

# Sedimentology and depositional environments of Yolde formation in Ngurore and environs, Yola sub-basin, Northeastern Nigeria

<sup>1</sup>Amodu, A., <sup>1</sup>Shuaibu, A. S., <sup>1</sup>Adam, M. and <sup>1</sup>Valdon, Y. B.

<sup>1</sup>Department of Geology, Modibbo Adama University, Yola, Adamawa State, Nigeria

## Paper History

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## Abstract:

The mature basin (The Niger Delta) is no longer the main focus of hydrocarbon exploration in Nigeria; instead, it is the frontier and inland basins, which include the Benue Trough. As a result, every piece of information is crucial in the search for hydrocarbons in the Yola sub-basin, and sedimentology is one of the diverse range of tools used to increase our understanding of an area's geology and paleoenvironment. Using integrated lithofacies, sieving, and petrographic investigations, this work aims to describe the geology and identify the sub-depositional environment under the more general transitional environment in the studied area. The Yolde Formation in the study area reveals a fining upward facies sequence with trough, planar, parallel, and hummocky cross beds, which are capped with interbedded fine-grained ripple sandstones and mudstones. The samples are poorly sorted, which is a sign that the sediments were subjected to fluctuating energy conditions and were texturally submatured. From the petrography, the samples in the studied area had a modal mineralogical composition that ranges from 74% to 85% quartz, 13% to 22% feldspar, and 2% to 4% rock fragments, which are subangular to subrounded. Based on the mineralogical percentages of the grains as displayed on Folk's classification scheme, they were categorized as arkose to subarkose sandstones, and the sandstone has an immature to sub-mature class mineralogical maturity index. The sub-environment of the studied area was ascertained through the integration of petrography, bivariate plots, and field work. The integration points to a series of sub-environments ranging from fluvial (braided river) to transitional (beach, deltaic, and tidal flat).

Corresponding author

Amodu, A.

[adeniyiamodu@mau.edu.ng](mailto:adeniyiamodu@mau.edu.ng)

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## 1. Introduction

The Yolde Formation is the second-oldest Formation in the Upper Benue Trough. It represents the onset of marine transgression in the Gongola, Yola, and Muri-Lam Arms of the Upper Benue Trough, and it conformably overlies the continental Bima Sandstone [1]. It was deposited during the Late Turonian to Late Cenomanian [2-3]. It is presumed by many workers to be deposited in transitional environments, that is, between continental and marine environments. The focus of oil exploration in Nigeria is now shifting from the matured basin (The Niger Delta) to the frontier and inland basins, which include the Benue Trough.

The clastic Cretaceous reservoirs of the Yolde and Bima sandstone Formations were found to contain hydrocarbons in the nearby Gongola sub-basin from well Komani River-I [4]. Therefore, in the search for hydrocarbons in the Yola sub-basin, every piece of

information is crucial, and sedimentology is one of the diverse range of tools used in building up the geological and paleoenvironmental knowledge of an area.

The study area is in Ngurore area, Adamawa State which is located in the North-eastern part of Nigeria as shown in Figure 1. It falls within the Yola arm of the Upper Benue Trough and lies within 9° 17'0" to 9° 19'0" N and longitude 12° 14'0" to 12° 17'0" E and the study area has some good outcrops of Yolde Formation which can be seen along the road and stream cuts. Many studies have been done on the Yolde Formation in the Upper Benue Trough [5, 6, 7, 8, 9] but most of the work carried out within the study area is centered on the study of igneous basaltic rock [10, 11]. Limited work has been done and there is no published work on the sedimentary aspect of the study area, hence this study. This work aims at describing the geology and establishing the sub-depositional environment under the broader transitional environment in the study area using integrated lithofacies, sieve and petrographic analyses.

