



## Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: <https://atbu.edu.ng/science-forum/>



### Lithostratigraphy and Geochemistry of Gombe Formation around Pindiga and Futuk Areas, Gongola Basin, Northern Benue Trough, North Eastern Nigeria

Celestine Asadigi Joseph, Maigari Abubakar Sadiq, Umar Dagauda, Eric Emmanuel

Department of Applied Geology, Abubakar Tafawa Balewa University, Bauchi, Nigeria

#### ABSTRACT

The Lithostratigraphy and geochemistry of the Gombe Formation around Pindiga and Futuk areas were carried out. Twenty (20) sandstone samples were subjected to granulometric analysis, three (3) mudstones samples were subjected for geochemical analysis and twelve (12) Sandstone samples were subjected for petrographic analysis. The result of the granulometric analysis shows the graphic mean size for the various samples ranging from  $1.77\phi$  to  $3.5\phi$ , which indicate medium to very fine grained, Inclusive Standard deviation ranging from  $0.28\phi$  to  $0.57\phi$ , this indicates very well sorted to moderately sorted, Inclusive Skewness values for various samples range from  $-0.36\phi$  to  $0.54\phi$  which indicate negatively skewed to positively skewed, kurtosis ranging from  $0.94\phi$  to  $3.48\phi$  which indicate mesortic to extremely leptokurtic. The Bivariate plot of standard deviation vs. skewness indicated dominance of fluvial environment. While, the probability plots show a dominance of three sand populations indicating influence of marine processes. Environmental discrimination formulae for Y1, Y2 and Y3 indicated dominance of aeolian, shallow agitated marine environment and shallow marine environment respectively. The plots of Y2 vs. Y1 and Y3 vs. Y2 showed a dominance shallow marine environment. The geochemical results indicate the  $\text{SiO}_2/\text{Al}_2\text{O}_3$  ratio fluctuate between 3.0 and 3.7 showing textural immaturity, the  $\text{Al}_2\text{O}_3/\text{TiO}_2$  ratio varies from 5.92 to 6.13 indicating derivation from mafic rocks, the values of Sr/Cu ranging from 0.51 to 0.63 with an average of 0.58, which shows deposition under humid climatic condition, an average Index Compositional Variability (ICV) value of 0.45 was recorded showing high degree of weathering processes. The discrimination plots indicate the tectonic a continental rift of passive margin setting for the Gongola basin. The Petrographic analysis of these sandstones tends to show that sorting ranges from poorly to well sorted but moderate sorting predominates. The grain shape ranges from sub angular to well-rounded with sub-angular dominating, and the sphericity varies from low-high. Quartz predominates in the framework grains of the sandstones. Monocrystalline quartz is dominant, while polycrystalline quartz occurs in very few samples.

#### ARTICLE INFO

Received 12 July 2023  
 Received in Revised Form 11 August 2023  
 Accepted 11 August 2023  
 Published 20 February 2024  
 Available online 20 February 2024

#### KEYWORDS

Lithostratigraphy,  
 Geochemistry,  
 Gombe Formation  
 Pindiga,  
 Futuk

## INTRODUCTION

The Benue Trough is a major NE – SW trending rift basin of 50 -150 km width. It extends for over 1000km starting from the northern margin of the Niger Delta in the South to Southern margin of the Chad Basin in the North. The trough contains over 6000m of Cretaceous –Tertiary sediments. It is geographically subdivided into Southern, Central and Northern trough (Nwajide 2013).

The Northern Benue Trough is made up of two major sub-basins: the N-S trending Gongola Sub-basin and E-W trending Yola sub-basin (Nwajide, 2013). Gongola sub-basin of the Northern Benue Trough comprises the Continental Bima Formation, The transitional-marine Yolde Formation, the marine Pindiga Formation, the Campano-Maastrichtian Deltaic Gombe Formation (the formation of interest in this study) and finally the Continental Keri-Keri Formation. The Gombe Formation is the youngest Cretaceous lithostratigraphic unit in the North South trending Gongola sub-basin of the Northern Benue Trough (Popoff *et al.*, 1986 and Nwajide, 2013).

The Gombe Formation unconformably overlies Fika shale and is overlain by Paleocene Keri-Keri Formation. The lithologic units of the Gombe Formation are divided into three according to Zaborskiet.*al.* (1997)

- i. Basal inter bedded unit
- ii. Middle bedded facie
- iii. Upper red Sandstone Facies

The basal unit comprises of alternating thin beds and silty shales, with some plant remains and fine to medium grained sandstones intercalated with flaggy ironstones.

The middle part consists of regularly horizontally bedded fine to medium grained quartz arenite, interbedded with silts, silty clays and ironstones.

The upper part of the formation consists of brick red colored sandstones with trough, tabular and planar cross bedding. The Gombe Formation is regarded as Maastrichtian in age (Carter *et.al* 1963; Kogbe 1979; and Popoff 1986).

The study area of Gombe Formation around Futuk and Pindiga towns lies between longitude E 10<sup>0</sup> 57' 09'' and E 10<sup>0</sup> 57' 37''<sup>1</sup> with an elevation of 476m and latitude N 09<sup>0</sup> 57' 09'' and N 09<sup>0</sup> 59' 34'' with and elevation of 499m, (Fig 1). It covers an area of about 350km. The area is accessible through the Gombe-Kashere-Futuk main road from the northern part through the Bauchi-Alkaleri-Futuk-Kashere road from the southern part. Localities and outcrop within the study area are well connected by a network of minor roads and footpaths.

This study is aimed at investigating the petrographic and geochemical attributes of outcropping rocks of Gombe Formation around Pindiga and Futuk areas,

The objectives of this study include:

1. To determine the lithofacies characteristics of the Gombe Formation outcropping within the study areas.
2. To ascertain the mineralogical composition of the rocks.
3. To determine the paleo-depositional environment of the sediments using lithofacies characteristics, granulometric and petrographic data.
4. To assess the palaeo-climatic and palaeo-environmental conditions of the rocks of the Gombe Formation within the study areas.

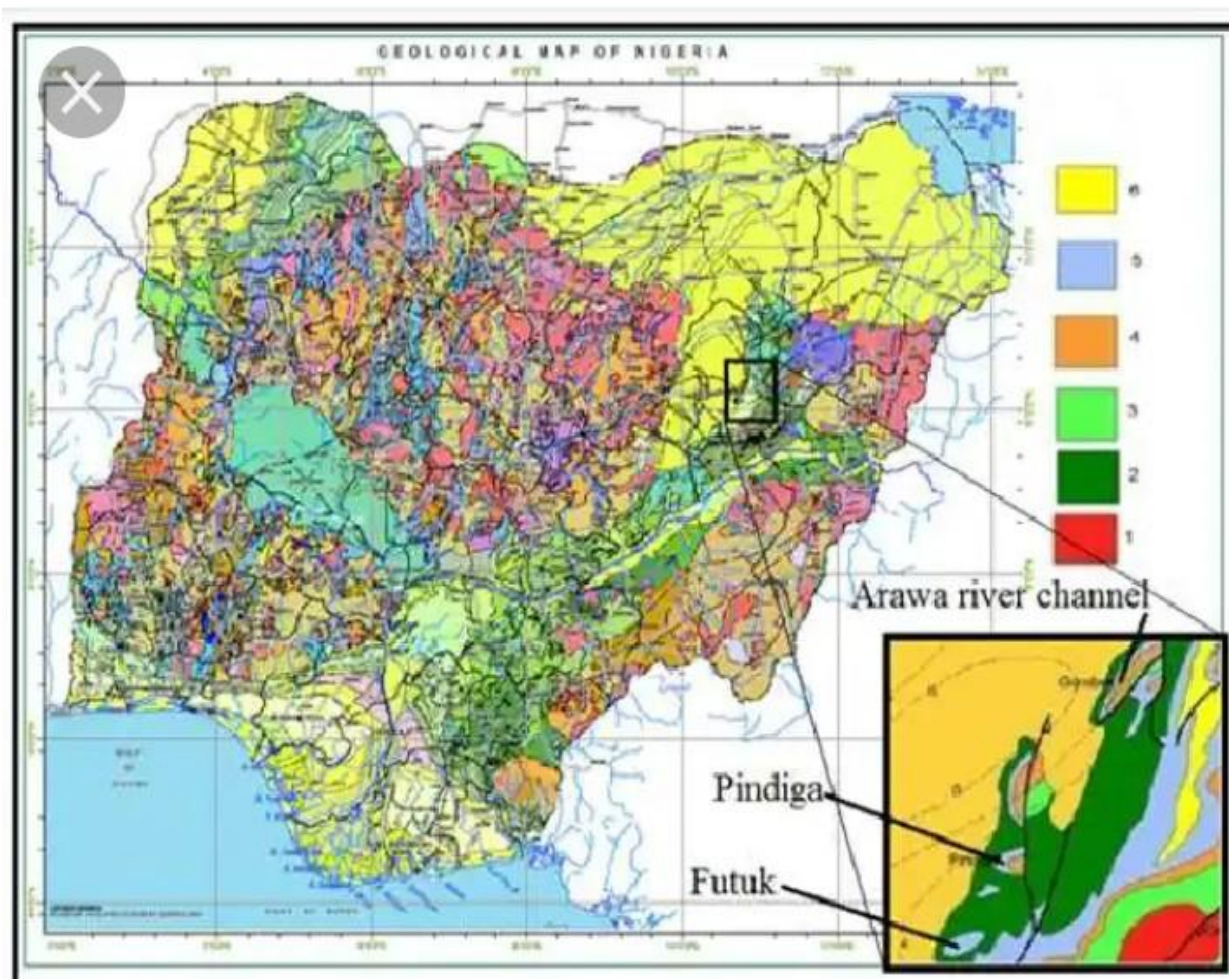


Fig 1: Geological map of Nigeria showing location of the study area (by Abdullahi Arabi Suleiman, 2011)

## 2. GEOLOGICAL SETTING AND STRATIGRAPHY OF THE BENUE TROUGH

The origin of the Benue Trough is associated with the opening of the Atlantic Ocean during the late Jurassic to early Cretaceous times. The first stage of evolution started in the Aptian, forming isolated basins with continental sedimentation in the Albian times, a great delta developed in the Northern Benue Trough, while the first marine transgression coming from the opening Gulf of Guinea occurred in the South and reached the Central Benue Trough. The Benue Trough is an intra-continental basin of about 1000km-long and 100-250 km wide, it is divided into the Northern, Central and Southern Benue Troughs. The mechanism of the formation of the basin has been proposed by (Nwajide 2013) which is

believed to be formed in response to the breakup of Gondwanaland, while Stoneley (1966) and Wright (1968) believed it to be a graben resulting from re adjustment of the African plate following Cretaceous opening of the Gulf of Guinea. Burke and Dewey (1971) regarded it as an aulucogen (failed arm) part of a three-arm rift system involving South Atlantic Ocean. Burke *et.al* (1972) put forward a three-arm rift model more recently. Benkheilil and Robuneau (1983) Popoffet.al (1983). Maurinet.al (1986) and Benkelil (1988) suggest that the Benue Trough is a set of pull-apart sub-basin generated by sinistral displacement along pre-existing NE-SW trans current faults.

