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Palaeoclimatic Evidences from the Quaternary Coastal Deposits, Southwestern, Nigeria

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Abstract

The studies on some samples retrieved from the coastal sediment deposit have been carried out. The palynological and geochemical indices were evaluated with the view of determining their chronology, palaeoclimatic conditions that prevailed during the time of their emplacement and also to re-asses the palaeoenvironment of the Lagos coastal deposit in Dahomey Basin. The identification of diagnostic species age entails the palynological analysis while the geochemical analysis determines the provenance of these Quaternary sediments. The occurrences of *Laevigatosporites* sp., *Zonocostites ramonae, Acrostichum aureum* in abundance along with few long ranging forms suggest that the vegetation development was under a humid climate and that the sediments were deposited during cooler and wetter conditions. The presence and high abundance of *Crassoretitriletes vanraadshooveni, Zonocostites ramonae*, *Canthiumidites* sp., *Sapotaceoidaepollenites* sp. and *Pachydermites-diederixi* palynomorphs indicate an age range of late Pliocene (Gelasian) to early Pleistocene (Calabrian) (2.588 - 1.806 Ma). This age range is known to correspond to the 3.7 - 3.8 depositional cycles of relative change of coastal On-lap. The geochemical appraisal showed that the ratios of organic carbon-nitrogen (C/N) indicate that the sediments were sourced from aquatic, protein-rich and cellulose-poor milieu. The wetter climatic period has enhanced algae productivity as a consequence of greater wash-in of soil nutrients, and these periods are recorded as increased rate of organic carbon mass accumulation. Conversely, the dominance of a mangrove habitat, *Zonocostites ramonae* suggests a mangrove swamp environment which was the most prevalent environment of the Lagos lagoon in the Pleistocene.

Keywords

Quaternary, Palynological, Lagoon, Organic Matter, Dahomey, Pleistocene, Environment

1. Introduction

The area of study is located within the Lagos lagoon and lies within latitudes 06˚10''N - 06˚40''N and longitudes 03˚10''E - 003˚40''E (Figure 1). It is bounded in the north by extensive land area comprising major population and industrial centers, also bounded to the south by highbrow business and residential areas. The depth of the lagoon ranges from 4 m (in most parts) to between 8 m and 13 m in the deepest part.

In the Quaternary period, the most recent geologic interval represents the last 1.8 million years. Its most striking feature is that the earth had cold Polar Regions, which led to periodic development of continental glaciers. It is also

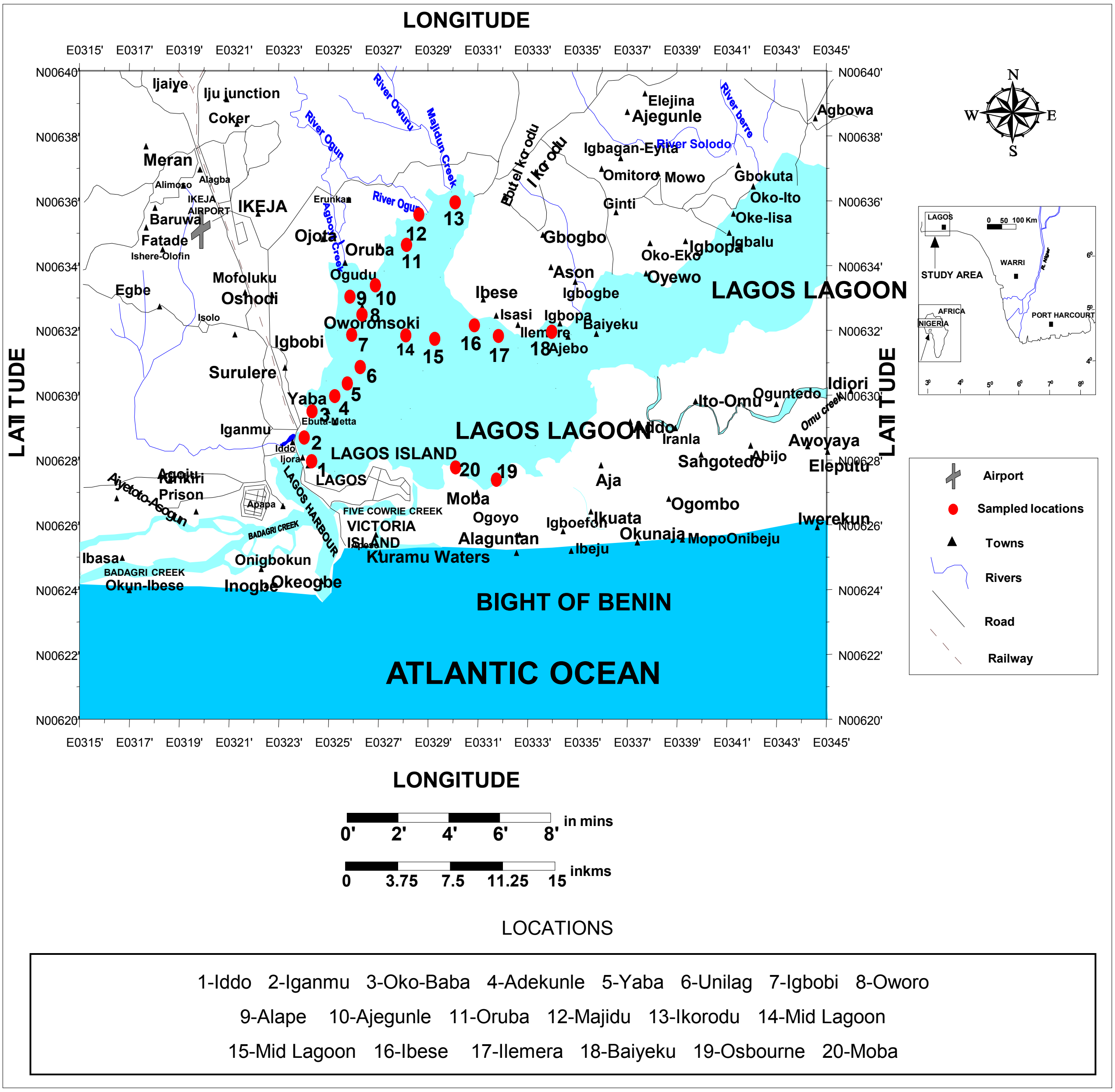


Figure 1. Location map of the study area showing the various sampling points.

