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Calcareous Nannofossils and Foraminifera Studies: An Integrated Approach to the Depositional Environmental Study and Biostratigraphy of Deb-1 well offshore Eastern Dahomey Basin, Southwestern Nigeria

O. C. Adeigbe[1], M. Adebowale[1], A. O. Ola-Buraimo[2], S. A. Bankole[2*] and H. A. Ayinla[3]

[1]*Department of Geology, University of Ibadan, Ibadan, Nigeria*
[2]*Department of Chemical and Geological Sciences, Al-Hikmah University, Ilorin, Nigeria.*
[3]*Department of Geology, Federal University Lokoja, Lokoja, Nigeria.*

Authors' contributions

This work was carried out in collaboration among the authors. Author OCA designed the study, author MA managed the analyses of study, authors AOO and MA performed the statistical analysis, author SAB managed the literature searches, authors OCA and HAA wrote the protocol, authors AOO and SAB wrote the first draft of the manuscript. The authors read and approved the draft of the manuscript.

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ABSTRACT

High resolution biostratigraphic study of Deb-1 well located in Dahomey Embayment, southwestern Nigeria was carried out on one hundred and eighteen (118) ditch cutting samples for nannofossils and fifty eight (58) samples for foraminifera studies with the view towards identifying the biostratigraphic zones, determine the age and paleoenvironmental reconstruction of the sediments. Laboratory preparation of both nannofossils and foramaminefa involve slide preparation and identification of forms present.
Six biozonations were recognised for the nannofossil which include NN11 (*Discoaster quinqueramus* zone), NN8-NN10 (*Catinaster coalithus zone*), NN5-NN7 (*Sphenolithus heteromorphus zone*), NN4 (*Helicosphaera ampliaperta*), CC13-CC22 (*Eiffellithus*

**Corresponding author: E-mail: bayus4sure2@yahoo.com;*

eximius zone, Micula decussata zone) and CC12 (*Eiffellithus eximius* zone) which belong to Late, Middle, Early Miocene, Coniacian-Campanian and Turonian ages respectively. However, the planktonic foraminifera zones identified are *Heterohelix reussi* zone (Upper Santonian), *Dicarinella primitive* zone (Lower Santonian), *Archeoglobigerina bosquensis* (Lowermost Santonian), *Hedbergella planispira* zone (Coniacian) and *Heterohelix reussi* zone (Turonian). The paleoenvironment of deposition based on Fisher's diversity index shows a value that is less than 5.52 which is suggestive of environment not deeper that outer neritic. This is further corroborated with p/b ratio which indicates that the base of the section analysed is within the deep marine, the middle section is shallowing while the upper part is characterised by prograding depositional system (deltaic in nature). This is suggestive of a marginal marine to open marine system.

Keywords: Biostratigraphy; Paleoenvironment; Calcareous nannofosil; Foraminifera; Miocene.

1. INTRODUCTION

The Dahomey Basin is an extensive marginal sedimentary basin located in the continental margin of the Gulf of Guinea, southwestern part of Nigeria (Fig. 1). The basin is a marginal pull – apart basin [1] or a marginal sag basin [2] which developed in the Mesozoic due to the separation of African plate from South American plate [3,4]. Reports on occurrence of bitumen, limestones, glass sands, phosphate and recent exploitation of hydrocarbon in the offshore part of the basin have attracted geological interest.

This study involves an integrative approach to biostratigrahic study involving calcareous nannofossils and foramineral studies carried out on Deb-1 well located within the offshore in Dahomey Basin. Despite numerous works on the basin involving sedimentology, hydrocarbon potential, tectonic evolution, among others, biostratigraphic studies on Dahomey Basin and research on the stratigraphic settings of the offshore part of the Dahomey Basin is rare. Hence integration of nannofossil and foraminiferal studies was carried out on Deb-1 well in order to highlight the biozones, and depositional environment of deposition which would assist exploration of other areas by solving geological problems through correlation.

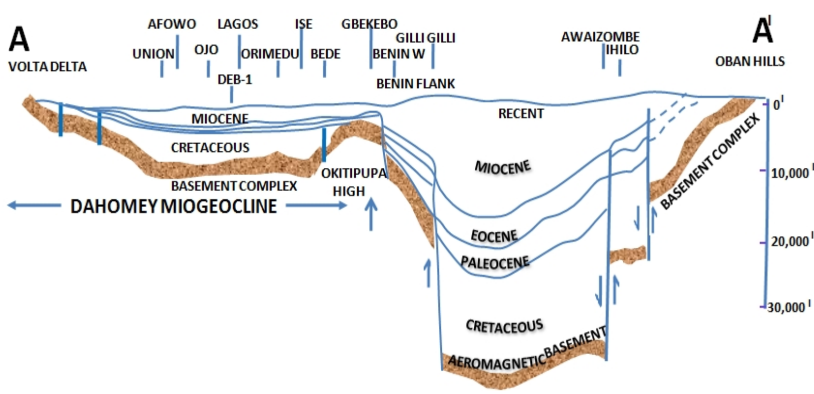


Fig. 1. East -West geological section showing position, extent and sediment thickness variations in the onshore Dahomey Basin and the upper part of the Niger Delta with location of DEB-1 well [4]

2. GEOLOGICAL SETTING OF THE BASIN

Dahomey Basin is a regional sedimentary basin that extends from Southeastern Ghana (Volta delta) in the west to the western flank of the Niger Delta in the east [4,5,6,7], southwestern Nigeria (Fig. 2). The basin is bounded by Ghana Ridge to the west, which is an extension of the Romanche Fracture Zone; and on the east, by the Benin Hinge line, a basement escarpment which separates the Okitipupa Structure from the Niger Delta Basin and also marks the continental extension of the Chain Fracture Zone [8]. The evolution of the basin is linked to the opening of the Gulf of Guinea during the Early Cretaceous-Late Jurassic [1,2,3,]. It is made up of inland, coastal and offshore sedimentary units [9]. The onshore margin is predominantly clastic sediments directly deposited on the basement complex and the offshore margins are thick, fine grained consisting of Cenozoic sediments [4].

