*Applied Ecology and Environmental Sciences, 2015, Vol. 3, No. 3, 66-74*
Available online at http://pubs.sciepub.com/aees/3/3/1

DOI:10.12691/aees-3-3-1

# Palynocycles, Palaeoecology and Systems Tracts Concepts: A Case Study from the Miocene Okan-1 Well, Niger Delta Basin, Nigeria

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*Received March 18, 2015; Revised April 25, 2015; Accepted May 05, 2015*

**Abstract** Palynocycles are recurrent palynological sequences reflecting vegetational changes determined by cyclic sea level oscillations and the associated climatic variations. This study presents the results of a study on Okan - 1 well from the Niger Delta. This study utilised new ecological indicators established according to their palaeocliamtic and sea level signal. The main aim is to identify the different species of sporomorphs (pollen and spores) present in the sample for the recognition of sea level and climate change during the Miocene as well as their biostratigraphic significance. The biostratigraphic age control of the study location was identified based on the first and last appearance datum of *Verrutricolporites rotundiporus (BZ6), Racemonocolpites hians (BZ4), Operculodinium centrocarpum (BZ2), and Magnastriatites howardi (BZ1).* The Nine climatic cycles were recognised and used to infer the depositional cycles that indicate recurrent palynogical sequences and vegetation changes based on the sea level change. The wet - dry cycles inferred indicates the fluctuation of the climate and sea level change during the Miocene, thus the use of the variation of vegetation at the different depth intervals as a proxy for the recognition of palaeoenvironmental change (palynocycles 1, 2, 3, 4). The wet cycle suggest highstand / transgressive systems tracts. While on the other hand, the dry cycle indicate lowstand systems tracts. We therefore present this model as a yardstick for the use of pollen and vegetation signals in the recognition of sequences stratigraphy, sea level and climate change.

***Keywords:*** *palynocycles, sea level, climate change, vegetation, niger delta, systems tracts, depostional settings, palaeocology*

**Cite This Article:** Onema Adojoh, Lucas F. A., and Silas Dada, "Palynocycles, Palaeoecology and Systems Tracts Concepts: A Case Study from the Miocene Okan-1 Well, Niger Delta Basin, Nigeria." *Applied Ecology and Environmental Sciences*, vol. 3, no. 3 (2015): 66-74. doi: 10.12691/aees-3-3-1.

## 1. Introduction

The Cenozoic Niger Delta was developed as regressive offlap sequences consisting of Akata, Agbada and Benin Formation(s). There are 36 wells drilled within Okanfield, but Okan -1 well, was analysed in order to identify and appraise the concept of palynocycles (wet and dry climate), systems tracts and paleodepositional settings (Figure 1). This is because the proximity of the well is near the shoreline where the impact of sea level cycles can easily be identified. The Okan field was fully described by Franklyn and Cordry (1967). The outcome of their study confirms Okan field as the first commercial field to be found on the continental shelf of Nigeria (Figure 1). The detail analysis of the geologic structures suggest the faulting systems of the study area to have resulted from the interruption of the original basin ward dip of slumped deposit, about 3 km to the North – East of the Niger Delta (Doust and Omatsola, 1990).

The use of palynofloral signals to decipher sea level, climate and systems tracts was introduced in the Niger Delta basin by Poumot (1989), but the concept of the palynological cycle was proposed by Van der Hammen (1957), who found a cyclic character in the palynological record and related it to astronomically driven climatic cycles (Rull, 2002) (Figure 2).

Poumot (1989) made a comprehensive palaeoecological study of palynocycles, showing their dependence on the effect of eustatic events on coastal ecosystems on the Niger Delta (Figure 2). Some years later, Morley (1995) came up with a new idea on the use of palynocycles for the Niger Delta. This same concept was redefined by applying a multiproxy approach (foraminifera, seismic, nannofossil and sedimentology) in correlating the sediment of Niger Delta with other similar geological settings (e.g India, Indonesia, and south East Asia). As a result, the sequential record of the fossil pollen assemblages turned into a practical tool for the study of sea level oscillations and their phases, which are linked to particular depositional systems tracts (Figure 2). For instance, in the Maracaibo and Falcon Basins in Venezuela, palynocylces and palyno block (fault) were used to describe the block building sequences and sea level history (Rull, 2002). But, in the Niger Delta this insight is still a fledging science. Therefore, we present this concept in this research, and its application from the Niger Delta depositional settings during the Miocene to create an awareness of the palynocycles model.

