Research Journal of Applied Sciences, Engineering and Technology 6(6): 961-968, 2013
DOI:10.19026/rjaset.6.3998
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: October 06, 2012 Accepted: December 17, 2012 Published: June 30, 2013

Research Article

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

[1]Abubakar Mijinyawa, [1]S.K. Bhattacharya, [2]A. Moumouni, [2]S. Mijinyawa and [1]Ibad Mohammad
[1]Department of Petroleum Geosciences, University of Technology, PETRONAS, Malaysia
[2]Department of Geology and Mining, Nasarawa State University, Keffi, Nigeria

Abstract: This research study attempt to evaluate the hydrocarbon potentials, thermal and burial history and the timing of hydrocarbon generation in Herwa-1 well within the Nigerian Sector of the Chad basin. Organic geochemical study of some ditch cuttings samples from Herwa-1 well and a One-dimensional basin modeling study was carried out. The result of the geochemical analysis revealed a moderate to good TOC greater than 0.5wt% in Fika and Gongila formation, the Hydrogen Index (HI) ranges from 150-300 (mgHC/g) and the Tmax values falls within the range of greater than or equal to 430°C. The hydrocarbon potentials in Herwa-1 well was further supported with the values of S1+S2 which is greater than or equal to 2 mg/g of rock in almost all the samples, suggesting a good hydrocarbon potentials. The 1-D basin model was constructed for Herwa-1 well in order to assess the burial history and thermal maturity of the potential source rocks in the Nigerian sector of the Chad basin. The modeling results indicate that maximum burial occurred in the late Miocene and suggesting erosion might have been the cause of the thinning of the Tertiary sediments in the present time. The calibration of Vitrinite reflectance against Temperature revealed the present day heat flow to be at 60 mW/m^2 and Paleo heat flow falls within the range of 68 mW/m^2. However, it is also revealed that Oil Window begins at (0.60-1.30% VRr) at the depth of (2000-3000 m) in the middle Cretaceous and the Gas Window start during the late Cretaceous to Tertiary with a value of (1.3-2.5% VRr) at a depth greater than (3500 m).

Keywords: Herwa-1 well, hydrocarbon potentials, one-dimensional modelling, thermal history

INTRODUCTION

Nigerian Sector of the Chad Basin is part of the Western Central African rift system, which was formed during the separation of African and South American plates in the cretaceous. The Chad basin constitute mainly of five countries namely; Niger republic, Nigeria, Cameroon, Chad and Central African republic. It covers a total area of approximately 2,335,000 km^2 (Obaje *et al*., 2004). The Nigerian Sector of the Chad basin is among the Nigerian inland basins occupying the north eastern part of Nigeria as seen in Fig. 1, it covers at least one tenth of the total area extent of the Chad basin. Nigerian Sector of the Chad Basin falls between longitude 11°45`E and 14° 45`E and latitude 9° 30`N and 13°40`N.

Significant discoveries of commercial hydrocarbon accumulation have been made on either side of the of the Nigerian sector of the Chad basin, such as Doba basin in the Chad republic and the Termit agadem basin in the republic of Niger, the source rocks contributing to the hydrocarbon generation in this basins were correlatable and similar to it counterpart Bima sandstone in the Nigerian sector of the Chad basin (Obaje *et al*., 1999, 2004).

Desperate attempts have been made by the Nigerian National Petroleum Corporation (NNPC) to explore hydrocarbon in the Nigerian sector of the Chad basin, but so far no success could be achieved.

In this basin, little or none has been presented on the burial history and thermal maturity of the potential source.

Basin modeling is becoming an essential tool in study regarding the burial history and thermal maturation of sedimentary basins (Waples, 1994).

The study aims at evaluating the source potentials and thermal maturation and to construct the thermal and burial history of Herwa-1 well in the Nigerian sector of the Chad basin, in this study one-dimensional model of Herwa-1 well was constructed for calibration purposes also geochemical analysis into the potential source rock was carried out to be able to possess a general knowledge of the thermal and burial history and the timing of hydrocarbon generation in Herwa-1 well from the Nigerian sector of the Chad basin. The vitrinite reflectance values have been measured from organic material rich sections of the well.

