C. O. Ajayi, and D. E. Ajakaiye, "The Origin and Peculiarities of the Nigeria Benue Trough. Another look from recent gravity data obtained from middle Benue", *Tectonophysics*, 286-329, 1981
[8] B. Alalade, and R. V. Tyson, "Hydrocarbon Potential of the Late Cretaceous Gongila and Fika Formations, Bornu (Chad) Basin, Northeastern Nigeria", *Journal of Petroleum Geology, 33*(4), 339–353, 2010
[9] A. S. Adamu, "*Formation and Fill of Continental Rift Basins: An Integrated Study Based on the Bornu Basin, Onshore NE Nigeria*", Basins Research Group (BRG), Department of Earth Science and Engineering, Imperial College, Prince Consort Road, SW7 2BP, UK. 101-136, 2016
[10] D. E. Ajakaiye, "Geophysical Investigations in the Benue Trough – a review", *Earth. Evolution Science*. 1: 126- 136, 1981.
[11] A. A. Avbovbo, E. O. Ayoola, S.A. Osahon, "Depositional and structural styles in Chad Basin of Northeastern Nigeria", AAPG 70(121):1787–1798, 1986
[12] S. A. Aminu, and M. Whiteworth, "Integrated well log and 2-D seismic data interpretation to image subsurface stratigraphy and structure in Northeastern Bornu Basin" *Journal of African Earth Science*, 121: 1 – 15, 2016.
[13] K. O. Omosanya, A. A. Akinmosin, and N. A. Adio, "Hydrocarbon potential of the Nigerian chad basin from wireline logs", *Indian Journal of Science*, 4(12): 1668-1675, 2011.
[14] S. K. Ahmed, K. Liu, H. Moussa, J. Liu, A. H. Ahmed, and L. K. Kra, "Assessment of petroleum system elements and migration pattern of Borno (Chad) Basin, Northeastern Nigeria", *Journal of petroleum science and engineering*, Vol. 208, 2022.
[15] G. C. Emujakporue, C. Nwankwo, and L. Nwosu, "Integration of well logs and seismic data for prospect evaluation of an x-field, onshore Niger Delta", Nigeria. International journal of Geosciences, 3, 872-877, 2012.

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[16] O. Oluwatoyin, and T. M. Olowokere, "Seismic attribute analysis as a precursor to hydrocarbon indicator: a case study of 'OK' field, Niger Delta", *Tanzania Journal of Science*, 47 (1): 134 – 144, 2021.
[17] J. A. Adeyinka, S. P. Ola, and S. O. Olabode, "Possible Bornu Basin Hydrocarbon Habitat", *International Journal of Geoscience*, 5 (9), 2014.
[18] L. Azevedo, F. N. Ruben, A. A. Jose, M. P. Luís, H. C. Maria, J. C. Pedro, and S. Amílcar, "Seismic Attributes for Constraining Geostatistical Seismic Inversion", Ninth International Geostatistics Congress, Oslo, Norway. Conference paper, 1-11, 2012.
[19] C. N. Didi, I. I. Obiadi, S. E. Okeke, S. N. Anakor, and M. K. Ikomi, "Lithostratigraphic interpretation and analysis of the depositional environment of Nigerian Chad basin using well log and seismic data", Meridian Journal of Physical Science, 2 (1), 2022.
[20] O. Kuffur, "Estimation of Petrophysical data for assessing hydrocarbon potential in Western Ghana oilfield (Tano Basin)". Retrieved from http://hdl.handle.net/123456789/604, (Accessed 05-8-2022), 2008.
[21] Schlumberger, "Log Interpretation Principles/Applications', Houston (Schlumberger), 1987.
[22] V. V. Larionov, "*Borehole radiometry*", Nedra, Moscow, 127, 1969
[23] A. Dressers, "Log Interpretation Charts", Dresser Industries Inc., Houston Texas, 107p, 1979.
[24] G. E. Archie, "The Electrical Resistivity as an Aid in Determining Some Reservoir Characteristics", Journal of Petroleum Technology, 5, 54-62, 1942.
[25] M. Rider, "The Geological Interpretation of Well Logs", 2nd Ed., Whittles Publishing, Caithness, 280p, 1996.
[26] A. Timur, "An investigation of permeability, porosity, and residual water saturation relationships for sandstone reservoirs", The Log Analyst, Jul-Aug, 1968, 8-17, 1968.
[27] G. B. Asquith and D. Krygowski, "Basic Well Log Analysis", American Association of Petroleum Geologists, Methods in Exploration Series: Tulsa, Oklahoma, No 16. pp. 12-135, 2004.
[28] G. B. Asquith, and C. R. Gibson, "Basic well log analysis for geologists", American Association of Petroleum Geologists, Methods in Exploration Series, 216 p, 1982.
[29] D. Tiab, and E. Donaldson, "*Petrophysics: theory and practice of measuring reservoir rock and fluid transport properties",* Gulf professional publishing, 2011.
[30] Atlas. (1985). Log Interpretation Charts, Atlas Wire Line Services, Houston Texas
[31] I. U. Chibuogwu, and T. N. Obiekezie, "Solar Forcing on Meterological Parameter in Nigeria, International Journal of Multidisciplinary Science and Advanced Technology, Vol. 2 (11), 15-23, 2021.

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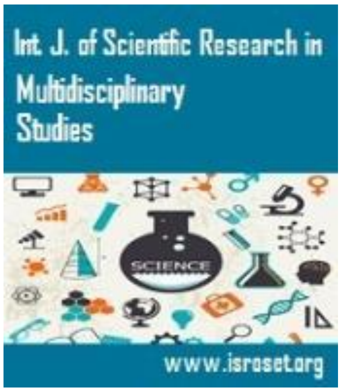

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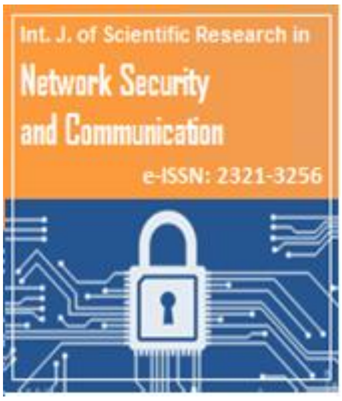

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