Research Journal of Applied Sciences, Engineering and Technology 12(10): 1031-1043, 2016
DOI:10.19026/rjaset.12.2823
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: August 21, 2015 Accepted: September 11, 2015 Published: May 15, 2016

Research Article

Geochemical Characterization of Source Rock and Modeling of Hydrocarbon Generation of the Cretaceous Fika and Gongila Formation in the Chad Basin, North Eastern Nigeria

[1]A. Mijinyawa, [1]M.S. Ismail and [2]A. Moumouni
[1]Department of Petroleum Geosciences, Universiti Technologi PETRONAS, Bandar Seri Iskandar, Tronoh Perak, Malaysia
[2]Department of Geology, University of Maradi, Niger Republic

Abstract: The Nigerian Sector of the Chad Basin has been the major focus for hydrocarbon exploration due to the recent hydrocarbon discoveries in the adjacent blocks in Chad and Niger Republic in the Chad Basin. But so far no success could be achieved, the hydrocarbon potentials and petroleum system of the study area is not fully understood. In this study, organic geochemical analysis of samples from Fika and Gongila formation in Faltu-1 and Herwa-1 well have been carried out and the results were integrated into basin modeling in order to have a better understanding into the thermal and burial history and timing of hydrocarbon generation. The TOC for the studied samples show a low to moderate values of 0.25-1.72wt.% and moderate to good from 0.4-4.46wt.% in Faltu-1 and Herwa-1 well respectively, hydrocarbon potentials (S1+S2) are negligible in almost all the samples, but some good intervals are seen with values (2.45, 2.99, 3.62 and 6.61) mg/g. The HI values are within the range of 50-150 mgHC/gTOC which indicate the kerogen as mainly type III. The Vitrinite reflectance values VRr ranges from 0.63-1.15%VRr, suggesting that the studied samples are within the oil window which is in agreement with the pyrolysis T_{max} values which ranges from 284-438°C. The modeling results suggest that the thermal and burial history of the studied wells have attained the hydrocarbon generation stage. In Herwa-1 well, the oil window fall within Fika and upper part of Gongila Formation in the early Cretaceous and Gas window in the lower part of Gongila and Bima Formation in the Late Cretaceous. However, in Faltu-1 well the Cretaceous sediments are seen within the oil window in Fika, Gongila and Bima, but the upper part of the Fika formation are within the immature stage while the lower part of Bima formation fall within the Gas window in the Late Cretaceous. This modeling result is in agreement with the organic geochemical analysis of the studied wells.

Keywords: Basin modeling, chad basin, hydrocarbon generation, source rock characterization

INTRODUCTION

Chad Basin encompasses five countries in Central West Africa which include Nigeria, Chad Republic, Niger Republic, Central African Republic and Cameroon (Fig. 1) (Obaje *et al*., 2006). The southwestern sector of the Chad Basin locally known as the Bornu Basin (Nigeria), which is one-tenth of the total Chad Basin, joins the northeastern-most sector of a SSW-NNE stretch of the Benue Trough. The Nigerian Sector of the Chad Basin, the Benue Trough, the Mid-Niger (Bida) Basin, and the Sokoto Basin made up of Nigeria's set of inland basins. These inland basins make up another set of a series of mid Cretaceous and younger rift basins in Central and West Africa whose origin is related to the opening of the South Atlantic (Genik, 1992).

Hydrocarbon accumulations have been discovered in Niger and Chad Republics in Chad Basin. Major discoveries are also seen in nearby Muglad Basin in Sudan Republic such as Unity 1 and 2, Kaigang, Heglig, etc. (Mohamed *et al*., 1999). In SW Chad, about 1 billion barrel has been discovered in the Doba Basin. The source rocks and reservoirs of the Muglad Basin in which hydrocarbon have been discovered are located in the Aptian-Albian-Cenomanian deposits of the Bentiu and Abu Gabra Formations, respectively (Obaje *et al*., 2006). These are similar and comparable with the Bima Sandstone in the Nigerian own portion of the Chad Basin. In the Niger Republic sector of the Chad Basin, oil and gas have also been encountered in Mesozoic-Cenozoic sequences in the East Niger Graben (Obaje *et al*., 2004).

The Nigerian National Petroleum Corporation (NNPC) through the National Petroleum Investments Management Services (NAPIMS) has drilled about 23 wells within its own portion of the Chad Basin, but so

Corresponding Author: A. Mijinyawa, Department of Petroleum Geosciences, Universiti Technologi PETRONAS, Bandar Seri Iskandar, Tronoh Perak, Malaysia

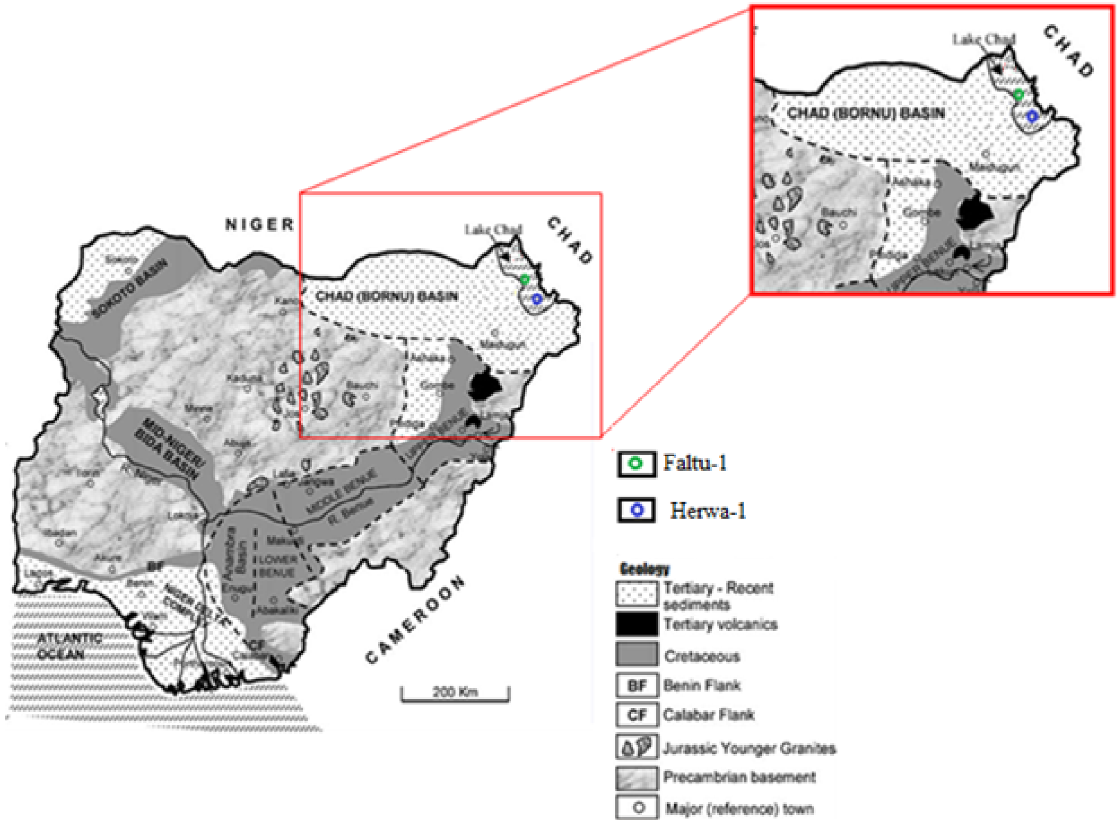

Fig. 1: Geological map of Nigeria showing location of the drilled wells in the Chad Basin Noth Eastern Nigerian (Obaje *et al*., 2006)

far no success could be achieved. The lack of knowledge of the subsurface geology and the petroleum system might have been the cause for the unsuccessful results.

Various studies had been carried out by previous workers on the source potentials of the Chad Basin North Eastern Nigerian (Obaje *et al*., 2004, 2006; Obaje, 2009; Ola-Buraimo, 2013; Ola-Buraimo and Boboye, 2011; Olugbemiro and Ligouis, 1999; Olugbemiro *et al*., 1997; Petters and Ekweozor, 1982). Results indicate gas prone nature of the source rock in the basin.

