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Provenance and Paleoenvironmental Study of Bima Sandstone in the Upper Benue trough, N.E., Nigeria

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Abstract

Provenance and paleoenvironmental study of Bima sandstone of Upper Benue Trough was attempted using representative samples from two widely separated areas, and taking azimuth directions of cross beds, ripple marks and elongation of pebbles in the areas. Analyses of the results show that the sandstones are mostly quartz-arenites and arkose of plutonic igneous and metamorphic origin. Rose diagrams of paleocurrent directions show predominance of 210^o - 240^o trend in the eastern margin of Gongola Arm, and a predominance of the 300^o - 330^o direction in the southern margin of Yola Arm of the Upper Benue Trough. Interpretation of the results revealed the crystalline basement of Adamawa, Cameroon, Mandara and Hawal Massifs, which border the trough as the source areas. Bima sandstone was formed during tectonic quiescence and in a humid tropical climate in the Mid-Cretaceous times. The deposition of the Bima sandstone was construed to have marine shoaling influence in a fluvio-deltaic environment.

Keywords: Bima sandstone, paleoenvironment, upper benue trough, petrography.

Introduction

Bima sandstone is the name given to the continental intercalaire in the Chad Basin and Upper Benue Trough of Nigeria[1]. It is the oldest sedimentary deposit in these regions. The composition of Bima sandstone, mainly arkose to quartz arenite and its depositional structures have generated wide speculations as to the source and environment of deposition[2-5].

Current-deposited sandstone bodies retain evidences of source direction or direction of flow of the depositing medium. The Bima sandstone has good exposures in the Upper Benue Trough, which aided the measurement of paleocurrent from cross-stratifications, ripple marks, and pebble lineation.

The study area comprises of Guyuk and Yola areas of the Upper Benue Trough (figure 1)[6]. The Guyuk area represents the Gongola arm while Yola area represents the Yola arm of the Upper Benue Trough. These two areas are widely separated and have good exposures of the Bima sandstone. The choice of the two areas (Yola and Guyuk), was informed by excellent exposures of Bima sandstone in these areas and the zeal to provide a regional outlook for the study.

Geological Background: The origin and evolution of the Benue Trough have been various described by many workers[7-17]. The depositional history of the area of study is marked by the deposition of Bima sandstone on the Precambrian Basement during the Aptian/Albian[18]. The Bima sandstone has been differentiated into three units: $Bima_1$ (B_1), $Bima_2$ (B_2), and $Bima_3$ (B_3) from the oldest to the youngest respectively. The B_1, which falls outside the study area, is alluvial fan deposits and fan deltaic deposits. It is exposed in Burashika area and in Lamurde Anticline. The B_2, which is fluviatile, is exposed in the centre of Bagale Hills in the Yola area, Tula area of the Gongola arm, and in the Lamurde Anticline of Lau Basin. It also occurs in Gwamba anticline, and Gagare anticline of Yola Arm. The B_3 is more widely exposed in all areas of the Upper Benue Trough than B_1 and B_2[19,20].

The deposition of Bima sandstone was followed by the transitional Yolde Formation which inturn was succeeded by marine sequences of Dukul, Jessu, Sukuliye, Numanha and Lamja Formations, with the Lunguda Basalt capping the sequence in the area. The Yolde to Lamja Formations were together regarded as marine sequences in this study.

This study was carried out on the $Bima_3$ (B_3). Therefore, any mention of Bima sandstone in this paper hitherto, refers to the $Bima_3$ formation only.

Material and Methods

Method of Study: Two areas (Yola and Guyuk) were selected for this study due to better exposure of the Bima sandstone. Each area was subdivided into a number of localities in which detail field observations, measurements and samples collection were made. From the numbers of samples collected, paleocurrent data were defined from azimuth of cross-beds, ripple-marks, and lineation of pebbles. In folded or tilted terrains the directional data have been corrected for the distortion caused by folding or tilting. The strata that are tilted more than 15^o were corrected before analysis using standard methods[21].

Results and Discussion

Structural Characteristics: Visual observation of Bima sandstone in the study area reveals a large range of syn-depositional sedimentary structures. These structures include cross stratifications, current ripple marks and alignment of long grains.

Cross Stratification: Cross stratifications (figure-2) were observed in all the localities of the study area. In the northern part, all localities consist wholly of tabular cross stratifications except locality 4, which consists of two types of cross stratifications (predominant tabular and few troughs cross stratification). The tabular cross stratifications consist of cross beds, generally planar with angular basal contacts. They are roughly parallel to the current direction.

Azimuth dip directions and other measurements of cross stratification in the four localities north of the study area were obtained. Out of 472 readings obtained from this area, 134 were taken from locality 1; 131 from locality 2; 119 from locality 3, and 88 readings from locality 4. From the readings, the number and percentage frequency for each 30^o class of Azimuth was calculated (table-1).

