Lithostratigraphic Interpretation, Geotemperature Analysis, and Hydrocarbon Windows Determination in Seloken Field, Chad Basin, Northeastern Nigeria

Akpunonu, Eliseus Okey

Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria.

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ABSTRACT

The aim of this study is to interpret the lithostratigraphic units, analyze geotemperature and determine the hydrocarbon windows in the Seloken Field. Gamma-ray logs and formation tops were used to interpret the lithostratigraphic units. Corrected bottom hole temperature (BHT) data from the wells were used to calculate the geothermal gradients. A formular was derived from the geothermal gradient equation to analyze the geotemperature. Another formular was derived from the geotemperature equation to obtain the hydrocarbon windows. Five major lithostratigraphic units were interpreted. They are: Bima and Gongila Formations, Fika Shale, Kerri-Kerri and Chad Formations...The calculated geothermal gradients range from 3.4^{o}C/100m to 4.0^{o}C/100m, with an average of 3.65^{o}C/100m and the standard deviation of 0.01^{o}C/100m. The temperature of shale units of the formations at various depths calculated from the geotemperature equation range from 30.99^{o}C to 202.45^{o}C. This shows that some of the shale units are thermally mature to cook petroleum The oil window calculated from the derived geomathematical equation is between 1178.1m and 2457.95m, while the gas window is from 2457.95m to 5424.7m. The boundary between the two windows is at 2457.95m. The results above were used to generate a hypothetical model for the hydrocarbon windows. The model indicates that the shale units are within the diagenesis and catagenesis phases. This work provides mathematical methods of source rock thermal maturity evaluation to complement geochemical methods. The outcome is a very important tool, which can be applied to other fields and sedimentary basins in hydrocarbon exploration.

Keywords: Geomathematical model, geothermal gradient, hydrocarbon windows, lithostratigraphic unit, geotemperature, thermal maturity,

INTRODUCTION

Seloken field is located in Chad Basin, Northeastern Nigeria. It lies between latitudes 11.5° 30`N and 14° 40`N and longitudes 11° 45` E and 14° 45`E (Fig. 1b). The Chad Basin is one of the several active intracratonic basins of the African continent. It is a physiographic province defined by several topographic highs, disposed elliptically in the south-central region of the Sahara and covering all of Chad Republic, parts of Libya, Niger Republic, Sudan, northern portions of Nigeria and Cameroun (Obaje *et al.*, 2006). The Nigerian section (Bornu Basin), which is a portion of the Chad Basin, is a broad sediment-filled depression that is associated with the split-up of the Africa and South America during the Early Cretaceous (Burke 1976b, Fairhead and Blinks 1991, Hartley and Allen, 1994, Ola et al., 2017). The basin is the largest basin in Africa, covering about 233,000km^2 (Matheis ,1986, Omosanya et al., 2011). The Nigerian portion of the basin is one-tenth of the total Chad Basin, and it joins the northeastern-most sector of the SSW-NNE extension of the Benue Trough (Olugbemiro et al., 1997, Nwankwo et al., 2009). The Nigerian sector of the Chad Basin is one of the Nigeria’s inland basins, occupying the northeastern part of the country and covering Bornu State and parts of Yobe and Jigawa States (Obaje et al., 2011; Adepelumi et al., 2011).

Previous works on the hydrocarbon potential of the Nigerian sector of Chad Basin include Obaje et al. (2006), Omosanya et al. (2011), Hamza and Hamidu (2011), Nwankwo et al. (2009, 2012), Adekoya et al. (2015), Ola et al. (2017), Suleiman et al. (2017), and Baku et al. (2019). The geochemical studies conducted on the source rocks show that the kerogen is type III, indicating that the Chad (Bornu) Basin is a gas province (Obaje et al., 2006, Omosanya et al., 2011, Ola et al., 2017). Baku et al. (2019) identified an oil seep at the outcrop of the Bima Formation on the western edge of the basin. Adepelumi et al. (2011) in characterizing the reservoir sand of the basin from well log data affirms that the net-to-gross values indicate the presence of quality potential reservoir rocks. Nwankwo et al. (2012) observed that the thickness of stratigraphic units, presence of source and reservoir rocks, structural-related traps and heat flow values are favorable criteria for high petroleum prospects.

Commercial volumes of hydrocarbons have been discovered in Chad, Sudan, and Niger Republic, but exploration efforts in the Nigerian sector of the Chad Basin recorded negligible success; as no oil or gas has been discovered in a commercial quantity (Hamza and Hamidu, 2011, Nwankwo et al., 2012). The reasons for the unsuccessful exploration campaign in the Nigerian sector include igneous activities, basin inversion, poor knowledge and understanding of the geology, tectonostratigraphic evolution, and petroleum system development of the basin (Obaje et al., 2006, Omosanya et al., 2011, Nwankwo et al., 2012, Ola et al., 2017, Suleiman et al., 2017).

Although, few reports are available on the organic richness and thermal maturity of the sediments, the hydrocarbon generative windows model for the basin has not been established and the thermal maturation potential of the source rocks of the lithostratigraphic units has not adequately been carried out. The study aims at interpreting the lithostratigraphic units, conducting geotemperature analysis of the shale beds, and generating a hydrocarbon windows model for Chad Basin in Nigeria using log data and geomathematics. The study is based on the works of Hyne (1984) and Selley (1996); and firmly rooted in Albrecht et al. (1976), Cooper (1977), Hunt (1979), Waples (1981) Allen and Allen (2002) and Akpunonu et al. (2009, 2010)

The geomathematical equations that are derived in this work would be vital tools for explorations and will be useful to researchers and oil companies in source rock potential evaluations.

