DEPOSITIONAL ENVIROMENTS OF THE BIMA SANDSTONE OF THE YOLA ARM, BENUE TROUGH.

BY

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A thesis submitted to the Postgraduate School, Ahmadu Bello University, in partial fulfilment of the requirements for the degree of Master of Science in Sedimentology

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March

DECLARATION

I hereby declare that this thesis was written by me and is a record of my own research work. It has not been presented before in any previous application for a higher degree. References made to published and unpublished literature have been duly acknowledged.

Nuhu Kadai Samaila — 7th April 1992.
Date

The above declaration is confirmed.

Dr. S.P. Braide
(Major Supervisor) — Date

CERTIFICATION

This thesis entitled "Depositional Enviroments Of the Bima Sandstone of the Yola Arm, Benue Trough", by Nuhu Kadai Samaila meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to Scientific knowledge of literary presentation.

Dr. S.P. Braide (Major Supervisor)	Dr. E.C. Ike (Second Supervisor)
Dr. E.C. Ike Head, Department of Geology	Professor D.I. Saror Dean, Postgraduate School

DEDICATION

To my dad, Samaila Gwani, who saw the beginning
of this work but could not see its end.

AND

To my dear wife, Mary, whose love, understanding,
and support made this work possible.

ABSTRACT

The Yola Arm of the Benue Trough is an elongate basin approximately 210km long, and average 70km in width,, It trends roughtly east-west, and was formed by sinistral displacements of inherited transcurrent faults during the Aptian-Albi an (Cretaceous)times.

A study of the sedimentary structures and depositional motif of the Bima Sandstone, the oldest formation in the Yola Arm, suggest deposition in alluvial fans, 1acustrine/f1oodplain, and f1uvial environments were dominant.

The alluvial fans consist of unstratified coarse-grained conglomerates on the southern margin, and parallel to cross-stratified fine grained conglomerates on the northern margin. The 1acustrine/f1oodplain depositional environment is characterised by silts and shales with wavy and lenticular bedding,mudcracks, and shale rip-up clasts.

The f1uvia1 environment is characterized by planar and trough cross-bedded structures of unimodal vectors.

Bynsedimentary deformation structures in the basin's axial deposits may suggest several tectonic causes, one which is penecontemporaneous seismic activity at the basin - margin faults.

The Yola Arm is considered a pull-apart basin for the following reasons: (i)rapid facies changes from basin margin to basin margin, (ii) migration of depocenter causing over-lap of basement by the sediments, (iii) great thickness of deposits estimated at 4.6km from geophysical

studies, (iv) complexity in sedimentary structures, and (v) evidence of strike-slip movement.

ACKNOWLEDGEMENT

When my major supervisor, Dr. S.P. Braide suggested the research topic, I was excited because Bima Sandstone is a formation of interest to me, probably because its type locality is very close to my village. But for some days, I did'nt know where to start the work. Later my supervisor gave me some insight. Increasingly, I realised what the project is all about. Dr. Braide's guidance, patience, and encouragement have been marvelous throughout all the stages in this work. I can't forget his gentle corrections in trying to see that the work is of high standard. I am so grateful to him. My profound gratitude also goes to Dr. E.C. Ike, who, as both my second supervisor and head of department contributed to the success of this work, through advice, corrections and moral support.

I cannot fail to mention Dr. E.F.C. Dike who has not only given me some of his valuable books and journals, but has also read through my write-up and gave some useful comments. My gratitude to him is profound.

Special appreciation goes to my colleague Mr. Innocent Ojukwu, who had been of great encouragement to me through the "rough roads" in the first and second years of our studies. I can't forget his kind gesture for allowing me to stay in his room, at a time when rooms were difficult to come by.

Iam also grateful to Mr.Lambert Ochibe who took time to draft all my diagrams.My special thanks also goes to Mr.Musa Iliyasu who type-set the thesis at a very critical

period.

Other friends and relatives have helped considerably. Without the help of Mr. Bello Zakari who gave both financial and moral support, Dr. Caleb Kudi and Mr. John Yusufu who allowed me to use their expensive cameras in the field; Ft/Lt. Jonah Jahun who was my host throughout the period of my stay in Minna, together with many others whose personal support in one way or the other have been of atmost value, the work couldn't have reached this stage.

I especially thank Musa and Regina Yashim and also Bulus and Salama Bossan, together with many others for their constant prayers, encouragement and love that have been quite extraordinary.

The debt I owe to many other friends is almost endless. Most of all I thank my God who has walked hand in hand with me throughout every stage of this work. To Him be the glory forever, Amen.

TABLE OF CONTENTS

PAGE

Title page.----------i

Declaration.----------ii

Certification.----------iii

Dedication.----------iv

Abstract. ----------v

Aknowledgement.----------vii

Table of contents.----------ix

List of Figures.----------xi

List of Tables.----------xiii

CHAPTER ONE:INTRODUCTION.----------1

1.1 Geological setting.----------1

1.2 Previous studies.----------1

1.3 Objective of the present study.----------6

CHAPTER TWO:SEDIMENTARY STRUCTURES.----------7

2.1 Introduction.----------7

2.2 presentation of data according to locality.----------8

2.2.1 The Shani locality.----------8

2.2.2 The Guyuk locality.----------12

2.2.3 The Mayo Ine locality.----------15

2.2.4 The Cham-Lafiya locality.----------17

2.2.5 The Bambam locality.----------22

2.2.6 The Tula locality.----------25

2.2.7 The Girei locality.----------28

2.2.8 The Ture locality. ----------31

CHAPTER THREE:DEPOSITIONAL FACIES.----------34

3.1 Introduction.----------34
3.2 Debris-flow alluvail fan facies.----------35
3.3 Stream-flow alluvial fan facies.----------36
3.4 Lacustrine/floodplain facies.----------37
3.5 Braided fluvial facies.----------38
3.5.1 Pebbly low-sinuosity subfacies.----------38
3.5.2 Sandy low-sinuosity subfacies.----------39
3.6 Meandering fluvial facies.----------39
3.6.1 Channel subfacies.----------39
3.6.2 Floodplain subfacies.----------40
CHAPTER FOUR:DEPOSITIONAL ENVIRONMENTS/MODEL.----------41
4.1 Introduction.----------41
4.2 Palaeocurrent analysis.----------43
4.3 Depositional model.----------43
4.4 Tectonic framework.----------45
CHAPTER FIVE:DISCUSSION AND CONCLUSIONS.----------47
5.1 Discussion.----------47
5.2 Conclusions.----------50
REFERENCES.----------52
APPENDIX.----------60

LIST OF FIGURES

FIGURE PAGE

1. Location map of the Yola Arm---------- 2
2. Shani locality showing fining-upward sequence---------9
3. Poorly-sorted fine-grained conglomerates of stream-flow alluvial fan deposit----------10
4. Well-stratified, inter bedded conglomerate and sandstone of stream-flow alluvial fan deposits-------11
5. Guyuk section showing fining-upward sequence---------13
6. Effect of erosion on large-scale planar cross-bedding----------14
7. Poorly-sorted and reverse-graded coarse-grained conglomerates of debris-flow alluvial fan deposit----15
8. Mayo Ine section showing coarsening upward sequence--16
9. Cham-Lafiya section showing a braided fluvial system with both primary and synsedimentary deformation structures----------18
10. Convolute bedding in fine-medium grained sandstone--19
11. Recumbent folds in medium-to coarse-grained sandstone----------20
12. Large-scale planer cross-bedding sandwiching massive beds----------20
13. Sand-volcanoes on top of the Lafiya-Cham outcrop----21
14. Kambam section showing a braided fluvial deposit with both primary and syn-sedimentary deformation structures----------23

15. Medium-scale planar cross-bedded fine-to medium grained sandstone----------24
16. Symmetrical Ripple-marks in fine-grained sandstones----24
17. Tula section showing meandering fluvial deposit--------26
18. Large-scale deformed trough cross-bedding in fine-to medium-grained sandstone----------27
19. Large-scale trough cross-bedding in medium to coarse-grained sandstone----------28
20. Girei section showing fining-upward sequence in a braided fluvial system----------29
21. Normal graded cosets of planar cross-bedded pebbly coarse-grained sandstone----------30
22. Cyclic sedimentation of massive beds sandwiched by small- to medium-scale planar cross bedding----------31
23. Ture section, showing fining-upward sequence of a massive medium-to coarse-grained sandstone----------33
24. Lacustrine facies photographed at a burrow pit near Kpassam off the Mayo Lope -Numan road- ----------37
25. Simplified geologic and palaeogeographic map of the Yola Arm, showing major rock types, and generalized direction of sediment transport----------42
26. Depositional model for the Bima Sandstone in the Yola Arm----------44

LIST OF TABLES

TABLES PAGE

1.Stratigraphic sequence of Upper Benue and Chad Basins. ---5

CHAPTER ONE

INTRODUCTION

1.1 GEOLOGICAL SETTING.

The study covered an area which lies between latitudes 9 N and 10 10'N, and longitudes 11 20'E and 12 40'E. The area forms an important part of the Benue Trough, and is known as the Yola Arm. The Benue Trough has been described as an intracontinental Cretaceous basin overlying the Precambrain shield of the West African mobile belt. It trends NE-SW for about 1000KM and has has been sub-divided into Upper, Middle and Lower sectors. The Yola Arm is part of the Upper Benue Trough, and is an elongate basin approximately 210km long, and average 70km in width. The basin contains a very thick Cretaceous strata, mainly sandstones with subordinate siltstones and shales but with a distinct basin edge fringe of conglomerates. This east-west trending basin, is bounded on both its southern and northern margins by Precambrian Basement rocks (Fig 1).

1.2 PREVIOUS STUDIES.

Bima Sandstone, is the basal formation of the Cretaceous system throughout the Upper Benue Trough and its outcrops cover the whole of the study area. Falconer (1911) pioneered the geological work in the area. He named the basal formation and described other sedimentary formations of Cretaceous and Tertiary ages in the region. Several other workers such as Raeburn and Jones (1934), Reyment (1954b and 1955) and Barber et al (1954) threw some more

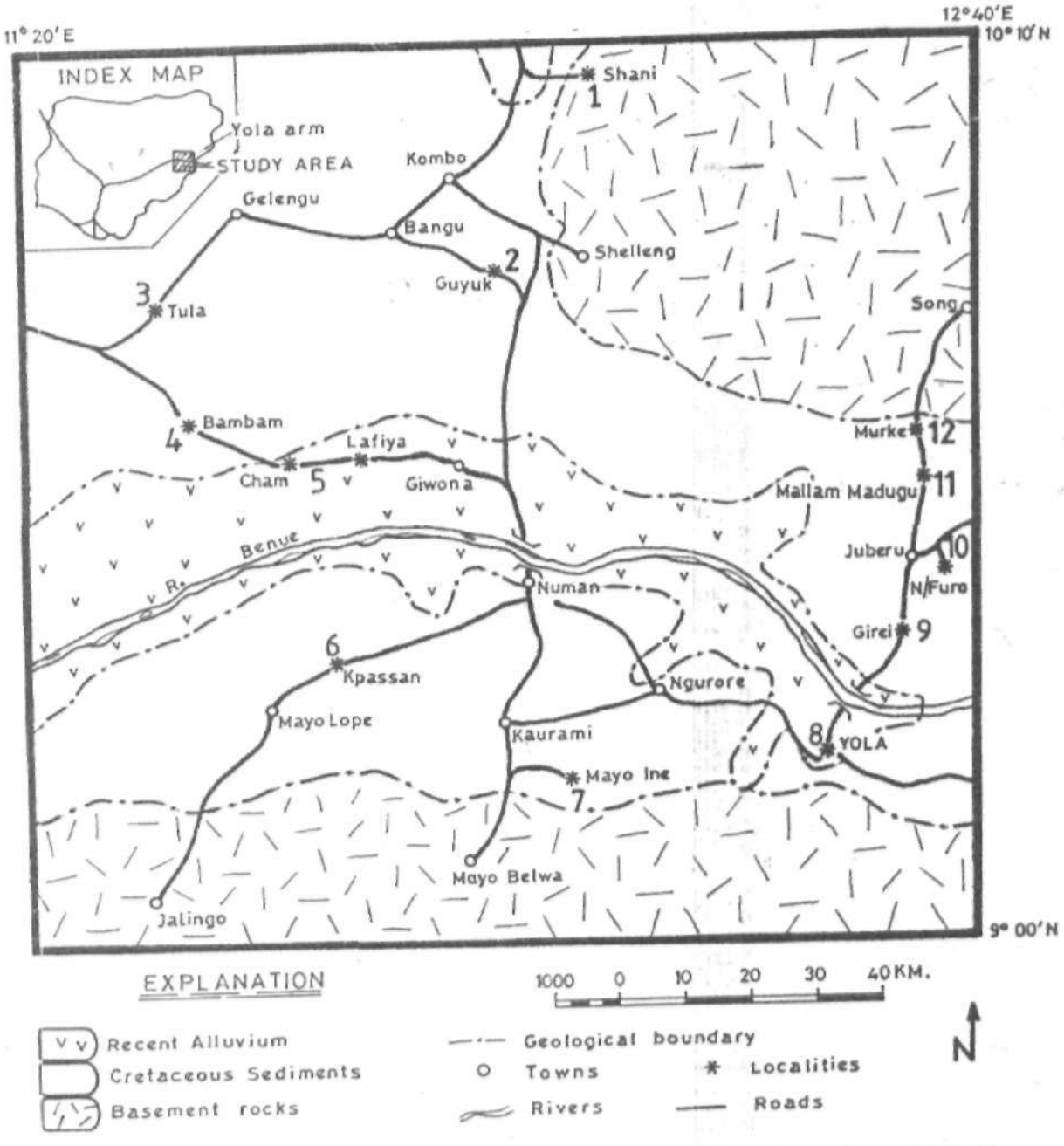


Fig. 1 Location map of the Yola Arm showing Localities and Road Networks.

light on the sedimentology, stratigraphy and paleontology of the region.