However, many researchers have suggested Fika and Gongila Formation as the potential source and reservoir rocks respectively, though most of these studies were carried out focusing mainly on the Pyrolysis techniques without integration of both geochemical and geophysical data. Espitalie *et al*. (1977) reported that pyrolysis methods have limitations on organically lean sediments, for having tendency of been affected by Mineral matrix.

This study focuses on the evaluation of the possible source rocks within Fika and Gongila Formations in the Nigerian Sector of the Chad Basin and integration of the geochemical data into Basin Modeling, in order to have insights into the Thermal and burial history and timing of hydrocarbon generation.

Geological settings and stratigraphy: The Chad Basin is part of the African Phanerozoic sedimentary basins evolved during the active plate divergence, although prominent exceptions to this suggestion have been proposed, which include its development as part of the deformed basin sequences in the Paleozoic fold belts of Mauritania and Morocco as a result of the Hercynian convergent motion and collision of Africa and South American plates in the Cretaceous (Fairhead and Binks, 1991). Also it has been suggested that the Chad basin is a member Western Central Africa Rift system (WCAS) that was developed as a result of the mechanical break up of African crustal blocks during Cretaceous (Genik, 1992). This has been proven in several studies on the evolution and Stratigraphy of the Chad Basin North Eastern Nigerian. For example (Genik, 1992) created a tectonic model of the Chad Basin, comprising of major intrabasin basement lineaments and faults formed during Pan African crustal consolidation. These structures developed precursor markers of direction for potential rift basins such as the major NE- SW trending fault system of the Chad Basin (Avbovbo *et al*., 1986; Benkhelil, 1989).

The predominant features of the basin include basement faults. Movement within these faults trigger higher angled faults in overlaying strata. Other secondary structural features such as horst, graben and

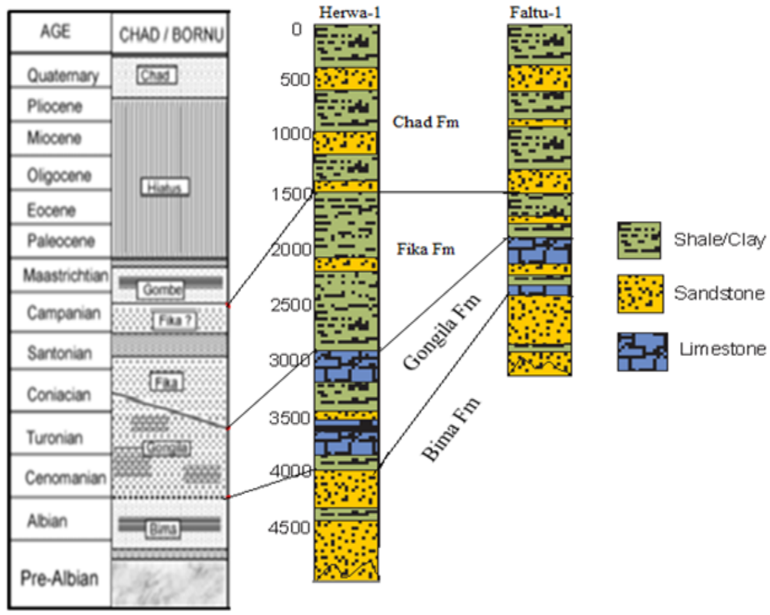

Fig. 2: Stratigraphy and Lithostratigraphic correlation of Herwa-1 and Faltu-1 well

similar structures are derived from these basement-involved faults (Avbovbo *et al*., 1986). The tectonic regime during the Chad basin evolution was possibly dominated through tensional motion as being shown by the dominance of higher-angled normal faults as well as the absence of the reverse faults. The intra-basinal faults were found to end beneath the cretaceous-Tertiary unconformity boundary. On the other side, folds within the basin are either plain or symmetrically inclined having low fold amplitude and frequencies that increase towards the basin center. They have been spatially restricted within the southern portion of the basin (Avbovbo *et al*., 1986). The various faults of the fault systems transgress the folds. The axes of the fold expand over considerable distance and with no effective strike closures in majority of cases. The main fold axes strike trends in direction of the NW-SW. These folds are possibly flexural folds which are formed through graben subsidence within the basement. The syncline and anticline outcropping within Dumbulwa and Mutwe trend in NW-SE direction, which constitutes the major folds in the basin (Okosun, 1995).

The Chad Basin development commenced in the early rift stage through the movement of the strike-slip fault formed from the breakup of the Africa and South American plates (Benkhelil, 1989; Fairhead and Binks, 1991). About 130 ma, during the early Cretaceous, lateral movement in accordance with other crustal blocks led to the transtensional opening up Benue trough as well as the Nigerian sector of the Chad basin (Obaje, 2009). The epicontinental transgressions that came from South Atlantic and Tethys through Algeria and Nigeria into the basin were related to the sea level rising onto Tethys during the late rift stage (Obaje, 2009). During these stages, major grabens were developed and sedimentation began.

The Stratigraphic sequence of the Chad Basin North Eastern Nigerian (Fig. 2) began with the deposition of Bima sandstone which rests unconformably on top of the Precambrian basement during Albian. It consists of sandstones and intercalations of shale. The Bima Sandstone is overlain by the Gongila Formation, which is made up of sandstones and calcareous shale laid down in a shallow-marine condition. The buildup of this particular formation is considered to indicate the beginning of the marine incursion within the Chad basin during the Turonian (Obaje *et al*., 2004; Olugbemiro *et al*., 1997). The Fika (Shale) Formation overlies the Gongila Formation and it was deposited at the time of the sustained marine transgression during the Turonian-Coniacian. During Maastrichtian, the Gombe Sandstone was laid down over the Fika Formation in estuarine/deltaic environment. It consists of intercalation of shale, siltstones and claystones, although without having the coal seams mentioned from the upper Benue trough (Obaje *et al*., 1999, 2004). The Tertiary phase has been described for the buildup of the Keri-Keri Formation outside the Bornu basin. Thus, the top most Pliocene – Pleistocene period Chad Formation is situated unconformably over the Gombe Sandstone (Wright *et al*., 1985).

SAMPLES AND METHODS

Total of 21 samples of the Late Cretaceous Fika and Gongila formation from the Nigerian sector of the Chad Basin were collected from Faltu-1 and Herwa-1

Table 1: Bulk geochemical data for Rock-Eval/TOC in Herwa-1 and Faltu-1 well with calculated parameters and their derivatives HI, OI and PI

				Rock-Eval Pyrolysis								
Sample ID	Depth(m)	Formation	TOC (wt. %)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	S1+S2 (mg/g)	PC (mg/g)	T_{max} (^oC)	HI	OI	PI
Herwa-1												
HW- 2650	2650	Fika	4.46	1.09	5.52	1.07	6.61	0.55	427	124	24	0.2
HW- 2750	2750	Fika	1.07	0.07	0.71	0.94	0.78	0.06	428	66	88	0.1
HW- 2800	2800	Fika	1.43	0.11	1.08	0.93	1.19	0.10	428	76	65	0.1
HW- 2900	2900	Fika	1.37	0.19	1.22	0.78	1.41	0.12	425	89	57	0.1
HW- 3050	3050	Fika	1.33	0.12	0.67	0.86	0.79	0.07	405	50	65	0.2
HW- 3100	3100	Fika	3.13	0.23	2.76	1.80	2.99	0.25	428	88	58	0.1
HW- 3300	3300	Gongila	2.51	0.23	1.75	2.32	1.98	0.16	425	70	92	0.1
HW-3500	3500	Gongila	0.96	0.34	1.42	2.36	1.76	0.15	435	148	246	0.2
HW- 3550	3550	Gongila	0.41	0.16	0.31	0.54	0.47	0.04	284	76	132	0.3
HW- 3850	3850	Gongila	0.90	0.16	0.53	0.43	0.69	0.06	410	59	48	0.2
HW- 3900	3900	Gongila	3.23	0.95	2.67	1.07	3.62	0.30	431	83	33	0.3
Faltu-1												
Fa- 1510	1510	Fika	1.72	0.04	2.41	0.93	2.45	0.20	427	140	54	0.0
Fa- 1540	1540	Fika	0.82	0.01	0.2	0.65	0.21	0.02	421	24	79	0.0
Fa- 1600	1600	Fika	1.06	0.01	0.32	0.77	0.33	0.03	424	30	73	0.0
Fa- 1640	1640	Fika	0.95	0.01	0.25	0.68	0.26	0.02	424	26	72	0.0
Fa- 1720	1720	Fika	0.94	0.01	0.23	0.57	0.24	0.02	428	24	61	0.0
Fa- 1880	1880	Gongila	0.51	0.01	0.07	0.26	0.08	0.01	441	14	51	0.1
Fa- 1900	1900	Gongila	0.25	0.01	0.05	0.25	0.06	0.00	438	20	100	0.2
Fa- 1920	1920	Gongila	1.07	0.01	0.02	0.44	0.03	0.00	421	2	41	0.3
Fa- 1960	1960	Gongila	0.55	0.01	0.03	0.43	0.04	0.00	427	5	78	0.3
Fa- 2000	2000	Gongila	0.76	0.01	0.13	0.42	0.14	0.01	428	17	55	0.1