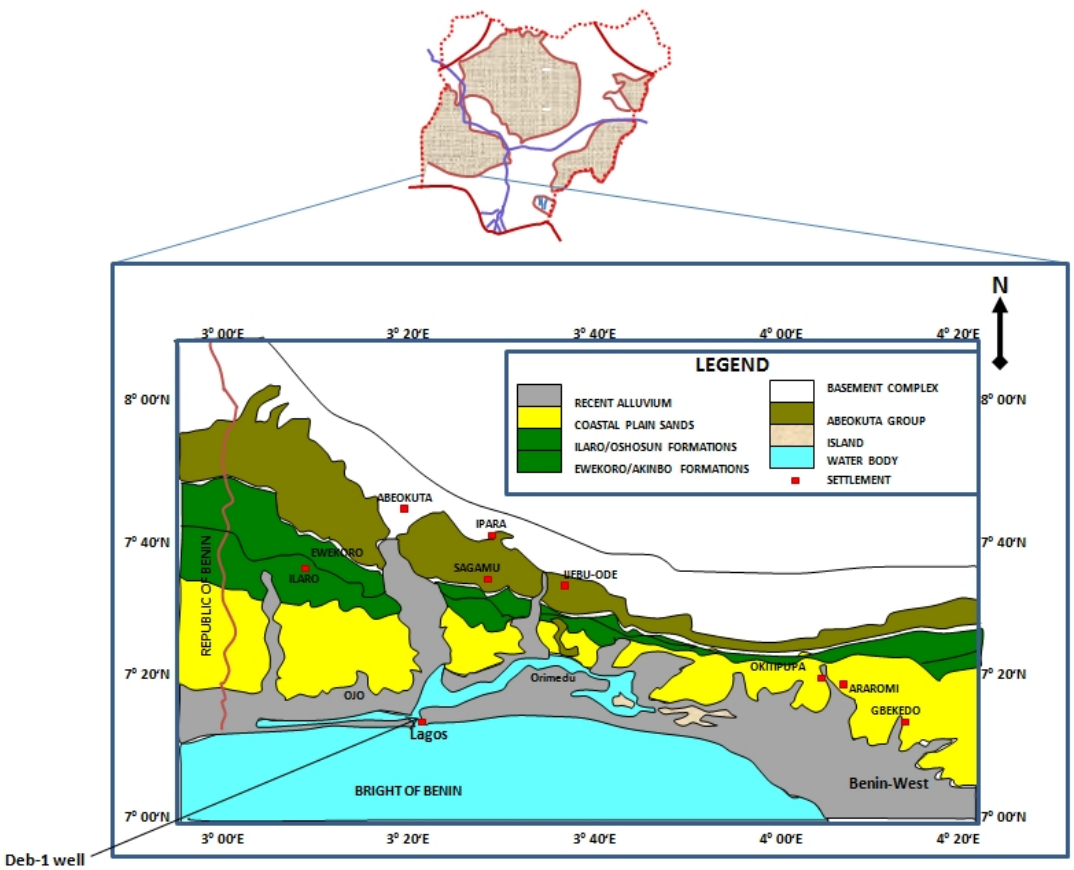


Fig. 2. Geological Map of the Dahomey Basin showing the well location with an inset map of Nigeria showing the location of Dahomey Basin (modified after [10])

Stratigraphically, the oldest sediments in the basin belong to the Abeokuta Group [7] which in turn consists of Ise Formation, Afowo Formation and Araromi Formation (Fig. 3). This group is the thickest sedmentary unit within the basin [11].

Ise Formation unconformably overlies the basement complex of southwestern Nigeria. It is made up of conglomerates and grits at the base and overlain by a coarse to medium grained sands with interbeded kaolinite [12]. An age range of Neocomian- Albian is assigned to this formation based on paleontological assemblages. Overlying the Ise Formation is the Afowo Formation; consisting of coarse to medium grained sandstone with shale, silt and claystone interdeds. Based on palynonogical evidence, the formation is assigned Turonian-Maastrichtian age [13]. Afowo Formation is succesively overlain by Araromi Formation which is made up of shale, siltstone and interbeds of limestone and sandstone. It was dated Maastrichtian to Paleocene based on foramifera contents [14]. The Abeokuta Group is overlain by the Imo Group (Ewekoro and Akinbo Formations) [5,6,15,16,17], the Ososhun Formation, Ilaro Formation and Coastal plain sands [5].

Ewekoro Formation is the oldest of the Tertiary sediments which overlies the Araromi Formation. It is made up of fossiliferous, shaley limestone sequence of Paleocene age [15]. Overlying the Ewekoro formation is the Akinbo Formation which consists of shale and clay units. The claystones are kaolinitic in nature and have concretions. The base of the formation is defined by glauconitic rock bands with limestone lenses [6]. It is dated Paleocene-Eocene age [7]. The Akinbo Formation is succeeded by Ososhun Formation which is made up of greenish-grey clay, black-grey shale and interbedded with sandstones. The shale is thick and laminated and glauconitic. Ososhun is phosphatic and this distinguishes it from the underlying Akinbo Formation [5]. The age of the formation is Eocene [5,6,18]. Ososhun Formation is conformably overlain by Ilaro Formation and it consists of massive, yellowish, poorly sorted, cross bedded sandstone. The formation shows a lateral change in facies. Eocene age is assigned to this formation by [6,14]. The youngest formation in the basin which succeeded the Ilaro Formation is the Benin Formations which is also known as coastal plain sands [5]. It consists poorly sorted sand with clays occurring as lenses. The sands are occasionally cross bedded are predominantly of estuarine, deltaic and continental in origin [19]. The formation is of Oligocene-Recent in age [6,14].

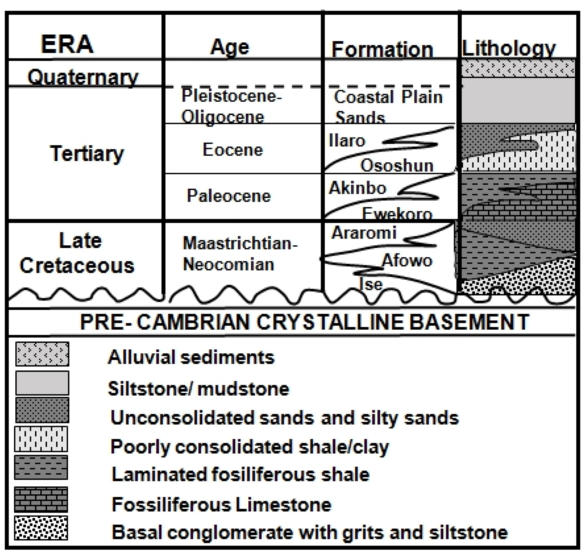


Fig. 3. Stratigraphy and lithologic features of Dahomey Basin according to [7]

3. METHODOLOGY

One hundred and eighteen (118) ditch cutting samples were obtained from the well at about 30 ft (9 m) interval for nanofossil slides. About 2 g of each of the samples were washed to remove drilling mud. The samples were then dispersed in water in a tube. A disposable glass pipette was employed to pipette the suspension to produce the slide. The pipette solvent is dried on a 22 x 40mm cover slip at a slightly hot temperature normally 60º-70ºC. The dried cover slip is then mounted on a glass slide using already heated Canada balsam as the mounting medium. Standard nannofossil zonation according to the schemes of [20,21,22,23] were adopted.