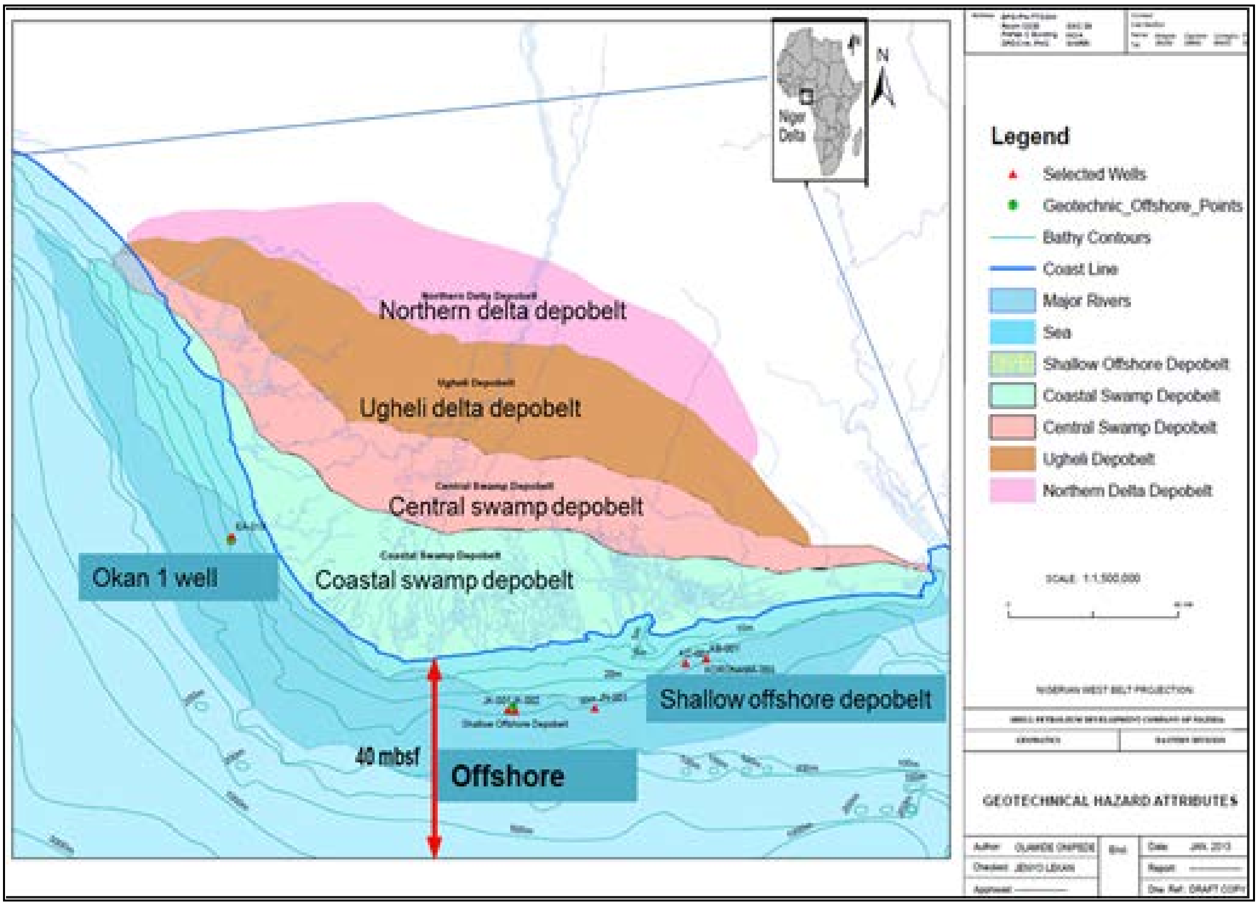


**Figure 1.** Location of the Okan-1 Well (Source: This study)

## 1.1. Relationship between Palaeovegetation, Palynocycles, Sea Level Change and System Tracts

At the initial stage of the lowstand systems tract (LST), sea levels drop rapidly, resulting in erosion and incision along coastal plain. The brackish water environments in which mangroves swamp (littoral setting) can thrive will be of minimal extent, as well as freshwater swamps (Figure 2, Figure 3 a). The initial stage of the lowstand systems tract would therefore be expected to be characterised by the low abundance of coastal species and a resultant increase in pollen from well-drained fluvial settings (Morley, 1995; Adojoh *et al*. 2012; 2013 & 2014). In this case, the hinterland groups (savanna) will dominate while the littoral groups (mangrove) decrease (Figure 2, Figure 3 a). Most authors agree that lowstand systems tract (LST) is also related to an abundance increase of terrestrial particles (phytoclasts) as marine palynomorphs such as dinoflagellates cysts decreases (Steffen and Gorin, 1993; Tyson, 1995). Sedimentation during this phase is by fluvial processes, transported into the deep water environment. Most terrestrially palynomorphs which become incorporated into marine sediments are mainly due to fluvial transport as against wind-transported (monsoon drive), which occur predominantly as silt-sized alluvial particles (Morley, 1995).

During sea level rise, sedimentation takes place in a transgressive systems tract (TST) setting (near shore – delta plain), the brackish, coastal - mangrove-dominated deltaic plain expand (Figure 3 b). This will consequently result in an obvious increase in marine sediments as compared to the lowstand systems tract. Since most sediment is deposited in the coastal – mangrove swamp region, it implies that sporomorphs abundance in deepwater settings would be much lower than in the lowstand systems tracts (Poumot 1989; Morley 1995). As the sea level rises, the littoral groups tend to increase while the hinterland groups gradually decreases (Figure 3 b).

During the highstand, there is a development of upper delta plain (flood plain). This is controlled by freshwater and alluvial wetlands (Poumot, 1989). Miospores from this source could be expected to exhibit a lowest representation during the highstand (Figure 2 c, Figure 3c). This is related to a decrease rate of sea-level rise and initial sea-level fall (Tyson, 1995). The presence of mangrove-derived sporomorphs in marine depositional environments is likely to show a related trend. This occurs as deposition takes place on the proximal to lower delta plain and the representation of mangrove pollen will increase. In this case the freshwater swamp and open forest vegetation tend to increase and expand until there is a fall in sea level (Morley, 1995; Rull, 2002).

