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Bio-Sequence Stratigraphy of Shagamu Quarry Outcrop, Benin Basin, Southwestern Nigeria

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Abstract: The Paleocene/Eocene boundary has been a significant subject globally for sometimes now. This work focuses on the application of sequence stratigraphy where diagnostic microfossils trends of abundances and qualitative parameters can be integrated with sedimentology in the recognition of stratigraphic surfaces. Such surfaces / boundaries are highstand systems tract (HST), transgressive systems tract (TST), lowstand systems tract (LST), maximum flooding surface (MFS) / condensed section (CD) and sequence boundary (SB). These will no doubt provide an excellent opportunity for the identification of a functional boundary in a fairly assemblage-rich basin. 14 outcrop samples from the Shagamu Quarry were studied for their palynomorphs and foraminifera. Correlation with previous works on nannofossils and palynomorphs was also carried out to aid interpretations. Systems tracts and surfaces recognized and proposed for the study area are: HST (4.2-7.1 m, 9.5-11.5 m and 26.8-28.0 m), TST (7.7-9.5 m, 11.5-19.0 m, 19.0-20.2 m {TST/CD)}), LST (1.3-4.2 m and 20.2-26.8 m), MFS (56.8, 58.1 and 59.7 Ma) and SB (56.5, 57.0, 57.5 and 60.4 Ma. Depositional environments varied from inner to outer neritic settings. This study will aid exploration efforts not only in the onshore but also in offshore settings where sizeable sections have been reported missing.

Key words: Bio-sequence stratigraphy · Palynomorph · Foraminifera and sedimentology

INTRODUCTION

The Paleocene/Eocene boundary (PEB) of basins has been argued not to be the same globally [1]. Boundaries are very important for ease of correlation and zone of target recognition as well as for other exploration and production utilization. The dearth of published biostratigraphic data on the Paleogene of Nigeria is however, a militating problem. Even, much of the available data on the Paleogene of Nigeria is proprietarily controlled by oil companies and this situation has seriously hampered cross-fertilization of ideas. A well published data on the Paleogene of Nigeria would have helped explorationists greatly in erecting a generally accepted "Functional Boundary" for the PEB at least for the Niger Delta.

There is no doubting the fact that the contributions of several workers [2-11] have made up our present knowledge of the sedimentary basins of Nigeria with respect to the exploitation of several mineral deposits they contain.

However, sequence stratigraphy is yet to be applied to many of the outcrops and wells studied by some of these workers. Application of this technique is long overdue for the contribution of high-resolution sequence stratigraphy would have added to the present knowledge for optimum mineral exploitation. Elsewhere, this technique has been applied [12, 13]. Most recently, sequence stratigraphy integrated with lithofacies and palynofacies was applied to the Paleogene strata of the Anambra Basin/Afikpo Syncline complex [14]. Five sequences and four regional boundaries were identified as against a single sequence [15].

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Application of sequence stratigraphy to strata from these sedimentary structures will no doubt create a good chronostratigraphic framework for a more efficient exploitation of the minerals contained. Efficient and effective exploitation is important now that the Federal Government of Nigeria is focusing, apart from oil, more attention on other minerals such as bitumen, gold, limestone and coal as possible alternative incomes. In the Benin Basin, “probable - in - place reserves of bitumen in outcrop zone (110 x 6sq km) are in the order of 170×10^6 bbls” [16]. This estimate is worthy of further investigation to provide encouraging data bank for future investors in the mineral exploitation. Besides, commercial quantity of hydrocarbons was reported in the offshore of Benin Republic [17]. Also, an indigenous company, Yinka Folawiyo Company Limited, is currently exploring oil in offshore Badagry, Nigeria.

Although, several geochemical studies [18, 19] have reported poor conventional oil prospect for the onshore Benin Basin, its reported gas potential is however a valuable asset. This is because of the current global need of gas for its environmentally friendly nature. Also there is need for more detailed geological, geophysical and geochemical studies which may lead to discovering of conventional oil, not only in the deep offshore, but also in the shallow offshore and onshore settings of this basin.

Meanwhile, Lucas [20] has applied palynology for sequence stratigraphic study of the Anambra Basin in the Paleocene / Eocene times. Recently, the palynostratigraphy and paleoenvironments of the Oshosun (Akinbo) Formation at the Shagamu Quarry was studied [21]. No sequence stratigraphy was attempted and a functional boundary for the PEB was not studied.

Accurate dating of the Paleocene / Eocene deposits of the Oshosun and Ewekoro Formations of the Dahomey (Benin) Basin was attempted using radiometric dating of the glauconites recovered from two levels within the Oshosun and Ewekoro Formations in southwest Nigeria [6]. This exercise confirms the age of the two formations to be Paleocene in the lower section and the lesser upper part more of Eocene being found to average 54.00 +/- 2400 my. In spite of this attempt however, there is need for a ‘functional’ and more definitive PEB in the study area at least for exploratory work. This can be aided by sequence stratigraphy as it offers the opportunity of dating sequences more accurately from recovered microfossils. The availability of microfossils in rock samples at high resolution will enable appropriate globally recognized flooding surfaces to be picked. With the recognition of these, a more definitive boundary can be erected. Applying this technique for the whole of Benin Basin will provide a better chronostratigraphic framework for the exploitation of its abundant mineral resources.

This paper therefore aims at recognizing a ‘functional’ and more definite boundary guided by recognized marine flooding surfaces and sequence boundaries. This is achievable through the use of qualitative and quantitative palynomorphs and foraminiferal trends and features as well as sedimentary parameters.

Geological Setting: The Shagamu Quarry is located within the northeastern part of the elongated Benin Basin that lies pseudo-parallel to the West African coast. This basin begins from the Ghana Ridge onshore and extends through Togo and Benin Republics to the Benin Hinge Line in Western Nigeria (Fig. 1). Formation of this sedimentary structure like most basins in Africa was in response to the separation of the African and South American landmasses and the subsequent opening of the Atlantic Ocean in the Jurassic - lower Cretaceous [11, 16, 22].

Two structural units within the Benin (Dahomey) Basin were recognized and these are the Benin Basin-proper, which extends from the Ghana Ridge to the Orimedu-Ijebu Ode - Ilorin axis and the Okitipupa Structure that stretches from the Ijebu Ode - Ilorin axis to the Benin Hinge Line [22]. The Benin Basin proper shows along strike, a steady drop in basement floor ranging from 1900 to 2200 m from east (in Union-1 Well) to west (Nigeria/Benin Republic border in B-1 Well) and a north-south steep profile from Bodashe-1 Well (1513 m) to Afowo-1 Well (2130 m) and D-2 Well (2727 m). On the other hand, the Okitipupa Structure indicates a shallower basement floor (1000 - 1400 m) except within the Ise graben (1800 - 2000 m) (Figs. 1 and 2).

The deposition of a thick sequence of continental grits and pebbly sands (over 1400m) over the entire basin was as a result of a rift - generated basement subsidence during the lower Cretaceous (Neocomian) [22]. Later in the Santonian, a probable tectonic event associated with the closure and folding of the Benue Trough led to the tilting and blocks faulting of granites, gneisses and associated pegmatites and other sediments to form a series of horsts and grabens. Subsequently, a great erosional activity accompanied this tectonism and this led to the erosion of the pre-drift sediments greatly from the horsts [22]. However, tectonic activity became insignificant in the Maastrichtian with only gentle subsidence taken place.

