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Palynological Evidence of Pliocene-Pleistocene Climatic Variations from the Western Niger Delta, Nigeria

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Abstract: Rich and well preserved assemblages of pollen, spores, and organic walled dinoflagellate cysts in 96 and 89 samples of Wells A and B from the Western Niger Delta Nigeria are recorded. The dominance of savanna pollen over wet climate indicators (mangrove, freshwater swamp species, brackish water swamp species and Palmae) and the preponderance of the dinocysts Polysphaeridium zoharyi and Operculodinium centrocarpum, species adapted to very saline and warm waters respectively, with abundant fungal spores dominated by *Exesisporites* sp., gives credence to a predominantly dry climate and lowered sea level during the Pliocene-Pleistocene (ca. 5.0-1.3 Ma) in the Gulf of Guinea. The most pronounced glacial events were around the 2.0-2.7 Ma, as well as between the 2.7-3.4 Ma.

Key words: Western Niger Delta, savanna, dinocysts, pliocene-pleistocene, lowered sea level

INTRODUCTION

Palynological studies in Nigeria are largely confined to the Tertiary Niger Delta, where numerous studies have been carried out following the discovery of petroleum resources in the Niger Delta in the late 1950s. Most of these reports exist as confidential reports of the oil and gas prospecting companies. The few published papers on the Niger Delta geological studies include those of Allen (1964a, b), Allen and Wells (1962), Short and Stauble (1967), Weber (1971), Weber and Daukoru (1975), Evamy *et al.* (1978), Doust and Omatsola (1990), Oboh *et al.* (1992), Haack *et al.* (2000). Furthermore, most palynological studies on the Niger Delta are concerned with zonation, age determinations and correlation. Only few had dealt with the vegetation vicissitudes and paleoenvironmental reconstruction for which palynological research is known for. Unfortunately, none had treated the global glacial records and the Plio-Pleistocene climatic variations of which much have been written in other parts of Africa and the world at large (Adam, 1993; Adam *et al.*, 1989, 1990; Dupont and Welnelt, 1996; Dupont *et al.*, 1998, 2000; Finch and Hill, 2008; Hooghiemstra, 1993; Hooghiemstra *et al.*, 1986, 2006; Jahns *et al.*, 1998; Lezine and Cazet, 2005; Leroy and Dupont, 1994, 1997; Weigelt *et al.*, 2008; Molnar and Cane, 2004).

Since climatic changes do affect the vegetation, the reconstruction of the past vegetation will help us understand the mechanisms of such changes (Ivanor *et al.*, 2007). Sowunmi (1987) had discussed the close relationship between the vegetation, soil and climate of an area. She opined that the flora of an area offers the clue to the major climatic regimes in such places. The most popular published works on the Niger Delta palynology are those of Sowunmi (1981a, b, 1986, 1987, 1999, 2002, 2004), Evamy *et al.* (1978), Biffi and Grignani (1983), Legoux (1978), Clarke and Fredriksen (1968), Knapp (1971), Jan du Chene and Salami (1978), Oboh and Salami (1989), Oboh, 1991a, b, 1993a, b, 1995), Oboh *et al.* (1992), Antolinez *et al.* (2006), Demchuk and Morley (2004), Ige (2009) and Adekanmbi and Ogundipe (2009). The modern Niger Delta appears, from sedimentological, faunal and floral evidence, to have a configuration today similar to those of the past. The physiography of the recent Niger Delta is governed by several factors, which influence transport, ultimate deposition of the sediment load and shape and growth of the Delta (Short and Stauble, 1967). Different workers have investigated climatic changes using palynomorphs in different parts of the world. The reports are scanty for Africa and the Gulf of Guinea to which the Niger Delta belongs.

Dupont *et al.* (1998) had used sporomorphs and dinoflagellate cysts in documenting the vegetation history of the West African forest during the last 700 ka in relation to changes in salinity and productivity of the eastern Gulf of Guinea from site GIK16867 in the northern Angola Basin. They found out that during most of the

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cool and cold periods, the Afromontane forest, rather than the open grass-rich dry forest, expanded to lower altitudes partly replacing the lowland rain forest of the borderlands east of the Gulf of Guinea.

