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HYDROCARBON RESOURCE POTENTIAL OF THE BORNU BASIN NORTHEASTERN NIGERIAN

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ABSTRACT

The separation of Africa from South America was accompanied by rifting and sinistral strike-slip movements that formed the Bornu Basin. The Bornu Basin form part of the West African Rift System. Geochemical analyse of samples from the Fika Shale shows that eighty percent of the samples have TOC values >0.5 wt%. Plots on the modified Van Krevelen diagram indicate organic matter that is predominantly Type III kerogen. A corresponding plot on the HI–T_{max} diagram indicates an entirely gas generative potential for the source rocks.

In the Bornu Basin which belongs to the West African Rift Subsystem (WARS) two potential petroleum systems are suggested. "Lower Cretaceous Petroleum System" – is the phase 1 synrift sediments made up of sandstones with an extensive system of lacustrine deposits developed during Barremian to Albian time. "Upper Cretaceous Petroleum System" – is the phase II rift sediments in the Bornu Basin which comprise mainly shallow marine to paralic shales, deltaic to tidal flat sandstones and minor carbonates. TOC values range generally from 0.23 wt. % to 1.13 wt. % with an average of 0.74 wt. % for the Fika Shale.

KEY WORDS: Bornu Basin; Fika Shale; Source rocks; Organic matter; Petroleum System.

INTRODUCTION

Exploration started in the Bornu Basin in the Gajigana area northeast of Maiduguri in 1979, when feasibility studies indicated the possibility of oil occurrences in the area. In the neighbouring Chad Republic a total of 43 wells were drilled before oil was found in commercial quantities. The Nigerian National Petroleum Corporation through its frontier exploration services arm (NAPIMS) had by that time drilled 23 wells in the Bornu Basin, of which only two wells encountered sub-commercial volumes of gas. Chevron Overseas Petroleum Inc's exploration programme in the Muglad Basin of Sudan was a good example of a successful drilling campaign in a remote, high risk and high cost area. This success together with commercial discoveries in the Chad and Niger Republics encouraged Chevron Nigeria Ltd, Elf Nigeria Ltd and Shell Nigeria Exploration and Production Company Ltd to acquire exploration leases in Nigeria's Gongola Basin in the upper Benue Trough in 1992. Exploration efforts in Nigeria's inland basins have so far resulted in little success. Many international companies have therefore turned their focus away from the Nigerian onshore to deep and ultradeep-water offshore frontier areas. But recently the Northern Nigerian Development Company (NNDC) in partnership with Chinese Company had acquired exploration lease/blocks in the Bornu Basin and exploration has resumed.

The Nigerian sector of the Chad Basin is known as the Bornu Basin and is one-tenth of the total area of the Chad Basin (Figure 1). It is contiguous with the N–S aligned part of the upper Benue Trough called the Gongola Arm or Gongola Basin. The Benue Trough and Bornu Basin form an integral part of the "West and Central African Rift System" (WCARS) of Fairhead (1986) and subsequent authors (Guiraud *et al.*, 1992; Genik, 1993; Keller *et al.*, 1995). Commercial volumes of hydrocarbons have been discovered in Chad and Sudan within the CARS rift. In southwestern Chad, exploitation of the Doba discovery (with estimated reserves of about 1 billion barrels) by Exxon-Mobil has led to the construction of a 1,070 km long pipeline through Cameroun to the Atlantic coast. In the Sudan, giant fields such as Unity 1 and 2, Kaikang and Heglig have been discovered in the Muglad Basin (Mohammed *et al.*, 1999). Major source and reservoir rocks in the Muglad Basin occur in continental Aptian to Cenomanian deposits of the Abu Gabra and Bentiu Formations respectively and can be correlated with the Bima Sandstone in the Bornu Basin. In Niger Republic, oil and gas shows have also been encountered in Mesozoic to Cenozoic sediments in the east Niger graben. Exploration efforts in the Bornu Basin have had negligible success. For this reason, many aspects of the exploration programme have been temporarily suspended and the vast amount of data generated over the years is being evaluated to assist in designing a future exploration programme.

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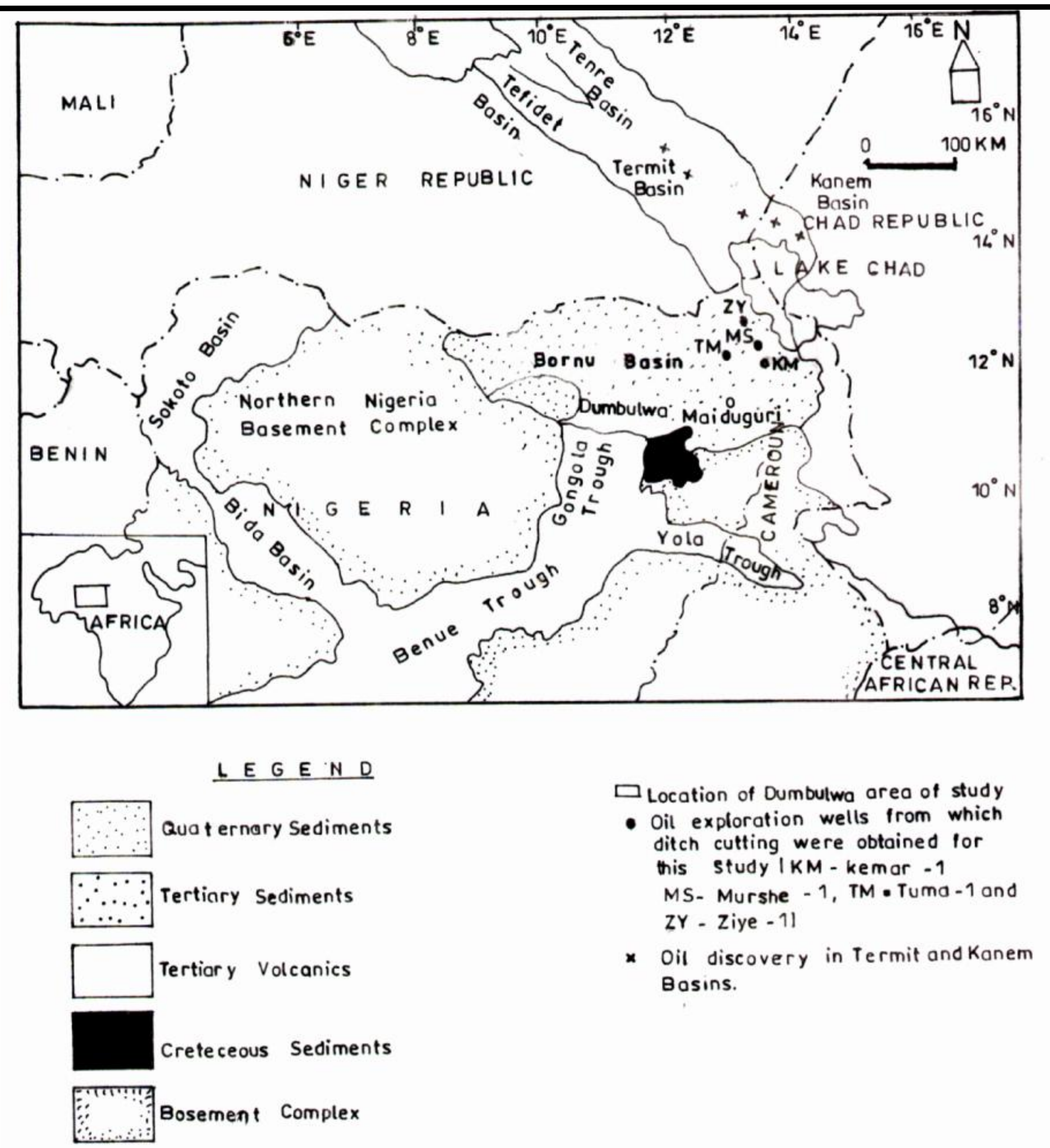


Figure 1: Geological map of part of Nigeria showing location of Bornu Basin, adjacent rift basins and study areas.

