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Evidence of Paleocene-Eocene Thermal Maximum (PETM) on Early Eocene Benthic Foraminifera in the Eastern Dahomey Basin, Southwestern Nigeria

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Abstract

Core samples from Ilaro BH-7 (51–202m) in the eastern Dahomey basin were subjected to standard foraminiferal biostratigraphic analysis to determine their foraminiferal assemblages, diversity, age and paleoenvironments. The benthic foraminiferal species were subjected to stable isotope analyses to identify possible records of the Paleocene-Eocene Thermal Maximum. The sediments are essentially silicified limestones, sandstones and shales/mudstones, with thin beds of siltstones. Identified foraminiferal assemblages consists of 16 planktic, 12 benthic and 2 agglutinated species belonging to two planktic foraminiferal zones, P4-P7 and P8, defined by *Acarinina pentacamerata* and the *Pseudohastigerina micra,* respectively. The planktic/benthic foraminiferal ratios varied between 22 and 84%. The Shannon-Wiener and Fisher Alpha species richness and diversity averages are 1.99 and 1.13, respectively. $\delta^{13}C$ in benthic foraminifera showed negative to strong negative chemostratigraphic curve from 0.59 ‰ to -15.66‰, while $\delta^{18}O$ showed slightly strong negative shift from -1.81‰ to -6.76‰. Recovered species exhibited moderate diversity and were almost entirely calcareous assemblages, indicating restricted environmental conditions in the borehole. The sediments were assigned ages of 50.2Ma, 50.5Ma and 57.7Ma corresponding to Late Paleocene to Early Eocene. The depositional environment ranged from inner shelf to upper continental slope. The oxygen isotope revealed a synchronous negative short-term excursion with cyclic fluctuation owing to the changing water temperature in the environment. The temperature may not play significant role in the extinction of the benthic foraminifera because of their adaptation to $\delta^{18}O$ depleted environment. However, strong negative shift of carbon isotope revealed Thermal Maximum event in the studied interval.

Keywords*: Paleocene-Eocene Thermal maximum; Benthic foraminifera; Stable isotopes; Paleoenvironment.*

1. Introduction

The Paleocene–Eocene Thermal Maximum (PETM) is one of the most intense and abrupt intervals of global warming in the geological record. It occurred around 56 million years ago, at the boundary between the Paleocene and Eocene epochs. This warming has been linked to a similarly rapid increase in the concentration of greenhouse gases in Earth's atmosphere, which acted to trap heat and drive up global temperatures by more than 5°C in just a few thousand years leading to rapid extinction of 30-50% of the deep-sea benthic foraminiferal species [1-2]. Other biotic responses to PETM include abundance and diversification of the dinoflagellates, terrestrial mammal migration [3-4] and accelerated origination and extinction of calcareous nannoplanktons [5]. In addition, the ocean-atmosphere also witnessed increased acidification and enormous injection of ^{13}C-depleted carbon with a consequent negative carbon isotope excursion (CIE) [6-7]. So far, the exact cause(s) of this severe extinction event remains unknown, it is likely that a change in food-web structure, affected by high temperatures, a decrease in the oxygenation state of the oceans, calcite under saturation, primary productivity or ocean current circulation changes played important role in the benthic foraminiferal extinction (BFE) and in the establishment of the opportunistic fauna that characterizes the PETM itself [1]. The extinction resulted in reorganization of the assemblages, including the last appearance of about a quarter to half of the species and the first appearance of some species.

The question arises on role played by these events in the development of early Eocene benthic communities? Answer to these questions could be obtained from detailed quantitative benthic foraminiferal data of core samples from sedimentary basins.

Dahomey basin became increasingly interesting in recent years because of its potential for hydrocarbon generation and accumulation, and the eventual oil production from its offshore section. Though large deposits of proven bitumen have been known, and it remained a strong indicator to the presence of commercial hydrocarbon accumulation in the basin. The basin is also characterised by large reserves of limestones estimated to be over 7.7 x 10^8 m^3 [8] apart from the fact that it has generated huge income for Nigeria from cement production in the last fifty years. Most studies on the Cretaceous-Eocene sediments of Dahomey basin were focused on lithostratigraphy, biostratigraphy and hydrogeology of the shales and limestones of Ewekoro Formation. Pioneer researches on the post Cretaceous stratigraphy of southern Nigeria were initiated by the British geologists in the early 19th century, and this made way for more intensive work on the basin. The five lithostratigraphic Formations covering the Cretaceous to Tertiary ages in Dahomey basin have been described [9-14]. Ogbe [15] studied the micropaleontology of the strata exposed at the Ewekoro quarry. He recorded a diverse foraminiferal fauna containing over 40 species from the limestone and erected the microfacies unit. Despite the relative abundance of studies conducted in the Dahomey basin spanning across biostratigraphy, palynology, paleoenvironments, mineral resources evaluation amongst others, very little attention is focused on the PETM events within the basin. Bankole *at al.* [16] used the abundance of dinoflagellates (genus *Apectodinium)* to recognize the PETM events in the Oshosun Formation within the eastern Dahomey basin. This study therefore aims at evaluating the variability in diversity and evolution of early Eocene foraminiferal faunas including their extinctions, originations and ecological preferences as evidence for the PETM events in the eastern Dahomey basin, Nigeria.