Fig. 1a is the base map showing the positions of the four wells while fig. 1b is the map of Nigeria showing the location of the study area.

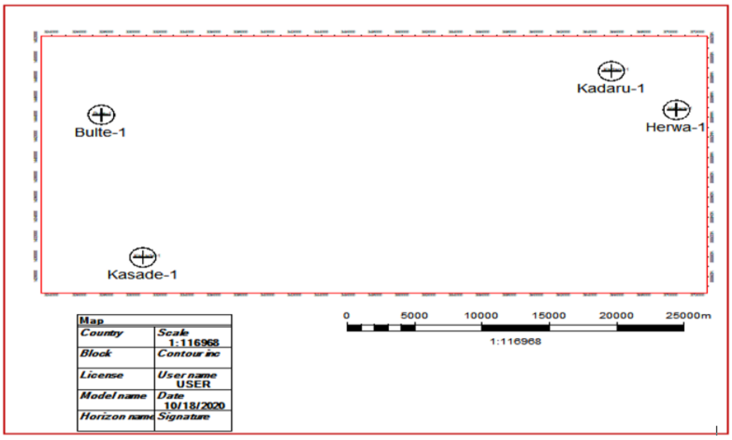

Fig 1a: Base map of the study area showing the positions of the four wells

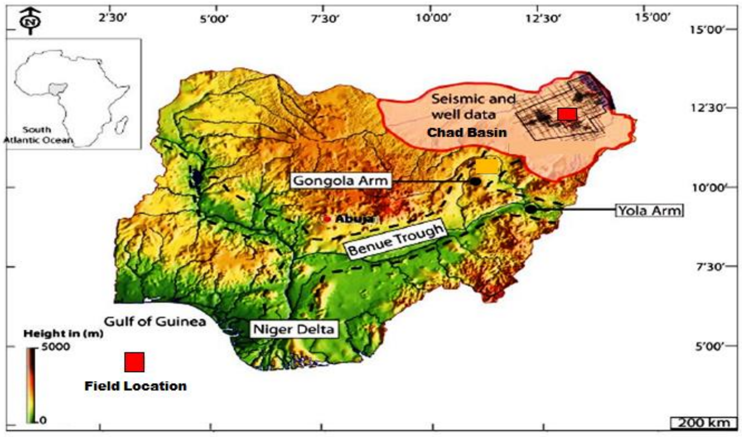

Fig 1b: Map of the Nigeria showing the location of the field in the Chad Basin (modified from Adamu, 2016).

1.1 Geologic Setting.

The Bornu Basin is part of the chain of the WARS (West African Rift System) basins (Hamza and Hamidu, 2011). The origin of the WARS is generally attributed to the breakup of Gondwana and opening of the South Atlantic and Indian Oceans at about 120-130 Ma (Fairhead and Green, 1989). The tectonic framework and origin of Bornu Basin is related to the evolution of the West African rift systems (Genik, 1993). Genik (1992, 1993) presented a model for the regional framework and tectonic evolution of the Cretaceous – Tertiary (Paleogene – Neogene) rift basins of Niger, Chad and the Central African Republic (C.A.R) which advances the concept proposed earlier by Fairhead and Blinks (1991) that oceanic strike-slip faults stretched into Africa and produced the orthogonal extension that opened the Niger and Sudanese rifts. The Nigerian Chad Basin is a broad structural depression or sag-rift intracratonic basin that lies within the Pan African Mobile Belt in Central West Africa (Omosanya et al., 2011)

The sedimentary fill of the Chad Basin started during the Early Cretaceous and ended in the Quaternary (Obaje et al., 2006). The basin comprises five lithostratigraphic units namely: Bima Formation at the basal part that lies nonconformably on the Precambrian Basement Complex, Gongila Formation, Fika Shale, Kerri–Kerri, and Chad Formations (Obaje et al., 2006) The Bima Formation is Albian – Cenomanian in age. It was deposited under continental conditions (fluvial, deltaic, and lacustrine) and consist of sparsely, fossiliferous, poorly sorted, and medium to coarse-grained feldspathic sandstone intercalated with carbonaceous clay, shale, and mudstone The Gongila Formation is Turonian and was deposited during marine incursions into the basin. It overlies the Bima Formation. It is in turn, overlain by the Fika Shale which is Santonian. The Kerri-Kerri Formation of Paleocene age represents an unconformable continental sequence of flat-lying grits, sandstone, and clay that overlies the marine Fika Shale. The Chad Formation (Quaternary) with a total thickness ranging from 300m to 1200m is the youngest unit in the basin

There was tectono-magmatism in the basin that resulted in intrusive igneous bodies (dykes and sills) in the Bima and Gongila Formations, and the Fika Shale (Fig. 2).

