Introduction

The Niger Delta is a major hydrocarbon producing basin in Nigeria where intensive exploration and exploitation activities have been on since early 1960's owing to the discovery of commercial oil in Oloibiri-1 well in 1956 (Reijers et al., 1996). Much palynological work has been done in this basin but there is little published information due to confidentiality maintained by the oil companies. Oil companies in Nigeria have their individual zonation schemes and a standard scheme is desirable. The section studied falls within the Biafra Member of the Agbada Formation as classified by Opara (1981). Most of the important hydrocarbon reservoirs in the Niger Delta are within the paralic Agbada Formation (Short and Stauble, 1967). These reservoirs are usually located in zones with structural and stratigraphic complexity. An excellent biostratigraphic framework is crucial for understanding the stratigraphy, characterization of the reservoirs and planning new exploration targets. Biostratigraphy has been shown to play an important role in the exploration of oil and gas in the Niger Delta. Spores, pollen and foram test linings were employed among other things to reconstruct the palaeoenvironments of the studied section. This is important because different depositional settings imply different reservoir qualities in terms of architecture, connectivity, heterogeneity and porosity-permeability characteristics (Simmons et al., 1999). This work therefore aims at identifying the recovered palynomorphs, using the identified palynomorphs to zone and date the section and combining palynology and sedimentology to decipher the environments of deposition in the studied section in order to assess the reservoir quality.

Regional Geologic Setting

The Niger Delta Basin is situated in the Gulf of Guinea in equatorial West Africa, between latitudes 3°N and 6°N and longitudes 5°E and 8°E (Reijers et al., 1996) (Fig. 1). The Niger Delta is framed by a subsurface continuation of the West African Shield, the Benin Flank. The eastern edge of the basin coincides with the Calabar Flank to the south of the Oban Masif (Murat, 1972). Well sections through the Niger Delta generally display three
vertical lithostratigraphic subdivisions: an upper delta top facies; a middle delta front lithofacies; and a lower pro-delta lithofacies (Reijers et al., 1996). These lithostratigraphic units correspond respectively with the Benin Formation (Oligocene-Recent), Agbada Formation (Eocene-Recent) and Akata Formation (Paleocene-Recent) of Short and Stauble (1967). The Akata Formation is composed mainly of marine shales, with sandy and silty beds which are thought to have been laid down as turbidites and continental slope channel fills. It is estimated that the formation is up to 7,000 metres thick (Doust and Omatsola, 1990). The Agbada Formation is the major petroleum-bearing unit in the Niger Delta. The formation consists mostly of shoreface and channel sands with minor shales in the upper part, and alternation of sands and shales in equal proportion in the lower part. The thickness of the formation is over 3,700 metres. The Benin Formation is about 280 metres thick, but may be up to 2,100 metres in the region of maximum subsidence (Whiteman, 1982), and consists of continental sands and gravels.

Materials and Methods
Ditch cutting samples from Ane-I well were supplied by Mobil Producing Nigeria Unlimited (MPN) and were composited at 60ft intervals. A total of 50 composited samples from depth of 6990ft to 9930ft were processed and analysed for sedimentological and palynological studies. These studies were carried out at Petrostrat Services Limited (PSL), Nigeria.

For sedimentological processing, about 80 grams of each sample was crushed and soaked with hot water and liquid detergent for about 24 hours. The
soaked samples were briskly washed under a distilled water nozzle tap using a 63µm sieve mesh. The retained samples on 63µm sieve were dried over hot plates. The essential parameters studied were: (i) the main rock types; (ii) colour and texture such as grain size, sorting and grain shape (roundness); and (iii) accessory mineral and fossil contents. The results are displayed in Fig. 3.

Palynological processing involved of 25 grams of dry sample being crushed between 0.25mm and 2.5mm. Standard palynological processing procedures employed were as follows: (i) disintegration of mineral matrix with dilute HCl for carbonates and digestion with concl. HF for silicates (15 hours); (ii) Removal of fluoride gel using hot concl. HCl (40 minutes) and wet sieving of samples using 10µm polypropylene Estal Mono sieve; (iii) oxidation (3 minutes) and heavy liquid separation using ZnCl₂ (sp. gr. 2.0). Slides were mounted using cellosize as a spreading medium and loctite as adhesive. One slide per sample was analysed under the optical microscope and the microphotography of the best palynomorphs specimens was done with the aid of an Olympus CHB microscope. Residues are stored at Petrostrat Services Laboratory while the slides are stored in the Geological Sciences Laboratory of Nnamdi Azikwe University, Awka, Nigeria.


