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### Geology of the Rocks Around the Gombe In-Lier, Northern Benue Trough, North –East Nigeria

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#### ABSTRACT

The rocks suite mapped in the study area are mainly Crystalline Rocks, Bima Sandstone, Yolde Formation and Pindiga Formation. The crystalline rocks found within the Inlier were metamorphosed by heat, pressure and fluid inclusion (metasomatism) caused by the strike-slip fault. Based on the petrographic study, the mineral constituents of the rocks are; Quartz, Biotite, K-Feldspars, Orthopyroxene, Plagioclase and some Opaque minerals. The petrographic examination shows evidence of Crystal Intergrowth, Quartz overgrowth and Suture grain content in the sandstone that have undergone metamorphism. Field observation shows the presence of Quartzite along the fault zone, implying that regional faulting in the study area triggered metamorphism of some sandstone in the area. The sedimentary rocks of the study area are mostly fluvial, Albian Bima Formation and fine grain transition of Cenomanian Yolde Formation and marine, Turonian Pindiga Formation. From the sieve analysis, the sedimentary rocks around the area were deposited by interchange between fluvial and marine activities. The rocks were analyzed to be very coarse sand, coarse sand and fine grain sand that are well sorted to moderately sorted. Coarse grained sands are dominant from the samples. At the end of the study the area was thoroughly mapped, structural analysis, macroscopic observations, microscopic analysis, the effect of diagenesis and metamorphism of mineral grains was analyzed. Finally, the environment of deposition was deduced as fluvial to marine and the arrangement of the grains was achieved using sieve analysis.

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#### 1. Introduction

The area under study is located between latitude 11°11' 01" and 11°13' 04"E and longitude 10° 16' 24" and 10° 19' 12"N part of sheet 152 (2:1,000) Gombe, and it covers an area extent of about 6sqkm within Gombe town around Gombe Inlier in the northern part of Gongola Basin within the Upper Benue Trough.

The aim of this research was to carry out a detailed geological mapping of the area around Gombe Inlier, thereby providing an updated map of the area and also determine the composition of the rocks using petrographic and sieve analysis.

The area has a gentle and steep slope of igneous rock surrounded by undulating sedimentary rocks. The mapped

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area has elevation between 421m to 387m above the sea level based on the readings during the field work.

The map covered (5 by 3.5) km surface area of sedimentary terrain part of the Gongola Basin of the Upper Benue Trough. The different rock types of the study area include; the Precambrian basement exposed by strike-slip fault, the metamorphosed sandstone of Bima Formation and the sedimentary rocks around the Gombe Inlier.

The Nigerian Benue Trough is an approximately 1000km long, 50-150km wide intercontinental basin that overlies the Precambrian shield of West African mobile belt (Benkheilil, 1989). It was described as a fault bounded depression filled by 6000m thick marine coastal and fluvial sediments which were compressively folded by Orogenic Shield environment (Carter, et al, 1963).

The Gongola Basin (arm) of Upper Benue Trough is N-S trending arm of 1000km long Benue Trough. Mechanism of the formation of the Trough dominated most of the early studies carried out in the area and although still controversial, an unstable RRF (rift-rift fault) triple junction model leading to plate dilation and opening of Gulf of Guinea (Benkheilil, 1989). Benkheilil (1989) also suggested that the evolution Trough could also be as a result of tension resulting in a rift or wrench related fault basin. Mesozoic to Cenozoic magmatism has accompanied the evolution of the tectonic rift as it's trough, a magmatic old rift was also suggested for the Gongola Basin. (Coulon et al, 1990).

The Cretaceous lithostratigraphic sequence of the Gombe Inlier has been affected by sinistral-strike-slip fault (Byami et al, 2015). The Inlier as a basement dome exposed most of the stratigraphic sequence; Bima Sandstone, Yolde Formation, Pindiga Formation and Gombe Sandstone (Haruna, 2007). The Gombe fault is synsedimentary fault movement started in at least the Mid-Santonian. Precambrian Basement up thrust along the Gombe fault, is likely to have initiated during the first of two compressional events that affected the Upper Benue Trough; the mid-Santonian N-S to N-E compression. The Wuro Ladde-Wurin Dole Fault is relatively younger because it sinistrally truncate the Liji hill anticline that occurs at the northern end of Gombe hill, resulting in NEE-SWW

trend and the orientation of transpressional structures along this fault suggested they developed during the end-Cretaceous N140°E to the N150°E compression.

### 1. Litriture Review

The Benue Trough is a Cretaceous sedimentary Basin in Nigeria. It is an elongated rift approximately 1000km long and 50 – 150km wide trending NE – SW and overlying the pre-Cambrian shield of the West African Mobile Belt (Benkheilil, 1989, Guiraud, 1990). It is partly fault-bounded elongate depressed trough occupied by up to 6,000m of marine and fluvio-deltaic sediments that have been compressively folded into a non-Orogenic shield environment (Carter et al, 1963). There has been systematic variation in the depositional environment within the trough over time such that, continental lacustrine or fluvial sediments occur at the base through various marine transgressive and regressive beds to immature continental sandstones at the top (Haruna 2007).



Figure 1: Map of Central West African Rift showing Benue Trough (Wright, 1968).