A Middle (?) Albian to Cenomanian age was suggested for the Bima Sandstone by Falconer (1911) and Barber (1957), based on correlations with sediments of the Lower Benue Trough, as there are no identifiable fossils for direct dating in the Bima Sandstone. Carter et al, (1963) gave a more elaborate suggestion of the age. According to them, the age of the top of the formation ranges from Upper Cenomanian to Lower Turonian, while that of the base is as old as Upper Albian. But recently, Allix et al (1983, in Guiraud, 1986) suggested an Aptian- Albian age (Table 1) based on the K/Ar method.

The sedimentary structures in the Bima Sandstone were first studied by Jones (1959, 1962) and later by Carter et al (1963), who also summarized the stratigraphy and the sedimentology of the deposits in the region.

The comprehensive study of the Upper Benue Trough by Carter et al (1963) generated some interest among different workers, many of whom suggested the origin and evolution of the Benue Trough. The results of the various geological and geophysical studies brought to light two major models, namely the "Rift" and the "Pull-Apart" models. Most of the early workers supported the rift model, and the reviews of their work could be seen in papers by Offodile (1976), Glade (1975), Petters (1978) and Ofoegbu (1988). The Pull-Apart model was suggested by Benkhelil (1982) Benkhelil and Robineau (1983), and Benkhelil (1989).

The thickness of the sedimentary fill in the study area had been of great interest to many geophysicists, including Osazuwa et al (1981) who estimated the thickness of the deposits using gravity and magnetic methods, to vary between 0.9km to about 4.9km. An aeromagnetic study by Ofoegbu (1988) gave a thickness of 0.5km to 4.6km. An earlier report by Carter et al (1963) gave a thickness of 0.9 to about 3 km.

The Bima Sandstone has its type locality at the Bima hill, 40km east of Gombe, but attains its maximum thickness in the Lamurde anticline, more than 20km southwest of Lafiya.

The Cretaceous rocks overlying the Bima Sandstone in the study area consist of transitional, and marine sediments, as follows:

Lamja Sandstone - youngest.

Numanha Shales.

Sekule Formation

Jessu Formation

Dukul Formation

Yolde Formation - Oldest

The Yolde Formation, consisting of sandstones, thinly bedded mudstones,shelly limestone and shales,is a transitional sediments between the underlying continental and the overlying marine sediments.The Yolde is overlain by the Dukul Formation,consisting of a sequence of black shales and thin limestones,followed by the Jessu

AGE		UPPER BENUE BASIN				CHAD BASIN
		YOLA ARM	GONGOLA TROUGH			
			ZAMBUK RIDGE			
		DADIYA – NUMANHA	ZAMBUK-GULANI	GOMBE-PINDIGA		
PALEOCENE AND YOUNGER				KERRI-KERRI Fm.		KERRI-KERRI Fm.
				Unconformity		
MAASTRICHTIAN		LAMJA Ss				GOMBE Ss
SENONIAN	CAMPANIAN	NUMANHA SHALES				
	SANTONIAN	SEKULE Fm.				
		Unconformity				
	CONIACIAN		GULANI Ss	PINDIGA FORMATION	GOMBE Ss	FIKA SHALES
		Unconformity				
TURONIAN		JESSU Fm.				
		DUKUL Fm.				GONGILA Fm.
CENOMANIAN		YOLDE Fm.				
ALBIAN		BIMA Ss	BIMA SANDSTONE	YOLDE Fm.		BIMA Ss
APTIAN				BIMA Ss		
			Unconformity			
PRE-CAMBRIAN		BASEMENT COMPLEX				

Table 1. Stratigraphic sequence of upper Benue Trough and Chad Basin.

(Modified from Ofoegbu, 1988 and Popoff et al, 1986)

Formation,which is an alternating sequence of grey,white,and brown shales, and light brown sandy mudstone.It is succeeded by Sekule Formation ,a sequence of shales and limestones having thicker shale units than the limestones.The Sekule Formation is overlain by the Numanha Formation,composed of shales with occasional bands of sandstones,nodular mudstones and limestones.The Lamja Sandstone which terminates the sedimentary succession in the region, is a sequence of fine grained sandstones with shales and limestones(Carter et al,1963). The respective ages of the formations is shown in Table 1.

1.3 OBJECTIVE OF THE PRESENT STUDY.

The primary objective of the study is to reconstruct the depositional environments of the Bima Sandstone in the Yola Arm of the Benue Trough, using the inherent sedimentary structures and the depositional motifs.

CHAPTER TWO

SEDIMENTARY STRUCTURES

2.1 INTRODUCTION

Sedimentary structures are very important indicators of depositional environments. They are studied in outcrops rather than in hand specimen or thin section. The vertical distribution of sedimentary structures within rock stratigraphic units can reflect the lateral distribution of processes at the time of deposition. Masters (1967) used the various sedimentary structures in the Mesaverde Formation, to determine the depositional environments in the formation, by analyzing the vertical sequences of the stratification types.

The study of sedimentary structures is as old as geology itself. Many sedimentary structures have been recognized by geologists even before Hutton's (1788, in Potter and Pettijohn, 1977) "Theory of the Earth" was published. Since then, sedimentary structures have been described by many authors, and at the moment there is a large number of text books and monographs partly or entirely devoted to describing and interpreting them. Some of these materials include the following: Pettijohn and Potter (1964), Gubler et al,(1966), Conybeare and Crook (1968), Allen (1970b,) Reineck and Singh (1973), Blatt et al, (1972), Allen (1982) and Collinson and Thompson (1982).

The sedimentary structures within the rock stratigraphic units of the Bima Formation in the Yola Arm, have been simply classified into primary and secondary

structures. Both types have been seen in some localities, although the former is more dominant, and generally occured in all the localities (Girei, Bambam, Ture, Tula, Shani, Mayo Ine, Cham/Lafiya, and Guyuk) studied in the present work. For each of these localities, the inherent sedimentary structures and depositional motifs will be discussed following their vertical distribution within the outcrops.

Special attention has been given to the planar cross-bedding in the different localities because of its reliability as a directional indicator in the area. Based on the azimuthal directions measured from the planar cross-bedding, a general palaeocurrent direction has been reconstructed for the Yola Arm.

2.2 PRESENTATION OF DATA ACCORDING TO LOCALITY

2.2.1 THE SHANI LOCALITY

The locality is situated on the northern margin of the Yola Arm (Fig 1).It is connected to a major road (Biu - Numan) by an access road, making a T-junction. From the junction to the locality, random changes in lithology were noticed.

The locality is characterized by outcrops that generally resemble weathered basement from a distance, but in reality are conglomerates. One of the outcrops studied is about 40m thick. The deposits are generally immature both texturally and mineralogically, and also consist of

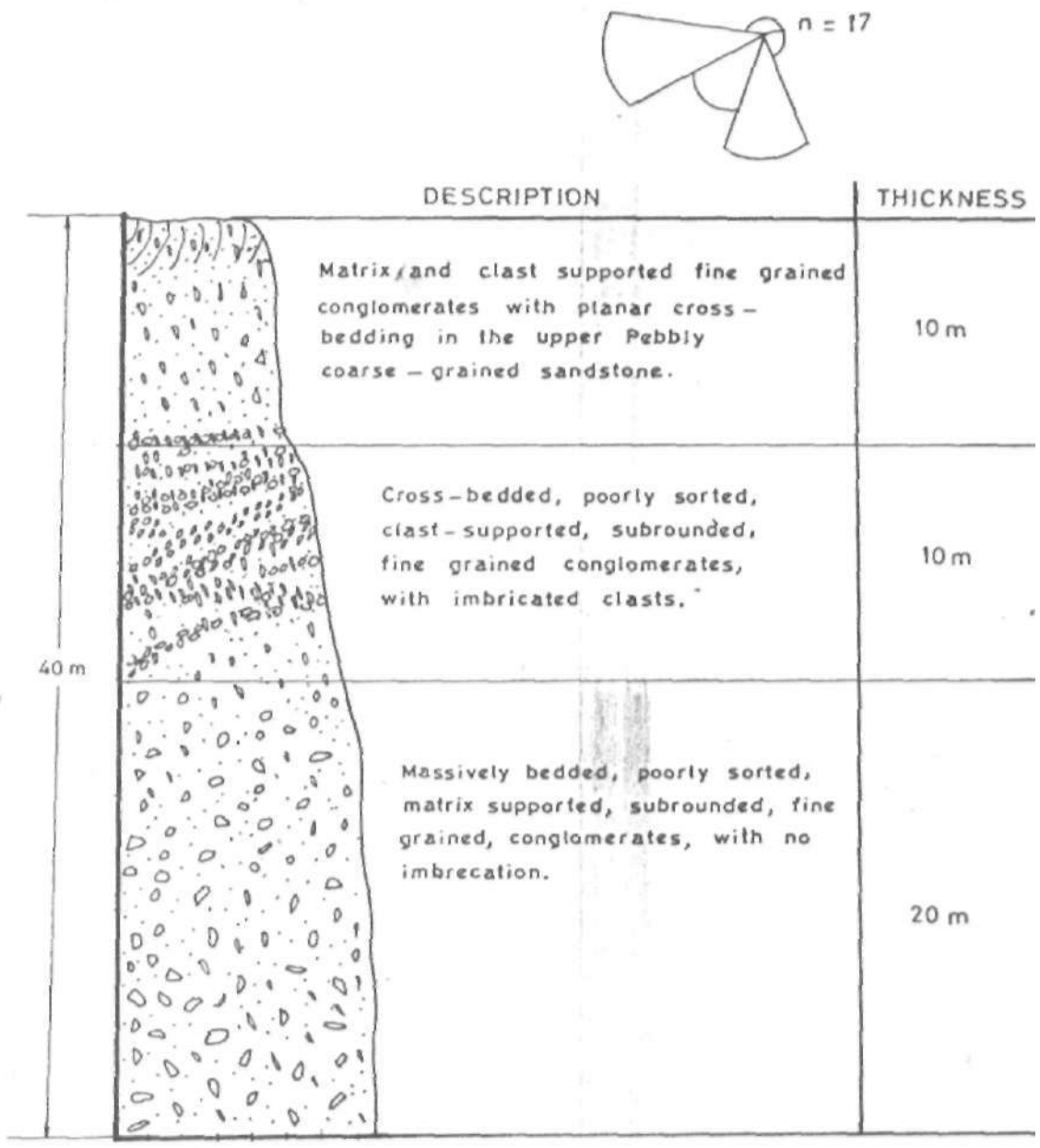


Fig. 2. Shani section showing fining-upward sequence in fine-grained conglomerates of the Northern-margin.

fine grained conglomerates, coarse-to-fine grained sandstones and siltstones (Figs.2&3).

The rocks exposed in the outcrop are divisible into three main units based on the inherent sedimentary structures as well as slight changes in grain sizes. The basal unit is about 20m thick. The sediments are generally massive, poorly sorted, with relatively coarser pebbles that are subangular to subrounded. The pebbles show no preferred direction or orientation and they range in size from 4mm to about 6mm (Fig 3).



Fig.3. Poorly sorted fine-grained conglomerate in the south eastern part of Shani town;hammer for scale.

The middle unit is about 10m thick. It consist of pebbles that are relatively finer than those in the basal unit. The pebbles in this unit tend to occur as stringers, parallel or inclined to the horizontal plane. The inclined stringers interpreted as planer cross-beds have elongated pebbles, oriented in the direction of the inclination (fig 4).



Fig. 4. well-stratified, interbedded conglomerate and sandstone in the southern part of Shani town;hammer for scale.

