STRATIGRAPHY AND STRUCTURE OF BASHAR AREA, NORTHEAST NIGERIA

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BY

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DECLARATION

I declare that the work in the thesis entitled 'Stratigraphy and structure of Bashar Area' has been performed by me in the Department of Geology under the supervision of Prof. P.M. Zaborski and Dr. A.E Bala.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

MORU, OYIZA OMOLOLA **JULY, 2010**

Name of Student	**Signature**	**Date**

CERTIFICATION

This thesis entitled "STRATIGRAPHY AND STRUCTURE OF BASHAR AREA" by Moru, Oyiza Omolola 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 knowledge and literary presentation.

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DEDICATION

This project is dedicated to Almighty God for his Grace and Mercy that enabled me to complete this thesis, and to my angels Anavami and Ohunene for their patience and understanding.

ACKNOWLEDGEMENT

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Finally, I acknowledge the help of Mallam Hamidu during my field work, without whose help this project would not be complete. I say thank you all.

ABSTRACT

The project concerns the stratigraphy and structure of the Bashar area situated in both Dengi and Wase Local Government Areas of Plateau State. Early Cretaceous rifting was accompanied by faulting which gave rise to the Garga extensional fault which controlled the deposition of the Bima Group; this was followed by a thermo tectonic sag stage of basin development accompanied by the deposition of the marine Yolde Formation. Synsedimentary tectonics which continued into the Cenomanian affected the Yolde Formation giving rise to an unconformity within the Yolde Formation. Santonian to Campanian compressioanl events are recognizable in the Yolde and Pindiga Formations which were accompanied by the eruption of lava on the latter. Late Campanian to Maastrichtian renewed rifting led to the deposition of the Gombe Formation above the Pindiga Formation. Late Cretaceous to early Paloegene compressional events, accompanied by faulting are recognizable in the Gombe Formation by the presence of the thrust/reverse Garga fault and the "Gwangen" anticline and "Gir" syncline. This second episode of compressional events affected the pre-Santonian beds, effect is most evident in the tightness of the Yolde Formation.

The Bashar area compared to elsewhere in the Upper Benue Trough has a marked angular unconformity between the Pindiga/Gombe contact and the Gombe Formation here is made up of a two main facies namely: the lower pebbly sand which is indicative of a braided river deposit (braided bar) and an upper "red sandstone" facies indicative of downstream migration of the braided bar deposit. These sandstones around Bashar can be interpreted as a fining-upward deltaic-like deposit prograding toward the north.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 AIM AND OBJECTIVES OF THE PROJECT

The aim and objectives of this project are to carryout detailed geological mapping of the Bashar area on a scale of 1:80,000; to identify the various rock types; to determine their field relationships; to determine the structural styles; stratigraphy; and the geological history of the region.

To achieve the aim and objectives a literature review of previous work done in the area were carried out, after which satellite image and aerial photograph interpretations were done to outline outcrop patterns and geological structure.

The field mapping exercise enabled observations, sampling of rock-types and plotting of sample points to be made. These were done with the use of a global positioning system (GPS) for determining the co-ordinates of the different locations, a compass clinometer for determining dip amount and direction of sedimentary beds, measuring tape for measuring bed thickness, hammer and sample bags for loosening and collection of rock samples respectively following procedures such as:

- Recording dip amounts and direction of sedimentary bedding and cross-bedding.
- Recording the lithologies, grain sizes, colour, texture and thickness of the sedimentary beds.
- Sampling of the rock types for laboratory analysis which include sieve analysis and thin section analysis.

The information obtained was used to produce a geological map with elevation of the Bashar area, and to describe its geological history.

1.2 PREVIOUS WORK

Geological investigations in the Bashar area have been few in number. The area south of Bashar was included in a photogeological map prepared by Dessauvagie (1969). Ayoola (1981) proposed the stratigraphical succession for the Bashar area. Benkhelil (1988; 1989) identified "Bashar" as one of the sub-basins in the Benue Trough with a relatively thick sedimentary succession. Guiraud (1991) indicated discontinuities and onlap within the Yolde Formation around Sabon-Gida area southeast of Bashar, which he called the Bima (3) sediment. Zaborski *et al*. (1997) produced an outline geological map of the Bashar-Yuli area (Fig. 1)

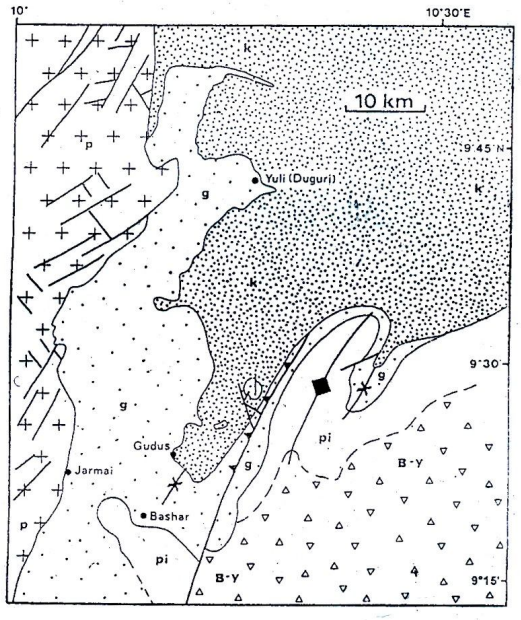


Fig. 1: Geological map of Bashar-Yuli area in the Southwestern part of the Upper BenueTrough (*after Zaborski et al., 1998*)

p.crystalline basement; B-y, Bima Group and Yolde Formation: pi, Pindiga Formation: g, Gombe Formation; k, kerri kerri Formation.

anticlinal axis; X synclinal axis; fault: thrust/reverse fault.

1.3 LOCATION AND ACCESSIBILITY

The area mapped is situated in Dengi and Wase Local Government Areas of Plateau State and forms part of Federal Survey of Nigeria 1:100,000 sheet 192 (Bashar). It lies between latitudes 9°15'N and 9°30'N and longitudes 10°00'E and 10°30'E. The area covers approximately 80km² (Fig. 2). Accessibility is difficult as there are no major roads in the area. Minor roads are the Dengi-Jarmai, Jarmai – Bashar, Jarmai – Turyam and Bashar-Yuli roads, but four-wheel drive is needed. The main settlements in the study area are Jarmai, Bashar, Gudus, Turyam, Garga and Yuli. The area has a network of footpaths and river channels which are dry from November to April.

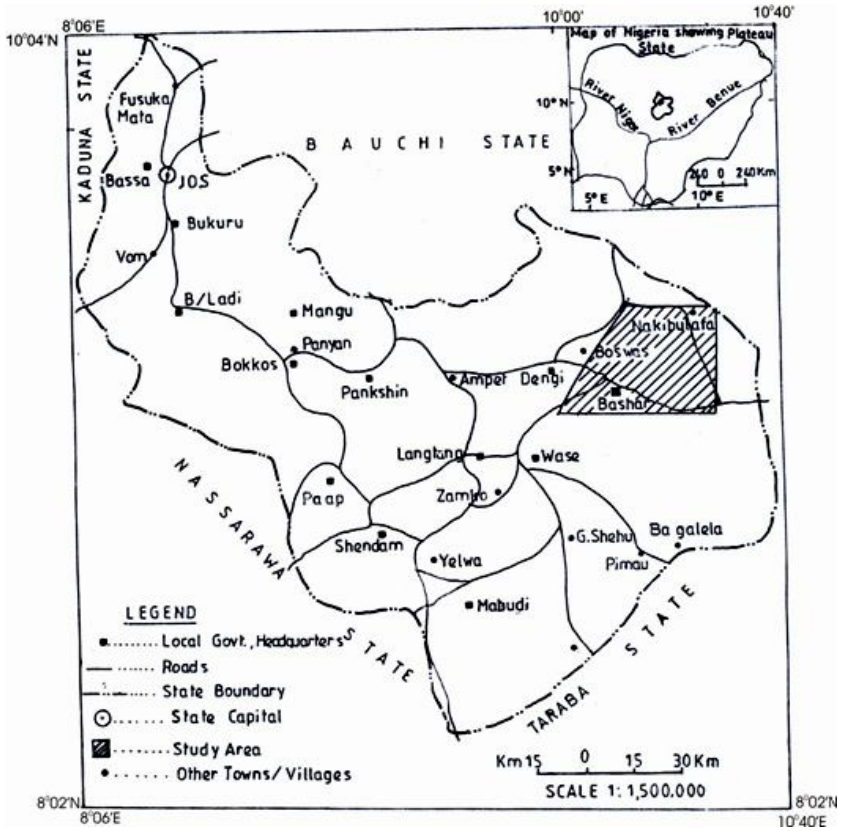


Fig. 2: Map of Plateau State showing Bashar in Dengi L.G.A. and study area.

1.4 TOPOGRAPHY AND DRAINAGE

The project is characterized by basement rocks and sediments creating a varied topography. The area is intersected by deep and wide river channels and small streams which drain the area. The flow direction of the rivers and streams is dominantly southwards. The basement rock portion is characterized by a trellis drainage pattern where the main streams are controlled by fractures and tributaries which join the main streams nearly at right angles. The sedimentary outcrops are characterized by dendritic, rectangular and angular drainage patterns where the streams have an irregular branching pattern and join the main streams at acute angles. The rivers are seasonal.

1.5 CLIMATE AND VEGETATION

The area, like other parts of northern Nigeria is characterized by two distinct (dry and wet) seasons. The wet season starts in the month of May (with the highest peak of rainfall in July – August) and ends in October. The dry season lasts from November to April. The area lies within the Sudan Savanna vegetational zone, which is characterized by grasses, thorny bushes, orchard bushes, and open forest.

1.6 SETTLEMENT AND LAND USE

The project area contains both nuclear and dispersed settlements but is overall sparsely populated. The land is used mainly for farming and hunting.

CHAPTER TWO

2.0 GEOLOGY OF THE BENUE TROUGH

2.1 INTRODUCTION

The linear NE–SW trending Benue Trough (Fig. 3) has a length of approximately 800km and distally opens into the Gulf of Guinea. Proximally it

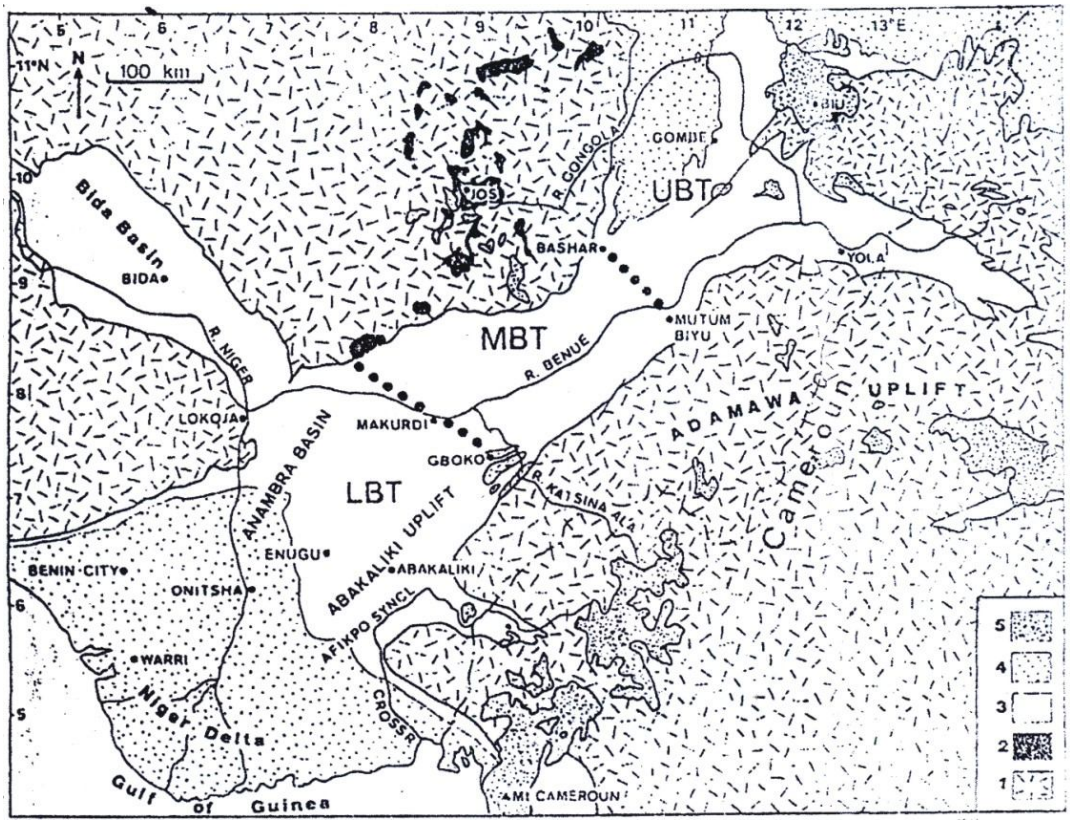


Fig.3: Outline geological map of the Benue Trough and adjacent area. LBT, lower Benue Trough; MBT, middle Benue Trough; UBT, upper Benue Trough. 1, Precambrian; 2, Jurassic "Younger Granites", 3, Cetaceous; 4, Post-Cretaccous Sediments, 6, Cenozoic-Recent basalts (including those of the Cameroun line).

bifurcates into an E–W trending Yola arm and a N–S trending Gongola basin. The Benue Trough "Proper" was terminated by a Late Santonian episode of compressional folding.

Subsequent sedimentation was centred in basins developed on the north–western flank of the resultant deformed sediments.

2.2 ORIGIN AND NATURE OF THE BENUE TROUGH

The Benue Trough is an elongated basin which forms an important part of the West and Central African rift system (Binks and Fairhead, 1992; Maurin and Guiraud, 1993). It is the most important of the Cretaceous sedimentary basins in Nigeria. It is a Mesozoic basin that extends from the Gulf of Guinea north – Eastwards to the Chad (Bornu) basin. The Benue Trough is conventionally sub-divided into a "Lower Benue Trough" [= "Abakaliki Trough" of Murat (1972) and Whiteman (1982)], a middle Benue Trough" and an "Upper Benue Trough" [= "Benue Trough" of Murat (1972); "Lower" and "Upper Benue Trough" respectively of Whiteman (1982); Fig. 3]. The study area falls at the north-western part of the junction of the middle and the upper Benue Trough.

Based on geomorphological, geophysical and paleontological evidence, five major theories have been postulated to explain the origin and mechanism responsible for the formation of the Benue Trough. These are: (a) King's rift theory; (b) Lee's compressional origin theory; (c) Burke *et al*., triple junction theory; (d) The Aulacogen theory; (e) Benkhelil's strike-slip model.

2.2.1 King's Rift Theory

King (1950) regarded the Benue Trough and the Bida Basin/Gao Trough as extensions of the rifts which produced the Equatorial and South Atlantic oceans, respectively. The evolution of the trough was related to the stresses that accompanied the separation of South America from

Africa Carter *et al*., (1963) and Wright (1968) accepted this view and developed it by using stratigraphic, structural and geophysical data.

2.2.2 Lee's Compressional Origin Theory

Lees (1952) suggested that the trough could be a compressional downwarp feature, since it had no marginal faults, the folding being induced by deep-seated basement contraction.

2.2.3 Burke's *et al*. Triple Junction Theory

Burke *et al*. (1971; 1972), believed that the relationship between the Benue Trough and the Equatorial and South Atlantic was of a R.R.R (rift-rift-rift) triple junction nature. The spreading of the Benue rift according to them was short-lived and a convergent episode was responsible for Santonian folding in the trough. The triple junction however was a R.R.F (rift-rift-fault) according to Grant (1971). The transform fault making up the Gulf of Guinea segment was due to the ephemeral nature of the spreading below the Benue Trough (Fig. 4b).

2.2.4 Aulacogen Theory

Olade (1975; 1976; 1979) related the Early Cretaceous magmatism to hotsport activity and interpreted the Benue Trough as an aulacogen related to intermittent mantle upwelling (Fig. 4a).

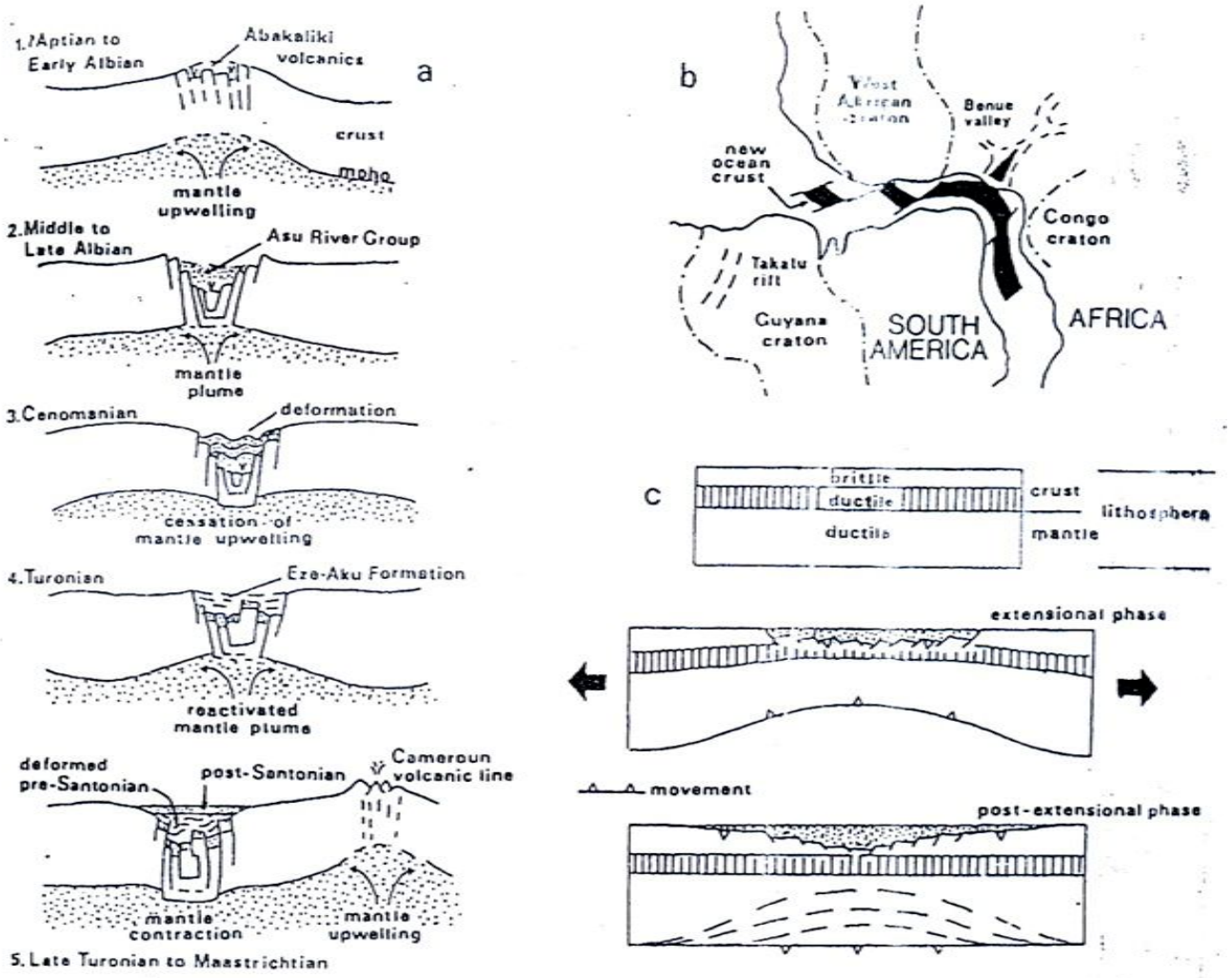


Fig. 4.a, Proposed stages in the tectonic evolution of the Benue Trough involving active mantle upwelling (after Olade, 1975). b, Sketch map of the Gulf of Guinea area in the Early Cretaceous with the lower Benue Trough floored by oceanic crust (after Burke et al., 1971, 1972). c, Lithospheric model for the WCARS basins involving extension and passive upwelling (after Fairhead, 1988).

