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By Peter Adegbenga Adeonipekun & Ayobami Oyelami
University of Lagos, Akoka Lagos Nigeria

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Keywords: *shagamu, nigeria, benin basin, palynology, paleoclimate, phyto-climatic zones, petm, apectodinium acme, botryococcus abundance, oshoshun formation, marine transgression.*

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PALYNOLOGYOFLATEPALEOCENEEARLIESTEOCENEOUTCROPSEDIMENTSFROMBENINBASINSWNIGERIAIMPLICATIONSFORPALEOCLIMATOLOGYANDPETMRECORDINTHETROPICS

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Palynology of Late Paleocene – Earliest Eocene Outcrop Sediments from Benin Basin, SW Nigeria: Implications for Paleoclimatology and *PETM* Record in the Tropics

Peter Adegbenga Adeonipekun [α] & Ayobami Oyelami [σ]

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Keywords: Shagamu, Nigeria, Benin Basin, Palynology, Paleoclimate, Phyto-Climatic Zones, PETM, Apectodinium Acme, Botryococcus Abundance, Oshoshun Formation, Marine Transgression.

I. Introduction

Palynology has been a veritable tool in vegetation reconstruction for paleoclimatic interpretation Faegri and Iversen (1966). That recovered palynomorphs reflect the vegetation of an area to a reasonable extent has been reported by several workers among whom are Faegri and Iversen (1966), Sowunmi (1987, 1981a and b, 1986) and Traverse (1988) as well as Morley and Richards (1993). Sowunmi (1986) used pollen and spores recovered from Niger delta sediments to interpret the paleoclimate of the area from the Eocene to Recent. Sowunmi (1987) later compared palynomorphs from Recent samples with older subsurface samples in the Niger delta and found that the composition of the surface sediment palynomorphs reflected the vegetation of the study area and bore a strong similarity with the subsurface. Morley and Richards (1993) have also used the distribution of charred Gramineae (Poaceae) cuticles to infer the paleoclimatic changes of the Neogene Niger delta. They posited that the abundance of these cuticles from the late Miocene upward indicates dry climate conditions as they were sourced from burnt savanna vegetation. Adeonipekun (2006) also used pollen and spores as well as charred Poaceae cuticles to infer the paleoclimatic changes of Neogene Niger delta. Ige (2009; 2011), Ige and Datta (2011) and Adebayo *et al.* (2012) recently used palynomorphs to reconstruct the paleoclimate of the Niger delta basin. Despite these efforts on the Niger delta sediments, the authors are not aware of any palynology based paleoclimate study on the eastern Benin basin sediments. Most of the works on Benin basin have dwelt on the stratigraphy, geochemistry and structural geology (Rayment, 1965; Adegoke, 1969; Ogbe, 1972; Omatsola and Adegoke, 1981; Coker and Ejedawe, 1987; Elueze and Nton 2004, Adeonipekun *et al.*, 2012). Knowledge of the paleoclimatic conditions from this basin will further enhance the understanding of the paleoclimate of the Paleogene of Nigeria and give further insight into the understanding of the Paleotropical Maximum events in the tropical areas.

The Paleocene–Eocene Thermal Maximum (PETM) at *c.* 55.8 Ma is a short interval of rapid greenhouse warming of global lithosphere, hydrosphere and atmosphere. The work of Jaramillo and Dilcher (2000) on tropical Paleocene – early Eocene sediments shows that there was extinction at the Paleocene – Eocene Thermal Maximum (PETM) after which in the younger Eocene, diversity increased in the Colombian eastern Andes. Harrington and Jaramillo (2007) also reported taxonomic diversity increases in the late Paleocene of the US Gulf Coast, a trend replaced by a marked extinction into the early Eocene. Wing and Currano's (2013) work on plant macrofossils in the Bighorn Basin, Wyoming, United States however recorded radical floristic change during the PETM. This reflects "local or regional extirpation of mesophytic plants, notably conifers, and colonization of the area by

Author α: Laboratory of Palaeobotany/Palynology, Department of Botany, Faculty of Science, University of Lagos, Akoka, Lagos.
e-mails: aadeonipekun@unilag.edu.ng, p1adeonipekun@yahoo.com
Author σ: GEC Energy Company Ltd, Lagos Nigeria.
e-mail: Aboyelami@yahoo.com

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thermophilic and dry-tolerant species, especially Fabaceae". They posited however that this floristic change reversed itself at the end of the PETM even "though some immigrant species persisted and some Paleocene species never returned". Apart from Jaramillo and Dilcher (2000), Prasad *et al.* (2006) in northern India and Schulte *et al.* (2011) in Dababiya Quarry section Egypt are other works in the tropics on the PETM.

While Prasad *et al.* (2006) utilized dinoflagellate *Apectodinium* acme for recognizing the PETM, Schulte *et al.* (2011) applied sequence stratigraphy to recognize the PETM at the base of the Eocene within a transgressive systems tract (TST). Jaramillo *et al*. (2010) studied the tropical rainforest response to the PETM event using palynomorphs in eastern Colombia and western Venezuela. They "observed a rapid and distinct increase in plant diversity and origination rates, with a set of new taxa, mostly angiosperms, added to the existing stock of low-diversity Paleocene flora". Jaramillo *et al.* (2010) recorded no evidence of aridity and that the rainforest survived the extreme temperature increase of the 200,000 years' event.