responsible for some important economic mineral deposits. The Quaternary period has been a time of environmental and climatic changes characterized by a sequence of approximately thirty glacial-interglacial cycles in the northern hemisphere [1]. This was a period of major environmental changes that were possibly greater than any other time in the last 60 million years. Nevertheless, there is no doubt that an understanding of climatic variation and changes during the Quaternary period is necessary not only to appreciate many features of the natural environment today, but also to comprehend fully our present climate [2]. The earth is right now entering a time of unusually warm climate. Significant and potentially rapid environmental changes could pose major challenges for human habitability.

One of the most pressing concerns for humans on earth today is climate change and what will happen in the future. Given that the climate is definitely warming, it is logical to ask two questions that have such changes happened before in the history of the earth and what will future climate holds? The expertise of Quaternary scientists is to interpret the changing world of the glacial ages and their impact on our planet's surface environments and understanding of the possible future climate change. The risk about global warming that we will face in coming years can be minimized through further climate based scientific research. Research on earth's climate in the recent geologic past provides insights into ways in which climate can change in the future. It also provides information that contributes to the testing and advancement of the computer models that are used to predict future climate change. Several excellent works on the basics of climate modelling are available [3] [4] [5] [6]. These models are the coupled general circulation models (GCMs) and are based on fundamental principles of physics and energy balance and the fluid flow of the earth's atmosphere and oceans. GCMs are designed to simulate earth's climate and test theories about climate change.

Climate research has expanded in tandem with a second component of the study of earth's climate: the extensive worldwide efforts to measure, observe, and monitor climatic variables using land and satellite-based methods. Global and regional atmospheric temperatures carbon budgets and sea level are just a few of the many types of data used by climatologists, atmospheric scientists, and oceanographers to examine secular trends and variability in climate [7] [8] [9] [10] [11]. A more complete synthesis of palaeoclimate is available through the integration of data from multiple proxies [12].

Pollen analysis plays a critical role in climate change studies during the Quaternary [13]. It is also the single most important branch of palaeoecology for the Pleistocene and Holocene [14]. A fundamental operating assumption is that the pollen-vegetation climate relationships that can be observed now also operated in the past [14]. Sediments organic matter provides a variety of elemental and molecular proxies to reconstruct past climates and ancient environments [15]. The organic matter content of sediment is the residue of past biota, the amount and types of organic matter present in sediments consequently reflect environmental conditions [16]. The proportions of sedimentary organic matter that originate from aquatic as opposed to terrestrial sources can be distinguished from compositional differences between algae and vascular land plants. The elevated C/N ratios found in sediment records implies periods of enhanced aquatic palaeoproductivity [17]. Phytoplanktons usually have low C/N ratios, of 4 and 10, while vascular land plants, that are cellulose-rich and protein-poor, have C/N ratios of 20 and above [18]. However, for the first time in Nigeria, this study entails multi-proxies approaches to evaluate the palaeoclimate, palaeoenvironment, document the information achieved within the Lagos lagoon Quaternary sediments and to give credence to the present climatic conditions which are of prime importance to the changing earth that is influenced by man and natural activities.

2. Physiographic Setting

The study area is generally low-lying of about 12.0 m above sea level in all the Islands (Lagos, Victoria Island, Apapa and Ikoyi) and a little higher in its mainland extensions (north of the Lagos Lagoon). The topography is generally undulating and the pattern of relief in the Lagos area reflects the coastal location of the area. The hinterland is flat sometimes giving rise to swampy terrain.

The area lies within the sub-equatorial climatic region and it has distinct seasons; the dry season which starts in November and ends in March, as well as the rainy season which starts in April and ends in October. The Lagos area however is known to have a very unpredictable weather pattern with the possibility of rain during any time of the year. The mean annual rainfall is 1200 ml per annum while the mean annual temperature is about 28˚C. The mean maximum temperature occurs in February and it is estimated to be 34˚C while the mean minimum temperature of about 22˚C has been recorded, particularly in August when there is dense cloud cover. A remarkable aspect of the climate due to its coastal location is the occurrence of land and sea breeze in which the cooling effect of the land breeze is more pronounced in the afternoon, while the sea breeze is more obvious at night.

The vegetation is typically rainforest, grading into mangrove type around the creeks surrounding the lagoons. Although, people seeking firewood and materials for the construction of fish traps as well as land developers have destroyed the mangrove in several areas.

The drainage pattern in the Lagos area reflects the coastal location of the area and forms part of a wider stretch of the coastal zone of southwestern, Nigeria (**Figure 1**). The Lagos lagoon areas serve as the convergence zone for a number of rivers. Each of these rivers such as Yewa, Ogun, Ona, Osun and Shahsa has developed prominent estuaries and flood plains into which other short streams drains (**Figure 1**). Two of these major rivers empty their contents into the Lagos lagoon. These are the fresh water bearing Ogun River and the brackish water laden Majidun River.

3. Previous Work

About nine lagoons have been described in southwestern Nigeria [19] [20] [21] they are the Yewa, Badagry, Ologe, Iyagbe, Lagos, Kuramo, Epe, Lekki and Mahin Lagoons. The Lagos lagoon has received much attention because of its location in a commercial center. Considerable works have been carried out on the Quaternary deposits in Nigeria and some have involved their palynological and organic geochemical analyses. It has been studied by various authors including geologist, soil scientist, archaeologists, engineers and geomorphologists using different methods of research, the soil scientist have carried out extensive mapping and classification of soils over large parts of Nigeria [22] [23] [24] [25] [26].

