FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

THE TRAVERSES OF A STRATIGRAPHER IN NIGERIAN SEDIMENTARY BASINS

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INAUGURAL LECTURE SERIES 26

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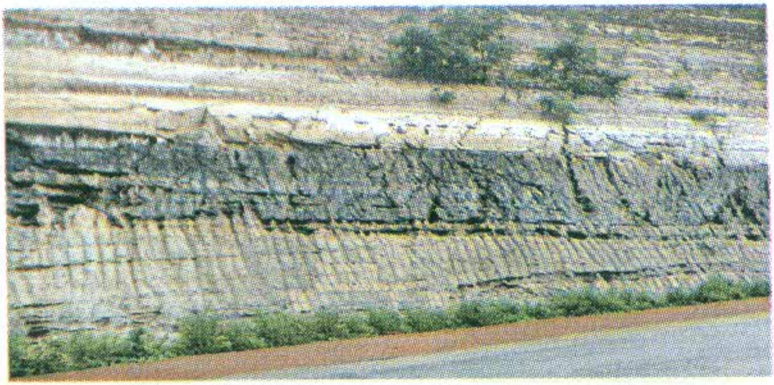

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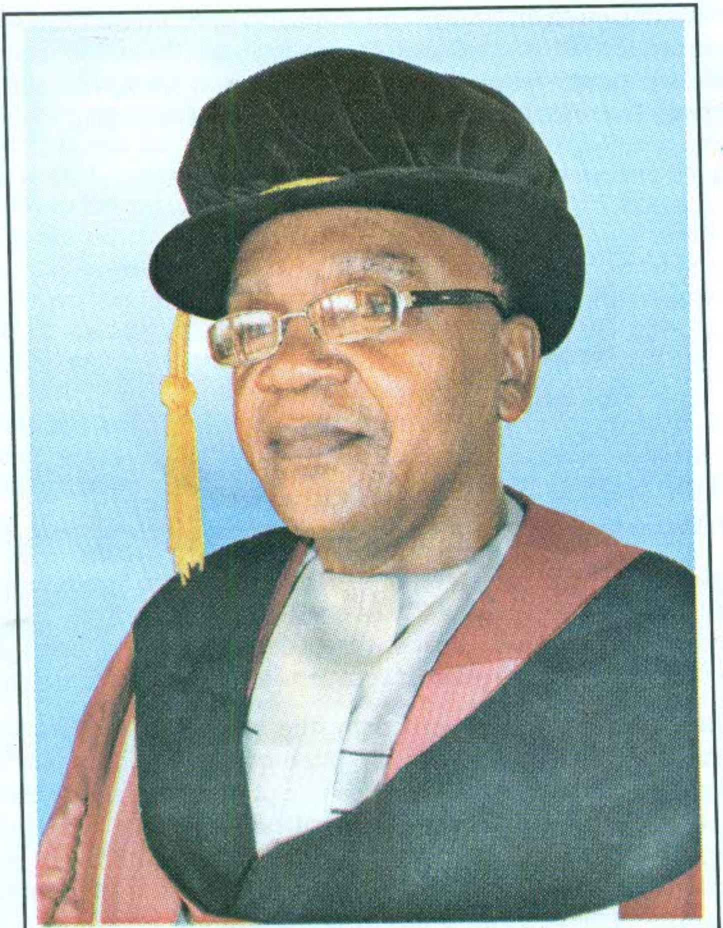

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1.0 Introduction

Stratigraphy is the description and classification of all rock bodies forming the Earth's crust into distinctive and mappable units on the basis of their inherent properties or attributes. It also includes the establishment of their distributions, relationship and succession in space and time respectively. The crust forms a relatively thin layer of rocks (Fig. 1).

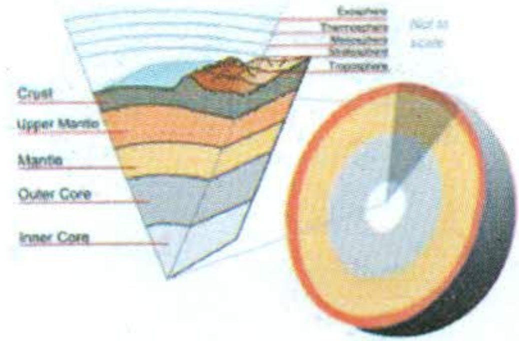


*Figure 1. The subdivision of the Earth's interior (en.wikipedia.org/wiki/**Crust** geology)*

The topic of this inaugural lecture "The traverses of a Stratigrapher in Nigerian sedimentary basins" was chosen to demonstrate how my research contributions in nearly three decades have addressed the keyword Stratigrapher in rocks of Cretaceous and Tertiary age in Nigeria.

Stratigraphic practice is governed by the principles and procedures enumerated in the 2nd edition of *International Stratigraphic Guide* (Murphy & Salvador, 1994). The *Guide* is a product of the International Subcommission on Stratigraphic Classification of the International Commission in Stratigraphy. The document was published by the International Union of Geological Sciences and the Geological Society of America. The *Guide* is a follow up to the first edition, edited by Hedberg (1976). Both editions found wide acceptance among stratigraphers globally. The document also serves to promote international agreement on the principles and procedure of stratigraphic practice. The principles and procedures in the *Guide* have been the hallmark of my stratigraphic practice.

Three basic and fundamental principles: "*superposition*", "*uniformitarianism*" and "*floral and faunal succession*" are very important in stratigraphy. They serve as keys to the understanding of the geologic past. The "*Principle of Superposition*" states that "*in any undisturbed succession of rocks, the oldest is at the base while the youngest is at the top*" (Stensen, 1669) and was formalized by Hutton (1815). The principle of "*Uniformitarianism*" states that the processes responsible for past geologic events are essentially similar to those operating today (Hutton, 1795). This can be interpreted to mean that the behaviour of nature (physical and chemical laws) is uniform throughout time, and the present is the key to the past. The principle of "*Faunal and Floral Succession*" states that "*fossil plants and animals succeed each other in a definite and determinable order and that any period of geological time can be recognized by its respective fossils*" (Smith, 1799). Strata containing identical flora and/or fauna in a generalized sense are of the same age irrespective of lithology and distance between the sequences. Such strata are correlatable. Correlation is the determination of equivalence in the geologic age and stratigraphic position of two or more formations in different areas or locations. The theory of organic evolution is of paramount importance in the biological scheme of dating or determining the ages of sedimentary rocks.

Rock bodies may be classified into five or more categories based on inherent properties or attributes (Tab. 1). Three categories or types of formal units will form the focus of this inaugural lecture: lithostratigraphic, biostratigraphic and chronostratigraphic units. Credible stratigraphic work requires strong adherence to sedimentologic and biostratigraphic principles.

Stratigraphic Categories	Principal Stratigraphic Unit-terms	Equivalent Geochronologic Units
Lithostratigraphic	Group Formation Member Bed(s), Flow(s)	
Unconformity-bounded	Synthem	
Biostratigraphic	Biozones: Range zones Interval zones Lineage zones Assemblage zones Abundance zones Other kinds of biozones	
Magnetostratigraphic polarity	Polarity zone	
Other (informal) stratigraphic categories (mineralogic, stable isotope, environmental, seismic, etc.)	-zone (with appropriate prefix)	
Chronostratigraphic	Eonothem Erathem System Series Stage Substage (Chronozone)	Eon Era Period Epoch Age Subage (or Age) (Chron)

Table 1. Categories and Unit - Terms in stratigraphic classification (Murphy & Salvador, 1994)

1.1 Lithostratigrapy

Adequate sedimentologic knowledge and practices are necessary for the study and comprehension of rocks classification and stratification (bedding). Classification of sedimentary rocks involves rock composition and grain size of particles (Tab. 2). There are terminologies for stratification (bedding) and grain size classes which are important for the description and classification of sedimentary rocks. (Ingram, 1954, Wentworth, 1922).

Clastic Sedimentary Rocks			
Texture (grain size)		Sediment Name	Rock Name
Coarse (over 2 mm)		Gravel (rounded fragments)	Conglomerate
		Gravel (angular fragments)	Breccia
Medium (1/16 to 2 mm)		Sand	Sandstone
Fine (1/16 to 1/256 mm)		Mud	Siltstone
Very Fine (less than 1/256)		Mud	Shale

Chemical Sedimentary Rocks			
Composition	Texture (grain size)	Rock Name	
Calcite	Fine to coarse crystalline	Crystalline Limestone	
		Travertine	
	Shells and cemented shell fragments	Coquina	Biochemical Limestone
	Shells and shell fragments cemented with calcite cement	Fossiliferous Limestone	
	Microscopic shells and clay	Chalk	
Quartz	Very fine crystalline	Chert (light color) Flint (dark color)	
Gypsum	Fine to coarse crystalline	Rock Gypsum	
Halite	Fine to coarse crystalline	Rock Salt	
Altered plant fragments	Fine-grained organic matter	Bituminous Coal	

1.2 Biostratigraphy

Biostratigraphy is the study of rock strata using fossils. Although the principle of faunal and floral succession (Smith, 1799) was to be the cornerstone for all subsequent work in biostratigraphy, a closer look at fossil succession was needed. The improvement at the earlier principles was the recognition that unique assemblages of fossils may include many formations (lithostratigraphic units) in one place and only a single formation in another, leading the concept of stage (D' Orbigny, 1842).

Oppel (1856) conceived the idea of small scale units defined by the stratigraphic ranges of fossil species irrespective of lithology. He noted that some fossils existed for a short geologic time, hence a short vertical range while others were quite long. Each of Oppel's zones was named after a particular fossils species, called an index fossil.

In the late 1800's, Gryzbowski realized that rock samples contained fossils that he could recognised from well to well. In addition, he could predict hydrocarbon reservoirs and even identify structural features such as faults and folds. The refinement of sequence stratigraphy by Exxon Group led to an increased demand for biostratigraphy, because high resolution biostratigraphy was a key component of this development. All these pave the way for applied biostratigraphy in exploration and production.

Rock samples from wells are often limited to ditch cuttings, but may also be sidewall samples or cores. These are then washed and prepared for picking of fossil forms to be followed by interpretation. The term microfossil is used here in its broad sense. However from a practical perspective there are three disciplines involved, micropalaeontology, nannopalaeontology and palynology. The separate disciplines have arisen due to differences in the size and chemical composition, specific preparatory and analytical procedures (Giwa *et.al,* 2004). The groups are listed below along with a brief description (Fig. 2).

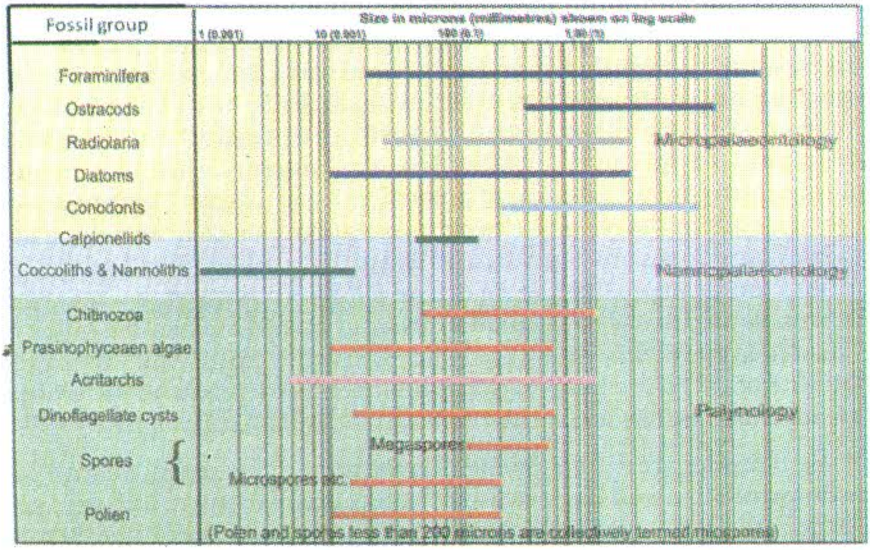


Figure 2. Microfossil groups from the Millennia consultant Website

1.2.1 Micropaleontology involves the study of foraminifera, ostracods and calpionellids, which mainly have a calcareous composition; diatoms and radiolaria that are composed of silica and conodonts, which are phosphatic.

1.2.2 Nannopaleontology covers the study of nannofossils, which are the smallest of the microfossils groups examined routinely. This group includes coccoliths and nannoliths, and also calpionellids. Nannofossils are calcareous and examined in transmitted light. They need polarization techniques for positive identifications to be made.

1.2.3 Palynology was once limited to the study of spores and pollen. However, it has recently been extended to encompass other organic walled microfossils, collectively termed palynomorphs. The groups studied include dinoflagelate cysts (dinocysts), acritarchs, marine prasionphycean algae and various freshwater algae, chitinozoa as well as spores and pollen. They are examined in transmitted light.

1.2.4 Biostratigraphic Zones

The fundamental unit of biostratigraphy is the biozone. Biozones are units of stratigraphy that are defined by the fossil taxa (usually species and subspecies) that they contain.

It can be argued that biozones are chronostratigraphic units. If speciation of events takes place rapidly enough to be considered to be 'an extent' in geologic time and the new taxon is quickly dispersed, then the base of a biozone can be regarded as an isochronous unit (Nichols, 1999). Marker species and or its associated assemblages have been identified and interpreted to give an insight into the environment and time of deposition. Previous works have subdivided the Niger Delta into major chronostratigraphic units based on marker assemblages. These units are the biozones in the Niger Delta chronostratigraphic chart widely in use today. These zones are given various codes that are identified by different forms, for example middle Miocene F9605 is marked by the First Downhole Occurrence FDO of *Floritus* ex gr *costiferum* and the influx of calcareous forms, while the base which is also the top of F9603 is marked by FDO of *Uvigerina subperegrina* with rich occurrences of *Heterolepa pseudoungerina, Lenticulina inornata* and *Cyclammina* cf *minima*.

These biozones are extremely useful in the exploration realm, where basin wide correlation and large scale rock units are of interest. Biozones and index fossil are very useful in the dating of rocks, that is the correct placement of strata in the geological time scale (Fig. 3).

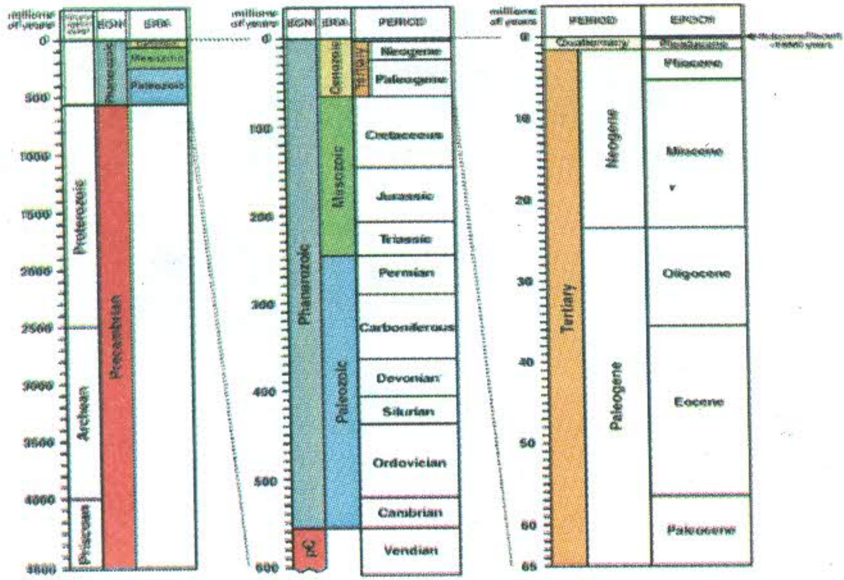


Figure 3. The Geological Time Scale

1.3 Overview of my Contributions

During my research, various rock units were studied in the field and laboratory. Some important boreholes cores from the Geological Survey of Nigeria (now Nigerian Geological Survey Agency) were also sampled and studied for litho- and biofacies. Detailed analyses of these two aspects of stratigraphy were undertaken in the sedimentary basins of Eastern Benin, Bida, Sokoto, Bornu, Benue Trough and the Niger delta. (Fig. 4). The Paleocene and Early Turonian paleogeography of Nigeria were reconstructed using ostracod distribution patterns. The lithostratigraphy of some formations has been reviewed based on the available new data from my research. Stratotypes (type sections) have been established where necessary.

Depositional environments of the formations were reconstructed based on microfossils. All biozonations have been correlated with regional and global chronological schemes. The geochemistry, fertilizer potential and reserves of the Sokoto phosphate and the hydrocarbon potential of the Bornu basin were investigated.

Results of these researches are presented below under the different basins.

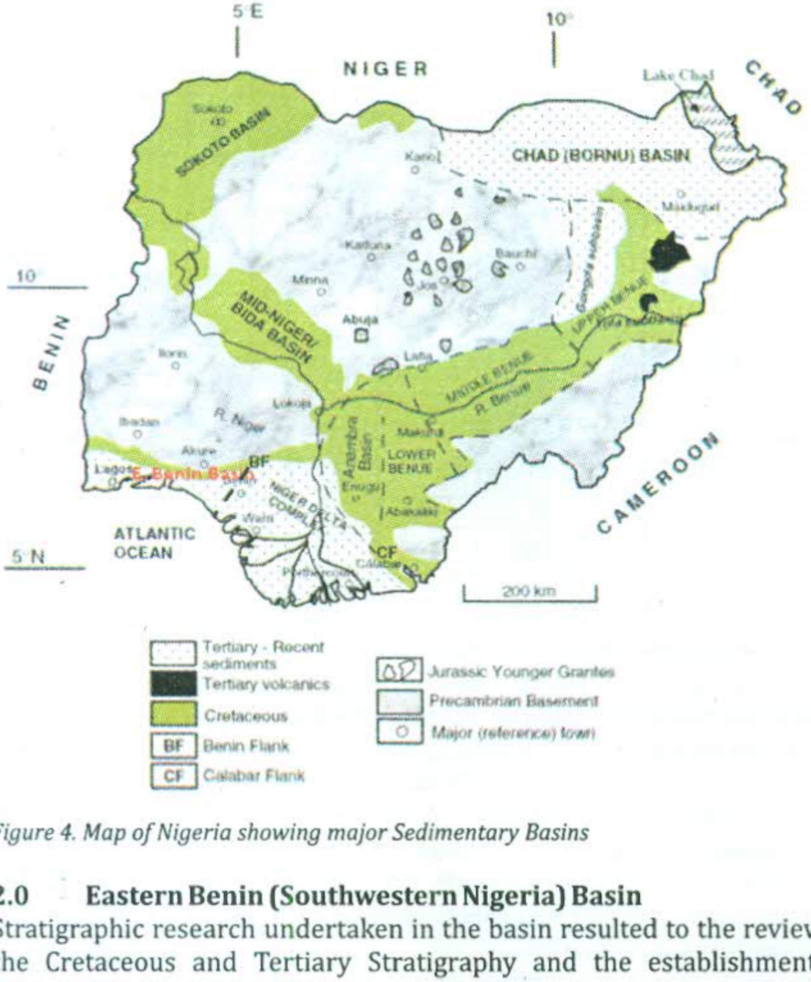


Figure 4. Map of Nigeria showing major Sedimentary Basins

2.0 Eastern Benin (Southwestern Nigeria) Basin

Stratigraphic research undertaken in the basin resulted to the review of the Cretaceous and Tertiary Stratigraphy and the establishment of Tertiary foraminiferal and ostracods biozones.