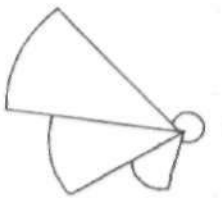
The upper unit, about 10m thick, contain smaller pebbles.The sediments in this unit could be described as pebbly.

A total of 16 azimuthal readings were taken in this locality. The palaeocurrent pattern that resulted from the measurements had been described by Selley (1967) as bimodal perpendicular mode. The dominant modal class points westward, while the subordinate modal class points southwards (Fig 2).

2.2.2. THE GUYUK LOCALITY

Guyuk is located along the Biu-Numan road, several kilometers away from the T-junction to Shani. The outcrop studied is at the northern part of the town. The exposed rock section is about 35m thick, and laterally extensive. The sediments are generally cross-bedded, poorly sorted, pebbly coarse-grained sandstones. Based on the depositional motif and the sedimentary structures in the rocks,four subfacies units have been identified (Fig 5).

The basal unit which is about 8m thick consist of pebbly coarse-grained sandstones, similar to those of the upper unit of the Shani locality. The sediments are graded normally, with medium - to large-scale planer cross-bedding towards the upper part of the unit. The contact between the basal unit and the one overlying it is gradual. This unit is about 10m thick. The planar cross-bedding is prominent in the unit. The third unit is just about 5m thick, and consist of moderately sorted, medium to coarse



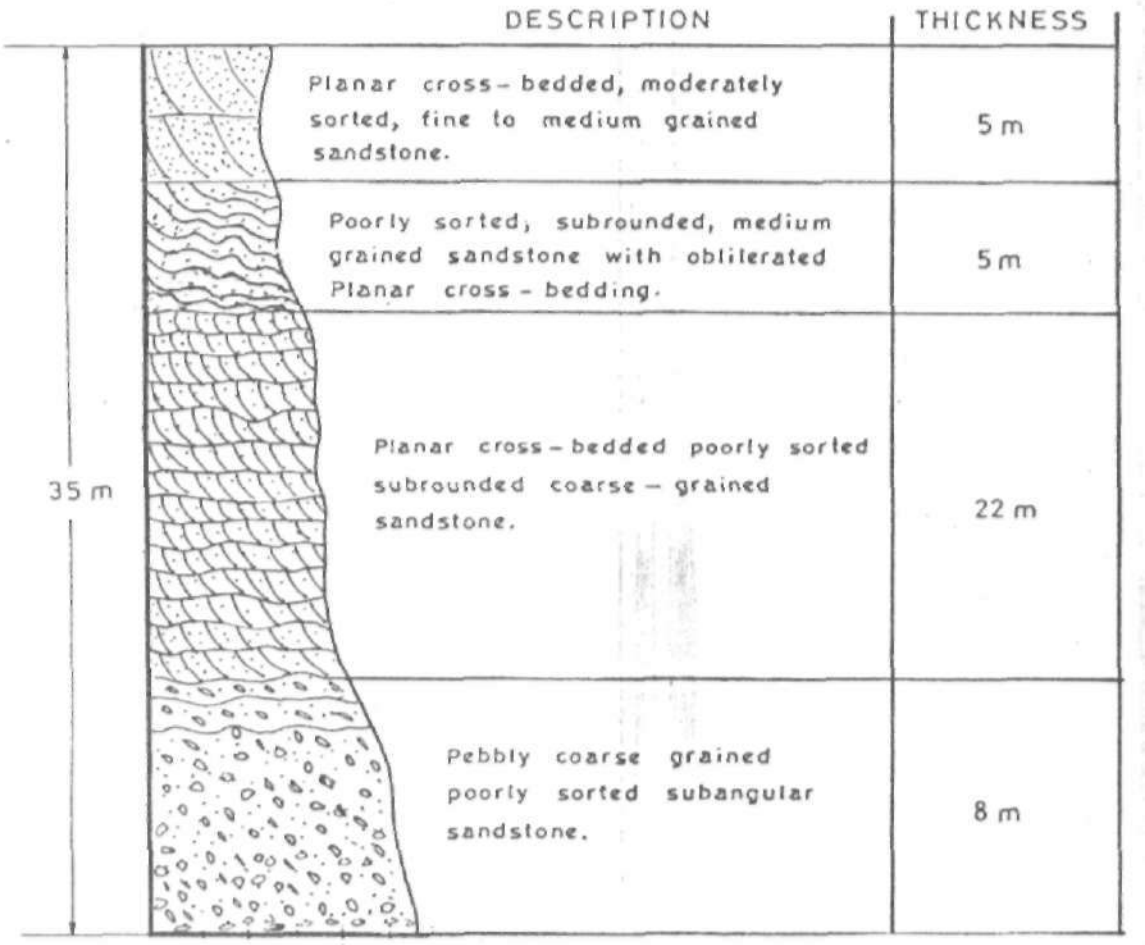


Fig. 5. Guyuk section showing fining-upward sequence in highly cross bedded fluvial deposit.

grained sandstone, with small amounts of siltstone. At the upper part of this unit, erosion appeared to have obliterated most of the planar cross-beds (Fig 6). The upper most unit is about 5m thick, and is highly cross-bedded. The sediments are moderately sorted, and consists of mainly fine to medium grained sandstones.



Fig. 6. Effect of erosion on large-scale planar cross-bedding. at the northern part of Guyuk town.Notice the badly affected area around the hammer.

The azimuthal readings collected from the locality, totalling 15, gave a unimodal palaeocurrent pattern, with a NNW direction (Fig 5).

2.2.3 THE MAYO INE LOCALITY

The locality is on the southern margin of the Yola Arm, near Mayo Belwa in Adamawa State. It is characterized by coarse-grained conglomerates supported by sandy to muddy matrix. This poorly sorted unit is more than 50m thick.

The deposit shows a general reverse grading, suggesting a coarsening-upward sequence. The conglomerates,composing of quartz and rock fragments vary in diameter from 6mm to more than 10mm and show no preferred orientation (Fig. 7).Towards the basal part of the rock sections, poorly developed planar cross-beds have been observed in the sandstone and siltstone matrix.

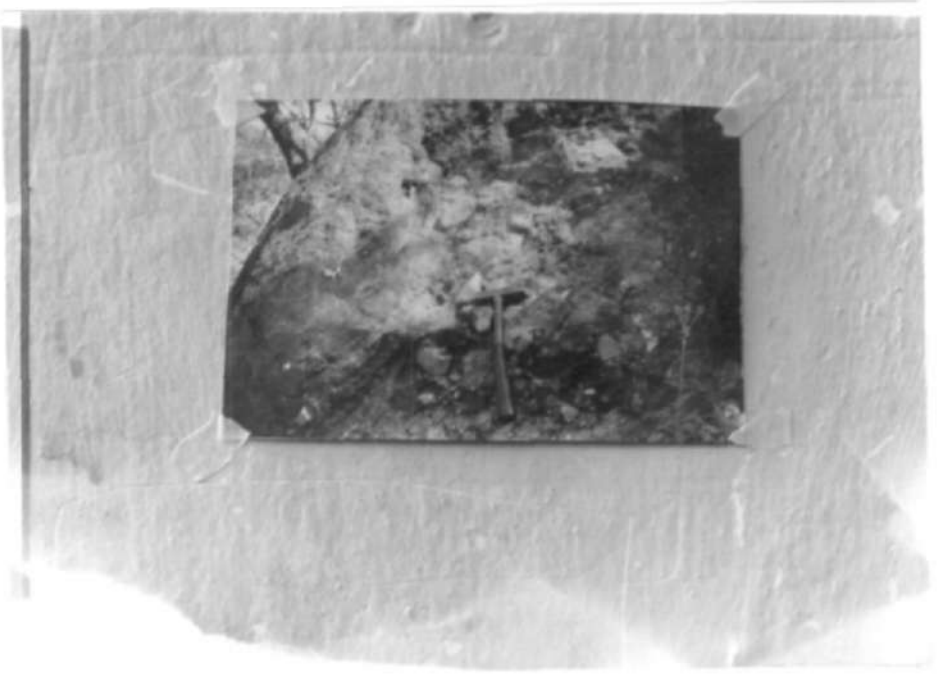


Fig. 7. Poorly sorted, and reverse-graded, coarse-grained conglomerate in an outcrop south of Mayo Ine village; hammer length for scale.

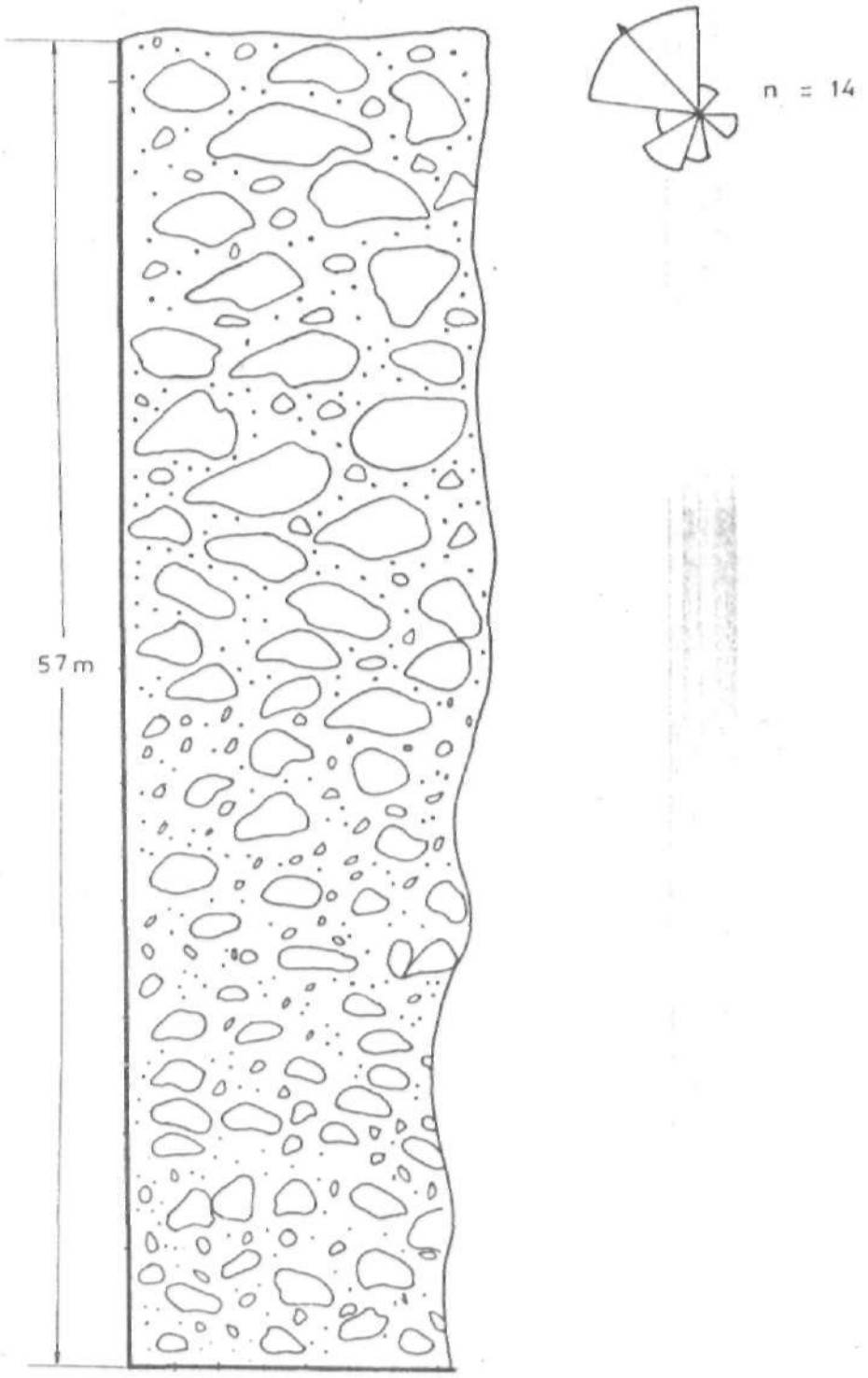


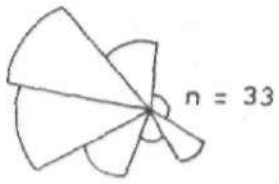
Fig. 8. Mayo Ine section, showing poorly sorted, matrix – supported, tabular clasts in coarse grained conglomerates.
Note the reverse grading.

A total of 14 measurements of the azimuthal directions were taken from the poorly developed cross-bedding in the locality. The analysis gave a polymodal pattern with the principal mode pointing to the northwestern direction(Fig.)8.

2.2.4 THE CHAM-LAFIYA LOCALITY

The locality is situated between Cham and Lafiya near the political boundary of Bauchi and Adamawa States. The outcrop studied is along the Gombe-Yola Road, in the axial part of the arm. Planar cross-bedding is the most striking sedimentary structure in the outcrop. The cross-beds range in thickness from 10cm to 1.5m.