Fifty eight (58) samples were used for foraminiferal study by compositing the samples at an interval of about 60 ft (18 m).The samples, each weighing 25 g, were processed, dried and weighed prior to wet sieving through a 63µm sieve. Unconsolidated samples were soaked in a 3% solution of hydrogen peroxide with a small amount of Calgon added and then washed with tap water over a 63-µm sieve. Friable samples were first partially disaggregated by hand and then soaked in hydrogen peroxide and Calgon before washing. Consolidated samples were disaggregated by mild heating and treatment with hydrogen peroxide. After every use, the sieve was dipped in a dilute solution of methyl blue dye to identify contaminants from previous samples. After washing, each sample was collected on a filter paper and then dried on a hot plate at ~50°C. Foraminifera and other calcareous microfauna were picked from the washed samples employing a binocular microscope at X1000 magnification [24,25]. The foraminifera were identified following classification of [26,27].

4. RESULTS AND BIOSTRATIGRAPHIC INTERPRETATION

4.1 Calcareous Nannofossil

Biostratigraphic interpretation of the studied section was attempted based on recognized index calcareous nannofossils present. Six nannofossil zones were recognized ranging from Cretaceous to Tertiary, belonging to CC12, CC13-CC22, NN5-NN7, NN4, NN8 and NN11. Biozonation schemes of [20,21,22] were used for the Tertiary and Cretaceous respectively. The recognized sections in the analyzed interval are given below while the identified forms are presented in Plate 1 and Appendix1.

Nannofossil zone	:	NN11
Stratigraphic Interval	:	4650-4800ft
Age	:	Late Miocene

Characteristics: The base of the analyzed interval is marked by the first downhole occurrence (FDO) of *Discoaster quinqueramus* and *Discoaster berggrenii* with high occurrence of *Catinaster coalitus, Helicosphaera carteri,* and *Reticulofenestra pseudounbilicus*. This is the youngest zone within the studied stratigraphic interval, marked by *Discoaster quinqueramus* and *Discoaster berggrenii.* The interval is compared with established zones in Niger Delta in terms of occurrence of diagnostic nannofossils [28]. A notable similarity of the nannofossil assemblage found in previous studies in the Niger Delta [28] is the acme of *Sphenolithus abies*.

Nannofossil zone : NN8-NN10
Stratigraphic Interval : 4800-5100ft
Age : Late Miocene

Characteristics: The base is marked by the last downhole occurrence (LDO) of *Catinaster coalitus* in association with *Helicosphaera carteri.* The base is further marked by the disappearance of *Discoaster berggrenii and Discoaster quinqueramus.* The interval is marked by paucity of nannofossils and belongs to *Catinaster coalitus* zone, dated Late Miocene.

Nannofossil zone : NN5-NN7
Stratigraphic Interval : 5100-5750ft
Age : Middle Miocene

Characteristics: Top of this zone is marked by the presence of *Cyclicargolithus floridanus*, in association with *Coccolithus pelagicus, Reticulofenestra haqii, Reticulofenestra minuta,* and *Pontosphaera multipora.* The base is defined by the appearance of (FDO) *Sphenolithus heteromorphus,* and *Helicosphaera ampliaperta.* There is another peak fossil abundance in this zone like in the first zone. Other nannofossils occurring in this zone are *Helicosphaera carteri,* and *Helicosphaera intermedia.* Thus, the interval is conveniently dated Middle Miocene age.

Nannofossil zone : NN4
Stratigraphic Interval : 5750-5900ft
Age : Early-Middle Miocene

Characteristics: Top of this zone is marked by the presence of *Sphenolithus heteromorphus,* and *Helicosphaera ampliaperta.* Other nannofossils occurring in this interval include *Coccolithus pelagicus, Pontosphaera multipora, Helicosphaera carteri, Reticulofenestra spp,* and *Helicosphaera intermedia.* The interval is further characterized by acme fossil abundance which may be as a result of prevailing favourable ecological and climatic conditions at the time.

The base of the zone is marked by the disappearance of *Sphenolithus heteromorphus, Helicosphaera ampliaperta, Reticulofenestra* spp, *Reticulofenestra haqii, Reticulofenestra minuta, Reticulofenestra minuluta, Pontosphaera multipora,* and *Sphenolithus moriformis.*

Nannofossil zone : Undefined
Stratigraphic Interval : 5900-6080ft
Age : Indeterminate

This Interval is undefined, due to its barren nature.

Nannofossil zone : CC13-CC22
Stratigraphic Interval : 6080-7050ft
Age : Santonian- Late Campanian

Characteristics: This zone is marked by the appearance (FDO) of *Eiffellithus eximius, Micula decussata, and Cyclagelospaera reinhardtii.* The base is marked by last downhole occurrence of *Micula decussata.* This interval is characterized by high abundance of *Cyclagelospaera reinhardtii*. The interval is dated Santonian to Late Campanian age.

Nannofossil zone : CC12
Stratigraphic Interval : 7050-8460ft
Age : Turonian

Characteristics: The top of this zone is marked by the last downhole occurrence (LDO) of *Eiffellithus eximius a*nd the continuous appearance of *Cyclagelospaera reinhardtii*. The bottom of the zone is placed at the deepest point of the analyzed section at 8460ft.

