Journal of Environmental Sciences and Resource Management *Volume 2, September 2010*

GEOCHEMICAL ASSESSMENT OF CRETACEOUS SEDIMENT IN THE NIGERIAN SECTOR OF THE CHAD BASIN FROM KADARU-1 AND HERWA-1 EXPLORATORY WELLS FOR POSSIBLE PETROLEUM GENERATION

Y. B. Mohammed
Department of Geology
University of Maiduguri, Maiduguri, Nigeria
Email: bzakirai@yahoo.com

ABSTRACT

Two of the exploratory wells, Kadaru-1 and Herwa-1 drilled in the Nigerian sector of the Chad basin were used for the research. The geochemical assessment was carried out using twenty (20) selected shale samples for the analytical work. The samples were raw shale from some Cretaceous sediment. The overall average SOM, SHC, AHC, and NSO values are 130ppm, 22.8ppm, 38.3ppm, and 67.8ppm in Kadaru-1 well and 280ppm, 33.5ppm, 65.3ppm, and 156ppm in Herwa-1 well. The concentrations of SOM, SHC, AHC, and NSO as a function of burial depth in both wells are generally inconsistent, but there is a progressive increase of these parameters with burial depth in Herwa-1 well between (1745- 2455) m, which is characterized as the source bed and reveals "oil shows". The general interpretation signifies that the samples are relatively of low quality and the nonhydrocarbon heteroatomic compounds (NSO) have higher concentration values than the hydrocarbon compounds (SHC&AHC) in the two studied wells and the anaerobes utilized sulfate and nitrate ions instead of molecular oxygen as electron acceptors for their metabolic processes and survived under anoxic-suboxic condition.

INTRODUCTON

The Chad basin is the largest intracratonic basin in Africa (Raeburn and Brynmor, 1934), covering an area of about 233,000km^2 and straddles five countries namely; Nigeria, Chad Republic, Niger Republic, Cameroon and Central African Republic *(Obaje et al., 2004).* Its western margin is marked by the watershed between the River Niger and River Chad drainage systems, and approximately one-tenth of the surface area of the Chad basin is in NE Nigeria, bounded to the east by the Northern Massif (Mandara Mountains) and in the south by the Benue Trough and Biu Plateau *(Olugbemiro et al., 1997)*. Figure.1 shows the location of S.W Chad basin in Nigeria.

The origin of the Chad basin is associated with the separation of the African and South American Continents in Early Cretaceous (Burke, 1976b; Fairhead and Blinks, 1991; Genik, 1993; Hartley and Allen, 1994) and from the structural styles, there is a strong indication that the evolution of the Chad basin is related to the Benue trough (Nur, 2001) or as a result of thermal subsidence following intrusion of anorogenic granites in response to changing heat flow during supercontinent breakup (Klein and Hsui, 1987) or due to subsidence caused by tectonic events at adjacent plate margins (Leighton and Kolata, 1990).

The Nigerian sector of the Chad basin has had some setback in the exploration for hydrocarbons in the basin principally because of the poor knowledge of subsurface geology, far distance from Niger Delta where oil has been found in large quantity and its adjacent offshore thereby not allowing investors to pay attention to the uncertain S.W. Chad basin in Nigeria. This sector of Nigeria's inland basins is one part in a series of Cretaceous and later rift basins in Central and West Africa whose origin is related to the opening of the South Atlantic. Commercial hydrocarbon accumulations have recently been discovered in Chad and Sudan within this rift trend. Hence there is the possibility of oil accumulation in the basin because most of the source rocks (Fika Shale and Gongila Formations) have reached greater depth of burial for onset of oil generation and the purpose of the research is to ascertain whether or not oil have been generated, the type section and depth at which it occurs.

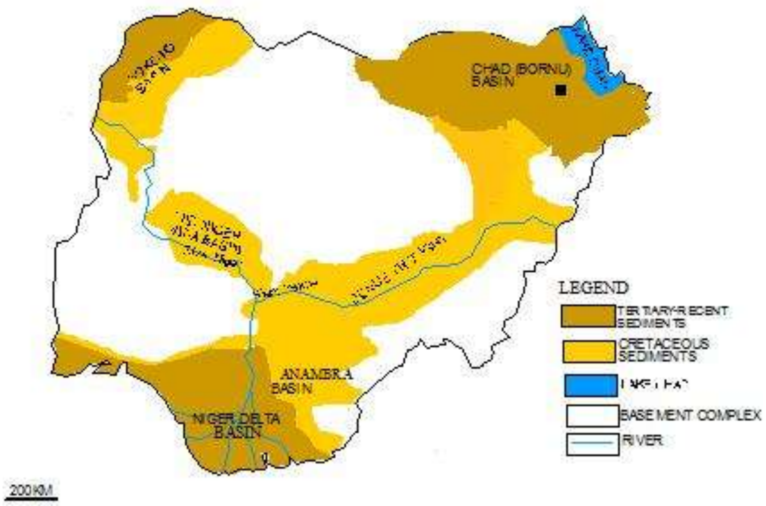

Fig.1 Sketch geological map showing the location Chad basins in Nigeria.