Adekanmbi and Ogundipe worked on fourteen plant species belonging to four families of Acanthaceae, Amaranthaceae, Apocynaceae and Aracaceae from Lagos lagoon swamp and hinterland vegetation [27]. It was concluded that pollen belonging to the family Acanthaceae are mostly prolate in equatorial view and trigonal to circular in polar view. Family Amaranthaceae pollens are eurypalynous comprising of different morphological types of pollen, ranging from inaperturate to polyporate. Genera in the family Apocynaceae exhibit palynological extremes indicated by variety in the shape of the pollen grains, aperture, size and ornamentation of the studied species. Pollen grains in Aracaceae also exhibit variations ranging from monocolpate to trichotomosulcate nature of aperture. Durugbo and other workers studied palynological evidence of Pliocene-Pleistocene climatic variations from the Western Niger Delta and opined that the dominance of Savanna pollen over wet climate indicators (mangrove, freshwater swamp species, brackish water swamp species and Palmae) and the preponderance of the dinocysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum*, species adapted to very saline and warm waters respectively, with abundant fungal spores dominated by *Exesisporites* sp., gives credence to a predominantly dry climate and lowered sea level during the Pliocene-Pleistocene (ca. 5.0 - 1.3 Ma) in the Gulf of Guinea [28].

Adekanmbi and Ogundipe studied the relationship between pollen assemblage and vegetation in the Lagos lagoon [27]. They sampled eight lagoonal communities quantitatively with respect to their floral diversity and palynomorph content and recorded a total of ninety-six (96) palynomorph species. They observed that the palynofacies are made up basically of pollen grains sourced from local vegetation and only one regional plant and concluded that the palynomorph from Lagos Lagoon sediments truly represent the vegetation hence could be used to characterize parent vegetation communities.

Sowunmi studied terrestrial core from Ahanve in Badagry area of the coastal southwestern Nigeria [29]. The area was a Typha dominated freshwater swamp annually flooded by the Badagry Creek. The report stated that the dominant vegetation communities that prevailed in the coastal southwestern Nigeria was made up of abundant forests, Rhizophora dominated mangrove forest in the tidal zone, freshwater swamp forest in the swampy regions under freshwater influence and drier, semi-deciduous forest on the well-drained areas with some woody, Savanna species and sparse grass cover at some intervals from ca. 8576 ± 48 BP to sometime prior to ca. 3109 ± 26 BP.

Allen recorded that two series Quaternary sediments occur on the surface of the Nigeria continental shelf and slope overlying the Nigeria coastal plain geosynclines while working on the Nigeria continental margin, bottom sediment submarine morphology and geological evolution [30] (**Figure 2**). As it became evident that the Quaternary climate was marked by alternating wet and dry climatic phases, its effects on soil formation has been examined [31] [32]. Nwankwo reported that two factors, fresh water discharge from rivers and tidal seawater incursions influence the biological, physical and chemical characteristic of the Lagos Lagoon [33].

Salzman and other workers used the multiproxy approach to determine the late Quaternary climate and vegetation of the Sudanian zone of northern Nigeria [34]. They observed from pollen, diatoms and sedimentary geochemistry evaluations that dry climate conditions prevailed throughout the late Pleistocene. Nyer recognized the existence of distinct lithological horizons in the soil profiles in Ibadan [35], where a stratigraphic approach was applied to the study of superficial deposits in the area. This approach has been extended to some parts of the crystalline rock areas of southwestern Nigeria [36].

It is expected that within the large area of Nigeria and with a wide range of tropical climate belts, different sedimentation environments exist consequently different types of sediments have been deposited along the narrow Guinea Coast,

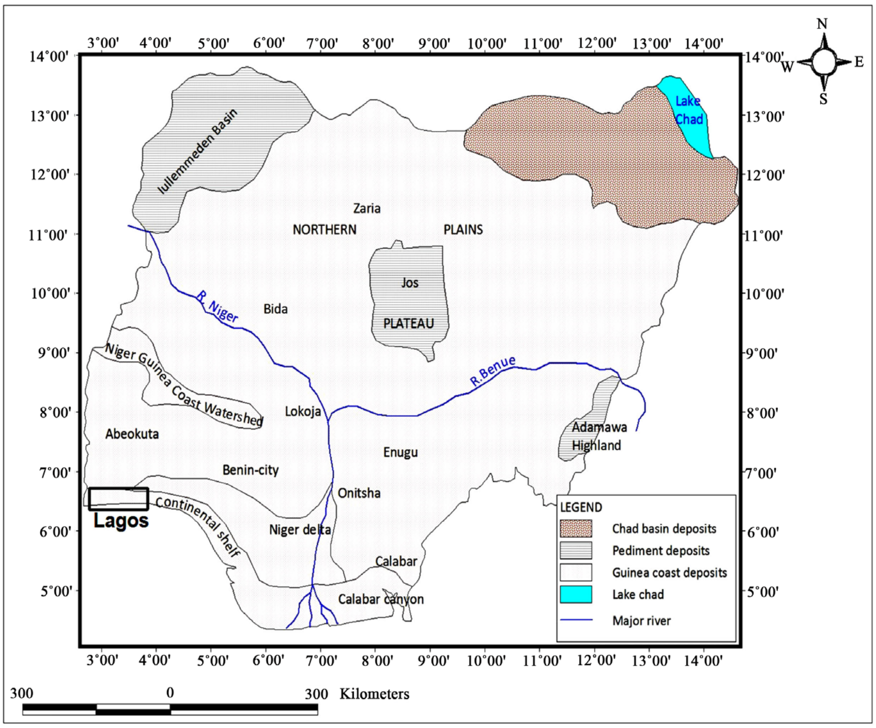


Figure 2. Map of quaternary deposits in Nigeria showing the study location (incised).

sediments were deposited under the influence of fluctuating Quaternary, the behavior and sedimentation processes of especially the lower parts of the major rivers that flowed into the sea. Over the rest of the country, Quaternary sediments were laid down under the influences of alternating wet and dry climatic phases. This claim was also supported by Sowunmi on aspects of late Quaternary vegetation changes in West Africa [37] [38].