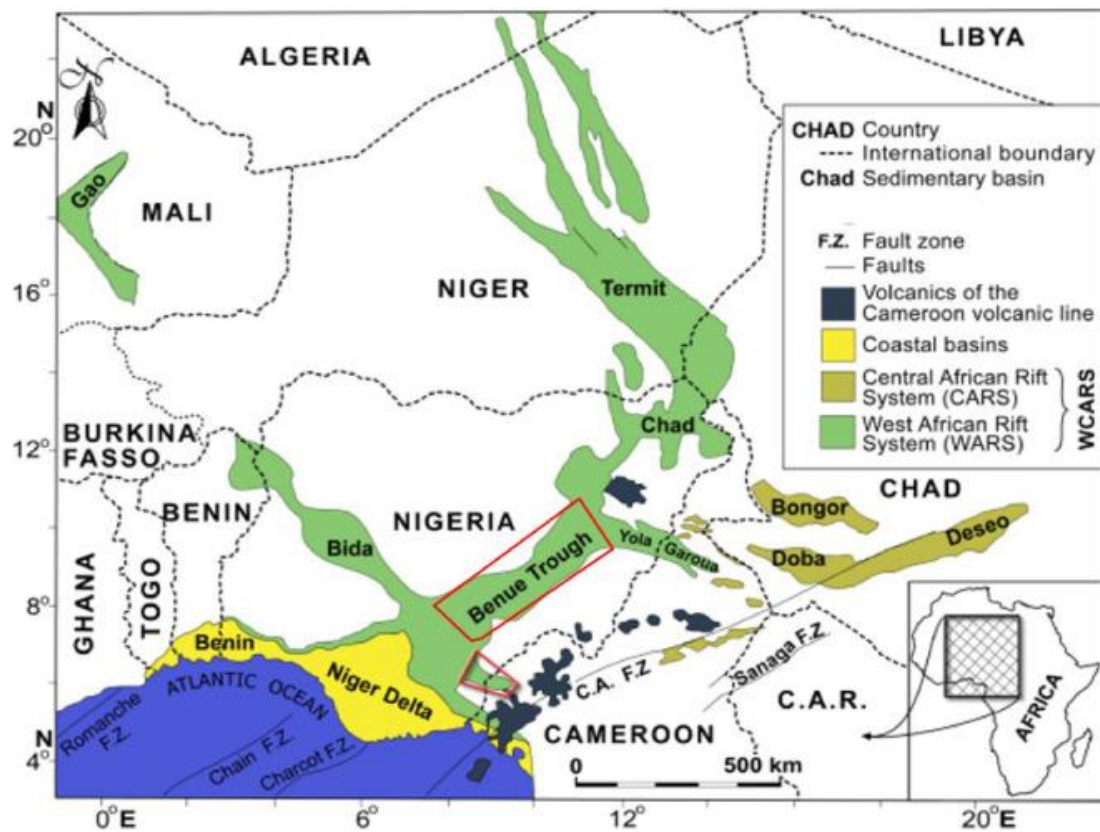


Figure 2: West and Central African Rift System (WCARS) and associated basin (Aymatt 2011)

The upper Benue Trough is located in the North eastern region of Nigeria and is the North eastern y-shaped part of the basin and can be subdivided into two sub basins, the Yola arm and Gongola arm. Many authors have reviewed and presented the stratigraphy of the Northern Benue Trough

among whom are Carter et al., (1963), Offodile, (19760), Popoff *et.al* (1983), Dike (1993), Zaborski *et.al*, (1997); Obaje, (2000), Dike (2002). The Gongola arm (Fig 3) is made up of formations such as the Bima, Yolde, Pindiga, Gombe and Keri-Keri Formations.

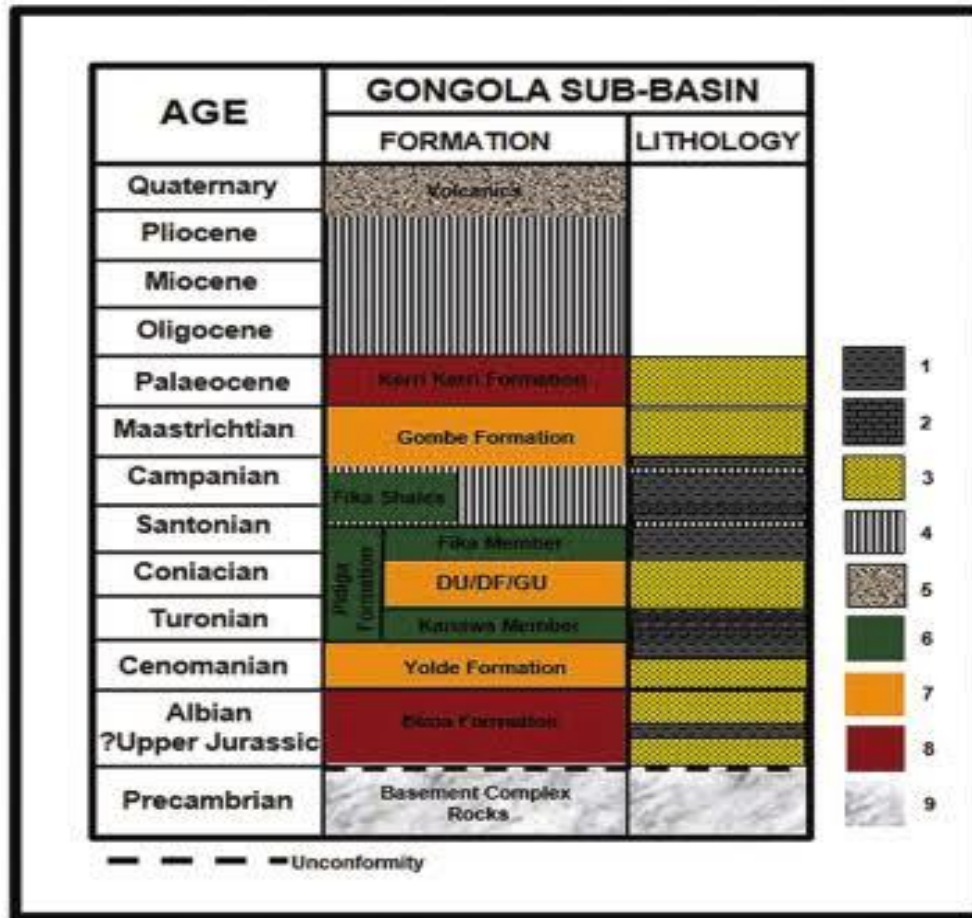


Fig 3: Shows the stratigraphic succession of the Northern Benue Trough (Obaje et al, 1999)

### 3. METHODOLOGY

#### Granulometric Analysis

Twenty (20) fresh sandstones samples collected from the field were prepared for sieve analysis. Most of the sandstone's samples of Pindiga section were loose and friable while those collected from Futuk section were highly ferruginised and indurated. The indurated samples were first disaggregated in a mortar using a rubber padded pestle to obtain 200grams of loose sample. The samples were then sieved for 25 to 30 minutes using a set of standard sieves (Plate 1). The statistical parameters of the grain size frequency distribution were then computed as described by Krumbein and PerttiJohn (1938), Folk and Ward (1957) and Folk (1966).

#### Geochemical Analysis

Geochemical analyses of three (3) fresh samples were conducted on only the mudstone samples collected. The analysis was carried out at the Geochemical Laboratory of the Geology Department of Gombe State University. The method adopted for the sample preparation for XRF analysis of the major elements is outlined below:

- About 25 g of spectroflux was placed in a platinum (pt.) dish and dried at 450<sup>o</sup>c for about 3 hours. It was allowed to cool and stored in desiccators.
- .05950g of sample powder and 3.00g of spectroflux were weighed out into a small Platinum-Rhodium-Gold (PT-RH-AU) crucible using a digital balance.

c. The crucible was placed in a furnace and fused at 105 for 25 minutes.

d. The crucible was withdrawn quickly but carefully with platinum tipped tongs and the melt was poured onto an aluminum platen held at 150° c and the plunger was brought down. Disc were separated from the platen immediately and allowed to cool. The hot plate and the furnace were switched off as soon as a batch of disc was made, and the samples were allowed to cool overnight.

e. The samples were then labeled on the convex side. The flat side of the disc was cleaned with toluene and stored in a plastic envelop ready for XRF analysis.

The XRF equipment used was fully automated and prints out in weight percent (wt. %) oxide, the concentration of the major elements in each sample.

#### **Petrographic Analysis**

A total of twelve (12) Fresh sandstones samples were collected from the field: for petrographic study from Pindiga section and six fresh sandstones from Futuk section.

Thin sections were prepared from the samples collected at each location. Most of the samples collected are indurated while some are friable. The hard compacted samples were thin sectioned directly, while the loose and friable samples were impregnated with araldite/epoxy resin and then heated on an electric hot plate for about 3 hours. They were then allowed to dry up completely. This produced highly indurated samples which then were easily cut into thin sections. Slides were mounted on petrographic microscopes and studied under plane and cross

polarized lights as recommended by Hatch and Rastal (1965), Adams (1984) and Banarjee and Battacharya (1994).

