FORAMINIFERAL BIOSTRATIGRAPHY AND PALECECOLOGY OF THE KALAMBAINA FORMATION, SOKOTO EMBAYMENT; NORTHWESTERN NIGERIA

BY

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (GEOLOGY)

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DECLARATION

I, Mr. Nuhu George Obaje declare that this Thesis is my own work and has not been submitted in any form for another degree or diploma at any other University or Institution. Information derived from published or unpublished work of others has been acknowledged in the text.

Signature of Candidate

CERTIFICATION

This Thesis entitled "Foraminiferal Biostratigraphy and Paleoecology of the Kalambaina Formation, Sokoto Embayment; Northwestern Nigeria" by Nuhu George Obaje meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

The Kalambaina Formation outcrops mainly in the central portion of the Sokoto embayment. The Sokoto embayment forms part of the southeastern flank of the lullemmeden Basin which covers an area of about 700,000 km^2 in Mali, Niger and Nigeria, and the Republic of Benin.

The foraminiferal microfaunas from the outcropping Kalambaina Formation in the Sokoto embayment are predominantly calcareous with some arenaceous taxa. The assemblages from all the horizons in the sections comprise calcareous taxa with porcelaneous to hyaline wall structure and some arenaceous taxa with simple structure. Most of the species encountered have previously been described and provided a useful data base for regional and local paleoecologic, paleogeographic and stratigraphic interpretations.

The foraminiferal assemblages of the Kalambaina Formation are characterised by the dominance of local Paleocene species, namely Elphidiella africana, and Operculinoides bermudezi, followed by Rosalina koeneni, Cibicides praecursorius, and Pararotalia perclara. Other stratigraphically important foraminifera identified and described include Nonion graniferum, Rotalia of trochidiformis, Nonionella sp., Pvramidina crassa, ProteJphidium sublaeve, Pleurostomella paleocenica and Thalmannita madrugaensis.

Foraminiferal species diversity is twenty and this is low enough to suggest shallow water marine environment of deposition.

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ABBREVIATIONS AND SYMBOLS

NW	Northwest
NNE	North-North East
SSW	South-South West
FN	Foraminiferal Number
KL	Kalambaina Formation
^{o}C	degree centigrade
sp.	species
?	not very sure
Fm	Formation
Lat	Latitude
Long	Longitude

Chapter 1

INTRODUCTION

1.1 General Introduction

The Kalambaina Formation is a fossiliferous marly limestone which is the main marine lithotope in the Sokoto Embayment. The Sokoto Embayment itself is that part of the southeastern portion of a wide intracratonic sedimentary basin known as the Iullemmeden Basin which covers part of Mali and the western boundary of the Republic of Niger and extends through northern Benin Republic and northwestern Nigeria into eastern Niger.

A low escarpment, the "Dange Scarp" is the most prominent feature in the basin and is closely related to the geology. The area to the east of this escarpment consists predominantly of a gently undulating, sandy plain, which extends southwestwards to the boundary with the Basement Complex. The escarpment retains a marked NNE - SSW trend which approximately parallels the regional strike.

It is interesting to note that in this basin, the character of the landscape, is to a large extent determined by the lithological differences among the rocks and the widespread occurrence of lateritic ironstones which form a resistant band above the weaker rocks. The regional dip is very gentle and is towards the northwest.

Although Palaeozoic and older sedimentary rocks occur

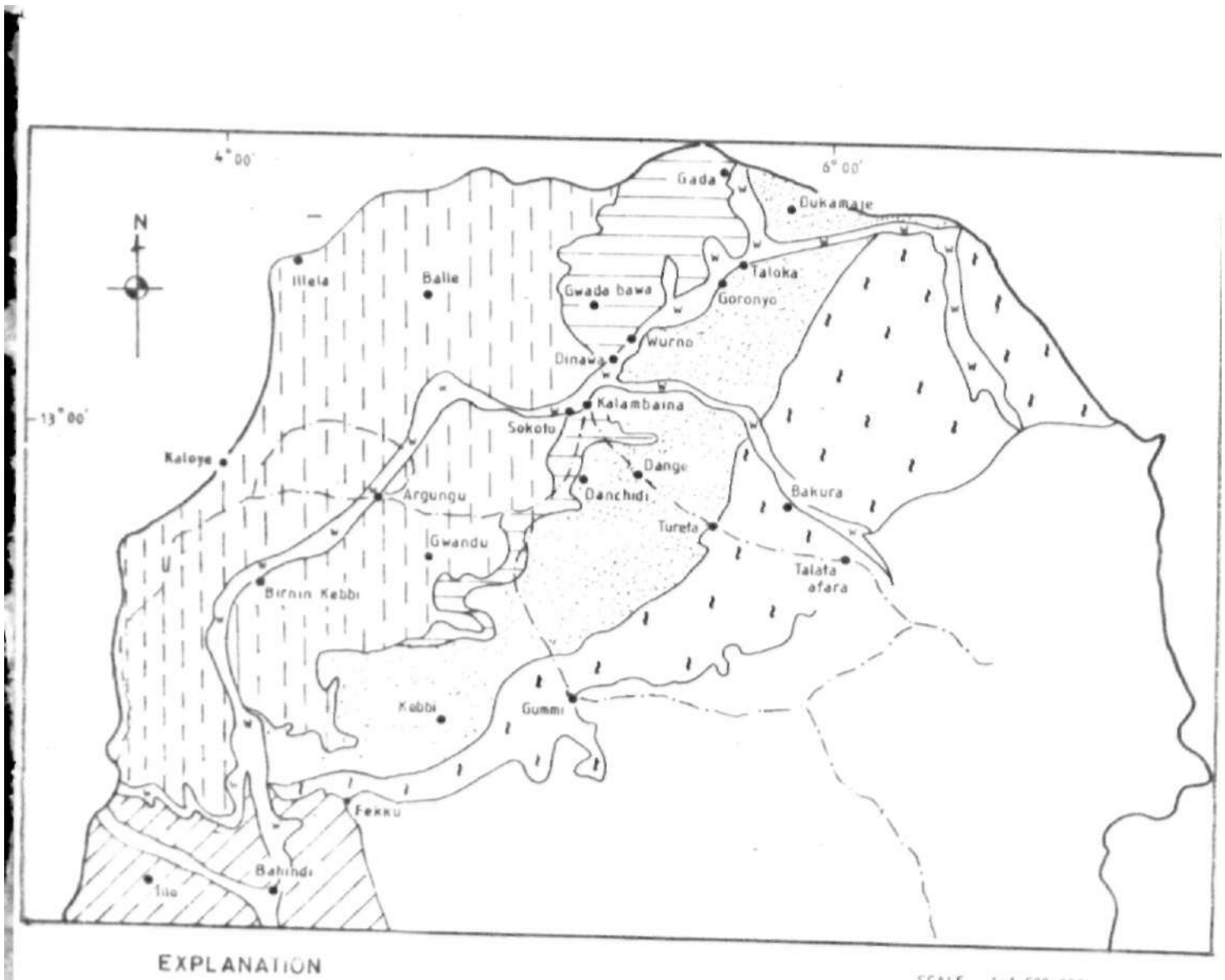


Fig. 1.1 Geological sketch map of the Sokoto embayment
(Inset: Index map showing the location of study area).

Index map showing study area

in the basin, much further north, in the Nigerian sector the rocks are Cretaceous and Tertiary in age. The environment of deposition of the sediments range from continental through marginal marine to normal marine. However, the lithostratigraphic unit studied in this project is the Upper Paleocene shallow marine marly limestone which overlies marine Maastrichtian epicontinental deposits. The marly limestone underlies the continental Gwandu Formation of Eocene age.

1.2 Location and Extent of Project Area

The project area is located in Sokoto in northwestern Nigeria (Fig. 1.1). The area is about 400km northwest of Zaria. Since the project is aimed at determining the age of the exposed part of the Kalambaina Formation, and at reconstructing the paleoecology of the formation from its foraminiferal composition and distribution, sampling was also carried out at Dange (16 km from Sokoto town along Sokoto - Gusau Road); Wurno (65 km north of Sokoto town) and at Malbaza (near the Nigeria - Niger border).

The major area covered is located between latitudes $13^{\circ}00'N$ - $13^{\circ}20'N$ and longitudes $5^{\circ}00'E$ - $5^{\circ}30'E$ with an overall area of about 1944 km^2 covering a length of 54 km and width of about 36 km.

1.3 Previous Work

Geological work in the Sokoto embayment dates back to the late 1800s, but most of the early published materials deal with the general geology and descriptions of fossil localities. Falconer (1911) published the result of his

pioneering study of the geology and geography of northern Nigeria which included the Sokoto embayment. His observations and descriptions are still of paramount importance to any study of the Sokoto embayment today. However, the 'regional tectonics' that resulted in the folding and fracturing of the rocks which he dated as Eocene is now thought to have occurred at the end of the Paleocene (Kogbe 1979). The subsequent period of intense erosion took place during the Eocene.

Jones (1948) carried out the first detailed stratigraphic study of the Sokoto embayment and his work has been published as a bulletin of the Geological Survey of Nigeria. Subsequent investigations by Asseez and Fayose (1972) and Petters (1977a, 1977b, 1978a, 1978b, 1980, 1982) confirmed the observations made by Jones (1948). Parker (1964) mapped a large segment of the Sokoto province. Kogbe (1972, 1974, 1976, 1977, 1978, 1979) and Petters (1976a, 1978a) worked on the geology and stratigraphy of the Sokoto embayment and described foraminifera from many of the formations.

The water resources of the embayment were first studied by Raeburn and Tattam (1930) and later by du Preez and Barber (1965). Others who have worked in the area include Carter (1964) and Reyment & Reyment (1978). Almost all these studies are limited to the description and illustration of different species of foraminifera from certain localities and from borehole samples. Consequently, many of the same Upper Paleocene species have been given different names by different workers. In most cases, the paleoecologic implications of the foraminifera described were not considered.

1.4 Aims and Objectives of Present Study

The aim of this study is to identify and describe in details the Foraminifera from the Kalambaina Formation and to deduce their paleoecologic implications and reconstruct the paleoenvironment from their distribution and composition. Their distribution should also be instrumental to the establishment of the foraminiferal biofacies and comparisons with Paleocene foraminiferal biofacies in other Nigerian sedimentary basins. Emphasis is on the diversity of species, population structure, benthonic/planktonic ratios, microfaunal composition and the morphology of species as a means of deducing paleoenvironment.

1.5 Methods of Study

Samples were taken from different localities where the Kalambaina marly limestones outcropt and from stratigraphic sections exposed along road cuts, gullies and the cement quarry. The highest number of samples (10) were obtained from the Kalambaina cement quarry. The samples were washed mainly for microfossils. The foraminifera were studied in detail, identified and classified through systematic paleontology. This contributed immensely to the understanding of the paleoecology of the formation and of the basin as a whole.

Each sample was crushed with mortar and pestle before it was boiled in water to which Hydrogen Peroxide has been added prior to washing through a 230-mesh sieve. Each washed sample was split so that approximately 100 - 200 specimens were available for counting (Table 3.1) and identification.

A list of statistically important species identified in this project is given in Chapter 3.3.1 and Table 3.1

Foraminiferal count was done using 10 gm of washed sample each to determine the relative abundance of species and foraminiferal population in each sample. This was a basis for calculating the foraminiferal number (FN) as the number of foraminifera/gm of the washed sample.

Chapter 2

OUTLINE GEOLOGY OF THE SOKOTO EMBAYMENT

2.1 Introduction

The southeastern flank of the Iullemmeden basin in Nigeria is locally known as the Sokoto Embayment. The sediments of this region cover an area of about 29,900 square kilometres. The physiography consists essentially of a gently undulating plain with an average elevation varying from 250 - 400 metres above sea level. This monotonous topography is interrupted at intervals by, mesas - isolated, steep-sided, flat-topped hills and also by a low escarpment named the 'Dange Scarp' by earlier workers (Kogbe, 1972).

The Sokoto Embayment forms a small portion (about one-tenth) of a far more extensive elongated sedimentary and structural basin, centred in the Republic of Niger and trending northwestwards. This basin is known as the Iullemmeden Basin (Radier, 1957) after the Tuareg tribe which inhabited the central part. In the Niger Republic, the basin attains its maximum development with the occurrence of Paleozoic, Mesozoic and Tertiary sediments.

The oldest rocks in the Sokoto Basin are continental in origin and belong to the Gundumi and Illo Formations which form part of the "Continental intercalaire" of French-speaking neighbouring countries. These formations were deposited disconformably on the Basement Complex. In the Sokoto Basin, the Illo Formation lies to the southwest while the Gundumi Formation occurs in the northeast. It

Age	Formation	Group	Environment	Type Locality	Brief descriptions at type locality
Quaternary	Sands, laterites and lateritic sands		Continental	Widespread	
Eocene / Miocene	Gwandu Formation	Continental Terminal	Continental	Dutsen Badua – 4Km North of Birnin Kebbi	Massive clays, clayey grits and sandstones
Upper Paleocene	Gamba Formation	Sokoto Group	Shallow Marine	Cement Quarry	Greenish-grey thinly laminated phosphatic shale
	Kalambaina Formation x		Shallow Marine	Cement Quarry	White clayey limestone and shale
	Dange Formation		Shallow Marine	Dange village – 24 Km South of Sokoto	Pale, greenish-grey, thinly laminated shale
	Wurno Formation	Rima Group	Deltaic/ Brackish water	Wurno village	Pale coloured fiable, fine-grained sandstones silstone & mudstones
Maastri-chtian	Dukamaje Formation		Marginal Marine	Dukamaje	Shales, limestones and mudstones with vertebrate fragments and limb bones.
	Taloka Formation		Deltaic/ Brackish water	Taloka – 2 Km east of Goronyo	White, grey, brown siltstones, friable sandstones, claystones, biogenic structures.
Lower most Cretaceous and Older	Illo and Gundumi Formations	Continental intercalair	Continental	Dutse Dambo – near Bakura	False-bedded, massive, feldspathic, clayey grits, clays, pebbley sand
Pre-cambrian	Basement complex				

x Formation studied (in detail)

Table 2.1 Stratigraphic framework of the Sokoto basin. (after Petters, 1979a)

is supposed that the two formations form one continuous outcrop partially separated by a basement ridge located in the area around Fekku. The Illo and Gundumi Formations are lucustrine/fluviatile deposits and are very poorly fossiliferous. Only fragments of silicified wood have been recovered from both formations (Kogbe, 1972). The Gundumi Formation is overlain by the Rima Group of Maastrichtian age, while the Illo Formation is overlain successively from east to west by the Rima Group, the Sokoto Group and the Gwandu Formation. (Table 2.1.)

2.2 Stratigraphic framework

The stratigraphic framework of the Sokoto Basin fits neatly into three major depositional episodes. The first episode occurred during the Uppermost Jurassic to Lowermost Cretaceous. This was a continental depositional phase during which the deposits of the Gundumi and Illo Formations were laid down unconformably on the Precambrian Basement Complex of gneisses, quartzites and granitic complexes (Fig. 2.1). The area was far more removed from the limits of the southern or Tethys seas and the deposits are probably fluviatile or lucustrine in origin.

The second episode began with the Maastrichtian transgression when the sea moved northwards from the Gulf of Guinea through the mid-Niger basin (Kogbe 1979). The Tethys seas moved southwards from north Africa through the Sahara. The transgression continued into the Paleocene during which the Rima Group (Maastrichtian) and the Sokoto

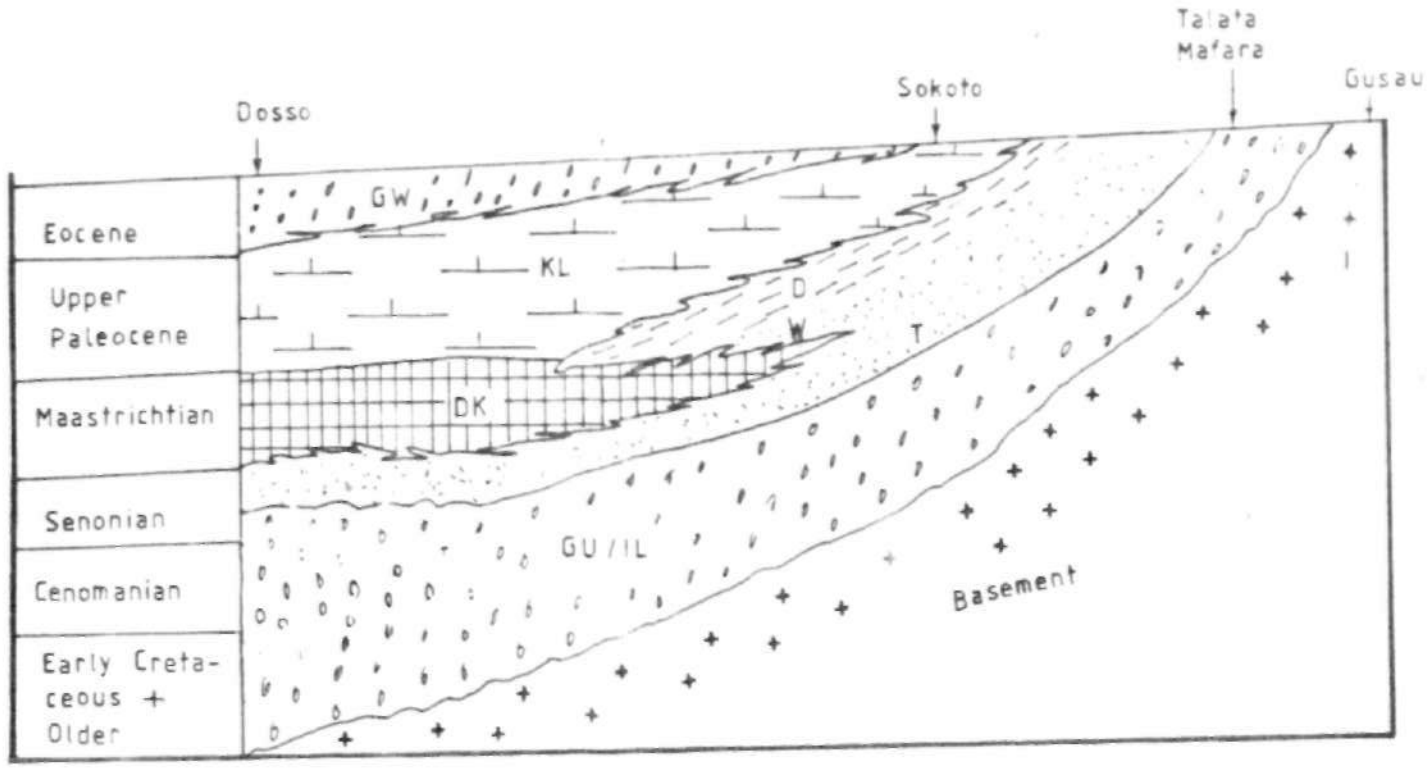


Fig. 2.1 Lithostratigraphic section across the Sokoto basin from Gusau through Sokoto to Dosso. (after Petters, 1979c)

GW - Gwandu Formation
KL - Kalambaina Formation
D - Dange Formation
W - Wurno Formation
DK - Dukamaje Formation
T - Taloka Formation
Gu - Gundumi Formation
IL - Illo Formation

Group (Paleocene) were deposited (Fig. 1.2 & Table 2.1).

The third and final episode began during the Eocene with the regression of the sea. Continental conditions prevailed again and continues until the present. The Gwandu Formation of Eocene to Miocene age was deposited during this episode and was followed by a period of laterization which was very widespread in Nigeria and is still in progress today.

2.2.1 The Rima Group

The second episode in the the history of the Sokoto basin commenced with the Maastrichtian marine transgression. The sediments deposited during this transgression belong to the Rima Group, which consists of three (3) formations

3) Wurno Formation

2) Dukamaje Formation

1) Taloka Formation

The Taloka and Wurno Formations consist predominantly of friable sandstones and siltstones with some clayey and carbonaceous horizons. The sediments are finely bedded and deposited in a brackish water environment. The Taloka and Wurno Formation are separated by the gypsiferous and calcareous Dukamaje Formation.