With this development, it has become necessary to evaluate the prospectivity of this frontier region, especially the availability or otherwise of favourable petroleum systems. Analysis of source rocks is an essential step in understanding the petroleum systems that may be available in the basin. At the core of any petroleum system is a good quality source rock which is an indispensable aspect in the buildup of any petroleum system (total organic carbon [TOC] >0.5 wt. %, hydrogen index [HI] >150 mg Hc/g TOC, liptinite content > 15%, Tmax ≥ 430°C, and Ro 0.5 – 1.2%). In this regard, geochemical data on samples from outcrops and wells in the Bornu basin have been evaluated by Petters and Ekweozor (1982); Olugbemiro (1997); Olugbemiro *et al*., 1997); Obaje *et al*. (2004a, 2004b) all confirmed the gas-prone nature of the source rocks. Other petroleum system elements must include reservoir and seal lithologies, establishable trapping mechanisms and favourable regional migration pathways. This paper highlights the potential petroleum systems in the basin based on geochemical data from four exploration wells Murshe-1, Tuma-1, Ziye-1 and Kemar-1 (Figure 1).

ORIGIN, STRUCTURE AND STRATIGRAPHY OF THE BORNU BASIN

The N-S trending Gongola Basin which is the northern-most outcroping part of the Benue Trough is separated from the Bornu Basin by the Dumbulwa-Bage High. The Cretaceous to Tertiary rifts of Niger, Chad, Central African Republic and Nigeria make up a large part of the "West and Central African Rift System" (WCARS) of Genik (1993) which is subdivided into two coeval, genetically related but physically separated rift systems known as the West African Rift Subsystem (WARS) and Central African Rift Subsystem (CARS). The Bornu Basin is part of the chain of the WARS basins. The origin of the WCARS is generally attributed to the breakup of Gondwana and the opening of the South-Atlantic Ocean and the Indian Ocean at about 120-130 Ma (Fairhead and Green 1989) (Figure 2a, b). The tectonic framework and the evolution of the Bornu

Basin took place during the evolution of the WARS basins (Termit and Ténéré Basins) and divisible into four phases as shown in Table 1 (Genik, 1993). Genik (1992, 1993) presented a model for the regional framework and tectonic evolution of the Cretaceous to Tertiary rift basins of Niger, Chad and the Central African Republic (C.A.R) which advances the concept proposed earlier by Fairhead (1986) that oceanic strike-slip faults extended into Africa and produced the orthogonal extension that opened the Niger and Sudanese rifts.

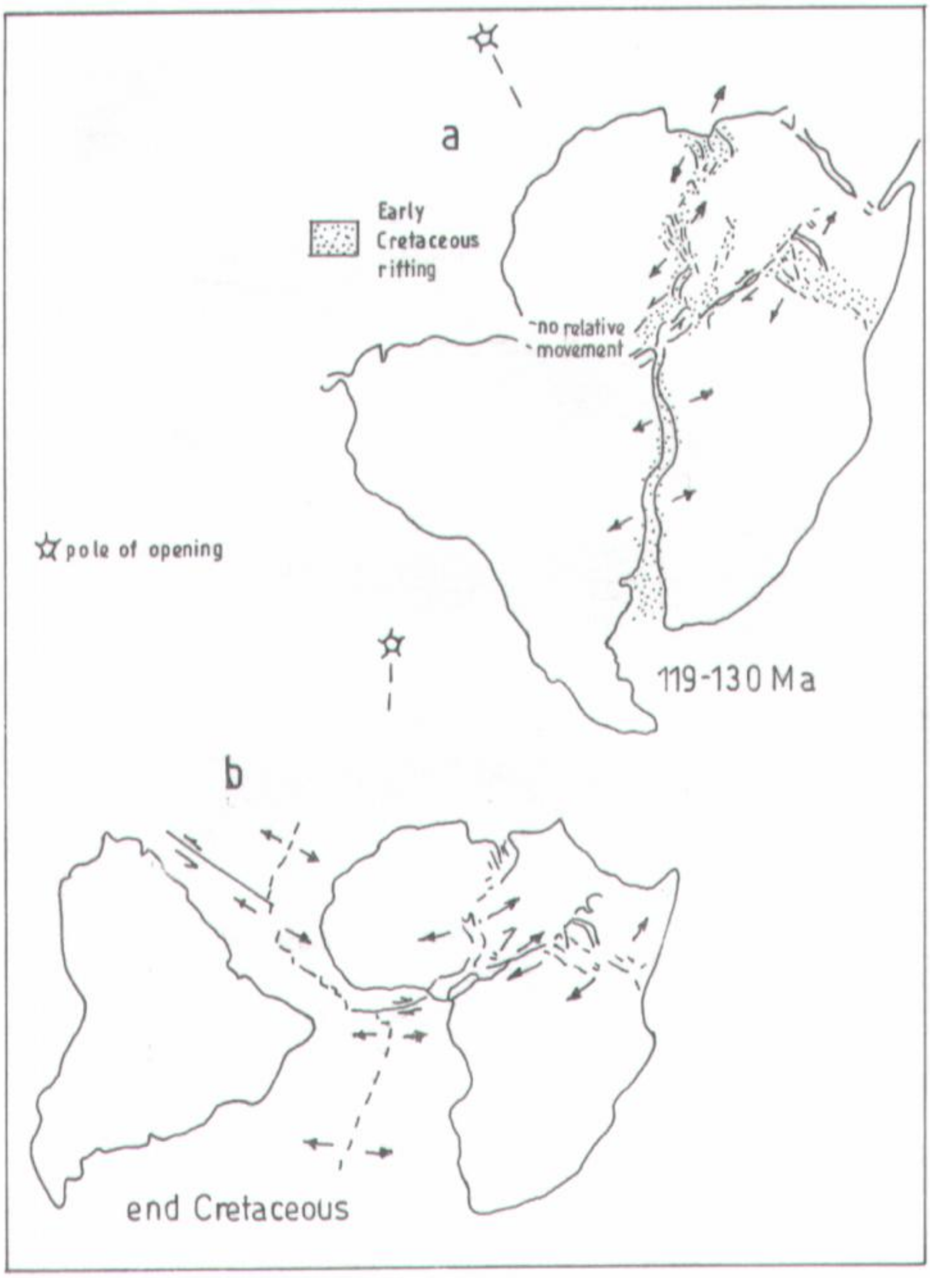
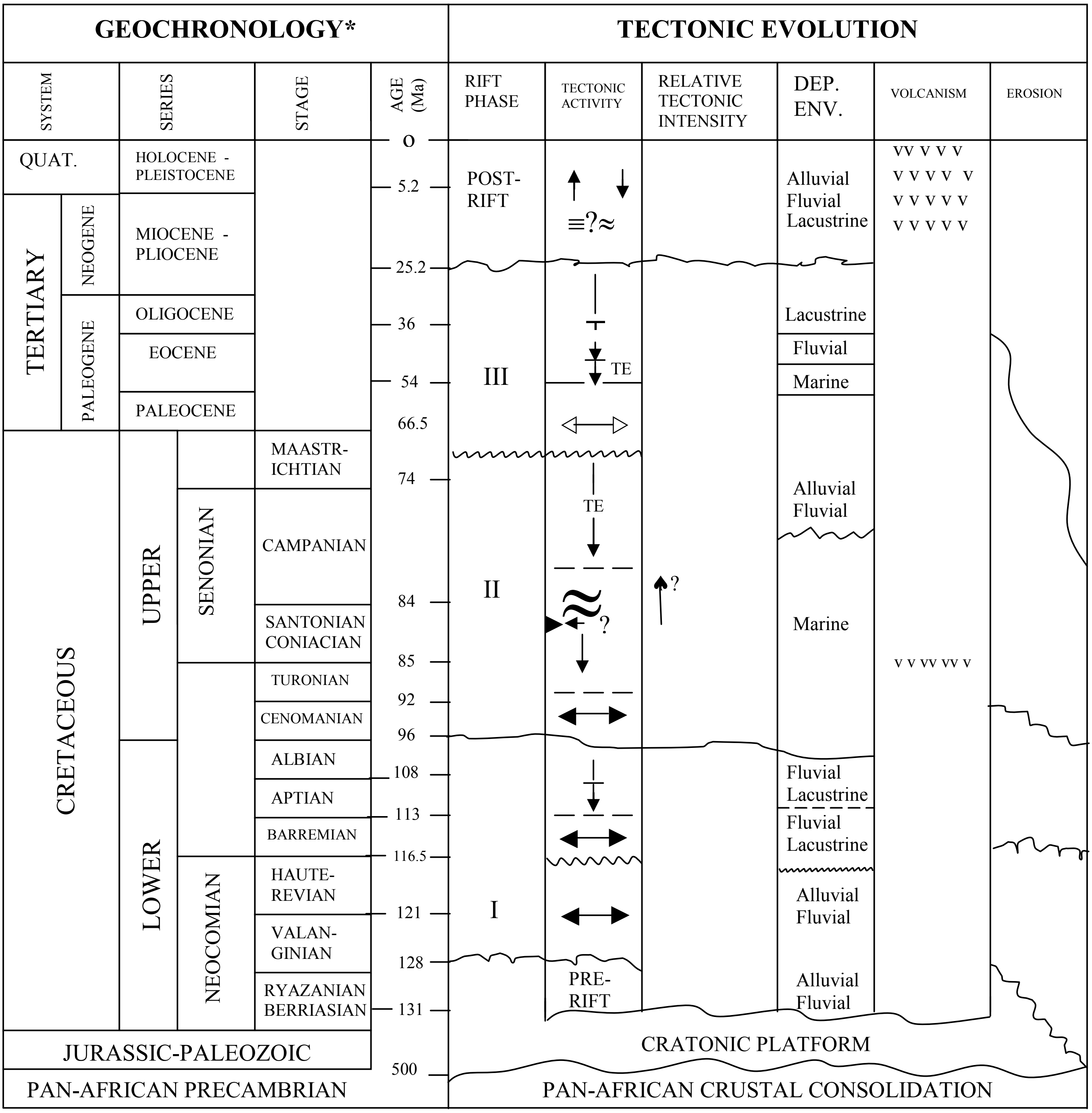