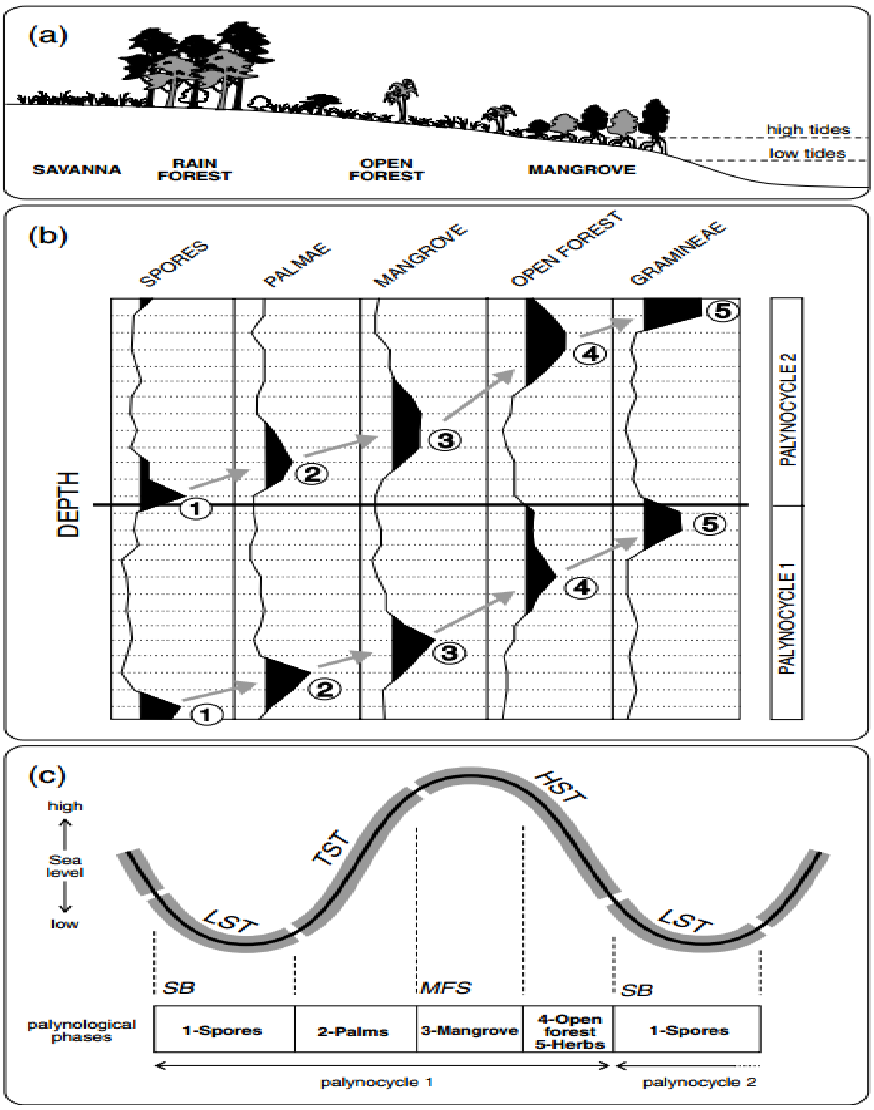


**Figure 2.** (a) Generalized transect of coastal vegetation zones for the tropics of Asia and west Africa (after Poumot, 1989). (b) Theoretical expression showing the stratigraphic example of palynocycles (after Rull and Poumot, 1997). (c) Interaction between the phases of the palynocycles and the depositional cycles of the sequence stratigraphic concepts (after Poumot, 1989; Rull and Poumot, 1997). HST highstand systems tract, TST transgressive systems tract, LST lowstand systems tract, SB sequence boundary, MFS maximum flooding surface.

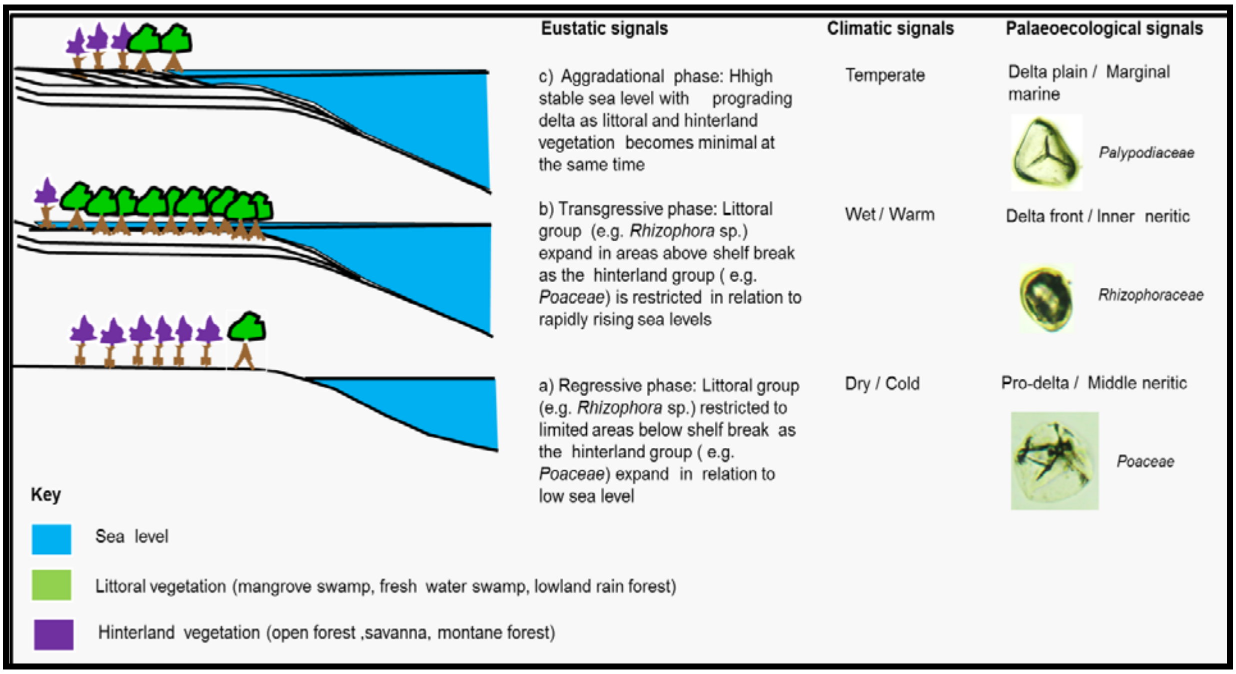


**Figure 3.** General relationship between palaeovegetation, ecstasy, climate, paleoecology for the tropical setting (Source: This study)