## **4. RESULTS AND DISCUSSION**

### **Lithostratigraphic Sections**

The lithology of Gombe Formation in the study area (Pindiga and Futuk areas) generally ranges texturally from very fine, fine to medium grained sandstones (80-90%), mudstone (5-15%) and ferruginised sandstone (5%) with fine grained sandstone predominating. These lithology's display a variety of colors ranging from light grey, grey, light brown, brown, and reddish. The estimated thickness in proportion of about 25m for sandstone, mudstone 5m and ferruginised sandstone 2m along Dada-buji stream in the Pindiga section (Figure 4) while at Futuk section (Dama yara) along Futuk-Alkaleri road (Figure 5) thicknesses ranges from 17m for sandstone, 3m for mudstone and 0.9m for ferruginised sandstone. The outcropping section of the Gombe Formation exposed at Pindiga town along Dadabuji River Channel have been logged at different location. Five facies were recognized based on lithology and sedimentary structures and they are as follows: Bioturbated Sandstone (Bst), Planar Bedded Sandstone (P.st), Interbedded Flat-Bedded Sandstone and Mudstones (I.s, m), Massive Sandstone (M.st), Tabular Cross-Bedded Sandstones while Lithofacies exposed at Futuk areas along Futuk-Alkaleri Road include, Parallel Laminated Sandstones (P. l, s), Trough Cross-Bedded Sandstone (T.c, b, s) and Bioturbated Sandstone (Bst).

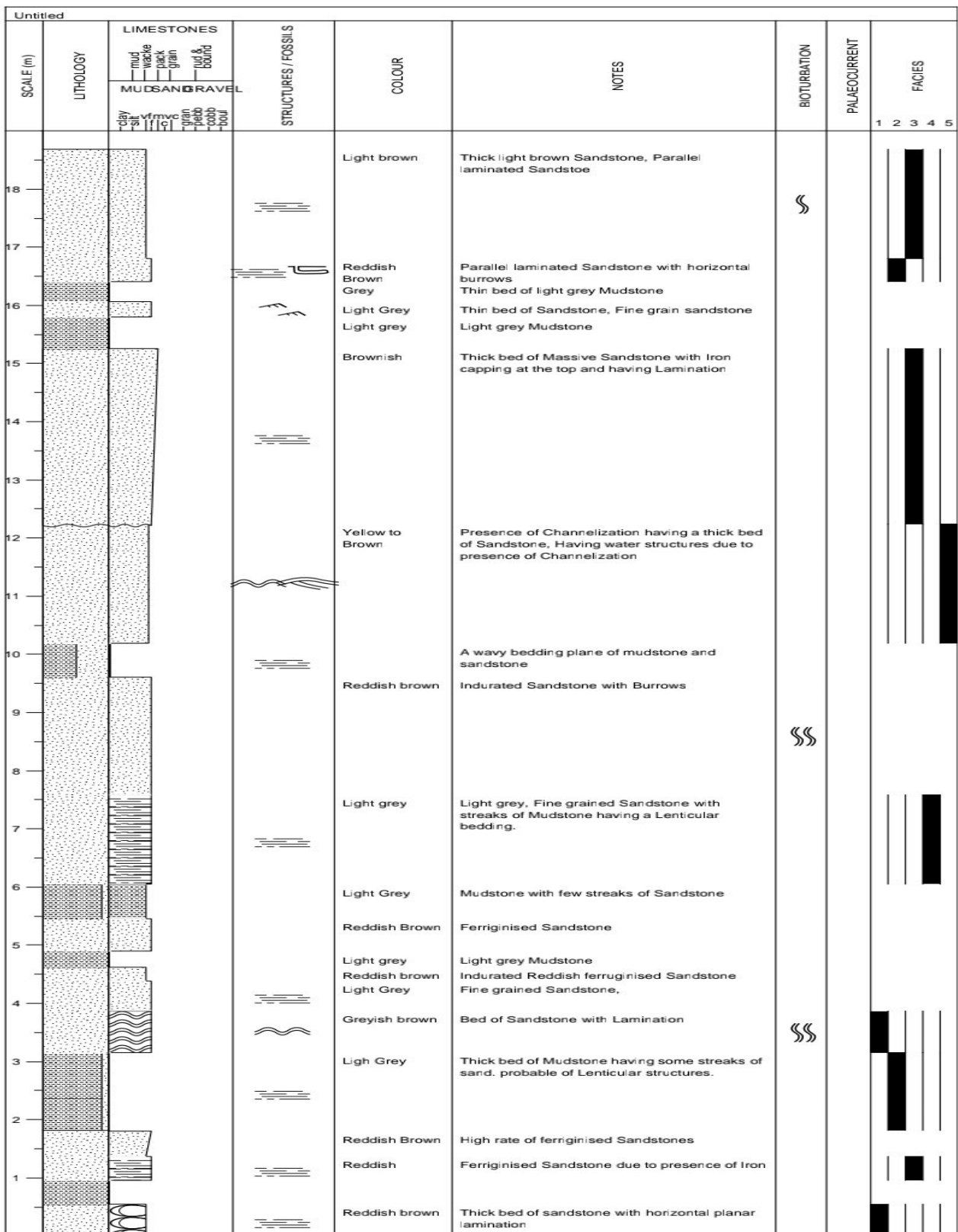


Figure 4: Lithostratigraphic section of Gombe formation exposed at Pindiga town along Dadabuji River Channel.

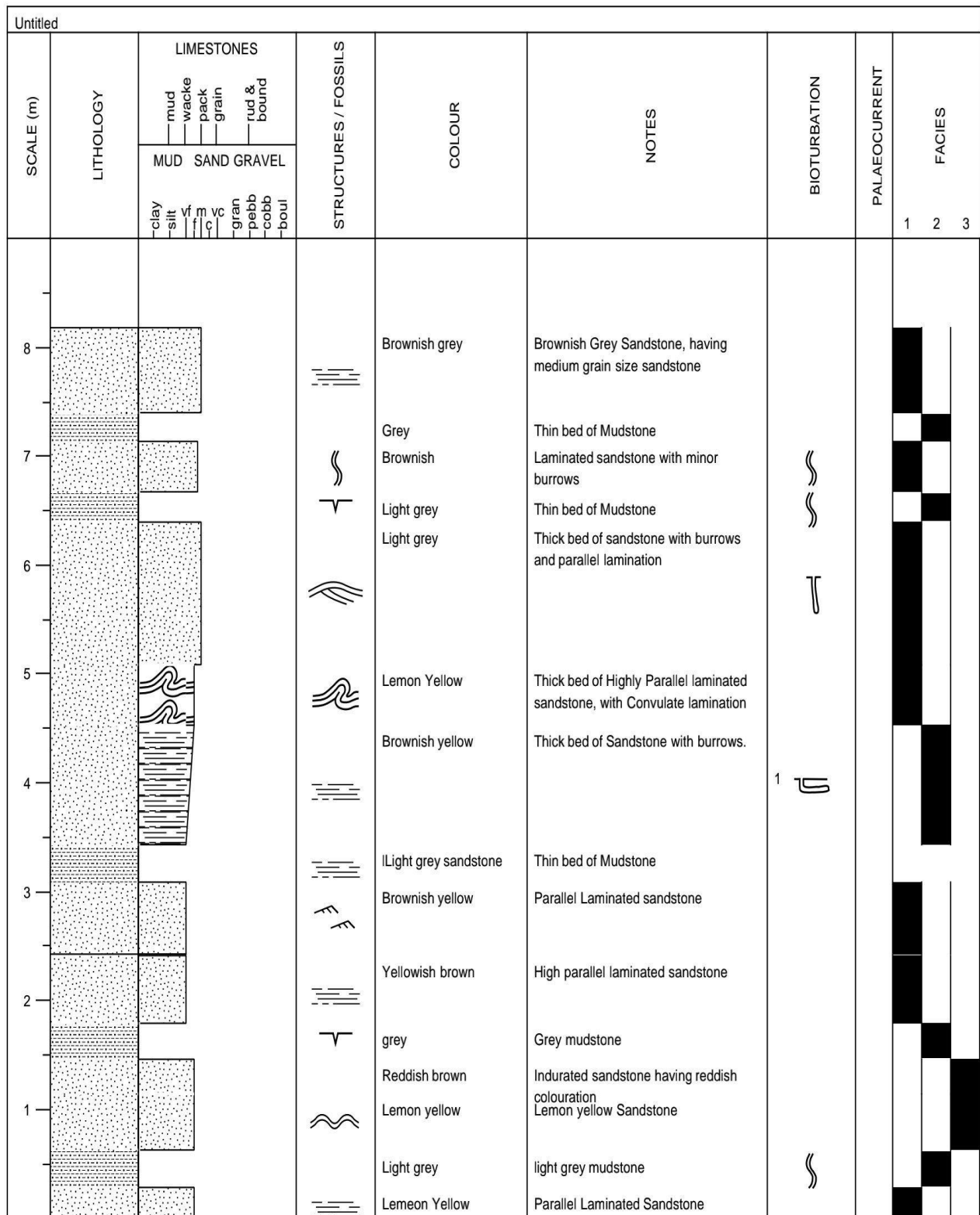


Figure 5: Lithostratigraphic section of Gombe Formation exposed at Futuk town (Dama-Yara) along Futuk-Alkaleri road.