Figure 2: a, Model showing the possible extension of the opening of the South Atlantic through Nigeria and eastern Niger into Kufra and Sirte Basins in Libya (After Fairhead and Green, 1989). b, Model showing the possible link between the opening of the central Equatorial and South Atlantic Oceans and development of the Caribbean and WCARS during the Late Cretaceous, (After Fairhead and Green, 1989).

Table 1: Paleotectonic evolution of the West African Rift Subsystem (WARS) as it affected the Bornu Basin (Genik, 1993)



LEGEND

↔ Extension

Possible Compression

Dextral Transtension

Sinistral Transtension

Uplift or relative structural high

v Igneous

Sag. Thermo-tectonic

E Sag. Eustatic & Thermo-teconic

* After Haq *et al*. (1987)

Cratchley and Jones (1965) recognized an ovoid-shaped negative Bouguer gravity anomaly north of Maiduguri (Figure 3a). Combining gravity data with seismic refraction studies, Cratchley *et al*. (1984) identified a "Maiduguri Trough", thought to contain some 3000m of Cretaceous and Quaternary sediments, running NNE from near Maiduguri in Bornu Basin and connecting with the Termit rift (Figure 3b). Two main fault systems were identified by Avbovbo *et al*. (1986); a dominant NE-SW trending and a subsidiary NW-SE trending set. Umar (1999) recently studied the structure of the Bornu Basin and indicated the presence of three major depressions: (1) the elongated oval depression oriented WNW-ESE, C1; (2) the elongated depression oriented NNE-SSE, C2; (3) a tabular zone between the two above, C3 (Figure 4). The two depressions correspond to depocentres or sub-basins. In the C1 depression, Umar (1999) identified Maiduguri and Gubio sub-basins to the SE and NW respectively. The C2 depression corresponds to the "Lake Chad sub-basin".