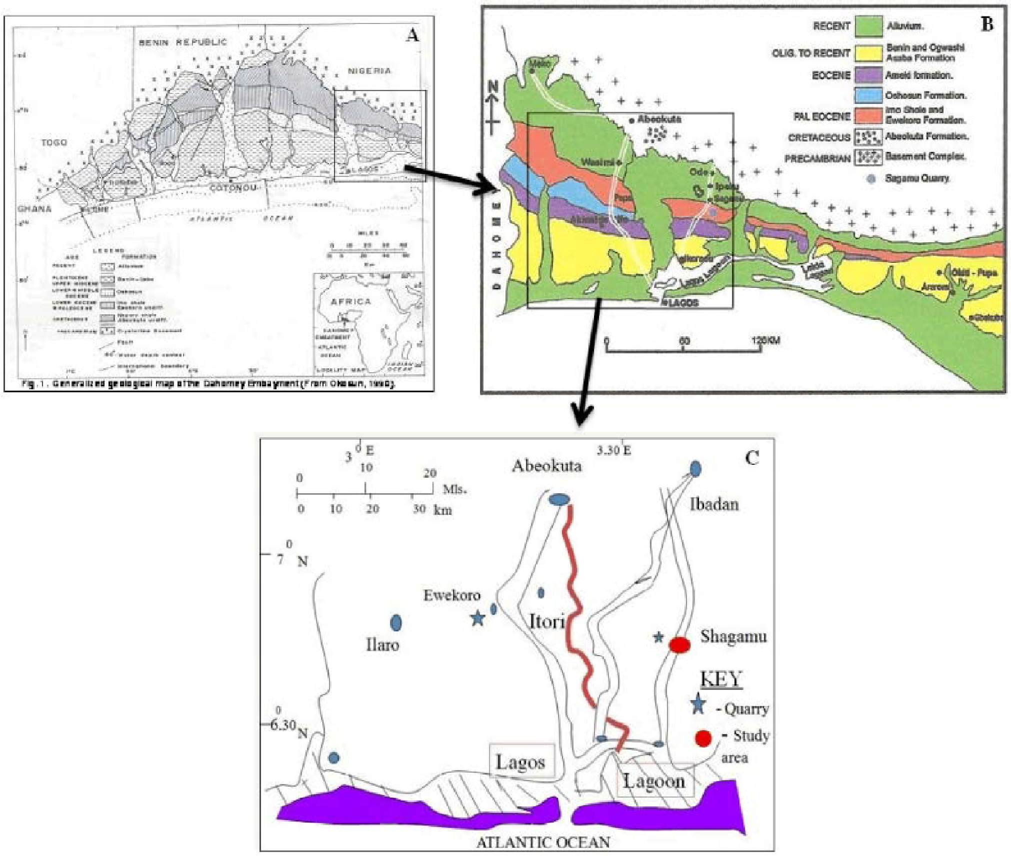


Fig. 1: Location Map of the Study Area. A and B is Geological maps, C is a planimetric map (Adapted from Okosum, 1990 and Adegoke *et al*., 19980)

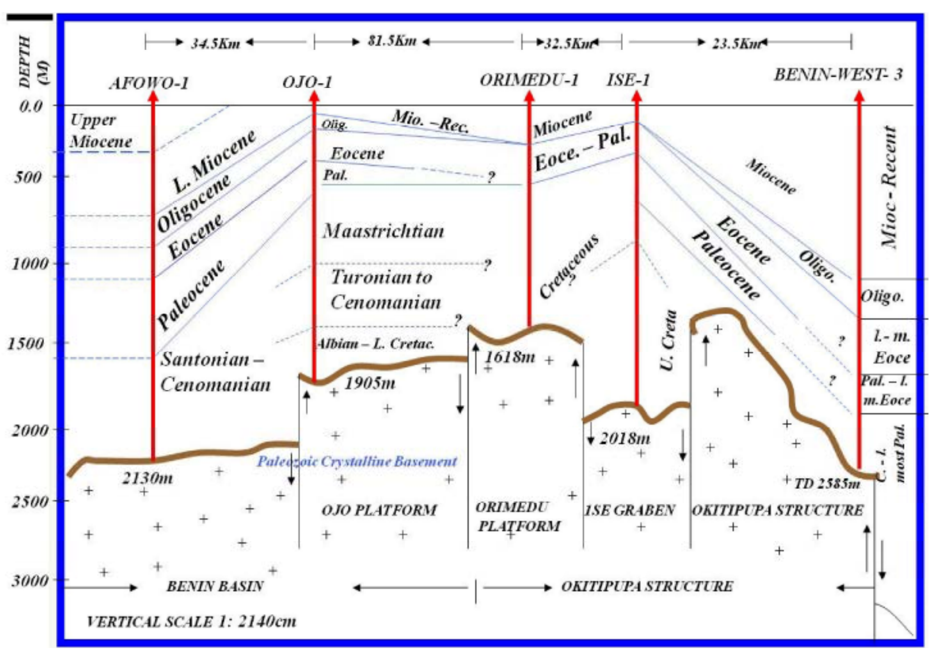


Fig. 2: Cross-section of wells drilled in various in structural elements of Benin Basin (Adapted from Coker and Ejedawe, 1987)

Table 1: Stratigraphy of Benin basin

AGE	FORMATION (Ogbe, 1972)	FORMATION (Omatsola & Adegoke,1981)
m. Miocene-Recent	BENIN	BENIN
Lower Eocene	ILARO	ILARO
Lower Eocene	OSHOSHUN	OSHOSHUN
Paleocene/Eocene	AKINBO	OSHOSHUN
Paleocene	EWEKORO	EWEKORO
Senonian/Paleocene	ABEOKUTA	ARAROMI
Senonian	ABEOKUTA	AFOWO
Neocomian-Senonian	ABEOKUTA	ISE

Stratigraphy: The oldest dated sediments onshore Benin Basin is lower Cretaceous [22] while the oldest dated offshore is a non-fossiliferous folded rocks of pre-Albian age [17]. However, the oldest known outcrop is the Maastrichtian part of the Abeokuta Formation that sits unconformably on the "highly weathered and fractured" basement complex [16]. The Abeokuta Formation, as shown by onshore drilled wells, sits conformably on the basement complex.

The Abeokuta Formation (Neocomian/Paleocene) has been assigned a group status and sub-divided into three formations that include: Ise (oldest), Afowo and Araromi (youngest) [22]. Overlying the Abeokuta Formation conformably is the Paleocene/Eocene limestone, marine shales and sandy shales and claystones of the Ewekoro, Oshosun and Ilaro Formations respectively. Late Tertiary sediments of Benin Formation terminate the stratigraphic sequence with shallow marine - none marine gravel, sand and sandy clay that sit "unconformably" on the Paleocene / Eocene sequence (Table 1). A thick sequence of the Benin Basin in the offshore Benin Republic, ranging in ages from pre-Albian to late Miocene has been reported [17].

MATERIALS AND METHODS

Fourteen outcrop samples collected on a field trip to Shagamu Quarry, southwest Nigeria primarily for a work on nannofossils were used. Hand trowel, spade and hammer were utilized for the collection. Although a total of 98 samples were collected at 50cm (0.5m) interval, only fourteen of them from the Oshosun (Akinbo) (11 samples), Ewekoro limestone (2 samples) and one from the shale intercalation within the limestone were available and therefore treated for this work.

Palynological Preparation: Twenty-five grams each of samples was palynologically treated with the use of HCI, HF and acidified $ZnCl_2$ solution for heavy mineral separation. Two sets of samples were prepared - oxidized and unoxidized. In the oxidized set, no *Hafnisphaera septata* dinocyst was recovered hence, the preference for unoxidized residue. Samples were microscopically studied using Olympus microscopes and photomicrographs of some important palynomorphs were taken (Plates 1-4). Identification of recovered forms was done using several published papers on the Paleogene of Nigeria on dinoflagellates [23, 24].

Foraminiferal Preparation: Twenty-five grams of rock sample was put in aluminum cups and soaked in kerosene overnight. Soaked sample was then washed with detergent and sieved through a 63 microns size sieve after which it was dried on a hot plate. Sample was then put in nylon sachets in readiness for picking. Fractions of the sample were done to separate recovered fossils into coarse, medium and fine fractions. Analysis and identification of recovered fauna were done using Bolli and Saunders [25] and other published atlases for the Paleogene. Bathymetric inferences were guided by Adegoke *et al*. [26].

Sedimentological Preparation: Slightly crushed samples were washed with water and dried for analysis. Roundness, colour, sphericity and sorting of the sand particles were recorded and occurrences and non-occurrences of accessory minerals such as ferruginous materials, glauconites, carbonaceous detritus, pyrites and calcites as well as shell fragments were also noted for each depth. The Sand: Shale: Calcite ratio trend generated from samples was improvised for electronic logs as this has signature similar to the logs.

RESULTS AND INTERPRETATION

Biostratigraphy: The distribution and abundances of the palynomorph species recovered from the outcrop sections are presented in Figure 3. Table 2 represents the palynostratigraphy scheme and the samples studied fall within the *Proxapertites operculatus* zone [2]. Correlating with the result of studies from adjacent Niger Delta, two zones: P200 and P300 (P330 subzone) were recognized [3]. These schemes assign the studied interval a Paleocene/ Eocene age. This zonation is complemented by foraminiferal data [1] and augmented by nannofossils data [27] and the application of Martini [28] scheme (Table 2).