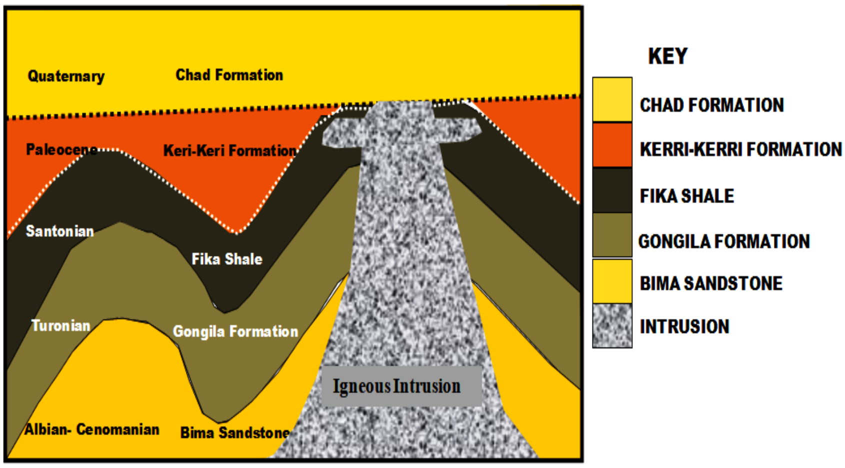

Fig. 2. Stratigraphic successions and igneous intrusion in the Nigerian sector of the Chad Basin (modified from Obaje et al., 2006, Nwankwo et al., 2012, Suleiman et al., 2017)

MATERIALS AND METHODS

2.1 Materials.

The materials used in order to accomplish the objectives of the study are the wireline logs (gamma-ray (GR), resistivity (ILD & RILD), density (RHOB), sonic (DT, DT8, DT10), and caliper) from the Bulte-1, Herwa-1, Kadaru-1 and Kasade-1 wells (Fig. 3). Borehole information on the corrected BHT of the four wells, the mean annual surface temperature of the entire region and formation tops were also provided (Tables 1 and 2). Also available were the petrel 2018 software, workstation, and lap-top computers. The petrel 2018 software installed in the workstation was used for the log interpretation.

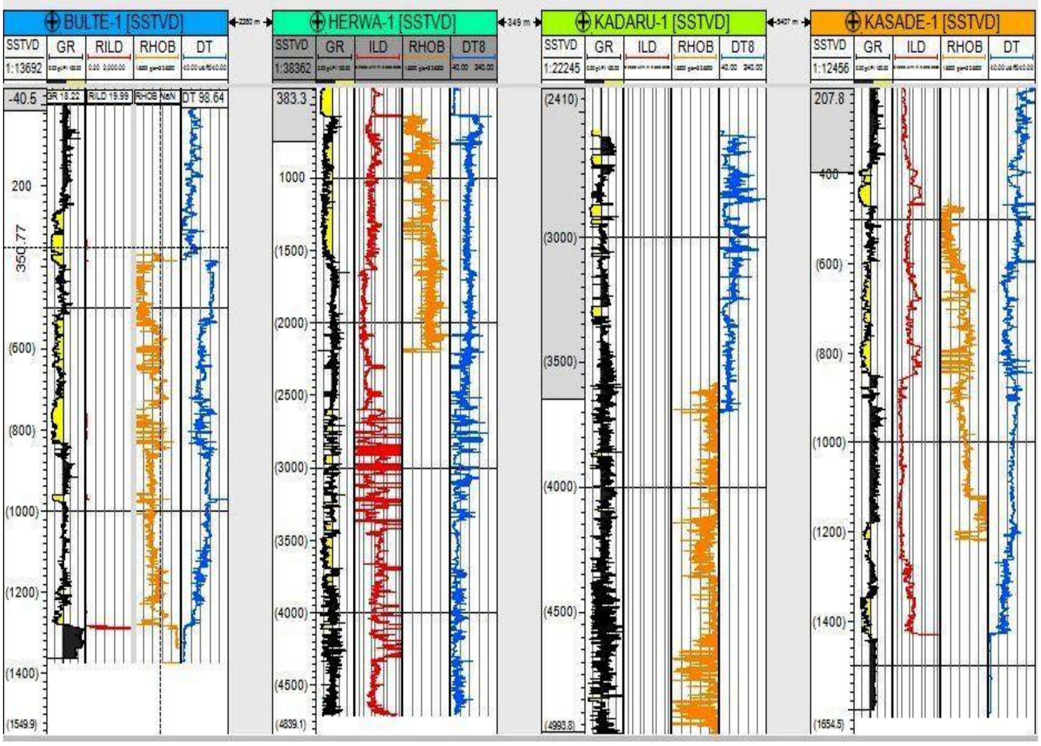

Fig. 3. A schematic display of the four well logs provided for this study

Table 1. Corrected BHT and mean annual surface temperature versus depth data of the wells in Seloken Field

WELL	**BHT t_2 (°C) (Corrected)**	**Annual Surface Temp. t_1(°C)**	**Depth to BHT d_2 (m)**	**Depth to Annual Surface Temp d_1(m)**
Bulte-1	158	27	1466.8	18.29
Kasade-1	175	27	1611.1	18.29
Herwa-1	350	27	4713.73	18.29
Kadaru-1	285	27	5013	18.29

Table 2. Formation tops from the wells in Seloken field

Lithostratigraphic Unit	**Bulte-1**	**Kasade-1**	**Herwa-1**	**Kadaru-1**
Chad Fm				
Kerri-Kerri Fm	480m	470m	50m	570m
Fika Sh	925m	848m	1633m	___
Gongila Fm	1276m	1350m	3052m	2735
Bima Fm	1467m	1598m	3835m	3520m

2.2 Methods

2.2.1 Wireline Log interpretation

The fundamental approach to the study starts with quantitative well log interpretation. The major lithostratigraphic units were identified across the field using a combination of gamma-ray logs provided for the four wells (Bulte-1, Kasade-1, Herwa-1 and Kadaru-1), formation tops data (Table 2) and information from the literature especially Obaje et al. (2006, 2011), Omosanya et al. (2011), and Nwankwo et al. (2012). The formation tops in Table 2 were used to identify the stratigraphic positions of the formations across the wells. The gamma-ray logs in Figure 3 were used to delineate the lithologic units within the formations; and most of the lithologies identified correspond to Obaje et al. (2006), Omosanya et al. (2011), and Nwankwo et al. (2012).