2. Geological setting

Dahomey basin is one of the marginal basins formed along the coasts of Africa and Brazil following the opening of the south Atlantic. The equatorial arm of the Benue Trough is a shear zone, thus the basin originated essentially as a wrench fault feature [17]. The basin extends from southwestern Ghana in the west through the Republics of Togo and Benin into the southwestern flank in Nigeria (Figure 1), as far the Okitipupa ridge [18].

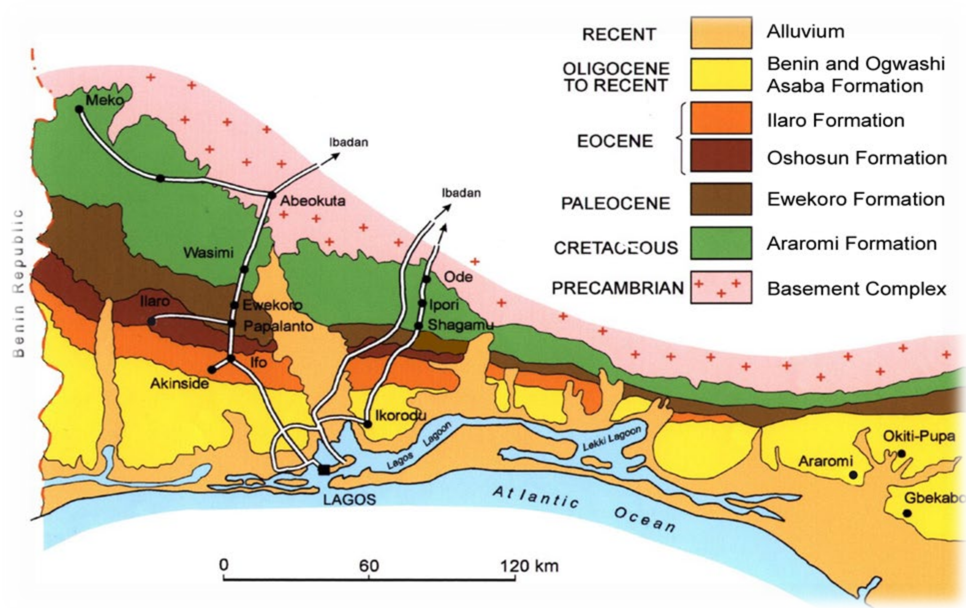


Figure 1. Geological map of the Dahomey basin (modified after [18])

About 40% of the basin containing 10,000-12,000 ft of Cretaceous and Tertiary rocks lies within Nigeria. The axis and the thickness of the sediments in the basin occur slowly to the west by faults and other tectonics structures associated with the landward extension of fracture zone [19]. The stratigraphy of the Dahomey basin has been discussed in varying details by several workers [9, 11, 20-22]. The basin contains Late Cretaceous to Recent sediments up to 2,100m which thickened markedly into the offshore and then thins beneath the deep water area. The Dahomey basin fill can broadly be packaged into two; the Cretaceous Abeokuta Group that comprises of the Ise, Afowo and Araromi formations and it is unconformably overlain by the Ewekoro, Akinbo, Oshosun, Ilaro and the Pleistocene to Recent Benin formations (Table 1) [23].

Table 1. Stratigraphy of Eastern Dahomey Basin [23]

<table>
<tr><td colspan="2" rowspan="3">AGE</td><td colspan="3">FORMATIONS</td></tr>
<tr><td colspan="3">SOUTHWESTERN NIGERIA BASIN</td></tr>
<tr><td colspan="2">Onshore
(Omatsola & Adegoke, 1981)</td><td>Offshore
Billman (1992)</td></tr>
<tr><td>QUART.</td><td>PLEISTOCENE-RECENT</td><td colspan="2">BENIN Fm.
(COASTAL PLAIN SANDS)</td><td>BENIN Fm.</td></tr>
<tr><td rowspan="4">TERTIARY</td><td rowspan="3">EOCENE-PLIOCENE</td><td colspan="2">ILARO Fm.</td><td>IJEBU Fm.</td></tr>
<tr><td colspan="2">OSHOSUN Fm.</td><td>OSHOSUN Fm.</td></tr>
<tr><td colspan="2">AKINBO Fm.</td><td>AKINBO Fm.</td></tr>
<tr><td>PALEOCENE</td><td colspan="2">EWEKORO Fm.</td><td>IMO Fm.</td></tr>
<tr><td rowspan="5">CRETACEOUS</td><td>CAMPANIAN-MAASTRICHTIAN</td><td rowspan="5">ABEOKUTA GROUP</td><td>ARAROMI Fm.</td><td>NKPORO Fm.</td></tr>
<tr><td rowspan="2">TURONIAN-CONIACIAN</td><td rowspan="2">AFOWO Fm.</td><td>AWGU Fm.</td></tr>
<tr><td rowspan="2">ABEOKUTA Fm.
(AFOWO Fm.)</td></tr>
<tr><td rowspan="2">NEOCOMIAN-CENOMAIAN</td><td rowspan="2">ISE Fm.</td></tr>
<tr><td>ISE Fm.
(FOLDED SEDIMENTS)</td></tr>
</table>