4. Geological Setting

The Lagos area falls within the Dahomey Embayment, an extensive sedimentary basin stretching from eastern Ghana, Togo and the Republic of Benin to the western part of Nigeria up to the Benin hinge line (**Figure 3**). The basin is one of the sedimentary basins in Nigeria; however, it is the eastern portion of the Dahomey Embayment that is exposed in the southwestern part of Nigeria. The eastern Dahomey Embayment is bounded in the north by the Precambrian Basement Complex of southwestern Nigeria, the Gulf of Guinea to the south and eastward by the Okitipupa ridge [39].

The Dahomey Embayment was initiated during the early Cretaceous as a result of separation of the Gondwanaland [40] [41] [42] [43] described the basin as pull-apart type-5 basin, while Kingston and other workers described it as a marginal sag basin [44]. The Benin flank marks the zone of constriction in the basin and the thinning of the sediments and this separates the Dahomey Embayment from the Niger Delta Basin. Other work on tectonic structures includes that of Omatsola and Adegoke [45]. The sediments of the Dahomey Embayment are early Cretaceous to Holocene in age and are dominantly clastic with occurrence

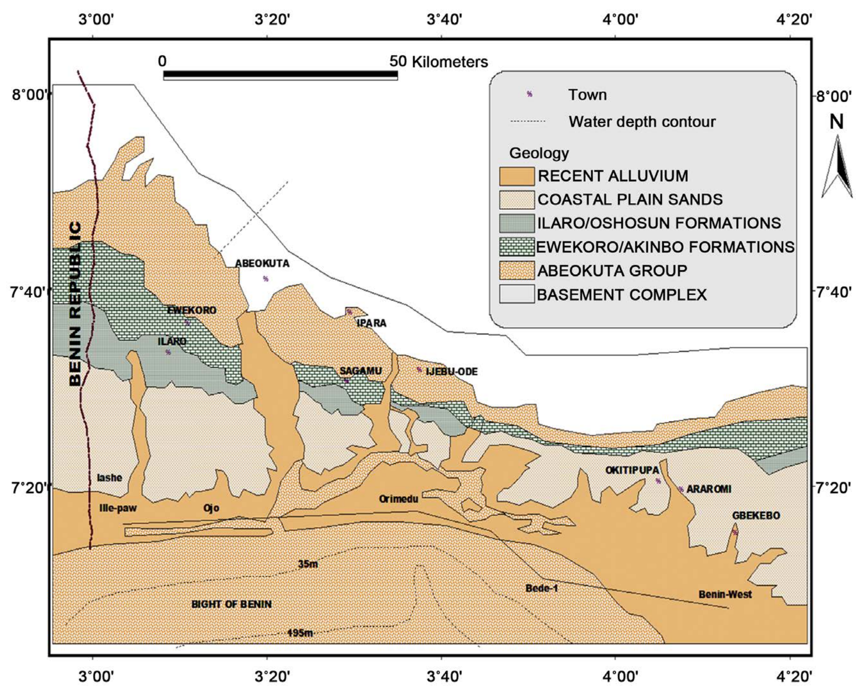


Figure 3. Geological map of the eastern Dahomey Embayment [46].

of shale and limestone [46]. The lithostratigraphy of the basin has been grouped: Abeokuta Formation which is the oldest formation in the basin [45] [47]. This group consists of conglomerate, sandstones, clays, shale and thin limestone. The Abeokuta Group is sub-divided into Ise, Afowo, and Araromi formations. The Ewekoro Formation is a lensoid shaped unit, which pinches out towards the east and south. The formation comprises limestone and marl that are fossiliferous particularly mollusks [46]. This formation has been subdivided into three units by Adegokeand other workers while Ogbe proposed a fourth unit of red phosphatic biomicrite (top), algal biosparite, shelly biomicrite and sandy biomicrosparite (bottom) [48] [49].

The Akinbo Formation overlies Ewekoro Formation of Palaeocene-Eocene age. It consists of well-laminated greenish grey and black shales. The base is defined by glauconitic rock bands in places [45]. The Oshosun Formation can be correlated to Ameki Formation which consists of grey mudstones in eastern Nigeria [50]. The Ilaro Formation overlies the Oshosun Formation which is predominantly made up of massive coarse, sandy estuarine deltaic and continental beds displaying rapid changes in facies. It consists of medium-fine grained sands yellowish in color with some clay fractions [47]. The formation is made up of both marine and continental massive yellowish consolidated sandstones. They are fine to medium grained, poorly sorted with some clay fractions. Ferruginous sandstones and ironstone bands indicate a hiatus in the depositional environment of the formation. It is assigned middle-upper Eocene based on the palynological studies. The formation is poor in microfauna but pollen and spores that are present indicate an Eocene age [39]. Jones described the Ilaro Formation as a lateral equivalent of the Oshosun Formation and estimated the thickness of 60 m [51].

The Coastal Plain Sands Formation is the youngest sedimentary unit in the eastern Dahomey Embayment, consisting of soft, very poorly sorted, clayey sands, sandy clay and rare thin lignite. The coastal plain sands are unfossiliferous except for plant remains. The thickness of the formation range from 10 m - 100 m [52]. They are seen as the overburden that lacks fossil but contains plant debris which have been sources of dating [53]. This formation has been assigned Oligocene age.