## 2. Methodology

Twenty four (24) ditch cutting samples from shaly interval was sampled. In order to isolate the palynomorph from the rock matrix, the selected rock samples were subjected to dissolution by various acid combinations and treatments following the standard palynological sample preparation method. 10 grams of the samples were weighed and dished into the labeled plastic cups with corresponding depth intervals. About (5 – 10) % dilute HCL was added to the samples to remove the carbon impurities. 40% (HF) was added to the samples to remove the silicate. 10% HCL was added to sample to remove silicon fluoride gels covering the palynomorph. Water was added and decanted 3 times at 60 minutes interval. Sieving was done to wash out dirt, clay, mud and other dissolved materials. The residue was poured into the 5 micron sieve and taken to the ultrasound machine (Branson Sonifier) and washed until neutral and transferred into the beakers. Water on top of the residue was decanted carefully and ready for spotting. Three drops of soffranin stain was added to the residue and stirred for uniform mixing. The residue was pipetted into the cover slips numbered and spread on top of a hot plate and evaporated to dryness. The slides were dried in the sun for 5 minutes, after which they were ready for microscopic examination. The palynomorphs slides were examined with a well condensed transmitted light microscope with immersion oil during microphotography.

## 3. Results and Discussions

Ecological stratigraphic methods are commonly dealt with various statistical computations, because they reflect ecosystems rather than individual species (Rull, 200). Thus, ecostratigraphic procedures need symbolic counts percentage (Rull, 1987; Poumot, 1989) to evaluate the reliable fossil abundances and occurrences, commonly designated as assemblage zones (Rull, 2002). There are two ecostratigraphic methods normally use in studying palaeovegetation dynamics. They are palynocycles and ecologs, which are used in most of the low latitude stratigrahic settings worldwide (Rull, 200). We adopted the concept of palynocycles for the interpretation of the miospores (pollen and spores) in the Okan 1 well because, events are limited in space, but if the geographical province in which they (vegetation) happen is known, a space-dependent stratigraphy is promising (Rull, 2002). In some cases, this stratigraphy could be local, but in others (e.g, in eustatic and glacial cycles), it can have a worldwide extent (Poumot, 1989).