3. Samples and methods

3.1. Samples

Core samples from Ilaro BH-7 (borehole) drilled by the Nigerian Geological Survey Agency (NGSA) in the onshore Dahomey basin were acquired for this study. The samples encountered at depth range of 51 m to 202 m were taken at approximately 6m interval from the base to the top of the borehole. The borehole penetrates parts of the Tertiary and the underlying Cretaceous sequences in the locality. The study area is geographically located in the southwestern region of the Nigeria specifically in the eastern Dahomey basin. Ilaro B-7 is located on the Okitipupa ridge to the western flank of the Niger Delta (Figure 2). The lithological log of the borehole (Figure 3) revealed three distinct lithological units comprising of silicified or sandy limestone, sandstones and shales/mudstones. The silicified limestone often contains lenses of mudstone and it is also intercalated by thin beds of siltstones. Limestone is the dominant lithology in Ilaro BH-7, occupying the interval from 202m to 129m and it is fossiliferous between 164m and 170m intervals as evident from the presence of shell fragments. The overlying lithology (128.7 – 28.5m) consists essentially of shale with varying colours of dark grey at 128.7 – 122.2m interval, light grey shale at 117 to 111m interval and subsequently grey shale to light grey shale from 111 to 28.5m interval. It is succeeded by a fine to medium grained sandstone at the top of the borehole section (28.5 to 10.6m interval). The boundary between the silicified limestone and the overlying shale mark the abrupt faunal change at 128.7m.