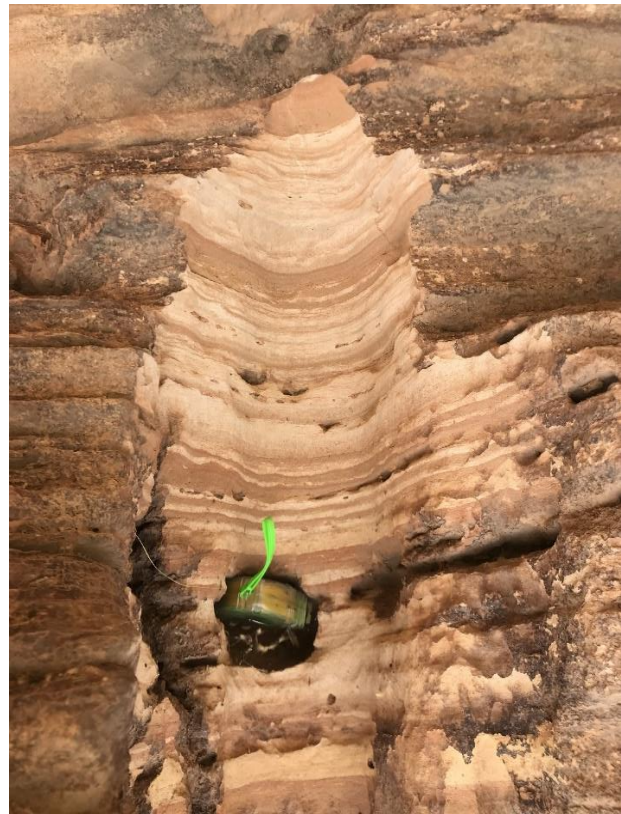
**Plate I:** showing Gombe Formation at Pindiga along Dada-Buji Stream Channel



**Plate II:** Showing Stream Channelization at Pindiga along Dada-Buji Stream Channel.



**Plate III:** Showing Gombe Formation with Parallel lamination at Pindiga stream Channel



**Plate IV:** Showing Gombe Formation with Parallel Lamination at Pindiga along Dada-Buji Stream Channel

TABLE 1: Grain Size Distribution and Quantitative Parameters for The Samples Analyzed

SAMPLE NO	GRAPHIC MEAN GRAIN SIZE ( $M_z$ )	STANDARD DEVIATION (SORTING) ( $\delta$ )	GRAPHIC SKEWNESS ( $S_{ki}$ )	GRAPHIC KURTOSIS ( $K_c$ )
F1A	3.5 Very Fine grained Sand	0.39 Well Sorted	0.30 Strongly fined Skewed	0.61 Very Platykurtic
P2	2.66 Fine grained Sand	0.45 Well Sorted	0.17 Fined Skewed	2.74 Very Leptokurtic
P3	2.83 Fine grained Sand	0.47 Well Sorted	0.19 Fined Skewed	0.94 Mesokurtic
P4C	1.77 Medium grained Sand	0.40 Well Sorted	0.03 Near Symmetrical	1.03 Mesokurtic
P5	2.73 Fine grained Sand	0.34 Very Well Sorted	0.34 Strongly fined Skewed	0.90 Mesokurtic
P5B	2.97 Fine grained Sand	0.43 Well Sorted	-0.36 Strongly Coarse Skewed	1.39 Leptokurtic
P6	2.90 Fine grained Sand	0.42 Well Sorted	-0.10 Near Symmetrical	1.84 Very Leptokurtic
P7A	2.80 Fine grained Sand	0.28 Very Well Sorted	0.05 Near Symmetrical	1.29 Leptokurtic
P7C	2.80 Fine grained Sand	2.37 Very Well Sorted	0.49 Strongly fined Skewed	1.30 Leptokurtic
P8	2.83 Fine grained Sand	0.62 Moderately Sorted	0.05 Near Symmetrical	1.05 Mesokurtic
F1A	2.77 Fine grained Sand	0.45 Well Sorted	0.02 Near Symmetrical	1.03 Mesokurtic
F2A	2.13 Fine grained Sand	0.47 Well Sorted	0.37 Strongly fined Skewed	2.47 Very Leptokurtic
F3A	2.63 Fine grained Sand	0.47 Well Sorted	0.06 Near Symmetrical	0.94 Mesokurtic
F5	2.45 Fine grained Sand	0.57 Moderately Sorted	0.01 Near Symmetrical	0.91 Mesokurtic
F6	2.67 Fine grained Sand	0.51 Moderately Sorted	-0.14 Strongly Coarse Skewed	1.30 Leptokurtic
F7	2.10 Fine grained Sand	0.43 Well Sorted	0.54 Strongly fined Skewed	3.48 Extremely Leptokurtic
F8B	2.77 Fine grained Sand	0.51 Moderately Sorted	-0.16 Strongly Coarse Skewed	1.30 Leptokurtic
F9	2.73 Fine grained Sand	0.55 Moderately Sorted	-0.20 Strongly Coarse Skewed	1.17 Leptokurtic
F9C	2.83 Fine grained Sand	0.47 Well Sorted	0.12 Fine Skewed	1.09 Mesokurtic
F10	2.73 Fine grained Sand	0.56 Moderately Sorted	0.06 Near Symmetrical	1.29 Leptokurtic

### Univariate grain size parameters

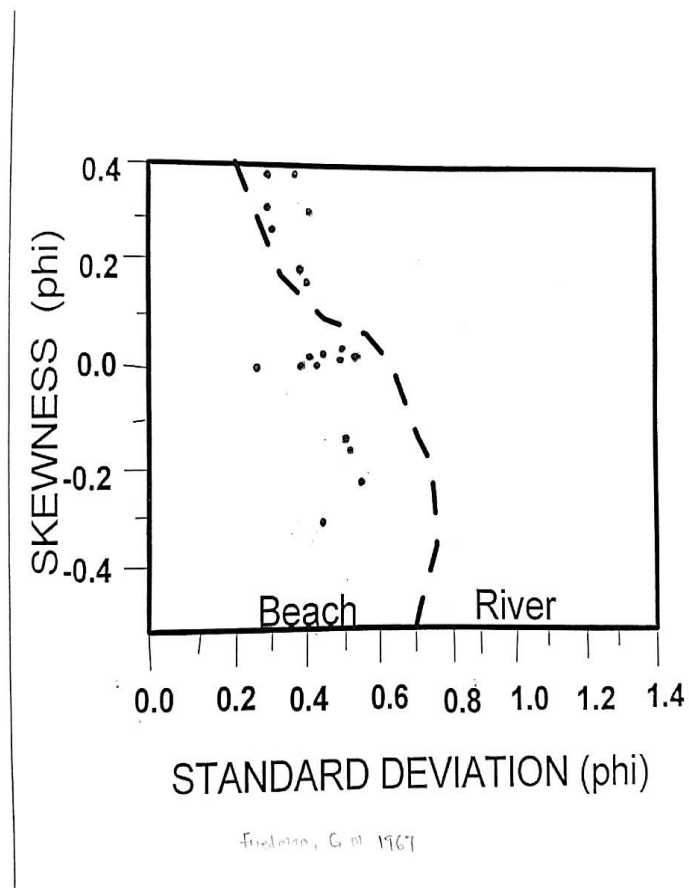
The graphic mean size for the various sample of Gombe Formation in the study area range from  $1.77\phi$  to  $3.5\phi$ , which indicate Medium grained to very fine grained. Freidman (1967) pointed out that grained size distributions are controlled by processes rather than environment. Therefore, the fluctuations in mean values suggest change in energy of the depositional conditions.

Sorting for various samples of the Gombe Formation in the Study area range from  $0.28\phi$  to  $0.57\phi$ , this indicates very well sorted to moderately sorted values predominate. The Very well to moderately sorted nature of Gombe Formation in the Study area may suggest reworking by wave activities, which removed clay material from the sand (Mason and Folk 1958; Freidman 1967).

### Bivariate grain size parameters

The bivariate plots of standard deviation vs. skewness is based on Friedman (1979) which

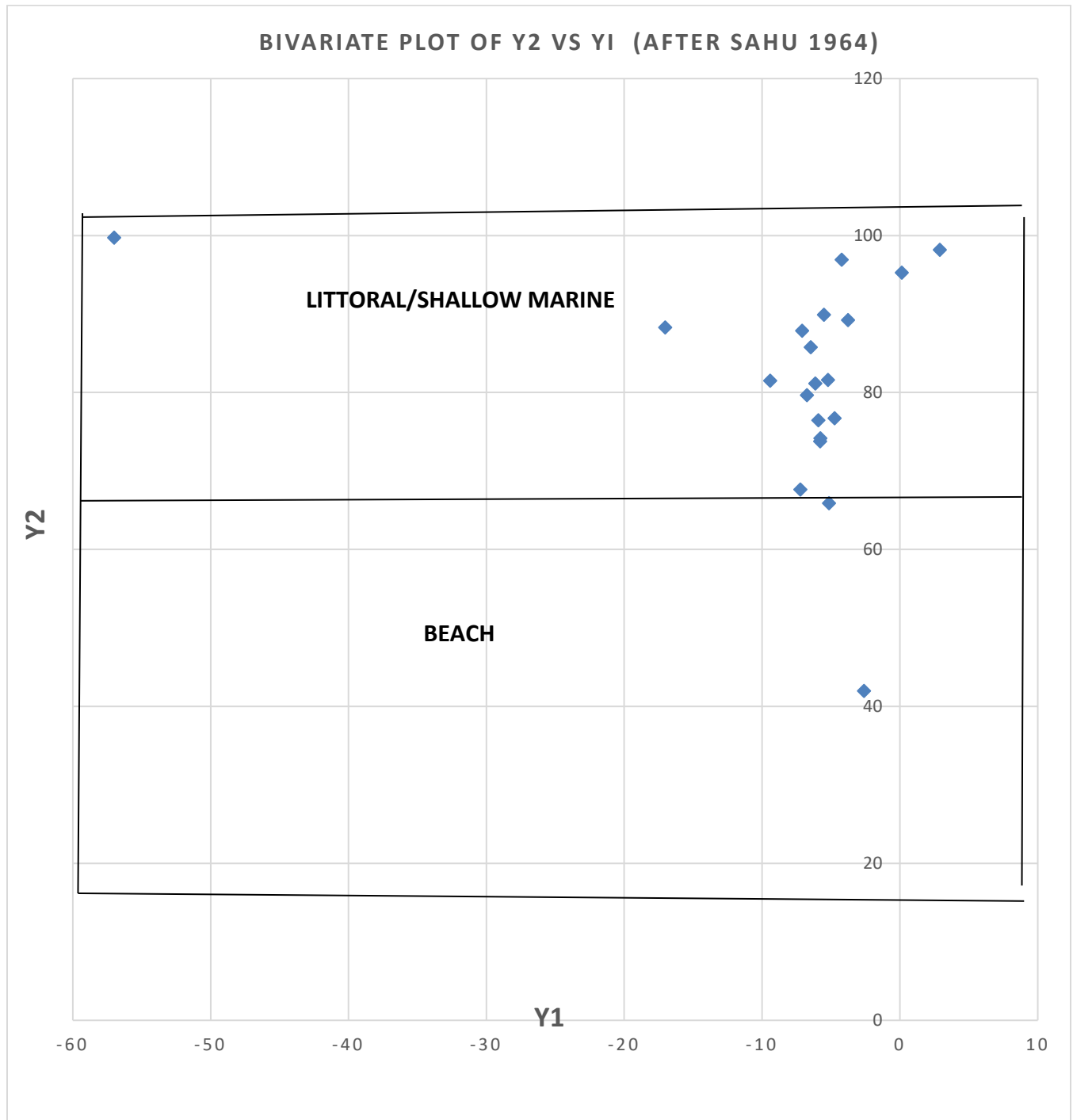
distinguishes Inland Dune Sand from Beach Sand, the plots indicates that 62.75% of the samples plotted within the river field and 38.25% of the samples plotted within the Beach Sand field (Figure 3). The dominance of samples within Inland Dune field was due to river flow with tremendous load of fines into the near shore environment and the available energy was unable to remove them (Friedman, 1967) Plotting of the three discriminate functions (Y1, Y2 and Y3) as bivariate scatter plots was used to improve the success rate and refinement of the discrimination of the depositional environment. A bivariate plot of Y1 and Y2 (Figure. 10) show most samples to be littoral or shallow agitated marine environment. A bivariate plot of Y2 and Y3 (Fig.6) show that most samples are of fluvial/deltaic environment.



