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A Late Tertiary Pollen Record from Niger Delta, Nigeria

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Abstract: This study presents the results of palynological investigations carried out on Atala-1 well, Niger Delta, Nigeria. The samples yielded pollen and spores and the identification of the pollen and spores, their relative diversity and abundance provide data on which the palaeoenvironmental interpretations were based. Nine informal lithological units were delineated for the well, characterized by silty clay and very fine to very coarse sand grains which are typical of Benin and Agbada formations of the Niger Delta. Four pollen zones (PZ I-IV) were recognized from the pollen diagram and attempt was made at the reconstruction of the vegetation for the zones. The early part of the zone (I) was characterized by unstable wet and dry climatic conditions characterized by contrasting fluctuations between the percentage occurrence of *Rhizophora* sp. and Poaceae. The vegetation was gradually dominated by mangrove swamp vegetation towards the later part of the zones (II-IV), indicating a wet and moist climates for the period and a rise in sea level.

Key words: Tertiary, palynology, vegetation, climate

INTRODUCTION

Most palynological studies in Nigeria in the past four and a half decades were primarily based on the needs of the oil industry. Because of the occurrence of hydrocarbon in the Niger Delta, oil companies carried out most of the works on the Niger Delta and information from them has remained confidential. Few published studies exist on the Niger Delta, among which are those of Burke (1972), Avbovbo (1978) and Legoux (1978). Most of the above listed studies are largely concerned with systematic descriptions of pollen and spores, or palynological zonations based primarily on foraminiferal assemblages and litho and bio-stratigraphy.

Oyelaran (1991) reported that palaeoenviromental reconstruction has so far made modest progress in Nigeria. Apart from the published works of Sowunmi (1981a) on the Late Quaternary Eastern Niger Delta and Oboh *et al*. (1992, 1995), Edet and Nyong (1994) and Ige and Sowunmi (1997), there has been a paucity of publish information on the palaeoenvironmental changes in the Niger Delta, Nigeria. Elsewhere in Africa, several studies exist documenting vegetation and climatic changes at various geologic periods especially in the Holocene (Sowunmi, 1981a ,1981b; Jahns *et al*., 1998; Salzman, 2000; Marchant and Taylor, 2000). However, very few palynological studies have been carried out detailing tertiary palaeoenvironmental changes especially in Nigeria's Niger Delta area.

The reconstruction of past environments is one of the goals of palynological research and this entails the study of the periodic changes in environment over geological time. This offers another way of studying the climatic changes of the past. The changes in climate are most evidently reflected in the vegetation. This is because the vegetation of any area is an integral and basic component of the ecosystem and is sensitive to changes in the ecosystem. According to Ivanor *et al*. (2007), the distribution pattern of vegetation strongly depends on climatic conditions and thus vegetation reconstructions help to understand past climates. Sowunmi (1987) reported that a close relationship exists between vegetation and the rest of the environment, particularly climate and soil. Thus, according to Sowunmi (1987), the flora of an area, generally speaking, provides a good reflection of the major climatic regime of that area. The influence of climate on other components of the environment is so great that every particular climatic zone has its own characteristic vegetation type. Therefore, plants are among the best indicators of the environment especially of the climate, soil and fauna. Certain individual or assemblages of plants are known to be characteristic of specific ecological zones and the occurrence of the fossils of such ecological indicator species in sediments is considered a reflection of contemporary ecological conditions.

Thus, with adequate evidence in the form of fossils in sedimentological data, it is possible to reconstruct and interpret past environments and biotic communities based upon processes operative today. As Davis *et al*. (1971) pointed out; the usefulness of fossil pollen and spores to palaeoecology is hinged on their potential for providing quantitative information on recorded ancient vegetation. Therefore, in the reconstruction of these past vegetations and environments from fossil pollen assemblages, the pollen data is commonly interpreted as a reflection of the type of vegetation and climate prevalent during the period under study.

Therefore, this study presents vegetational and climatic changes in the Late Tertiary Niger Delta, Nigeria based on pollen record from Atala 1-well. This study will serve as a further contribution to the knowledge of the Niger Delta environmental changes as reflected by vegetation particularly at Miocene/Pliocene periods where there is a dearth of published information.

MATERIALS AND METHODS

The Atala-1 well is an exploratory well drilled in the coastal swamp of the Niger Delta, Nigeria. The Niger Delta is situated on the continental margin of the Gulf of Guinea on the West Coast (equatorial) of Central Africa (Fig. 1). It lies between Latitude 3° and 6°N and Longitude 5° and 8°E. During the Tertiary, it built out into the Atlantic Ocean at the mouth of the Niger-Benue River System, an area of catchment that encompasses more than a million square kilometre of predominantly savanna-covered lowlands (Doust and Omatsola, 1992). It is one of the worlds largest, with the subaerial portion covering about 75,000 km^2 and extending more than 300 km from apex to mouth. The regressive wedge of clastic sediments, which it comprises, is thought to reach a maximum thickness of about 12 km (Doust and Omatsola, 1992). When compared with other African basins, it is the most prominent and actually the largest delta in Africa. Recent exploration activities in the onshore and offshore areas have shown that the sedimentary basin of the Niger delta encompasses a much larger region than the geographical extent of the modern delta.

Location of the studied well: The studied samples come from Atala-1 well drilled by Shell Petroleum Development Company on-shore Western Niger Delta. The well is situated in the Vampire Creek field Oil Mining Lease (OML) 46 (Fig. 2). Atala-1 well was drilled to a total depth of 4003 m. The sections sampled for this study are ranged from 36 to 4003 m totaling 50 samples.

Lithology: For lithological and textural characteristics, the ditch cutting samples were washed under running water using 63 μm sieve to remove drilling mud. The samples were oven dried, examined and described with the aid of a Leitz-Wetzlar binocular microscope.

pH: The determination of pH values for the samples was carried out using the pH meter. To calibrate the pH meter, standardized pH solutions of 4 and 9 were used.

A small quantity (5 g) of each sample was put in a beaker and water was added. The beaker was then put on a magnetic stirrer and after thorough stirring, a known