TOC: Total organic carbon, wt. %, HI: Hydrogen Index= S_2*100/TOC mgHC/gTOC, OI: Oxygen Index = S_3*100/TOC, mgCO_2/g rock, PI: Production Index = $S_1/(S_1+S_2)$, S1: Volatile Hydrocarbon content mgHC/g rock, S2: Remaining Hydrocarbon generative potential mgCO_2/g rock, S_3: Content of Carbon dioxide, mgCO2/g rock

well respectively, which are located in the North Eastern Nigeria towards Lake Chad (Fig. 1).

Analytical methods: The 21 samples collected from Fika and Gongila formation were subjected to organic geochemical analysis, for the determination of total organic carbon by the use of LECO CS125 carbon analyzer, and the Rock-Eval pyrolysis (RE) was determined using Rock-Eval 6 Pyrolyser. The measured parameters includes, the Total Organic Carbon (TOC), the free hydrocarbon in the sample (S_1), the amount of hydrocarbon generated through the thermal cracking of non-volatile organic matter (S_2), the amount of carbon dioxide (CO_2) produced during pyrolysis (S_3), the temperature at the S_2 peak (Tmax) and the derivatives Hydrogen Index (HI = [100×S2]/TOC) and Oxygen Index (OI = [100×S3]/TOC). The above mentioned parameters were measured and calculated as described by Espitalie *et al*. (1977).

Vitrinite reflectance: Vitrinite Reflectance (VRr) is a coal Maceral group, which are usually used for reflectance measurement. The VRr is a reliable parameter which is used in calibrating thermal history of sedimentary basins in basin modeling.

After the pyrolysis techniques about 8 samples were selected for Vitrinite reflectance measurement, the analysis were carried out on a polished samples using a Zeiss Standard Universal reflected microscope equipped with suitable oil immersion objective at a magnification of about 500x measurements were done at 546 nm (wavelength) on clear sports of the Vitrinite particle size approximately equal to or greater than 10μm before each series of measurements. The microscope set up was calibrated with standard glass of known Vitrinite reflectance within the range to be measured. The reflectance values were therefore read off directly from the digital read out (Table 1).

Modeling methods: Basin modeling principles were published by Belaid *et al*. (2010), Waples (1985), Welte and Yukler (1981), Mijinyawa *et al*. (2013), Ben-Awuah *et al*. (2013, 2014). Basin modeling is used widely to understand the thermal and burial history of a basin.

In this study, Petromod 1D software was used to reconstruct the thermal and burial history and to determine the timing of hydrocarbon generation in Faltu-1 and Herwa-1 well respectively based on Yalcin *et al*. (1997).

The Stratigraphic succession of the Chad Basin North Eastern Nigerian gives information of Lithology, non-deposition, deposition, erosion, thickness and depths (Table 2 and 3) from which the model is built. The geochemical input data for the model were assigned, which include the Total Organic Carbon (TOC), Petroleum system elements and the Kinetics (Table 2 and 3).

Table 2: Vitrinite reflectance values for the studied samples in Faltu-1 and Herwa-1 well

Wells	Formation	Depth(m)	Vitrinite reflectance (%VRr)	SD	N
Herwa-1	Fika	2800	1.13	0.05	11
	Fika	3100	1.15	0.11	13
	Gongila	3300	1.15	0.10	28
Faltu-1	Fika	1510	0.63	0.09	30
	Fika	1640	0.67	0.13	11
	Fika	1720	0.75	0.06	12
	Gongila	1880	0.76	0.12	27
	Gongila	1920	0.89	0.10	13

Standard Deviation = SD; Mean random Vitrinite reflectance = VRr%; Quantity of measurement = N

Table 3: Input data for 1D model reconstruction in Herwa-1 well

Layer	Top (m)	Base (m)	Thick (m)	Eroded (m)	Depo from (ma)	Depo to (ma)	Eroded from	Eroded to
Chad-1	0	500	500		5.3	0		
Chad-2	500	1500	1000	800	75	45	45	5.3
Fika-1	1500	2200	700		84	75		
Fika-2	2200	2900	700	200	89.3	84	85	84
Gongila-1	2900	3400	500		93.5	89.3		
Gongila-2	3400	3800	400		99.6	89.3		
Bima-1	3800	4200	400		112	99.6		
Bima-2	4200	4650	450		125	112		
						125		

Layer	Lithology	PSE	TOC	Kinetic	HI mgHC/gTOC
Chad-1	(A)	Overburden rock			
Chad-2	(A)	Overburden rock			
Fika-1	(B)	Source rock	0.5	Burnham	50
Fika-2	(B)	Seal		(1989)_TIII	
Gongila-1	(C)	Reservoir			
Gongila-2	(C)	Source rock	0.5	Burnham	50
Bima-1	(D)	Under burden rock		(1989)_TIII	
Bima-2	(D)	Under burden rock			

Boundary conditions such as the Paleowater depth (PWD), Sediment Water Interface Temperature (SWIT) were assigned. The heat flows were adjusted to reach the maturities that are indicated by the Vitrinite reflectance VRr and the present temperatures measured from the borehole. The Easy% kinetic model of Sweeney and Burnham (1990) was used.

EVALUATION OF SOURCE ROCK

Analysis of TOC/Rock Eval Pyrolysis: The Total Organic Carbon (TOC) for the studied samples show a low to moderate values of 0.25-1.72wt% and moderate to good ranging from 0.41-4.46wt% in Faltu-1 and Herwa-1 well respectively (Table 3).

The analysis of Rock-Eval Pyrolysis (Table 3) show the measured free hydrocarbon in the sample (S_1), the amount of hydrocarbon generated through thermal cracking of kerogen (S_2), the amount of carbon dioxide CO_2 produce during pyrolysis (S_3) and the derivatives Hydrogen Index (HI), Oxygen Index (OI), Production Index (PI) and the temperature corresponding to the S_2 maxima Tmax (Espitalie *et al*., 1977).

The hydrocarbon potentials (S_1+S_2) is negligible in almost all the analyzed samples but some good intervals are seen with a value of (6.61, 3.62, and 2.99) mg/g at the depth of 2650m, 3900m and 3100 m in Herwa-1 well respectively, whereas only one interval is seen at the depth of 1510 m with a value of 2.45 mg/g in Faltu-1 well. The corresponding Tmax from both Faltu-1 and Herwa-1well are low, only few intervals are seen within the maturity limit at the depth of 3500 m, 3900 m, in Herwa-1 well and at the depth of 1900 m in Faltu-1 well. The production Index (PI) is within the production limit of 0.1 – 0.4 in Herwa-1 and the lower part of Faltu-1 well. Further, the Hydrogen Index (HI) falls below 150mgHC/g TOC in almost all the studied samples, which indicate the kerogen as mainly type III (Fig. 4).