Gebhardt *et al.* (2010) is the only work known to the authors on the Benin basin with respect to the terminal thermal events. Gebhardt *et al.* (2010) studied the foraminifera and carbon isotopes Excursion (CIE) of sediments from the Shagamu Quarry, southwest Nigeria and recognized the Initial Eocene Thermal Maximum (IETM) at the Paleocene - Eocene boundary as being characterized by the dominance of dysoxic benthic foraminifera - *Bulimina* and *Nonionella* spp. with concomitant great reduction in planktic and benthic foraminifera. This work did not apply much of the palynological data and that not much of the Eocene section was involved. It rather emphasized more of foraminiferal and Carbon Isotope Excursion indices apart from limiting the thermal events to the late Paleocene.

While fuller and more recent information in literature abounds for the temperate and other regions of the world, there is little information on the Paleocene/Eocene sediments from Nigeria. The excellent recovery of marker palynomorphs, foraminifera and nannofossils by Adeonipekun *et al.* (2012) in the Shagamu Quarry Benin basin is sufficient to make paleoclimatic inference with respect to the PETM.

II. Geology of Benin Basin

Benin basin lies pseudo-parallel to the West African coast beginning from the Ghana ridge onshore and extending through Togo and Benin republics to the Benin Hinge Line in Western Nigeria (Fig. 1). It was formed 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 (Omatsola and Adegoke, 1981).

The oldest dated sediments onshore Benin Basin is lower Cretaceous (Omatsola and Adegoke, 1981) while the oldest known outcrop is the Maastrichtian part of the Abeokuta Formation that sits unconformably on the basement complex. The Abeokuta Formation, as shown by onshore drilled wells however, sits conformably on the basement complex. This Neocomian - Paleocene Abeokuta Formation has been assigned a group status and sub-divided by Omatsola and Adegoke (1981) into three formations – Ise, (oldest); Afowo; and Araromi (youngest). Sitting on top of the Abeokuta Formation conformably are the Paleocene/Eocene limestone; marine shales and sandy shales; and claystones of the Ewekoro, Oshosun, and Ilaro Formations respectively in ascending order. 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).

Table 1 : Stratigraphy of Benin basin (Omatsola & Adegoke, 1981; Ogbe, 1972)

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

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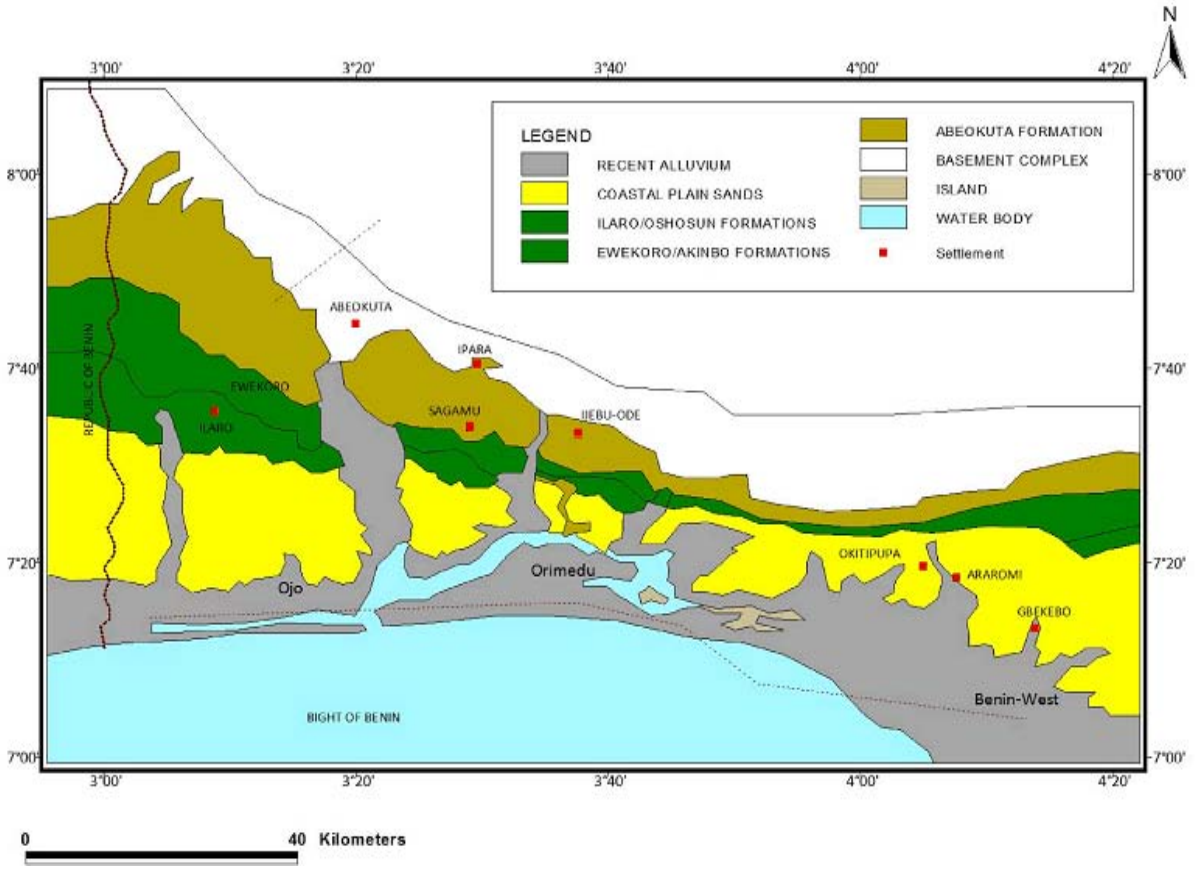