2.2.5 Benkhelil's Strike-Slip Model

Benkhelil (1989) regarded the Benue Trough as always having been floored by continental crust. On this basis he developed a strike-slip model for the Benue Trough for which he later provided syntheses (Benkhelil 1986, 1988, 1989). He later retreated slightly from a pure

strike-slip model regarding the evolution of the Benue Trough as best explained by a combination of extension and strike-slip movements (Benkhelil 1988; Fig. 5).

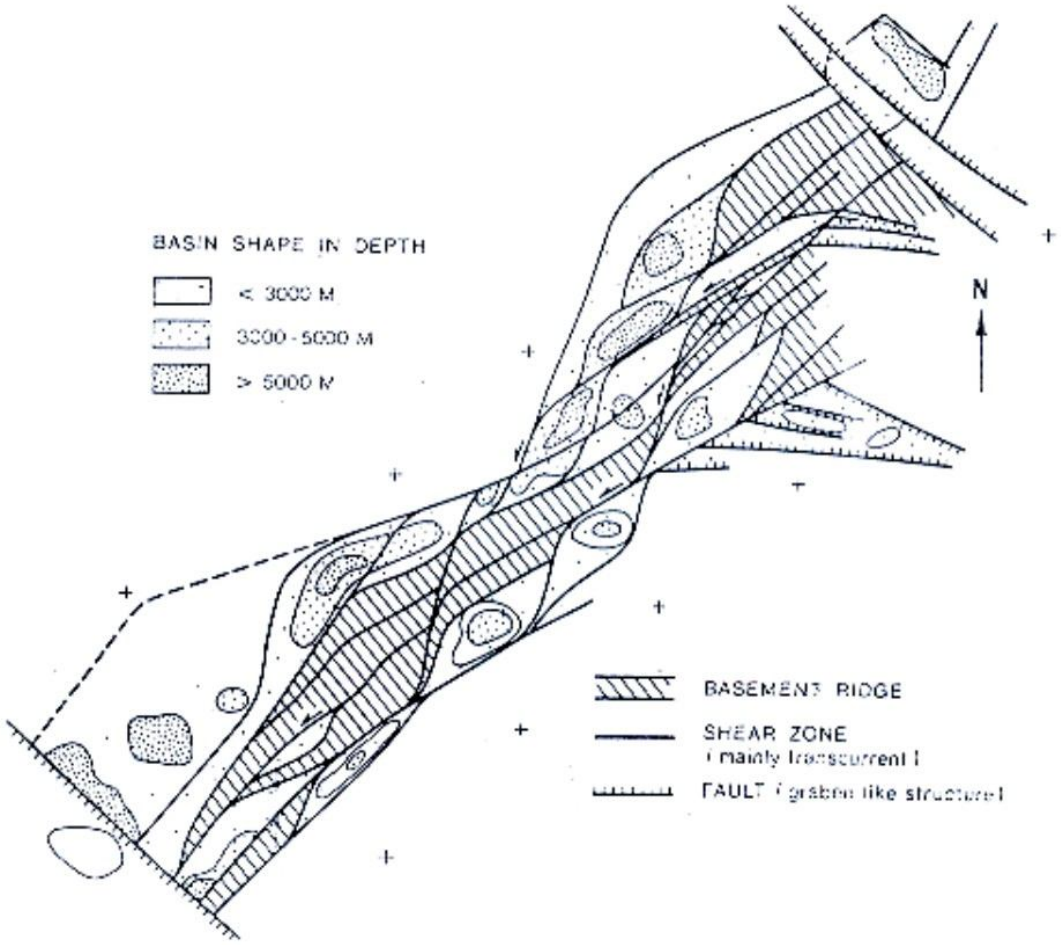


Fig. 5: Model of evolution of the Aptian-Albian sub-basins of the Benue Trough along a transcurrent fault system (after BENKHELIL 1988).

2.3 Geology of the Upper Benue Trough

The Upper Benue Trough comprises the area extending from the Bashar- Mutum Biyu line as far north as the "Dumbulwa Bage high" Zaborski *et al*. (1998), which separates it from the Bornu Basin. The Bashar-Mutum Biyu line marks the junction that separates the middle Benue Trough and the Upper Benue Trough. The project area falls around the northwestern part of this line (Fig. 3). This boundary marks the southern limits of the Gombe and Kerri-Kerri formations while the older sediments of the Upper Benue Trough undergo lateral facies changes in the area. Early studies of the Upper Benue Trough were carried out by Falconer (1911), Jones (1932), Raeburn and Jones (1934) and Barbar *et al*. (1954). The basis for all later work was provided by Carter *et al*. (1963). The Upper Benue Trough has since become known in greater detail and has been almost entirely re-mapped through the work of Allix (1983), Benkhelil (1985; 1986; 1988), Popoff (1988), Guiraud (1989, 1990; 1991; 1993) and Zaborski *et al*. (1998).

2.3.1 Structure

The Upper Benue Trough includes an E – W trending Yola arm and a N – S trending Gongola arm or Gongola Basin (Fig. 6). These two branches are separated by an area structurally dominated by four major NE – SW trending sinistral strike-slip faults, the Gombe, Bima-Teli, Kaltungo and Burashika faults; basement inliers, notably the Kaltungo inlier are associated with them (Zaborski *et al*. 1998; Figs 6, 7).

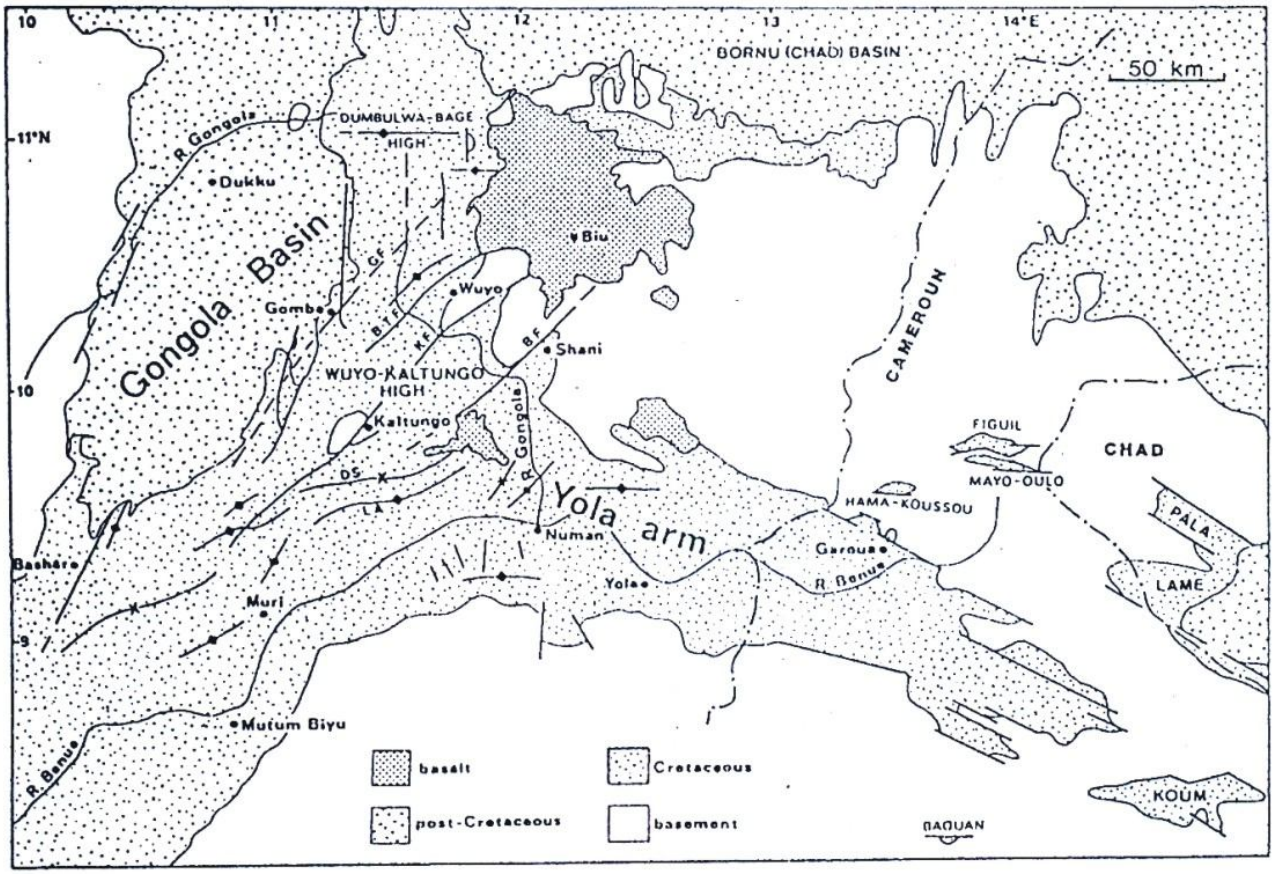


Fig.6: Outline geological map showing the main features of the upper Benue Trough region; GF, Gombe Fault; B-TF, Bima-Teli Fault; KF, Kaltungo Fault; BF, Burashika Fault; DS, Dadiya syncline; LA, Lamurde anticline. (*after Zaborski et al., 1998*).

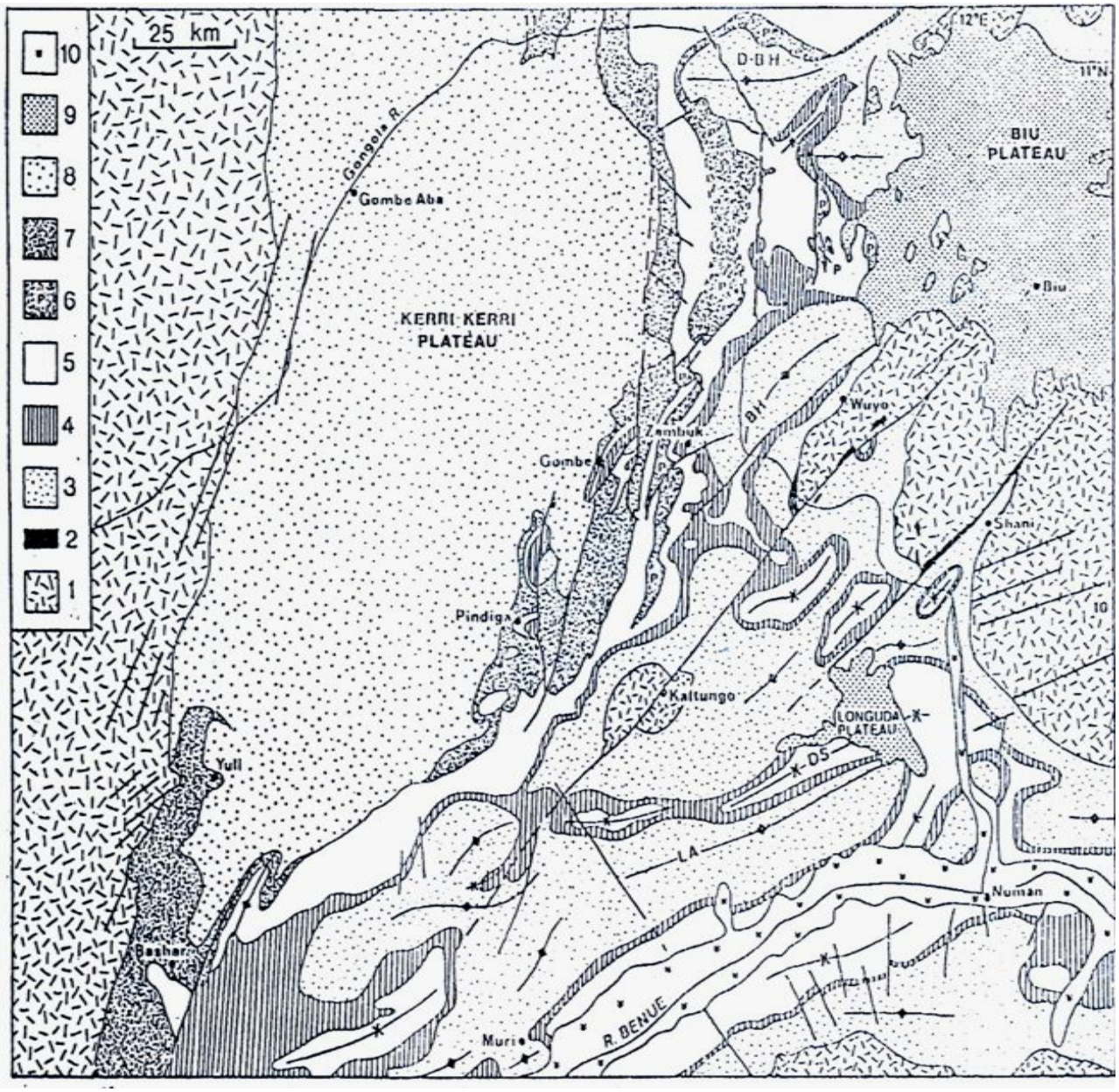

25 km
10
9
8
7
6
5
4
3
2
1
11
12°E
11°N
D-D H
Gongola R.
Gombe Aba
KERRI KERRI
PLATEAU
BIU
PLATEAU
Biu
Wuyo
BH
Zambuk
Gombe
Shani
Pindiga
Kaltungo
LONGUDA
PLATEAU
DS
LA
Yuli
Numan
Bashar
Muri
R. BENUE

Fig. 7: Geological map of the Upper Benue Trough region (based on Benkhelil, 1985; Guiraud, 1989; Zaborski et al., 1998). 1, Precambrian; 2, Late Jurassic? To Early Cretaceous volcanic; 3, Bima Group; 4, Yolde Formation; 5, Pindiga Formation and lateral equivalents in the Yola arm; 6, sandy members of the middle part of the Pindiga Formation in the Gongola Basin; 7, Gombe Sandstone; 8, kerri kerri Formation; 9, Neogene to Quaternary basalt; 10, alluvium; D-BH, Dumbulwa-Bage high, BH, Bima Hills; DS, Dadiya syncline; LA, Lamurde anticline.

A series of N – S to NNE – SSW trending faults controls the trend of the Gongola Basin (Zaborski *et al*. 1998; Fig. 6) while deep seated E – W trending fractures appear to characterize the Yola arm (Benkhelil, 1988; Maurin and Guiraud, 1989; 1990; Braide, 1992). The thickest sedimentary successions occur in the western part of the Gongola Basin to which Campano – Maastrichtian and Cenozoic deposits are restricted. Over 5 km of sediments occur in the "Dukku", "Ako" and "Bashar" sub-basins, thinner successions occur in the "lau" and "Numan" sub-basins of the Yola arm (Benkhelil, 1988; 1989: Fig. 8). The Yola arm extends eastwards into Cameroun where it is known as the Garoua Basin, bounded at its eastern extremity by NW – SE trending, sinistral strike slip-faults. A number of small, barremo – Aptian, E – W trending half-grabens of transtensional origin also occur in this region, the Hama – Koussou, Figuil, mayo-Oulo, Koum (Mayo Reg) and Baouan basins, which have fluvio-lacustrine infill (Maurin and Guiraud, 1989; 1990).

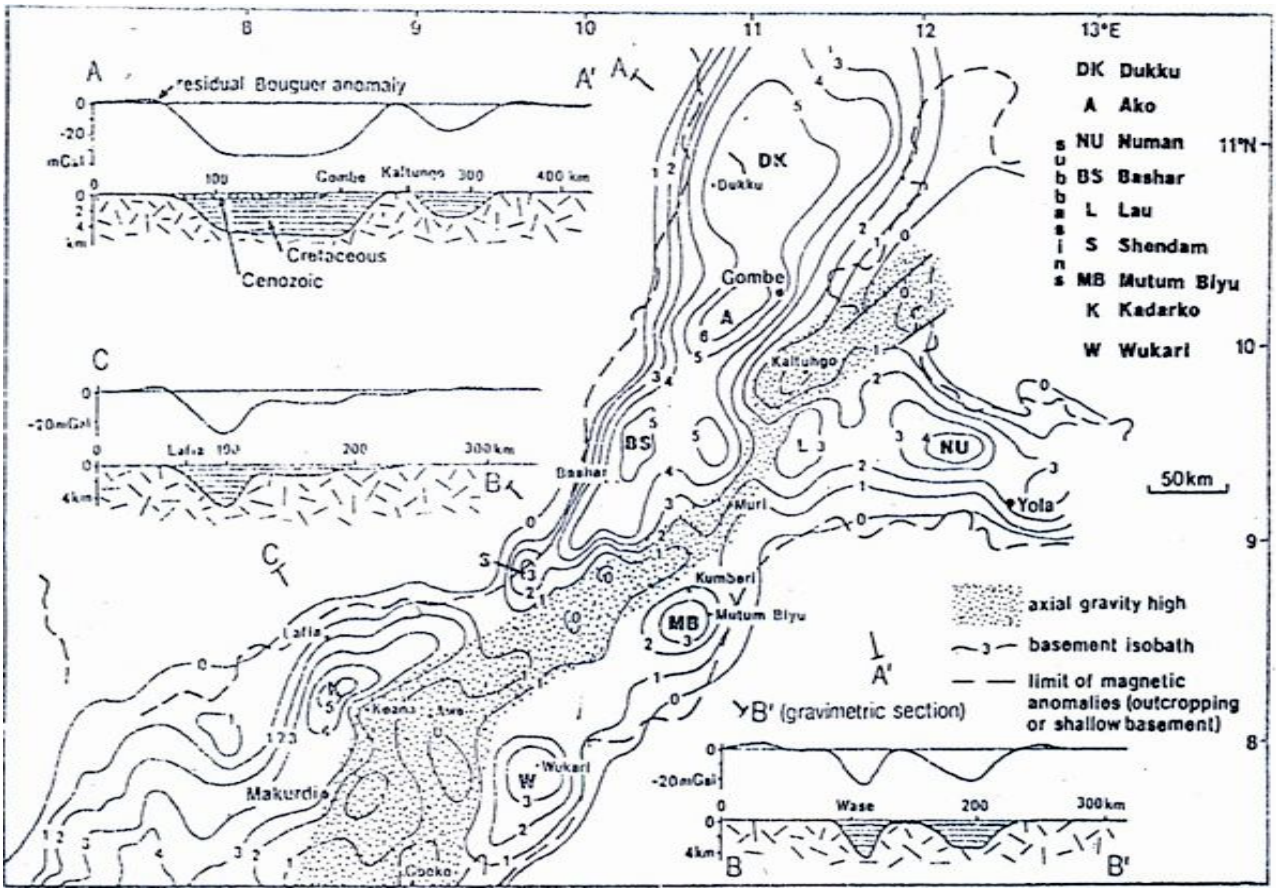
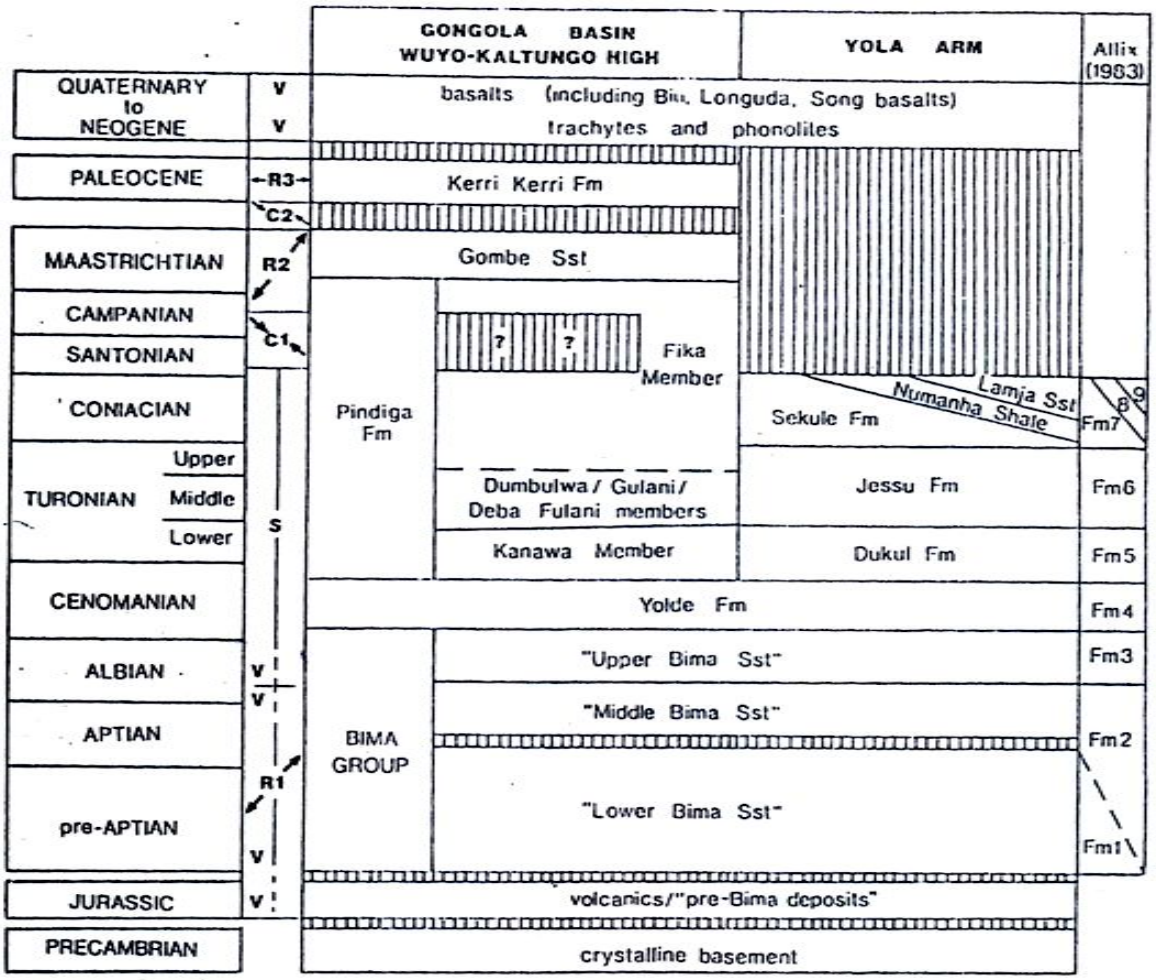