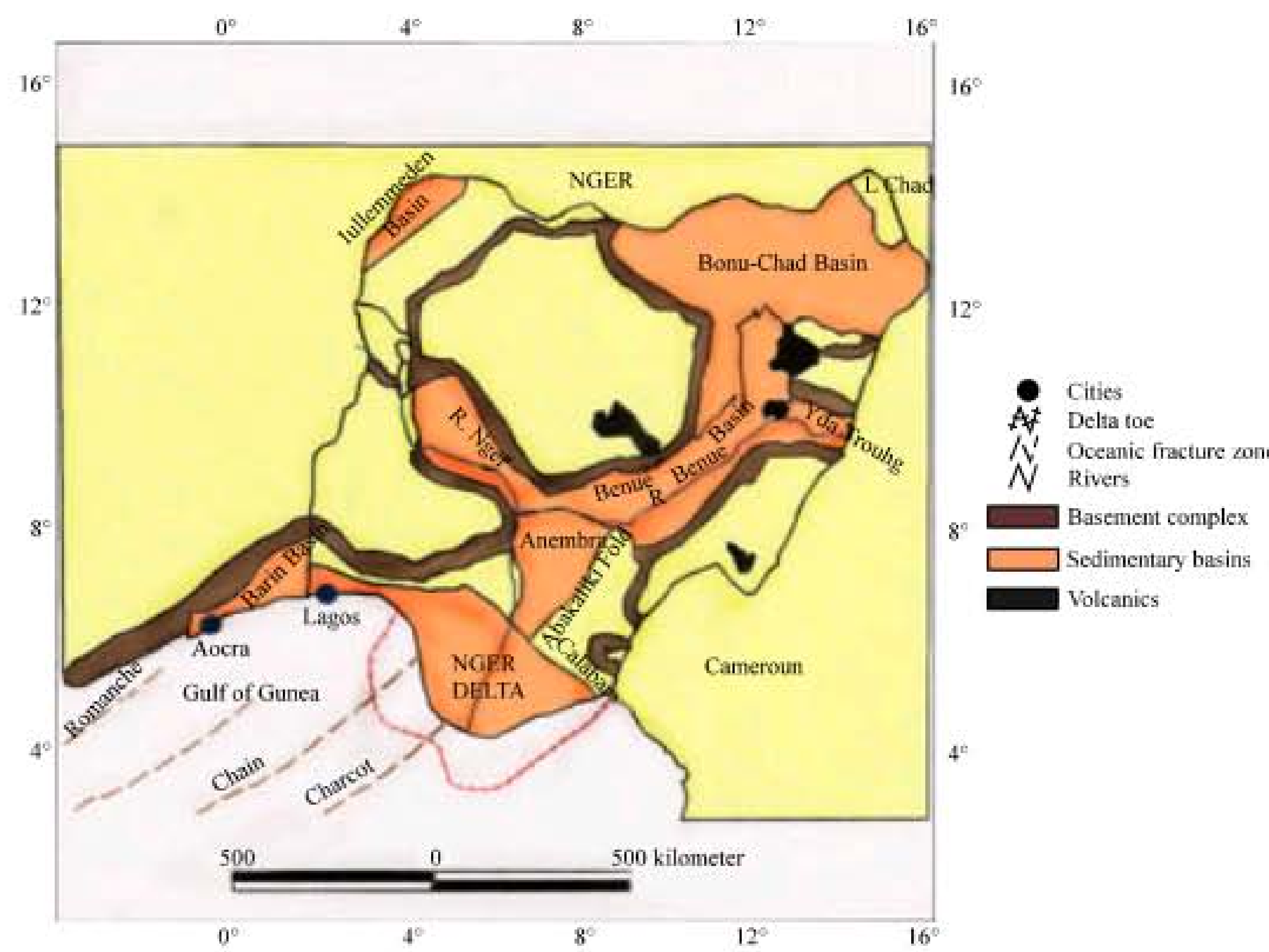

Fig. 1: Regional setting of Cenozoic Niger Delta (Knox and Omatsola, 1998)

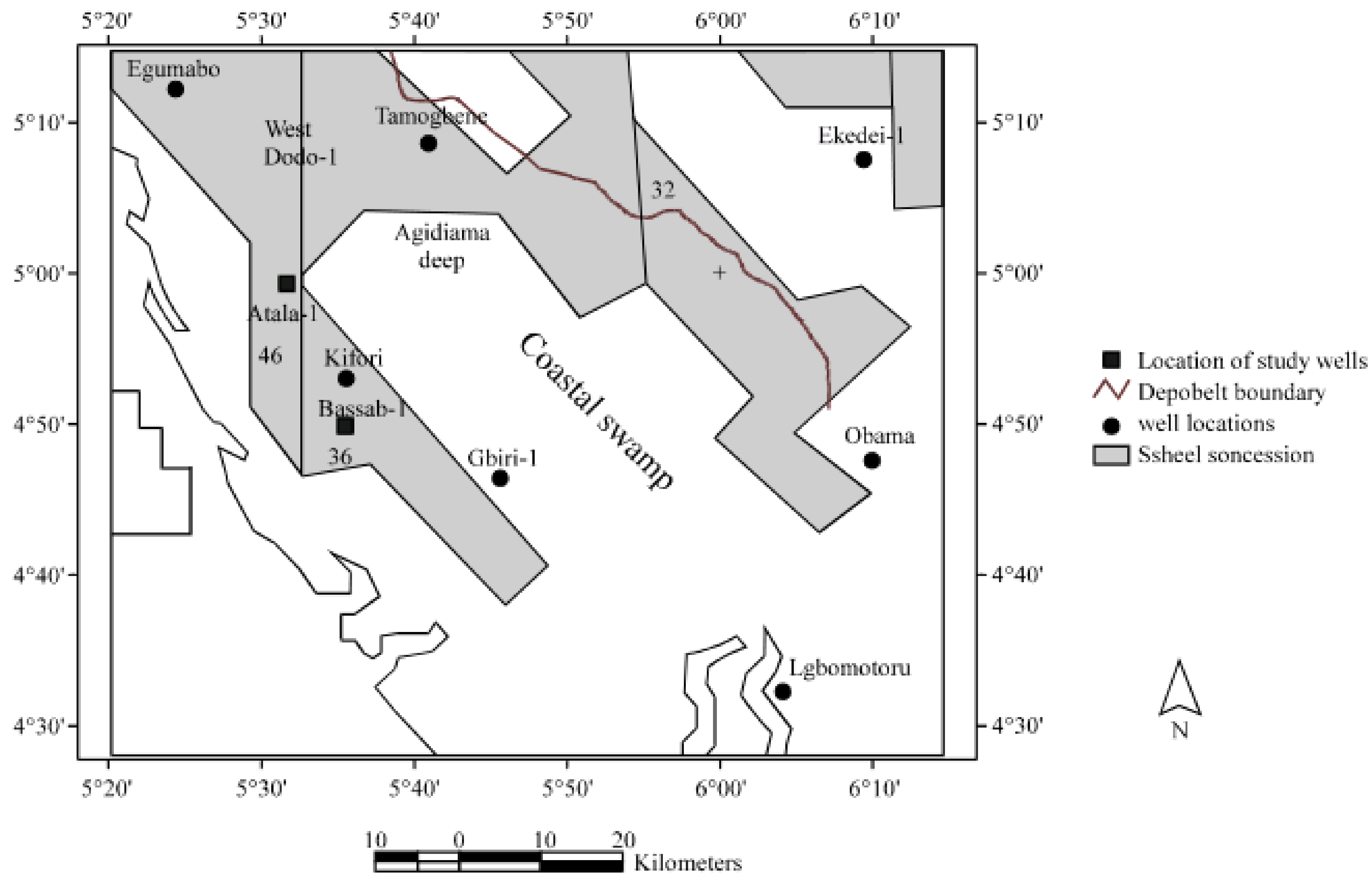

Fig. 2: Concession map of Western Niger Delta showing the location of Atala-1 Well (SPDC, 1993)

volume of the mixture was put in a vial and electrodes inserted. The pH value was then read on the digital pH meter.

Processing of samples: For palynological analysis, fifty samples (2 g) were treated using standard palynological methods. These include HF treatment to remove siliceous materials and HCl and Heavy liquid separation and finally acetolysis to dissolve cellulose and to darken palynomorphs for easy identification (Faegri and Iversen, 1989).

Identification: For the identification of pollen and spores, the atlases of photomicrographs in the photoalbum of the Palynology Laboratory, Department of Archaeology and Anthropology, University of Ibadan, Nigeria, as well as those published in literature such as Legoux (1978), Moore and Webb (1978), Duenas (1980), Salard-Cheboldaeff *et al*. (1992), Elsik and Ediger (1990) and Sowunmi (1995). Reference pollen slides of modern taxa in the Palynology laboratory, Department of Archaeology and Anthropology, University of Ibadan, Nigeria were also consulted.