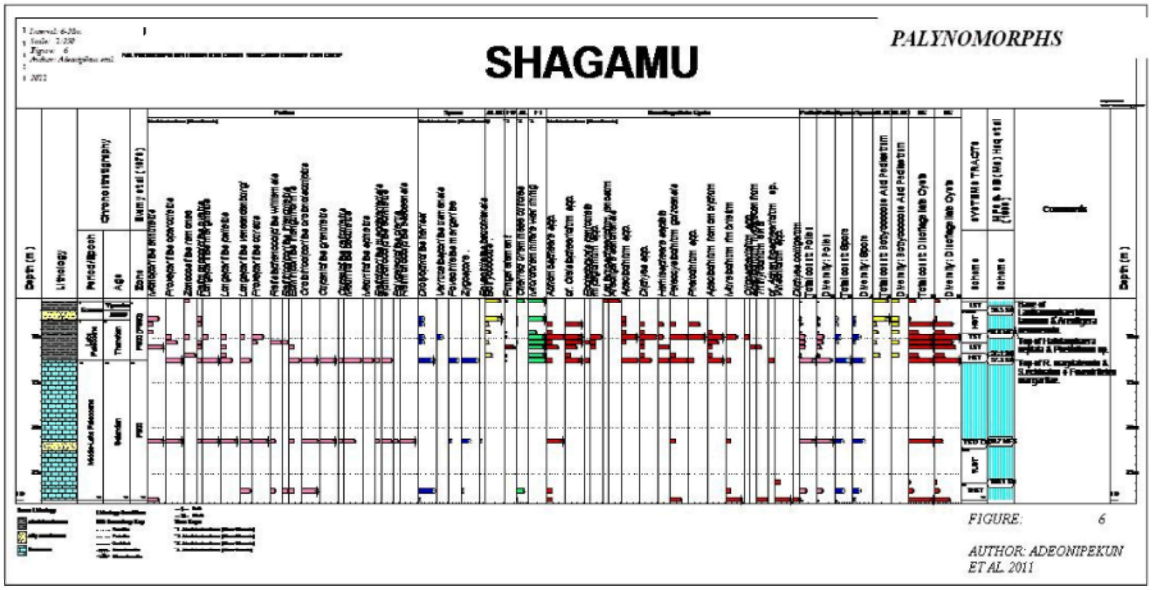


Fig. 3: Distribution and abundances of palynomorphs from the study section

Table 2: Palynostratigraphy of shagamu quarry outcrop

SAMPLE NO.	DEPTH approx (M)	AGE	PROPOSED BOUNDARY	Williams '77	This work		Evamy et al. (1978)	BIOEVENTS
53A	4.00	late Paleocene-early Eocene	Early Eocene	Homotryblium tennuispinosum /Hafuiaspaera septata	A. senonensis/ L. lanosum	PROXAPERTITES OPERCULATUS ZONE	P300 (P330)	Areoligera senonensis (53a)
51A	5.00							Lanternosphaeridium lanosus (51a)
49A	8.00							Top: Proxapertites cursus (49a)
48A	8.50		middle–late Paleocene		Apectodinium hormomophum/ Hafuisphaera septata			Top: Hafuiasphaera septata, Phelodinium sp.(48a)
46A	9.50							Top: Dictyophillidites harrissi (46a)
45A	10.00							Top: Longapertites psilatus (45a)
44A	10.50							Top: Retistephanocolpites williansi (44a)
43A	11.00							*Abundant Apectodinium spp, Ifecysta sp. & Cleistosphaeridium sp.
41A	12.00							Top: Foveotriletes margaritae (41a)
40A	12.50	?middle–late Paleocene		Ceratiopsis speciosa/Apectodinium	Apectodinum spp.		P200	Q.Top: Dictyophillidites harrisi (40a); Top: Retidiporites magdalensis (40a)
								*Abundant Longapertites vaneendiburgi
21A	21.50							Top: Polygalacidites clarus (21a)
	21.76							Occ. Homotryblum sp.
								Top: Echitricolporites triangulatus
14A	26.00							occ: Muratodinium fimbriatum
12A	27.00							
10A	28.00							OCC..: cf. Trithyrodinium evitti

Samples 10A- 40A (˜28.00-11.57 m) P200 Zone (Selandian) late Paleocene (Planktic ?P3 - P5): Top of this interval was marked by the Quantitative top occurrences of *Crototricolpites crotonoisculptus*, *Dictyophillidites harrissi* (Shell Spore 11) and *Adenanthera simplex* at sample 40A (11.57m). The base was provisionally marked at sample 10A (˜28.00m) - base of analyzed interval - due to the non recognition of

PLATE 1

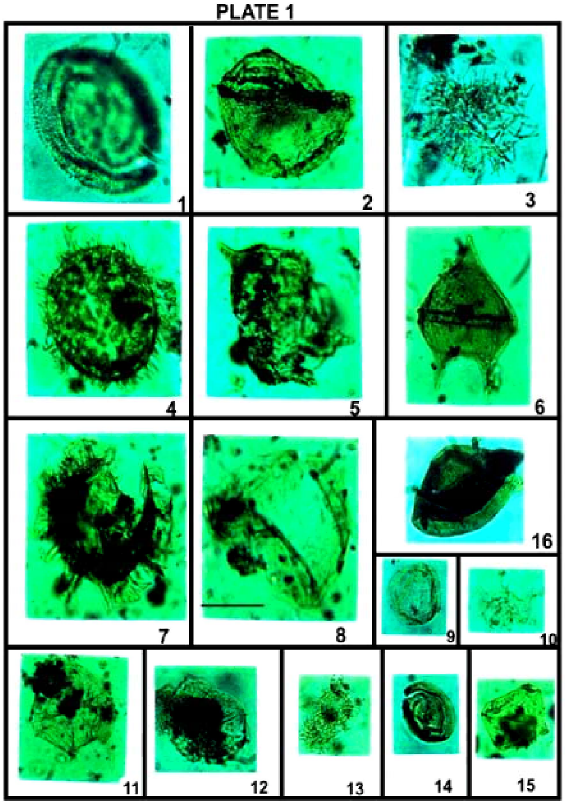


PLATE – 1

(Magnification x1000, except otherwise indicated)

1: Kallosphaeridium yorubaense Jan Du Chene and Adediran 1985 (Sample 40A)

2. Indeterminate Dinocyst (cf. Kallosphaeridium?) (Sample 21A)

3: Apectodinum hormomorphum (Deflandre and Cookson 1955) Lentin and Williams 1977 (Sample 40A)

4: Indet Dinocyst (Operculodinum sp.?) Sample 40A

5: Muratodinium fimbriatum (Cookson and Eisenack 1967) Drugg 1970 (Sample 21A)

6: Lentinia orei (Jan Du Chene and Adediran 1985; Stover and Williams, 1987) (Sample 40A)

7: Fibrocysta **sp. (Sample 21A)**

8: Parabohaidina laevigatus **Song** *et al.* **1978 (40A)**

9: Kallosphaeridium yorubaensis **(Jan Du Chene and Adediran, 1985) (Sample 40A)x400**

10: Achomosphaera andalusiella **(Sample 40A) x400**

11: Lentinia orei **(Jan Du Chene and Adediran, 1985) (Sample 40A)x400**

12: Kallosphaeridium **sp. (Sample 40A)**

13: Cordospheridium **cf.** *minimum* **(Morgenroth 1966) Benedek 1972 (Sample 40A)x400**

14: Kallosphaeridium ochiensense **Jan Du Chene and Adediran 1985 (Sample 40A) x200**

15: **cf.** *Horologinella micirugi* **He 1984. (Sample 40A)**

16: Parabohaidina granulata **Song** *et al.* **1978 (40A)x400**

PLATE 2

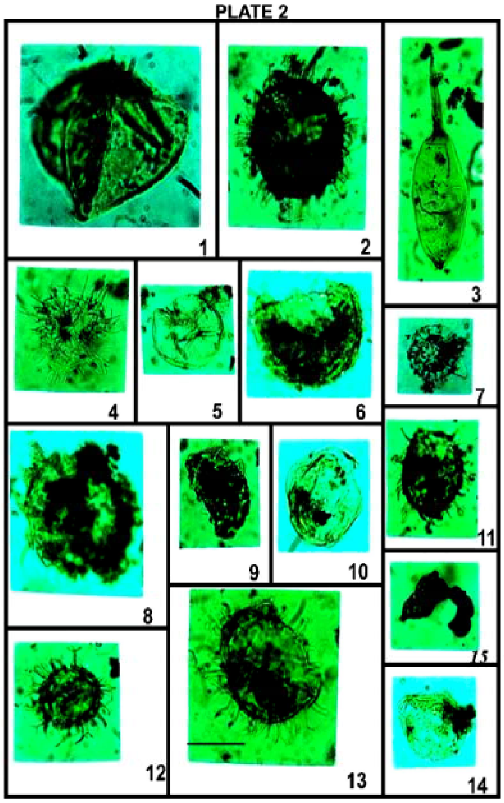


PLATE – 2 **(Magnification x400)**

1: Bohaidina granulata **Song et al. 1978 (Sample 40A) x1000**

2: Polysphaeridium **sp.1 (Sample 40A)x1000**

3: Palaeocystodinium golzowenze **(Sample 40A)x1000**

4: Apectodinum hormomorphum **(Deflandre and Cookson 1955) Lentin and Williams 1977 (Sample 40A)**