The trough has its Southern limit at the Northern boundary of the Niger Delta, where it dips down and is overlaid with tertiary and more recent sediments. It extends in the Northeasterly direction to the Chad basin and it is about 150km wide (Obaje, 2009). It is subdivided arbitrarily into lower, middle and upper portions. Although no concrete or clear outline can be drawn to demarcate the individual subdivided portions, some major localities (towns or settlements) which constitute the major depo-centers of the different portions have been well documented (Haruna, 2007).

The Cretaceous sediments of the Northeastern region were deposited in two major basins of the Chad (Borno) and the Upper Benue Trough. These two basins were separated by

the Zambuk ridge (Carter et al., 1963). However, Zaborski et al. (1997) reported that the Gongola Basin which is the northern part of the Upper Benue Trough is separated from the Borno Basin to the north by an anticlinal feature termed the Dumbulwa-Bage high. The summary of the stratigraphy and description of the formations comprising the Gongola Basin which is more relevant to the study area is given below. The sedimentary succession in the Gongola Basin comprises Bima group (Oldest sediments), Yolde Formation, Pindiga Formation, Gombe sandstone, Kerri-Kerri Formation -the youngest sediments (Carter et al., 1963; Popoff et al., 1986; Zaborski et al., 1997) and Neogene to Quaternary Basalts (Haruna 2007).

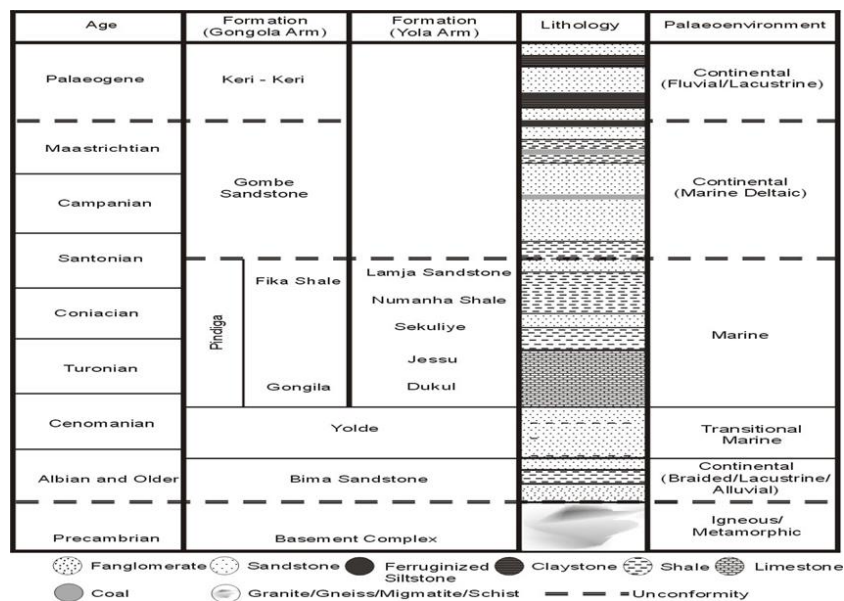


Figure 2: Stratigraphy of the Upper Benue Trough (After Abubakar et al, 2006).

### 3. Materials and Methods

#### 3.1) Geology

The field mapping was carried out taking significant exposures into consideration. Dips, strikes and GPS coordinates were taken and fresh samples were collected. A concise and updated geological map of the area was produced.

#### 3.2) Petrography

The collected samples were cut into considerably small chips of various sizes and each glued to a slide, using araldite solution. The glass slides were then mounted on a hot plate to be baked i.e., for the samples to firmly stick it to the glass slide. The procedure lasted for 5 – 10 minutes. After baking, each sample was then taken to the finding machine for further grinding so that it will be much thinner. The slide is then further polished by robbing it using a process referred to as abrasion.

The slides were viewed as thin section under plane polarized and cross polarized light under a microscope. The stage is rotated to view different section of the rock's morphological features. Percentages of the various minerals were taken at different points and the average was calculated to get the actual percentage of the various minerals in each slide.

### 3.3) Granulometric Analysis

Standard mechanical sieving method was used for the granulometric analysis. The samples were first disaggregated using a mortar and pestle. 200g of each sample was placed in the uppermost sieve of the stacked set of sieves. The sieve were arranged with mesh sizes decreasing from top to bottom in the following order: 4.75mm, 3.35mm, 2.36mm, 1.18mm, 0.850mm, 0.425mm, 0.300mm, 0.212mm, 0.106mm, 0.0063mm, and the pan (<0.063mm). The sieves were then covered and fastened against the Endicott sieve shaker and allowed to run for 10 minutes. Weight of the materials retained in each sieve was measured and recorded.

Statistical measures of frequency distribution were determined graphically. The phi ( $\Phi$ ) values were obtained

using the formula  $\Phi = -\log_2 D$  where D is grain diameter (mm). The individual weight percentages were obtained by dividing the weight (g) of each retained material by their total and multiplying it by 100. Whereas, the cumulative weight percentage were obtained by adding the individual weight percentage of the first sieve to the next, and the answer obtained is added to the subsequent weight percentage, continuously to the end. Cumulative frequency curves were plotted using the obtained values.