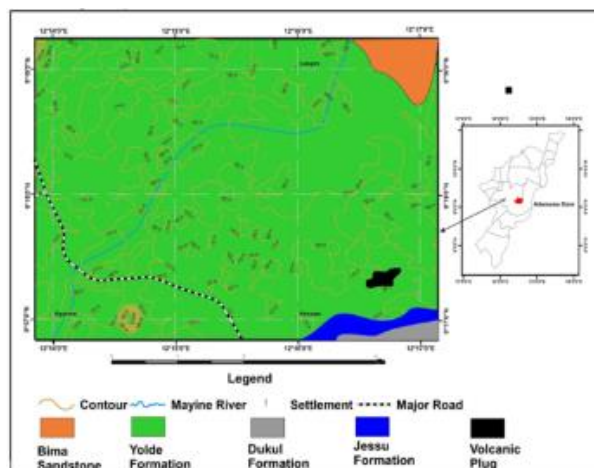


Figure 1: The geological map of the study area

## 1.1 Geological Settings

The Benue Trough of Nigeria is part of the West and Central African Rift Systems, a mega-tectonic structure formed by the tension generated due to the separation of the African and South American plates during the early Cretaceous [12, 13]. The Benue Trough is arbitrarily subdivided into the Upper, middle, and Lower Benue Troughs. The Upper Benue Trough is further subdivided into the N-S striking Gongola Arm, the E-W striking Yola Arm, and the NE-SW striking Muri-Lau Arm [14]. The stratigraphy of the Yola Arm is composed of Cretaceous sequences that overlie the Precambrian basement complex and this is

unconformably overlain by Aptian-Albian continental Bima Sandstone [5, 14] as shown in Figure 2. The non-marine Bima Sandstone is overlain by the Yolde Formation, which is transitional in nature; the formation is composed of shale sandstone intercalation from the bottom and it passes into siltstone. The Yolde Formation is overlain by the transgressive Dukul Formation, which is a purely marine deposit characterized by thick grey shales that pass up into a thin silty bed of shale limestone intercalation. In an upward sequence, the formation is overlain by the transitional Jessu Formation, marine Sekuliye, Numanha Formation, and finally capped by the Lamja Formation.

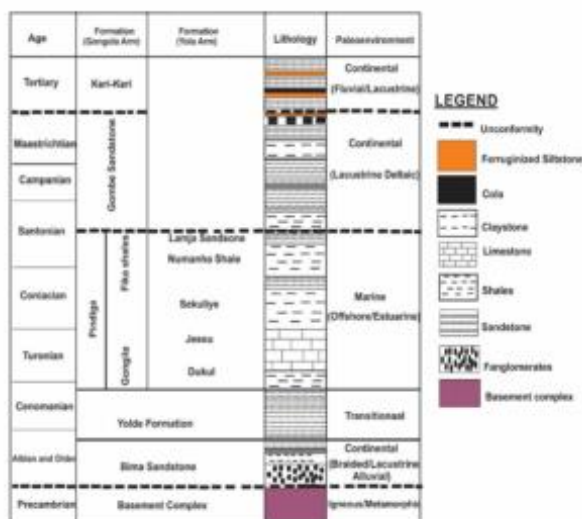


Figure 2: The Stratigraphic Succession of the Upper Benue Trough [15].

## 2. Methodology

This study involved both field studies and laboratory analyses. The field study and analyses are described below.

### 2.1 Field Study

The field study entails mapping (outcrop logging, lithological variation, bed attitude measurement, photography, and noting sedimentary texture and structures), as well as sample collection for laboratory analyses. These data were utilized to produce a geological

map, litho-sections, and identify sub-depositional environments.

### 2.2 Laboratory Analyses

The representative's samples collected from the field were subjected to sieve and petrographic analyses.

#### 2.2.1 Sieve Analysis

For the sieve analysis, a mortar and rubber-padded pestle were used to disaggregate the representative

samples after they had been air dried. Then, using the Ro-Tap mechanical shaker, they were weighed and sieved for particle-size distribution in accordance with established standards. The approaches of [16, 17] were used to obtain and compute the statistical parameters of the grain size frequency distribution. To determine the relationship between variances displayed by parameters, [18, 19] employed the linear discrimination functions of [20]. For paleoenvironmental discrimination, the following formulas from [20] were used:  $Y_1 = -3.5688 MZ + 3.7016 \delta^2 - 2.0766 SK + 3.1135 KG$ ;  $Y_2 = 15.6534 MZ + 65.7091 \delta^2 + 18.1071 SK + 18.5043 KG$ ;  $Y_3 = 0.2852 MZ - 8.7604 \delta^2 - 4.8932 SK + 0.0482 KG$ . Where MZ: mean value,  $\delta^2$ : standard deviation, SK: Skewness and KG: kurtosis.

