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Reservoir Potentials of the Cretaceous Gombe Sandstone, Gongola Basin, Upper Benue Trough, North Eastern Nigeria

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Abstract: *The Campano – Maastrichtian Gombe Sandstone of the Gongola Basin of the Upper Benue Trough is composed of arenaceous lithology that is laterally extensive and has reached a thickness of over 300m. The petrophysical evaluation of the formation on the basis of bivariate plots, petrographic analysis and falling head permeability indicated average porosity values of 15%, 33% and 23% respectively. Average permeability values of 5.2D and 100md were also obtained from bivariate plots and falling permeameter analysis respectively. These values are comparable to the reservoir rocks of proven petroleum basin of the North Sea and Niger Delta. Therefore, the Gombe Sandstone can serve as a potential reservoir rock in the Gongola Basin.*
Keywords: *Reservoir rock, porosity, permeability, bivariate plots, Gombe Sandstone, Gongola Basin*

I. Introduction

Reservoir rock's ability to host and produce hydrocarbon is largely dependent on the degree of reservoir connectivity and the porosity/permeability characteristic of the reservoir unit acquired during sediment deposition and subsequent deposition. The Campano – Maastrichtian Gombe Sandstone of the Gongola Basin of the Upper Benue Trough is dominantly composed of arenaceous sediment which can possibly serve as a reservoir rock. Earlier sedimentological studies indicated that this formation is composed of quartz-arenite to arkosic sands which are mature to submature formed in a deltaic environment with thickness of over 300m [1]. These coupled with relative position of the formation in the stratigraphy of Gongola Basin may suggest that the formation can serve as a potential reservoir rock in the basin. Therefore, the present research is aimed at evaluating the reservoir potential of the Gombe Sandstone.

II. Stratigraphic Setting

The Benue Trough is a major NE-SW trending rift basin of 50 – 150km width and over 1000km length. It is geographically sub-divided into Lower, Middle and Upper portion ″Fig.1‶ [2]. The Upper Benue Trough is Y shaped made up of three arms , namely: the E – W trending Yola Arm, N – S trending Gongola Arm or Gongola Basin and the NE – SW trending main arm (Muri – Lau Basin) (Dike, 2002) ″Fig. 2‶.

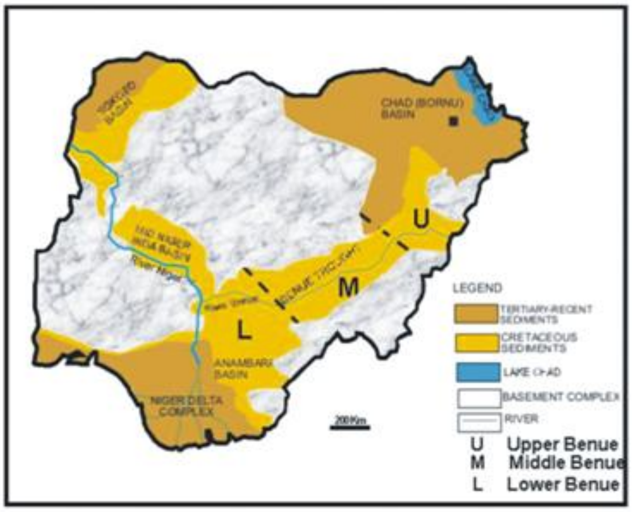

Figure 1: Geological Map of Nigeria showing the Benue Trough

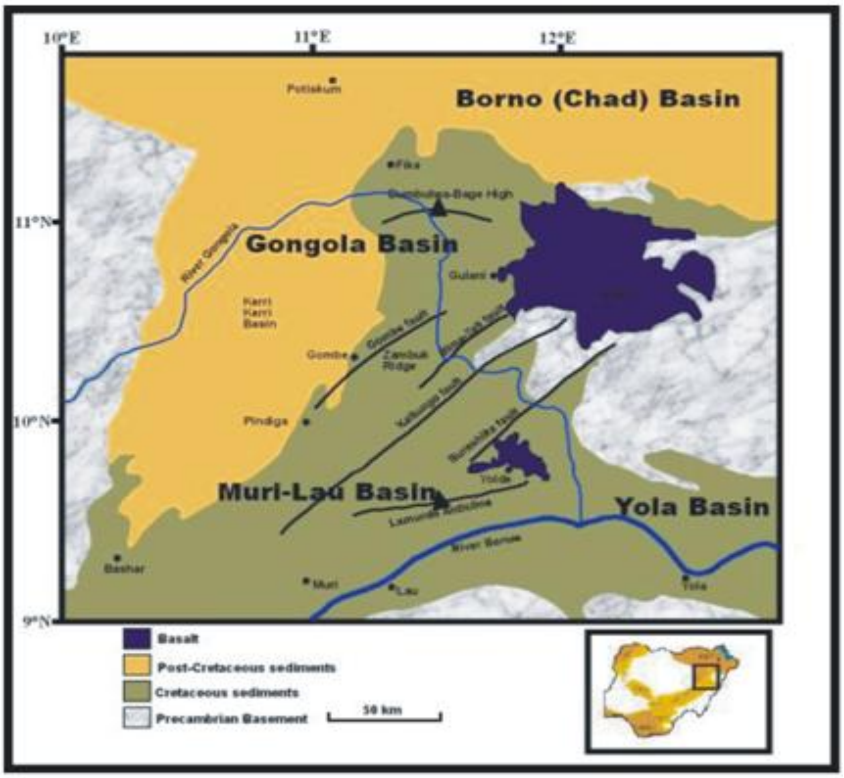

Figure 2: Geological Map of Upper Benue Trough (modified from Zaborski *et al* 1997)

In the Gongola Arm, the Aptian–Albian Bima Sandstone, a continental formation represents the basal part of the sedimentary succession. It unconformably overlies the Precambrian Basement Complex and consists of three siliciclastic members: the lower Bima (B1), middle Bima (B2) and the upper Bima (B3). Its lithology and depositional environments have been discussed by [3] (Fig. 3).