The study area is located approximately 15km southwest of Baga town from the studied wells, Kukawa L.G.C. It is situated between latitudes 13^{0} 02^{1} 38^{11}N to 13^{0} 06^{1} 13^{11}N and longitudes 13^{0} 45^{0}E to 13^{0} 50^{1}E. It is part of the 1:50,000 Federal Surveys Map of Nigeria on the Chad-Baga sheet 25 SE (Fig. 2). The area is accessed by tarred roads from Maiduguri to Baga from where footpaths link to the wells.

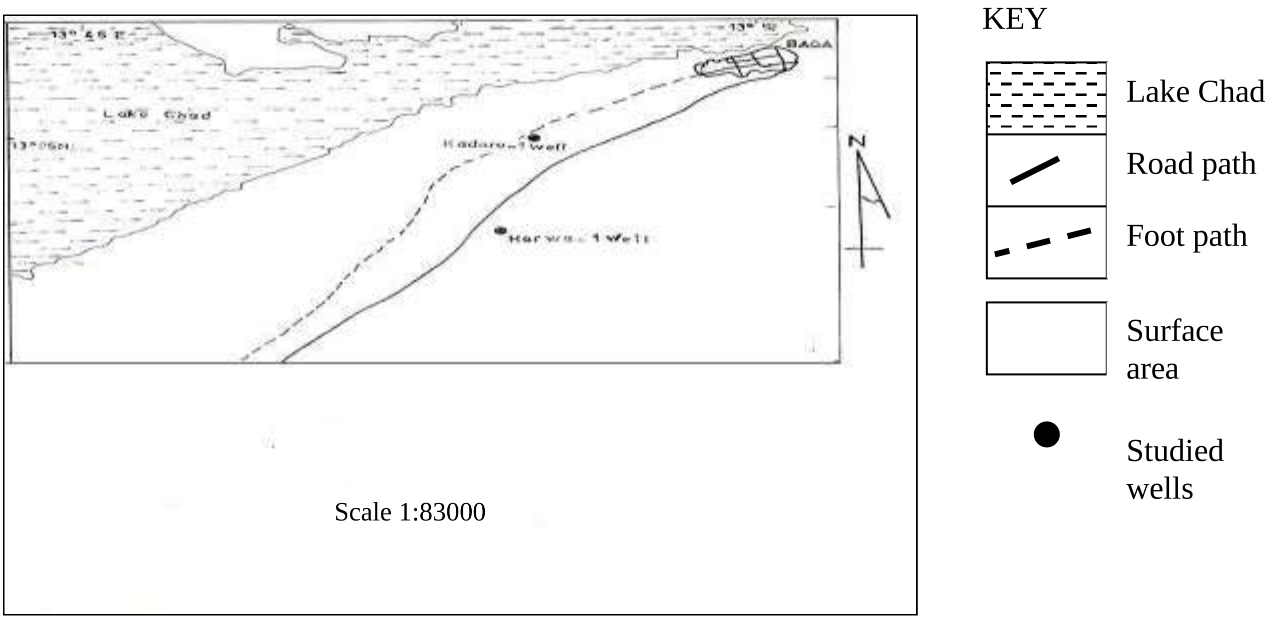

Fig.2 Map of the study area showing the surface area and the Lake Chad (Chad-Baga S.E. sheet 25)

EVOLUTION OF THE CHAD BASIN

Various mechanisms have been proposed to explain the evolution of the ba (1952), *Carter et al., (1963)* and *Burke et al., (1970)* maintained that the Benue-Chad trough is believed to be the third and "failed arm" of a triple junction rift-system that preceded the opening of the South Atlantic during the early Cretaceous, and the subsequent separation of Africa and South American Continents. Cratchley and Jones (1965) and Ajakaiye and Burke (1973) have shown from geophysical evidence that the Benue trough's structural alignment and that of the Manga area may pass into one another in the Nigerian sector of the Chad basin. The basin is thus genetically linked with Benue trough. A mid-Cretaceous phase of active seafloor spreading in the Atlantic resulted in subsidence of the West African intracratonic basins, which lead to widespread Cenomanian-Turorian marine transgression into the Chad basin (Furon, 1963; Franks and Nairn, 1973).

GEOLOGY OF THE STUDY AREA

STRATIGRAPHIC COLUMN OF KADARU-1 AND HERWA-1 WELLS

The stratigraphic column constructed (Fig 3) was used to correlate the individual facies and facies that are similar. Some of the facies in one well have no stratigraphic equivalence with the adjacent well. In Kadaru-1 well the sand and silty sand strata that occur at the uppermost part of the profile has no correlation with the facies in Herwa-1 well. Similarly, silty clay, clay, gravel and clay and sand and gravelly sand which also occur at uppermost part of Herwa-1 well have no stratigraphic correlation with the corresponding facies in the Kadaru-1 well.

There are facies units however which correlates with the corresponding well, which include; shale, shaly silt, silty shale and shaly sand. These profiles (Fig. 3) tend to give a picture of a geologic cross-section that is not visible at surface because the area is generally covered by thick sand and lacks outcrops.