2.2.2 Geothermal gradient calculation

Geotemperature analysis focuses on the shale units of the formations in the Chad Basin. The analysis starts with the determination of geothermal gradients, average geothermal gradient and standard deviation of geothermal gradient of the field. Geothermal gradient is defined as an increase in temperature with the corresponding increase in depth (Hyne 1984, Levorsen, 1967). It is expressed mathematically in Akpunonu (2008) as **$G = \Delta T/\Delta H$------ (Equation1a)**

where G = geothermal gradient, ΔT = change in temperature and ΔH = change in depth; and in Masum (2014) as $G = \partial t/\partial z = \frac{T2-T1}{D2-D1}$--------------------- **(Equation1b)**

where G = geothermal gradient, T_1 = starting temperature, T_2 = ending temperature, D_1 =Starting depth, D_2 = ending depth. The equations above are the same and were derived from the bottom hole and mean annual surface temperature data (Table 1). It is used to calculate the geothermal gradients of the field of study from the four wells.

In other to obtain a representative geothermal gradient of the field, the average (arithmetic mean) of the geothermal gradients of the wells was calculated using equation 2 of Akpunonu (2008) which was derived from the arithmetic mean equation of Spiegel (1972)

$$G_a = \frac{\Sigma \Delta T/\Delta H}{N} = \frac{\sum G}{N} \text{------------------------ (Equation 2)}$$

Where

G_a = average geothermal gradient

N = number of the wells in the field

Also, to authenticate the use of the value obtained from the equation above as the geothermal gradient of the field, we calculated the standard deviation of average geothermal gradient with equation 3 below of Akpunonu (2008) which was derived from the standard deviation equation of Spiegel (1972)

$$S = \sqrt{((\sum (G - Ga)^2)/N)} \text{ ----------- (Equation3)}$$

Where

S = standard deviation

2.2.3. Geotemperature analysis

The temperatures at all depths where shale was deposited were calculated from a geotemperature equation derived from linear equation of Godman and Talbert (1971). Since increase of temperature with depth is a linear function as y = mx + c (Godman and Talbert, 1971), the geotemperature equation goes as follows

$$T_d = (\Delta T/\Delta H)\, d + Ts \text{ -------------------- (Equation 4)}$$

Where

T_d = temperature at a depth (threshold temperature)

d = depth at which shale is deposited

Ts = mean annual surface temperature (constant temperature)

2.2.4. Hydrocarbon windows determination

The depths at which both oil and gas begin and stop generating and the boundary between oil and gas windows were determined with the geomathematical equation derived from equation 4 as follows: $T_d = (\Delta T/\Delta H)\, d + Ts$

Since geothermal gradient $G = \Delta T/\Delta H$ and average geothermal gradient is G_a from equation 2,

Then

$$\mathbf{T_d = (G_a)\, d + Ts.}$$

Making d the subject of the equation gives

$$\mathbf{d = (T_d – Ts) /G_a} \text{ ----------------------- } \mathbf{(Equation\ 5)}$$

The values obtained from the equation above were used to design a hypothetical model for hydrocarbon generative windows of the Seloken Field.

RESULTS

3.1 Lithostratigraphic Interpretation.

The quantitative log interpretation shows that five lithostratigraphic units were penetrated by the wells (Bulte-1, Kasade-1, Herwa-1 and Kadaru-1) drilled in the Seloken Field (Fig. 4). The lithologies of the formations as interpreted from the gamma-ray logs are shown in Fig. 5.