The type locality of the Taloka Formation is at the village of Taloka about 2 kilometres east of Goronyo. The Dukamaje Formation is richly fossiliferous and the famous Mosasaurus nigeriensis was recovered from the formation (Kogbe 1979). The Dukamaje Formation was deposited during

the Maastrichtian marine incursion. This is confirmed by the presence of the Upper Maastrichtian ammonite (Libycoceras ap.) at the type locality in Dukamaje. In Taloka village, the Dukamaje Formation overlies the Taloka Formation with its characteristic bone bed lying directly at the base of the formation.

The Wurno Formation is well exposed at its type section at Wurno, but elsewhere exposures are quite rare. The formation is about 23 metres thick at Wurno and consists of whitish-grey coloured friable, fine grained sandstones, siltstones and intercalated mudstones. The sediments are very loosely consolidated and susceptible to weathering.

2.2.2 The Sokoto Group

Still in the second episode in the depositional history of the sedimentary rocks of the Sokoto basin is the Sokoto Group of sediments, consisting of the Dange, Kalambaina and Gamba Formations. This group is entirely marine in origin. The formations within the group increase in thickness northwestwards and attain maximum thicknesses towards the centre of the Iullemmeden basin in the Niger Republic. The beds are of Upper Paleocene in age and richly fossiliferous. The type locality of the Dange Formation is along the road cutting north of the village of Dange on the Sokoto - Gusau road. Type localities and type sections of the Kalambaina and Gamba Formations can be observed at the quarry of the Cement Company of Northern Nigeria near the village of Kalambaina about 6 kilometers southwest of Sokoto town.

Several metres of Dange shales can be observed along the road cutting about 17 kilometres south of Sokoto on the Sokoto - Gusau road. The shale is pale greenish-grey, thinly laminated and plastic when wet. It becomes light grey, pale yellow and marly towards the top where it is overlain by the Kalambaina Formation. The Dange Formation is very rich in macrofossils, most importantly some echinoids, gastropods and lamellibranchs. Ostracodes and foraminifera have been described separately and at different times by Reyment (1960, 1963, 1965, 1966), Kogbe (1976, 1979), and Petters (1979c, 1982).

The Kalambaina Formation which is the subject of this work is extensively discussed in Chapter Three.

The Gamba Formation consists of thinly laminated phosphatic shale with a greenish - grey colour. Dark brown patches are observed along the exposed bedding planes. Outcrops of the formation are rare, but excellent exposures are observed at the cement quarry. At this quarry, it reaches a maximum thickness of about 2.5 metres.

2.2.3 The Gwandu Formation

The third episode and of course the last one in the depositional history of the Sokoto basin is deposition of the Post-Paleocene continental sediments of the Gwandu Formation. The Gwandu Formation outcrops most extensively in the Sokoto basin, covering an extensive area and overlying the Paleocene marine shales of the Gamba Formation. The formation is characterised by some prominent ranges and

groups of flat-topped steepsided hills and usually capped by lateritic ironstones. The Gwandu Formation is made of massive clays, clayey grits and sandstones varying from fine to coarse grain size. The formation bears a general resemblance to those of the Gundumi and the Illo Formations but in the Gwandu Formation there is a considerably higher proportion of clay. The clays are massive, non-plastic and vary in colour from entirely white to blue and sometimes purple. The grits are variegated, white, red, and blue and contain a considerable amount of clay and sometimes grade to gritty clays.

The type section of the Gwandu Formation occurs near the village of Dutsin Badua about 4 kilometres north of Birnin Kebbi on the Argungu road (Kogbe, 1972).

The Gwandu Formation overlies the Gamba Formation unconformably in the northern and central parts of the Sokoto basin. To the south, the formation overlaps the Paleocene formations and rests directly on the pre-Maastrichtian Illo Formation and the Maastrichtian Rima Group.

The age of the Gwandu Formation has been very uncertain. It was usually referred to the Pleistocene, but palynologic determination by Shell B.P. indicates a possible Eocene age (Reyment 1965) and this has been confirmed by subsequent palynologic determinations by Kogbe and Sowunmi (1975) in which an Eocene-Miocene age was assigned.

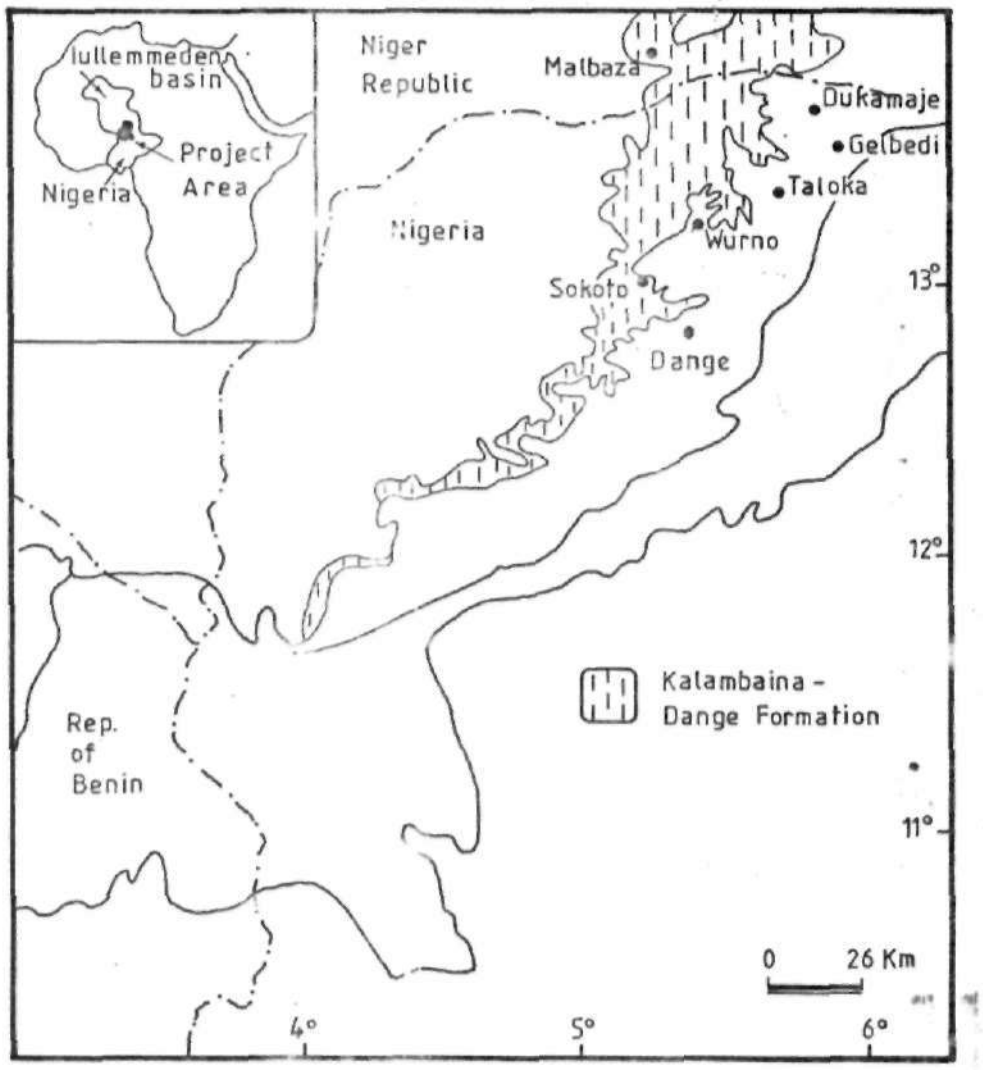


Fig. 3.1 Geological sketch map showing the location and areal extent of the Kalambaina Formation in the Sokoto basin, Nigeria.

Chapter 3

THE KALAMBAINA FORMATION

3.1 Introduction

The Kalambaina Formation (Fig. 3.1) consists of a white marine, clayey, marly limestone and shale. The type section of the formation is at the quarry of the Cement Company of Northern Nigeria, near the village of Kalambaina, located about 6 kilometres to the southwest of Sokoto township. The thickness of the formation is variable because of the subsurface dissolution of the limestone. The maximum thickness recorded from boreholes, according to Kogbe (1976) is over 20 metres, but usually only about 10 metres of section is exposed at the quarry (Fig. 3.2). The Kalambaina Formation is reduced to about 4 metres near the village of Dange (Fig. 3.3) and further south at Birnin Kebbi, the Formation attains an approximate thickness of about 18 metres.

The Kalambaina Formation is very rich in invertebrate fossils, mainly echinoids, corals, nautiloids, lamellibranchs, and gastropods. Foraminifera and ostracods have been described from the formation (Kogbe 1972; Foster et al., 1983; Reyment, 1965).

At the type locality, i.e. the Kalambaina quarry, the type sections of the Kalambaina and Gamba Formations are well exposed. The profile consists of the Kalambaina Formation, which in turn is succeeded by an ironstone unit

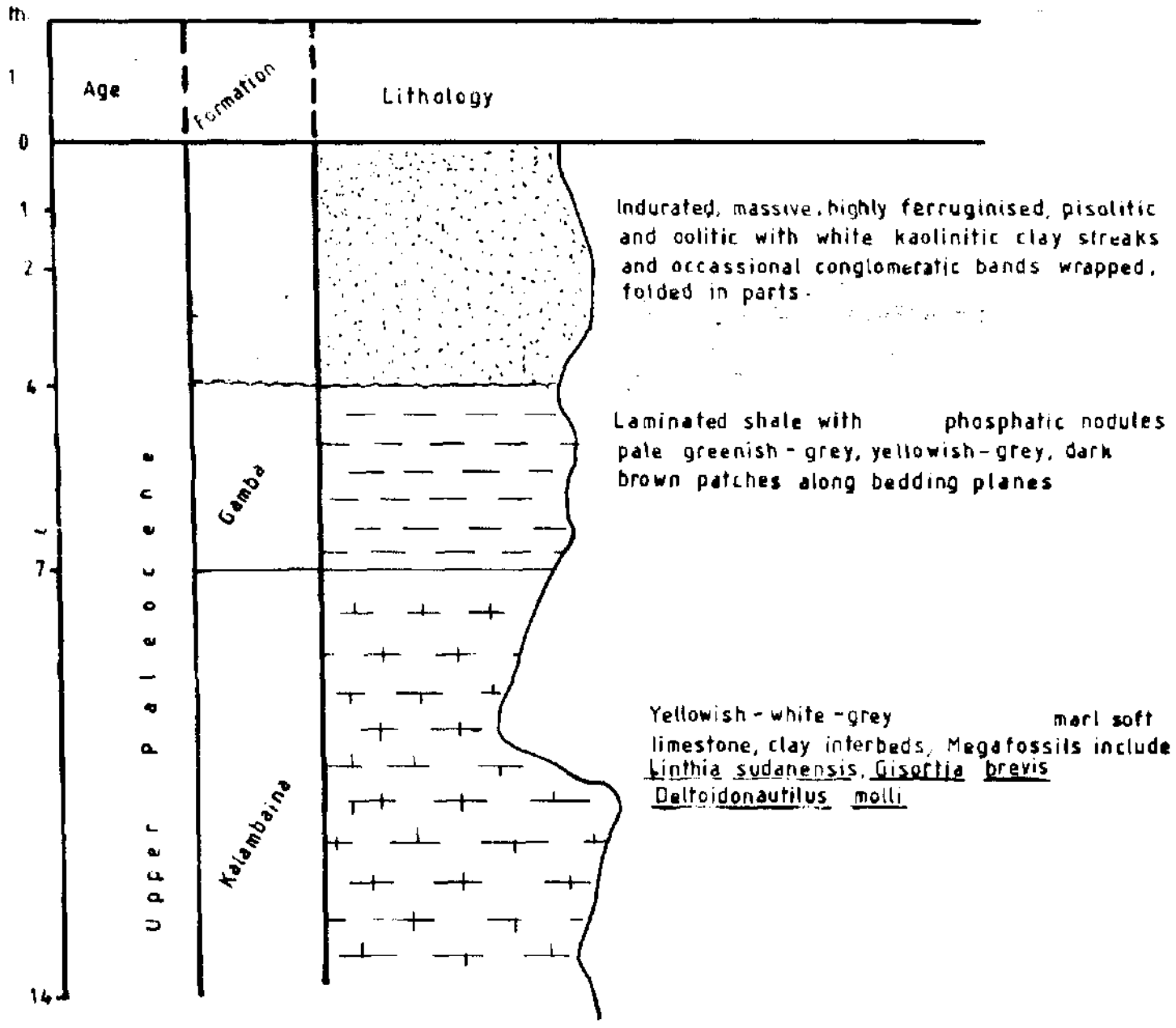


Fig. 3.2 Type section of the Kalambaina Formation, cement quarry.

(Fig. 3.2). About 7 metres from the top of this section begins the Kalambaina Formation. It continues down to about 14 metres from the top. The Kalambaina Formation in this locality is essentially yellowish-grey, white, marly, soft limestone, with clay interbeddings. Clay content increases upwards and the formation is generally richly fossiliferous. Megafossils include the shallow water pelecypods - Lucina cf. pharaonis, Panopea sahariensis, Pseudoheligmus nigeriensis, Ostrea multicostata, Mucula sp., the gastropod - Volutilithes cf muricina; some nautiloids - Deltoidonautilus molli and Cimonia sudanensis. Echinoids are very abundant especially Linthia sudanensis, Gisortia brevis, and Rhabdocidaris cottreani. There is a rich ostracod fauna; and some bryozoans and corals, which are yet to be described.

In this work, the Kalambaina Formation refers only to the calcareous member and calcareous shale member of the 'Calcareous Group' of Raeburn and Tattam (1930), Jones (1948) and Parker (1964).

The calcareous clays of the Kalambaina Formation contain vertebrate remains, mostly fish teeth, which have been studied by Swinton (1930), White (1934) and Kogbe (1979). They included the teeth of Odontaspis; Ginglymostoma; Squartina; Eotorpedo; Myliobatis; and Rhinopters. Two forms, Pycnodus variabilis togoensis (Stomer) and Hypolophites myliobatoides (Stromer), are also known from the Eocene of Adabion in Togo.

At Malbaza, in the Niger Republic, the limestone is generally purer with a variable thickness of between 6 to 18 metres Kogbe (1979). On the flat lying terrain from Sokoto town, southeast along the Sokoto-Gusau Road, only laterite is exposed until about 15 kilometers from Sokoto town, where a few weathered sections of the Kalambaina marly limestones begin to outcrop. The section here is about 4.5 metres of exposed Kalambaina limestone along the road cutting and capped by a thin layer of laterite. The Gamba Formation here has been eroded so that laterite forms directly on the limestone. Samples collected from here and washed for foraminifera contain abundant Rotalia cf. trochidiformis, Nonionella insecta, Elphidiella africana, Thalmannita madrugaensis, Pararotalia tuberculifera and Cibicides praecursorius. These samples also contain abundant echinoid spines and ostracods.

In the village of Dange, about 8 metres of stratigraphic section is exposed with the Dange shale accounting for up to 4 metres at the base of this section (Fig. 3.3). The Dange shale here is pale-greenish-grey, thinly laminated and plastic under wet condition. At the top, it becomes pale yellow and marly. This point is assumed to be the point of transition from the Dange Formation to the Kalambaina Formation. The Kalambaina Formation here is identified on the basis of its typical lithology and also on its content of megafossils such as Lucina cf. pharaonis.

Most of the area along the road to Wurno consists of

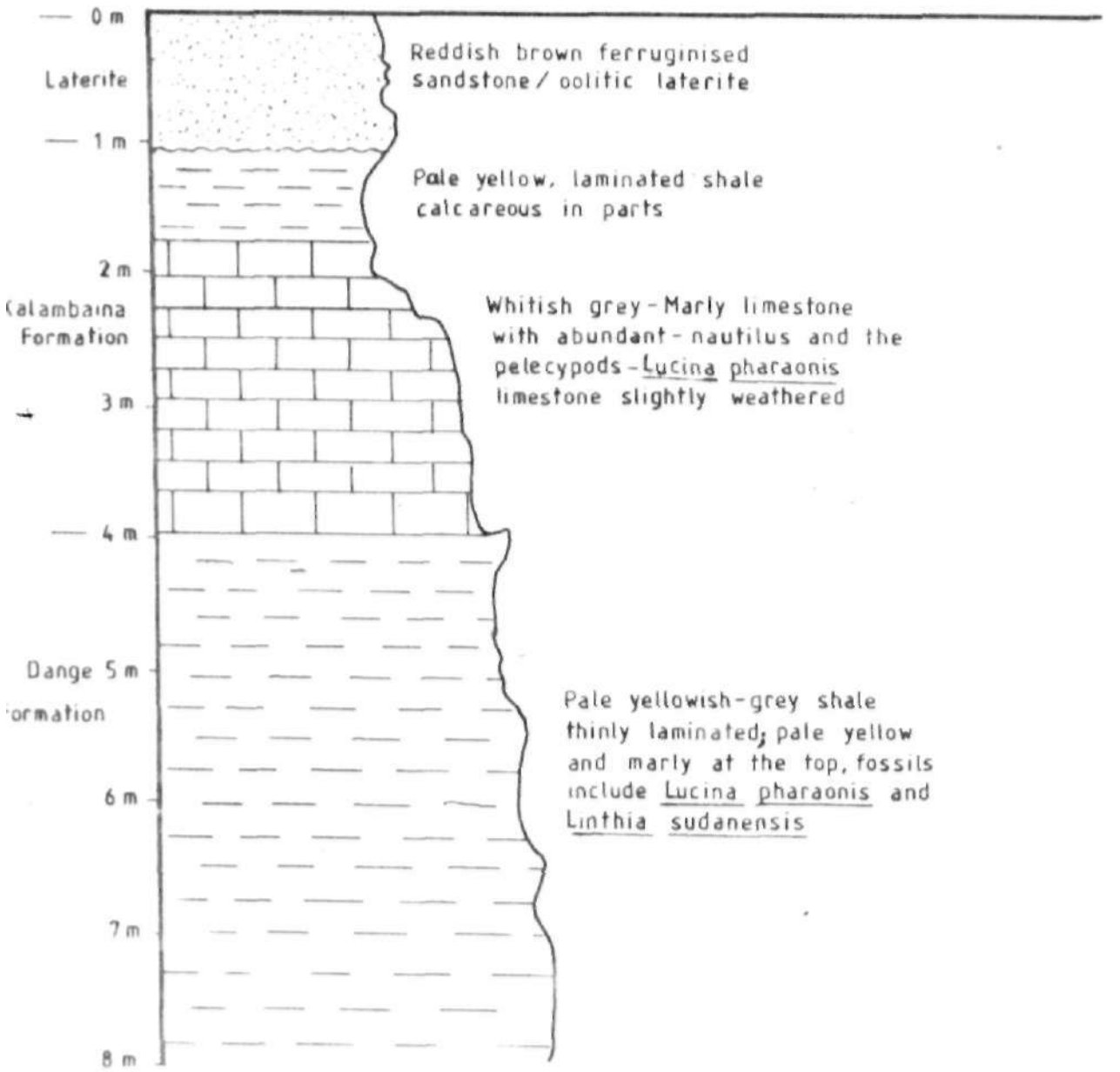


Fig. 3.3 Road-cut section at Dange. (Sokoto - Gusau road)

laterite and sand cover with poor Kalambaina exposures. However, at Dinawa, small exposures of the Kalambaina Formation are found in a little road side gully, and mainly consists of limestone pebble and cobbles. At the Wurno Hill near the village of Wurno, a good section of the Kalambaina Formation is exposed overlying the Dange and Wurno Formations (Fig. 3.4).

The contact between the Dange and the Kalambaina Formations is gradational and well exposed on the slopes of the ridge at the northern extremity of Sokoto Basin. (Geological Survey of Nigeria, 1:250,000 series, Sokoto Sheet 2) at $5^{o}45'E$ and $13^{o}45'N$. The lithologic change is marked by a gradual increase in calcareous content. The lower marls as correlated to the Kalambaina quarry section contain the richest microfauna in the Kalambaina Formation. This is a shallow-water benthonic foraminiferal assemblage dominated by smaller foraminifera principal amongst which are rotaliids, nonionids, and cibicidids. The overlying limestones contain predominantly larger foraminifera with low population but relatively higher diversity and permit precise age determination.