2.1 Review of the Cretaceous Stratigraphy

The Dahomey Basin, previously referred to as Dahomey Embayment stretches from Ghana through Togo and Republic of Benin to southwestern Nigeria. Sediment deposition follows an east-west trend. Onshore and offshore, the Cretaceous strata in the Republic of Benin consist of about 200 m and over 1000 m sequences respectively (Billman, 1976, De Klasz, 1977). The stratigraphy of the Nigerian sector is very similar to that of the Republic of Benin.

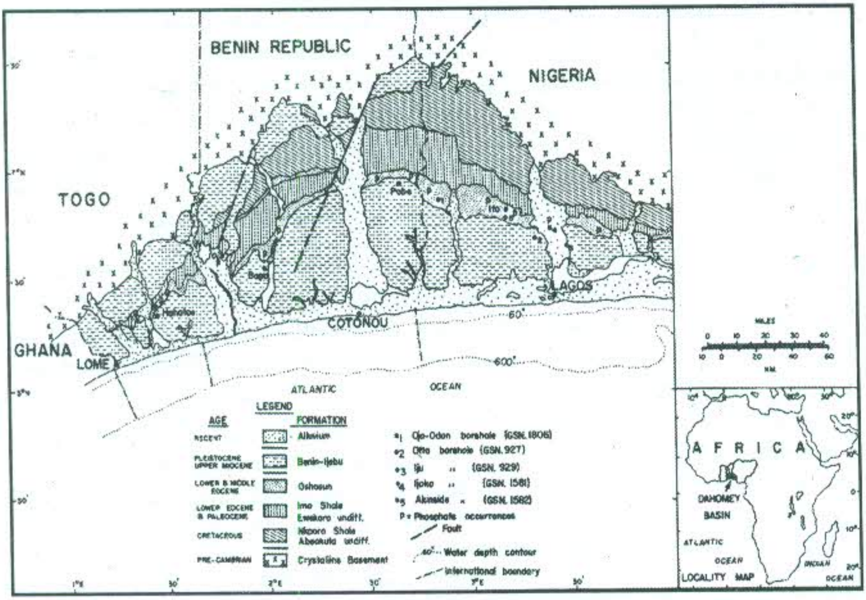


Figure 5. Generalized geological map of the Benin Basin(Modified after Billman, 1976)

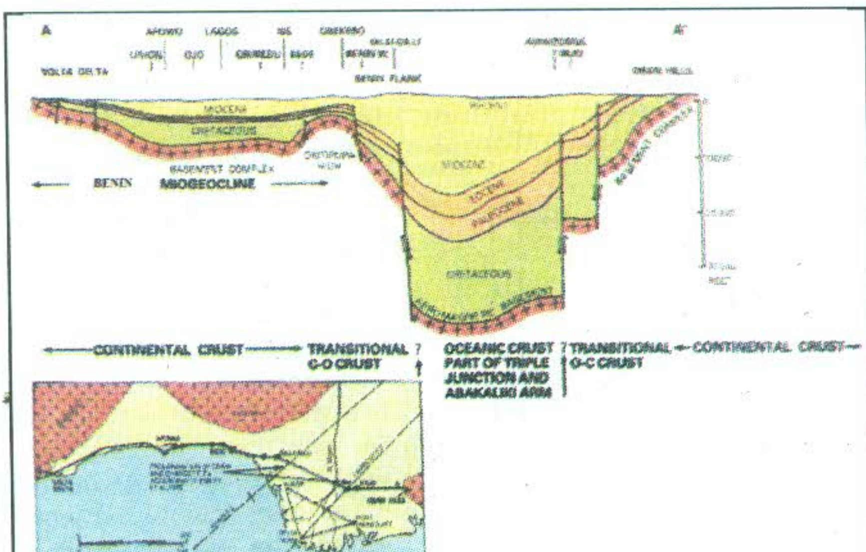
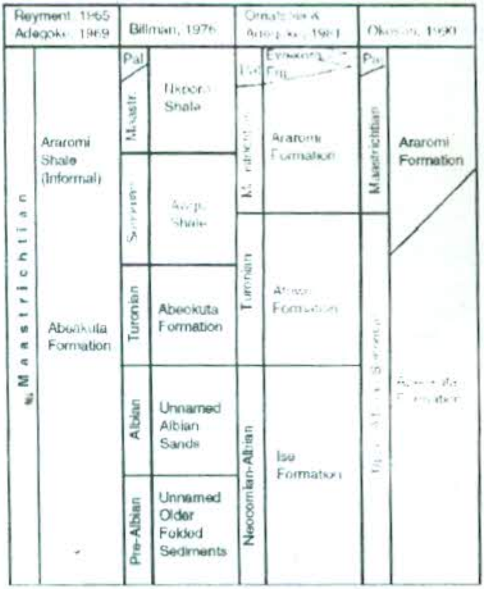


Figure 6. Generalized geological section from Volta delta through Benin miogeosyncline to Oban hills (Modified after Whiteman, 1982).

The Cretaceous rocks comprise of coarse to fine grained, unconsolidated sand with shale, clay, silty mudstone and limestone intercalations dark grey shale with sandstone, unconsolidated sand and limestone interbeds. The succession in the basin shows marked lithological changes which have been expressed in terms of formal and informal lithostratigraphic nomenclature by previous workers. This has resulted in dual or multiple nomenclature and thus confusion in stratigraphic nomenclature.

Abeokuta Formation was proposed for the Cretaceous rocks by Reyment (1965). Adegoke (1969) proposed Abeokuta and "Araromi shale" for the Cretaceous sediments in the Nigerian sector of basin. From a study of offshore sequences in the Republic of Benin, Billman (1976) proposed two informal lithostragraphic units: unnamed older folded sediments and unnamed Albian sands. The remaining portion of the Cretaceous sequence was referred to as Abeokuta Formation, and the Awgu and Nkporo Shales (Tab. 3). Jan du Chene *et al.* (1979), from a study of a coastal borehole (Ojo-1, Fig .6) reported the occurrence of Albian to Maastrichtian strata in the Nigerian sector of the basin.

Table 3 Stratigraphic relationship of the formations in the Eastern Benin Basin.



Omatsola and Adegoke (1981) disagreed with the nomenclature of Billman (1976) on two main grounds. Firstly that the rule of accepted stratigraphic practice (Chapter 3, Article H, P. 20 International Stratigraphic Guide, Hedberg, 1976) was contravened because when the Abeokuta Formation was subdivided, the same name was used for only one part of the succession. Secondly, the application of the well established Anambra basin names, Nkporo and Awgu shales to the Benin basin solely on the basis of age is invalid. As a result, Omatsola and Adegoke

(1981) established three new, formal lithrostratigraphic units: Ise, Afowo and Araromi Formations, the first two of which corresponds to the unnamed older folded sediment and unnamed Albian sands respectively (Table 3). The Araromi Formation was considered to be equilavent to the Nkporo shale and parts of Awgu shale of Billman (op cit). The Ise and Afowo Formations were dated as Neocomian (Valeginian) and Albian – Turonian respectively by these workers (Table.3)

The lithology of Ise and Afowo Formations as defined by Omatsola and Adegoke (op cit) show a high degree of similarity. Both are essentially sand and sandstone, but the latter contains thick interbeds of shale. Present observations indicate that the Ise, Afowo and Abeokuta Formations have similar lithologic and electric log characters. The presence of thick interbeds of shale in Afowo Formation is not sufficient to warrant its establishment as a separate lithostrattigraphic unit. The Ise and Afowo Formations are considered synonymous in my research.

2.2 A Neostratotype for Abeokuta Formation

The stratotype of the Abeokuta Formation was compiled by Jones and Hockey (1964) from data derived from the correlation of three different boreholes, the 'Itori', Wasimi and Ishaga (GSN 1583, 1585 and 2435). This means that the formation has no definitive holostratotype that could be curated for reference, a practice that contravenes the rules of accepted stratigraphic practice (Chapter 3, Article 7, International Stratigraphic Guide, Hedberg, 1976). From my research, the interval 1075 - 1923m of Ojo-1 borehole, which is situated at Lat. 6 27'86"N and Long. 5 10'0", and comprises fine to coarse sand with thin interbeds of shale and limestone, was proposed as a neostratotype for the formation (Okosun, 1990). The stratigraphic details are as follows:

Depth (m)	Description	Thickness (m)
1075-1084	Sand, loose, fine and medium grained, with thin interbeds of grey shale.	9
1084-1181	Sand, white, fine to coarse, round to sub-angular grains, unconsolidated, with thin dark grey and shale intercalation.	97
1081-1224	Sand, brown to white with massive limestone intercalation.	43
1224-1384	Shale, grey with brown, unconsolidated, medium grained, round to sub-angular sand interbeds.	160

1384-1446	Sand, brown, fine to coarse grained, with grey to brown thin shale intercalations.	62
1446-1692	Sand, brown, medium to coarse grained, with dark grey shale intercalations. Locally, micaceous intervals are present in the shale together with sporadic traces of bluish-green horizons.	246
1692-1723	Sand, brown with multicoloured (red, bluish-green, grey, dark brown, grey, and purple) shale intercalations. The sand is unconsolidated with fine to coarse, sub-angular grains.	31
1723-1893	Shale, dark grey, micaceous with interbeds of fine to coarse grained, unconsolidated brown sand.	170.
1893-1923	Shale, dark grey with occasional traces of brown limestone interbeds.	30
	Total thickness	**848 m**

The age of the neostratotype is late Albian-late Senonian. This dating is based on the foraminifera, pollen and spores recovered from my research and by Jan du Chene *et. al.* (1979).

2.3 Holostratotype for Araromi Formation

The interval 446-583m in the Araromi Borehole (GSN 1131), co-ordinates E267.572, N272.749) which was proposed as the holostratotype for the formation (Omatsola & Adegoke, 1981) was redescribed. This became necessary because the holostratotype was not properly described when it was formally established (Okosun, 1990).

446-465	Shale, sandy, dark grey	19
465-480	Shale, dark grey	15
480-490	Shale, glauconitic, dark grey	10
490-505	Shale, abundant fragments of bivalves, dark grey	15
505-510	Sandstone, fine medium grained, brown	5
510-539	Shale, a few pyrite nodules, dark grey	29
539-549	Limestone, massive, shelly in parts, grey	10
549-582	Shale, dark grey	33
582-583	Sand, fine medium grained, brown	1
	Total thickness	**137m**

The holostratotype was found in this study to be Campanian to early Paleocene in age. This dating is based on the presence of diagnostic foraminifera species. Omatsola and Adegoke (1981) gave the thickness of the holostratotype as 307 m, which is a marked contrast to the 137 m obtained for it in my research.

The two formations of Omatsola and Adegoke (1981) properly belong to the Abeokuta Formation (Tab.3). Thus the use of the names Ise and Afowo Formations should be discontinued and replaced by the name Abeokuta Formation which has priority of publication and a wider accepted usage.

2.4 Review of the Early Tertiary Stratigraphy

The stratigraphy of the early Tertiary strata of the eastern Benin basin was studied from 27 new boreholes (Okosun, 1998). Information from this study necessitated a review of the early Tertiary stratigraphy of the basin (Fig. 5).

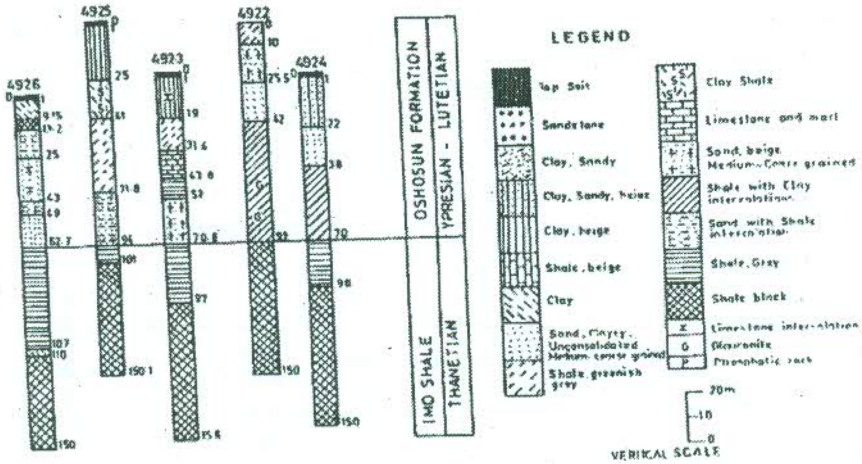


Figure 7a. Borehole columnar section from the eastern Benin basin

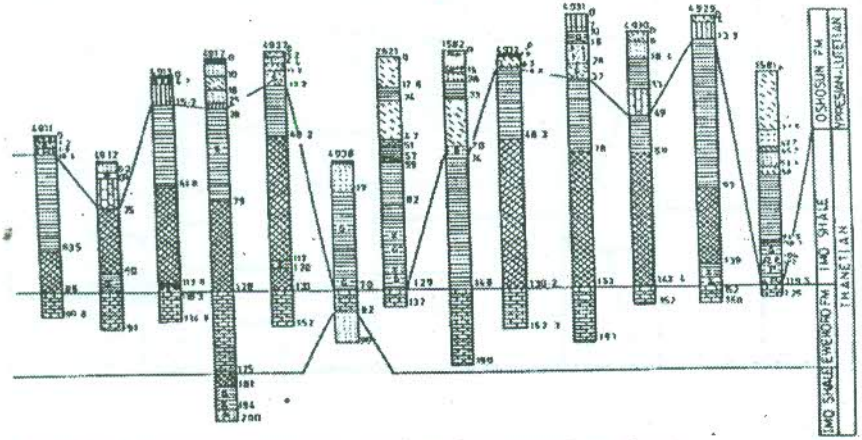


Figure 7b. Borehole columnar sections from the eastern Benin basin

The presence of a thick sequences of Imo Shale below the Ekeworo Formation in BH4917 (Fig. 7b) indicates that the latter is enveloped by the Imo Shale in some areas of SW Nigeria as was noted in Benin and Togo. Borehole evidence in and around Ilaro, the type locality of the Ilaro Formation shows the loosely consolidation sandstone designated the Ilaro Formation (Reyment, 1965) to be limited and non-persistent along strike. This implies that the sandstone is of local development, not mappable and therefore cannot be recognized as a formation. Its establishment as a formation therefore is against the principles of stratigraphic practice (Hedberg, 1976 Murphy & Salvador, 1994). The sandstone should appropriately be regarded as a facies of the Oshosun Formation which contains arenaceous subunits the sandstone described previously as Ilaro Formation and the strata referred to Ameki Formation in the area are correlatable with facies of Oshosun Formation to which they are now referred. The usage of the two names in the stratigraphy of the basin should be discontinued (Tab. 4). Table 5 shows the correlation of the Paleocene - Eocene strata in Nigeria.

Table 4. Revised Biostratigraphy of eastern Benin basin Southwestern Nigeria.

	Jones and Hockey 1964	Rayment 1966	Antolini 1968	Adegoke 1969	Ogbe 1972	Ako *et al* 1981	Okosun, 1998 Inland	Okosun, 1998 Coastal
Post Eocene to Recent	Coastal Plain Sands	Benin Fm	Coastal Plain Sands			Benin Fm	Benin Fm	Benin Fm
Eocene	Ilaro Fm	Ameki Fm Ilaro Fm Oshosun Fm	Ameki Fm Ilaro Fm Oshosun Fm	Ameki Fm Oshosun Fm	Ilaro Fm Oshosun Fm Akinbe Fm	Ilaro Fm Oshosun Fm Imo Shale	Oshosun Fm Imo Shale	Oshosun Fm Imo Shale
Paleocene	Ewekoro Fm	Imo Shale Ewekoro Fm	Ewekoro Fm	Imo Fm Ewekoro Fm	Ewekoro Fm	Ewekoro Fm	Ewekoro Fm Imo Shale	Araromi Fm

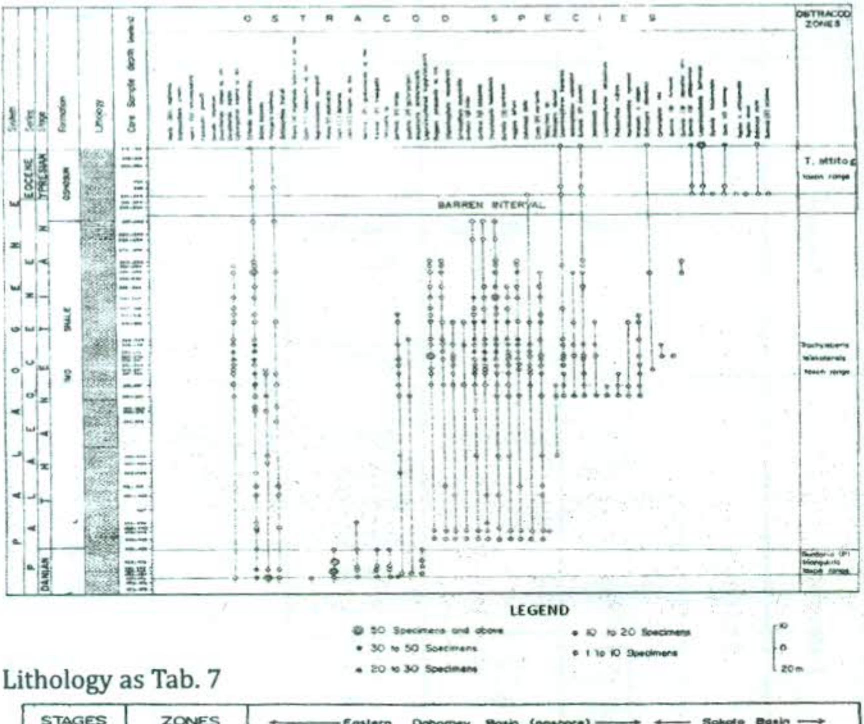
Series	Stage	SW Inland	SW Coastal	SE	NW	NE
Eocene	Ypresian - Lutetian	Oshosun Fm	Oshosun Fm	Ameki Fm (. Nanka Fm)		
Paleocene	Thanetian	Oshosun Fm / Imo Shale	Imo Shale	Imo Shale (.Ebenezer Sandstone Umunna Sandstone Igbalu Sandstone)	Kalambaina Fm	Kerikerri Fm
		Ewekoro Fm			Dange Fm	
		Imo Shale	Araromi Fm	Nsukka Fm		

Table 5 Correlation of early Tertiary formations in Nigeria

2.5 Early Tertiary Ostracod and foraminiferal biostratigraphy

The foraminifera and ostracod biostratigraphy was studied from outcrops and several boreholes among which are Araromi (GSN BH 1131), Gbekebo – I (GSN 1132), Akinside boreole (GSN BH 1582), Itori boreholes (GSN BH 1583). Diverse ostracod assemblages were recorded (Tab. 6, Fig. 8).