**Figure 6:** Bivariate Plot of Standard Deviation verse Skewness for the Whole Samples (After Friedman 1967)

Table 2: The Discriminate Function and Environment of Deposition

SAMPLE NO	Y1	Y2	Y3
P1A	-9.41 Aeolian Deposit	81.51 Shallow agitated marine	-1.79 Shallow Marine
P2	-057 Beach Environment	108.72 Shallow agitated Marine	-3.88 Shallow Marine
P3	-6.75 Aeolian Deposit	79.65 Shallow agitated Marine	-2.01 Shallow Marine
P4C	-2.61 Beach Environment	41.97 Beach Environment	-0.99 Shallow Marine
P5	-7.22 Aeolian Deposit	67.64 Shallow agitated Marine	-1.85 Shallow Marine
P5B	-5.14 Aeolian Deposit	65.88 Shallow agitated Marine	1.06 Fluvial Deposit
P6	-3.76 Aeolian Deposit	89.22 Shallow agitated Marine	-0.14 Shallow Marine
P7A	-5.79 Aeolian Deposit	73.76 Shallow agitated Marine	-0.07 Shallow Marine
P7C	-6.46 Aeolian Deposit	85.78 Shallow agitated Marine	-2.74 Shallow Marine
P8	-5.51 Aeolian Deposit	89.89 Shallow agitated Marine	-2.75 Shallow Marine
F1A	-5.91 Aeolian Deposit	76.46 Shallow agitated Marine	-1.03 Shallow Marine
F2A	0.14 Beach Environment	100.26 Shallow agitated Marine	-3.02 Shallow Marine
F3A	-5.77 Aeolian Deposit	74.16 Shallow agitated Marine	-1.43 Shallow Marine
F5	-4.73 Aeolian Deposit	76.72 Shallow agitated Marine	-2.15 Shallow Marine
F6	-4.23 Aeolian Deposit	100.90 Shallow agitated Marine	-0.77 Shallow Marine
F7	2.90 Aeolian Deposit	119.19 Shallow agitated Marine	-3.51 Shallow Marine
F8B	-5.21 Aeolian Deposit	81.61 Shallow agitated Marine	-0.64 Shallow Marine
F9	-7.09 Aeolian Deposit	87.88 Shallow agitated Marine	-0.84 Shallow Marine
F9C	-6.14 Aeolian Deposit	81.16 Shallow agitated Marine	-1.66 Shallow Marine
F10	-17.03 Aeolian Deposit	88.29 Shallow agitated Marine	-2.21 Shallow Marine



**Figure 7:** Bivariate plot of Y2 Versus Y1 (After Sahu 1964)

#### Geochemical Analysis

Three representative mudstone samples were selected amongst the sample of Gombe Formation from the study area and were

geochemical analyzed using X-ray fluorescence (XRF).

#### 4.3.1 Major element oxide geochemistry

Geochemical concentrations of the major element oxides of Gombe formation are shown in Table 4,

The major oxides obtained are SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O, CaO, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, TiO<sub>2</sub>, and MnO, The oxides average percentage range as follows:

SiO<sub>2</sub> has an average percentage of 69.5% and range from 67.1% to 71.8%, Al<sub>2</sub>O<sub>3</sub> has an average percentage of 20.8% and range from 19.2% to 22.3%, Fe<sub>2</sub>O<sub>3</sub> has an average percentage of 2.86% and range from 2.26% to 3.46%, TiO<sub>2</sub> has an

average percentage of 3.42% and range from 3.13% to 3.71%, Na<sub>2</sub>O has an average percentage of 2.93% and range from 2.48% to 3.25%, CaO has an average percentage of 0.17% and range from 0.08% to 0.26%, K<sub>2</sub>O has an average percentage of 1.01% and range from 0.92% to 1.09%, P<sub>2</sub>O<sub>5</sub> has an average percentage of 1.77% and range from 1.74% to 1.81%, MnO has an average percentage of 0.2% and range from 0.01% to 0.2%

**Table 4: Result of major oxides of mudstone samples from Gombe Formation**

**N.B:** P4 and P7 are from Pindiga Stream and F8 from Futuk section

**Table 6: Ratios of Some parameters calculated from the major oxides**

Oxides/Parameters	P4A (wt. %)	P7B (wt. %)	F8A (wt. %)	Average (wt. %)	Range (wt. %)
SiO <sub>2</sub>	71.8	58.47	67.1	69.5	67.1% - 71.8
Al <sub>2</sub> O <sub>3</sub>	19.2	17.70	22.3	20.8	19.2% - 22.3
Fe <sub>2</sub> O <sub>3</sub>	2.26	2.46	3.46	2.86	2.26% - 3.46
TiO <sub>2</sub>	3.13	2.99	3.71	3.42	3.13% - 3.71
Na <sub>2</sub> O	3.25	2.48	3.06	2.93	2.48% - 3.25
CaO	0.26	0.82	0.08	0.17	0.08% - 0.26
K <sub>2</sub> O	1.09	1.11	0.92	1.01	0.92% - 1.09
P <sub>2</sub> O <sub>5</sub>	1.74	1.81	1.79	1.77	1.74% - 1.81
MnO	0.01	0.02	0.02	0.02	0.01% - 0.02
Oxides/parameters	P48	P7B	F8A	Average	Range
K <sub>2</sub> O / Al <sub>2</sub> O <sub>3</sub>	0.057	0.063	0.041	0.054	0.041-0.063

K <sub>2</sub> O / Na <sub>2</sub> O	0.34	0.45	0.30	0.36	0.30-0.45
SiO <sub>2</sub> / Al <sub>2</sub> O <sub>3</sub>	3.7	3.3	3.0	3.3	3.0 - 3.7
Al <sub>2</sub> O <sub>3</sub> / TiO <sub>2</sub>	6.13	5.92	6.08	6.04	5.92 – 6.13
CIA	57.13	80	84.59	73.91	57.13-80
ICV	0.46	0.50	0.46	0.47	0.46-0.50

N.B: CIA (Chemical Index Alteration)

ICV (Index of Compositionally Variability)

### Trace Element Geochemistry

The concentrations of the trace elements and their average values of the analyzed mudstone

sample of Gombe Formation from the Study area are presented in Table 8

**Table 7: Result of Geochemical results of Minor Elements and Trace Elements**

Trace/Parameters	P4A	P7B	F8A	Average	Range
S	718	920	1330	989.3	718 – 1330
V	396	324	544	421	324 – 544
Cr	150	166	136	150.6	150 – 166
Ni	29.1	27.6	33.9	31.5	29.1-33.9
Cu	225	207	231	221	207 – 231
Zn	156	807	1200	721	156 - 1200
Ga	46.8	44.9	59.9	50.5	46.8 - 59.9
As	8.54	19.7	28.7	18.9	8.54 - 28.7
Kr	10.8	ND	ND	10.8	10.8 - 10.8
Rb	103	98	108	103	98 – 108
Sr	143	126	118	129	118 – 143
Zr	1040	764	955	919.6	764 - 1040
Y	166	107	126	133	107 – 166
Nb	52.9	51.2	69.5	61.2	52.9 - 69.5
Ag	6.64	ND	8.7	7.7	6.64 - 8.7
Cd	ND	ND	5.82	5.82	5.82 - 5.82
Sn	3.58	8.54	10.4	7.5	3.58 - 10.4
Ba	356	324	323	334.3	323 – 356
Pb	51.2	35.6	10.7	32.5	10.7 - 51.2
La	109	55	94.6	86.2	55 - 109
Ce	189	126	166	160.3	126 – 189
Pr	44.9	ND	35.5	40.2	35.5 - 44.9
Nd	81.3	47.6	88.4	72.4	47.6 - 88.4
Dy	73.2	ND	ND	73.2	73.2 - 73.2
Ac	ND	ND	51.2	51.2	51.2 - 51.2
Cl	317	357	305	326	305 – 357
Sr/Cu	0.64	0.61	0.51	0.59	0.51 – 0.64

N.B: Not Discovered (N.D)

## Palaeo-environmental interpretation

Table 8: Some parameters calculated from the major oxides and Trace Elements

Oxides/parameters	P48	P7B	F8A	Average	Range
$K_2O / Al_2O_3$	0.057	0.063	0.041	0.054	0.041-0.063
$K_2O / Na_2O$	0.34	0.45	0.30	0.36	0.30-0.45
$SiO_2 / Al_2O_3$	3.7	3.3	3.0	3.3	3.0- 3.7
$Al_2O_3 / TiO_2$	6.13	5.92	6.08	6.04	5.92 – 6.13
CIA	57.13	80	84.59	73.91	57.13-80
ICV	0.46	0.50	0.46	0.47	0.46-0.50
Sr/Cu	0.63	0.61	0.51	0.58	0.51 – 0.63
$\frac{\Sigma (Fe + Mn + Cr + Ni + V + Co)}{\Sigma (Ca + Mg + Sr + Ba + K + Na)}$	1.67	1.15	1.62	1.48	1.15 – 1.67

### Textural Maturity

The maturity (textural and compositional) of the shales was determined using the  $SiO_2 / Al_2O_3$  ratio. Tawfik et al. (2017) and Armstrong-Altrin et al. (2016) indicated that the ratio of  $SiO_2 / Al_2O_3$  revealed the nature of textural maturity of sediments.