### 4) Results

The map covered (5 by 3.5) km surface area of sedimentary terrain part of the Gongola Basin of the Upper Benue Trough. The different rock types of the study area include; the Precambrian basement exposed by strike-slip fault, the metamorphosed sandstone of Bima Formation and the sedimentary rocks around the Gombe Inlier.

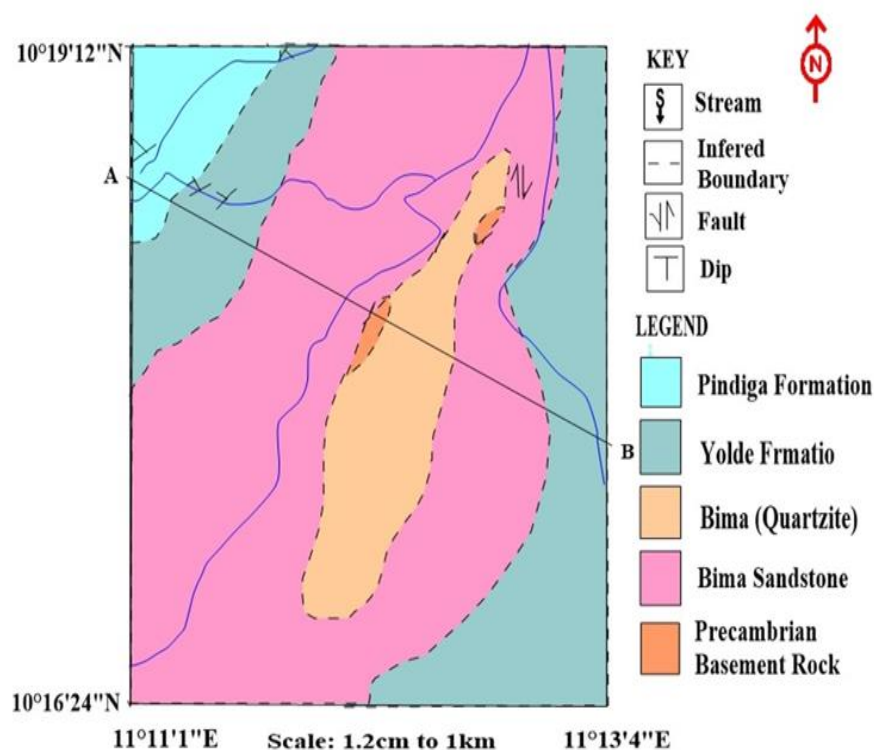


Figure 3: Geological Map of the study area (Gombe Inlier)



The macroscopic and petrographic analyses of the three (3) samples used for this exercise are given below:

#### 4.1) Sample A

From the macroscopic analysis of the rock, it's characterized by partially crystallized pegmatite with quartz crystallization

found along fracture zone of metamorphosed Bima Sandstone (Location A). The quartz is green (fluorite) in color indicating presence of impurities during crystallization.



Plate 1: Photograph of sample A

Below are the petrographic analyses of sample A under plane and crossed polarized light.

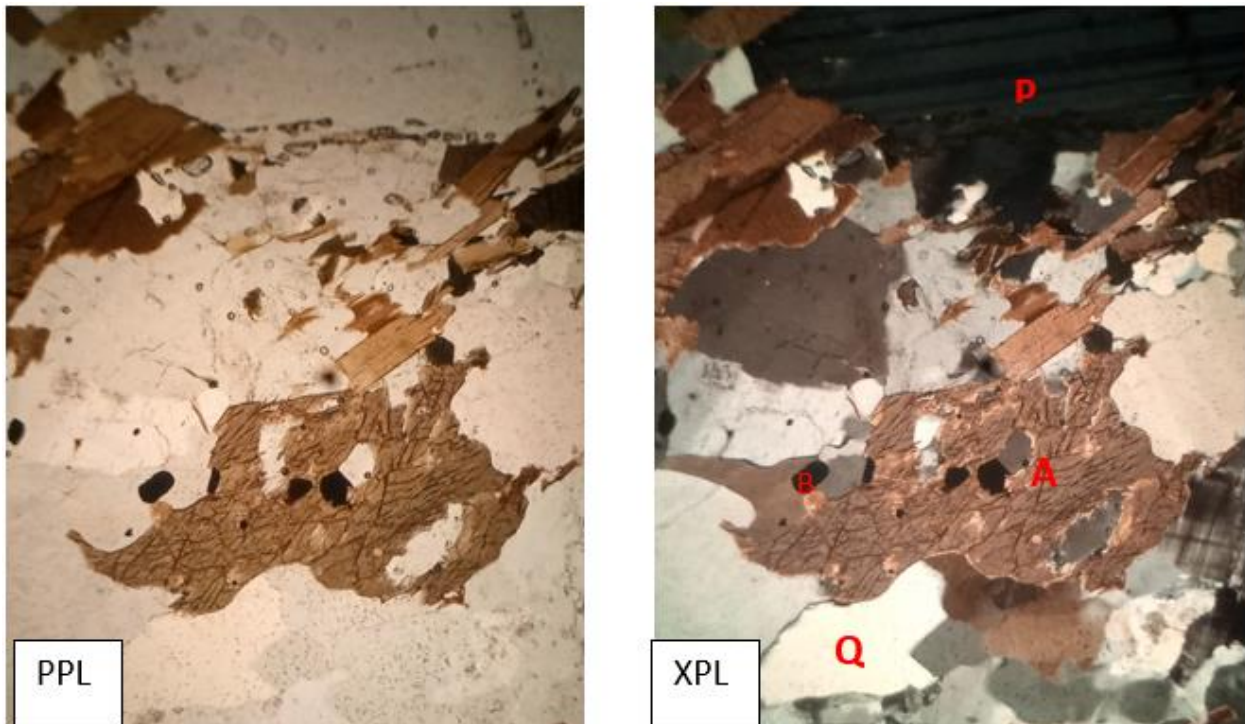


Plate 2: Photo micrograph of Sample A.