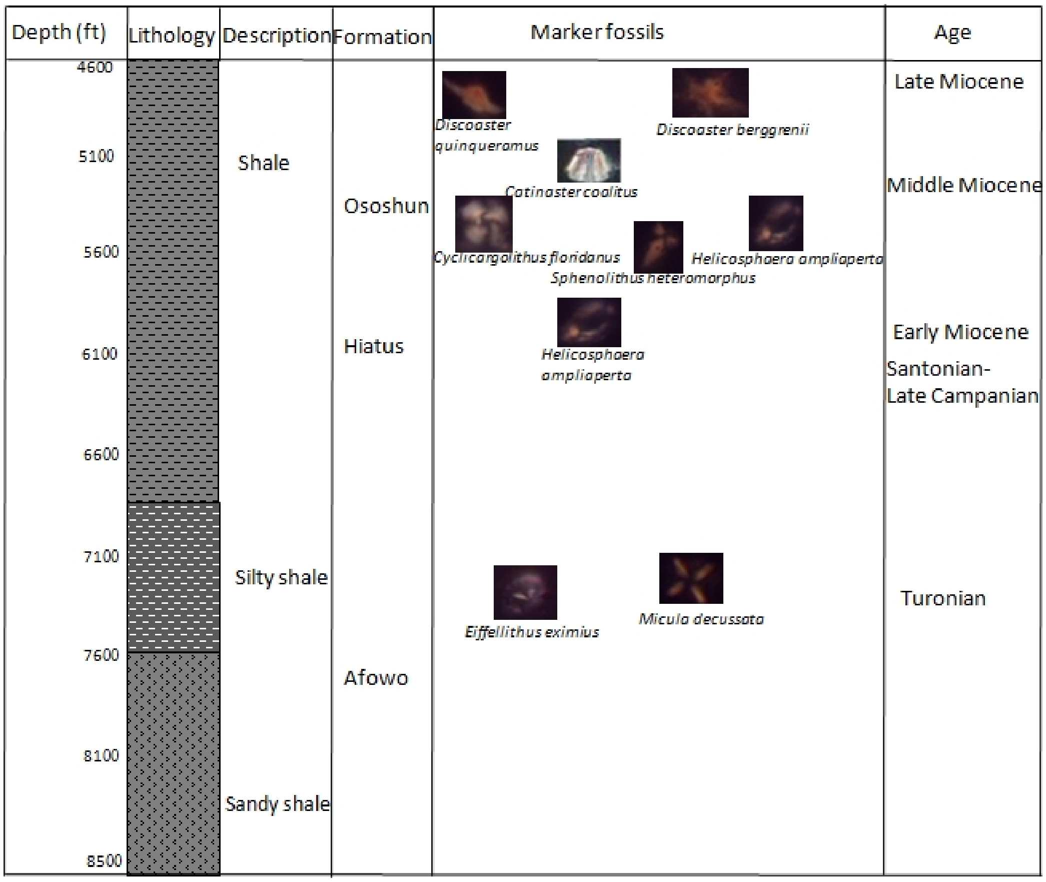
Interval 5900-6080ft contains nannofossils that are not recognizable and of no stratigraphic importance, therefore referred to as an Indeterminate zone. The indeterminate zone is overlain by an unconformity which represents period of non-deposition or erosional removal of Paleogene sediments. However, the appearance of CC13-CC22 Nannofossil zone at deeper depth is suggestive of Santonian to Campanian age sediments [19,20]. Turonian age is also interpreted by the identification of bio-zone CC12 of [29].

A Campanian- Oligocene erosional surface is suggested to be present in the offshore Dahomey Embayment because it is unaccountable for within the stratigraphic interval analyzed for this study. This hiatus is similar to previous observation on the offshore stratigraphic dating of Dahomey Embayment by [13]. Summary of the nannofossil marker forms, their respective zones and bioevents established after [20,21,22] are presented below in Table 1 and the evolutionary trend of the nannofossils is presented in Table 2.

Table 1. Calcareous nannofossil zones recognized in Deb-1 well

Depth (ft)	Epoch	Age (ma)	Zones (Perch-Nielsen, 1979; 1983)	Zones (Martini, 1971)	This study
4650	Late Miocene	8.3 ma - 10.8 ma		NN11 Discoaster quinqueramus	NN11 Discoaster quinqueramus
				NN10 *D. calcaris* Zone	NN8–NN10 *Catinaster coalitus* Zone
				NN9 *D. hamatus* Zone	
5100				NN8 *Catinaster coalitus* Zone	
	Early-Middle Miocene	10.8 ma - 13.2 ma		NN7 *D. kugleri* Zone	NN5-NN7 *Sphenolithus heteromorphus* Zone
				NN6 *D. exilis* Zone	
5750	Early-Middle Miocene	15.6 ma - 18.2 ma		NN5 *Sphenolithus heteromorphus* Zone	
5900				NN4 *Helicosphaera ampliaperta* Zone	NN4 *Helicosphaera ampliaperta* Zone
	Indeterminate	Indeterminate		NN3 *S. belemnos* Zone NN2 *D. druggi* Zone NN1 *Triquetrorhabdulus carinatus* Zone	Indeterminate
6080					
7050	Santonian-Late Campanian	75.3 ma - 87.2 ma	CC22 *E. eximus (FDO)* CC21 *U. sissinghii* CC20 *C. aculeus* CC19 *M. furcatus* CC18 *A. parcus* CC17 *C. obscurus* CC16 *L. cayeuxii.* CC15 *R. anthophorus* CC14 *M. decussata* CC13 *M. Furcatus*		CC13-CC22 *E. eximus (FDO)*
8460	Turonian and older	91.ma and older	CC12 *E. eximus (LDO)*		CC12 *E. eximus (LDO)*

Table 2. Trend of appearance and evolutionary changes in nannofossils in Deb-1 well



4.2 Foraminifera

Foraminifera recovery is generally poor in the entire interval analyzed. Therefore, interval 4650-6300ft is barren to very poor in recovery of foraminifera fossils. Few fossils recovered are poorly preserved and non-diagnostic for biostratigraphic age dating (Plate 2 and Appendix 2). Thus, the characterization of the analyzed interval starts from 6300ft where there is presence of little recovery of index fossils as presented below. However, the planktonic foraminifera zones such as *Heterohelix reussi* zone was established and is after [30]; *Dicarinella primitiva* zone, after [31]; *Archeoglobigerina bosquensis* interval range zone, after [32] and *Hedbergella planispira* zone, after [33].

Foram Zone : Heterohelix reussi zone
Interval : 6300 –6540ft
Age : Upper Santonian

Characteristics: The interval is marked by poor recovery of foraminiferal forms. Few forms present are *Heterohelix reussi* and *Globigerinelloides spp.* which are long ranging in age suggestive of Turonian to Santonian age. However, as a result of the stratigraphic position of the interval, it is tentatively dated Upper Santonian age. Stratigraphically, the interval is equivalent to Afowo Formation.

Foraminifera Zone : Dicarinella primitive zone
Interval : 6540 –6900ft
Age : Lower Santonian

Characteristics: The top of the zone is marked by the first downhole appearance (FDO) of *Dicarinella primitiva* at 6540ft horizon, which also marks the extinction or disappearance of the form in deb-1 well. The base of the zone is placed at 6900ft where *Archeoglobigerina bosquensis* show first downhole occurrence (FDO).