Usually, Basic igneous rocks display average  $SiO_2 / Al_2O_3$  ratio of 3, while a value of 5 is recorded in acidic igneous rocks (Cox et al., 1995).

In view of Cox et al. (1995) and Hernandez-Hinojosa et al. (2018), average  $SiO_2 / Al_2O_3$  value of > 5 in clastic sediments signifies high sediment maturity, whereas a value of < 5 indicates immaturity. The  $SiO_2 / Al_2O_3$  values fluctuates from 3.0 to 3.7 in the the Study area showing textural immaturity (Table 7).

### Provenance

Numerous studies have revealed that the chemical compositions of siliciclastic sedimentary

rocks are linked to those of their provenance materials (Akkoca et al., 2019). In view of this, several authors proposed various major, trace elements ratios and discrimination plots for provenance determination (Akkoca et al., 2019; Armstrong-Altrin et al., 2013; Roser & Korsch, 1986). The  $Al_2O_3 / TiO_2$  ratio is broadly used to characterize the nature of provenance materials (Akkoca et al., 2019; Gabriel et al., 2019; Hayashi et al., 1997; Tawfik et al., 2017). Mafic igneous rocks display a ratio of 3–8; whereas, ratios of 8–21 and 21–70 are recorded for intermediate and felsic igneous rocks, respectively (Gabriel et al., 2019).

The  $Al_2O_3 / TiO_2$  ratio of the study area varies from 5.92 to 6.13. (Table 7), indicating derivation from Mafic igneous rocks

### Paleoclimate

The concentrations of some major and trace elements are employed to reconstruct the paleoclimatic conditions under which terrigenous



sediments were deposited (Abubakar et al., 2019; Li et al., 2020 ;).  $C$  value is regarded as a valuable pointer of paleoclimatic condition and is computed as the  $\Sigma$  (Fe + Mn + Cr + Ni + V + Co)/  $\Sigma$  (Ca + Mg + Sr + Ba + K + Na), all in ppm (Li et al., 2020). Zhao et al. (2007) suggested that sediments deposited under humid condition are enriched with Fe, Mn, Cr, Ni, V, and Co whereas sediments deposited under arid condition are concentrated with Ca, Mg, Sr, Ba, K, and Na. In this regard, high  $C$  values usually show humid paleoclimates and low values indicate arid paleoclimate. Qiu et al. (2015) suggested  $C$  values  $> 0.8$  and  $0.6-0.8$  for humid and semi humid paleoclimates respectively. Semiarid–semi humid paleoclimates display range of values of  $0.4-0.6$ . The range values between  $0.2$  and  $0.4$  were recorded for semiarid paleoclimates.

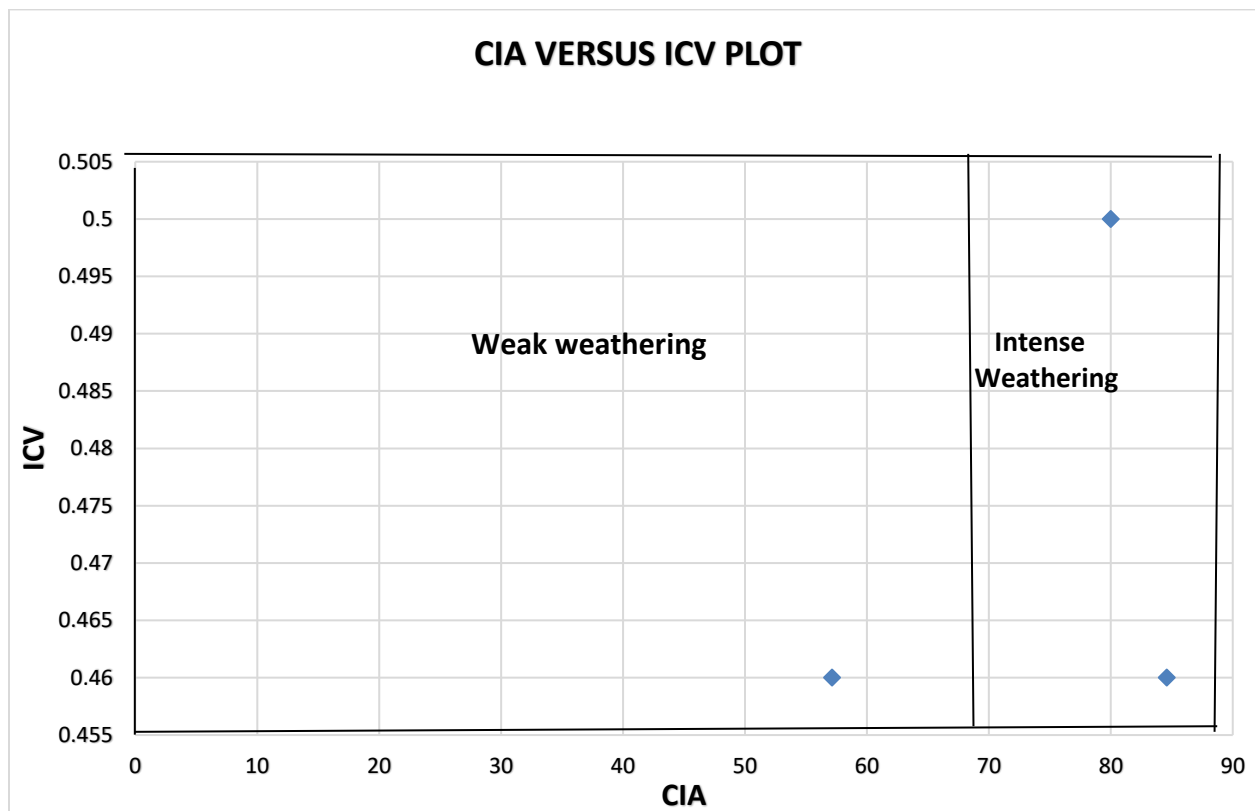
The Mudstone of the Gombe Formation of the study area have a range of  $C$  values from  $1.15$  to  $1.67$ , with an average of  $1.48$  (Table 7). These range and average of the  $C$  values are  $> 0.8$ , suggesting deposition under humid conditions. The Sr/Cu ratios have been employed by many researchers to interpret the paleoclimate conditions under which terrigenous sediments were deposited (e.g., Akkoca et al., 2019; Gabriel et al., 2019; Li et al., 2020; Liu & Zhou, 2007; Moradi et al., 2016). Liu and Zhou (2007) indicate

that low values of Sr/Cu ratios ranging from  $1.3$  to  $5.0$  are related to humid climatic conditions, whereas high values ranging from  $5.0$  to  $10$  indicate arid climatic conditions and greater than  $10$  indicate a hot and arid climate. The values of Sr/Cu of Gombe Mudstone of the study area range from  $0.51$  to  $0.63$  with an average of  $0.58$ , which shows deposition under humid condition (Table 7)

### **Paleo-weathering**

The weathering condition in the provenance area was estimated using the Chemical index of alteration (CIA) and the bivariate plot of CIA vs. ICV. The Index of Compositional Variability (ICV) has proved to be a very useful tool for determination of weathering conditions by several authors (Cox et al., 1995; Armstrong-Altrin et al., 2015; Tawfik et al., 2017; Gabriel et al., 2019; Tchouatcha et al., 2021). Cox et al. (1995) showed that an average ICV value of  $> 0.85$  was recorded for rock-forming minerals and  $< 0.85$  for alteration products.

In this regard, an average ICV value of  $0.45$  was recorded for the Gombe formation of the study area of Pindiga and Futuk, That of Pindiga samples shows High degree of weathering processes and that of Futuk areas shows Weak weathering. (Fig 10)



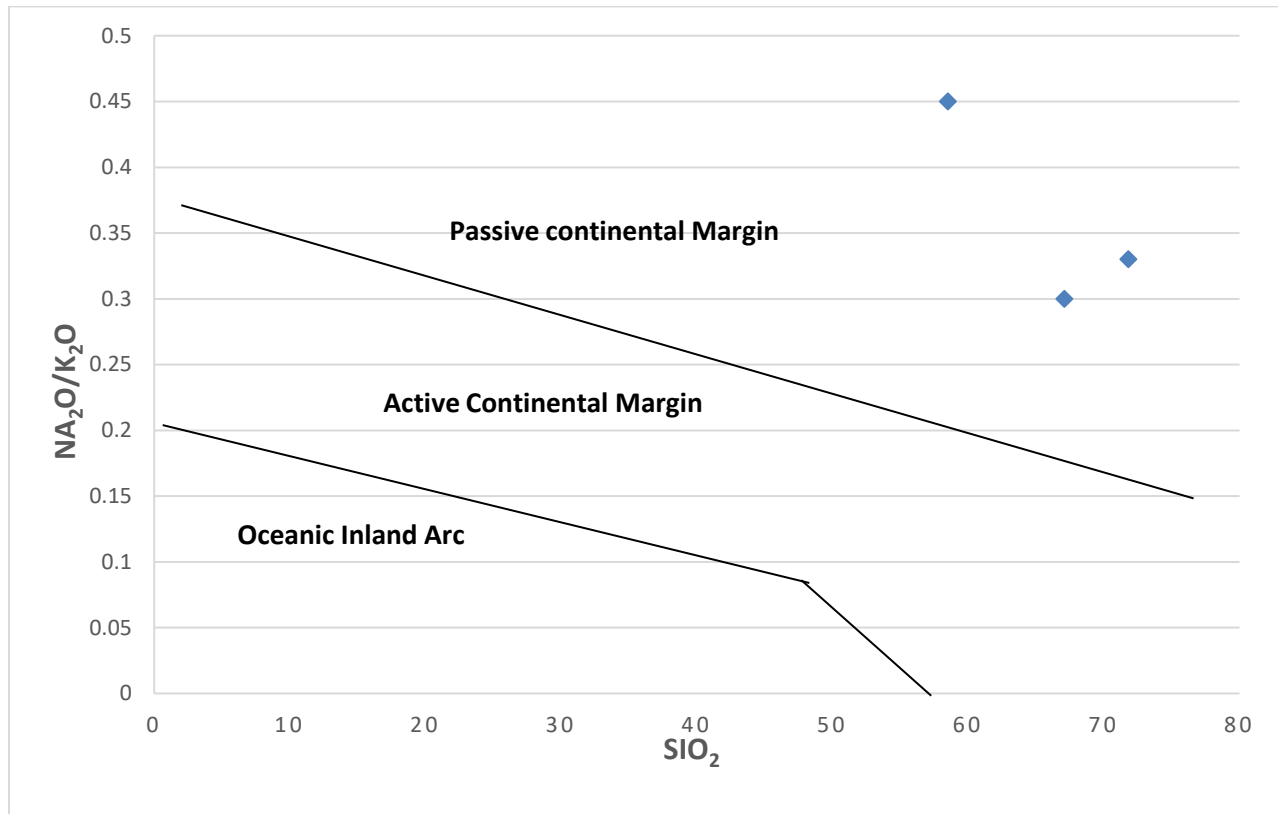
**Figure 8:** CIA versus ICV plot displays the intensity of weathering of the Mudstone of the Gombe Formation (after Long et al., 2012).