5. Sampling and Methodology

This work involved the field study and laboratory analyses. The field exercise was carried out with the aid of sample Corer and motorised boat in the month of July, which lasted for two days due to the expansive nature of the lagoon and high water depth as a result of heavy downpour of late July. Systematic sampling covered the western part of the lagoon, Iddo, UNILAG, Oworo, Ikorodu, Agege and Ibese areas. These samples were taken by coring the basal floor of the lagoon, with the help of professional marine divers to depths ranging from 30 cm - 1.0 m (**Figure 4**). This exercise was to collect samples for laboratory studies

Figure 4. Fieldwork exercise on the Lagos lagoon.

while the exact locations and elevations of sampling points were made possible via the Global Positioning System (GPS) (Garmin Ventures HCx model). Samples were selected for palynological, organic geochemical (TOC) and elemental (N) analyses.

5.1. Palynological Analysis

Total of twenty (20) samples of the Lagos Lagoon sediments were analysed for this study. 10 g of each sample were crushed to 3mm size before the treatment with 10% hydrochloric acid (HCl) to remove the carbonates that might be present in the samples. To ensure a complete removal of the carbonates, the hydrochloric acid (HCl) was added in excess until no more effervescence was observed. After 24 hours, the acid was decanted and water added for another 24 hours for the first time and six hours for the second and third time. This is to ensure that the effect of the HCl is completely neutralized. The process was followed by the treatment of the samples with hydrofluoric acid (HF) for the removal of the silicates. Thirty five percent (35%) HF was added and the whole set up were placed on a shaker for twenty four (24) hours. Thereafter, the content was allowed to settle for another twenty four (24) hours before the HF was carefully decanted. Neutralization with distilled water was repeated. To remove Fluorosilicate compounds which might be formed from the reaction of HF, the content were again treated with HCl. Distilled water was again added to neutralise the effect of the acid. It should be noted here that no oxidation step was involved in this preparation as this process could selectively destroy the dinoflagellate present in the samples. The residues were then sieved using 10 μm sieve for the recovery of the palynomorphs. The slides were carefully studied using a binocular microscope (LeitzDiaplan) for identification, counting and photographic documentation. The age determination is based on Evamy and other workers [53] and STRATCOM schemes.The results are presented in **Table 1**, **Table 2**, **Table 3** and **Table 4** and **Figures 4-8**.

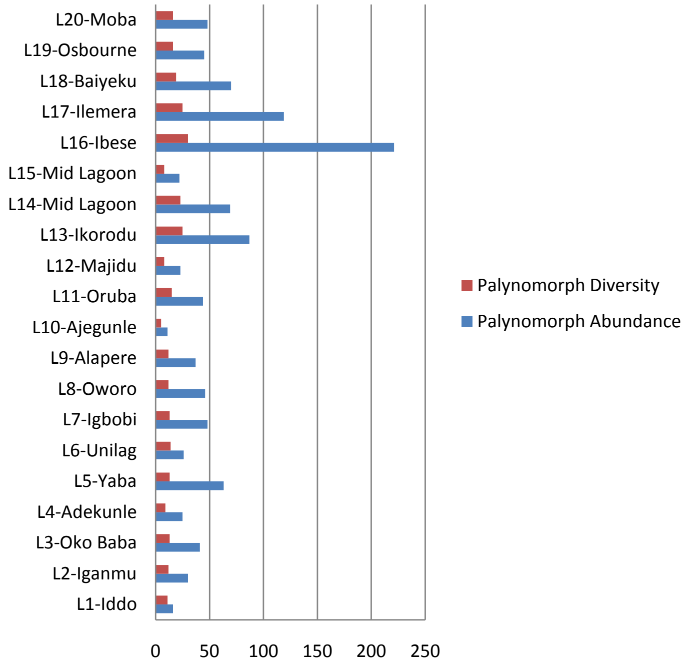
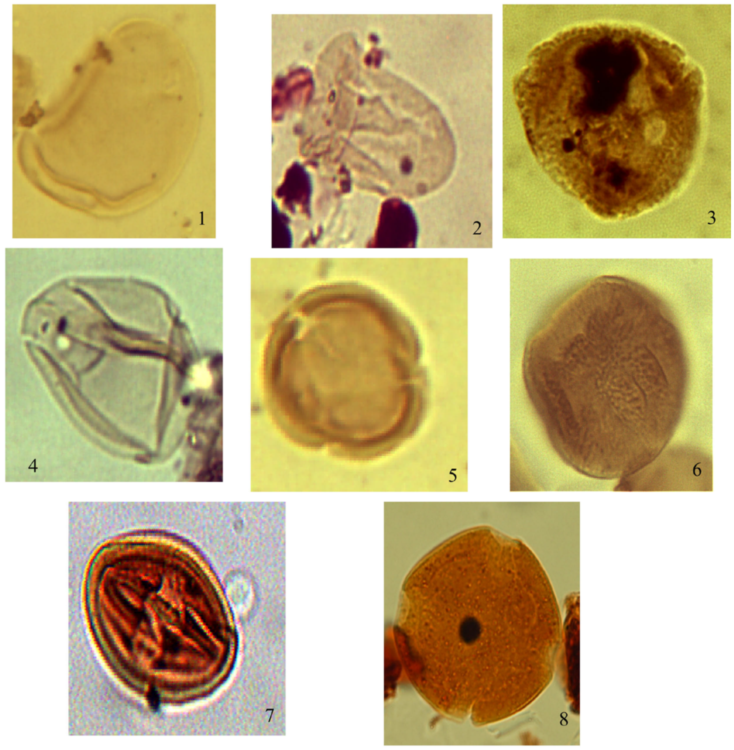


Figure 5. Palynomorphs abundance and diversity at diverse locations.

Table 1. Palynomorph abundance, diversity and their respective system tracts.