Fig. 8: Basement isobaths (km below sea level) in the middle and upper Benue Trough deduced from gravity and magnetic data; selected gravimetric profiles (as indicated) and their interpretation also shown (after Benkhelil, 1988, 1989; Benkhelil et al., 1988).

2.3.2 Stratigraphy

The Cretaceous succession in the Upper Benue Trough comprises Early Cretaceous continental clastics (the Bima Group) and a dominantly marine Late Cretaceous succession (Yolde Formation). The former includes the oldest sediments known in the Benue Trough, deposited during active rifting. During the Late Cretaceous thermo-tectonic sag conditions prevailed and sedimentation was strongly influenced by transgressive-regressive events. The Upper Cretaceous may be divisible into discrete pre-Santonian and Campano-Maastrichtian parts. The latter includes the Upper Fika Member of the Pindiga Formation and the Gombe Formation, deposited during a renewed phase of rifting (Zaborski *et al*. 1998; Fig. 9).



fFig. 9: Lithostratigraphical successions present in the upper Benue Trough region (subdivision of the Bima Group after Guiraud (1990a, 1991a), see text for other sources). V, volcanic episodes; R1, Early Cretaceous strike-slip related rifting; S, thermo-tectonic sag phase; CI, first compressional phase, associated with strike-slip movemements; R2, Campano-Maastrichtian rifting; C2, terminal Cretaceous compression, associated with strike-slip movements; R3, Paleocene rift stage. (*after Zaborski et al., 1998*).

2.3.3 The Lower Cretaceous Series (Bima Group)

The continental Bima Group comprises the oldest sediments in the Upper Benue Trough which directly overlie the crystalline basement rocks. Guiraud (1990; 1991) described its three parts as: the Upper Bima; Middle Bima and Lower Bima Sandstones.

The "Upper Bima Sandstone" ("B3"), fairly homogenous, relatively mature, fine to coarse-grained sandstone characterized by tabular cross-bedding with sets a few tens of centimeters to a few metres thick; convolute bedding and over-turned cross-bedding are common. The average thickness is 500 metres with a maximum of 1,500 metres;

The "Middle Bima Sandstone" ("B2"), a widely distributed, fairly uniform unit consisting of fining – upward cycles each 5 to 10 metres thick. Trough and tabular cross-bedding characterise the sandstones, while clays and palaeosols may occur at the top of individual cycles. The overall thickness is some 100 to 500 metes.

The "Lower Bima Sandstone" ("B1"), a highly variable unit with an overall thickness of 0 to over 1500 metres. Individual lithofacies distribution was controlled by synsedimentary tectonic activity which created a number of sub-basins consisting of conglomeratic alluvial fan/debris flow deposits, adjacent to active basin-forming faults grading laterally into fining upward fluvial sequences and in places, into lacustrine deposits with inter-bedded clays, fine-grained sandstones and calcareous sandstones.

2.3.4 The Upper Cretaceous Series

The Yolde Formation

The name "Yolde Formation" was proposed by Carter *et al*. (1963) for the "transition beds" recognized earlier by Falconer (1911) and Barber *et al*. (1954) between the Bima Group and the Pindiga Formation. A type section was designated in the Yolde stream in the western part of the Yola arm. More recent descriptions of the Yolde Formation in that area were given

by Allix (1983). The lower part of the formation consists of alternating sandstones and dark grey mudstones. Above, the Yolde Formation consist of regularly bedded sandstones with argillaceous intercalations. Bioturbations (*Planolites*) is common towards the top while groove marks are present on some beds.

The Pindiga Formation

The name "Pindiga Formation" was proposed by Carter *et al*. (1963) for the "Calcareous Beds" and "clay-shales" previously described by Barber *et al*. (1954). It makes up the greater part of the Upper Cretaceous deposits in the Upper Benue Trough. The nature of the Pindiga Formation is best understood by regarding it as consisting of five members, according to Zaborski *et al*. (1997).

Above, the Fika Member, being the equivalent of the "Fika shales" of Carter *et al*. (1963) and the Upper shaly part of the "Pindiga Formation" of the same authors;

The Dumbulwa Member, being the probable equivalent of the Upper Sandstone shale member of the "Gongila Formation" of Carter *et al*. (1997);

The Deba Fulani Member, a unit first recognized by Zaborski *et al*. (1997);

The Gulani Member, being the "Gulani Sandstone" of Carter *et. al*. (1963); and below, the Kanawa Member, being the "Kanawa Formation" of Thompson (1958) and the lower, shale-limestone members of the "Pindiga Formation" and "Gongila Formation" of Carter *et al*. (1963).

The Gulani, Deba Fulani and Dumbulwa Members are lateral lithofacies equivalents occurring in the middle part of the Pindiga Formation Zaborski *et al*. (1997).

The Gombe Formation

The Gombe Formation corresponds to the name "Gombe Sandstone" which was proposed by Carter *et al*. (1963) for the "Gombe grits and clays" previously identified by Falconer (1911). The Gombe Formation is restricted to the western part of the Gongola Basin.

2.3.5 The Post-Cretaceous Rocks

The Kerri–Kerri Formation

The continental clastics of the Kerri–Kerri Formation, which reach a thickness of over 320 metres, have been described by Adegoke *et al*. (1986) and Dike (1995) to be of Paleocene in age. The irregular topography of the unconformity surface that separates the Kerri–Kerri Formation from the Gombe Formation is exposed on the northern outskirts of Gome town.

Volcanics

Numerous small intrusions composed of basalt, trachyte and phonolite penetrate all the Cretaceous Formations. Grant *et al*. (1972) gave radiometric ages ranging from 22.8 ± 0.6 Ma to 2.5 ± 0.1 Ma for these bodies. Pliocene and Quarternary eruptive and associated volcaniclastic depositional phases were separated by an interval of weathering and erosion (Turner, 1978, Braide, 1994). From aeromagnetic data, Benkhelil (1986, 1988) identified a concentration of volcanic rocks with a NE – SW alignment north of Bashar. Although mostly concealed, they include basalts dated 41 Ma and 30 Ma which lie upon the Kerri-Kerri Formation (Fig. 20).

CHAPTER THREE

3.0 GEOLOGY OF THE BASHAR AREA

3.1 INTRODUCTION

The area comprises the north-western part of the Bashar–Mutum Biyu line which is also the junction that separates the Middle Benue Trough and the Upper Benue Trough.

3.2 PREVIOUS WORK

Studies of the Bashar area were carried out by Dessauvagie (1969) who produced a photogeological map including the area south of Bashar (Fig. 10). Lithostratigraphically six units were recognized. The Basement Complex, Bima Group, Yolde, Pindiga, Gombe and Kerri-Kerri formations. It was identified that the Bima Group outcrops both east and west of Bashar. Within the latter area, the Bima Group directly overlie the basement. Overlying the Bima Group was the Yolde Formation followed by the Pindiga Formation, and the Gombe Formation. A few kilometres east of Bashar the Gombe Formation was mapped cross-cutting the Yolde and Pindiga formations. Overlying the Gombe Formation is the Kerri-Kerri Formation deposited after folding of the Gombe Formation in the Maastrichtian. The Kerri-Kerri Formation extended into the "Gwangen" anticline of the Gombe fold and to the west on top of the basement (Fig. 10). This lithostratigraphy is similar to that of the map of Geological Survey of Nigeria (Fig. 11) except for the presence of Gombe Formation around the Bashar area, which is absent in the geological survey map.

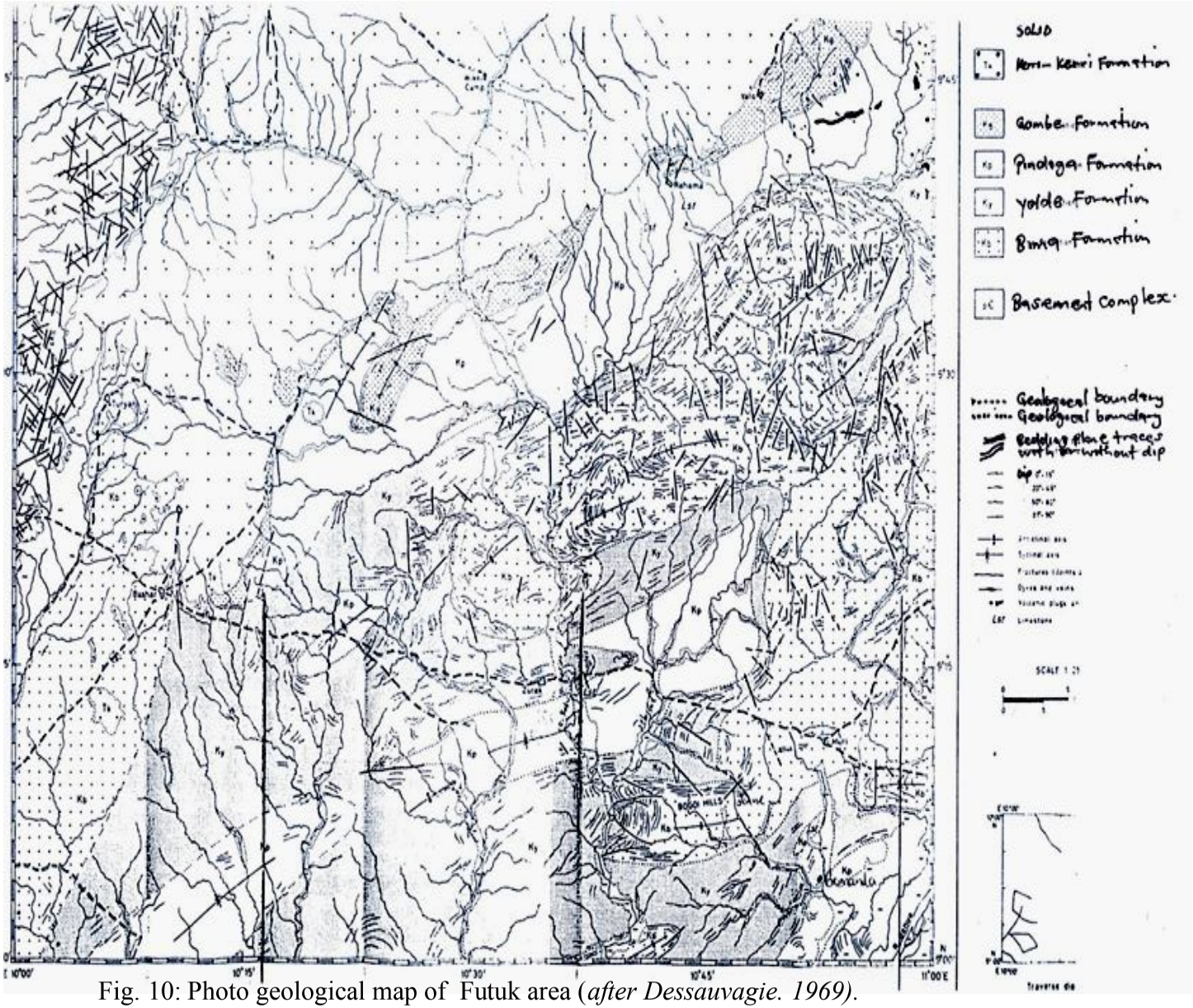


Fig. 10: Photo geological map of Futuk area (*after Dessauvagie. 1969).*

Dessauvagie drew two sketch sections (Fig. 12) to show the generalized geology of the Futuk area. Section 1 was from east of Bashar to Yuli. Structurally he divided the succession into four parts separated by unconformities comprising: (i) The Basement Complex; (ii) Bima, Yolde and Pindiga Formations; (iii) Gombe Formation; (iv) Kerri-Kerri Formation.

Numerous fractures was identified within the basement controlling river courses and trending NE – SW and NW – SE. Folded Gombe Formation trending NE – SW affected by a NW – SE compressional episode produce the "Gwangen" anticline and the "Gir" syncline in the Bashar area. Further east of Bashar folded Yolde Formation with fold axes which follow a NE – SW trend was identified. The sections showed that the basement was folded (Fig. 12).

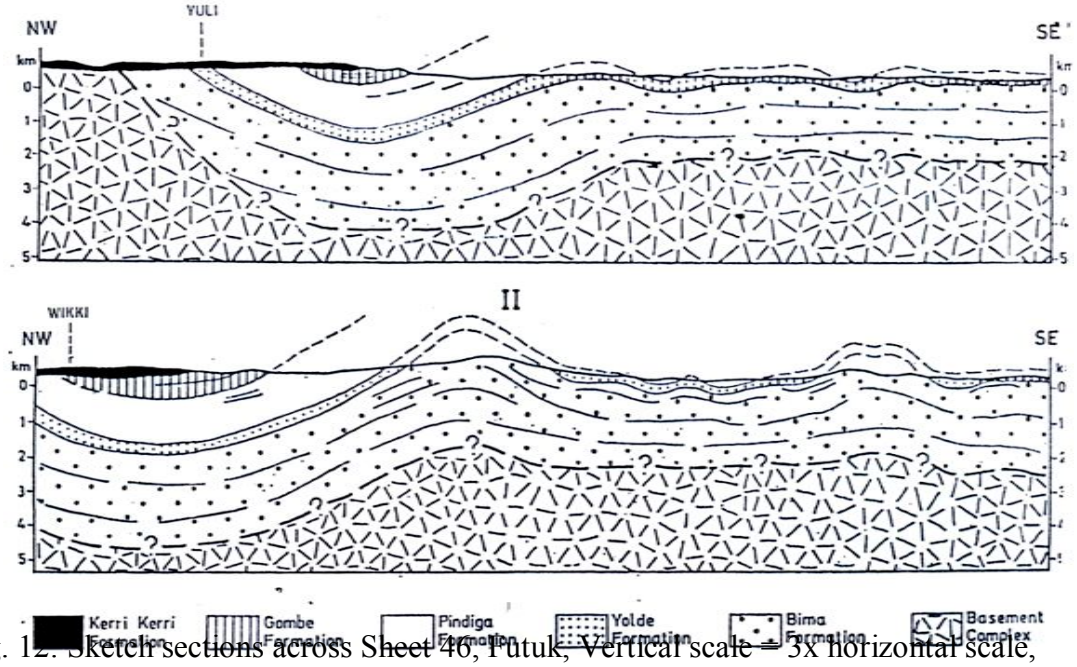


Fig. 12. Sketch sections across Sheet 46, Futuk, Vertical scale = 3x horizontal scale, Gravimetric data (Cratchley & Jones, 1963) have been used to establish the approximate depth of the basement. (*after Dessauvagie, 1969*).

Ayoola (1981; Table 1 and Fig. 13) identified the Bima and "Muri" sandstone east of Bashar, and the Keana Formation (which is the lateral equivalent of the "Muri" sandstone) west of Bashar where it was indicated directly overlying the basement. Overlying the "Muri" Sandstone was the "Zurak Formation" succeeded by an "unnamed marine sediment" then the Gombe Formation which was unconformably overlain by the Kerri-Kerri Formation. North of Bashar the Kerri-Kerri Formation was indicated directly overlying the basement to the west.