Table 6. Staratigraphic distribution of ostracods in Araromi -1 Borehole (GSN 1131)



Lithology as Tab. 7

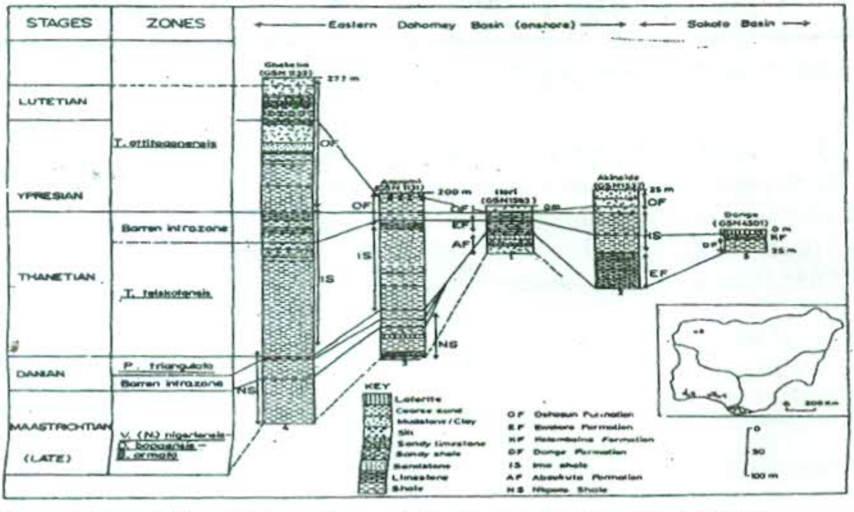


Figure 8. Correlation of Ostracod zones in the Eastern Benin and Sokoto Basin (Inset map shows the location of the sampled boreholes).

The following ostracod zones: *Veenia (N) nigeriensis, Dactylia bopaensis* and *Brachycythere armata* assemblage zone, *Buntonia (P) triangulata, Trachyleberis teiskotensis and Buntonia attitogonesis* taxon range zones (Fig. 8) were proposed. The zones have been used to correlate rocks in the eastern Benin and Sokoto basins (fig. 5).

The foraminifera biostratigraphy of the Paleocene – early Eocene of the basin gave fairly diverse planktic and benthic assemblage (Tabs. 6 & 7). Six planktic biozones comprising *Praemurica pseudobulloides, P. inconstans, Morozovella angulata, Globanomalina pseudomenardi, Morozovella velascoensis* and *M. subbotinae* were identified. Two benthic concurrent range zones, *Anomalinoides uboniferus – Eponides pseudoelevatus and Planulina oyae - Uvigerina hourcqi* were also identified.

Table 7. Stratigraphic distribution of Foraminifera in Araromi Borehole [GSN BH 1131]

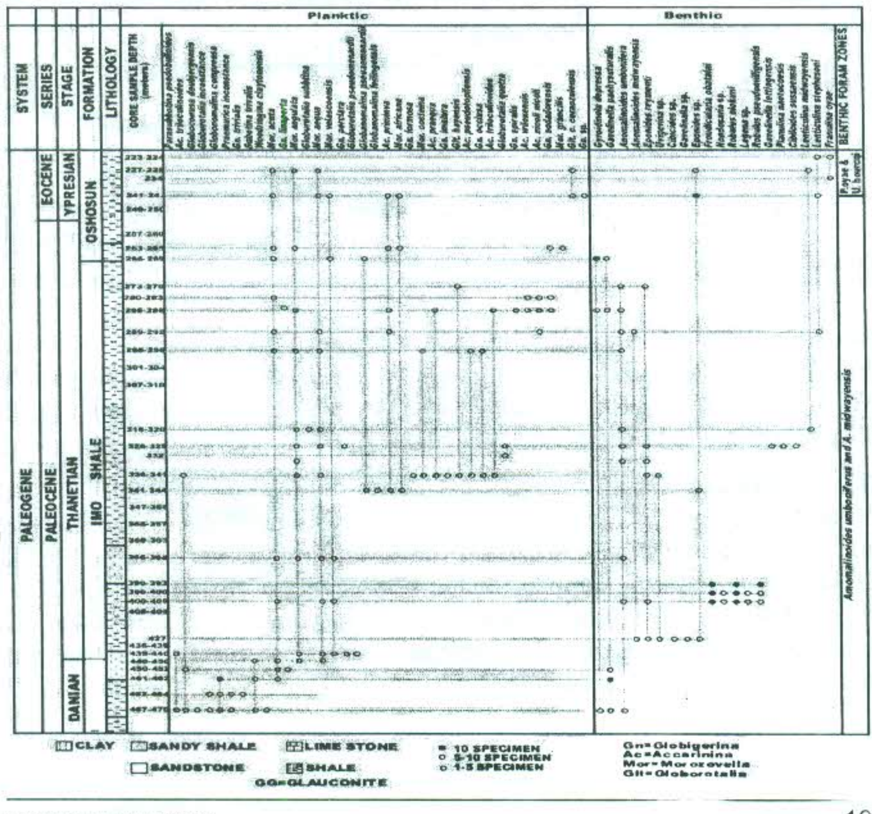


Table 8. Planktic and benthic foraminiferal biostratigraphy of the eastern Benin Basin and correlation with the inter-regional schemes.

Datum events: *P. pseudobulloides*, *P. trinidadensis*, *P. uncinata*, *M. angulata*, *I. pusilla*, *G. pseudomenardii*, *M. velascoensis*, *M. edgari*, *P. eugubina*

Age	Inter - Regional: Toumarkine & Luterbacher. 1985	Inter - Regional: Berggren et al. 1995		Eastern Benin Basin (Okosun & Alkali, 2012): Afowo - 1 BH Fayose, 1970	Eastern Benin Basin: Planktics, Araromi GSN 1131	Eastern Benin Basin: Benthics
E. Eocene	*M. edgari*	P_6	*M. subbotinae*		*M. subbotinae*	*Planulina oyae* & *Uvigerina hourcqi*
Late Paleocene	*M. velascoensis*	P_5	*M. velascoensis*		*M. velascoensis*	*Anomalinoides umboniferus* and *A. midwayensis*
Late Paleocene	*P. pseudomenardii*	P_4	*G. pseudomenardii*	*G. pseudomenardii*	*G. pseudomenardii*	
Late Paleocene	*P. pusilla pusilla*	P_{3b}	*I. albeari*	*I. albeari*		
Late Paleocene	*M. angulata*	P_{3a}	*M. angulata*	*M. angulata*	*M. angulata*	
Early Paleocene	*M. uncinata*	P_2	*P. uncinata*	*P. uncinata*		
Early Paleocene	*M. trinidadensis*	P_{1c}	*P. inconstans*	*P. trinidadensis*	*P. inconstans*	
Early Paleocene	*M. pseudobulloides*	P_{1b}	*G. compressa*	*P. pseudobulloides*	*P. pseudobulloides*	
Early Paleocene		P_{1a}	*S. triloculinoides*			
Early Paleocene	*G. eugubina*	$P\alpha$	*P. eugubina*			
Early Paleocene		P_0	*G. cretacea*			

Both the ostracod and foraminiteral biozones will serve as significant biochoronologic and stratigraphic correlation tools in Nigerian sedimentary basins (Fig. 8, Tab. 8), the West African coastal and Central West African inland sedimentary basins.

3.0 Sokoto Basin

New stratigraphic data from my research necessitated the establishment of a supplementary type section for the Dange Formation (Okosun, 1989). New insights into the depositional environments of the Kalambaina and Dange Formations have been highlighted. A geochemical characterization of the phosphate from the basin indicates its high potential as raw material for the production of fertilizer (Okosun, 1997).

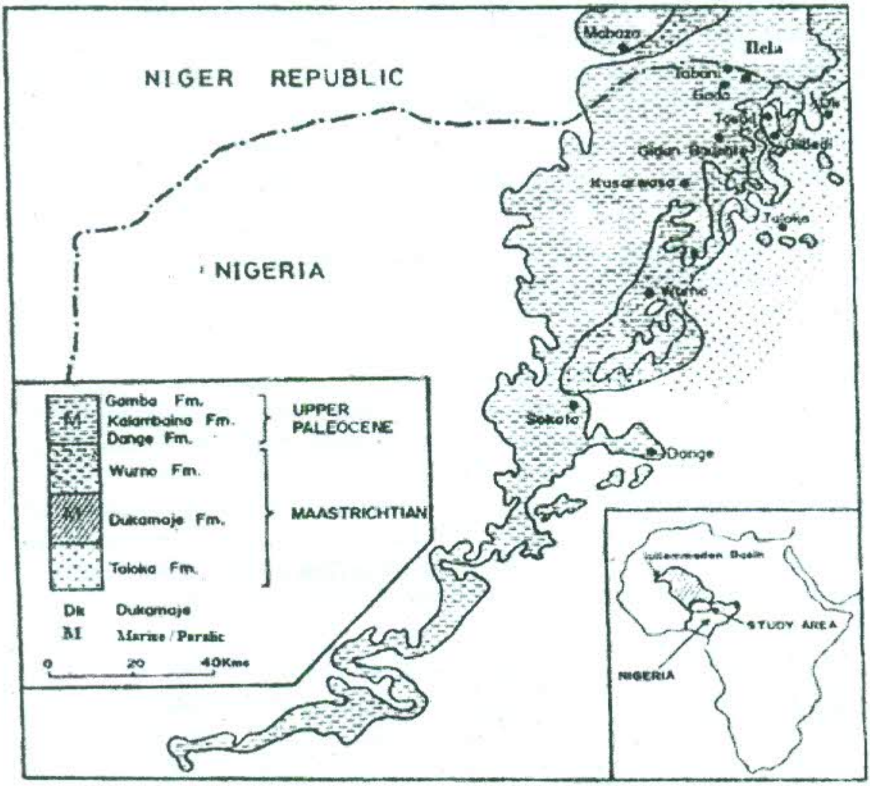


Figure 9. Outcrop of marine and paralic sediments in south eastern Iullemeden Basin

3.1 The Dange Formation

The Dange Formation outcrops in northwestern Nigeria in the Sokoto Basin which itself constitutes the southeastern portion of the Iullemmeden Basin (Fig. 9). It constitutes the lower member of the Sokoto Group, the Kalambaina and Gamba Formation comprising the middle and upper members respectively. The Sokoto Group was deposited during the Tethys sea transgression in the Paleocene. Sediments of equivalent lithologic characters to the formation occur in Niger Republic and Mali in central West Africa.

Kogbe (1972) described a type section along a road cutting by Dange village, 28km south of Sokoto town along Sokoto – Gusau road. Due to the non outcropping of the basal sequence of the formation at this locality, the information provided by the holostratotype as the standard for the definition of the formation is only restricted to the upper portion of the formation and thus incomplete. The lithologic characteristics of the formation were stated by Kogbe (1979) to consist of grey shale with limestone interbeds towards its base.

Thin beds and disseminations of phosphatic nodules frequency occur in the grey shale. Generally, outcrops are restricted to the flanks of the "Dange Scarp" which runs in a NNE-SSW direction in the Sokoto basin.

A detailed lithostratigraphic study of the Dange Formation (Paleocene) from boreholes cores, surface outcrops and pit profiles shows the formation of consist of grey shale, brown shale, marl, black shale and siltstone facies. The marl occurs as intercalations in the grey shale, the black shale and black siltstone facies occur as interbeds of moderate thickness below the oldest marl bed. Silty shale may form a transitional facies between the formation and the underlying Wurno Formation, otherwise the contact is sharp (Fig.10). Mineralogically, the grey and brown shale and siltstone facies contain thin beds and disseminations of phosphatic nodules, these facies are also gypsiferous. Ostracods and foraminifera are sparsely dispersed. Based on the observed lithofacies, a new supplementary stratotype was proposed (Okosun, 1989).

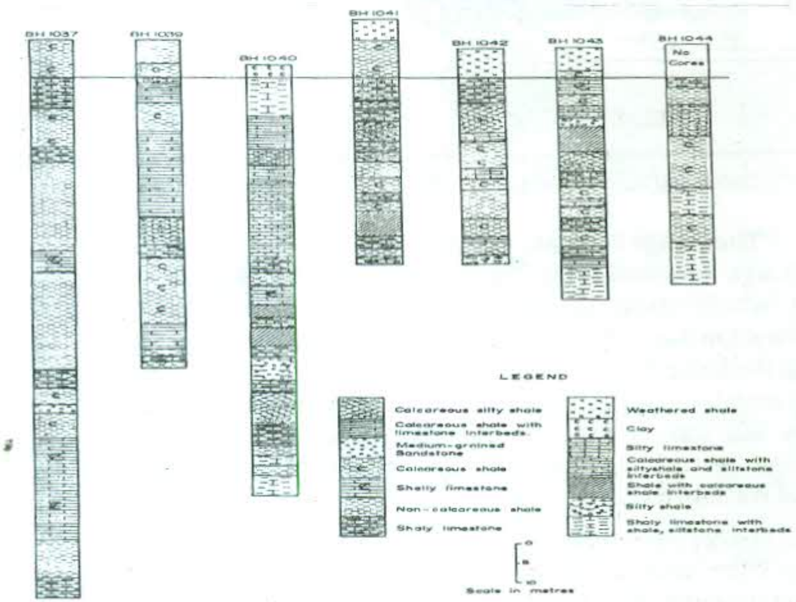


Figure 10. Borehole columnar sections showing the biofacies of Dange Formation. BH 6,000 shows the columnar section of the supplementary stratotype.

3.1.1 Supplementary Stratotype for Dange Formation

A supplementary stratotype from Geological Survey of Nigeria (GSN) Boreholes No. 6000 from 3.9 m - 61.6 m (Fig.10) is described below for the Dange Formation, the base of the formation was however not penetrated in this borehole.

Location - Dange area (GSN BH 6000), Long. 5° W, Lat. 12.9° N
Depth - 3.9 m - 61.6 m
Description - Base of Kalambaina Formation at 3.9 m depth.

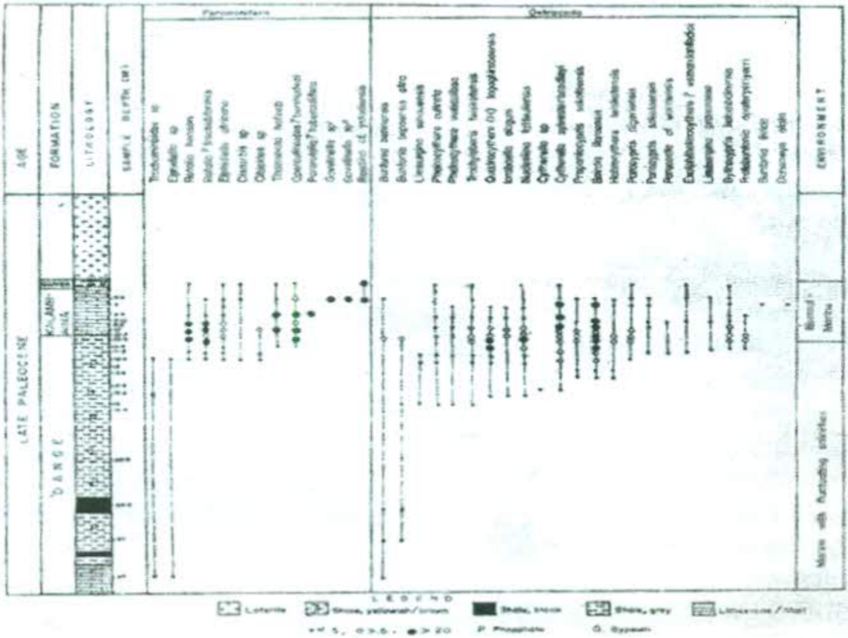
Calcareous fissile grey shale with phosphatic nodules	1.1 m
Grey fissile shale with phosphatic nodules	10.3 m
Calcareous fissile grey shale with phosphatic nodules	0.5 m
Grey fissile shale with phosphatic nodules	1.5 m
Brown fissile shale with phosphatic nodules in the upper horizons	2.2 m
Yellowish marl	0.8 m
Brown fissile shale	1.6 m
Yellowish marl	0.8 m
Calcareous fissile shale with marl intercalation, gypsum occurs towards the base	3.8 m
Siltstone	6.0 m
Black fissile shale with pyrite nodules	18.8 m
Black siltstone	2.2 m
Black fissile shale with gypsum	2.6 m
Siltstone	6.7 m

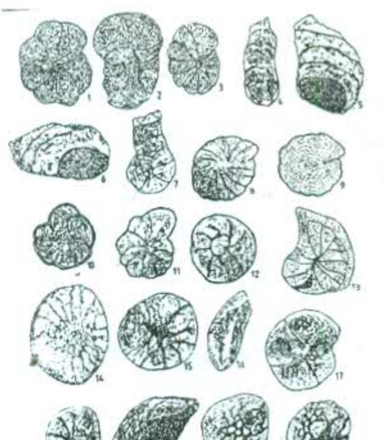
As mentioned earlier the basal portion of the formation was not penetrated by the borehole. The top of the grey calcareous non-phosphatic shale which underlies the Kalambaina Formation marks the upper boundary while the base though not seen in this study is marked by the first occurrence of shale in the underlying sand, siltstone and mudstone of the Wurno Formation.

