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AQUIFER POTENTIALS OF THE CAMPANO – MAASTRICHTIAN GOMBE SANDSTONE, GONGOLA BASIN, UPPER BENUE TROUGH, NORTH EASTERN NIGERIA

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Abstract
The Campano – Maastrichtian Gombe Sandstone occurs as a relatively linear strip of an outcrop, striking northeast–southwest adjacent to the Kerri Kerri plateau in the Gongola Basin. This formation is of deltaic origin and has attained a thickness of over 340 meters. Its arenaceous content is about 80%, therefore, it may constitute a very important aquifer for the underground water system in Gombe town and adjacent areas. The aquifer properties of the Gombe Sandstone were evaluated based on petrographic studies, permeameter analysis and bivariate plot relationship of standard deviation versus mean. The average values of porosities obtained from these analyses for this formation standout at 15%, 23% and 33% respectively. While permeability varied from 100–200mD in permeameter analysis and 10 – 1400mD in bivariate plot of standard deviation versus mean. Notwithstanding the relatively good porosity and permeability values for this formation, the yields observed from boreholes are relatively low in Gombe town, usually ranging from 1.4 – 2.8 litres per second. However, in the west and northwest, especially around Kwadon village, the yield appreciably improves to 4.8 – 5.6 litres per second. The larger part of the Gombe Sandstone in the Gombe area is generally uplifted, while at Kwadon village in the western part of the basin, its greater thickness occurs in the subsurface. Considering the fact that the Gombe Sandstone was formed in a deltaic environment, the upper part defined by delta front sand which have been observed from outcrop studies to consist of good porosity and permeability are usually uplifted in the Gombe area. This makes the moderate – poorly sorted delta slope sand of the lower part of the Gombe Sandstone as the dominantly possible aquifer for underground water, hence, the poor yield. However, in the Kwadon area, the greater thickness of the well sorted delta front sands are well preserved in the subsurface, and this led to the generation of a high yield which is further supported by the drainage pattern of the basin, which directs flow towards the Kwadon area in the west.
Keywords: Gombe Sandstone, Aquifer potentials, Gongola basin

1. Introduction

The Gombe Sandstone is the youngest Cretaceous formation in the Gongola Basin of the Upper Benue Trough and it forms a northeast – southwest trending outcrop along the western margin of the basin owing to the mid – Cretaceous tectonism (Figure1). A large number of conurbations forming important towns located on the landmass formed by the Gombe Sandstone outcrop derive their domestic source of water from it. This formation is dominantly arenaceous in nature, however, the aquifer yield is relatively low in most parts of the formation in which cosmopolitan towns like Gombe experience acute water scarcity. In view of this, this present research is aimed at evaluating the aquifer potentials of the Gombe Sandstone and to also propose a possible explanation for the variation in the aquifer potential from one location to the other on the Gombe Sandstone.

1.1 Geologic and stratigraphic setting

The Gongola Basin is part of the Benue Trough which was believed to have developed from extensional processes that broke – up the continent of Africa from South America during the Late Jurassic – Early Cretaceous times (Grant, 1971). The trough trends NE – SW for over 1000km in length and varies between 50 – 150km in width (Figure 1). It contains up to 6000m of Cretaceous – Tertiary sediments and arbitrarily sub – divided into lower, middle and upper parts. The upper Benue