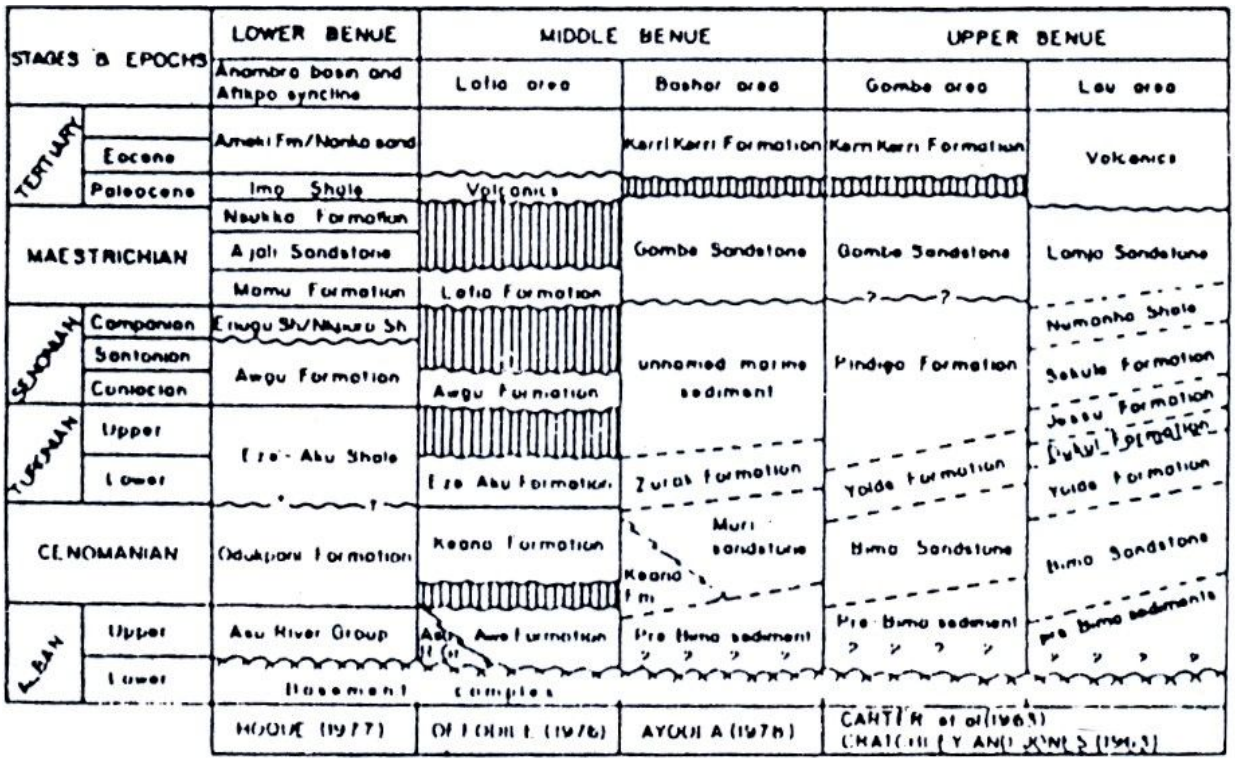


TABLE 1: Correlatable Stratigraphic Sequences in the Benue Trough and Eastern Nigeria. According to Ayoola (1981).

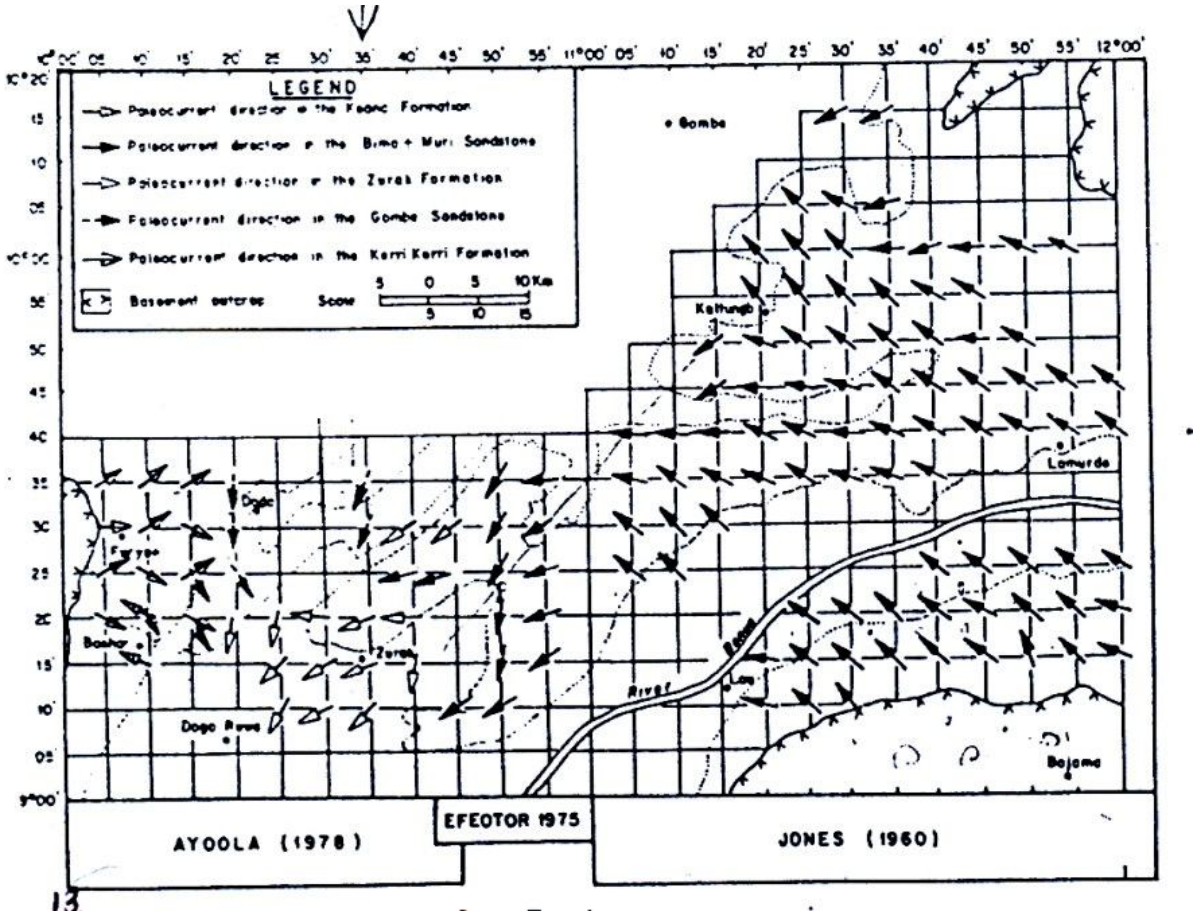


Fig. 13: Paleocurrent trends across the upper Benue Trough. (*after Ayoola 1981).*

Structurally the Bashar successions was divided into four unconformity -bounded units which differ from those of Dessauvagie: (i) The basement Complex; (ii) pre-Bima sediment, Muri Sandstone, Zurak Formation, unnamed marine sediment; (iii) Gombe Formation; and (iv) Kerri-Kerri Formation.

Benkhelil (1988, 1989) identified "Bashar" as one of the sub-basins with a thick sedimentary successions in the western part of the Gongola Basin (Figs. 5, 8). The Ganjuwa area northeast of Bashar was indicated as the southern part of a Tertiary basin which contains a series of continental sandstones. The sandstones around Bashar was divided into "red sandstones" which are the Gombe Formation, and around Ganjuwa as "white sandstones" which are the Kerri-Kerri Formation (Fig. 14).

Structurally Benkhelil indicated faults, west of Ganjuwa which partly affected the Tertiary sediments. Also north of Ganjuwa was a basin which he said is the southern end of the Tertiary basin. It was reported that the southern end is formed by decametric folds (Figs. 14, 15). These folds of the basins are said to have affected the Gombe Formation. It was also indicated that an unconformity can be found between the Gombe Formation and the Kerri–Kerri Formation.

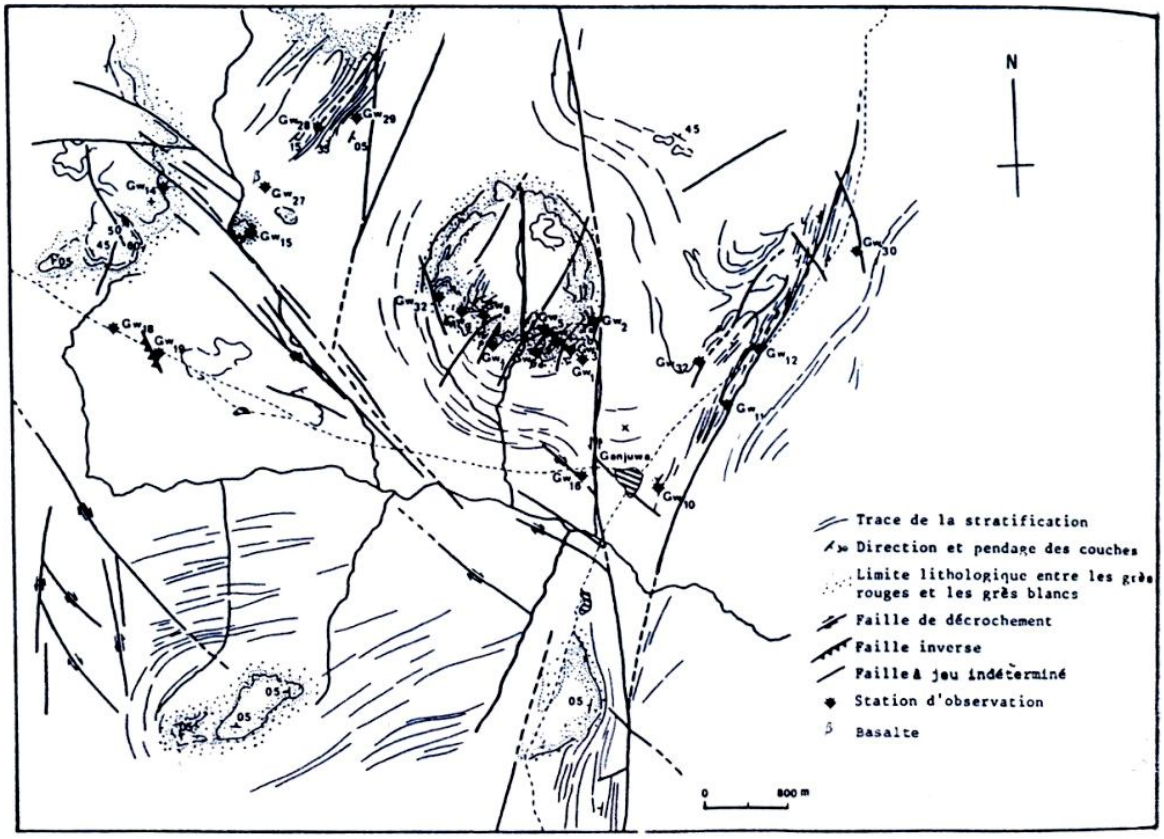


Fig. 14: Map of the structural elements in the Cretaceous and the Tertiary of the Ganjuwa area. (*after Benkhelil, 1988).*

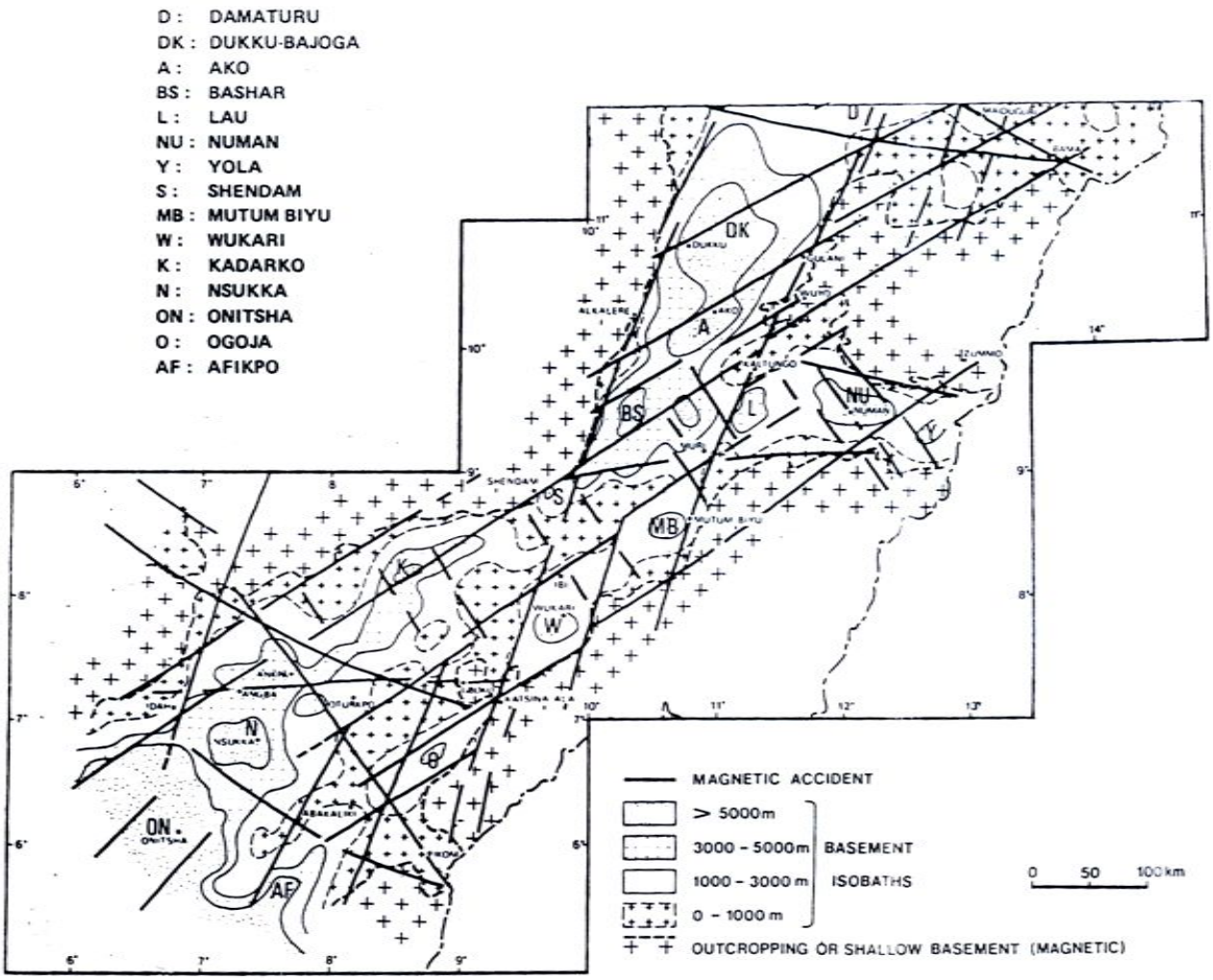


Fig. 15:Sketch map showing the distribution of the Mesozoic basins relative to the main magnetic discontinuities. (*after Elf Nigeria Ltd., 1985).*

Guiraud (1991) identified discordances accompanied by many onlaps within sediments around north of Sabon-gida area southeast of Bashar village which he called he Bima (3) sediments (Fig. 16).

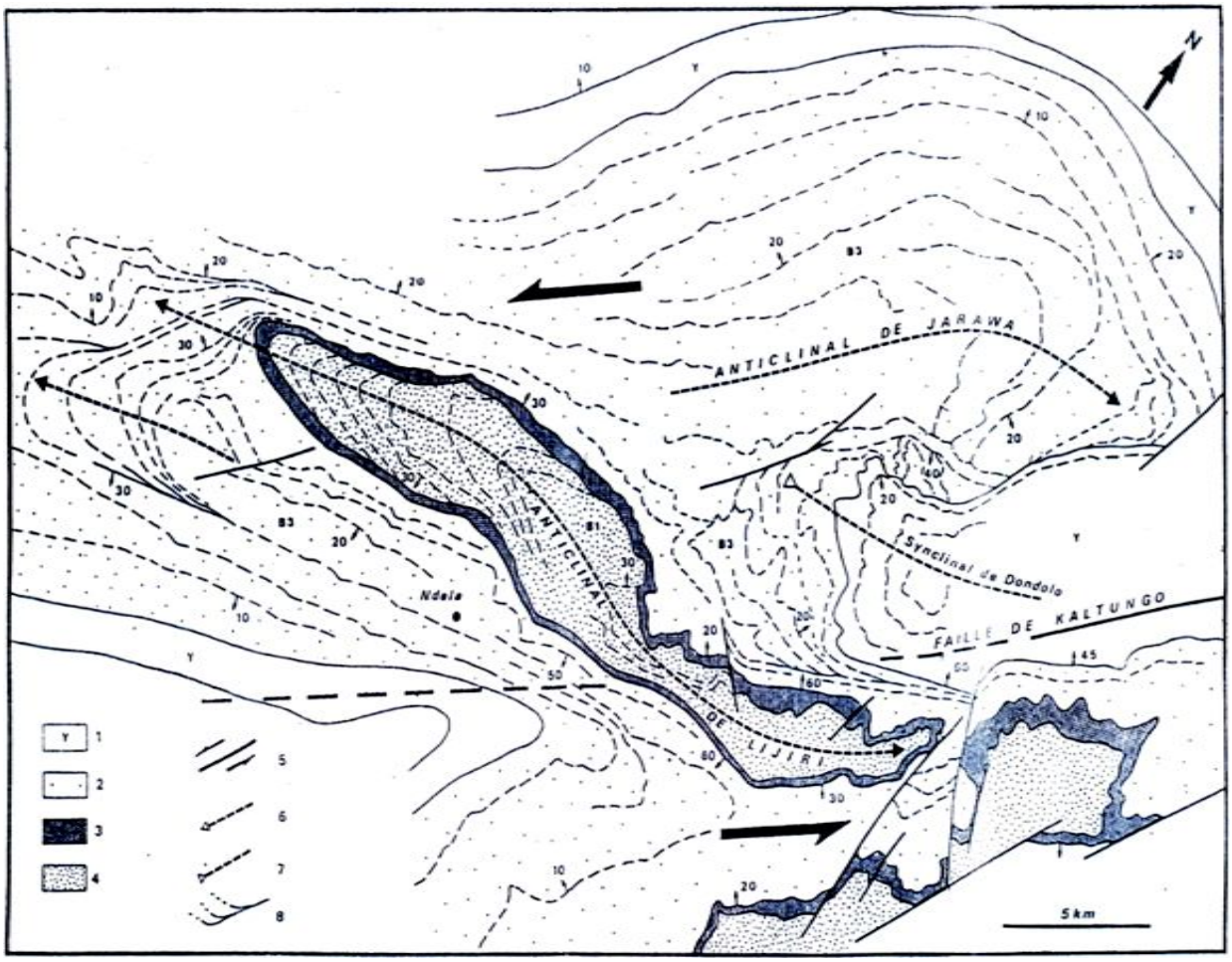


Fig. 16: Geological map of the folds of the Jarawa Hills area (location Fig. 31): 1 – Yolde formation: 2 – Bima 3 braided-river deposits: 3 – Bima 2 braided-river deposits; 4 – Bima 1 braided-river deposits: 5 – prolongation of the basement-induced Kaltungo-Guburunde fault; 6 – anticline axis; 7 – syncline axis; 8 – association of progressive unconformity and angular unconformity. (*after Guiraud 1991).*

Structurally Guiraud indicated the Zurak area to be a syncline and the Sabon-gida area to be an extension of the anticline of Lijiri consisting of the Bima (3) and Yolde Formations respectively.

Zaborski *et al*. (1997) produced an outline geological map of the Bashar-Yuli area (Fig. 2). It was reported that the Bima-Yolde Formation was overlain by the Pindiga Formation with a Santonian-Campanian hiatus and an unconformity at the base of Gombe Formation which to the

west was mapped directly overlying the basement. Unconformably overlying the Gombe Formation is the Kerri-Kerri Formation, north of Yuli the Kerri-Kerri Formation was mapped directly overlying the basement. Zaborski *et al*. (1988) structural division is similar to that of Ayoola.

The succession at Bashar was divided into four unconformity-bounded units: (i) Crystalline basement; Bima Group, Yolde Formation and Pindiga Formation; (iii) Gombe Formation and (iv) Kerri-Kerri Formation.

The following structures was identified (i) numerous basement fractures trending NE – SW and NW – SE; (ii) East of Bashar they indicated the Gombe Formation crosscutting both the Yolde and Pindiga formations; (iii) folds affecting the Gombe Formation; the "Gwangen" anticline and the "Gir" syncline, (iv) a major thrust fault extending north and south of Garga trending NNE/SSW.