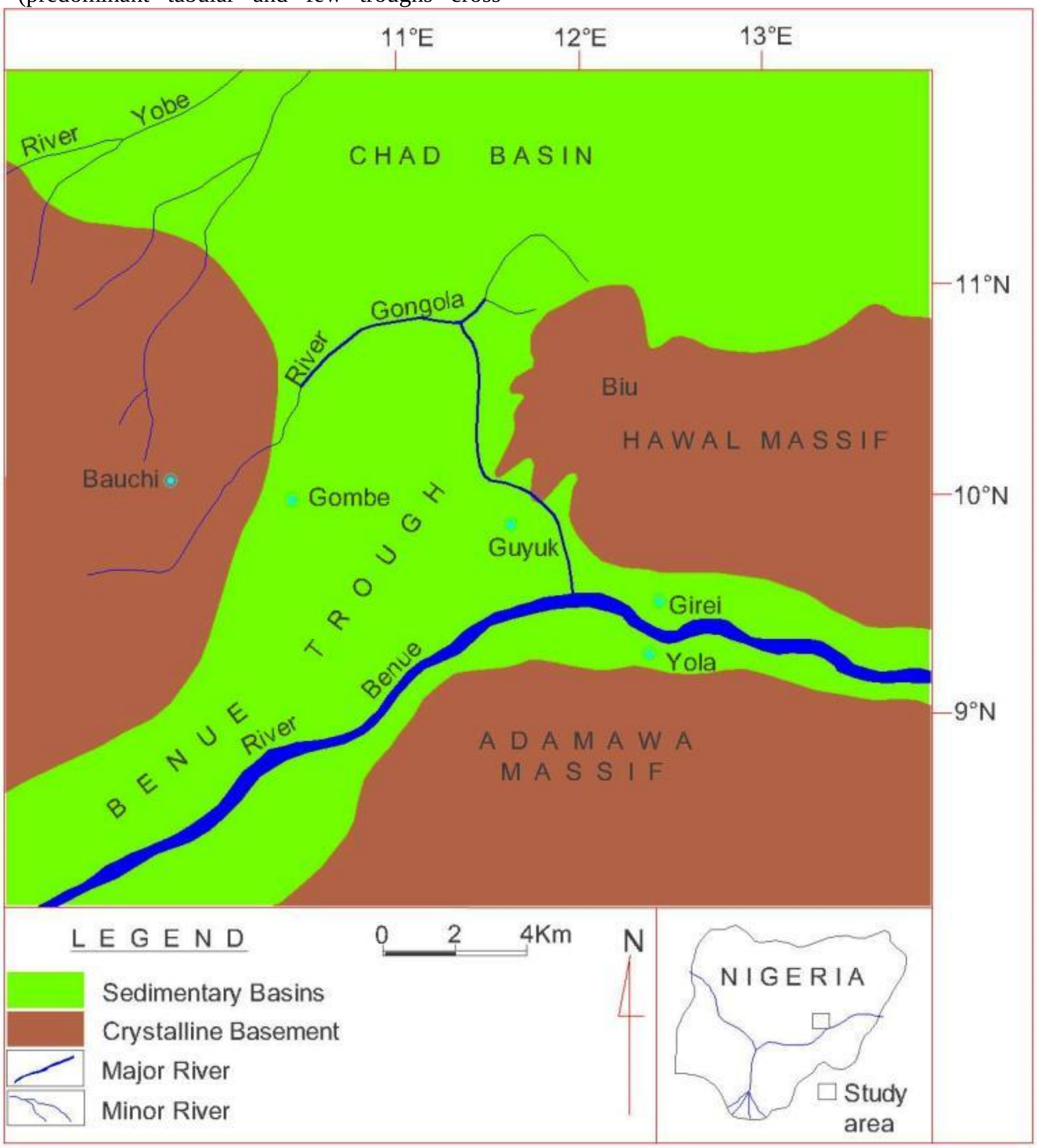


Figure-1
The Benue Trough and the bordering crystalline basement during Cretaceous[6]

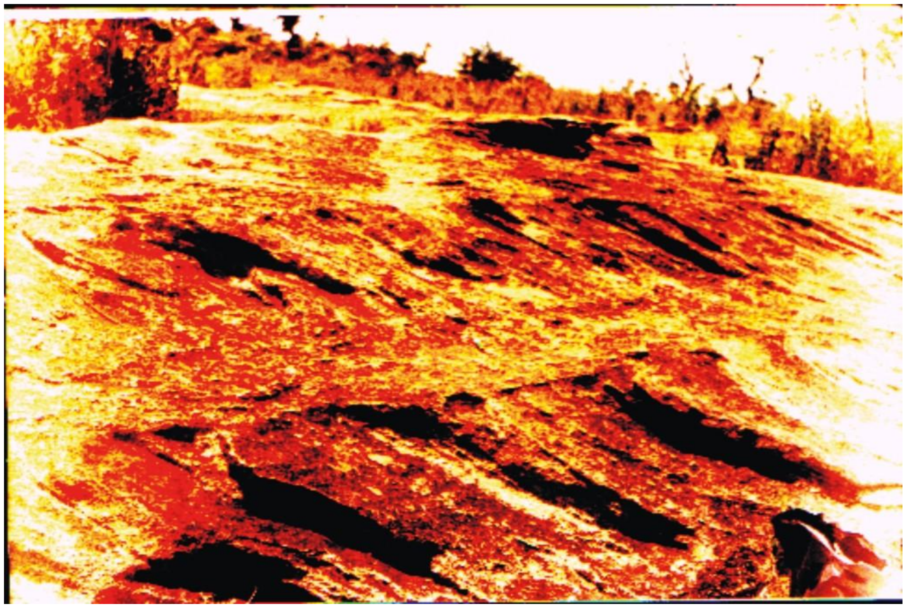


Figure-2
Cross beds in the northern part of the study area

Table-1
Class of azimuths, frequency (Freq.) and percentage frequency calculated from cross –bed data from various localities (Loc.) north and south of the study area[22,23]