### Tectonic setting

Tectonic settings of ancient sedimentary basins can be revealed from numerous major and trace elements geochemical discrimination plots proposed by some researchers

In view of establishing the tectonic setting of the basin of deposition in the Gombe formation of the study area, we adopted the Bhatia and Crook (1986) and Verma and Armstrong-Altrin (2013) major oxide tectonic settings diagrams, Roser & Korsch (1986) classify the tectonic

settings into oceanic island arc, active continental margin, and passive margin, while Verma and Armstrong-Altrin (2013) recognized three main tectonic settings: island or continental arc, continental rift, and collision. On the Roser and Korsch (1986) diagram (Figure.11), all the studied Mudstone samples were fall within a passive margin continental setting, Therefore, the plots revealed the tectonic setting of the basin as a continental rift of passive margin setting.



**Figure 9:** Bivariate plot of  $\text{SiO}_2$  versus  $\text{K}_2\text{O}/\text{Na}_2\text{O}$  indicating tectonic setting discrimination diagram (After Roser & Korsch, 1986).

### Petrographic Study

Twelve samples ranging from Very fine to Medium 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 Plates. The texture of these sandstones tends to show that sorting ranges from poorly to well sorted but moderate sorting predominates from the Slides viewed under the Microscope. The grain shape ranges from sub angular to well-rounded with sub-angular dominating, and the sphericity varies from low-high. Quartz predominates in 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 is minimal in the samples analyzed.

Using Folk's (1954) sandstone classification, the Gombe Formation's sandstone range from sub-arkose to quartz arenite, and their textural maturity based on Folk (1974) ranges from sub mature to mature.

### QAPF diagram - Si oversaturated

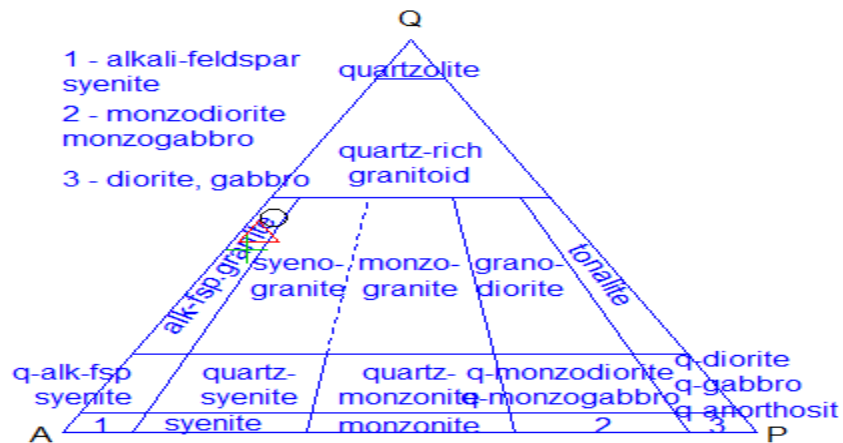


Figure 10: Showing QAPF diagram of Alkali-Feldspar Syenite dominant.

#### SAMPLE F1

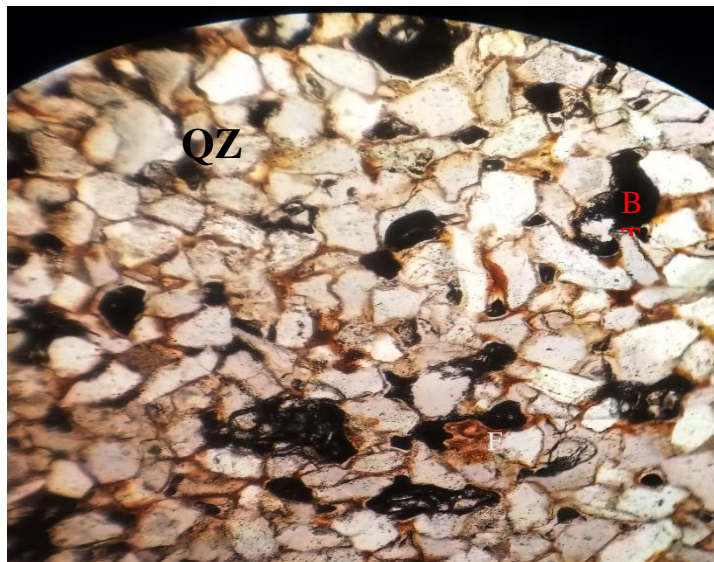


Plate I: Under Plain Polarized

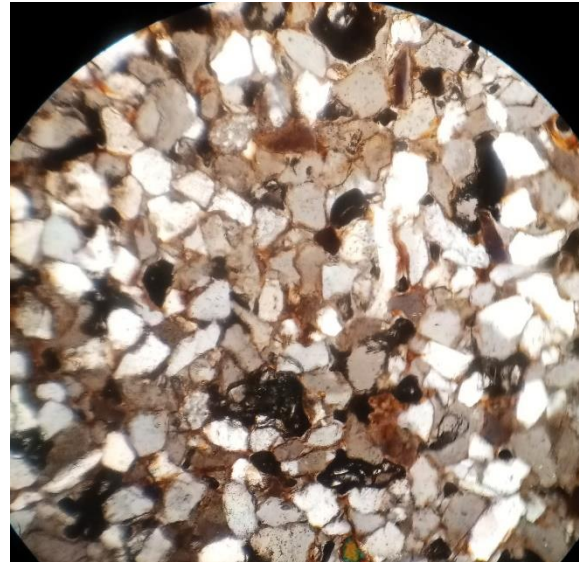
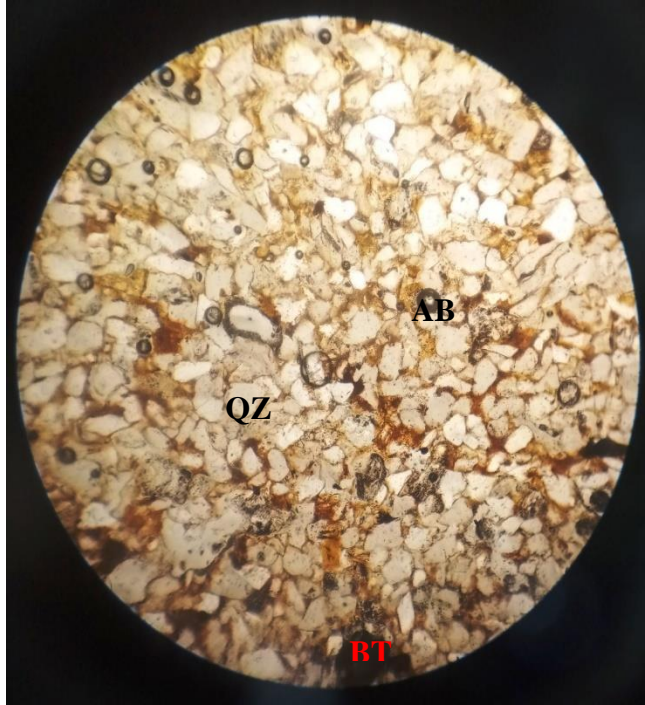
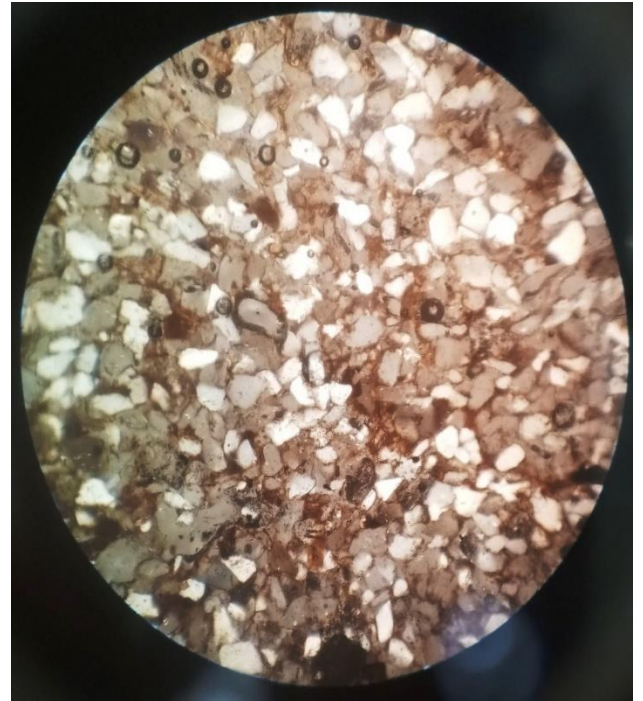
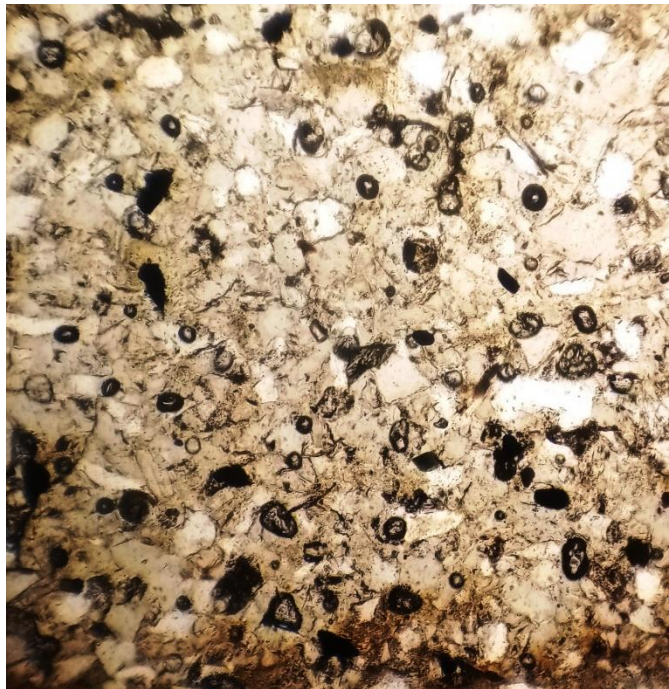
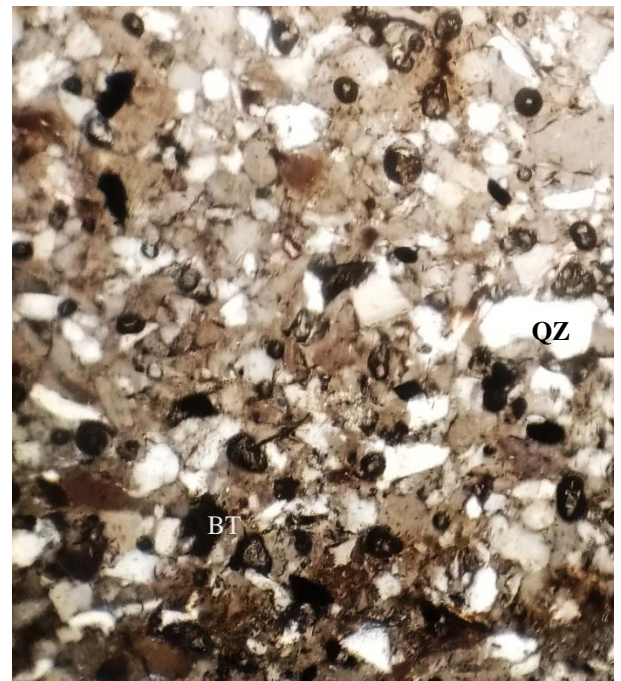
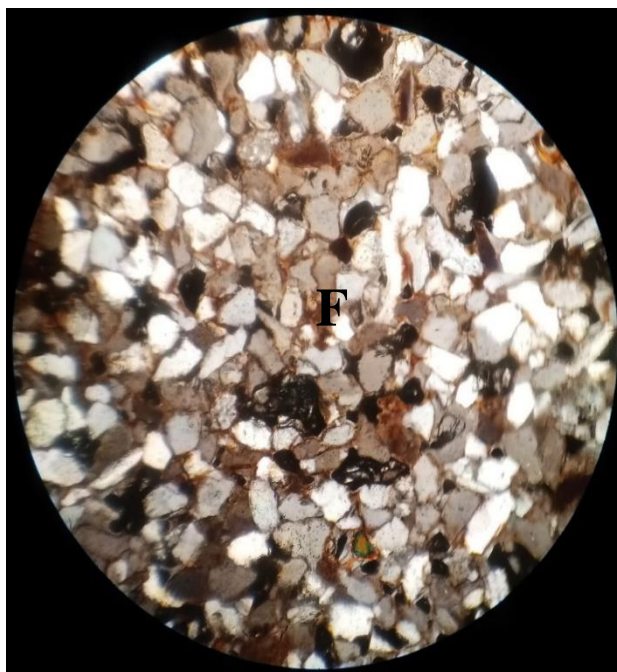