Organic matter type: The type of organic matter in the studied samples from Faltu-1 and Herwa-1 well is illustrated in a modified Van krevelan diagram (Fig. 3). Where hydrogen index HI (S_2/TOC*100) is plotted against oxygen index OI (S_3/TOC*100) (Tissot and Welte, 1984). From this diagram, majority of the HI values plotted were low within the range of (59-148) mgHC/gTOC and (2-140) mgHC/gTOC in Herwa-1 and Faltu-1 well respectively (Table 3), which suggest these samples contain gas prone type III kerogen.

The Organic matter quality: The quality of Organic matter was determined by plotting HI against Tmax which is used to determine the maturity and Organic matter type (Fig. 4). The 0.5%-1.3% Ro maturity window is only approximate on this plot. From the plots it indicates all the samples fall within the type III kerogen, while majority of the samples are seen within the immature stage. However, about 4 samples from Herwa-1 and Faltu-1 well are seen within the oil window, which is in agreement with the Tmax values from the pyrolysis data (Table 3).

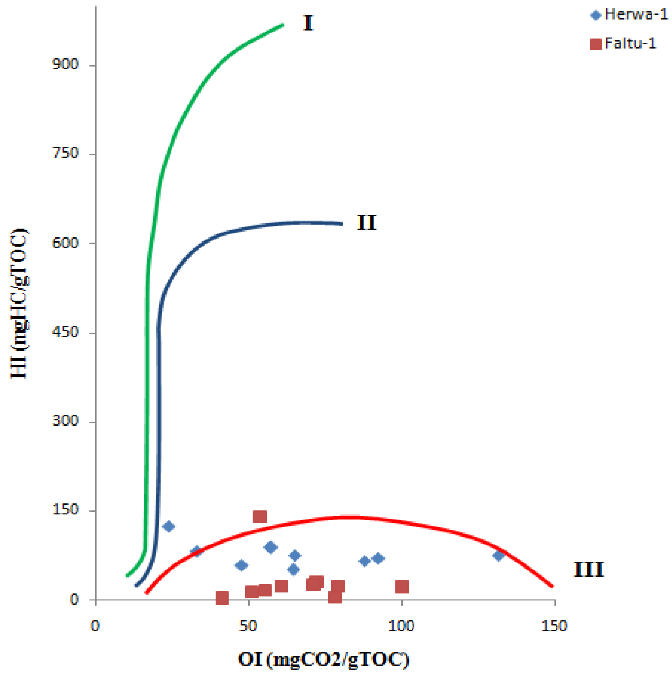

Fig. 3: Modified Van Krevelen diagram of studied samples from Faltu-1 and Herwa-1 well, showing maturation pathways of type I, II and III kerogen

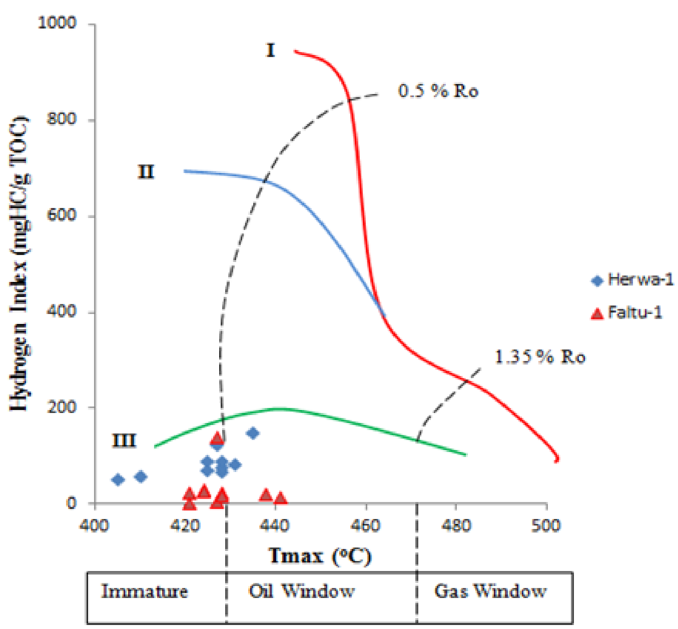

Fig. 4: Plot of Hydrogen Index (HI) versus Tmax for the studied samples showing the stage of thermal maturity and Kerogen quality

Maturity of organic matter: The maturity of organic matter in the studied samples was determined by use of pyrolysis Tmax (Table 3) and Vitrinite reflectance values VRr (Table 4). The oil and gas generation interval is classified as 0.6-1.35%VRr and 1.35-3.5% VRr for oil and gas window respectively (Espitalié *et al*., 1984). The analyzed samples in Fika and Gongila Formation from Herwa-1 and Faltu-1 well show Vitrinite reflectance values ranges from 0.63-1.15%VRr (Table 4). These values suggest that all the samples are within the oil window. The Tmax values are not consistent with the Vitrinite reflectance values from the pyrolysis data (Table 3), this inconsistency in the Tmax values might be due to presence of coke and droplets in the samples which came possibly from the drilling mud additives. Peters (1986) reported that other variations in the Tmax values may be due to unconformities, Faults, changes in geothermal gradient and contamination from migrated oil, otherwise the Tmax values increases with depth regularly.

This analysis is in line with the findings of Olugbemiro *et al*. (1997) who reported that lignite from mud additives and Bitumen might be responsible for the inconsistencies of the Tmax values in the Nigerian Sector of the Chad basin. Therefore, it is much reliable to use the Vitrinite reflectance data than the Tmax values in maturity assessment in the study area.

Hydrocarbon generation potentials: The interpretation of TOC/Rock-Eval pyrolysis from the studied samples indicates TOC values of 0.21-1.72 wt% and 0.41-4.46wt%, and the source rock potential S_2 show values less than 2 mg/g HC/g of rock in most of the samples, but however, few intervals are seen with higher values of (5.52, 2.76 and 2.67) mg/g at the depth of (2650, 3100 and 3900) meters in Herwa-1 well, respectively, whereas only one interval is seen in Faltu-1 well at the depth of 1510 m with a value of 2.41 mg/g.

The pyrolysis S_2 against the TOC content (Fig. 5), show a moderate to good in Herwa-1 and low to moderate in Faltu-1 well. But based on this interpretation, conclusion has not be drawn on whether hydrocarbon has been generated from these formations, but if any, it would be mainly gases, the low S_1 pyrolysis yield support this interpretation. Littke and Leythauser (1993) reported that low value of S_1 pyrolysis yield is noticed in coal samples which are mainly type III.

Table 4: Input data for 1D model reconstruction in Faltu-1 well

Layer	Top (m)	Base (m)	Thick (m)	Eroded (m)	Depo from (ma)	Depo to (ma)	Eroded from	Eroded to
Chad-1	0	500	500		5.3	0		
Chad-2	500	1500	1000	800	75	45	45	5.3
Fika-1	1500	1700	200		84	75		
Fika-2	1700	2000	300	200	89.3	84	85	84
Gongila-1	2000	2200	200		93.5	89.3		
Gongila-2	2200	2400	200		99.6	89.3		
Bima-1	2400	2800	400		112	99.6		
Bima-2	2800	3115	315		125	112		
						125		

Layer	Lithology	PSE	TOC	Kinetic	HI mgHC/gTOC
Chad-1	(A)	Overburden rock			
Chad-2	(A)	Overburden rock			
Fika-1	(B)	Source rock	0.5	Burnham	50
Fika-2	(B)	Seal		(1989)_TI	
Gongila-1	(C)	Reservoir		II	
Gongila-2	(C)	Source rock	0.5	Burnham	50
Bima-1	(D)	Under burden rock		(1989)_TI	
Bima-2	(D)	Under burden rock		II	

Chad -70% Sst+15%+15% Silt+15% Clay = (A); Fika-3% Sst+97% Shale = (B); Gongila–15% Sst+50% Shale+35% Limestone = (C); Bima-75% Sst+25% Shale = (D)

