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Textural and Compositional Studies of Sediments from Parts of the Albian Bima Sandstone, Upper Benue Trough, Nigeria

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Abstract

Studies were carried out on fresh samples of sandstones from parts of the Bima Sandstone to classify it on the basis of its textural and compositional characteristics. Grain size analysis of samples reveals that they are fine to coarse-grained, moderately sorted to poorly sorted, coarse skewed to strongly fine skewed and very platykurtic to extremely leptokurtic. Thin-section analysis reveals the sandstones to be lithic subarkoses, subarkoses, and lithic arkoses comprising averagely of 66.6% quartz, 21% feldspar and 12.4% rock fragments. The appreciable amount of feldspar, the dominance of subangular to angular grain shape and the poorly sorted nature of the sandstones suggest that they are texturally and mineralogically immature sediments. Bivariate plots of graphic mean versus standard deviation, skewness versus standard deviation and simple sorting versus simple skewness indicates a fluvial origin for sandstones deposited under a moderate to high energy level.

Keywords: Bima sandstone, fluvial, immature, poorly sorted

1. Introduction

The Benue Trough in Nigeria is an intracratonic linear shaped sedimentary basin that extends from NNE-SSW for about 800km in length and 150km in width. The valley contains up to 6,000m of Cretaceous-Cenozoic sediments of which those pre-dating the Mid-Santonian sediments have been compressionally deformed, faulted and uplifted in several places. The Upper Benue Trough is characterized by a Y shape. One Arm of the Y is the N180^{0}E Gongola Arm and the other is the E-W trending Yola Arm.

The origin and evolution of the Benue Trough has been a subject of several publications; King(1950), Cratchly and Jones, (1965), Grant (1971), Burke *et al*, (1972), Burke and Whiteman (1973), Olade (1975), Freeth (1978), Wright (1981), Ofoegbu (1984), Nwajide (1990) among others, with the rift model being the most widely accepted. However, the views of Benkhelil (1987,1989) suggests that sinistral wrenching was a dominant process for the structural re-adjustment and geometry of the sub-basins recognized in the lower, middle and upper Benue regions.

According to studies carried out by Haruna *et al* (2013), results from field observation and measurement show the same agent of transportation for the Bima sandstone as they were laid down by river channels while the fine grain ripple- marked and cracked siltstone beds were deposited in flood plains associated with the river channels. This was evidenced from the abundant tabular and few cross beddings, flat beddings and party lineations , ripple and cross lamination found in finer grain sandstones and lenticlar stream deposited sediments which are indicative of fluviatile conditions. Moreso, Haruna *et al*. (2013) proposed that the Bima Sandstone was derived from the crystalline rocks of the Hawal Massif, Mandara Massif as well as the Adamawa and Cameroun Massifs.

This study focuses on the textural and compositional characteristics of the Bima sandstone, the earliest sedimentary fill of the Yola Arm. The present study was carried out in the Yola area of North-Eastern Nigeria which is entirely underlain by the Bima sandstone Formation. The aim of the study is to classify the sandstones exposed in the study area on the basis of their textural and compositional characteristics.

1.1 Location of the Study Area

The study area (figure 1) lies between longitude 12° 35' 36" and 12° 38' 12" °E and latitudes 9°22'40" and 9° 20' N within the Yola area in Adamawa state, North- eastern Nigeria. The area generally has high relief which is more pronounced in the central, southern and south-eastern parts. The area is well drained by high discharge seasonal streams and rivers during the rainy season.