Corresponding Author: Abubakar Mijinyawa, Department of Petroleum Geosciences, University of Technology, PETRONAS, Malaysia

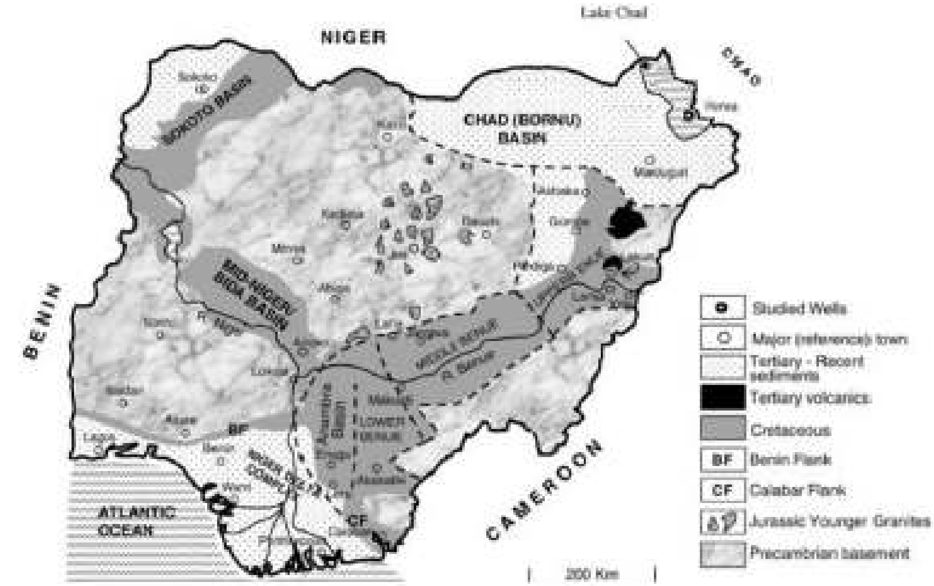

Fig. 1: Geological map of Nigerian indicating studied well (Obaje *et al*., 2006)

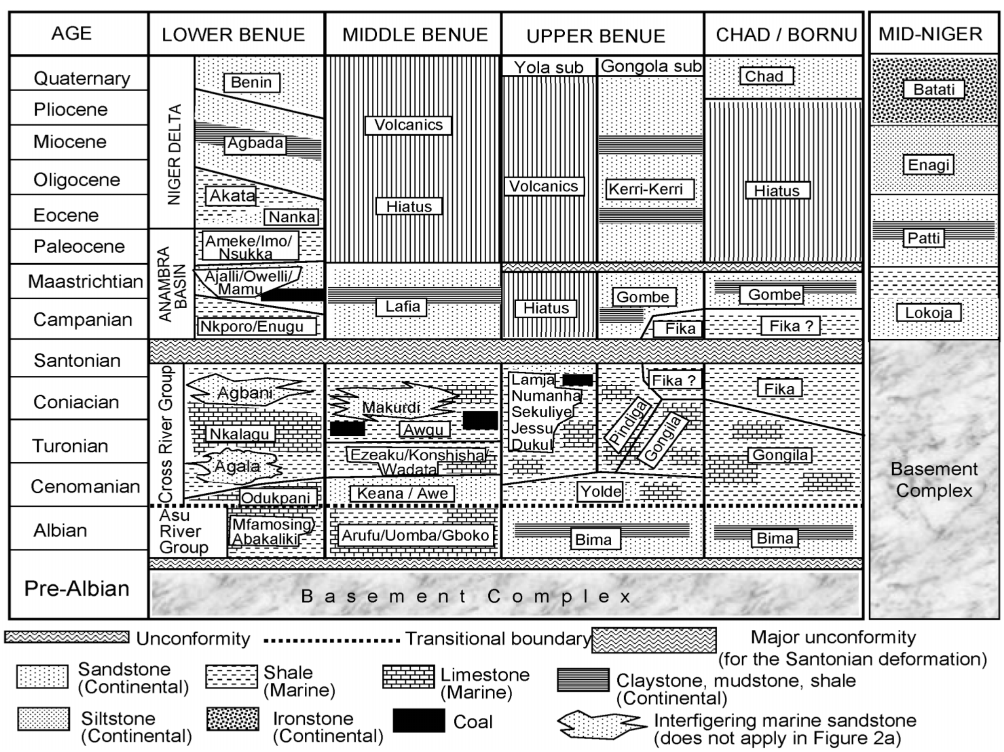

Fig. 2: Stratigraphy of chad basin in relation to the Benue trough (Obaje *et al*., 2006)

STRATIGRAPHY OF THE STUDY AREA

The Chad Basin is known as a large intracratonic depression within Western Central Africa rifts (Obaje *et al*., 1999). The model of the tectonic setting in the Chad basin generally was presented by Genik (1992). Major lineaments within the basement and faults were being form in the basin within the Pan African crustal consolidation, typically the structures developed precursor directions for the future rift basins. All the major NE-SW trending fault system within the basin is associated to this phase (Avbovbo *et al*., 1986; Benkhelil, 1989) During the early rift stage, it had been reported that the formation of the basin was connected to the movement of the strike-slip fault which source had been linked with the split up of the Africa and South American plates (Benkhelil, 1989; Fairhead and Blinks, 1991).