The thickness of the exposed rocks is about 35m, and displays both primary and deformation structures. The sediments are generally coarse-to medium-grained and moderately sorted sandstones. The basal part of the rock section is about 0.5 to 8m thick. It is characterized by planar cross-bedding with cosets of about 1m thick, moderately sorted medium-to coarse-grained sandstone (Figs 9 and10).A highly convoluted unit with a thickness of about 5m overlies the basal unit. This sedimentation unit is highly complex, having many irregular folds (Fig 10). The convoluted unit is overlain by a thick bed of overfolded sedimentation unit made up of smaller over folds referred to as recumbent folds. (Fig 11). The unit is about 8m thick, and the sediments are well-sorted, medium grained sandstones. The recumbent unit which has its axial surfaces parallel to the bedding surfaces above and below it, is overlain by more than three cyclic sedimentation



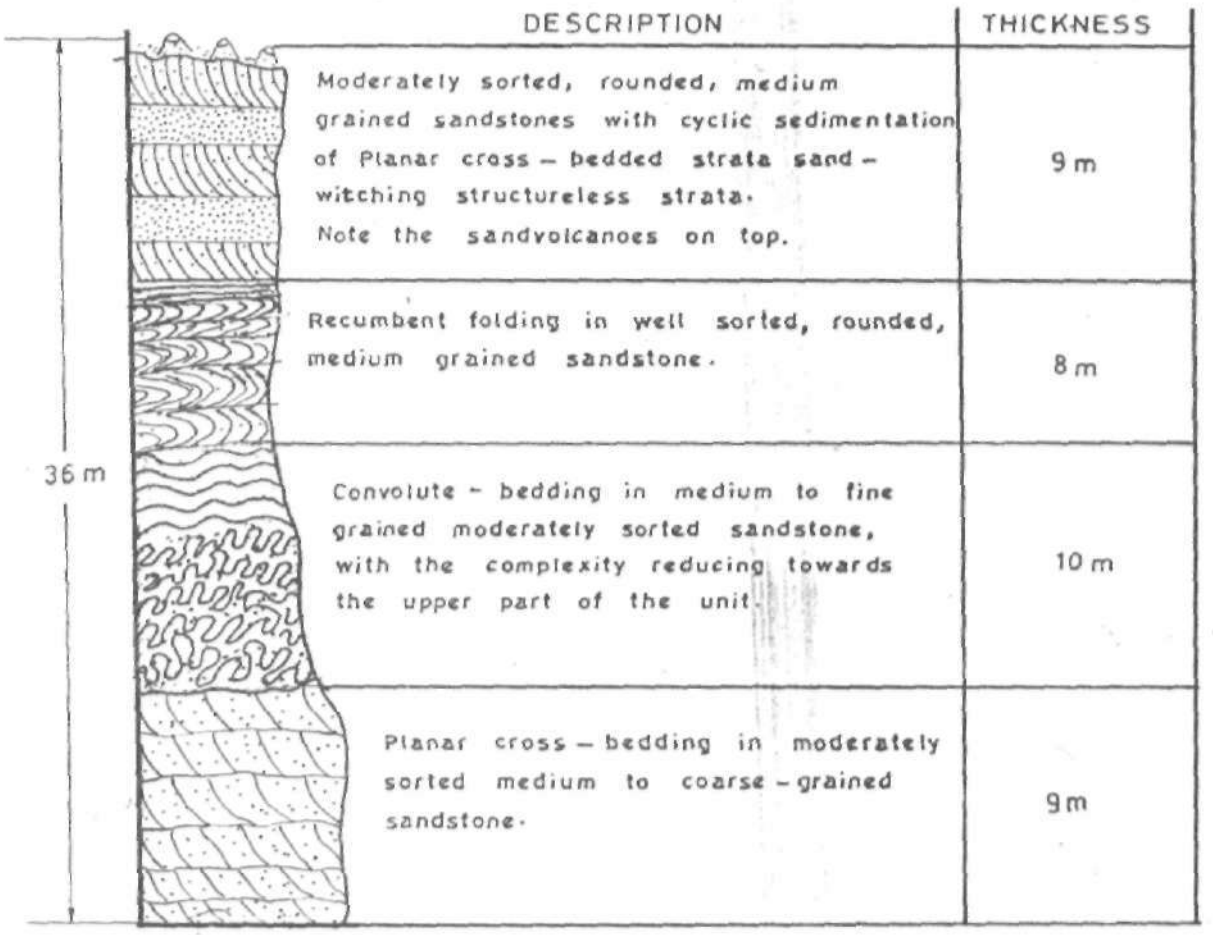


Fig. 9. Cham – Lafiya section showing both primary and Syn-sedimentary deformation structures.

units. These units are characterized by medium-to large-scale planar cross-bedding sandwiching thin structureless medium-grained sandstones. The thickness of the cross-beds ranges from 30cm to about 1m. (Fig 12).

On the upper most part of the section, sand-volcanoes were observed (Fig. 13). This rare deformation structure is like a small volcanoe with a small well-formed crater. The circular structure has a diameter of about 2cm. The sediments around the vent are much finer than the rest of the sediments surrounding the sand-volcanoes.



Fig. 10. Convolute bedding in fine-to medium grained sandstone,near Lafiya town;hammer for scale.

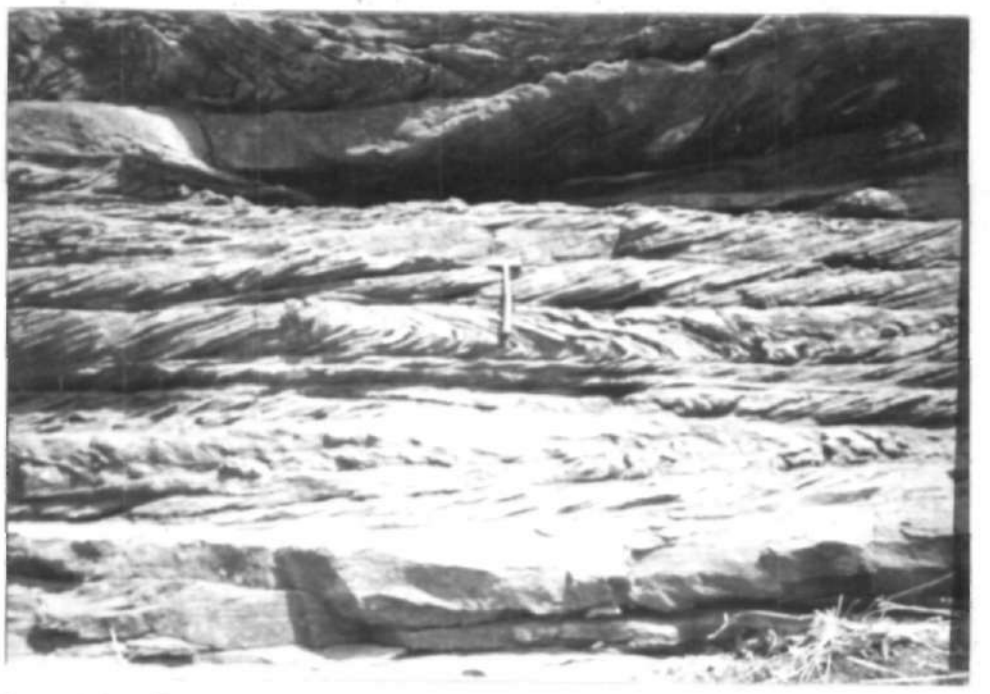


Fig. 11. Recumbent folds in medium-to coarse-grained sandstone;hammer for scale.

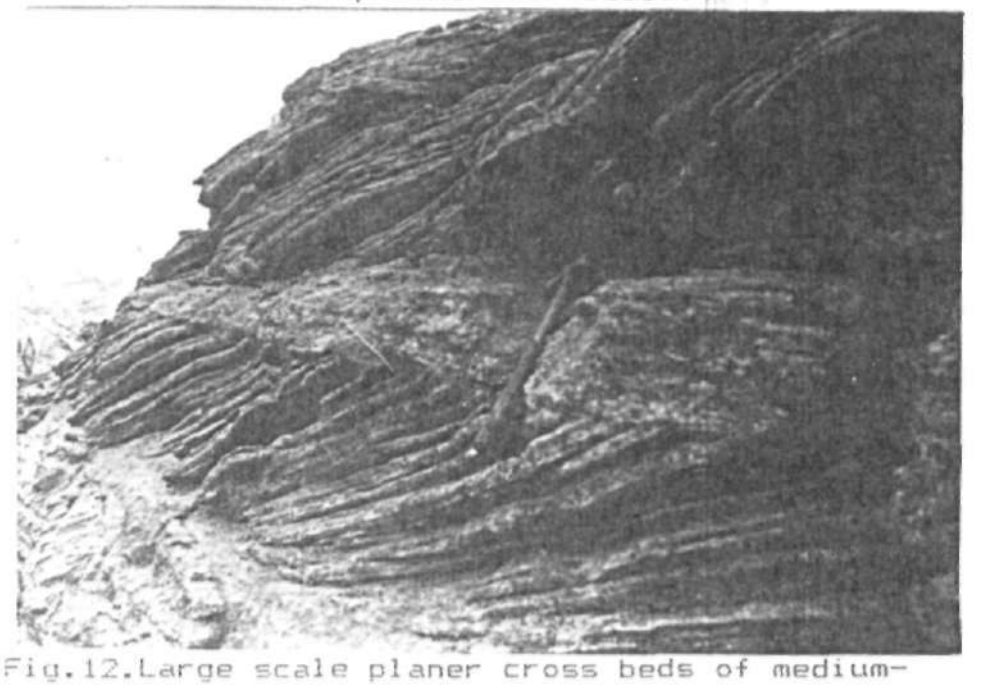


Fig.12.Large scale planer cross beds of medium-to coarse-grained sandstone,sandwitching massive beds;hammer for scale.



Fig.13 Sand-volcanoe on the upper most part of the rock section in Lafiya-Cham locality.

Courtesy:S.P Braide.

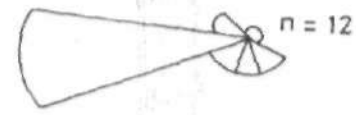
Because of the abundance of the planer cross-beds in the locality,about 33 azimuthal readings were taken.A polymodal palaeocurrent pattern,with a WNW direction for the principal mode was obtained(Fig.9)

2.2.5 THE BAMBAM LOCALITY

The locality is along the Gombe-Yola road, before the Cham-Lafiya locality. The study was conducted along the western bank of the major stream in Bambam, near the bridge. The thickness of the rock section is about 20m (Fig. 14).

Starting from the stream channel, a sedimentation unit of about 2m thick was observed. The unit is characterized by fine-grained, well-sorted, 10-30cm planar cross-bedded sandstone (Fig 15). Associated with this unit is a thin layer marked by symmetrical ripple-mark. The contact between the planar cross-bedded unit and the ripple marked unit is not sharp; however, there is a slight variation in grain sizes. The wavelength of the ripple mark is about 7cm and its height ranges between 0.5cm to 1cm (Fig 16). Overlying the ripple-marked unit, is a partially convoluted unit. This 2.5m thick unit is made up of fine to medium-grained sandstone .Above the convoluted unit is a bed that is poorly cross-bedded, having a thickness of more than 10m. The sediments are well sorted, medium to coarse grained sandstone.

A total of 13 azimuthal measurements were taken from the locality. The analysis gave a unimodal palaeocurrent pattern, with the principal mode pointing to the western direction (Fig. 14).



	DESCRIPTION	THICKNESS
21m	Planar cross-bedding in well sorted, well rounded, medium to coarse grained sandstone.	10 m
	Convolute bedding in well-sorted, well rounded, fine to medium grained sandstone.	5m
	Symmetrical ripple-marks in well sorted, fine to medium grained sandstone.	2 m
	Planar cross-bedding in well sorted fine to medium grained sandstone.	4 m

Fig. 14. Bambam section showing a deposit with both Primary and Syn-sedimentary deformation structures.



Fig. 15. Horizontal-bedded planar cross-stratified fine-medium grained sandstone.



2.2.6THE TULA LOCALITY

The locality is situated in Bauchi state between Kaltungo and Bambam.It is about 22 km off main Gombe-Yola road in a north western direction.

The outcrop is an escarpment at the western part of the town.It is characterized by well-sorted,well-rounded,pebbly coarse- to- medium grained sandstone with large-scale planar and trough cross beds.Interbedded thick beds of siltstones and claystones are common,especially at the upper part(Fig.17).The rock section is about 60m thick.