Quartz = Q, B = Biotite, Plagioclase = P, and Orthorpyroxine = A

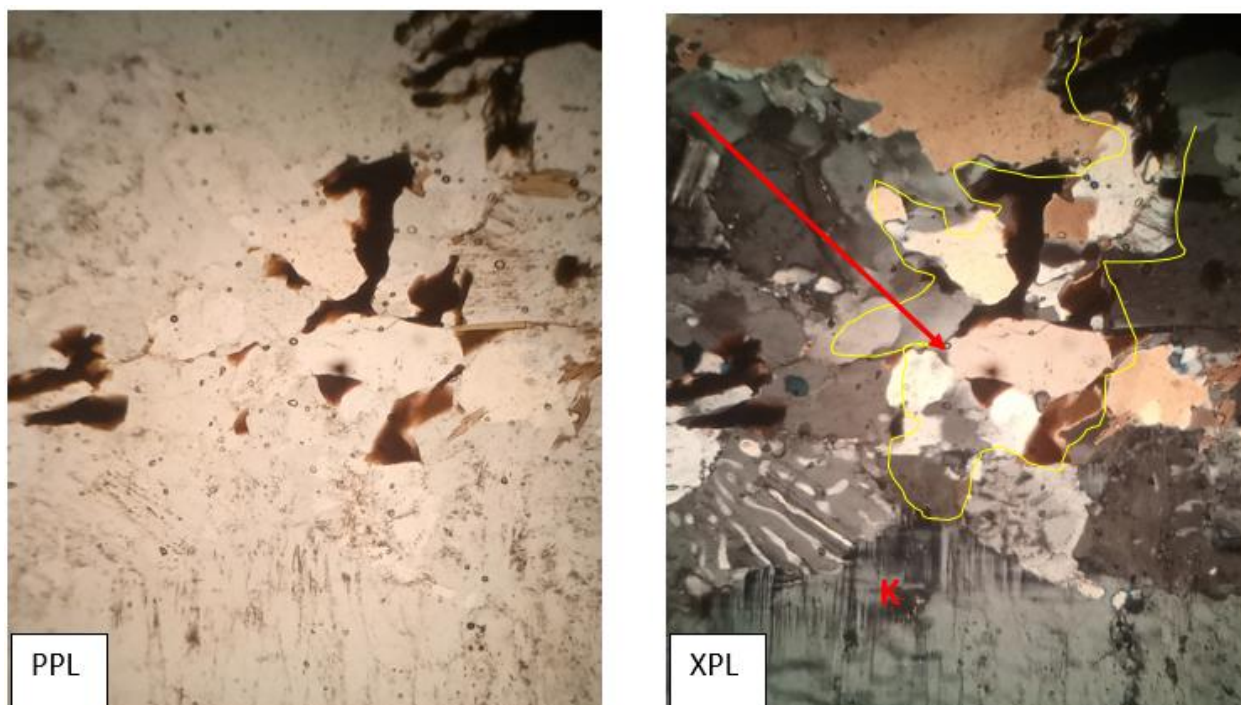


Plate 3 : Photo micrograph Sample A 3rd view

K- Feldspar = K, while the red arrow and the area covered by the yellow line are indicating myrmekite intergrowth of minerals as they are surrounded by coarser mineral grains near microcline.

Table 1: Showing minerals number and percentages of the petrographic views (sample A).

S/No	Minerals	Count And Number Of Views	Percentage (%)
1.	Quartz (Q)	6, 14 and 15	40%
2.	Biotite (B)	7, 4 and 10	24%
3.	K feldspar (K)	0, 0 and 1	1%
4.	Orthopyroxene (A)	8, 6 and 4	25%
5.	Plagioclase (P)	2, 4 and 2	10%

Table 2: Minerals properties observed under PPL and XPL microscope (sample A).