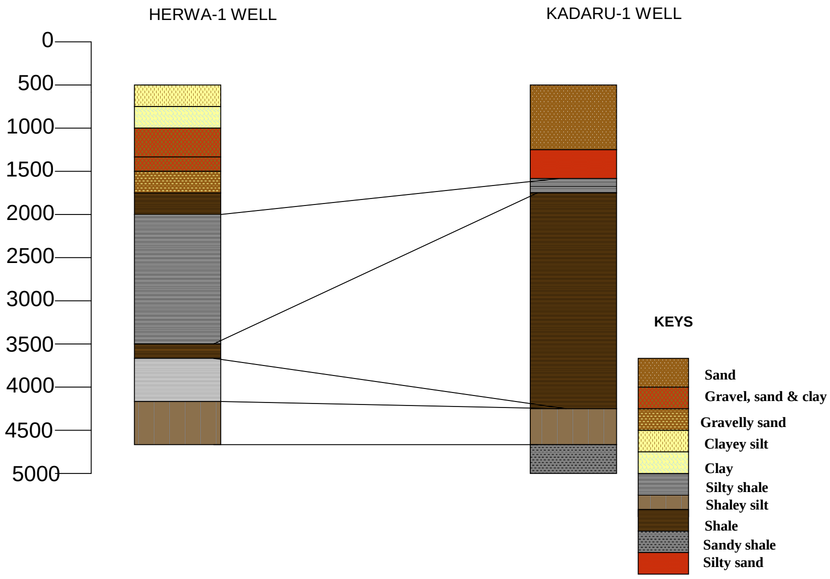

Fig.3 Stratigraphic columns and correlation between Kadaru-1 and Herwa-1 wells.

BIMA SANDSTONE

Investigation on this formation has not been carried out on both wells because drilling into the search for hydrocarbon terminates at the Gongila Formation in Herwa-1 well and penetrates the formation in Kadaru-1 well; this was also studied by Okosun (2000) and (Hamza *et al.,* 2002) both reported the presence of the formation among the facies that have been drilled in Kinasar-1 Kanadi-1 and Wadi-1wells. Many authors have reported the existence of Bima Sandstone Formation as the basal sedimentary formation in both the Chad basin and Benue trough. There was no disagreements that have been reported so far on the formation as being the basal strata (e.g. Carter *et al.,* 1963; Petters and Ekweozor, 1982; Popoff *et al.,* 1986*;* Guiraud, 1990, 1991 and Obaje *et al.,* 2004). Variable thicknesses have been reported for instance Matheis (1986) reported a thickness of 3054m and 965m was reported by (Hamza *et al.,* 2002) in Kinasar-1 well. The formation is moderately sorted, fine- medium grained, dark brown in colour and has interbed of shale and sand. The formation has a thickness of 30m (5010- 4980) m in Kadaru-1 well.

GONGILA FORMATION

The Gongila Formation is proposed to overlie the Bima Sandstone in Kadaru-1 well within the study area. The formation is transitional between the continental basal sedimentary rock units and the overlying marine formation. It consists of variable shale units in both wells as it intercalates, such as; silty shale, shaly silt, in both wells and intercalation of sand and shale in Kadaru-1 well between 5010- 4980 m. The formation has a thickness of 1035m (4705- 3670) m in Herwa-1 well and 785m (4980-4195) m in Kadaru-1 well. The formation has variable colours which include; blackish brown, grayish black, dark brown in Kadaru-1 well and black, dark gray, dark grayish brown in Herwa-1 well, Carter *et al.,* (1963), Okosun (1995) and Obi, (1998) have also reported similar colours in the formation around Upper Benue trough and other exploratory wells in the Chad basin.

FIKA SHALE

The Fika Shale overlies the Gongila Formation in the study area directly and was found to have thicknesses of 1695m (3670-1995) m in Herwa-1 well and 2550m (4195-1645) m in Kadaru-1 well. The Fika Shale is generally monotonous, except where it forms boundary with other formations, it intercalates, exhibiting lithological difference. It is moderately hard with variation in colour from brown, dark brown, dark gray, and black at the top to the bottom of Kadaru-1 well and have blackish brown, black, dark gray and grayish brown in Herwa-1 well. Similar colours have been reported by Carter *et al.,* (1963) in the exposed section of the Benue trough and Okosun (1995) from Kanadi-1, Kinasar-1, Sa-1 and Wadi-1 wells. Pebbles of volcanics have been observed in Kadaru-1 well between 2995- 2800m within the Fika shale.

CHAD FORMATION

The Chad Formation was found to be unconformably laid down on the Fika Shale as observed from the lithofacies, and the stratigraphic break exhibits red colouration, showing evidence of weathering, erosion and period of non-deposition. These stratigraphic hiatus (unconformities) separates the Cretaceous from the Quaternary sediments. The unconformities were observed at depths of 1255m in Herwa-1 and 1250m in Kadaru-1 wells and have thicknesses of 240m and 165m in Kadaru-1 and Herwa-1 wells respectively.

Table1.Stratigraphical succession for the Chad basin in Nigeria towards the shores of the Lake Chad from Kadaru-1 and Herwa-1 exploratory wells

AGE	FORMATION	LITHOLOGY	THICKNESS (M)	DEPOSITIOAL ENVIRONMENT
Pliocene, Pleistocene	Chad Formation	Clay, Sand, Silt & Gravel	975& 925	Continental
Turonian-Santonian	Fika Shale	Shale & shaly siltstone	2355& 1925	Marine
Turonian	Gongila Formation	Silty shale	1035& 555	Marine, Estuarine
Cenomanian	Bima Formation	Sandstones	260	Continental

***************CRYSTALLINE BASEMENT**************************

Analytcal Method

The samples collected for the analytical work were raw shales from Kadaru-1 and Herwa-1 wells. Extraction was carried out using quantitative Soxhlex Avanti system, set at a temperature of 120^0C with 80ml of DCM (Dichloromethane)/Hexane slurry to pack the column. The NSO were fractionated from the oil/extracts recovered from the samples using Silica/Hexane slurry to pack the column, and 15ml of Hexane/Toluene in the ratio 3:1, 15ml of DCM/Methanol in the ratio of 1:1 and 10ml of DCM were used. The total weight of SHC, AHC and NSO are presented in (Table 2&3).