Sowunmi (2004) had studied an 11 m terrestrial core from Ahanve in Badagry area of the coastal South-Western Nigeria as part of the Dahomey Gap project. The area was a *Typha* dominated freshwater swamp annually flooded by the Badagry Creek. She recognized 141 pollen and spore species out of which 104 were identified. She reported that the dominant vegetation communities that prevailed in the coastal South-Western Nigeria was made up of abundant forests, *Rhizophora* dominated mangrove forest in the tidal zone, freshwater swamp forest in the swampy regions under freshwater influence and drier, semi-deciduous forest on the well drained areas with some woody, savanna species and sparse grass cover at some intervals from ca. 8576±48 BP to sometime prior to ca. 3109±26 BP. Furthermore, between ca. 5780 and ca. 5682±32 BP, there was a marked decrease in all the three forest types and a corresponding marked increase in monolete fern spores *Lygodium* and *Alchornea* which she opined indicated a short-lived, drier climate. Again, just prior to ca. 3109±26 BP, *Rhizophora* declined sharply and later disappeared, it got replaced by freshwater swamp, an expanded freshwater swamp forest and coastal savannas made up of abundant grasses, *Alchornea* and *Elaeis guineensis*. The drier forest later became more opened leading to the development of derived savanna. This mosaic of more open forest and savannas established just prior to ca. 3109±26 BP she said constituted the eastern-most extension of the Dahomey Gap. She reasoned that from palynological evidence that from sometime after ca. 3109±26 BP, anthropogenic effects had caused the phenomenal rise in *Elaeis guineensis* pollen and concluded that though climatic and geomorphological factors appeared the main causes of the late Holocene vegetation changes, information from palynology and archeology indicated outstanding human impact.

Leroy and Dupont (1994) studied a 200 m long marine pollen record from ODP Site 658 (21°N, 19°W) which revealed cyclic fluctuations in vegetation and continental climate in northwestern Africa from 3.7 to 1.7 Ma. These cycles they found paralleled oxygen isotope stages. Prior to 3.5 Ma, the distribution of tropical forests and mangrove swamps reached Cape Blanc, 5°N of the present distribution. Between 3.5 and 2.6 Ma, forests occurred at this latitude during irregular intervals and nearly disappeared afterwards. Likewise, a Saharan paleoriver flowed continuously until isotope Stage 134 (3.35 Ma). When river discharge ceased, wind transport of pollen grains prevailed over fluvial transport. They observed that pollen indicators of trade winds gradually increased between 3.3 and 2.5 Ma. Again, strong aridification of the climate of northwestern Africa occurred during isotope Stage 130 (3.26 Ma). Humid conditions were reestablished followed by another aridification around 2.7 Ma. Afterwards repetitive latitudinal shifts of vegetation zones ranging from wooded savanna to desert flora dominated for the first time between 2.6 and 2.4 Ma as a response to the glacial stages 104, 100 and 98. They reported that as climatic conditions recorded in the Pliocene were not as dry as those of the middle and Late Pleistocene, latitudinal vegetation shifts near the end of the Pliocene resembled those of the interglacial-glacial cycles of the Brunhes chron.

Leroy and Dupont (1997) further carried out a high resolution pollen analysis on ODP site 658, off Cape Blanc, N-W Africa. They observed that the periods before 3.5 Ma were marked by warmer and wetter climates from northwestern Europe as far south as equatorial West Africa. They opined that the long term variation denoted the onset of a drier climate between 3.5 and 3.2 Ma. At 3.2 Ma, their pollen record revealed the aridification of Northwestern Africa probably in connection with enhanced Trade winds. After a period of re-established humidity, a second and stronger step to aridification started at ca. 2.6 Ma. They documented a reduction of the savannah vegetation from 2.8 Ma which they suggested could have resulted in the development of a desert in West Africa.

Jahns *et al.* (1998) had reconstructed the West African vegetation history for the last 400 ka from pollen analysis of a sediment core from the Atlantic Ocean off Liberia. They noted that an arid climate was indicated by the cold oxygen isotope stages 12, 10, 8, 6, 4, 3 and 2, which resulted in a southward shifting of the southern border of the savanna. They inferred that the Late Pleistocene glacial stages were more arid than those of the Middle Pleistocene. They recorded the persistence of the rain forest even during the glacial stages which they attributed to a glacial refuge of rain forest situated in the Guinean mountains.