The basal unit of the section is about 5m thick,and consists of coarse-grained sandstone with abundant large scale planar cross-beds,ranging in thickness from 10 to 30 cm.The unit is overlain by another 3m thick unit characterized by deformed trough cross-bedding (fig.19). The deformed trough cross-bedded units is overlain by a massive,well-sorted,reddish siltstone unit,about 10m thick,with a thin layer of pebbles on top.Overlying this massive unit is a thick unit of trough cross bedded,medium-coarse-grained sandstone (Fig.19),overlain by planer cross-bedded units sandwiched by thin layer of claystone in the upper part of the rock section.

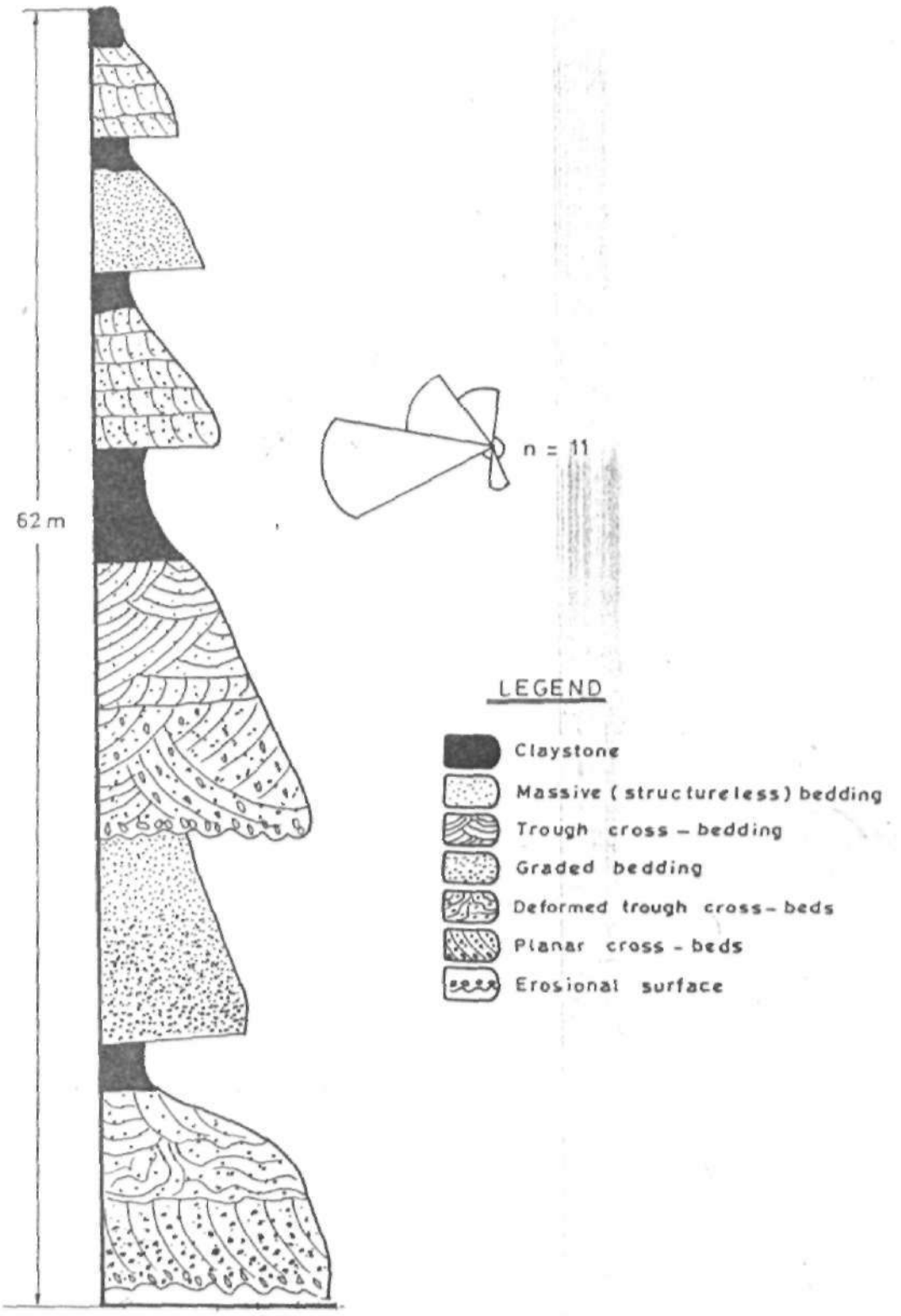


Fig. 17 Tula section showing fluvial deposit with trough and Planar cross - bedding.

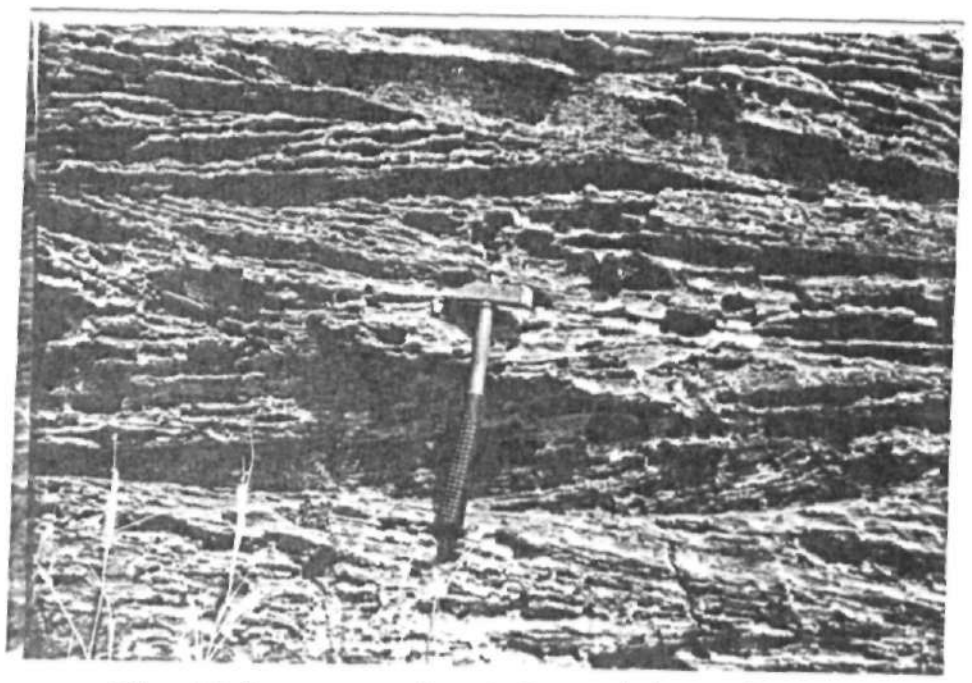


Fig.18 Large-scale deformed trough cross-bedding in fine-to medium-grained sandstone;hammer for scale.



Fig 19.Large-scale undeformed trough cross-bedding in medium-grained sandstone.

Eleven azimuthal measurements were taken.The readings gave a polymodal palaeocurrent pattern,with the principal mode pointing westwards(Fig.17) .

2.2.7 THE GIREI LOCALITY.

The locality is located few kilometers after the Federal University of Technology Yola on the Yola-Mubi road .The locality is some 40km away from the northern margin of the arm.

The sediments in the locality are generally planer cross-bedded,coarse-to medium grained sandstone.The thickness of the rock sections in the outcrop is about 35m (Fig.20).

The basal unit of the outcrop consist of pebbly coarse-grained sandstone. The pebbles have no preferred orientation, they are distributed evenly throughout the poorly sorted sediments.The unit has a thickness of about 5m. It is overlain by a coarse to medium grained sandstone which is highly cross-bedded. The individual cross-stratum of each planar cross-bedded set is graded normally, with the coarser detritus at the base and the finer material at the top. Each coset is about 1m thick (Fig. 21). This unit is about 8m thick. The overlying Unit is about 15m thick, and is charcterized by more than 5 sets of medium-to large-scale planar cross-bedding sandwitching structureless beds of medium to fine grained sandstone (Fig. 22). The upper most unit is made up of medium- to fine-grained sandstone, and contain some planar cross-beds that show no grading in their individual cosets.

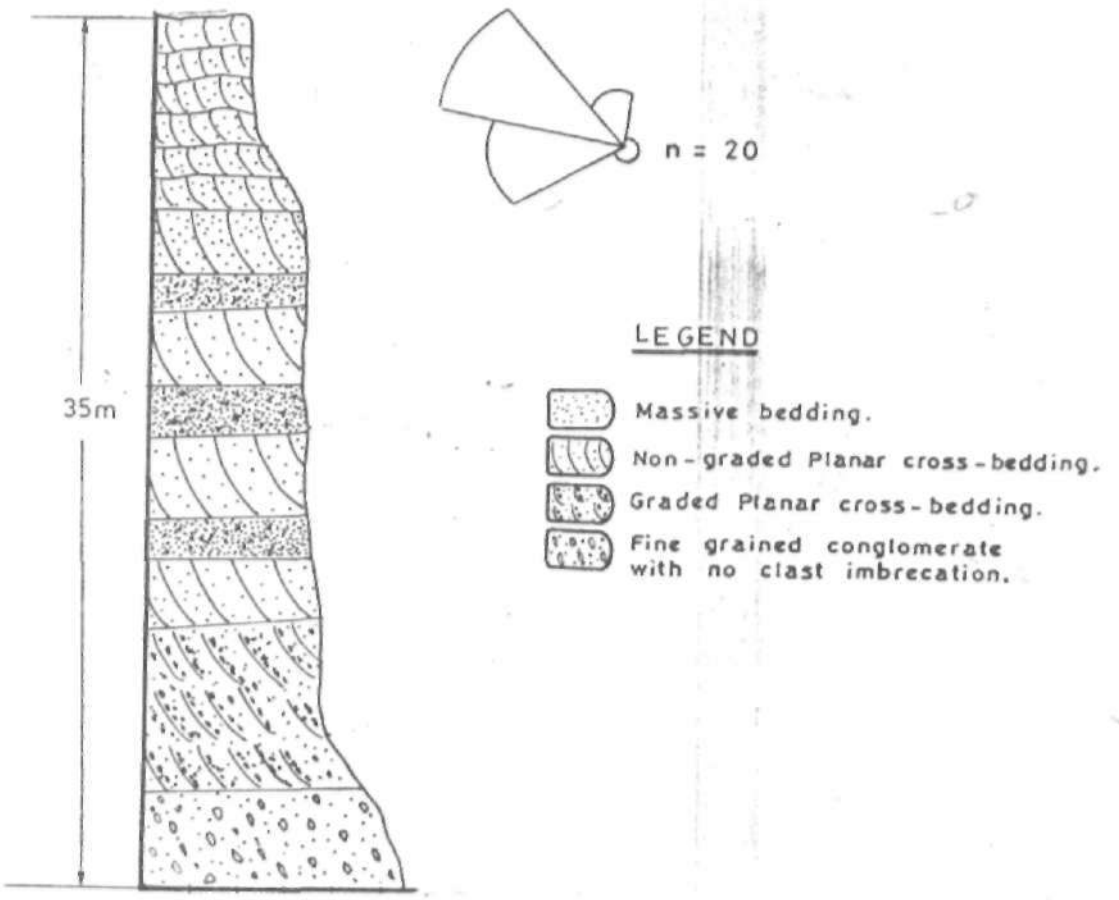


Fig. 20 Girei section showing fining-upward sequence in a fluvial system dominated by graded Planar cross-bedding.