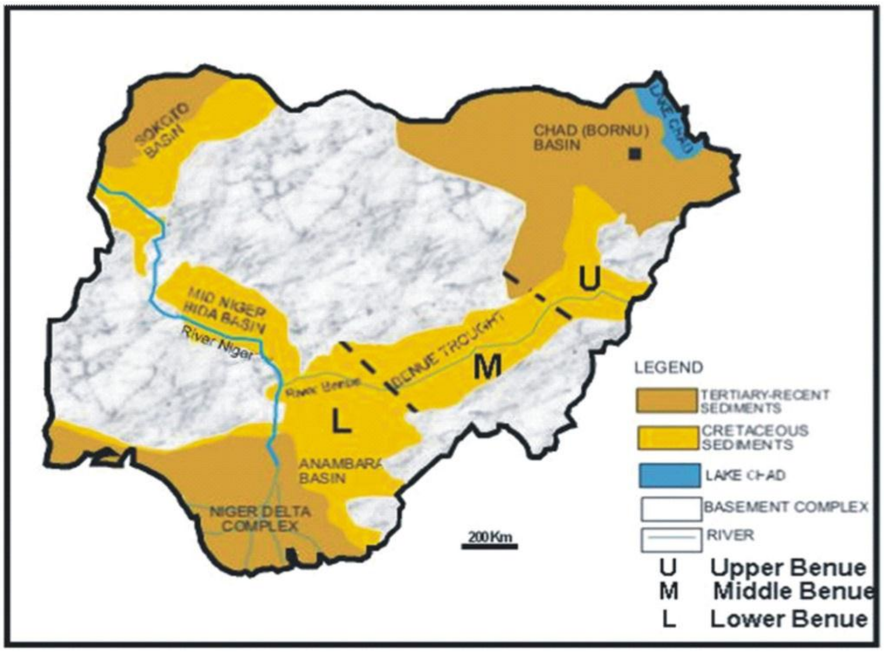

Figure 1: Geological map of Nigeria showing the Benue trough

Trough comprises of the main arm (Muri – Lau Basin) that trends NE – SW, which bifurcates into E – W trending Yola Basin and the N – S trending Gongola Basin where this study was carried out (Dike, 2002) (Figure 2). In the Gongola Basin, the Aptian – Albian Bima Sandstone represents the oldest sedimentary unit in the basin. This essentially continental formation overlying the Precambrian Basement Complex rocks consists of the lower Bima (BI), middle Bima (BII) and upper Bima (BIII) (Allix, 1983) (Figure 3). It is conformably succeeded by the Cenomanian Yolde Formation consisting of transitional deposits marking the onset of marine transgression into the basin (Zaborski *et al*., 1997). The formation is composed of deltaic to shoreface sequences (Shettima, 2005). Full marine deposits are represented by the Turonian – Santonian Pindiga Formation composed of limestone and shale sequences (Zaborski *et al*., 1997) and it is laterally equivalent to the Gongila Formation and Fika Shales (Popoff, *et al.*, 1986). The Gombe Sandstone of Maastrichtian age fallows conformably and it is the youngest Cretaceous sediment in only record of Tertiary sedimentation in the Gongola Basin (Dike, 1993) (Figure 3).

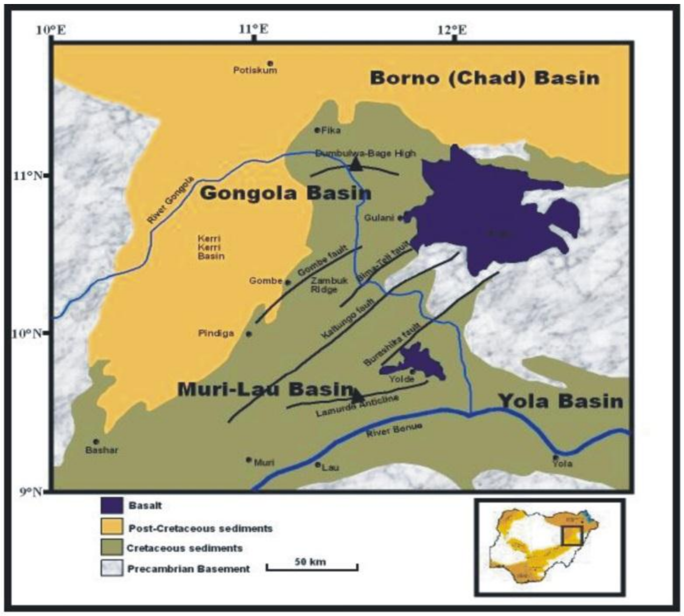

Figure 2: Geological map of the Upper Benue trough

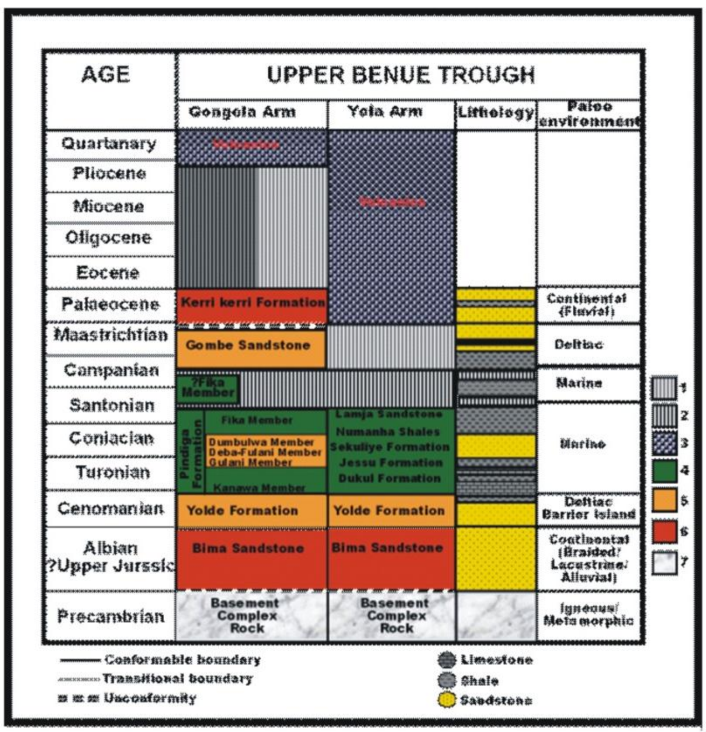

Figure 3: Diagram of the stratigraphy of the Upper Benue trough

2. Materials and Methods

Twenty five samples of the Gombe Sandstone were collected around Gombe and environs where its thickest section occurs (Figure 4). These samples were collected from five outcrop sections with careful attention as to avoid weathered horizons (Figures 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 (1957). Petrographic analysis was also carried out on 30 samples using Ziess petrographical microscope to determine sorting, intergranula 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 Head (1990), in order to determine porosity and permeability for the Gombe Sandstone.