Lezine and Cazet (2005) had carried out a high resolution pollen study of core KW31 off the mouth of Niger River (3° 31' 1N-05° 34'1E), from the Gulf of Guinea. The core was collected at a water depth of 1181m close to the coast and it revealed vegetation changes between 40,000 and 3500 cal yr B.P. in the West African lowlands. The microflora was highly diverse from the studied 69 samples with the counts ranging between 124 and 1026, excluding the mangrove pollen *Rhizophora*. Fern and herbaceous pollen grains of Poaceae and Cyperaceae dominated the assemblages. The percentages reaching 46, 76 and 27%, respectively. Though trees, shrubs and lianas never exceeded 33%, they were represented by 157 pollen taxa (about 62% of the total microflora). They delineated three main pollen zones based on differences in tree pollen percentages. Pollen zone 1 from the base (38,500 cal year B.P.)-917 m (22,000 cal year B.P.) was characterized by influx of minimum values of pollen and spores which they opined resulted from the reduction in the organic material transport from the continent. However, ferns and *Typha* were dominant with low arboreal pollen except *Podocarpus.* Again pollen types from Sahara, Sahelian desert and wooded grasslands also occurred in appreciable amounts together with numerous pollen types from the Guineo-Congolian ecosystems. The results indicated the permanency of rainforests and secondary forests in the Niger river catchment possibly as gallery forests along rivers during the last glacial period when enhanced trade wind conditions led to dry conditions. They pointed out that the increase in forest diversity and the expansion of rain and secondary forests in the adjoining continent could have arisen from the post glacial warming coupled with increase in monsoon fluxes over West Africa. Furthermore, they were able to note migration rates of tropical forest populations throughout North West Africa at the beginning of the Holocene through comparison of the KW31 pollen data and continental pollen data from 5°S to 25°N. They further reported the vegetation response to the shift toward aridity recorded widely at the end of the African Humid Period around 4000 cal yr B.P. This wet period had been proposed by DeMenocal *et al.* (2000) from the study of ODP site 658C off Cape Blanc and was corroborated by the fresh water algal records of Lezine and Cazet (2005).

Hooghiemstra *et al.* (2006) had studied the distribution patterns of pollen grains in recent marine sediments off NW Africa. They related the distribution patterns to modern pollen source areas (vegetation belts) and the prevailing transport systems (wind belts and ocean currents). Revealing the positions of these vegetation belts in the adjacent continent were the patterns of *Quercus*, *Artemisia*, *Chenopodiaceae-Amaranthaceae, Ephedra, Gramineae* and wet forest trees. The northeast trade winds and the African Easterly Jet (AEJ) were responsible for wind transport of pollen species. They further observed that rivers also transported pollen and fern spores in the rain forest belt. When they compared the recent pollen rain samples from terrestrial and marine sites between 21 and 12°N, clear latitudinal ranges of the vegetation belts were evident in the pollen samples of both environments. A migration of the Southern border of the Sahara was reflected by the changing ratio between *Chenopodiaceae-Amaranthaceae* pollen from the desert and *Gramineae* pollen from the savannah belt.

Based on the foregoing, this present study was undertaken to investigate the effects of the Plio-Pleistocene climatic changes/sea level changes as contained in Western Niger Delta palynomorphs.

MATERIALS AND METHODS

Description of study area: The Tertiary Niger Delta (Fig. 1) is a large arcuate delta of the destructive, wave dominated type, which is found in Southern Nigeria. It covers an area of about 7500 km^2 and is composed of an overall regressive clastic sequence, which reaches a maximum thickness of 9,000-12,000 m (30,000-40,000 feet). It covers an area located between longitude 4°-9° E and latitude 4°-9° N. Its development has been dependent on the balance between the rate of sedimentation and the rate of subsidence. The stratigraphic distribution of surface outcrops of Tertiary rocks in Southern Nigeria has been previously established by Reyment (1965) and Adegoke (1969). However, the first information on the subsurface distribution of stratigraphic units in the Delta was provided by Short and Stauble (1967) and Frankl and Cordry (1967). According to Short and Stauble (1967), the recent Niger Delta may be divided into 3 main sedimentary environments: the continental, transitional and the marine environments. The continental environment comprises the alluvial environments including the braided stream and meander belt system of the upper deltaic plain. The sediments deposited in this zone are predominantly sandy. Feldspar grains are fairly common and sandy grains commonly are limonite coated. Fine grained sediments (silt and clay) are deposited in the adjacent fresh water back swamps and ox-bows together with large quantities of plant remains. The transitional environment comprises the brackish water lower deltaic plain (mangrove swamp, flood plain, marsh) and the coastal area with its beaches, barrier bars and lagoons.