3.3 SUMMARY

Previous workers in the Bashar area all drew up a similar stratigraphic sequence for the area, except for Ayoola (1981) whose names for some of the Formations differ from others probably due to his placement of Bashar area in the Middle Benue Trough while others placed Bashar in the Upper Benue Trough. In the identifications of these lithostratigraphic units on a geological map of Bashar area differences in opinions arose.

Dessauvagie (1969) mapped the Bima Group west of Bashar directly overlying the basement (Fig. 10), while Ayoola (1987) mapped the Kerri-Kerri Formation directly overlying the basement (Fig. 13). Zaborski *et al*. (1997) mapped the Gombe Formation west of Bashar directly overlying the basement (Fig. 1).

Structurally, they all divided Bashar into four unconformably bounded units, but Zaborski *et al*. (1997) described the presence of a Santonian – Campanian hiatus between the Pindiga Formation and Gombe Formation. Dessauvagie in his section showed the basement as folded while Zaborski *et al*. (1997) described the basement as faulted.

CHAPTER FOUR

4.0 STRATIGRAPHY AND STRUCTURE OF BASHAR AREA

4.1 INTRODUCTION

The Bashar area is situated in Dengi and Wase Local Government Areas of Plateau State and forms part of Federal Surveys of Nigeria 1:100,000 Sheet 192 (Bashar). Earlier studies of the Bashar area were carried out by Dessauvagie (1969), Ayoola (1981), Benkhelil (1988, 1989), Guiraud (1991) and Zaborski *et al*. (1998).

4.2 STRATIGRAPHY

The lithostratigraphical units identified in the Bashar area in the present work are: (i) The crystalline basement; (ii) The Yolde Formation; (iii) The Pindiga Formation; (iv) The Gombe Formation; (v) The Kerri-Kerri Formation; (vi) Volcanics and (vii) Alluvium.

4.2.1 The Crystalline Basement

The basement outcrops in the western part of the study area, where it is well exposed. From aerial photographical study it produces a hilly and rugged topography characterized by numerous fractures which control the main streams. Tributaries join the main streams nearly at right angle, giving the basement a trellis drainage pattern (Fig. 17a).

4.2.2 Yolde Formation

The Yolde Formation outcrops over the greater part of the southeastern corner of the map (Fig. 17a). As seen on aerial photographs and satellite images, it gives rise to a subdued topography with a dendritic drainage pattern. It is characterized by bedding traces that are parallel, evenly spaced and continuous. These bedding traces also show evidence of folds. Ayoola (1981) called this formation the "Zurak Formation" (Fig. 13). Dessauvagie called it the Yolde Formation (Fig. 11). Zaborski *et al*. (1997) did not distinguish it as the Yolde Formation, rather they mapped a "Bima-Yolde Formation" (Fig. 1).

4.2.3 Pindiga Formation

The Pindiga Formation outcrops over an area extending from the extreme northeastern part of the area mapped (Fig. 17a) southwestwards to the area south of Mulas. It is exposed along the Bashar-Jarmai road, 1.7 km west of Bashar village, where it consists of alternating silty shale and thin fine-grained sandstone beds that are reddish brown in colour. The beds each has a thickness of about 20 – 25 cm (Plate 6). The outcrop has a dip of about 14º at 122. On satellite images and aerial photographs, the Pindiga Formation consistently forms low ground covered by vegetation, with a dendritic drainage pattern. In the southwestern part of Fig. 17a, the Pindiga Formation can be seen lying upon the basement, also it lies conformably on top of the Yolde Formation.

4.2.4 Gombe Formation

The Gombe Formation directly overlies the basement in the western part of the study area. The original lateral extent may have been as much as 52 km to the west (Fig. 18). This was derived from the determination of the peak of Gombe Formation around Bashar area which is at a height of about 600 metres above sea level having a horizontal attitude, from the satellite image (Figs. 17, 18) with a scale of about 1:431,000 the farthest lateral extent of the Gombe Formation to the west is about 12 cm determined from (Fig. 18).

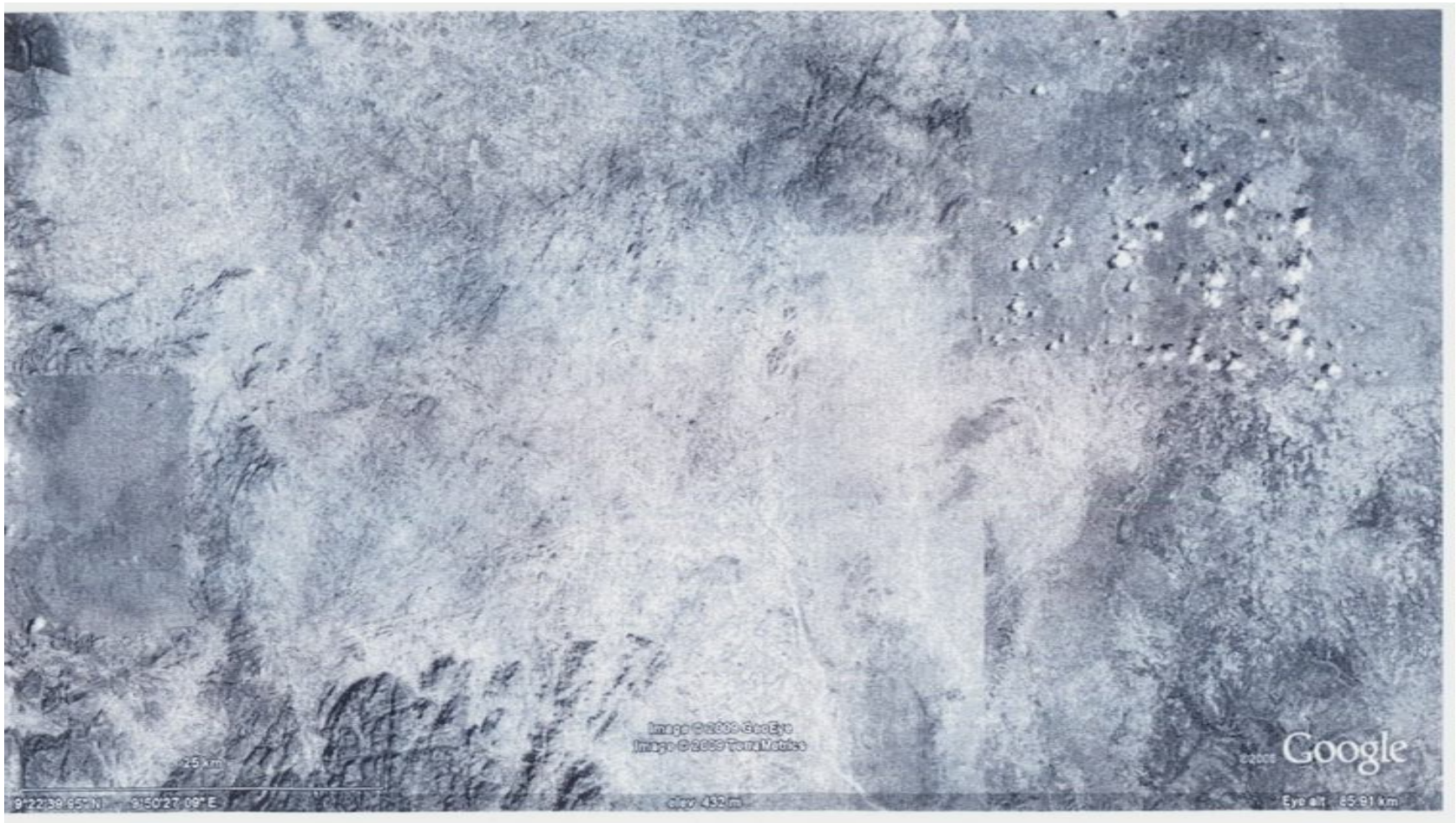


Fig. 18 lateral extent of the Gombe Formation overlying the basement to the West.

To the east the formation crosscuts the Pindiga and Yolde Formations which it unconformably overlies. It is well exposed around Jarmai, Guduk, Turyam, Tunga, Bashar and also around Gwangen and Gir villages, where it can be seen to be folded forming an anticline and syncline which has axis trending NNE – SSW after being affected by a NW – SE compressional episode. The formation produces a distinctive hilly topography characterized by a dendritic drainage pattern. From field observations, at Jarmai, the basal portion consist of coarse-grained pebbly sandstone (Plate 1), from the cross-section (Fig. 17b). The base level of the Gombe Formation around Bashar occurs at a height of about 375 metres above sea level. The pebbles are made up of quartz with a maximum length of about 4.5 cm, they occur concentrated in layers. At Turyam (Fig. 17a) a sandstone of about 30 m thick was seen to have a base which consist of conglomeratic sandstone with subangular to subrounded pebbles.

The upper portion consist of tabular cross-bedded red sandstone with sets ranging from 10 cm to 1 metre in thickness (Plates 3 – 5). From cross-sectional view (Fig. 17b) the peak of the Gombe Formation around Bashar stands at a height of 600 metres above sea level with a low angle of dip of about 3º. The difference between the height of the peak and the base of the Gombe Formation around Bashar gives an estimated minimum thickness of 225 metre for the Gombe Formation around Bashar. The pebbly conglomeratic nature of the basal portion of the Gombe Formation around Bashar indicates a braided/alluvial environment of deposition. The upper portion from the rose diagram plots (Figs. 27 – 30) shows a westerly paleocurrent trends which indicate the basement as the source area because the trends corresponds with the trends of the basement fractures, this is as a result of the direct contact of the Gombe Formation around Bashar with the basement (Fig. 17a). The minimum amount of erosion of Gombe Formation around Bashar is up to at least 200 metres of eroded sediments before the deposition of the overlying Kerri-Kerri

Formation whose contact with the Gombe Formation lies at a minimum of 400 metres above sea level.

The Gombe Formation around Bashar differs from the Gombe–Pindiga area in that it is made up of two main parts namely: the lower pebbly sand and the upper cross-bedded sandstone. In the latter area it composes of three main parts according to Zaborski *et al*. (1998) namely: The lower "transitional portion", "The middle bedded facies" and "the upper red sandstone facies" (Fig. 19). The lower pebbly sand at Bashar is equivalent to a braided deposit and the cross bedded sandstone at Bashar is equivalent to the "Upper red sandstone facies" found elsewhere in the Upper Benue Trough which was described by Zaborski *et al*. (1998).

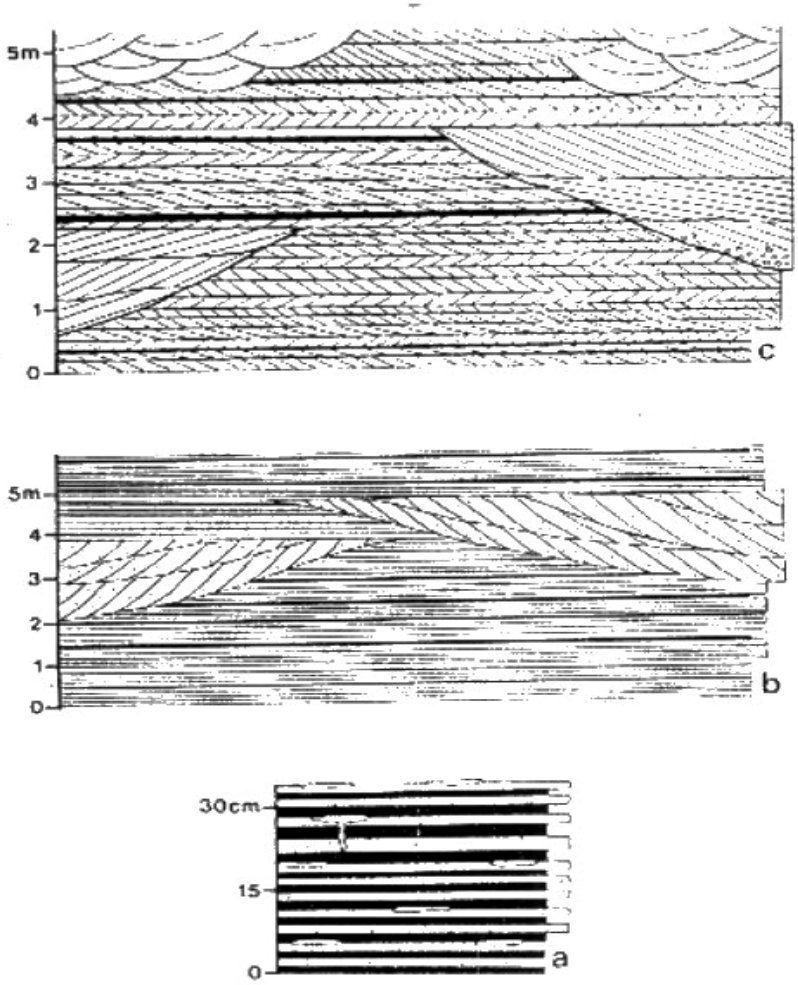


Fig. 19: Gombe Formation, Lithofacies recognizable within the formation.
a, basal transitional portion; b, "bedded facies", c, "red sandstone facies".
(*after Zaborski et al., 1997).*

4.2.5 Kerri–Kerri Formation

The Kerri–Kerri Formation outcrops over part of the northern part of the mapped area; its outcrop has few surface streams. On satellite images it forms an elevated but relatively flat topography with a dendritic drainage pattern. Most of the outcrop is weathered. The Kerri–Kerri Formation unconformably overlies the folded and faulted Gombe Formation. The Gombe/ Kerri–Kerri contact lies at 400 metres above sea level around Bashar from the cross-sectional view. To the northeast, outside the project area, the Kerri–Kerri Formation supports a medium density forest extending over the Yankari game reserve. Dessauvagie mapped the Kerri–Kerri

Formation in part of the core of the "Gwangen" anticline, while Zaborski *et al*. (1997), and the present work shows Pindiga Formation there.

4.2.6 Volcanic Rocks

A lava flow occurs on top of the Pindiga Formation west of Bashar village (Plate 8). It is highly weathered having a reddish-brown surface but is greyish internally. Its original composition is not known. From aeromagnetic data, Benkhelil (1988) identified a concentration of volcanic rocks with a NE – SW alignment north of Bashar that corresponds with the dominant trend of the fractures on the basement complex. Although mostly concealed they include basalts dated 41 Ma and 30 Ma which lie upon the Kerri–Kerri Formation (Figs. 14, 20).

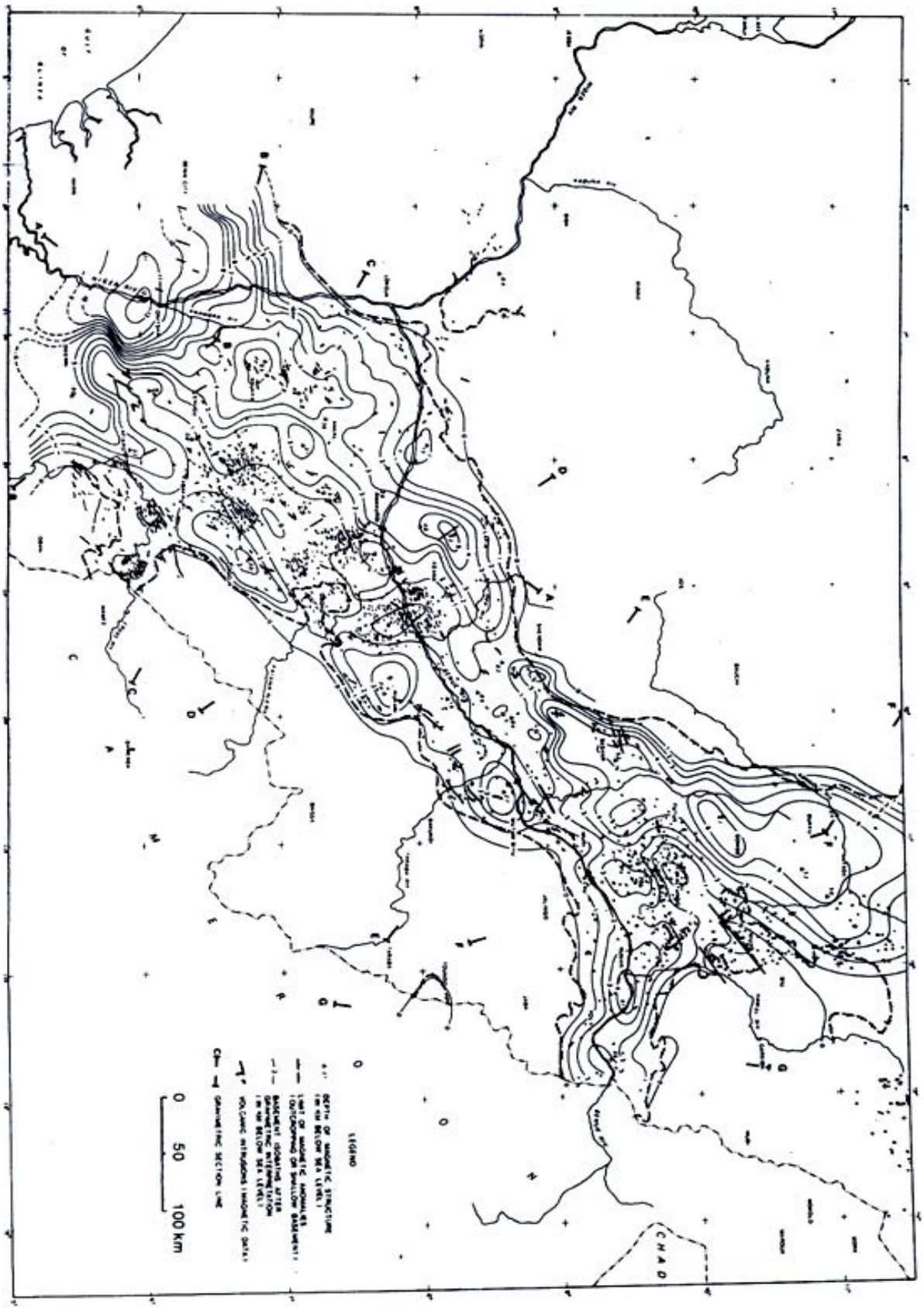


Fig. 20: Basement Isobaths deduced from the gravity and magnetic data (after Benkhelil et al., 1988).

4.2.7 Alluvium

Alluvium covers large parts of the plains of the Jekel river, north of Jarmai concealing the basement/sedimentary boundary.

4.3 STRUCTURE

The Bashar area displays structures such as fractures, faults, folds and unconformities that affect the different formations found in the area.

4.3.1 Fractures

Numerous linear fractures characterize the Basement Complex, they have trends of NE – SW and NW – SE which control the trellis drainage pattern that can be observed on the geological map of Bashar area (Fig. 17a). The length of the fractures varies between 400 metres to 7.2 kilometres. The dominant trends is NE – SW. These fractures can also be seen in both the vertical and oblique view of satellite image (Fig. 21).