Locations	Abundance	Diversity	System Tracts
L1-IDDO	16	11	
L2-IGANMU	30	12	
L3-OKO BABA	41	13	
L4-ADEKUNLE	25	9	
L5-YABA	63	13	
L6-UNILAG	26	14	
L7-IGBOBI	48	13	
L8-OWORO	46	12	
L9-ALAPERE	37	12	
L10-AJEGUNLE	11	5	Transgressive system tract (TST)
L11-ORUBA	44	15	
L12-MAJIDU	23	8	
L13-IKORODU	87	25	
L14-MID LAGOON	22	8	
L15-MID LAGOON	22	8	
L16-IBESE	221	30	
L17-ILEMERA	119	25	
L18-BAIYEKU	70	19	
L19-OSBOURNE	45	16	
L20-MOBA	48	16	



1. *Laevigatosporites* sp.; 2. *Cyperaceaepollis* sp.; 3. *Retibrevitricolporites bodoensis*;
4. *Monoporites annulatus*; 5. *Zonocostites ramonae*; 6. *Retistephanocolpites gracillis*;
7. *Sapotaceoidaepollenites* sp. and 8. *Pachydermites diederixi*

Figure 6. Photomicrographs of selected palynomorph taxa from the studied areas.

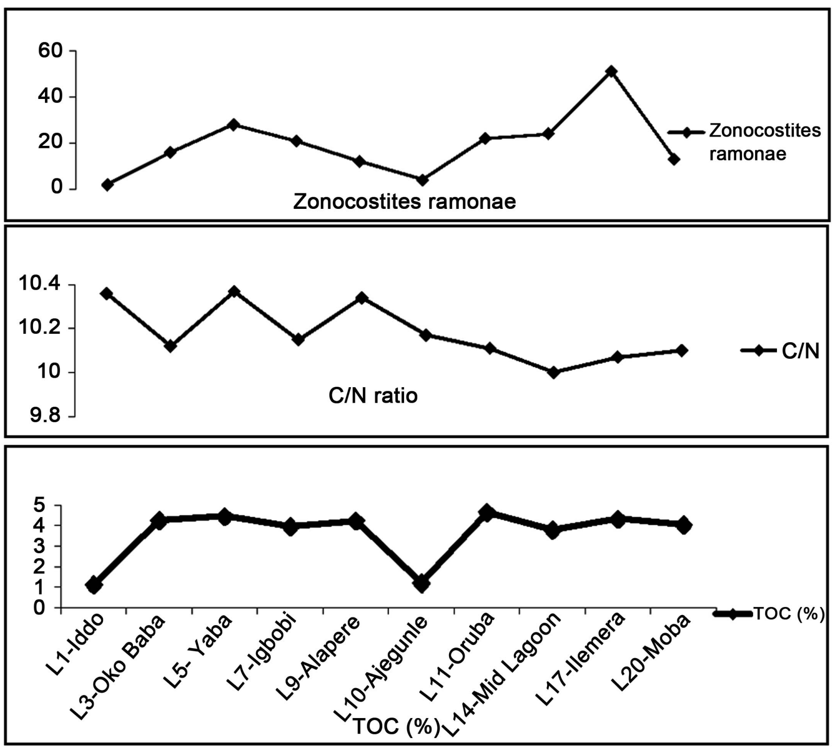


Figure 7. Organic carbon concentrations, atomic C/N ratios, and the abundance of *Zonocostites ramonae* in sediments collected from different locations in the study area.

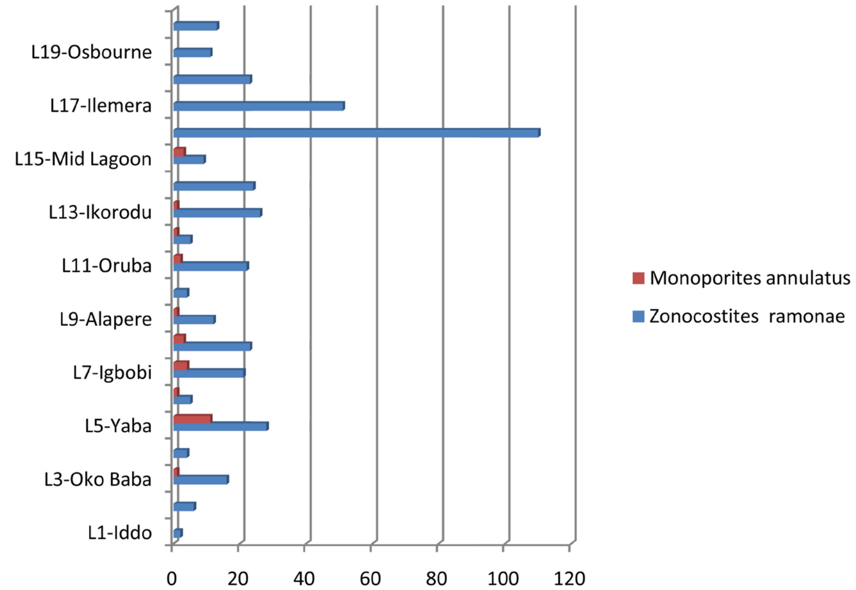


Figure 8. Distribution of *Zonocostites ramonae* and *Monoporites annulatus* in the study area.

Table 2. Abundance of diverse palynomorphs recovered from the study area.

Locations	*Zonocostites ramonae*	*Monoporites annulatus*	*Laevigatosporites* sp.	*Crassoretitriletes*	*Sapotaceoidae pollenites*
L1-IDDO	2	-	2	1	3
L2-IGANMU	6	-	4	-	-
L3-OKO BABA	16	1	8	1	5
L4-ADEKUNLE	4	-	4	-	2
L5-YABA	28	11	11	4	8
L6-UNILAG	5	1	5	-	2
L7-IGBOBI	21	4	-	-	5
L8-OWORO	23	3	8	4	2
L9-ALAPERE	12	1	8	-	2
L10-AJEGUNLE	4	-	3	-	1
L11-ORUBA	22	2	5	3	2
L12-MAJIDU	5	1	7	4	-
L13-IKORODU	26	1	12	2	1
L14-MID-LAGOON	24	-	14	-	1
L15-MID LAGOON	9	3	3	4	-
L16-IBESE	110	-	33	3	4
L17-ILEMERA	51	-	27	1	3
L18-BAIYEKU	23	-	10	2	-
L19-OSBOURNE	11	-	9	1	1
L20-MOBA	13	-	14	1	-

Table 3. Palaeoclimatic conditions based on the recovered palynomorphs.