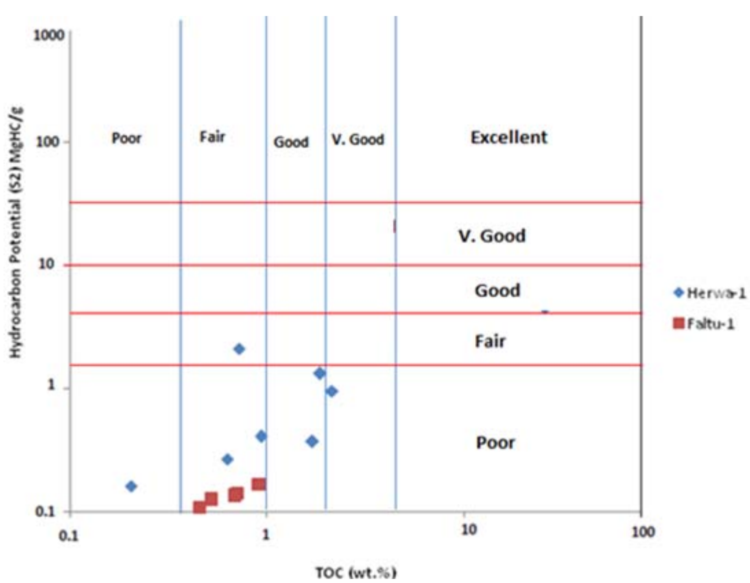

Fig. 5: Plot of Total Organic Carbon (TOC) versus S2 for the analyzed samples from Faltu-1 and Herwa-1 well, (Obaje *et al*., 2004)

Table 5: Maturity window and transformation ratio fraction (Adopted from Mahadir, 2004)

Maturity window	Transformation ratio (Fraction %)
Early maturity oil	10-25
Mid mature oil	25-65
Late mature oil	65-85
Main gas generation	85-100

NUMERICAL MODELING

Burial history model: From the burial history model, it is shown that the maximum burial occurred in mid Eocene with the deposition of the Bima Formation within the Nigerian Sector of the Chad Basin. The series of erosion and non-deposition have been deduced from Upper Cretaceous to Miocene, the Tertiary thickness at the point of maximum burial ranges between 1200-1500 m suggesting erosion might have been the cause of thinning of the Tertiary sediment at present time as shown in the Fig. 6.

Thermal history model: Heat flow controls the thermal history of a basin (Allen and Allen, 2013). These authors also suggested that in an active rift, the average heat flow is about 80 mW/m^2 and decreases to 50 mW/m^2 during the post rift stage.

In this model, the thermal history is calibrated using Vitrinite reflectance and Bottom Hole Temperature values from the Cretaceous sediments. Figure 7 and 8 show plots of Vitrinite reflectance and Bottom Hole Temperature values against depth of the Wells in Faltu-1 and Herwa-1 well respectively. A best fit curve was achieved between the measured and calculated lines of Vitrinite reflectance and Bottom Hole Temperature in the modeled wells. The heat flow values ranges from 64.9 mW/m^2 in the present day while the paleo heat flow was estimated to be 104 mW/m^2.

Timing of hydrocarbon generation: The thermal and burial history of the modeled wells was influenced by the tectonic evolution of the Nigerian Sector of the Chad basin. Therefore, an in-depth understanding of the thermal and burial history is important in predicting the timing of hydrocarbon generation and expulsion within the study area.

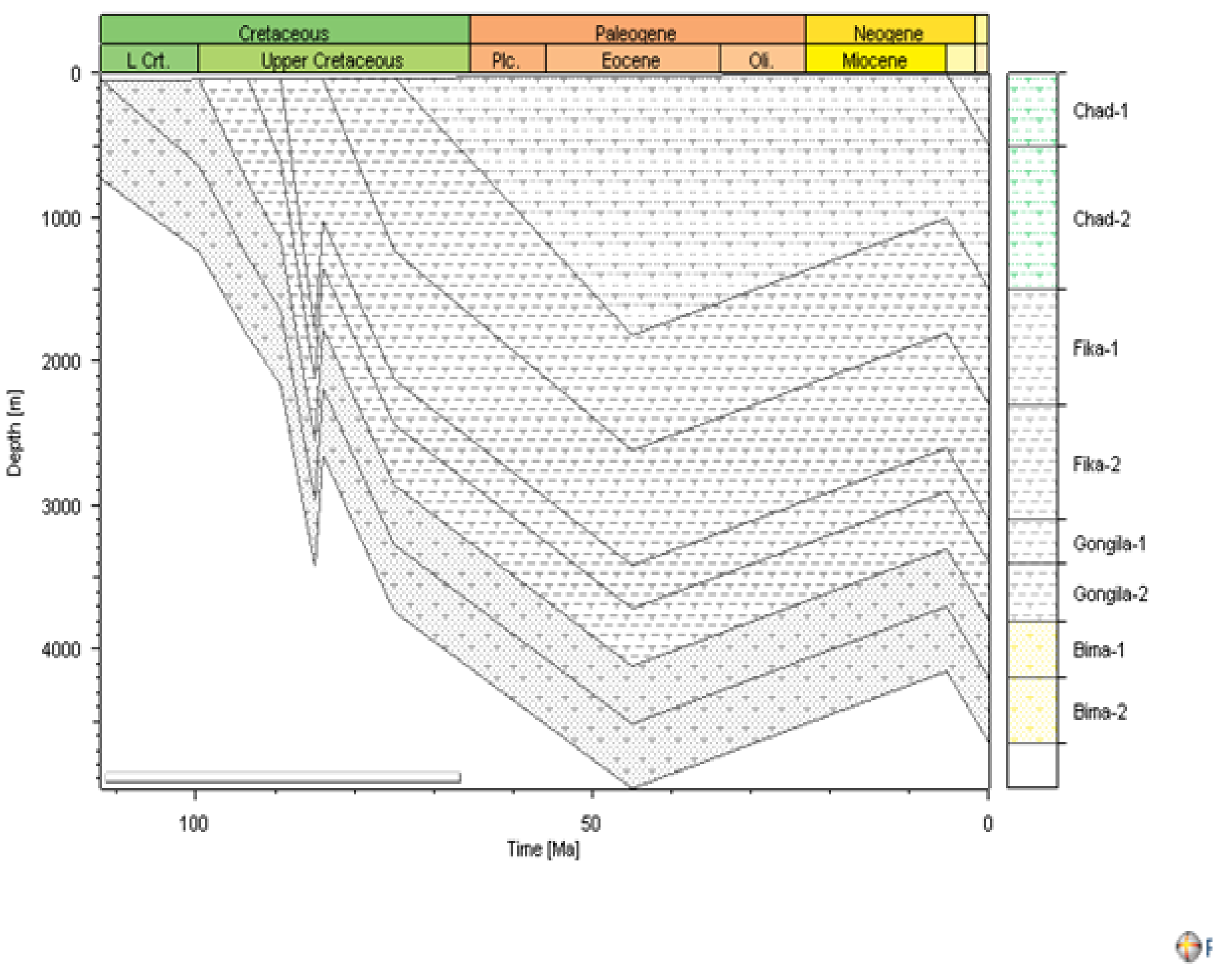

Fig. 6: Burial history plot in Herwa-1 well from the Nigerian sector of the Chad Basin