Around 130 ma, in the beginning of the Cretaceous the horizontal shifting relative to the various other crustal blocks triggered the transtensional opening of the Benue trough and the Nigerian sector of the Chad basin (Obaje, 2009). The sedimentation relating to the Chad Basin began with the deposition of continental, poorly sorted, sparsely fossiliferous, medium to coarse grained, sandstone known as the Bima Formation which lies unconformably on the Precambrian basement as seen in Fig. 2. This stated that the formation consists of intercalation of shale as well as the sandstones, as cited by some researchers (Obaje *et al*., 1999; Petters and Ekweozor, 1982). Overlying the Bima Formation is the Gongila Formation which is made up of sandstones and blue black calcareous shale deposited within a shallow marine environment. These depositions indicate the beginning of marine incursion within this basin (Obaje *et al*., 1999, 2004), this transgression attained its peak in the Turonian, (in which the Fika Shale Formation was deposited in an open marine environment) During the Maastrichtian period, estuarine/ deltaic environment prevailed which resulted in the deposition of the Gombe Sandstone within some portion of the Nigerian sector of the Chad basin. It contains intercalated shale, siltstones and mudstones, not the coal seams reported from the upper Benue Trough (Obaje *et al*., 2004).

The Tertiary period has been characterized by the deposition of the Keri-Keri Formation outside of the Nigerian sector of the Chad basin. Thus, the uppermost Pliocene-Pleistocene period Chad Formation rests unconformably above the Gombe Sandstone. The Chad Formation is made up of fluviatile as well as lacustrine clays and sands (Wright *et al*., 1985).

METHODOLOGY

- **Organic geochemistry:** Forty (40) ditch cutting samples were collected from Herwa-1well and are subjected to Leco/carbon sulphur analysis for determination of Total Organic Carbon (TOC), Rock-Eval pyrolysis (RE) and Vitrinite reflectance (VRr) to determine hydrocarbon generative potential of the organic matter S1, S2, S3, the thermal maturity (Tmax) and the derivatives Hydrogen Index (HI) and Oxygen index (OI).All the samples were prepared according to Organic geochemical procedures as described by Espitalie *et al*. (1977).
- **Construction of 1-D model:** Basin modeling principles were published by Tissot *et al*. (1987), Waples (1994) and Welte and Yu¨ kler (1981). The model begins with the development of conceptual model, which has been subdivided into sequence of events (deposition, erosion and non deposition) of certain age and duration (Belaid *et al*., 2010).

In this study, burial history and thermal maturity were constructed with the aid of Petromod 1D software. Some input data were utilized from the stratigraphy and

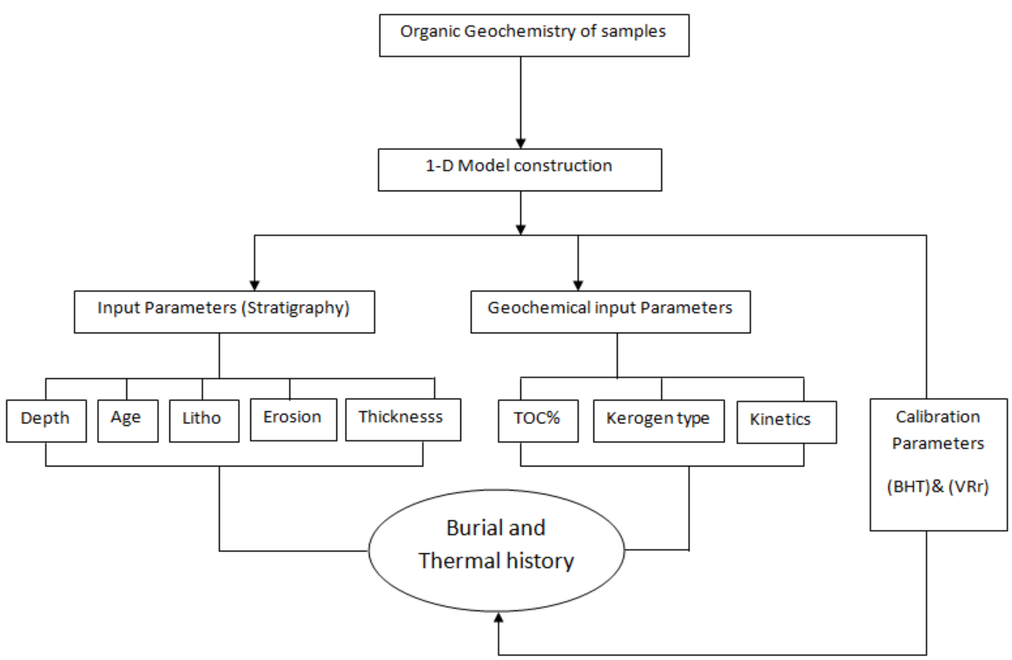

Fig. 3: Methodology flow chart

Exploratory well from the Nigerian Sector of the Chad basin, i.e. Thicknesss, Lithology of the layers, Erosion, Deposition, non deposition, Hiatus and the present day depth.

