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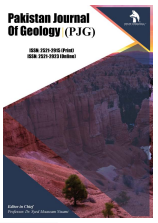

RESEARCH ARTICLE

SEDIMENTOLOGY AND PALYNOLOGY MODELS OF SEDIMENTARY SECTIONS ALONG LEMNA SECTION OF THE BENIN FORMATION, CROSS RIVER- SOUTHERN NIGERIA

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ABSTRACT

The paleodepositional environment and age of sedimentary outcrops along Lemna Road, northeast of Calabar Town, Cross River State, were determined using sedimentological and palynological studies. The sediments are primarily made up of sand gravel, carbonaceous shale with plant roots, and clays. Sedimentological and Palynological analyses were performed with the goal of determining the textural properties, age, and depositional environment of the sediments. Graphic mean grain sizes, sorting, skewness, and kurtosis are the grain size factors. Sorting of coarse-grained sediments deposited in a river setting was low to extremely poor as a result of graphic mean estimated coarse-grained sediments. The overall skewness is well formed, with a platykurtic kurtosis. Scatter plots of the coefficient of flatness vs sphericity and sphericity versus the oblate-prolate index show that pebbles formed in a highly energetic system (beach). According to the results of pebble morphometric indices, the sandstones are in an extremely energetic (beach) environment. Bivariate plots of sand textural metrics including graphical skewness vs graphical standard deviation and second moment skewness versus second moment standard deviation confirmed the high intensity (beach) origin of the sandstones. In the palynological analysis it was observed that there was absence of foraminifera's while index taxa such as Magnstriatites howardii, Zonocostites ramonae, Verrucatosporitea lienus and Psilatricolporites sp. Were identified inferring early to late Miocene in age of sediments exposed in the study area.

KEYWORDS

Grain size parameters, coefficient of flatness, sphericity, oblate-prolate indices, pebble morphometric indices.

1. INTRODUCTION

Sedimentology, which is the scientific study of sedimentary rocks and the processes that cause them to form, and palynology, which is the study of pollen and spores and their distribution in a given geographical region, will yield the type of "pollen finger print" to expect in samples from that area. Plants are excellent environmental indicators; floral assemblages of plants are known to be characteristic of various ecological zones, and the presence of fossils of such ecological indicator species in sediment is seen as a reflection of current ecological circumstances in palynology investigations. The current work employs textural parameters derived from sandstone sieve analysis, as well as morphometric analysis, to infer the depositional conditions and age of a sedimentary outcrop along Lemna Road in Calabar, Cross River State.

Murat 1972 used the name Calabar Flank to describe a section of the Southern Nigerian Sedimentary basin characterized by crustal block faults extending NW-SE. The Calabar flank's formation is inextricably linked to the development of the Benue right system, both of which are tied to the opening of the South Atlantic and the occurrence of an RRR triple junction active in early Cretaceous periods under the Niger Delta Miogeocline.

The Calabar Flank is a part of the Southern Nigerian Sedimentary Basin which is surrounded to the north by the Oban Massif, towards the south by the Calabar Hinge Line demarcating the Niger Delta basin, and to the west by the Ikpe platform by a NE-SW trending step fault system that resulted in the formation of horst and Graben structures. The vertically tectonics of such fault blocks, and also periodic sea level fluctuations in the nearby South Atlantic Ocean, impacted the flank's later stratigraphic evolution.

2. LOCATION OF THE STUDY AREA

The area under investigation is part of the Calabar flank located along Lemna road in Calabar Municipality, Cross River State (Figure 1). The geographic coordinates are between longitudes N05°01¹42.0¹¹ – N05°01¹54.7¹¹ and latitudes E008°21¹49.1¹¹ – E008°21¹57.4¹¹, respectively. Ten (10) samples from three locations were collected along Lemna road in Calabar with coordinates as follows and shown in Table 1.