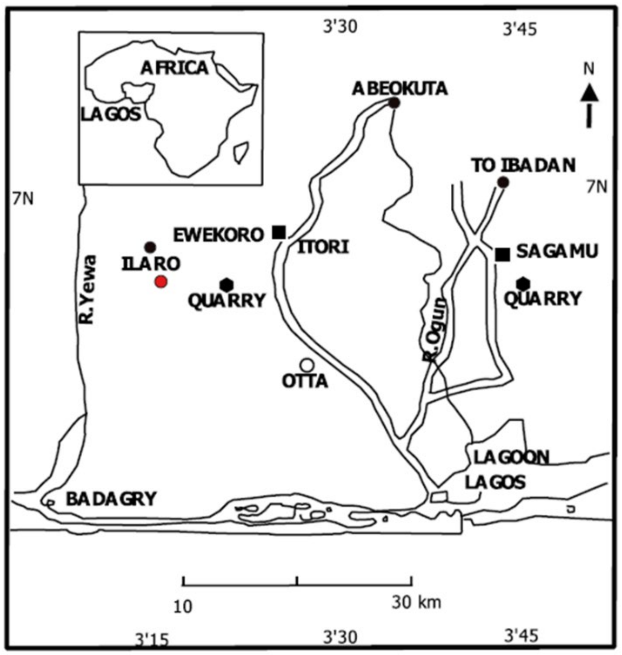


Figure 2. Location map of the study area

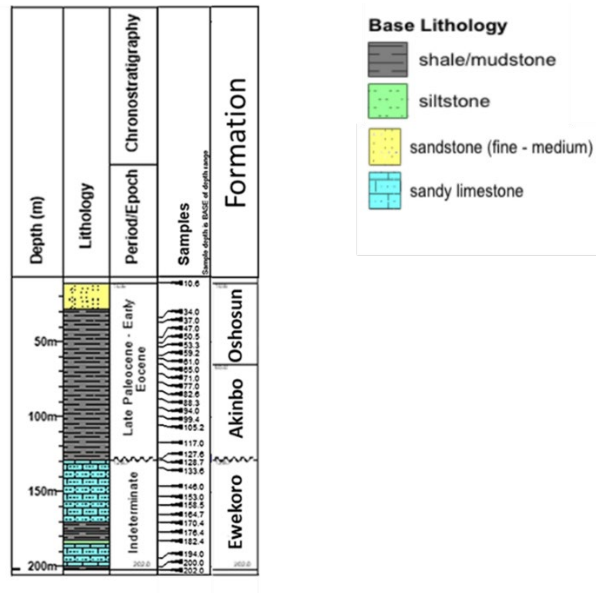


Figure 3. Lithological log of Ilaro BH-7

3.2. Methods

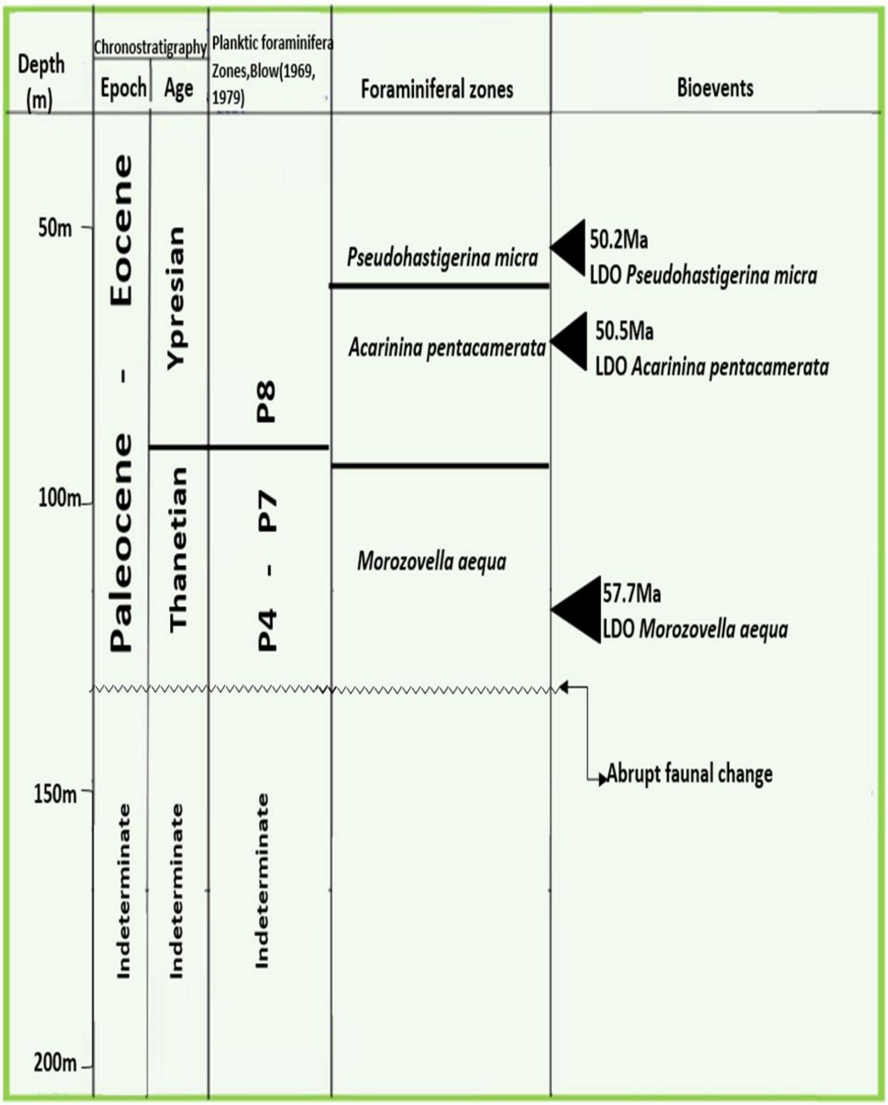
Twenty six (26) composited samples at 6m intervals were subjected to standard foraminiferal biostratigraphic analysis to identify the foraminiferal assemblages and their diversity. Sequel to identifying the different foraminiferal assemblages consisting of planktic, benthic and agglutinated species, pristine epifaunal benthic species which have been examined under optical microscope to contain primary wall mineralogy and devoid of iron-stains and secondary mineral in-fills were selected for stable isotope analysis. Four (4) selected foraminiferal taxa (*Lenticulina midwayensis, Fursenkoina elongata, Anomalinoides umbonifera, Gavelinella guineana*) were capsulated and placed in 5mL glass vial which were purged of ambient atmosphere with helium in a purge station and subsequently reacted with 100% phosphoric acid in a reaction station. Isotopic ratios of carbon and oxygen were measured repeatedly using a Gas Bench II connected to a Thermo Scientific Delta V Advantage Mass spectrometer, at the stable isotope laboratory, school of geoscience, University of Florida, U.S.A. Standard correction procedures was employed with typical precision of <0.15 per mil for $\delta^{13}C$ and <0.30 per mil for $\delta^{18}O$. The mean stable isotope values were also calibrated to the Vienna Pee Dee Belemnite standard (VPDB) and converted to conventional delta notation.

4. Results and discussions

4.1. Foraminiferal biozonation

The analysed samples yielded fairly rich and well preserved assemblages of planktics and benthic foraminifera species. A total of thirty (30) species comprising of 12 benthic, 16 planktics and 2 agglutinated species were recovered. The foramineral biozonation for Ilaro BH-7 is presented in Table 2. The Cenozoic chronostratigraphic scheme of Blow [24-25] was adopted for this study and the samples from the borehole was determined to belong to the planktic foraminiferal zones P4-P7 and P8 which is evident by the biostratigraphic interval between the First Appearance Datum (FAD) of the *Morozovella aequa* in the P4 zone and the First Appearance Datum of both the *Acarinina pentacamerata* and *Pseudohastigerina micra* in the P8 zone recovered.

Table 2. Foraminiferal zones for Ilaro BH-7



Definition of Zones

Morozovella aequa (Cushman and Renz) [26]

Foraminifera zone: P

Stratigraphic Interval: 50m-120m

Age: Late Paleocene – Early Eocene

Key foraminifera event: Last Downhole Occurrence (LDO) of *Morozovella* at 120m

This zone is characterized by the first appearance of the *Morozovella aequa* from the base of the borehole at 120m to the last appearance at the top 50 meter interval in the Ilaro BH 7, which is equivalent to the upper P4 zone.

Acarinina pentacamerata (Subbotina) [27]

Foraminifera zone: P7-P8

Stratigraphic Interval: 59m- 69m

Age: Early Eocene (Ypresian)

Key foraminifera event: Last Downhole Occurrence of *Acarinina pentacamerata at 69m*

This zone was defined as the partial range zone of the nominate taxon of the Last Downhole Occurrence of the *Acarinina Pentacamerata* (Subbotina) [27].

Pseudohastigerina micra (Cole) [28]

Foraminifera zone: P8
Stratigraphic Interval: 59m – 65m
Age: Early Eocene (Ypresian)
Key foraminifera event: Last Downhole Occurrence of the *Pseudohastigerina micra* at 65m.

This zone was defined by Olsson and Hembleben [29] as the E7 zone which corresponds to the P8 zone of Blow [25] chronostratigraphic zonation chart scheme. It is characterized by the Last Downhole Occurrence of the *Pseudohastigerina micra* at 65m towards the top of the Ilaro borehole 7 section.

Indeterminate zone
Stratigraphic Interval: 128.7 – 202m
Age: Indeterminate
Key event: Abrupt faunal change

Recovery of foraminifera tests was very poor from this section of the borehole, it was found that the faunal change is abrupt with only the benthic *Gavelinella guineana* recovered in the interval. Also, there is a sudden change of sedimentation from limestone to shale at the lower section of the borehole, at about 171 – 180 m (9 m interval), where a layer of shale and thin siltstone interbed was found to occur below the thick limestone bed. This marked a change in faunas across the boundary. The different sediment types containing the faunas indicate an uncomformity at this level, therefore rendering this zone indeterminate.