The sediment in this environment are distinctly finer-grained than in the continental environment. Feldspar is scarce and brackish water faunas may occur. The marine environment includes part of the delta fringe with its fine sand, silt and clay and the associated marine faunas. The environment grades laterally into the holomarine environments, which is not affected by deltaic activity (Short and Stauble, 1967).

Sample collection: Ninty six and eighty nine ditch cutting samples of the wells A and wells B from the offshore Western Niger Delta (Fig. 1), were donated for the investigation by Chevron Nigeria Ltd. in January 2005.

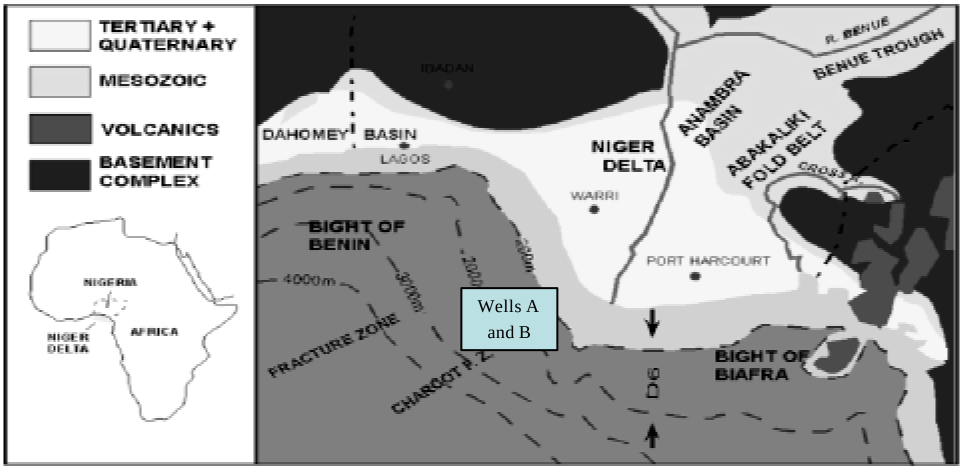

Fig. 1: Map of the Niger Delta showing the location of the studied wells after Doust and Omatsola (1990)

Sample preparation: Thirty grams of each sample was initially treated with hot Hydrochloric acid to remove carbonates, prior to complete digestion in (60%) Hydrofluoric Acid (HF) under a fume cupboard. Agitation of the acid/sample mixture was carried out to aid digestion. The sample was further treated with hot Hydrochloric Acid (HCL) and wet-sieved over a 5 micro mesh polypropylene sieve. The 5-micro sieve was used so that small sporomorphs such as *Zonocostites ramonae* were not washed off. The Branson Sonifier 250 was further employed during sieving to facilitate complete removal of silt and clay particles. Each residue was oxidized using concentrated nitric acid (HNO_3). The residues were prepared for study as strewn mounts using Loctite on 22×32 mm cover slips. The slides were stained with Safranin O to enhance the study of dinoflagellate cysts.

Sample analysis: The prepared samples were analyzed between May to December 2005 in the Paleobotanical Laboratory of the University of Lagos. A Leitz Dialux 20 EB microscope was used for the analysis. All species (pollen, spores, dinoflagellate cysts, fungal remains, algae and foraminiferal linings) present were recorded. This enhanced the palyno-ecological groupings and paleovegetational/paleoenvironmental reconstructions processes.

Coordinates of index markers were aligned with the England Finder coordinates for easier location of the specimens on the slides.

The slides, residues, unprocessed samples, negatives and duplicate prints are in the palynological collections of the Department of Biological Sciences, Redeemer's University, Mowe, Ogun State, Nigeria.