Locations	*Zonocostites ramonae*	*Monoporites annulatus*	Palaeoclimatic
L1-Iddo	2	-	
L2-Iganmu	6	-	
L3-Oko Baba	16	1	
L4-Adekunle	4	-	
L5-Yaba	28	11	
L6-UNILAG	5	1	
L7-Igbobi	21	4	
L8-Oworo	23	3	
L9-Alapere	12	1	
L10-Ajegunle	4	-	Wet
L11-Oruba	22	2	
L12-Majidu	5	1	
L13-Ikorodu	26	1	
L14-MidLagoon	24	-	
L15-MidLagoon	9	3	
L16-Ibese	110	-	
L17-Ilemera	51	-	
L18-Baiyeku	23	-	
L19-Osbourne	11	-	
L20-Moba	13	-	

Table 4. Palaeoenvironment of the study area based on the recovered palynomorphs.

Locations	*Zonocostites ramonae*	*Monoporites annulatus*	Environment
L1-Iddo	2	-	
L2-Iganmu	6	-	
L3-Oko Baba	16	1	
L4-Adekunle	4	-	
L5-Yaba	28	11	
L6-UNILAG	5	1	
L7-Igbobi	21	4	Marginal Marine
L8-Oworo	23	3	
L9-Alapere	12	1	
L10-Ajegunle	4	-	
L11-Oruba	22	2	
L12-Majidu	5	1	
L13-Ikorodu	26	1	
L14-MidLagoon	24	-	Marginal Marine
L15-MidLagoon	9	3	
L16-Ibese	110	-	
L17-Ilemera	51	-	
L18-Baiyeku	23	-	Marginal Marine
L19-Osbourne	11	-	
L20-Moba	13	-	

5.2. Total Organic Carbon (TOC) Analysis

A total of ten (10) samples (mudstone) were analysed for the total organic carbon (TOC) content. The samples were pulverized to pass through 0.5 mm mesh sieve before weighing. 250 mg of the sample was weighed before it was transferred to a 250 ml conical flask. Potassium Dichromate ($K_2Cr_2O_7$) was added by means of a 10 ml pipette swirled for proper mixing. This was followed by the addition of 20 ml of concentrated sulphuric acid (H_2SO_4) into the mixture and was allowed to stand for 20 to 30 minutes. The suspension diluted with about 100 ml of distilled water. 10 ml of 1.10 phenantroline indicator was added. The excess dichromate (Cr_2O_7) was back titrated with 0.5 N ferrous solution to green endpoint. The reagent was then run blank. It is imperative to run a blank titration so as to be able to measure the amount of reducing substances present in the reagent as impurities. The method described above is the Wackley-Black wet oxidation method [54].

% Org C = (me$K_2Cr_2O_7$ − me$FeSO_4$ × 0.003 × 100 × f)/g of air-dry soil

Correction factor, f = 1.33; Me = Normality of solution × ml of solution used;

% Org matter in sample = % Org Carbon × 1.729. The results of the analyses are presented in Table 5.

5.3. Elemental Analysis

For the total Nitrogen (N) content, ten (10) samples were analysed which were pulverized and made passed through a 0.5mm sieve before weighing 0.5 g that was transferred into 50 ml digestion tubes. 2.5 ml of sulphuric acid-selenium mixture was added into each tube then 6.25 g of selenium was dissolved into 1litre of concentrated sulphuric acid and the sample was mixed the acid on a vortex mixer. 2 × 1 ml of hydrogen peroxide (H_2O_2) was added into each tube after which they were placed on a hotplate preheated to 300˚C. After 30 minutes of boiling, the condensing bottles were placed over each digest tube. The temperature was then increased to 320˚C and left on the hotplate until the digest

Table 5. Geochemical results from the study area.

Locations	Sample ID	TOC (wt%)	N (%)	C/N Ratio
Iddo	L1	1.14	0.11	10.36
Oko baba	L3	4.25	0.42	10.12
Yaba	L5	4.46	0.43	10.37
Igbobi	L7	3.96	0.39	10.15
Alapere	L9	4.24	0.41	10.34
Ajegunle	L10	1.22	0.12	10.17
Oruba	L11	4.65	0.46	10.11
Mid lagoon	L14	3.80	0.38	10.00
Ilemera	L17	4.33	0.43	10.07
Moba	L20	4.04	0.40	10.10

is clean, after which the samples were allowed to cool before diluting to 50 ml with distilled water (**Table 5** and **Figure 7**).