RESULTS AND DISCUSSION

The organic geochemical analyses of core samples taken from some Cretaceous sediment have been carried out and the results are given in tables 2&3.

KADARU-1 WELL

The overall SOM values analyzed from the Cretaceous sediment range from 100 – 200ppm with an average of 130ppm. The overall SHC values range from 1 – 110ppm with an average of 22.8ppm. The overall AHC values range from 1 – 115ppm with an average of 38.3ppm. The overall NSO values range from 2 – 163ppm with an average of 67.8ppm

HERWA-1 WELL

The overall SOM values analyzed from the Cretaceous sediment range from 100 – 800ppm with an average of 280ppm. The overall SHC values range from 1 – 200ppm with an average 33.5ppm. The overall AHC values range from 7 – 221ppm with an average of 65.3ppm. The overall NSO values range from 33 – 423ppm with an average of 156.5ppm.

Table 2. Organic geochemical analysis of some sampled sections from Kadaru-1 well

Depth (m)	SOM (ppm)	SHC (ppm)	AHC (ppm)	NSO (ppm)
1645	200	41	37	163
1950	100	7	90	2
2200	100	2	1	71
2590	100	1	30	58
2800	100	30	21	48
3270	200	27	115	70
3445	200	110	7	93
3825	100	8	1	90
4300	100	1	74	2
5000	100	1	7	81

Table 3. Organic geochemical analysis of some sampled sections Herwa-1 well

Depth (m)	SOM (ppm)	SHC (ppm)	AHC (ppm)	NSO (ppm)
1745	200	1	31	125
1995	300	10	221	43
2250	500	10	70	383
2450	800	200	131	423
2875	200	2	5	171
3250	100	3	21	112
3500	200	3	8	172
3750	200	101	7	81
4355	200	4	108	52
4650	100	1	51	172

The concentrations of SOM, SHC, AHC and NSO as a function of burial depth in the wells were generally inconsistent. There seems to be a progressive increase in SOM, SHC, AHC and NSO values with depth of burial in Herwa-1 well between 1745- 2450m, the SOM values at this level are above the minimum threshold for hydrocarbon generation (i.e. 150ppm) while the sediments in Kadaru-1 well and other sections of Herwa-1 well show no significant correlation between SOM, SHC, AHC and NSO concentrations with burial depth (Tables 2&3).

The plot of soluble organic matter (SOM) against depth in the Herwa-1 well (Fig. 4) shows that there is a corresponding increase in the maturation of organic matter between the depth (1745- 2450)m which is of the shale unit and depicts a fair to good petroleum source bed and a general average of fair source rock quality. Figure 5 shows a plot of soluble organic matter (SOM) against depth in the Kadaru-1 well and showed that there is no corresponding increase of source bed maturation of organic matter with respect to the depth of burial, and the general average results of the parameters analyzed are relatively of poor source rock quality.

Figures 6 and 7 show the plot of petroleum compounds against depth of burial in the two studied wells and reveal that the hydrocarbon compounds (SHC&AHC) have relatively low values compared with the nonhydrocarbon compounds (NSO) which has much higher values in most of the strata and the high peaks further show that this nonhydrocarbon compounds (heteroatomic/heterocompounds) contain molecules common to living organisms such as, lignin (wood-derived), carbohydrates and amino acids. Many of the heterocompounds present in organisms are converted to hydrocarbons during diagenesis and catagenesis (Hunt, 1996).

The high peak of NSO against SHC & AHC in Kadaru-1 and Herwa-1 wells (Fig. 6&7) show that the microorganism (anaerobes) utilized sulfate and nitrate ions instead of molecular oxygen as electron acceptors in their metabolic processes and survived underanoxic condition (oxygen-depleted), which is shown by the dark gray and black colour which is exhibited by most of the marine and transitional facies in the studied wells and depicts organic rich sediments and Waples (1981) reported such colours as an indication of anoxic condition.