Fig. 1 : Geological map of the study area (SHAGAMU)

III. Vegetation of Eastern Benin Basin

Two main types of pseudo-parallel vegetation types (savanna and rainforest) exist in the eastern Benin basin in southwest Nigeria. They are the Guinea savanna; the Lowland rainforest, Freshwater swamp forest and a thin strand of Mangrove as well as Beach vegetations. These are extensions from the other parts of southern Nigeria as described by Keay (1959) Fig. 2. The Guinea savanna has characteristic plants such as *Daniella oliveri, Irvingia gabonensis, Isoberlinia dalziella, Afzelia africana*, *Terminalia glaucuscens* and *Elaeis guineensis*. Constituting the Guinean Lowland rainforest are Meliaceae, *Ceiba*, Sapotaceae, *Triplochiton*, *Calpocalyx*, *Celtis*, *Canthium*, *Mimosa*, Ceasalpinaceae and Papilionaceae (Keay, 1959). Taxa such as *Pandanus, Calamus, Uapaca, Crudia*, *Cyperus, Nymphaea, Symphonia, Cleistopholis, Raphia* and shrubs, ephiphytes as well as ferns dominate the Freshwater swamp forest. The Beach vegetation has plant taxa such as *Ipomoea, Dalbergia, Sporobolus, Eugenia, Hibiscus and Phoenix* while the thin strand of Mangrove contains relics of *Rhizophora* spp., *Avicennia germinans* and *Acrostichum aureum*.

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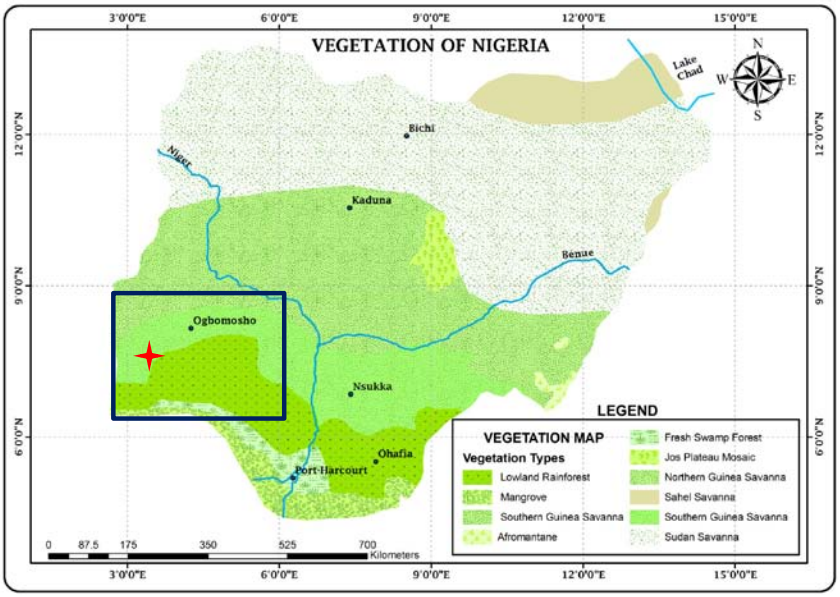

Fig. 2 : Vegetation Map of Nigeria showing the location of studied Quarry with a red star

IV. Materials and Methods

Ten outcrop samples from Shagamu Quarry, Shagamu, south west Nigeria were collected at an average of 0.5 m interval from the Oshoshun (Akinbo) Formation. Twenty-five grams each of sediments was palynologically treated with the use of HCl, HF, and acidified $ZnCl_2$ solution for heavy mineral separation. Samples were studied using Olympus microscope CH2 Model, and photomicrographs of some important palynomorphs were taken using Motic Camera 2.0 as shown in Adeonipekun *et al*. (2012). Identification of recovered palynomorphs was done using several published papers and atlases on the Paleogene of Nigeria such as Germeraad *et al.* (1968), Sowunmi (1986; 1987), Adegoke *et al.* (1991) and Jan du Chene *et al.* (1978). Recovered palynomorphs were assigned to palynoecological groups of Poaceae, Aracaceae, Freshwater Swamp forest, Mangrove, and Pteridophyte spores while charred Poaceae cuticles were used to substantiate paleoclimatic deductions. These were further grouped into Wet paleoclimate and Dry paleoclimate indicating palynomorphs. The inverse relationship between Poaceae and Pteridophyte spores forms the basis of the paleoclimatic deductions. Poaceae are open vegetation dwellers while Pteridophytes are humid moist habitat dwellers. Abundant Aracaceae, Mangrove, and Freshwater swamp forest pollen substantiated wet paleoclimate condition while abundance of charred Poaceae cuticles support inferred dry paleoclimatic condition. Spearman's correlation statistical tool was applied to the recovered palynomorph data with their correlation features noted.