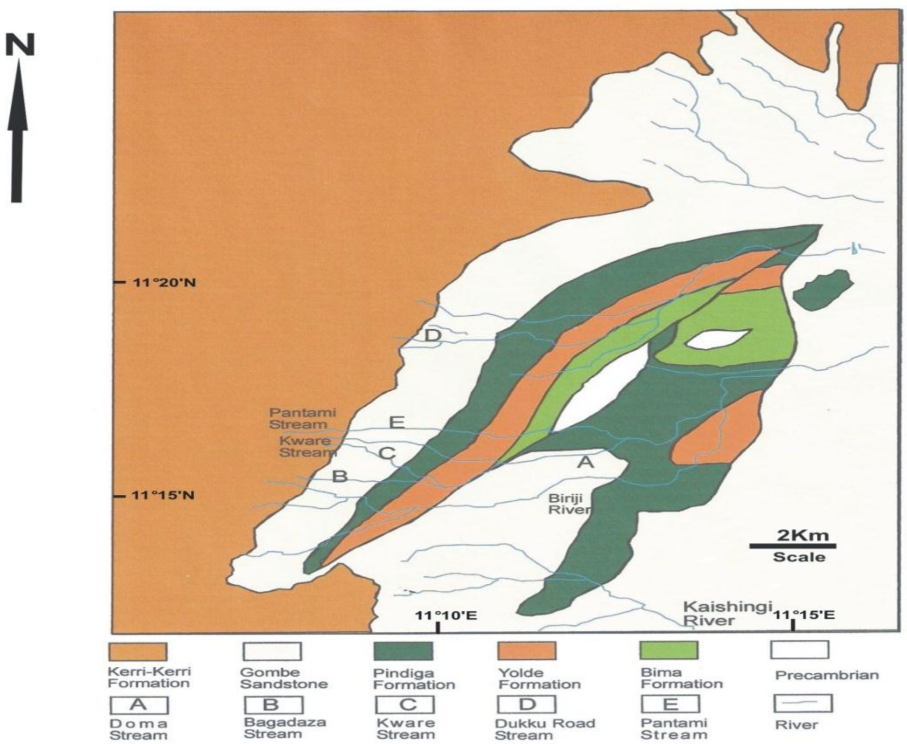

Figure 4: Geologic map of Gombe and adjacent areas showing location of section studied

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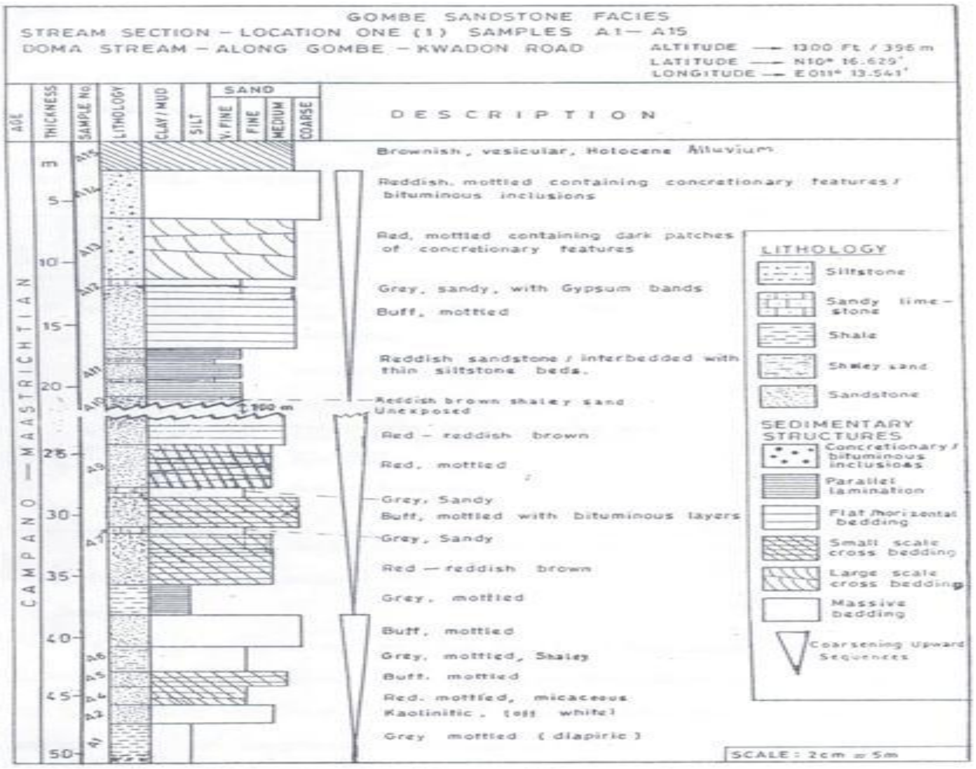