Dicarinella primitiva is the bio-marker used for defining this zone based on its short interval range within the well section. Other important foraminifera forms present in the interval include; *Hastigerinelloides spp* at 6720ft horizon; while important planktonic fauna present are *Hedbergella planispira, Whiteinella inornata, Heterohelix* spp, *Hedbergella* spp, *Hedbergella holmdelensis, Heterohelix reussi* and *Globigerinelliodes* spp. Therefore, the interval is conveniently dated Lower Santonian age, belonging in part to Afowo Formation.

Foraminifera Zone : Archeoglobigerina bosquensis interval range zone
Interval : 6900 – 7140ft
Age : Lowermost Santonian

Characteristics: The top of the interval is defined by first downhole appearance (FDO) of *Archeoglobigerina bosquensis* at 6900ft. The interval is deficient of microforaminiferal recovery, but the only form present is indicative of Santonian age. At 7140ft *Archeoglobigerina bosquensis* shows discontinuous occurrence down to the well hole. Importantly, *Archeoglobigerina bosquensis* shows a short stratigraphic range within the interval thereby making it an excellent interval range zone, thus, dated Lowermost Santonian age of the Afowo Formation.

Foraminifera Zone : Hedbergella planispira zone
Interval : 7320 – 7500ft
Age : Coniacian

Characteristics: The top of the interval is marked by the first downhole appearance (FDO) of *Hedbergella planispira* at 7320ft while the base is defined by the last downhole (LDO) occurrence of the form at 7500ft. However, Hedbergella planispira shows high quantitative occurrence at the base of the interval compared to paucity frequency exhibited at the top of the interval. Its extinction at the 7320ft defines a Coniacian age and it may as well suggest Lowermost Coniacian age for the interval.

Foraminifera Zone : Heterohelix reussi zone
Interval : 7500 –8460ft
Age : Turonian

Characteristics: The top of the interval is marked by the LDO of *Hedbergella planispira* co-occurring with *Hedbergella holmdelenensis, Whiteinella inornata, Heterohelix spp,* and *Heterohelix reussi*. There is a continuous occurrence of *Heterohelix reussi* throughout the interval. Its continuous appearance stratigraphically at the lower part of the well is suggestive of Turonian age [33]. This interval (7500-8460ft) is straigraphically equivalent to Afowo Formation in Dahomey Embayment.

The peak abundance and diversity of plantonic foraminifera assemblages within interval 6360-6780ft is suggested to have been due to rise in sea level at about 83.9ma [34]. The marine transgression that occurred in Santonian period may also be associated with favourable ecological factors such as salinity, PH, nutrients, temperature, and water clarity within the photic zone. These factors are suggested to be responsible for high rate of reproduction and consequent high abundance and diversity in microforaminiferal. Some of the forms recovered within the condensed section of the analyzed stratigraphic interval under study include *Whiteinella inornata, Heterohelix spp, Hedbergella spp, Hedbergella holmdelensis, Heterohelix reussi, Globigerinelliodes spp, Globigerinelliodes ultramicrus* and *Dicarinella primitiva.*

4.3 Paleoenvironmental Interpretation

Paleoenvironmental reconstruction of the sediment deposited within the studied interval is dependent on the environmental marker forms recovered from both nannofossil and benthic foraminifera present in the assemblages. These have served as relevant tools for reconstruction of paleoenvironmental studies.

Calcareous nannofossil stratigraphical distribution of Deb-1 well shows high abundance and diversity at the upper part of the well; showing episodic peaks of abundance and diversity at different intervals of upper section of the analyzed well 4650ft to 4900ft and 5600ft – 5750ft. At the middle section of the well, representing 6200ft to 6800ft.This interval also corresponds to the top of foraminifera stratigraphic interval characterized by acme abundance and diversity of planktonic foraminifera at interval 6300-6750ft. Foraminiferal forms that characterized the interval include*Heterohelix spp, Hedbergella holmdelensis, Heterohelix reussi, Globigerinelliodes spp, Globigerinelliodes ultramicra,* and *Dicarinella primitiva.* At this top interval are few benthonic foraminifera (calcareous and agglutinated).

Lack of benthonic foraminifera has been attributed to an oxygen minimum zone impinging at the bottom of the sea. [35] suggested that low oxygen at the bottom of sea may be due to a lower global thermal gradient during the Cretaceous time. The oceanic circulation was suggested to be more sluggish and there was low concentration of oxygen in the Late Cretaceous time than present age. Stratigraphically environ B mentally important Calcareous benthonic foraminifera encountered include *Valvulineria spp, Anomalinoides spp, Cibicides spp, Anomalina spp, Nodosaria spp,* and *Eponides spp.* Agglutinated benthonic Foraminifera present are *Ammobaculites spp, Ammodiscus spp, Karreriella spp,* and *Martinotiella spp.* The presence of this forms are indicative of brackish water to inner neritic environment (Appendix 3). The recovery of these benthic forms from dark shale, dark silty to dark sandy shale facies is indicative of anoxic water conditions that correlate with minimum oxygen concentration [35].

Other factors used in deducing the paleoenvironment of deposition include Fisher's diversity index which is used in determining Fisher's diversity values (Fisher's alpha value = ά).Fisher's diversity index was made with the help of chart having S against N-S as calculated and plotted by the [36]. Where S is the number of species, N is the number of individual abundance. [37] indicated that the maximum Fisher's alpha value for hyposaline assemblage is 2.5 and in most cases the values are around 1.0. However, when the value is above 7 or 8 is indicative of normal marine environment. Deeper marine settings such as bathyal and abyssal produce values of 10 and above. Therefore, the Fisher's value obtained for the well varies from 0.00-5.52 which is suggestive of paleobathymetry not deeper than outer neritic environment.

The planktonic and benthonic foraminifera ratio (P/B ratio, frequently expressed as a percentage of plantonic foraminifera with respect to the bethonic forms), is another reliable proxy used to estimate paleo-water-depths. Percentage of planktonic foraminifera in modern sediments increases with depth [38,39,40]. The percentage of benthonic foraminifera is inversely proportional to depth because their rate of reproduction depends on the amount of nutrient and other ecological factors affecting the sea floor. Benthonic foraminifera take up organic matter three times as effectively as planktonic foraminifera [40].

Planktonic foraminifera tend to be more abundant than benthonic because the frequency of type of foraminifera is dependent on the organic matter influx and the amount reaching the sea floor decreases with depth due to oxidation. Thus, the p/b ratio tends to increase with depth [41]. Planktonic foraminifera are more abundant in Deb-1 well than benthonic foraminifera due to the suggested conditions. The ratio of planktonic to benthonic foraminifera has provided useful palaeoenvironmental guide in this study and the higher the ratio of the planktonics the deeper the paleo-depth [41,42].