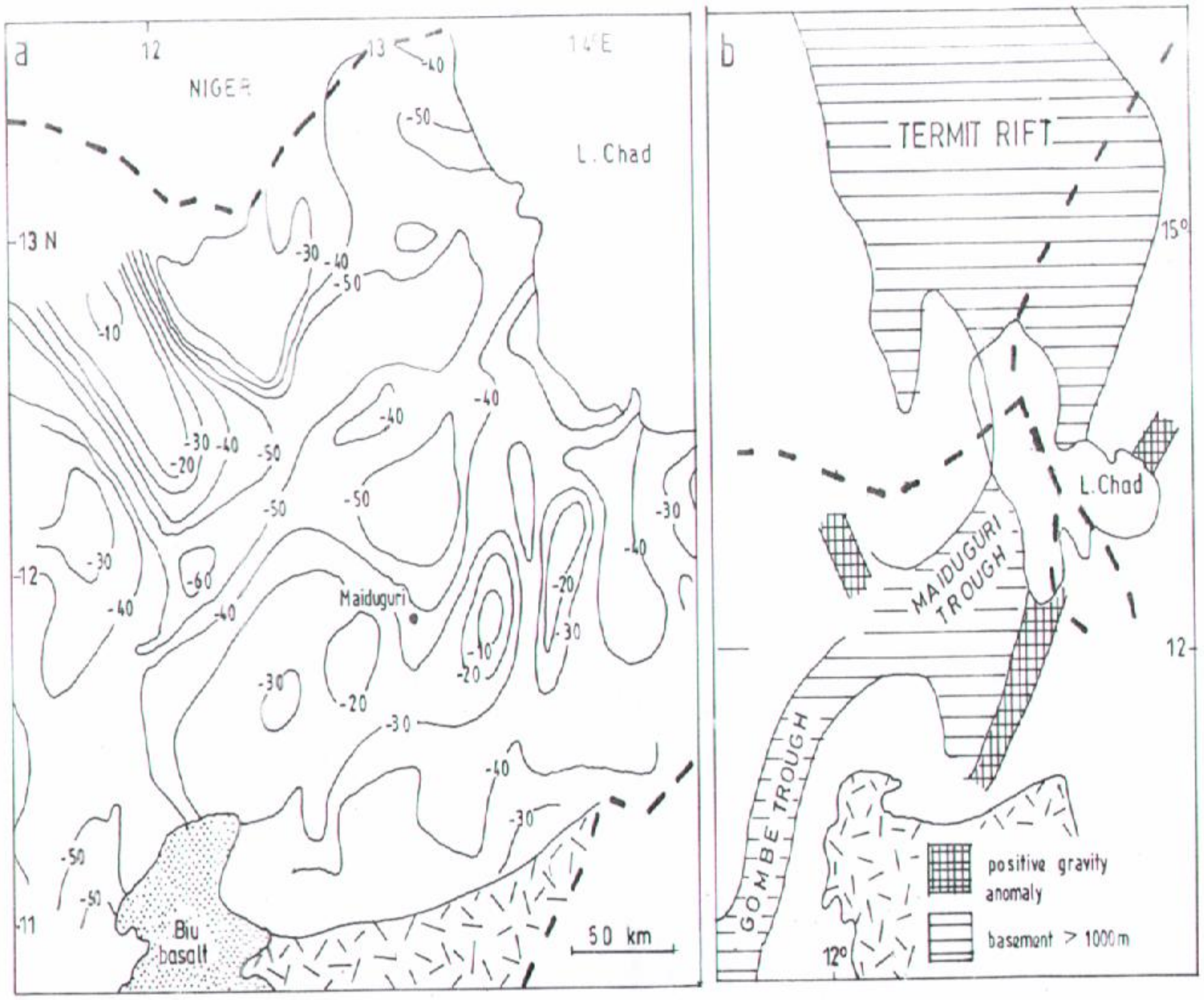


Figure 3: a, Bouguer gravity anomaly map of the Bornu Basin (Contours at 10mGal intervals) (Simplified from Cratchley *et al*., 1984 and Avbovbo *et al*., 1986). b, Generalized structural interpretation of the Bornu Basin and adjacent areas on basis of geophysical data (Simplified from Cratchley *et al*., 1984), (After Zaborski *et al*., 1997).

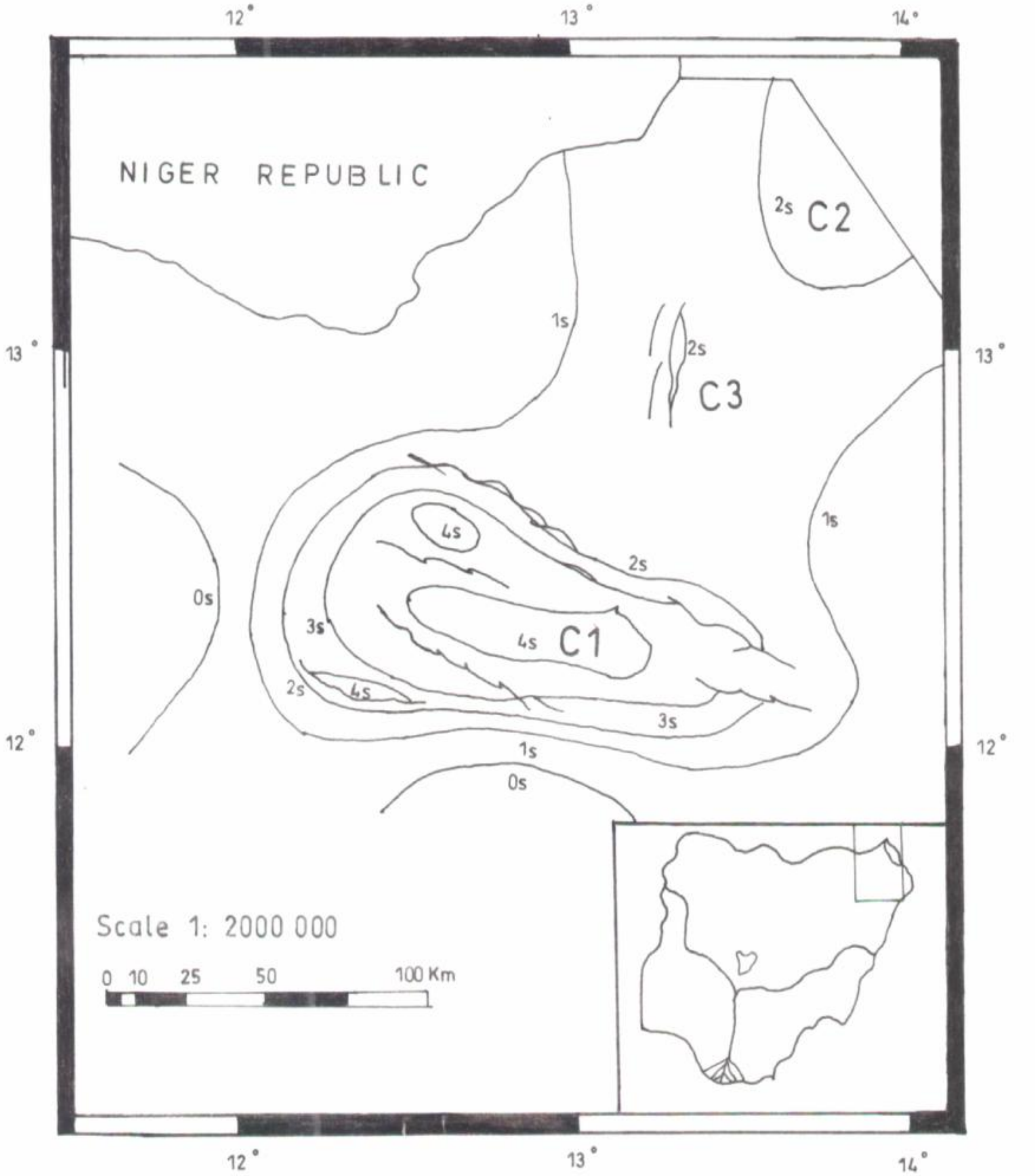


Figure 4: Map of the depth to the basement in the Bornu Basin. Two depressions define the principal depocentres, (After Umar, 1999).

The Cretaceous sediments in the Bornu Basin are almost entirely concealed below the continental Pleistocene Chad Formation. Cretaceous outcrops are confined to its southern periphery. Carter *et al*. (1963) ascribed the outcropping sediments in the southwest of the Bornu Basin previously described by Jones (1932) and Raeburn and Jones (1934) to the Gongila Formation, Fika Shale and Gombe Sandstone. At Damagum and Maiduguri, 100m and 450m respectively of beds belonging to the Fika Shale were identified in boreholes which bottomed within the unit. In the Dumbulwa-Bage High area, Zaborski *et al*. (1997) subdivided the Cretaceous outcrops into the Kanawa, Dumbulwa and Fika Members of the Pindiga Formation above the “lower Bima Sandstone”.