Table 1: Locations along Lemna road in Calabar

Location ID	Longitude (N)	Latitude (E)
L1	05⁰ 01¹ 42.0¹¹	008⁰ 21¹ 57.4¹¹
L2	05⁰ 01¹ 42.2¹¹	008⁰ 21¹ 57.1¹¹
L3	05⁰ 01¹ 53.8¹¹	008⁰ 21¹ 49.7¹¹

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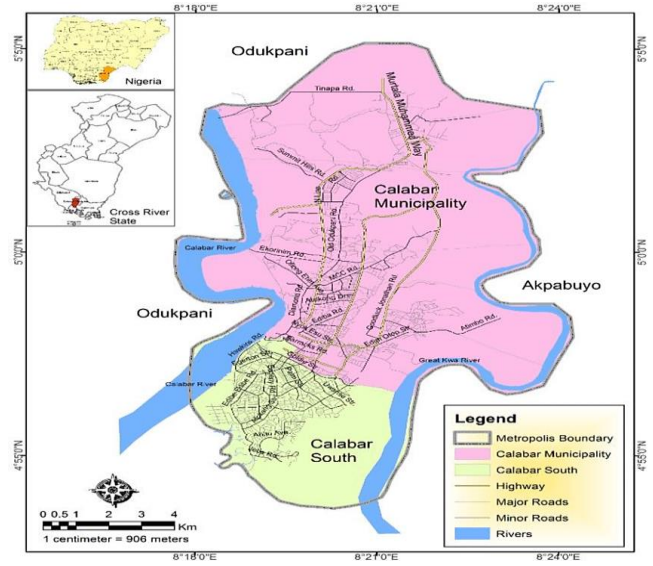

Figure 1: Topography map of Calabar Metropolis showing the study Area

The exposures are made up of predominantly carbonaceous shales, sandstones, ironstone, and clay, which belong to the Calabar Flank as also shown in Figure 2 below.

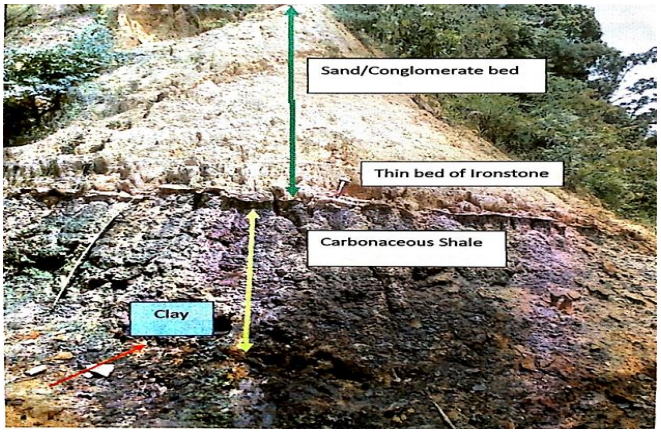

Figure 2: Litho-section of Outcrop of the Study Area

2.1 Geomorphology and Physiography

The geomorphic setting is associated with geomorphic features like topography and landforms, climate, superficial deposition and drainage pattern found in Calabar region and these features are defined below

2.2 Topography and Drainage

The area belongs to the lowlands and seaplanes of South Eastern Nigeria (Ileose, 1991). Elevation here is generally less than 100m above sea level. The area is hilly. The hills are also most of equal height and separated in some places by narrow, steep sided passes which are frequently courses by thick bushes.

The hills are main sources of streams; the direction of flow is NW-SE. the drainage pattern is dendritic, that is has an arrangement of stream course that on a map or viewed from air, resembles branding habit of certain stress, such as oak or maple. This drainage pattern is mainly associated with coastal area and clay, silt dominated environment. The area is drained majorly by the Cross – River and its major Calabar River.

2.3 Climate and Vegetation

The climate of the area is characterized by tropical rainfall belts where rainfall usually seasonal and at times very heavy. It has within the sub-equatorial south climatic region (Ileose, 1991). The seasons predominate in this area namely the rainy season and dry season, the rainy season usually begin from a ranges from October to March. Temperatures in these areas range between 24 -29^{0}C, the annual rainfall is 1500 – 3000mm and the humidity is 60 – 90%. Finally the climate of the studied area is not stable due to seasonal variation. The vegetation in the area is often a mangrove spanning the rainforest belt, with scattered trees, low covering shrubs, and grassland. It is classed as grassland, rainforest, or Guinea savannah (Iloeje, 1985). Geology, climate, and the distribution of rivers in the area all have an impact on the vegetation. Those covered by unconsolidated sandstone are characterized by huge green trees and plants, whilst areas covered by consolidated and sediments are characterized by grasses and shrubs. Tall trees and evergreen plants mimic the pattern of the area's major and smaller river courses.