Plate II: Under Cross Polarized

**SAMPLE F2A***Plate III: Under Plain Polarized**Plate IV under Cross Polarized***SAMPLE P5***Plate V: Under Plain Polarized**Plate VI: Under Cross Polarized*

**SAMPLE P6*****Plate VII: Under Plain Polarized******Plate VIII: Under Cross Polarized*****CONCLUSION**

After a detail study of the Lithology, Granulometric study, geochemical analyses and petrography around Pindiga and Futuk areas of Gombe Formation, the following were deduced:

1. The Gombe Formation in the study area is predominantly very fine to medium grained Sandstone, very well to moderately sorted, near symmetrical to strongly fine skewed, Mesokurtic to Extremely Leptokurtic.
2. Lithologs result indicates that the Gombe formation at Pindiga town along Dadabuji river channel and at Futuk town in an exposure along Futuk-Alkaleri highway is generally very fine to medium grained, having dominantly Sandstones and Mudstone. Their color varies from light grey to reddish brown. Presence of reddish-brown color results from hematite pigmentation characteristics of oxidizing condition. Dominant structures include Parallel Lamination, Minor Bioturbation, Convolute Lamination, and Channelization which indicates low energy river deposits due to Suspension processes.

3. Geochemical analysis shows that the rock samples has  $\text{SiO}_2$  as having the highest percentage and  $\text{MnO}$  as the lowest. The  $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$  ratio with an average of 0.054%, suggesting that mudstone have Minimal K-feldspar.

4. The Major and trace element geochemistry of the mudstone of Gombe Formation, Gongola Sub-Basin, Northern Benue Trough, and Nigeria disclosed derivation of the mudstone mostly from felsic rocks with little influence from intermediate igneous and quartzes sedimentary rocks.

5. The provenance materials experienced high degree of weathering activities. Thus, quartz is the major source of silica in the study area. Similarly, all the trace elements except Cu and Zn were not sourced from clay minerals.

6. The mudstone were deposited under humid climatic condition in an oxic and high salinity marine depositional environment. The sediments were geochemically classified as mudstone that are texturally immature.

7. Continental rift of passive margin setting was suggested for the deposition of the mudstone in the basin; accordingly, the inferred tectonic settings are comparable to the accepted model on the origin and evolution of the Benue Trough established based on the geophysical methods.

8. The result of this integrated study area indicate that the sediments are fine grained, well sorted, texturally Immature, having a minimal K feldspar, which undergone an intense Chemical weathering and are of Plutonic Source deposited under Humid Condition and the sediments are deposited at shallow marine environment under Fluvial environment.

9. Petrographic provenance of the study area reveal granitic terrain which might probably be Basement Complex sediment which are sourced ENE of the study area.

## REFERENCES

Abubakar, M. B. (2006). *Biostratigraphy, palaeoenvironments and organic geochemistry of the cretaceous sequences of the Gongola Basin, Upper Benue Trough* (Ph.D. Unpublished thesis).

Abubakar Tafawa Balewa University Bauchi, Nigeria, p. 315.

Abubakar, M. B. (2014). *Petroleum potentials of the Nigerian Benue Trough and Anambra Basin: A regional synthesis*. *Natural Resources*, 5, 25–58.

Abubakar, U., Usman, M. B., Bello, A. M., Garba, T. A., & Hassan, S. (2019). *Geochemical and palaeocurrent analysis of the Tertiary Kerri-Kerri Formation in the Gongola Sub-Basin of the Northern Benue Trough Northeastern Nigeria: Implications for provenance, tectonic setting, and palaeoweathering*. *SN Applied Sciences*.

Akkoca, B. D., Eriş, K. K., Cağatay, M. N., & Biltekin, D. (2019). *The mineralogical and*

*geochemical composition of Holocene sediments from Lake Hazar, Elazığ, Eastern Turkey: Implications for weathering, paleoclimate, redox conditions, provenance, and tectonic setting*. *Turkish Journal of Earth Sciences*, 28, 760–785.

Armstrong-Altrin, J. S. (2015). *Evaluation of two multidimensional discrimination diagrams from beach and deep-sea sediments from the Gulf of Mexico and their application to Precambrian clastic sedimentary rocks*. *International Geology Review*, 57, 1446–1461.

Armstrong-Altrin, J. S., Lee, Y. I., Kasper-Zubillaga, J. J., & Trejo-Ramirez, E. (2016).

*Mineralogy and geochemistry of sands along the Manzanillo and El Carrizal beaches, southern Mexico: Implications for provenance and tectonic setting*. *Geological Journal*.

Armstrong-Altrin, J. S., Nagarajan, R., Madhavaraju, J., Rosalez-Hoz, L., & Lee, Y. I. (2013). *Geochemistry of the Jurassic and upper Cretaceous shales from the Molango Region, Hidalgo, Eastern Mexico: Implications of source-area weathering, provenance, and tectonic setting*. *Comptes Rendus Geoscience*, 345, 185–202.

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

Bhatia, M. R. (1983). *Plate tectonics and geochemical composition of sandstones*. *Journal of Geology*, 91, 611–627.

Bhatia, M. R. (1985). *Composition and classification of flysch mud rocks of Eastern Australia: Implication in provenance and tectonic setting interpretation. Sedimentary Geology, 41, 249–268.*

Dypvik, H. (1984). *Geochemical compositions and depositional conditions of Upper Jurassic and Lower Cretaceous Yorkshire clays, England. Geological Magazine, 121, 489–504.*

Bhatia, M. R., & Crook, K. (1986). *Trace element characteristics of greywacke's and tectonic setting discrimination of sedimentary basins. Contributions to Mineralogy and Petrology, 92, 181–193.*

Cox, R., Lowe, D. R., & Cullers, R. (1995). *A conceptual review of regional-scale controls on the composition of clastic sediment and the co-evolution of continental blocks and their sediment cover. Journal of Sedimentary Research, 1, 1–12.*

Cullers, R. L. (1994). *The controls on major and trace element variation of shale's, siltstones, and sandstones of Pennsylvanian-Permian age from uplifted continental blocks in Colorado to platform sediment in Kansas, USA. Geochimica ET Cosmochimica Acta, 58, 4955–4972.*

Cullers, R. L., Basu, A., & Suttner, L. (1988). *Geochemical signature of provenance in sand-size material in soils and river sediments near the Tobacco Root batholith, Montana, USA. Chemical Geology, 70, 335–348.*

Descourvieres, C., Douglas, G., Leyland, L., Hartog, N., & Prommer, H. (2011). *Geochemical reconstruction of the provenance, weathering and deposition of detrital-dominated sediments in the Perth Basin: The Cretaceous Leederville Formation, southwest Australia. Sedimentary Geology, 236, 62–76.*