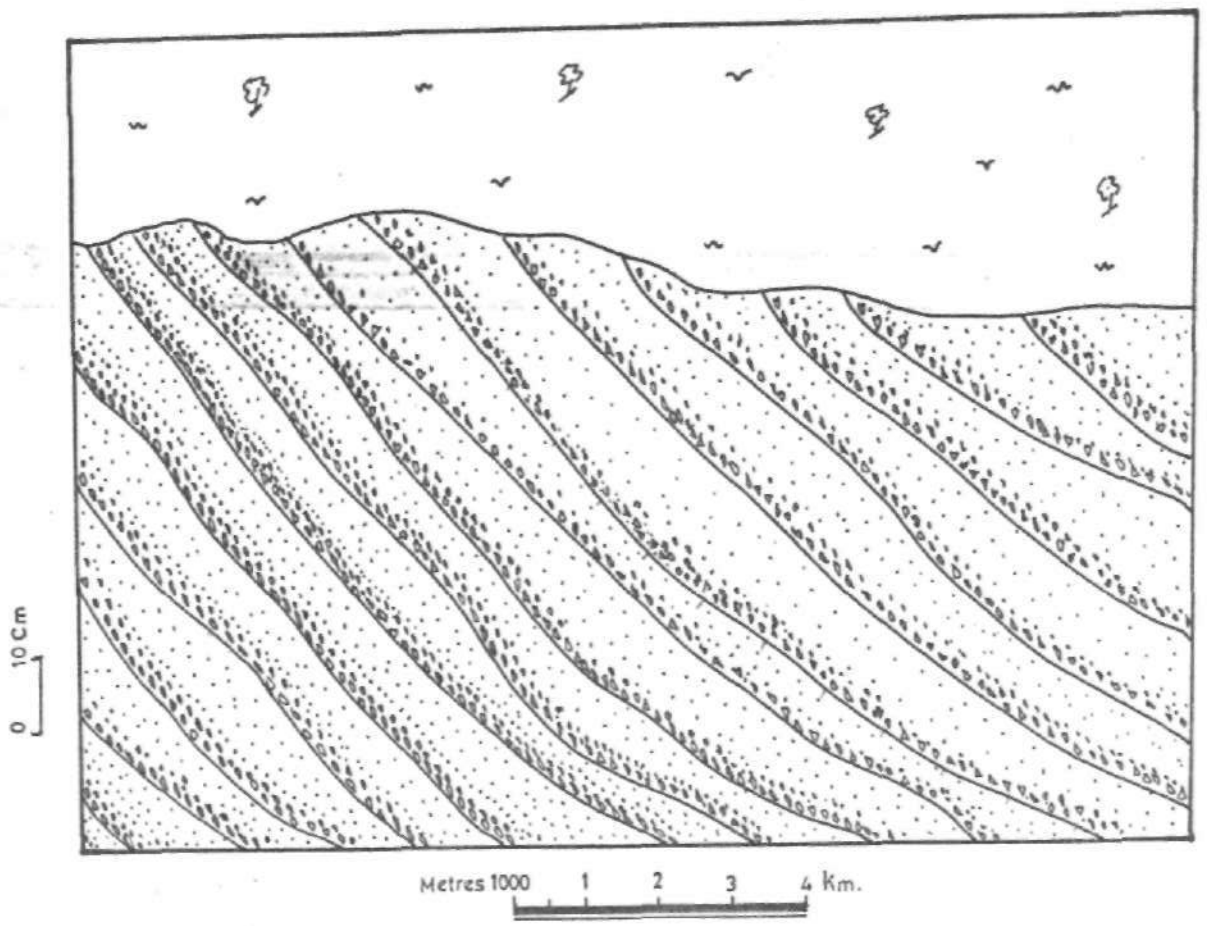


Fig.21 Large scale cross-bedding in Girei locality showing, normal grading in individual cross-strata.

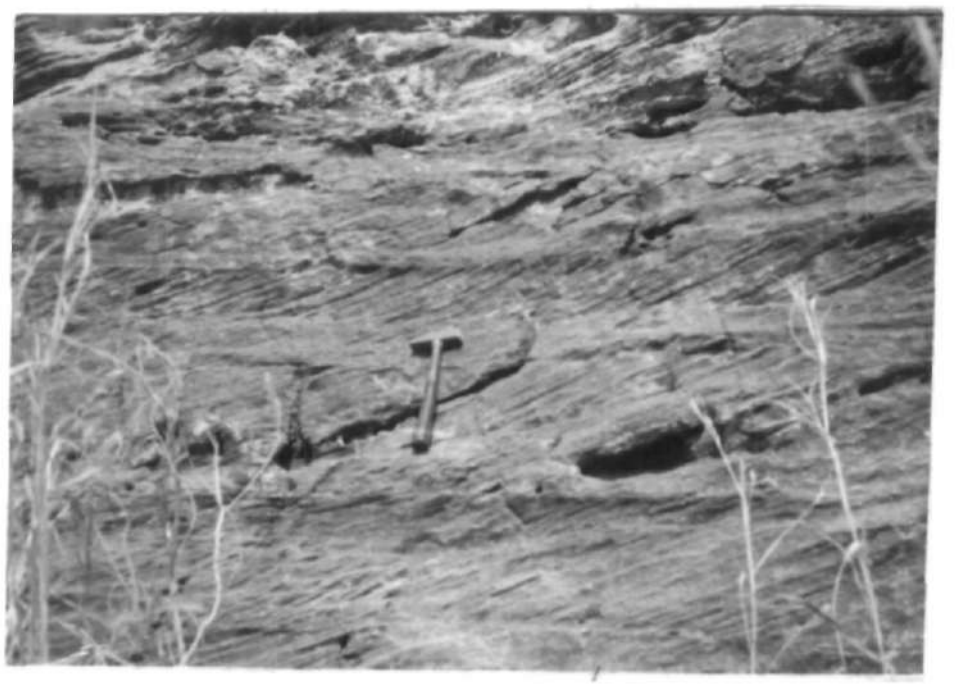


Fig. 22 Cyclic sedimentation of massive beds sandwiched by small scale planar cross-beds.

A total of 20 azimuthal measurements were taken. The readings gave a unimodal palaeocurrent pattern, pointing to a NW direction. (Fig 20).

2.2.8 THE TURE LOCALITY

Ture locality is located a few kilometers after Kaltungo, along the Gombe-Yola road. It is characterized by outcrops of thick sandstones at different locations in the area. One of the outcrops that was studied is on the left side of the Gombe-Yola road. The sandstone unit is generally massive.

The basal part of the rock section is composed of moderately sorted, coarse-grained sandstone that is fairly graded. Overlying the basal unit is a thick sequence of

poorly sorted, coarse-to medium-grained sandstone lacking stratification. The thickness of this unit is more than 45m. The unit is overlain by a slightly different sedimentation unit made up of fine to medium grained sandstone. The thickness of the unit is about 15m. There is a general fining-upward sequence in the locality (Fig.23).

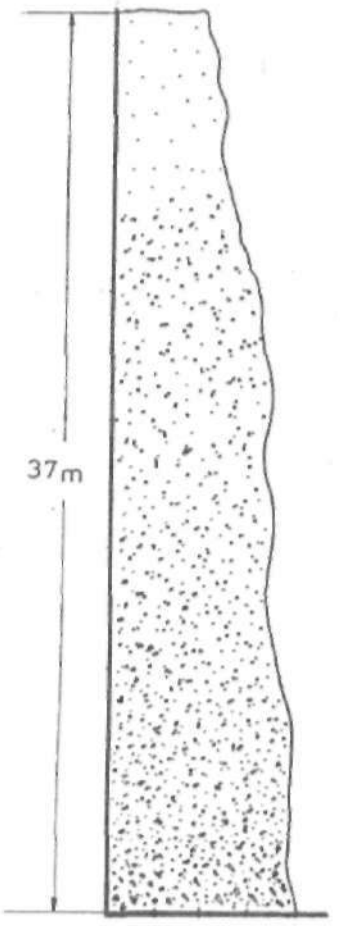


Fig.23 Ture section showing fining-upward sequence of a massive medium-to coarse-grained sandstone.

CHAPTER THREE

DEPOSITIONAL FACIES

3.1 INTRODUCTION:

Sedimentary facies have been defined by Moore (1949) as any areally restricted part of a designated stratigraphic unit which exhibits characters significantly different from those of other parts of the unit. Reading (1978) also added that facies may be delineated on the basis of colour, bedding, composition, texture, fossil and sedimentary structures. They may also be subdivided into subfacies or grouped into facies associations or assemblages.

The deposits of the Yola Arm have been studied in considerable detail and the general patterns of sedimentation could be traced from the southern margin through the centre of the basin to the northern basin margin. The vertical distribution of the rock-stratigraphic units reflect the lateral distribution of the various depositional environments. The vertical distribution of the inherent sedimentary structures within the rock-stratigraphic units have also been used as major tools for identifying the lateral distribution of depositional processes (Masters, 1967).

The basin's marginal deposits are dominantly conglomerates of varying sizes. The coarse grained conglomerates of the southern margin, and the fine grained conglomerates of the northern margin, represent alluvial fans.It was interpreted as alluvial fans based on the types

of facies present,textural and compositional immaturity,and coarseness(Nilsen,1982).Fan deposits have been subdivided into two types,those resulting from debrisflow and related processes and those resulting from streamflow.The deposits of the the northern margin which are well stratified,and those of the southern margin which are poorly stratified have been described as streamflow and debrisflow deposits respectively.

The basin wide fining upward sequences that average about 100M in thickness,was divided into three distinct facies,namely (1)lacustrinene/floodplain facies, (2) braided fluvial and (3) meandering fluvial facies.

3.2 DEBRIS-FLOW ALLUVIAL FAN FACIES.

The facies is present along the entire southern margin of the Yola Arm, probably adjacent to a covered basin margin fault. The debris flow alluvial fans have radii of 0.3-1.5km, thickness of 60-80m,and are characteristically poorly sorted,angular,poorly stratified,have large amounts of clay-sized matrix,and contain clasts with no imbrication. the clasts are tabular and composed of rock fragments derived from the adjacent igneous rocks(Fig.7).Packing is dominantly matrix supported and the deposits are reversed graded(Fig.8).

The size and composition of the clast,as well as the poor sorting,poor stratification and large amount of clay matrix,is characteristic of proximal areas and arid-region fans(Nilsen,1982). The fans in the Yola Arm which prograded into a lacustrine environment adjacent to the

southern margin as a result of ponding by uplifted blocks due to tectonism along the margin, have a wedge shape geometry, thickest towards the basin margin. The deposits result from transport of sediment as viscous muddy flow in which the muddy matrix provides support for suspended clasts(Nilsen,1982).This explains why the sorting of the deposits is poor and the clasts,angular.

3.3 STREAM- FLOW ALLUVIAL FAN FACIES.

The fine grained conglomerates present along the entire northern margin of the Yola Arm, was interpreted as streamflow alluvial fan and generally have radii of more than 2km,and thickness of 40 - 65m. They are generally well stratified,contain a variety of sedimentary strutures including cross-bedding and parallel bedding indicative of different flow regimes, have small amount of clay-size matrix,are clast supported and contain clasts that are imbricated and oriented to flow direction (fig 3&4).The clasts are made of quartz material.The size, composition,and imbrication of the clasts as well as scarcity of clay-size material suggest that the facies was deposited at the distal or lower part of the fan(Nilsen,1982).The deposits result from deposition sediment transported by traction,saltation,and suspension by running water.The clasts are therefore subrounded to rounded because they have been subjected to clast-to-clast collision and the deposit are better sorted, but typically not as well as in alluvial plain sequencies.

3.4 LACUSTRINE/FLOODPLAIN FACIES.

The facies was observed between Kpaccam and Maya Lope, around the southern margin of the Yola Arm(Fig 21). Carter et al (1963) also reported lacustrine facies around the northern margin.

The lacustrine/floodplain depositional environment is characterized by silts and shales with some varving in the former which suggest intermittent ponding by upliftment of basement blocks that prematurely dammed the fluvial system(Braide,1990). They are also characterized by wavy and lenticular bedding,mudcracks, and shale rip-up clasts.

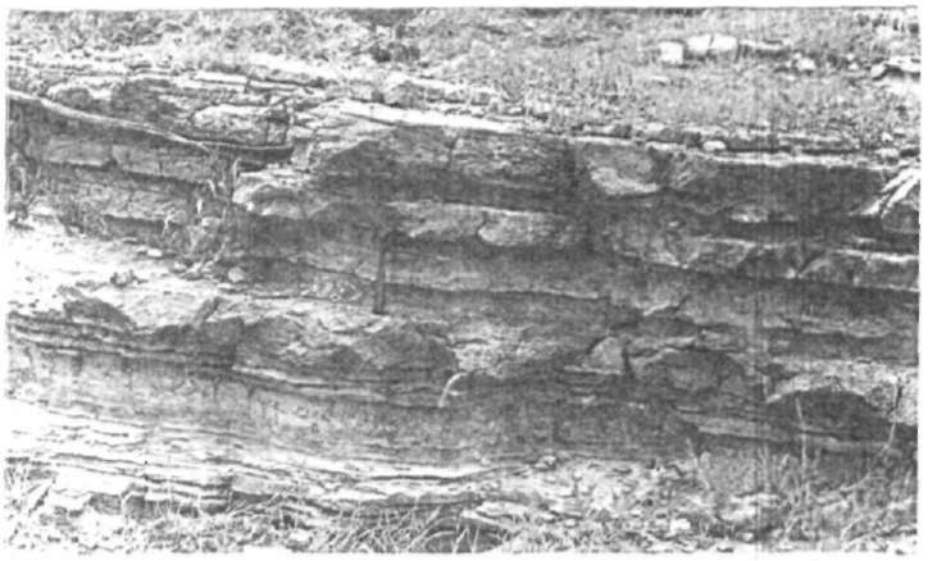


Fig.24.Lacustrine Facies photographed at a burrow pit near Kpaccam off the Maya Lope Numan road.
Courtesy:S.P.Braide.