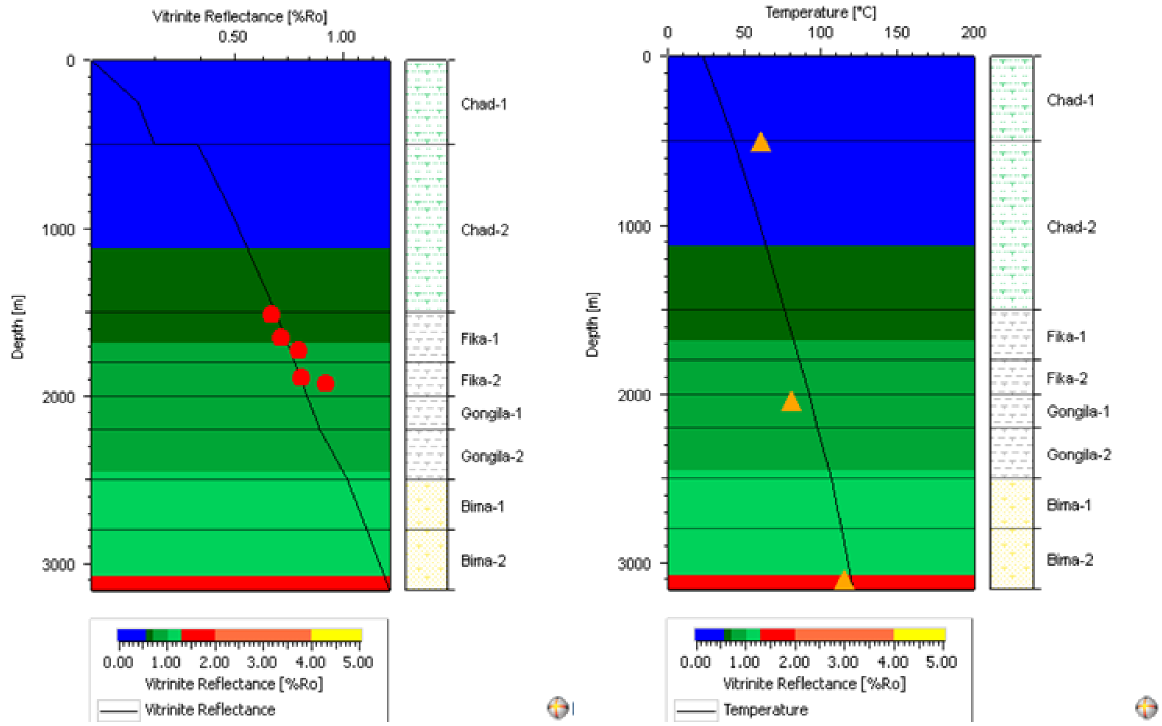

Fig. 7: Calibration between bottom hole temperature and Vitrinite reflectance in Faltu-1well

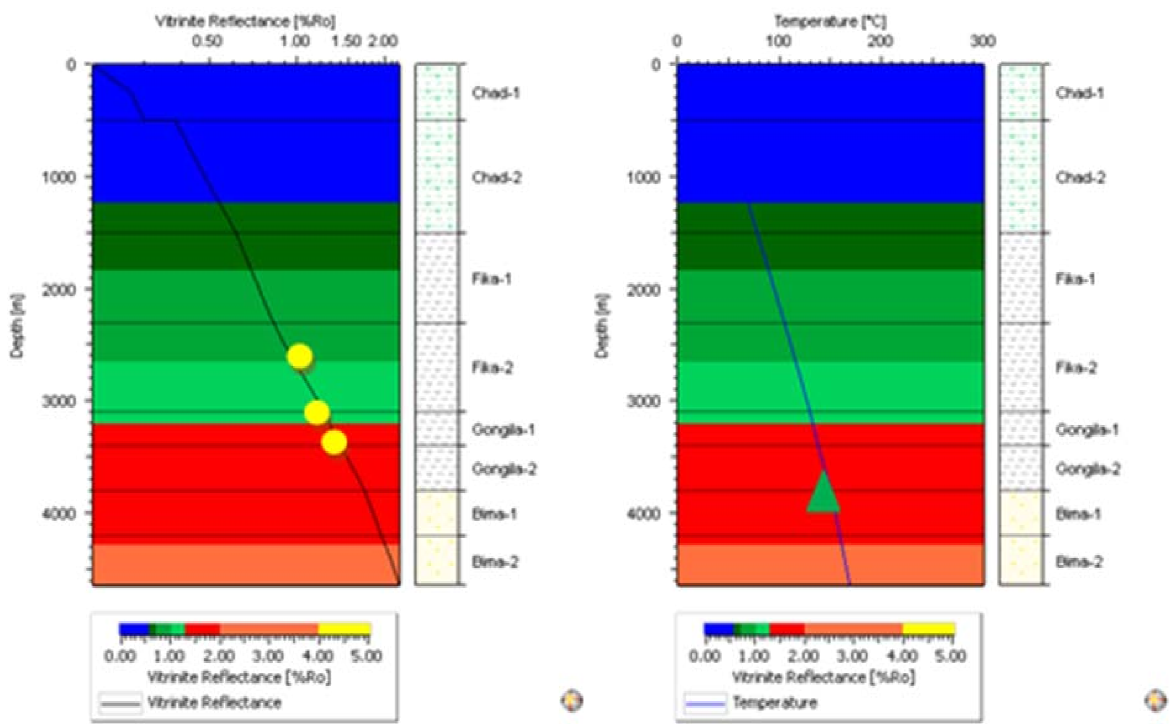

Fig. 8: Calibration between bottom hole temperature and Vitrinite reflectance in Herwa-1well

From the modeling results, the timing of hydrocarbon generation in Faltu-1 and Herwa-1 well is deduced from thermal and temperature of the basin, this hydrocarbon potential stages were determined using calibration of Vitrinite reflectance (Sweeney and Burnham, 1990). The hydrocarbon generation potentials of the modeled well are shown in Fig. 9 and 10. This models indicates that the early oil window stage began from 0.60-0.83 %Ro during the early Cretaceous at the depth of 1500-2000 m in Herwa-1