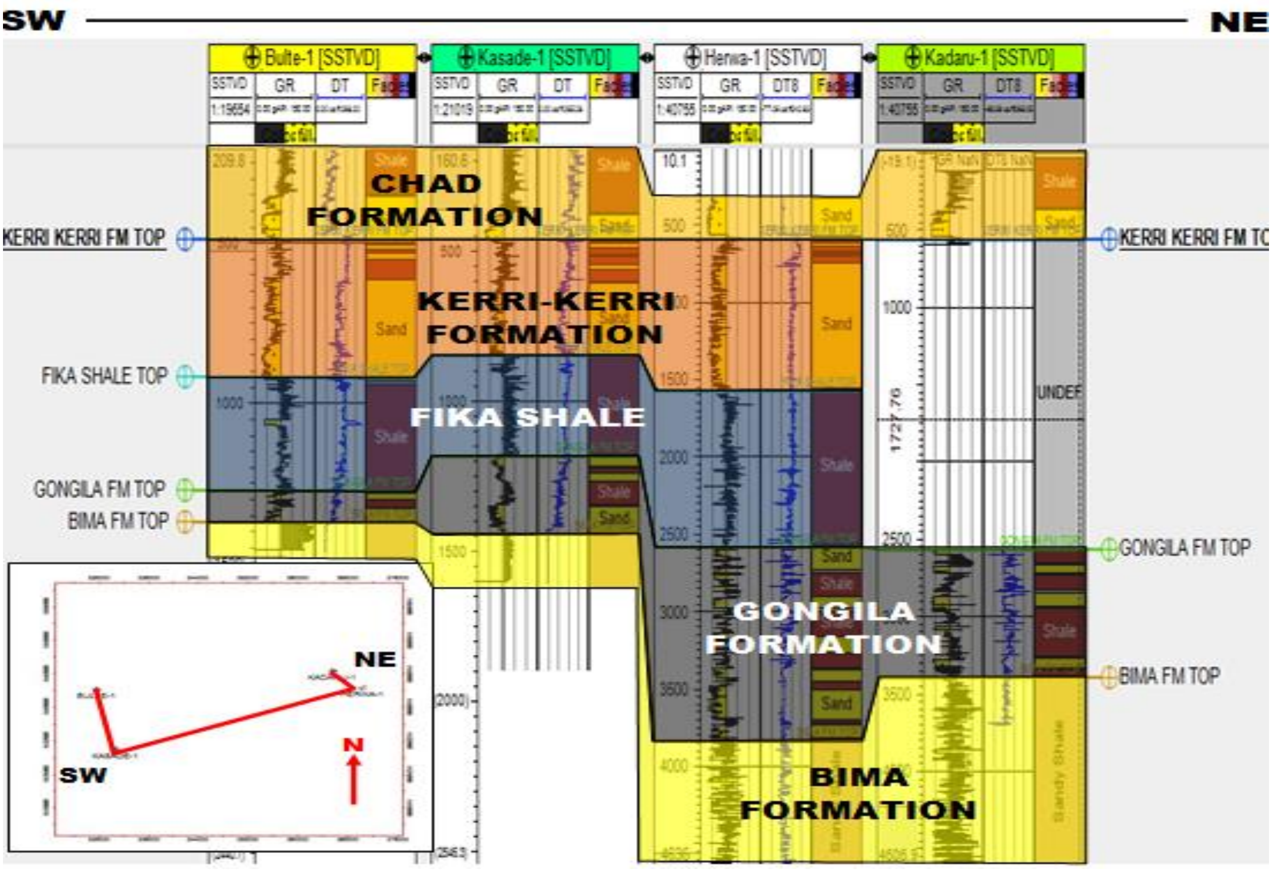

Fig. 4. Lithostratigraphic units of Chad Basin in Seloken Field

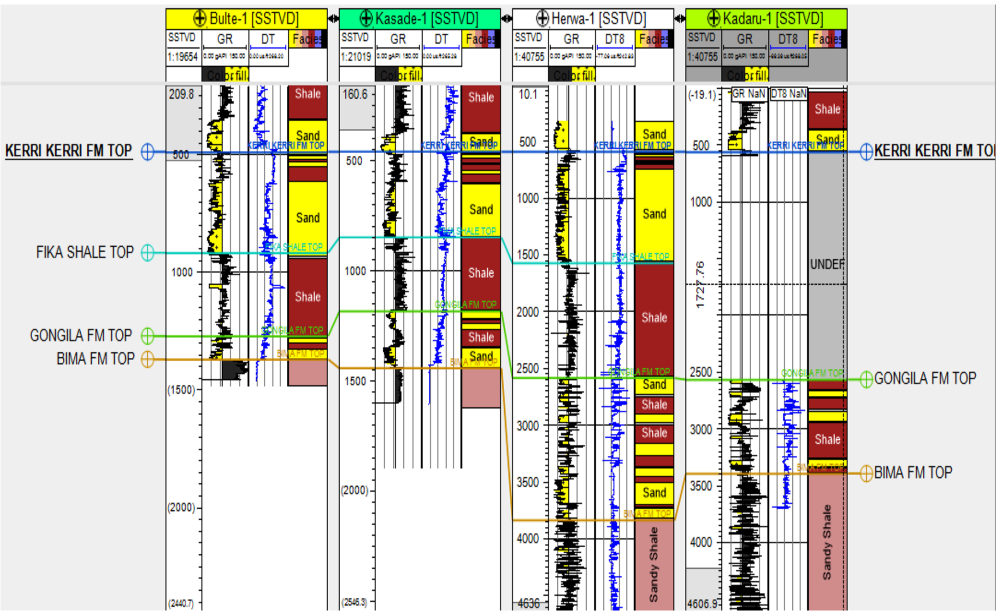

Fig. 5. Lithologies of the formations interpreted from gamma ray logs

3.2 Geothermal Gradient

The geothermal gradients (G) of the wells in the Seloken Field calculated from equation 1 are recorded in Table 3 below:

Table 3. Computed geothermal gradient of wells in the Seloken Field

Well	**G (^{O}C/100m)**
Bulte-1	**3.7**
Kasade-1	**4.0**
Herwa-1	**3.4**
Kadaru-1	**3.5**

The average geothermal gradient (G_a) which is used as the geothermal gradient of the field is calculated with equation 2 as follows:

$$\mathbf{G_a = (3.7+4.0+3.4+3.5)/4}$$

$$\mathbf{= 3.65^{o}C/100m}$$

The standard deviation (S) calculated from equation 3 is as follows in Table 4

Table 4. Standard deviation calculated from geothermal and average geothermal gradients across the wells

Well	**G (^{O}C/100m)**	**Ga (^{O}C/100m)**	**G –Ga (^{O}C/100m)**	**(G –Ga)^2 (^{O}C/100m)**
Bulte-1	3.7	3.65	0.05	0.0025
Kasade-1	4.0	3.65	-0.25	-0.0625
Herwa-1	3.4	3.65	-0.15	-0.0225
Kadaru-1	3.5	3.65	0.35	0.1225
				$\sum$ (G – Ga)^2 =0.04

$$S = \sqrt{0}.04/4$$

$$= 0.01^{O}C/100m$$

3.3 Geotemperature Analysis

The results of temperatures at various depths where shale was deposited calculated from equation 4 are recorded in Tables 5a, b, c and d. Table 6 is the display of the depth – temperature relationship of shale deposits from the wells in the Seloken Field that is expressed as a graph in Figure 6 below.