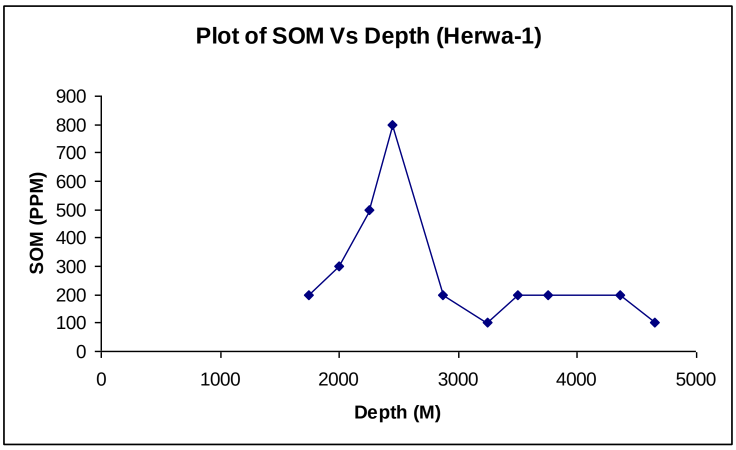

Fig. 4 Plot of soluble organic matter against depth for Herwa-1 well

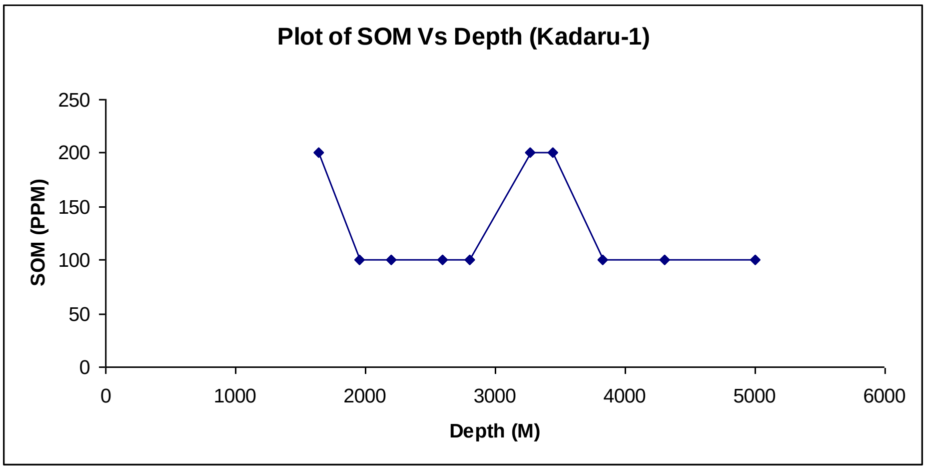

Fig. 5. Plot of soluble organic matter against depth for Kadaru-1 well

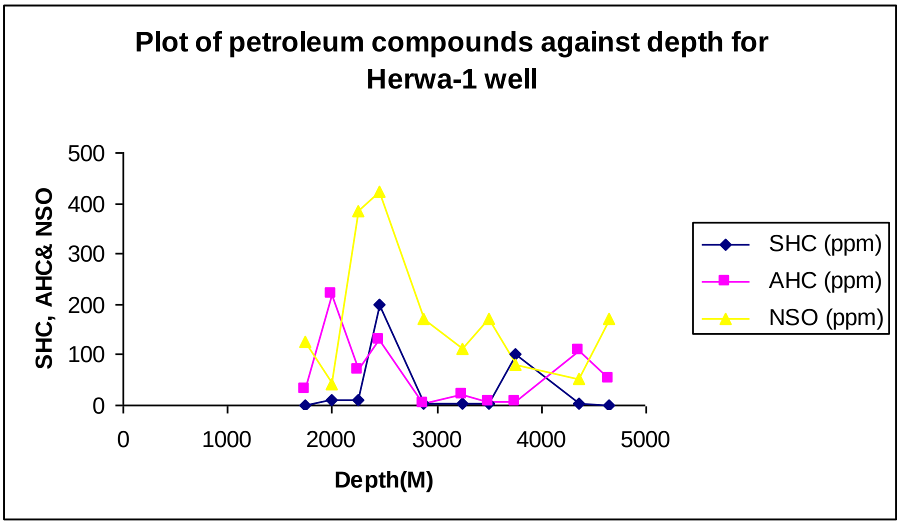

Fig. 6. Plot of petroleum compounds against depth for Herwa-1 well

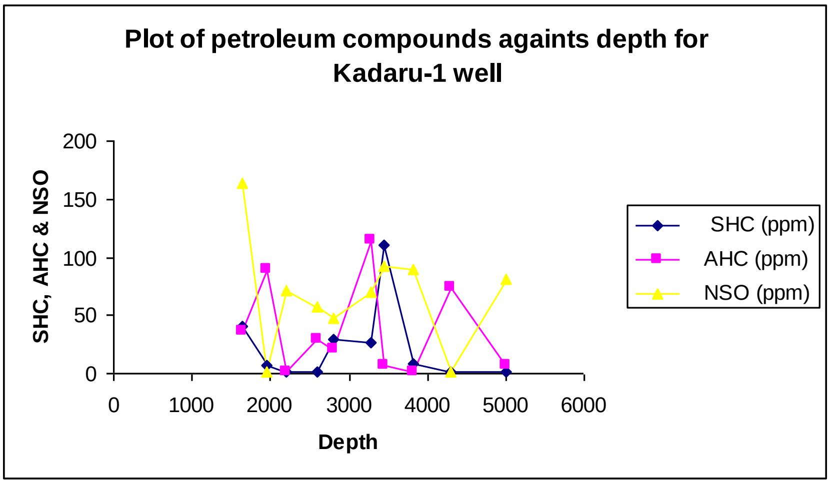

Fig. 7. Plot of petroleum compounds against depth for Kadaru-1 well

The evaluation of the degree of thermal evolution of the sedimentary organic matter and depth with respect to SOM, SHC, AHC, and NSO are presented in Tables. 2 & 3 are generally having low values and do not show any significant trends with burial depth. These low values were also reported by Petters and Ekweozor (1982), Idowu and Ekweozor (1989) and Idowu and Ekweozor, (1993). In this investigation traces of intrusives were observed in Kadaru-1 well and this may suggest that there has been high paleotemperature which may have exceeded the gas deadline and may have overcooked the source rocks due to high temperature generated by the intrasedimentary intrusives, otherwise there would have been an increasing maturation of organic matter with depth of burial. Furthermore it has been observed in Herwa-1 well that there is no significant increase, and relationship between the source organic quality concentrations of soluble organic matter and the depth of the facies below the source bed, i.e., between (1745-2450) m.