Northern	**Part**									
Class of Azimuth	Locality	1	Locality	2	Locality	3	Locality	4	Total	Area
(in degree)	Freq.	Freq. (%)	Freq.	Freq. (%)	Freq.	Freq. (%)	Freq.	Freq. (%)	Freq.	Freq. (%)
0–30	-	-	-	-	-	-	-	-	-	-
30–60	-	-	-	-	-	-	-	-	-	-
60–90	-	-	-	-	-	-	-	-	-	-
90–20	-	-	-	-	-	-	-	-	-	-
120–150	-	-	-	-	-	-	-	-	-	-
150–180	5	3.7	1	0.8	2	1.7	1	1.1	4	0.9
180–210	30	22.3	26	20.2	28	23.5	19	21.6	103	21.9
210–240	53	39.6	49	37.9	50	42.0	38	40.9	190	40.4
240–270	39	29.1	40	31.0	30	25.2	23	26.1	132	28.1
270–300	4	2.9	6	4.7	3	2.5	2	2.3	15	3.2
300–330	3	2.2	4	3.0	1	0.8	1	1.1	1	1.9
330–360	-	-	-	-	1	0.8	-	-	1	0.2
Total	134		129		119		88		470	
Southern	**Part**									
Class of Azimuth	Mautech	Loc.	Viniklang	Loc.	Girei	Loc.	Total	Area	nil	nil
(in degree)	Freq.	Freq. (%)	Freq.	Freq. (%)	Freq.	Freq. (%)	Freq.	Freq. (%)	nil	nil
0–30	2	1	-	-	-	-	2	0.6	nil	nil
30–60	-	-	6	9.0	-	-	6	2.0	nil	nil
60–90	-	-	-	-	-	-	-	-	nil	nil
90–20	-	-	5	8.0	1	1.0	6	2.0	nil	nil
120–150	-	-	-	-	-	-	-	-	nil	nil
150–180	-	-	1	1.5	2	3.0	3	1.0	nil	nil
180–210	8	4.5	-	-	3	5.0	11	3.5	nil	nil
210–240	11	6.0	3	5.0	3	5.0	17	5.0	nil	nil
240–270	16	9.0	5	8.0	6	9.0	27	9.0	nil	nil
270–300	42	23.5	10	15.0	21	32.0	73	24.0	nil	nil
300–330	57	32	23	35.0	26	40.0	106	34.0	nil	nil
330–360	43	24	12	18.5	3	5.0	58	19.0	nil	nil
Total	179		65		65		309		nil	nil

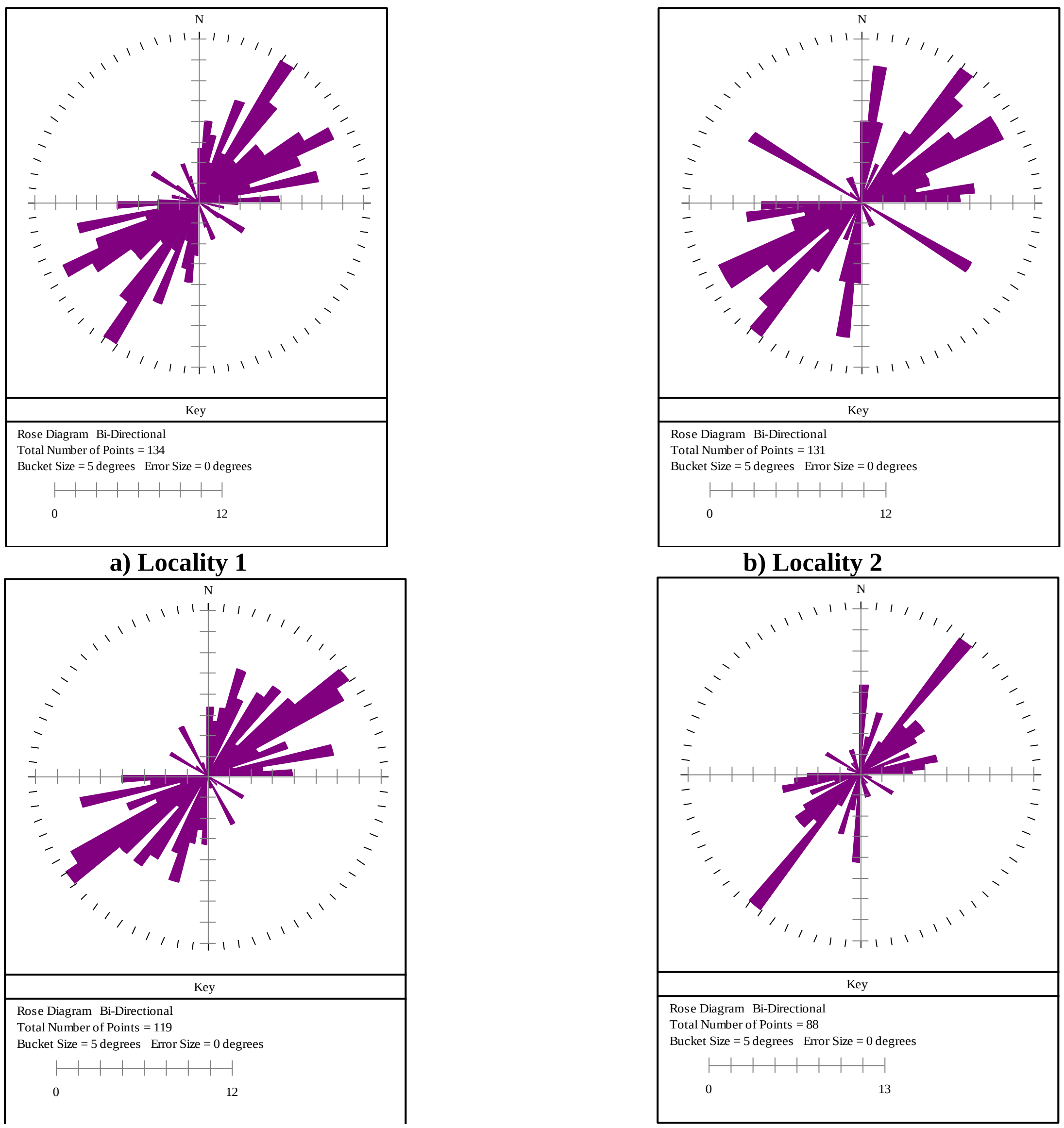
Loc. = locality; Freq. = frequency.

