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.

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

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 on 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 foraminifera 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 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.

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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 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 biostratigraphic study involving calcareous nannofossils and foraminferal 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, research on the stratigraphic settings of the offshore part of the Dahomey Basin is rare. Hence integration of nannofossil and foraminferal 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 [10]. The onshore margin is predominantly clastic sediments directly deposited on the basement complex and the offshore margins are thick, fine grained, 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 Agagu, 1985).

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. This group is the thickest sedimentary 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 interbeds. Based on palynological evidence, the formation is assigned Turonian-Maastrichtian age [13]. Afowo Formation is successively 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 foraminifera contents [7]. 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 predominantly of estuarine, deltaic and continental in origin [19]. The formation is of Oligocene-Recent in age[6,14].

![Stratigraphy and lithologic features of Dahomey Basin according to Omatsola and Adegoke (1981).](image)

**Fig. 3.** Stratigraphy and lithologic features of Dahomey Basin according to Omatsola and Adegoke (1981).

### 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 the 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 60°-70°C. 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 NANNOFOSIL

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.

<table>
<thead>
<tr>
<th>Nannofossil zone:</th>
<th>NN11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratigraphic Interval:</td>
<td>4650-4800ft</td>
</tr>
<tr>
<td>Age:</td>
<td>Late Miocene</td>
</tr>
</tbody>
</table>

**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*.

<table>
<thead>
<tr>
<th>Nannofossil zone:</th>
<th>NN8-NN10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratigraphic Interval:</td>
<td>4800-5100ft</td>
</tr>
<tr>
<td>Age:</td>
<td>Late Miocene</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>Nannofossil zone:</th>
<th>NN5-NN7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratigraphic Interval:</td>
<td>5100-5750ft</td>
</tr>
<tr>
<td>Age:</td>
<td>Middle Miocene</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>Nannofossil zone:</th>
<th>NN4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratigraphic Interval:</td>
<td>5750-5900ft</td>
</tr>
</tbody>
</table>
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*, *Micerca decussata*, and *Cyclagelospaera reinhardtii*. The base is marked by last downhole occurrence of *Micerca 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* and 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.
Table 1: Calcareous nannofossil zones recognized in Deb-1 well.

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Epoch</th>
<th>Age (Ma)</th>
<th>Zones (Perch-Nielsen, 1979; 1983)</th>
<th>Zones (Marini, 1973)</th>
<th>This study</th>
</tr>
</thead>
<tbody>
<tr>
<td>4650</td>
<td>Late Miocene</td>
<td>8.3 Ma</td>
<td>NN11 Discoaster quinqueramus</td>
<td>NN11 Discoaster quinqueramus</td>
<td>NN8–NN10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.8 Ma</td>
<td>NN10 D. calcis Zone</td>
<td></td>
<td>Coticaster coactus Zone</td>
</tr>
<tr>
<td>5100</td>
<td>Early-Middle</td>
<td>10.8 Ma</td>
<td>NN9 D. hamatus Zone</td>
<td></td>
<td>NN8 Coticaster coactus Zone</td>
</tr>
<tr>
<td></td>
<td>Miocene</td>
<td>13.2 Ma</td>
<td>NN8 Coticaster coactus Zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5750</td>
<td>Early-Middle</td>
<td>15.6 Ma</td>
<td>NN7 D. kugleri Zone</td>
<td></td>
<td>NN6–NN7</td>
</tr>
<tr>
<td></td>
<td>Miocene</td>
<td>18.2 Ma</td>
<td>NN6 D. exilis Zone</td>
<td></td>
<td>Sphenoilithus heteromorphus Zone</td>
</tr>
<tr>
<td>5900</td>
<td>Indeterminate</td>
<td>Indeterminate</td>
<td>NN5 Sphenoilithus heteromorphus Zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6080</td>
<td></td>
<td></td>
<td>NN4 Helicosphaera ampliaperta Zone</td>
<td></td>
<td>NN4 Helicosphaera ampliaperta Zone</td>
</tr>
<tr>
<td>7050</td>
<td>Santonian-Late</td>
<td>75.3 Ma</td>
<td>NN3 S. belemnos Zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Campanian</td>
<td>87.2 Ma</td>
<td>NN2 D. droppi Zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NN1 Triquetrorhabdulus carinatus Zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8460</td>
<td>Turonian and</td>
<td>91.1 Ma and</td>
<td>CC12 E. eximus (PDO)</td>
<td></td>
<td>CC13–CC22</td>
</tr>
<tr>
<td></td>
<td>older</td>
<td>older</td>
<td></td>
<td></td>
<td>E. eximus (PDO)</td>
</tr>
</tbody>
</table>
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. 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 holmdelensis, Heterohelix reussi and Globigerinelloides 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 holmdelensis, 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 stratigraphically 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*.