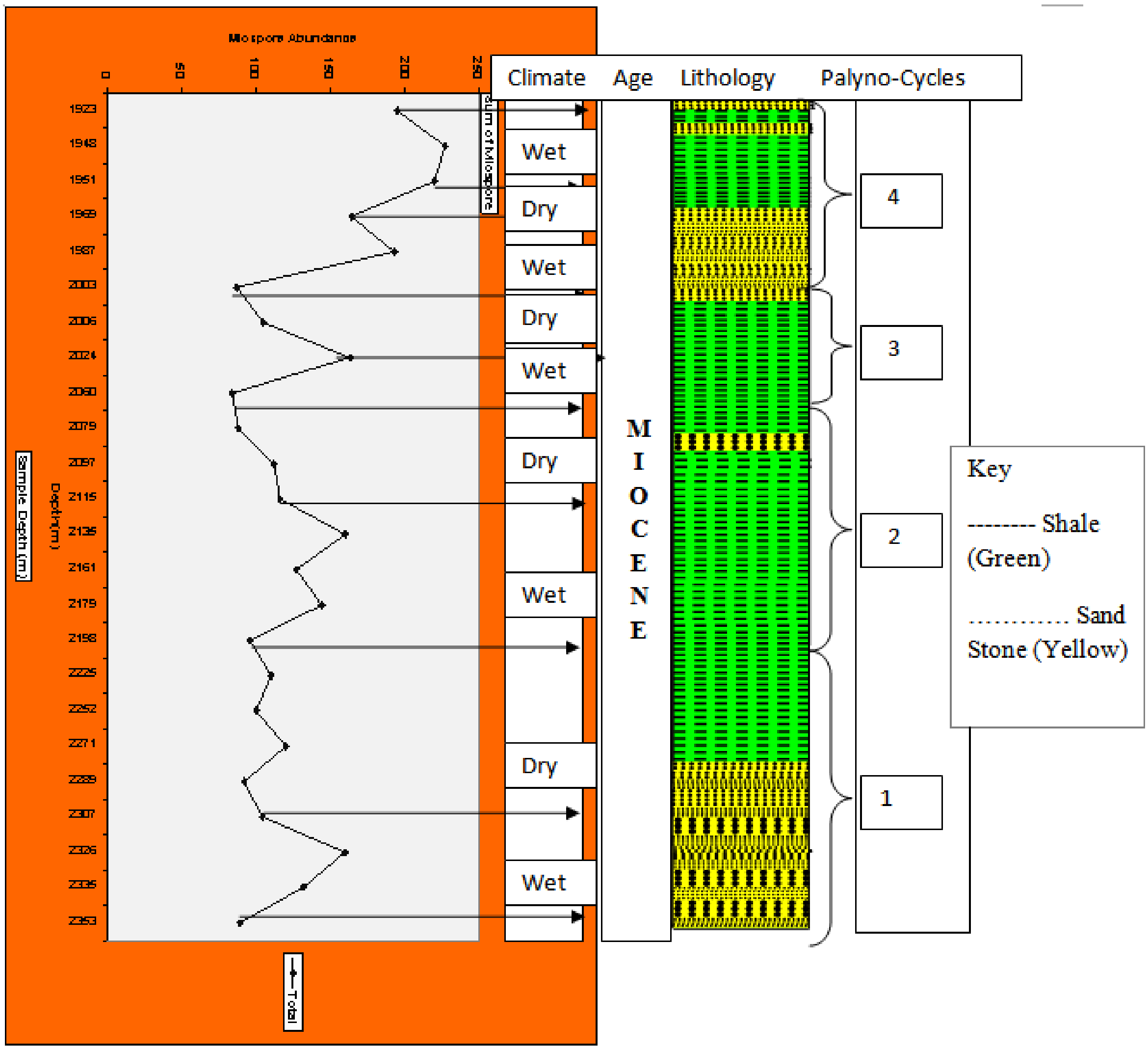


**Figure 4.** Plot of the miospores with depth, geologic and palynocycle model of the Okan-1 well

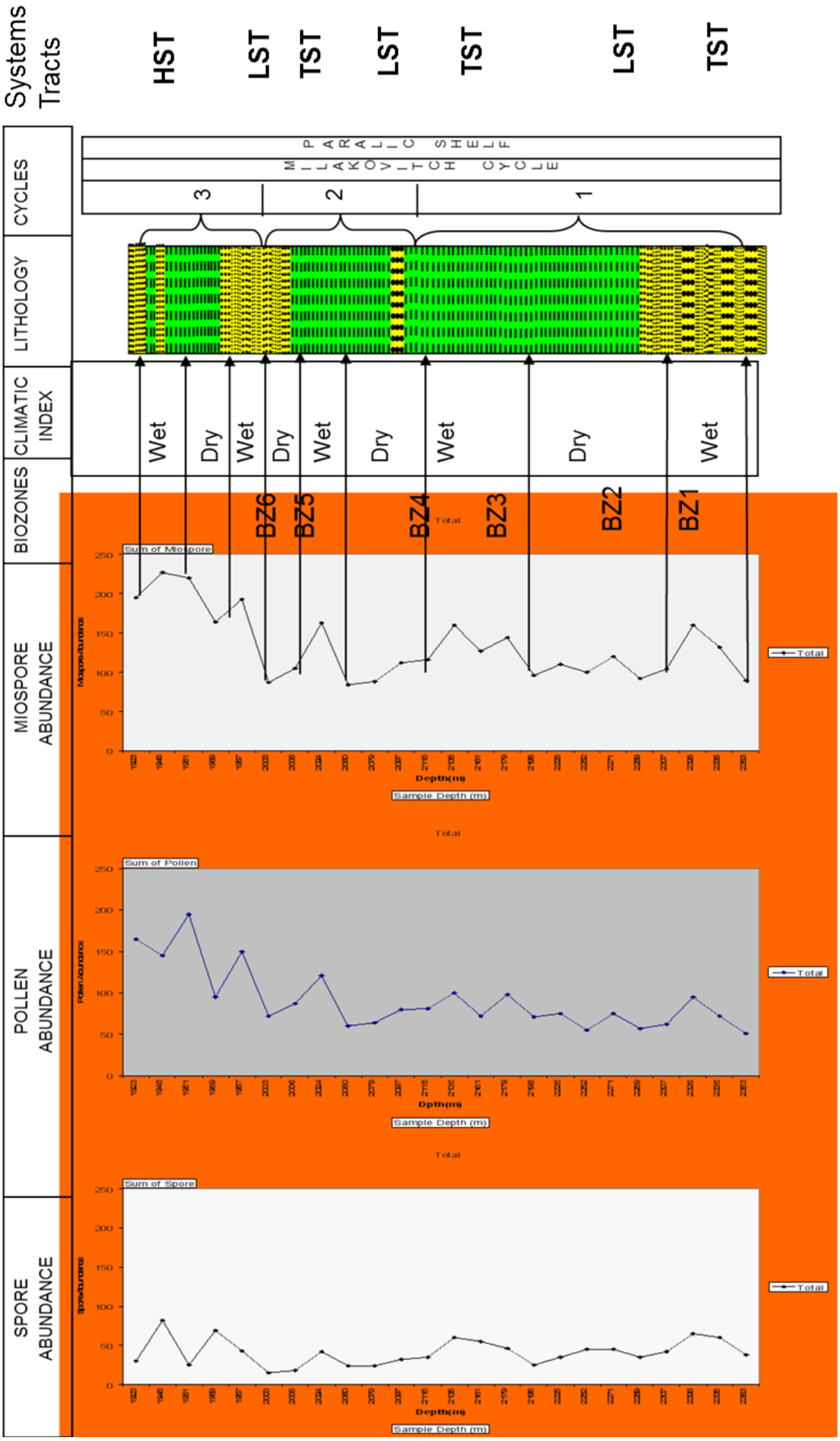


**Figure 5.** Plot of miospores with depth, geologic and palynocycles model of Okan-1 well

The result obtained from the Okan-1 well (Figure 4, Figure 5) identified nine paleoclimatic signals using the concept of palynocycles (wet – dry). The general outline of the studied interval recognised five wet and four dry climatic intervals (Figure 4, Figure 5). The consequences of these signals suggest four palynocycles sequence within sediments which could have been deposited during the Miocene sea level change (palynocycles i.e. wet-dry cycles) (Figure 4, Figure 5). The knowledge of this definition could be linked to the orbital oscillation triggered by the summer insolation during the West African Monsoon (WAM) circulation (Shanahan *et al.* 2007). We further subdivide these sequences of the Okan -1 well (palynocylces) into six zones. The possible implications are highlighted below:

**BZ1 - BZ2 Unit (2196 -2335) m**

The first palynocycle (1) (wet – dry climate) falls within the depth interval of (2335-2196) m (Figure 4, Figure 5). This suggests a rise and fall of the sea level resprenting the transgressive and lowstand systems tracts, characterised with the deposition of miospores, silt and sand lithofacies respectively.