Pollen spectra constitution: From the palynomorphs recovered during the pollen analysis, the pollen spectra of the ditch cutting samples were constituted. The percentage composition was calculated thus: numerical composition of each pollen and spore species in a sample divided by the pollen sum, multiplied by 100.

Pollen sum: Only pollen grains, which were identified to species, genus or family level and spores as pointed out by Moore and Webb (1978) were selected to constitute the pollen sum. *Rhizophora* sp. and Poaceae pollen were excluded from the pollen sum, as they were over-represented in the samples (Lezine and Vergnaud-Grazzini, 1993). Their numbers were however calculated and expressed each as percentage of the pollen sum. All the unidentifiable and unknown grains were also excluded from the pollen sum.

Phytoecological zones: In order to reconstruct the palaeovegetation communities from which inferences about the environmental conditions prevailing at the time of deposition of the sediments of these wells can be made, the pollen types were grouped into vegetation zones or phytoecological units based on the present day natural distribution of their modern analogues. The approach of Sowunmi (1981a, b) was followed in classifying the taxa into different phytoecological groups. Reference was made to Hutchinson and Dalziel (1968) and Germeraad *et al*. (1968) in grouping the taxa to their ecological ranges. The grouping was based on the assumption that the physiology and environmental requirements of the fossil species were identical to their extant analogues (Ritchie, 1987).

Pollen diagram construction: The pollen diagrams were constructed using Tilia and Tilia graph computer software (Grimm, 1991). The percentage composition of individual pollen and spores as listed under the pollen spectra were generated and used in the construction of the pollen diagram.

RESULTS AND DISCUSSION

Lithology: The samples were divided into nine horizons (A-I) on the basis of textural characteristics. These units, from top to the base are shown in Fig. 3. The section was characterized by shaly sand and shale with the sand grains exhibiting coarse to granule-sized characteristics. They were moderately well to poorly sort with abundant carbonaceous detritus and ferruginous materials at the upper horizon. The sand grains were smooth, sub-angular to sub-rounded, poor to moderately well sort. The grains were grayish to dark grayish in color while the shale was dark grey and fissile.

The colors and pH of the samples were shown in Table 1. The pH values were ranged from 4.1 to 8.0.

Palynological analysis: All the pollen and spore types identified from the Well and their percentage composition were listed in Table 2. The pollen diagram was presented in Fig. 4. Figure 5 and 6 showed the photomicrographs of some selected palynomorphs. All magnifications 800x except otherwise stated.

Phytoecological zones: The phytoecological zones are listed below:

i. Mangrove Swamp Forest
   Rhizophora sp.
ii. Freshwater Swamp Forest
   Symphonia globulifera
   Pandanus candelabrum
   Cleistopholis patens
iii. Lowland Rain Forest
   Canthium sp.
   Fern spores
   Gaertnera paniculata
   Canarium schweinfurthi
   Pentadesma butyraceum
iv. Montane Forest
   Podocarpus milianjianus
v. Riverine/Fringing Forest