3.2 Paleocene Foraminifera and Ostracods of the Sokoto Basin

A microfossil study of the Kalambaina Formation at its stratotype and the Gamba, Kalambaina and Dange Formations from two boreholes was undertaken in the Sokoto Basin (Okosun, 1995, 1999; Obiosio *et. al,* 1998). Twenty-five ostracods species and 31 benthic foraminifera species were recovered from the basin.

Table 9. Stratigraphic distribution of foraminifera and ostracods in GSN borehole No. 4501





1.2 *Haplophramiodes* sp2
Fig. 1 side view, Fig. 2 edge view, x 210

3 *Haplophramiodes* sp1
Fig. 3 side view, x 210

4.5 *Ammobaculite* sp1
Fig. 4 side view, x 210 Fig. 5 apertural view, x 210

6.7 *Ammobaculite* sp2
Fig. 6 side view, x 210 Fig. 7 side x 210

8.9 *Elphidiella africana* (Leroy), 1953
Fig. 8 side view, x 210, fig. 9 view of sutural pores x 280

10,11 *Pararotalia tuberculifera* (Reuss), 1862
Fig. 10 dorsal view, x 210, fig. 11 ventral view, x 21

12 *Rotallia hensoni* Smout, 1954
Fig. 12 ventral view, x 210, Fig. 13 dorsal view, x 210

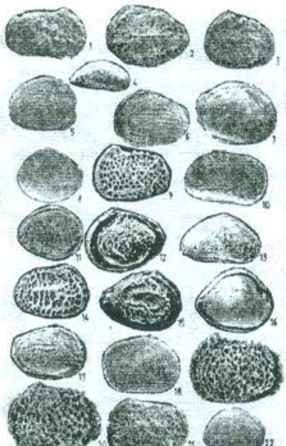
13,14 *Operculiniodes bermudezi* (Arni), 1966
View of axial section, x 350

15, 16 *Rosaline ystadiensis* Brotzen, 1948
Fig. 15 ventral view, x 210, Fig. 16 sied view, x 210

17 *Trochammina* sp
Ventral view, x 210

Plate I. Photomicrographs of Foraminifera from Sokoto basin

The taxonomy and biostratigraphy of the microfauna were documented. The ostracods and foraminifera show similar distribution pattern in the 2 boreholes and outcrop. The most stratigraphically important species in the Dange Formation are *Ammobaculites* sp 1, *Trochaminoides* sp 1 and *Trochaminoides* sp 2. The foraminiferal fauna of the Kalambaina Formation consisits exclusively of calcareous benthics which are dominated by *Rotalia hensoni, Opercuhnoides bermudeizi, Thalmanita hafeezi* and *Elphidella africana.* Some of these species occur in flood abundances in the formation. Agglutinated foramnifera were found restricted to the Dange Formation where their ranges terminated at 2m to 3m to the Kalambaina Formation (Tab. 9). The calcareous foraminiferal assemblage belongs to the "Terthyan carbonate fauna" of Berggern (1974). Plates 1 and 2 shows the photomicroghs of foraminifera and ostracods respectively.



1. *Trachyleberis teiskotensis* Apostolescu, 1961 Right side of the male carapace, x 60.
2. *Paracosta cf warriensis* (Reyment), 1963 Left side of carapace, x 60
3. *Quadracythere (Hornibrookella) lagaghiroboensis* Apostolescu, 1961 Left side of female carapace, x55.
4. *Paracypris sokotoensis* Reyment, 1981 Right side of carapace, x 75
5. *Nucleolina tatteulensis* Apostolescu, 1961 Right side of carapace, x 80
6. *Iorubaella Ologuni* Reyment, 1963 Left side of carapace, x 65
7. *Buntonia beninensis* Reyment, 1963 Right side of carapace, x 65
8. *Buntonia bopaensis* Reyment, 1963 Left side of carapace, x 65
9. *Phalcocythere cultrata* (Apostolescu), 1961 Left side of carapace, x 65
10. *Bythocypris kalambianenesis* Reyment, 1981 Right side of carapace, x 80
11. *Habrocythere teikotensis* Apostbiescu, 1961 Right side of carapace, x 70
12. *Dahomey alata* Apostolescu, 1961 Left side of carapace, x 60
13. *Paracypris nigeriensis* Reyment, 1981 Right side of carapace, x 50
14. *Paracosta cf warriensis* (Reyment), 1963 right side of carapace, x 70 Material from southwestern Nigeria.
15. *Buntonia apateryeriyerri* Reyment & Reymen 1963 Right side of carapace, x 70
16. *Bairdia ilaroensis* Reyment & Reyment 1959 Right side of carapace, x 40
17. *Buntonia livida* Apostolescu, 1961 Right ide of carapace, x 65
18. *Cytherrella Sivesterbradleyi* Reyment, 1963 Left side of carapace, x 60
19. Limburgina praecrassa Apostolescu, 1961 Left side of carapace, x 70
20. *Phalcocythere vesiculosa* (Apostolescu), 1961 Left side of carapace,
21. *Limburgina sehounsis* (Apostolescu), 1961 Left side of carapace, x 60
22. *Pronpontocypris* Sokotoensis Okosun. (in press) Right side of carapce, x 70.

Plate II. Photomicrographs of ostracods from Sokoto Basin

The foraminiferal assemblages from the Kalambaina Formation at its stratotype which is the Cement Company of Northern Nigeria (CCNN) quarry includes the following taxa:

Cibicides praecusorius, Ammobaculites sp Rotalia koani, Operculinoides bermudezi, Elphidiella africana, Pyramidina crassa, Haplophragmodies sp, *Pararotalia perclara, Gavelinella* sp, *Anomalinoides umboniferus, Pararotalia tuberculifera, Nonion insecta, Rotalia saxorum, Nonion graniferum, Quinqueloculina,* sp, *Rotalia trochidiformis, Protoelphidium* *subclaeva, Thalmanita madrugaensis, Cibicides simplex, Cibicides burlingtonensis, Ammodiscus* sp, *Cibicides* sp, *Buliminella* sp, *Gaudryina pyramdala, Gibicides succedens, Cibicdes* sp, *cancris* sp, *Pyrgo* sp, *Planorotalites ehrenbergi* and *Globigerina* sp.

3.3 Paleoenvironmental Interpretations

The Kalambaina Formation was deposited in a shallow marine environment in a paleodepth of less than 10 meters while the Dange Formation was deposited in marginal environments of lagoons and estuaries with some marine intervals. The latter are environments with fluctuating salinities and occasional dysaerobic conditions. The black shale and siltstone facies were deposited under anoxic conditions.

3.4 Phosphate

Sedimentary phosphate occurs as thin nodular beds and nodular disseminations in the Dange Formation of Sokoto basin. Six phosphate priority prospects were identified (GSN, 1986). One of the prospects, Kasarwasa was re-evaluated during my research in the basin (Fig. 11).

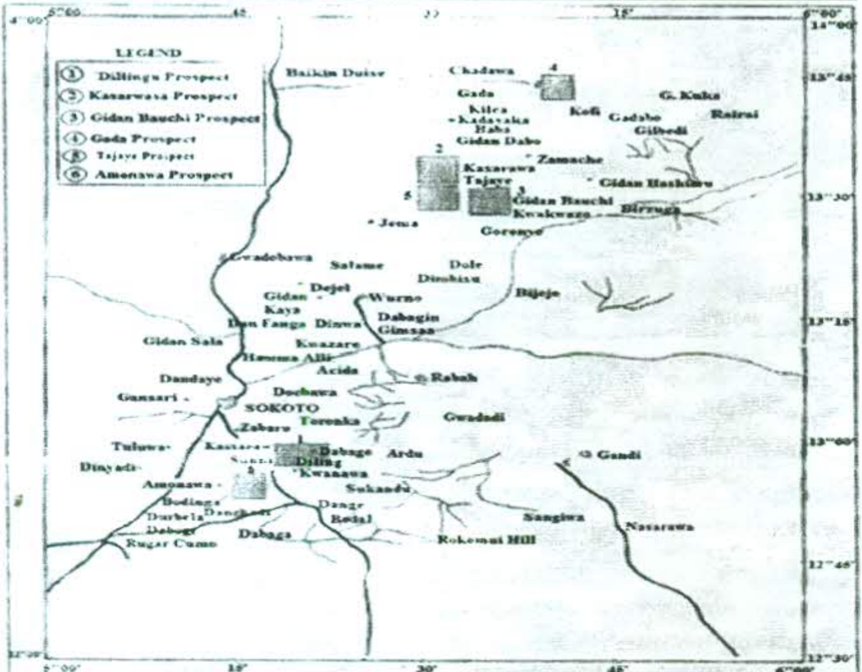


Figure 11. Map Showing Locations of Phosphate Priority Prospects (Modified after GSN, 1986)

Analytical results show the nodules to contain 18-34.7% P_2O_5 (Tab. 10). The P_2O_5 values and other major elements indicate the nodules to be suitable for the production of phosphate fertilizers. There is a similar potential for SPP manufacture for the Sokoto phosphate and those of Niger Republic, Togo, Senegal and Portugal (Tabs. 11, 12). The neutral ammonium (citrate solubility value of 3.5% for the P_2O_5) suggests the possibility of direct application as fertilizer of the Sokoto phosphate to soil. The exploration and exploitation of this agro geological resource will be a boost to agricultural production and also save some national foreign exchange which is now expended on the importation of rock phosphate from other countries.

Table 10. Chemical Composition of Sokoto Phosphate Nodules (Okosun, 1997)

	1X	2	3	4	5	6	7	8	9	10	11
P_2O^5	34.2	34.7	29.7	29.66	29.23	29.04	28.85	23.16	25.92	23.39	20.18
CaO	47.9	47.70	56.60	53.45	53.36	53.29	52.04	49.98	49.54	42.20	35.96
SiO_2	4.2	4.7	6.7	2.70	3,21	6,58	7.87	10.05	15.05	19.06	19.71
Al_2O_3	1.7	1.73	0.53	0.43	0.69	1.53	2.43	2.09	2.17	2.93	6.24
Fe_2O_3	3.0	3.57	0.57	0.93	0.22	0.70	0.68	0.61	2.39	1.04	2.22
MgO	0.10	0.99	0.99	0.10	0.87	0.20	0.21	0.118	0.39	0.27	0.65
Na_2O	0.24	0.28	0.26	0.25	0.95	0.26	0.15	0.16	0.31	0.15	0.19
K_2O	0.08	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05
MnO		0.43	0.45	0.71	0.18	0.23	0.10	0.14	0.53	0.10	0.46
H_2O	0.77	1.26	1.22	1.72	0.77	0.82	1.05	1.21	1.17	1.44	2.81
CO_2	1.9	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
F	3.4	3.64	2.6	2.44	2.84	2.68	2.72	3.03	2.83	2.63	2.26
Cl	109ppm	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
L.O.I[a]	5.30	5.44	5.4	5.55	5.36	5.33	3.15	3.21	6.68	3.48	5.12
NAC Sol. P_2O_5[b]	3.5	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
CaO/P_2O_5	1.40	1.90	1.90	1.86	1.89	1.88	1.80	1.77	1.91	1.80	1.78
F/P_2O_5	0.0 9	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.17	0.11	0.11

IX Analysis by Von Kauwenberg (1985)

n.d not determined

a Loss on ignition, heated I how at 1100°c

NAC Neutral Ammonium Citrate (AOAC method)

Table 11. Comparative Phosphate Rock Analysis (FSFC, 1985).

Sample description		Analysis					
		P_3O_2%	CaO%	CO_2%	F%	$Fe2O_3$%	Al_2O_3
Sokoto Phosphate	a,	34.16	44.92	2.56	2.94	1.84	1.12
Rock (Nodules)	b,	32.46	47.44	2.95	3.27	0.07	
	c,	32.02	47.95	2.00	3.45	1.96	
Togolese phosphate rock		34.88	51.95	1.61	4.09	1.19	0.48
Senegalese Phosphate rock		32.6	45.79	1.30	5.20	0.92	1.12
Niger Republic Phosphate rock							
a) Tahuoa		31.32	28.86	1.40	5.15	2.23	10.01
b)		26.62	39.23	1.43	3.15	1.44	1.55

Table 12. Comparative product single superphosphate (SSP) fertilizer analysis (FSFC, 1985)

Sample description	Analysis			
	Moisture %	Total Phosphate AS P_2O_3%	Water Soluble AS P_2O_3%	Free Phosphate AS P_2O_3%
Sokoto	5.34	21.87	16.65	6.50
Togo	5.13	22.78	19.12	1.89
Senegal	5.70	22.15	16.18	1.86
Niger Republic (Tahua)	3.47	18.83	10.76	2.61
Niger Republic (Tapoa)	5.77	18.52	15.14	9.46
Portugal	6.75	19.06	16.48	1.71

3.5 Phosphate Reserve

Six priorities phosphate prospects were identified by the Geological Survey of Nigeria (now Nigerian Geological Survey Agency). Kasarwasa prospect was recently reinvestigated and evaluated. Only two out of the twenty four hectares contain economic phosphate deposit (Okosun and Alkali, 2013).

3.6 Ostracod Evidence for the Paleocene Trans-Saharan Sea way

Marine ostracods are benthonic and strongly substrate and latitude-controlled. They have no planktonic larvae and cannot therefore easily cross geographic barriers. These attributes qualify them as excellent paleobiographical markers and their study is of great value in tracing paleogeographical changes.

A study of ostracods from the Kalambaina village near Sokoto (Okosun, 1996) gave 18 species which belong to 15 genera. Majority of the species have wide geographic distribution in West and North Africa (Tab. 13). They are well represented in Mali, Libya, Niger Republic and coastal Nigeria. The assemblage has a transitional status between the Paleocene assemblages of North and West Africa. Although only 18 species were recovered in the research, a full documentation of the geographic distribution of the known Paleocene species of the Sokoto Basin presented in Table 13 enables an adequate paleogeographic interpretation. The table shows an impressing close affinity between the assemblages from southwestern Nigeria and the Kalambaina Formation with a recorded occurrence of 20 common species. A strong affinity also exists between the Kalambaina assemblage and those from Mali, Niger Republic and Libya (Tab. 13).

Table 13. Paleobiographic distribution of ostracod species from the Kalambaina Formation.

No.	Ostracod species	Countries / Basins								
		Nigeria		Niger	Rep.	Tunisia	Libya	Egypt	Mali	Senegal
		S.W	N.W	South	North					
1	Phalcocythere vesiculosa (A)		X	X	X		X		X	
2	Phalcocythere tubra R		X	X	X		X		X	
3	Phalcocythere cultrata (A)		X	X	X		X		X	
4	Xestolebris kekere R		X	X	X		X		X	
5	Dahomeya alata A	X	X	X		X	X	X		X
6	Bairdia daroensis R&R	X	X	X	X		X			
7	Habrocythere teiskotensis. A		X	X	X		X		X	
8	Lorubaella ologui R	X	X	X	X		X		X	
9	Paracosta warriensis R	X	X	X	X				X	X
10	Ovocytheridea pulchra R	X	X							
11	Krithe kalambainanesis R		X	X	X					
12	Nucleolina tattuensis A		X	X	X		X		X	
13	Tachyleberis teiskotensis (A)	X	X	X	X		X	X	X	
14	Uroleberis uppsalaensis C		X	X	X		X		X	
15	Paracypris sokotoensis R		X	X						
16	Paracypris nigerensis R	X	X	X						
17	Alocopocythere (1) immodica C		X	X	X		X		X	
18	Brachycythere ogboni R	X	X							
19	Cytherelloidea saharaensis R	X	X	X						
20	Exopthal. usmandanfodiol R	X	X							
21	Limburgina praecrasa A		X	X			X		X	
22	Buntonia livida A	X	X	X						
23	Quadracthere lagaghirobensis A	X	X	X						
24	Buntonia apateryeriyerri R	X	X	X	X		X			
25	Buntonia tenulpunctata A	X	X						X	
26	Buntonia bopaensis A		X	X						
27	Propontocypris sokotoensis		X	X						
28	Platella ewekoroensis R	X	X	X						
29	Cytherela sylve-bradleyi R	X	X	X	X					
30	Buntonia beninensis R	X								
31	Legumminocythereis lagaghiroboensis A	X	X				X			
32	Leguminocythereis bopaensis A	X	X	X		X	X			

A = Apostolescu B = BarsottiC = Carbonnel *et al,*
R = Reyment R&R = Reyment & Reyment

This similarity of the ostracod assemblage from the above areas led many workers (Reyment, 1978, 1980, 1981 and Carbonnel et al., 1990) to suggest that a marine connection existed between the Gulf of Guinea and the Sokoto Basin via the area now occupied by the River Niger during the

Paleocene (Fig. 8). The Koch index of biotal dispersity of 55.7 indicates a high level of homogeneity between the Kalambaina and coastal Nigeria assemblages (Reyment, 1980). Ostracod paleobiogeographical data from the foregoing provides an irrefutable paleonotologic evidence of the existence of a marine correction between the Tethys Sea of the Sokoto basin and the South Atlantic of southwest Nigeria in the Paleocene via the Bida basin (Fig. 12). It is important to mention that only Maastrichtian marine strata have been reported in the Bida Basin from the Ahoko (Ojo & Akande, 2006, Okosun, 2000).

The connecting Paleocene marine strata might have been eroded over the last 60 million years; shallow boreholes in selected areas of the basin might reveal their presence. Any argument of a migration from the West African coastal basins via northwest Africa and down through the Sahara to the Iullemeden basin is very questionable because of the long distance involved and the lack of paleontologic evidence along the route. Only two Ostracod species are common to Senegal on the north-west African route and the Paleocene of the Sokoto Basin.