## 2.2.2 Petrography Analysis

The representative rock samples were cut into thin sections, which were then examined under a petrographic microscope to identify the minerals and determine their relative abundance. For the purpose of compositional classification, the relative abundance of each mineral constituent and the modal composition were determined using the point count method [21, 22]. Using the work of [23, 24], the study area's textural and mineralogical maturity was also determined.

## 3. Results and Discussion

The lithostratigraphic sections of the study area are described, and the results of the samples analyzed are presented and discussed below.

### 3.1 Lithostratigraphy

#### 3.1.1 Kwana Waya Section

The outcrops were exposed by local miners, and the total thickness of the section is about 4 m as shown in Figure 3. From the bottom of the section, it is made up of coarse-grained sandstone that ranges in color from milky to brownish, with primary sedimentary structures of trough cross-beds. The trough cross-beds are overlain by planar cross-beds and thin parallel-bedded sandstone as can be seen in Plate 1, which progresses upward into intercalation of fine-grained ripple cross-stratified sandstone and a thin layer of mudstone deposit that is about 5 cm thick and greyish, which marked the end of the first depositional cycle. The second depositional cycle started with medium- to coarse-grained planar cross bedded sandstone, overlain by parallel-bedded sandstone, and this bed is also overlain by intercalation of sandstone and mudstone.

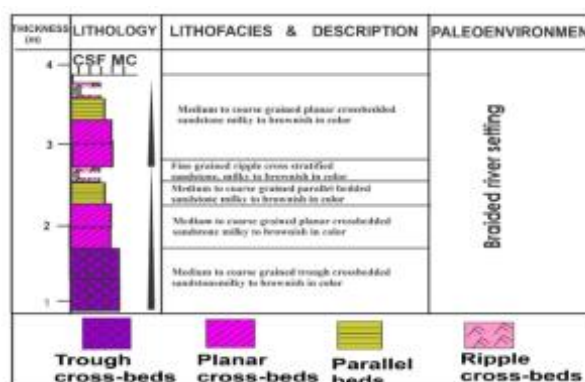


Figure 3: Lithologic section at Kwana-Waya

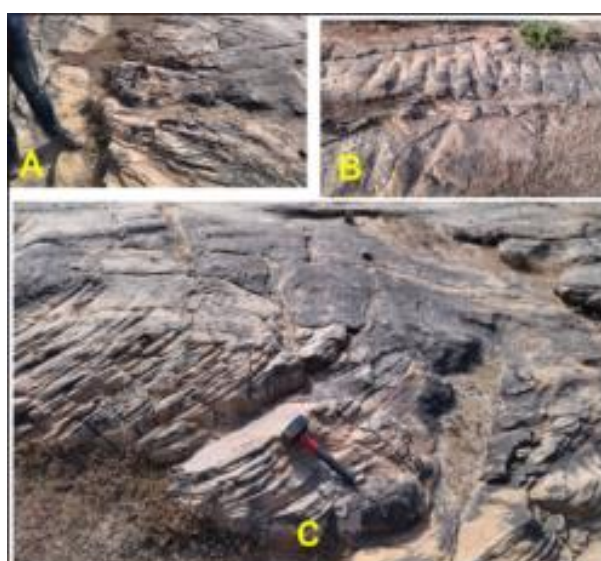


Plate 1: A & C is a field picture of trough cross bedded sandstone facies from Kwana-Waya and B represent planar cross bedded/ripple cross laminated sandstone facies

### 3.1.2 Tashan Rake Section

Tashan Rake is a small village along the Mayo-Belwa road in Ngure. It is a flat terrain with few outcrops; most of the outcrops in this location are exposed by streams and channels, and the location is about 194m above mean sea level. The logged section at this location begins from the base with a medium- to coarse-grained planar cross-bedded sandstone. A parallel-bedded sandstone deposit was formed and deposited on the planar cross bed, and the sequence continued with a medium-grained hummocky cross-bedded sandstone. An intercalation of sandstone and mudstone overlaid the hummocky cross-bedded sandstone, which marked the end of the first depositional cycle. The second depositional cycle started with a deposit of medium to coarse planar cross-bedded sandstone. This was followed by deposits of medium-grained parallel-bedded sandstone and grey mudstone. The sequence is completed and capped by a bed of fine-grained ripple-laminate sandstone that has some bioturbation on it, and the entire sequence has a thickness of about 6m as shown in Figure 4 and Plate II.