4.2. Paleoenvironment

The identified paleoenvironment from the species fall within the inner shelf to upper continental slope with the proportion of planktonic foraminifera varying between 22 and 84% (Table 3). This succession shows an initially low percentage values at the upper section which is the part of zone P8, followed by constant increase at the middle P8 to P7 and sudden decrease is followed by an increase at P4 zone.

Table 3. Foraminifera abundance data for Ilaro BH-7

Core section interval (m)	Planktonics	Benthics	P/B ratio	Planktonic %	Environment
47.00m – 50.50m	2	4	0.5	33.33	**Middle shelf**
50.50m – 53.50m	2	9	0.29	22.22	**Middle shelf**
53.30m – 59.20m	42	20	1.27	67.74	**Middle shelf**
59.20m – 61.00m	98	88	1.11	52.69	**Middle shelf**
61.00m – 65.00m	78	42	1.85	65.00	**Outer shelf**
65.00m – 71.00m	61	14	4.35	81.33	**Upper continental slope**
71.00m – 77.00m	-	-	-	-	-
77.00m – 82.60m	-	-	-	-	-
82.60m – 88.30m	-	-	-	-	-
88.30m – 94.00m	2	2	1.00	50.00	**Middle shelf**
94.00m – 99.40m	76	14	5.43	84.44	**Upper continental slope**
99.40m – 105.20m	22	7	3.14	75.86	**Upper continental slope**
105.20m – 111.00m	-	-	-	-	-
111.00m – 117.00m	11	23	0.48	32.35	**Middle shelf**
117.00m – 122.20m	-	-	-	-	-
122.20m – 127.60m	7	3	2.33	70	**Outer shelf**

4.3. Foraminiferal habitats

4.3.1. Planktonic foraminifera

This study of the Eocene planktic foraminifera is largely based on environmental inferences, which takes the ratio between planktonic and benthonic abundances into consideration. The genera occurring at shallow to deep habitat in the studied borehole include Morozovella and *Acarinina*. These two genera are of particular interest because of their dominance among tropical and subtropical assemblages of the early Paleogene. These genera also show a major turnover in taxonomic diversity close to the beginning of the Early Eocene. The deepest dwelling taxa are the *Planorotalites* and *Globorotaloides* with the latter being absent in the studied samples. The absence or rarity of these taxa may be a result of reduction in water depth or rising oxygen minimum zone.

4.3.2. Benthonic foraminifera

Benthonic (benthic) foraminifera have been extensively studied by geologists due to their good fossilization potential. Their shells have been particularly useful in the reconstruction of paleoclimate and paleoenvironment. Benthic foraminiferal assemblages are mainly controlled by two often inversely co-varying parameters: oxygen and nutrients [30]. The benthic foraminiferal recovered from the studied samples were distinguished in terms of infaunal (dysoxic indicator) and epifaunal (oxic indicator) and used to infer oxygen levels during sediments deposition. The infaunal taxa include the *Haplophragmoide, Trochammina,* and *Nonionella* while the epifaunal taxa are *Gavelinella, Lenticulina* and *Fursenkoina,* which suggests a dysoxic and high ratios of suboxic conditions.

4.4. Foraminifera diversity

Species diversity was used as a measure of species number and richness (evenness) or distribution of group of studied organisms in the borehole environment. The Shannon-Wiener diversity [H(S)] and Fisher alpha (ɑ) indices were employed in this study to adequately describe the faunal diversity. The [H(S)] and (ɑ) indices ranged from of 1.71 to 2.16 and 1.18 to 5.45 respectively, while their averages are 1.99 and I.33 respectively. These values indicated moderate diversity for the recovered species in the borehole (Figures 4 and 5). The cross plot of Shannon-Wiener [H(S)] diversity index and Fisher alpha (ɑ) diversity index (Figure 6) was equally used for accuracy of the results and foraminifera diversity characterizing the borehole section. The diagram revealed almost entirely calcareous assemblages characterizing the borehole section, thus indicating restricted environmental conditions throughout the borehole samples.