Minerals	PPL	XPL
Quartz	Color: Colorless Transparency: Yes Pleochroism: Milky	Twinning: None Interference: Colorless, b Brown, Black, Yellow and Milky.
Plagioclase	Color: Colorless Transparency: None	Interference: Brown to Dark-brown Twinning: Albite
Orthopyroxene	Color: Green and pink Relief: High Cleavage: Two direction Form: Euhedral Pleochorism: It is pleochoric	Twinning: None Interference color: Milky
k- feldspar	Color: Colorless Transparency: None	Twinning: Polysynthetic twinning. Pleochorism: Dark-brown to white

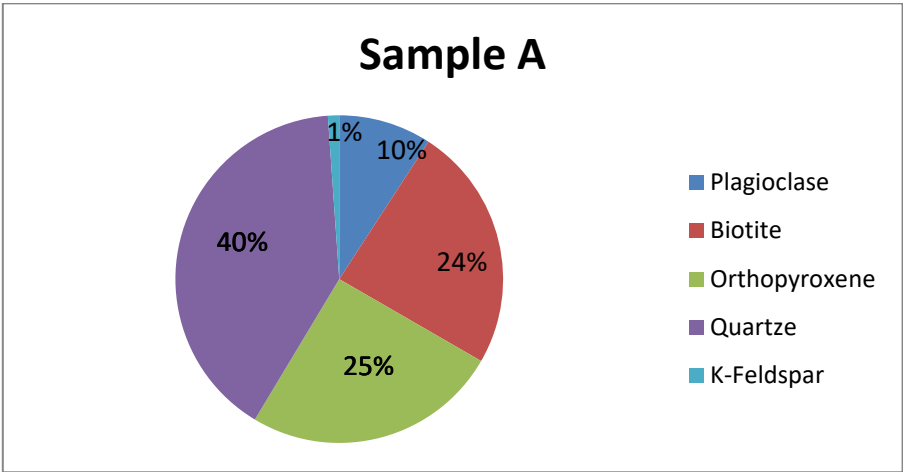


Figure 7: Pie Chart Showing the Percentage Composition of Minerals in Sample A.

4.2) Sample B (Metamorphosed sandstone (quartzite))

The rock has a mixture of black and white color of the fine grain sandstone location B.



Plate 4: Photograph of sample B



The views of the minerals (sample B) under PPL and XPL microscope.

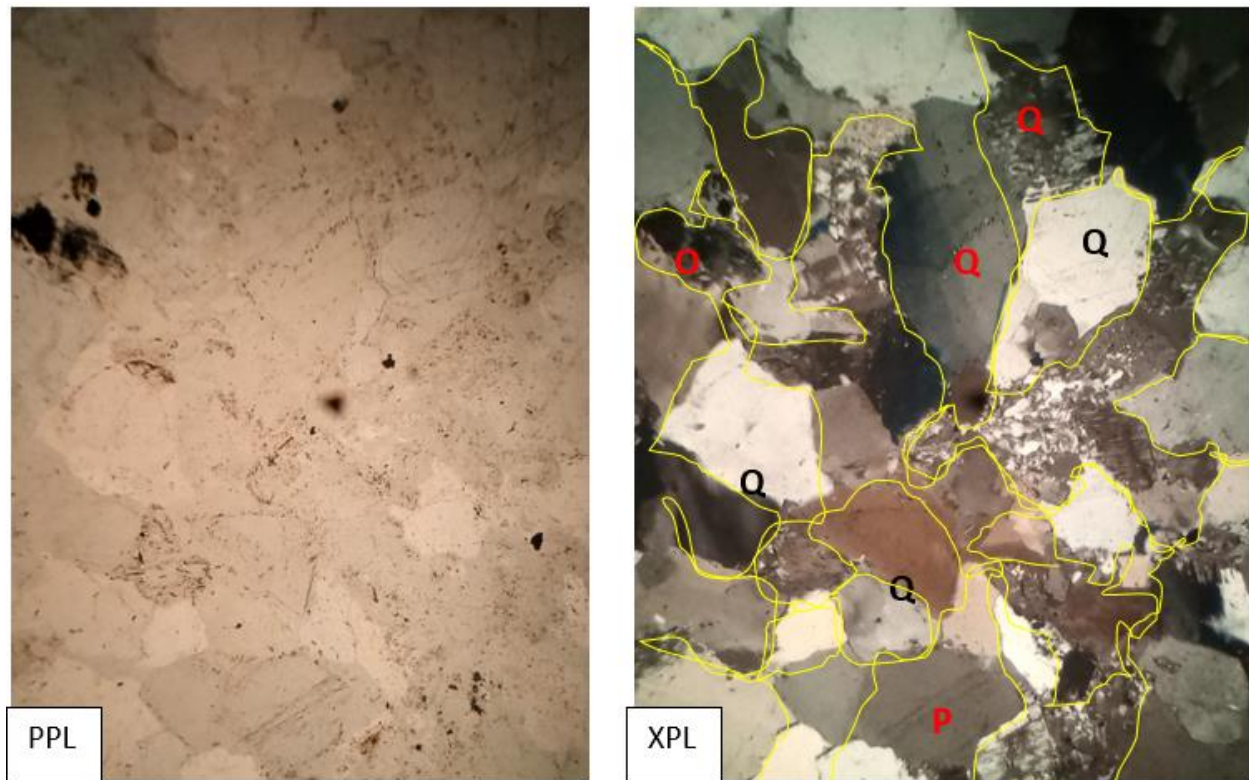


Plate 5: Photo micrigraph of sample B

Quartz = Q, Opaque mineral = O, Plagioclase = P and the yellow line is indicating suture zones.

Table 3: Showing minerals number and percentages of the petrographic views (Sample B).

S/No	Minerals	Count And Number Of Views	Percentage (%)
1.	Quartz (Q)	39, 158 and 64	94%
2.	Plagioclase (P)	3, 0 and 3	2%
3.	Opaque minerals (O)	6, 2 and 4	4%

Table 4: Minerals properties observed under plane (PPL) and cross polarized (XPL) microscope of sample B.