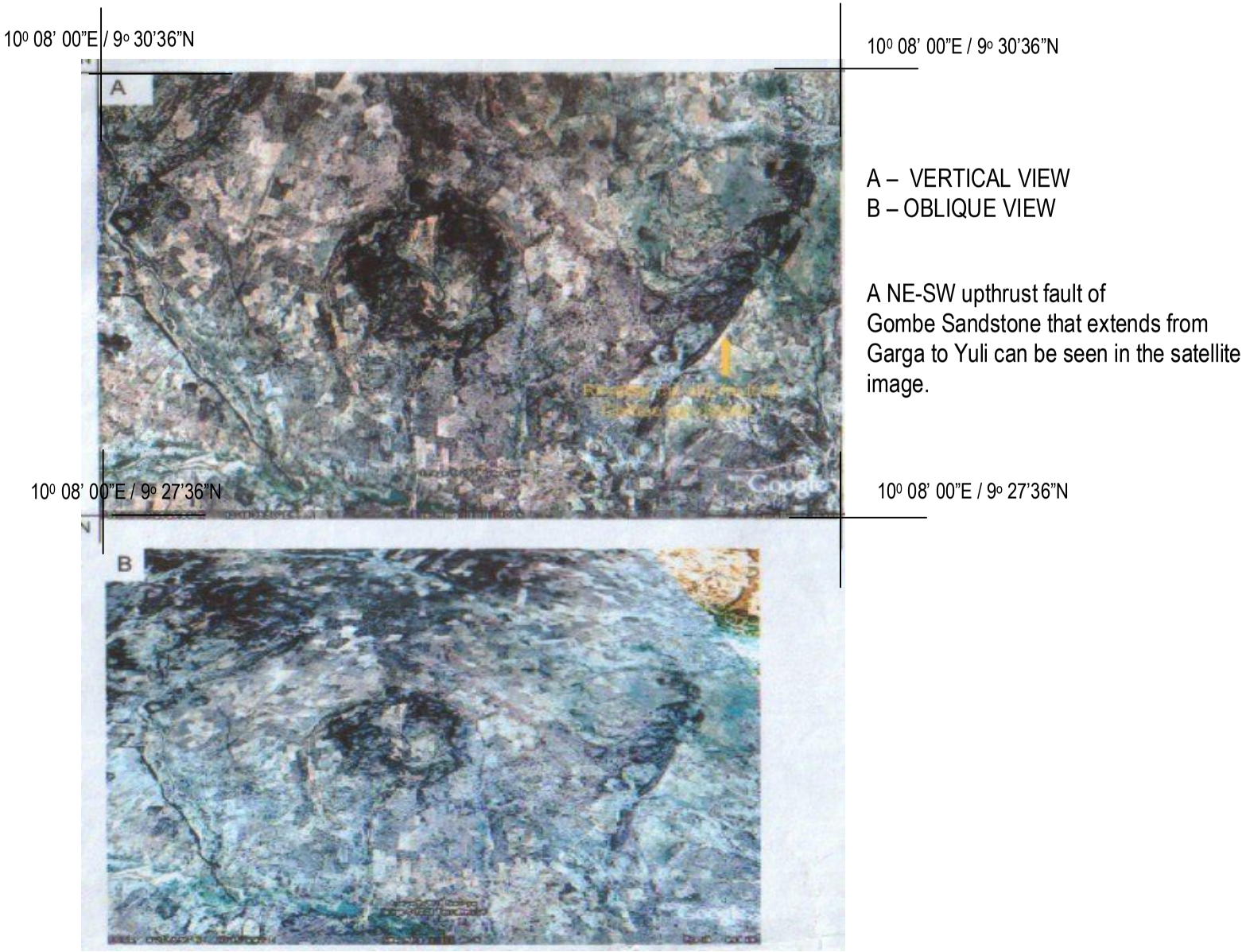


Fig. 21: Satellite image of Garga area.

4.3.2 Faults

A major fault in the Bashar area occurs affecting the Gombe Formation (Fig. 17a) satellite image (Fig. 22). It is a thrust/reverse fault which extends from Garga to Yuli and covers a distance of about 16 km, it does not extend into the Kerri–Kerri Formation. The Garga thrust/reverse fault has a NNE – SSW trend. Zaborski *et al*. (1997) also indicated this fault as a thrust/reverse fault.

4.3.3 Folds

The folds in the Bashar area are confined to its eastern part. They affect the Yolde and Gombe formations. The folded Gombe Formation has an anticline and a syncline named the "Gwangen" anticline and the "Gir" syncline. The folds are asymmetrical, open and with an axial trend of NNE – SSW produced by a NW – SE compressional episode (Fig. 23). The folds of the Yolde beds are tighter, crosscutting can be observed within the Yolde Formation. The folds of the Yolde beds also have a NNE – SSW axial trend so also formed display a NW – SE compressional episodes. The cross-cutting within the Yolde folds might have originated due to a synsedimentary tectonic activity. The tightness of the Yolde folds might have been caused by a second episode of compression which occurred towards the end of Cretaceous – initial Paleogene time. These folds were also mapped by Dessauvagie (1969) and Guiraud (1992). Zaborski *et al*. (1998) also mapped the folds of the Gombe Formation.

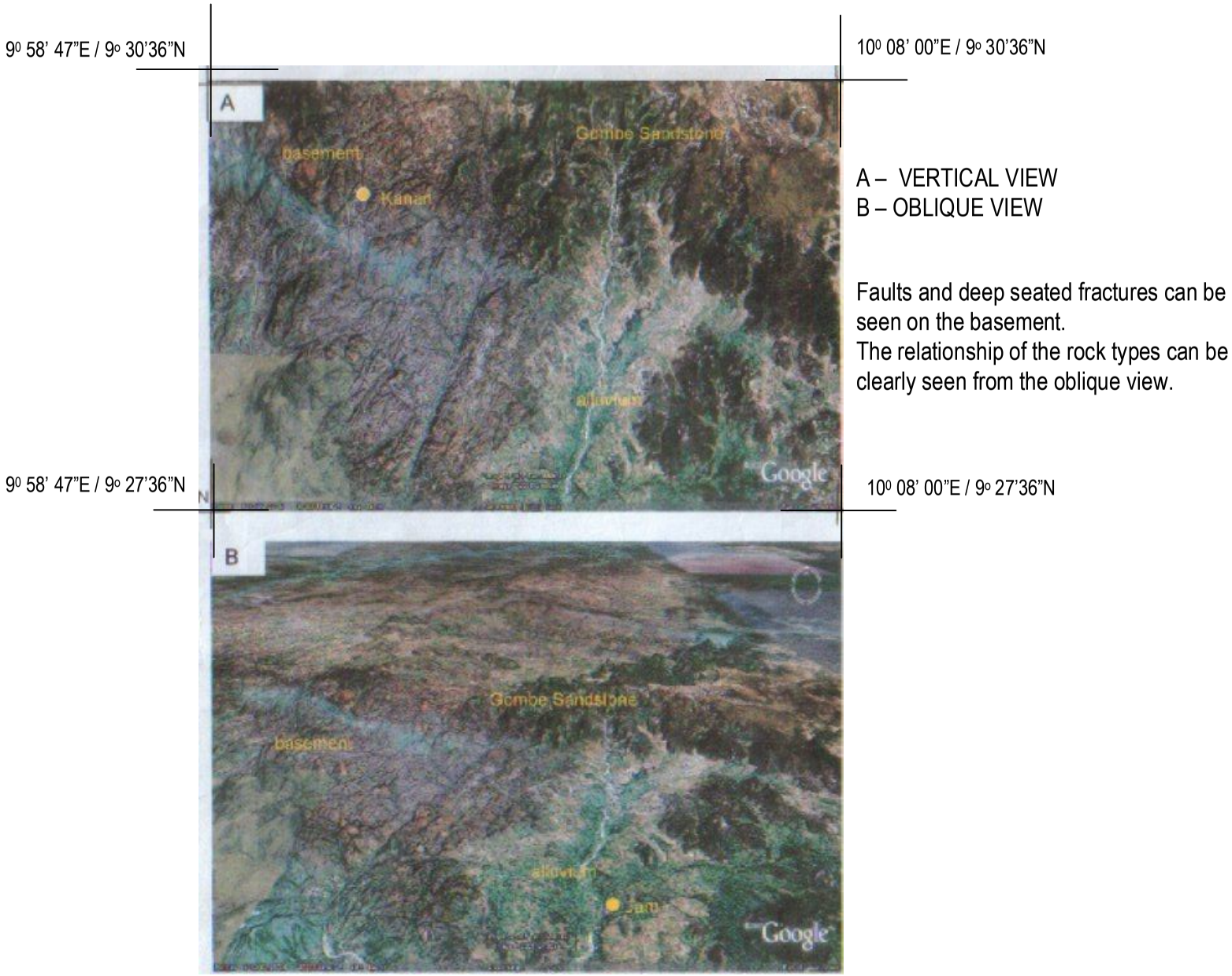


Fig. 22: Satellite image NW of BASHAR (SHEET 192)

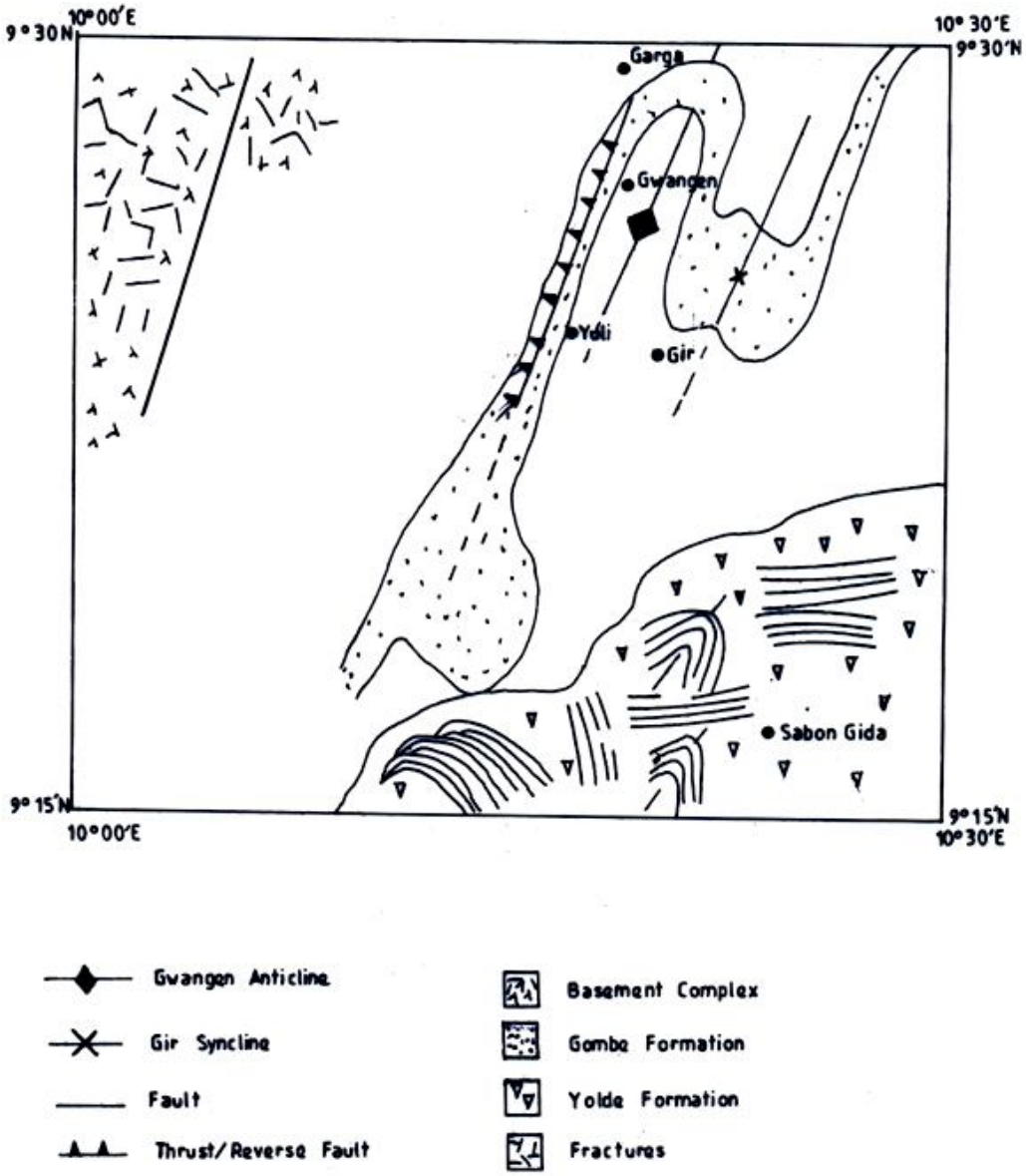


Fig. 23: Structural map of Bashar Area

4.3.4 Unconformity

At location Am6 (Fig. 17a) and Plate 7, west of Bashar an angular unconformity can be seen at the base of the Gombe Formation. It was identified from the difference in dip direction of the Gombe Formation which is about 3° almost horizontal and that of the Pindiga Formation

which is 14º. North of Sabon-gida (Fig. 17a) within the Yolde Formation an unconformity can be observed due to the presence of cross-cutting within the Yolde Formation. Guiraud (1991) indicated a progressive discordance accompanied by many onlaps within the Lijiri anticlinal axis which extends into the Yolde Formation around Sabon-gida area of the present work, Guiraud called the Formation Bima '3' sediment (Fig. 15). Zaborski *et al*. (1998) presented some evidence for the presence of an angular unconformity around Bashar area, where it was reported that a hiatus in the form of sandy lithologies dominated the upper part of the Pindiga Formation around Bashar. At the western part of (Fig. 17a) an unconformity exist between the basement and Gombe Formation. It was identified from the presence of conglomerate with pebbles at the base of the Gombe Formation (Plate 1). At the southwestern corner of (Fig. 17a) an unconformity exist between the basement and Pindiga Formation.

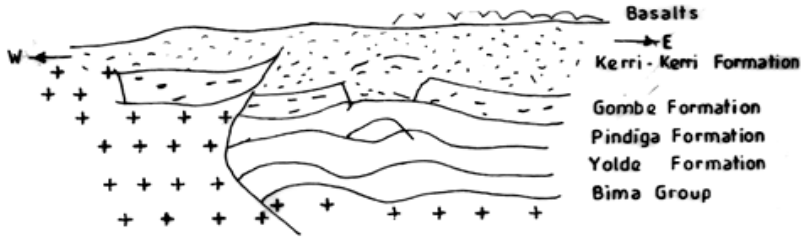
CHAPTER FIVE

5.0 SUMMARY AND CONCLUSION

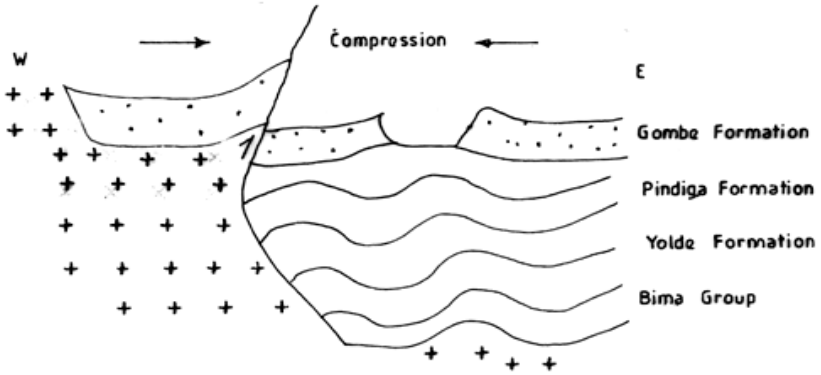
5.1 SUMMARY

The Bashar is one of the sedimentary sub-basins described by Benkhelil (1988; 1989) in the north-eastern part of the Upper Benue Trough. The Geological history of Bashar area represents rifting processes accompanied by normal faulting which controlled the deposition of the Bima Group, which was followed by a thermotectonic sag stage of basin development, and then various deposition and tectonic events which can be summarized in the following phases. See Fig. 24

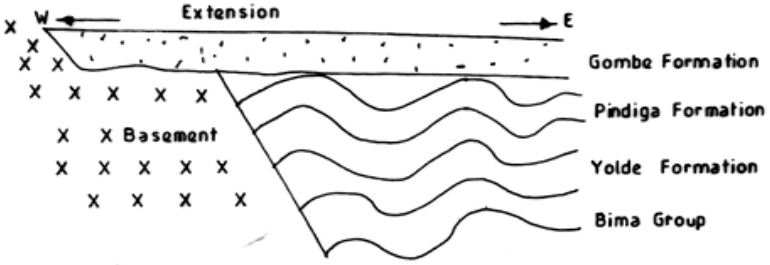
Phase V
Paloocene
rifting.



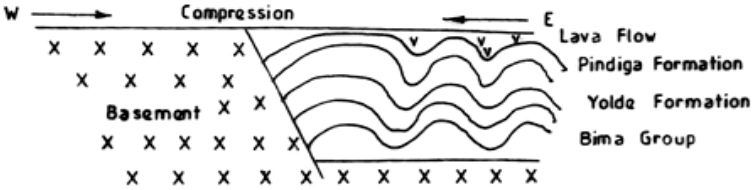
Phase IV
late Cretaceous
To early
Paleogene
compression.



Phase III
late Campanian
to Maastrichtian
Rifting



Phase II
Santonian to
Campanian
compression



Phase I
pre-Santonian
rifting

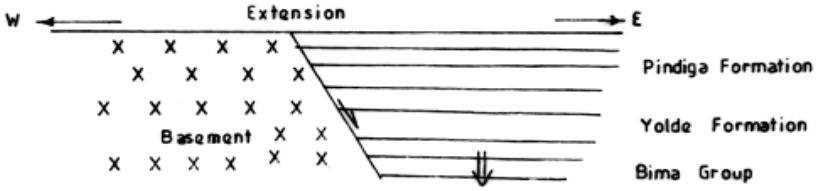


Fig. 24: Diagrammetic representation of the structural history of Bashar Area.

5.1.1 Phase I

During pre-Santonian times rifting processes accompanied by strike-slip tectonics gave rise to a NNE – SSW trending Garga extensional fault which controlled the deposition of the Bima Group. This was followed by a thermotectonic sag stage of basin development accompanied by a transgression that led to the deposition of the marine Yolde Formation. Synsedimentary tectonic activity which continued into the Cenomanian affected part of the "Upper Bima Sandstone" and the Yolde Formation, giving rise to crosscutting within the Yolde Formation. The Yolde Formation is directly overlain by the Pindiga Formation.

5.1.2 Phase II

During Santonian to Campanian time a reverse of stress occurred, that is compression with a NW – SE direction. This caused the parallel and open folding of the Bima Group, Yolde and Pindiga formations. This was accompanied by the eruption of lava on top of the Pindiga Formation around Bashar.

5.1.3 Phase III

During Late Campanian to Maastrichtian time renewed rifting took place and this led to the deposition of the Gombe Formation above the folded Pindiga Formation and directly upon the Basement Complex. The Gombe Formation was derived from the Basement Complex, to the west as indicated by paleocurrent data (Figs. 27 – 30).

5.1.4 Phase IV

During terminal Cretaceous to initial Paleogene times folding due to compressional stress was accompanied by pronounced movement along the "Garga" fault, reactivating it as a reverse fault, and the folding of the Gombe Formation around Gwangen and Gir. This second episode of compression also affected the pre-Santonian beds with a similar compression direction of NW – SE, this second episode of compression is most evident in the Yolde Formation.

5.1.5 Phase V

During the Paleocene renewed E – W rifting occurred accompanied by the deposition of the Kerri–Kerri Formation according to Benkhelil (1988) aeromagnetic data. He identified basalts north of Bashar which lie upon the Kerri–Kerri Formation indicating a late volcanic eruptive episode.

5.2 CONCLUSION

Compared with the Upper Benue Trough, the geological history of the Bashar area differs in the following ways:

a) In Pindiga/Gombe contact

b) Nature of Gombe Formation

Elsewhere in the Upper Benue Trough the Pindiga/Gombe contact is transitional except for the Bashar area where a marked angular unconformity can be seen (Plate 8).