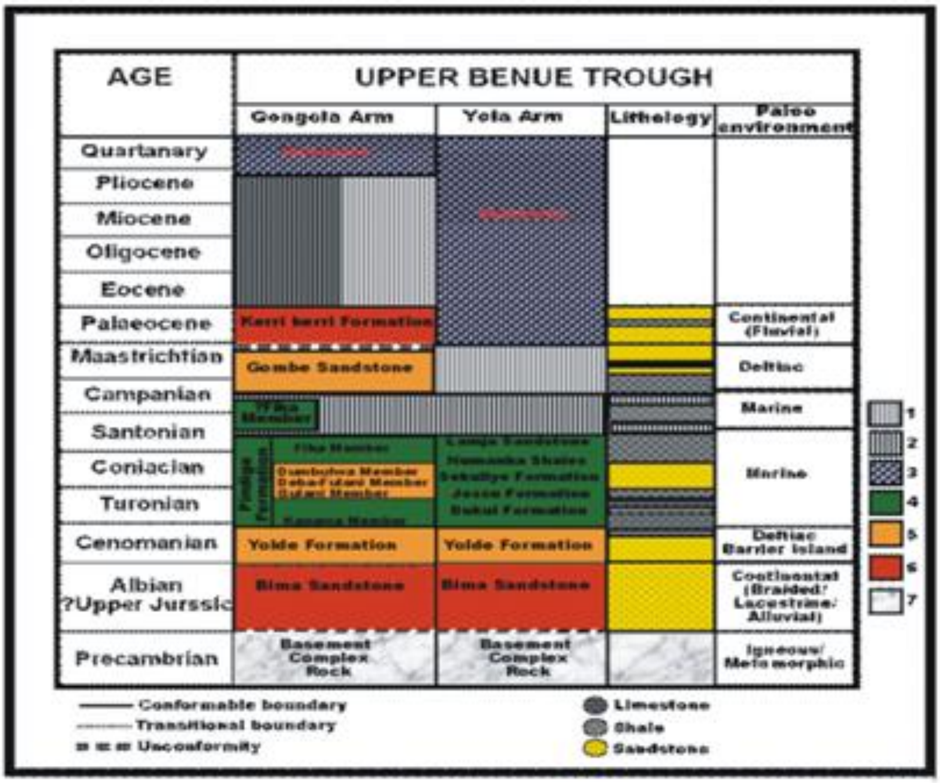

Figure3: Diagram showing the stratigraphy of the Upper Benue Trough (Obaje et al, 1999)

The Yolde Formation lies conformably on the Bima Sandstone. It is Cenomanian in age [4] represents the beginning of marine incursion into the Gongola Arm. The Yolde Formation was deposited in a barrier island, deltaic settings [5] [6]. The Turonian-Campanian Pindiga Formation conformably overlies the Yolde Formation[7][8] ,[8] subdivided the Pindiga Formation into five lithostratigraphic members: the Kanawa Member which is the basal member comprises of limestone and shale intercalations, the Gulani Member, the Deban-Fulani Member, the Dumbulwa Member and the Fika Member which is the top-most member consisting of shale and very few limestones. The Gulani, Deba-fulani and the Dumbulwa members are lateral equivalents occurring in the middle part of the Pindiga Formation. They are deposited during the middle Turonian regional regressive episode that occurred in the Benue Trough [8].

The estuarine/deltaic Gombe Sandstone of Maastrichtian age [9] overlies the Pindiga Formation and it represents the youngest Cretaceous sediment in the Gongola Arm. The Paleocene Kerri-Kerri Formation unconformably overlies the Gombe Sandstone and represents the only record of Tertiary sedimentation in the Gongola Arm [10] [11].

III. Methodology

Twenty five samples of the Gombe Sandstone were collected around Gombe and environs where its thickest section occurs (Fig. 4). These samples were collected from five outcrop sections with careful attention as to avoid weathered horizons (Figs . 5, 6, 7, 8 and 9) Granulometric analysis was carried out by the conventional method and about 200g of each sample was sieved for about 30 minutes in a Ro-Tap shaker. The graphical parameters of graphic mean, standard deviation, skewness and kurtosis were determined using the formula of Folk and Ward [12]. Petrographic analysis was also carried out on 30 samples using Ziess petrographical microscope to determine sorting, intergranular relationships, porosity and diagensis. Falling head permeameter test was likewise conducted on some few core samples according to the British standard (BS1377) procedure indicated by [13], in order to determine porosity and permeability for the Gombe Sandstone. Clay mineralogy of samples of the formation were analyzed using Shimadzu diffractometer (XRD-6000) coupled with discriminator, proportional counter, Co filter and Cu radiation at 40kv with scan range of 5 – 60^{o} 2Θ.

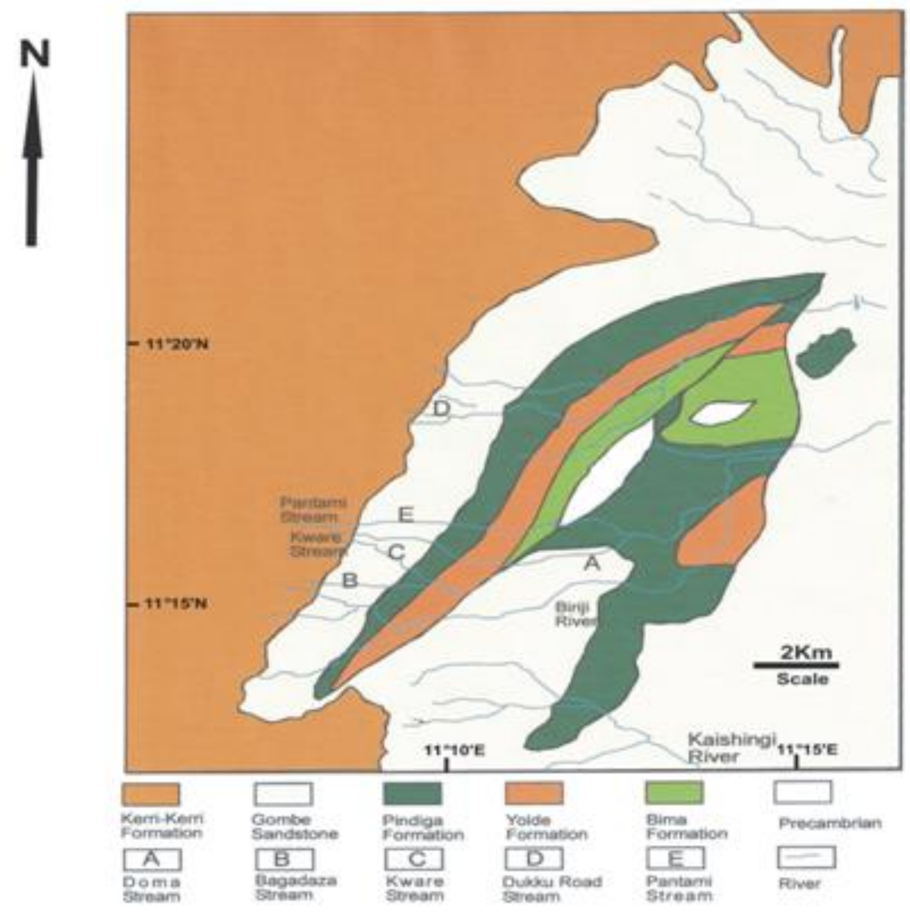

Figure 4: Geologic Map of Gombe and adjacent areas showing the location of section studied (modified from Zaborski et al, 1997)