Table 5 (a, b, c, d): Temperature of the shale units at various depths in the wells

a: Bulte-1 Well		
Shale Unit (Sh)	**Depth (m)**	**Temp. (°C)**
	0	27
1	108	30.9
2	450	43.65
3	900	60.30
4	1100	67.7
5	1300	75.1

b: Kasade-1 Well		
Shale Unit (Sh)	**Depth (m)**	**Temp. (°C)**
	0	27
1	108	39
2	450	49.8
3	900	67.4
4	1100	79.8
5	1300	91.44

c: Herwa-1 Well		
Shale Unit (sh)	**Depth (m)**	**Temp. (°C)**
	0	27
1	500	57.9
2	2000	95
3	3250	137.5
4	4000	163
5	4214	187.28

d: Kadaru-1 Well

Shale Unit (Sh)	**Depth (m)**	**Temp. (ºC)**
	0	27
1	2800	125
2	3500	149.5
3	4100	170.5
4	45oo	184.5
5	5013	202.45

Table 6: Display of Depth against temperature of shale units in the wells

Depth (m)	**Bulte-1 Well**	**Kasade-1 Well**	**Herwa-1 Well**	**Kadaru-1 Well**
0	27	27	27	27
450	43.65	49.8		
900	60.3	67.4		
1100	67.7	79.8		
1300	75.1	91.44		
2000				95
2800			125	
3250				137.5
3500			149.5	
4100			170.5	
4214				187.28
4500			184.5	
5013			202.45	

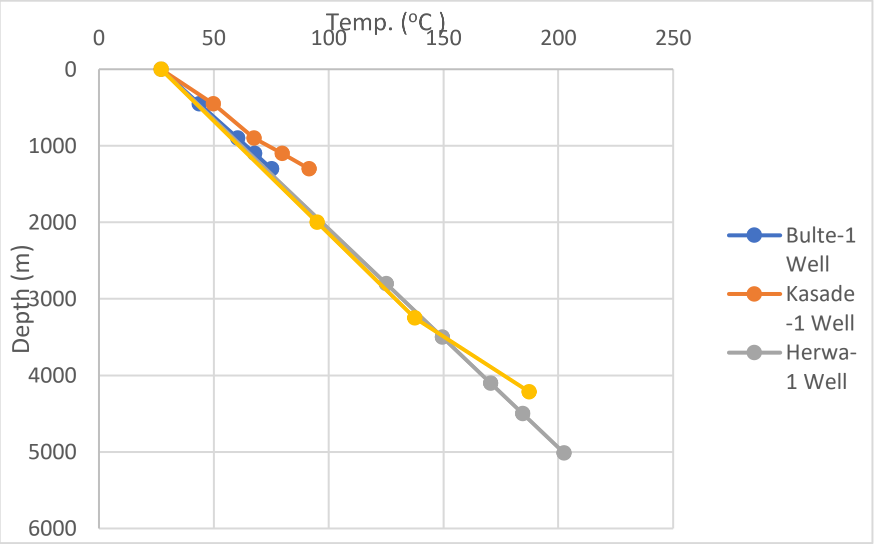

Fig. 6: Graph of Depth against Temperatures of shale units in the Wells

3.4 Hydrocarbon Windows Determination

The hydrocarbon generative windows of the field were determined with equation 5 and the model generated is shown in Figure 7

From equation 5,

$$d = (60^{\circ}C - 27^{\circ}C)/(3.65^{\circ}C/100m)$$

$$= 1178.1m \text{ (oil ceiling)}$$

$$d = (120^{\circ}C - 27^{\circ}C)/(3.65^{\circ}C/100m)$$

$$= 2547.9m \text{ (oil floor/gas ceiling)}$$

$$d = (225^{\circ}C - 27^{\circ}C)/(3.65^{\circ}C/100m)$$

$$= 5424.7m \text{ (gas floor)}$$

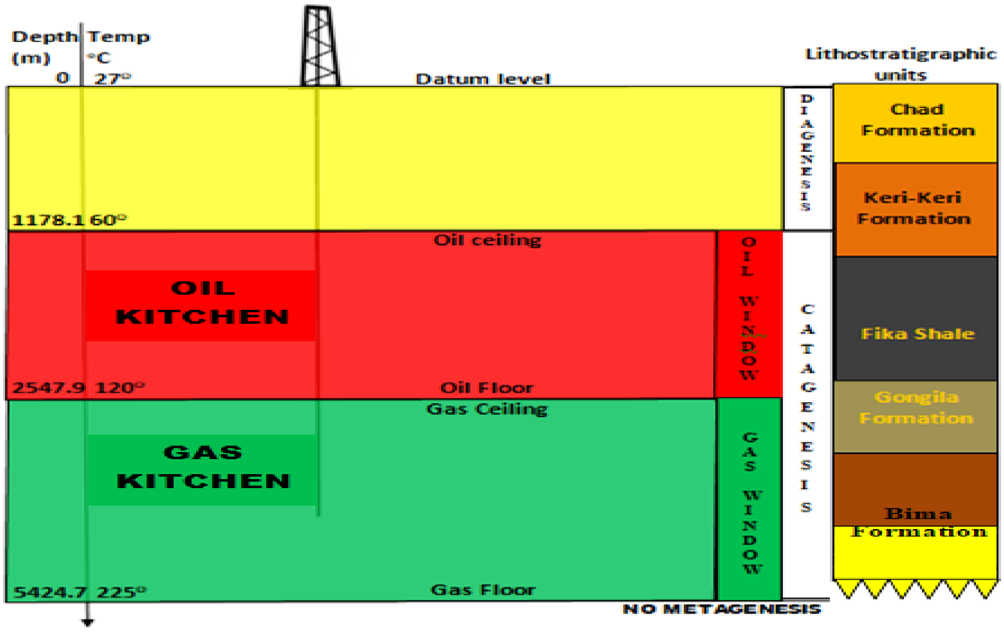

Fig. 7. Geomathematical model showing Hydrocarbon generative windows in Seloken Field.