It is apparent that in terms of concentrations, thermal maturity of sedimentary organic matter, the samples selected from the Fika Shale are generally thermally immature within vast sections of the lithostrata. Therefore, the potential source beds occur in Herwa-1 well and lies between (1745- 2450) m and are mainly gas prone as was previously reported by Petters and Ekweozor (1982); Idowu and Ekweozor (1989); Idowu and Ekweozor (1993); Obaje *et al.,* (2004) and Waples (1980) reported that the upper limit of wet gas generation starts from the depth of 1500ft (457.2) m to 65,000ft (19,812) m which is the dry gas preservation deadline.

Much higher percentage (%) values of NSO compounds occur in combination with the hydrocarbon compounds (Tables 5&6). They disproportionately increase the non-hydrocarbon fraction of a crude oil by being incorporated in the molecules (Hunt, 1996) and give the oil a higher specific gravity, since these elements are heavier than carbon and hydrogen.

The "oil window" deduced from the Herwa-1 well (1745- 2450) m is not far from those proposed by Genik (1993) who suggested that the "oil window" in the West African Rift Subsystems is around 2500- 4000 m. Thomas (1996) estimated the threshold of the "oil window" in the Bornu basin (the Chad basin in Nigeria) to be at a depth of 2000m, or just below the intra-Maestrichtian unconformity, and it is comparable to the 2000- 4000 m interval (the mature zone) in the Middle Benue trough (Nwachukwu, 1985). The thickness of the "oil window" in the Nigerian sector of the Chad basin appears to be much reduced compared to the Niger Delta (Olugbemiro *et al.,* 1997), where 2,200- 7,000 m has been estimated to be the oil-generative "window" (Ejedawe and Okoh, 1981).

PETROLEUM POTENTIALS

This sector of Nigeria's inland basins is one part in a series of Cretaceous and later rift basins in Central and West Africa whose origin is related to the opening of the South Atlantic. Commercial hydrocarbon accumulation has recently been discovered in Chad and Sudan within this rift trend (Obaje *et al.,* 2004).

The Fika Shale Formation has the best potential with TOC and S_1+S_2 values that are characteristics of a fair source rock (Tissot and Welte, 1984; and Obaje *et ai.,* 2004). Okosun (2000) reported that the Fika Shale and the shale unit of Gongila Formation are good source rocks capable of hydrocarbon generation. Petters and Ekweozor (1982) stated that it is evident that the Fika Shale of the southeastern Chad basin is a good source rock, and the highly terrrigenous character of these mature shales, evident from their low n-alkane ratio, indicates that mainly wet gas might have been generated, but also the marine shale is capable of generating liquid hydrocarbon. The Chad basin which attains a thickness of 10km and formed as a rift, and many rifted basins have high geothermal gradients and traps for hydrocarbon (Avbovbo *et al.,* 1986) and 35% of rifted basins contain giant oil fields (Klemme, 1980).

Reservoir may be provided by shelf sandstone facies of the Gongila Formation and Fika Shale. Santonian and Maestrichtian deformations were quite intense in the Benue trough (Benkhelil, 1989) and also affected many parts of the Chad basin. Rapid facies changes are also characteristics of the successions. Traps are therefore likely to be a combination of structural and stratigraphic. Juxtaposition (vertical movement) of sandstone facies against shaley source rocks as a result of block faulting that produced numerous horst and graben structures in this basin can provide good drainage for generated hydrocarbons (Obaje *et al.,* 2004) and this hydrocarbon can be trapped in the thick underlying Bima Sandstone.

There is a real possibility that kerogen-rich non-marine basal Albian- Aptian basin fill lacustrine source rocks, as found in the Doba basin (Thomas, 1996) could be present in the deepest section in the Nigerian sector of the Chad basin, which have not yet been penetrated (Obaje *et al.*, 2004).

This study investigates the Fika Shale for its SOM, SHC, AHC, and NSO, and found their relative values of good source bed capable of generating hydrocarbon. The "oil window" occurs between the depth (1745- 2450) m in the Herwa-1 well.

Odusina *et al.,* (1993) on the basis of seismic interpretations suggested seven possible types of trapping mechanisms. These are hydrocarbon entrapment updip against intrusive rocks, anticlinal trap, graben structural entrapment, unconformity, onlap structural trap, growth faults and basement traps. The high angle normal faults in the basin could serve as structural trapping mechanism (Okosun, 2000) and the long distance separating the Chad Formation sands and the mature shales of the Fika Shale might be a constraint to hydrocarbon entrapment.