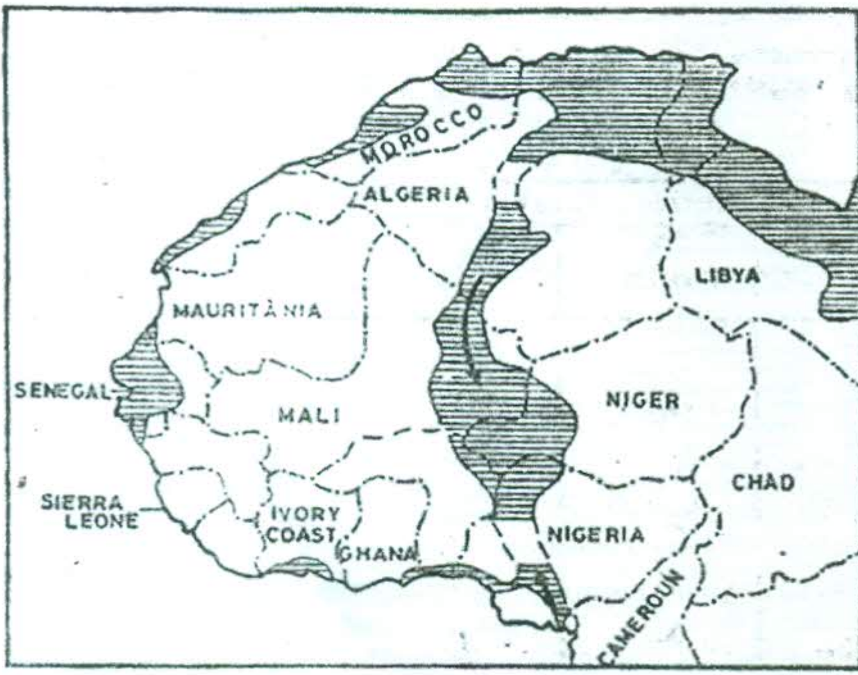


Figure 12. Paleocene trans-Sahara sea way

4.0 Bornu Basin

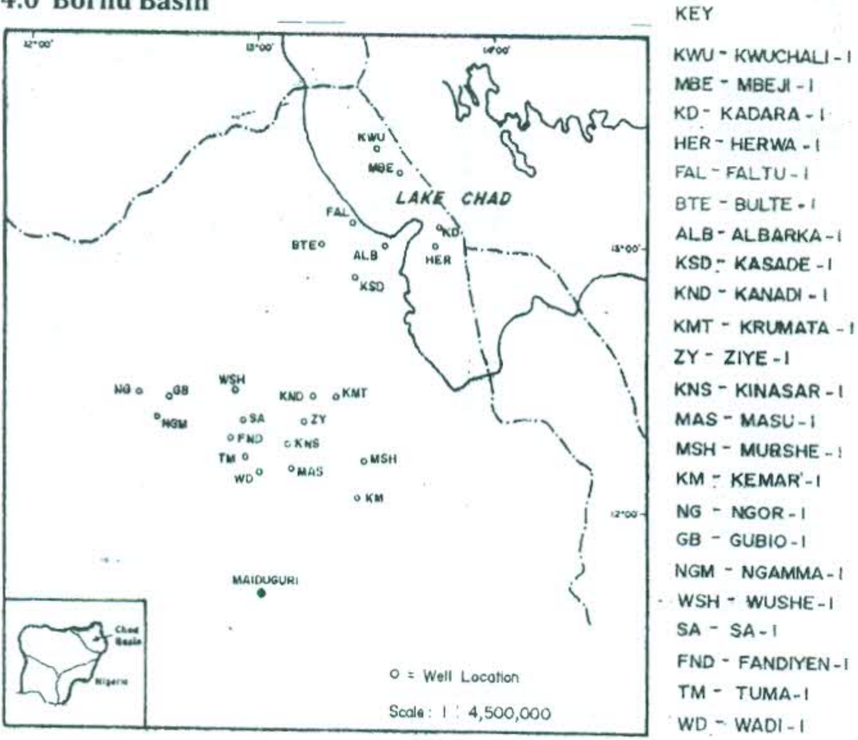


Figure 13. Location map of exploration wells in the Bornu basin (inset map illustrates the position of Chad basin in Nigeria)

The Chad basin is a large intracratonic basin that covers part of Cameroon, Central Africa Republic, Chad, Sudan and Niger Republic.

In Nigeria, the Chad basin is referred to as the Bornu basin. The Nigerian National Petroleum Corporation (NNPC) commenced an intensive petroleum exploration in the basin in the eighties. The discovery of hydrocarbons in the neighbouring countries of Niger and Chad gave further impetus to the exploration programme. About 21 exploration wells were drilled by the NNPC in the first phase of exploration (Fig. 13). The drilled wells provided ditch cuttings for various analysis for the early workers (Okosun, 1992, 1995; Olugbemiro, 1997) and many others. The results of these studies have contributed immensely to our geological knowledge of the basin. Hitherto, limited information was available from shallow water boreholes in the Bornu basin because of the inadequate rock outcrops.

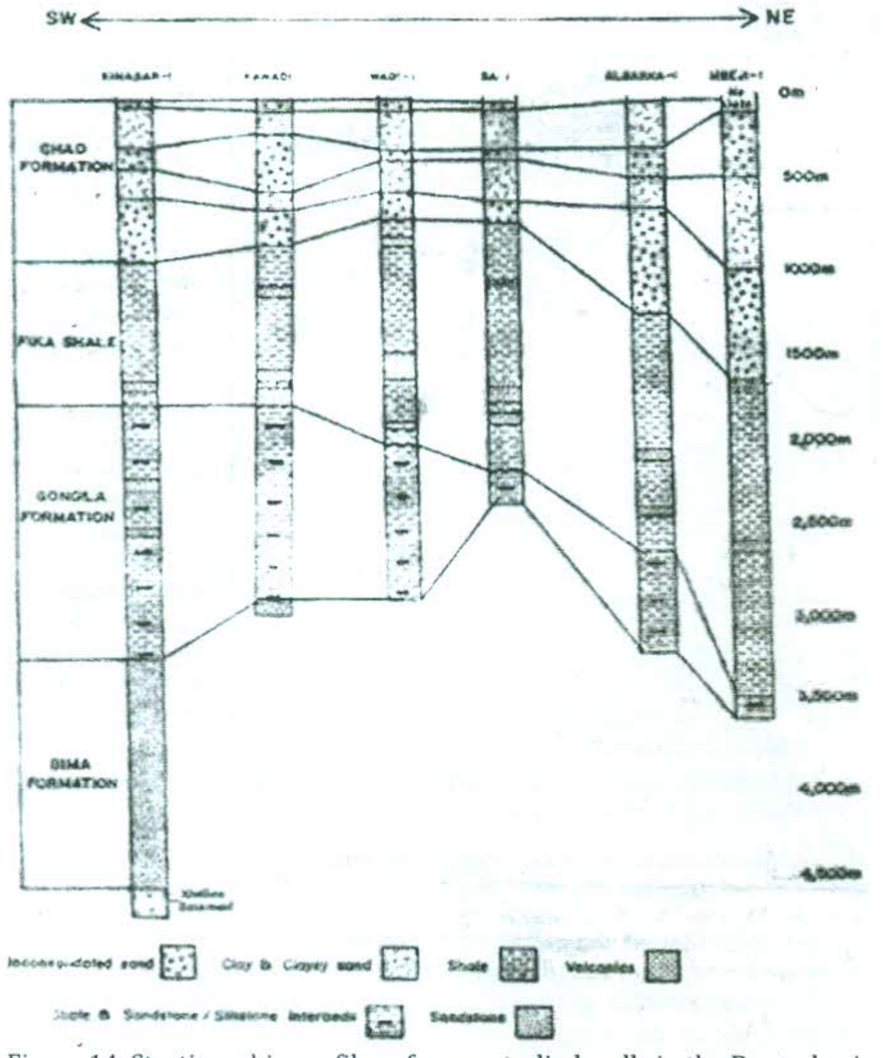


Figure 14. Stratigraphic profiles of some studied wells in the Bornu basin.

The ditch cuttings from the NNPC wells provide new vistas for my research in the Bornu basin. Fourteen out of the 23 wells drilled by the NNPC have been studied by the inaugural lecturer (Okosun, 1992, 1995, 1998). The studied wells are located along the long axis of the basin (Figs. 13, 14).

The following four stratigraphic units, beginning from the oldest Bima

Sandstone, Gongila Formation, Fika Shale and Chad Formation were recognized in the basin. The Kerri Kerri Formation (Paleocene) was found to be restricted to the western margin of the basin. It was not encountered in any of the studied wells.

4.1 Stratotypes for the Chad and Gongila Formations and the Fika Shale

Available materials from the studied wells have revealed more details of the consitutent lithofacies of the formations in the Bornu Basin. It has become necessary to propose stratotypes for more accurate definition of some of the stratigraphic units. A neostratotype is proposed for the Chad Formation to replace the original stratotype provided by Cartner *et al* (1963) which was compiled from many boreholes. This earlier stratotype is invalid since it was compiled from many boreholes. The formation thus has no definite holostratotype. This is a contravention of the rules of accepted stratigraphic practice (Murphy & Salvador, 1994).

The Fika Shale and Gongila Formation were found to contain varied lithofacies and volcanic rocks at several horizons. A hypostratotype is therefore proposed for the Gongila Formation, this is to serve as a supplementary stratotype taking cognizance of the new stratigraphic details. Since no stratotype was erected for the Fika Shale when the formation was established and none has been erected since then, a lectostratotype is now proposed. All the stratotypes are curated at the Nigerian Geological Survey Agency (NGSA) Kaduna and at the Nigerian National Petroleum Corporation, Lagos.

Details of the stratotypes are provided below.

4.1.1 Neostratotype for the Chad Formation

Neostratotype for the Chad Formation

Location	-	Kanadi-1 well, Bornu Basin.
		Long. 13 x 25', Lat. 12 x 25'N (Approximately).
Depth	-	50 m - 810 m
Description	-	Upper and Lower boundaries at 50 m and 810 m

respectively. The former is marked by sand and the latter is marked by shale (Fig. 13).

Sandstone, yellowish grey, loosely indurated	5 m
Clay, grey	20 m
Sand, fine to medium grained, light brown	15 m
Clay, greenish grey	60 m

Shale, black	5 m
Clay, grey gritty	150 m
Sand, fine to medium grained, light brown	30 m
Clay, sandy, light yellow	30 m
Clay, light yellow or cream, gritty	260 m
Sand, light yellow or cream, fine to medium grained with occasional calcareous horizons	175 m

4.1.2 . Lectostratotype for the Fika Shale

Kandi-1 well from 810 m - 1700 m

Dark grey shale	790 m
Dark grey shale and volcanic rocks	25 m
Blue black shale	5 m
Blue black shale and volcanic rocks	5 m
Dark grey shale and sandstone interbed	45 m
Dark grey shale and volcanic rocks	5 m
Dark grey shale	15 m

4.1.3 Hypostratotype for the Gongila Formation

Location - Kanadi -1 well, Bornu Basin. Long. 13x25', Lat. 12x25'N (Approximate).

Depth - 1700 m - 290 m

Description - Upper and Lower boundaries at 1700 m and 2905 m respectively. The former is defined by sandstone while the latter is marked by the last shale occurrence. (Fig. 13) presents the geologic column (1700 - 2905) for the hypostratotype.

Sandstone and dark grey shale	5 m
Dark grey shale	5 m
Sandstone and volcanic rocks	5 m
Dark grey shale and volcanic rocks	5 m
Volcanic rocks	5 m
Dark grey shale and volcanic rocks	5 m
Volcanic rocks	5 m
Dark grey shale and volcanic rocks	5 m
Volcanic rocks	5 m
Dark grey shale and sandstone	5 m
Dark grey shale and volcanic rocks	5 m
Dark grey shale and sandstone	5 m
Dark grey shale, volcanic rocks and sandstone	5 m

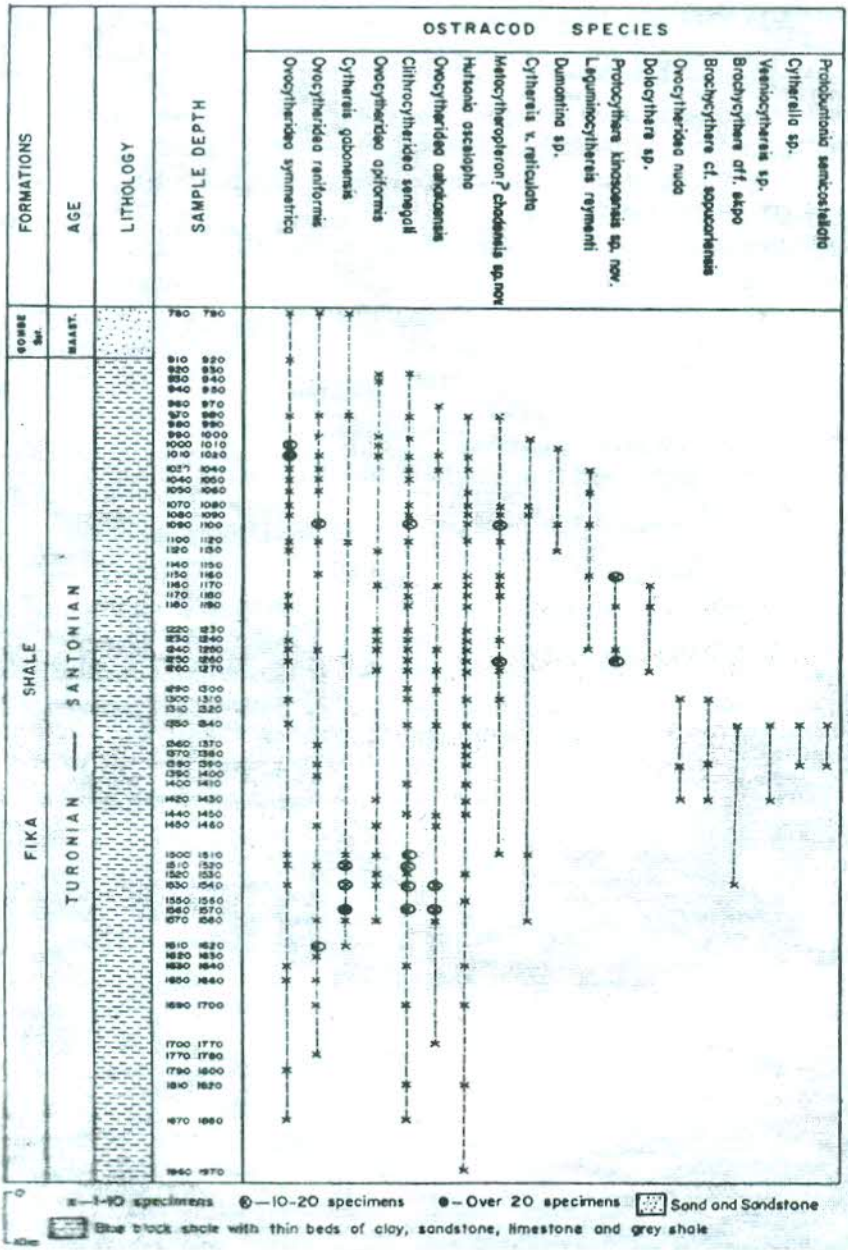
Dark grey shale	5 m
Dark grey shale and volcanic rocks	5 m
Dark grey shale	20 m
Dark grey silty shale	5 m
Dark grey shale with sandstone	465 m
Dark grey shale and siltstone interbeds	35 m
Dark grey shale and sandstone interbeds	10 m
Dark grey shale and siltstone	5 m
Dark grey shale and sandstone interbeds	25 m
Dark grey shale	15 m
Dark grey shale & sandstone interbeds with some volcanic rocks	360 m
Dark grey shale and sandstone interbeds	20 m
Dark grey shale	15 m
Dark grey shale and volcanic rocks	5 m
Black shale with brown sandstone intercalations	150 m

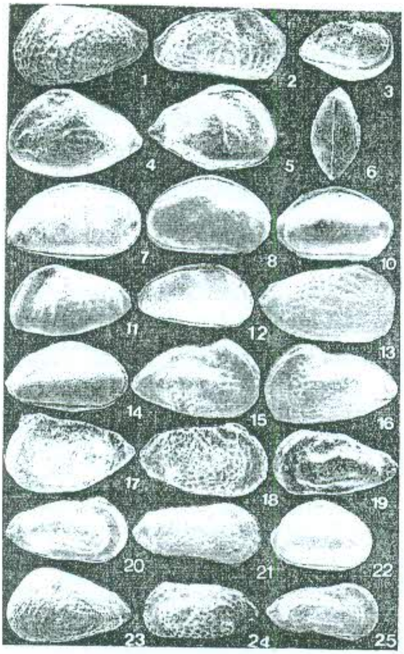
4.2 Cretaceous Ostracod Biostratigraphy of the Bornu Basin

4.2.1 Biostratigraphy

A study of ostracods from the Kinasar - I well produced a fairly diverse assemblage (Okosun, 1992). The assemblage comprises of 13 genera and 19 species (Tab. 15, Pl. 3) and is useful for paleoenviromental analysis, inter-regional biostratigraphical correlation and paleobiogeographic reconstruction in West and North Africa.

Table 15. Stratigraphic distribution of ostracods for Kinasar-1 Well.





1, 2, 23. *Hutsonia ascalapha* Bold,

3-6, 11-12 *Metacytheropteron chadensis* Okosun,

7. Dolocytheridea sp .Okosun

8. *Ovocytheridea reniformis* Bold

10. *Ovocytheridea_apiformis* Reyment,

13. *Leguminocythereis_reymenti* Neufville,

14. *Clithrocytheridea senegali* Apostolescu,

15-16. *Cythereis gabonensis* Neufville

17. *Veeniacythereis* sp Okosun,

18,24. *Cythereis vitiliginosa reticulate* Apostolescu

19-20. *Protocythere kinasaensis* Okosun

21, 25. *Dumotina* sp Okosun.

Plate III. Photomicrographs of Kinasar-1 well ostracods

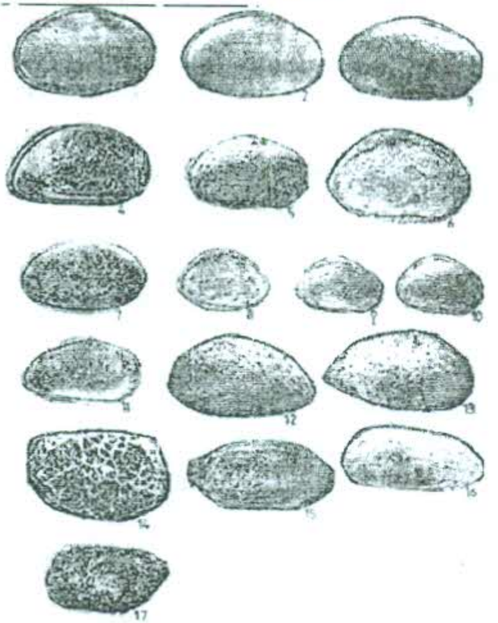
4.2.2 Foraminiferal and Ostracod biostratigraphy of Tuma-I well

Twelve species of agglutinated benthic foraminifera that belong to 13 genera were recovered from the well as follows:
Haplophragmoides saheliensis (Petters), *H.bauchensis* Petters, *H.pindigensis* Petters, *Ammotium nkalagum* Petters, *Reophax globosus* (Sliter),*Ammobaculites pidigensis* ,Petters, *A. jessensis* Petters, *A. benuensis* (Petters) *A. gambensis* (Petters), *Ammobaculites* sp *I*, *A. parvus* (Gebhardt) and *Heterohelis globulosa* Ehrenberg.