Subsamples of the outcrop were gently crushed and dried so as to visually study the color, sphericity and sorting of the sand particles. The shale: sand: calcite ratio and their features were identified and recorded. Accessory minerals considered are pyrites, mica flakes, carbonaceous detritus and shell fragments. The work of Selly (1976) guided all lithological deductions (Table 2). The sediments belong to the Oshoshun Formation as described by Omatsola and Adegoke (1981).

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Table 2 : Palyno-ecological Groups, Lithology and age with *Botryococcus* and *Apectodinium Values* Adeonipekun *et al.* (2012)

DEPTH (m)	LITHO	AGE	SAMP. NO.	*M. annu.*	C.P.C.	Areca.	F.SW. FR	Spores	Mang.	Botry.	Apect.
4	SHALE	EOCENE	53A	2	0	1	0	0	0	2	0
6	SHALE/ SAND		51A	0	4	1	0	0	1	18	0
8	SHALE	PALEOCENE	49A	2	1	1	0	2	o	27	1
8.5			48A	1	1	1	0	2	0	4	1
9.5			46A	1	0	0	0	0	0	6	2
10			45A	0	0	5	0	6	1	0	11
10.5			44A	0	1	4	4	2	0	4	3
11			43A	4	0	2	1	0	0	0	1
12			41A	0	0	1	0	0	2	8	1
12.5			40A	0	0	14	13	11	2	0	12
TOTAL				10	7	30	18	23	6	69	32

M. annu. – *Monoporites annulatus* (Poaceae); C.P.C – Charred Poaceae cuticles; F. SW. FR – Freshwater Swamp Forest; Mang. – Mangrove; Areca. – Arecaceae; Botry. – *Botryococcus*; Apect – *Apectodinium* dinocyst, PETM Interval - Red colored symbol ; Important Palynomorph events - Red colored font

V. Results

A total of 23 pollen and seven pteridophyte taxa were recovered along with continentally derived charred Poaceae cuticles and fungal spores. Diversity and abundances of pollen and spores decreased from the Paleocene section to almost zero values in the earliest Eocene from the studied area in spite of little difference in lithology (Fig. 3). Pollen diversity and depth correlate positively with significant level of 0.045 and correlation coefficient of 0.642. Diversity of spores correlates positively with depth but it is insignificant (Tables 3 and 4). Good correlation was also observed between Pollen abundance and depth with Spearman's correlation coefficient value of 0.654. This is not the case with Spore abundance which is characterized by weak and insignificant positive correlation. Spore and Pollen abundances also correlate positively well but insignificantly. All these point to a floristic change and taxonomic extinction that have been reported for this climatic phenomenon when there was increased carbon dioxide in the hydrosphere and atmosphere which led to temperature increase of approx. 6 ^{0}C (Jaramillo and Dilcher, 2000; Harrington and Jaramillo, 2007; Jaramillo *et al*., 2010; Wing and Currano, 2013).

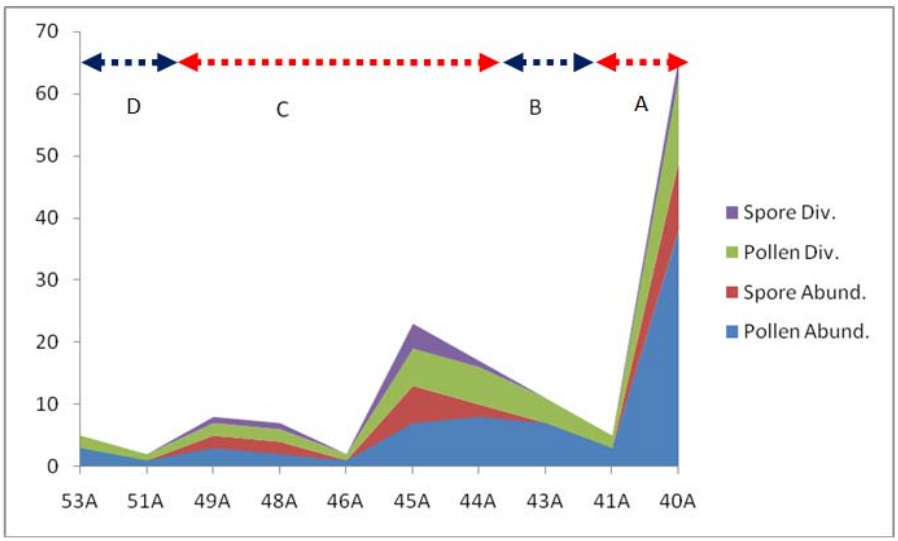

Fig. 3 : Sporomorph statistics and recognized phyto-climatic zones of study area (A, B, C, and D)