Avbovbo *et al*. (1986) identified seven “seismic sequences” in the Maiduguri depression. Okosun (1995) and Olugbemiro (1997) provided direct lithological data from boreholes located to the north of Maiduguri. Three Cretaceous units were identified by Okosun. Umar (1999) proposed the stratigraphic succession recognizing the Gombe and Kerri-Kerri Formations and proposing different ages for most of the formations as compared with Carter *et al*. (1963) and Okosun (1995). Correlation of the Cretaceous succession in the basin remains controversial. Okosun (1995) and Olugbemiro (1997) respectively suggested Albian to Turonian and Albian to Cenomanian ages for sedimentary unit of the Bima Group; Lower Turonian and Turonian ages for the Gongila Formation; and Turonian to Mastrichtian and Turonian to Santonian ages for the Fika Shale. Although Okosun (1995) indicated that Kanadi-1 well bottomed in the basement rocks, Olugbemiro (1997) reported only the Kinasar-1 well as penetrating the full thickness of the Bima Group and “pre-Bima” beds (Figure 5a, b). Olugbemiro (1997) reported *Heterohelix* from the upper part of the Bima Group in the Mbeji-1 and arenaceous foraminifers were recovered from "Bima" deposits in the Kanadi-1 and Albarka-1 wells. Inspite of all these observations, it is unlikely that the Bima Group was penetrated by the above mentioned wells. The wells actually bottomed within the Fika Shale or the equivalent of what is referred to herein as "Formation 1". Microfossils were only recovered in the present study from the Fika Shale. The earliest Cretaceous marine beds in the upper Benue Trough south of the Bornu Basin and the Mega Chad Basin to the north are Cenomanian (Bellion *et al*, 1989; Genik, 1993).

It is unlikely that the Albian "pre-Bima" shales of Avbovbo *et al*. (1986) are marine deposits or that the "pre-Bima" shales of Olugbemiro (1997) are pre-Albian marine deposits. Olugbemiro (1997) suggested that sedimentation in the Bornu Basin began only in the Albian to Cenomanian. This conflicts with the Gongola Basin and Termit Basin where sediments as old as latest Jurassic occur (Genik, 1993). Further data and correct dating of the sediments in the Bornu Basin is required to resolve these apparent discrepancies. Based on field evidence in the southwestern part of the Bornu basin around the Dumbulwa-Bage High, together with deep borehole lithostratigraphic studies northeast of Maiduguri, a newly proposed lithostratigraphic succession (Hamza, 2007) has been set up (Table 2). This is in agreement with the new proposed lithostratigraphic succession of the Gongola Basin in the upper Benue Trough by Zaborski *et al*., (1997).

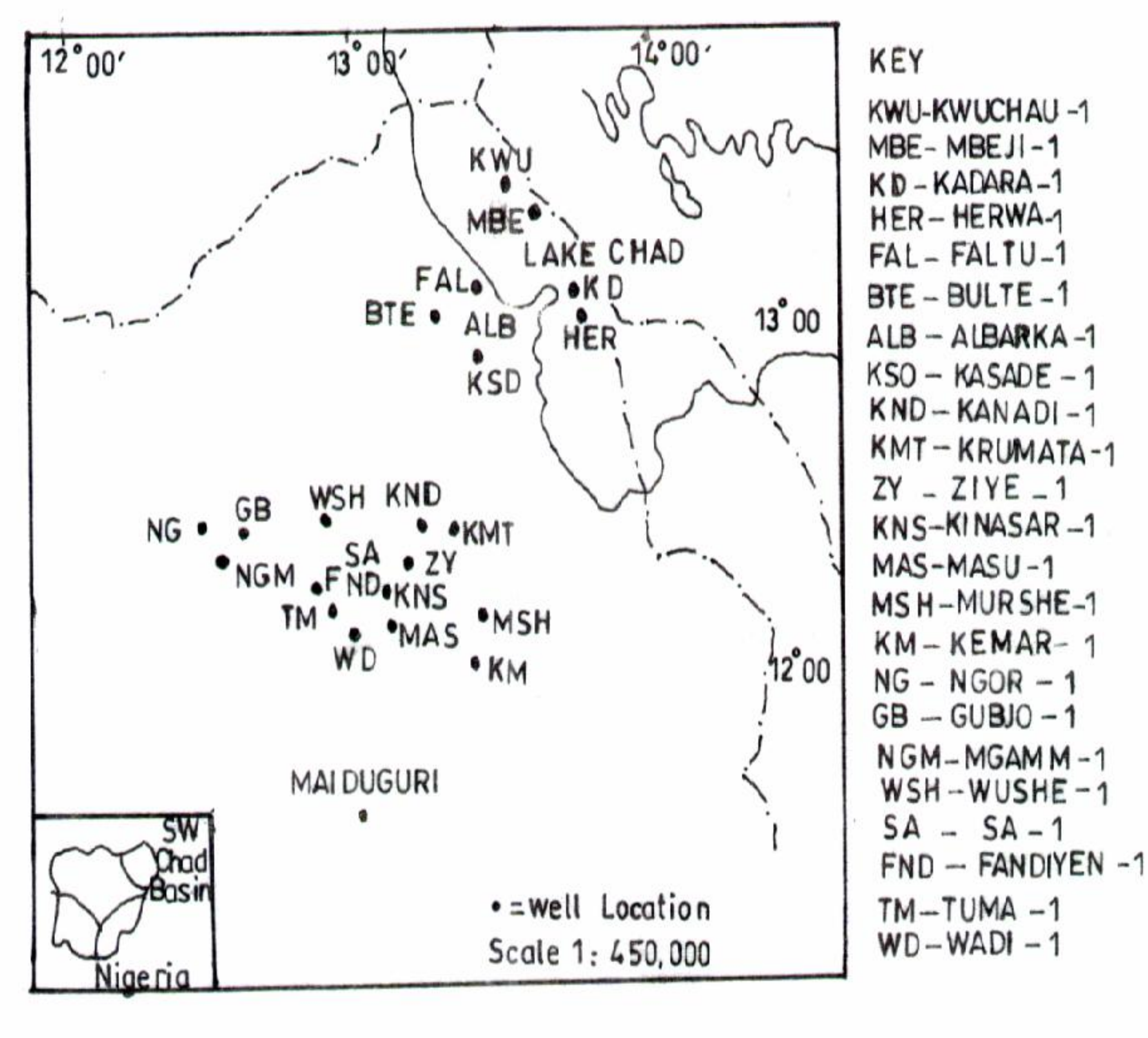


Figure 5a: Location map of exploration wells in the southwestern part of Chad Basin (Insert map illustrates the position of Chad Basin in Nigeria) (After Okosun, 2002).