3.5 BRAIDED FLUVIAL FACIES.

This low-sinuosity facies is dominant in the Yola Arm. It was both observed around the basin margins and also within the basin's axis. The facies is characterised by low variability of paleocurrent vectors and absence of shale beds.Based on the grain-sizes of the deposits in the basin axis and those around the margins, two subfacies have been delineated. The two subfacies are: (1) the pebbly low-sinuosity subfacies, and (2) the sandy low-sinuosity subfacies. The thicknesses of the subfacies vary from 50 - 60m.

3.4.1 PEBBLY LOW-SINUOSITY SUBFACIES.

The subfacies is dominated by planar cross-stratified, pebbly medium to coarse grained sandstones around the northern margin of the Yola Arm. The deposits are generally graded. The normal grading is very clear in most of the planar cross-strata in Girei locality and elsewhere around the margin (Fig 21). The large-scale planar cross stratified pebbly sandstones, probably represent the channel deposits as they prograde down the channel into the axis of the basin. The deposits are generally well rounded and moderately-sorted. The lateral contact between the stream flow fan facies and this subfacies is not very clear.

3.4.2 SANDY LOW-SINUOSITY SUBFACIES.

This subfacies is found in and around the basin axis, where the gradient is relatively gentle compared to the pebbly-low sinuosity subfacies. The deposits consist of medium to coarse grained sandstone and siltstones. They are generally characterized by planar cross-stratified sandstones and siltstones, and locally show deformed cross-bedding, convoluted bedding, parallel bedding and sand volcanoes (Fig 13). The large and small scale planar cross-stratifications in the subfacies generally lack grading in their individual cross-stratum

3.5 MEANDERING FLUVIAL FACIES.

This high-sinuousity facies is found in the basin axis of the Yola Arm, where the gradient is low. The facies is generaly very rare in the study area. The only locality where the facies was observed in the study area is in Tula (Fig 17). The facies is characterised by high variability of paleocurrent vectors and displays more shale beds.It is divided into two subfacies based on the grain sizes and the sedimentary structures. The two subfacies are: (1) Channel subfacies, and (2) Flood plain subfacies.

3.5.1 CHANNEL SUBFACIES.

The subfacies is characterized by a thin unit of pebbly coarse-grained sandstone at the basal part of the deposits. The unit is generaly very massive. It is overlain by a unit of coarse to medium grained sandstones with a general fining upward sequence. The deposits are characterized by

both planar and trough cross-bedding (Fig 17). Deformed planar and trough cross-beds are common. Ripple mark have been reported by Jones (1959) and was confirmed in the rock-section studied. The deposits are generally well-sorted, well rounded and well stratified.

3.5.2 FLOODPLAIN SUBFACIES.

The subfacies is dominant in the upper part of the outcrop studied at Tula (Fig 17). The claystone to siltstone deposits sandwiched between the medium- to coarse-grained sandstones are probably deposited out of suspension when the channel overflooded, its banks.The deposits vary in colour from white to reddish, and are generally massive.

CHAPTER FOUR

DEPOSITIONAL ENVIRONMENTS/MODEL

4.1 INTRODUCTION:

A depositional environment may be defined as a geographically restricted complex that can be described in geomorphic terms. The conditions that prevail in the site of deposition can effect the resulting sediments and subsequently the inherent sedimentary structures. The characteristics of the forming sediments depend largely on the intensity or energy of the process of formation, governed largely by the physical and chemical conditions of the depositional environment. It is also governed by the time or duration through which the action of the formative process is extended and is a function of the tectonic stability or instability of the region (Scholle and Spearing,1982).

The recognition of sandstone depositional environment is not a straight forward procedure, however, substancial progress has been made using palaeoecological principles: but many important rock columns contain inadequate fauna, which means that other methods of environmental determination are necessary. Masters (1967) used the sedimentary structures in the Mesaverde Formation to determine the environments of deposition in the sediments In the present work, both the sedimentary structures and the motif have been used to determine the environment of

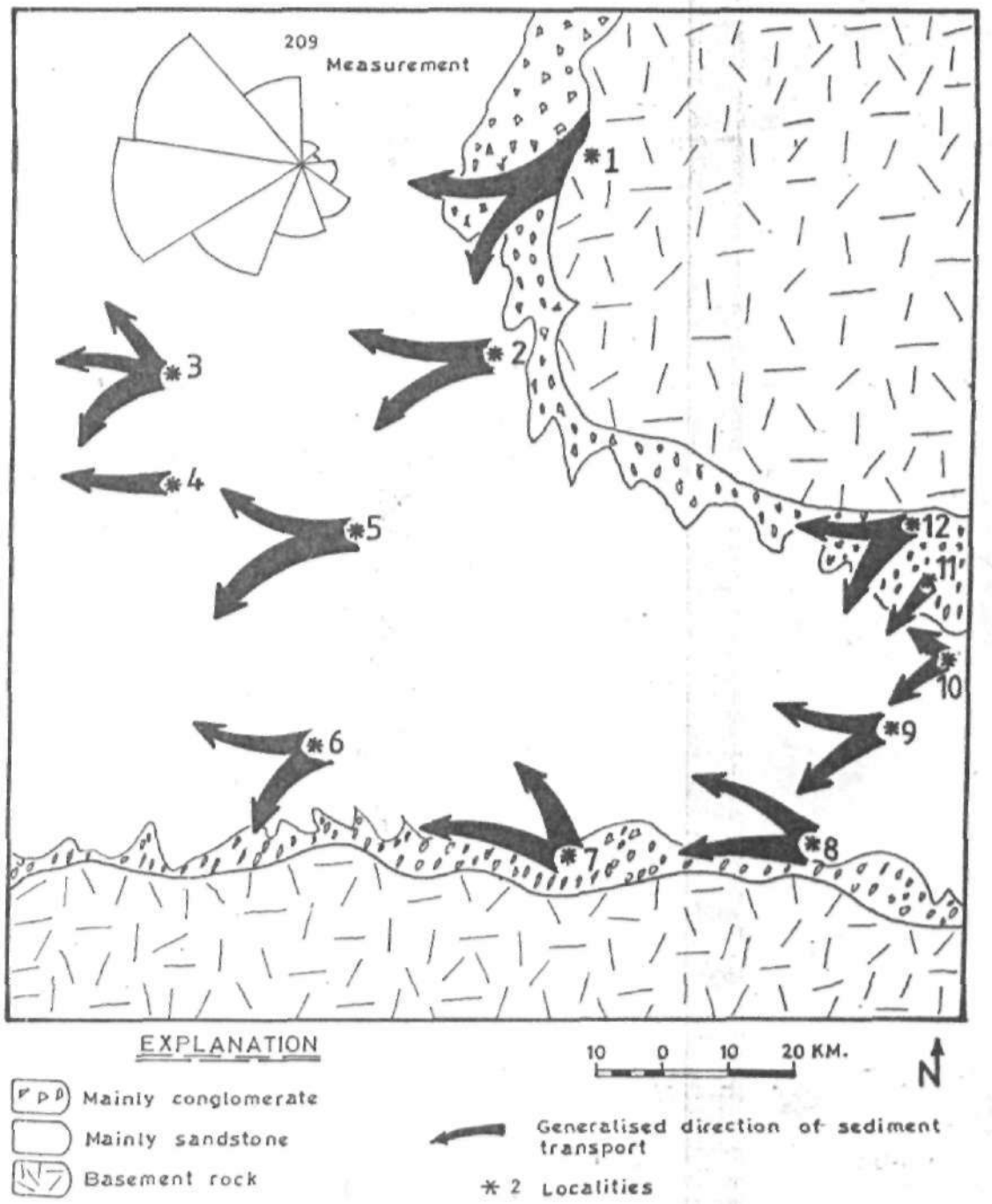


Fig. 25 Simplified Geologic and Palaeogeographic map of the Yola Arm showing major rock types and generalized direction of sediment transport.
FOR LOCALITIES, SEE FIGURE 1.

deposition of the continental sediments of the Bima Sandstone in the Yola Arm.

The depositional environments in the Yola Arm are represented by alluvial fans, fluvial and lacustrine environments each of which is characterized by variation in sediment types and sedimentary structures.

4.2 PALAEOCURRENT ANALYSIS

Palaeocurent directions within the Yola Arm vary considerably from one locality to the other. A total of 209 azimuthal readings were collected from twelve localities, four of which were not discussed in Chapter 2. The number of readings collected from each locality is determined by the availability of the directional structures in the locality.

The readings were not corrected for tilt, because the terrain did not show serious indications of tilting or folding. They were,therefore, used in determining the vector mean of the entire arm, as well as, for the individual localities. The readings for all the localities, are presented in appendix A-F.

The general direction of flow is westwards, but the sediments from the margins tend to flow towards the axis of the basin (Fig 25) in both southward and northward directions for the northern and southern margins, respectively.

4.3 DEPOSITIONAL MODEL

The distribution of the depositional environments in

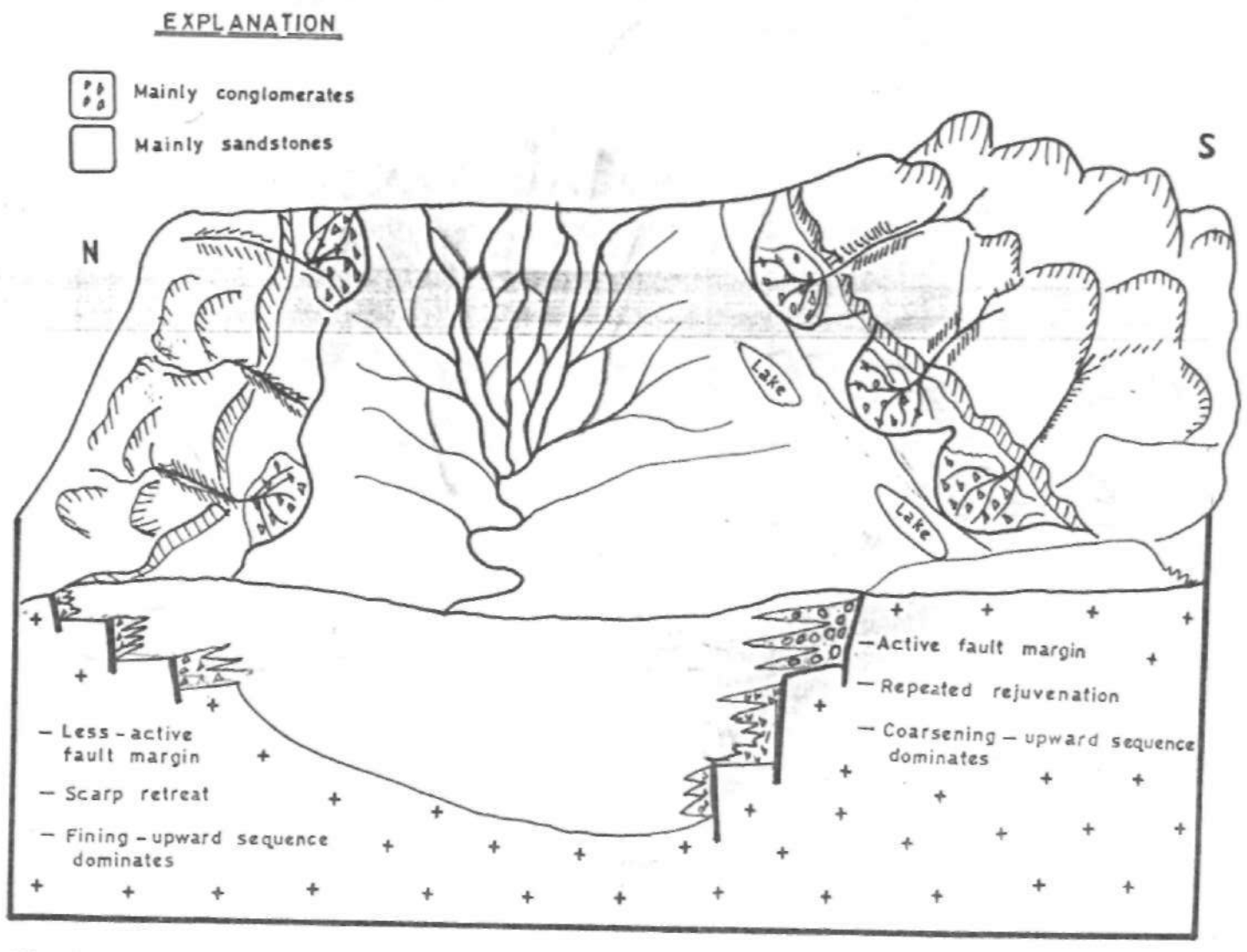


Fig. 26. Depositional model for the Bima Sandstone in the Yola Arm.

(Modified from Steel, 1979)

palaeocurrent data, permits the reconstruction of a depositonal model for the basin (Fig 26).