Result of the calculation show the mode in 210^o - 240^o classes i.e. southwest (figure 3). The average dips of cross beds were as follows: Locality 1: 10.48^o, Locality 2: 10.05^o, Locality 3: 11.48^o and locality 4: 11.66^o. The average dip for the entire northern part of the study area is 10.83^o and the average bed thickness for the area is 0.58m.

Measurements of wavelengths and amplitudes of current ripple marks in locality 1 show the average wavelength, amplitude and ripple indices of 11.69cm, 1.41cm and 8.35cm respectively.

In the southern part of the study area, cross stratification is ubiquitous. The cross beds, like in the northern part, are largely tabular. Cross strata sets range from a few decimetres to a metre or more in thickness.

A total of 309 readings of cross strata azimuthal dip directions were taken from seven areas grouped into three broad localities: Locality 5 (MAUTECH); locality 6 (Girei) and Locality 7 (Viniklang). 179 readings were taken from locality 5, while 65 each were taken from localities 6 and 7 respectively. From these, the number and percentage frequency for each 30^o class of azimuths was calculated (table 1). The mode from all the three localities is in the 300 - 350^o class i.e. northwest (figure 4). The average dip of cross beds in localities 5, 6 and 7 are respectively 12.5^o, 12.0^o and 21.0^o. The average cross bed dip for the entire area is 15^o. Bed thickness for the area is 1m on the average.



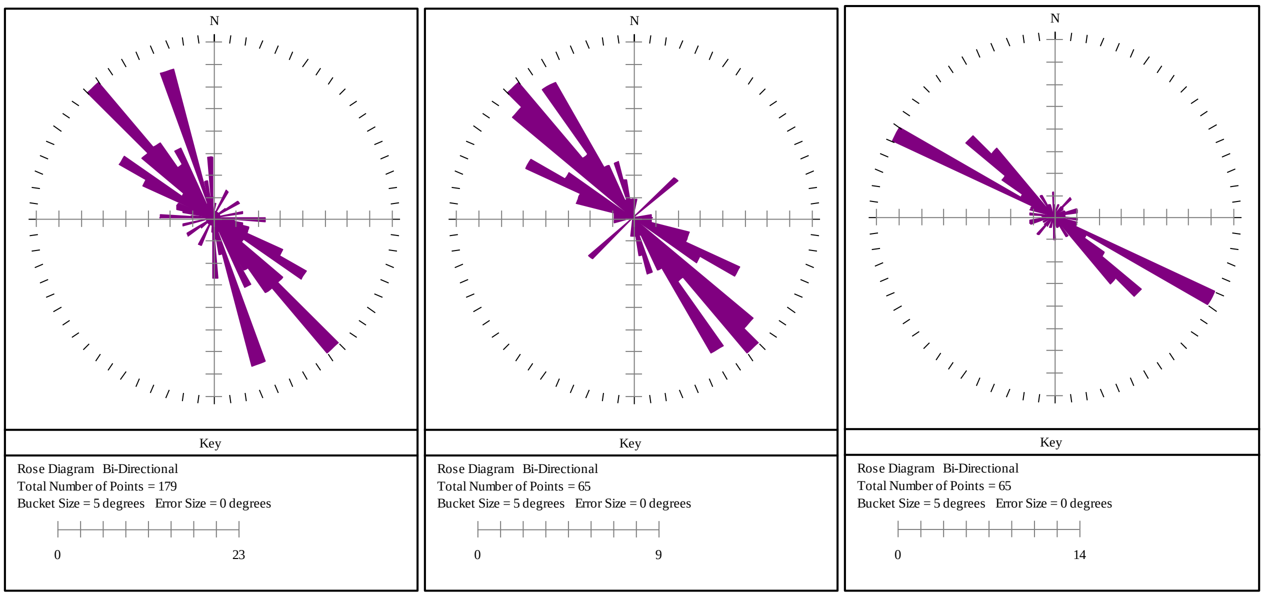
a) Locality 1 **b) Locality 2**

c) Locality 3 **d) Locality 4**

Figure-3

Prominent paleocurrent directions in the northern part of the study area,
a) Locality 1, b) Locality 2, c) Locality 3, and d) Locality 4

Current Ripple Marks: In the northern part of the study area, current ripple marks were observed only in locality 1. The asymmetrical current ripple marks, (figure 5) in this locality show continuous crest lines which reflect the co-existence of current and waves. The directions, wavelengths and amplitudes of the ripple marks were measured and their indices calculated. The class of azimuths, number of frequency and percentage frequency was calculated from their azimuths. The results were summarized (table 2) and graphically presented as rose diagrams (figure 6a).