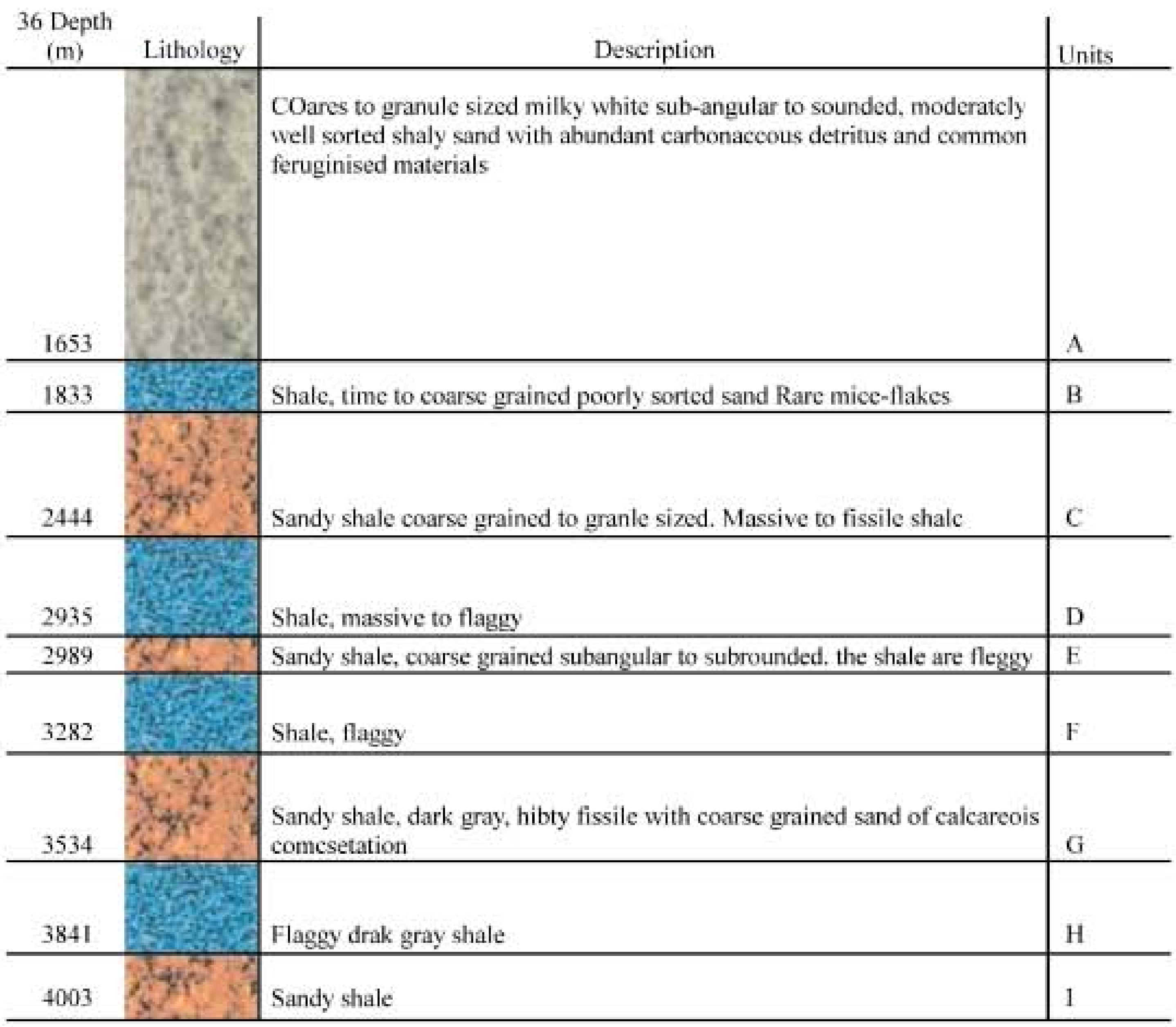

Fig. 3: Lithology of Atala-1 well, Niger Delta, Nigeria

Table 1: Colour, pH and palynomorph abundance of Atala-1 well

Lithology	Colour	Description	pH	Total No. of palynomorph g^{-1} of sample
Sandy shale	2.5Y4/2	Dark grayish brown	4.1	10656
Shaly sand	10YR5/1	Grey	7.4	1590
Shaly sand	10YR5/1	Grey	7.4	2266
Shaly sand	10YR6/1	Grey	7.6	53
Shaly sand	10YR3/2	Very dark grayish brown	5.9	484
Shaly sand	10YR5/2	Greyish brown	6.2	1305
Shaly sand	10YR5/2	Greyish brown	6.2	6375
Shaly sand	10YR5/1	Grey	6.4	504
Shaly sand	10YR5/1	Grey	8.0	720
Shaly sand	10YR6/1	Grey	7.8	968
Sandy shale	10YR5/2	Greyish brown	6.2	844
Sandy shale	10YR5/3	Brown	6.1	326
Sandy shale	10YR5/2	Greyish brown	7.8	563
Sandy shale	10YR5/2	Greyish brown	7.6	516
Sandy shale	10YR5/2	Greyish brown	7.8	535
Sandy shale	10YR5/2	Greyish brown	7.2	128
Shale	10YR3/2	Dark grayish brown	7.1	771
Sandy shale	10YR6/3	Pale brown	7.6	197
Sandy shale	10YR5/2	Grayish brown	7.3	1125
Sandy shale	10YR4/2	Dark grayish brown	7.0	135
Sandy shale	10YR6/3	Pale brown	7.1	525
Sandy shale	10YR5/2	Greyish brown	7.4	165
Sandy shale	10YR5/1	Grey	7.0	540
Sandy shale	10YR6/3	Pale brown	7.6	158
Sandy shale	10YR6/2	Light brownish grey	7.4	175
Sandy shale	10YR6/2	Light brownish grey	7.0	233
Shale	10YR5/2	Greyish brown	7.1	424
Shale	10YR5/2	Greyish brown	6.3	830
Sandy shale	10YR5/2	Greyish brown	7.4	919
Sandy shale	10YR5/2	Greyish brown	7.2	1395
Sandy shale	10YR5/1	Grey	6.4	1170
Shale	10YR5/2	Grey	6.7	896
Shale	10YR4/1	Dark grey	7.0	570
Shale	10YR4/1	Dark grey	7.3	128
Shale	10YR4/2	Dark grayish brown	7.1	701
Sandy shale	10YR3/2	Very dark greyish brown	7.1	120
Sandy shale	10YR5/4	Yellowish brown	7.4	165
Sandy shale	10YR6/4	Light yellowish brown	7.1	600
Sandy shale	10YR7/3	Very pale brown	7.2	454
Sandy shale	10YR6/2	Light brownish grey	7.1	45
Sandy shale	10YR5/2	Grayish brown	7.3	180
Shale	10YR6/3	Pale brown	7.2	86
Shale	10YR6/2	Light brownish grey	6.8	30
Shale	10YR6/2	Light brownish grey	7.2	285
Shale	10YR5/2	Greyish brown	7.1	495
Shale	10YR6/2	Light brownish grey	7.3	60
Shale	10YR5/2	Grayish brown	6.6	144
Shale	10YR6/2	Light brownish grey	6.9	244
Shale	10YR5/2	Grayish brown	7.2	430
Shale	10YR6/2	Light brownish grey	6.6	305

Brachystegia eurycoma

vi. Savanna
Acacia sp.

vii. Poaceae

The summary of the lithological interpretation for the well was represented in Fig. 3. The topmost section in this well from 36 m down to 1653 m was characterized by coarse-grained milky white sand bodies. Textural features varied from sub-angular to rounded, moderately well sorted with abundant carbonaceous detritus and ferruginous materials. These massive sand bodies have been deposited under continental environments. The next section was ranged from 1653 to 2444 m, consisting of two lithologic units. This section was predominantly sandy with shale at intervals. The shale was massive to fissile. The sand bodies were characterized by blocky, upward coarsening and multistory upward coarsening log profiles. They were coarse grained and poorly sorted with little mica flakes. These features are suggestive of low energy marine environments. The interval between 2444-3282 m was consisted of massive shale with few sand bodies. The dominance of shale suggested marine influenced environment of deposition.

Table 2: Components of the pollen spectra, Atala-1 well (occurrence represented as percentage of pollen sum)

	Depth (m)																					
Species	36	217	325	397	686	795	1048	1264	1364	1382	1544	1598	1616	1653	1707	1761	1833	2083	2155	2282	2300	2390
Acacia sp. (Miller)	4.3	5.6	4.7	-	25.8	-	3.2	-	-	-	-	-	14.4	-	-	-	3.6	-	5	-	2.9	-
Arecaceae (Schultz)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.3	-
Botryococcus	-	-	-	-	-	-	3.2	-	-	-	8.1	-	-	-	-	-	-	-	-	-	-	-
Brachstegla eurycome(Benth)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caesalpinaceae (L.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Canarium schweinfurthi (L.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Canthium sp. (Lam.)	-	-	-	-	-	-	3.2	-	-	-	8.1	-	-	-	-	-	-	-	-	-	-	-
Cleistopholis patens (Benth)	-	-	-	-	-	16.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Croton sp. (L.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinocyst	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dipterocarpus Arbocarpifolus (Gaertner)	4.3	-	-	-	-	-	6.5	-	-	-	17	-	-	6.5	-	6.5	-	-	15	-	9.5	-
Euphorbiaceae (Juss)	4.3	-	-	-	-	-	-	-	-	-	-	16.4	-	-	-	-	-	-	-	-	-	-
Fungal spore	22.7	66.7	71.6	50	12.4	-	19.4	53	37.7	87	325	34.3	50	478	77	79	46.7	80.3	40	-	45.4	44.2
Gaertnera paniculata (Lam.)	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-
Laevigatosporites	27.4	-	9.5	-	-	16.4	19.4	-	12	-	-	-	-	6.5	15.6	-	65	-	5	-	9.2	15.4
Leiotriletes	9.2	5.6	-	15	12.4	-	6.5	26.5	-	-	-	16.4	21.2	6.5	-	-	65	-	-	33.3	2.9	5.8
Ludwigea stenorraphe (L.)	-	-	-	-	12.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Malvaceae (L.)	-	-	-	-	-	-	-	-	-	-	-	-	-	6.5	-	-	-	-	-	-	-	-
Pandanus candelabrum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Papillionaceae	-	-	-	-	-	-	-	-	12	-	-	-	-	6.5	-	-	-	-	-	-	-	-
Pediastrum	-	-	-	-	-	-	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pantadesma butyrecea	4.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poaceae (L.)	59.5	53.8	60.1	-	41.8	74	46.8	96.9	86.5	94.5	43.6	50.6	78.7	27.7	100	74.2	46.5	60	63.6	78.9	57	46.3
Podocarpus milianjianus	4.3	-	4.7	-	-	16.4	3.2	-	-	-	-	-	-	-	-	-	3.6	-	5	-	2.9	-
Polygonum sp. (Juss)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psilatricolporites sp.	-	-	-	-	-	-	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Racemonolporites hians	-	-	-	-	-	-	-	-	-	-	-	16.4	-	-	-	-	-	-	-	-	-	-
Retibrevitricoloporites obodoensis	-	-	-	-	12.4	-	-	-	-	-	8.0	-	-	6.5	-	-	-	-	5	-	6.3	-
Retitricolporites irregularis	-	-	-	-	-	-	3.2	-	-	-	-	16.4	-	-	-	-	6.5	-	-	-	-	-
Rhizophora sp. (L.)	94.5	93.1	94	82.6	81.2	93.9	90.6	71.4	81.5	95.9	55.8	81.2	72.9	62.8	100	88.2	86.2	75.2	70.7	85.5	57.9	74.1
Sapotaceae (Juss)	-	11.1	-	-	-	12.4	34.3	3.2	-	-	17	-	-	6.5	-	-	-	-	5	-	-	5.8
Stereiosporites	13.7	-	-		12.4	34.3	3.2	-	-	-	17	-	-	6.5	-	-	-	-	5	-	-	-
Striamonocolpites rectostriatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Symphonia globulifera (L.)	-	-	-	-	-	16.4	3.2	-	-	-	-	-	-	-	-	-	3.6	-	-	-	-	-
Unknown	4.3	-	-	-	-	-	-	-	12	-	-	-	6.8	-	-	-	-	17.7	-	-	2.9	-
Verrucatosporites	4.5	11.1	-	-	12.4	-	16.1	-	25.6	12.7	17	-	14.4	6.5	-	-	16.6	-	15	66.7	15	28.8