MODEL OF SEDIMENTATION OF ORGANIC MATTER WITHIN THE FIKA SHALE

Sedimentation is thought to have taken place in the Chad basin in a trophical climate with marine transgression from either or both the Tethys Sea and the South Atlantic Ocean (Carter *et al.,* 1963; Burke *et al.,* 1972; Kogbe, 1976; and Popoff *et al.,* 1986). This unit is said to have been deposited during the lower- Turonian by an epicontinental sea which flooded the southern Chad basin from the South Atlantic (Petters, 1978) or the Tethys Sea (Popoff *et al.,* 1986). There is low diversity of benthic assemblage, paucity of planktonic species and dwarfed nature of the foraminifera, all attest to shallow marine conditions (Petters, 1978; Olaleye, 1983; Petters and Ekweozor, 1982). This then implies that sedimentation took place at mainly oxic water column (Idowu and Ekweozor, 1993).

The sporadic occurrence of glauconite in some sections of the Fika Shale and predominance of low molecular weight n-alkanes (nC_{13}- nC_{23}) in the sediments support the literature opinion that the Fika Shale is exclusively marine (Carter *et al.,* 1963;Idowu and Ekweozor, 1993). Furthermore, the relatively high Pr/Phy values (>1.0), low TOC and

SOM (0.9% and 195ppm respectively) as well as virtual absence of biodegraded algae in the various shales can be inferred that the lithostratigraphic unit was laid down under mainly oxic conditions (Idowu and Ekweozor, 1989). The top of the Fika Shale marked the final withdrawal of the sea.

CONCLUSION

This study focuses on only two exploratory wells out of the 23-drilled holes, which may not be sufficient enough to draw general conclusions on the petroleum prospect of the Chad basin. However, it proves that the Fika Shale has matured source rock as reveal by its high SOM, SHC & AHC values between (1745- 2450)m, but has lower values of the same parameters in most of the investigated strata and this showed that there is a relatively immature source rocks in majority of the sections, whereas the relatively high values of NSO incorporated in the hydrocarbon suggests a much higher specific gravity and predominates the hydrocarbon compounds.

REFERENCES

AJAKAIYE, D. E., and BURKE, K., 1973: A bouguer Gravity map of Nigeria: *Tectonophysics,* 16, 103-115.

AVBOVBO, A. A, EYOOLA, E. O., and OSAHON G. A., 1986: Depositional and structural styles in Chad basin of northeastern Nigeria. *American Association of Petroleum Geologists,* Bulletin, 80, 1787-1798.

BENKHELIL, J., 1989.The evolution of the Cretaceous Benue Trough, Nigeria. *Journal of African Earth Sciences*, 8, 251- 282.

BURKE, K. C., 1976b: Development of graben associated with the initial rupture of the Atlantic Ocean. I.: sedimentary basins of continental margins and cratons (Ed. By M. H. P BOTT), *Tectonophysics*, 36, 93- 112.

BURKE, K. C., DESSAUVAGIE, T. F. J., and WHITEMAN A. J., 1970: Geological History of the Benue Valley and adjacent areas, in T. F. J. DESSAUVAGIE and A. J. WHITEMAN, eds. African geology, Cretaceous rocks of Nigeria and Adjacent areas: Ibadan, Nigeria. *University of Ibadan press*, 187- 205.

BURKE, K. C., DESSAUVAGIE, T. F. J., and WHITEMAN, A. J., 1972. Opening of the Benue depression and Niger Delta, *Natural Physical Science*, 233(23), 51-55.

CARTER, J. D., BARBER, W., and TAIT. E. A., 1963: The geology of parts of Adamawa, Bauchi, and Bornu Provinces in northeastern Nigeria: *Geological Survey of Nigeria*, Bull. 30, 99.

CRATCHLEY, C. R., and G. P. JONES., 1965. An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria; *Overseas Geological Survey*, Geophysical Paper. 1, 26.

EJEDAWE, J. E., and OKOH, S.U., 1981. Prediction of optimal depths of petroleum occurrence in the Niger Delta basin. *Oil and Gas Journal.*, June 8, 190- 204.

FAIRHEAD, J. D., and BLINKS, R., 1991. Differential opening of the Central and South Atlantic Oceans and the opening of the West African rift-system. *Tectonophysics*, 1987, 191- 203.

FRANKS, S. and NAIRN, A. E. M., 1973. The equatorial marginal basins of West Africa. In. NAIRN, A. and STEHLI, F. (Eds), the ocean basins and margins. *The South Atlantic Plenum press*, 301- 350.

FURON, R., 1963. Geology of Africa. *Oliver and Boyd*, London. 377

GENIK, G. J., 1993. Petroleum Geology of Cretaceous-Tertiary rift basins in Niger, Chad and Central African Republic. *American Association of Petroleum Geologists*, Bull. 77 (8) 1405- 1434.

GUIRAID, M. 1990. Tectono-sedimentary framework of the Early Cretaceous continental Bima Formation (Upper Benue trough, NE, Nigeria). *Journal of African Sciences*, 10, 3410353.

GUIRAUD, M. 1991. Mechanisme de formation du basin Cretace Sudecrochements multiples de la Haute- Benoue (Nigeria). *Centres Rech. Explor-Prod*, Elf- aquintaine, 15,, 11-67.