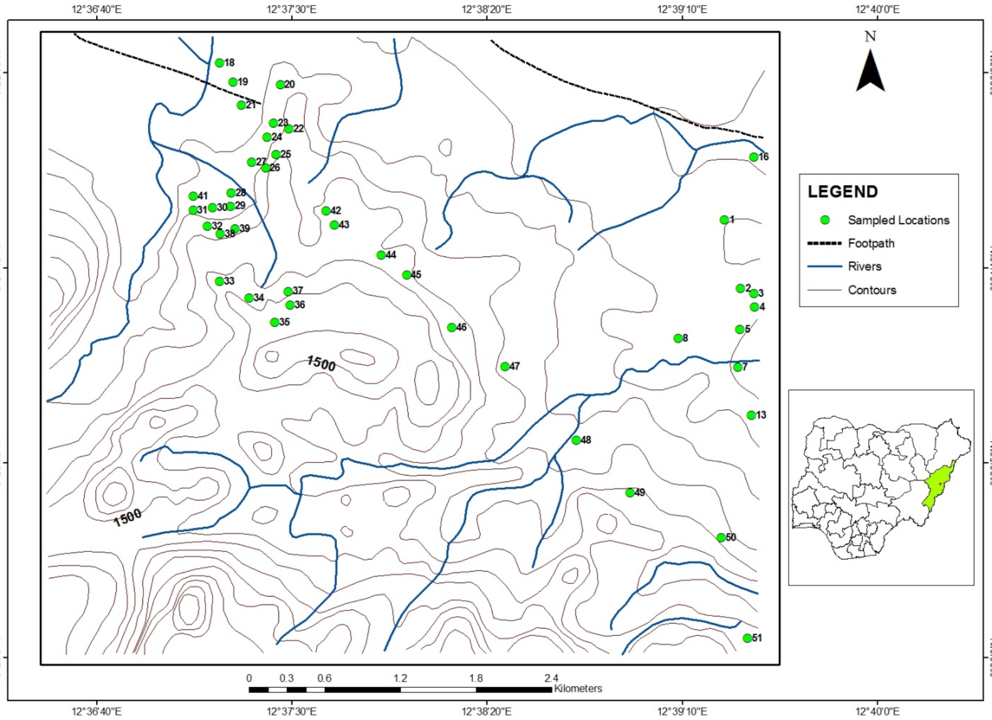

Figure 1. Location of the study area

1.2 Regional Stratigraphic Setting

The regional geology and stratigraphy of the Benue Trough have been comprehensively discussed, reviewed and presented by carter et al (1963), offodile (1976), Petters (1982), Whiteman (1982), Nwajide (1990), Ojoh (1992), Akande et al. (1998), Obaje et al (1999) among others. In both arms of the Upper Benue Trough (Figure 2), the continental Albian Bima Sandstone lies unconformably on the Precambrian basement as the oldest known Cretaceous sediment in the region. The Yolde formation which is Cenomanian to Turonian in age lies conformably on the Bima Sandstone. It is made up of a variable sequence of sandstones and shales that marks the transition from continental to marine sedimentation.

AGE	UPPER BENUE TROUGH	
	GONGOLA BASIN	YOLA BASIN
PALEOCENE	KERRI-FORMATION	
MAASTRICHTIAN	GOMBE SANDSTONE	LAMJA SANDSTONE
CAMPANIAN		
SANTONIAN	PINDIGA FORMATION	NUMANHA
CONIACIAN		JESSU /SEKULE
TURONIAN	GONGILA	DUKUL FORMATION
CENOMANIAN	YOLDE FORMATION	YOLDE FORMATION
ALBIAN	BIMA SANDSTONE	BIMA SANDSTONE

Figure 2. A Generalized Stratigraphic Correlation in the Gongola and Yola Basin (After Ojo, 1999)

The sandstone occurrence is suggestive of a beach environment (Opeloye and Obaje, 2005). In the Gongola Arm, the laterally equivalent Gongila and Pindiga Formations lie conformably on the Yolde Formation. These formations represent full marine incursion into the Upper Benue during the Turonian- Santonian times and are lithologically characterized by dark/black carbonaceous and pale colored limestones and shales with minor sandstones. In the Yola Arm, Dukul, Jessu, Sekule and Numanha are the Turonian-Santonian equivalents of the Gongila and Pindiga Formations. These successions are overlain by the Campanian to Maastrichtian Gombe Sandstone in the Gongola Basin and Lamja Sandstone (Lateral equivalent) in the Yola Basin (Carter *et al*, 1963). The Tertiary Kerri-Kerri Formation caps the succession west of Gombe in the Gongola Basin. The Gombe Sandstone and the Kerri- Kerri Formation are lithologically composed of sandstones, siltstones and abundant coal intercalations.

2. Materials and Methods

A total number of 28 samples were obtained randomly at different outcrop locations of the Bima Sandstone. Eighteen (18) of these samples were subjected to grain size analysis and the remaining ten (10) were used for Thin-section Analyses as detailed below.

2.1Grain Size Analysis

The selected samples were disaggregated, air dried and homogenized. 50g of each sample was sieved using the Ro-tap electro-mechanical sieve shaker (M-Tyler) adjusted to shake for 20 minutes. Quantitative data of cumulative weight percent was plotted against sieves sizes (in ϕ unit) to obtain a cumulative plot from which statistical parameters were calculated using formulae by Folk and Ward (1957).