Calibration parameters includes Bottom Hole Temperature (BHT) and Thermal maturity data i.e. Vitrinite reflectance were used to calibrate the Temperature history of the basin as presented in the methodology flow chart in Fig. 3.

However, some geochemical parameters were used which include TOC%, Kerogen type and Kinetics (Sweeney and Burnham, 1990). Easy% Ro algorithm was adopted for the calculation of Vitrinite reflectance from the temperature history.

For the boundary conditions, the Sediment Water Interface Temperature (SWIT) and the Paleowater Depth (PWD) were deduced. In this model the Heat Flow (HF) scenarios was adjusted to reach the maturity that are pointed out by Vitrinite reflectance (VRr) data and the present well temperatures measured in the borehole.

RESULTS AND DISCUSSION

- **Hydrocarbon generative potentials:** The result of the geochemical data in Table 1 and the plot of the analyzed data from Fig. 4, revealed a moderate to good TOC greater than 0.5wt% in Fika and Gongila formation. However, some intervals are seen with TOC greater than or equal to 4wt%, the Hydrogen Index (HI) ranges from 150-300 (mgHC/g) suggesting type II to type III Kerogen that could generate oil and gas when subjected to adequate burial and heating. The Tmax values falls at the range of greater than or equal to 430^{o}C. The hydrocarbon potentials in Herwa-1well was further supported with the values of S1+S2 which is greater than or equal to 2 mg/g of rock in almost all the samples, suggesting a good hydrocarbon potentials.
- **Reconstruction of thermal and burial history:** Based on the modeling result, the maximum burial occurred in the late Miocene with the deposition of Bima formation within the Nigerian Sector of the

Table 1: Rock Eval Pyrolysis data of samples from Herwa-1 wells in the Nigerian sector of the Chad Basin

Depth	TOC	S1	S2	S3	Tmax	HI	OI	PI
HW-1500	0.07	0.01	0.04	0.35	434	57	500	0.2
HW-1550	0.07	0.01	0.05	0.19	424	71	271	0.2
HW-1600	3.98	0.03	1.10	7.11	436	28	179	0.0
HW-1650	1.98	0.03	0.91	1.41	419	46	71	0.0
HW-1750	1.06	0.01	0.24	1. 14	426	23	108	0.0
HW-1800	1.03	0.02	0.19	1.19	423	18	116	0.1
HW-1850	1.05	0.01	0.25	1.25	424	24	119	0.0
HW-1900	1.01	0.01	0.21	1.17	424	21	116	0.0
HW-1950	1.19	0.02	0.34	1.11	425	29	93	0.1
HW-2200	1.59	0.11	2.55	1.16	432	160	73	0.0
HW-2300	1.28	0.11	2.86	1.1	437	223	86	0.0
HW-2400	1.68	0.09	1.40	1.18	440	83	70	0.1
HW-2450	1.39	0.11	1.02	1.33	437	73	96	0.1
HW-2500	1.00	0.12	0.73	1.27	435	73	127	0.1
HW-2600	0.90	0.09	0.48	0.94	428	53	104	0.2
HW-2650	4.46	1.09	5.52	1.07	427	124	24	0.2
HW-2750	1.07	0.07	0.71	0.94	428	66	88	0.1
HW-2800	1.43	0.11	1. 08	0.93	428	76	65	0.1
HW-2900	1.37	0.19	1.22	0.78	452	89	57	0.1
HW-3050	1.33	0.12	0.67	0.86	405	50	65	0.2
HW-3100	3.13	0.23	0.76	1.80	428	88	58	0.1
HW-3200	1.47	0.15	0.82	0.55	415	56	37	0.2
HW-3250	0.34	0.09	0.18	0.43	294	53	126	0.3
HW-3300	2.51	0.23	1.75	2.32	425	70	92	0.1
HW-3350	0.75	0.04	0.16	0.31	361	21	41	0.2
HW-3500	0.96	0.34	1.42	2.36	435	148	246	0.2
HW-3550	0.41	0.16	0.31	0.54	284	76	132	0.3
HW-3850	0.9	0.16	0.53	0.43	410	59	48	0.2
HW-3900	3.23	0.95	2.67	1.07	431	83	33	0.3
HW-3950	0.50	0.25	0.36	0.66	418	72	132	0.4
HW-4000	0.46	0.18	0.41	0.44	296	89	96	0.3
HW-4050	0.49	0.08	0.26	0.40	297	53	82	0.2
HW-4100	0.31	0.18	0.21	0.35	292	68	113	0.5
HW-4150	1.38	0.96	1.80	1.20	415	130	87	0.3
HW-4300	0.4	0.19	0.34	0.47	294	85	118	0.4
HW-4350	0.68	0.15	0.48	0.42	358	71	62	0.2
HW-4400	0.54	0.17	0.48	0.44	361	89	81	0.3
HW-4550	1.04	0.44	3.27	0.99	372	314	95	0.1
HW-4600	0.40	0.10	0.35	0.22	362	88	55	0.2
HW-4650	0.17	0. 07	0.21	0.23	367	124	135	0.3