	Depth (m)																											
Species	2444	2498	2516	2534	2625	2700	2754	2935	2989	3043	3115	3192	3282	3319	3389	3407	3425	3462	3498	3534	3570	3642	3751	3841	3877	3913	3985	4003
Acacia sp. (Miller)	-	-	-	-	-	-	1.28	-	-	-	3.3	-	1.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Arecaceae (Schultz)	2.7	-	-	-	5.2	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-
Botryococcus	-	-	-	-	-	-	3.2	-	-	-	-	8.1	-	-	-	-	2.7	-	-	-	-	-	-	-	-	-	-	-
Brachstegla eurycome(Benth)	-	-	-	-	-	-	-	-	-	-	-	-	1.9	-	10.2	-	12.2	-	12.9	-	-	-	-	-	-	-	2.3	-
Caesalpinaceae (L.)	-	-	-	-	-	-	-	-	-	2.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Canarium schweinfurthi (L.)	-	-	-	-	-	-	-	-	-	-	-	-	1.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Canthium sp. (Lam.)	-	-	-	-	-	-	-	-	-	2.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.3	-
Cleistopholis patens (Benth)	-	-	-	-	-	-	-	5	-		-	-	-	-	-	8	-	-	-	-	-	-	-	-	7.4	8.1	2.3	5.3
Croton sp. (L.)	-	-	-	-	-	-	-	2.5	1.5	5.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinocyst	-	-	-	-	-	12	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dipterocarpus Arbocarpifolus (Gaertner)	5.5	-	-	11	-	4	10.9	-	4.5	-	16.7	14.1	6.9	7.7	23.5	12	2.7	-	-	-	-	-	13.6	-	-	11.1	7	
Euphorbiaceae (Juss)	-	-	-	-	-	-	-	-	-	-	6.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fungal spore	232	51.9	42	-	19.5	12	22.7	22.5	11.9	16.2	10	21.1	13.2	69.2	41.6	16	36.1	100	12.9	56.6	33.3	75.9	20.1	100	38.3	11.1	30.2	21
Gaertnera paniculata (Lam.)	-	-	-	-	-	-	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laevigatosporites	2.7	14.8	14.5	15.1	30	-	10.9	7.5	7.5	16.2	13.2	14.1	4.6	-	8.2	8	7.5	-	6.5	17.4	-	5.2	10.5	-	23.5	-	6.3	15.8
Leiotriletes	10.3	-	14.5	5.5	-	12	4.8	2.5	16	-	3.3	21.1	5.1	-	-	4	15.6	-	-	-	-	11.6	10.5	-	-	19.2	2.3	10
Ludwigea stenorraphe (L.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Malvaceae (L.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pandanus candelabrum	-	-	-	-	-	-	-	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Papillionaceae	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pediastrum	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pantadesma butyrecea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poaceae (L.)	36.4	56	20	31.8	39.8	66.1	37.7	85.7	62.2	83	42.5	59.2	63.2	66.6	12.3	79.8	60.8	100	45.4	43.4	50	49.1	42.5	-	43.1	52.7	42.3	13.8
Podocarpus milianjianus	2.7	-	-	31.5	-	28	7.4	35	31.3	26.8	13.3	7	19	7.7	4.1	44	12.9	-	12.9	8.7	-	-	10.5	-	23.5	19.5	16.3	10.3
Polygonum sp. (Juss)	2.7	-	-	-	5.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psilatricolporites sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Racemonolporites hians	-	-	-	-	-	4	-	-	-	-	3.3	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Retibrevitricoloporites obodoensis	2.7	-	14.5	5.5	5.2	-	3.5	-	3		-	-	5.1	-	-	-	-	-	-	-	-	-	-	-	-	-	2.3	-
Retitricolporites irregularis	-	-	-	-	-	-	-	2.5	-	-	-	-	1.9	-	-	-	-	-	-	-	-	-	-	-	-	6.1	-	-
Rhizophora sp. (L.)	74.6	19.3	74.5	37	82.8	29	65.5	63.4	49.5	56.4	69.7	63.3	44.8	33.3	53	22.2	65.2	100	59.4	38.8	57.9	79.5	43.5	100	27.5	21.8	26.7	50
Sapotaceae (Juss)	13	9.3	-	11	5.2	-	8.3	5	4.5	-	-	-	6.9	-	8.2	-	2.7	-	12.9	-	-	-	3.6	-	-	4	7	-
Stereiosporites	5.5	-	-	-	-	-	2.6	-	1.5	-	6.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Striamonocolpites rectostriatus	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Symphonia globulifera (L.)	-	5.6	14.5	-	-	-	3.5	-	3	-	-	7	3.7	-	-	-	-	-	-	-	-	-	3.6	-	-	-	-	-
Unknown	-	-	-	-	-	-	-	-	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6	-	-	4	2.3	-
Verrucatosporites	26	8.5	-	20.5	30.1	12	22.7	15	25.4	26.8	20	7	7	15.4	4.1	8	7.5	-	41.9	17.4	55.7	-	27.3	-	7.4	15.2	18.6	21