Around Bashar area the Gombe Formation has a continuous nature from the east to the west, consisting of two main types namely: the lower pebbly conglomerate sandstone which is indicative of braided river (braided bar) deposit and the upper "red sandstone" facies which is indicative of a downstream migration of the braided bar deposit elsewhere in the Upper Benue Trough.

The Gombe Formation consists of three types namely: (a) basal transitional portion; (b) “bedded facies”; (c) “red sandstone facies”.

Zaborski *et al*. 1998 described the sandstones around Bashar as coarsening-upward, deltaic-like deposit prograding from the southwest (and west) into a sea open only to the north (Fig. 25). These sandstones around Bashar can be interpreted as the proximal part of a fining-upward deltaic-like deposit prograding from the southwest and west into a sea open only to the north.

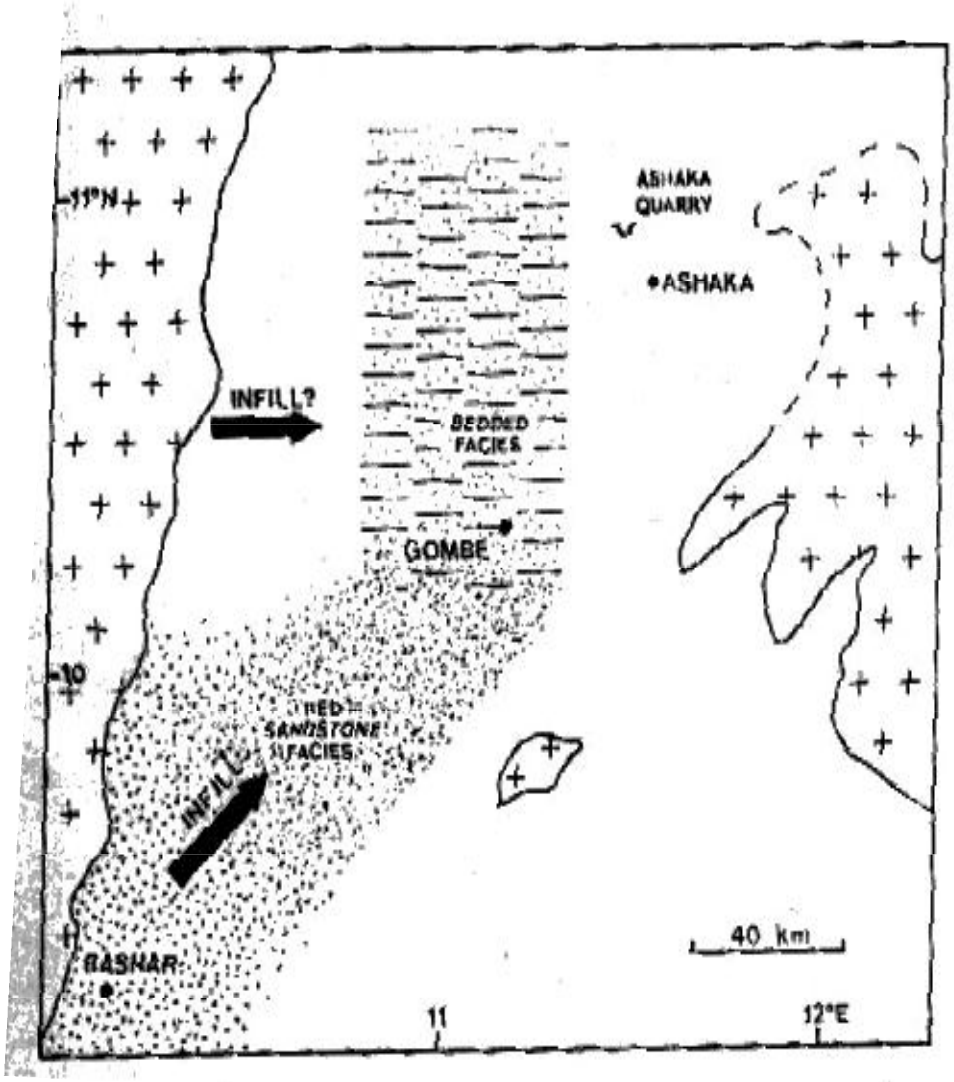


Fig. 25: Map showing lateral facies relationships within the Gombe Formation. (*after Zaborski et al., 1998*)

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APPENDIX

1.0 SIEVE ANALYSIS

Sieving is commonly used in determining the grain size distribution of sands and sandstones. The set of sieve with mesh sizes 15mm, 10mm, 4mm, 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, 0.063mm were first weighed on the weighing balance before they were arranged in the order of decreasing mesh size for sieving. These mesh sizes correspond to the ϕ (phi) scale values of –3.9, –3.3, –2, –1, 0, 1, 2, 3 and 4 phi ϕ scale. This method was adopted because of its regular size interval it splits up the gram sizes into approximately equal classes, 100g of the sample was measured and placed in first sieve 15 mm for sample Am1 and 1mm for samples Am3a and Am5. The stack of sieves was then placed on the shaker and the timer was set to 10 minutes each sieve was weighed together with the sand particles after which the weight of the sand particles in each sieve was recorded and expressed in cumulative weight percent of the original sample. Was expressed for each size. The result of the analysis was subjected to graphical representation.

1.1 PRESENTATION AND EVALUATION OF RESULTS

The results obtained from the sieve analysis were tabulated. The weight and weight percentages for each sample were complied together with cumulative percentages, after which curves of cumulative frequency were plotted as shown in Fig. 26a – c. Results of these analysis are presented in Table 2 a–c from these the percentages of various grades in phi scale (ϕ) can be read from Table 2 a–c. Inclusive graphic skewness (ski), inclusive graphic standard deviation (δ_1), Graphic Kurtosis (KG), Graphic mean (Mz) were calculated for each sample using their

appropriate equations and their corresponding characteristic names are then recorded for each sample (Table 4). Percentiles obtained from the cumulative frequency curve for each sample is shown in (Table 3).

1.2 MEANS SIZE (Mz)

The mean is a measure of the average diameter of grains in the sediments. It is given by the equation below:

$$Mz = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

By the application of Folk and Word (1957) equation in conjunction with the Udden–Wentworth grade scale of particle size distribution, the following interpretation could be made.

Mz ϕ Scale	**Interpretation**
– 1 to 0.00	Very coarse sand
0.00 to 1.00	Coarse sand
1.00 to 2.00	Medium sand
2.00 to 3.00	Fine sand
3.00 to 4.00	Very fine sand
4.00 to 5.00	Coarse silt

The computed results is given in Table 4 which shows that the samples are composed of medium sand grain size and granule gravel. This agrees with field observation.

1.3 INCLUSIVE GRAPHIC STANDARD DEVIATION (δ_1)

This is a measure of the degree of sorting out the spread of the distribution around the mean. Based on the Folk and Ward (1957) formula which is given below:

$$\delta_1 = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

The obtained graphic standard deviation gives clues to the sediments sorting as shown below:

GSD values (in ϕ units)	Interpretation
< 0.35	Very well sorted.
0.35 – 0.50	Well sorted
0.50 – 0.70	Moderately well sorted
0.70 – 1.00	Moderately sorted
1.00 – 2.00	Poorly sorted
>4.00	Extremely Poorly sorted

The calculated values are given in Table 4. Results show that the sample range between moderately sorted and poorly sorted indicating their closeness to their source, the basement Complex.

1.4 INCLUSIVE GRAPHIC SKEWNESS (SKI)

This parameter is a measure of the degree of a symmetry of the distribution curves. It is also related to the maturity, length of transportation and sorting. The numerical value could be positive or negative. If positive it means fine ad-mixture exceeds the coarse grains, while the reverse is the case for negative skewness. The formular proposed by Folk and Ward (1957) is given as:

$$SKi = \frac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_{5} - 2\phi_{50}}{2(\phi_{95} - \phi_{5})}$$

The interpretation of the Ski values is given below:

Ski Values (in ϕ Units)	**Interpretation**
+0.3 to +1.0	Very positively skewed
+0.1 to +0.3	Positively skewed

+0.1 to -0.1	Symmetrical
–0.1 to –0.3	Negatively skewed
+0.3 to 1.0	Very negatively skewed

The computed results given in Table 4 result indicates that one-third of the sediments are coarse or negatively skewed while the remaining two-third of the sediment are symmetrical. This indicates that the sediment range from excess coarse particle to normal distribution.

1.5 GRAPHIC KURTOSIS (k_G)

This is a measure of the peakedness of the distribution curves it essentially measures the ratio of the sorting in the central portion of the distribution to that in the tails. According to Folk and Ward (1957) Kurtosis or peakedness of distribution is expressed mathematically as:

$$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$$

The interpretation of the K_G values is given as.

KG Values (in ϕ units)	**Interpretation**
<0.67	Very platykurtic
0.67 – 0.90	Platykurtic
0.90 – 1.11	Mesokurtic
1.11 – 1.50	Leptokurtic
1.50 – 3.00	Very Leptokurtic
>3.00	Extremely Leptokurtic

The computed result given in Table 4 indicates that the samples range between platykurtic, Meoskurtic and very Leptokurtic.

Phi Results for Location Am1 Gombe Sandstone

ϕ_5	ϕ_{16}	ϕ_{25}	ϕ_{50}	ϕ_{75}	ϕ_{84}	ϕ_{95}
–4.32	–3.91	–3.5	–1.49	–0.5	0.29	1.60

Mean: $\frac{\phi 16 + \phi 50 + \phi 84}{3} = \frac{(-3.91) + (-1.49) + (0.29)}{3}$

$$\frac{-3.91 - 1.49 + 0.29}{3} \Rightarrow \frac{-5.4 + 0.29}{3} = \frac{-5.11}{3} = \underline{\underline{-1.70}}$$

Standard Deviation:

Sorting $[\delta_1]$: $\frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6} \Rightarrow \frac{0.29 - [-3.91]}{4} + \frac{1.6 - (-4.32)}{6.6}$

$$\frac{4.2}{4} + \frac{5.92}{6.6}$$

$$1.05 + 0.897$$

$$= \underline{1.95}$$

Skewness: $\frac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_5 - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$

$$\frac{0.29 + (-3.91) - 2(-1.49)}{2[0.29 - (-3.91)]} + \frac{1.6 + (-4.32) - 2(-1.49)}{2[1.60 - (-4.32)]}$$

$$\frac{-3.62 + 2.98}{2(4.2)} + \frac{-2.72 + 2.98}{2(5.92)}$$

$$\frac{-0.64}{8.4} + \frac{-0.26}{11.84}$$

$$-0.076 + -0.022$$

$$= \underline{-0.098}$$

Graphic Kurtosis (K_G): $\frac{(\phi_{95} - \phi_5)}{2.44(\phi_{75} - \phi_{25})} + \frac{1.60 - (-4.32)}{2.44[(-0.5) - (-3.5)]}$

$$\frac{5.92}{2.44(3)} \Rightarrow \frac{5.92}{7.32}$$

$$= \underline{0.81}$$

Phi Results for Location Am3a Gombe Sandstone

ϕ_5	ϕ_{16}	ϕ_{25}	ϕ_{50}	ϕ_{75}	ϕ_{84}	ϕ_{95}
0.25	1.10	1.43	1.89	2.17	2.43	3.20

Mean: $\frac{\phi 16 + \phi 50 + \phi 84}{3} = \frac{(1.10) + (1.89) + (2.43)}{3} = \frac{5.42}{3} = \underline{1.81}$

Standard Deviation (δ_1): $\frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6} + \frac{2.43 - 1.10}{4} + \frac{3.20 - 0.26}{6.6}$

$$\frac{1.33}{4} + \frac{2.94}{6.6}$$

$$0.33 + 0.45$$

$$= \underline{0.78}$$

Skewness: $\frac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_5 - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$

$$\frac{2.43 + 1.10 - 2(1.89)}{2(2.43 - 1.10]} + \frac{3.20 + 0.26 - 2(1.89)}{2[3.20 - (0.26)]}$$

$$\frac{3.53 - 3.78}{2(1.33)} + \frac{3.46 - 3.78}{2(2.94)}$$

$$\frac{-0.25}{2.66} + \frac{-0.32}{5.88}$$

$$-0.09 + -0.05$$

$$= \underline{-0.14}$$

Graphic Kurtosis (K_G): $\dfrac{(\phi_{95} - \phi_5)}{2.44(\phi_{75} - \phi_{25})} + \dfrac{3.20 - 0.26}{2.44(2.17 - 1.43)}$

$$\frac{3.20 - 0.26}{2.44(0.74)} = \frac{2.94}{1.81} \qquad = \underline{1.62}$$

Phi Results for Location Am5 Gombe Sandstone

ϕ_5	ϕ_{16}	ϕ_{25}	ϕ_{50}	ϕ_{75}	ϕ_{84}	ϕ_{95}
-0.1	0.27	0.60	1.55	2.10	2.40	3.90

Mean: $\dfrac{\phi 16 + \phi 50 + \phi 84}{3} = \dfrac{0.27 + 1.55 + 2.40}{3} = \dfrac{4.22}{3} = \underline{1.41}$

Standard Deviation (δ_1): $\dfrac{\phi_{84} - \phi_{16}}{4} + \dfrac{\phi_{95} - \phi_5}{6.6}$

$$\frac{2.40 - 0.27}{4} + \frac{3.90 - (-0.1)}{6.6}$$

$$\frac{2.13}{4} + \frac{4.0}{6.6} = 0.53 + 0.61$$

$$= \underline{1.14}$$

Skewness: $\dfrac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \dfrac{\phi_{95} + \phi_5 - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$

$$\frac{2.40 + 0.27 - 2(1.55)}{2(2.40 - 0.27)} + \frac{3.90 + (-0.1) - 2(1.55)}{2[3.90 - (-0.1)]}$$

$$\frac{2.67 - 3.1}{2(2.13)} + \frac{3.80 - 3.1}{2(4.0)}$$

$$\frac{-0.43}{4.26} + \frac{0.7}{8.0}$$

$$-0.10 + 0.09$$

$$= \underline{-0.01}$$

Graphic Kurtosis (K_G): $\frac{(\phi_{95} - \phi_5)}{2.44(\phi_{75} - \phi_{25})} + \frac{3.90 - (-0.1)}{2.44(2.10 - 0.60)}$

$$\frac{3.90 - (-0.1)}{2.44(1.5)} = \frac{4.0}{3.66} \quad = \underline{1.09}$$

Table 2a: Sieve Analysis Result for Pebbly Conglomeratic Gombe Sandstone

Sieve Size (mm)	Sieve Size (ϕ)	Weight in (g)	Weight %	Cumulative Weight %	Sample Number
15.000	-3.9	16.76	16.8	16.8	
10.000	-3.3	9.33	9.3	26.1	
4.000	-2	7.78	7.8	33.9	
2.000	-1	28.90	28.9	62.8	Am1
1.000	0	19.84	19.8	82.6	
0.500	1	9.16	9.2	91.8	
0.250	2	4.55	4.6	96.4	
0.125	3	2.06	2.1	98.5	
	4	0.84	0.8	99.3	
Pan		0.68	0.7	100.0	
Total			100.0		

Table 2b: Sieve Analysis Result for Tabular Cross-Bedded Gombe Sandstone

Sieve Size (mm)	Sieve Size (ϕ)	Weight in (g)	Weight %	Cumulative Weight %	Sample Number
1.000	0	1.87	1.9	1.9	
0.500	1	12.16	12.2	14.1	
0.250	2	52.13	52.1	66..2	Am 3a
0.125	3	27.62	27.6	93.8	
0.063	4	4.66	4.7	98.5	
Pan		1.51	1.5	100.0	
Total			100.0		

Table 2c: Sieve Analysis Result for Tabular Cross-Bedded Gombe Sandstone

Sieve Size (mm)	Sieve Size (ϕ)	Weight in (g)	Weight %	Cumulative Weight %	Sample Number
1.000	0	5.41	5.4	5.4	
0.500	1	28.59	28.6	34.0	
0.250	2	37.26	37.3	71.3	Am5
0.125	3	19.26	19.3	90.6	
0.063	4	4.90	4.9	95.5	
Pan		4.53	4.5	100.0	
Total			100.0		

Table 3: Percentiles Obtained from Cummulative Frequency Curve Converted from mm to ϕ (Phi)

Formation/Location	ϕ5	ϕ16	ϕ25	ϕ50	ϕ75	ϕ84	ϕ95
Location Am1: Gombe Sandstone N09º21'46" E10º04'26" Conglomeratic Pebbly Sandstone Horizontal & Trough Bedded	-4.32	-3.91	-3.5	-1.49	-0.5	0.29	1.60
Location Am3a: Gombe Sandstone N09º22'57"	0.26	1.10	1.43	1.89	2.17	2.43	3.20

E10º10'08" Tabular Cross bedded Gombe Sandstone							
Location Am5: Gombe Sandstone N09º21'46" E10º04'26" Tabular Cross-bedded Gombe Sandstone	-0.1	0.27	0.60	1.55	2.10	2.40	3.90

Table 4: Computed Results of Graphic Measure and Descriptive Terms

Sample Number	Graphic Mean (Mz)	Inclusive Graphic Standard Deviation (δ_1)	Inclusive Graphic Skewness (Ski)	Graphic Kurtosis (K_G)
Am1 – Conglomeratic Pebbly Gombe Sandstone N09º21'46" E10º04'26" Location: Jarmai	-1.70 Granule (gravel)	1.95 Poorly sorted	-0.098 Symmetrical	0.81 Platykurtic
Am3 – Tabular				

Cross-bedded Gombe Sandstone N09º22'57" E10º10'08" Location: Gudus	1.81 Medium Sand	0.78 Moderately sorted	-0.14 Negatively Skewed	1.62 Very Leptokurtic
Am5 – Tabular cross bedded Gombe Sandstone N09º28'50" E10º13'47" Location: Tunga	1.41 Medium Sand	1.14 Poorly sorted	-0.01 Symmetrical	1.09 Mesokurtic

ROSE DIAGRAM

1. Dip direction of foresets for location Am3a Gudus, Gombe Sandstone (09º22'57"N/10º10'08"E).

   146, 325, 240, 162, 083, 272, 250, 240.

2. Dip direction of foresets for location Am3b Gudus, Gombe Sandstone (09º22'43"N/10º10'36"E).

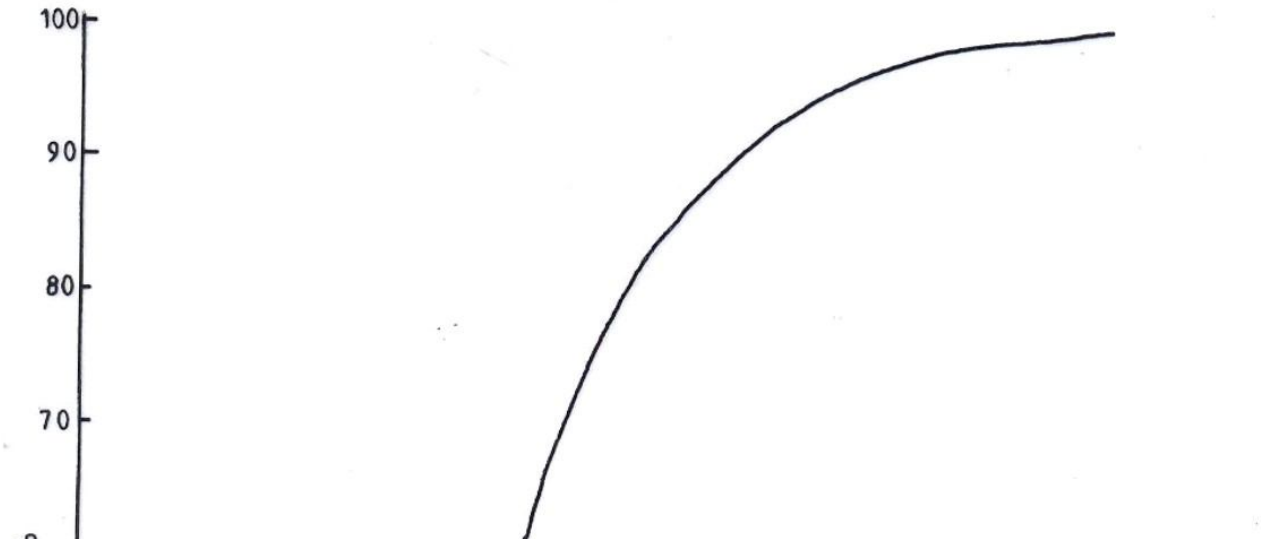
   140, 190, 320, 300, 210, 310, 270.