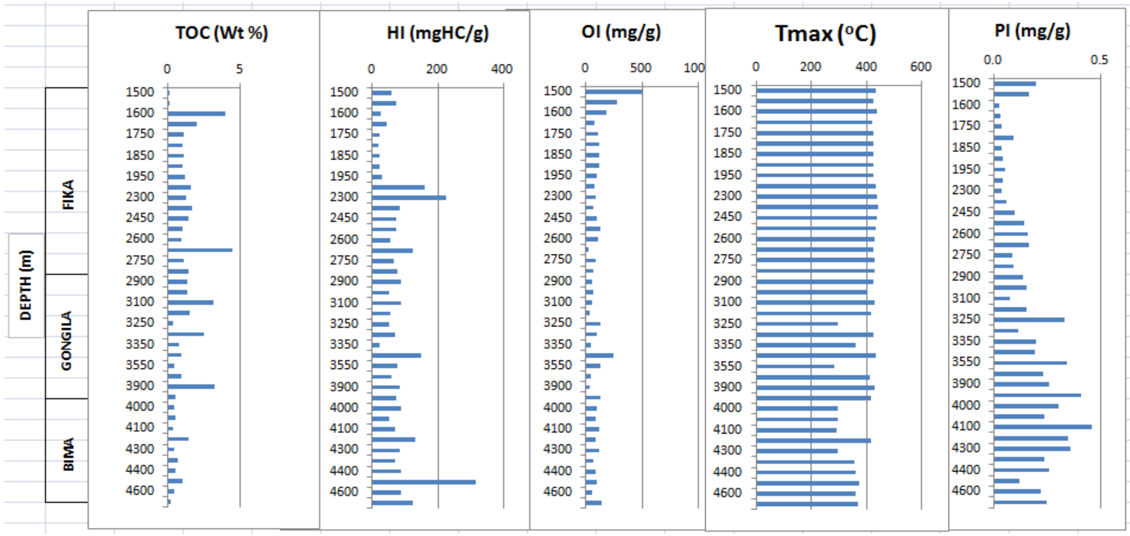

Fig. 4: Plot of TOC, HI, OI, PI and Tmax against depth in Herwa-1

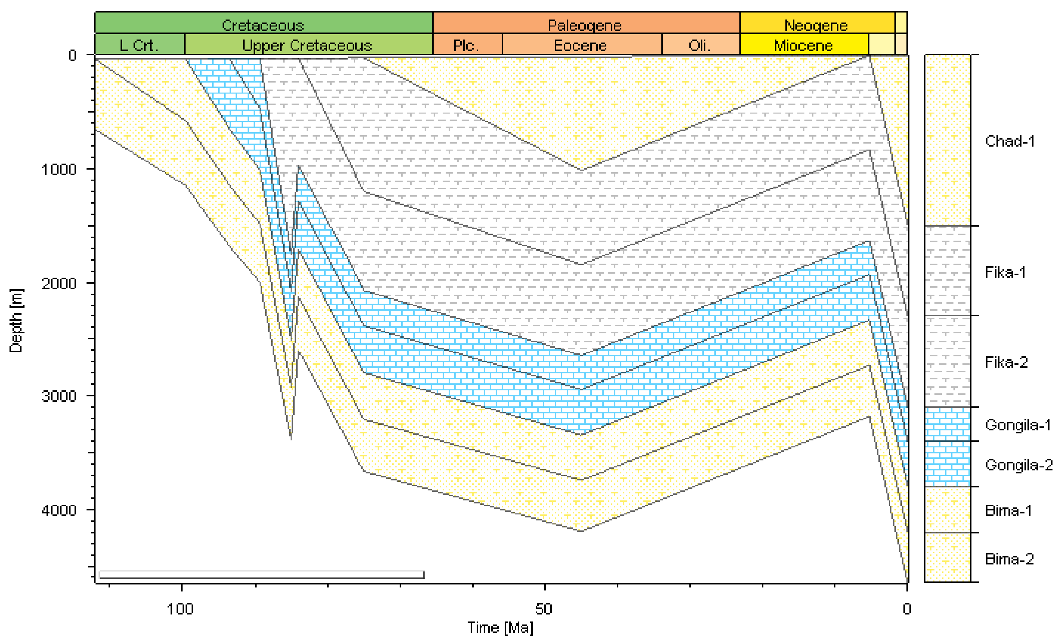

Fig. 5: Burial history plot of Herwa-1 from the Nigerian sector of the chad basin

Chad basin. Series of erosion and non deposition has been deduced from Miocene to Pliocene, the tertiary thickness at the point of maximum burial ranges between (1200-1500 m) suggesting erosion might have been the cause of the thinning of Tertiary sediment at the present time. The burial history plot is presented in the Fig. 5.