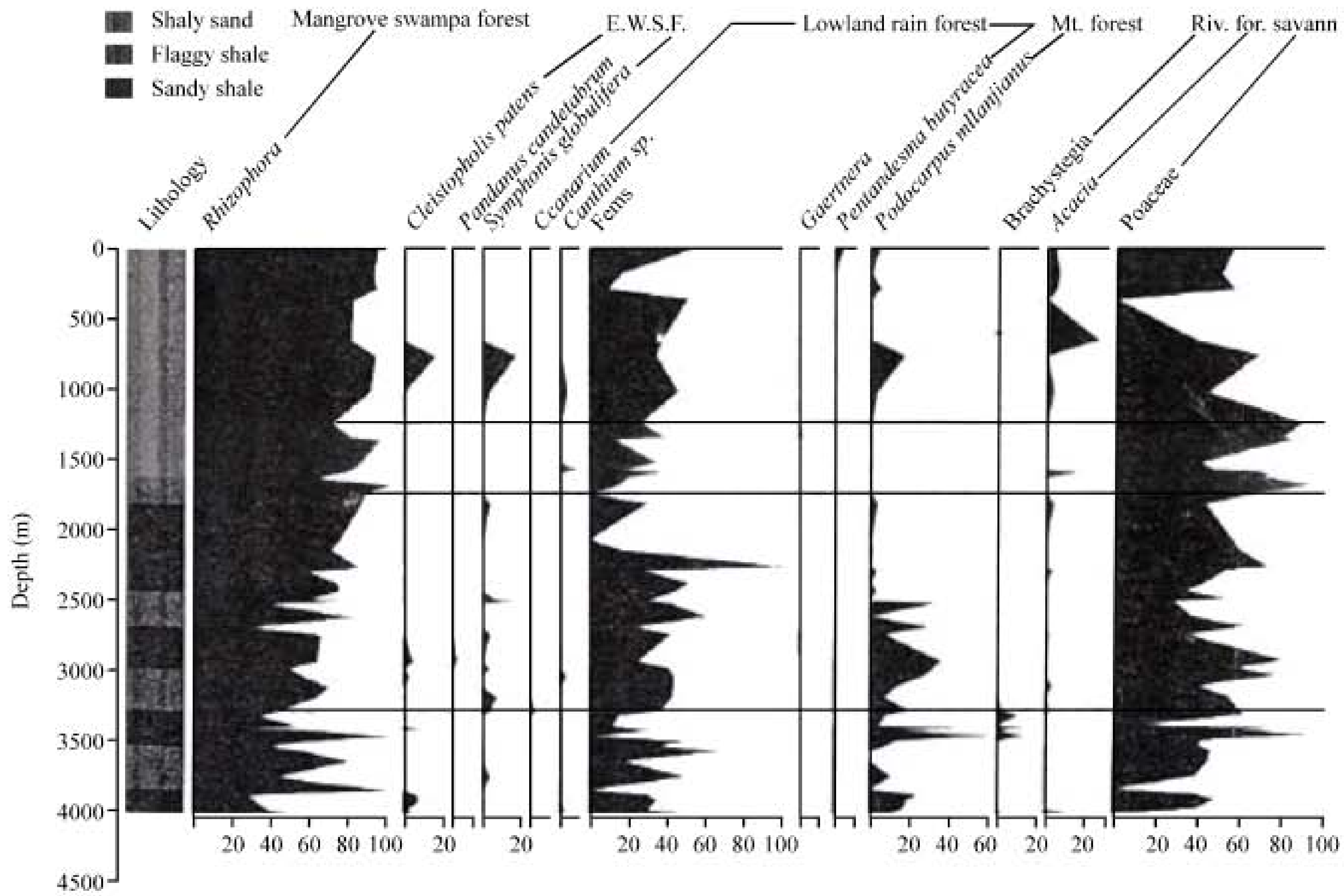

Fig. 4: Pollen diagram, Atala-1 well, Niger Delta, Nigeria

The last section between the intervals 3282 to 4003 m was made up of three lithologic units dominated by sandy shale. The shales were fissile and dark grey, sand bodies are coarse grained and calcareous.

The distribution of palynomorph types varies from depth to depth throughout the section studied. Pollen concentration is relatively low with an average of 811 pollen grains g^{-1} of sediment. The total number of palynomorphs counted per gram of sample varied from 30 to 10,656 g^{-1} of sample with the lowest and highest occurrences at depths 3570 and 36 m respectively (Table 1). Potter (1976) also recovered few pollen assemblages in middle Eocene samples from a mine in Tennessee. Potter (1976) attributed this low occurrence of pollen assemblages to pH of the samples, bacterial and fungal attack, differential floatation and activities of burrowing organisms.

The reasons for the low occurrence in pollen assemblages recorded in this study may be related to the pH of the samples as most of the sediments have high pH values. For example, the pH values for the sediments range from 4.1 to 8.0 with nearly all the values tending towards 8.0, for examples, 1364 m (pH 8.0), 1382 m (pH 7.8) and 1616 m (pH 7.8).

Havinga (1971) reported intense deterioration of pollen at pH 7.2. Since, most of these samples have pH values well above 7.2, this factor of high alkalinity can be suggested as one of the major causes of paucity of pollen. Pollen and spores have been reported to be destroyed by oxidation and high alkalinity (high pH value) (Traverse, 1988), hence they are not usually recoverable from deposits with these features. However, the colour of the samples from the well did not reveal any sign of intense oxidation. The colours range from light brownish grey to dark grayish brown (Table 1). Consequently, the high pH value seems to be a significantly possible cause of pollen destruction in the well.

Another factor that may be responsible for this paucity is pollen deterioration, which may be caused by bacterial and fungal attack. Pollen, according to Havinga (1971) becomes corroded, fragmented, degraded, perforated or shows ball-like protrusions as a result of microbial attack. It is suspected that the longer pollen lies in the soil, the more it is susceptible to attack by bacteria and fungi particularly Actinomycetes, thereby drastically reducing the actual number of pollen and spores that are recoverable. Since bacterial and fungal attack leading to pollen deterioration are usually prevalent in sediments with high pH as in this case, Atala-1 sediments, this factor is suggested as part of the probable cause of paucity of pollen in the sediments.