4.2.3 Paleoenvironment of Deposition

The dominant ostracod species in the assemblage are *Ovocytheridea symmetrica, O. reniformis, O. apiformis, O. ashakaensis, Clithrocytheridea senegali, Hutsonia ascalapha and Metacytheropteron? chadensis*. The former belong to the Cytheridea group of genera (Pl. IV).

It has been reported that the littoral and estuarine taxa which characterize the shoreline ecology belong to the cytheridea group of genera (Howe, 1971). In the United State Gulf Coast, hydrocarbon reservoirs were found to be located in sands close to ancient shorelines (How, 1971). Their identification is thus very important to the petroleum geologist.The presence of these cytheridiids indicate that the Fika Shale was deposited in very shallow water close to ancient shorelines. The occurrence of abundant Trachyleberids, Hemicytherids Cytherellids and Baridids also indicates lithoral facies. But since they are also found in offshore facies they are unreliable shoreline indicators. Conversely, assemblages rich in Bythocytherids, Cytheropteroninnes and Macrocypridids are characteristic of deep water.



	Ovycytheriaea ashkaensis Okosor Right view of carapace, x 60
2,3	*Ovocytheridea reinformis* Bold 2,3, right view of carapace, x 45
3	*Ovovytheridea obliqus* Okosun Right view of carapace, x 45
4,5,8,9	*Ovycytheridea apiformis* Reyment 4, right view of carapace, x 40 5, " " " " , x 53 8,9 " " " " , x 25
7	*Ovocytheridea symmetrica* Reym Right view of carapace, x 50
10	*Ovocytheridea nuda* Grekof Right side of carapace, x 25
11	*Clithrocytheridea senegali* Apost Right view of carapace, x 25
12, 13	*Cytheridea reymenti* Okosun 12, female carapace, left view, x 13, male carapace, right view, x
14	*Semicytherura* sp Okosun Right view of carapace, x 200
15	*Cytherura* sp Okosun Right view of carapace, x 80
16	*Cytherura* sp Okosun Left view of carapace, x 60
18	*Cyprideis* sp Okosun Right side of carapace, x 46.

Plate IV. Photomicrographs of shoreline facies ostracods from Fika Shale

The high dominance of the agglutinated foraminifera in the assemblages indicates brackish water depositional environment (Boersma, 1980, Murray 1991). The low diversity and dominance of the assemblage by species of *Ammotium, Haplophragmoides* and *Ammobaculites* is indicative of near shore brackish water environment (Murray, 1991, Hamza *et al*, 2002): Calcareous benthic tests are typical of normal marine assemblages. Their paucity in the Fika Shale assemblages corroborates the inferred near shore brackish water depositional environment. The scarcity of planktic foraminifera also indicates shallow environment of deposition (Phleger, 1960, Boersma, 1978). The dominance of agglutinating foraminifera with small tests is indicative of depleted oxygen during the deposition of the Fika Shale (Murray, 1990). Thus from the interpretation of the foraminifera and ostracods from the two wells, it is inferred that the Fika Shale was deposited in very shallow water depth of less than 20 m.

4.2.4 Ostracod Evidence for the mid- Cretaceous Trans-Saharan Sea way

Ostracods as earlier mentioned have been widely used for paleobiogeographic reconstructions because of their benthic nature and their restricted mode of dispersal. Some elements in the ostracod assemblages from the Kinasar-I well from the Bornu basin have useful interregional biostratigraphic values; they provide elucidation on the palaeogeography of Africa during the mid-Cretaceous.

Table 16. Palaeobiologeographical distribution chart for the mid-Cretaceous ostracods from Nigeria (Kinasar -1 Well Ostracods).

Ostracod Species	NIGERIA		Cameroon	Gabon	Cote Ivôire	Senegal	Gambia	Egypt	Tunisia	Libya	Algeria	Morocco	Israel
	Benue Trough	Chad Basin											
Ovocytheridea symmetrica	•	•		•									
Ovocytheridea reniformis	•	•		•				•	•				•
Ovocytheridea nuda	•	•	•	•	•	•	•	•					
Ovocytheridea apiformis	•	•	•	•			•	•					
Ovocytheridea ashakaensis	•	•	•										
Cithrocytheridea senegali	•	•		•		•		•					
Brachycythere sapucariensis	•	•		•				•	•		•		
Huntonia ascalapha	•	•		•				•					•
Brachycythere anguiata	•					•		•	•	•			•
Brachycythere epko	•								•	•	•	•	
Cytheresis gabonensis	•	•		•									
Cytheresis Villigninensis reticula	•	•		•		•	•		•			•	•
Luguminocytheresis reymenti	•	•		•									

Kinasar-I well ostracod assemblages show a strong affinity to the coeval assemblages from Egypt, Tunisia, Morocco, Algeria, Libya in North Africa and Gabon in West Africa (Tab. 16). A few species in the assemblages are also common to Senegal, Gambia and Cote d'Ivoire.

The prevalence of common species between Gabon, Nigeria and North Africa gives support to the suggestion of a brief union and interchanges of fauna between the Tethys and South Atlantic arms of the transgression. There were two possible routes for marine ostracod dispersal between

North and West Africa during Cretaceous time. One is dispersal through Morocco, Rio de Oro Basin, Senegal, Gambia, Cote d'lvoire, Ghana, Togo and Benin Republic coastal basins, the other is through the trans- Saharan epicontinental sea way.

Many ostracod species from Gabon, Benue Trough and the Bornu basin assemblage are common to the North African assemblages (Tab. 16). Only one doubtful species *Cythereis vitiliginosa reticulata* Apostolesu which is considered in this study to be possibly conspecific with *Oertliela tarfayaensis* Raiment is common to Gambia, Senegal, Tunisa and Morocco. Thus the probability of some species that are common to Gabon, Nigeria and North African basins having migrated through the northwest African route is most likely. The only dispersal route is via the trans- Saharan epicontinental sea (Fig. 15).

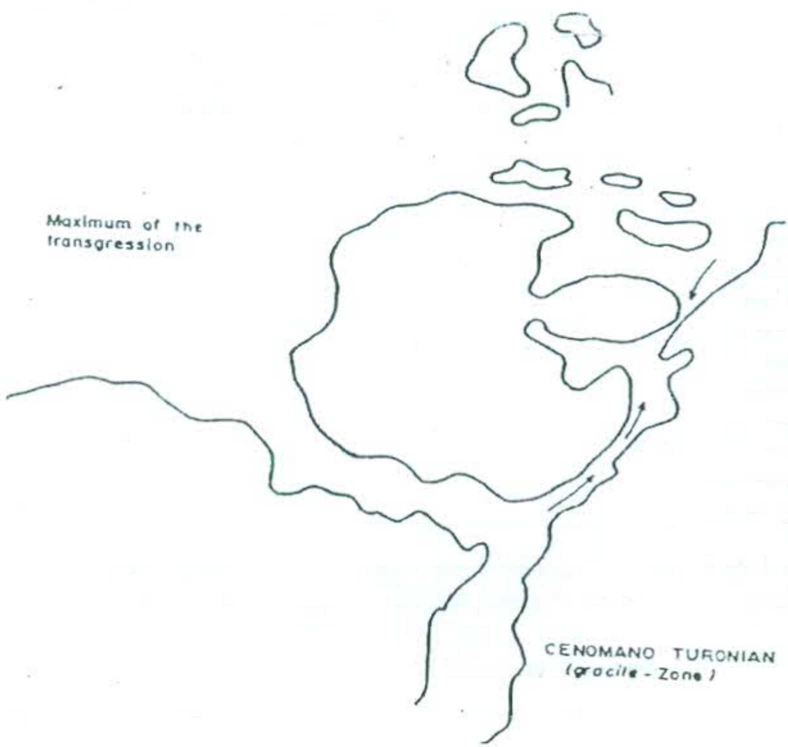


Figure 15. The maximum extent of the Cenomanian- Turonian transgression during which there was a short union between the Tethys and South Atlantic.(After Reyment and Dingle 1987)

The above palaeontological evidence is supported by lithologic observations. Furon (1963) reported the occurrence of early Turonian marine sediments with Tethys characteristics in Adar Doutchi at the Niger Republic- Nigerian border, Different workers (Furon, 1935; Boundoureque *et al.*, 1982; Dufaure *et al.*, 1984; Reyment, 1980; Zaborski, 2000) have suggested possible pathways which are in agreement with figure 15 for the Cenomanian-Turonian trans-Saharan epi-continental transgression based on ammonites and gastropods.

4.3 Hydrocarbon Potential of Bornu Basin

Organic geochemical and petrological studies of the Cretaceous strata of the Bornu basin have been undertaken (Olubgemiro, 1977, Olugbemiro *et al.*, 1977). The hydrocarbon potential of the basin was also reviewed (Okosun, 2002, 2006). The hydrocarbon potential of the basin is presented here with reference to the following parameters: TOC/ Source Rock, maturation gradient, Tmax/oil window, trapping mechanism/reservoirs.

4.3.1 TOC/ Source Rock

TOC shows a lateral enrichment from SW to the NE that is from the Kinasar-1 to Mbeji-1 well. Organic matter is Type III which is gas prone. Highest TOC values were reported in the Fika Shale of Kanadi-1 (1.26 wt %), Albarika-1 (1.38 wt %) and Mbeji-1 (3.87 wt %). Only in the Kinasar-1 was a high TOC of 2.82 wt % reported from the Gongila Formation. Thus the Fika Shale and the Gongila Formation are good source rocks having attained more than the minimum TOC of 0.5 wt % requirement for good source rocks (Tissot). It is a significant observation that all TOC values from the Mbeji-1 well are above 0.5 wt %.

4.3.2 Maturation Gradients

The maturation gradients of 0.85 % Rm/km, 0.52 % Rm/km, 0.41 % Rm/km and 0.35 % Rm/km for Kinasar-1, Kanadi-1, Albarika-1 and Mbeji-1 show a decrease from SW to NE (Fig. 16).

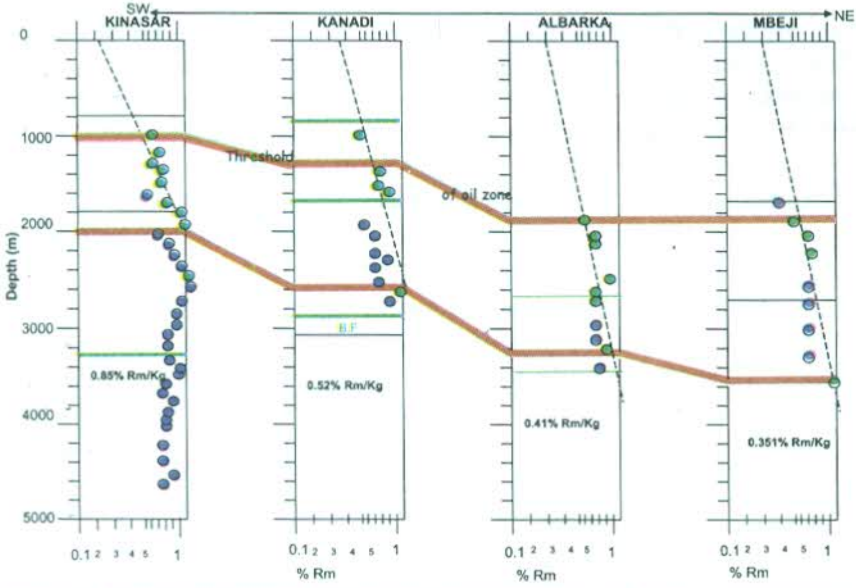


Figure 16. Vitrinite Reflectance (%Rm) profiles, maturation gradients and oil window (Modified after Olugbemiro, 1997)

The decrease in maturation follows the trend of sediment thickness. This anomaly has found explanation in 2 theories. Shallow depth to basement could have induced radiogenic heat from the granitic basement (Kantsler and Cook, 1979). Rapid sedimentation rate towards the depocenter as evidenced by higher TOC in a SW - NE direction might have been another probable cause. Low maturation gradient due to rapid subsidence and high sedimentation rate was reported for the Los Angeles and Ventura basins (Bostick *et al.*, 1978). Similar high geothermal gradients have been documented from the shallow areas of the Peath basin (Katslea and Cook, 1979).

4.3.3 Tmax and Oil Window

Tmax data for the Fika Shale for Kanadi- I, Albarika- I and Mbeji- I wells range 430–435°C which suggest immature to marginally maturity status. The lower part of the formation in Kanadi-I has higher Tmax values and is in the oil window. But the plot of HI versus Tmax suggests the Fika Shale to be at the margin of the oil window. The Gongila Formation in Kanadi- I, Albarika- I and Mbeji- I wells have Tmax of 470-500^{0} C, 435-470^{0} C and

435-460 °C respectively. The values indicate that the formation is in the oil and gas generating zones. This was corroborated by the plots of HI versus Tmax. The threshold and end of the oil window, the depth to the oil window and its thickness increased towards the depocenter of the basin (Fig. 16). The oil window occurs around 1,270 – 3600m in the Bornu basin. This is in agreement with the 2,500 - 4,000m proposed for the West African Rift System by Genik (1993).

4.3.4 Trapping Mechanism, Reservoirs

Block faulting and juxtaposition of lithofacies could lead to hydrocarbon entrapment. The faults and fold structures recognized from seismic could form the needed structural traps in the basin (Odusina *et al.*, 1983). The sandy facies found in the Fika Shale and the Gongila Formation could serve as reservoirs.

The hydrocarbon potential of the Bornu basin is moderate. Possible oil generating potential has been noted in some wells (Olugbemiro, 1977, Olugbemiro *et al.*, 1997, Obaje *et al.*, 2004, Okosun, 2002, 2006). The lower part of the Fika Shale and the Gongila Formation has good hydrocarbon generation prospects. The upper part of the Fika Shale though richer in organic matter is thermally immature. The absence of high vitrinite reflectance (Rm 2.5%) indicates that the paleotemperature was insufficient to have caused thermal degradation of hydrocarbons.

5.0 Benue Trough and the Calabar Flank

5.1 The Stratigraphy of the Nkalagu Formation

Grey, dark grey to black shales with intercalations of limestone, siltstones and sandstones of Late Cretaceous age crop out in the Benue Trough and the Calabar Flank. These rocks show similar lithologies in outcrops and subsurface. They have, however, on the basis of age been given different formational names (Reyment, 1965). In the Calabar Flank where they are of Cenomanian age, they are referred to as Odukpani Formation while in the Benue Trough those of Early Turonian and Coniacian – Santonian ages have been referred to as Ezeagu and Awgu Formations respectively (Reyment, 1965). This nomenclature was adopted by later workers (Murat, 1972; Fayose and De Klasz, 1976; Arua and Rao, 1978). This procedure of naming strata according to age is against accepted stratigraphic practice (Murphy & Salvador, 1994). Later workers reported the difficulty of distinguishing between Ezeagu and Awgu Formations in the field (Offodile and Reyment, 1976, Petters, 1980), both units being of identical lithologies. Field studies were carried out in the Benue Trough during my research and the result is in full agreement with this observation.

To redress this stratigraphic classification anomaly, Petters and Ekweozor (1992) proposed the Nkalagu Formation for the grey, dark grey to black shales with limestone, siltstone and sandstone intercalations. They selected the limestone quarries behind the Nigerian Cement Factory at Nkalagu as the type locality and the limestone quarry east of the untared road behind the cement factory as the type section. The type section shows the formation to be composed of about 50m of alternating grey to black shales and limestones. The basal part consists of a massive dark grey shaly limestone about 6m thick which is overlain by dark grey to black laminated shales with limestone intercalations.

My research describes in detail the stratigraphy of the Nkalagu

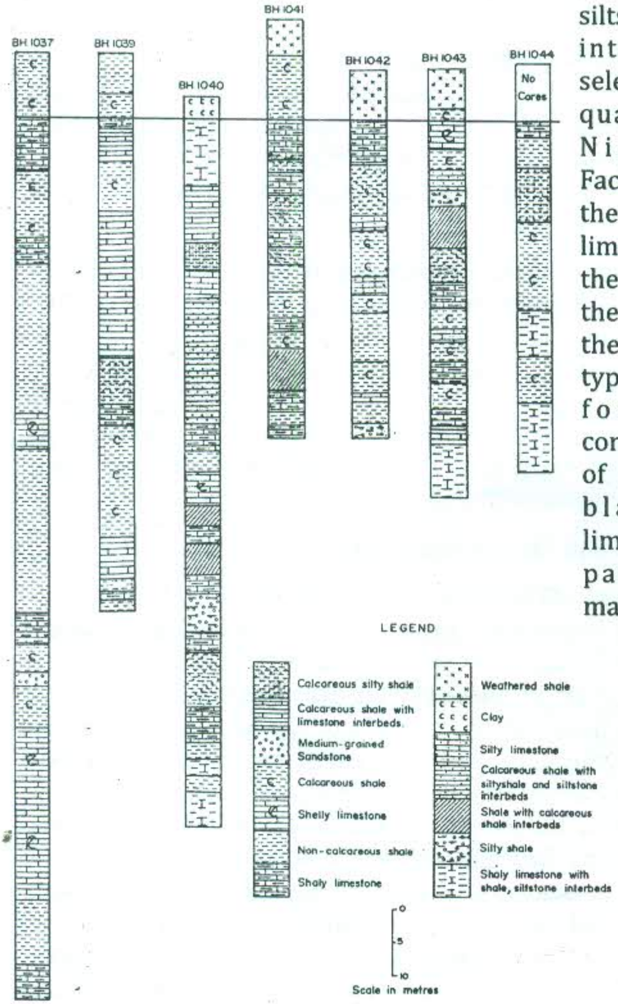


Figure 17. Borehole columnar sections showing the lithofacies of the Nkalagu Formation. BH 1037 represents the Hypostratotype for the formation.