The Kalambaina Formation has been referred to as a bioclastic wackestone with mudstone intercalations and packstone nodules (Petters, 1979b). Some of these nodules contain turtle carapaces. Ostracods and Foraminifera occur abundantly in the wackestones. Small mounds of domal stromatolites have been reported from the base of the Kalambaina Formation (Petters, 1979b). There is an abundant occurrence of the coccolith Braarudosphaero bigelowli which,

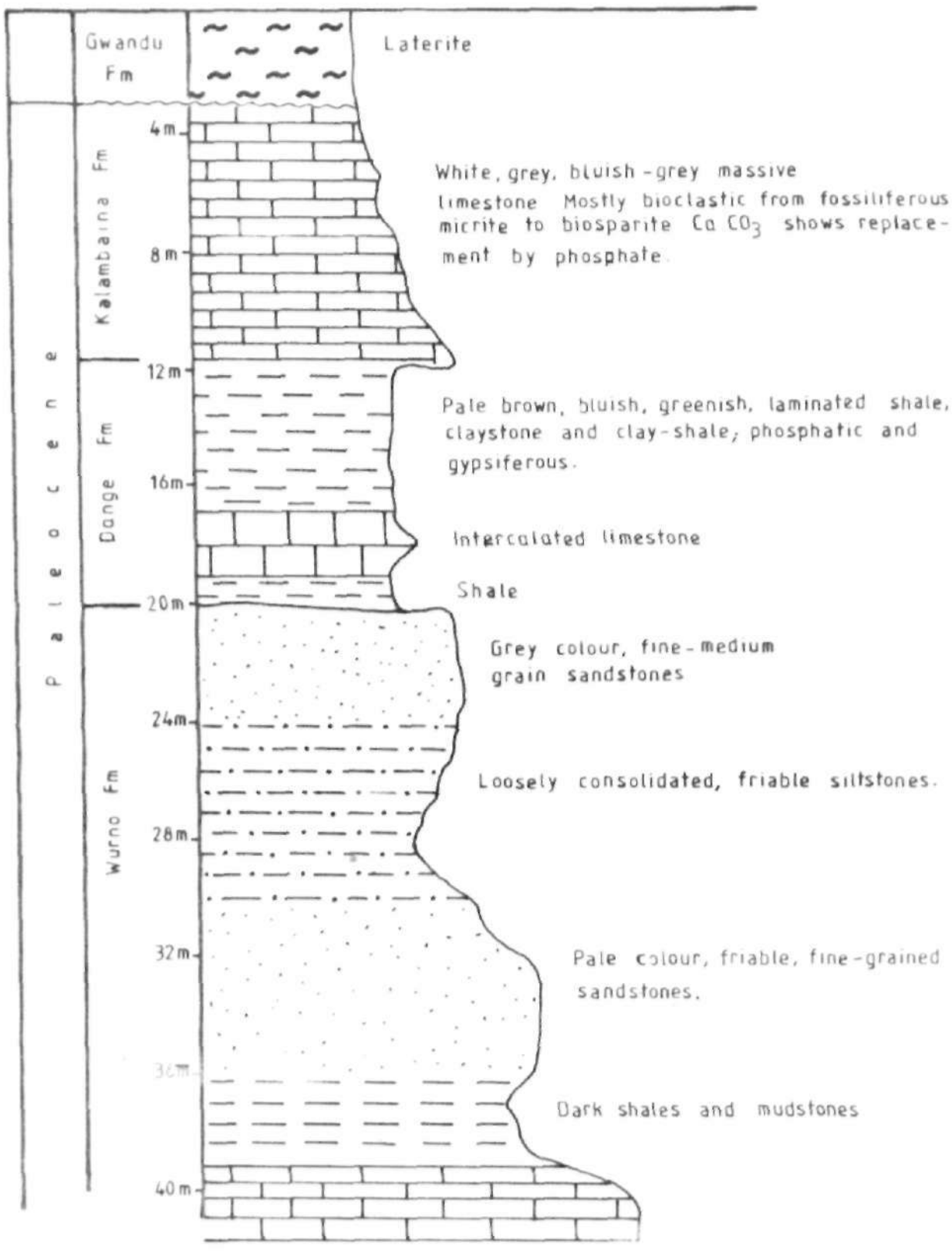


Fig. 3.4 Wurno type section at the Wurno Hill near the village of Wurno Lat= 5° 26'Long= 13° 17'

together with the pelecypod Lucina, suggests a very shallow and restricted environment of deposition for the Kalambaina Formation (Petters 1982). However, living conditions in the Paleocene Saharan epeiric sea had ameliorated to the extent that pelagic invertabrates like nautiloids and rare planktonic foraminifera, together with a rich benthonic foraminiferal assemblage, could survive in the basin, unlike during Maastrichtian times.

The work of Krasheninnikov and Trofimov (1969) in the Mali Republic shows that the Paleocene carbonate sequence is more extensively developed toward the centre of the basin, where four benthonic foraminiferal zones, spanning the entire Paleocene, were recognized. (fig. 3.5).

The Kalambaina Formation is very argillaceous at the top and changes gradually into the Gamba paper shales. The Gamba Formation is lithologically akin to the Dange Shales in that it is phosphatic, greenish-grey, and well laminated. The Gamba Formation is not known to be gypsiferous, however. Calcium phosphate occurs in the form of small ellipsoidal pellets with horizontal burrows lined with fecal pellets. These occur along the shale bedding planes, suggesting the activity of some near shore organism that mined the mud for nutrients. An impoverished arenaceous foraminiferal assemblage comprising Ammobaculites, Haplophragmoides, and Trochammina occurs in the Gamba shale (Petters, 1979b). The Gamba Formation marks the final withdrawal of the sea from the Sahara. The Dange and the Gamba Formations represent marginal marine environments,

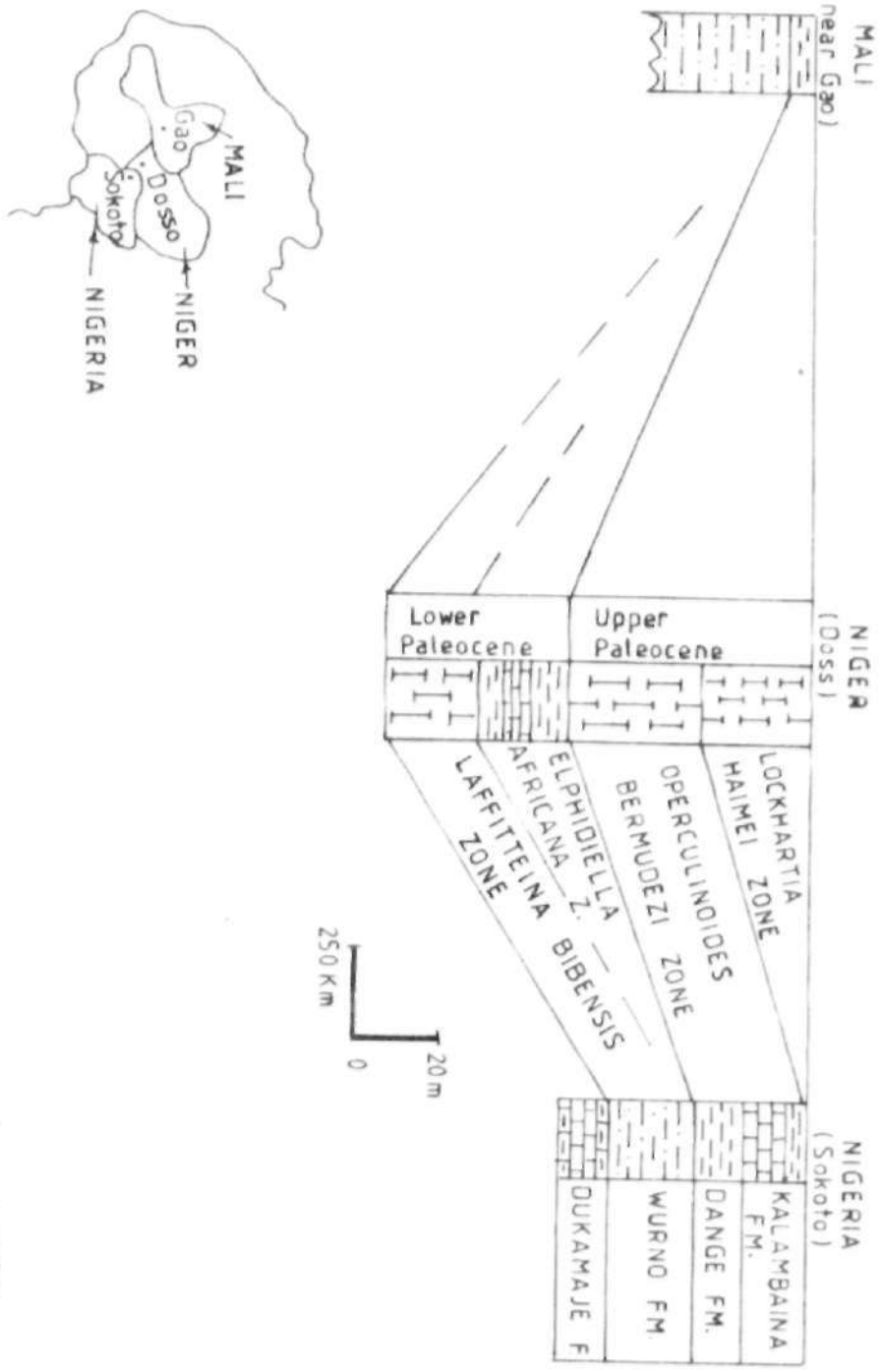


Fig. 3.5 Paleocene correlation for part of the Iullemmeden basin (based on Krasheninnikov and Trofimov, 1969 and Petters, 1979 a)

while the Kalambaina marl and limestone originated in a warm, shallow epeiric sea.

3.2 Paleontology

Macrofossils from the Kalambaina and associated formations in the Sokoto Basin have been described by several workers (de Lapparent, 1903; Bather, 1904; Newton, 1904; Parker, 1964; Kogbe, 1979). The macrofossils collected during this project work were identified by comparing them with those described by earlier workers. The great majority of the fossils were collected from the Kalambaina exposures at the cement quarry type locality and at Wurno.

Among the macrofossils collected from the Kalambaina Formation are :

BIVALVES	-	Lucina pharaonis
	-	Cyclocardia hanguensis,
	-	Heligmotenia cf. molli,
	-	Carbula cf atlantica,
	-	Liostrea lammellaris,
	-	Cardium sp
	-	Ostrea multicostata
NAUTILUS	-	Deltoidonautilus chudeani ,
	-	Deltoidonautilus togoensis ,
	-	Cimonia landsensis ,
	-	Cimonia sudanensis .
CORALS	-	Adegokeastrea ewekoroensis .
GASTROPODS	-	Gisortia brevis ,
	-	Turriterlla sp.
ECHINOIDS	-	Linthia sudanensis ,
	-	Plesiolampas saharae.

3.3 Micropaleontology

The sediments of the Kalambaina Formation is rich in many microfossils. The method used in washing the samples for this study (as described in section 1.5) made it possible to identify the following microfossils and their distribution population as they occur in the Kalambaina sediments.

Foraminifera	-	large population - evenly distributed throughout the samples.
Ostracods	-	large population - evenly distributed throughout the samples.
Micro-molluscs	-	Scanty population - unevenly distributed
Sponge spicules	-	Scanty population - unevenly distributed
Coccoliths	-	Scanty population - unevenly distributed

All the samples studied were very rich in ostracods. Kogbe (1979) and Reyment (1960, 1963, 1965, 1966) studied the ostracods from the Sokoto embayment. Foster et al., (1983) identified and described the following ostracods species from the Kalambaina Formation:

Ambocythere tatteuliensis (Apostolescu);

Buntonia cf. tichittensis (Apostolescu);

Bradleya sehonensis (Apostolescu);

Buntonia bonaensis (Apostolescu);

Veenia warriensis (Reyment);

Bythocypris daredodui (Reyment);

Quadracythere sp. ex. gr. lagachiroboensis (Apostolescu);

Xestoleberis kekere (Reyment);

Bairdia sp. ex. gr. magna (Alexander);

Actinocythereis modesta (Apostoleacu);

Acanthocythereis ex. gr. teiskotensis (Reyment);

Krithe sp. cf. perratica (Alexander);

Buntonia tenuipuncatata (Apostolescu);

Buntonia apatayeriveri (Reyment);

Bradleya cf. praecrassa (Apostolescu);

Acanthocythereis ex. gr. vesiculosa;

Icrubaella cf. n. sp. I.;

Aurila nov. sp.?

Ovocytheridea nov. sp.?

3.3.1 Foraminifera

The foraminiferal microfauna is predominantly calcareous with some arenaceous taxa. The assemblages from all the horizons in the sections comprise calcareous taxa with porcelaneous to hyaline wall structure and some arenaceous taxa with simple structure. Most of the species encountered have previously been described by Petters (1978a, 1978b, 1979b, 1982) and Kogbe (1979) and provide a useful data base for regional and local paleoecologic, paleogeographic and stratigraphic interpretations.

The Kalambaina foraminiferal fauna is composed of 17 genera, and 10 families. However, only 5 genera - Rotalia, Elphidiella, Cibicides, Nonion, and Operculinoides - are present in all the samples studied. The generic and family names conform to the classification according to Loeblich & Tappan, (1964) with some modifications. Most of the genera are benthonic; the ratio is 16 benthonic

genera to one planktonic genus. The most abundant families in terms of individuals are the Elphidiidae and Rotaliidae.

The characteristic foraminiferal species of the Kalambaina Formation are given below and arranged from top to bottom in total decreasing abundance from all samples combined:

1. Elphidiella africana (Leroy 1953)
2. Cperculinoides bermudezi (Palmer)
3. Rosalina koeneni (Brotzen 1948)
4. Cibicides praecursorius (Schwager 1883)
5. Pararotalia perclara (Loeblich & Tappan 1957)
6. Nonion graniferum (Terquem 1882)
7. Rotalia cf. trochidiformis (Lamarck 1804)
8. Anomalinoides umboniferus (Schwager 1883)
9. Pararotalia tuberculifera (Reuss 1962)
10. Protelphidium sublaeve (Ten Dam 1944)
11. Pleureostomella paleocenica (Cushman 1947).
12. Pyramidina crassa (Brotzen 1948)
13. Thalmannita madrugaensis (Cushman & Bermudez)
14. Gavelinella sp
15. Planorotalites ehrenbergi Morozova 1957 (Planktonic foraminifera)
16. Nonionella sp
17. Buliminella sp.
18. Rotalia saxorum D'orbigny
19. Pyrgo sp
20. Quinqueloculina sp.

Twenty samples from different localities and different layers were selected and washed and their foraminiferal fauna assemblage studied. (Many more samples were taken but this study concentrates more on these 20 samples as representative samples).

Samples 1 - 8 were taken from the top of the formation and labelled KL 1; samples 9 - 13 were taken from the middle and labelled KL 2; samples 14 - 20 were taken from the bottom

Sample No.	Foraminiferal Assemblage
KL1.1	Elphidiella africana, Cibicides praecursorius, Anomalinoides umboniferus, Operculinoides bermudezi, Rosalina koeneni, Rotalia cf trochidiformis, Pararotalia perclara, Protelphidium sublaeve, Nonion graniferum, Pyramidina crassa, Nonionella sp., Rotalia saxorum.
KL1.2	Cibicides praecursorius, Rotalia cf. trochidiformis, Rosalina koeneni, Elphidiella africana, Operculinoides bermudezi, Protelphidium sublaeve Nonion graniferum, Thalmannita madrugaensis, Pararotalia tuberculifera, Buliminella sp., Planorotalites ehrenbergi, Pleurostomella paleocenica
KL1.3	Rosalina koeneni, Protelphidium sublaeve, Rotalia cf. trochidiformis, Operculinoides bermudezi, Buliminella sp. Elphidiella africana, Cibicides praecursorius, Pararotalia perclara, Nonion graniferum, Gavelinella sp., Nonionella sp.

KL1.4 Anomalinoides umboniferus, Protelphidium sublaeve, Pararotalia tuberculifera, Cibicides ..paecursorius, Rotalia cf. trochidiformis, Elphidiella africana, Nonion graniferum, Operculinoides bermudezi, Pyramidina crassa Pleurostomella paleocenica, Buliminella sp.

KL1.5 Pararotalia perclara, Elphidiella africana, Rotalia of trochidiformis, Cibicides praecursorius, Nonion graniferum, Rosalina, koeneni, Operculinoides bermudezi, Pararotalia tuberculifera, Thalmannita madrugaensis, Pleurostomella paleocenica, Planorotalites ehrenbergi.

KL1.6 Protelphidium sublaeve, Pararotalia tuberculifera, Rosalina koeneni, Elphidiella africana. Pleurostomella paleocenica, Operculinoides bermudezi, Nonion graniferum, Planorotalites ehrenbergi, Rotalia cf. trochidiformis, Cibicides praecursorius, Anomalinoides umboniferus, Gavelinella sp., Rotalia saxorum.

KL1.7 Pyramidina crassa, Anomalinoides umboniferus, Rosalina koeneni, Pararotalia perclara, Operculinoides bermudezi, Cibicides praecusorius, Nonion graniferum, Protelphidium sublaeve, Elphidiella africana, Rotalia cf. trochidiformis Gavelinella sp., Thalmannita madrugaensis, Nonionella sp.

KL1.8 Operculinoides bermudezi, Nonion graniferum, Anomalinoides umboniferus, Elphidiella africana, Rotalia cf. trochidiformis, Pararotalia tuberculifera, Rosalina koeneni, Cibicides praecursorius, Pleurostomella paleocenica, Pararotalia perclara, Pyramidina crassa, Planorotalites ehrenbergi.

KL2.9 Nonion graniferum, Pararotalia perclara, Pleurostomella paleocenica, Elphidiella africana, Cibicides praecursorius, Rotalia cf. trochidiformis, Operculinoides bermudezi, Protelphidium sublaeve, Anomalinoides umboniferus, Pararotalia tuberculifera, Planorotalites ehrenbergi, Rotalia saxorum.

KL2.10 Rotalia cf. trochidiformis, Pararotalia perclara, Rosalina koeneni, Thalmannita madrugaensis, Operculinoides bermudezi, Anomalinoides umboniferus, Cibicides praecursorius, Elphidiella africana, Nonion graniferum, Protelphidium sublaeve, Pyramidina crassa, Pyrgo sp.

KL2.11 Cibicides praecursorius, Rotalia cf. trochidiformis, Anomalinoides umboniferus, Rosalina koeneni, Elphidiella africana, Protelphidium sublaeve, Nonion graniferum, Operculinoides bermudezi, Pararotalia perclara, Pleurostomella paleocenica, Pararotalia tuberculifera, Pyramidina crassa, Pyrgo sp

KL2.12 Pararotalia tuberculifera, Elphidiella africana, Pararotalia perclara, Rosalina koeneni, Cibicides praecursorius, Nonion graniferum, Rotalia cf. trochidiformis, Gavelinella sp. Operculinoides bermudezi, Anomalinoides umboniferus, Pleurostomella paleocenica, Pyramidina crassa

KL3.14 Elphidiella africana, Cibicides praecursorius, Anomalinoides umboniferus, Rotalia cf. trochidiformis, Operculinoides bermudezi, Nonion graniferum, Pararotalia tuberculifera, Pleurostomella paleocenica, Rotalia saxorum.

KL3.15 Rosalina koeneni, Pararotalia perclara, Anomalinoides umboniferus, Rotalia cf. trochidiformis, Elphidiella africana, Cibicides praecursorius, Nonion graniferum, Operculinoides bermudezi, Thalmannita madrugaensis, Buliminella sp.

KL3.16 Nonion graniferum, Thalmannita madrugaensis, Pleurostomella paleocenica, Operculinoides bermudezi, Elphidiella africana, Cibicides praecursorius, Rotalia cf. trochidiformis, Buliminella sp., Nonionella sp.

KL3.17 Protelphidium sublaeve, Anomalinoides umboniferus, Pararotalia perclara, Cibicides praecursorius, Rotalia cf. trochidiformis, Elphidiella africana, Nonion graniferum, Operculinoides bermudezi, Nonionella sp.

KL3.18 Operculinoides bermudezi, Anomalinoides umboniferus, Pararotalia perclara, Cibicides praecursorius, Rotalia cf. trochidiformis, Elphidiella africana, Nonion graniferum. Protelphidium sublaeve, Nonionella sp., Quinqueloculina sp.