5: Selenopemphix **sp. (Sample 40A)**

6: Cylonephelium **sp. (Sample 40A)**

7: cf. Cleistosphaeridium **sp. (Sample 40A)**

8: cf. Ifecysta sp. **(Sample 40A)**

9: Ifecysta pachyderma **Jan Du Chene and Adediran 1985 (Sample 40A)**

10: Kallosphaeridium **sp. (Sample 40A)**

11: Fibrocysta sp. **(Sample 21A)**

12: Hafniasphaera septata **Cookson and Eisenack, 1967b (Sample 40A)**

13: cf. Operculodinium **sp. (Sample 40A) x1000**

14: Heteraulacacysta **sp. cf. H. pustula Jan Du Chene and Adediran 1985 (40A)**

15: **Microforaminiferal wall lining (Sample 21A)**

PLATE 3

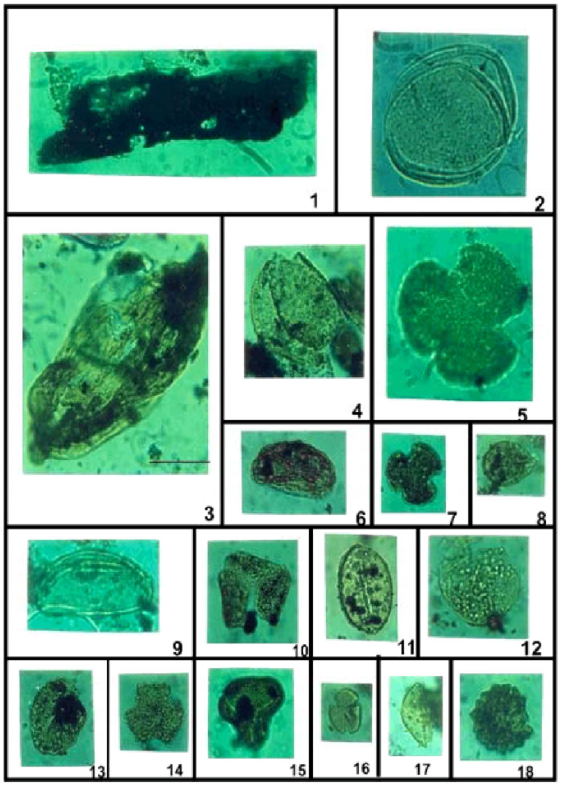


PLATE - 3
(Magnification x400 except otherwise indicated)

1: Charred Gramineae cuticle (Sample 12A) x1000
2: Proxapertites operculatus (Van der Hammen 1954) Van der Hammen 1956 (Sample 40A) x1000
3: Ephedripites sp. (Sampe 40A) x1000
4: Longapertites retipilatus Kar 1985 (40A)
5: Croton sp. (Sample 40A) x1000
6: Striatopollis sp. (?Ephedripites) Sample 40A
7: Croton sp. (Sample 40A)
8: Mauritidites baculatus (Sample 40A)
9: Longapertites psilatus Frederiksen 1994 (Sample 21A) x1000
10: Foveotriletes margaritae Van der Hammen (Sample 21A)
11: Mauritidites baculatus (Sample 21A)
12: Gemmamonocolpites sp. aff. Cleistopholis patens (Sample 40A)
13: Mauritidites spinosus (Sample 40A)
14: Retitricolpites "racemosa"(Sample 40A)
15: Foveotriletes margaritae Van der Hammen (Sample 21A)
16: Psilatricolpites sp. (Sample 40A*)*
17: Echimonocolpites minor (Sample 40A)
18: Ctenophonidites costatus (Sample 40A)

PLATE 4

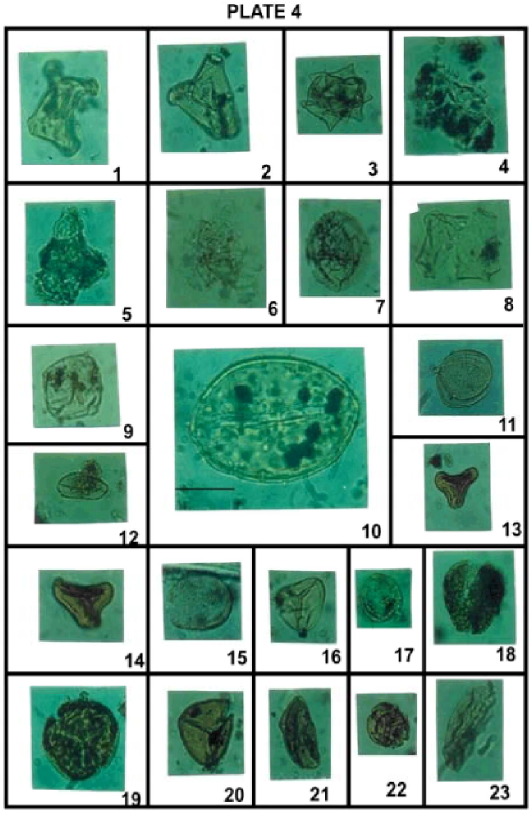


PLATE -4
(Magnification x400, except otherwise indicated)

*1: "Acritarchus protrutetralobus" (*Sample 40A)
2: "A. protrutetralobus" (Sample 40A)
3: "Acritarchus starrus" (Sample 40A)
4: Impagidinium sp. (Sample 40A)
5: Crassivestibulites karri Frederiksen 1994 (Sample 21A)
6: Hystricolkopoma rigudae (Sample 40A*)*
7: Leosphaeridium sp. (Sample 40A)
8: cf. Horologinella micirugi He 1984 (Sample 40A)
9: Indeterminate Acritarch (Sample 40A)
10: Mauritidites baculatus (Sample 40A) x1000
11: Proxapertites operculatus (Van der Hammen 1954) van der Hammen 1956 (Sample 40A)
12: Psilamonocolpites sp. (Sample 40A)
13: Dictyophillidites harrisi (Sample 40A)x100
14: D. harrisi (Sample 40A)
15: Proxapertites cursus Van Hoeken-Klinkenberg 1966 (Sample 40A)
16: Cyathidites spore. (40A)
17: Momipites sp. (Corylus) (Sample 40A)
18: Proxapertites sp. (Sample 40A)
19: Indeterminate spore (Sample 40A)
20: Deltoidosporites sp. (Sample 40A)
21: Longapertites vaneendenburgi (Sample 40A)
22: Syncolporites sp. (Sample 40A)
23: Pterospermella sp. (Sample 40A)

the base occurrence of *Mauritidites crassiexinus*. However, the base of an event of *Proxapertites operculatus* at sample 21A (20.21m) could not be accurately utilized due to:(i) poor recovery of palynomorphs within the limestone section, (ii) irregular sampling which prevented higher and regular interval resolution and (iii) the possibility of recovering *P. operculatus* in the 'unsampled' section of the limestone between 28.00 and 33.73 m outside the studied interval (Fig. 3 and Table 2).

However, characteristic late Paleocene sporomorphs and their features include abundant occurrences of *Foveotriletes margaritae*, *Crototricolpites crotonoisculptus*, *Retidiporites magdalenensis*, *Longapertities vernendiburgi* and *Proxapertites cursus* at 20.21m as well as quantitative top and abundant occurrences of *D. harrissi, Retistephanocolpites williamsii* and *Echitriporities trianguliformis* (Plates 1, 2, 3 and 4).

Recovered characteristic Paleocene dinoflagellates and their observed features within this interval also include *Hafniasphaera septata*, *Apectodinum* spp. and *Trithyrodinium evitti* as well as *Bahaidinia* spp. and *Parabahaidinia laevigatus* (Plates 1, 2 and 3). Other important Paleogene dinocysts include *Paleocystodinium golzoensis, Diphyes colligerum, Muratodinium fimbriatum, Ifecysta pachyderma, Kallosphaeridium* spp. and *Cleistosphaeridium* spp (Fig. 3).