This phenomenon is observed in this study whereby the p/b ratio tends to be highest at interval 8280-8340ft; moderate at 6960-7020ft and 6360-6480ft and lowest at 6780-6840ft and 6300-6360ft (Table 3). Therefore, the study shows that the paleobathymetry of the well section fluctuates but shows prograding nature; retrograding (shallowing) at 6780-6840ft, and deepening at depth 6300-6480ft. The sharp difference in paleobathymetry from 6480-6780ft may be suggestive of surface of unconformity or stratigraphic gap (Fig. 4). However, interval 6840-8340ft shows a continuous increase in bathymetry probably from maginal marine to open marine system.

Table 3. P/B ration for analyzed interval

Depth (ft)	Planktonic abundance	Benthonic abundance (calcareous & agglutinated)	P/B ratio
6360-6360	3	6	0.5
6360-6420	33	2	16.5
6420-6480	62	2	31
6780-6840	2	1	2
6900-6960	25	3	8.3
6960-7020	35	3	11.7
7320-7380	20	1	20
8280-8340	28	1	28

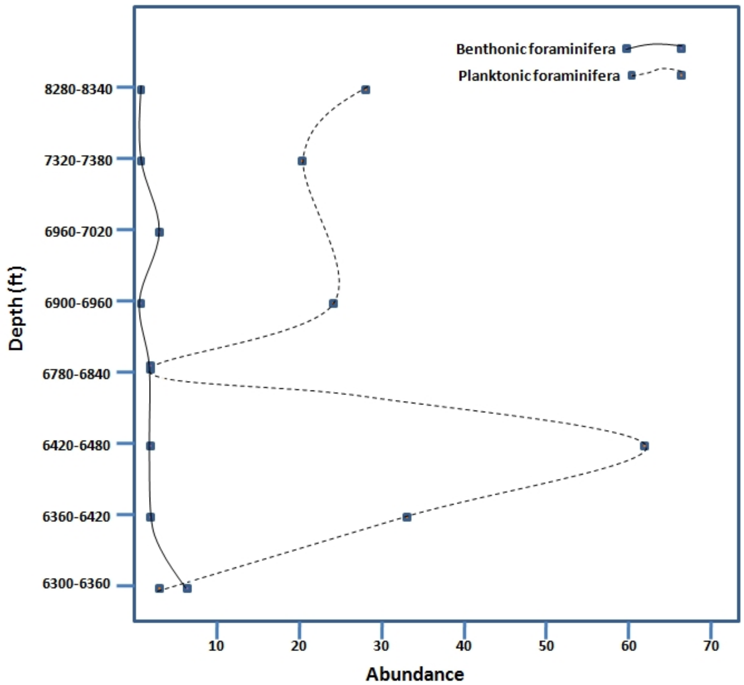


Fig. 4. Planktonic and Benthonic foraminifera abundance curve for 6300-8340ft of Deb-1 well Offshore Dahomey Basin, Southwestern Nigeria

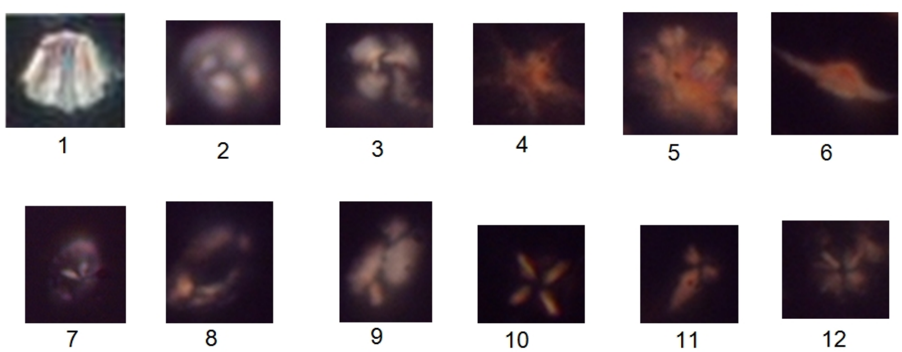


Plate 1. Calcareous nannofossil photomicrographic images

1. *Catinaster coalitus* Martini and Bramlette, 1963 1000X sample 5100-5150
2. *Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930 1000X sample 5750-5800
3. *Cyclicargolithus floridanus* (Roth and Haq et al., 1967) Bukry, 1971 1000X sample 5700-5750
4. *Discoaster berggrenii* Bukry, 1971 1000X sample 4750-4800
5. *Discoaster deflandrei* Bramlette and Riedel, 1954 1000X sample 5700-5750
6. *Discoaster quinqueramus* Gartner, 1969 1000X sample 4650-4700
7. *Eiffellithus eximius* (Stover, 1966) Perch-Nielsen, 1968 1000X 6100-6150
8. *Helicosphaera ampliaperta* Bramlette and Wilcoxon, 1967 1000X sample 4800-4850
9. *Helicosphaera carteri* (WALLICH, 1877) Kamptner, 1954 1000X sample 5750-5800
10. *Micula decussata* Vekshina, 1959 1000X 6100-6150
11. *Sphenolithus heteromorphus* Deflandre, 1953 1000X sample 4750-4800
12. *Sphenolithus moriformis* (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967 *1000X sample 5700-5750*

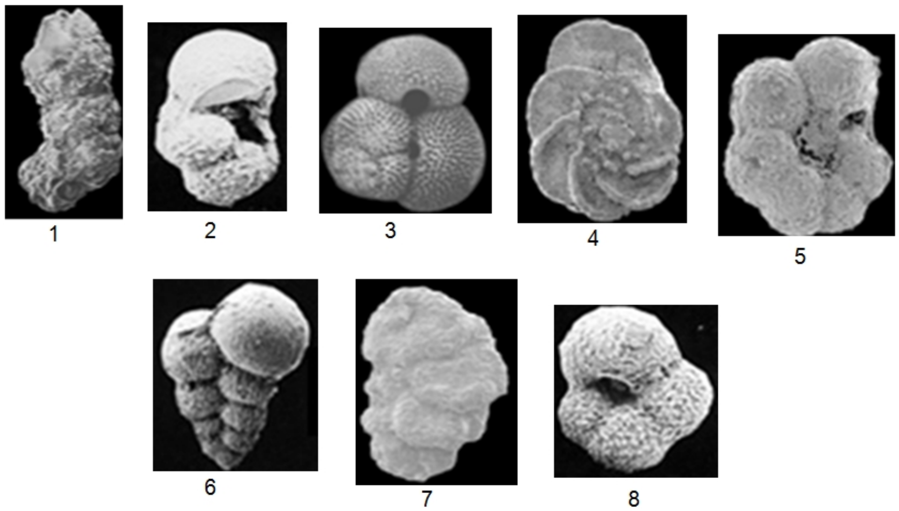


Plate 2. Foraminifera photomicrographic images
1. *Ammobaculites spp* 25X sample 6300-6360
2. *Archaeoglobigerina bosquensis* Pessagno, 1967 25X sample 6660-6720
3. *Globigerinelloides spp* 25X sample 6480-6540
4. *Globotruncanita spp* 25X sample 6420-6480
5. *Hedbergella planispira* Tappan, 1940 72X sample 6300-6360
6. *Heterohelix spp* 25X sample 6420-6480
7. *Valvulineria spp* 25X sample 6300-6360
8. *Whiteinella inornata* 25X Bolli, 1957 sample 6540-6600