Results and Discussion

Sedimentology

In general, the well shows a clastic regressive succession with sand predominating. It is made up of alternating sand and shale including appreciable siltstone. The shale/sand ratio increases progressively towards the base of the studied interval as seen from the log of the well section in Fig. 2. Glauconite pellets are few to common mineral found in the studied interval. Shell fragments, ferruginous materials, pyrite and mica flakes are rare to few (see Fig. 3).

The sands are predominantly clean white to grayish, buff or brownish, fine to coarse grained, sometimes pebbly, angular to well rounded, moderately to poorly sorted and occasionally well sorted in some samples. The shales are light to dark grey or brownish, soft to moderately indurated, platy, flaggy, slabby and blocky in appearance. Based on sedimentological and palynological data, the interval studied in Ane-1 well belongs to the paralic Agbada
Fig. 3: Lithostratigraphic/accessory mineral chart of Ane-1 well
Formation. The lithostratigraphic units recognized in the well are presented below on Table 1.

Biostratigraphy

A total of 632 palynomorphs were counted after screening comprising spores, pollen grains, fungal spores, Botryococcus, and foram test linings. Some of the corroded or highly distorted palynomorphs were not counted since they could not be placed within any group. Marine indicators found were foram test linings. The biozonation of the studied section was based on the pollen and spores. The reference scales used were those of Evamy et al. (1978) and Morley (1997). Some of the subzones of these two schemes were lumped together because some of diagnostic fossils that mark their boundaries were not found (Fig. 4 and Table 2).

The entire section falls within the *Echitricolporites spinosus* Zone of Germeraad et al. (1968). The diagnostic palynomorphs recovered permitted the zonation and dating of the analysed section. A Late Miocene to Early Pliocene age was assigned to the studied section with Miocene/Pliocene boundary placed at 8150ft and marked by First Appearance Datum (FAD) of *Nymphaeapollis clarus* and increase in *Monoporites annulatus*.

### Table 1: Lithostratigraphic subdivisions of ANE-1 Well

<table>
<thead>
<tr>
<th>Depth interval (ft)</th>
<th>Thickness (ft)</th>
<th>Member</th>
<th>Formation</th>
<th>Shale/Sand Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>6990-7115</td>
<td>125</td>
<td>Upper</td>
<td>Biafra</td>
<td>30/70%</td>
</tr>
<tr>
<td>7115-8035</td>
<td>920</td>
<td>Middle</td>
<td>Biafra</td>
<td>50/50%</td>
</tr>
<tr>
<td>8035-9930</td>
<td>1895</td>
<td>Lower</td>
<td>Biafra</td>
<td>70/30%</td>
</tr>
</tbody>
</table>

### Early Pliocene Interval

Two subzones *Podocarpus milanjianus* (P880) and *Gammanimonopores* sp. (P870-P860) of Evamy et al. (1978) and four subzones *Retibrevitricolporites oboedensis* (P2), *Arecipites* sp. (P3), *Sapotaceoideapollenites* sp. (P4/P5) and *Zonocostites ramonae/Charred graminae* (P6/P7) of Morley (1997) are recognized in the Early Pliocene interval of this well. The boundary of *Podocarpus milanjianus* (P880) and *Gammanimonopores* sp. (P870-P860) subzones is defined by Last Appearance Datum (LAD) of *Gammamonoporites* sp. The boundary between *Retibrevitricolporites oboedensis* (P2) and *Arecipites* sp. (P3) subzones is defined by FAD of *Arecipites* sp. Boundary between *Arecipites* sp. (P3) and *Sapotaceoideapollenites* sp. (P4/P5) subzones is defined by decrease in *Sapotaceoideapollenites* sp., while that of *Sapotaceoideapollenites* sp. (P4/P5) and *Zonocostites ramonae/Charred graminae* (P6/P7) subzones is defined by increase in *Zonocostites ramonae* and charred grass. Some of these subzones were not combined because their diagnostic marker species were not found. Some characteristic palynomorphs in this interval are Stereisporites spp., Retimonocolpites sp., *Monoporites annulatus*, *Pachydermites diederixii*, *Multiareolites formosus*, *Elaeis guineensis*, *Retibrevitricolporites oboedensis/prostrudens*, Perfotricolpites digitatus, *Vernucautosporites proscendus*, *Polypodiaceoisporites gracillimus*, *Arecipites crassimuratus*, *Echiperiporites estelae*, *Nymphaeapollis clarus*, *Cyatheacidites sp.*, *Magnastriatites howardi*, *Crototricolpites densus*, *Spiroycolpites brunii*, *Crasseotretriletes vanradshooveni*, *Psilastephacolporites laevigatus*, *Podocarpus milanjianus*, etc.