This interval contains foraminifera *Globigerina triculinoides, Morozovella pseudobulloides, Epinoides pseudoelevatus, Valvulineria* spp.*, Valvulineria aegyptica*, *Heterolepa mickanni*, *H. pseudoungeriana* and *Cibiscorbis influenta* (Fig. 4 and Table 3). This assemblage suggests a ?P3 - P5 Planktic zone. Jan Du Chene *et al*. [4] assigned the lower section of this interval to the *Globorotalia pusilla pusilla / Morozovella angulata* (P3) Zone of Berggren [1]. The upper part of the shale intercalation within the limestone up to its top to the *Planorotalites pseudomenardii* (P4) Zone belong to ?P3-P5 Plankton Zone. Nannofossil data from Olowu [27] recognized the NP4 Zone [28] on the strength of picking the LDOs of *Ellipsolithus macellus* and *Fasciculithus tympaniformis* within the 21A sample. This further supports the recognition of the P3 Planktic zone and the occurrence of the 59.7 Ma marine events within this interval. Other characteristic nannofossils recovered [28] are *Neochiastozygus perfectus* and *Chiasmolithus bidens* (Tables 2 and 3).

Informal dinoflagellate zonation of this interval recognized an *Apectodinum* abundance zone within the middle - late Paleocene age. The top is marked by the top occurrence of "*Acritarchus starrus"*. It is characterized mainly by the occurrences of *Homotryblum* sp., *Muratodinium fimbriatum*, *Trithyrodinum evitti,* "*Acritarchus starrus"* and "*Normapollis protrutetralobus"*. This informal zone is equivalent to the *Ceratiopsis speciosa/Apectodinium* zone.

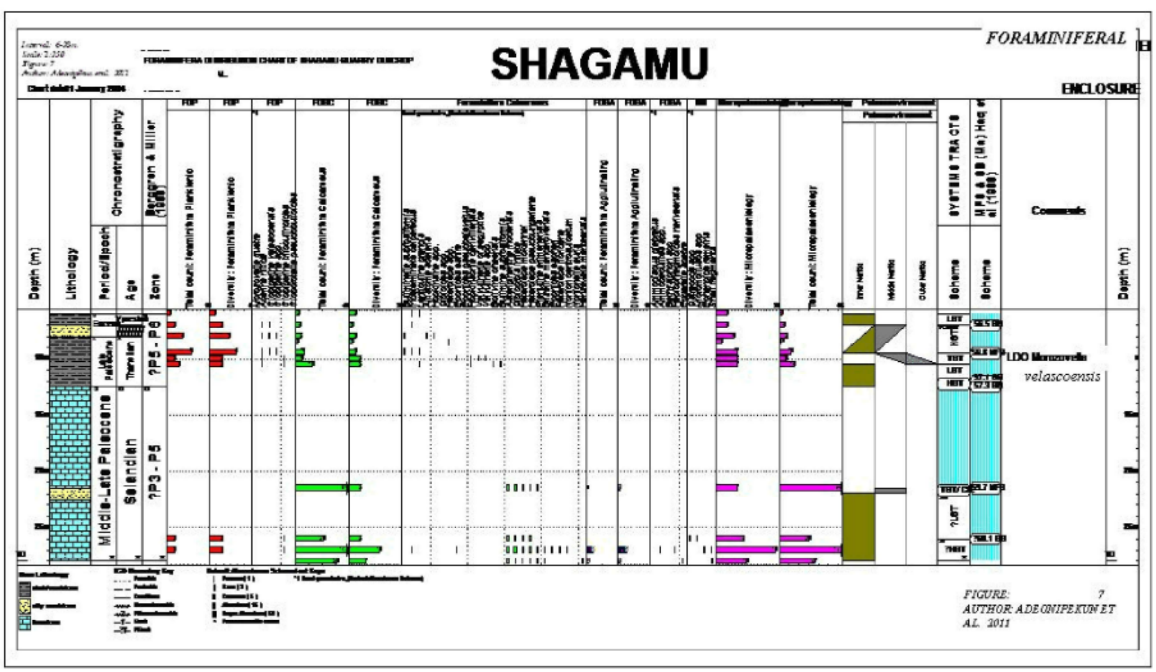
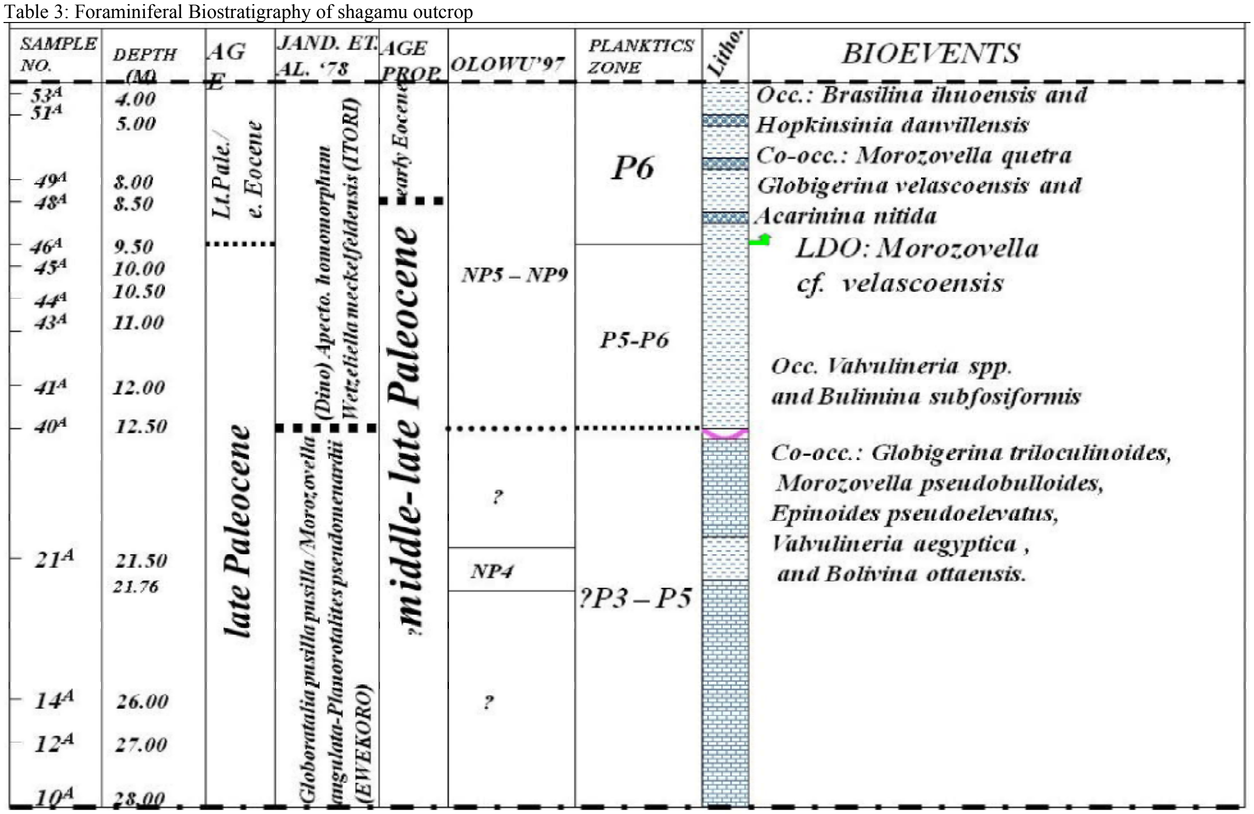


Fig. 4: Distrbution and abundances of foraminiferal species from the study section

Table 3: Foraminiferal Biostratigraphy of shagamu outcrop



Samples 40A (11.57m) - 53A (11.57 - ˜2.00 m) P300 (P330 Subzone) ?P5-P6 Planktic Zone, Thanetian-Ypresian (Late Paleocene - Early Eocene): The top here was provisionally placed at sample 53A (˜2.00m), being the top of analyzed interval. Its base was recognized by the Quantitative top occurrences of *Crototricolpites crotonoisculptus*, *Dictyophillidites harrissi* (SHELL Spore 11) and *Adenanthera simplex* at 40A (11.57 m).

Palynological characteristic features include: very rich occurrences of *Proxapertites operculatus*, *Proxapertites cursus*, *Longapertitites* spp., *L. vaneendiburgi, Retimonocolpites* spp., *Corsipollenites jussiensis*, *Spinizoconocolpites* spp. and *D. harrissi. Foveotriletes margaritae, Deltoidosporites* sp., *Cupaneidites* spp. and *Verrucatosporites* sp. were also recovered (Plates, 1, 2, 3 and 4). Diagnostic dinoflagellates recovered within this interval include *Phelodinium* sp., *Apectodinium* spp., *Eocladopyxis panicualata*, *Areoligera senonensis*, *Kallosphaeridium* spp, *Diphyes colligerum*, *Ifecysta pachyderma, Lingulodinium machaerophorum*, *Polysphaeridium subtle* and *Paleocystodinum golzoensis* as well as *Cleistospharidium* spp. Other dinoflagellates recovered include *Bohaidinia* spp., *Parabohaidinia* spp. and *Areoligera* sp (Fig. 3 and Table 2). These palynological assemblages support a late Paleocene - early Eocene age. Jan Du Chene *et al*. [4] assigned this interval to the *Apectodinum homomorphum / Wetzeliella meckelfeldensis* Zone [29].