KL3.19 Pararotalia tuberculifera, Gavelinella sp., Planorotalites ehrenbergi, Operculinoides bermudezi, Protelphidium sublaeve, Nonion graniferum, Rotalia cf. trochidiformis, Elphidiella africana, Cibicides praecursorius, Rotalia saxorum.

KL3.20 Protelphidium sublaeve, Anomalinoides umboniferus Rotalia cf. trochidiformis, Operculinoides bermudezi, Cibicides praecursorius, Elphidiella africana, Nonion graniferum, Pararotalia tuberculifera, Nonionella sp. Quinqueloculina sp.

Foraminiferal population and foraminiferal number (FN) for each sample are shown in Table 3.1.

Foraminiferal species	Sample 1	%α	2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19		20			% A
Elphidiella africana	85	52	72	46	55	32	52	33	56	33	36	25	30	20	35	21	40	31	15	9.0	21	11.7	38	20	60	23	82	57	84	48	70	56	91	49	82	43	85	55	76	48	1154	35.2
Spirolinoides bermudezi	40	24	51	33	83	48	90	57	77	45	58	40	49	32	57	34	69	37	70	42	84	47	76	40	62	35	60	27	44	25	32	23	41	22	54	29	42	27	48	31	1147	35.0
Rosalina floridana	10	6.0	13	8.3	13	7.5			5	3.0	20	14	18	11.8	22	13.2			25	15	21	11.7	18	9.5	18	10			18	10.2											201	6.1
Cibicides praecursorius	2	1.2	3	1.9	2	1.2	3	1.9	11	6.4	5	3.5	10	6.6	11	6.6	6	4.6	15	9.0	12	6.7	9	4.8	13	7.3	4	2.7	10	5.6	13	9.3	16	8.6	11	5.8	10	6.4	13	8.3	179	5.5
Pararotalia perclara	8	4.9			4	2.3			3	1.8			12	7.9	17	10.2	15	11.5	15	9.0	8	4.4	13	6.9	16	9.0			10	5.6			20	10.8	19	10.1					160	4.9
Nonion graniferum	3	1.8	5	3.2	8	4.6	3	1.9	6	3.5	5	3.5	10	6.6	7	4.2	8	6.1	5	3.0	14	7.8	6	3.1	11	6.2	6	4.1	4	2.3	2	1.4	8	4.3	11	5.8	7	4.5	1	0.6	130	4.0
Rotalia cf trochidiformis	5	3.1	2	1.3	4	2.3	2	1.3	5	3.0	6	4.1	8	5.3	7	4.2	4	3.1	10	6.0	10	5.6	12	6.3	8	4.5	3	2.1	2	1.1	9	6.4	3	1.6	6	3.2	4	2.6	7	4.5	117	3.6
Anomalinoides umboniferus	3	1.8					1	0.6			3	2.1	8	5.3	3	1.8	1	0.8	4	2.4	1	0.6	4	2.1	6	3.4	4	2.7	2	1.1			3	1.6	2	1.1			3	1.9	48	1.5
Pararotalia tuberculifea			2	1.3			1	0.6	2	1.2	3	2.1			2	1.2	2	1.5			4	2.2	6	3.1			5	3.4									3	1.9	5	3.2	35	1.1
Protelphidium sublaeve	2	1.2	1	0.6	1	0.6	2	1.3			1	0.7	1	0.7			1	0.8	3	1.8	1	0.6			3	1.7							2	1.1	1	0.5	2	1.3	2	1.3	23	0.7
Pleurostomella paleocenica			2	1.3			1	0.6	1	0.6	3	2.1			1		1	0.8			1	0.6	2	1.1			1	0.7			2	1.4									15	0.5
cf Pyramidina crassa	2	1.2					1	0.6					2	1.3	3	1.8			2	1.2	2	1.1	3	3.1																	15	0.5
Thalmannita madrugaensis			2	1.3					4	2.3			2	1.3					1	0.6									2	1.1	1	0.7									12	0.4
Gavelinella sp.					2	1.2					2	1.4	1	0.7									2	1.1													1	0.6			8	0.24
Planorotalites ehrenbergi			2	1.3					1	0.6	1	0.7			1	0.6	2	1.5																			1	0.6			8	0.24
Nonionella sp.	1	0.6											1	0.1																	1	0.7	1	0.5	2	1.1			1	0.6	7	0.21
Buliminella sp.	1	0.6	1	0.6	1	0.6	1	0.6																	1	0.6			1	0.6	1	0.7									7	0.21
Rotalia saxorum	2	1.2									1	0.7					2	1.5									1	0.7									1	0.6			7	0.21
Pyrgo sp.																			1	0.6	1	0.6																			2	0.06
Quinqueloculina sp.																																			1	0.5			1	0.6	2	0.06
FORAMINIFERAL POPULATION	164		156		173		157		171		144		152		166		131		166		180		189		178		146		177		140		185		189		156		157	3277 163.85	
FORAMINIFERAL NUMBER(FN/g)	164		15.6		17.3		15.7		17.1		14.4		15.2		16.6		13.1		16.6		18.0		18.9		17.8		14.6		17.7		14.0		18.5		18.9		15.6		15.7	16.4	

Table 3.1 Foraminiferal count per 10g of washed sample and the calculated Foraminiferal Number (FN/g) per gm of the sample.

%α = Percentage abundance of species in each sample
% A = Percentage abundance of species in all samples combined.

Chapter 4 Chapter 4

BIOSTRATIGRAPHY AND AGE CORRELATION

4.1 Biostratigraphy

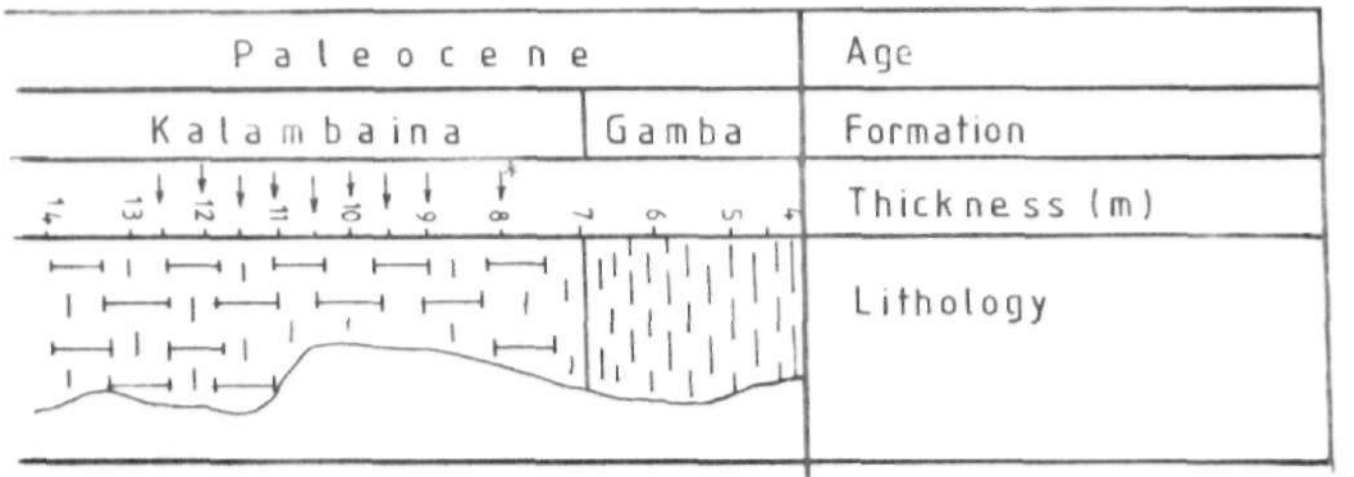
Within the last 25 years, planktonic foraminiferal microfossil zonation has become extensively developed. In particular, each of the epochs of the Tertiary has been provided with a zonation that makes it possible to study them in great detail. Planktonic foraminiferal biostratigraphic zonation of the Paleocene was first introduced by Bolli (1957). Bolli's zonation was then improved upon and extended widely by different investigators such as Leonov and Alimarina (1961); Hillebrant (1962, 1965); Alimarina (1963); Luterbacher and Primoli-Silva (1964), Berggren (1965); Bolli (1960), and Olsson (1970). The Paleocene planktonic zonation (Table 4.1) developed by these investigators makes it possible to compare relatively short intervals of time between near and distant geographic areas. Using planktonic biostratigraphic control, it is possible to deal with various types of paleogeographic problems. It is noted that the planktonic foraminiferal species - Planorotalites ehrenbergi - in the Kalambaina Formation corresponds to the Globorotalia pseudomenardii zone of Bolli (1957)

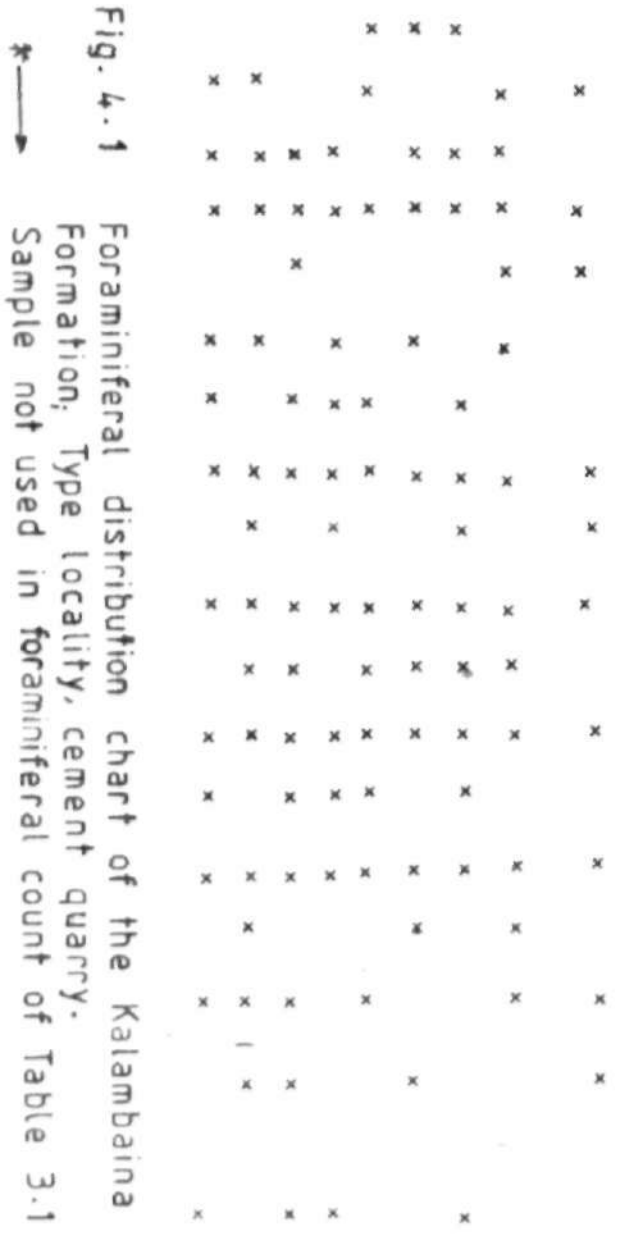
Age		Zones
Eocene		Globorotalia subbotinae
P a l e o c e n e	Upper	Globorotalia velascoensis Globorotalia pseudomenardii
	Middle	Globorotalia pusilla pusilla Globorotalia angulata Globorotalia uncinata
	Lower	Globigerina trinidadensis Globigerina edita Globigerina eugubina

Table 4.1. Planktonic foraminiferal biostratigraphic zonation - after Bolli (1957).

For the purpose of analysing Paleocene foraminiferal bathymetric trends, the Paleocene is arbitrarily divided into Lower, Middle, and Upper parts. The 3 divisions are based on the planktonic zonation shown in Table 4.1. The reason for doing this is that the rate of evolutionary change of benthonic foraminifera is in general slower than that of planktonic foraminifera. The low evolutionary rate of the benthonic foraminifera is balanced by the widespread evolution of planktonic foraminifera from the Upper Cretaceous time. It is therefore possible to detect biofacies changes and certain evolutionary events in the Paleocene by sampling on this basis.

The biostratigraphic distributions of the benthonic and planktonic foraminifera in the Kalambaina Formation are shown in the distribution charts of Figs. 4.1, 4.2, 4.3, 4.4.





Quinqueloculina sp
Pyrgo sp
Buliminella sp
Pyramidina crassa
Rosalina koeneni
Rotalia *trochidiformis*
Rotalia saxorum
Pararotalia perclara
Pararotalia tuberculifera
Operculinoides bermudezi
Thalmannita *madrugaensis*
Elphidiella africana
Protelphidium sublaeve
Cibicides praecursorius
Pleurostomella paleocenica
Nonion graniferum
Nonionella sp
Anomalinoides umboniferus
Gavelinella sp

Planorotalites ehrenbergi

Fig. 4.1 Foraminiferal distribution chart of the Kalambaina Formation; Type locality, cement quarry.
Sample not used in foraminiferal count of Table 3.1



Fig. 4.2 Foraminifera distribution chart of the Kalambaina Formation, 10-8 Km from Gada-



Fig. 4.3 Foraminiferal distribution chart of the Kalambaina Formation; 11.2 Km from Gada.

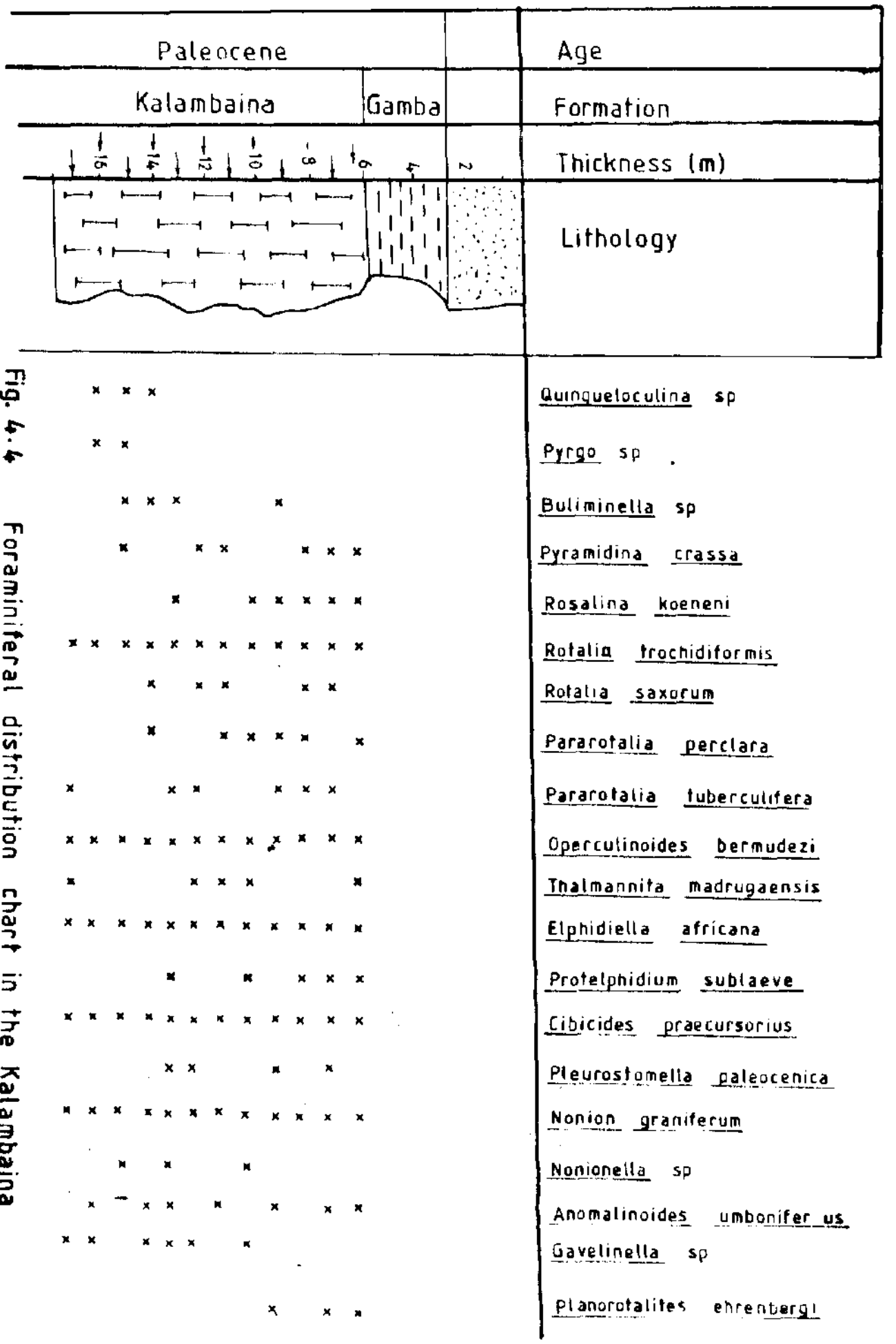


Fig. 4.4 Foraminiferal distribution chart in the Kalambaina Formation at Malbaza (Niger Republic).

4.2. Age correlation

Stratigraphically significant foraminiferal species such as Operculinoides bermudezi, Elphidiella africana and Thalmannita madrugaensis were identified and described in the assemblages from the Kalambaina Formation. These species enable the correlation of the Kalambaina Formation with the Upper Paleocene Operculinoides bermudezi zone in Mali and Niger (Krasheninnikov and Trofimov, 1969), and the lower part of the Esna Shale in Egypt (biostratigraphic unit II of Leroy, 1953).

Some ostracods described from the Kalambaina Formation also confirm an Upper Paleocene age. These include Bairdia ilaroensis (Reyment & Reyment); Ambocythere? (Apostolescu); Buntonia bopaensis (Apostolescu); Cytherella sylvester bradleyi (Reyment); Paracypris nigeriensis (Reyment); and Xestolaberis kekere (Reyment). These were also described by Reyment (1965) from the Paleocene of southern Nigeria.

Ammonites and Pelecypods furnish broad ages for correlating marine deposits in the Iullemmeden Basin (Faure, 1966; Furon, 1963; and Radier, 1957). Tertiary megafossil studies have focussed on the Paleocene Kalambaina Formation (Parker 1964). The Sokoto Embayment is also famous for its rich Maastrichtian and Paleocene vertebrate fishes, crocodiles, turtles and mosasaurus (Halstead, 1974: Swinton, 1930: and White, 1934). On the basis of the Paleocene ostracods from the Wurno Formation, Ficarelli (1976) revised the position of the Cretaceous - Tertiary boundary in southeast Iullemmeden basin and placed it at the base of the Wurno Formation, a position arrived at by Petters (1978a) on forminiferal

evidence and corroborated in this study.

Descriptions of new Late Cretaceous - Tertiary benthic Foraminifera from Gabon by Chenouard et al., (1960) de Klesø and Rerat (1961), de Klasz et al (1970) and Le Calvez et al (1974) also support an Upper Paleocene age for the foraminifera identified and described from the Kalambaina Formation. Some of the benthic foraminifera in the coastal and interior central West African basins have restricted stratigraphic distribution. In the Kalambaina assemblages, the geologic ages were determined using the associated planktonic foraminifera - Planorotalites ehrenbergi and published paleontological and palynological ages for the various lithostratigraphic units. Some species (Elphidiella africana, Operculinoides bermudezi, Nonion graniferum, Rotalia trochidiformis, and Cibicides praecursorius) were present in all the samples studied and therefore span the entire Upper Paleocene while others are restricted to certain stratigraphic levels (See Table 3.1).

Similar biostratigraphic use has been made of benthic foraminifera for age correlation in other parts of the world. For example, broad benthic foraminiferal zones were established for the Mesozoic-Cenozoic of the Scottish Shelf in eastern Canada (Ascoli, 1976).

The Paleocene is by far the most widely studied and best known Tertiary epoch in Nigeria. This is due to the rich invertebrate faunas of the Paleocene strata of northwestern and southwestern Nigeria. Major reviews of the stratigraphy of this epoch are available in Adegoke

(1969, 1977), and Petters (1982).

The geomorphic maturity of interior West Africa during the Paleocene contributed to the widespread marine invasion of the region by a shallow southward embayment of the Tethys sea. The Kalambaina Formation of northwestern Nigeria is a shallow water organogenic marl that accumulated in this epeiric sea (Petters 1977a). In the coastal basin of southern Nigeria, the distribution of marine Paleocene beds shows that the Paleocene marine transgression was not as extensive northward as the earlier Late Cretaceous transgressions. Two Paleocene marine sedimentary provinces occur in the south, namely, an eastern predominantly clastic province, and a western shoal water skeletal carbonate province which occurs west of the Benin Hinge Line. Deposits of the eastern clastic province constitute the Imo Shale, while the western carbonate sequence belongs to the Ewekoro Formation.