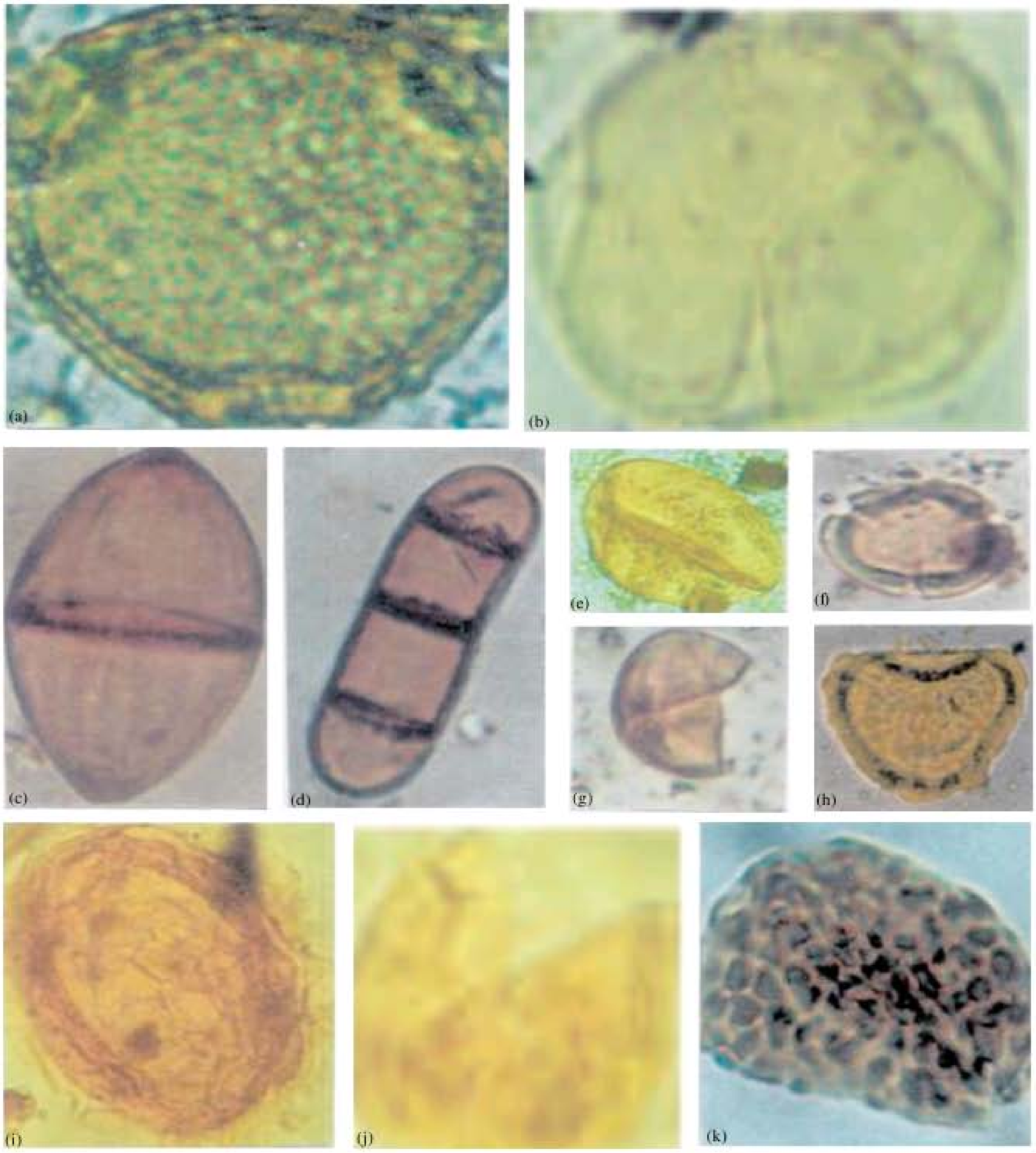

Fig. 5: (a) *Canthium* sp., (b) Stereiospontes, (c, d) Fungal spore, (e) Poaceae, (f) *Rhizophora* sp., (g) Broken pollen, (h) Trilete spore, (i) Dinocyst, (j) Broken trilete spore and (k) Verrucatosporites usmensis showing distict verrucae

Furthermore, the fact that well contained more of Benin Formation, which contained more sand, can be a very strong factor. It is suspected that Atala-1 well sediments being sandy will be more aerated. This will provide a suitable environment for biodeterioration of the pollen. The presence of pollen, which are fragmented and degraded in the samples (Fig. 5, 6), would seem to support this suggestion.

Pollen zonation: The pollen diagram (Fig. 4) showed the 13 most important taxa for Atala-1 well. These have been classified according to their phytoecological zones and thus considered to be ecologically significant. The species were not ubiquitous, but belong to distinct ecological zones. Furthermore, they have been identified to species level or to types identifiable with species.

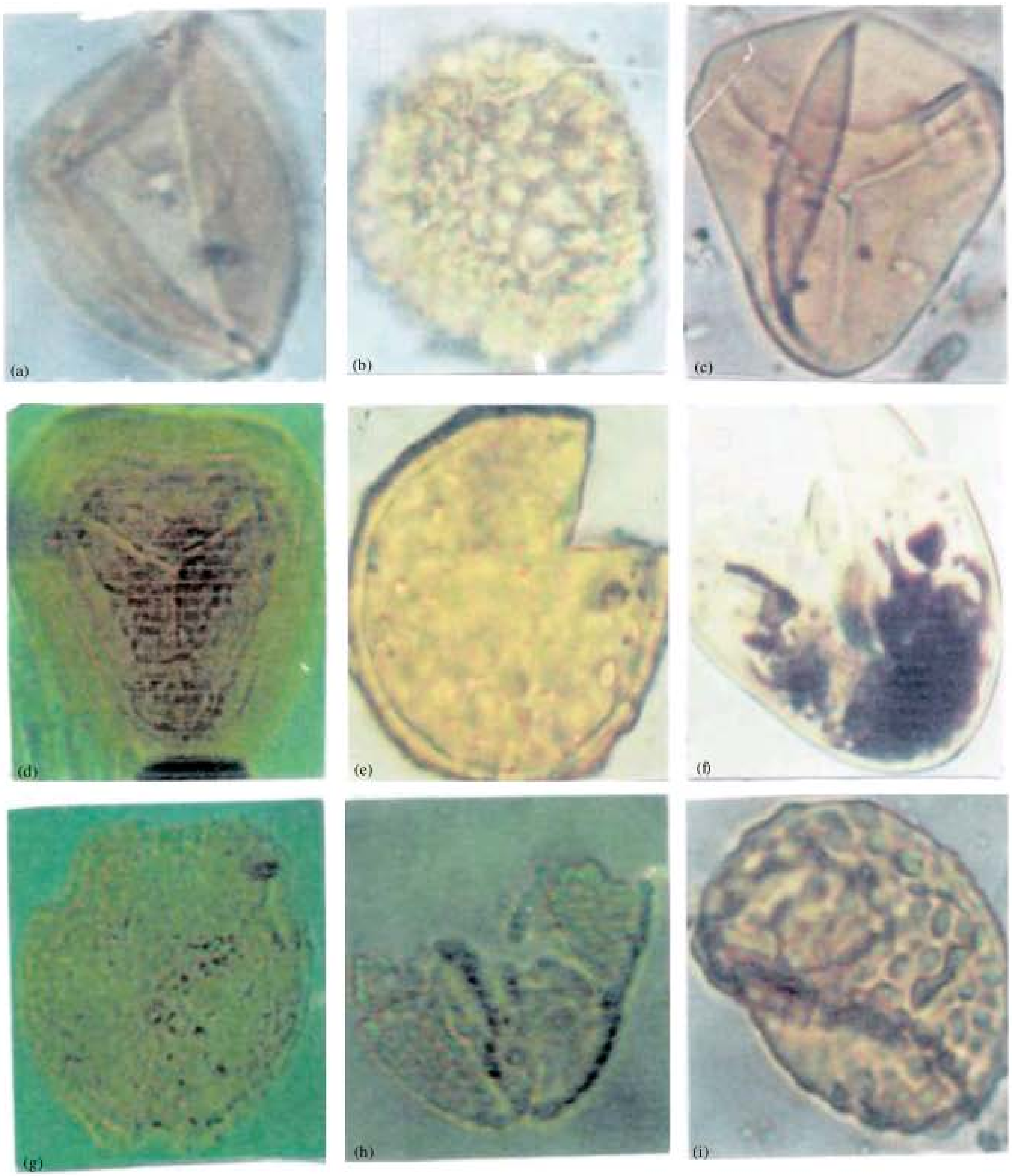

Fig. 6: (a) Poaceae, (b) *Polygonum* sp., (c) Tilete spore (Smooth exine), (d) Tilete spore, (e) Broken spore, (f) Degraded pollen, (g) *canthium* sp., (h) Degraded pollen and (i) Verrucatosporites

According to marked vegetation changes reflected in the pollen diagram (Fig. 4), four pollen zones were recognized in the studied sections. These were:

Zone IV	1264-36 m
Zone III	1761-1264 m
Zone II	3282-1761 m
Zone I	4003-3282 m

Zone I (4003-3282 m): This zone was characterized by unstable climatic conditions exemplified by the contrasting fluctuations between the percentage occurrence of Poaceae and *Rhizophora*. For example, at 4003 m *Rhizophora* recorded 50% while Poaceae pollen occurrence was 13.8% and at 3985 and 3913 m, the percentages of Poaceae pollen were 42.3 and 52.7% respectively, as against 38.7 and 31.8% for *Rhizophora* (Table 2). *Cleistopholis patens* (2.3-8.1%) and *Symphonia globulifera* (3.6-3.7%) sparsely represented the fresh water swamp forest vegetation. Also, noticeable in this zone were the fluctuations in the percentage occurrence of ferns and *Podocarpus*.