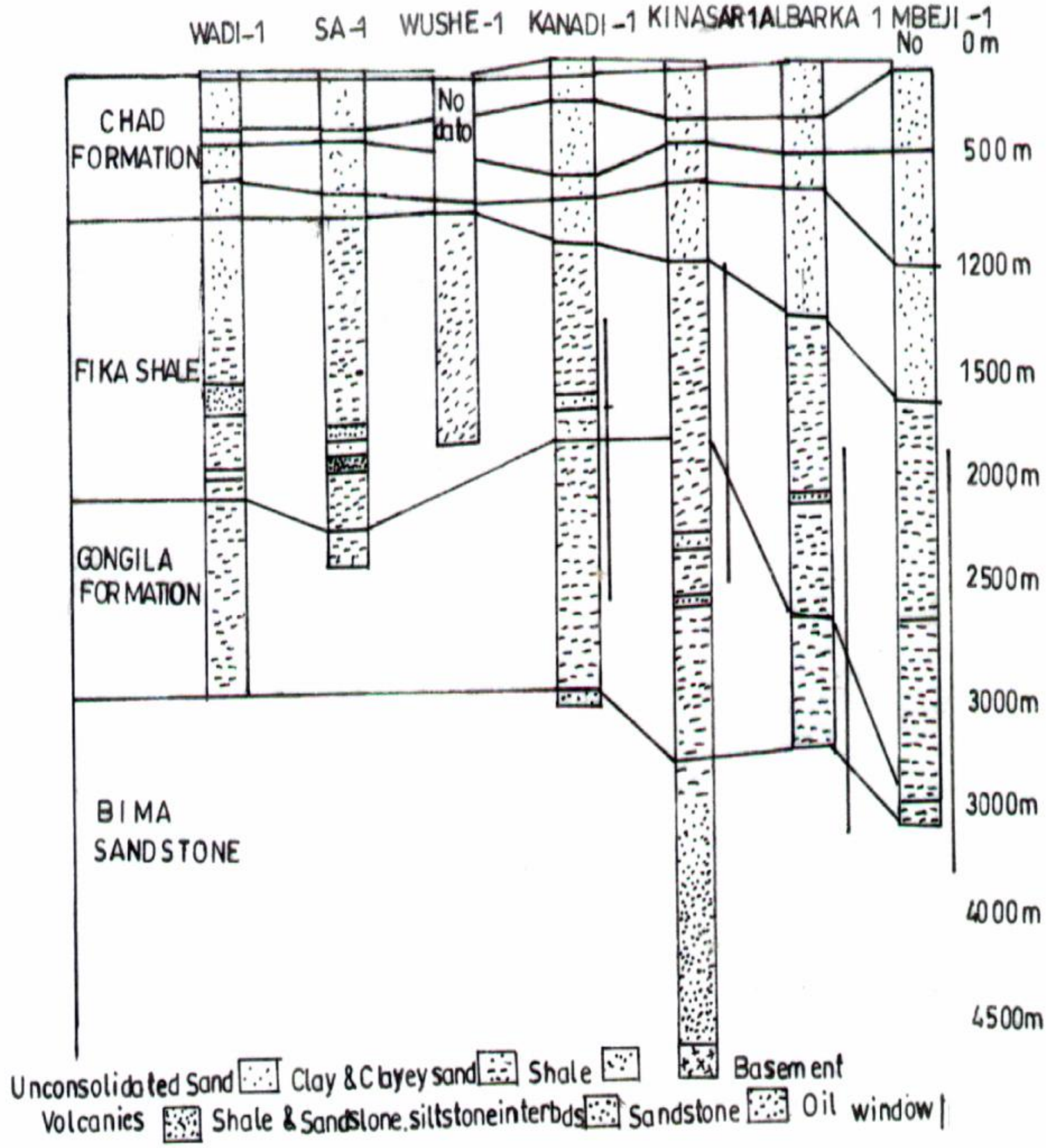


Figure 5b: Stratigraphic profiles of the studied wells Oil Window (After Olugbemiro, 1997).

Table 2: Lithostratigraphical succession for the Bornu Basin proposed herein and compared with that of Carter *et al*. (1963) and Zaborski *et al*. (1997) of the neighbouring Gongola Basin.

ADAPTED HEREIN FROM ZABORSKI *et al*. 1997		CARTER *el al* (1963)		ZABORSKI *et al*. (1997)	
BORNU BASIN		CHAD BASIN (BORNU BASIN)	ZAMBUK RIDGE	GONGOLA BASIN	
Chad Formation	PLEISTOCENE - PLIOCENE	CHAD FORMATION			PLEISTOCENE
Kerri-Kerri Formation	PALAEOCENE-EOCENE	Kerri-Kerri Formation		Kerri-Kerri Formation	PALAEOCENE (at least in part)
Gombe Sandstones	MAASTRICHTIAN	Gombe Sandstones		Gombe Sandstone	MAASTRICHTIAN
FIKA SHALE: "FORMATION 5"	CAMPANIAN	Fika Shale	Gulani Sandstone	PINDIGA FORMATION: Fika ? Unconformity Member	CAMPANIAN
"FORMATION 4"	SANTONIAN				SANTONIAN
"FORMATION 3"	CONIACIAN		Pindiga Formation		CONIACIAN
"FORMATION 2"	TURONIAN: UPPER			Dumbulwa/Gulani/ Deba Fulani Members	TURONIAN: U
	MIDDLE	Gongila Formation	Yolde Formation		M
	LOWER			Kanawa Member	L
"FORMATION 1"	CENOMANIAN	Bima Sandstones		Yolde Formation	CENOMANIAN
BIMA GROUP: "Upper Bima Formation"	ALBIAN	Unconformity		BIMA GROUP: "Upper Bima Formation"	ALBIAN
"Middle Bima Formation"	APTIAN			"Middle Bima Formation"	APTIAN
"Lower Bima Formation"	Pre-APTIAN			"Lower Bima Formation"	Pre-APTIAN
++ ++ ++ Crystaline basement ++	PRECAMBRIAN	++ + + Crystaline basement ++		++ Crystaline ++ ++ basement +++	PRECAMBRIAN

Unconformity

METHODS OF STUDY

Forty three samples from four exploration wells drilled in the Bornu Basin were pulverized and analyzed for total organic carbon (TOC) by means of a LECO-CS analyzer and pyrolyzed in a *Vinci Rock-Eval 6* instrument. The samples for TOC determination were treated with HCl to remove carbonate-bonded carbon before combustion in the LECO-CS analyzer. The general principles of Rock-Eval Pyrolysis were followed. The analysis was carried out in the Organic Geochemistry Laboratory, Institute of Geosciences and Natural Resources, Hannover, Federal Republic of Germany, under the auspices of the Alexander Von Humboldt Foundation Fellowship.

RESULTS AND INTERPRETATION

Table 3 shows the Rock Eval pyrolysis results of samples from studied wells indicating TOC values generally ranging from 0.23 wt. % to 1.13 wt. % with an average of 0.74 wt. % for the Fika Shale in this study. Eighty percent of the samples have TOC values >0.5 wt. %, the minimum limit for hydrocarbon generation. Plots on the modified Van Krevelen diagram of samples from the four wells in the Bornu Basin indicate organic matters that are predominantly of Type III Kerogen (Figure 6). A corresponding plot on the HI–Tmax diagram based on the values given by Peters (1986) indicates an entirely gas generative potential for the samples analyze from the four wells studied (Figure 7). Olugbemiro (1997) obtained values of TOC from 0.07 wt. % to 3.87 wt. % with an average of 0.5 wt. % while Umar (1999) obtained values from 0.18 wt. % to 1.95 wt. % with an average of 0.89 wt. %. Although the potential source rocks of the late Cretaceous sediments in the Bornu Basin are marine in origin, the organic facies are predominantly terrestrial hence low liptinite and high vitrinite-inertinite. Mainly Type III organic matter has been indicated in this study (Figures 6, 7), Olugbemiro (1997) and Umar (1999) obtained similar results which indicate the possibilities of generating gas.