Heat flow controlled the thermal history of a basin (Allen and Allen, 1990). One dimensional modeling was used in the analysis of the tectonic evolution of the basin. In an active rift, the average heat flow is about 80mW/m^2 (Allen and Allen, 1990), while decreases to 50mW/m^2 during the post rift stage. In this model the thermal history was calibrated using Vitrinite reflectance and corrected Bottom Hole Temperature (BHT) data from the cretaceous sediment. Figure 6 below shows the calibration curves of the studied well, indicating that a good match between measured and calculated Vitrinite reflectance values was achieved. In Herwa-1 well which is the studied well, heat flow values ranges from 60 mW/m^2 in the present time while the Paleo heat flow was within the range of 68mW/m2.This result shows no significant difference between Present day and the Paleo heat flow in the Herwa-1 well. The heat flow model which has been

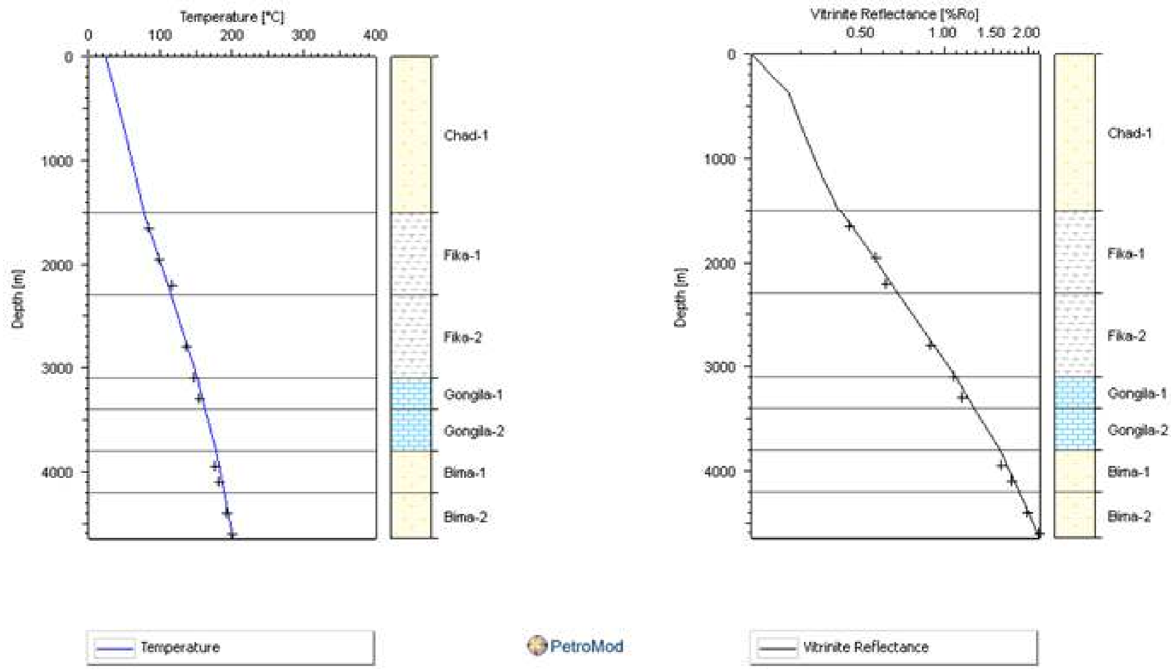

Fig. 6: Plot of Bottom Hole Temperature (BHT) and the vitrinite reflectance values versus depth in Herwa-1 well