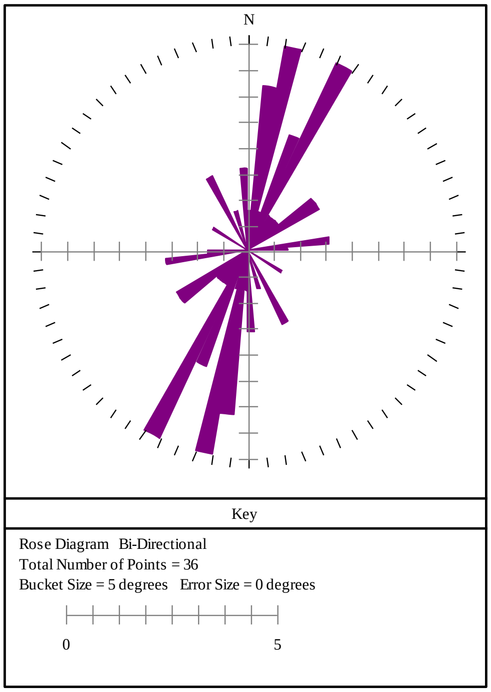
a) MAUTECH **b) Viniklang** **c) Girei**

Figure-4

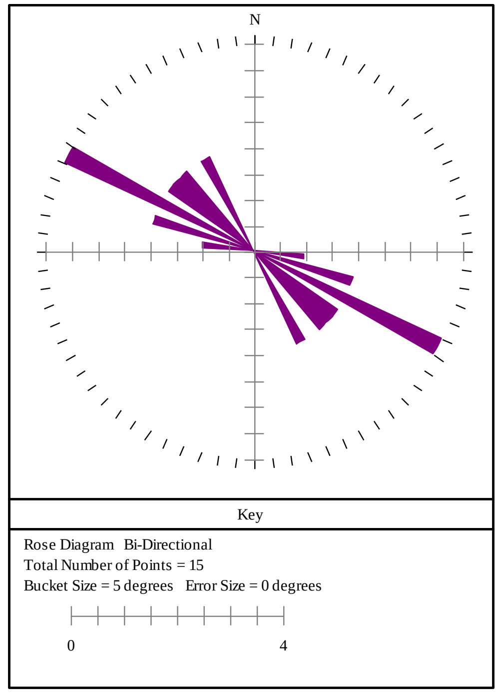
Prominent paleocurrent directions for cross beds in the southern part of the study area. a) MUATECH; b) Viniklang; and c) Girei

Figure-5

Current ripple marks in the northern part of the study area



a) Current ripples in the northern part



b) Current ripples in the southern part

Figure-6
Prominent paleocurrent directions for current ripple marks in: a) northern part and b) southern part of the study area

Table-2
Summary of current ripple data north and south of the study area

Northern Part		
Class of azimuth (°)	**Frequency**	**Frequency (%)**
120 – 150	1	2.8
150 – 180	4	11.1
180 – 210	21	58.3
210 – 240	8	22.2
240 – 270	2	5.6
Total	36	
Southern Part		
Class of azimuth	**Frequency**	**Percentage (%)**
270 – 300	7	46.7
300 – 330	7	46.7
330 – 360	1	6.6
Total	15	100

This summary of current ripple shows that the ripple direction is unimodal in 180^o - 210^o. The wavelength, amplitude and ripple indces are respectively 11.7cm, 1.4cm and 8.4cm.

In the southern part of the study area, 15 readings of current ripples were taken at separate localities where they occur, summarized (table 2) and graphically presented as rose diagrams (figure 6b).

This summary shows that current ripple direction is bimodal in 270^o - 300^o and 300^o - 330^o class directions. The average wavelength, amplitude and ripple indices are respectively 11^{o}cm, 1.8cm and 7.7cm.

Alignment of long grains: In the northern part of the study area, a large number of elongated grains were found embedded in some outcrops in locality 2. Their directions of lineation were measured in many outcrops and their averages recorded. From these readings, the classes of azimuths, the frequency and percentage frequency were calculated and the summary of the result presented in table-3.

Table-3
Summary of long grains data north and south of the study area

Northern Part		
Class of azimuth (^{o})	**Frequency**	**Frequency (%)**
150 – 180	2	6.25
180 – 210	4	12.05
210 – 240	20	62.05
240 – 270	3	9.38
270 – 300	3	9.38
Total	32	100
Southern Part		
Class of azimuth	**Frequency**	**Percentage (%)**
240 – 270	7	27
270 – 300	13	50
300 – 330	6	23
Total	26	100

In the southern part of the study area, average alignments of pebbles were measured on several beds in the field. The class and frequency of azimuths calculated from the data are as shown on table 3. From the table the mode is in the 270 - 300^O

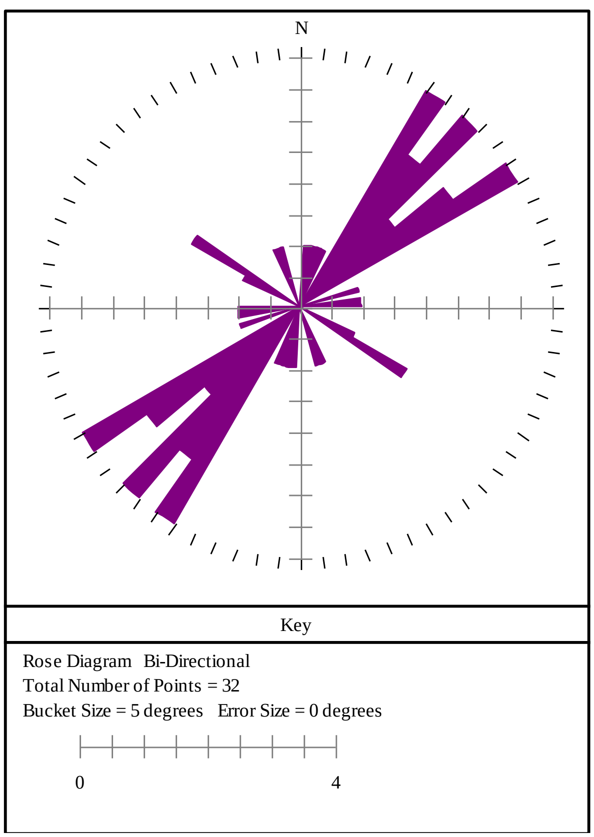
class. Rose diagrams was also plotted from the data of both the northern and southern parts of the study area (figure-7).