5. CONCLUSION

Calcareous nannofossil and foraminifera investigation of Deb-1 well in the deep offshore of eastern Dahomey Basin has resulted in the interpretation of the chronology, biostratigraphy and environment of deposition of the studied interval 4650 – 8460ft (1417 – 2579m). This investigation gave six (6) nannofossil zones subdivided into Late, Middle, and Early Miocene Which are marked by the FDO of *Discoaster quinqueramus, Catinaster coalitus,* and FOD of *Sphenolithus heteromorphus* and *Helicosphaera ampliaperta*, within the interval of 4650 – 5900 ft. The FDO of *Eiffellithus eximius and LOD of Micula decussata* (CC14/CC22) marked Santonian to Campanian age (5900 – 7050ft). The zone of CC12 and older sediments of Turonain age is marked by the LDO of *Eiffellithus eximius,* (7050–8460ft). The Santonian to Turonian age also corroborate with the appearance of some foraminifera bio-markers like; the FDO of *Heterohelix reussi* (4650 – 8460 ft), *Dicarinella primitiva* (6540 – 7140 ft), *Archeoglobigerina bosquensis* (6900 – 7140 ft), and *Hedbergella planispira* (7320 – 7500 ft). The presence of little organic matter, woody materials indicates near shore source of sediments deposition. Specks of pyrites (FeS_2) deposited within the shales at some depths suggest that the sediments were deposited in a reducing (anaerobic or anoxic) environment. The presence of some benthonic foraminifera like *Cibicides spp, Anomalinoides spp, Ammodiscus spp, Karrerialla spp, Martinotiella spp*indicates an open marine environment (Inner Neritic). Fisher's diversity index (ά) of below 2 or above 2.0 also indicates an environment beyond a hyposaline environment (ά =1), which is also suggestive of an open marine environment (Inner Neritic – Outer Neritic). The P/B ratio as well shows dominance of planktonic foraminifera down the well, which indicates deeper paleo-water-depth (paleobathymetry), is trending towards open marine water environment of outer neritic setting.

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COMPETING INTERESTS

Authors declare that there are no competing interests.

REFERENCES

1. Klemme HD. Geothermal Gradient, Heat Flow and Hydrocarbon Recovery. In: Fischer AG, Judson S, editors. Petroleum and Global tectonics. Princeton: University Press; 1975;251-304.
2. Kingston DR., Dishroon, CP, Williams PA. Global basin classification system. A.A.P.G Bull. 1983;67:2175-2193.
3. Burke KCB, Dessauvagie TFJ, Whiteman AJ. The opening of the Gulf of Guinea and the Geological History of the Benue Depression and Niger Delta. Nature, Phys. Sci. 1971;233(38):51-55.
4. Whiteman AJ. Nigeria: Its petroleum geology, resources and potential. Grahman and Trottan Ltd, London. 1982;394.
5. Jones HA, Hockey RD. The geology of part of Southwestern Nigeria. Geological Survey of Nigeria. Bull. 1964;31:87.
6. Ogbe FGA. Stratigraphy of strata exposed in the Ewekoro quarry, Western Nigeria. In: Dessauvagie TFJ, Whiteman AJ, editors. African Geology. Nigeria: University Press; 1972.
7. Omatsola ME, Adegoke OS. Tectonic Evolution and Cretaceous Stratigraphy of the Dahomey Basin. Journal of Mining and Geology. 1981;18(1):130-137.
8. Wilson RCC, Williams CA. Oceanic transform structures and the developments of Atlantic continental margin sedimentary basin a Review. In: Olabode SO. (2006), Siliciclastic slope deposits from the Cretaceous Abeokuta Group, Dahomey (Benin) Basin, Southwestern Nigeria. Journal of African Earth Sciences. 1979; 46:187–200.
9. Obaje NG.The Dahomey Basin, Lecture notes in earth sciences. *Geology and Mineral Resources of Nigeria.* Springer Berlin Heidelberg. 2009;120:103-108.
10. Agagu OKA Geological Guide to Bituminous sediments in Southwestern, Nigeria. Unpublished Report, Department of Geology, University of Ibadan, Ibadan. 1985;1-16.
11. Akinmosin AA, Omosanya KO, Ikhane PR, Mosuro GO, Goodluck I. Characterization of a bitumen seepage in Eastern Dahomey Basin, Southwestern, Nigeria. Advances in Applied Science Research. 2012;3(4):2078-2089.
12. Nton ME, Ikhane PR, Tijani MN. Aspect of Rock-Eval Studies of Maastrichtian-Eocene sediments from subsurface in the eastern Dahomey Basin, southeastern Nigeria. European Journal of Scientific Reasearch. 2009;25(3):417-427.
13. Billman HG. Offshore Stratigraphy and Paleontology of the Dahomey Embayment, West African. NAPE Bulletin. 1992;7(2):121–130.