DISCUSSION

4.1 Lithostratigraphic Interpretation

The four wells (Bulte-1, Kasade-1, Herwa-1 and Kadaru-1) drilled in the Seloken Field as interpreted from the gamma- ray logs and formations top penetrated the Chad and Kerri-Kerri Formations, the Fika Shale, the Gongila and Upper Bima Formations (Figs. 4). Figure 5 shows the various lithologies associated with the lithostratigraphic units.

The Upper Bima Formation comprises sandy shale with sandstone and mudstone intercalations; and it has a thickness of about 158m in the Bulte-1 well, 27m in the Kasade-1 well, 852m in the Herwa-1 well and 1612m in the Kadaru-1 well. None of the wells penetrated the lower Bima Formation which is characterized by poorly sorted, fossilized, medium-coarse sandstone according to Obaje et al. (2006), Omosanya et al. (2011), and Nwankwo et al. (2012). The Gongila Formation comprises shale and sandstone heteroliths and has a thickness of about 95m in the Bulte-1 well, 260m in the Kasade-1 well, 1060m in the Herwa-1 well and 580m in the Kadaru-1 well. The Fika Shale is made up of mainly hemipelagic shale and it has a thickness of about 300m in the Bulte-1 well, 250m in the Kasade-1 well, 370m in the Herwa-1 well, and is absent in the Kadaru-1 well. The Kerri-Kerri Formation comprises coarse-grained sandstone and shaly sandstone, and has a thickness of about 440m in the Bulte-1 well, 370m in the Kasade-1 well, 960m in the Herwa-1 well and is absent in the Kadaru-1 well. The Chad Formation is made up of sandy shale and coarse-grained sandstone lithologies and it has a thickness of about 155m in the Bulte-1 well, 165m in the Kasade-1 well, 300m in the Herwa-1 well and 210m in the theKadaru-1 well.

4.2. Geothermal Gradient

Hydrocarbon generation in an area depends on the temperature or geothermal gradient of that area. In the Seloken field, the geothermal gradients in the Bulte-1, Kasade-1, Herwa-1, and Kadaru-1 wells calculated from equation 1 are 3.7^{o}C/100m, 4.0^{o}C/100m, 3.4^{o}C/100m and 3.5^{o}C/100m respectively. Figure 8 below shows the distribution of geothermal gradient from the Bulte-1 well (3.7^{o}C/100m), through the Kasade-1 well (4.0^{o}C/100m) and Herwa-1well (3.4^{o}C/100m) to the Kadaru-1 well (3.5^{o}C/100m).

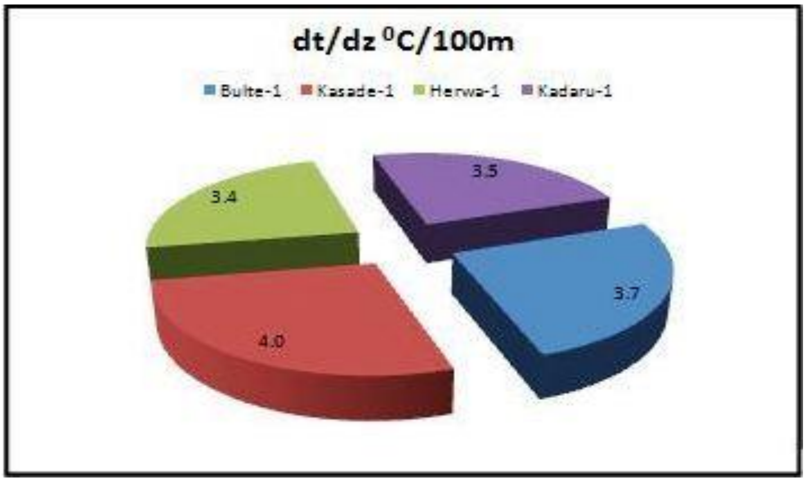

Fig.8. Pie Chart showing the various geothermal gradients across the four wells

The geothermal gradient varies from well to well. From the geothermal gradient contour map in Figure 9 below, it could be seen that the places with yellow to red have moderate to high geothermal gradient values, while the light green to purple regions represents low geothermal gradient regions. The Bulte-1 and Kasade-1 wells were both drilled in the southwestern part of the Seloken Field which coincides with the moderate to high geothermal gradient region; while the Herwa-1 and Kadaru-1 wells were drilled towards the northeastern part which coincides with the moderate geothermal gradient regions. However, this signifies that the source rocks within this field have been buried sufficiently to make them thermally mature. No well in the field was drilled in the low geothermal gradient region.