2.4 General Stratigraphy

Vertical movements of faulted blocks, particularly the Itu High and the Ikang trough, as well as associated transgression and regressions, appear to have influenced lithostratigraphic evolution in the Calabar Flank. The mid-Albian, Latest Albian to Cenomanian, Turonian, Conacian, and late Campanian are the five transgressive phases recognized (Figure 3). The Calabar Flank's sedimentation began with the deposition of fluvio-deltaic clastic of Early Cretaceous (probability Aptian) age, which accumulated on a prograding deltaic border as deltaic and non-marine sediments, these sediments are from Awi formation (Adeleye and Fayose, 1978). The Aptian-aged Awi formation is a basal stratigraphic unit composed of calcareous arkosic sandstones sitting on the foundation surface. The Albian Mfamosing Limestone is on top of the Awi formation. The Mfamosing Limestone is overlain by the turonian Nkalagu formation, which is composed of alternating dark grey shales with thin calcareous limestone bands intercalated. This formation was known as the Eze-Aku Shale and Awgu Shale, as well as the Odukpani Formation's alternating shales and limestones. Conician to Early Santonian New Nnetim Marl overlies the Ekenkon Shale. Volcanic body fragments have been discovered in the Nkalagu Formation at the Anua-1 and Ikono-1 wells. The Campanian-Maastrichtian Nkporo Shale lies unconformably overlying the New Nnetim marls and consists of dark grey to bluish-black, friable to flaggy carbonaceous shales with bands of marly and silty to sandy shales and mudstones. Tertiary to recent strata overlaying the Nkporo Shale include the Imo Shale, Ameki formation, and Benin sandstone.

Tetiary to Recent continental fluvialite sands and clays make up the Benin formation. This deposit, previously known as the Coastal Plain Sands (Tattam, 1944; Simpson, 1955), covers a large area of Nigeria's coastal region, adjacent to the Deltaic Plain Sediments. This formation is distinguished by the presence of an alternating succession of loose gravels, sand, silt, clay, lignite, and alluvium (Short and Stauble, 1967). Because to the limonitic layer, the sands are white or yellowish brown. Plant remnants and lignite streaks can be found in some locations, along with haematite and feldspar grains (Webber, 1971). It is largely underlain by rocks from the Cretaceous Calabar Flank and the pre-Cambrian Oban Massif (Figure 1). The Coastal Plain Sands (Benin Formation) are by far the most abundant aquiferous hydrogeologic settings in the Calabar Flank Area, with all water boreholes located in this formation (Esu and Amah, 1999). The Benin Formation is underlain by an alluvial deposit aquifer.

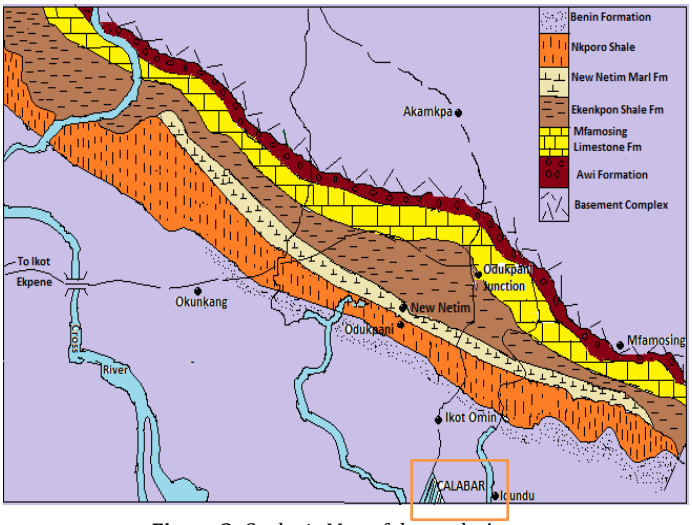

Figure 3: Geologic Map of the study Area

3. Materials and Method

Three approaches were involved in the study. These were desk study, in situ field study and observations, and laboratory analysis (sieve analysis, Palynological analysis and pebble morphometric analysis).

For the desk work, information about the study area was gathered through the review of literature. Topographic and geologic maps of the area were collected and studied, and a review of previous works carried out on the study area was done. The field study and observation were used to revise

the geology and geology processes in the study area as well as the physical characteristics of the surficial material, extent of weathering, topography, vegetation, outcrop type, color, texture, thickness, etc. The following equipment was used to aid this work in the field: Base map, Field note, Pen and pencil, hammer, camera, sample bags, measuring tapes and an E-TREX Global Positioning System (GPS).