2.2 Thin- Section Analysis

Thin section of the ten (10) representative rock samples were prepared and viewed under a petrographic microscope (MEIJI ML 9000). The relative abundance of each mineral constituent and modal composition was estimated, for the purpose of compositional classification. Mineral identification was based on its optical properties outlined in basic optical mineralogical texts.

3. Result and Discussion

3.1Grain Size Distribution

The results obtained from the grain size analysis carried out on the clastic sediments are presented in table 1.

3.1.1Graphic Mean Size (M_Z)

The graphic mean value depicts the average particle size. An evaluation of the sieve analysis result show that the calculated graphic mean size for the sandstones varies from -0.15 to 2.20ϕ (very coarse to fine grained), with an average size of 1.10ϕ that indicates a medium grained sandstone (Wentworth, 1922). The average value shows the dominance of medium sand-size sediments. More so, 6% of the rocks in the study area are very coarse grained, 33 % are coarse grained, and 50% medium grained. This suggests deposition under moderate to high energy (Friedman and sanders, 1978, Eisema 1981). The variability of grain size makes it poorly sorted admixture.

3.1.2 The Inclusive Graphic Standard Deviation (σ_1)

Graphic standard deviation measures the sorting or uniformity of particle size distribution.The inclusive graphic standard deviation computed for the sandstone range from 0.99 to 1.78ϕ suggesting moderately to poorly sorted. However, most of the values range from 1.0 to 2.0ϕ, which indicate poor sorting. The poor sorting is indicative of the fluctuation of the depositing currents (Amaral and Pryor, 1977, Tucker 1988). The poor sorting of the particles may also indicate sediments deposited in fluvio-continental setting (Friedman, 1967).

Table 1. Result of the statistical parameters obtained for the sandstone in the study area

SAMPLES	GRAPHIC MEAN (ϕ)	STANDARD DEVIATION(ϕ)	SKEWNESS	KURTOSIS	SIMPLE SKEWNESS	SIMPLE SORTING	INTERPRETATION
S_{47}	0.79	1.50	0.39	1.44	2.21	2.93	Coarse grained, poorly sorted, strongly fine skewed, leptokurtic sandstone.
S_{53}	2.00	1.63	-0.15	0.65	0.2	3.2	Fine grained, poorly sorted, coarse skewed, very platykurtic sandstone
S_{50}	1.34	1.28	-0.16	1.15	0.68	2.51	Medium grained, poorly sorted, coarse skewed, leptokurtic sandstone,
S_{23}	1.94	1.50	0.32	1.76	2.83	3.30	Medium grained, poorly sorted, strongly fine skewed, very leptokurtic sandstone.
S_{29}	0.82	1.14	0.08	1.14	0.82	2.04	Coarse grained, poorly sorted, near symmetrical, leptokurtic sandstone
S_3	2.20	1.58	0.03	3.42	0.80	3.4	Fine grained poorly sorted, near symmetrical, extremely leptokurtic sandstone.
S_{49}	1.38	1.78	0.36	1.84	2.95	3.41	Medium grained, poorly sorted, strongly fine skewed, very leptokurtic sandstone.
S_{12}	0.61	1.45	0.45	1.83	2.96	2.90	Coarse grained, poorly sorted, strongly fine skewed, very leptokurtic sandstone.
S_{30}	1.58	1.25	0.55	1.72	2.48	2.30	Medium grained, poorly sorted, fine skewed, very leptokurtic sandstone.
S_7	1.57	1.13	- 0. 11	1. 95	0.1	2.25	Medium grained, poorly sorted, Coarse skewed , very leptokurtic sandstone.
S_{17}	0.25	1.68	0.12	1.23	1.4	2.85	Coarse grained, poorly sorted, fine skewed leptokurtic sandstone.
S_{45}	1.08	0.99	-0 .11	1.46	0.02	1.78	Medium grained, moderately Sorted, coarse skewed, leptokurtic sandstone.
S_{25}	1.30	1.45	0.01	1.82	1.25	2.92	Medium grained, poorly sorted, near symmetrical, very leptokurtic sandstone.
S_{28}	0.15	1.13	- 0.05	1.43	-0.04	2.10	Coarse grained, poorly sorted, near symmetrical, leptokurtic sandstone.
S_{33}	1.52	1.25	-0.16	1.50	0.26	2.2	Medium grained, poorly sorted, coarse skewed, leptokurtic sandstone.
S_7	0.18	1.07	-0.02	1.27	0.05	1.75	Coarse grained, poorly sorted,near symmetrical,l eptokurtic sandstone
S_6	1.19	0.86	0.05	1.05	0.29	1.55	Medium grained, poorly sorted, near symmetrica, mesokurtic sandstonel
S_5	-0.15	1.37	0.73	0.43	1.99	2.08	Very coarse, poorly sorted, strongly fine skewed ,very platykurtic, sandstone
Average	1.10	1.34	0.13	1.51	1.30	2.53	Medium grained, poorly sorted, fine skewed, very leptokurtic sandstone