### 3.1.3 Composite Section

The composite section in Figure 5 represents the sum total of the individual lithostratigraphy of the Yolde Formation in the study area. The section generally exhibits a fining upward facies sequence and the sub-environment is a braided river setting to fluvial tidal channel.

## 3.2 Sieve Analysis

The percentile values from the sieve analysis for the seven samples are shown in Table 1 and used to evaluate univariate and multivariate results. Table 2 displays the results obtained from the statistical calculations of the analyzed samples.

### 3.2.1 Univariate Analysis

Table 3 summarizes and describes the grain size results. The mean of sandstones from samples 1 to 7 varies between 1.9 to 2.2 with an average grain size of 1.96. These imply that the sandstones range from medium to fine grained and the variation in the grain sizes indicates a fluctuation in the energy of deposition [16, 25]. On average, the sandstones are medium-grained. The standard deviation, which is a measure of the sorting, ranges from 1.2 to 1.46 with an average of 1.36. These values indicate poor sorting [10]. The poor sorting is indicating that the sediments were deposited in a variable energy setting [26, 27]. The range of the kurtosis value is 0.91 to 2.04 with an average of 1.27. The interpretation of these is that they range from platykurtic to very leptokurtic, and on average, the sandstones are leptokurtic. The values of skewness range from -0.51 to 0.04, with an average of -0.30. [28] interpreted the skewness ranges as strongly coarse-skewed to nearly symmetrical. On average, the samples are coarse skewed, which is an indication that the energy was moderate for most of the time. The sandstones' predominance of fine- to medium-grained particles suggests a low- to moderate-energy depositional environment with a bimodal direction of flow pattern, similar to that of a transitional to fluvial setting.

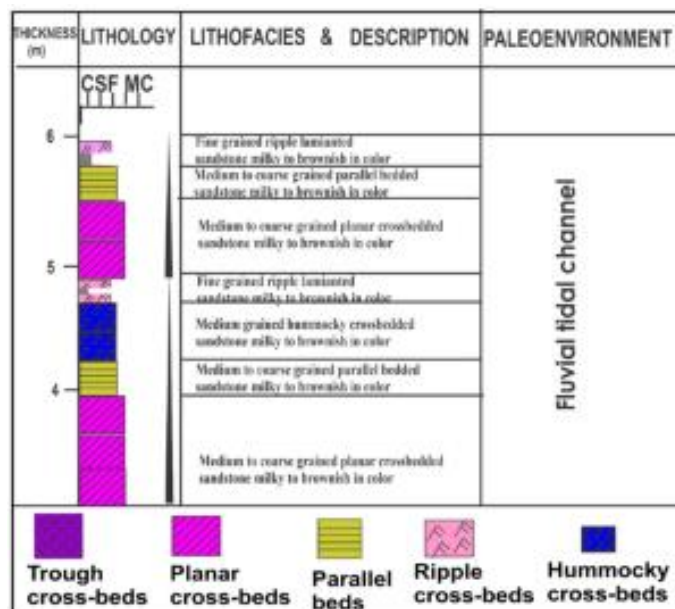


Figure 4: Lithostratigraphic section at Tashan-Rake





Plate II: Outcrop section at Tashan Rake. The section shows planar cross-bedded and parallel-bedded sandstone