**BZ3 - BZ4 Unit (2060 - 2179) m**

Overlying the above depositional cycle is the sequence consisting of dominant shale facies. The second palynocycle (2) (wet – dry climate) falls between interval 2179 m – 2060 m. The tracking of the position of the palynocycle within this unit has been able to recognise the paralic shelf depositional environment (Figure 5). This also suggests that the rise in the sea level could have been responsible for more abundance of the miospores in this unit when compared to first palynocycle (1) (wet-dry).

**BZ5 – BZ6 Unit (2003 - 2024) m**

The third palynocycle (3) (wet - dry climate) is between (2024 – 2003) m interval. It is characterised by a mixture of silt, sand and shale lithofacies. These compositons are quite different from the previous units. The possible control could have been triggered by the rise of sea level, and the subsequent fall of the sea level (transgression and regression) during the Miocene climatic optimum respectively (Figure 5). The fouth palynocycle (1923 – 2003) m which is at the top most part of the lithofacies sequences is suggestive of the lasting aggradation or highstand in the sea level (Poumot 1989; Morley, 1995).

**Implication of palynocycles from the palaeovegetation on the palaeoenvironment**

The climate of an area is mirrored by its vegetation type (Samant and Phadtare, 1997; Bankole *et al.* 2014). Variations in plant communities or changes in composition / abundance of an assemblage or individual species are regularly, partly a direct consequence of change in climate and/ or palaeoenvironment. The consequence of this variation on palynofloral groups depends on whether such a prevailing climate change encourages or affects the prevailing plant community. Qualitative and quantitative evaluation of the various groups of palynomorphs were evaluated from Okan-1 well. This is meant for deducing the climate and sea level phase and the kind of environments which prevailed during the deposition of the Miocene sediments (Table 1). The recognition can be modified to reflect the variation of mangrove forest (littoral), rain forest and savanna grass and spores (hinterland). The data plotted generically, suggest a changing climate and sea level during the prevailing palaeoclimatic period (palynocycles) (Figure 4, Figure 5). During a dry climate, the savanna, montane pollen and spores dominated the intervals designated as a dry climate. Furthermore, when it becomes wetter (wet climate) the mangrove vegetation and the rainforest which indicate the wet climate will expand further into the flood plain, and later it is being replaced by the deltaic front mangrove swamp (Figure 2, Figure 3, Figure 4, Figure 5) (Table 1) (Morley, 1995).

**Table 1. Palaeocological groupings and climatic indicators from pollen and spores**

| Paleaocological Groupings | Miospores | Climatic indicators |
|---|---|---|
| Coastal Vegetation | *Echiperiporites estalae* | wet |
| Mangroves Swamp Forest | *Zonocostites romanae* | wet |
| Fresh Water Swamp Forest | *Verrutricoporites rotundiporus* | wet |
| Tidal Estuaries,Creek | Spinizonocolpites sp. | wet |
| Fresh Water Swamp Forest | *Parchydemite diderixi* | wet |
| Fresh Water Swamp Forest | *Syncolporites marginatus* | wet |
| Mangroves Swamp Forest | *Psilatricolporites* sp. | wet |
| Guinea Lowland Rainforest | *Verrucatosporites* sp. | wet |
| Mangrove Swamp Forest | *Elaeis gunnensis* | wet |
| Savanna Vegetation | Aff. *asteraceae* | dry |
| Savanna | *Monoporites annulatus* | dry |
| Savanna Vegetation | *Retibrevitricolporites* sp. | dry |
| Savanna | *Retitricoprites* sp. | dry |
| Marine | *Spiniferites* sp., *Selenopemphix nephroides* | wet |
| Marine | *Kiokonsum* sp., *Operculodinium centrocarpum* | wet |

The variations in the relative abundances of the terrestrial pollen (savanna vs. mangrove pollen and dinoflagellates) which were classified as miospores are characteristic of a varied palaeoenvironments of the prograding paralic succession (Poumot, 1989, Morley, 1995) (Figure 5). The wet climatic indices inferred could suggest flooding surfaces (MFS) when combined with planktonic foraminiferal and pyrite abundance count (Morley, 1995). These were recognised palynologically within the palynocles 3 and 4 (BZ5 – BZ6 unit) (Figure 4, Figure 5) (2003 – 2024) m, and can be calibrated to third and fourth order cycles on the Haq *et al.* (1978) worldwide sea-level curve if combined with foraminiferal data. These flooding events (MFS) (wet climate) are characterised by high abundances of mangrove pollen (predominantly *Zonocostites ramonae* - *Rhizophora*) as well as the dinoflagellates taxa such as O*perculodinium centrocarpum, Selenopemphix nephroides Spiniferites* sp. and *Kiokonsum* sp. (plates 1 and 2). Their presence suggests a shallower and transgressive marine, possibly delta plain environment (Morly, 1995; Durugbo *et al.* 2010). The presence of these dinoflagellate cysts and microforaminiferal test linings in the sediments are indicative of lagoonal to shallow marine environment (Muller, 1995).