Formation based on field and subsurface data. The subsurface data was collected from 7 of the exploratory boreholes drilled around Nkalagu for limestone investigation (Fig. 17). The cores from the drill holes are curated at the Nigerian Geological Survey Agency, Kaduna. In order to enhance the elucidation of the formation, a Hypostratotype (reference section) that illustrates the lithofacies not covered by the type section has been proposed.

5.1.1 Hypostratotype for the Nkalagu Formation

To further elucidate the stratigraphy of the formation, the sequence penetrated by BH 1037 is described below as a reference section. The borehole columnar section is provided in Fig.17.

Location:	Nkalagu
Identification:	GSN BH 1037
Depth:	141 m
Description:	Nkalagu Formation is represented by the entire sequence penetrated by the borehole.

Top of borehole

Calcareous grey to dark grey shale	10 m
Shaly limestone, grey to dark grey with molluscan shell fragments	7.5 m
Calcareous grey laminated shale	9.5 m
Shaly limestone	3.75 m
Non-calcareous shale, grey to dark grey, fissile and laminated in parts	22.5 m
Shelly limestone, greyish, shells and shell fragments of mollusk common	4.75 m
Non-calcareous shale, grey to dark grey, locally fissile and laminated	24 m
Shelly limestone, grey to dark grey, few shells of bivalves	5.25 m
Calcareous shale, grey to dark grey, finely laminated	3.5 m
Medium grained grey to brown sandstone, moderately sorted, quartz arenite	2.5 m
Calcareous shale, grey to dark grey	6.25 m
Shelly limestone, grey to dark grey, shell fragments fo molluscs common	26.5m
Non-calcareous shale, finely laminated grey to dark grey	10 m
Shaly limestone, grey to dark grey with few shells of bivalves	5 m

The section illustrated by the hypostratotype comprises essentially of an alternating sequence of limestone and shale which are grey, dark grey to black and a single bed of sandstone. Neither the upper nor lower boundaries of the formation were penetrated by the borehole.

Another subfacies of the formation is oolitic limestone which crops out north of Igumale at Ugugweo and along revers Ichire and Kpoko in the lower Benue Trough. The oolitic limestone is dense and whitish grey with few small shells of bivalves which have been diagenetically altered and replaced by secondary calcite, oolitic grained sandstone crops out around Igumale, and the sandstone is grey to brown in colour, moderately well sorted. Both the sandstone and oolitic limestone were found to be intercalated with thick bedded grey to dark grey shales at a location near Igumale.

5.1.2 Foraminifera and Ostracod Biostratigraphy of the Hypostratotype

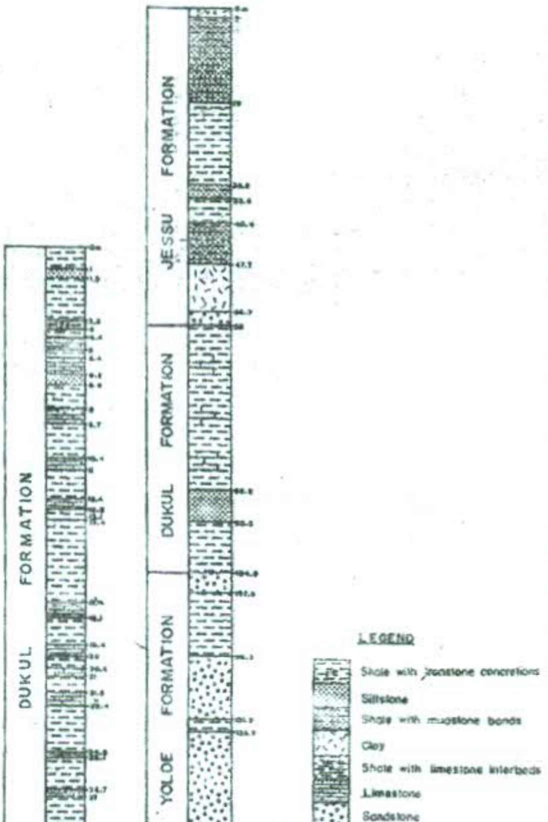
Diagnosic foraminifera and ostracods were recovered from the reference section (Okosun, 1987). The foraminifera included *Marginulina austiniana* Cushman, *Gavelinopsis* cf. *cenomanica* Brotzen, *Pseudouvigeriana cretacea* Cushman, *Haplophragmoides globosus* (Lozo), *Siphogenerinoides* cf clavata. Chenouard *et al., Heterohelix globulosa* (Ehrenberg), *Rotalipora turonica* Brotzen, *Hedbergella infracretecea* (Glaessner), *Globotruncana* cf *marginata* Reuss, *Ammobaculites subcretaceous* (Gushman & Alexander) and some specimens of *Nodosaria, Lenticulina, Ammomaginulina marginulina*. The ostracod species included *Ovocytheridea reniformis* Bold, *O.apiformis* Apsotolescu, *O. symmetrica* Reyment, *O. nuda* Grekoff, *Cythereis vitiligonosa reticulata* Apostolescu, *Brachycytehre sapucarienis* Krommelbein, *Cytheresis gabonensis* Neufville and *Buntonia semicostelata* Grekoff.

Heterohelix pulchra was found restricted to the Lower Turonian of the western interior of the United States of America (Eicher, 1967). *Brachycythere sapucariensis* and *Ovocytheridea reniformis* were found to be restricted to the Lower Turonian by Krommelbein (1966) and Bold (1964) and Neufville (1973) respectively. The foraminifera and ostracod assemblages suggest a Lower Turonian age for the reference section.

The Nkalagu Formation can be correlated chronostratigraphically with part of the Pindiga, Sekule, Yolde, Dukul, Jessu and Gongila Formations in the Upper Benue Trough. It can also be correlated with the lower part of Fika Shale which has a Turonian – Maastrichitian age (Carter *et al.*, 1963).

5.2 Dukul Formation

The Dukul Formation was defined by Carter *et al.* (1963) as comprising a sequence of shale and thin limestone intercalations with a type locality at Dukul in the north-eastern part of Dadiya syncline. During my research, the formation was found to be composed of grey shales with thin limestone and siltstone beds (Okosun and Onike, 2003). The thin limestone beds are evenly distributed in the studied section at Lakun which has a thickness of 30 metres (Fig. 18). The thin siltstone beds occur in the middle and top of the Kutari and Lakun sections respectively. The entire sections at these two localities form part of the Dukul Formation.



Carter *et al* (1963) did not provide a type section for the Dukul Formation when it was established, only a type locality was designated. A type section is the best means of defining a stratigrahic unit (Hedberg, 1976). The absence of a type section gives room for ambiguities in the interpretation of the lithofacies of the unit. A unit stratotype or boundary stratotype provides the most stable and unequivocal standard definition for a stratigraphic unit. The limestone - shale sequence exposed at Lakun is now proposed as a lectostratoype. Lectostratotype is a rock section selected later to

Figure 18. Lectostratotype for Dukul Formation (A) Lithologic profiles of Dukul, Jessu and Yolde Formations in the GSN BH1612 (B)

serve as the type section of a formation in the absence of an adequately designated original stratotype (Hedberg, 1976, Murphy and Salvador, 1994).

5.2.1 Lectostratotype for the Dukul Formation

Location - Lakun, along a stream channel, 3 - 4km west of Lakun
Thickness - 30 m

The section exposed at Lakun village is proposed as a lectostratotype for the Dukul Formation (Fig. 13A).

Shale, grey	1.0 m
Siltstone, grey	0.5 m
Shale, grey	2.1 m
Shale, grey with ironstone concretions	0.4 m
Shale, grey	0.4 m
Limestone, grey, grain supported	0.6 m
Shale, grey, fissile	0.4 m
Limestone, grey calcareous	0.8 m
Siltstone, slightly calcareous	0.6 m
Shale with gypsum disseminations	1.2 m
Limestone, grey, mud supported	0.7 m
Shale, grey	1.7 m
Limestone, grain supported	0.6 m
Sale, grey, slightly silty	1.4 m
Limestone, grey, grain supported	0.5 m
Shale, grey	0.2 m
Limestone, grey	0.3 m
Shale, grey with a band each of ironstone concentration and traces of gypsum	4.0 m
Limestone, grey	0.7 m
Shale, grey	1.3 m
Limestone, clayey	0.6 m
Shale, slightly silty	0.6 m
Limestone, clayey	0.4 m
Shale with ironstone concretions	0.8 m
Limestone, grey, mud supported	0.6 m
Shale, grey	2.4 m
Limestone, clayey	0.3 m
Shale, grey, laminated in parts	1.6 m
Limestone, grey, laminated	0.3 m
Shale, grey	2.3 m
Limestone, grey	0.7 m

The Dukul Formation is correlatable with the Kanawa Member (Zaborski *et al.*, 1997) of the Pindiga Formation and possibly to the lower part of the overlying sandy units in most parts of the Gongola Basin in age. The ammonites *Pseudotissotia nigeriensis* Zone, *Pseudaspidoceras pseudonodosoides, Thomasites gongilensis* and *Vascoceras globosum* have been documented in the Kanawa Member by Zaborski (1990). Some unidentified gastropod and echinoid species are common to both formations. The Dukul Formation contains a good Early Turonian ammonite fauna, including *Wrightoceras munien* (Pervinquiere), *Hoplitoides ingens* (Koenen) and *Eotissotia simplex* Barber. On the basis of the proposed lectostratotype the formation is now better defined and should no longer be confused with the Jessu or Yolde Formation. The formation is equivalent in age to parts of the Pindiga, the Makurdi and Nkalagu Formations.

6.0 Niger Delta

Many Neogene foraminiferal zones have been proposed by workers for the Niger Delta (Adeniran, 1992, Ozumba, 1994, 1995 Okosun and Lebau, 1999, Obaje *et al.*, 2010, Okosun *et al.* 2012, Obaje and Okosun, 2013). The zones are limited in scope, refinement and applicability. Thus there are no delta wide foraminiferal zones; this is largely due to the strong overpowering influence of the deltaic environment of the basin with rapid lateral and vertical lithofacies changes. The large terrigenous influxes of sediments from rivers Niger and Benue often disrupt the sequential occurrence of species in the delta. The foraminiferal assemblages become diluted, resulting to the scarcity / absence of planktic taxa and the depression of the FDO of biochronologically important taxa (Adegoke, 2002).

My research in the Niger Delta was two pronged. The first was focused on the foraminifera and calcareous nannofossil biostratigraphy of Akata and Tomboy fields in the onshore and offshore respectively (Fig. 19). The second was a taxonomic review of Shell Petroleum Development Company (SPDC) benthic foraminiferal catalogue.

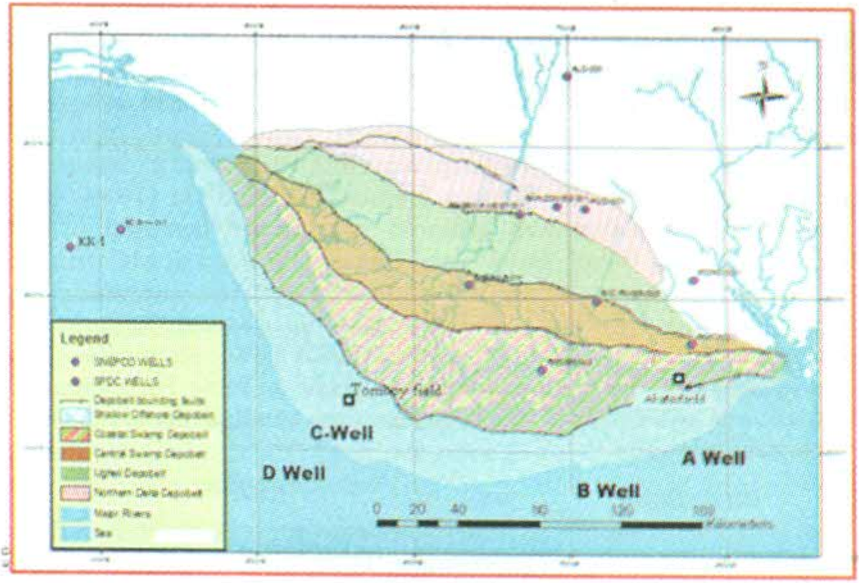


Figure 19. Map of the Niger Delta showing the locations of the studied fields and wells

6.1 Akata Field Onshore, Eastern Niger Delta (Fig. 19)

Diverse assemblages of foraminifera were recovered in this field (Pl. 3). The studied wells were Akata 2, 4, 6 and 7 (Okosun *et al.*, 2012).

Correlation of the wells using biozones was limited due to the wide separating distances between the wells.

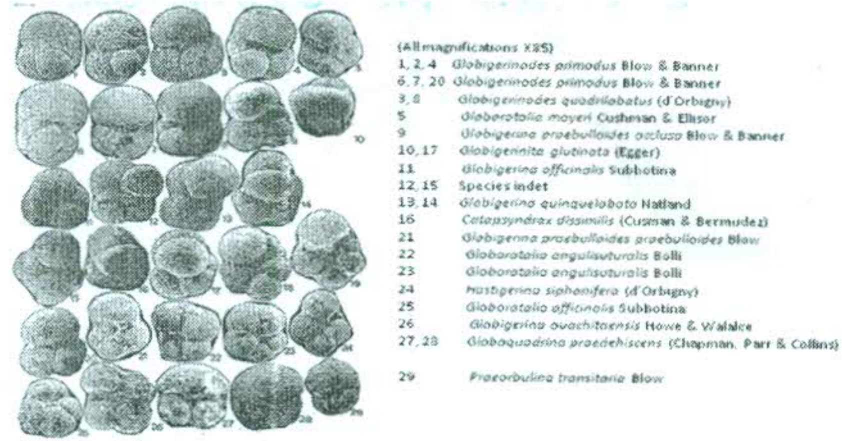


Plate V. Some planktic foraminifera from Akata Field.

Three planktic and three benthic foraminiferal zones were identified for Akata-2 and Akata-4 wells as follows.

One planktic and one benthic zone each were obtain for Akata-6, 7 and Akata -6 7 respectively.

Planktic Zones

i. *Globorotalia continuosa* zone (N 15)
ii. *Globorotalia obesa / Globorotalia ayeri* zone (N 11-N 14)
iii. *Globorotalia peripheroacuta* zone (N 10)

Benthic Zones

i. *Spirosigmolina oligoceanica* zone (N 15)
ii. *Uvigerina sparsicostata* zone (N 11- N 14)
iii. *Eponides eshira / Brizalina mandoroveensis* zone (N 10?)

Planktic Zone

Praeorbulina glomerosa zone for Akata - 6, 7 (N 8 - N 9)

Benthic Zone

Brizalina mandoroveensis / Eponides eshira zone for Akata - 6 (N 8 - N 9)
Poritextularia panamensis zone fo Akata - 7 (N 8 - N 10)

6.2 Tomboy Field offshore, western Niger Delta (Fig. 17)

The studied wells in this field are Tomboy 1-2, 4-6 offshore, western Niger Delta (Figs. 16 and 20). Three planktic and two benthic foraminiferal zones were identified from four studied wells (Obaje *et al.,* 2010, Obaje and Okosun, 2013).

Planktic Zone

Globigerinoides subquadratus zone (N 13 - N 14)
Globigerinoides obliquus zone (N 14 - N 15)
Globigerinoides extremus zone (N 15 - N 16)

Benthic Zone

Spirosigmolina oligoceanica zone (N 13 - N 14)
Florilus ex. gr nonion costiferum zone (N 14 - N 16)

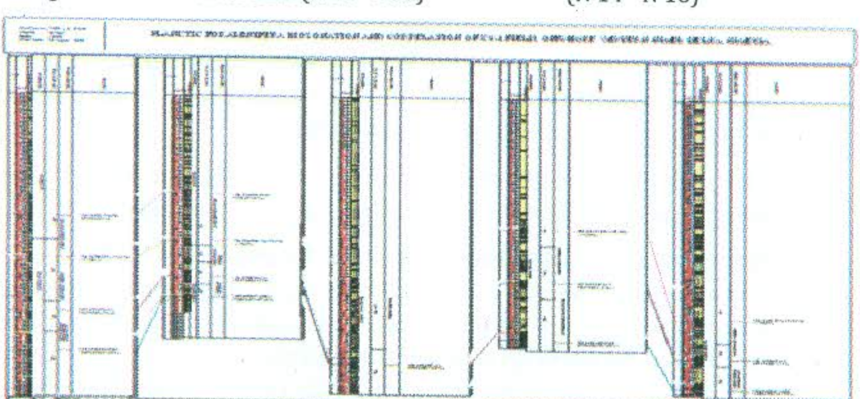


Figure 20. Planktic Foraminifera Biozonation and Correlation Chart of XY-1(Obaje and Okosun, 2013)

6.3 Taxonomic Review of SPDC Benthic Foraminiferal Catalogue

The catalogue of benthic foraminifera which was produced over three decades ago have majority of the taxa listed in a codified system of generic names and numbers. The catalogue is the basic tool for foraminiferal biostratigraphic work in the delta. It needed to be reviewed to conform to changes in modern paleontology.

About 163 out of the over 300 taxa in the catalogue were identified and given complete taxonomic names. Paleoenvironmental / bathymetric data, stratigraphic ranges of the species and reference lists were also provided for the species in the catalogue.

The revised taxonomy and the added species information have made the catalogue more useful in biochronology, paleoenvironmental reconstruction and stratigraphic correlation. The result of this research has added value to the application of foraminifera in hydrocarbon exploration in the Niger delta.

7.0 Conclusions

1. Mr Vice Chancellor Sir, I have at this inaugural lecture shown and discussed the eight stratotypes (type sections) that were proposed from my research for some Cretaceous and Tertiary formations in four basins of Nigeria.
2. With the aid of microfossils, the stratotypes have been correlated with other coeval formations in Nigeria. These stratotypes will improve our understanding of the stratigraphy of the four sedimentary basins.
3. Ostracod evidence from my research supports the union and faunal exchange between the Trans – Saharan sea and the Gulf of Guinea during the Cretaceous and the Paleocene. The route of the transgressions is now more properly defined.
4. The Sokoto phosphate is an important agro resource. The economic potential of one of the six prospects has been presented.
5. Microfossils (ostracods, foraminifera and calcareous nannofossils) were used for age and paleoenvironmental reconstructions in some Cretaceous and Tertiary strata. The results will be useful in future basin analysis.
6. The biozonations from the two fields of the Niger delta have enriched the biostratigraphic database of the delta. They will

enhance the application of biostratigraphy in exploration activities in the onshore and deepwater areas of Niger delta.