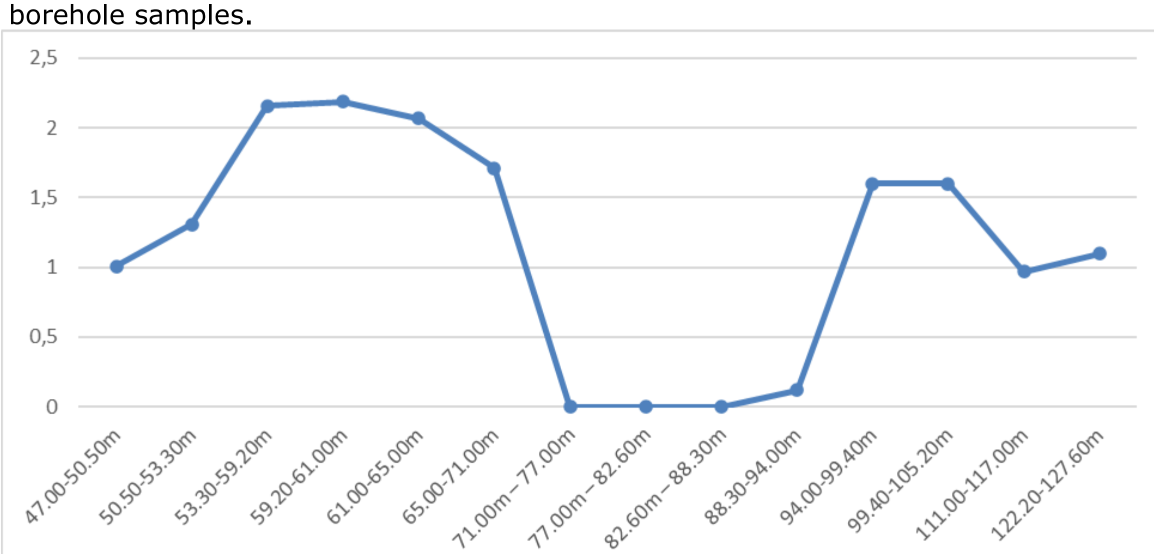


Figure 4. Distribution of the Shannon-Wiener [H(S)] diversity index of foraminifera in Ilaro BH-7

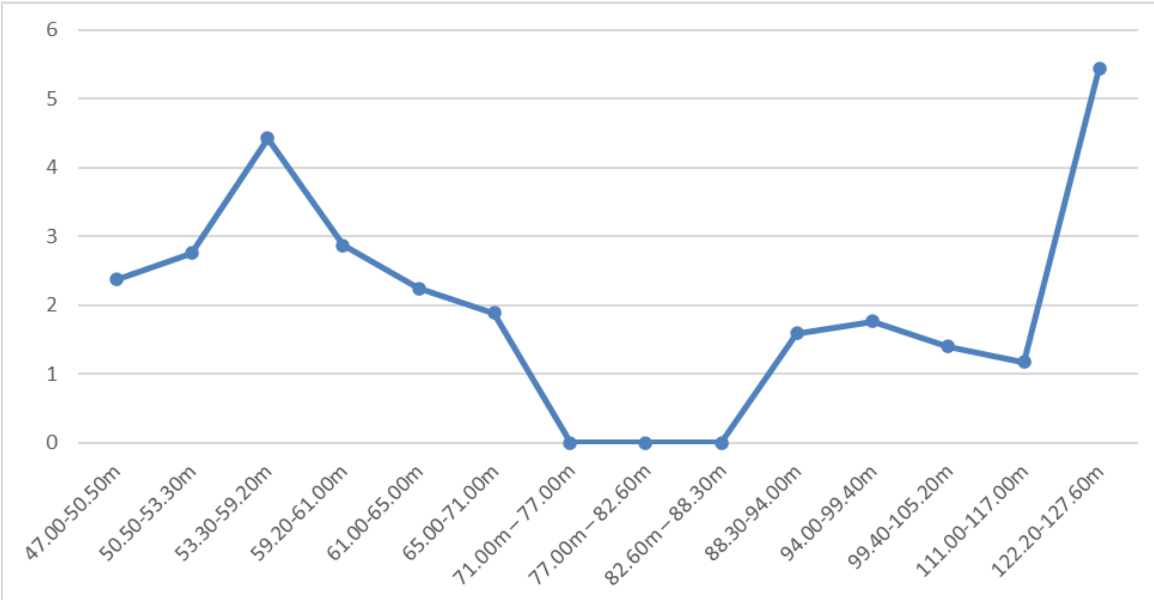


Figure 5. Distribution of the Fisher alpha (α) diversity index of foraminifera in Ilaro BH-7