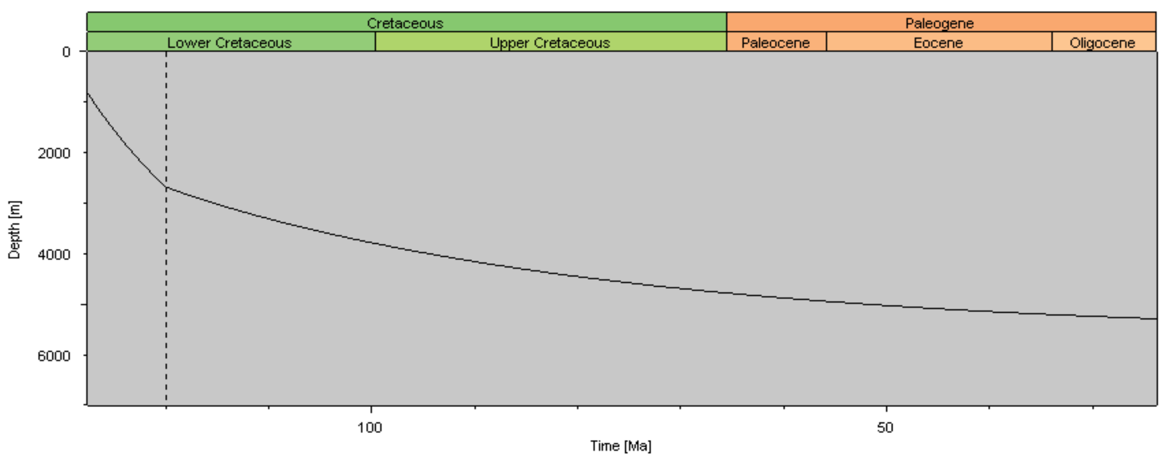

Fig. 7: Plot of subsidence trend depth against time

developed based on the tectonic history of the basin and calibration to the available maturity data suggest that, ending of Pan African Orogeny lead to the gradual decrease in the paleo heat flow within the Cretaceous (Yalcin *et al*., 1997).

- **Timing of hydrocarbon generation:** The thermal and burial history of Herwa-1 well was influenced by the tectonic evolution of the Nigerian sector of the Chad basin. Therefore, an in depth understanding of Thermal history and subsidence is important in predicting timing of hydrocarbon generation in this part of the basin. In this study the subsidence trend as shown in Fig. 7 was estimated from the Mckenzie model, which suggest the subsidence begin from early cretaceous around 120 ma at the depth of 2678 meters which shows a low burial rate, this subsidence trend ended in the late Miocene around 20 ma at a depth of 5276 meters which is characterized by a high burial rate, this fact has been confirmed from the burial history plot of Herwa-1 well which also indicate the maximum burial occurred in the late Miocene.

From the modeling result, the timing of hydrocarbon generation was deduced from thermal history and temperature of the basin. In Fig. 8 below it indicate that the early oil generation stage falls between (0.45- 0.60 %) VRr which begin during the early Cretaceous at the depth of (2000-2200 m), the oil

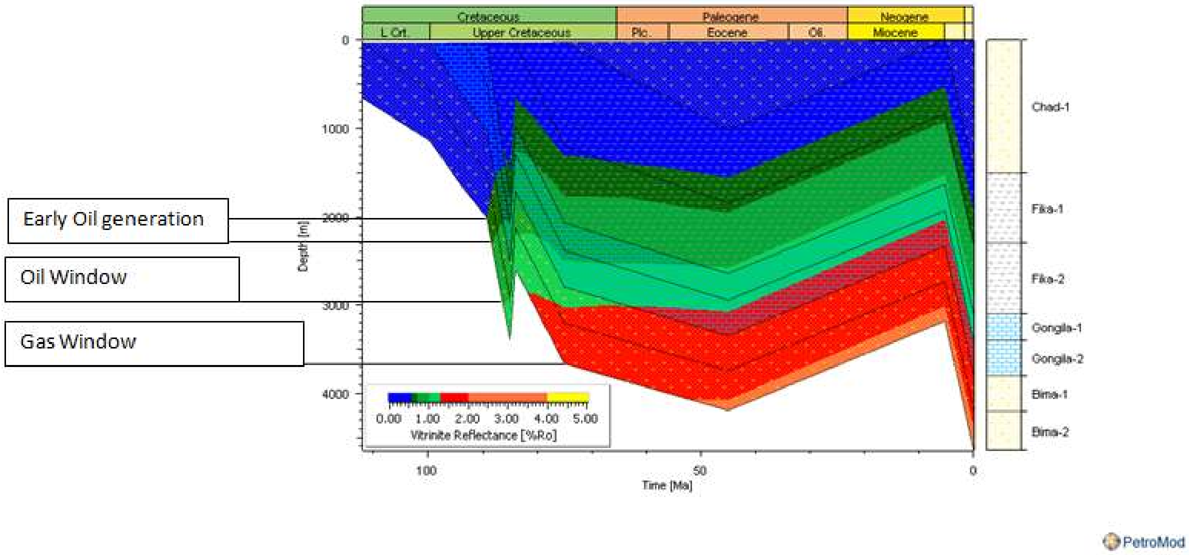

Fig. 8: Burial history curves showing intervals of hydrocarbon generation in Herwa-1 well

window begins from (0.60- 1.3%) VRr at the depth of (2000-3000 m) in the mid Cretaceous, while the gas window was generated during the late Cretaceous to Tertiary with a value of (1.3-2.5%)VRr at a depth greater than 3500m. However, the Hydrocarbon generative potentials in this studied well has been characterized into mixed type II and type III kerogen.