Lithofacies description was carried out based on careful visual observation on the field. The physical characteristics of the outcrops such as thickness, colour, contact type and grain sizes were considered. The thicknesses of the different beds were measured using a pogo stick and these beds displayed different colors. Contact types observed in the field were usually gradational or sharp contacts. The grain sizes ranged from coarse grained to fine grained. All these were carried out in order to infer depositional environment of these outcrop.

Ten (10) samples were collected from three different locations within the study area for palynological, granulometric and morphometric analysis. On the whole, five samples were used for the palynological analysis, five samples for the granulometric analysis and were labeled Ei to Ev.

Furthermore, for the granulometric analysis, the labeled samples were used as stated earlier and each sandstone samples were taken and separately run through a set of ASTM sieves comprising of the following mesh openings in Phi scale, -1.25, -1.00, -0.25, -0.75, -1.75, -1.75, 2.25 and 4.00. The procedures for the sieve analysis ranged from sample preparation, selection/assembling of sieves, sieving, weighing and lastly and weighing.

For the Pebble Morphometric Analysis, a total of forty (40) quartz pebbles from the sandstone unit within the study area along Lemna road, Calabar Municipal in Cross River State, were sampled for morphometric analysis. Samples were washed and then dried before use, at the end of which the pebbles were subjected to pebble morphometric analysis. To achieve this, a vernier caliper was used in the measurement of the long (L), intermediate (I) and short (S) axis of pebbles. Morphometric parameters obtained include flatness ratio, (FR) and elongation ratio (ER) after, maximum projection sphericity index (M.P.S.I). These parameters were evaluated as single function and as independent variables on scattered plots of M.P.S.I Vs O.P to discriminate depositional environment of pebbles. From all the measurements and calculations with the aid of appropriate fromulas, several parameters were used to discriminate the depositional environment of the pebbles. These parameters are: elongation ratio, sphericity/maximum projection sphericity, flatness ratio and oblate-probate index. Morphormetric parameters obtained using their various function include:

1. Flatness Ratio (FR) = $S/_L$ (1)
2. Elongated Ratio (ER) = $I/_L$ (2)
3. Maximum Projection Sphericity Index (M.P.S.I) = $\sqrt[3]{S^2}/_{LI}$ (3)
4. Coefficient of flatness = $S/_{LX100}$ (4)
5. Oblate Prolate Index (OPI) = $\frac{10(^{L-1}/_{L-S}-0.5)}{S/_L}$ (5)

The identification and counting of palymorphs for the Palynological analysis were performed using a Laborlux 6 (Leitz) light microscope with objective magnifications of 25 and 40. Albums formed from shell, agip, and other relevant literature were used to identify the palynomorph species (Clarke, 1996; Germeraad et al., 1968; Legoux, 1968). The size, exine structure, form, sculptures, and aperture type were used to identify the object. The procedures used for the analysis included dissolving carbonates with HCl, dissolving silicates with HF, removing fluoride gel with warm 36 percent HCL and later with cold HCl, separating organic content by washing the sample with 0.5 percent HCl, and neutralizing acids with warm potassium hydroxide (KOH) added to the residues and allowed to stand for 30 minutes. Finally, after a series of preparations, the slides were examined under a binocular microscope with the goal of identifying and counting the important polymorphs present in the slides, such as pollen, spores, dinoflagellates, microforaminiferal wall lining, algae, and fungal spores, for age and paleo-environmental studies. Under the microscope, important palynomorph images were captured.

4. Data Analysis and Discussions

4.1 Granulometric Analysis

The data obtained from grain size analysis of each sample were presented in the form of histogram, cumulative and frequency distribution curves (Table 2). The textural parameters such as mode, mean, median, sorting, skewness and kurtosis for each sample were statistically determined.