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 important Calcareous benthonic foraminifera encountered include *Valvulineria spp, Anomalinooides spp, Cibicides spp, Anomalina spp, Nodosaria spp, and Eponides spp*. Agglutinated benthonic Foraminifera present are *Ammobaculites spp, Ammodiscus spp, Karriera spp, and Martinotiella spp*. The presence of these 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 = α). 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 planktonic foraminifera with respect to the benthonic 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. 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 marginal marine to open marine system.

Table 2: P/B ration for analyzed interval

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Planktonic Abundance</th>
<th>Benthonic Abundance (Calcareous &amp; Agglutinated)</th>
<th>P/B ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>6360-6360</td>
<td>3</td>
<td>6</td>
<td>0.5</td>
</tr>
<tr>
<td>6360-6420</td>
<td>33</td>
<td>2</td>
<td>16.5</td>
</tr>
<tr>
<td>6420-6480</td>
<td>62</td>
<td>2</td>
<td>31</td>
</tr>
<tr>
<td>6780-6840</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6900-6960</td>
<td>25</td>
<td>3</td>
<td>8.3</td>
</tr>
<tr>
<td>6960-7020</td>
<td>35</td>
<td>3</td>
<td>11.7</td>
</tr>
<tr>
<td>7320-7380</td>
<td>20</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>8280-8340</td>
<td>28</td>
<td>1</td>
<td>28</td>
</tr>
</tbody>
</table>
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 – 8460 ft (1417 – 2579 m). 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 – 7050 ft). The zone of CC12 and older sediments of Turonian age is marked by the LDO of Eiffellithus eximius, (7050–8460 ft). 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 (FeS2) 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, Anomalalinoides spp, Ammodiscus spp, Karrerialla spp, Martinotiella spp indicates an open marine environment (Inner Neritic). Fisher’s diversity index (α) of below 2 or above 2.0 also indicates an environment beyond a hyposaline environment (α =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.
PLATE 1

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
8. *Helicosphaera ampliaperta* Bramlette and Wilcoxon, 1967 1000X sample 4800-4850
11. *Sphenolithus heteromorphus* Deflandre, 1953 1000X sample 4750-4800

PLATE 2

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

PLATE 1

Calcareous nannofossil photomicrographic images

![Image 1](image1.png)
![Image 2](image2.png)
![Image 3](image3.png)
![Image 4](image4.png)
![Image 5](image5.png)
![Image 6](image6.png)
![Image 7](image7.png)
![Image 8](image8.png)
![Image 9](image9.png)
![Image 10](image10.png)
![Image 11](image11.png)
![Image 12](image12.png)
REFERENCES


**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
*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

<table>
<thead>
<tr>
<th>Brackish zone</th>
<th>Inner neritic</th>
<th>Outer neritic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valvulineria spp</td>
<td>Cibicides spp</td>
<td>Nodosaria spp</td>
</tr>
<tr>
<td>Ammobaculites spp</td>
<td>Anomalinoides spp</td>
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<tr>
<td></td>
<td>Ammobaculites spp</td>
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<tr>
<td></td>
<td>Ammodiscus spp</td>
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<tr>
<td></td>
<td>Karrerilla spp</td>
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<tr>
<td></td>
<td>Martinotiella spp</td>
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</tbody>
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