Species identification: The different palynomorphs (pollen, spores) were identified by comparison with local palynological catalogues of Shell (1980), Legoux (1978), Germeraad *et al.* (1968), Clarke and Frederiksen (1968), Evamy *et al.* (1978), Salard-Cheboldaeff (1979, 1990). For dinoflagellates and acritarchs, monographs of Fauconnier *et al.* (2004), Rochon *et al.* (1999), Wrenn *et al.* (1986), Lentin and Williams (1973, 1989), Head and Wrenn (1992), Powell (1992), Fensome *et al.*, (1993, 1996) and Sluijs *et al.* (2003) were used. Generally, species nomenclature for dinoflagellate cysts followed by Fensome and Williams (2004).

Photomicrography: The specimens were examined and index species and dinoflagellate cysts photographed at X400 and X1000 using the Motic 2.0 camera at the Paleobotanical Laboratory of the University of Lagos.

Ecological grouping: The definition of the ecological groups were based on the study of Sowunmi (1981a, b, 1986), Salard-Cheboldaeff (1981), Rao (2001), Frederiksen (1985), Germeraad *et al.* (1968) and Rull (2003). Only *Zonocostites ramonae* and *Avicennia* sp. are taken as mangrove following (Rao, 2001; Richards, 2001; Germeraad *et al.*, 1968; Frederiksen, 1985), while *Monoporites annulatus* is listed under savanna according to Germeraad *et al.* (1968) (Table 1 and 2; Fig. 2-5).

Chronostratigraphy: The chronostratigraphic ages were provided by diagnostic foraminifera using planktonic foraminiferal Zones of Blow (1969, 1979) and Hardenbol *et al.* (1998). The MFS's were used as the zonal boundaries for convenience.

Table 1: Well A ecological groups abundance/glacial record indicative dinoflagellate cysts data