Figure 5: Section of Gombe Sandstone at Doma stream

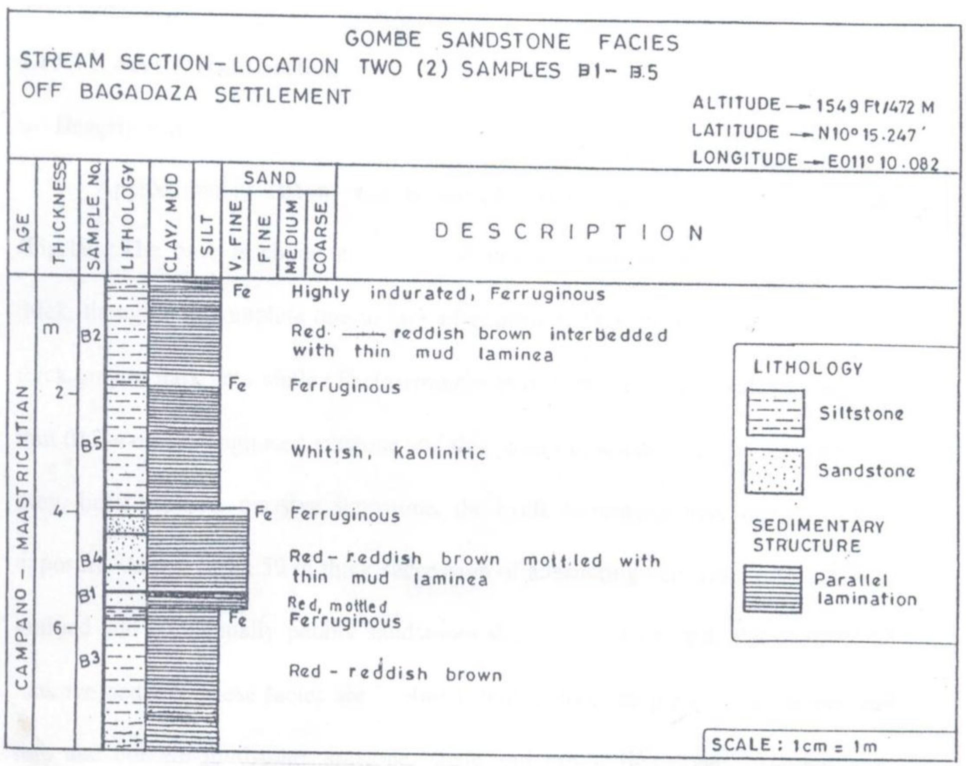


Figure 6: Section of Gombe Sandstone at Bagadaza stream

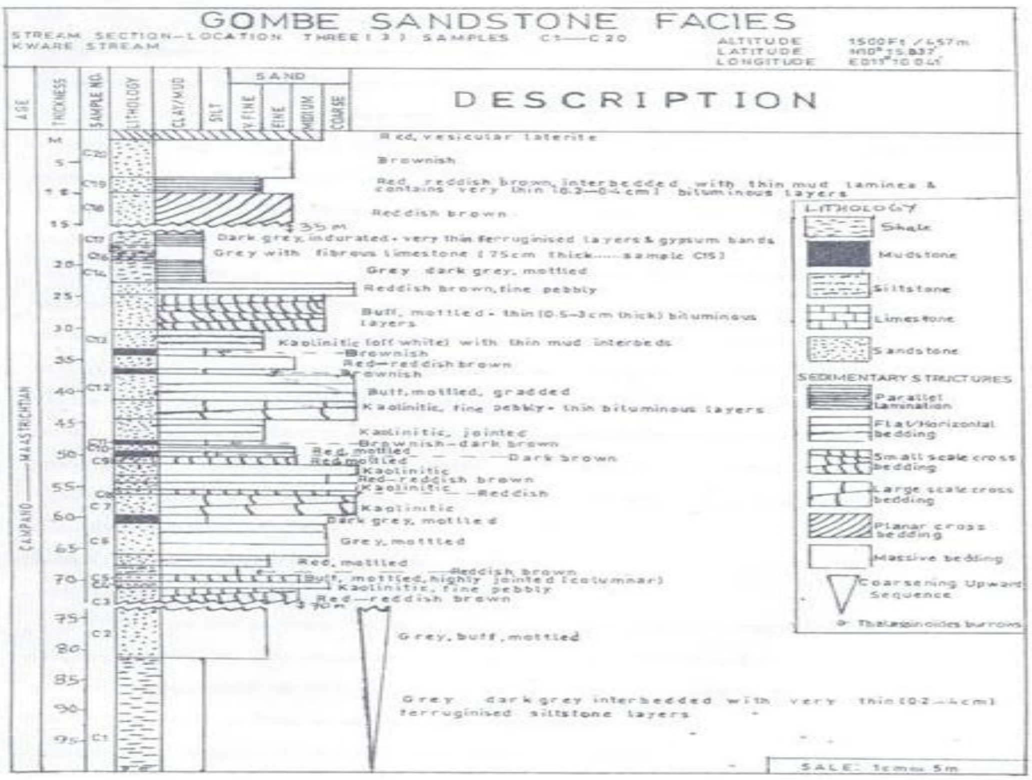


Figure 7: Section of Gombe Sandstone at Kware stream

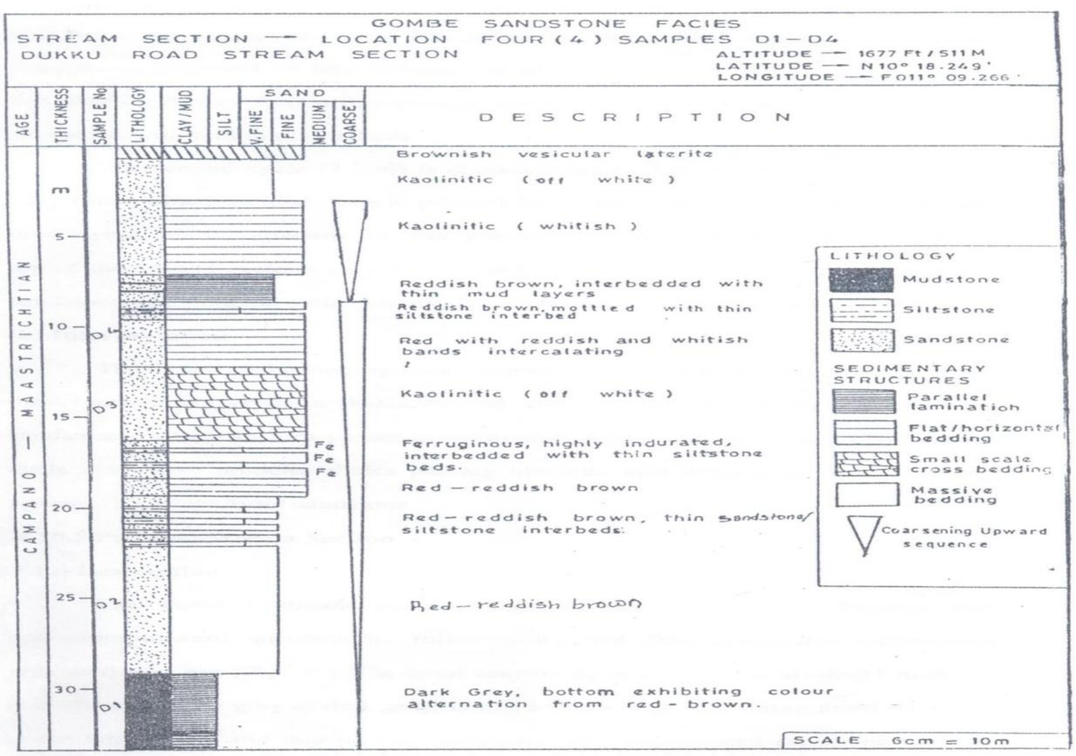


Figure 8: Section of Gombe Sandstone at along Dukku Road

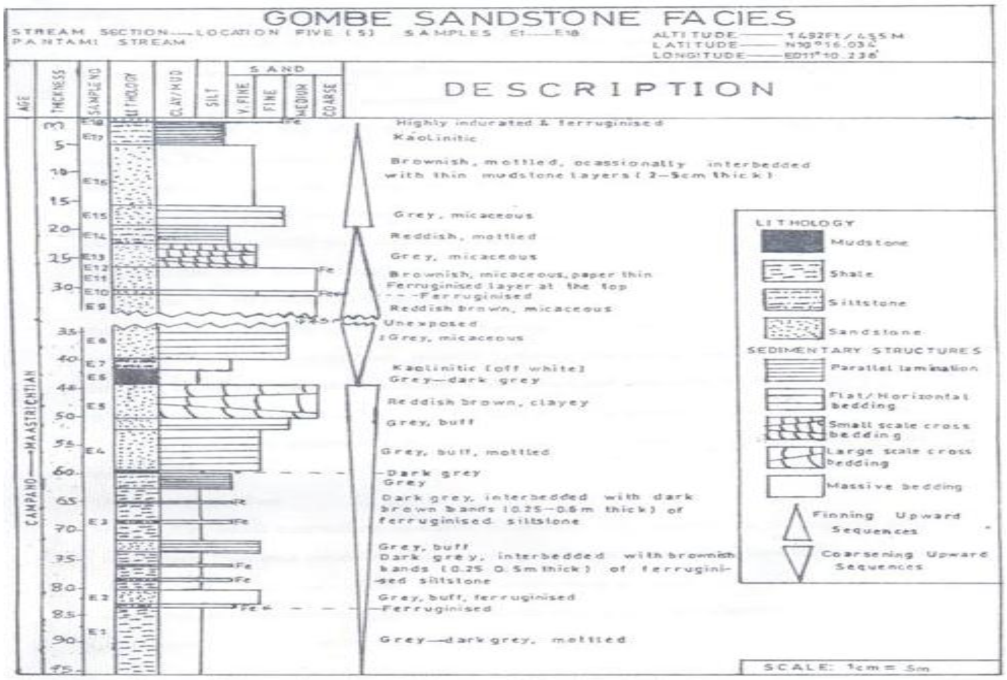


Figure 9: Section of Gombe Sandstone at Pantami stream

3. Results and Discussion

3.1 Results

3.1.1 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) tends 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 analyzed have skewness values ranging from -0.12ø to 0.44ø i.e. from negatively skewed to very positively skewed. 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).

3.1.2 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 cements. 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). 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 Folk's (1954) sandstone classification, the Yolde Formation's sandstone range from subarkose to quartzarenite, and their textural maturity based on Folk (1974) ranges from submature to mature. Petrographic evaluation of the porosity based on the estimation methods of Swanson (1985) shows that the Gombe Sandstone has porosity values ranging from 7 – 19% with an average of 19% (Table 2).