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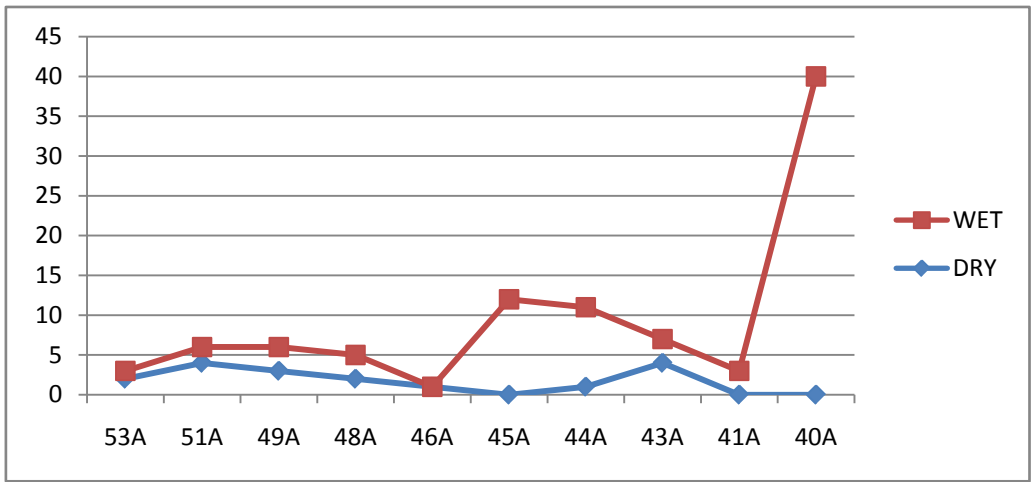

Fig. 4 : Relationship between Wet, and Dry paleoclimatic groups across the studied column

Table 3 : Correlation details: Pollen and Spore abundances with depth

			Depth (m)	Pollen Abundance	Spore Abundance
Spearman's rho	Depth (m)	Correlation Coefficient	1.000	.654*	.321
		Sig. (2-tailed)	.	.040	.365
		N	10	10	10
	Pollen Abundance	Correlation Coefficient	.654*	1.000	.608
		Sig. (2-tailed)	.040	.	.062
		N	10	10	10
	Spore Abundance	Correlation Coefficient	.321	.608	1.000
		Sig. (2-tailed)	.365	.062	.
		N	10	10	10

**. Correlation is significant at the 0.05 level (2-tailed).*

Table 4 : Correlation details: Pollen and Spore diversity values with depth

			Depth (m)	Pollen Diversity	Spore Diversity
Spearman's rho	Depth (m)	Correlation Coefficient	1.000	.642*	.269
		Sig. (2-tailed)	.	.045	.453
		N	10	10	10
	Pollen Diversity	Correlation Coefficient	.642*	1.000	.708*
		Sig. (2-tailed)	.045	.	.022
		N	10	10	10
	Spore Diversity	Correlation Coefficient	.269	.708*	1.000
		Sig. (2-tailed)	.453	.022	.
		N	10	10	10

**. Correlation is significant at the 0.05 level (2-tailed).*

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Table 5 : Correlation details: Phyto-climatic phases with depth

			Depth (m)	Wet Phase	Dry Phase
Spearman's rho	Depth (m)	Correlation Coefficient	1.000	.652*	-.582
		Sig. (2-tailed)	.	.041	.077
		N	10	10	10
	Wet	Correlation Coefficient	.652*	1.000	-.526
		Sig. (2-tailed)	.041	.	.119
		N	10	10	10
	Dry	Correlation Coefficient	-.582	-.526	1.000
		Sig. (2-tailed)	.077	.119	.
		N	10	10	10

**. Correlation is significant at the 0.05 level (2-tailed).*

Palynoecological and subsequent phyto-climatic groupings enabled the recognition of four Phyto-climatic zones A – D from the base of the studied section. The Zone A (40A – 41A) is rich in Pteridophyte spores, Aracaceae and Freshwater swamp forest pollen, but lacks Poaceae and charred Poaceae cuticles. From the floral assemblages, it represents a wet paleoclimatic condition (Table 2 and Figs. 3 and 4). Zone B (43A) is represented by a depth, with characteristic abundance of Poaceae, low proportions of Aracaceae and Freshwater swamp forest with absence of Pteridophytes. This record indicates a dry paleoclimate condition. Following this is the extensive Zone C (44A – 49A) with abundant occurrences of Pteridophytes, Arecaceae, Mangrove and Freshwater swamp forest pollen. Charred Poaceae cuticle is very low to absent while Poaceae also occurred in relatively low proportions. The high diversity and abundance of sporomorphs within this zone indicate a pronounced wet paleoclimatic episode. Zone D (51A and 53A) recorded high proportions of Poaceae, charred Poaceae cuticles and low occurrence of Aracaceae as well as none occurrence of Pteridophytes and Freshwater swamp forest pollen. This assemblage indicates a dry paleoclimate condition.

Several species of dinoflagellates and microforaminiferal wall linings were also recovered which have been extensively dealt with in Adeonipekun *et al*. (2012). The studied section was dated Paleocene/ Eocene by Olowu (1996) using calcareous nannofossils, and by Adeonipekun *et al.* (2012) using *Proxapertites cursus, P. operculatus, Retistephanocolpites williamsii, Longapertites vaneendiburgi, L. marginatus, Dictyophillidites harrisi* and *Foveotriletes margaritae.* These pollen and spore markers were corroborated by marker dinoflagellates such as *Phelodinium, Hafniasphaera, Apectodinium, Areoligera* and *Cordosphaeridium*; and foraminiferal *Morozovella, Globigerina velascoensis, Acarina nitida and Bulimina subfosiformis.* Zone D is the only phyto-climatic zone that falls within the early Eocene while the rest (C - A) falls within the late Paleocene/earliest Eocene. This Eocene section (53A and 51A) is interpreted as a dry paleoclimatic phase while the Paleocene part (40A – 41A) and Paleocene/earliest Eocene part (44A – 49A) are interpreted as wet phases with a brief profound dry phase indicated at sample 43A by abundant fungal elements (Appendix 1).