Zone II (3282-1761 m): This zone was characterized by a constantly high occurrence of *Rhizophora* and ferns. The occurrence of freshwater swamp forest elements typified by *Cleistopholis patens* (2.8-5%), *Pandanus candelabrum* (2.5%), *Symphonia globulifera* (3-14.5%) and lowland rainforest vegetation represented by *Canarium schweinfurthii* (1.9%), *Canthium* sp. (2.8%) was noted in this zone.

Zone III (1761-1264 m): This zone was characterized by high percentage occurrence of *Rhizophora* and a low percentage occurrence of ferns with a concomitant high occurrence of savanna elements typified by *Acacia* sp. (14.4%) and Poaceae. The latter had its highest percentage occurrence of 100% and 95.9% at 1707 m and 1264 m, respectively. There was a noticeable absence of fresh water swamp forest, while *Canthium* sp. (8.1%) and *Gaertnera paniculata* (12.2%) represented lowland rainforest.

Zone IV (1264-36 m): A decrease in the pollen of Poaceae from 95.9 to 46.8% and an increase in mangrove pollen from 71.4% at 1264 m to 90.6 and 93.9% at 1048 and 795 m, respectively were recorded in this zone. Also, the character of this zone was the high occurrence of mangrove pollen throughout the zone.

High percentages of fern spores, (9.5-54.8%) and fresh water swamp forest vegetation typified by *Symphonia globulifera* (3.2-16.4%) and *Cleistopholis patens* (16.4%) were also recorded. Lowland rain forest was represented by species of *Canthium* and *Pentadesma.*

COMMENTS

Zone 1: These fluctuations in percentage occurrence of *Rhizophora and* Poaceae suggest a period of unstable environmental conditions which might be caused on the one hand by variations in the extent and intensity of the tidal flow resulting in fluctuations in the occurrence of *Rhizophora* and by extension mangrove vegetation on the coast as well as by drier conditions inland resulting in the absence of lowland rain forest and extensive expansion of savanna Southwards.

Zone II: The high percentage occurrence of *Rhizophora* sp. in this zone was an indication that mangrove swamp vegetation was well established during the period covered by this section. It also shows that there was a rise in sea level with the coast predominantly taken over by *Rhizophora*. This conclusion was further strengthened by the very low percentage occurrence of Poaceae pollen and total absence of the pollen of other savanna elements in the zone. Other vegetation communities in existence during this period were fresh water swamp forest and lowland rain forest suggesting a wet and warm climate for this period.

Zone III: The period covered by this zone can be suggested to be a period of rapid and unstable climatic conditions culminating in rapid sea-level changes (rise and fall). This may account for the rapid changes noticed in the pollen assemblages in this zone particularly, *Rhizophora* and Poaceae. However, the non-occurrence of montane forest vegetation typified by *Podocarpus milianjianus* in this zone indicates that the climate was wet and ward and that the vegetation was probably more open. Furthermore, it can be suggested that during the lowering of the sea level, there was an extensive development of savanna vegetation indicated by the highest percentage occurrence of Poaceae (100%) in this zone. This unstable wet/dry period may have accounted for the extensive development of the savanna as Germeraad *et al.* (1968) have reported that a drier climate with marked rainy seasons favors the development of extensive grass areas. The prevalence of wet conditions during this period was corroborated by the existence of lowland Rain forest vegetation throughout the zone.

Zone IV: These high percentages of *Rhizophora* pollen indicate that mangrove vegetation was well established during this period and that there was a rise in sea level with the mangrove being dominant over the coast. Furthermore, the representation of fresh water swamp forest and lowland rain forest suggest their continued existence during this period. The climatic inference deducible from this zone is that the climate was wet and warm.

The high percentages of Poaceae recorded for Zone I indicate the prevalence of savanna vegetation and dry conditions during the period. Several other workers (Germeraad *et al*., 1968; Morley, 1991, 1995) have reported that relative high abundance of Poaceae pollen reflects dry climate which indicates sea level fall.

An establishment of both wet and warm conditions as well as mangrove swamp forest vegetation was indicated in Zones II, III and IV in the well. *Rhizophora* sp. was over represented in most layers of the sediments. Sowunmi (1981a) also found that *Rhizophora* was heavily over-represented in the pollen spectra of the modern vegetation of a core from Ofuabo creek, Niger Delta. The reasons adduced for this overrepresentation is that *Rhizophora* produces enormous quantities of pollen which are also wind dispersed and the pollen is very well preserved in non-sandy deltaic shale. High percentages of *Rhizophora* in sediments therefore indicate large extension of mangrove vegetation near the coast in response to rise in sea level while very low percentages of *Rhizophora* indicate a great reduction of mangrove swamps.

Therefore, it can be suggested that sea levels were low during the period covered by Zone I in this well. On the basis of this, it can be suggested that only limited mangrove swamps were growing along the Niger Delta during this period. The lower sea level also restricted the distribution of the lowland rainforest and promoted the expansion of savanna and open woodland.

During the periods covered by Zones II, III and IV, the environment changed drastically. The sea level was high and the mangrove swamps grew over large areas. Therefore, mangrove expansion around the Niger Delta in the late Tertiary was largest during the periods represented by Zones II, III and IV, indicative of sea-level rise.

Palaeoclimatic changes: The importance of considering climatic effects and changes I n pollen association was reiterated by Graham (1989). Such effects have been demonstrated on pollen and spore data from Quaternary Sediments (Webb, 1985; Bartlein *et al*., 1986). In this study, minor palaeoclimatic changes were evident as shown in the vegetation change reflected in the pollen diagram (Fig. 4). The climate fluctuated between dry climate with high occurrence of Poaceae pollen and low occurrence/absence of mangrove swamp forest vegetation and wet conditions indicated by the high abundance of mangrove swamp forest vegetation and abundance of monolete and trilete spores.

Many plants have been reported to be sensitive climatic indicators and their fossils can give a good idea of past climates (Khan, 1974). The relevance of pollen of *Rhizophora* as indicator of climate has been stressed by several researchers. Muller (1959) and Muller and Caratini (1977) submitted that an abundance of fossil *Rhizophora* pollen in sediments indicate a humid tropical lowland climate. Dupont and Welnelt (1996) reported that *Rhizophora* pollen seems most abundant during periods of sea level rise associated with wet conditions. Therefore, it is suggested that a wet and warm climate predominates during the studied period. This is occasioned by the high abundance of *Rhizophora* in most of the studied sequence with occasional and intermittent prevalence of dry and arid conditions as indicated by the occurrence of Poaceae in some of the intervals and also marked by the reduction or total absence of fresh water swamp and lowland rain forest vegetation communities. This deduction is further supported by the fact that a very low occurrence of mangrove forest vegetation was recorded in these zones with concomitant very high percentages of Poaceae, which is usually associated with dry Guinea and Sudan savanna except as occasional patches in lowland rain and freshwater swamp forest.

CONCLUSION

This study shows that the palynologic record and the environment have a direct relationship with respect to vegetation and climate. The study identified four pollen zones on which the climate and vegetation of the late Tertiary period were inferred to consist of unstable wet and dry climatic regimes with the vegetation dominated for most of the period by mangrove swamp vegetation.

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