Minerals	PPL	XPL
Quartz	Color: Colorless Transparency: Yes Pleochorism: Milky	Twinning: None Interference: Colorless, Brown, Black, Yellow and Milky.
Plagioclase	Color: Colorless Transparency: None	Interference: Brown to Dark-brown Twinning: Albite
Opaque mineral	Color: Black Transparency: None Pleochorism: None	Twinning: None Interference: None



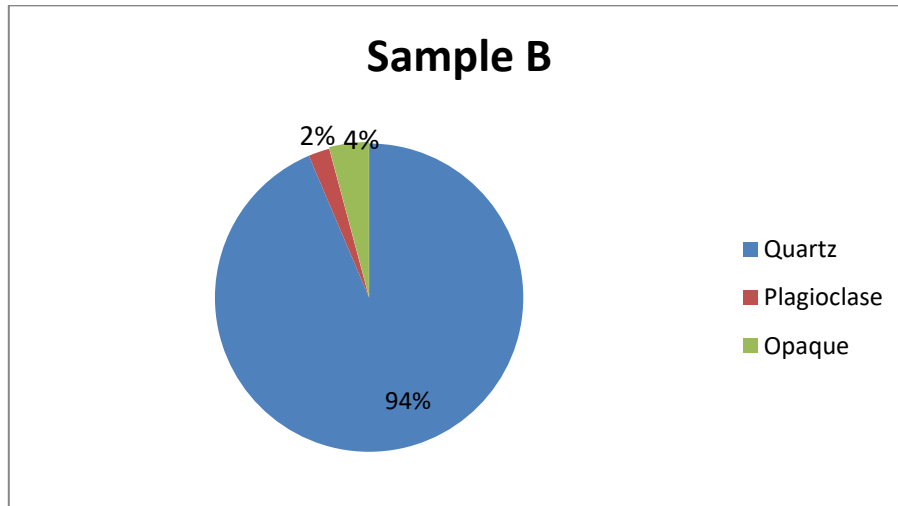


Figure 8: Pie Chart Showing the Percentage Composition of Minerals in Sample B.

#### 4.3) Sample C

This is a metamorphic granitic rock that is characterized by the presence of chalcopyrite (fool's gold). It is leucocratic in color by the presence of white and black color minerals.



Plate 10: Photograph of sample C

The views of the sample C under Plane (PPL) and crossed polarized light (XPL) microscope:

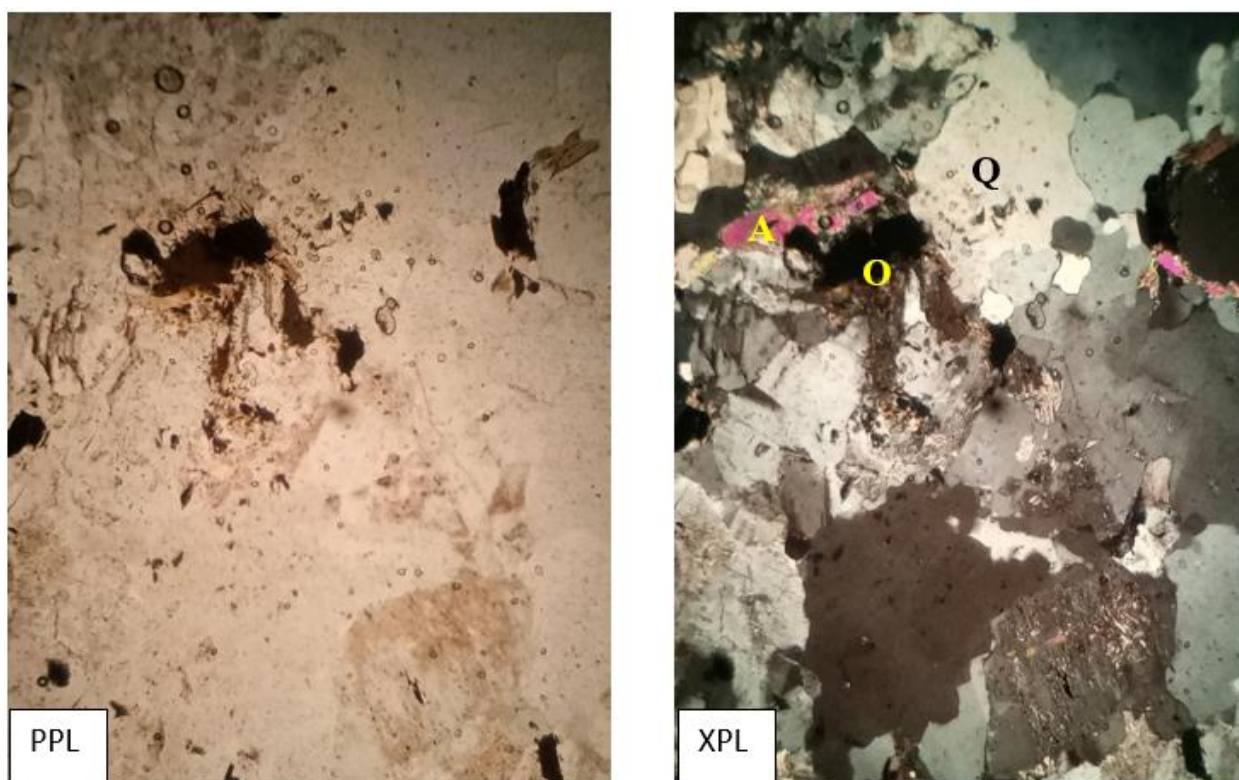


Plate 14: Photo micrograph of sample C.