Table 3: Rock-Eval Pyrolysis data of samples from studied wells in the Bornu Basin

BORNU BASIN										
S/No.	LIMS-PrNr	Locality	Sample No.	TOC(wt.%)	S1(mg/g)	S2(mg/g)	S3(mg/g)	Tmax(ºC)	a HI	b OI
1	207198	Kemar-1 well	KM-1 680	1.13	0.03	0.84	0.39	435	74	35
2	207199	Kemar-1 well	KM-1-770	1.11	0.02	0.43	0.44	433	39	40
3	207200	Kemar-1 well	KM-1-855	0.6	0.01	0.22	0.42	434	37	70
4	207201	Kemar-1 well	KM-1-975	0.86	0.02	0.32	0.45	437	37	52
5	207202	Kemar-1 well	KM-1-1070	0.8	0.02	0.2	0.55	440	25	69
6	207203	Kemar-1 well	KM-1-1290	0.76	0.02	0.22	1.03	431	29	136
7	207204	Kemar-1 well	KM-1-1385	0.72	0.02	0.12	0.75	441	17	105
8	207205	Kemar-1 well	KM-1-1480	0.77	0.02	0.18	0.59	438	23	76
9	207206	Kemar-1 well	KM-1-1620	0.72	0.04	0.64	1.24	447	90	173
10	207207	Kemar-1 well	KM-1-1720	0.59	0.02	0.08	0.75	437	14	128
11	207208	Murshe-1 well	MS-1-640	0.96	0.02	0.22	0.74	419	23	77
12	207209	Murshe-1 well	MS-1-735	0.89	0.02	0.23	0.54	421	26	61
13	207210	Murshe-1 well	MS-1-820	0.78	0.02	0.21	0.61	429	27	78
14	207211	Murshe-1 well	MS-1-1005	0.96	0.03	0.69	0.46	435	72	48
15	207212	Murshe-1 well	MS-1-1155	0.97	0.04	0.84	0.54	439	87	56
16	207213	Murshe-1 well	MS-1-1260	1.05	0.04	0.38	0.67	437	36	64
17	207214	Murshe-1 well	MS-1-1365	0.69	0.03	0.21	0.81	438	31	118
18	207215	Murshe-1 well	MS-1-1440	0.83	0.02	0.27	0.57	443	32	68
19	207216	Murshe-1 well	MS-1-2035	0.66	0.02	0.07	0.61	444	11	93
20	207217	Murshe-1 well	MS-1-2375	0.79	0.02	0.04	0.93	330	5	118
21	207218	Murshe-1 well	MS-1-2445	0.69	0.02	0.04	0.96	322	6	139
22	207219	Murshe-1 well	MS-1-2515	0.55	0.01	0.02	0.73	311	4	133
23	207220	Murshe-1 well	MS-1-2755	0.78	0.01	0.02	0.82	330	3	105
24	207221	Tuma-1 well	TM-1-935	0.33	0.01	0.1	0.64	429	31	197
25	207222	Tuma-1 well	TM-1-1125	0.93	0.01	0.31	0.41	431	33	44
26	207223	Tuma-1 well	TM-1-1515	0.79	0.05	0.28	0.42	441	35	53
27	207224	Tuma-1 well	TM-1-1685	0.57	0.02	0.15	0.54	445	27	95
28	207225	Tuma-1 well	TM-1-1780	0.92	0.03	0.24	0.59	446	26	64
29	207226	Tuma-1 well	TM-1-1810	0.69	0.02	0.11	0.57	440	16	83
30	207227	Tuma-1 well	TM-1-1985	0.77	0.03	0.09	0.42	452	12	55
31	207228	Tuma-1 well	TM-1-2190	0.6	0.03	0.1	0.56	443	17	93

32	207229	Tuma-1 well	TM-1-2285	0.92	0.06	0.33	0.62	451	36	68
33	207230	Tuma-1 well	TM-1-2605	0.37	0.15	0.22	0.57	290	59	152
34	207231	Ziye-1 well	ZY-1-885	0.71	0.02	0.54	0.5	431	76	71
35	207232	Ziye-1 well	ZY-1-990	0.66	0.02	0.32	0.55	430	48	83
36	207233	Ziye-1 well	ZY-1-1210	1.07	0.06	1.34	0.50.	442	125	47
37	207234	Ziye-1 well	ZY-1-1325	0.72	0.03	0.61	0.55	441	85	77
38	207235	Ziye-1 well	ZY-1-1880	0.59	0.06	0.34	1.13	457	58	192
39	207236	Ziye-1 well	ZY-1-2085	0.34	0.02	0.15	0.69	457	44	204
40	207237	Ziye-1 well	ZY-1-2205	0.23	0.01	0.09	0.38	452	39	166
41	207238	Ziye-1 well	ZY-1-2405	0.35	0.02	0.12	0.48	482	35	139
42	207239	Ziye-1 well	ZY-1-2685	0.67	0.02	0.26	0.59	437	39	88
43	207240	Ziye-1 well	ZY-1-2840	0.84	0.12	1.04	0.80.	448	124	96