Coarse-grained conglomerates belonging to the small debris-flow alluvial fan deposits on the southern margin were transported into the basin. Tectonic events along the margin probably uplifted some blocks that must have caused the ponding of some of the sediments, giving rise to the lacustrine deposits around the southern margin.

From the northern margin, fine grained conglomerates, belonging to the large stream- flow alluvial fan deposits were transported southwards into the basin axis The braided fluvial deposits around the northern margin grade distally into meandering fluvial deposits.

The basin margins of the Yola Arm are generally higher, steeper and are responsible for the coarser sediments shed into the basin, just as, Steel and Gloppen (1980) described the Hornelen Basin,explaining that the northern margin fault of the basin,responsible for the coarser grained conglomerates was the dominant fault that controlled sedimentation within the basin.This conclusion explains why the margin of the Yola Arm shed coarser grained conglomerates,and may futher suggest strike-slip faulting, as was the case in Hornelen basin.The pull-apart model for the Benue Trogh was earlier suggested by some workers(Benkhelil,1982;Benkhelil et al.1983;Guiraud et al 1989;Benkhelil,1989;and Guiraud,1990).

4.4 TECTONIC FRAMEWORK

Abundant evidences of syn-sedimentary deformation in the basin fill, which subsequently affected the sedimentary structures in the basin axis suggest possible penecontemporanous seismicity. This implies that the basin-margin faults were seismically active during sedimentation when much of the sedimentary fill was water-saturated (Mclaughlin and Nilsen, 1982). The deformational structures in the basin axis, which may be sandwiched by non-deformed structures, as was the case in the Cham-Lafiya locality (Fig 9), could be explained on the basis of the basin margin tectonics. The deformed structures were generated when sediments were deposited at the same time as the seismic shocks from the basin margins were generated, thus deforming the bedding patterns of the water-saturated sediments. Jones (1962) had earlier tried to explain the origin of deformational cross-stratification in the Bima Sandstone. According to him, the shock waves that went through the sediments was generated from the Cameroom volcanics. He, however, did not explain why all the deposits were not deformed, neither did he give reason for the non-deformation of some sediments along the Cameroon "volcanic line".

The basin margin tectonics responsible for the generation of seismic waves that caused the deformation of the sedimentary structures, may be a futher prove for the Cretaceous strike-slip faulting that formed the Yola Arm.

CHAPTER FIVE

DISCUSSIONS AND CONCLUSIONS

5.1 DISCUSSIONS.

The Yola Arm, formed during the Aptian-Albian times, is elongated parallel to the east- west inherited transcurrent faults. The basin was filled by sediments derived from the southern and northern margins. The active Southern margin fed the basin with coarse-grained, debris flow conglomerates, while the passive northern margin transported the fine-grained streamflow conglomerates into the basin.

The alluvial fans from both margins prograded into the basin by braided streams. The braided streams also graded laterally into meandering streams. The lakes along the southern margin were probably formed when blocks were uplifted by tectonism leading to the ponding of some streams, heading for the basin's axis. These events were reponsible for the three depositional environments in the arm (alluvial fans, fluvial and lacustrine).

Blair (1987) studied the tectonic and hydrologic controls on cyclic alluvial fans, fluvial and lacustrine rift-basin sedimentation of Todos Santos Formation, Mexico, and concluded that the three environments are common to both modern non-marine rifts and pull-apart basins. This conclusion makes it difficult to distinguish between rifts and pull-apart basins on the basis of depositional environments. The problem of distinguishing rifts from

pull-apart basins started as far back as 1921, when Gregory (in Hempton and Dunne, 1984) reported his findings on the East African rift valleys. Since then, nearly all early workers see every extensional basin as a rift. Even after Quennel (1958), Kingma (1958) and Lensen (1958) showed that extensional basins may be formed in strike-slip fault zones, many geologists still misinterprete pull-apart basin deposits as rift deposits.

For more than 35 years, geologists have generally believed that the genesis and evolution of the Benue Trough is connected to continental rifting of purely extensional origin. Recently, Benkhelil (1982) proposed the pull-apart model, explaining that the Benue Trough is a set of juxtaposed pull-part basins initiated and formed by sinistral displacement along some strike-slip faults. Since then, Benkhelil and Robineau (1983), Guiraud et al (1989) and Benkhelil (1989) have improved on the model.

Several workers, including Hempton and Dunne (1984); Crowell (1974a, 1974b, 1975, 1982); Link and Osborne (1978, 1982); Heward and Reading (1980); Steel and Gloppen (1980); McLaughlin and Nilsen (1982), and many others believed that the deposits of alluvial fans, fluvial and lacustrine environmnts in rift basins may be distinguished from those of pull-apart basins. According to them, pull-apart basin deposits have, (1) higher sedimentation rates, (2) greater complexity in structures, (3) greater thicknesses in smaller areas, (4)evidence of strike-slip

including displaced fan/source relationships and (5) successive overlap of basement by sediments caused by a depocenter migrating parallel to the master fault.

The shape, depositional facies and tectonic framework of the Yola Arm, generally resembles those of the better known pull-apart basins of the World, such as the Devonian Hornelen and some adjacent basins of Western Norway (Nilsen, 1973; Steel, 1976; Steel and Gloppen, 1980) and the Miocene and Pliocene Ridge basin of Southern California (Crowell, 1974a, 1974b). These basins, like the Yola Arm, are characterized by active strike-slip bounding faults, that shed coarser grains along, at least one flank of the basin. In the case of the Yola Arm, the southern margin was responsible for all the coarse-grained conglomerates in the basin.

Yola Arm is characterized by a very thick sedimentary fill (Carter et al, 1963; Cratchley and Jones, 1965; Osazuwa et al, 1981; and Ofoegbu, 1988), especially when compared with other pull-apart basins around the world (Hempton and Dunne, 1984). The sedimentary fill ranges from 0.5-4.6km.

The rate of sedimentation is difficult to measure in ancient rocks, however, the presence of sand-volcanoes and convolute bedding have been used by Reineck and Singh(1972) as indication of high sedimentation rate.Therefore the sand-volcanoe observed in the Cham - Lafiya locality (Fig 13) is an indication of the high sedimentation rate in the arm.

The various sedimentary structures in the deposits of the Yola Arm, have been very useful tools in delineating the various depositional facies. Most of these structures are very complex, particularly those in Cham-Lafiya, Bambam and Tula localities. (Fig 9, 14 and 17). The complexity of these structures is caused by the effects of the strike-slip faulting at the southern and northern margins. These tectonic events are also responsible for the coarse-grains transported into the basin.

Successive overlaps of basement by sediments were observed in the Shani locality. These overlaps are caused by the lateral movement of the depocenter parallel to the basin margin fault.

5.2 CONCLUSION

The study shows that the Cretaceous Bima Sandstone in the Yola Arm of the Benue Trough was deposited in alluvial fans,lacustrine,and fluvial environments during the Aptian-Albian times. The alluvial fans has been divided into two facies based on the inherent sedimentary structures and the depositional motifs.Thus the debrisflow facies of the southern margin, which is coarse grained, poorly sorted, unstratified, matrix-supported conglomerates,and the streamflow facies of the northern margin,characterirized by fine grained,morderatly sorted,well stratified,clast-supported conglomerates.

The fluvial deposisional environment was also classified into two facies.Thus the braided facies

characterised by low variability of paleocurrent vector and the absence of shale;and the meandering facies with high variability of the paleocurrent vector and the display of shale beds.

The lacustrine enviroment is characterised by silts and shales,wavy and lenticular bedding,mudcracks,and shale rip-up clasts.

Yola Arm is considered as pull-apart basin formed by strike-slip faults,based on sedimentological data,such as, the evidence of strike-slip,responsible for the coarser grains shed into the basin,the very thick sedimentary fill in smaller areas,indicated by the presence sand-volcanoes and convolute bedding,the complexity of sedimentary structures,and the higher sedimetation rate.

Stike-slip systems are said to be both actually and potentially important areas for oil reserves (Moody,1973;Harding,1974;Holmgren et al,1975).The reason is that strike-slip fault systems provide ideal conditions for source rocks, reservior rocks,seals and traps(Reading,1980).The Yola Arm,however, is a pull-apart basin with a difference.Although the basin has fulfilled all the requirements of being a good petroleum reserve,but because of the the Tertiary volcanic plugs distributed throughout the basin(Carter et al,1963),the intense heat generated during the volcanic eruption could have 'overcooked'the possible oil reserve.

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APPENDIX A

FREQUENCY DISTRIBUTION OF AZIMUTHAL READINGS FROM SHANI AND GUYUK LOCALITIES

SHANI LOCALITY.

Class interval	Frequency	% Frequency
0 - 40	0	0
41 - 80	0	0
81 - 120	1	6
121 - 160	1	6
161 - 200	5	34
201 - 240	4	25
241 - 280	6	46
281 - 320	0	0
321 - 360	0	0

GUYUK LOCALITY

Class Interval	Fequency	% Frequency
0 - 40	0	0
41 - 80	0	0
81 - 120	0	0
121 - 160	0	0
161 - 200	0	0
201 - 240	2	12
241 - 280	5	33
281 - 320	8	56
321 - 360	0	0

APPENDIX B

FREQUENCY DISTRIBUTION OF AZIMUTHAL READINGS FROM MAYO INE AND GIRIE LOCALITIES

MAYO INE LOCALITY

Class Interval			Frequency	% Frequency
0	-	40	1	7
41	-	80	0	0
81	-	120	1	7
121	-	160	0	0
161	-	200	1	7
201	-	240	2	14
241	-	280	1	7
281	-	320	4	28
321	-	360	4	28

GIREI LOCALITY

Class Interval			Frequency	% Frequency
0	-	40	0	0
41	-	80	0	0
81	-	120	0	0
121	-	160	0	0
161	-	200	0	0
201	-	240	0	0
241	-	280	7	35
281	-	320	10	50
320	—	360	3	15

APPENDIX C

FREQUENCY DISTRIBUTION OF AZIMUTHAL READINGS
FROM NASSAWO FURO AND MALLAM MADUGU

NASSARAWA FURO LOCALITY

Class Interval			Frequency	% Frequency
0	-	40	0	0
41	-	80	0	0
81	-	120	0	0
121	-	160	0	0
161	-	200	3	25
201	-	240	7	50
241	-	280	1	7
281	-	320	0	0
321	-	360	3	25

MALLAM MADUGU LOCALITY

Class Interval			Frequency	% Frequency
0	-	40	0	0
41	-	80	0	0
81	-	120	0	0
121	-	160	0	0
161	-	200	2	17
201	-	240	3	25
241	-	280	3	25
281	-	320	5	50
321	-	360	0	0

APPENDIX D

FREQUENCY DITRIBUTION OF AZIMUTHAL READINGS FROM KPASSAM AND MURKE LOCALITIES

KPASSAM LOCALITY

Class Interval			Frequency	% Frequency
0	–	40	0	0
41	–	80	0	0
81	–	120	0	0
121	–	160	1	7
161	–	200	3	21
201	–	240	0	0
241	–	280	2	14
281	–	320	6	42
321	–	360	2	14

MURKE LOCALITY

Class Interval			Frequency	% Frequency
0	–	40	0	0
41	–	80	0	0
81	–	120	0	0
121	–	160	6	50
161	–	200	1	7
201	–	240	1	7
241	–	280	2	14
281	–	320	2	14

APPENDIX E

FREQUENCY DISTRIBUTION OF AZIMUTHAL READINGS
FROM YOLA AND LAFIYA/CHAM LOCALITIES

YOLA LOCALITY

Class Interval			Frequency	% Frequency
0	-	40	1	3
41	-	80	0	0
81	-	120	2	6
121	-	160	0	0
161	-	200	4	12
201	-	240	7	25
241	-	280	10	35
281	-	320	3	10
321	-	360	5	16

LAFIYA CHAM LOCALITY.

Class Interval			Frequency	% Frequency
0	-	40	0	0
41	-	80	0	0
81	-	120	0	0
121	-	160	4	12
161	-	200	0	0
201	-	240	6	20
241	-	280	8	25
281	-	320	9	27
321	-	360	6	20

APPENDIX F

FREQUENCY DISTRIBUTION OF AZIMUTHAL READINGS
FROM TULA AND BAMBAM LOCALITIES

TULA LOCALITY.

Class Interval			Frequency	% Frequency
0	-	40	0	0
41	-	80	0	0
81	-	120	0	0
121	-	160	0	0
161	-	200	1	10
201	-	240	0	0
241	-	280	5	50
281	-	320	3	30
321	-	360	2	20

BAMBAM LOCALITY

Class Interval			Frequency	% Frequency
0	-	40	0	0
41	-	80	0	0
81	-	120	0	0
121	-	160	1	8
161	-	200	1	8
201	-	240	1	8
241	-	280	8	66
281	-	320	1	8
321	-	360	0	0