Chapter 5 Chapter 5

FORAMINIFERAL PALEOECOLOGY AND PALEOBIOGEOGRAPHY

5.1 Foraminiferal Paleoecology

5.1.1 Introduction

Benthonic foraminifera have a wide bathymetric distribution from various near-shore environments to continental shelves and deep-sea. However, some species, genera or communities have limited depth ranges. The study of community structure and composition of Paleocene populations from the Kalambaina Formation give clues on the bathymetry and ecology of the strata in which they are found.

The object of this project is to study the paleoecologic implications on the Kalambaina Formation from the distribution and composition of Upper Paleocene benthonic and planktonic foraminifera in the sediments of this formation. The foraminiferal distribution is also instrumental to the establishment of palecbathymetric facies and probably to compare these facies with other similar facies in the Nigerian sedimentary environments.

In this project, the following generalized trends were used to establish certain paleoecologic parameters and reconstructing a general Upper Paleocene Kalambaina paleoecology based on the forəminifera:

1. Composition, structure and form have been correlated with environments.

2. Diversity gradients show a decrease in species number towards shallow water. High dominance (lower diversity) is characteristic of near shore-shallow water marine environment.

3. Increase in percentage of planktonic foraminiferal tests relative to the tests of benthonic foraminifera is a general index of increasing water depth (Phleger, 1960). The reverse case which applies to the Kalambaina Formation indicates a shallow water marine condition.

5.1.2 Foraminiferal distribution and Paleoecologic Interpretation

Five species - Elphidiella africana, Operculinoides bermudezi, Rosalina koeneni, Pararotalia perclara, and Cibicides praecursorius comprise about 80% of the population in the Kalambaina Formation. The number of characteristic species is 15. The diversity is 20 species and the dominance averages about 35% (Table 3.1). Planktonic foraminiferal percentage is very low - 1%. All these results indicate a paleoenvironment of shallow water marine condition of deposition for the Kalambaina Formation. This is in accordance with Walton's (1964) paleoenvironmental interpretation of the Northwestern Gulf of Mexico.

The foraminifera from KL1 are relatively larger in size with relatively higher diversity while those from KL3 are smaller with low diversity. Appearance and disappearance of species in different strata, size variations, and diversity fluctuations indicate slight intra-formational changes in

paleoecologic parameters such as salinity and trophic resources. The Kalambaina assemblage is also characterised by high morphologic variability of species and large populations.

Models of modern ecosystems and their evolution have been erected by Valentine (1968, 1969, 1972, 1973) and Johnson (1964, 1972). These models help in reconstructing ancient communities and ecosystems. They include models of diversity gradients and diversity trends, models of adaptive strategies for trophic resources, and models of ecosystems and their evolution. Margalef (1968) constructed two communities models.

1. Communities occupying near-shore shallow marine environments are characterised by low species diviersity. They fluctuate in composition under the direct impact of the physical environment.

2. Off-shore communities of stable continental shelves are characterised by high diversity, low dominance, small species population and low morphologic variability.

This study indicates that the Kalambaina Formation belongs to the first model which further buttreses the assumption that the sediments of the Kalambaina Formation were deposited in near-shore shallow marine environment.

In some samples, one species such as Elphidiella africana or Operculinoides bermudezi reach relative abundance of 56/57 percent. Lack of abundance studies on some species has led

previous investigators working in North America e.g. Nogan (1964) to consider that the less abundant fauna were of relatively deep shelf origin. Apart from the 15 characteristic species that occur more often in high abundance, the other species in the assemblages are usually very rare. These are the ubiquitous species which occur in several upper Paleocene biofacies of the Kalambaina Formation and appear not to be characteristic of any one paleoenvironment. Some workers (e.g Margalef, 1968) referred to such communities as observed in the Kalambaina Formation as low grade or immature communities while others like Bretsky and Lorenz (1969) called them unstable environments. Following Margalef's term, we can in general infer that the low grade foraminiferal fossil communities of the Kalambaina Formation are characterised by low species diversity and fluctuation in composition, large population and persistence of species (low evolutionary rate) and high morphologic variability.

Walton (1964), working in the northwestern Gulf of Mexico, produced a curve on a scattergram plot of faunal diversity and percentage occurrence of dominant species. He observed the distribution of the samples with respect to diversity, dominance and depth and concluded that

(a) Without exception, allfaunas with less than 20 species occur in water shallower than 20 metres.

(b) All faunas whose dominant species constitute over 35% of the entire fauna occur in water shallower than 20 metres.

It is therefore reasonable to assume here that the relationship between diversity, dominance and depth, and a low planktonic foraminiferal percent places the Kalambaina Formation in a less than 20 metre marine environment.

The shallow water origin of the Kalambaina Formation is also supported by megafossils study of Kogbe (1979) who described shallow water pelecypods - Lucina cf. pharaonis, Panopea sahariensis, Ostrea multicostata and abundant echinoids especially Linthia sudanensis and Gisortia brevis.

Different types of faunal characteristics of benthonic foraminifera have been used in the past for delineation of the environmental parameters of the Upper Paleocene and other epochs of the Tertiary. For example, one type is the specific faunal characteristic, which includes those aspects of the populations based on specific, generic or morphogroup features (Walton 1964). Attempts have been made on the generic level for the delineation of paleoenvironments. For instance, high frequencies of the genera Operculinoides, Elphidiella, and Cibicides suggest shallow water depths. Attempts at the specific and generic levels to delineate deeper water foraminifera from the Kalambaina assemblage did not indicate any of such nature. If by any chance they occur as the area is open for further investigations, they might only be said to occurr in association with the Upper Paleocene shallow water species. They should be part of a community with a typical shallow water structure. Low percentage of planktonic foraminifera and relatively low

diversity of species is enough reason to infer a shallow water environment for all the Upper Paleocene genera in this formation.

Modern ecologic studies have provided descriptions of many of the circumstances which could have affected fossil communities, and in many instances, the more that we learn, the more complex the environment appears. Certainly, many of the chemical actions and interactions between organism and environment may never be understood for certain fossil groups, and other more apparent relationships among organisms associated in the rocks may not always be apparent.

Ecologic interpretations based on species in Tertiary foraminiferal faunas are regarded by most workers as being impossible, even with the broadest definition of species (Albritton et al., 1954; Glaessner, 1963). However, Phleger (1960) has suggested that certain general aspects of the faunas such as planktonic - benthonic ratio and number of benthonic genera and species, may be more useful in summarizing ecologic information on foraminifera.

According to Norton (1930) the family Anomalinidae which formerly included the genus Cibicides is rather uniformly present at all depths and as a family does not seem to possess very significant ecologic value. The high calcium carbonate content of the Kalambaina sediments, abundant calcareous mudstone and shale, and absence of siliceous organisms indicate a shallow water depth of deposition.

Paleoenvironmental conditions are reconstructed using some paleoecologic parameters and in this study emphasis is mostly on reconstructing paleoecology with regard to the temperature, salinity, depth and turbulence.

5.1.2.1 Temperature

As a group, the foraminifera are very tolerant of wide temperature variations. The group occurs all the way from tropical lagoons and tide pools whose temperature may be over 40°C to high latitude areas where sea water is freezing at nearly -2°C. However, individual species are much limited in their temperature tolerances. The distribution of planktonic species in particular seems to be temperature controlled and has been more thoroughly studied than the distribution of benthonic species.

The fact that the foraminiferal assemblage from all the localities sampled in the Kalambaina Formation are dominantly benthonic makes it more difficult to determine the paleotemperature under which the sediments were deposited. Factors other than temperature may be involved in their distribution and of course temperature seldom operates completely independently of other variables. For example a foraminifera may be able to survive over one temperature range at a certain salinity but the survival temperature may be different at another salinity. Not only does temperature exert great influence on the geographic distribution of the foraminifera, but it also is important in controlling vertical distribution: this is often difficult to prove decisively, though. Some foraminifera exhibit the feature of 'equatorial submergence'

in their distribution. A species that lives at the surface or in shallow water at higher latitudes occurs at progressively greater depths at lower latitudes. This apparently is explained by temperature control.

Many examples of morphologic features of foraminifera that vary with temperature have been described by Kennet (1976). Perhaps the most widely studied and used character of this type is coiling direction. Students of foraminifera have long noted that the coiled shells of certain species may coil either to the right (dextral) or to the left (sinistral). Bandy (1960) and Erickson (1959) independently noted that the coiling direction in modern assemblages of Neogloboquadrina pachyderma appeared to depend on the growth temperature. When the temperature was less than 9°C, specimens of this species were dominantly sinistral in coiling direction. At temperatures higher than about 15°C, assemblages are predominantly dextral with mixtures of dextral and sinistral occurring between 10° and 15°C. Applying this to the Kalambaina Formation and if this should be applicable to the planktonic species - Planorotalites ehrenbergi, it is observed that this species separately and strongly coiled to the right in some samples (KL1,5; KL1.8) and also coiled to the left in the remaining samples from which they were identified. This observation, though of high speculative value would possibly place the paleotemperature at the time of deposition of the Kalambaina sediments in the Upper Paleocene time at between 10° and 15°C.

Could there be any functional significance to this correlation between coiling direction and temperature? This question does not seem to have ever been satisfactorily answered, but several suggestions have been made. Perhaps coiling direction is genetically linked with some physiologic features of foraminifera that do not have adaptive significance relative to temperature. Perhaps the dextral and sinistral forms actually represent separate species that have different temperature sensitivities. Perhaps one of the coiling directions is found in sexually produced forms and the other in asexually produced individuals.

Several other features of foraminiferal morphology vary with temperature in modern species. The near-conical shape of the planktonic foraminifera - Planorotalites ehrenbergi - indicates subtropical climates as such conical planktonic foraminifera are found in present day subtropical waters (Dodd & Stanton Jr. 1981). The porous appearance of the same species - Planorotalites ehrenbergi is associated with tropical climatic zones where sea water is less dense than in colder climates. The presence of evaporites and carbonates along the margins of the Sokoto basin suggests that the basin was closed (Petters, 1979b) and the occurrence of abundant reptilian remains (Swinton, 1930; White, 1934) indicates tropical conditions.

5.1.2.2 Salinity

The complex ornamentation and thick walls of the foraminifera from the Kalambaina Formation point to a hypersaline condition during the deposition of the sediments

of the Kalambaina Formation. Boltovskoy and Wright (1976) indicated that forms from lower salinity habitats tend to have reduced ornamentation and thick walls. However there was a slight variation in the salinity as transgression continued. The upper 8 meters of the Kalambaina Formation probably represent a relatively more open marine conditions and higher salinity than the lower part. This is inferred from the fact that overall test size is bigger in the samples from the upper part and relatively smaller in those from the lower part. Boltovskoy and Wright (1976) attributed such size variations of the same species from different localities to salinity changes.

Petters (1980, 1981) attributed the sediments of the Kalambaina Formation and indeed the Iullemmeden Basin to the saharan epeiric sea that witnessed salinity crisis throughout most of its existence. He concluded that the development of hypersaline conditions is evident in the marginal marine shales and the organogenic marls in the Iullemmeden Basin and indeed in the Kalambaina Formation. He also found benthic foraminiferal evidence for hypersaline environments in the late Paleocene Kalambaina Formation by comparing them with those of recent environments (eg. Culver & Buzas, 1980, 1981, 1982; Douglas, 1979; Harris, 1981; Murray, 1973).

The dominantly calcareous benthic foraminiferal assemblage in all the samples from the Kalambaina Formation plot within the hypersaline lagoon field in the triangular diagram (Fig. 5,1, 5.2, 5.3) and are somewhat similar to that of the inner lagoons in the Trucial coast of the Arabian Gulf

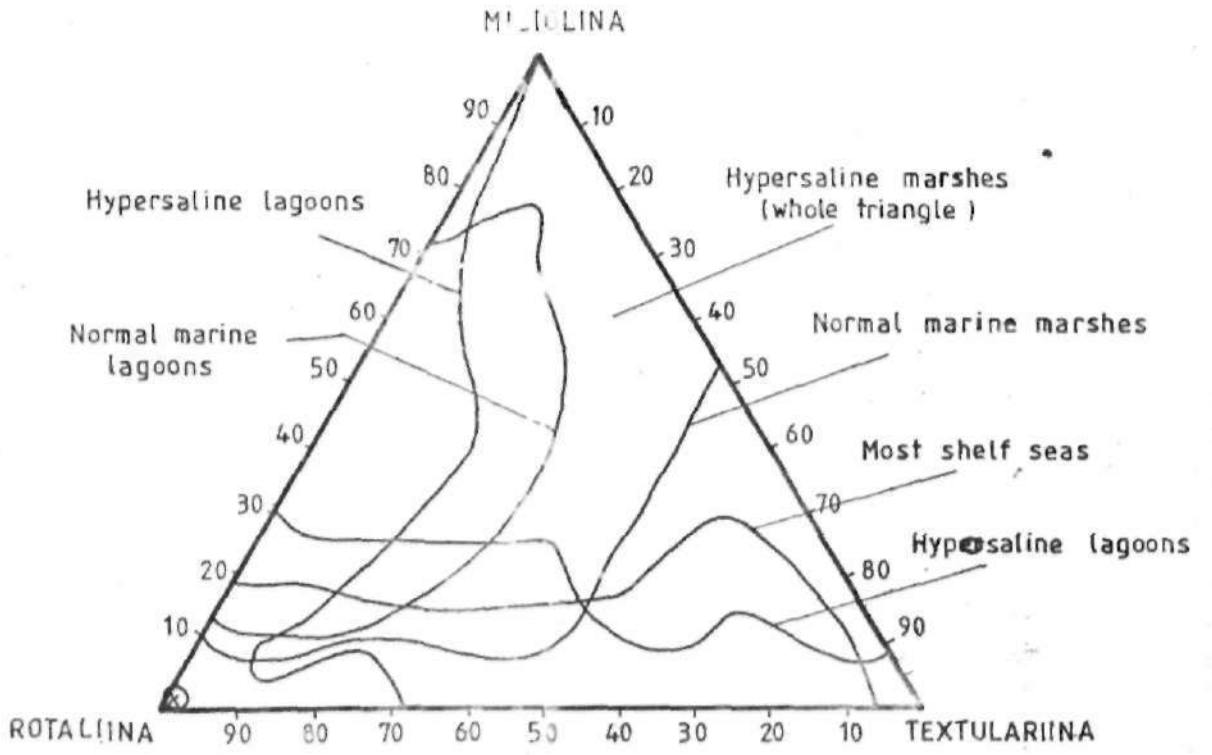


Fig. 5.1 Triangular plot for Kalambaina benthic foraminifera (fields for Recent environments based on Murray, 1973).

⊗ - Top of the Kalambaina Formation (samples KL1)
Total foraminiferal population = 1279
Rotaliina = 1279 = 100 %
Miliolina = — = 0 %
Textulaliina = — = 0 %

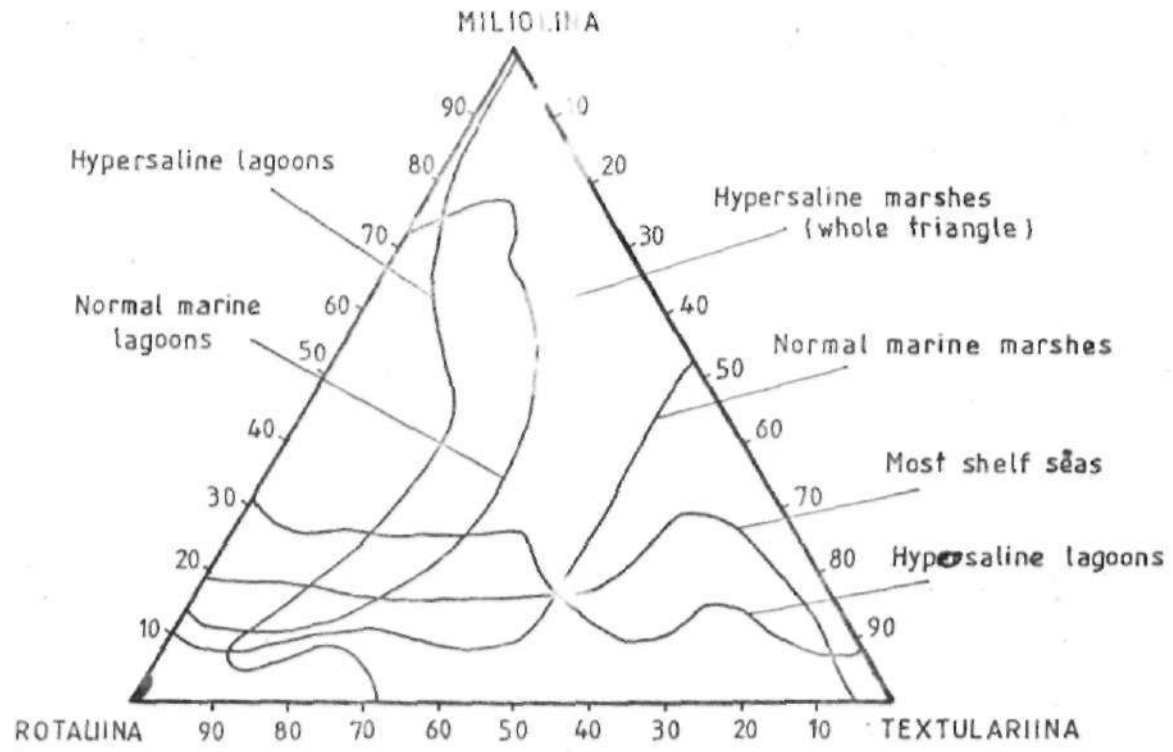


Fig. 5.2 Triangular plot for Kalambaina benthic foraminifera (fields for Recent environments based on Murray, 1973).

●-Middle of the Kalambaina Formation (samples KL2)
Total foraminiferal population = 842
Rotaliina = 840 % = 99.8%
Miliolina = 2 = 0.2 %
Textulariina = — = 0 %

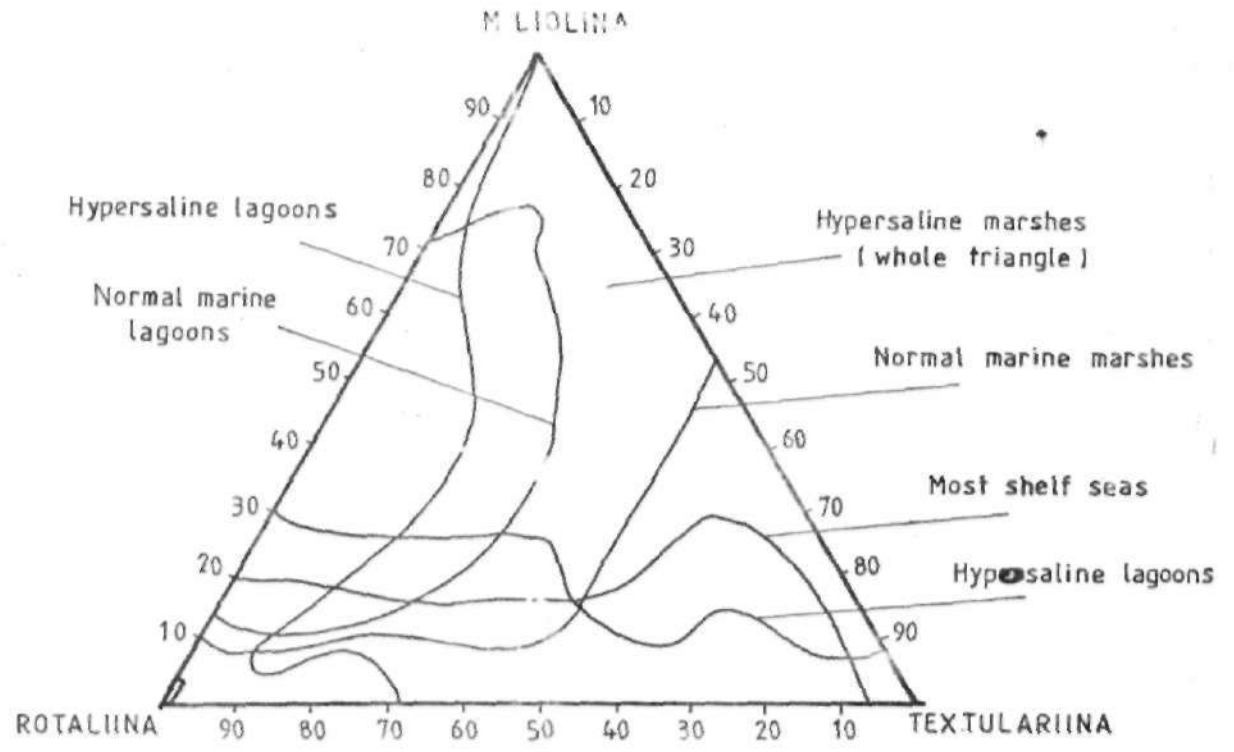


Fig. 5.3 Triangular plot for Kalambaina benthic foraminifera (fields for Recent environments based on Murray, 1973).