14. Omatsola ME, Adegoke, O.S. Tectonic Evolution of Dahomey Basin. Min. Geol. 1981;54:65-87.
15. Adegoke OS. Stratigraphy and Paleontology of the Ewekoro Formation (Paleocene) of Southwestern Nig. Bulletin American Paleontology. 1977;71(295):275.
16. Nton ME. Sedimentology and Geochemical Studies of rock units in the Eastern Dahomey Basin, Southwestern Nigeria. Ph.D Thesis, University of Ibadan, Ibadan, Nigeria. 2001;315.
17. Nton ME, Elueze AA. Compositional characteristics and industrial assessment of sedimentary clay bodies in part of Eastern Dahomey basin, Southwestern Nigeria. Journal of Mining and Geology. 2005;4(12):175 -184.
18. Ako BD, Adegoke OS, Petters S. Stratigraphy of Oshosun Formation in Southwestern Nigeria. Journal of Mining and Geology. 1980;17:99-106.
19. Kogbe, CA. Paleogeographic history of Nigeria from Albian Times. In: Kogbe CA, editor. Geology of Nigeria. Rock View International Tour Onyx Paris Cedix 13 France. 1989;257-275.
20. Martini E. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, editors, Proceedings II planktonic conference, Roma. 1971;2:739-785.
21. Perch-Nielsen K. Calcareous nannofossil zonation at the Cretaceous/Tertiary boundary in Denmark. In: Birkelund T, Bromley, RG, editors. Cretaceous-Tertiary Boundary Events, The Maastrichtian and Danian of Denmark. Copenhagen: University of Copenhagen. 1979;1:115-135.
22. Perch-Nielsen K. Cenozoic calcareous nannofossil. In: Bolli HM, Saunders JB, Perch-Nielsen K, editors. Plankton Stratigraphy. Cambridge Earth Sciences Series: Cambridge University Press. 1983;427-554.
23. Okada H, Bukry D. Supplementary modification and introduction of code numbers to the low latitude coccolith biostratigraphic zonation. Marine Micropaleontology, Netherlands. 1980;5(2):321-325.
24. Fayose EA. Stratigraphic paleontology of Afowo-1 well, southwestern Nigeria. Journal of Mining and Geology. 1982;5(1):23-34.
25. Petters SW. Central West African Cretaceous-Tertiary benthic foraminifera and stratigraphy. Palaeontographica Abt. A. 1982;179:1-104.
26. Bolli HM, Saunders, JB. Oligocene to Holocene low latitude planktic foraminifera: In Bolli HM, Saunders, JB, Perch-Nielsen K editors. Plankton stratigraphy. Cambridge University Press, Cambridge. 1985;155-262.
27. Loeblich AR Jr, Tappan H. Foraminiferal genera and their classification. New York: Van Nostrand Reinhold company; 1987.
28. Boboye O.A, Adeleye A.M. High resolution biostratigraphy of Early Pliocene to Late Miocene Calcareous nannoplankton and foraminiferal, deep offshore, Niger Delta, Nigeria. European Journal of Scientific Research. 2009;34(3):308-325.
29. Siissingh W. Biostratigraphy of Cretaceous calcareous nannoplankton. Geol. Mijnbouw. 1977;56:37-65.
30. Cushman JA. A monograph of the foraminiferal family Valvulinidae. Cushman laboratory for foraminiferal research. Special publication. 1937;8:210.
31. Dalbiez F. The genus Globotruncana in Tunisia. Micopaleontology. 1955;1:161-171.
32. Pessagno EA Jr. Upper Cretaceous planktonic foraminifera from the western Gulf Coastal plain. Palaeontographical America. 1967; 5:245-445.
33. Tappan H. 1940. Foraminifera from the Grayson Formation of northern Texas. Journal of Paleontology. 1940;4:93-126.
34. Haq BU, Hardenbol J, Vail PR. Mesozoic and Cenozoic Chronostratigraphy and Eustatic cycles. SEPM Sp. Publ. 1988;42:71-108.

35. Fruch MP, Eicher, DL. Cenomanian and Turonian foraminifera and paleoenvironments in the big brend region of Texas and Mexico. Geological Association of Canada special paper. 1975;13:227-301.
36. Fisher RA, Corbet AS, Williams. The relationship between the number of species and the number of individuals in a random sample of an animal population. J. Anim. Ecol. 1943;12(1):42-58.
37. Murray JW. An atlas of British Recent foraminiferids. New York : Elsevier; 1971.
38. Boltovoskoy E, Wright R. Recent foraminifera. Dr.W. junk.b.v., the hague. 1976;515.
39. Gibson TG. Planktonic/benthonic foraminifera ratios: modern patterns and Tertiary applicability. Marine Micropaleontology. 1989;15:29-52.
40. Van der Zwaan, GJ, Duijnstee, IAP, Den Dulk M, Ernest SR, Jennink NT, Kouwnhoven TJ. Benthonic foraminifers: proxies or problems? A review of paleoecological concepts. EarthScience Review. 1999;46:213-236.
41. Brasier MD. The Cambrian radiation event. In: House MR editor. The origin of major invertebrate groups. Systematic Association Special. 1979;12:103-159.
42. Haq BU, Boersma A. Introduction to marine micropaleontology. New York: Elsevier; 1978.

APPENDIX-1

List of Identified Nannofossils

Catinaster coalitus Martini and Bramlette, 1963

Coccolithus pelagicus (Wallich, 1877) Schiller, 1930

Cyclicargolithus floridanus (Roth and Haq et al., 1967) Bukry, 1971

Cyclagelosphaera reinhardtii (Perch-Nielsen, 1968) Romein, 1977

Discoaster. berggrenii Bukry, 1971

Discoaster deflandrei Bramlette and Riedel, 1954

D. quinqueramus Gartner, 1969

Eiffellithus eximius (Stover, 1966) Perch-Nielsen, 1968

Helicosphaera ampliaperta Bramlette and Wilcoxon, 1967

Helicosphaera carteri (WALLICH, 1877) Kamptner, 1954

Helicosphaera intermedia (Martini, 1965)

Micula decussata Vekshina, 1959

Pontosphaera multipora (Kamptner 1948) Roth 1970

Reticulofenestra haqii Backman, 1978

Reticulofenestra minuta Roth 1970

Reticulofenestra pseudoumbilica Gartner, 1969

Reticulofenestra sp. (Levin, 1965) Martini and Ritzkoski, 1968

S. heteromorphus Deflandre, 1953

S. moriformis (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967

APPENDIX-2

List of identified Foraminifera

Archeoglobigerina bosquensis Pessagno, 1967

Dicarinella primitiva Dalbiez, 1955

Globigerinelloides spp

Globigerinelloides ultramicrus Subbotina, 1949

Hastigerinelloides spp

Hedbergella holmdelensis Olsson, 1964

Hedbergella planispira Tappan, 1940

Hedbergella spp

Heterohelix reussi Cushman, 1938

Heterohelix spp

Whiteinella inornata Bolli, 1957

APPENDIX-3

Benthonic Foraminifera Encountered and their Environment

Brackish zone	Inner neritic	Outer neritic
Valvulineria spp	*Cibicides spp*	*Nodosaria spp*
Ammobaculites spp	*Anomalinoides spp*	
	Ammobaculites spp	
	Ammodiscus spp	
	Karrerialla spp	
	Martinotiella spp	

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