3.1.3 Bivariate plots

The bivariate plots of grain size versus standard deviation based on the works of Terry and Chilinger (1964) and Beard and Weyl (1975) used for evaluation petrophysical properties was also implored in this studies to determine the porosity and permeability of the Gombe Sandstone. Twenty five (25) samples were plotted in the diagram (Figure10), and the porosity ranged from 25% - 41%, with an average of 33.37%. While the permeability varied from 0.1D – 15D, with an average of 5.2D (Table 1).

Table 1: Univariate grain size parameters, 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

Table 2: 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

3.1.4 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 was evaluated to range between 19.3% – 25.4%, with average of 23%, while the permeability ranged from 100 – 200md (Table 3).

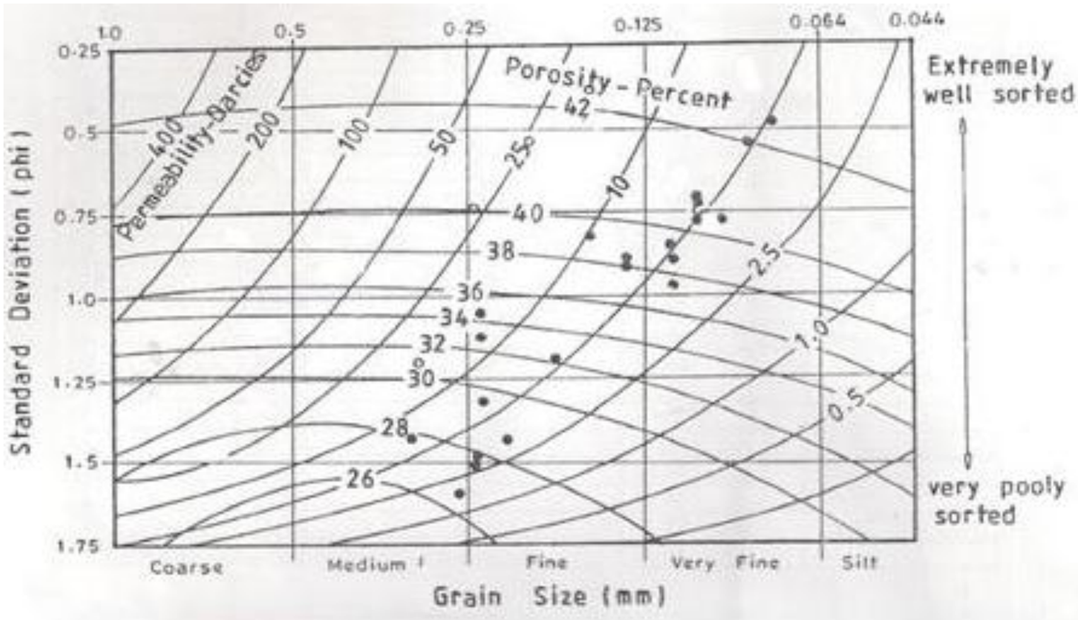


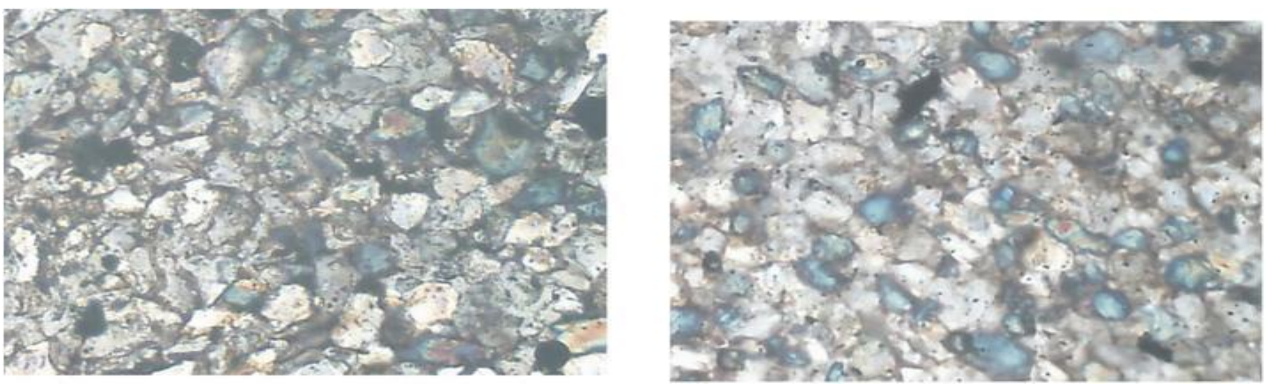
Figure 10: Porosity and permeability plot of Gombe Sandstone

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 ($^O C$)	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^oC 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