This interval is equivalent to the ?P5-P6 Planktic zone based on the recognition of the LDO of *Morozovella* cf. *velascoensis* at sample 46A (7.74 m). Other associated foraminifera include *Brasilina ihuoensis* and *Hopkinsinia danvillensis* as well as co-occurrence of *Globigerina velascoensis* and *Acrinina nitida* (Fig. 4 and Table 3).

The informal zonation of this interval produced the *Apectodinum homomorphum/Hafniasphaera* septata zone within the late Paleocene section. The top of the interval is marked by the top occurrence of *Hafniasphaera septata.* Its base is marked by the top occurrence of "*Acritarchus starrus*". It is characterized by abundant *Apectodinum* spp., *Ifecysta* sp. and *Cleistopheridium* sp.

Also recognized in the upper section is the *Areoligera senonensis*/*Lanternospheridium lanosus* zone of Eocene age. It is characterized by dinocysts *Areoligera senonensis* and *Lanternospheridium lanosus.* This separates the *Homotryblium tenuispinosum/ Hafniaspaera septata* zone.

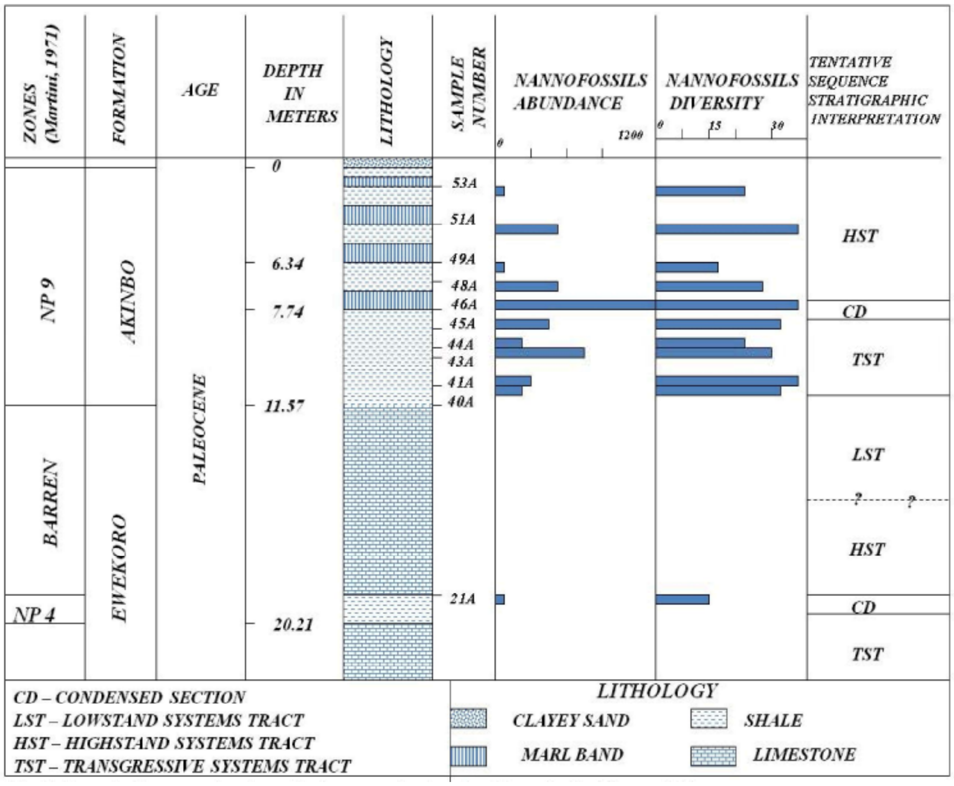


Fig. 5: Tentative Sequence stratigraphic interpretationbased on Nannofossils (Olowu, 1997)

Depositional Environments: In deducing the depositional environments of the studied quarry samples, six lithological units were demarcated. They are the (i) Basal Shelly Calcite, (ii) Calcareous Sandy Limestone, (iii) Lower Dolomitic Shaly-sand, (iv) Lower Shale, (v) Upper Dolomitic Shale and (vi) the Upper Shale unit.

Inferences from palynomorphs and foraminifera synchronized with those of accessory minerals and lithology were utilized. The works of Selley [30] and Adegoke *et al*. [26] were employed in the paleoenvironmental interpretation (Fig. 5 and Table 3). Bathymetric and proximity inferences were derived from foraminifera and palynomorphs respectively. The lithological units are briefly described below:

The Basal Shelly Calcite Unit (10A-12A) 28m- ˜27m: Two samples represent this interval. They are abundantly rich in calcite and shell fragments with low proportion of sandstones. The few sand grains are dominantly fine-grained in texture. Sample 10A has greyish hard calcite with rare quartz while sample 12A contains yellowish white, often brownish grains which are dominantly fine-grained. The above lithological indices coupled with regular occurrence of rare carbonaceous detritus suggest deposition in a middle-low energy shallow shelf setting.

The occurrences of palynological indices such as *Apectodinium* spp., *Paleocystodinium golzoensis, Trithyrodinium evitti*, *Muratodinium fimbriatum* and *Achomosphaera* sp. as well as continental charred Gramineae cuticles, fungal elements and microforaminiferal wall linings, support a nearshore possibly estuarine sub-environment [29, 31]. Recovered benthic foraminifera include *Ammobaculites* sp., *Heterolepa floridana, H. mckannai*, *Nonionella* sp., *Cibicorbis inflata* and *Eponides* sp. These, together with echinoid remains, ostracods and shell fragments further support a coastal to inner neritic bathymetry. Planktics are very few within this interval.

The Calcareous Sandy Limestone Unit (14A) (˜26m): The sole sample representing this unit has sand, shale, calcite ratio of 50:0:50. Its sand particles are buff, fine to coarse-grained, but dominantly medium-grained. They are subangular, very poorly sorted and well cemented. Some limestone pebbles (milky coloured) are present in the sample. Recovered accessory minerals include shell fragments, carbonaceous detritus, pyrites, glauconites and rare coaly fragments. These indices suggest a high energy deltaic setting. Palynomorphs are extremely poor due to secondary re-crystallization typical of calcite and dolomite deposits [32]. However, appreciable recovery of benthics which include *Heterolepa pseudoungeriana, H. mckannai, Asterigerinatha rhodensis* and *Nonion centrosulcatum* as well as micromulluscs and shell fragments confirm a coastal deltaic setting.

The Lower Dolomitic Shaly Sand Unit (21A) 20.21m: The representative sample here has sand, shale, calcite ratio of 60:40:0 and it represents a sizeable lithological section within the Ewekoro limestone. The sand are whitish, dominantly fine-grained, angular and very poorly sorted. The shale is flaggy, grayish and hard. Its accessory minerals include shell fragments and glauconites. These indices indicate a low-intermediate energy shallow marine setting.

Dinoflagellates recovered include *Kallosphaeridium* spp., *Polysphaeridium zoharyi, Apectodinium* spp., *Parabohaidinia* spp and *Spiniferites* spp. Abundant occurrences of shallow to slightly deep water *Achomosphaera* spp. and few deep water *Impagidinium* sp. suggest a deepening over the underlying into the middle neritic realm. This inference is supported by the non recovery of freshwater *Botryococcus brauni*, fungal elements and continental charred Gramineae cuticles. Foraminiferal recovery is similar to the underlying sample except that populations increased appreciably to confirm a middle neritic setting.

The Lower Shale Unit (40A-49A) 11.75m-6.34m: This sizeable unit is predominantly shaly with no sand, silt or calcites. The shale is grayish, flaggy and slabby in shape with no accessory minerals. These indices indicate low energy quiet water settings. Palynological components of samples 40A - 43A are dominated by *Apectodinum* spp., *Cordosphaeridium* cf *minima*, *Selenopemphix* sp and *Spiniferites* spp. as well as *Paleocystodinium* spp. These dinoflagellates are shallow marine dwellers [21, 31, 33]. Appreciable proportions of pollen and spores as well as other palynomorphs of this interval indicate a shallow marine setting in the neritic realm.