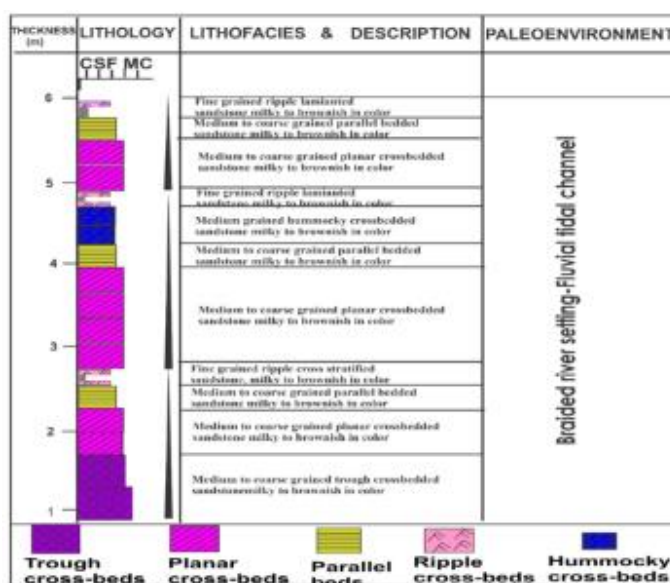


Figure 5: Composite Section of the Yolde Formation from the study area

Table 1: Percentile value from cumulative curve plots

Samples	5 $\phi$	16 $\phi$	25 $\phi$	50 $\phi$	75 $\phi$	84 $\phi$	95 $\phi$
1	-0.8	0.4	0.9	2.2	2.9	3.2	4.3
2	-0.6	0.5	1.2	2.3	2.9	3.2	4.0
3	-1.0	0.1	0.5	2.0	2.7	3.0	3.9
4	-1.0	0.4	1.7	2.6	3.2	3.6	4.1
5	-0.9	0.5	1.5	2.3	2.8	3.0	4.0
6	-1.0	0.5	1.9	2.4	2.9	3.2	4.0
7	-1.0	0.2	1.7	2.3	3.0	3.3	3.8

Table 2: Calculated results of the sieve analysis

Samples	Mean	Sorting	Skewness	Kurtosis
1	1.9	1.46	-0.22	1.04
2	2.0	1.43	-0.32	1.11
3	1.7	1.20	0.04	0.91
4	2.2	1.46	-0.51	1.39
5	1.93	1.33	-0.37	1.54
6	2.03	1.37	-0.38	2.04
7	1.93	1.29	-0.35	0.85
Average	1.96	1.36	-0.30	1.27

Table 3: Summary of grain size results and description

Samples	Mean Size	Sorting	Skewness	Kurtosis	Descriptions
1	1.9	1.46	-0.22	1.04	Medium sand, poorly-sorted, coarse skewed and mesokurtic
2	2.0	1.43	-0.32	1.11	Fine sand, poorly-sorted, strongly coarse skewed, and mesokurtic
3	1.7	1.2	0.04	0.91	Medium sand, poorly-sorted, near symmetrical and mesokurtic
4	2.2	1.46	-0.51	1.39	Fine sand, poorly-sorted, strongly coarse skewed and leptokurtic
5	1.93	1.3	-0.37	1.54	Medium sand, poorly-sorted, strongly coarse skewed and very leptokurtic
6	2.03	1.37	-0.38	2.04	Fine sand, poorly-sorted, strongly coarse skewed and very leptokurtic
7	1.93	1.29	-0.35	0.85	Medium sand, poorly-sorted, strongly coarse skewed and platykurtic
Average	1.96	1.36	-0.30	1.27	Medium sand, poorly-sorted, coarse skewed and leptokurtic

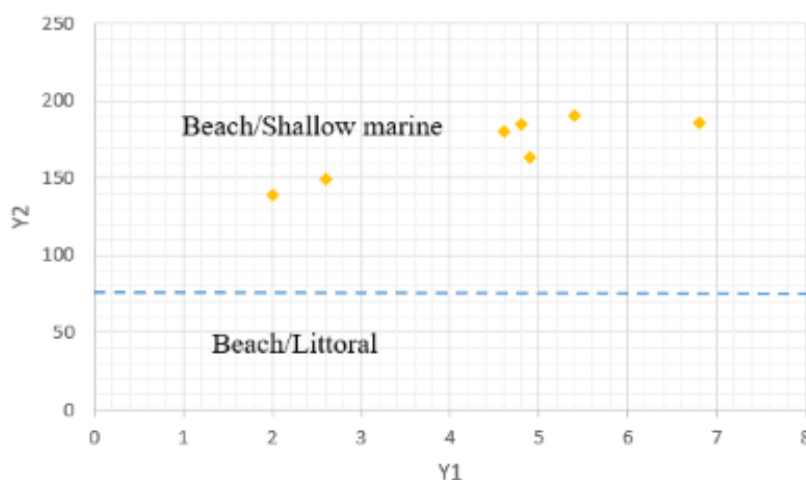
### 3.2.2 Bivariate and Multivariate Analysis