▯ – Bottom of the Kalambaina Formation (samples KL3)
Total foraminiferal population = 1149
Rotaliina = 1147 – 99.8%
Miliolina = 2 = 0.2%
Textulariina = — = 0 %

(Murray, 1973). All samples from the base of the Kalambaina Formation are characterised by a low diversity assemblage dominated by miliolids/rotaliids. This microfaunal assemblages are similar to those of Recent hypersaline lagoons and tropical shallow water carbonate environments (Murray, 1973). The evidence presented here and as correlated with other marine facies suggests the existence of extensive hypersaline epeiric phases in the northwestern region of Nigeria during the Upper Paleocene time.

5.1.2.3 Depth

Foraminiferal assemblage from the Kalambaina Formation is dominated by calcareous forms. Because the solubility of calcium carbonate ($CaCO_3$) increases with depth, most calcareous forms would have disappeared at greater depths. Agglutinated species usually increase in abundance at great depths. In fact the high ratio of calcareous to agglutinated forms can be used as an approximate index of depth. This phenomenom as observed in the Kalambaina assemblage, suggests shallow depth of deposition.

Saidova (1961) noted that the calcareous to agglutinated ratio in the sublittoral zone of the north Pacific was usually about 100:1. The ratio drops to about 30:1 in the upper bathyal zone and less than 1:1 in the abyssal zone. The very low planktonic/benthonic ratio which in the Kalambaina Formation is 0.24% suggests a near-shore shallow-marine environment. The relative proportion of planktonic to benthonic foraminifera in the sediments is strongly influenced by depth

of deposition. Planktonic foraminifera are much less common in shallow near-shore water than in deep open ocean water (Dodd and Stanton 1981). This may be due to the less stable environment in the near shore area and the lesser volume of water in which the specimens can live to depths of several hundred metres in the open ocean. In shallow water only a portion of the potential space for occupancy is available, thus a small number of planktonic foraminifera live in a given area in shallow water than in deep water. On the other hand, the abundance of benthonic species is greater in shallow water where food on the sea floor is likely to be more abundant. This technique of planktonic/benthonic ratio to determine water depth has been used by several workers including Stehli and Creath (1964) who used it to determine the paleobathymetry of the Cretaceous in the Gulf Coast area.

A number of morphological features that vary with depth have been described in the literature (eg. Bandy, 1964; Boltovskoy and Wright, 1976). For example, the porcelaneous wall structure foraminifera which are common in the Kalambaina assemblage do not usually occur at depth greater than a few tens of metres.

5.1.2.4 Turbulence

The foraminiferal assemblage in the Kalambaina Formation is characterised by a large population. Because of their small size, foraminifera usually have difficulty in maintaining their position in turbulent environments. Consequently, the large population of foraminifera in the Kalambaina Formation

can be attributed to a low-energy environment. The scarcity of current-induced sedimentary structures in the transitional paralic facies of the sedimentary rocks in the basin and the prevalence of muddy sediments attest to very low-energy conditions toward the limits of the marine embayment (Petters, 1979b).

5.2 Paleobiogeography

Water depth and lithofacies strongly control the distribution of benthonic foraminifera (Berggren and Aubert, 1975). Thus, neritic assemblages are quite distinct from slope and abyssal plain assemblages and each assemblage has many cosmopolitan elements. In the neritic deposits of the Atlantic, Caribbean and Mediterranean basins, Berggren (1974) showed that the Paleocene benthonic foraminiferal assemblages of shallow water, inner-shelf to middle-shelf carbonate deposits - termed the "Tethyan carbonate fauna" are different from the assemblages of detrital shelf deposits termed the "Midway-type fauna." Two aspects of the "Tethyan carbonate fauna" were also distinguished based on latitudinal position. The first assemblage is tropical and is confined to latitude 5° - 35°N with Operculinoides bermudezi among other species in the assemblage. The second assemblage is both tropical and boreal and is characterised by Rotalia trochidiformis and Thalmannita madruggensis among others. Elements of both subdivisions of the "Tethyan carbonate fauna" occur in the Kalambaina Formation.

The Saharan faunal province has been proposed for the Late Cretaceous - Early Tertiary benthic foraminifera of the

West African interior basins. The Maastrichtian - Paleocene benthic foraminiferal assemblages in the lullemmeden basin contain mostly endemic arenaceous foraminifera (Petters, 1979b) and dwarfed and impoverished calcareous taxa. The Paleocene benthics clearly belong to the "Tethyan carbonate fauna" with characteristic species such as Operculinoides bermudezi, Thalmannita madrugaensis, Rotalia trochidiformis Lamarck and Pararotalia tuberculifera (Reuss). This assemblage is similar to the Tethyan carbonate faunas in Cuba, Guinea, Senegal and Pakistan (Berggren, 1974; Hague, 1956). The Saharan "Tethyan carbonate fauna" contain many species in common with the coeval western European Meridional Faunal Province - Paris Basin, Mons Basin, Limburg Basin - the faunas of which are discussed by Pozaryska and Szczechura (1968, 1970). The presence of the "Tethyan carbonate fauna" in Senegal on the West African coast was due to proximity to direct "Tethyan influence" towards the northern boundary of the Guinea Faunal province.

Studies on the Maastrichtian - Paleocene marine sediments in the Sokoto embayment show that it forms an arcuate belt that trends in a N - SW direction. Regionally the outcrop belt narrows to the SW where there is pronounced thinning and wedging out of marine units. They represent the proximal portion of the sedimentary sequence that thickens towards the northwest, and attains its maximum development in Niger and Mali (Kogbe, 1979). It is assumed that limited marine conditions prevailed in the Nigerian side during Maastrichtian times, when the Tethys sea extended to the southeast of the

interior of Western Africa. This resulted in the deposition of evaporite-bearing shales, the Dukamaje Formation from where many workers including Kogbe and Wozny (1979) have described reptilian and fish remains.

Chapter 6

DISCUSSION AND CONCLUSION

The Kalambaina Formation is the most marine of all the sedimentary formations in the Sokoto embayment. The age of the Kalambaina Formation is determined using local diagnostic benthic foraminiferal species (eg. Thalmannita madrugaensis and Operculinoides bermudezi) as Upper Paleocene.

The sedimentary sequence in the Sokoto embayment is broadly divisible into

a. Basal non-marine sandstones, siltstones and mudstones of the Gundumi and the Illo Formations.

b. Middle marine shales and limestones intercalated with sandstones and siltstones of the Rima and Sokoto Groups.

c. Upper continental/paralic sequence of the Gwandu Continental terminal (Table 2.2).

The basal non-marine sequence of the Sokoto embayment was named the Damergo sequence by Petters (1979a). This unconformity-bounded sequence rests on a wide-spread Permian - Triassic erosion surface and is disconformably overlain by marine deposits of the Maastrichtian - Paleocene transgression. The overlying non-marine beds of the continental terminal constitute the Dosso sequence (Petters, 1979a).

The marine Maastrichtian - Paleocene beds of the Sokoto embayment were described by Falconer (1911); Greigert (1966); Jones (1948); Kogbe (1979); Petters (1979c, 1980, 1981) and Raeburn & Tattam (1930). Two cyclothems constitute the

Maastrichtian - Paleocene marine sequence in the Sokoto embayment (Petters, 1980). The Rima cyclothem of Maastrichtian age comprises the Taloka Formation (about 50m of brown, laminated, parallel-bedded, carbonaceous fine grained sandstones, siltstones and mudstones), overlain by the Dukamaje Formation (about 10m of basal bone bed, gypsiferous, fissile, grey lower and upper shales and middle marls). The Paleocene Sokoto cyclothem comprises the Wurno Formation (approximately 20m of soft, tabular mudstones, muddy siltstones and fine grained sandstones) at the base and grades upward into the Dange Shale (10m thick), and the Kalambaina Formation (about 12 - 20m of nodular marly limestones and shales) at the top. The Kalambaina Formation was studied in detail in this project with special emphasis on its foraminiferal content.

A shallow fluctuating embayment of the Tethys sea occupied the West African Saharan interior basins from Cenomanian to Paleocene (Petters, 1982). In the south, another fluctuating embayment which was the inland extension of the Gulf of Guinea lay along the Benue Trough. The saharan epeiric sea that led to the deposition of the Kalambaina sediments was warm, shallow and subject to high salinities while the shallow Benue sea was subject to low salinities and oxygen depletion (Petters, 1982).

Results obtained in this study based on the following foraminiferal methods conform with the paleoenvironmental analysis of the Sokoto embayment by Petters (1982).

1. The relative abundance of the foraminiferal suborders - Miliolina (Porcelaneous) and Rotaliina (hyaline calcareous) were plotted on a triangular diagram on which the composition or fields for Recent environments (Murray, 1973) are shown (Fig. 5.1, 5.2, 5.3).

2. Benthic foraminiferal predominance in the Sokoto province was compared with those of Recent environments (eg. Culver & Buzas, 1980, 1981, 1982; Douglas, 1979; Harris, 1981; Murray, 1973).

3. For stratigraphic intervals where foraminiferal counts were made, quantitative species diversity calculations were done based on 10gm of the washed sample from which the corresponding Foraminiferal Number (FN) were also calculated.

Based on these methods the Kalambaina Formation is placed in a hypersaline epeiric sea.

All the samples from the Kalambaina localities contain abundant calcareous foraminifera and a few arenaceous species. Diagnostic deep water species were not observed. This confirms the shallow and marginal condition under which the Kalambaina sedimentation took place.

Maximum marine transgression occurred in the Late Paleocene and resulted in the deposition of the marly limestone lithofacies of the Kalambaina Formation. The bottom sections (usually about 8m from the separation from the Dange Formation) contains the richest microfauna in terms of population but low diversity while the top part

has the richest assemblage in terms of diversity of species. Samples from all sections are characterised by shallow water benthic foraminiferal assemblage with the bottom section assemblage dominated by large rotaliids, nonionids, and cibicidids while the overlying section contains larger foraminifera that permit precise age determination.

Chapter 7

SYSTEMATIC PALEONTOLOGY

The Foraminifera are members of the Order Foraminiferida, Subclass Rhyzopoda, Class Sarcodina, Phylum Protozoa. They constitute about 2.5% of all animals known from the Cambrian to the Recent.

There are 20 species in all identified from the Kalambaina Formation. The systematics as presented here conform with the Treatise on Invertebrate Paleontology of Loeblich & Tappan (1964).

Order : Foraminiferida
Suborder : Miliolina Delage & Herouard 1896.
Superfamily : Miliolacea Ehrenberg 1839
Family : Miliolida Ehrenberg 1839
Subfamily : Quingueloculinae Cushman 1927
Genus Quingueloculina D'orbigny 1926.

Quingueloculina sp

Plate I, fig.(a)

Description

Test small, compressed, broadly elliptical, periphery broadly rounded, chambers inflated, a half coil in length, 5 in number, sutures distinct, depressed, aperture rounded with a simple tooth at the end of the last formed chamber, wall calcareous, porcelaneous, imperforate

Remarks

Quinqueloculina sp occurs sporadically at the bottom part of the Kalambaina Formation. One species each was identified based on foraminiferal count per 10gm of washed sample in samples No. KL 3.18 and KL 3.20 as obtained from the localities in the appendix.

Genus : Pyrgo Defrance 1824

Pyrgo sp

Plate 1, fig.(b)

Description

Test free, inflated, discoidal to ovate, proloculus followed by chambers one-half coil in length, chambers arranged in biloculine pattern, with successive discoidal to hemispherical chambers opposing each other; wall calcareous, imperforate, porcelaneous; aperture terminal, near junction of last 2 chambers, rounded to elongate, with distinct bifid tooth.

Remarks

Occurs sporadically in samples KL2.10 and KL2.11 obtained from the bottom of the Kalambaina section at the quarry and the Kalambaina-Dange contact at Dange village respectively.

Suborder : Rotaliina Dalage & Herouard 1896.

Superfamily : Buliminacea Jones 1895

Family : Turrilinidae Cushman 1927

Subfamily : Turrilininae Cushman 1927

Genus : Buliminella Cushman 1911

Buliminella sp

Plate 1, fig (c)

Description

Test free, elongate, with high closed spiral side formed by numerous narrow chambers; wall calcareous, perforate, radial in structure, surface smooth, slightly striate to spinose; aperture loop-shaped, with upper and relatively broad, internal tooth plate connecting aperture with that of previous chamber.

Remarks

Occurs sporadically in the top 4m in the Kalambaina section at the quarry and in samples KL2.13 and KL3.15 obtained from the Kalambaina outcrop at Wurno village.

Genus : Pyramidina Brotzen 1948.

Pyramidina crassa

Plate IV , fig. (K)

Description

Test free, subtriangular in section, chambers broad, low, triserially arranged and subangular; wall calcareous, finely perforate, surface somewhat nodose; aperture a high loop-shaped opening with a tendency to close at basal part, remaining only as more or less defined suture connecting subterminal aperture to base of chamber.

Remarks

Occurs sporadically at the top, middle and bottom parts in the Kalambaina section at the quarry; and in samples No. KL2.11 and KL2.12 obtained from the Kalambaina

exposure at the Dange road-cut section.

Superfamily : Discorbacea Ehrenberg 1838

Family : Discorbidigae Ehrenberg 1838

Subfamily : Discorbidinae Ehrenberg 1838

Genus : Rosalina 1826

Rosalina koeneni Brotzen 1948.

Part III , fig. (i)

Description

Test planoconvex, free, all chambers visible from convex spiral side, only those of final whorl visible around open umbilicus on umbilical side; aperture a low interiomarginal arch at the base of final chamber near periphery on umbilical side, with broad chamber flap just beneath aperture extending into open umbilicus, secondary sutural opening at opposite side of flap, those of previous chambers also remaining open.

Remarks

Occurs abundantly in the samples obtained from the top and middle part of the Kalambaina section at the quarry and 18 species were identified, based on foraminiferal count of 10gm of washed sample from sample No. KL3.15 obtained from the Kalambaina section at Wurno.

Rosalina koeneni was originally described from the Paleocene of Sweden.

Superfamily : Rotaliacea Ehrenberg 1839

Family : Rotaliidae Ehrenberg 1839

Subfamily : Rotaliinae Ehrenberg 1839

Genus : Rotalia Lamarck 1804

Rotalia cf. trochidiformis Lamarck 1804

Plate VI, fig. (r)

Description

Test free, trochospiral to plano-convex, all whorls visible from spiral side, spire multilocular, direction of coiling random, chambers simple; septa primarily double, formed by upward bending of chamber floor; wall calcareous, coarsely perforate, of radially fibrous calcite; spiral side smooth, umbilical side with plug split by anastomosing fissures into numerous tubercles.

Remarks

Rotalia cf. trochidiformis occurs in all the samples obtained from the Kalambaina Formation.

Rotalia saxorum

Plate III fig.(j)

Description

Test free, biconvex, low trochospiral coil of three volutions; sutures slightly curved, thickened, depressed on umbilical side, septa primarily double; wall calcareous, finely perforate, radial in structure; umbilical surface with irregular granules along suture, umbilicus with open umbilical fissures and plug; aperture interiomarginal.

Remarks

Occurs in samples KL 1.1, KL1.6, KL2.9, KL3.14 and KL3.19 (see appendix for localities)

Genus : Pararotalia Le calvez 1949

Pararotalia perclara. (Loeblich & Tappan 1957)

Plate 1, fig. (d)

Description

Test free, trochospiral, umbilicus filled by plugs broken out in preservation, chambers rounded to ovate with smoothly rounded periphery, umbilical region of each chamber partially covered by umbilical flap; wall calcareous, perforate, radially built, variously ornamented with fine scattered spines, aperture on umbilical side, extraumbilical, with lip; intercameral foramen narrow, elongate and comma-shaped, consisting of portion of former aperture.

Remarks

Occurs abundantly in most of the sample obtained from the Kalambaina Formation. This species was originally described as Globorotalia perclara by Loeblich & Tappan (1957) from the Paleocene - Lower Eocene of the United States Atlantic coastal plain.

Pararotalia tuberculifera (Reuss 1862)

Plate IV, fig.(m)

Description

Test biconvex, ventral side more convex, dorsal side less, outline circular, peripheral margin sharp, ragged.

Each chamber of the last formed whorl has sometimes more, sometimes less developed spines at the periphery. Chambers visible only in last formed whorl, centre of dorsal side covered by numerous tubercles, the centre of ventral side filled by distinct knobs, well separated from chamber walls. Wall calcareous, perforate; sutures depressed, distinct on ventral side, almost not visible on dorsal side; aperture more or less loop-shaped, surface rough.

Remarks

This species occurs in most of the samples from the Kalambaina Formation. It has been reported from the Maastrichtian - Paleocene of Holland, and in the Paleocene of Belgium and Poland.

Genus: Operculinoides Hanzawa 1935

Operculinoides bermudezi

Description

Test planispiral, coiled, involute, wall calcareous, porcelaneous, imperforate; sutures distinct; aperture terminal. This species is larger than all the foraminiferal species from the Kalambaina Formation and can easily be seen with the naked eye.

Remarks

Occurs abundantly in all the samples from the Kalambaina Formation but most abundant in the samples from the top parts of the Kalambaina sections.

Subfamily : Cuvillierininae Loeblich & Tappan 1957

Genus : Thalmannita Bermudez 1952

Thalmannita madrugaensis Cushman & Bermudez 1947

Plate III fig.(h)

Description

Test small, slightly trochoid in early stage, later planispiral, peripheral outline lobulate, peripheral margin rounded, sutures slightly curved, wall calcarous, surface ornamented, with strong spiraling costae interrupted at sutures, sometimes spinose; aperture a low equatorial slit.

Remarks

Occurs sporadically in six samples from the Kalambaina Formation. (See table 3.1)

Family : Elphidiidae Galloway 1933

Subfamily : Elphidiinae Galloway 1933

Genus : Elphidiella Cushman 1936

Elphidiella africana (Leroy 1953)

Plate II, fig. (e)

Description

Test free, planispiral, involute, bilaterally symmetrical with equant. chambers commonly leaving axial umbilical plug which lacks radial canals; sutures with openings to subsutural and vertical canals, generally forming double row of alternating pores along each radial suture, without retral processes; wall calcareous, radial and laminated in structure; aperture multiple, consisting of scattered pores in apertural face.

Remarks

Elphidiella africana occurs abundantly in all the samples from the Kalambaina Formation. This species was originally described as Elphidium africana by Leroy (1953) from the Paleocene of Egypt.

Genus : Protelphidium Haynes 1956

Protelphidium sublaeve (Ten Dam 1944)

Plate II, fig. (f)

Description

Test coiled, planispiral involute, wall calcareous, perforate with radial wall structure, no sutural pores or retral processes, vertical canals piercing umbilical plug of secondary shell material; primary aperture not seen, possibly interiomarginal.

Remarks

Occurs sporadically in most of the samples from the Kalambaina Formation. Protelphidium sublaeve was originally described as Nonion sublaeve by Ten Dam (1944) from the Paleocene of Hofland.

Superfamily	Globigerinacea	Carpenter, Parker & Jones 1862
Family	Globorotaliidae	Cushman 1927
Subfamily	Globorotaliinae	Cushman 1927
Genus	Planorotalites	Morozova 1957

Planorotalites ehrenbergi

Plate V, Fig.(O)

Description

Test free, trochospiral, periphery carinate, chambers angular-conical; sutures thickened; wall calcareous, finely perforate, nonporous keel, surface smooth to cancellate; aperture extraumbilical - umbilical arch bordered by lip. Species is planktonic foraminifer.