The decrease in the abundance of *Zonocostites romonae* (pollen) in sediments (dryimate climate) during progradation is an indication of prodeltaic palaeonvironment (Morley, 1995). Also the abundance of *Monoporites annulatus (Poacaea)* (spores) is indicative of savanna vegetation (dry climate) and prodeltaic palaeoenvironment (Morley, 1995; Poumot, 1989) (Table 1). Their recovery (dry climate taxa) in this section may indicate a contribution even from distant afromontane and savanna environments, probably from the Cameroun and Congo Mountain range (Bankole *et al*. 2014. The palynological fingerprint interpreted from this study is an interpretation of the palaeoecology and palynocycles based on the miospores (pollen & spores) and few dinoflagellates component analysed. Thus, these varied palynological fingerprints observed from the seasonal oscillation of the vegetation, have aided in the development and confirmation of a sequence stratigraphic model through the recognition of highstand, transgressive and low stand systems tracts in the study area(Figure 5).

## 4. Conclusions

The recovery of the miospores (pollen and spores) was poorly diversified at some intervals. However, the combination of the spores and pollen data has been used for the interpretation of the palynological cycles, palaeoecology and climate change. The nine climatic indicators were used to infer palynocycles as recurrent palynological sequences reflecting vegetational changes determined by cyclic sea level oscillations and the associated climatic pulses. The presence of dinocyst such as *Operculodinium centrocarpum*, *Selenopemphix nephroides*, *Spiniferites* spp. and *Kiokansium* spp., indicates a marine environment (lagoon – tidal estuaries). The dominance of other sporomorphs such as *Zonocostites ramonae*, *Verrutricolporites rotundiporous* suggest a fluvio – estuarine deltaic environment (Brackish influence) (wet climate). *Monoporites annulatus*, *Distraverrusporites simplex*, *Retricoporites irregularies* (plate 1 and plate 2) indicate a near shore terrestrial environment sediment (dry climate) on the prodelta. Application of wet - dry climate has been identified to indicate the fluctuations of the sea level. Thus, it can now be documented as a useful tool in the evaluation of the variation of palynomorphs in the sediments. Therefore, the wet climate is related to the transgressive / highstand systems tracts, while the dry climate is linked to the lowstand systems tracts. These possible signals deduced from the palynocyles have enabled the reconstructions of the environments, climate and sea level change during the Miocene in the Niger Delta.