3. Dip direction of foresets for location Am5 Tunga Gombe Sandstone. (09º28'50"N/10º13'47"E).

150, 250, 150.

Intervals	Location 3a	Location 3b	Location 5
0 – 30	–	–	–
31 – 60	–	–	–
61 – 90	I	–	–
91 – 120	–	–	–
121 – 150	I	I	II
151 – 180	I	–	–
181 – 210	–	I	–
211 – 240	II	I	–
241 – 270	I	I	I
271 – 300	I	I	–
301 – 330	I	II	–
331 – 360	–	–	–

CUMMULATIVE FREQUENCY CURVE FOR SAMPLE AM 1



CUMMULATIVE FREQUENCY CURVE FOR SAMPLE Am 3a

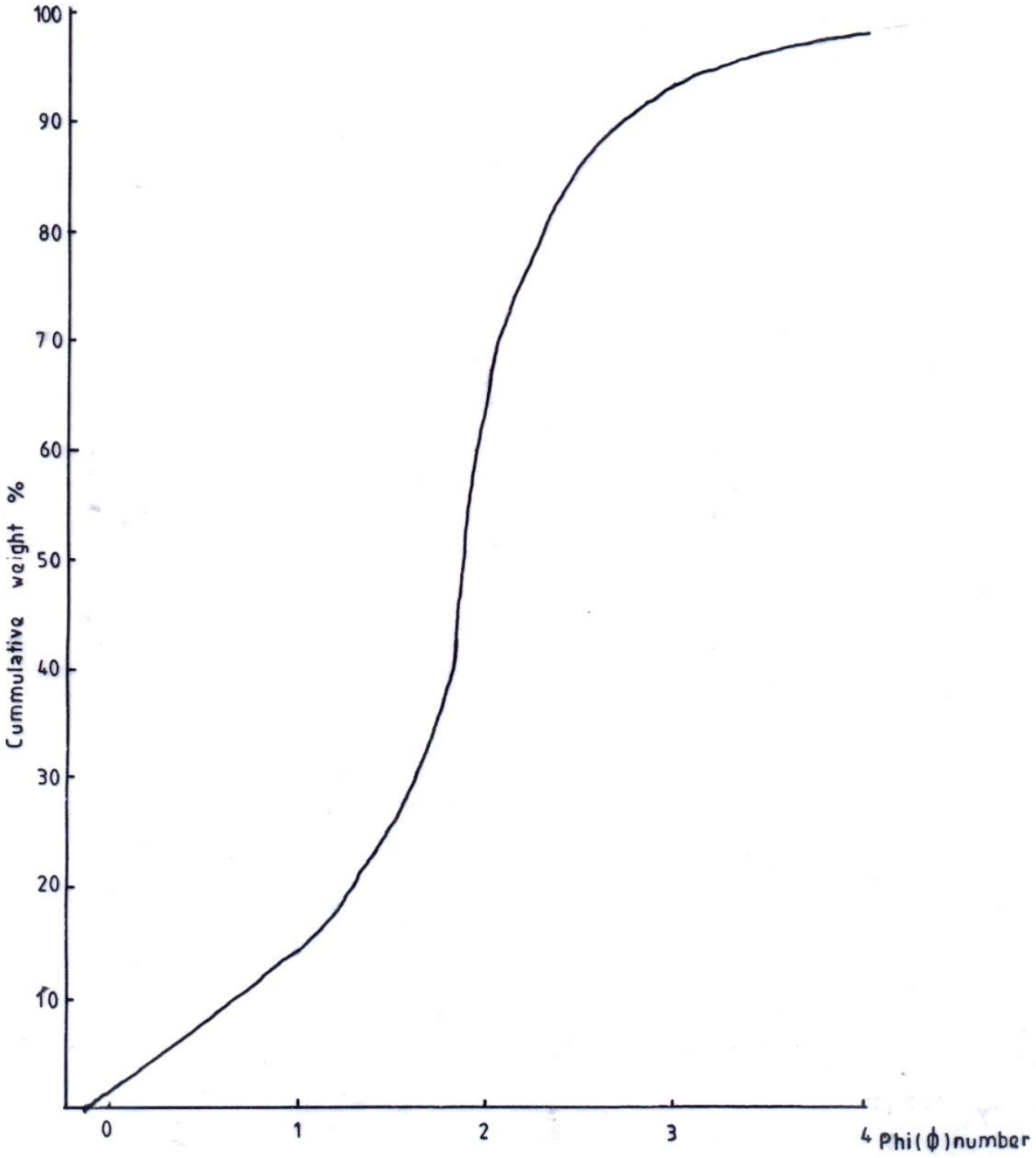


Fig. 26b: Gombe Sandstone (red sandstone) location Am 3a

CUMMULATIVE FREQUENCY CURVE FOR SAMPLE Am 5

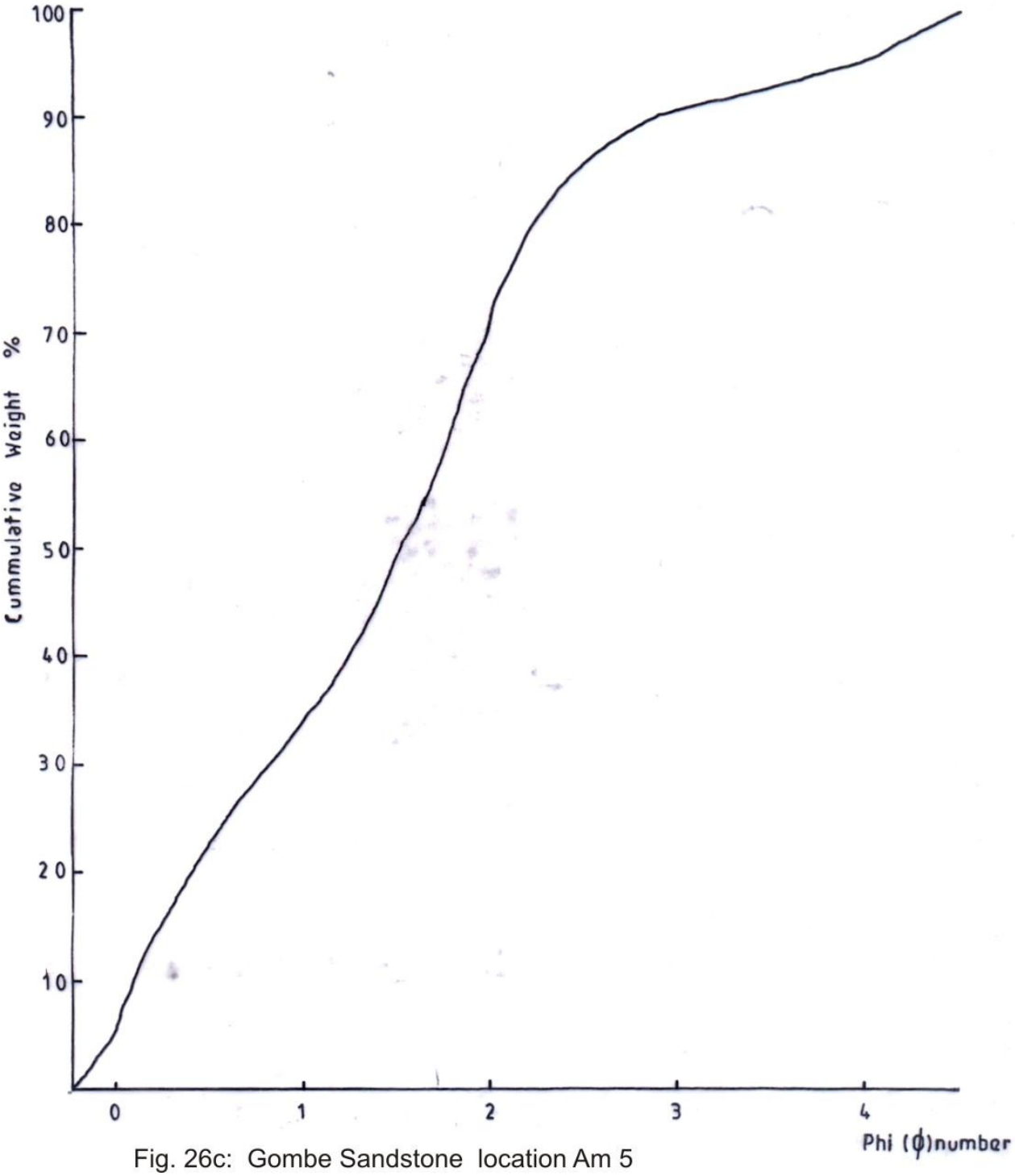


Fig. 26c: Gombe Sandstone location Am 5

Rose diagram of Paleocurrent data from location 3a Guduk Gombe sandstone (eight readings)

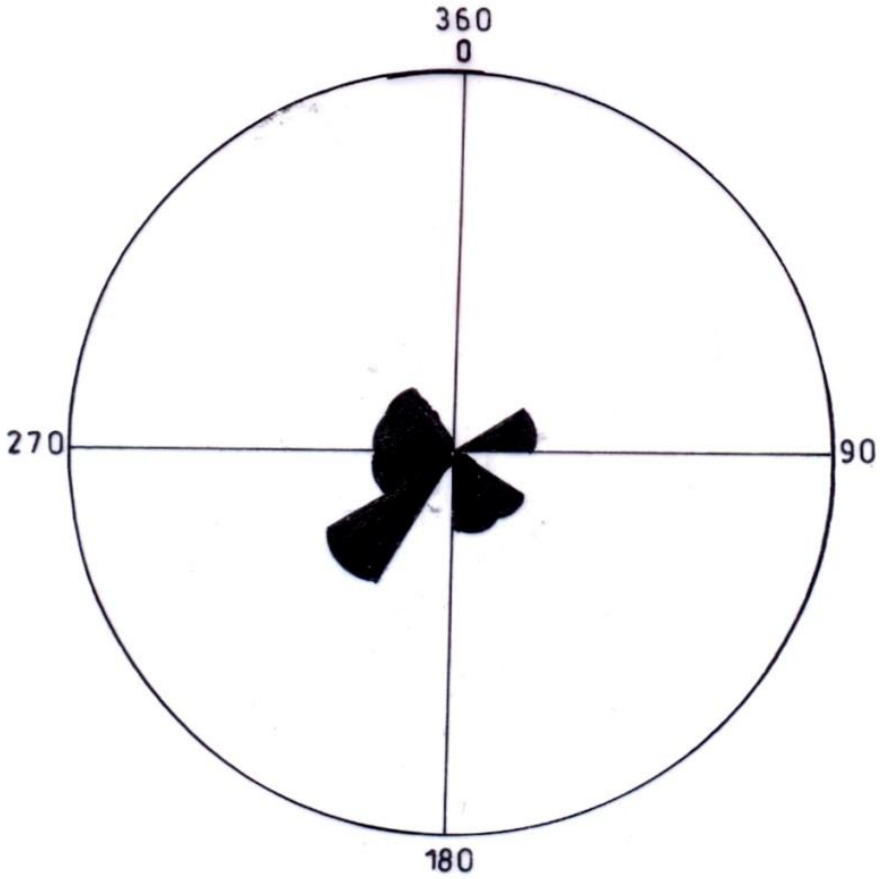


Fig. 27: Paleocurrent is bimodal bipola, Dominant trend SW

Rose diagram of paleocurrent data from location 3b Guduk Gombe sandstone (seven readings)

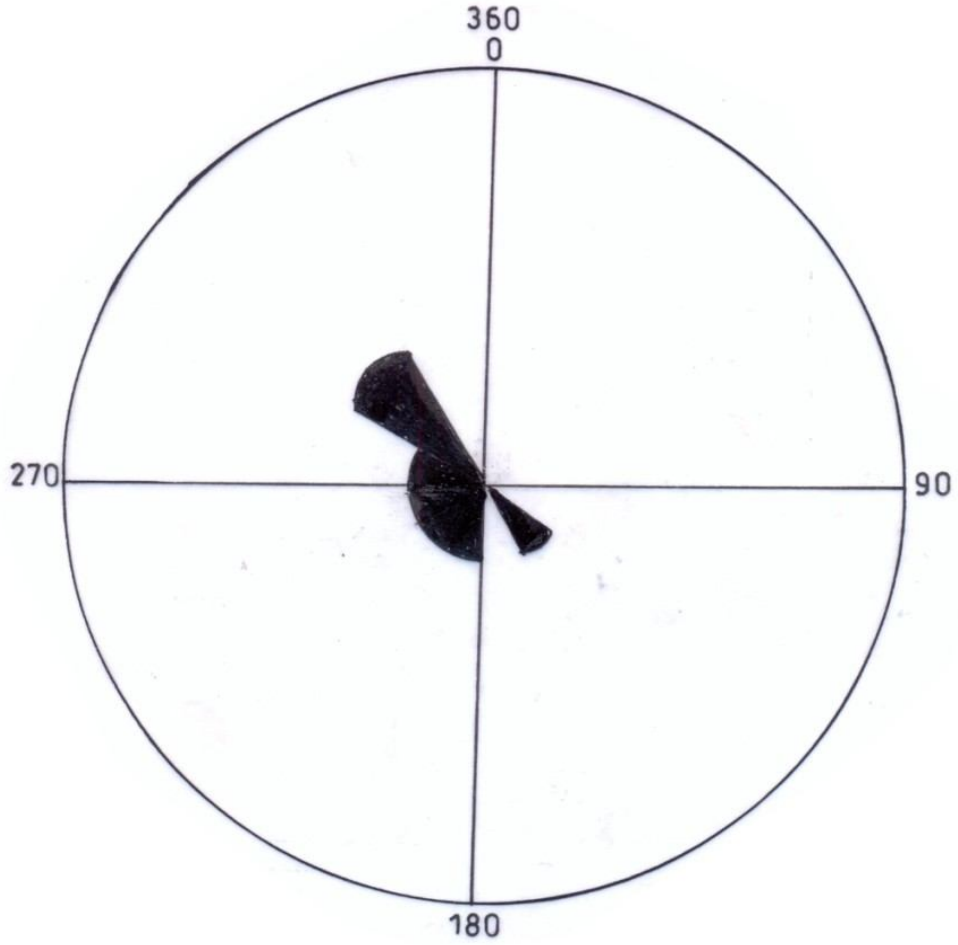


Fig. 28: Paleocurrent pattern is bimodal oblique. Dominant trend NW

Rose diagram of paleocurrent data from location 5 Tunga, Gombe
Rose diagram of Paleocurrent data from Bashar area over all plot (eighteen readings)

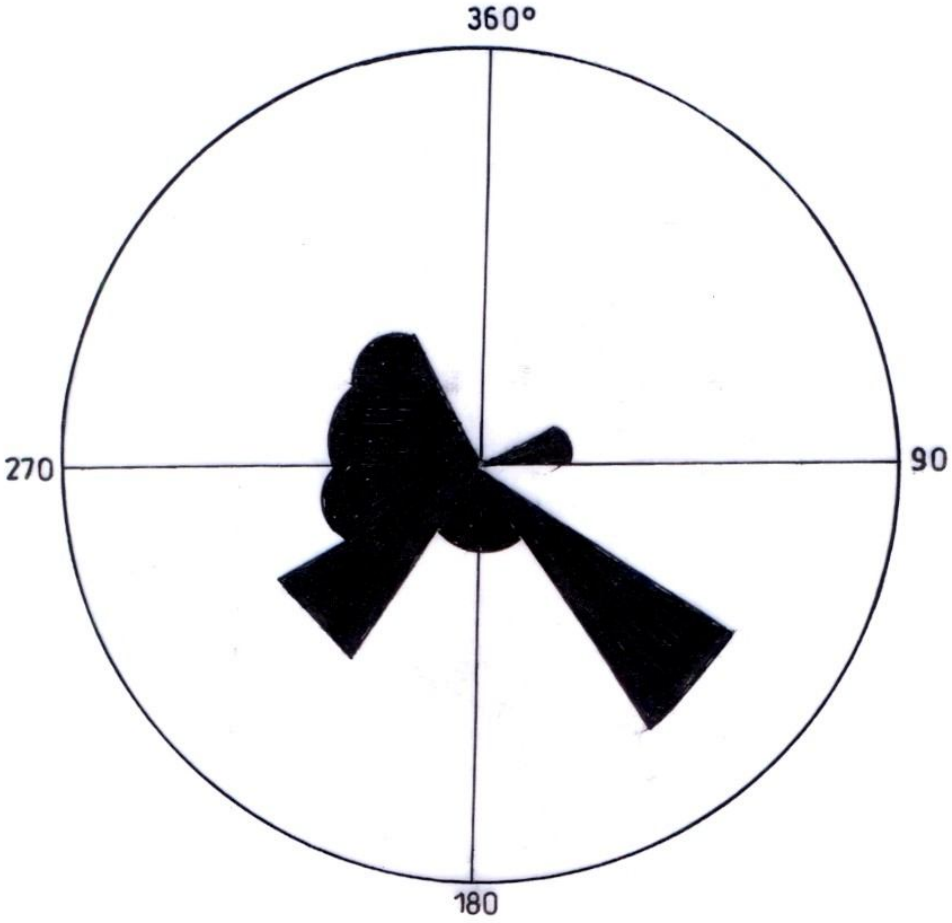


Fig. 30: Paleocurrent is polymodal



Plate i: 09^0 21'46"N/$10^0$04' 21"E
Coarse – grained pebbly sandstone at Jarmai.



Plate ii: 09^0 21'46"N/$10^0$04' 21"E
Trough crossbedding of the basal part of Gombe formation at Jarmai.



Plate iii: 09^0 22' 57"N/10^0 10' 08"E
Tabular crossbedded Gombe Formation at Guduk.



Plate iv: 09^0 28' 50"N/10^0 13' 47"E
Tabular crossbedded Gombe Formation at Tunga.



Plate v: 09^0 18’ 59”N/10^0 09’ 53”E
Silty shale at Bashar capped by fine – grained sandstone with tough crossbeds of the Pindiga Formation.



Plate vi: 09^0 18’ 59”N/10^0 09’ 53”E
A view of the Gombe Formation at Bashar.



Plate vii: 09^0 18’ 59”N/10^0 09’ 53”E
Volcanic basic lava flow on top of the Pindiga Formation at Bashar.



Plate viii: 09^0 28’ 50”N/10^0 28’ 52”E

Thrust/reverse fault of the Gombe Formation at Garga.