Table 2: Summary of Grain size analysis from the study area

S/N	Φ5	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95	Mz	Σ1	SK1	K1	Remark
Ei	0.00	0.00	-0.8	1.0	1.5	1.7	2.3	0.90	1.55	-0.023	0.41	Cg,PoSo,Cs,VP
Eii	0.00	-0.20	0.7	1.1	1.4	1.8	2.2	0.90	1.67	-0.05	1.29	Cg,PoSo,ns,L
Eiii	0.00	-1.1	0.00	1.1	1.6	1.8	2.6	0.60	2.24	-0.18	0.67	Cg,VPoSo,Scs,VP
Eiv	0.00	-1.2	-0.2	1.0	1.5	1.6	2.1	0.47	2.04	0.13	0.51	Cg,VPoSo,Fs,VP
Ev	0.00	0.00	-0.7	0.0	1.2	1.7	2.8	0.57	1.70	1.00	0.60	Cg,PoSo,Sfs,VP
Mean	0.00							0.58	1.84	0.38	0.67	Cg,PoSo,fs,VP

4.2 Grain Size Analysis Interpretation

Graphic Mean: The graphic mean size analysis of the study samples ranges tromps 0.47 to 0.90 suggesting sediments are coarse grained. The coarse-grained sediments indicate high energy at deposition.

Standard Deviation/ Sorting: Sorting of sediments varies with grain size and energy of deposition from the analyses the average sorting is 1.840 and ranges between 1.550 and 2.04 entering poorly to very poorly sorted lithofacies. This agreed with the facts that as sorting values increases, sediments become more and more poorly sorted. These sorting values are glacio-fluvae environment of deposition.

Skewness: The skewness shows the distribution is bell shape or shifted to side. The sample analyzed have average skewness of 0.38 and ranges between -0.18 to 1.00 with most facies having negative phi (D) infering coarse grained sediments.

Kurtosis: The results obtained from the analyzed graphic Kurtosis values ranges from 0.41 to 1.29, with average value of 0.67 platykurtic, infering uneven distribution of grained sizes, with contribution from two sub populations. Sands from beach environments are well sorted and negatively skewed while river sands are less well sorted and usually positively skewed. From the analyzed results, all the samples data are poorly to very poorly sorted while 60% are negatively skewed and 40% are positively skewed (McManus, 1995). The poorly to very poorly nature of the grained and positively to negatively nature of the sample support fluvial origin.

Pebbles Morphometry Analysis. A total of forty (40) samples within the study section were collected from the field (Table 3).

Table 3: Summary of the Analysis

	L(cm)	I(cm)	S(m)	S/L	S/LX100	I/L	L-1/L-S	MPSI	OP
MIN.	2.10	1.30	0.50	0.23	23.0	0.39	0.33	0.45	-0.09
MAX.	4.10	2.00	1.50	0.54	47.0	0.86	0.84	0.78	10.71
MEAN	3.1	1.65	1.00	0.38	35	0.63	0.58	0.62	5.31

4.3 Interpretations of Morphometric Analysis

According to the results, the average elongation ratio varies from 0.39 to 0.86, the flatness ratio varies between 0.23-0.54, the maximum projection sphericity index ranges from 0.45-0.78, and the oblate-prolate index varies from 0.23-0.54.

4.4 Bivariant Schattergraphics of Grain Sizes Parameters

There is always a general trend for sorting values to increase (as sediments become more poorly sorted) as mean grain sizes increases (Figure 4 – 7). According to recent study, fine grained sediments are moderately to well sorted. This can also be seen as, coarser grained are poorly to very poorly sorted as shown in the plot (Figure 6 of mean grain size vs sorting shows that all the samples are plotted in the coarse-grained field (Mz = 0.0 Φ) and 60% and 40% of one plotted value in poorly sorted and very poorly sorted fields respectively. The bivariate plots of graphic skewness (Ski) against graphic standard deviation (61) in (Figure 7) shows that both positive and negative skewed are poorly and very poorly sorted and all the plotted in one fluvial setting (Asharhan and Elsammak, 2004).