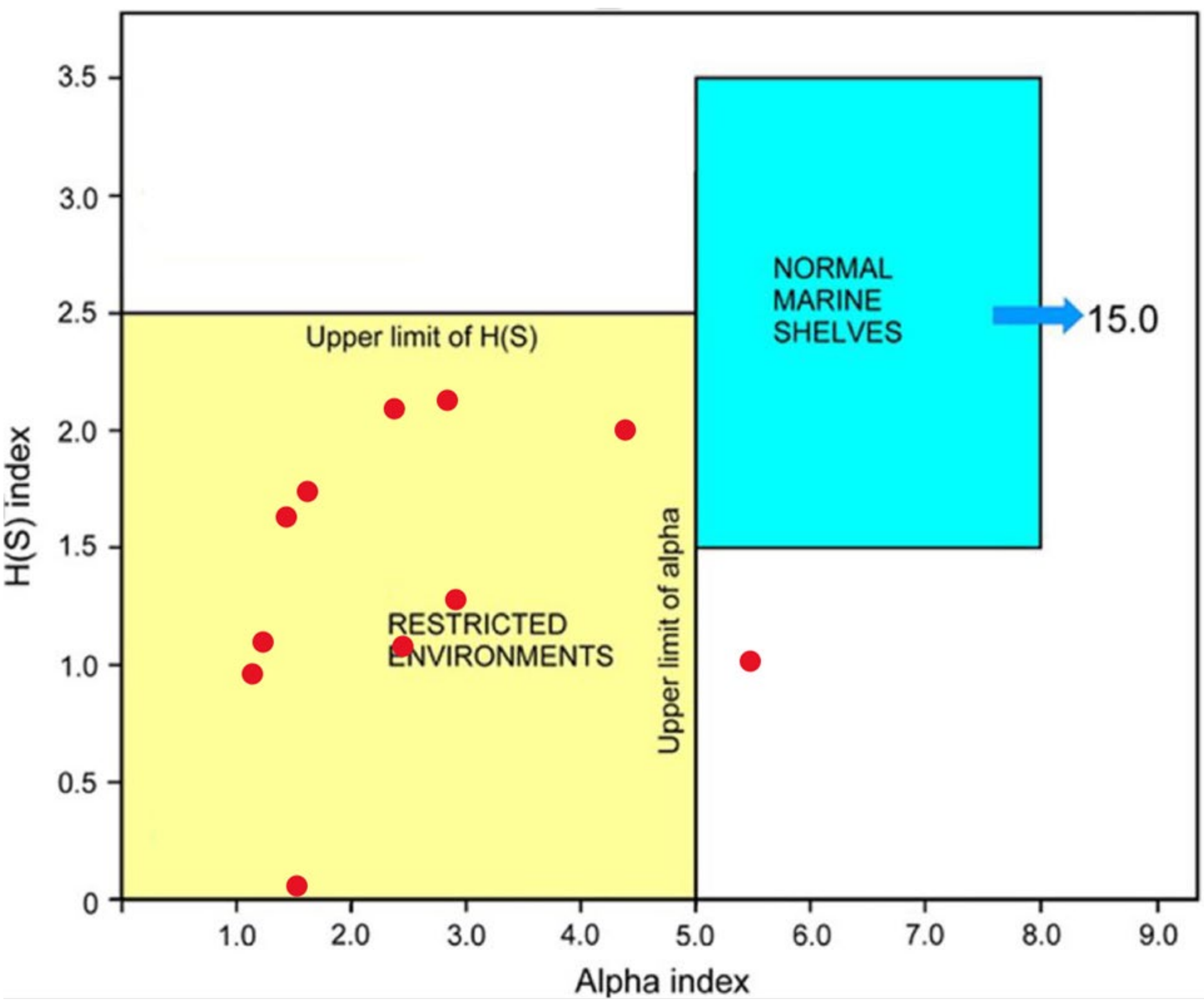


Figure 6. Cross plot of Shannon-Wiener [H(S)] and Fisher Alpha (α) diversity indices for foraminiferal species in Ilaro BH-7

4.5. Stable isotopes

The results of the carbon and oxygen isotopes ($\delta^{13}C$ and $\delta^{18}O$) measured for the ten (10) benthic species selected from intervals of the borehole section following their discontinuous abundance are presented in Table 4. The results show an overall negative trend of both carbon and oxygen isotopes with the exception of a single point at interval of 94.00 - 99.40 m exhibiting a positive $\delta^{13}C$ value.

Table 4. Isotopic carbon and oxygen data of samples with depth

Sample depth	$\delta^{13}C$	$\delta^{18}O$
50.50-53.30	-15.66	-5.64
53.30-59.20m	-8.15	-3.76
59.20-61.00m	-6.4	-2.85
61.00-65.00m	-12.09	-4.21
65.00-71.00m	-2.16	-2.92
71.00-77.00m	-2.99	-6.55
77.00-83.00m	-1.72	-2.13
88.30-94.00m	-0.55	-3.87
94.00-99.40m	0.59	-6.76
99.40-105.20m	-1.04	-1.81

4.5.1. Carbon isotope

Negative $\delta^{13}C$ excursion (CIE) in benthic foraminifera was recorded in the studied section. This shows a chemostratigraphic curve of $\delta^{13}C$ reflecting a decrease from 0.59 ‰ to -0.55‰ at interval between 83.30 to 89.30 m and subsequently a gradual decrease towards the top of the section was maintained while a strong negative value of -15.66 ‰ at 50.30 to 53.30 m was also attained. The Paleocene-Eocene thermal maximum was also established within the section by the onset decrease of carbon isotope excursion (CIE) value at approximately -2‰ on the curve (Figure 7).

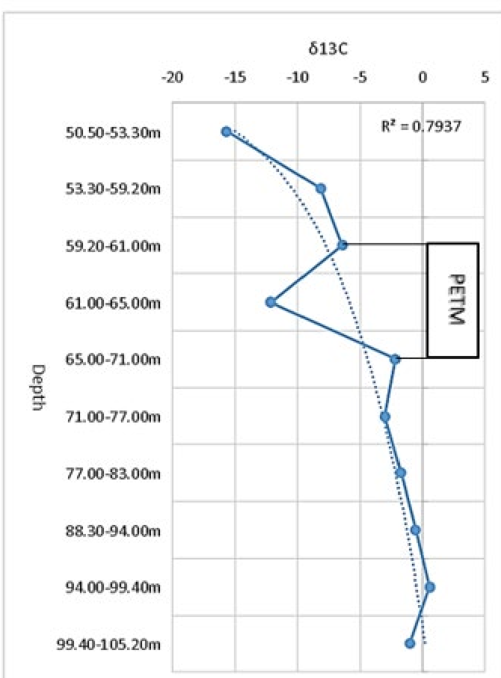


Figure 7. Diagram showing chemostratigraphic curve of strong negative carbon isotope indicating Paleocene-Eocene thermal maximum

Depleted $\delta^{13}C$ isotope values of -2‰ to -15.66‰ suggests that the epifaunal taxa including the *Fursenkoina elongata, Anomalinoides spp* possibly utilized the released $\delta^{13}C$ depleted CO_2 to build their calcite tests. The positive $\delta^{13}C$ values occurring at a single point in the section (89.30 - 95.30 m) can be interpreted as the presence of an epifaunal species which can be indicative of gradual increase in organic carbon influx in the environment [31]. The benthic foraminifera extinction is thought to have occurred before the last appearance of the *Morozovella aequa* [32] in the planktic foraminifera zone P4 – P5 as modified by Blow [24-25].