## Palynomorph Photo Montage

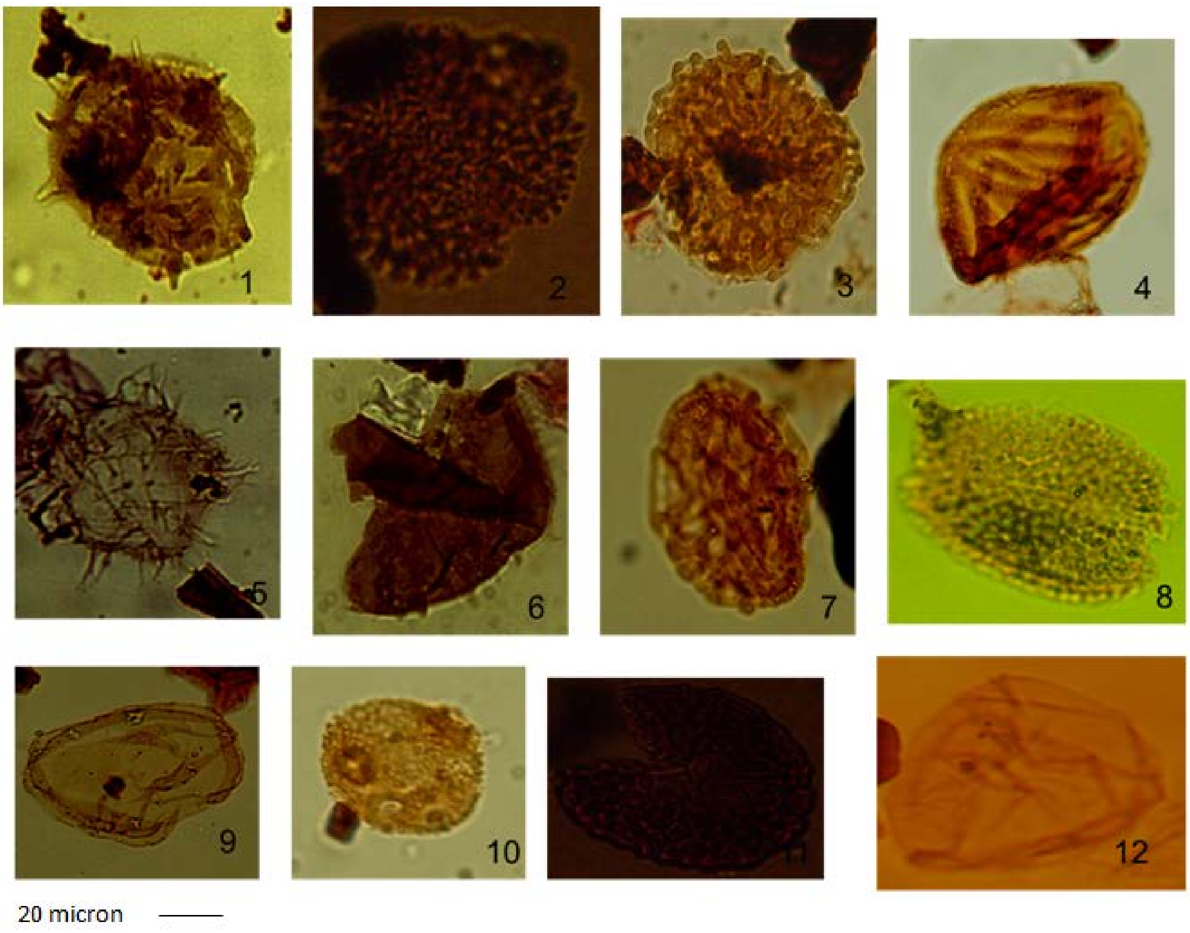


**Plate 1.** 1. Echiperiporites estalae, 2. Retitricolporites irregularis, 3. Spirosyncolpites bruni, 4. Magnastriatites howardi, 5. Operculodinium centrocarpum, 6. Sumatradinium sp., 7. Peregrinipollis nigericus, 8. Racemonocolpites hians, 9. Selenopemphix nephroides 10. ? Retibrevitricolporites obodoensis / protrudens, 11. Crassoretitriletes vanraadshooveni, 12. Leiosphaeridia sp.

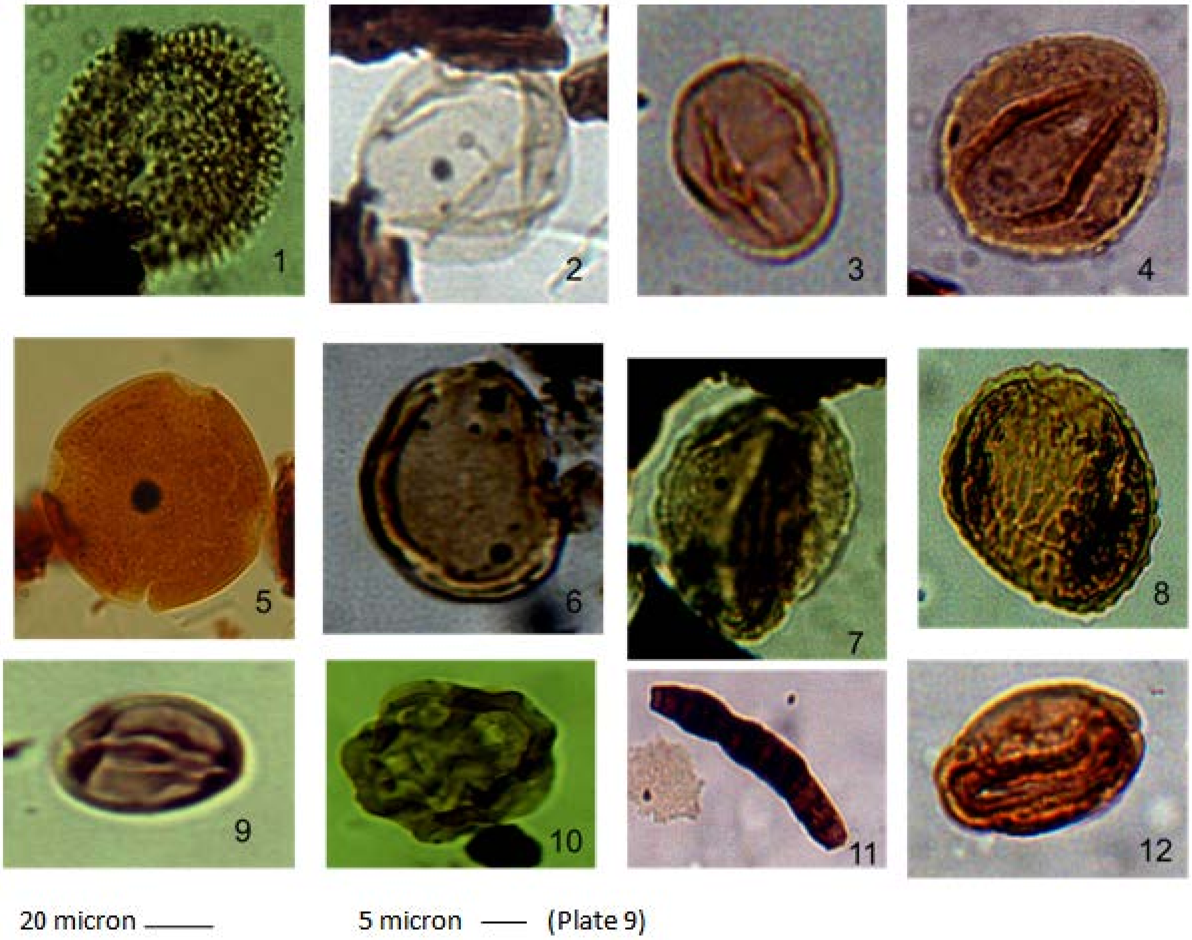


**Plate 2.** 1. Racemonocolpites hians, 2. Monoporites annulatus, 3. Sapotaceoidaepollenites sp., 4. Verrutricolporites rotundiporus, 5. Pachydermites diederixi, 6. Laevigatosporites sp.,7. Verrutricolporites rotundiporus, 8. Verrucatosporites sp., 9. Zonocostites ramonae, 10. Ctenolophonidites costatus, 11. Fungal spore, 12. Marginipollis concinnus

## Acknowledgements

My sincere thanks to Mr. Chinyere Ewerem, Mrs Safinatu Hajia of the Geological Agency of Nigeria, Kaduna for their support and assistance throughout the sampling stage. Also, I sincerely appreciate the role played by Dr. Lucas in suggesting different articles to support my findings from the Niger Delta.

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