Remarks

Occurs sporadically in six samples from the Kalambaina Formation. (See Table 3.1)

Superfamily : Orbitoidacea Schwager 1876

Family : Cibicididae Cushman 1927

Genus : Cibicides De Montfort 1808

Cibicides praecursorius (Schwager 1876)

Plate VI, fig. (p)

Description

Test planoconvex, spiral side flat, evolute, umbilical side strongly convex, involute; wall calcareous, coarsely perforate on spiral side, finely perforate on umbilical side; aperture a low interiomarginal opening with narrow lip.

Remarks

Occurs abundantly in all the samples from the Kalambaina Formation. This species was originally described as Discorbina praecursorius by Schwager and Leroy (1876) and it is a widely distributed Paleocene species in many parts of the world.

Superfamily : Cassidulinacea D'Orbigny 1839

Family : Pleurostomellidae Reuss 1860

Subfamily : Pleurostomellinae Reuss 1860

Genus : Pleurostomella Reuss 1860

Pleurostomella paleocenica Cushman 1947

Description

Test small, elongate, chambers in early stages curneate, later uniserial, sutures oblique in early stage, later straight and horizontal, wall calcareous, granular, aperture terminal, with projecting hood at one side.

Remarks

Occurs sporadically in eleven of the washed samples from the Kalambaina Formation. (See table 3.1 for sample number and appendix 1 for sample localities).

Pleurostomella paleocenica was originally described from the Paleocene of the Gulf coast.

Family : Nonionidae Schultze 1854

Subfamily : Nonioninae Schultze 1854

Genus : Nonion De Montfort 1808

Nonion graniferum (Terquem 1882)

Plate IV, fig. (1)

Description

Test planispiral, involute, slightly compressed, chambers numerous, increasing gradually in size as added; sutures distinct, slightly curved; wall calcareous, granular in structure; aperture equatorial arched.

Remarks

Nonion graniferum occurs abundantly in all the samples from the Kalambaina Formation. This species was originally described as Nonionella graniferum by Terquem and Le Calvez (1882) in the Paleogene of Europe.

Genus Nonionella Cushman 1926

Nonionella sp.

Plate V, fig.(n)

Description

Test trochospiral, slightly compressed, spiral side partially evolute, opposite side involute with final chamber overhanging umbilical region and appeared to form distinct umbilical flap; chamber relatively many; wall calcareous, perforate; aperture a low arch near periphery extending somewhat onto umbilical side.

Remarks

Occurs sporadically in six samples from the Kalambaina Formation (See Table 3.1).

This species is differentiated from Nonion graniferum in being asymmetrical and trochospiral, and in possessing an asymmetrically developed final chamber.

Family : Anomalinidae Cushman 1927

Subfamily : Anomalininae Cushman 1927

Genus : Anomalinoides Brotzen 1942

Anomalinoides umboniferus

Plate II fig.(g)

Description

Test small, plano-convex, involute on both sides, compressed, peripheral margin bluntly acute, lobulate, chambers 6 in number in the last whorl, rapidly increasing in size as added; sutures distinct, depressed, wall calcareous, perforate; aperture slit bordered by a narrow lip.

Remarks

Occurs in most of the samples from the Kalambaina Formation. Abundant in the Paleocene Ewekoro Formation, widely reported in the Paleocene strata in many parts of the world.

Genus : Gavelinella Brotzen 1942

Gavelinella sp

Plate VI, fig.(q)

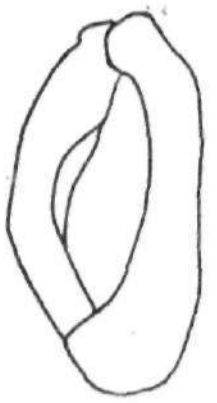
Description

Test small, biconvex, low trochospiral coil; circular to subcircular outline, sutures depressed and curved; wall calcareous, perforate; aperture a low extraumbilical arch at the base of the chamber.

Remarks

Occurs sporadically in five samples from the Kalambaina Formation. See table 3.1 and appendix I for sample No. and localities.

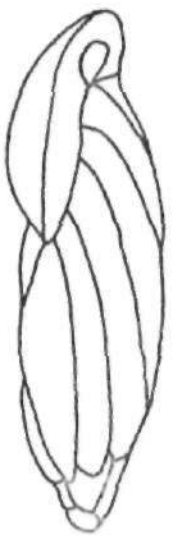
PLATE I



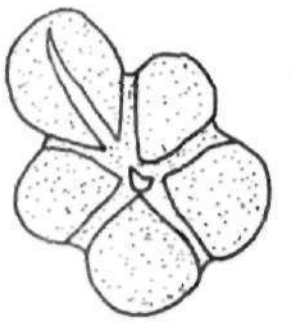
(a)



(b)

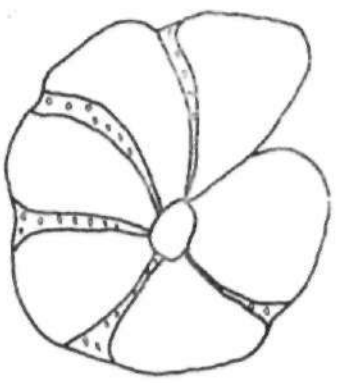


(c)

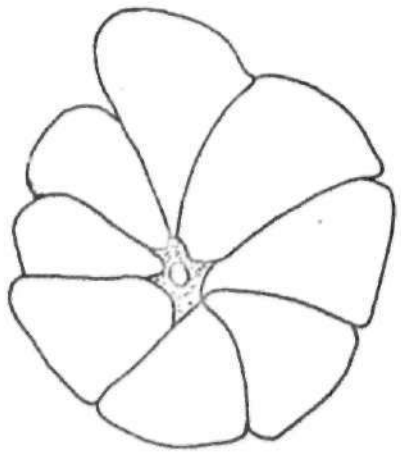


(d)

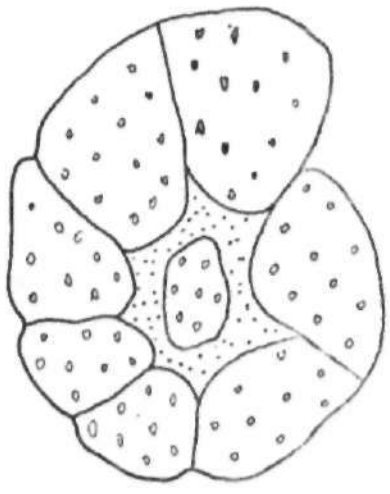
PLATE II



(e)



(f)

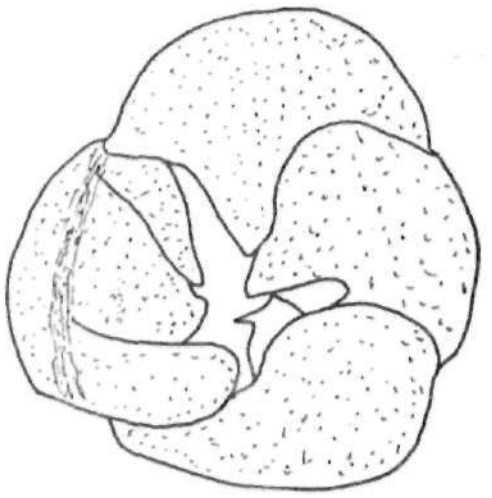


(g)

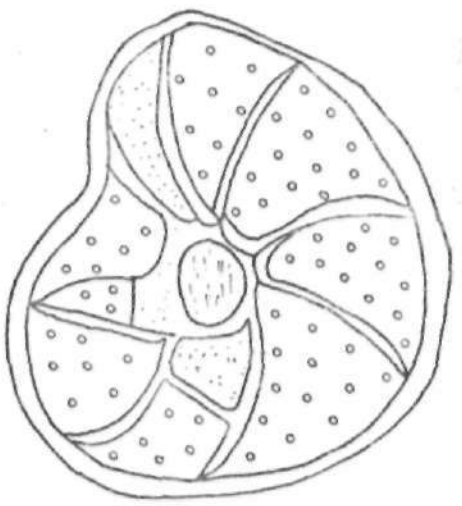
PLATE III



(h)

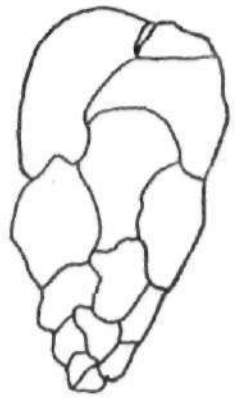


(i)

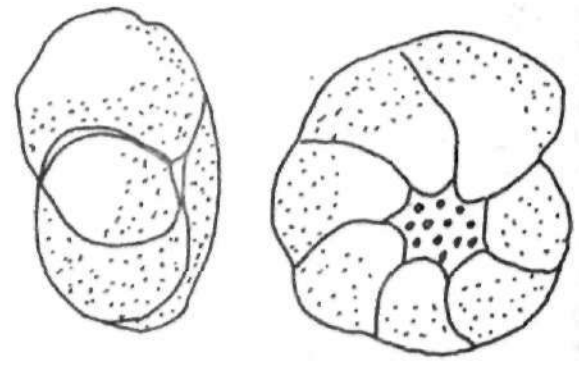


(j)

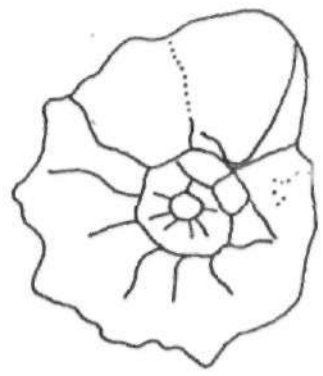
PLATE IV



[K]



[l]



[m]

PLATE V

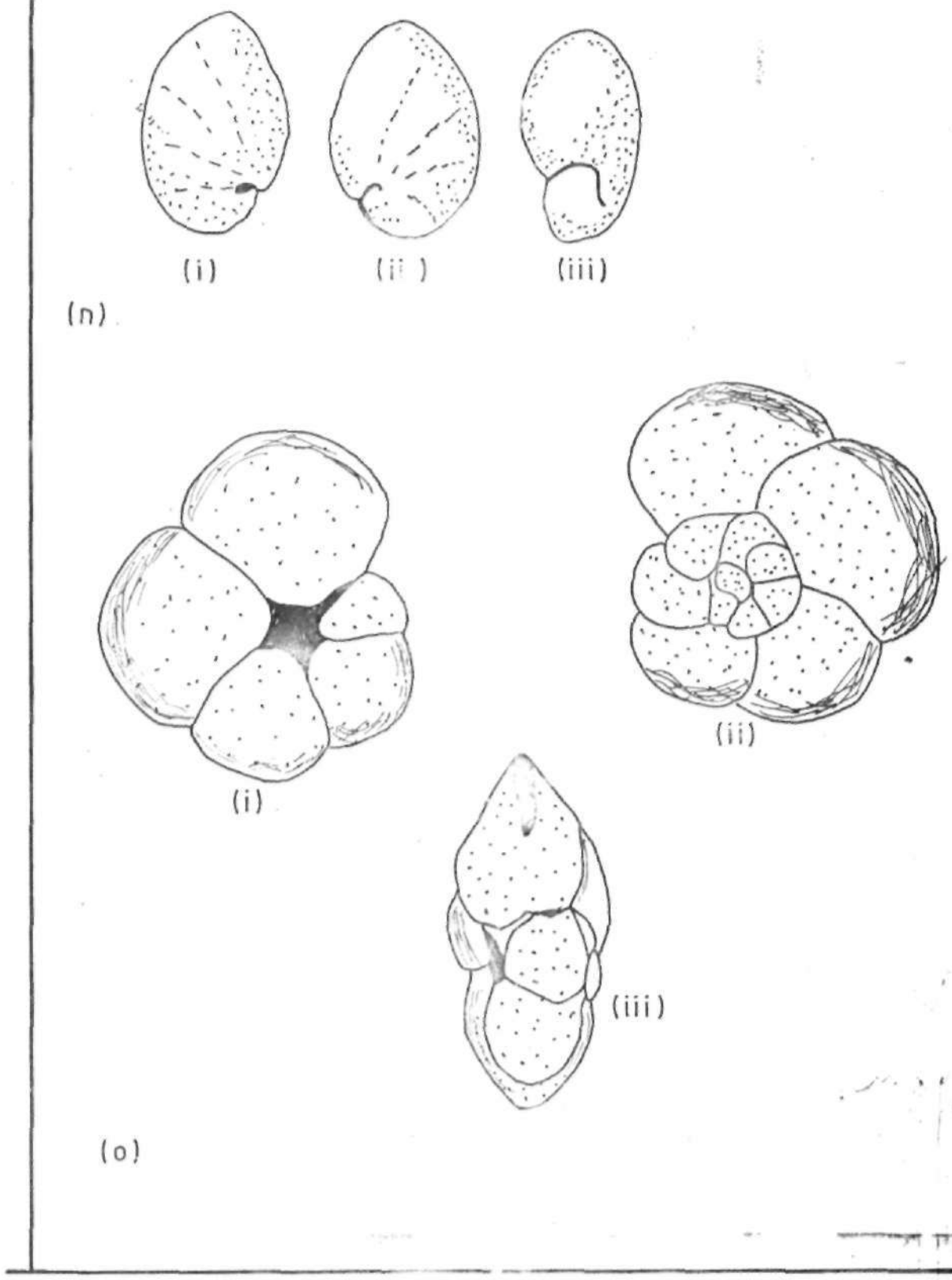
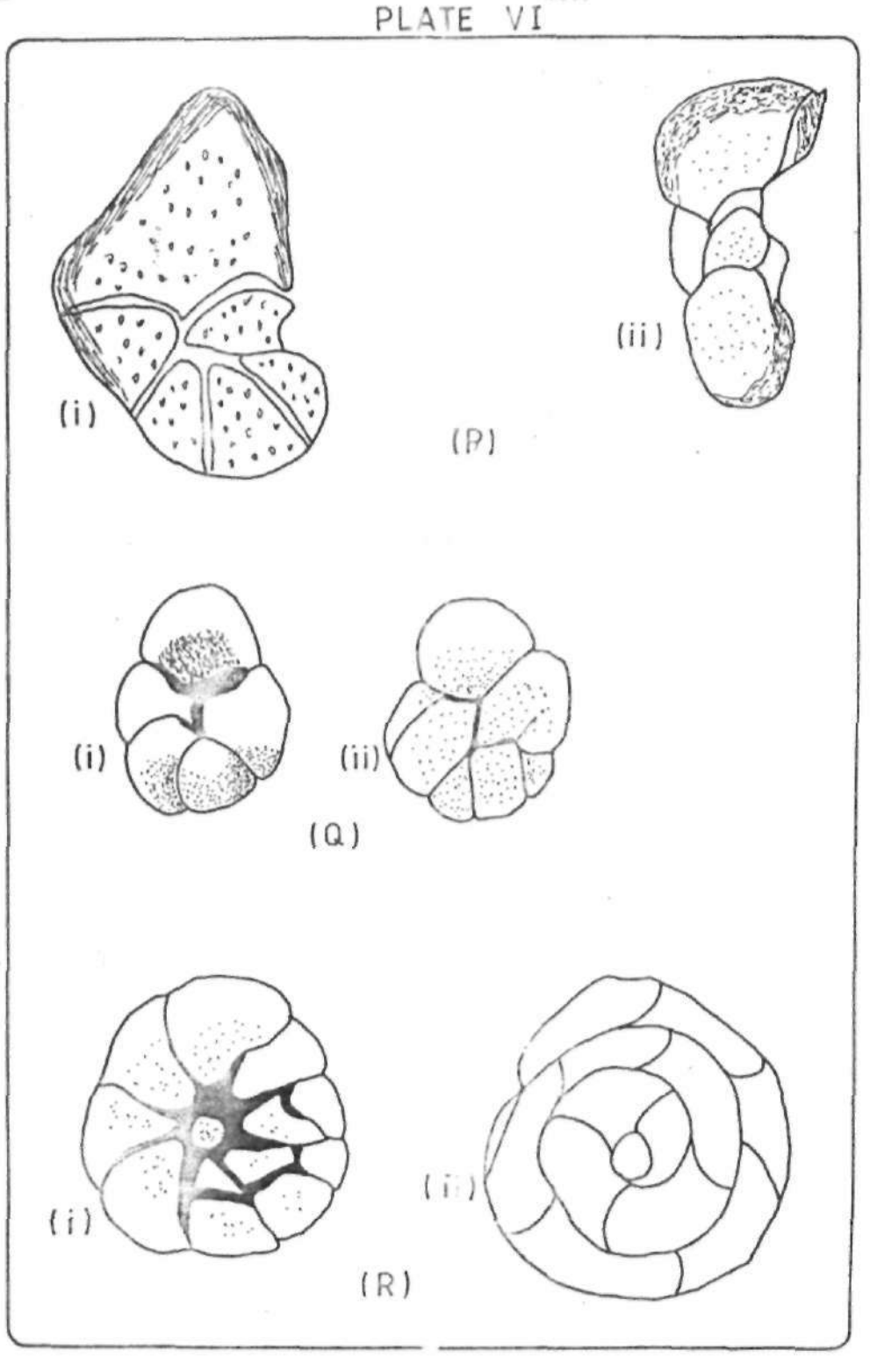


PLATE VI



REFERENCES

Adegoke, O.S. (1969) - Eocene stratigraphy of Southern Nigeria. Coll. L'Eocene, III, Mem. Bur. Rech. Geol. Min. 69; 23 - 48

Adegoke, O.S. (1977) - Stratigraphy and paleontology of the Ewekoro Formation (Paleocene) of Southwestern Nigeria. Bull. Amer. Paleont. 71,295: 1 - 379

Alam, M. (1986). Depositional history of a muddy sabka complex, the Sokoto Basin of Nigeria, West Africa. Geol. Jour. V. 21: 387 - 40

Albitton, C.C., Jr., Schwell, W.W., Hill, C.S., and Puryear (1954) - Foraminiferal population in the Grayson marl. Geol. Soc. America Bull. V.65, 327 - 336.

Alimarina, V.P. (1963) - Some peculiarities in the development of planktonic foraminifera and the zonation of the Lower Paleogene of the northern Caucasus. Voprosy micropaleont. v.7. p.158 - 195.

Asseez, O, and Fayose, E.A. (1972) - Biostratigraphy of the Lower Paleogene Calcareous unit in Sokoto area, Northwestern Nigeria, In: Dessauvagie, T.F.J. and Whiteman, A.J. (eds.), African Geology; Dept. Geol., Univ. Ibadan, Nigeria. p.281 - 289.

Bandy, O.L. (1960) - The geologic significance of coiling ratios in the foraminifera Globigerina Pachyderma (Ehrenberg): Jour. Paleont., 34: 671 - 681.

Bandy, O.L. (1964) - General correlation of foraminiferal structure with environment: In J. Imbrie and N.D. Newell (eds). Approahces to paleoecology. Willey, New York, p. 25 - 90.

Bather, F.A.(1904) - Eocene echinoids from Sokoto. Geol. Mag., Vol. 1, pp 292 - 301.

Berggren, W.A. (1965) - Paleocene: Micropaleontologist's point of view. Amer. Assoc. Petroleum. Geol. Bull v. 49 (9) p.1473 - 1484.

Berggren, W.A. (1974) - Paleocene benthonic foraminiferal biostratigraphy, biogeography and paleoecology of Libya and Mali Micropal., 20, 4: 449 - 465.

Berggren, W.A. & Aubert, J.(1975) - Paleocene benthonic foraminiferal biostratigraphy and paleoecology of Atlantic Tethyan regions. Palaeogeogr., Paleoclimatol., Palaeoecol., 18: .72 - 192.

Bermudez, P.J.(1952) - Estudio sistematico de Pos foraminiferos rotaliformes: Venezuela Minist. Minas and Hidrocarb. Bull. Geol. 2, 4: 1 - 230

Bolli, H.(1957) - The Genera Globigerina and Globorotalia in the Paleocene - L. Eocene Lizard Springs Formation of Trinidad, B.W.1; U.S. Nat. Mus. Bull. 215. p. 61 - 81.