6. Results and Discussion

The twenty (20) samples processed for palynological study yielded a total of one thousand and forty-four (1044) palynomorphs of moderate to high abundance of pollen. Results show mainly dominance of *Zonocostites ramonae* (38%), followed by *Laevigatosporites*sp. (16.7%) while the abundance of *Monoporites annulatus*is about 2% of the total population (**Table 1** and **Table 2** and **Figure 5** and **Figure 6**). Most of the samples with the exception of L1 and L4 consist mainly of *Zonocostites ramonae*and*Laevigasporites*sp.They showmoderate to high palynomorphs abundance anddiversityrate that range from 30 - 221 and 12 - 30 respectively suggesting marine deposition environment and/or very close to marine shoreline (**Table 1**, **Figure 5**). Samples L1 and L4 are low in palynoflora; however *Zonocostites ramonae* and *Laevigatosporites* sp. are common in these two samples. Samples L6, L10, L12, and L15 show low to moderate palynomorphs abundance and diversity which range from 11 - 43 and 5 - 18 respectively. The general trend of the abundance and diversity plots indicatea high palynomorphs abundance and diversity in the locations. This pattern is suggestive of high marine water level equivalent to a Transgressive Systems Tract (TST) (**Table 1** and **Figure 5**). The use of palynomorph abundance and diversity in predicting eustatic sea level has been reported by Vail and Wornardt, hence suggesting the relative sea level position to be high [55] [56]. The total organic carbon (TOC) is to show an important component of palaeo environment evaluation in identifying the sources of organic matter in sediments and the carbon-nitrogen (C/N) ratios to identify the general origin of organic matter from aquatic and/or land plants [15]. The elemental analysis of the nitrogen (N) in the samples and the different carbon-nitrogen (C/N) ratios show that the TOC range from 1.14 wt% to 4.65 wt% (**Table 5** and **Figure 7**). Samples L1 and L10 recorded the lowest TOC values having 1.14 wt% and 1.22 wt%. The C/N ratio for all the samples is 10.00 to 10.37 indicating that they are from algal source and the high TOC values show they are deposited during a wet climate [18]. This corroborated with the palynological results that recorded a high abundance of *Zonocostites ramonae* which has been known as a wet climate indicator [57] [58] (**Figure 7**).

7. Palaeoclimate and Palaeoenvironment

The climatic condition of Lagos lagoonal area was determined by considering the total amount of mangrove pollen compared to the graminae pollen. However, the pollen (*Zonocostites ramonae*) was used against the grass type pollen (*Monoporites annulatus*) which is a known warm climate indicator [59] [60]. (**Table 3**). The total count of *Zonocostites ramonae* is generally higher than that of *Monoporites annulatus* in all locations suggesting a predominantly wet climate for the sediments [16] [57] (**Table 3** and **Figure 8**). The patterns of *Zonocostites ramonae*'*s* frequency to *Monoporites annulatus* at diverse locations are different (**Figure 8**). According to Meyers the amount and types of organic matter present in sediments consequently reflect environmental conditions such as climate that impacted ecosystems at different past times [61]. Reliable source information can be derived in moderately preserved organic matter since algae which are protein-rich and cellulose-poor typically have atomic C/N ratios of 4 - 10, while vascular plants which are protein-poor and cellulose-rich (those composed in part of vascular tissue, including all flowering plants and the higher cryptogamous plants) have C/N ratios greater than 20 [62]. Times of wetter climate result in enhanced algal productivity as a consequence of greater wash-in of soil nutrients, and these periods are recorded as lowered organic C/N ratios and increased organic carbon mass accumulation rates [55]. The C/N ratio values for each of the samples analyzed is 10 (**Table 5**). This is an indication that algal sources have dominated organic input to the sediments which means they are protein-rich and cellulose-poor. The TOC values are generally high, hence, the climate is suggested to be wet based on the values of C/N ratios and the high organic carbon content as evident with the recovered palynomorph assemblages [63] [64] [65] (**Table 5** and **Figure 7**). The major groups include pollen, spores, dinoflagellate and other associated forms which include foraminiferal wall linings. The high diversity and exclusive occurrence of land derived miosporesis an indication of fresh water condition. Schrank suggested that palynomorph assemblages with higher content of land derived miospores indicates terrestrial influence and vice versa [65].

However, the results show that mangrove pollen is generally higher than graminae pollen in all locations; this condition is suggestive of a marginal marine environment. The idea of marginal marine or shallow marine environments with low and fluctuating salinities is also supported by the low occurrence of dinoflagellates. Harland described the ratio of number of Gonyaulaceans to Peridiniods as a guide to palaeosalinity [66]. Nevertheless, the presence of non-pollen palynomorph (NPP); algae, fungi, charred graminae cuticle and foraminiferal wall linings; were considered along with them and some locations like L1, L2, L13 and L20 to have foraminiferal wall linings though the abundance of mangrove pollen is higher than the linings in these locations. The linings are probably organic remains of benthonic foraminifera which indicatenear shore shallow marine environment [67] [68].

Locations with fairly high amount of algae, fungi and charred graminae cuticle suggest the degree of the influence of fresh water inlet into the system, whereby high non-pollen palynomorphs show high influx of fresh water and vice-versa. Conversely, the presence of charred graminae cuticle suggest the proximity of the location to land and/or the degree of influx of wind and/or the amount of bush burning in the area as a result of anthropogenic factor. Ages are determined based on the presence and abundance of *Zonocostites ramonae*, *Canthi-*

umidites sp., *Crassoretitriletes vanraadshooveni, Sapotaceoidaepollenites* sp., *Pachydermitesdiederixi* and some few long ranging forms. These forms largely occurred in the Gelasian (late Pliocene) and Calabrian (early Pleistocene).

8. Conclusion

The palaeoclimatic and palaeoenvironment evidences from the Quaternary deposits around Lagos lagoonal area have been established based on the recovered palynomorphs assemblages. The abundance of *Zonocostites ramonae* over *Monoporites annulatus*as well as other forms in the study area suggests a predominantly wet palaeoclimate in a marginal marine environment. However the absence of *Podocarpus milanjianus* and an age range of late Pliocene (Gelasian) to early Pleistocene (Calabrian) (2.588 - 1.806 Ma) corresponds to the 3.7 - 3.8 depositional cycles of relative change of coastal On-lap. The palynological and organic geochemical indices revealed that the sediments were deposited during a wet climate and the C/N ratio revealed that the source of the Lagos Lagoon organic matter is from algal productivity. The palynomorphs' assemblages further showed that the depositional environment is marginal marine and the age of the samples range from early Pleistocene to late Pliocene.

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