- **Conclusion and future directions:** Ditch cuttings samples have been collected from Herwa-1 well to study the Organic geochemistry of the samples. The results indicate moderate to good TOC greater than or equal to 0.5wt%, with some isolated interval showing TOC greater than or equal to 4wt%. The hydrogen index HI ranges from 150-300 mgHC/g and the Tmax value falls within the range of greater than or equal to 430°C, suggesting good hydrocarbon potentials in this part of the basin.

The modeling result, from the burial history curve indicates maximum burial has occurred in the late Miocene also suggest erosion might have been the cause of the thinning of the Tertiary sediment in the present time.

From the calibration result of Vitrinite reflectance and Temperature, the present day heat flow was estimated at 60 mW/m^2 and the paleo heat flow at the range of 68 mW/m^2.

The hydrocarbon generation begins in the early Cretaceous, with the early oil stage at (0.45-0.60% VRr) within the depth of (2000-2200 m), the oil window begins from (0.60-1.30% VRr) in the mid Cretaceous at the depth of (2000-3000 m) while the gas window was generated during the late Cretaceous to Tertiary with a value ranges between (1.3-2.5% VRr) at a depth greater than (3500 m).

In this study, evaluation of the hydrocarbon potentials, thermal and burial history and the timing of hydrocarbon generation in Herwa-1 well has been achieved. However, further study in this basin is recommended in order to find out the best possible migration and trapping scenarios.

REFERENCES

Allen, P.A. and J.R. Allen, 1990. Basin Analysis: Principles and Applications. Blackwell, Cambridge, pp: 451.

Avbovbo, A.A., E.O. Ayoola and G.A. Osahon, 1986. Depositional and structural styles in the chad basin of Northeastern Nigeria. AAPG Bull., 70: 1787-1798.

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

Benkhelil, J., 1989. The evolution of the cretaceous Benue trough, Nigeria. J. Afr. Earth Sci., 8: 251-282.

Espitalie, J., J. Laporte, M. Madec, F. Marquis, P. Leplat, J. Paulet and A. Boutefeu, 1977. Rapid method for characterization the petroleum potential and degree of evolution of source rocks. Rev. French 1'Inst. Petrol (French), 32: 23-42.

Fairhead, J.D. and R.M. Blinks, 1991. Differential opening of the central and South Atlantic oceans and opening of the central African rift system. Tectonophysics, 187: 191-203.

Genik, G.J., 1992. Regional framework, structural and petroleum aspects of rift basins in Niger, chad and Central African Republic (CAR). Tectonophysics, 213: 169-185.

Obaje, N.G., 2009. Geology and Mineral Resources of Nigeria. Springer, Berlin, London, pp: 69-72.

Obaje, N.G., S.I. Abaa, T. Najime and C.E. Suh, 1999. Economic geology of Nigeria coal resources: A brief review. Afr. Geosci. Rev., 6: 71-81.

Obaje, N.G., H. Wehner, G. Scheeder, M.B. Abubakar and H. Jauro, 2004. Hydrocarbon prospectivity of Nigeria's inlands basins: From the viewpoint of organic geochemistry and organic petrology. AAPG Bull., 87: 325-353.

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

Petters, S.W. and C.M. Ekweozor, 1982. Petroleum geology of the Benue trough and southern Chad basin, Nigeria. AAPG Bull., 66: 1141-1149.

Sweeney, J.J. and A.K. Burnham, 1990. Evolution of a simple model of vitrinite reflectance based on chemical kinetics. Am. Assoc. Petr. Geol. B., 74: 1559-1570.

Tissot, B., R. Pelet and P. Ungerer, 1987. Thermal history of sedimentary basins, maturation indices and kinetics of oil and gas generation. Am. Assoc. Petr. Geol. B., 71: 1445-1466.

Waples, D.W., 1994. Maturity modelling: Thermal indicators, hydrocarbon generation and oil cracking. Petrol. Syst. Source Trap Am. Assoc. Petr. Geol. (AAPG) Memoir, 60: 285-306.

Welte, D.H. and M.A. Yu¨ kler, 1981. Petroleum origin and accumulation in basin evolution: A quantitative model. Am. Assoc. Petr. Geol. B., 65: 1387-1396.

Wright, J.B., D.A. Hastings, W.B. Jones and H.R. Williams, 1985. Geology and Mineral Resources of West Africa. Pergamon Press, pp: 94-96.

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