Many different features of sedimentary rocks can be used as paleocurrent indicators. Some structures record the direction of movement (Azimuth) of the current while others only record the line of movement (trend). They can be used to deduce the processes and conditions of deposition, the direction of the current which deposited the sediments and in areas of folded rocks, the way up of the strata. Certain paleocurrent patterns are restricted to a particular depositional environment.

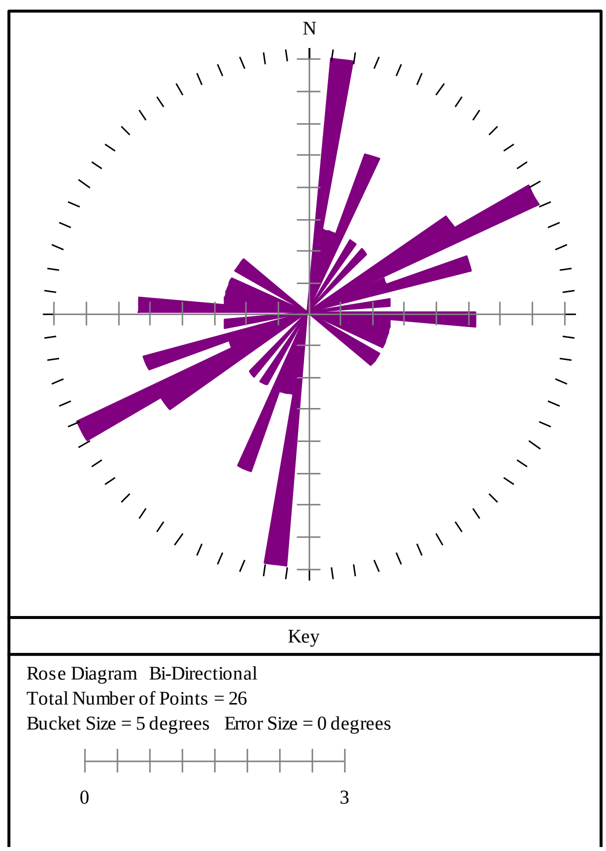
Paleocurrent Direction: Measurements of azimuths of cross strata dips, current ripple marks and alignment of long grains pebbles were grouped in classes of 30^o intervals and plotted on rose diagrams for paleocurrent interpretation. In the northern part of the study area, the azimuths of cross bed (figure 3) show that the paleocurrent direction is predominantly in the 210 - 240^o class, That is in the southwest direction. In figure 6, the azimuth of current ripple marks is mostly in the 180 - 210^o class, indicating a SSW - SW paleocurrent direction. In figure 7, the alignment of long grains falls mostly in the class 210 - 140^o, supporting a southwest direction.

From these figures (figures 3, 6 and 7), it is clear that the prominent paleocurrent direction is in the 210^o - 240^o class i.e. southwest. The modal direction is in the 180^o - 210^o and 210^o - 240^o classes (SSW and SW). Therefore it could be concluded that the direction of depositing current in this part of the study area varied within narrow limit in the southwest direction.

For the current rose diagrams (figure-4) plotted for the different sets of data in the southern part of the study area, the azimuths of cross bed dips show that the direction of transport is mostly in the 300 - 330^o class, i.e. NW direction. The current ripple data is bimodal in the 270 - 300^o and 300 - 330^o classes. The alignment of long-grain pebbles indicates a direction 270 - 300^o (WNW). This places the prominent direction of transport is the 300 - 330^o class in the NW direction. Since the modal directions in the 270 - 300^o and 330 - 360^o (WNW and NNW directions respectively) are also high, it could be concluded that the direction of transport is extensive in the entire Northwest quadrant, of course, with the 300 - 330^o directions as the most prominent. Figures 8 and 9 respectively show the dominant paleocurrent directions in the northern and southern part of the study.



a) Long grains in the northern part



b) Long grains in the southern part

Figure-7
Prominent paleocurrent directions for elongated grains in: a) northern part and b) southern part of the study area