### Late Miocene Interval

Evamy et al. (1978) used the FAD of *Nymphaeapollis clarus* to mark the Miocene/Pliocene boundary. This FAD is found at a depth of 8150ft. Morley (1997) in his zonation scheme used increase in *Monoporites annulatus* to mark Miocene/Pliocene boundary which was also found at the same depth of 8150ft. Thus Miocene/Pliocene boundary was confirmed at that depth.

The *Multiareolites formosus* (P800) Zone and *Nymphaeapollis clarus* (P850-830), Stereisporites sp. (P820), and *Multiareolites formosus* (P780) subzones of Evamy et al. (1978) were recorded in the Late Miocene of the Ane-1 well. The boundary between *Nymphaeapollis clarus* (P850-830) and *Stereisporites* sp. (P820) subzones is defined by FAD of *Nymphaeapollis clarus* at 8150ft while that of *Stereisporites* sp. (P820) and *Multiareolites formosus* (P780) subzones is defined by FAD of *Multiareolites formosus* at 9420ft.

Morley (1997) uses increase and decrease in abundance of *Zonocostites ramonae* and *Monoporites annulatus* to subdivide the Late Miocene. M1, M2, M3 and M4 subzones of Morley (1997) were recorded in the Late Miocene interval of this well. The boundary between M1 and M2 subzones is defined by increase in abundance of *Zonocostites ramonae* while the boundary between M2 and M3 subzones is defined by
Fig. 4: Palynoflora distribution chart of Ane-1 well
Fig. 5: Representative spores in Ane-1 well

**PLATE 1 (X 1000)**

Figures: 1&2: Magnastria tites how ard i:
2: Cyatheacidites minor;
4: Polypodiaceo is porites gracillim us
5, 6&7: Echitriletes muelleri
8 & 11: Verrucato sporites usm ensis
9 & 10: Verrucato sporites tenellis;
12: Laevigato sporites discordatus
13: Laevigato sporites ovatus
Fig. 3 (X 1000)
Figures: 31: Brevicolporites molinae
32 & 33: Retibriviricolporites obodoensis
34, 35 & 36: Retibriviricolporites protrudens
37 & 38: Psilatricolporites crassus
39 & 41: Retitricolporites irregularis
42 & 45: Zonocostites ramonae
43: Psilastephanocolporites laevigatus
44: Polyadosporites sp.
46: Psilodiporites ellipsoideus
47: Fusiformisporites pseudocrabbi
48 & 49: Foram test linings
50 & 51: Botrococcus braunii

Fig. 6: Representative pollen, fungal spores and others in Ane-1 well
Fig. 7: Representative pollen in Ane-1 well

PLATE 1 (X 1000)
Figures: 14: Psilamonocolpites sp.
15: Arecipites sp.
16 & 17: Arecipites crassimuratus
18: Psilamonocolpites simplex
19 & 20: Perforotricolpites digitatus
21: Monoporites annulatus;
22: Nummulipolis neogenicus
23: Brevicolporites guinetii
24 & 25: Momipites africanus
26 & 27: Pachydermites diederixi
28: Echiperiporites estelae
29 & 30: Multiareolites formosus
decrease in abundance of Zonocostites ramonae and increase in Monoporites annulatus. The boundary between M3 and M4 subzones is defined by increase in Zonocostites ramonae.

Some characteristic palynomorphs within this interval include: Monoporites annulatus, Pachydermites diederixi, Zonocostites ramonae, Lanigatosporites spp., Verrucatoxporites tenellis/lusensis, Echitriletes muelleri, Reititricolporites irregularis, Mumitipites africanus, Polyposiaceosporites gracilissimus, Retitricolporites irregularis, Anrecipites crassimuratus, Echipteriporites estalae, Nummulipollis neogenicus, and fungal spores.