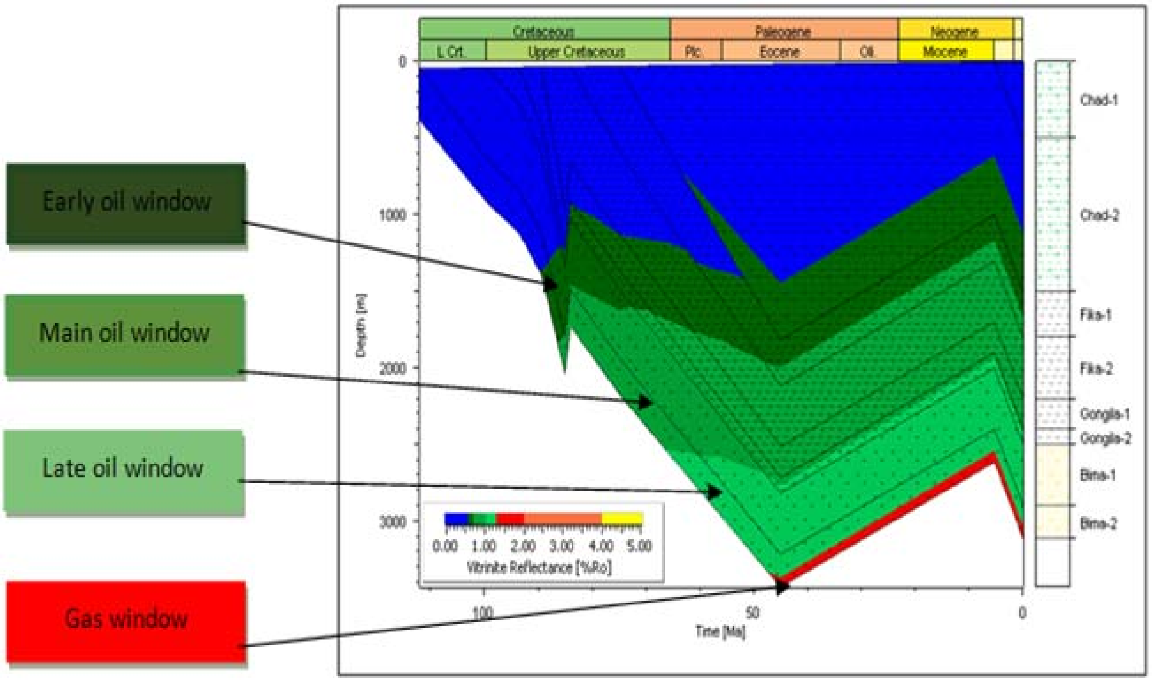

Fig. 9: Burial history curve and Vitrinite reflectance overlay in Faltu-1 well

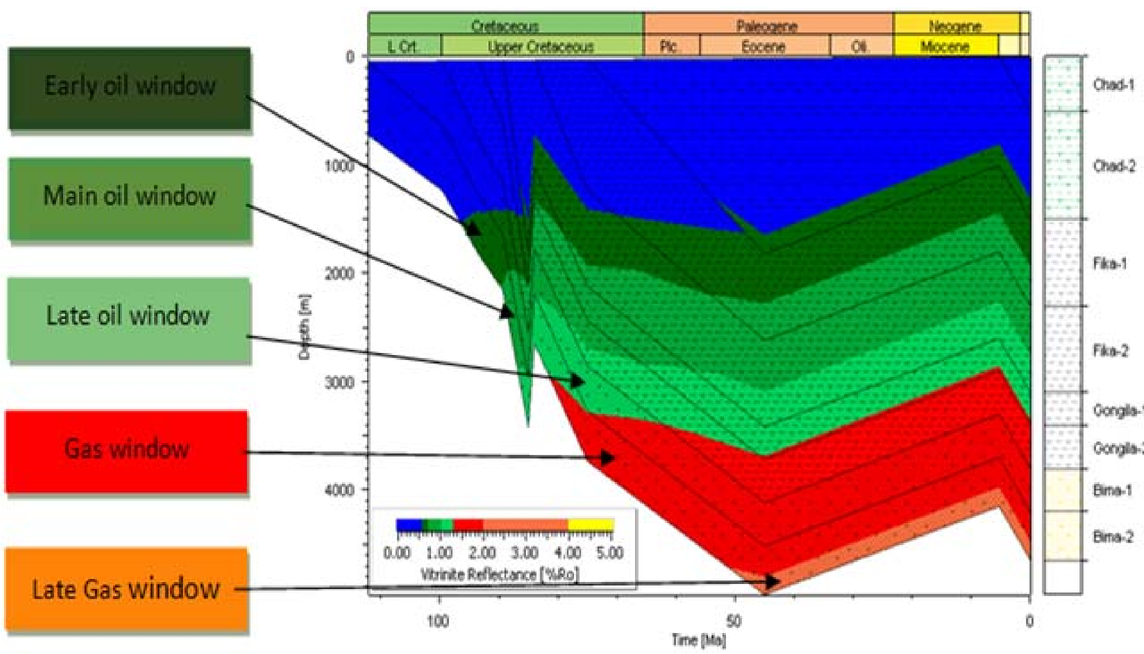

Fig. 10: Burial history curve and Vitrinite reflectance overlay in Herwa-1 well

well and 1500-1800 m in Faltu-1 well, the main oil window falls within the range of 0.83-1.00 % Ro at the depth of 1953-2309 m in Herwa-1 well and 1800-2200 m in Faltu-1 well, while the late oil window starts at the depth of 2309-2722 m and 2200-2900 m at the range of 1.00-1.27 % Ro in Herwa-1 and Faltu-1, respectively.

The gas window begins at the depth of 2751-4500 m and 2900-3115 m within the range of 1.29-1.96 % Ro in Faltu-1 and Herwa-1 well respectively, and the late gas window begins during the Tertiary with a value of 2.0-2.25 % Ro at the depth of 4200-4650 m in Herwa-1 well.

Based on the maturity model, the petroleum generation potential from Fika-1 and Herwa-1 well is estimated to be mainly gases. This interpretation is in agreement with the organic geochemical analysis of

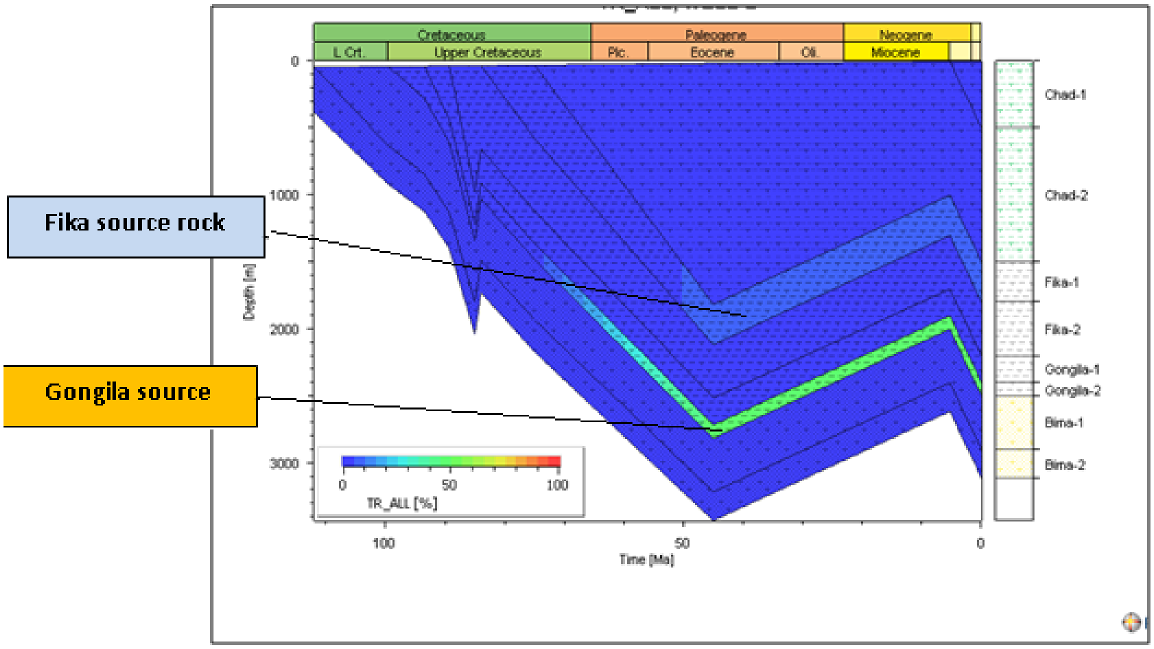

Fig. 11: Burial history with transformation ratio plot of Faltu-1 well

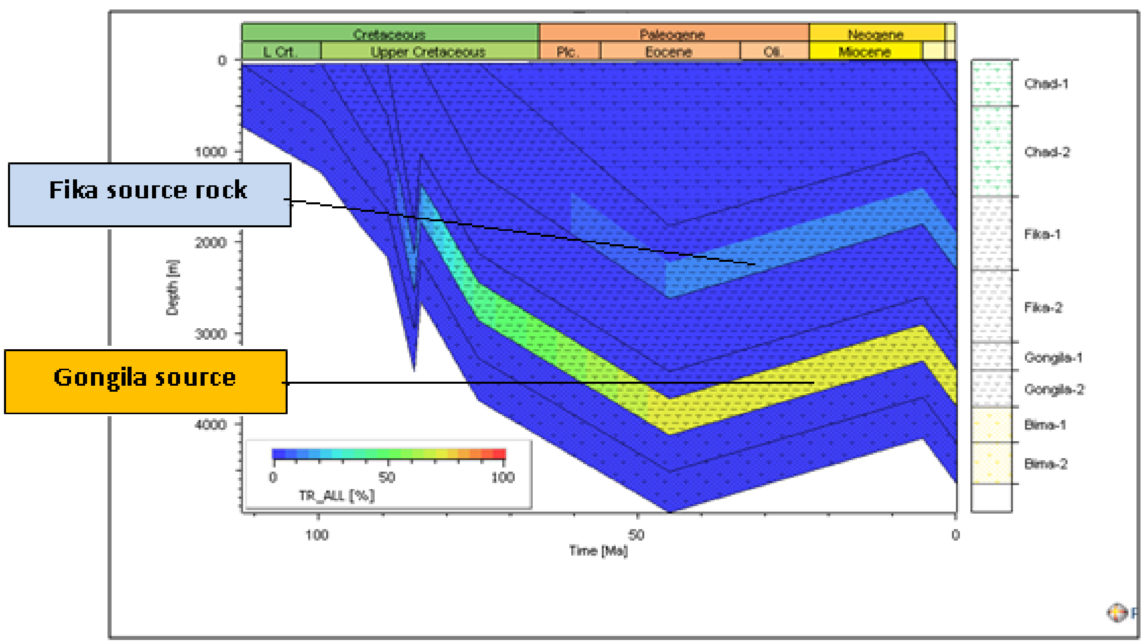

Fig. 12: Burial history with transformation ratio plot in Herwa-1 well

samples by Obaje *et al*. (2006) and Mijinyawa *et al*. (2013).

Transformation ratio: The maturation and hydrocarbon windows were also interpreted by adopting the transformation ratio defined by Mahadir (2004) as follows:

The plot of transformation ratio in Faltu-1 and Herwa-1 well is shown in Fig. 11 and 12 respectively. The source rock in Gongila Formation in Faltu-1 well entered the mid mature oil window with transformation ratio of 48.35% in the early Cretaceous to Miocene, while the Fika source rock has very low transformation ratio of 10.2% which falls within the early mature oil window.