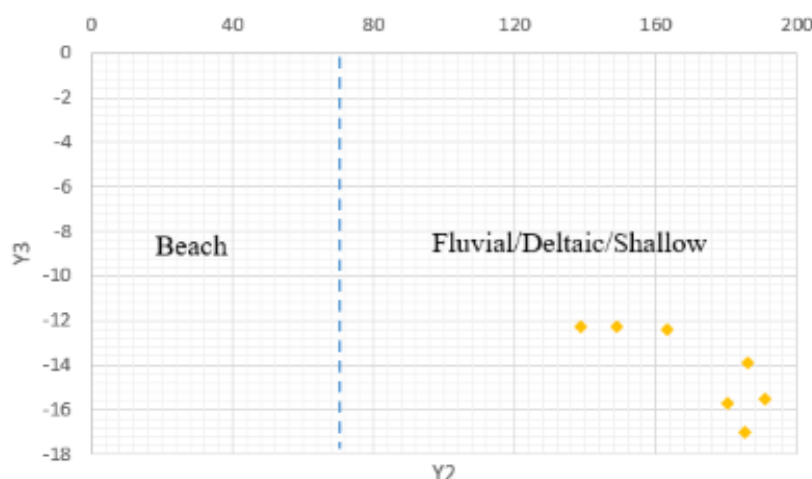
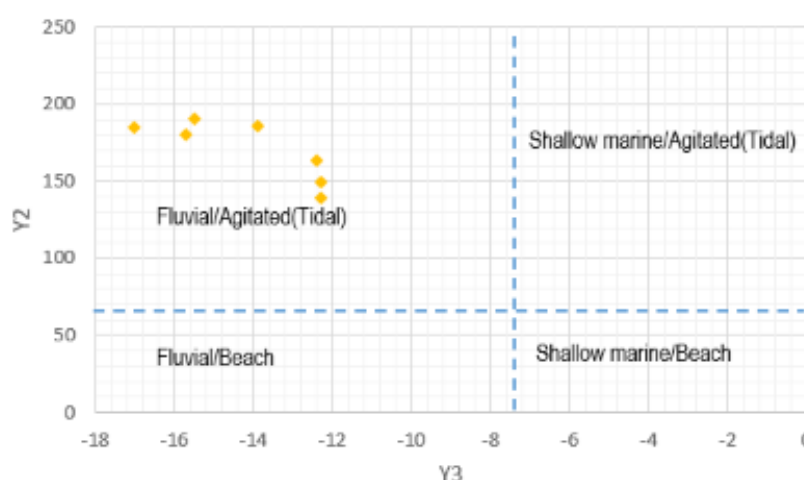
The findings from the environmental discrimination functions are shown in Table 4 using the multivariate environmental discriminant functions ( $Y_1$ ,  $Y_2$  and  $Y_3$ ) of [20], which were adapted from [18, 19]. For  $Y_1$ ; when  $Y_1$  is less than -2.7411, Aeolian deposition is indicated whereas if it is greater than -2.7411, a beach environment is suggested. For  $Y_2$ ; when  $Y_2$  is less than 65.3650 beach deposition is indicated whereas if it is greater than 65.3650 a shallow agitated marine environment is suggested. For  $Y_3$ ; when  $Y_3$  is less than -7.419 the sample is identified as a fluvial

(deltaic) and if it is greater than -7.419 the sample is identified as a shallow marine. To increase the rate of success and refine the discrimination of the depositional environment, the discriminate functions ( $Y_1$ ,  $Y_2$ , and  $Y_3$ ) were plotted as bivariate scatter plots [18, 19]. A bivariate plot of  $Y_1$  against  $Y_2$  in Figure 6 shows a beach/shallow marine environment. Plot of  $Y_2$  against  $Y_3$  in Figure 7 shows that the samples are of a fluvial/deltaic/shallow environment while the plot of  $Y_3$  against  $Y_2$  in Figure 8 shows a fluvial/agitated(tidal). The samples are all deposits of tidal influenced fluvial to transitional settings.