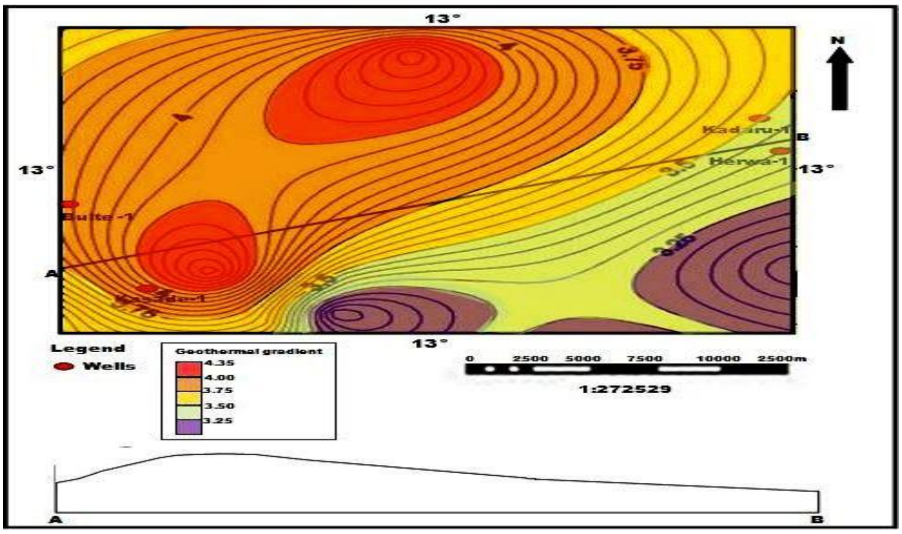

Fig. 9 Geothermal gradient contour map and cross-section across the Seloken Field.

The average geothermal gradient (**G_a**) in the Seloken Field as calculated from equation 2 is 3.65^{o}C/100m, while the standard deviation (S) calculated from equation 3 is 0.01^{o}C/100m. The small value of the standard deviation qualifies the average geothermal gradient value to represent the geothermal gradient of the field.

4.3 Geotemperature Analysis

The temperature values of shale units at various depths calculated from equation 4 range from 30.99^{o}C to 75.10^{o}C, 39.00^{o}C to 79.80^{o}C, 44.00^{o}C to 187.28^{o}C, and 125.00^{o}C to 202.45^{o}C in wells Bulte-1, Kasade-1, Herwa-1, Kadaru-1; respectively. Equation 4 is a linear function which expresses the temperature-depth relationship in Figures. 6. The analysis of the above results shows that the values of temperature operating on most shale units of the Bima and Gongila Formations and the Fika Shale are high enough to cook oil and gas. Sh-1 and Sh-2 of the Bulte-1 and Kasade-1 wells respectively and Sh-1 of the Herwa-1 well in the Seloken Field have temperatures slightly less than 60^{o}C. All other shale units in both wells have temperatures above 60^{o}C which are sufficient for thermal maturation.

4.4. Hydrocarbon Windows Determination

The depths at which both oil and gas begin and stop generating and the boundary between oil and gas windows were determined with equation 5. The results of the calculations from the above equation show that crude oil starts generating from about 1178.1m and ends at about 2547.9m (oil window). It also shows that the thermal gas generation occurs between about 2547.9m and 5424.7m (gas window). The floor of gas generation is located at 5424.7m which is beyond the depth of 5023m penetrated (Fig. 7).

Figure 7 is a hydrocarbon generative windows model, which indicates the various stages involved in hydrocarbon maturation (diagenesis, catagenesis, and metagenesis). In the Seloken field, diagenesis begins from some depth beneath the mean sea level to a temperature less than 60^{o}C (Selley, 1996) and depth less than 1178.1m. At this stage, bacterial action on organic matter forms biogenic gas. The Chad Formation and the greater part of the Kerri-Kerri Formation are within the diagenetic stage and so biogenic gas can be produced therefrom. Catagenesis takes place from 60^{o}C to 225^{o}C according to Selley (1996), and at the depth from 1178.1m to 5424.7m. Hence it occurs within the Bima and Gongila Formations, the Fika Shale and the Lower Kerri-Kerri Formation. These formations are thermally mature since they are within the hydrocarbon generative windows. The oil ceiling is at the lower part of the Kerri-Kerri Formation, while the oil floor is at the upper part of the Gongila Formation (Fig. 7). The Fika Shale lies at the mid-part of the oil window. The gas ceiling is found at the upper part of the Gongila Formation while the gas floor extends down beyond the depth investigated. The Upper Bima Formation lies in the mid-part of the gas window. Metagenesis is the last stage and extends beyond 225^{o}C (Selley, 1996) and 5424.7m. Metagenesis was not observed in the Seloken field as Figure 7 shows.

CONCLUSION

The study aims at interpreting the lithostratigraphic units, re-assessing their source rock thermal maturity with geomathematics and develop hydrocarbon windows model for Chad Basin in the Seloken field. The results obtained show that five lithostratigraphic units with their associated lithologies were interpreted from the combination of gamma-ray logs, formation tops and literature. They also show that diagenesis occurs within the Chad Formation and the greater part of Kerri-Kerri Formation, while catagenesis occurs within the Bima and Gongila Formations, the Fika Shale and the Lower Kerri-Kerri Formation. The study also indicates that the Upper Gongila Formation, the Fika Shale, and the Lower Kerri-Kerri Formation are within the oil kitchen while the Bima and Lower Gongila Formations are within the gas kitchen

This study has provided mathematical methods of source rock evaluation which are faster and cheaper than petroleum geochemical methods used by the other researchers to achieve similar results. The methods constitute important tools for the evaluation of hydrocarbon generative potentials prevalent in frontier and even mature petroliferous basins especially in situations which no geochemical information was provided.

Although this study indicates the presence of source rock that generates oil and gas, it does not elucidate the reasons for the unsuccessful petroleum exploration campaign in the Nigeria's section of the Chad Basin.

Furtherto this, 3-D seismic data are required to carry out a comprehensive structural interpretation, migrational potential and fault-seal analyses to ascertain what happens to the petroleum that generates in the area.

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