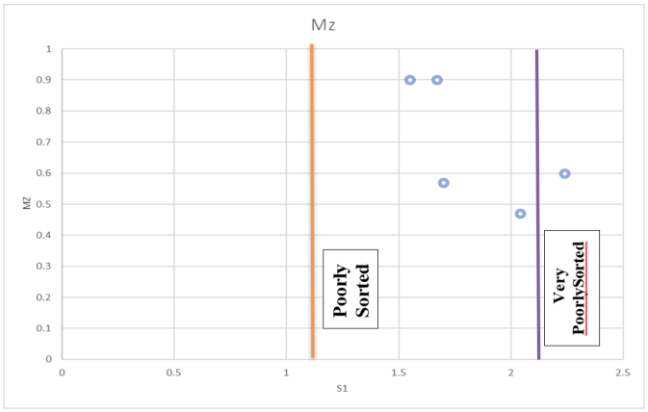

Figure 4: Bivariate plots of Mean grained size (Mz) against Sorting

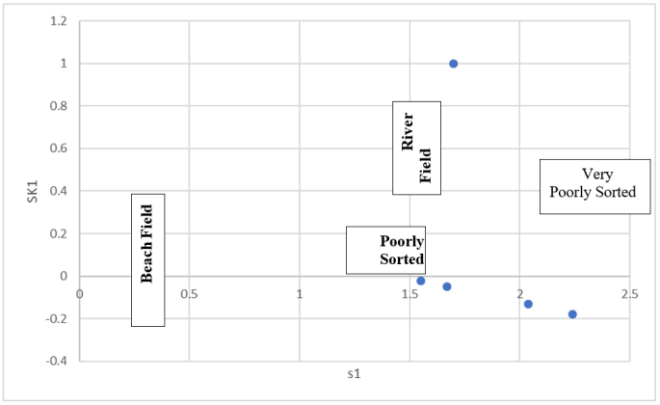

Figure 5: Bivariate plots of Skewness (SK1) versus Sorting

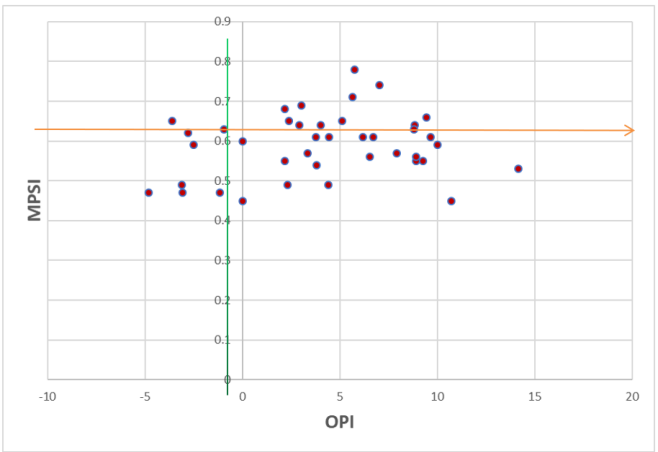

Figure 6: Bivariate plot of oblate – prolate index (OPI) against maximum projection sphericity index (MPSI) from the study area

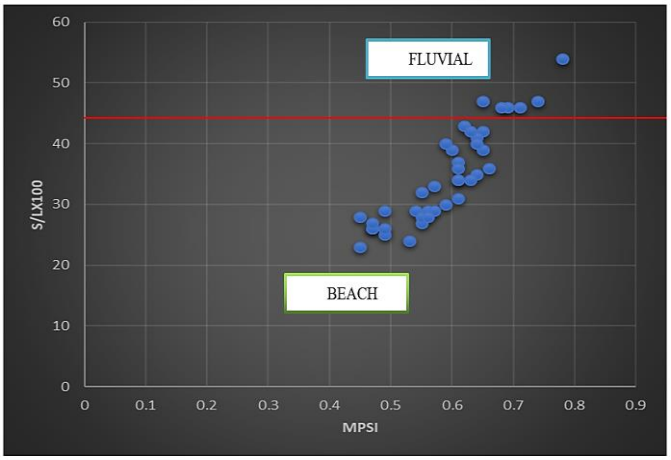

Figure 7: Bivariate plot of coefficient of flatness (CF) against maximum projection sphericity index (MPSI) from the study area

4.5 Palynological Analysis

From the composited outcrop samples that were prepared and analyzed, it was observed that the area is deficient of foraminiferas but have high abundance and diversity of terrestrial (land) palynomorphs, The palynormorphs consist of angiosperm pollen grains, spores (pteridophyte and fungi spores), fresh water algae and indeterminate marine foraminifera linings, acritarch and dinoflagellate cyst.

In general, the examined outerops have a high concentration of palynomorphs. A total of 45 species were encountered, with a total of 1,106 palynomorph species recorded. The pollen taxa recovered are: *Retitricolporites irregularis, Retibrevitricolporites obodoensis, Striaricolporites calatumbus. Psilatricolporites crassus, Psilatricolporites sp, Brevicolporites guinetii, Retitricolporites amazoensis, Zonocostites ramonae, Botryococcus brauni, Psilastephanocolporites laevigatus, Echiperiporites estelae, Concentricystes circulus.*

The palynomorphs distribution shows the different specimens encountered on the different outcrop samples. The different taxa vary in abundance: some are considered common while some are relatively rare.