Orthopyroxene = A, Quartz = Q, and Opaque mineral = O

Table 5: Showing minerals number and percentages of the petrographic views (sample C).

S/No	Minerals	Count And Number Of Views	Percentage (%)
1.	Quartz(Q)	18, 9 and 20	36%
2.	Orthopyroxene(A)	7, 7 and 11	26%
3.	Plagioclase(P)	4, 2 and 1	5%
4.	Opaque minerals (O)	17, 19 and 7	33%

Table 6: Sample C Minerals properties observed under plane (PPL) and cross polarized (XPL) microscope of location C.

Minerals	PPL	XPL
Quartz	Color: Colorless Transparency: Yes Pleochorism: Milky	Twinning: None Interference: Colorless, Brown, Black, Yellow and Milky.
Plagioclase	Color: colorless Transparency: None	Interference: Brown to Dark-brown Twinning: Albite
Othorpyroxine	Color: Green and pink Relief: high Cleavage: Two direction Form: euhedral Pleochorism: It is Pleochoric	Twinning: None Interference color: Milky.

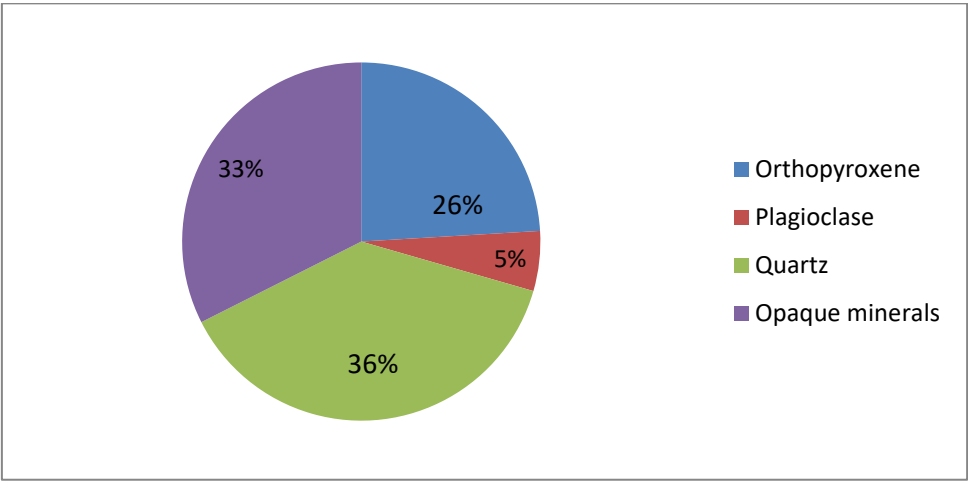
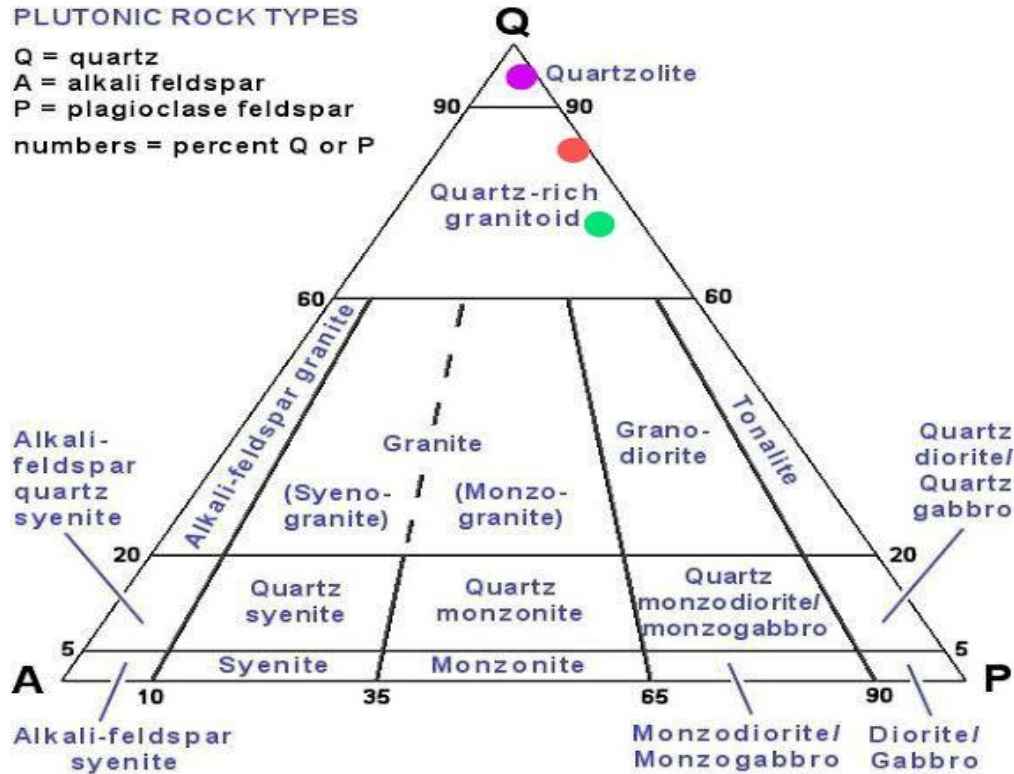


Figure 9: Pie Chart Showing the Percentage Composition of Minerals in Sample C.