However, within samples 44A - 46A, the presence of deep water *Impagidinium* sp. and shallow to deepwater *Achomosphaera andalusiella* as well as cf. *Nematosphaeropsis labyrinthus* indicates a favourable low energy deeper marine setting (middle - outer neritic) than the underlying samples of 40A - 43A. This is corroborated by the regular recovery of benthic and planktic foraminifera such as *Buluminella subfusiformis, Lenticulina grandis, Hopkinsonia danvillensis* and *Alistoma scalaris* as well as *Globigerina velascoensis, Morozovella* cf. *velascoensis* and *Eponides* spp. Incidentally, while proportion of *Buliminella* spp. (deep marine dweller foraminifer) is high, that of shallow marine dweller dinoflagellate - *Apectodinium* spp. is low to non occurrence. Environments “shallowed” up to middle neritic within sample 48A-49A with the dominance of the dinoflagellate assemblage by *Lejeunecysta* cf. *cummunis*, *Cordosphaeridium* spp and *Paleocystodinium* sp.

The Shelly Calcite and Sandy Unit (51A) ˜4.00m: This sample is dolomitic with weathered shaly sand particles. Its sand, shale, calcite ratio is 40:30:30. The sands are whitish, dominantly fine-grained, angular and well sorted. Its yellowish and weathered shale is flaggy and soft. The sample contains rare carbonaceous detritus, shell fragments with 30% calcite proportion. These lithological features indicate a proximal intermediate to high energy marine setting.

Expectedly, palynomorph occurrence is poor due to secondary crystallization that produced dolomite. Traverse [32] noted that re-crystallized rocks lack good proportion of palynomorphs. However, the few dinoflagellates recovered are *Cleistosphaeridium* spp., *Cordosphaeridium* spp., O*perculodinium* sp. and *Apectodinium hormomophum*. Also poor in proportions are pollen and spores while high resistant continental fungal elements, charred Gramineae cuticles and freshwater *Botryococcus* are fair in proportions. These palynological indices suggest a degree of continental influence of imputs by river systems and therefore indicate a proximal fluvio-marine setting. Foraminiferal diversity and populations nose-dived appreciably, however, the occurrence of some planktics and benthic - *Buliminella subfosiformis* confirm an inner neritic bathymetry.

[The Upper Shale Unit (53A) 2.00m: The representative sample of this unit is made up of shale solely. The shale is yellowish, platy and soft to hard. Continental and freshwater palynomorphs disappeared from this sample. Deep marine dinoflagellate - *Impagidinium* sp. - was recovered along with other shallow marine forms. These indicate a slightly deeper setting than the underlying unit. An inner neritic is confirmed by the occurrence of *B. subfosiformis* and *M.* cf. *velascoensis* as well as *Lenticulina grandis*.

Dinocyst Zonation

***Apectodinum* Zone (Middle - Late Paleocene):** This informal zone is characterized by occurrences of *Homotryblum* sp., *Muratodinium fimbriatum*, *Trithyrodinum evitti,* “*Acritarchus starrus”* and “*Normapollis protrutetralobus”*.

Table 4: Sequence stratigraphy of shagamu outcrop

SAMPLE NO.	DEPTH (M)	LITHOFACIES	SYSTEMS TRACTS	Haq et al. 88 MFS / SB (Ma)	AGE	PLANK	ENVIRONMENT	LITHO.	BATHYMETRY 0 – 5
	4.00	100% Shaly	LST		EARLY EOCENE	?P5-P6	(Upper Shelf)		
53A	5.00	Shaly sand Dolo.					INNER NERITIC		
51A				?56.5					
49A	8.00	100% Shaly	HST				(Lower Shelf)		
48A	8.50						MIDDLE NERITIC		
				?56.8					
46A	9.50		TST		LATE PALEOCENE		MIDLLE – OUTER		
45A	10.00						NERITIC(Upper slope)		
44A	10.50								
43A	11.00		LST				INNER NERITIC		
				?57.0					
41A	12.00								
40A	12.50		HST ?57.3	?57.5					
		Algal calcite limestone	?TST	58.1		?P3-P5	?		
			?						
				?59.7					
21A	21.50	Mudstone Calcite	TST / CS				MIDDLE NERITIC		
	21.76						?		
14A	26.00	Shelly calcite calcareous limestones + Glauconites	?LST				PROXIMAL FLUVIO-MARINE		
				?60.4					
12A	27.00		?HST				INNER NERITIC		
10A	28.00								

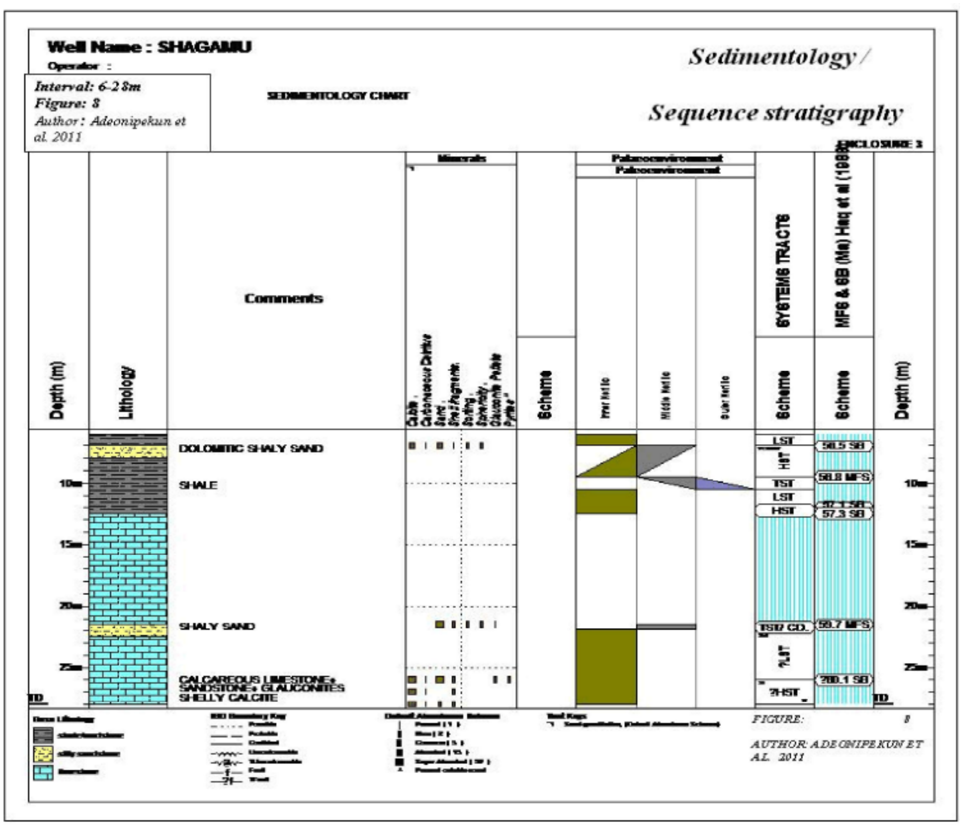


Fig. 6: Sedimentology and sequence stratigraphy of the study section

***Apectodinum Homomorphum/hafniasphaera Septata* Zone (Late Paleocene):** This zone is characterized by abundant *Apectodinum* spp, *Ifecysta* sp. and *Cleistopheridium* sp.

***Areoligera Senonensis/lanternospheridium Lanosus* Zone (Eocene):** Characteristic dinocyst are *Areoligera senonensis* and *Lanternospheridium lanosus*.

Sequence Stratigraphy: The application of sequence stratigraphy according to Vail and Wornardt [34] to the Ewekoro/Akinbo Formations of Shagamu Quarry yielded some useful results. This application was made possible by the recovered palynomorphs, foraminifera and lithological parameters as well as the data from Olowu's [27] work on nannofossils from same samples. Recognition of sequence stratigraphic features was further guided by the work of Ventris [35]. The recognized surfaces have been correlated with the Global Cycle of Haq *et al.* [44] (Table 4 and Fig. 6).

SEQUENCE-1 (28m-27m): Interval 10A - 12A (28m - 27m) seems to be a Highstand systems tract. This is based on the abundant shell fragments and calcite grains with relatively fair occurrence of carbonaceous detritus. The abundant occurrence of benthic foraminifers and low occurrence of planktics give credence to this deduction. The poor recovery of palynomorphs was due to the calcite re-crystallization. However, the occurrences of more resistant charred Gramineae cuticles, fungal elements, few sporomorphs and few shallow marine dinoflagellates are indicative of terrestrial communication.

SEQUENCE - 2 (27m - 21.50m): Within the limestone, section represented by sample 14A points to a Lowstand systems tract based on its unprecedented 50% sand content, with no shale but 50% calcite. Palynomorphs are extremely low with *Verrucatosporites* cf. *usmensis* spore and charred Gramineae cuticles being the only forms recovered. This coincides with a general decrease in foraminiferal abundance and population. Therefore a probable Sequence Boundary equivalent to the 60.4 Ma event may mark the beginning of this tract at 14A.