Sample depth (feet)	Total mangrove	Total savanna	Total freshwater	Total brackish	Total lowland	Total montane	Total palmae	Total beach	Total algae	Total dinoflagellates	Total other pollen	Total other spores	Total miscellaneous	Grand total	Polysphaeridium zoharyi	Operculodinium centrocarpum	Maximum flooding surface	Sequence boundary
1980-2040	465	267	144	41	53	16	0	0	46	50	4	5	22	1113	11	3		
2040-2130	185	86	98	28	47	19	7	0	52	38	4	2	13	579	9	3	1.3 Ma (2070 feet)	
2130-2220	155	395	88	17	34	9	4	0	35	30	3	3	20	793	6	5		
2220-2310	130	230	35	10	15	8	1	0	13	17	1	0	11	471	5	0		
2310-2400	55	170	20	3	13	4	0	0	12	11	1	0	6	295	3	1		
2400-2490	35	141	22	7	6	6	0	0	12	7	0	0	6	242	2	0		
2490-2580	80	415	65	9	30	6	4	0	31	19	3	2	10	674	2	3		
2580-2670	130	302	49	9	24	7	7	1	24	20	1	2	6	582	4	2		
2670-2760	160	66	19	0	13	2	0	0	6	0	0	0	2	268	0	0		
2760-2850	30	56	7	0	2	0	0	0	4	0	1	0	0	100	0	0		
2850-2940	30	55	13	1	7	0	1	0	7	3	0	0	10	127	0	0		
2940-3030	55	168	29	12	25	5	1	0	29	2	0	0	5	331	1	0		
3030-3120	55	177	34	10	14	4	2	0	7	0	0	1	3	307	0	0		
3120-3210	30	57	5	1	2	0	0	0	1	0	0	0	1	97	0	0		
3210-3300	80	220	36	9	19	3	1	0	19	3	0	2	5	397	0	0		
3300-3390	30	59	20	3	5	1	0	0	13	0	2	1	0	134	0	0		
3390-3480	80	32	12	6	3	1	0	0	3	0	0	0	2	139	0	0		
3480-3570	30	57	8	1		1	0	0	0	0	0	0	0	97	0	0		
3570-3660	35	69	16	2	3	1	0	0	2	0	1	0	1	130	0	0		
3660-3750	55	25	5	6	7	1	1	0	2	1	0	0	2	105	0	0		
3750-3840	80	37	8	1	5	1	0		2	1	0	0	1	136	0	0		1.6 Ma (3838 feet)
3840-3930	160	461	81	40	118	7	2	1	58	2	1	17	7	955	0	0		
3930-4020	130	500	68	20	124	11	3	0	35	5	3	13	23	935	0	0		
4020-4110	55	283	38	12	45	8	2	1	34	8	0	4	12	502	0	1		
4110-4200	60	228	38	15	66	6	3	0	30	5	0	6	6	463	0	0		
4200-4290	55	231	41	8	41	1	0	0	17	2	1	0	12	409	0	0		
4290-4380	80	204	32	9	31	2	0	0	20	2	1	3	8	392	0	0		
4380-4470	160	343	86	26	53	2	8	0	49	2	1	13	18	761	0	0		
4470-4560	80	281	60	25	40	1	1	0	71	0	1	3	31	594	0	0		
4560-4650	80	219	61	15	32	0	2	0	60	8	0	1	11	489	1	2		
4650-4740	235	390	170	63	73	29	4	0	186	64	3	2	56	1275	8	17	2.0 Ma (4680 feet)	
4740-4830	495	409	188	102	57	44	14	0	238	84	1	8	28	1668	6	10		
4830-4920	495	684	105	21	80	24	5	0	170	26	1	2	8	1621	3	7		
4920-5010	235	418	151	49	78	5	5	0	168	21	1	2	13	1146	7	3		
5010-5100	260	421	122	29	46	14	2	0	136	18	0	7	21	1076	5	6		
5100-5190	185	567	103	0	27	17	3	0	80	17	0	1	9	1009	4	2		
5190-5280	185	88	32	6	12	1	0	0	2	1	0	1	3	331	0	1		
5280-5370	210	90	21	4	15	1	1	0	28	1	0	2	7	380	0	0		
5370-5460	80	194	47	7	21	4	1	0	26	1	0	1	1	383	0	0		
5460-5550	160	399	61	15	21	5	1	0	70	3	0	1	3	739	0	0		2.4 Ma (5485 feet)
5550-5640	210	390	152	21	61	8	1	0	169	2	2	4	9	1029	1	1	2.7 Ma (5550 feet)	
5640-5730	390	504	274	38	63	11	2	0	222	11	1	5	16	1537	3	0		
5730-5820	235	548	176	20	66	9	4	0	203	13	2	1	6	1283	1	0		
5820-5910	365	554	271	65	97	15	3	0	184	9	2	8	6	1579	1	2		
5910-6000	210	283	192	29	41	7	2	0	70	16	1	0	6	857	0	2		
6000-6090	550	727	214	66	89	23	7	0	292	35	2	6	20	2031	3	10		
6090-6180	340	472	282	66	73	10	5	1	220	33	0	5	20	1527	2	7		
6180-6270	260	577	207	35	73	13	3	0	182	9	4	4	11	1378	0	2		
6270-6360	160	277	92	10	47	13	1	0	138	4	1	5	15	763	0	0		