Samples 51A - 53A recorded high proportions of Poaceae, charred Poaceae cuticles and fungal elements with non occurrence to low record of Pteridophyte spores, Aracaceae and Freshwater swamp forest pollen. Samples 44A – 49A and 40A – 41A contain abundant Pteridophyte spores, Arecaceae, and Freshwater swamp forest as well as Mangrove with low proportions of charred Poaceae cuticles and Poaceae. Sample 43A however recorded abundant Poaceae and none occurrence of Pteridophytes as well as poor recovery of Freshwater swamp forest (Table 2 and Appendix 1).

Dinoflagellate *Apectodinium* spp. has two peaks within the studied section. One (in 45A within a Transgressive systems tract - TST) is very close to the recognized maximum flooding surface 56. 8 Ma at sample 46A and another at sample 40A at the base of the Oshoshun Formation close to the 57.5 Sequence Boundary as recognized by Adeonipekun *et al.* (2012) Fig. 5. *Apectodinium* spp. are important markers associated with the maximum flooding surface of the PETM. Prasad *et al.* (2006) used the coincidence of *Apectodinium* acme, negative carbon isotope excursion and palynofacies to recognize the PETM in India. Aubry *et al.* (2007) have also associated *Apectodinium* species' global proliferation with the PETM. The reported extinction of planktic and benthic foraminifera (Nagy *et al.,* 2013) at the PETM has also been linked to algal bloom since the algae had no foraminiferal fauna to feed on them Hansen (1990). This faunal extinction was recorded in the latest Paleocene/earliest Eocene sections of the studied outcrop with the greatest impact recorded within sample 48A Adeonipekun *et al.* (2012) Table 2.

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Two lithological units were recognized; the short solely shaly-sand (51A) and the extensive shaly units. The shaly-sand unit is dolomitic with high proportions of calcite and few carbonaceous detritus and shell fragments. These accessory minerals are absent within the shaly section. The sample number with their corresponding depths in meters are as follows: 53A -6m; 51A-7m; 49A-8m; 48A-8.50m; 46A-9.50m; 45A-10m; 44A-10.50m; 43A-11m; 41A-12m; 40A-12.50m. Details of the depositional environments within the shaly and shaly sand lithology have been recognized in Adeonipekun *et al.* (2012) as varying from inner neritic to middle neritic with occasional foray into outer neritic settings.

VI. Discussion

a) Floristic features

The late Paleocene/early Eocene has been reported as the warmest paleoclimatic period in the Paleogene and it is popularly referred to as Paleotropical Maximum or Paleocene - Eocene Thermal Maximum (PETM). At this geologic period, present temperate areas experienced tropical-like paleoclimate with high temperature and therefore tropical-like vegetations (Traverse, 1988). Even the present Canadian Arctic area recorded warm temperate vegetations. Sluijs *et al*. (2006) reported temperature increase from ~18 °C to over 23 °C during the PETM in the North Pole Arctic region thus recording a subtropical Ocean temperature in the Arctic Ocean. Sluijs *et al*. (2013) recently found also that "continental air and sea surface temperatures warmed from 27–29 °C to ~35 °C" during the PETM from deep sea core sediments.

Jaramillo and Dilcher (2000) worked on tropical Paleocene – early Eocene sediments and reported extinction at the PETM after which in the younger Eocene, diversity increased in the Colombian eastern Andes. Harrington and Jaramillo (2007) also reported taxonomic diversity increases in the late Paleocene of US Gulf Coast, a trend replaced by a marked extinction into the early Eocene. Wing and Currano's (2013) work on plant macrofossils in the Bighorn Basin, Wyoming, United States however recorded "radical floristic change" during the PETM. Much of what happened in the early Eocene of our study area could however not be ascertained as this section is rather short. It is however clear that there was a significant reduction in diversity and abundance of pollen from the latest Paleocene into the earliest Eocene where Pteridophyte spores disappeared to suggest a drier paleoclimatic condition than the late Paleocene after the PETM (Fig 3).

The Paleocene part though with a brief dry interval at 43A, was of wetter climatic condition with regular occurrence of Pteridophyte spores, Mangrove, Arecaceae and Freshwater swamp forest pollen while Poaceae and charred Poaceae cuticles recorded great reduction in proportions. This agrees with the transgressive phase report of Nagy *et al*. (2013) for the PETM. However within sample 43A, Poaceae value soared to a maximum with no record of spores, all within a monotonously shaly section. This represents the only short dry paleoclimatic phase within the late Paleocene section studied. From Table 5, the significant Spearman's correlation coefficient value of 0.652 confirms that there is a positive correlation between depth (m) and wet phase. i.e with increase depth, wet phase indicator palynomorphs increased in proportion. Dry phase indicator palynomorphs however have insignificant negative correlation values with depth since with increase depth, dry phase indicators decreased. These indices point to a generally wet late Paleocene and generally dry earliest Eocene paleoclimates in the study area.