Bolli, H.(1960) - Zonation of Cretaceous to Pliocene marine sediments based on Planktonic foraminifera; Inform. Assoc. Venezolana Geol. Min. Petrol. 60/9 p. 3 - 32.

Boltovskoy, E. and Wright, R. (1976) - Recent foraminifera: Dr. W. Junk b.r., publisher, The Hague, Netherlands, 515p.

Bretsky, P.W. and Lorenz, D.M.(1969) - Adaptive response to environmental stability:a unifying concept in paleoecology: Proc. North Amer. Paleoconvention, Part E. p. 522 - 550.

Brotzen, F. (1948) - The Swedish Paleocene and its foraminiferal fauna. Sver Geol. Undersok, (C) 42, 2:(493): 1 - 140.

Carter, J.D.(1964) - A note on the sedimentary rocks of the northern part of Sokoto province. Sheet 2. Geol. map. series of Nigeria. Geol. Survey. Nigeria.

Chernouard, L., de Klasz, I, & Meijer, M.(1960) - Deux neuvelles especes du genre (Siphegenerinoides (forminifere) du Cretace superier de I'Afrique occidentale - Rev. Micropal. 3, 2:71-76

Culver, S.J and Buzas, M.A.(1980) - Distribution of Recent benthic foraminifera off the North American Atlantic Coast. Smithson. Contr. Mar. Sc., 6:1 - 512.

Culver, S.J. and Buzas, M.A.(1981) - Recent benthic foraminiferal province on the Atlantic continental margin of North America. Jour. Foram. Res. 11, 3: 217 - 240.

Culver, S.J. and Buzas, M.A. (1982) - Distribution of Recent benthic foraminifera in the Gulf of Mexico Smithson. Contr., Mar. Sc. 8: 1 - 898.

Cushman, J.A.(1926) - Miocene species of Nonionina from California. Cushman. Lab. Foram. Res. Contr. 3, 1:1 - 105.

Cushman, J.A. (1947) - Some new foraminifera from the Paleocene of the Southern United States. Cushman. Lab. Foram. Res. Contr 23, 4:81 - 86

Cushman, J.A. and Bermudez, P. (1936) - New genera and species of foraminifera from the Eocene of Cuba. Cushman. Lab. Foram. Res. Contr. 12, 2: 27 - 38.

De France, M.J.L.(1824) - Dictionaire des sciences Natures v. 32. p. 1 - 567.

de Klasz, I. Le Calvez, Y., & Rerat. D.(1970) - Nonveaux foraminiferes du bassin sedimentaire du Gabon (Afrique equatoriale) - Proc. 3rd African micropal. Coll. (Cairo).

de Klasz, I. & Rerat. D. (1961) - Quelques nouveaux forminiferes du cretace' et du Tertiaire du Gabon (Afrique equatoriale) - Rev. micropaleont. 4,4: 175 - 189.

Delage, Y. and Herouard, E. (1896) - Traite' de Zoologie concrete, Tome I la cellule et les Protozoaires. Paris, 584 pp

De monfort, D (1808) - Conchyliologic systematique et classification methodique des conquilles. vol. 1:

Dodd, J.R. and Stanton R.J. Jr.(1981) - Paleoecology, Concepts and Applications - Willey. Interscience. John Willey & Sons. pub.

D'Orbigny, A.D.(1826) - Tablen methodique de la classe des cephalopodes. Ann. Sci. Nat. Paris. 7: 245 - 314

D'Orbigny, A.D.(1839) - Voyage dans I'Amerique meriodionale - foraminiferes, Pitois - Lovrenit et ce Paris 5, 5: 1 - 86

Douglass, R.G. (1979) - Benthic foraminiferal ecology and Paleoecology. Soc. Econ. Paleont. Min., Short. Course 6: 21 - 53.

Du Preez, J.W., and Barber, W. (1965) - The distribution and chemical quality of ground-water in Northern Nigeria. Geol. surv. Nig. Bull. No. 36. p.38 - 45.

Ehrenberg, C.G. (1839) - Die infusionthierchen als vollkommene Organismen. L. Voss (Lei p zig)

Erickson, D.B. (1959) - Coiling direction in Globigerina pachyderma as a climatic index. Science 130:219 - 220

Falconer, J.D. (1911) - The geology and geography of northern Nigeria. MacMillan, London, 286 pp.

Faure, H. (1966) - Reconnaissance geologique de formations sedimentaires post - Paleozoiques du Niger oriental. Mem. Bur. Rech. Geol. Min. 46: 1 - 630.

Ficarelli, G.(1976) - Upper Cretaceous and Paleocene microfaunas from the Sokoto Basin (NW, Nigeria). Riv. Ital. Paleont 82, 4:721 - 748.

Foster, C.A., Swain, F.M., and Petters, S.W. (1983) - Late Paleocene ostracoda from Nigeria. Revista Espanola de Micropaleontologia, v.15 No. 1:103 - 166

Furon, R.(1963) - Geology of Africa - Oliver & Boyd, London, 377 pp.

Galloway, J.J.(1933) - A manual of foraminifera, Principia Pross, Bloomington, Indiana 483 pp.

Glaessner, M.F. (1963) - Principles of micropaleontology: New York, Hafner Pub. Co. 297 pp.

Greigert, J.(1966) - Descriptions des formations Critaces at Tertaires du Basin des Iullumeden Mem. Bur. Rech. Geol. Min: 36: 1 - 234.

Hanzawa, S. (1935) - Some fossil Operculina and Miogypsina from Japan and their stratigraphical significance. Tohoku Imper. Univ., Sci. Repts., Ser. 2 (Geol) v.18, No. 1, p - 1 - 29.

Haque, A.F.M.M. (1956) - The foraminifera of the Ranikot and the Laki of the Mammal Gorge, Salt Range: Geol. Surv. Pakistan. Paleont. Pakistanica. 1 1 - 300.

Harris, D.K. (1981) - Paleoenvironmental interpretations and foraminiferal biostratigraphy of cores offshore from the Niger Delta. (Unpubl. Dissert.). Univ. Coll. Swansea.

Haynes, J. (1956). Certain smaller British Paleocene foraminifera, Pt.1 Nonionidae, Chilostomellidae, Espistomenidae, Discorbidae, Amphitiginidae, Globigerinadae, Globorotallidae and Guembalinidae, Cushman, Found, Foram. Res. Contr. 5,4: 79 - 101.

Hillebrandth Axel, Von, (1965) - Foraminifera Stratigraphic in Altertertiar von Zumaya (Previnz Guipuzesa, N.W. Spanien) and ein vergleich mit anderen Tethys - Gebieten: Bayerische Akad. Wiss., Match-Naturwiss. K1 Abh. 123, 62p.

Johnson, R.G. (1964) - The community approach to Paleoecology. In Imbrie, J. and Newell, W.D. (eds)., Approaches to Paleoecology: New York, Willey & Sons, Inc. p 215 - 221.

Johnson, R.G. (1970) - Variations in diversity within benthic marine communities. Amer. A Naturalist. v. 104. p.285 - 300.

Johnson, R.G. (1972) - Conceptual models of benthic marine communities: In Schupt, J. (ed): Models of Paleobiology; San Francisco, Freeman, Cooper and Co. p. 93 - 100.

Jones, B. (1948) - Sedimentary rocks of the Sokoto Province, Bull 18. Geol. Surv. Nig. Kaduna 79 pp.

Jones, T.R. (1895) - A monograph of the Foraminifera of the Crag., Pt. 2. Paleont. Soc. London, p.73 - 210

Kennet, J.P. (1976) - Phenotypic variations in some Recent and Late Cenozoic Planktonic foraminifera: In R.H. Hedley and C.G. Adamss (eds), Foraminifera v.2; Academic, New York 111 - 170.

Kogbe, C.A. (1972) - Geology of the Lower Tertiary sediments of the Southeast flanks of the Iullemmeden Basin (Northwestern Nigeria). Geologische Rundschau vol. 62/1. 197 - 201.

Kogbe, C.A. (1974) - Paleoecologic significance of vertebrate fossils in the Dukamaje and Dange Formations (Maastrichtian and Paleocene) of Northwestern Nigeria. Journ. of Min. and Geol. (Nigeria) v. 8 Nos. 1 & 2.

Kogbe, C.A. (1976) - Paleogeographic history of Nigeria from Albian times. Geology of Nigeria (ed) C.A. Kogbe Elizabethan pub. Co., Lagos p.237 - 252.

Kogbe, C.A. (1977) - The Cretaceous - Tertiary boundary in Northwestern Nigeria. Zeitsdright deutchen geology gesellschaft. 128 p. 209 - 214.

Kogbe, C.A.(1978) - The Transaharan Seaway during the Cretaceous . Proc. 4th Conference African Geology. Univ. Ibadan.

Kogbe, C.A. (1979) - Geology of the South eastern (Sokoto) Sector of the Iullemmeden Basin. Bull. Dept. Geol. A.B.U., Zaria, Nigeria., v.2 No. 1 420 pp.

Kogbe, C.A. and Sowunmi, B.(1975) - The age of the continental Terminal as suggested by the sporopolliniti analysis. Savana, June, v.4. No. 1, p.47-55 A.B.U., Zaria.

Kogbe, C.A. and Wozny, E. (1979) - Upper Maastrichtian and Lower Tertiary Macrofauna from the Iullemmeden Basin and their paleobiogeographic distribution. Proc. 5th conf. African Geology, Cairo, Egypt. p.21-26

Krasheninnikov, V.A., and Trofimov, D.M. (1969) - Sravitel'nyy analiz bentosnylch foraminifer datskopaleotsenovykh Otlozhenily Mali, Oblasti tetisa i severo - zapadnoy Evropy. Akad. Nauk SSSR Voprosy mikropal. v.12. p 108 - 144, In: Petters S.W. (1979) West African cratonic stratigraphic sequences, Jour. Geol. v.7 p.528 - 531.

Lamarck, J.B (1804) - Suite des menicres sur les fossiles des environs de Paris. Mus. Nat. Hist. Nat. Paris Ann., 5:179 - 188.

Le Calvez, Y.(1949) - Revision foraminiferes Lutetiens du Basin de Paris; II Rotaliidae et familles affines. Carte. Geol. Detaille'e France, Mem. p.1-54.

Le Calvez, Y., de Klasz, I. & Brun. L. (1974) - Nonvelle contribution a la connaissance des microfaunes du Gabon - Rev. Esp. Micropal., 6, 3: 381 - 400.

Leonov, A and Alimarina, V.P (1961) - Stratigraphy and Planktonic foraminifera of the Cretaceous - Paleocene transition beds of the Central part of the North Caucasus: 21st Inter. Geol. Cong. Colln. Papers. Geol. Fac. Moscow. Univ. p.29 - 69

Leroy, L.W. (1953) - Biostratigraphy of the Magfi Section,

Levine, N.D. (1962) - Protozoology: Jour. Protozool. 9. 1:1-6.

Loeblich, P.A.R. and Tappan, H. (1957) Planktonic Foraminifera of Paleocene and early Eocene age from the Gulf and Atlantic Coastal plains. U.S. Nat. Mus. Bull. 215: 173 - 198.

Loeblich, A.R. and Tappan, H.(1964) - Treatise on invertebrate paleontology, Part C: Protista 2, Sarcodina chiefly "Thecamobians" and Foraminiferida Univ. Kansas Press for Geol. Soc. Amer., Lawrence 1 - 2. 900 pp.

Margalef, R.(1968) - Perspective in ecological theory: Chicago, Univ. Chicago, Press 111 p.

Morozova, V.G.(1957) - Nadsemeystvo foraminifer Globigerinidea superfam. nova i nekotorye ego predstaviteli: Akad. Naulk. SSSR. Doklady, v.114, n.5. p 11109 - 1112.

Murray, J.W.(1973) - Distribution and ecology of living benthic foraminiferids. Crane, Russaka Co. New York, 274pp.

Newton, R.B. (1904) - A notice to some marine Tertiary fossils from Northern Nigeria. Geol. Jour. v.24. p.522 - 524.

Norgan, D.S.(1964) - Foraminifera, stratigraphy and paleoecology of the Aquia formation of Maryland and Virginia. Cushman Found. Foram. Res. Spec. Publ. n.7 50p.

Norton, R.D.(1930) - Ecologic relations of some foraminifera. Scripps Inst. Ocean. Bull. Tech. Serv. v.2, 331 - 388.

Olsson, R.K. (1970) - Paleocene planktonic foraminiferal biostratigraphy and paleozoogeography of N. Jersey. Jour. Paleont. v.44. no. 4. p.589 - 597.

Parker, D.H. (1964) - Paleocene fossils from Sokoto Province, Northwestern Nigeria. Rec. Geol. Surv. Nig. 7:23 - 36.

Petters, S.W.(1976a) - Benthonic foraminiferal biotratigraphy of latest Cretaceous and earliest Tertiary in NW Nigeria and SE Niger. African micropaleontological colloquium, 7th Ile-Ife, Nigeria, Proceedings.

Petters, S.W. (1976b) - The marine Maastrichtian and Paleocene sediments of the Dukamaje Formation and Sokoto Group. Geological Guide to some Nigerian Cretaceous! - Recent localities: Ile-Ife, Nigeria, Univ. Ife, Geol. Dept.

Petters, S.W.(1977a) - Ancient Seaway across the Sahara. The Nigerian Field. v.42:22-30.

Petters, S.W.(1977b) - West African Late Cretaceous - Early Tertiary foraminiferal paleoecology and paleobiogeography. International Congress of Protozoology, 5th, New York, Abstracts, p. 470

Petters, S.W.(1978a) - Foraminiferal paleoecology of the South eastern part of the Maastrichtian - Paleocene Saharan epeiric sea. Jour. Foram. Res. v. 8(4): 303 - 313.

Petters, S.W.(1978b) - Maastrichtian - Paleocene foraminifera from North West Nigeria and their paleogeography. Acta paleontologica polonica, v.23 no. 1: p 131 - 152.

Petters, S.W.(1979a) - Stratigraphic history of the South Central Saharan region. Geol. Soc. Amer. Bull.

Petters, S.W.(1979b) - Nigerian Paleocene benthonic foraminiferal biostratigraphy, Paleoecology and Paleobiogeography. Marine micropaleontology: 4. p 85 - 99.

Petters, S.W. (1979c) - West African cratonic stratigraphic sequences. Jour. Geol. v.7, p528-531.

Petters, S.W. (1980) Maastrichtian - Paleocene cyclothem and Paleoclimate in S.E. Iullemmeden Basin, West Africa. Newsl. Stratigr: 8,3: 180 - 190.

Petters, S.W.(1981) - Stratigraphy of Chad and Iullemmeden Basins, West Africa. Eclogae Geol. Helv., 74,1:139 - 159.

Petters, S.W. 1982 - Central West African Cretaceous - Tertiary Benthonic Foraminifera and Stratigraphy Paleontographica, 179, 1 - 104

Phleger, F.B. (1960) - Ecology and distribution of Recent foraminifera. Baltimore, John Hopkins Press. 502 pp

Pozaryska, K. and Szczechura, J.(1968) - Foraminifera from the Paleocene of Poland, their ecological and biostratigraphical meaning. Palaeont. Polonica, 20:1-107.

Posaryska, K. and Szczechura, J.(1970) - On some warm water foraminifers from the Polish Montian. Polska Akad Nauk. Zaklad. Paleozool. Acta. Paleont Polonica, 15:95 - 108.

Radier, H.(1957) - Contribution a l'stude geologique du. Soundan Oriental (A.O.F) Theses Fac. Sci. Univ. Strasbourg. In Kogbe C.A. (1979) Geology of the South Eastern (Sokoto) Sector of the Iullemmeden Basin. Bull, Dpt. Geol. A.B.U., Zaria

Raeburn, C., and Tattam, C.M.(1930) - A preliminary note on the sedimentary rocks of Sokoto Province. Bull. Geol. Surv. Nig. no. 12, p.57 - 60 Kaduna

Reuss, A.E.(1860): Die Foraminiferen der Westphalischen Kreideformation - K. Akad. Wiss. Wien. Math. Naturwiss. cl. Sitzungsber 40: 147 - 238

Reuss, A.E.(1862) - Entwart ciner systematischen Zusammenstellung der Foraminiferen. K.Akad. Wiss Wien. Math. Naturwiss. Cl., Sitzungsber., 44 355 - 396.

Reyment, R.A.(1960 - 1966) - Studies on Nigerian Upper Cretaceous and Lower Tertiary Ostracoda. Stock. Contr. Geol. Part 2, Danian, Paleocene, and Eocene Ostracods. v.10:1-286.

Reyment, R.A., and Reyment, E.A. (1978) - The Paleocene Transaharan transgression and its Ostracod fauna. Proc. 2nd. Symp. Geol of Libya, Tripoli 1978

Saidova, K.M.(1961) - Ekologia foraminifer i paleo-geografia dal' nevostochnykh morej SSSR i severeo - zapaduoj chasti Tikhogo Okeana: Akad. Neuk. SSSR, Inst. Okeanol., 182p.

Schultze, M.S.(1854) - Uber den Organismas der polytha-lamien (Foraminiferen), Wilhelm. Engelmann, Leipzig, 68 pp.

Schwager, M.S. (1876) - Saggio di una classificazione dei foraminiferi avuto riquado alle loro famiglie naturali. R. Comitato. Geol. Ital. Bull. 7:11-12; 475 - 485.

Schwager, M.S.(1883) - Die foraminiferen aus den Eocaentographica, der Libyschen Wuste and Aegyptens. Paleontographica, 30:79 - 154.

Stenli, F.G. and Creath W.B.(1964) - Foraminiferal ratios and regional environments: Amer. Assoc. Petrol Geol. Bull. 48. 1810 - 1823.

Swinton, W.E. (1930): On fossil Recptilia from Sokoto Province - Geol. Survey. Nigeria. Bull. 13. 1 - 61

Ten Dam, A(1944) - Die stratigraphische Gliederung des neiderlandischen Palaozans und Eozans nach foraminiferen - Med. Geol. Strichting, 3:102

Terquem, O.(1882) - Les foraminiferes de I'Eocene des environs de Paris. Soc. Geol. France. Mem.(3) 3,2: 1 - 193.

Valentine, J.W. (1968) - The evolution of ecological units above the population level. Jour. Paleont. v.42. no. 2, p.253 - 267.

Valentine, J.W.(1969) - Patterns of Taxonomic and ecologic structure of the shelf benthos during the Phanerozoic time. Jour. Paleont. v.12. p.684 - 709.

Valentine, J.W.(1972) - Conceptual models of ecosystems evolution. In Schoff, J.(Ed) Models in Paleobiology, San Francisco. Freeman. Cooper & Co.

Valentine, J.W. (1973) - Evolutionary paleoecology of the Marine Biosphere, New Jersey, Prentice-Hall, Inc. 256 pp.

Walton, W.R.(1964). Recent Foraminiferal ecology and Paleoecology. In Imbrie, J. and Nowell; N.D. (eds), Approaches to paleoecology, New York, Willey & Sons Inc.

White, E.I.(1934) - Fossil Fishes of Sokoto Province - Geol. Surv. Nig. Bull. 14:1 - 78

APPENDIX

Simple Localities

KL.1.1 - Kalambaina Quarry 2.0m from top

KL.1.2 - Kalambaina Quarry 2.5m from top

KL.1.3 - Kalambaina Quarry 3.0m from top

KL.1.4 - Kalambaina Quarry 3.5m from top

KL.1.5 - Kalambaina Quarry 4.0m from top

KL.1.6 - Kalambaina Quarry 4.5m from top

KL.1.7 - Kalambaina Quarry 5.0m from top

KL.1.8 - Kalambaina Quarry 5.5m from top

KL.2,9 - Dange Village 4m. from boundary with Dange Shale

KL.2.10 - Kalambaina Quarry 9m. from top

KL.2.11 - Dange Village 20km from Sokoto town Road Cut Section

KL.2.12 - Dange Village 20km from Sokoto town Road Cut Section

KL.2.13 - Wurno Village - Road Cut Section

KL.3.14 - Dange Village. Contact with Dange Shale.

KL.3.15 - Wurno Village Road Cut Section

KL.3.16 - 1 Km. West of Dinawa Village

KL.3.17 - Wurno Village Road Cut Section

KL.3.18 - Kalambaina Quarry 4m from bottom of section

KL.3.19 - Wurno Village Surface Sample

KL.3.20 - Wurno Village Contact with Dange Shale.