Figurer 10: Showing QAP Plot of Samples A , B and C.

## GRANULOMETRY

Table 7: Data Presentation and Interpretation of the Granulometry below.

S/N	Sample Number	Graphic Mean(Mz)	Graphic Kurtosis (Kg)	Graphic Inclusive Skewness (Ski)	Standard Deviation (Sd)	Histogram
1	Sample 1	-0.23 (very coarse sand)	0.92 (mesokurtic)	0.01 (very fine skewed)	0.30 (very well sorted)	Unimodal
2	Sample 2	0.56 (coarse sand)	0.85 (platykurtic)	2.06 (very fine skewed)	0.65 (moderately well sorted)	Unimodal
3	Sample 3	2.16 (fine grain sand)	1.21 (leptokurtic)	0.79 (fine skewed)	1.50 (poorly sorted)	Bimodal
4	Sample 4	-0.01 (very coarse sand)	0.53 (very platykurtic)	3.38 (very fine skewed)	0.54 (moderately well sorted)	Polymodal

## 5. Discussion

The effect of diagenesis on the cretaceous rocks has significant relation to the presence or absence of fluid (oil or water); as oil or any fluid tend to maintain the porosity or permeability of many cretaceous rocks during diagenesis while the absence of the fluid was observed as an effect on mineral grains from petrographic analysis as it created suture zones and silica overgrowth (Bata et al., 2017).

From the macroscopic and microscopic study of sample A, the rock was formed as the result of metasomatism forming fluorite as green quartz with an embedded partially crystalline pegmatitic rock. The petrographic study reveals the presence of minerals such as Quartz, Biotite, K-Feldspar, Orthopyroxene and Plagioclase Feldspar with coarse grained minerals surrounding the matrix indicating the intergrowth caused by high pressure and temperature along the sheared zone of the Strike-Slip fault.

The petrographic study of metamorphosed Bima Sandstone shows minerals such as Quartz having 94%, plagioclase and some opaque minerals having the

remaining percentages. The evidence of porosity loss here are the Crystal Overgrowth and Suture zone which signified the degree of Diagenesis, Cementation or the Metamorphism.

The environment of the deposition was proximal; this is due to the shape (sub angular in shape) of the minerals grain from the petrographic study. This indicated that the transportation was by traction or saltation.

The Precambrian metamorphic rock of location C was characterized as leucocratic metatexite. Minerals such as Quartz, Orthopyroxene, Plagioclase Feldspar and some Opaque minerals were observed under the microscope. The Bima Sandstone was very coarse sand, well sorted and unimodal. This means that it was formed under the same current (agent of deposition) of medium energy near the source that can allow the settlement of fine sediment alone with the coarser ones to be well sorted. It has less permeability due to the grain size variation since it is well sorted.

The Yolde Formation was coarse grain sand, moderately sorted and unimodal. The rock was formed under current of medium energy which transported the grains by saltation having less variation in grain sizes. This means that it is relatively permeable. There was also Yolde Formation that is very coarse, moderately sorted and poly modal. It was



deposited by three mode systems, one or two of high current (indicating regression) that can move the grains by traction signifying proximal environment and other of medium or less energy either by saltation or by suspension (indicating transgression) that filled off the pore spaces to be moderately sorted. This indicated that it has low permeability although it is coarse grained.

The crystalline and sedimentary rocks found within the Inlier were metamorphosed by heat and pressure while some by fluid inclusion (metasomatism) caused by the strike-slip fault. Based on the petrographic study the mineral constituents of the rocks are; Quartz, Biotite, K-Feldspars, Orthopyroxene, Plagioclase and some Opaque minerals. The petrographic examination shows evidence of Crystal Intergrowth, Quartz overgrowth and Suture grain content in the sandstone that have undergone metamorphism. Field observation shows the presence of Quartzite along the fault zone, implying that regional faulting in the study area triggered metamorphism of some sandstone in the area.

The sedimentary rocks of the study area are mostly fluvial of Albian Bima Formation and fine grain transition of Cenomanian Yolde Formation and marine of Turonian Pindiga Formation. From the sieve analysis, the sedimentary rocks around the area were deposited by interchange between fluvial and marine activities. The rocks were analyzed to be very coarse sand, coarse sand and fine grain sand that are well sorted to moderately sorted. Coarse grained sands are dominant from the samples.

## 6. Conclusions

At the end of the study, the area was thoroughly mapped, structural analysis, macroscopic observations, microscopic analysis, the effect of diagenesis and metamorphism of mineral grains was analyzed. Finally the environment of deposition was deduced as fluvial to marine and the arrangement of the grains was archived using sieve analysis.

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