The Eocene part involved in this study is short thus precluding making conclusions with respect to diversity trends beyond the top of studied section. Also only one outcrop was involved in the study. In spite of these, Jaramillo *et al.*'s (2010) conclusions that the tropical rainforest was not affected by the PETM events in eastern Colombia and western Venezuela where it was reported to have survived the high temperatures and high proportion of atmospheric carbon dioxide, may not be applicable to the Benin basin sediments. Previous findings indicating floral extinction and migration by Jaramillo and Dilcher (2000), Harrington and Jaramillo (2007) and Wing and Currano (2013) are supported by results from this present study. The conclusion of lack of evidence for aridity in the tropical rainforest areas within the PETM is supported by findings from our work, however two dry paleoclimatic phases recognized in this present study most likely serve as terminal boundaries of the PETM interval. A short one was recorded in the late Paleocene - Zone B at sample 43A, while the other was recorded in the early Eocene - Zone D at interval 51A – 53A. Pteridophyte spores disappeared from this Eocene part with corresponding increase in Poaceae and charred Poaceae cuticles (Table 2; Figs 3 &4). Results from present work agree with Garel *et al*. (2013) record of dry episodes just before the PETM and moister climate during it in Normady, France from geochemical and palynofacies studies.

Despite the monotony of lithology, paleoclimatic records deducible from paleo-vegetational changes were recognizable. This shows that facies change does not always represent paleoclimatic change while the fact that it is monotonous also does not mean that paleoclimate had not changed (Table 2).

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VII. The Paleocene - Eocene Thermal Maximum (PETM)

Various authors have attempted the recognition of the PETM in different areas of the world tying it to eustacy since increased CO_2 would have led to increased sea level with melting of ice in the polar region and consequent sea transgression globally. Prasad *et al.* (2006) recognized the PETM onset at the peak of *Apectodinium* spp. in Northeastern India. Sluijs *et al*. (2006) however reported from Arctic Ocean sediments that the Paleocene–Eocene Thermal Maximum indicated a sea level rise deducible from the temperature rise from 18 ^{0}C – 23 ^{0}C. Schulte *et al.* (2011) recorded its recognition at the base of the Eocene within a transgressive systems tract (TST) in Dababiya Quarry section, Egypt. Aleksandrova and Shcherbinina (2011) working on sediments from Nasypnoe section in Eastern Crimea, Ukraine reported that nannofossil and dinocyst distribution suggests that "a drastic sea-level fall preceded the PETM and occurrence of two transgressive episodes during it". Rivandi *et al.* (2013) reported the possible presence of the PETM at the end of a high stand systems tract (HST) that is characterized with deposition of shale and marl facies. The end of the HST specifically at the sequence boundary represented by a paleosol was interpreted as a major sea level fall in the latest Paleocene. Associated with this paleosol according to Rivandi *et al.* (2013) is the river channel sediments (conglomerate). Minelli *et al.* (2013) recognized the PETM within a sea level rise interval (TST of Serraduy Sequence) in the Ager Basin of Central Pyrenees, Spain. Sluijs *et al*. (2013) also most recently recorded a sea level rise during the PETM from deep sea core sediments. Nagy *et al.* (2013) observed that the PETM acme coincides with the maximum flooding surface (MFS) of the Gilsonryggen depositional sequence in Spitsbergen Norway. Its transgressive phase was initiated by local tectonics, while the eustatic sea-level rise of the PETM was superimposed on this transgression.

Gebhardt *et al.* (2010) from the study of the foraminifera and carbon isotopes Excursion (CIE) of sediments from the Shagamu Quarry, southwest Nigeria recognized the Initial Eocene Thermal Maximum (IETM) at the Paleocene - Eocene boundary being characterized by dominance of dysoxic benthic foraminifera - *Bulimina* and *Nonionella* spp. with concomitant great reduction in planktic and benthic foraminifera. Frieling *et al.* (2011) working on the tropical sediments from Nigeria also observed a coincidence of the PETM with the Carbon Isotope Excursion (CIE) interval where *Apectodinium* was absent but abundantly present before their recognized interval of CIE. Nagy *et al.* (2013) reported that the faunal extinction at the PETM was co-eval with hyposaline and hypoxic conditions caused by continental influx into the marine environments. High kaolinite indicating high humidity was also recorded within the climatic anomaly. Samples 48A and 49A in the present work recorded high humidity with relatively high pteridophyte spores' values (see Table 2 and Appendix 1). Freshwater alga *Botryococcus* recorded an unprecedented upsurge at sample 49A in the earliest Eocene within the HST interval recognized at the terminal marine transgression (Adeonipekun *et al.,* 2012) associated with the PETM in the Shagamu Quarry outcrop. With samples 44A - 49A showing high humidity and particularly Sample 48A having all the reported faunal and floral features of the PETM (extinctions with high humidity), we propose this interval as the PETM in the Shagamu Quarry, Southwest Nigeria. These samples represent the terminal TST and HST recognized by Adeonipekun *et al* (2012) see Fig. 5, and is defined in the present work as the wet paleoclimatic Zone C (Fig. 2). Incidentally, the marker dinoflagellate for the Paleocene/Eocene boundary - *Hafniasphaera septata* applied by Adeonipekun *et al.* (2012) has its top within Sample 48A. The extinction of calcareous foraminifera and other planktonic organisms has also been linked to *Botryococcus* pulse since their death would have provided nutrients for the alga thereby leading to a bloom Hansen (1990). The two dry paleoclimate phases recognized also have one preceding the PETM (Phyto-climatic Zone B) and the other terminating it (Phyto-climatic Zone D). From Appendix 1, *Botryococcus*, a freshwater alga commonly recovered from marine sediments recorded an unprecedented abundance from sample 49A upwards.