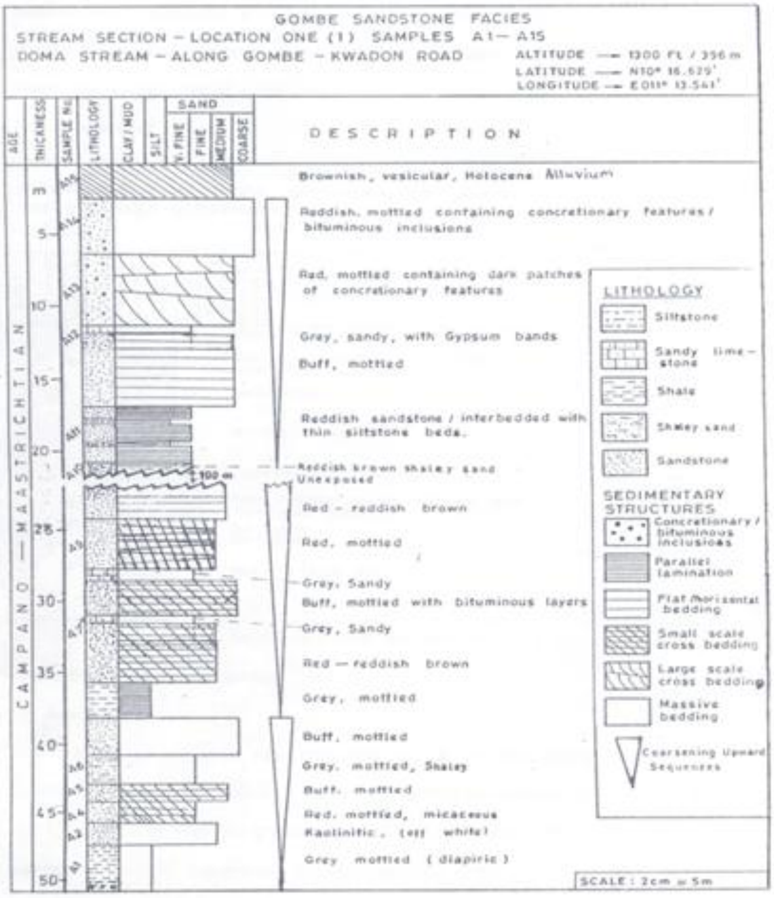

Figure 5: Section of Gombe sandstone at Doma stream

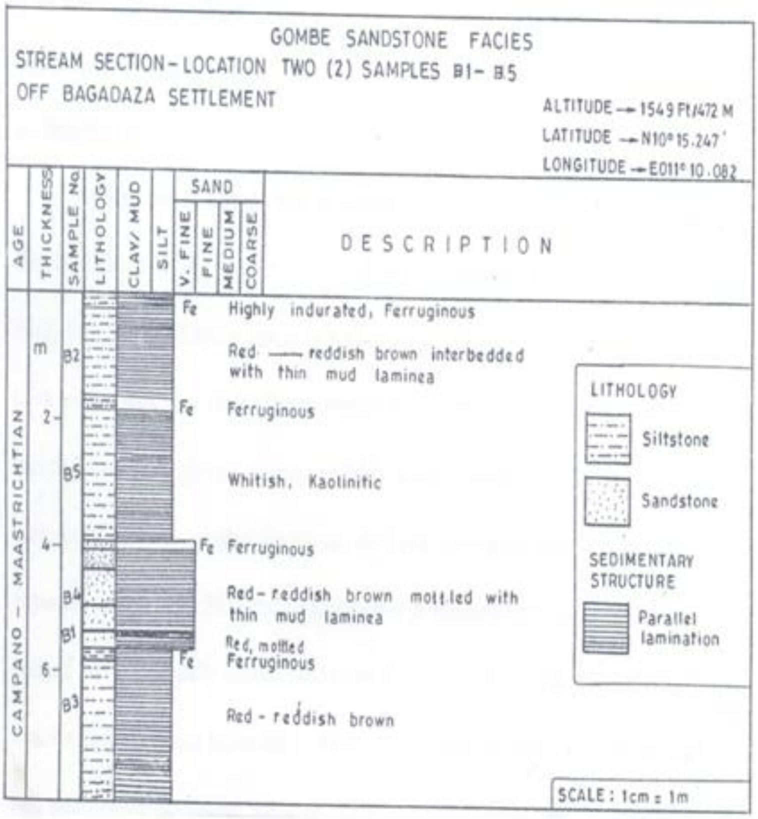

Figure 6: Section of Gombe sandstone at Bagadaza stream

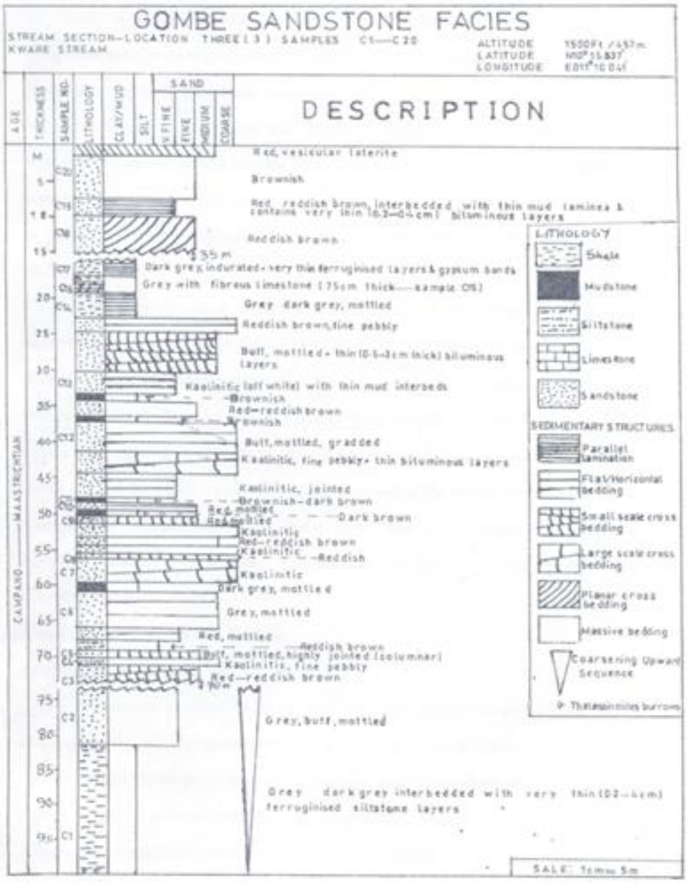

Figure 7: Section of Gombe sandstone at Kware stream

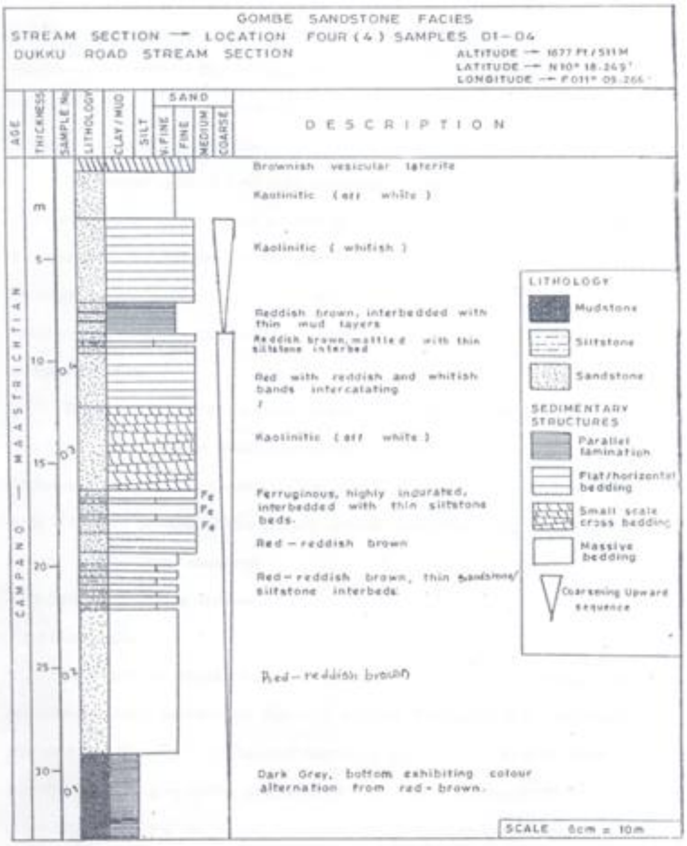

Figure 8: Section of Gombe Sandstone along Dukku road

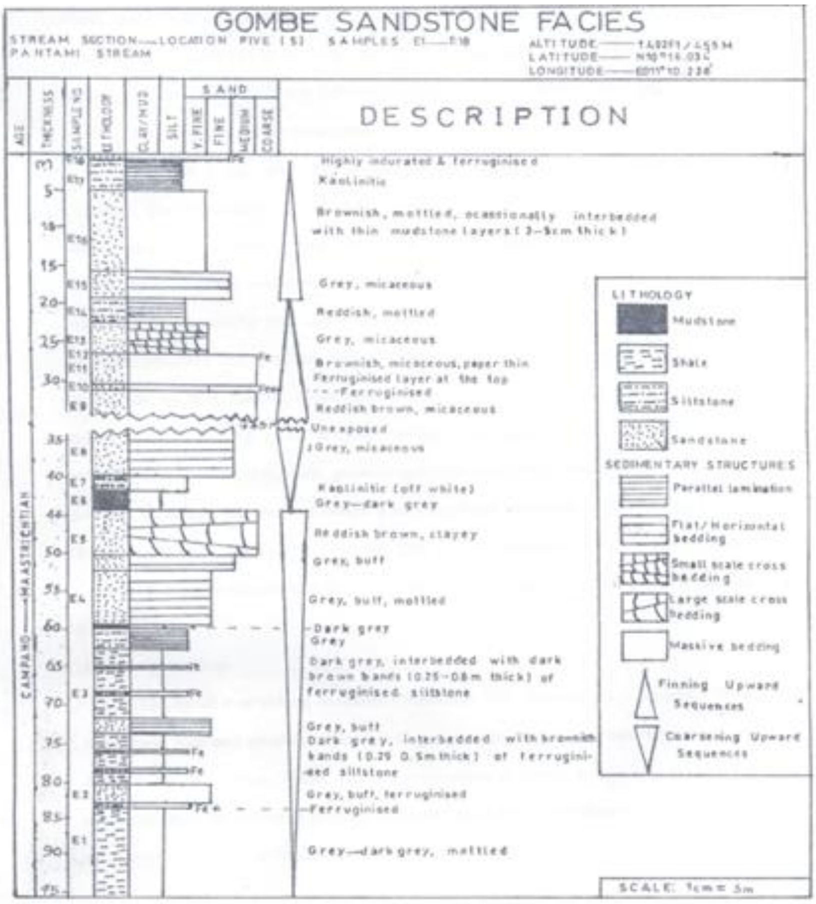

Figure 9: Section of Gombe Sandstone at Pantami

IV. Results

4.1 Univariate grain size parameters:

The graphic mean size for the various samples (Table 1) range from 1.24ø – 3.36ø i.e. (medium to very fine-grained sands) and the fluctuation of the values may reflect change in the strength of the deposition medium.The values of standard deviation (Table 1) tend to show that the samples ranged from well sorted (0.48ø) to poorly sorted (2.09ø) with an average of (1.17ø) which implies that the whole formation is poorly sorted.

The samples analysed have skewness values ranging from -0.12ø to 0.44ø i.e. from negatively skewed to very positively skewed respectively. However, positively skewed values predominate (Table 1) with an average of 0.25 ø, and this may be due to the fact that much of the silt and clay were not removed by current , though the clay may be secondary .The values of kurtosis (Table 1) for the various samples range from 0.62ø to 2.39ø (very platykurtic to very leptokurtic), with an average of 1.00ø (mesokurtic).