7. The lower part of the Fika Shale and the Gongila Formation are good hydrocarbon source rocks in the Bornu basin. The sandstones in these formations could serve as potential reservoirs.

8. The juxtaposition of faulted blocks and other fold structures that have been identified from previous seismic studies could provide hydrocarbon entrapment in the basin. The hydrocarbon potential of the Bornu basin is moderate.

9. I have made some contributions to manpower training during my research. Some of those mentored are in the oil industry, government agencies, service outfits and the academia.

8.0 Recommendations

1. In order to encourage an active and sustained stratigraphy and paleontologic research, the followings are hereby recommended:

i. The establishment of a National Geological Museum for the housing\curation of representative collections of Nigerian fossils. This will ensure that the nation does not continue to lose materials that are taken abroad for studies and curated overseas.

ii. All type materials discovered by staff of the oil companies and the Nigerian Universities should be deposited at the proposed Geological Museum.

iii. The statutory requirement that all cores and ditch cuttings from boreholes and oil wells should be deposited at the Nigerian Geological Survey Agency, Kaduna should be strongly enforced. This enforcement will make cores and ditch cuttings more readily available for research to interested specialists and postgraduate students.

iv. Microfossils (foraminifera, pollen and spores, nannofossils) used by the oil companies should be curated in the proposed museum.

v. The storage facilities for boreholes / oil well ditch cuttings at the Nigerian Geological Survey Agency, Kaduna should be expanded and upgraded for adequate curation services.

vi. Stratotype sites all over the country should be demarcated and protected from any form of destruction / degradation. In this way, they will remain useful reference sites.

2. The graben structures earlier identified in the Bornu basin (Ayoola *et al.,* 1986, Odusina *et al.,* 1993) are expected to contain higher volume of sediments. The aeromagnetic and gravity maps covering the basin should be reinterpreted for the location of these structures. The structural lows when delineated should be marked out for seismic investigation.

3. 3-D method of seismic data acquisition should be employed in future subsurface exploration work of the basin for betterstructural resolution.

4. The result of the completed comprehensive integrated study of the basin by the NNPC should provide a definite direction for future exploration in the basin.

5. The reserve evaluation of the Sokoto phosphate should be continued until all the 6 prospects are evaluated.

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Selected References

Adegoke, O. S. 1969. Eocene Stratigraphy of Southern Nigeria. *Bur. Rech. Geol. Min. Mem.*, 69. P. 23 – 48.

Apostolescu, V. 1961. Contribution a L'etude Paleonotoloquique (Ostracodes) et Tertiores de L'Afrique Occidentale. *Revue Inst. Fr. Petrole.* 16, P. 779 – 830.

Arua, L. and Rao. V. R. 1978. Ammonite Evidence for the Age of Nkalagu Limestone, Anambra State. Nigeria. *Jour. Min. Geol.* 15, P. 48 – 49.

Ayoola, E. O., Amechi, M. and Chukwu, R., 1986. Nigeria's new petroleum exploration provinces, Benue, Chad and Sokoto basins. *Jour. Min. Geol.*, 19, (1), 72-87.

Barsotti, G. 1963. Paleocenic Ostracodes of Libya (Sirte Basin) and their wide African Distribution. *Revue Inst. Fr. Petrole* Vol. 18. P. 1520 – 1535.

Berggren, W. A. 1972. Cenozoic Time-scale, some Implications for Regional Geology and Paleobiography, *Lethaia,* 4, P. 195 – 215.

Billman, H. G. 1976. Offshore Stratigraphy and Paleontology of the Dahomey Embayment. *Proc. of 7th Micropaleotology Colloquium, Ile-Ife,* Nigeria.

Boersma, A. 1978. Foraminifera In Bilal & Boersma (Editors) Introduction to Marine Micropaleontology. *Elsevier North Holland, Inc.* P. 376

Boudouresque, L., Dubios, D., Lang, J. and Trichet, J. 1982. Contribution a la Stratigraphie de la Bordure Occidentale du Bassin des Iullemeden au Cretace Superior et au Cenozoique (Niger et Mali, Afrique de I'Ouest). *Bull. Soc. Geol. Fr.* 124, P. 685 – 695.

Carbonnel, G., Alaxouma, K., and Dikouma, M. 1990. Les Ostracodes Paleocene du Niger: *Taxonomie-un Temoignage de L'existence Evetualle de la mer Tanssaharienne? Geobios.* 23(6), P. 671 – 697.

Carter, J. G., Barber, W. and Tait, E. A. 1963. The Geology of Part of Adamawa, Bauchi and Bornu Provinces, NE Nigeria. *Bull. Geol. Surv. Nigeria,* 30, P. 1 – 108.

Chukwu, J. N., **Okosun, E. A** and Alkali, Y. B. 2012. Foraminifera Biostratigraphy & Depositional Environment of Oloibiri-1 well, Eastern Niger Delta. *Journal of Geography & Geology,* Vol. 4, (4), P. 114 – 122.

De Klasz, I. 1977. The West African Sedimentary Basins. In the Phanerozoic Geology of the World. The Mesozoic 1. (Eds. Moullade, M. & Nairn, A. E. M.). p. 371 – 399. *(Elsevier Amsterdam).*

Dufauze, P., Fourcade, E. and Massa, D. 1984. Realite des Communication Marines Trans-Sahariennes entre la Tethys et Atlantique Durant le Cretace Superieur. *C. R. Acad. Sci. Paris* 298, 2 (15), P. 665 – 670.

Fayose, E. A. and De Klasz, I. 1976. Microfossils of the Eze-Aku Formation (Turonian) at Nkalagu Quarry, Eastern Nigeria. *Nig. Journ. Min. Geol.* 13. P. 51 – 61.

Federal Superphosphate Fertilizer Company (FSFC) 1985. Phosphate Analytical Result. *Correspondence with Geological Survey of Nigeria*, Kaduna.

Furon, R. 1963. The Geology of Africa, *Oliver & Boyd, Edinburgh,* P. 337. Geological Survey of Nigeria (GSN). 1986. Sokoto Phosphate Exploration Report. 60 p. Unpublished report.

Giwa, G. O., Oyede, A. C. and **Okosun, E.A**. 2004. Emerging trends in the Application of Biostratigraphy to Petroleum Exploration and Production. *NAPE Bulletin,* Vol. 18, No. 1, P. 12 – 27.

Hedberg, H. D. 1976 (Ed.). International Stratigraphic Guide: A Guide to Strategraphic Classification, Terminology and Procedure. *Wiley, New York.* P. 200.

Howe, M. V. 1971. Ecology of American torose Cytherideidae. *Bull. Centre Rech., Pau – SNPA 5 (Suppl.),* P. 349 – 359.

Ingram, R. L. 1954. Terminology for the Thickness of Stratification and Parting Units in Sedimentary Rocks. *Bulletin of Geological Society America.* 65, P. 937 – 8.

Jan Du Chene, R. E. 1980. Palynological study of the Tar Sand, Upper Maastrichtian of southwest Nigeria. *Proceedings, IV International Palynological Conference, Lucknow* (1976-1977) 2, 794-799.

Jan Du Chene, R. E., Klasz, I. D. E. and Archibong, E. E. 1979. Biostratigraphic Study of the Borehole Ojo-1, SW Nigeria, with Special Emphasis on the Cretaceous Microflora. *Revue De Micropaleontologic* 21, P. 123 – 139.

Jones, H.A. and Hockey, R.D. 1964. Geology of Parts of Southwestern Nigeria. *Bulletin of the Geological Survey of Nigeria* 41, P. 101.

Kauwenbergh, S. J. Van. 1985. Cursory Characterization of Phosphate Nodules from Sokoto State Nigeria. Dev. Indigenous Phosphate Deposit Training, May 26 – June 1985 *(IFDC) Alabama U.S.A.*

Kogbe, C. A. 1979. Geology of Southeastern Portion of the Iullemmeden Basin (Sokoto Basin). *Bulletin Dept. Geology Ahmadu Bello University, Zaria Nigeria,* 2, (1), P. 420.

Murat, R. C. 1972. Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In Africa Geology (Dessauvagie, T. F. and Whiteman, A. J. Eds), *Ibadan Univ. Press 1970.* P. 251 – 266.

Murphy, M. A. and Salvador, A., 1994. International Stratigraphic Guide – An abridge version: International Sub-commission on Stratigraphic Classification of IUGS. *International Commission on Stratigraphy. Episodes,* Vol. 22, No. 4, P. 225 – 270.

Murray, J. W. 1991. Ecology and Paleoecology of Benthic Foraminifera. Longman Group. U.K. Ltd., P. 397

Nichols, G. 1999. Sedimentology and Stratigraphy. *Blackwell Science Ltd, United Kingdom.* P. 551.

Obaje, N. G., Wehmer, Scheeder, G., Abubakar, M. B. and Jawio, A. 2004. Hydrocarbon prospectivity of Nigeria's inland basins: From the view point of organic geochemistry and organic petrology. *AAPG bull.*, 88, (30), 325-353.

Obaje, S. O., Obaje, N. J. and **Okosun, E. A.** 2011. Provenance and Depositional Environment of Kerri-Kerri Formation in Duguri area (Sheet 171, S. W.), Northeastern Nigeria. *Records of Nigerian Geological Survey Agency (NGSA),* 12, 10 – 35.

Obaje, S. O., **Okosun, E. A.,** Olasehinde, P. I. and Udensi, E. E. 2010. Biostratigraphy and Paleoenvironmental Analysis of XY-1 Field, Offshore Western Niger Delta, Nigeria. *The Free Library Earth Sciences Communities Journal (online)* Vol. 14.

Obaje, S. O. and **Okosun, E. A**. 2013. Planktic Foraminifera Biozonation and Correlation of XY – Field, Offshore western Niger Delta, Nigeria. *International Journal of Science and Technology*, 3, (3), 160-166.

Odusina, A. A., Mubarack, S. O., Beka, F. T. and Nwangu, U. 1993. Geology and petroleum potential of the Nigerian sector of the Chad basin. Res. Bull III, Exploration Research Section (R & D). Project No. ER/RD/42. NNPC, Port Harcourt, 47p.

Offodile, M. E. and Reyment, R.A. 1976. Stratigraphy of the Keana-Awe area of the Middle Benue Region of Nigeria. *Bull. Geol. Inst. Uppsola (N.S)*, 7, P. 37 – 66.

Ojo, O. J. and Akande, S. O. 2006.Sedimentological and Palynological studies of the Patti Formation, Southeastern Bida Basin, Nigeria: Implications for Paleoenvironments and Paleogeography. *NAPE Bulletin*, 19, (1), 61-77.

Okosun, E. A. 1987. Ostracod biostratigraphy from Nkalagu area in Nigeria. *Records of the Geological Survey of Nigeria*. 10, 18-31.

Okosun, E. A. 1987. Ostracod biostratigraphy from Dahomry Embayment, Niger Delta and the Benue Truogh in Nigeria. *Geological Survey of Nigeria Bulletin*, No. 41, 151 pp., 21 plates.

Okosun, E. A. 1988. The occurrence of hinge reversal in *Buntonia beninesis* Reyment (Ostracoda). *Journal of Paleontology*, 62, (4), 654-656.

Okosun, E. A. 1989. A review of the stratigraphy of Dange Formation, Paleocene, Northwestern Nigeria. *Newsletters on Stratigraphy*, 21, (1), 39-41.

Okosun, E. A. 1989. Eocene Ostrcoda from Oshosun Formation, Southern Nigeria. Journal of Afri-Earth Science, 9, (3/4), P. 669 – 676.

Okosun, E. A. 1990. A review of the Cretaceous of the Stratigraphy of the Dahomey Embayment, West-Africa. *Cret. Res.*, 11, 17 – 27.

Okosun, E. A. 1992. Cretaceous Ostracod Biostratigraphy from Chad Basin in Nigeria. *Journal of African Earth Science,* 14, (3), P. 327 – 339.

Okosun, E. A. 1995. Paleocene Ostracoda from Sokoto Basin, NW, Nigeria. *J. Min. Geol.,* 28, P. 148 – 156.

Okosun, E. A. 1995. Review of the geology of the Bornu Basin, Nigeria. *Journal of Mining and Geology,* 31, (2), 123-133.

Okosun, E. A. 1996. Biostratigraphy of the Cretaceous – Tertiary boundary in SW Nigeria, West Africa. In: S. Jardine; I de Klasz and J. P. Debenay (eds). *Geolgy dcl. Afrique et de L Atlantique Sud. 12e Coll. African de Micropalaontologie, France.* 203-207.

Okosun, E. A. 1997. The potential application of Sokoto phosphate for the manufacture of fertilizer. *Journal of Agricultural Technology,* 5, (2), 59-64.

Okosun, E. A. 1997. A note on the stratigraphical value of Buntonia and Protobuntonia (Turonia-Pliocene) in Nigeria, West Africa. *Newsletters on Stratigraphy,* 35, (1), 165-172.

Okosun, E.A. 1998. Review of the Early Tertiary Stratigraphy of SW Nigeria. *J. Min. Geol.* 34 (1), P. 27 – 35.

Okosun, E. A. 1998. Ostracods, their attributes and applications. *Journal of Mining and Geology.* 34, (1), 203-218.

Okosun, E. A. 1999. Late Paleocene biostratigraphy and paleoecology (Foraminifera and Ostracoda) of two boreholes in Sokoto Basin, NW Nigeria. *Journal of Mining and Geology.* 34, (2), 155-170.

Okosun, E. A. 1999. The Stratigraphy of Gboko Formation, middle Benue Trough, Nigeria. *Journal of Environmental Science.* 3, (2), 169-174.

Okosun, E. A. 1999. Stratigraphy and petroleum geology of the southwest portion of Chad Basin. *Journal of Pure and Applied Science.* 1, (2), 169-174.

Okosun, E. A. 1999. Stratigraphy of the Nkalagu Formation, Benue Trough, Nigeria. *Science Forum. J. Pure and Applied Science* 1 (2), 1 – 7.

Okosun, E. A. 2000. New stratigraphic ranges for some Tertiary Ostracodes from southern Nigeria. *N. Jb. Geol. Palaont. Mh.* 2000, (6), 378-384.

Okosun, E. A. 2001. Manual of Cretaceous and Tertiary Ostracoda from Nigeria. 42 pp. *Moredays Printers,* Kaduna, Nigeria.

Okosun, E. A. 2002. A preliminary assessment of the petroleum potential of the SW Chad basin, Nigeria. *Nig. Jour. Techn. Res.* 1, 87-94.

Okosun, E. A. 2003. Albian ostracoda from Gboko Limestone, Middle Benue Trough, Nigeria. *Spectrum* 10, (1-2), 96-103.

Okosun, E. A. and Onike, F. N. 2003. Stratigraphy of Dukul Formation (L. Cenomanian - M. Turonian) Upper Benue Trough, Nigeria. *Spectrum,* 10, (1-2), 24-30.

Okosun, E. A. 2006. Hydrocarbon potential of the Bornu basin, Nigeria. In: Abaa, S. I. & Baba, S. (Eds.) Proceedings of the 1st PTDF Workshop, University of Maiduguri, Nigeria.

Okosun, E. A., Isah, G., Olobaniyi, S., Shekwolo, P. D. and Nwosu, J. E. 2007. Stratigraphy and Sedimentology of Bida Formation, Bida Basin, Nigeria. *Borno Jour. Geology.* 4 (2), 21 – 31.

Okosun, E. A., Chukwu, J. N., Ajayi, E. O. and Olatunji, O. A. 2012. Biostratigraphy Depositional Environment and Sequence Stratigraphy of Akata Field (Akata 2, 4, 6 & 7 wells), Eastern Niger Delta, Nigeria. *International Journal of Scientific & Engineering Research,* 3, (7), 1 – 27.

Okosun, E. A. and Alkali, Y. B. 2012. Paleocene-early Eocene Foraminifera Biostratigraphy of the Eastern Dahomey Basin, SW Nigeria. *International Journal of Scientific & Engineering Research,* Vol. 4.

Okosun, E. A. and Alkali, Y. B. 2013. The Geochemistry, Origin & Reserve Evaluation of the Sokoto Phosphate Deposit, North Western Nigeria. *Earth Science Research*, Vol. 2, No. 2.

Omatsola, M. E. and Adegoke, O. S. 1981. Tectonic evolution and Cretaceous Stratigraphy of the Dahomey Basin. *Journal of Mining and Geology* 18, P. 130 – 137.

Oppel, A. 1856 – 1858. Die Juro formation Englands, Frankreichs und des sudwestlichen Deutschlands, nach ihren einzelnen Gliedern eingeteilt und verglichen, 857 pp. Stuttgart: Ebner & Seubert.

Orbigny, A. de. 1842 – 1851. Paleontologie Francaise Description zoologique et geologique de tous les animaux mollusques et rayonnes fossil de France, comprenant leur application a la reconnaissance des couches. Terrains oolithiques ou jurassiques. 1, Cephalopods. Paris, Masson, 624p.

Petters, S. W. 1980. Biostratigraphy of Upper Cretaceous Foraminifera of the Benue Trough, Nigeria. *Journal Foram. Research* 10, P. 191 – 204.

Petters, S. W. and Ekweozor, M. C., 1982. Petroleum Geology of Benue Trough and Southeastern Chad Basin, Nigeria. *Amer. Assoc. Petr. Geol.* P. 1141 – 1150.

Reyment, R. A. 1965. Aspects of the Geology of Nigeria, *Ibadan University Press,* P. 133.

Reyment, R. A. 1978. The Paleocene Trans-Saharan Transgression and its Ostracode Fauna. *Proc. 2nd Symposium of Geology of Libya, Tripoli.*

Reyment, R. A. 1980. Biogeography of the Saharan Cretaceous and Paleocene Epicontinental Transgression. *Cretaceous Research* (1) P. 299 – 327.

Wentworth, C. K. 1922. A Scale of grade and class terms for Clastic Sediments. *Journal of Geology*, 30, P. 377 – 392.

Whiteman, A. J. 1973. Geology and Hydrocarbon Prospects of Nigeria Exploration Consultant Ltd. *Marlowe England*. Vol. 1 & 2.

Zaborski, P. M. 2000. The Cretaceous and Paleocene Transgressions in Nigeria and Niger. *Journal of Mining and Geology*, 36, P. 153 – 173.