Although sampling interval is irregular within the Ewekoro Formation, a representative sample of the shale intercalation - 21A, most likely indicates that this shaly sand unit is a condensed section. It contains the Transgressive systems tract and its maximum flooding surface (MFS). This MFS is suspected to be the 59.7 Ma event based on the recognition of the NP4 calcareous nannofossil zone [27, 28] and the equivalent ?P3-P4 Planktic zones [28]. Supportive of this marine event are the high abundance and diversity of foraminifera and palynomorphs as well as absence of continental fungal elements and charred Gramineae cuticles.

Samples between 21A and 40A were not available for analysis hence much could not be said about the trend of fossils' abundance and diversity. However, Jan Du Chene *et al.* [4] reported abundance of planktic foraminifera about 50cm below the top of the Ewekoro Formation at the Ewekoro Quarry. This abundance may most likely represent a condensed section containing the maximum flooding surface equivalent to the 58.1 Ma. This is because this event occurred within the *Planorotalites pseudomenadii* zone of planktic foraminifera recognized by Jan Du Chene *et al*. [4]. Extrapolating this observation to the present study, therefore it probably means that the 58.1 Ma events occurred at slightly below the top of the Ewekoro Formation. Its systems tracts, however, could not be identified in this study since samples were not available. However, the unconformity below the Akinbo Formation may represent stratigraphically, the 57.5 Ma Sequence Boundary.

SEQUENCE-3 (40m - 41m): At sample 40A from the Akinbo Formation, an abundance of palynomorphs is observable with no record of foraminifera. However, high nannofossil diversity and abundance recorded by Olowu [27] indicate that this sample represents the vestiges of a marine event, most likely the Highstand systems tract (HST) type. This tract may be the HST of the 57.3 Ma events of which the major part might have been lost to erosion, faulting or non-deposition as indicated by the unconformity that separates the Akinbo from the Ewekoro Formations. Characterizing this HST is the marked reduction of marine indices, low abundance and diversity of palynomorphs while fresh-brackish water *Botryococcus* and continental fungal elements have high and regular occurrences.

Be that as it may, a Sequence Boundary equivalent to the 57.0 Ma terminates this sequence at 41A.

SEQUENCE-4 (41m -51m): This sequence commenced with the Lowstand systems tract that is characterized by non recovery of foraminiferal species, fair occurrence of sporomorphs and abundant fungal elements. Above this, is the Transgressive systems tract that commences at Sample 44A. From Sample 44A, proportions of palynological marine components increased. A concomitant increase in both benthic and planktic foraminifera also characterized the interval 44A - 46A. Regular occurrence of planktics however peaked at 46A with high diversity and abundance of planktics and benthics as well as abundant dinoflagellates. At the top of this tract - 46A, the 56.8Ma MFS is recognized based on the recognition of the LDO of *Morozovella* cf. *velascoensis* [25]. Olowu [27] also recognized this marine flooding surface (MFS) with similar abundance and diversity peaks in nannofossils (Fig. 6). Further credence is given to this event (MFS) by the reduction in marine palynomorph population and diversity within a generally high abundance together with no record of fungal elements and charred Gramineae cuticles all within the wholly shaly deposit. Within 46A - 51A, high diversity and reduced abundance of foraminifera coupled with high proportions of fresh - brackish water *Botryococcus* and high to low diversity and population of dinoflagellates characteristic of a Highstand systems tract are observable.

SEQUENCE-5 (51m-53m): At Sample 51A, a sequence boundary likely equivalent to the 56.5 Ma SB was recognized based on commencement of abundant occurrences of continental charred Gramineae cuticles and fungal elements with concomitant reduction in the proportions of pollen and spores. These palynological features characterize the terminal Lowstand systems tract of this sequence along with appreciable reduction in the foraminiferal population, particularly planktics. The dolomitic shalysand lithology with shell fragments and carbonaceous detritus of this tract indicate improved continental communication relative to the underlying.

DISCUSSION

Typical Paleocene pollen and spore reported in Nigeria and found in this study include *Retidiporites magdalensis*, *Longapertites vernendiburgi* and *Foviotriletes margaritae* [2]. The top occurrences of these three sporomorphs, however, do not mark the Paleocene/ Eocene boundary according to Germeraad *et al*. [2]. Several other typical sporomorphs of Paleocene age offer possibility of utilizing their tops at same or very close depth as a possible boundary. Some of these sporomorphs have been reported in Nigeria and other tropical sedimentary deposits to be essentially Paleocene.

Frederiksen [24] reported that *Longerpertites psilatus, Retimonocolpites ovatus*, *Proxapertites cursus*, *Rhombipollis geniculatus, Psiladiporites* sp. and *Polygalacidites clarus* were found not younger than late Paleocene in age from Bara and Lankhia Formations of Pakistan. These sporomorphs were also recovered in this present work and their tops at sample 49A (6.34m) suggest that the PEB is close to this depth. Also recovered from the Shagamu Quarry are typical PEB forms such as *Echitriporites trianguliformis* (?top below the boundary), *Spinizonocolpites echinatus, Trilatiporites kutchensis*, *Spinizocolphites baculatus* and *Dictyophillidities* sp. as well as *Adenanthera simplex.*

In support of a possible boundary at 6.34m is the recovery of typical Eocene dinoflagellates - *Areoligera senonensis* and *Lanternosphaeridium lanosus* at 4.0m (51A) and 2.0m (53A) respectively. These dinocysts were not recovered below these levels (Table 4 and Fig. 6). This gives strong support for a possible boundary between the Paleocene and Eocene to be located below the lower depth - 4.0 m. Since there was no sample between 4.0 and 6.34 m much cannot be said of the interval. However the extinction of typical Paleocene dinoflagellate forms such as *Hafniasphaera septata* and *Phelodinum* sp. at 6.70 m (48A) suggests a boundary at 6.34 m or younger but not younger than 4.0 m (51A). A boundary at 6.34 m looks more appropriate since it has strong backing from the sporomorphs. Corroborating this 6.34 m proposed PEB is the peak occurrence of charred Gramineae cuticles at 4.0 m.

The abundant recovery of nannofossils from this quarry [27] also enabled the recognition of the top of zonal marker Paleocene nannofossil - *Biantheolithus sparsus* to be picked at 49A (6.34m) while *Fasciculithus reichardii* was also found restricted to the Paleocene.

Sequence sratigraphy also gives strong support to this 6.34 m boundary. At 7.74m (46A), the last downhole occurrence (LDO) of *Morozovella* cf. *velascoensis* synonymous with the 56.8MFS was recognized. Therefore, a PEB around 56.5 Ma could not be found below, but above.

The three informal dinoflagellate zones recognized are equivalent to the *Ceratiopsis speciosa/ Apectodinium* and the *Homotryblium tenuispinosum/ Hafniaspaera septata*. The *Apectodinium* zone (middle - late Paleocene) of this work is equivalent to the *Ceratiopsis speciosa/Apectodinium*. The demarcated *Apectodinium homomorphum/Hafniasphaera septata* zone (late Paleocene) and the *Areoligera senonensis /Lanternospheridium lanosus* zone (Eocene) are equivalent to the *Homotryblium tenuispinosum/ Hafniaspaera septata*. With availability of more works on the sediments of this basin, this informal zonation may prove useful for biostratigraphic purposes.

CONCLUSIONS

The richness of the studied part of the Shagamu Quarry in palynomorphs and foraminifera is good enough for sequence stratigraphic study. This richness has led to the proposal of a “functional boundary” for the PEB from the integration of the recovered fossils, augmented by sequence stratigraphy. The proposed boundary will provide a basis for chronostratigraphy of the Benin Basin for oil and bitumen as well as other mineral resources' expolitation. Charred Gramineae cuticles were observed to have a peak occurrence close to this boundary. This may be useful as a bio-event if generally registered across the Benin Basin.

The recovery of *Zonocostites ramonae* (*Rhizophora* spp.) from the studied samples may mean that *Rhizophora* has been an integral part of the West African mangrove vegetation since Paleocene. This is because caving that is commonly associated with ditch cuttings, is ruled out from this outcrop samples. Informally named acritarch - "*Acritarchus starrus"* and normapolles - "*Normapollis protrutetralobus"* together with *Bohaidina* recorded in Paleocene Nigeria for the first time deserves more detailed study.

Three informal zones were recognized which include: the *Apectodinium* zone (middle - late Paleocene); the *Apectodinium homomorphum/Hafniasphaera septata* zone (late Paleocene) and the *Areoligera senonensis* /*Lanternospheridium lanosus* zone (Eocene).

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