Table 1: Continued

Sample depth (feet)	Total mangrove	Total savanna	Total freshwater	Total brackish	Total lowland	Total montane	Total palmae	Total beach	Total algae	Total dinoflagellates	Total other pollen	Total other spores	Total miscellaneous	Grand total	Polysphaeridium zoharyi	Operculodinium centrocarpum	Maximum flooding surface	Sequence boundary
6360-6450	80	234	98	20	30	10	3	0	70	30	0	0	14	589	0	1		
6450-6540	130	239	91	21	41	4	2	0	95	0	0	4	7	634	0	0		3.0 Ma (6450 feet)
6540-6630	135	207	109	23	56	4	4	1	59	8	0	3	4	613	0	1		
6630-6720	210	674	267	53	102	19	1	0	73	20	0	6	4	1429	1	0		
6720-6810	205	400	204	36	64	9	2	1	80	8	1	5	9	1024	0	2		
6810-6900	260	424	142	24	36	10	2	0	71	2	0	1	7	979	0	0		
6900-6990	260	821	177	37	79	9	2	0	82	25	0	4	17	1513	4	0	3.4 Ma (6900 feet)	
6990-7080	285	687	149	23	42	4	0	0	86	9	1	1	19	1306	2	3		
7080-7170	285	519	216	45	68	4	6	1	188	25	1	2	10	1370	1	3		
7170-7260	195	407	68	17	26	7	6	0	40	5	0	1	3	775	0	1		
7260-7350	180	544	98	15	32	17	7	0	202	5	0	1	4	1105	0	1		
7350-7440	210	379	57	20	30	15	3	0	146	0	0	2	5	867	0	0		
7440-7530	185	921	212	20	116	15	3	1	140	2	1	6	6	1628	0	0		
7530-7620	235	669	321	36	43	51	0	0	285	8	1	1	14	1664	0	1		
7620-7710	260	334	135	16	40	26	3	0	140	1		1	3	959	0	0		
7710-7800	210	701	215	24	54	16	1	0	290	3	2	5	18	1539	0	0		
7800-7890	260	695	214	47	53	40	5	1	215	3	2	2	41	1578	0	0		3.8 Ma (7810 feet)
7890-7980	130	741	277	25	34	25	5	1	390	6		1	26	1661	0	0	4.0 Ma (7900 feet)	
7980-8070	130	943	170	28	42	18	1	0	389	8	1	5	33	1768	0	1		
8070-8160	315	1035	320	58	94	23	7	2	492	11	3	10	28	2398	1	0		
8160-8250	365	926	202	53	62	10	2	2	244	9	1	2	26	1904	0	0		
8250-8340	160	520	145	26	47	13	2	0	257	3		6	21	1200	0	0		4.2 Ma (8310 feet)
8340-8430	130	435	188	48	53	13	3	1	251	7	1	7	25	1162	0	0		
8430-8520	490	783	194	69	110	10	1	1	179	5	5	10	32	1889	0	0		
8520-8600	650	887	256	52	99	14	12	2	393	15	5	7	30	2422	0	1	5.0 Ma (8545 feet)	
8600-8690	390	584	208	46	78	10	10	1	239	25	3	2	27	1623	1	2		
8690-8780	260	622	246	58	83	8	4	3	147	13	1	5	32	1482	0	0		
8780-8870	390	674	245	73	121	37	14	3	220	14	5	6	35	1837	1	0		
8870-8960	650	531	196	45	92	27	15	2	210	31	3	2	65	1869	3	3		
8960-9050	625	560	195	23	74	21	5	0	212	18	2	4	37	1776	2	1		
9050-9140	495	868	301	56	94	6	8	2	292	20	5	1	43	2191	3	0		5.5 Ma (9160 feet)
9140-9230	390	752	342	88	94	10	5	1	399	13	4	9	36	2143	0	1		
9230-9320	390	685	364	115	113	11	6	1	261	12	3	5	44	2010	0	0		
9320-9410	260	645	170	43	71	2	4	0	187	1	2	6	27	1418	0	0	5.8 Ma (9380 feet)	
9410-9500	160	544	188	45	71	4	5	1	113	12	2	5	34	1184	0	1		
9500-9590	445	738	360	119	167	10	8	0	289	109	6	11	53	2315	10	10		
9590-9680	335	710	188	43	73	8	6	0	310	38	2	6	20	1739	3	5		
9680-9770	520	809	360	53	111	5	7	1	393	25	3	3	39	2329	1	5		
9770-9860	780	609	320	87	89	12	5	2	259	24	2	4	31	2224	0	2		
9860-9950	705	736	274	54	182	17	7	4	404	16	7	8	43	2457	0	1		
9950-10040	160	99	41	11	17	2	2	0	81	2		1	9	425	0	0		
10040-10130	340	538	251	46	76	10	5	0	183	7	3	3	20	1482	0	1		6.3 Ma (10030 feet)
10130-10220	390	839	231	47	89	17	8	2	135	18	2	2	17	1797	3	1		
10220-10310	210	611	260	27	74	5	4	0	182	13	0	3	27	1416	2	0		
10310-10400	470	780	268	41	81	16	8	0	247	15	0	5	14	1945	3	2		

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Table 1: Continued

Sample depth (feet)	Total mangrove	Total savanna	Total freshwater	Total brackish	Total lowland	Total montane	Total palmae	Total beach	Total algae	Total dinoflagellates	Total other pollen	Total other spores	Total miscellaneous	Grand total	Polysphaeridium zoharyi	Operculodinium centrocarpum	Maximum flooding surface	Sequence boundary
10400-10490	445	915	275	49	102	26	3	0	191	15	0	3	36	2060	1	1		
10490-10570	495	759	350	51	88	14	5	0	407	19	2	9	43	2242	0	2		
Total	23365	43559	14256	3048	5410	1050	341	41	13696	1282	132	339	1650	108169	130	143		