4.2. Petrographic study

Twenty samples ranging from fine to coarse grained sandstone were thin sectioned and subjected to petrographic studies. The sandstones consist mainly of quartz, feldspars and mica as framework elements with clay matrix and cement .The framework composition of these sandstones is varied and is presented in (Table 2). The texture of these sandstones tends to show that sorting ranges from poorly to well sorted (1.0 – 0.4) but moderate sorting predominates (Table 2). The grain shape ranges from subangular to well rounded (0.2 – 0.5) with sub-angular dominating, and the sphericity varies from low-high (0.3 – 0.9) (Figs. 11 - 16).

Quartz comprises an average of 73% of the framework grain of the sandstones. Monocrystalline quartz is dominant, while polycrystalline quartz occurs in very few samples. Most of the quartz grains are characterized by various features such as dust lines, and quartz overgrowth.The feldspars generally range from 4 – 15% and Potassium feldspars dominate, followed by plagioclase feldspar. Seriticization of the feldspar is quite a common feature in most of the studied samples. Muscovite makes up to (1%) of the grains and opaque minerals range between (1 – 2%) in the samples analysed.Using [14] sandstone classification, the Yolde Formation sandstone range from subarkose to quartzarenite, and their textural maturity based on [15] ranges from submature to mature.Petrographic evaluation of the porosity based on estimation shows that the Gombe Sandstone has porosity values ranging from 7 – 19% with an average of 19% (Table 2).

Table 1 Showing univariate grain size parameters and porosity and permeability data

SAMPLE No.	MEAN (Mz) Φ	STANDARD DEVIATION (SORTING) Φ	SKEWNESS (Ski) Φ	KURTOSIS (Kc) Φ	POROSITY (%)	PERMEABILITY (D)
A4	3.11 Very fine grained	0.86 Moderately sorted	0.28 Positively skewed	0.77 Platykurtic	38.5	4.7
A5	3.05 Very fine grained	0.89 Moderately Sorted	0.23 Positively skewed	0.94 Mesokurtic	40.2	4.2
A9	3.02 Very fine grained	097 Moderately Sorted	0.15 Positively skewed	0.70 Platykurtic	38.5	5.2
A10	3.31 Very fine grained	0.77 Moderately Sorted	0.18 Negatively skewed	0.62 Platykurtic	40	5
A13	2.53 Fine grained	1.21 Poorly Sorted	0.36 Positively skewed	0.98 Mesokurtic	31	5
A14	2.27 Fine grained	1.32 Poorly Sorted	0.41 Positively skewed	1.14 Leptokurtic	29	4
B1	3,37 Very fine grained	0.56 Moderately sorted	0.00 Symmetrical	1.34 Leptokurtic	41	7
B4	3.36 Very fine grained	0.48 Well sorted	0.11 Nearly symmetrical	1.34 Leptokurtic	41	6.5
C3	2.38 Fine grained	1,44 Poorly sorted	0.12 Positively skewed	0.74 Very platykurtic	28.5	3.5
C4	1.79 Medium grained	1.79 Poorly Sorted	0.27 Positively skewed	0.88 Platykurtic	25	0.2
C5	2.06 Fine grained	1.52 Poorly sorted	0.38 Positively skewed	0.85 Platykurtic	27.5	3
C6	1.94 Fine grained	1.60 Poorly Sorted	0.39 Positively skewed	0.88 Platykurtic	27	1.5
C7	1.77 Medium grained	1.83 Poorly Sorted	0.32 Positively skewed	0.82 Very platykurtic	26	0.1
C8	1.64 Medium grained	1.84 Poorly Sorted	0.44 Positively skewed	1.26 Leptokurtic	26	0.15
C9	2.06 Fine grained	1.49 Poorly Sorted	0.35 Positively skewed	0.93 Mesokurtic	27	2.8
C12	2.26 Fine grained	1.06 Poorly Sorted	0.09 Nearly Symmetrical	1.19 Leptokurtic	35.5	15
C18	3.16 Very fine grained	0.71 Moderately Sorted	0.37 Positively skewed	0.84 Platykurtic	39	6
D2	2.92 Fine grained	0.90 Moderately Sorted	0.02 Nearly symmetrical	1.49 Leptokurtic	37	5
D3	2.76 Fine grained	0.83 Moderately Sorted	-0.12 Negatively skewed	2.39 Very leptokurtic	37	7.5
D4	3.15 Very fine grained	0.73 Moderately sorted	0.44 Positively skewed	1.03 Mesokurtic	40.5	7
E5	1.24 Medium grained	2.09 Very poorly Sorted	0.24 Positively skewed	1.02 Mesokurtic	25	0.1
E9	2.26 Fine grained	1.14 Poorly Sorted	0.38 Positively skewed	1.10 Mesokurtic	27	12
E11	1.73 Medium grained	1.41 Poorly sorted	0.16 Positively skewed	1.04 Mesokurtic	31	13

E13	3.17 Very fine grained	0.78 Moderately Sorted	0.33 Positively skewed	0.70 Platykurtic	39	6
E15	2.92 Fine grained	0.93 Moderately Sorted	0.28 Positively skewed	1.02 Mesokurtic	37	5.5
Average	**2.55 Fine grained**	**1.17 Poorly sorted**	**0.25 Positively skewed**	**1.00 Mesokurtic**	**33.37**	**5.20**