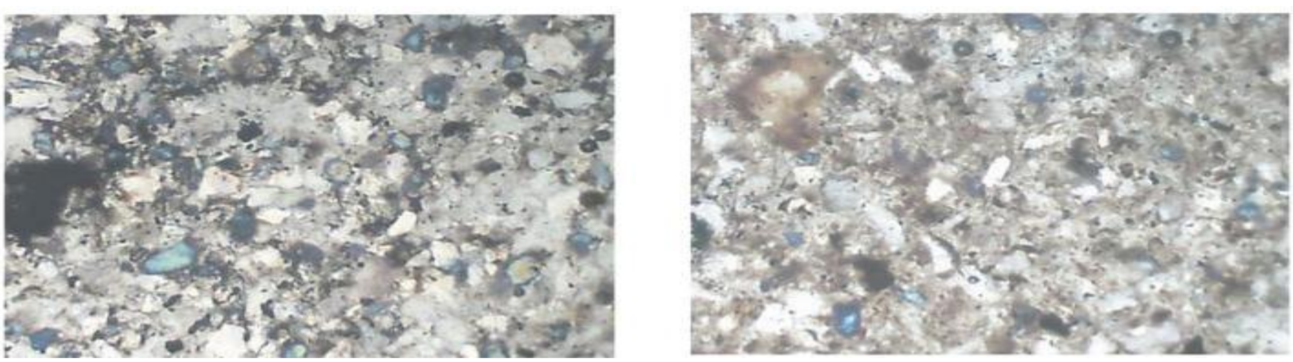
3.2 Discussion

Granulometric analysis indicated that the mean grain size of the Gombe Sandstone generally ranged from medium to fine grain (Table 1). Medium to fine grained sandstone usually consists of more porosity compared to coarse sandstone, hence it may be suggested that the Gombe Sandstone can possibly yield good aquifers. Better sorted sandstone usually yield good porosity (Pettijohn *et al.*, 1987; Boggs, 1995) and sorting for the Gombe Sandstones varied from well to moderate to poor, with the well to moderately sorted grains restricted to the thick sandstone units while the poor associated with the intercalated sandstone with claystone (Figures 5, 6, 7, 8 and 9), therefore, the thick sandstone units of this formation may have the highest aquifer potential. However, skewness are generally positive for this formation (Table 1) and this may suggest that, though the parking of the grains as observed from sorting is generally relatively good, there must have been crystallizations of clay minerals in the voids which may have reduces the porosity to certain extent because positive skewness indicates occurrence of fine grained materials (Folk, 1974). Petrographic analysis also showed that the sorting varied from well, moderate to poor (Figures 11 and 12) and the fabric is generally grain supported with shapes ranging from sub-angular to rounded (Figure 13). The porosity evaluated from petrographic analysis ranged from 7% - 19%, with lower values associated the sandstones intercalated with mudstones and higher values restricted to the thick sandstone units. Dike and Onumara (1999) suggested that the Gombe Sandstone was formed under a deltaic environment having delta slope sands and clays passing upwards to delta front sands. These sands generally constitute of well to moderately sorted grain, having porosity and permeability values ranging from 19.36 – 24.50% and 100 – 200Md respectively from the analysis of their core samples (Table 3).



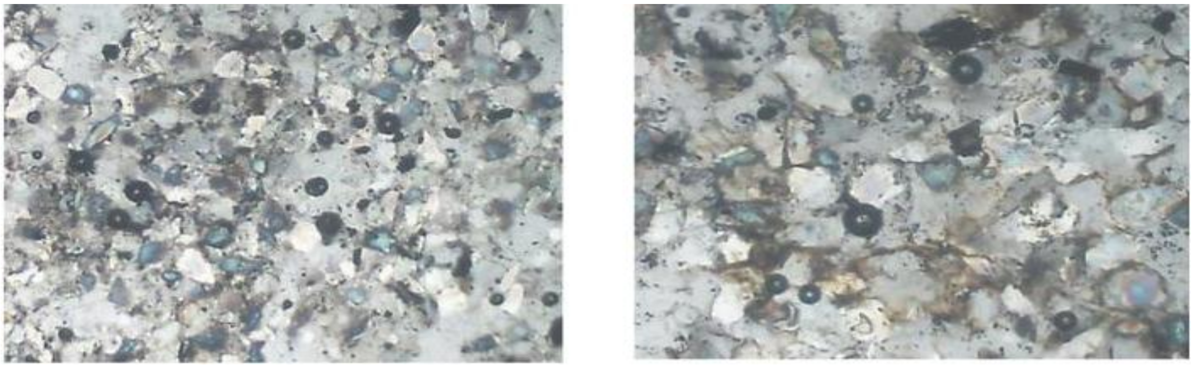
(A) (B)

Figure 11: Well sorted grains (A) – Sample B4x40 and (B) – Sample D2x40



(A) (B)

Figure 12: Moderately sorted grains (A) – sample E5x40 and poorly sorted grains (B) – sample D2x40



(A) (B)

Figure 13: Subangular grains (A) – sample D4x40 and rounded grains (B) – sample C18x40