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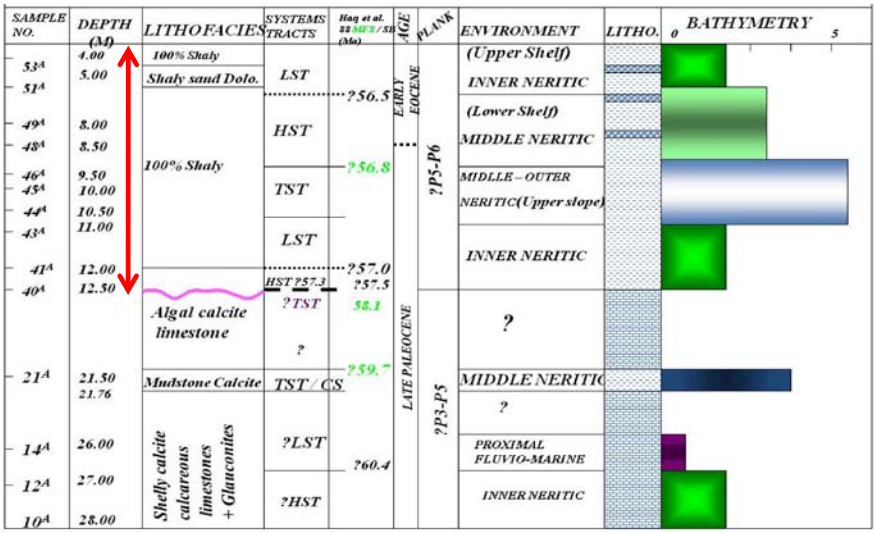

Fig. 5 : Sequence Stratigraphy of Shagamu Quarry (Adeonipekun et al. 2012). Red symbol indicates the studied *section* in the present work

Within much of the early Eocene section studied, the climate was extremely dry (Phyto-climatic Zone D) with no record of pteridophyte spore while recovery of Poaceae and charred Poaceae cuticles were relatively high. This record is synonymous with palynological features of low sea level (LST)/ later part of Highstand Systems tract (HST) in sequence stratigraphy of deltaic sedimentary basin in the tropics (Morley, 1995; Adeonipekun, 2006).

VIII. Conclusion

Palynological and sedimentological analyses of sediments from the Shagamu Quarry outcrop in the Eastern Benin basin revealed that diversity and abundance of plants decreased from the late Paleocene into the earliest Eocene. Four phyto-climatic zones (A – D, dry B and D; wet A and C) were recognized with the Paleocene/Eocene boundary falling within the extensive wet Zone C. The PETM was recognized within the wet Zone C marked by acme of *Apectodinium*, abundance of *Botryococcus*, high humidity from abundant pteridophyte spores and high floral diversity. It was further tied to the 56.8 Ma marine events with the TST recording high humid wet climate and the HST containing the bloom in algae. Two dry paleoclimatic phases bound the PETM at both the top and bottom.

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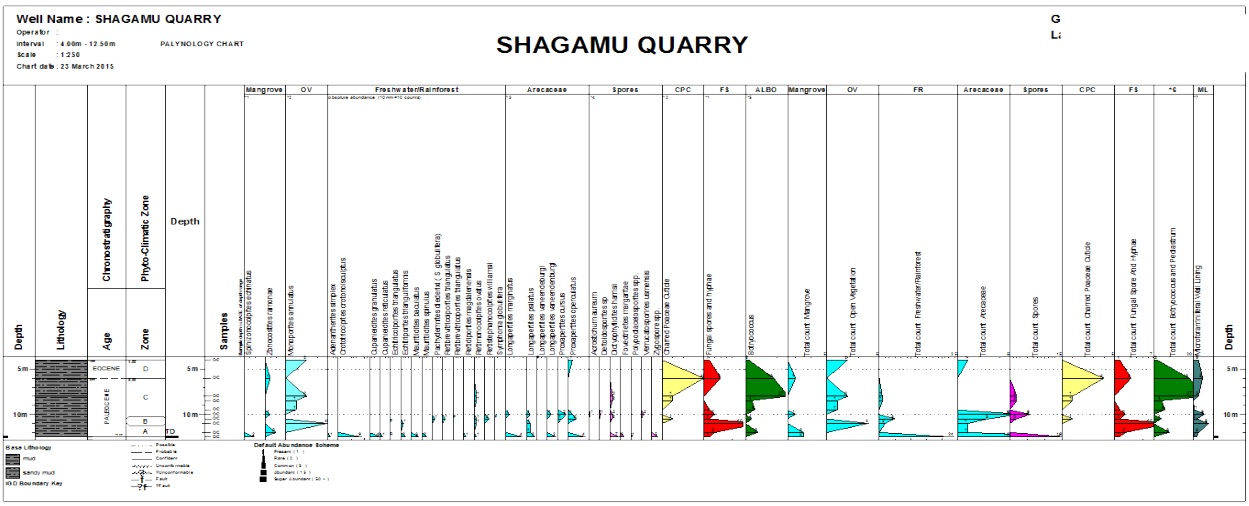
Appendix 1



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