II. Table 2 Showing the petrographic framework components and optical porosity of the Gombe Sandstone

S/No	SAMPLE NO.	SORTING 1	ROUNDNESS 2	SPHERICITY 2	GRAIN FABRIC 3	FRAME WORK COMPONENT 4					
						Quartz (%)	Feldspar (%)	Mica (%)	Opaque (%)	Cement Matrix (%)	Porosity (%)
1	A4	Moderately sorted (0.4)	Subrounded (0.4)	0.9 (high)	Grain Supported	72	8	1	1	4	18
2	A5	Moderately sorted (0.5)	Subangular (0.3)	0.4 (Low)	Grain Supported	70	10	1	1	3	16
3	A9	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	68	10	1	1	5	15
4	A10	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	65	12	1	2	4	18
5	A13	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	65	13	1	2	2	16
6	A14	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	67	10	-	1	4	18
7	B1	Moderately sorted (1.0)	Subangular (0.3)	0.2 (low)	Grain Supported	68	12	1	1	5	18
8	B4	Well sorted (0.3)	Subangular (0.3)	0.8 (high)	Grain Supported	65	15	-	2	5	17
9	C3	Poorly sorted (1.0)	Subrounded (0.4)	0.3 (low)	Grain Supported	70	8	-	1	4	18
10	C4	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	68	11	1	1	4	11
11	C5	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	65	15	-	2	3	14
12	C6	Poorly sorted (1.0)	Subangular (0.3)	0.3 (Low)	Grain Supported	70	8	-	1	4	12
13	C7	Poorly sorted (1.0)	Subangular (0.3)	0.6 (high)	Grain Supported	68	13	1	1	3	17
14	C8	Poorly sorted (1.0)	Subrounded (0.4)	0.9 (high)	Grain Supported	72	8	-	1	4	16
15	C9	Poorly sorted (1.0)	Subrounded (0.4)	0.9 (high)	Grain Supported	70	10	1	2	4	15
16	C12	Poorly sorted (1.0)	Well rounded (0.6)	0.9 (high)	Grain Supported	95	2	-	1	3	13
17	C18	Well sorted (0.4)	Rounded (0.5)	0.9 (high)	Grain Supported	95	3	-	1	2	8
18	D2	Well sorted (0.4)	Well rounded (0.6)	0.9 (high)	Grain Supported	96	2	-	1	2	15
19	D3	Moderately sorted (0.5)	Subrounded (0.4)	0.9 (high)	Grain Supported	70	8	1	1	4	15
20	D4	Moderately sorted (0.5)	Subangular (0.3)	0.7 (high)	Grain Supported	70	12	1	2	5	15
21	E5	Poorly sorted (1.0)	Subangular (0.3)	0.8 (high)	Grain Supported	72	10	1	1	3	14
22	E9	Moderately sorted (0.5)	Subangular (0.3)	0.7 (high)	Grain Supported	69	15	-	1	4	16
23	E11	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	73	10	-	2	3	8
24	E13	Well sorted (0.4)	Rounded (0.5)	0.9 (high)	Grain Supported	80	8	1	2	4	16
25	E15	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	62	15	1	2	5	11

1 – Estimates based on Folk (1972), 2 – Estimates based on Powers (1953), 3 – Estimates based on Swanson (1985), 4 – Estimates based on Terry and Chillinger (1955)

III. Table 2 Showing the petrographic framework components and optical porosity of the Gombe Sandstone

S/No	SAMPLE NO.	SORTING 1	ROUNDNESS 2	SPHERICITY 2	GRAIN FABRIC 3	FRAME WORK COMPONENT 4					
						Quartz (%)	Feldspar (%)	Mica (%)	Opaque (%)	Cement Matrix (%)	Porosity (%)
1	A4	Moderately sorted (0.4)	Subrounded (0.4)	0.9 (high)	Grain Supported	72	8	1	1	4	18
2	A5	Moderately sorted (0.5)	Subangular (0.3)	0.4 (Low)	Grain Supported	70	10	1	1	3	16
3	A9	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	68	10	1	1	5	15
4	A10	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	65	12	1	2	4	18
5	A13	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	65	13	1	2	2	16
6	A14	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	67	10	-	1	4	18
7	B1	Moderately sorted (1.0)	Subangular (0.3)	0.2 (low)	Grain Supported	68	12	1	1	5	18
8	B4	Well sorted (0.3)	Subangular (0.3)	0.8 (high)	Grain Supported	65	15	-	2	5	17
9	C3	Poorly sorted (1.0)	Subrounded (0.4)	0.3 (low)	Grain Supported	70	8	-	1	4	18
10	C4	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	68	11	1	1	4	11
11	C5	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	65	15	-	2	3	14
12	C6	Poorly sorted (1.0)	Subangular (0.3)	0.3 (Low)	Grain Supported	70	8	-	1	4	12
13	C7	Poorly sorted (1.0)	Subangular (0.3)	0.6 (high)	Grain Supported	68	13	1	1	3	17
14	C8	Poorly sorted (1.0)	Subrounded (0.4)	0.9 (high)	Grain Supported	72	8	-	1	4	16
15	C9	Poorly sorted (1.0)	Subrounded (0.4)	0.9 (high)	Grain Supported	70	10	1	2	4	15
16	C12	Poorly sorted (1.0)	Well rounded (0.6)	0.9 (high)	Grain Supported	95	2	-	1	3	13
17	C18	Well sorted (0.4)	Rounded (0.5)	0.9 (high)	Grain Supported	95	3	-	1	2	8
18	D2	Well sorted (0.4)	Well rounded (0.6)	0.9 (high)	Grain Supported	96	2	-	1	2	15
19	D3	Moderately sorted (0.5)	Subrounded (0.4)	0.9 (high)	Grain Supported	70	8	1	1	4	15
20	D4	Moderately sorted (0.5)	Subangular (0.3)	0.7 (high)	Grain Supported	70	12	1	2	5	15
21	E5	Poorly sorted (1.0)	Subangular (0.3)	0.8 (high)	Grain Supported	72	10	1	1	3	14
22	E9	Moderately sorted (0.5)	Subangular (0.3)	0.7 (high)	Grain Supported	69	15	-	1	4	16
23	E11	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	73	10	-	2	3	8
24	E13	Well sorted (0.4)	Rounded (0.5)	0.9 (high)	Grain Supported	80	8	1	2	4	16
25	E15	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	62	15	1	2	5	11

1– Estimates based on Folk (1972), 2 – Estimates based on Powers (1953), 3 – Estimates based on

Bivariate plots

The bivariate plots of grain size versus standard deviation [16] for evaluation of petrophysical properties was also employed in this studies to determine the porosity and permeability of the Gombe Sandstone. Twenty five (25) samples were plotted in the diagram (Fig .10), and the porosity ranged from 26% - 42%, with an average of 35%. While the permeability varied from 0.5D – 14D with an average of 6.5D (Table 1).

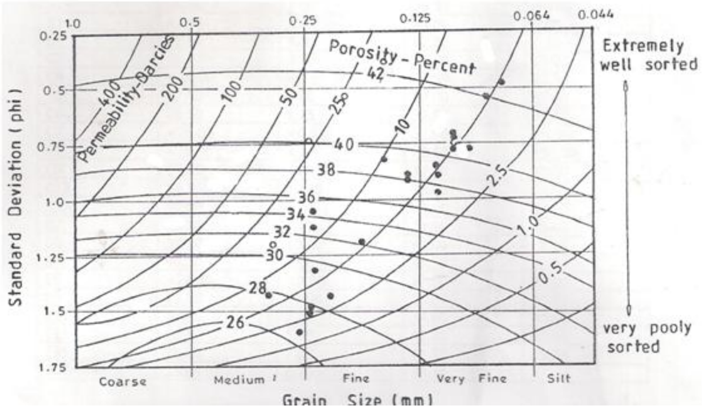

Figure 10: Porosity and permeability plot (kreisa *et al* 1999)

4.3. Permeameter analysis

Core samples of the Gombe Sandstone were subjected to falling head permeameter analysis in order to determine its porosity and permeability. The porosity evaluated ranged between 19.3% – 25.4%, with an average of 23%, while the permeability ranged from 100 – 200md (Table 3).