3.1.3 Inclusive Graphic Skewness (Sk_1)

The graphic skewness is the measure of symmetrical distribution, i.e. predominance of coarse or fine sediments. The inclusive graphic skewness of the sandstone varies from -0.11 to 0.55 (coarse skewed to strongly fine skewed) with an average of 0.13 that indicates that the sandstones are fine skewed and it suggests that the velocity of the depositing current was lower than the average responsible for the deposition of the medium to coarse grained fraction present in the sediments (Sahu, 1964)**.** It also suggests a unidirectional current and selective deposition for the sandstones (Martins, 1965; Valia and Cameroon, 1977; McLaren, 1981).

3.1.4 Inclusive Graphic Kurtosis (K_G)

The graphic kurtosis relates the peakedness of the distribution and measures the ratio between the sorting in the tails as well as in the central portion of the curve. If the central portion shows better sorting than the tails, then curve is termed leptokurtic .It is platykurtic if the tails are better sorted and if both are equally sorted, then it is mesokurtic. The values obtained for kurtosis indicates that the sediments are mainly leptokurtic, however they range in values from 0.43 to 3.42 indicating a very platykurtic to extremely leptokurtic sandstone. The preponderance of leptokurtic and positively skewed curves is consonant with Friedman's (1962) observation that most sands are leptokurtic and positively or negatively skewed.

3.2 Mineralogical Composition and Grain Morphology

The result of the thin-section analysis carried out in the study area is presented in Table 2. The modal composition of quartz, feldspar and rock fragment is presented in Table 3 and this was used for the construction of Ternary diagrams (Figure 3 and 4). Thin-section studies revealed that the average modal mineralogical composition of the sandstone comprise of approximately 66.6% quartz, 21% feldspar and 12.4% rock fragments.

K-feldspar occurs as the dominant feldspar present in the rocks. Generally, the preservation of feldspar requires rapid uplift, erosion, and rapid sedimentation. Climate also plays a role. When feldspar is subjected to hot humid conditions, it weathers to clay minerals, but very rapid erosion and short transport history which characterize a high relief source area favour the preservation of feldspar (Tucker, 1988). According to Haruna et al (2013), the basis for the possible paleoclimatic interpretation of the source area for the sediments is the detrital clay mineral composition (Predominantly Kalsinite) of the Bima sandstone and the plaeoclimatic setting is the humid tropics.This abundance of kalsinite is typical of acid tropical areas where leaching or alteration is intensive. Hence the presence of both fresh and weathered angular to subangular shaped feldspar in the sediments is indicative of their derivation and deposition in a hot and humid climate in which feldspar preservation was guaranteed as a result of rapid erosion in relation to weathering as well as short transport path for the ancient sediments. Cement constitutes a significant portion in some of the samples ranging from 2 to 10% with an average of 5.5% in the total samples studied. Three different types of cement were recognized and these include iron oxide, silica and clay minerals, with the latter rarely observed in the samples studied. The iron oxide occurs as clots between grains especially in areas where they are not in contact with each other, while silica cement occurs as microcrystalline aggregates in pores as overgrowth on silica grains.