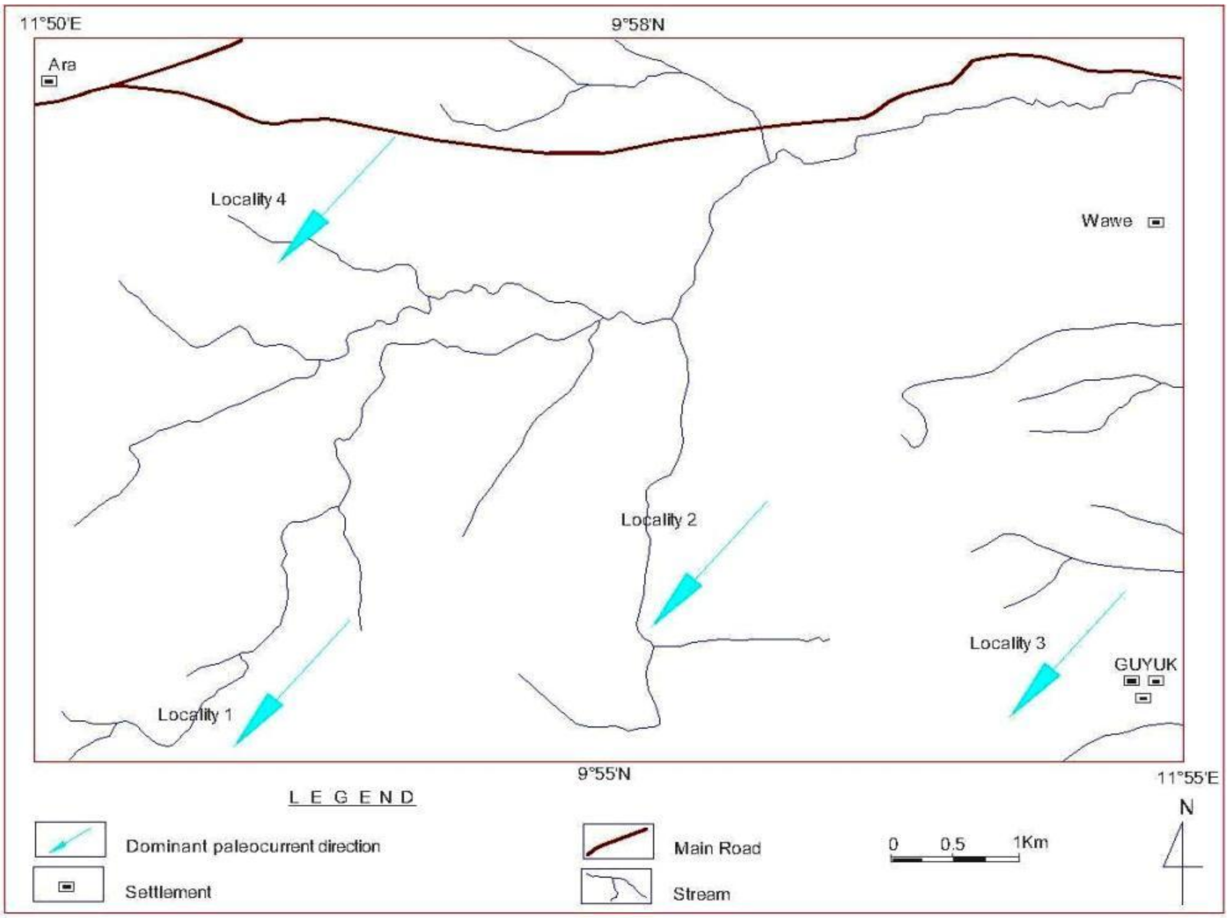


Figure-8
Dominant paleocurrent direction in the northern part of the study area

Agent of Transport: Results of field observations and measurements show the same transport agent for the entire study area. Water is the agent of transport of Bima sandstone in the study area. Evidences such as type of crossbed, average dip, bed thickness (averaging 3m), and current formed ripples all indicate deposition in a relatively shallow depth water by river or shallow marine currents[21].

Environment of Deposition: Syn-depositional sedimentary structures record environmental conditions in which they were formed and preserved. The sedimentary structures observed in both parts (north and south) of the study area indicate deposition in the same type of environments.

Abundant tabular and few cross beddings, flat beddings and parting lineations observed in most localities of the study area are reflective of fluviatile conditions. Ripples and cross laminations found in finer grained sandstones and the presence of lenticular stream-deposited sediments with crude cross beddings are all indicative of fluviatile conditions. The red sandstone consisting of rounded to well rounded grains, with moderate sorting support this contention. Depositional conditions are indicated by graded cross stratification. Graded cross beds observed in locality 3 indicate deposition in slowly moving body of water. Shrinkage cracks observed in some areas of locality 2 buttress the assertion that Bima sandstone is a continental deposit, deposited in shallow water. The general absence of fauna fossils in the study area also supports this assertion.

The Bima sandstone in the study area were laid down in river channels while the fine grain ripple-marked and cracked siltstone beds were deposited in flood plains associated with the river channels. It is therefore most probable that fluviatile conditions were the dominant mode of deposit for the sandstone in the area.

Depth of Water: There exists a relationship between ripple amplitude and depth of water[24]. According to Kindle's observation, normal symmetrical ripple marks of the order of 0.2 -0.4 inches (0.5 - 1.0cm) in amplitude must have been formed in water less than 1 foot (0.3m) deep. In the same vein, large scale rippling with amplitude of 2.5 - 3.0 inches (6.25 to 7.5cm) may be found in water having a depth of as much as 10 feet (3m). By applying Kindle's observations to the study area where the measured ripple amplitude range from 1 - 2cm, the depth of water in this area may range from 60cm to 2m or more.