Table 3 Porosity and permeability results of the Gombe Sandstone from permeameter analysis

SAMPLE NUMBER		A9	C7	C18	RCS
Mass M (g)		965.50	865.00	1010.10	1223.40
Length (mm)		60	50	60	76
Diameter (mm)		100	100	100	100
Volume $V = \pi r^2 L$ (cm^3)		471.24	392.70	471.24	596.90
Specific Gravity S_G (g/cm^3)		2.65	2.65	2.65	2.65
Moisture Content W (%)		3.50	3.50	3.50	3.50
Test Temperature (°C)		27.50	27.50	27.50	27.50
Area $A = \pi D^2/4$ (mm^2)		7853.98	7853.98	7853.98	7853.98
Bulk Density $\rho = M/V$ (g/cm^3)		2.05	2.20	2.14	2.05
Dry Density $\rho_D = 100\rho/(100 + e)$ (g/cm^3)		1.98	2.13	2.07	1.98
Void Ratio $e = S_G/\rho_D - 1$		0.34	0.24	0.28	0.34
Porosity $n = (e/1+e) * 100$ (%)		25.40	19.36	21.88	25.40
Standpipe diameter d (mm)		4.50	4.50	4.50	4.50
Standpipe area a (mm^2)		15.90	15.90	15.90	15.90
Height above outlet h (mm)	h1	1460	1460	1460	1460
	h3	981.60	981.60	981.60	981.60
	h2	660	660.00	660.00	660.00
Height ratios	h1/h3	1.49	1.49	1.49	1.49
	h3/h2	1.49	1.49	1.49	1.49
Test time* (min)	1 – 3	0.67	0.40	0.50	0.83
	3 – 2	0.80	0.33	0.58	0.87
Average test time t (min)		0.74	0.37	0.54	0.85
Permeability at test temp. $K_T (m/s) = \frac{2.303al}{1000*A*60t} * Log_{10}\frac{h1}{h2}$		$1.0912 * 10^{-6}$	$1.8186 * 10^{-6}$	$1.0912 * 10^{-6}$	$1.2033 * 10^{-6}$
Permeability is usually given at 20°C Thus: $K_{20} = K_T (\eta_T/\eta_{20})$ (m/s)		$9.3644 * 10^{-6}$	$1.5607 * 10^{-6}$	$1.2832 * 10^{-6}$	$1.0326 * 10^{-6}$
Permeability K (Millidarcy)		100	200	100	110

IV. Discussion

Reservoir evaluation requires data concerning individual sand bodies that are both qualitative and quantitative. The Gombe Sandstone was formed under a deltaic and braided river environment [1], and these environments generally tend to consist of thick sandstone facies [17]. Considering the laterally extensive nature and thickness of the Gombe Sandstone (over 320m) [18]. The formation can serve as a potential reservoir rock for the hydrocarbon that might have been generated in the Gongola Basin. Granulometric analysis indicated that sorting varied from well to moderate to poor (Table 1), with well to moderate sorting restricted to the thick sandstone facies of the delta front sand and channel deposits of braided river systems, while the poor is associated with the intercalated to interbedded sandstone and claystones of the delta slope environment (Figs . 5, 6, 7, 8 and 9). Skewness values are generally positive for the Gombe Sandstone, and this may suggest that, though the parking of the grains as observed from sorting is generally relatively good, but there must have been crystallizations of clay minerals in the voids which may have led to loss of porosity to certain extent, because positive skewness indicates occurrence of fine materials in between grains [15].Texture, amount and type of cement and interstitial clays, angularity, packing of grain and size distribution of pore spaces are the main factors affecting reservoir properties of sandstone[19],[20]. Petrographic analysis revealed that the Gombe Sandstone is generally grain supported (Figs. 11 – 16).

They are usually well rounded to subangular and the clays associated with it are typically kaolinite (Figs. 17 and 18). Authegenic and detrital kaolinite bridge pore throat and reduce porosity and permeability [21], considering this, core samples of the Gombe Sandstone were subjected to falling head permeameter test and based on this it, was observed that porosity values varied from 19 – 25% with average of 23%, while permeability values ranged from 100md – 200mD with average of 100mD (Table 3). In the same light porosity and permeability evaluation based on bivariate plot of [16] indicated porosity values 26 – 42% with an average of 35% for the Gombe Sandstone, while permeability varied from 0.5D – 14D with an average of 6.5D (Table 1). The marked variations in the results of the two separate techniques may largely be attributed to lateral facies changes across the study location, because diagensis may have been intensive in the area where the core samples were collected compared to the other areas, because the more intense it is, the less the porosity [22].

The Gombe Sandstone when compared to reservoir rocks of major petroleum fields of prolific hydrocarbon provinces of the North Sea and Niger Delta Statfjord Formation of the North Sea displays porosity values of up to 25% with permeability in darcy ranges,[24] and the Agbada Formation of the Niger Delta has porosity ranging between 15% - 26% with permeabilities varying between 1 - 2 darcy [24]. Therefore, the Gombe Sandstone is a potential reservoir rock in the Gongola Basin of the Upper Benue Trough.