Table 2. Mineralogical composition of sandstone in the study area

Sample	Quartz (%)	Feldspar (%)	Cement (%)	Matrix (%)	Mica (%)	Rock fragment (%)	Heavy Minerals (%)
S_{38}	61	17	4	1	1	11	5
S_{21}	60	22	2	3	3	10	3
S_7	60	15	5	3	2	10	5
S_{28}	60	18	3	1	4	7	2
S_{29}	60	20	5	2	3	7	3
S_{12}	60	16	4	2	4	12	2
S_{40}	47	22	8	4	4	15	-
S_{50}	60	17	5	1	1	16	-
S_{17}	50	17	10	4	4	13	2
S_{30}	55	17	9	3	6	6	4

Table 3. Modal composition of sandstone in the study area

Sample	Quartz (%)	Feldspar (%)	Rock fragment (%)
S_{38}	69	19	12
S_{21}	65	24	11
S_7	70	18	12
S_{28}	71	21	8
S_{29}	69	23	8
S_{12}	68	18	14
S_{40}	56	26	18
S_{50}	65	18	17
S_{17}	63	21	16
S_{30}	70	22	8
Mean	66.6	21	12.4

Comparing the Ternary diagrams (Figure 3 and 4) with similar works of Mcbride (1963) and Pettijohn et al (1987), the sandstones in the study area are classed as lithic subarkoses, subarkoses and lithic arkoses.

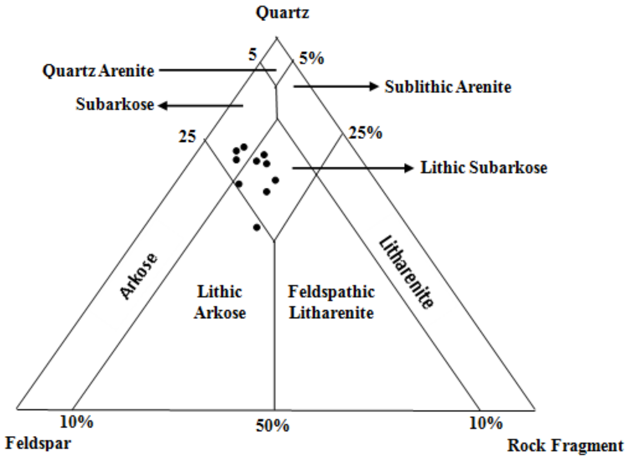

Figure 3. Ternary diagram showing the modal composition of the sandstone facies in the study area (After Mcbride, 1963)

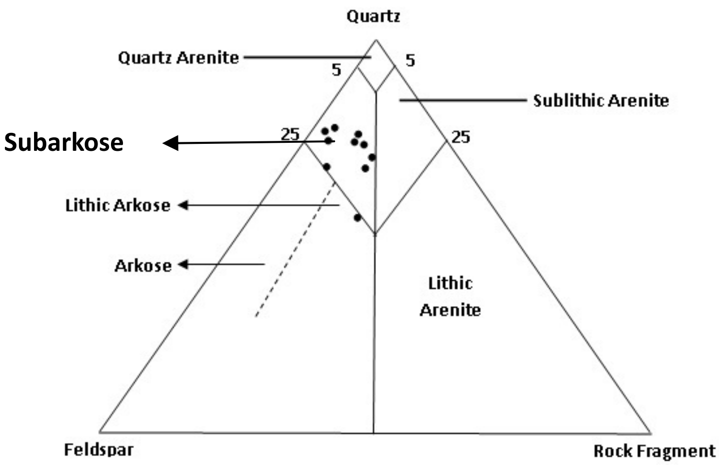

Figure 4. Ternary diagram showing the modal composition of the sandstone facies in the study area (After Pettijohn et al, 1987)

Table 4 shows the summarized petrographic description of the sandstone in the study area. The morphology of framework grains of sandstones often varies with grain size and mineralogy. These parameters are in turn dependent on the type of source rock as well as the degree of weathering and abrasion (Tucker, 1988).

Table 4. Petrographic description of sandstone in the study area

Sample	Grain size	Grain shape	Sorting
S_{38}	Fine	Sub rounded to rounded	Well sorted
S_{21}	Medium	Subangular rounded	Poorly sorted
S_{7}	Coarse	Angular	Poorly sorted
S_{28}	Medium	Subangular-rounded	Moderately sorted
S_{29}	Medium	Angular	Poorly sorted
S_{12}	Coarse	Angular- Subangular	Moderately sorted
S_{40}	Coarse	Angular- Subangular	Poorly sorted
S_{50}	Medium	Sub –angular	Moderately sorted
S_{17}	Medium	Angular- subangular	Moderately sorted
S_{30}	Coarse	Angular- Subangular	Poorly sorted

Majority of the framework grains varies from angular to sub-angular and occasionally sub-angular to rounded in shape. There are very scanty well rounded coarse grains .Quartz was observed to exhibit better roundness than feldspars, rock fragments and mica. Feldspars and lithic fragments occur in lesser quantities as framework grain. The matrix is mainly composed of tiny angular (sometimes irregularly shaped) micas, feldspar and quartz which fill part of the intergranular voids and acts as subordinate binder to the framework grain. From the grain morphology, it may be inferred that the sandstones were not transported for a long distance before their deposition (Pettijohn, 1975).