HAMZA, H., OBAJE, N. G., and OBIOSO, E. O., 2002. Foraminiferal assemblage and palaeoenvironment of the Fika Shale, Bornu Basin, Northeastern Nigeria. *Journal of Mining and Geology,* 38(1) 49- 55.

HARTLEY, R. W., and ALLEN, P.A., 1994. Interior cratonic basins of Africa: Relation to continental break- up and role of mantle convection. *Basin Research*, 6, 95- 113.

HUNT, J. M., 1996. Petroleum geochemistry and geology. Second edition. *W. H. Freeman and Company*, 743.

IDOWU, J. O., and EKWEOZOR, C. M., 1989. Petroleum geochemistry of some Upper Cretaceous shales from Upper Benue Trough and southern Chad basin, Nigeria, *Journal of Mining and Geology*, 26, 1&2, 131- 151.

IDOWU, J. O., and EKWEOZOR, C. M., 1993. Preliminary organic geochemical analysis of some Upper Cretaceous formations from Southwest Chad basin. *Nigerian Association of Petroleum Explorationist,* 8/01, 48- 60.

KLEMME, H. D., 1980. Petroleum classification and descriptions: *Journal of Petroleum Geology*, 3, *187*- 207.

KLEIN, G. D., and Hsui, A. T., 1987. Origin of intracratonic basins: *Geology,* 15, 1094-1098.

KOGBE, C. A., 1976. Paleogeographic history of Nigeria from Albian times, in: Geology of Nigeria, Kogbe, C. A (ed) *University of Ife Press*, 237- 252.

LEES, G. M. 1952. Foreland Folding: *Quarterly Journal of Geology Society*, London, 108.

LEIGHTON, M. W., and KOLATA, D. R., 1990. Selected interior cratonic basins and their place in the scheme of global tectonics: a synthesis: *American Association of Petroleum Geologists Memoir*, 51, 729- 797.

MATHEIS, G. 1986. Short review of the geology of the Chad basin in Nigeria, in C. A. KOGBE (ed). Geology of Nigeria: *Elizabeth Publishing*, Surulere Nigeria. 289- 294.

NUR, A. 2001. Spectral analysis and Hilbert transformation of gravity data over the Southwest of Chad basin, Nigeria. *Journal of Mining and Geology*, 37(2), 153- 161.

NWACHUKWU, J. I., 1985. Petroleum prospects of Benue trough, Nigeria. *American Association of Petroleum Geologists*, Bulletin., 69(4), 601- 609.

OBI, G. C., 1998. Upper Cretaceous Gongila Formation in the Hawal Basin, NE Benue trough: A storm and wave dominated regressive shoreline complex. *Journal of African Earth Sciences,* 26(40) 619- 632.

OBAJE, N. G., WEHNER, H., HAMZA, H. and SCHEEDER, G., 2004. New geochemical data from the Nigerian sector of the Chad basin: implication of hydrocarbons prospectivity. *Journal of African Earth Sciences,* 38, 477- 487.

ODUSINA, A. A., MUBARAK, S. O., BEKA, F. T., and NWANGWU, U., 1993. Gelogy and petroleum potential of the Nigerian sector of the Chad basin. Res. Bulletin. 111, *Exploration Section (R&D, Project N0.ER/RD/43*. NNPC, Port Harcourt, 47.

OKOSUN, E. A. 1995. Review of the geology of Borno Basin. *Journal of Mining and Geology*, 31(2), 113- 122.

OKOSUN, E. A. 2000. A preliminary assessment of the petroleum potential from Southwest Chad basin, Nigeria. *Borno journal of Geology*, 2, 40- 50.

OLALEYE, B. A., 1983. Microstratigraphy and paleoenvironments of the Fika Area, Borno State of Nigeria. Unpublished M. Sc. Thesis, University of Ibadan.

OLUGBEMIRO, R. O., LIGOUIS, B., and ABAA, S. I., 1997. The Cretaceous Series in the Chad basin, NE, Nigeria: source rock potential and thermal maturity. *Journal of Mining and Geology*, 20(1), 51- 68.

PETTERS, S. W., 1978. Central West African Cretacoeus- Tertiary benthic foraminfera and stratigraphy. *Palaeontographica*, A, 179, 1- 104.

PETTERS, S. W., and EKWEOZOR, C. M., 1982. Petroleum Geology of Benue trough and Southeastern Chad basin, Nigeria. *American Association of Petroleum Geologists*, 66, 1141- 1149.

POPOFF, M., WIEDMAN, J., and DE-KLASZ, I., 1986. The Upper Creyaceous Gongila and Pindiga Formations, Northeastern Nigeria: Subdivisions Age, Stratigrapic correlations and palaeogeographic implications. *Eclogne Geological Helv*, 79(2) 343- 363.

THOMAS, D., 1996. Benue trough and the mid- African rift system: Nigeria-5. *Oil and Gas Journal.,* Jan 29, 1996, 102- 105.

TISSOT, B. P., and WELTE, D. H., 1984. Petroleum Formation and Occurrence. 2nd Ed., Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 699.

WAPLES, D. W., 1980. Time and temperature in petroleum formation: Application of Lopatin's method to petroleum exploration. *American Association of Petroleum Geologists*, 64(6), 916- 926.

WAPLES, D, W., 1981. Organic geochemistry for exploration geologists. *Burgess Publ. Com, Mineapolis*, 151.