Fig.11 well sorted grains sample B4 X40

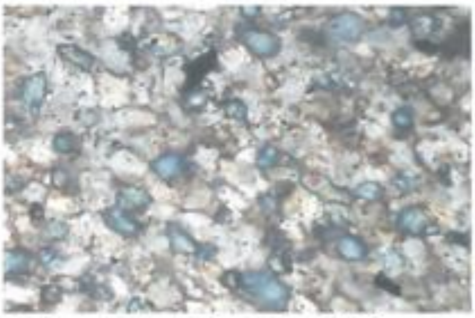

Fig.12 well sorted grains sample D2 X40

Fig.13 Moderately sorted grains sample E5 X40

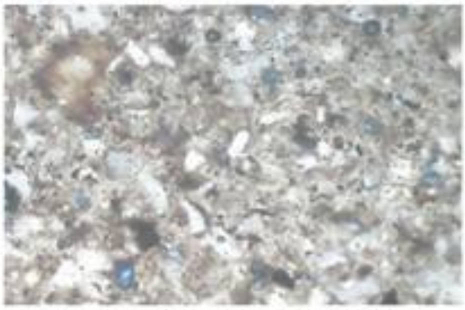

Fig.14 poorly sorted grains sample D2 X40

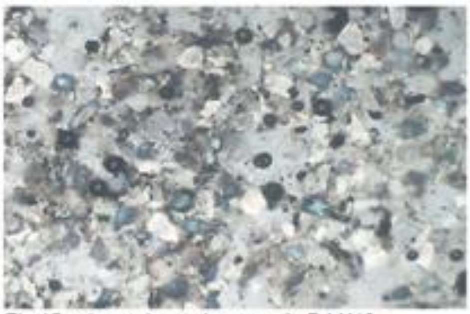

Fig.15 subangular grains sample D4 X40

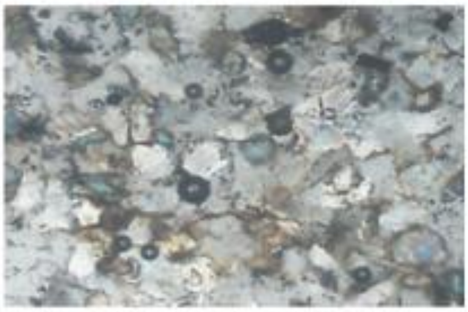

Fig.16 rounded grains sample C18 X40

V. Conclusion

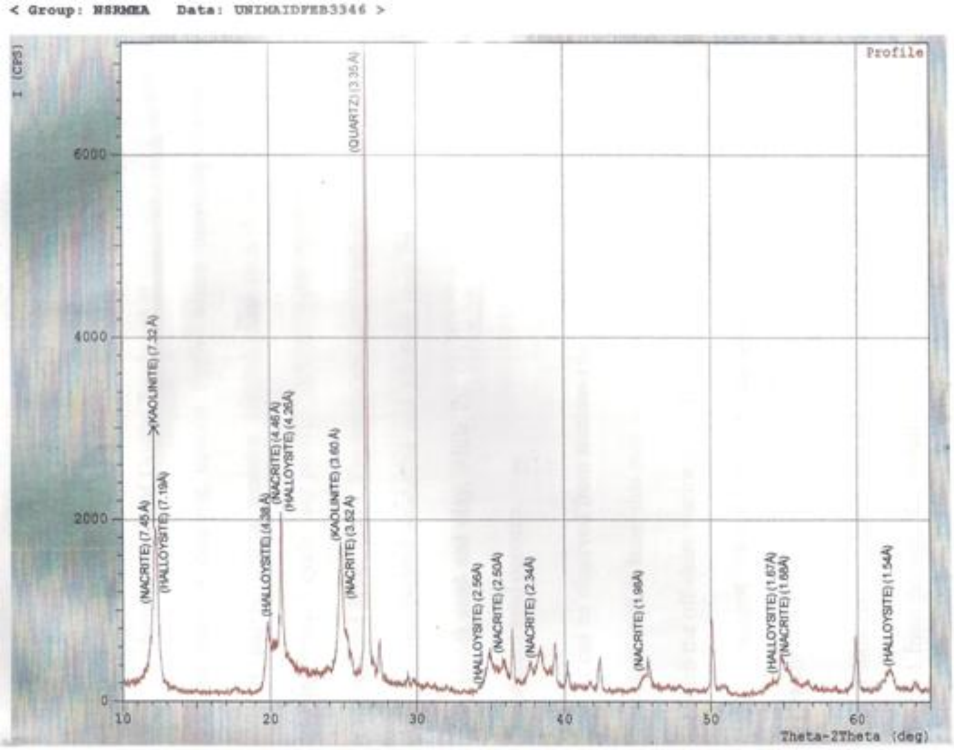

Fig.17 X-ray diffractogram of clays from Gombe Sandstone

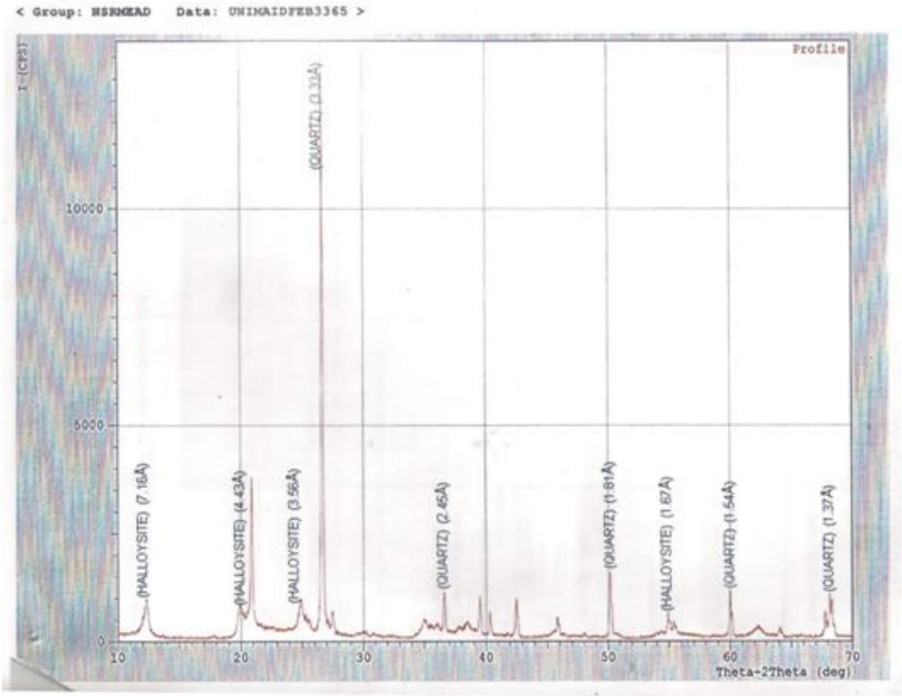

Fig.18 X-ray diffractogram of clays from Gombe Sandstone

The relative stratigraphic position of the Campano – Maastrichtian Gombe Sandstone in the overall stratigraphy of the Gongola Basin has made it a probable reservoir rock owing to the underlying source rocks of the shales of the Pindiga and Yolde Formation. Petrophysical evaluation of the Gombe Sandstones shows appreciable porosity and permeability that is comparable to that of known reservoir rocks of prolific petroleum basin of the North sea and Niger delta. Hence, the Gombe Sandstone has the ability to store and transmit hydrocarbons.

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