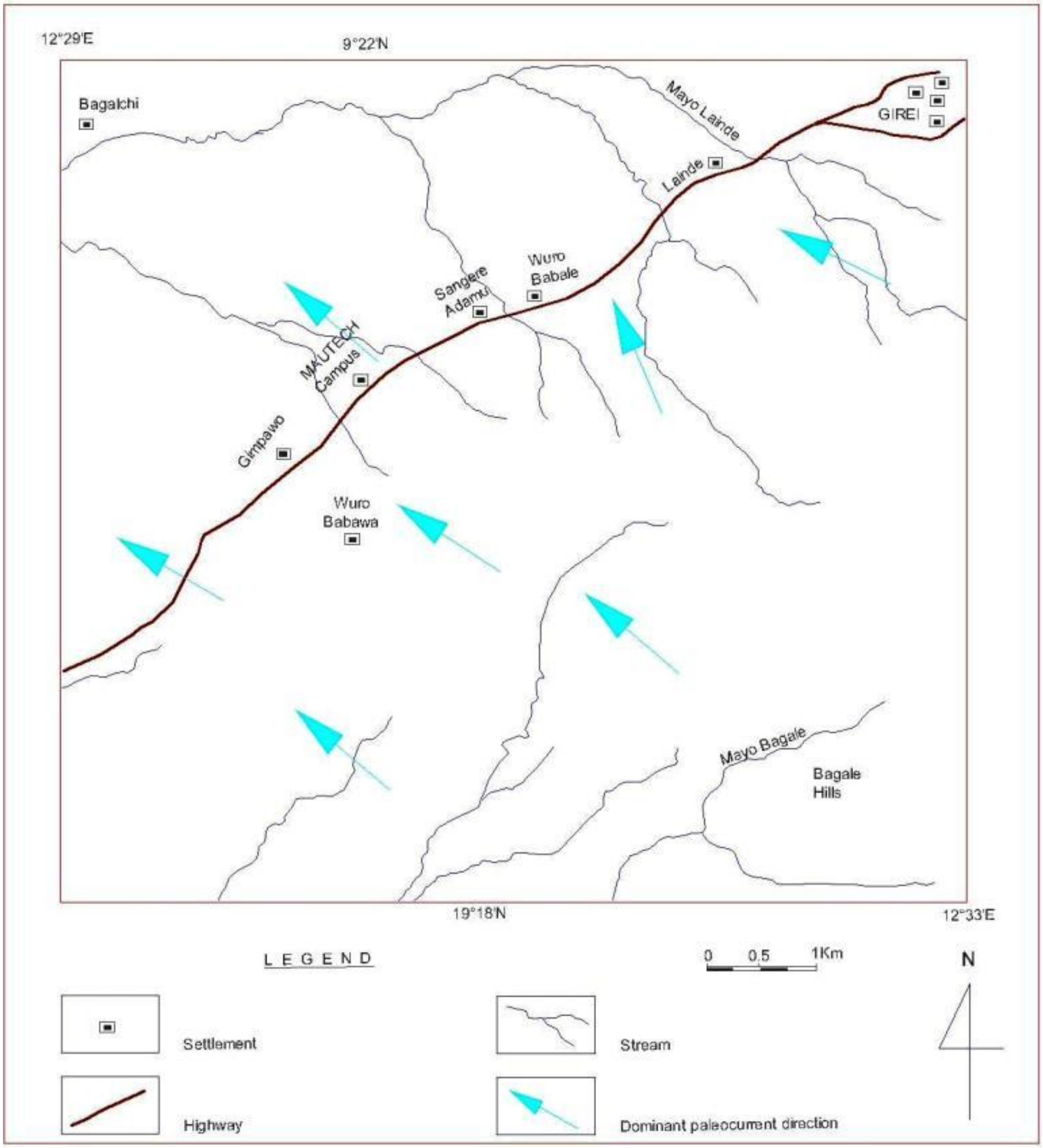


Figure-9
Dominant paleocurrent direction in the southern part of the study area.

This result is consistent with the environment of deposition (i.e. fluviatile or fluviodeltaic conditions) suggested in this work.

Paleogeography: The paleogeography of the Upper Benue Trough during the Mid-Cretaceous times can be inferred from this study. The general trend of the paleocurrent direction being southwesterly along the axis of the Benue Trough is indicative of the direction of deeper areas of the basin (figure 7). The deeper part of the Benue Trough as at the time of the formation of the Bima sandstone lies to the southwest of the study area (i.e. toward the Gulf of Guinea). Any epicontinental sea must have therefore, come from the Gulf of Guinea.

The width of the Benue Trough in the Mid-Cretaceous must have been more than twice the present state (more than 100km across) considering the amount of folding of strata in the trough. This is more than any fluvial system alone can accommodate. Influences of shallow marine incursion from the Gulf of Guinea can not be ruled out completely as analysed by some workers[25].

The late Middle Albian transgression in the Benue Trough[26-28], must have had influences on the Bima sandstone. The earliest marine incursions into the Benue Trough and their extents have been a matter of controversy[29-32]. It is now clear that the shooting areas extend to the Upper Benue Trough.

Conclusion

The result of this study points to the crystalline borderlands of the Upper Benue Trough such as the Hawal Massif, the Mandara Massif and the Adamawa and Cameroon Massifs or their remote extensions as the most probable source of Bima sandstone. For the composition and texture of these crystalline borderlands were found to be concomitant with the ones discovered in this study. The Adamawa, Cameroon, Mandara and Hawal Massifs, like most Precambrian to lower Paleozoic Basement Complex rocks of Northern Nigeria, consist mostly of migmatite gneisses, metasedimentary and granitoid rocks[33].

Bima sandstone was derived from the borderlands during period of tectonic quiescence, low relief and in a humid tropical climate that enhanced rapid weathering of the rocks. The weathered products were worked by minor streams and piled in alluvial plains and fans, which were further, reworked by meandering streams and intermittent shallow marine inundations at the central part of the trough. Hence the fluviodeltaic origin of Bima sandstone is hereby confirmed.

This paleocurrent analysis and study of other physical observations made in the field, show that the sediments were transported in an obliquely convergent manner from the marginal areas toward the center and southwestwards in the area of the trough. This observation is in line with that of other workers, using facies architecture models of the Bima sandstone in the Yola arm. The study differs greatly from that of some workers[34-38] in the region and some[39-41] in other parts of the world.

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