Table 4: Discriminate functions and environment of deposition

Samples	$Y_1$	$Y_2$	$Y_3$
1	4.80 Beach	185.07 Shallow agitated marine	-17.01 Fluvial(deltaic) deposit
2	4.55 Beach	180.42 Shallow agitated marine	-15.72 Fluvial(deltaic) deposit
3	2.02 Beach	138.81 Shallow agitated marine	-12.28 Fluvial(deltaic) deposit
4	5.43 Beach	190.99 Shallow agitated marine	-15.48 Fluvial(deltaic) deposit
5	4.93 Beach	163.06 Shallow agitated marine	-12.37 Fluvial(deltaic) deposit
6	6.84 Beach	185.97 Shallow agitated marine	-13.91 Fluvial(deltaic) deposit
7	2.65 Beach	148.95 Shallow agitated marine	-12.27 Fluvial(deltaic) deposit

Figure 6: Bivariate plot of  $Y_1$  against  $Y_2$


Figure 7: Bivariate plot of  $Y_2$  against  $Y_3$ 

Figure 8: Bivariate plot of  $Y_3$  against  $Y_2$ 

### 3.3 Petrography

The thin section photomicrographs with their minerals composition that were examined are displayed in Plate III, and the shapes of mineral grains show subhedral to anhedral. The mineralogical composition of the studied area's sandstone is composed of quartz (70–80%), feldspar (12–20%), rock fragments (2–4%), iron oxide (2%), Biotite (1–3%) and clay (1–3%) (Table 5). The building of QRF Ternary diagrams shown in Figure 9 utilizes Table 6's presentation of the modal composition of quartz, feldspar, and rock fragment. According to the mineralogical percentages of the grains plotted on Folk's classification of sandstones scheme [23], the analyzed sandstone samples were categorized as arkose to subarkose sandstones, as illustrated in Figure 9. The samples are grained supported with long-contact, sub-angular to sub-rounded grains that are moderately to poorly sorted.

#### 3.3.1 Textural and Mineralogical Maturity

Maturity refers to the degree to which clastic sediment has been modified by physical and chemical processes at Earth's surface [29]. Textural maturity is a property that relates to the amount of mechanical energy input on transported sediments through the abrasive power of currents and tides [23]. According to the analysis of the samples, the sandstone is submature, meaning that the sediment includes less than 5% clay and the sand grains are poorly sorted and subangular to subrounded, as shown in Table 7 [23]. The mineral maturity index of sandstone is commonly expressed as the ratio of quartz to feldspar + rock fragments. The mineralogical maturity of the analyzed samples is computed using the mineral maturity index (MMI) of [14] and the value ranges are as follows, the mineral maturity index value <3 (Immature), 3–9 (Submature), 9–19 (Mature) and >19 (Supermature). The samples in the study area have a mineral maturity index that ranges from 2.8 to 5.7, which is in the immature to submature class (Table. 6).

Table 5: Mineralogical composition of sandstone in the study area

Samples	Quartz (%)	Feldspar (%)	Rock fragment (%)	Clay (%)	Iron oxide (%)	Biotite (%)
FY1	70	20	4	3	-	3
FY2	75	17	4	2	-	2
FY3	78	15	4	3	-	-
FY4	77	16	2	3	-	2
FY5	80	12	2	2	2	2
FY6	78	15	3	1	2	1
FY7	80	14	2	2	-	2

Table 6: Calculated QFR composition of sandstone samples with mineral maturity indices

Samples	Quartz (%) Q	Feldspar (%) F	Rock Fragment (%) RF	Mineral Maturity Index = $\frac{Q}{F+RF}$	Interpretation
FY1	74	22	4	2.8	Immature
FY2	78	18	4	3.5	Sub-mature
FY3	80	16	4	4.0	Sub-mature
FY4	81	17	2	4.3	Sub-mature
FY5	85	13	2	5.7	Sub-mature
FY6	81	16	3	4.3	Sub-mature
FY7	83	15	2	4.9	Sub-mature
Average	80.3	16.7	3	4.2	Sub-mature