3.3 Depositional Environment

Several researchers have employed different methods and criteria to distinguish depositional environment from grain size distributions; Folk and Ward, (1957), Friedman (1961, 1967), Moiola and Weiser, (1968), Sahu, (1964) and others.

Comparing the bivariate plots of Simple Skewness against Simple Sorting (Figure 5), Graphic means versus Standard deviations (Figure 6) and Skewness versus standard deviation (Figure 7) with similar works of Friedman (1967), all the samples plotted are indicative of fluvial origin. The dominance of medium to coarse grained particles for the sandstones in the study area probably points to a moderate to high energy depositional environment that may be likened to those of a fluvial setting.

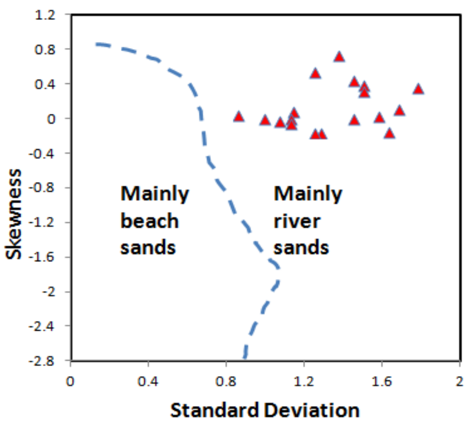

Figure 5. Bivariate Plot of Skewness versus Standard deviation

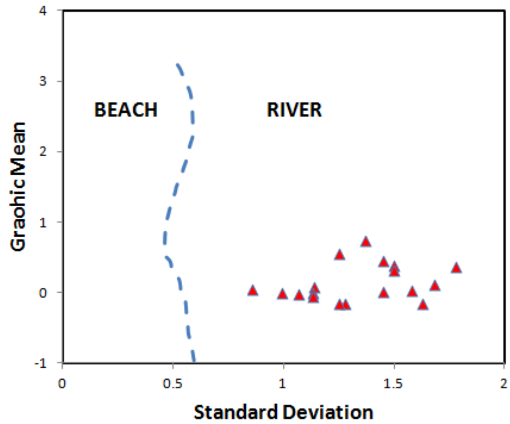

Figure 6. Bivariate Plot of Graphic Mean versus Standard deviation

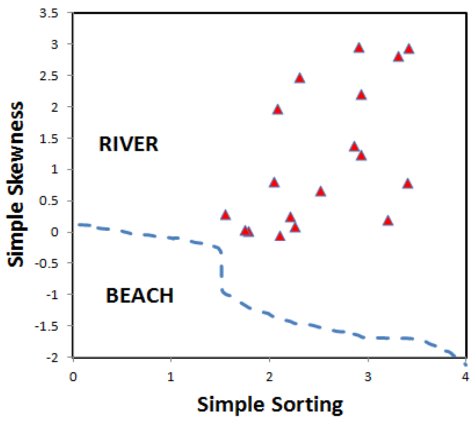

Figure 7. Bivariate Plot of Simple Skewness versus Simple sorting

4. Conclusion

Textural and compositional studies of sediments from parts of the Bima Sandstone have led to some notable conclusions. The sandstones are composed of fine to coarse grains which are mainly angular to sub-angular and occasionally sub-angular to rounded in shape and moderately sorted to poorly sorted. This variability in grain size which makes it a poorly sorted admixture is indicative of the fluctuation of the depositing currents. The modal mineralogical composition consists averagely of 66.6% quartz, 21% feldspars and 12.4% rock fragments. These sandstones are classed as lithic subarkoses, subarkoses, and lithic arkoses deposited in a fluvial setting where current energy was mainly moderate to high.The appreciable amount of feldspar, the dominance of subangular to angular grain shape and the poorly sorted nature of the sandstones suggest that they are texturally and mineralogically immature sediments.

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