The common forms are: *Retitricolporites amazoensis, Laevigatosporites discordatus, Laevigatosporites sp, Retitricolporites rregularis, Acrostichum aureum, Magnastriatites howardi, Echiperiporites estalae, Zonocostites ramonae, Pachydermites diederixi, fungal spore, Psilatricolporites crassus.*

The rare forms are: *Aletesporites sp, Multiareolitesformsus, Acritarch sp, Dinocyst indeterminate, Cyperaceopollis sp, Elaeisguineesis, Peregrinipollis nigericus, Nypa sp, Fenestrites sp, Spirosyncolpites bruni, Adenantherites simplex.*

The establishment of palynozonation was difficult, which may have been due to low degree of vertical and lateral variation of the recovered palynomophs as a result short geological time interval for the deposition of these sediments in this study area. This same result was encountered to working from data of 3 wells in the Central Swamp 1 and Coastal Swamp I and 2 of the Niger Delta basins in Nigeria (Peters et al., 1995). Despite these difficulties an attempt was made on the biozonation using the Pantropical Zones (Germerrad et al., 1968; Evamy et al., 1978). Based on occurrence of some index markers such as *Zonocostite ramonae, Pachydermites diederixi, MagnaStriatites howardi. Echiperiporites estelae, Psilatricolporites crassus,Ctenolophondites coastatus, Multiareolites Jormosus and Striatricolpiles calatumbus.* Three palynozonation were established and these are: *Upper Magnstriatites howardii, Crassoretiriletes vanraadshoveni and Echitricolporites spinosus Zones.* The corresponding informal palynological zontation for the Niger Delta (Evamy et al., 1978), using alpha- numeric nomenclature ranges from P680 to P860 Pollen Zonation. The Palynozones are *Magnstriatites howardii* (P680) of Early-Moicene and *Echitricolporites spinosus* Zones of Late -Miocene (Alard, 1978).

4.6 Paleoenvironment Interpretation

The strata were interpreted by incorporating the linkage of ecologically constrained marker species, the percentage of Zonocostitesramonae (Rhizophora) in the cumulative palynoflora, the essence of organic matter in the sediment, the lithological characteristics of the strata, the diversity and abundance of certain palynomorphs, and the marine-terrestrial

proportion of certain palynomorphs. The presence of appreciable palm pollen such as *Zonocostites ramonae* suggests a brackish condition of sedimentation, according to (Hammen, 1954; Peters et al., 1996). The shale and ironstone at Ll and L2 contain woody fragments and indicate a land locked body of water system typical of non-marine swamp environments (Oboe et al., 2005). The percentage of *Zonocostitesramonae* ranges from 5-20% in different locations and this indicate a mangrove environment in the intertidal area (Nyong, 1995). *Verrucatosporitealienus* is a hinterland spores in a coastal environment. The occurence of the form genus *Psilatricolporites sp,* which according to Van der Hammen 1954, is morphologically comparable to the extant palm pollen *Rhizophora sp*, further supports the presence of mangrove vegetation.

The intermittent occurrence of *Magnastiapites howardi* in L2 shows the incursion of freshwater in the immediate vicinity and the presence of more open vegetation. The marine to continental ratio of some polymorph indicates that generally the section ranges from continental and fluvial to overbank deposits.

5. Conclusion

The area of study falls within the Calabar Flank which comprises nine formations which are Oban Basement Complex, Awi Formation, Mfamosing Limestone,Ekenkpong Shales/Nkalagu Formation. New Netim Marl, Nkporo Shale, Imo Shale, Ameke Formation and most recent Benin Formation which is of interest in these researches.

The average grainsize distribution of the sediments indicates poor to very poorly sorted and coarse grained. The skewness is well shaped while the scatter diagrams constructed indicates a beach environment for its deposition. Folks sorting-mean size plot also shows that the environment is beach and the energy condition is high.

From the palynomorph analysis, a total of 45 species were encountered and a sum total of 1,106 species of palynomorphs were counted. The Pollen taxa recovered were 26 in number, Spores were 15 and Fresh water algae included *Concentricyst circulus* (6 specimens) and *Botryococcus braunii* (7 specimens).

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