a mgHC/g TOC, b $mgCO_2$/g TOC

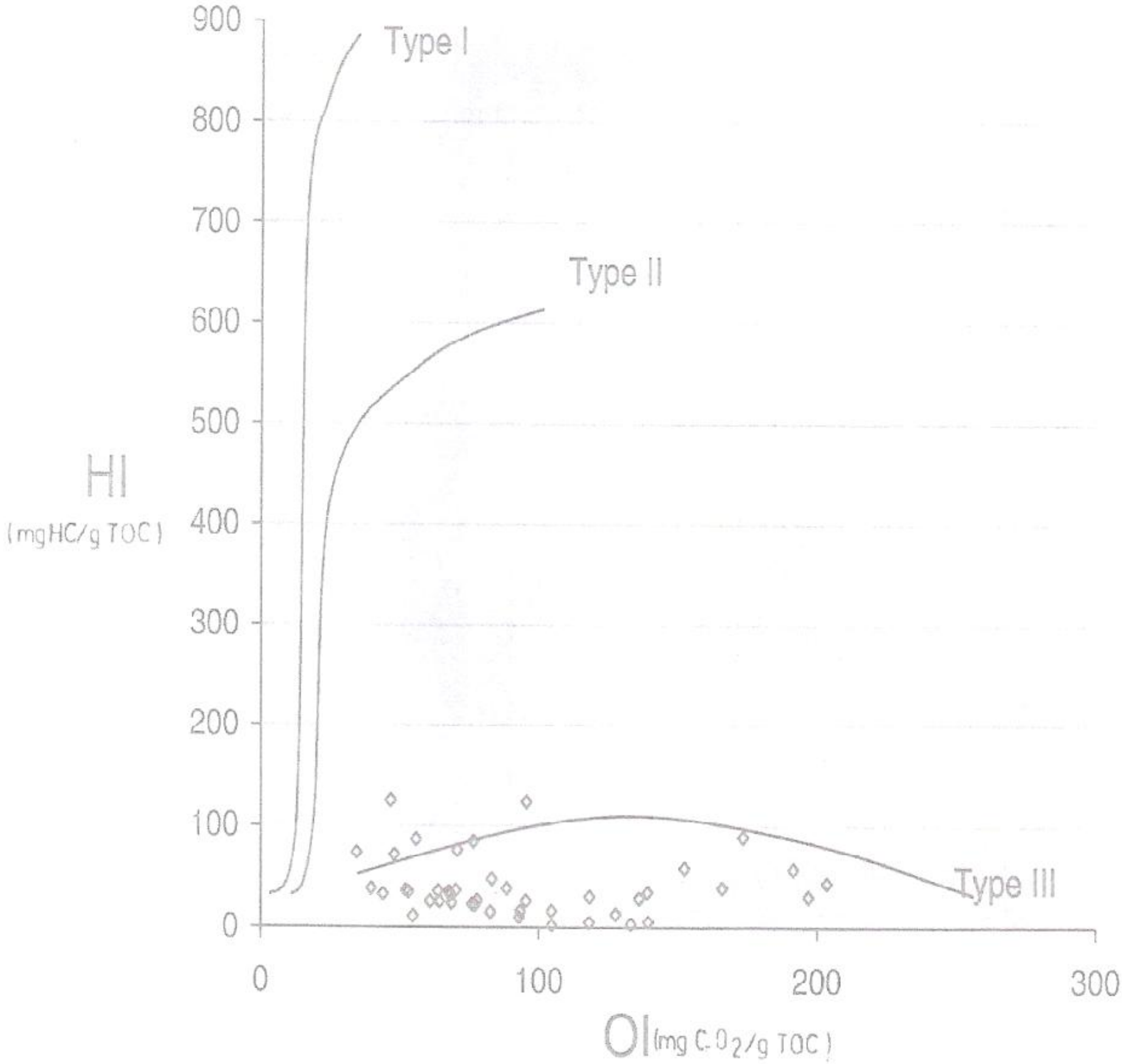


Figure 6: HI vs OI plot of the modified Van Krevelen diagram of samples from the Bornu Basin.

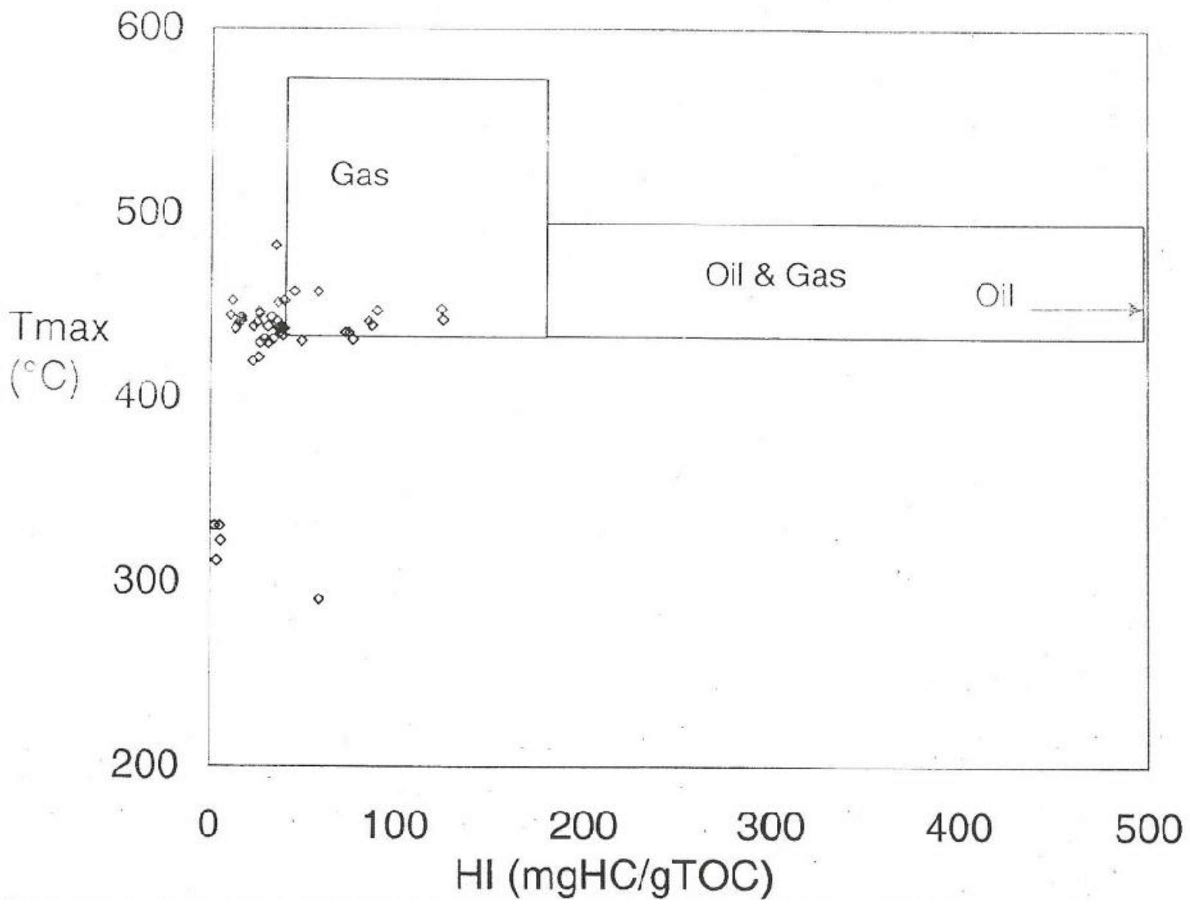


Figure 7: HI-Tmax plots of samples from Bornu Basin (diagram constructed based on values given by Peters (1986) depicting entirely gas generative potential and organic matter in most of the samples as inert.

CHALLENGES OF OIL EXPLORATION IN THE BORNU BASIN

It took the oil companies more than 30 years of exploration efforts in southern Nigeria before commercial finds were made. In the Chad and Niger Republics exploration work began in 1954. Exploration in the Bornu Basin only started in 1979. The exploration exercise in the Bornu Basin undertaken by the Frontier Exploratory Services (F.E.S) of the NNPC, resulted in drilling 23 wells in nearly 14 years with little or no success. All wells were within the Upper Cretaceous sediments which correspond to the phase II rift sediments. It has been suggested that an extensive system of lakes existed during the Barremian to Albian and that lacustrine deposits exist at the base of the Lower Cretaceous succession in WARS basins Genik (1993). In our opinion, the Bima Group of sediments had not been penetrated so far in all the wells that have been drilled in the basin.

Therefore, since the Lower Cretaceous sediments have not been penetrated, their organic matter contents is assumed not to have been analyzed in all the organic geochemical analyses carried-out by previous workers. Exploration efforts should target those deeper sediments overlying the possible lacustrine succession in the basin.

CONCLUSIONS

The Bornu Basin is one of the least geologically documented areas in Nigeria. Based on the estimated sediment thicknesses of about 10 km (Avbovbo *et al*., 1986) and/or 6 km (Umar, 1999) and considering the depths of the studied wells, the Bima Group might not have been penetrated by the wells drilled by the N.N.P.C. so far. Lacustrine source rocks may have formed during the Barremian to Albian with overlying sandstones as potential reservoir rocks. Sealing and trapping structures may also have developed following later sedimentation and deformation episodes. Deeper exploration wells are hereby suggested to be drilled which could penetrate the Lower Cretaceous sediments, which may contain commercial volume of hydrocarbons in the basin and hence should be targeted.

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