Environmental Interpretation

Four main criteria are involved in this environmental interpretation:

(i) Association of environmentally restricted marker species such as Magnastriatites howardi, Pachydermites diederixi, Zonocostites ramonae and foram test linings;
(ii) percentage of Zonocostites ramonae (Rhizophora type) in the total palynoflora sum;
(iii) nature of organic matter in the sediment; and
(iv) lithological characters of the strata.

Results of Environmental Interpretation

(i) Environmental marker species: Marker species such as Magnastriatites howardi (a small aquatic fern of alluvial plain and coastal swamps), Pachydermites diederixi (an angiosperm of coastal swamps), Zonocostites ramonae (mangrove pollen) and Monoporites annulatus (gramineae pollen suggesting open vegetation found in coastal savannah) and foram test linings are present. The abundance of these marker species (with exception of foram test linings), though with rare occurrence of M. howardi and regular occurrence of fungal spores suggests that the interval studied represents mainly deposition in a coastal to marginal marine setting. Foram test linings are good indicators of marine environments was used to further divide the macro environment into coastal deltaic, coastal deltaic inner neritic and inner neritic.

(ii) Percentage of Zonocostites ramonae: Z. ramonae is a distinctive pollen type found in extant genera of mangroves notably Rhizophora (Germeraad et al., 1968). Rhizophora shows its optimal development on unconsolidated clayey to sandy soils in a marine to brackish environment. Its quantitative distribution therefore, makes it a useful species for environmental interpretation. Rhizophora is frequent to abundant throughout the interval described here, suggesting the presence in the area. The percentage of Z. ramonae ranges from

Table 2: Biostratigraphic summary table of Ane-1 well

<table>
<thead>
<tr>
<th>Depth</th>
<th>Biostratigraphic</th>
<th>Chemostratigraphic</th>
</tr>
</thead>
<tbody>
<tr>
<td>7900</td>
<td></td>
<td></td>
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<td>7800</td>
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<td>7500</td>
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<tr>
<td>7400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
4% to 36% in the studied interval. The absence of this species from some horizons indicates that deposition of those sediments occurred some distance from the mangrove edge.

The intermittent occurrence of *M. howardi* from 8100 ft and above shows the incursion of fresh water in the immediate vicinity and the presence of more open vegetation.

The paucity of foram test linings from 7980 ft depth to the base of the well indicates a slight marine influence. The slight marine influence and high percentage of *Z. ramonae* suggests deposition in mangrove environments.

(iii) **Organic matter:** The accumulation and degradation of organic matter is related to surface conditions in the depositional environment and to diagenetic changes (Oboh et al., 1992). The organic matters recorded in this study ranges in size from small to large, indicating that sediments have not been long transported. Deposition occurs under conditions of variable energy where both coarse and fine particles settled out. The organic matter is predominantly structured woody material with sparse opaque organic matter, cuticles, pollen and spores. Macerals present are liptinite-like alginite typified by *Botryococcus* and showing fresh water influence (Bustin, 1988). Terrestrially derived kerogen types II and III predominate showing that the organic matter is from higher plants (Bustin, 1988).

(iv) **Lithology:** In the studied intervals, glauconite is rare to common while pyrite, shell fragments, ferruginous materials and mica flakes are rare (Fig. 2). Glauconite and pyrite are the most important accessories used for environmental studies. Glauconite forms as an authigenic mineral during the early stage of diagenesis of marine sediment. It is extremely susceptible to sub-aerial weathering and is not known as a reworked second cycle detrital mineral (Selley, 1980). The presence of glauconite in sand, therefore, indicates a marine origin. On the other hand, pyrite in the shale bodies suggests reducing conditions. The combination of these accessory minerals with a gamma ray log helps in the sub-division of the environments. The sub-environments recognized here are: regressive barrier bar, tidal sand wave, and tidal channels. These sub-environments suggest shoreface deposits in marginal marine setting. The presence of pyrite in the Upper Biafra unit (6990-7115 ft) indicates deposition in a slightly anoxic marine setting.

**Summary and Conclusion**

Lithological and palynological analyses of the Ane-1 well have contributed to the stratigraphic study of the section. A combination of spores and pollen is the basis for dating the section as Late Miocene to Early Pliocene. The palynological zonation conformed to those of Evamy et al. (1978) and Morley (1997) and shows that the two zonation schemes can be combined for better resolution. The combination of parameters showed the environments of deposition to be coastal to marginal marine which was further subdivided into coastal deltaic, coastal deltaic inner neritic, and inner neritic. The sub-environments recognized are tidal channel, regressive barrier bar and shoreface deposits.

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