Plate III: The representative photomicrographs of the Yolde Formation from the study area (Mag. X40).  
Qtz=Quartz, Fds=Feldspar, Bt=Biotite, Cm=Clay matrix, Io=Iron oxide



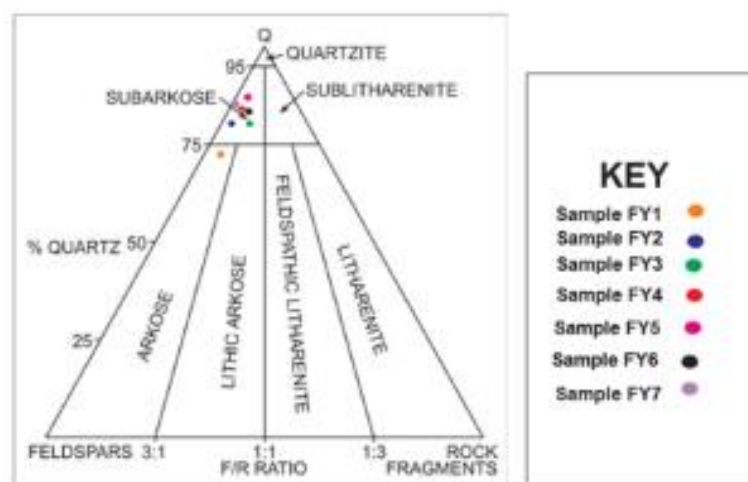


Figure 9: Ternary diagram showing the sandstone modal composition in the study area [23]

Table 7: Sandstone Maturity description [23]

Stages of Maturity	Description
Immature	The sediment contains greater than 5% clay and sand grains are poorly sorted and angular
Sub-mature	The sediment contains less than 5% clay and sand grains are poorly sorted and subangular to subrounded
Mature	The sediment contains little or to no clay and sand grains are well sorted but not well rounded
Super-mature	The sediment contains no clay and sand grains are well sorted and well rounded

#### 4. Conclusion

Data from the geological mapping, lithologic logs produced, sieving and petrographic studies have been useful for building up the geological and sub-depositional environment of the study area. The litho-sections exhibit a fining upward facies sequence that has trough, planar, parallel, and hummocky cross beds, and is capped with interbedded fine grained ripple sandstones and mudstones. The samples from the study area are averagely medium grained sand and range from strongly coarse skewed to nearly symmetrical but majorly coarse skewed and also range from platykurtic to very leptokurtic and on the average the samples are leptokurtic. Additionally, the samples are poorly sorted, which is a sign that the sediments were subjected to fluctuating energy conditions and were texturally submatured. From the petrography, the sample FY1 composed of 74% quartz, 22% feldspar, and 4% rock fragments; FY2 composed of 78% quartz, 18% feldspar and 4% rock fragments; FY3 composed of 80% quartz, 16% feldspar and 4% rock fragments; FY4 composed of 81% quartz, 17% feldspar and 2% rock fragments; FY5 composed of 85% quartz, 13% feldspar and 2% rock fragment; FY6 composed of 81% quartz, 16% feldspar and 3% rock fragments; FY7 composed of 83% quartz, 15% feldspar and 2% rock fragments. The samples in the studied area had an average modal mineralogical composition of 80.3% quartz, 16.7% feldspar, and 3% rock fragments, which are subangular to subrounded. Based on the mineralogical percentages of the grains as displayed on Folk's classification scheme, they were categorized as arkose to subarkose sandstones, and the Mineral Maturity

Index of the sandstone in the study area falls within the immature to submatured class. The sub-environment of the studied area was ascertained through the integration of petrography, several bivariate plots, and field work. The sub-environment of the studied area was ascertained through the integration of petrography, several bivariate plots, and field work. The integration points to a series of sub-environments ranging from fluvial (braided river) to transitional (beach, deltaic, and tidal flat).

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