4.5.2. Oxygen isotope and temperature

In many species of foraminifera, the shell calcite is in oxygen isotopic equilibrium with seawater, and thus the isotopic separation factor between calcite and seawater is inversely related to calcification temperature equilibrium fractionation (i.e. the $\delta^{18}O$ of calcite decreases by approximately 0.21–0.23‰ for a 1°C increase in temperature) [33]. The $\delta^{18}O$ isotope was used in this research to provide information about the composition and the environmental conditions in which the tests were secreted. Lowest $\delta^{18}O$ were recorded in the following intervals of the studied section of Ilaro BH-7: 50.50 – 53.30m, 71.00 – 77.00m, and 94.00 – 99.40m. These showed slightly strong negative shift values of measured $\delta^{18}O$ of -5.64‰, -6.55‰ and -6.76‰ respectively, while other samples showed slight gain in $\delta^{18}O$ values from -1.81‰ to -3.87‰ (Figure 8).

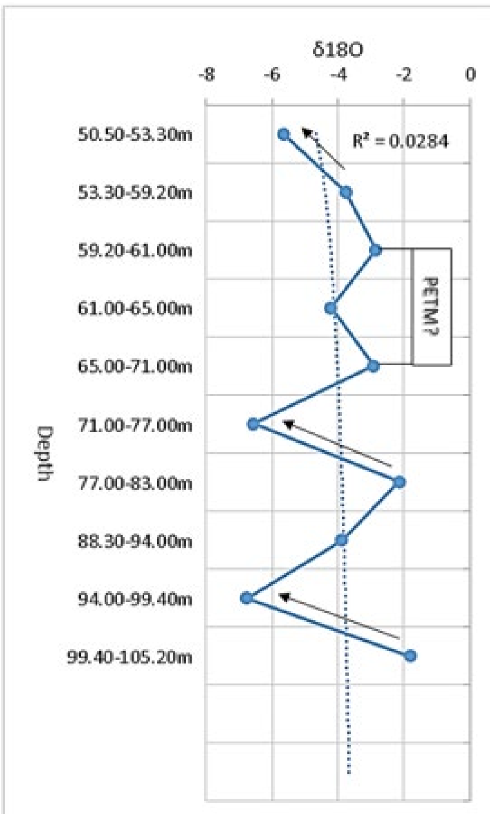


Figure 8. Diagram showing possible Paleocene-Eocene thermal maximum with the identified oxygen isotope minimal (arrows)

The overall average of -4.05‰ for $\delta^{18}O$ in this study does not indicate possibility of $\delta^{18}O$ enrichment but suggests a gradual increase in temperature that may not necessarily relate directly to the microhabitat preferences of some benthic foraminifera as many species are adapted to preference of food over oxygen. This scenario is validated by the dominance of *Lenticulina midwayensis* and *Nonionella auris* species which preferred high organic flux environment to oxygen influenced environment [34]. However, low $\delta^{18}O$ values of the benthic foraminifera suggested that the temperatures of bottom waters were relatively warm, and calcification of foraminiferal shells took place within the environment. Therefore, negative $\delta^{18}O$ observed in the samples indicates the possibility of the Paleocene-Eocene thermal maximum event in the studied sediments from the Dahomey basin.

5. Conclusion

Core samples (51–202 m) from Ilaro BH-7 in the Dahomey basin comprised of silicified or sandy limestones with siltstone intercalation, sandstones and dark to light grey shales/mudstones. The borehole is fairly fossiliferous at interval of 51-128 m with 16 planktic foraminiferal species, 12 benthic foraminiferal species and 2 agglutinated foraminiferal species. Adopted biostratigraphic scheme revealed that the interval belongs to two planktic foraminiferal zones of P4-P7 and P8 which are defined by the Last Downhole Occurrence (LDO) of the *Acarinina pentacamerata* (P4-P7) and the *Pseudohastigerina micra* (P8) respectively. The depositional environment ranged from inner shelf to upper continental slope using the planktic/benthic foraminiferal ratio. Benthic foraminiferal microhabitat indicates a partially oxygenated zone at

P8 (dominated *by Lenticulina – Gavelinella*) while the dominance of *Fursenkoina* indicates a short dysoxic phase.

The average species richness and diversity from Shannon-Wiener [H(S)] and Fisher Alpha (ɑ) of 1.99 and 1.13 respectively, indicate fairly moderate diversity in the studied section. While the cross-plot of Shannon-Wiener diversity index [H(S)] and Fisher Alpha (ɑ) index shows almost entirely calcareous assemblages characterizing the borehole section, thus indicating restricted environmental conditions throughout the borehole. Negative $\delta^{13}C$ excursion (CIE) in benthic foraminifera were recorded in the studied section by the onset decrease of carbon isotope excursion (CIE) value at approximately -2‰ on the curve, while the negative excursion of measured $\delta^{18}O$ showed a strong negative shift values of -4.21‰, -5.64‰, -6.55‰ and -6.76‰, suggesting a very possible rise in bottom water temperatures. Adaptation of the some benthic foraminifera species to $\delta^{18}O$ depleted environment displayed by the dominance of *Lenticulina midwayensis* and *Nonionella auris* species in this study, indicating their preference for organic flux environment to oxygen influenced environment, has shown that temperature may not play significant role in the extinction of the benthic foraminifera. However, strong negative shift of carbon isotope revealed thermal maximum event in the studied interval of the borehole. These records offered evidences for the presence of Paleocene-Eocene thermal maximum event within the eastern Dahomey basin.

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