The porosity and permeability values evaluated for the Gombe Sandstone shows that the formation has relatively good aquifer potential (Table 3). Therefore, it has the ability to store and transmit water within its mass, but that notwithstanding, the aquifers formed by this formation within Gombe town and environs tend to produce relatively low yield in the boreholes drilled, with performances ranging between 1.4 – 2.8 l/s (Zircon Investment Report, 2008). However, in the North and Northwestern part of Gombe town, particularly around Kwadon village, the borehole yields appreciably improved to about 4.8 – 5.6 l/s. The variations in the borehole yield may probably be attributed to the tectonic setting of the Gombe Sandstone in the areas where it outcroped to serve as an aquifer. The larger part of the Gombe Sandstone is generally uplifted in the Gombe Town and environs because it falls on an anticlinal structure thereby making it vulnerable to erosion in which the thick sandstone represents the delta front sand that has been greatly reduced leaving behind dominantly intercalated sandstone mudstones. The sandstone of the facies generally has low porosities and permeability and this ultimately resulted in the low borehole yield in the Gombe Sandstone around the town and environs. Towards the North and Northeast, particularly around Kwadon area, the Gombe Sandstone falls in a synclinal structure in which the greater part of its arenaceous content especially the thick sandstone was well preserved. These thick sandstone generally had well to moderate sorted sands with porosity and permeability of 28 – 42% and 5 -14D respectively and this resulted in the relatively good borehole yield observed around Kwadon village. The relatively high yield in these areas was improved by the drainage regime in the setting, because all the streams direct their flows towards the Northeast thereby ultimately recharging the Gombe Sandstone aquifer around Kwadon area for better performances.

4. Conclusion

The petrophysical properties of the Cretaceous Gombe Sandstone show that the aquifer within this formation has the capacity of storing and transmitting underground water. The acute low borehole yield in the aquifer of this formation from Gombe Town is structurally related in which greater thickness of the thick sandstone facies that can serve as the aquifer has been greatly reduced due to uplifting and erosion. However, in the Northeast and Eastern part of the Gombe Town, precisely around Kwadon village, the thick sandstone facies are well preserved and this results in the good borehole yield in the area. The yield is further improved by the drainage pattern in the setting, because it directs its source to the East thereby recharging the Gombe Sandstone aquifer for better yield.

References

Beard, DC. and Weyl, DK. 1973. Influence of texture on porosity and permeability of unconsolidated sands. American Association of Petroleum Geologists Bulletin, 57: 349 -369.

Benkhelil, J. 1989. The origin and evolution of the Cretaceous Benue Trough (Nigeria). Journal African Earth Sciences, 8: 251-282.

Boggs, SJr. 1995. Principles of Sedimentology and Stratigraphy, (2nd ed). Prentice Hall, New Jersey, pp. 109.

Dike, EFC. 1993. The stratigraphy and structure of the Kerri-Kerri Basin North-eastern Nigeria. Journal Mining and Geology, 29(2): 77-93.

Dike, EFC. 2002. Sedimentation and tectonic evolution of the Upper Benue Trough and Bornu Basin, North-eastern Nigeria. Nigerian Mining and Geoscience Society Annual and International Conference. Port Harcourt 2002, 32: 37.

Dike, EFC. and Onumara, IS. 1999. Facies and facies architecture and depositional environments of the Gombe Sandstone, Gombe and Environs. Science Association of Nigeria Annual Conference, Bauchi, 13: 21.

Folk, RL., 1954. The distinction between grain size and mineral composition in Sedimentary rocks (sic) nomenclature: Journal of Geology, 62: 344-365.

Folk, RL. 1974. Petrology of sedimentary rocks. Austin Texas, Hemphill Book Store In: Scolle P.A. (Ed), A colour illustrated guide to constituents, textures, cements and porosities sandstones and associated rocks. American Association of Petroleum Geologists, Memoir, 28, Tulsa, p170.

Folk, RL. and Ward, WC. 1957. Brazos River bar, a study in the significance of grain- size parameters. Journal of Sedimentary Petrology, 30: 514-529.

Grant, NK. 1971. The south Atlantic Benue Trough and Gulf of Guinea Cretaceous Tripple. Geological Society of American Bulletin, 82: 2295-2298.

Guiraud, M. 1990. Tectono-sedimenatry framework of the Early Cretaceous continental Bima Formation (Upper Benue Trough N.E. Nigeria). Journal African Earth Sciences, 10: 341-353.

Head, KH. 1990. Manual of soil laboratory testing, permeability, shear strength and compression tests. Oxford University Press, London, pp 302.

Lawal, O. and Moullade, M. 1986. Palynological biostratigraphy of Cretaceous sediments in the Upper Benue Basin N.E. Nigeria. Revenue Micropaleotologie, 29: 61-83.

Pettijohn, F J., Potter, PE. and Siever, R. 1987. Sand and Sandstones (2nd Ed). Springer-Verlag, Berlin, pp 407.

Shettima, B. 2005. Sedimentology and Reconstruction of the Depositional Environments of the Yolde Formation in the Gongola Arm of the Upper Benue Trough Northeastern Nigeria. M.Sc. Thesis (unpublished), Abubakar Tafawa Balewa University, pp 84.

Swanson, RG. 1985. Sample Examination Manual. American Association of Petroleum Geologists Publication Tulsa, Oklahoma, pp 111.

Terry, RD. and Chilinger, GV. 1987. Summary of Concerning some additional aids in studying sedimentary formations. Journal of Sedimentary Petrology 25: 229-234.

Zircon Investment Ltd. 2008. Productivity of Boreholes around Gombe and Environs. Unpublished report, Zircon Investment Limited, Gombe, pp 12.