In Herwa-1 well, the source rock in Gongila Formation entered the Late mature oil window from early Cretaceous to Miocene with transformation ratio value of 76.95%, while the source rock in Fika Formation fall within the early mature oil window with transformation ratio of 14.38% (Table 5).

CONCLUSION

The Fika and Gongila Formations are reported to be the potential source rock in the Chad Basin North Eastern Nigerian by several authors. Organic geochemical and petrological studies have been carried out on samples from Faltu-1 and Herwa-1 well. The results suggest that, the samples from Fika and Gongila Formation in this studied well contain type III kerogen which is mainly gases, with Hydrogen Index (HI) ranging from less than 50-150 mgHC/gTOC. The modeling results from the studied wells indicate that the Cretaceous sediments have entered mature to late matured stages which corroborate with the result of the measured Vitrinite reflectance. The oil window begins in the upper Cretaceous to Tertiary at the depth ranging from 1500-2900 m, whereas the gas window fall within the Tertiary in Faltu-1 well and in Cretaceous to Tertiary in Herwa-1 well at the depth of 2731-4650 m.

Even though the Cretaceous sediments from the studied wells have attained sufficient thermal and burial depth to generate hydrocarbon, 2-dimensional model is required to determine generation, migration and entrapment of hydrocarbon in the studied wells.

ACKNOWLEDGMENT

The authors are grateful to the University Technology PETRONAS for the financial support and the Frontier Exploration Services of the Nigerian National Petroleum Corporation (NNPC) for providing the data used in this study.

REFERENCES

Allen, P.A. and J.R. Allen, 2013. Basin Analysis: Principles and Application to Petroleum Play Assessment. Wiley-Blackwell, Chichester, West Susex, UK.

Avbovbo, A.A., E.O. Ayoola and G.A. Osahon, 1986. Depositional and structural styles in Chad basin of northeastern Nigeria. AAPG Bull., 70(12): 1787-1798.

Belaid, A., B.M. Krooss and R. Littke, 2010. Thermal history and source rock characterization of a paleozoic section in the Awbari trough, Murzuq basin, SW Libya. Mar. Petrol. Geol., 27(3): 612-632.

Ben-Awuah, J., G.W. Adda, A. Mijinyawa, A. Spariharijaona and N. Siddiqui, 2013. 2D basin modelling and petroleum system analysis of the Triassic play in the Hammerfest basin of the Norwegian Barents Sea. Res. J. Appl. Sci. Eng. Technol., 6(17): 3137-3150.

Ben-Awuah, J., S. Andriamiaja, A. Mijinyawa, A. Ali, N.A. Siddiqui and G.W. Adda, 2014. Effect of some input parameters on 3D basin and petroleum systems modelling: A case study of the Norwegian Section of the Northern North Sea. Res. J. Appl. Sci. Eng. Technol., 7(18): 3746-3762.

Benkhelil, J., 1989. The origin and evolution of the cretaceous Benue trough (Nigeria). J. Afr. Earth Sci. Middle East, 8(2-4): 251-282.

Espitalié, J., K. Senga-Makadi and J. Trichet, 1984. Role of the mineral matrix during kerogen pyrolysis. Organ. Geochem., 6: 365-382.

Espitalie, J., M. Madec, B. Tissot, J.J. Mennig and P. Leplat, 1977. Source rock characterization method for petroleum exploration. Proceeding of the 9th Offshore Technology Conference. OTS, Houston, Texas, pp: 439-442.

Fairhead, J.D. and R.M. Binks, 1991. Differential opening of the Central and South Atlantic Oceans and the opening of the West African rift system. Tectonophysics, 187(1-3): 191-203.

Genik, G., 1992. Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and the Central African Republic (C.A.R.). Tectonophysics, 213(1-2): 169-185.

Littke, R. and D. Leythauser, 1993. Migration of oil and gas in coals. Am. Assoc. Petrol. Geol. Stud. Geol., 38: 219-236.

Mahadir, R., 2004. Petroleum system modeling of the Southern Malay Basin, Malaysia. Unpublished Report, pp: 80.

Mijinyawa, A., S.K. Bhattacharya, A. Moumouni, S. Mijinyawa and I. Mohammad, 2013. Hydrocarbon potentials, thermal and burial history in herwa-1 well from the Nigerian sector of the Chad basin: An implication of 1-D basin modeling study. Res. J. Appl. Sci. Eng. Technol., 6(6): 961-968.

Mohamed, A.Y., M.J. Pearson, W.A. Ashcroft, J.E. Iliffe and A.J. Whiteman, 1999. Modeling petroleum generation in the southern muglad rift basin, Sudan1. AAPG Bull., 83(12): 1943-1964.

Obaje, N., S. Abaa, T. Najime and C. Suh, 1999. Economic geology of nigerian coal resources; a brief review. Afr. Geosci. Rev., 6: 71-82.

Obaje, N.G., 2009. Geology and Mineral Resources of Nigeria. Springer, Berlin, Heidelberg, Vol. 120.

Obaje, N.G., D.O. Attah, S.A. Opeloye and A. Moumouni, 2006. Geochemical evaluation of the hydrocarbon prospects of sedimentary basins in Northern Nigeria. Geochem. J., 40(3): 227-243.

Obaje, N.G., H. Wehner, M.B. Abubakar and M.T. Isah, 2004. Nasara-I well, Gongola basin (upper Benue trough, Nigeria): Source-rock evaluation. J. Petrol. Geol., 27(2): 191-206.

Okosun, E.A., 1995. Review of the geology of Bornu basin. J. Min. Geol., 31(2): 133-122.

Ola-Buraimo, A.O., 2013. Biostratigraphy and Paleoenvironment of deposition of Bima and Gongila formations in M-1 well, Bornu basin, Northeastern Nigeria. Int. J. Sci. Technol. Res., 2(8): 320-328.

Ola-Buraimo, A.O. and O.A. Boboye, 2011. Palynological investigation of the albian to lower cenomanian bima formation, Bornu basin, Nigeria. World Appl. Sci. J., 12(7): 1026-1033.

Olugbemiro, O.R. and B. Ligouis, 1999. Thermal maturity and hydrocarbon potential of the cretaceous (Cenomanian-Santonian) sediments in the Bornu (Chad) basin, NE Nigeria. B. Soc. Geol. Fr., 170(5): 759-772.

Olugbemiro, R.O., B. Ligouis and S.I. Abaa, 1997. The cretaceous series in the Chad basin, NE Nigeria: Source rock potential and thermal maturity. J. Petrol. Geol., 20(1): 51-68.

Peters, K.E., 1986. Guidelines for evaluating petroleum source rock using programmed pyrolysis. AAPG Bull., 70(3): 318-329.

Petters, S.W. and C.M. Ekweozor, 1982. Petroleum geology of Benue trough and southeastern Chad basin, Nigeria: Geologic notes. AAPG Bull., 66(8): 1141-1149.

Sweeney, J.J. and A.K. Burnham, 1990. Evaluation of a simple model of vitrinite reflectance based on chemical kinetics (1). AAPG Bull., 74(10): 1559-1570.

Tissot, B.P. and D.H. Welte, 1984. From Kerogen to Petroleum. Petroleum Formation and Occurrence. Springer, Berlin, Heidelberg, pp: 160-198.

Waples, D.W., 1985. Geochemistry in Petroleum Exploration. International Human Resources Development Corp., Boston.

Welte, D.H. and M.A. Yukler, 1981. Petroleum origin and accumulation in basin evolution--a quantitative model. AAPG Bull., 65(8): 1387-1396.

Wright, J.B., D.A. Hastings, W.B. Jones and H.R. Williams, 1985. Geology and Mineral Resources of West Africa. Allen and Unwin, London.

Yalcin, M.N., R. Littke and R.F. Sachsenhofer, 1997. Thermal History of Sedimentary Basins. In: Welte, D.H., B. Horsfield and D. Baker, (Eds.), Petroleum and Basin Evaluation. Springer, Berlin, pp: 71-167.