Table 2: Well B Ecological groups abundance/glacial record indicative dinoflagellate cysts data

Sample depth (feet)	Total mangrove	Total savanna	Total freshwater	Total brackish	Total lowland	Total montane	Total palmae	Total beach	Total algae	Total dinoflagellates	Total other pollen	Total other spores	Total miscellaneous	Grand total	Polysphaeridium zoharyi	Operculodinium centrocarpum	Maximum flooding surface	Sequence boundary
1920-1980	130	299	43	12	29	1	0	0	45	2	0	2	18	581	0	0		
1980-2070	100	176	32	10	19	0	0	1	66	1	1	1	14	421	0	1		
2070-2160	310	251	79	12	28	6	2	0	108	2	1	4	14	817	0	0		
2160-2250	150	298	68	15	22	3	1	0	72	3	0	4	18	654	0	0	1.3 Ma (2230 feet)	
2250-2340	160	266	41	7	18	1	2	1	82	1	0	4	5	588	0	0		
2340-2430	275	399	53	28	35	5	2	0	126	6	2	1	12	944	1	0		
2430-2520	205	289	48	19	41	2	0	0	132	5	2	1	24	768	0	0		
2520-2610	230	364	47	13	40	4	1	0	147	6	1	1	13	867	0	0		
2610-2700	135	111	86	12	62	9	1	1	183	6	2	3	23	634	0	0		
2700-2790	250	363	62	22	42	9	1	0	85	9	1	4	27	875	0	0		
2790-2880	280	533	111	39	62	13	9	0	184	7	5	5	30	1278	0	0		
2880-2970	430	647	219	51	86	7	5	2	204	3	5	4	18	1681	0	0		
2970-3060	340	622	142	28	62	2	6	0	69	7	2	6	17	1303	0	1		
3060-3150	200	424	112	27	51	7	8	1	87	4	4	3	13	941	0	0		
3150-3240	130	287	109	20	45	10	5	0	88	5	3	2	5	709	0	0		
3240-3330	445	565	120	43	57	9	3	1	50	10	3	3	20	1329	0	0		
3330-3420	495	666	149	29	70	10	11	2	85	7	1	1	21	1547	0	0		
3420-3510	370	739	162	32	47	4	11	2	109	3	3	3	26	1511	0	0		
3510-3600	580	661	189	44	55	16	5	1	72	10	2	3	21	1659	2	1		
3600-3690	350	637	157	57	68	26	10	2	98	10	3	5	29	1452	1	1		
3690-3780	460	802	245	54	106	63	17	2	184	40	5	9	77	2064	0	1		1.6 Ma (3700 feet)
3780-3870	890	753	239	58	86	59	18	1	156	30	4	7	60	2361	0	2	2.0 Ma (3780 feet)	
3870-3960	400	798	184	47	65	26	4	0	107	3	6	12	67	1719	0	0		
3960-4050	360	722	237	41	43	27	3	1	165	6	7	7	58	1677	0	0		
4050-4140	210	436	74	15	25	14	1	0	51	0	2	4	31	863	0	0		
4140-4230	300	510	173	31	51	21	7	0	165	10	0	6	34	1308	0	0		
4230-4320	365	466	122	23	35	6	3	0	148	4	0	1	46	1219	0	0		
4320-4410	520	901	253	77	107	8	1	1	204	6	2	10	73	2163	0	0		
4410-4500	245	463	174	41	55	8	4	2	137	7	2	3	44	1185	1	0		
4500-4590	915	572	166	29	33	8	3	1	186	5	1	2	43	1964	0	0		
4590-4680	745	782	274	48	78	39	16	1	202	24	3	4	66	2282	1	1		
4680-4770	345	576	134	37	45	22	1	0	159	12	4	2	37	1374	0	0		
4770-4860	520	633	205	20	42	15	5	1	178	6	3	3	37	1668	1	0		
4860-4950	465	384	124	22	37	13	5	1	182	9	0	1	33	1276	0	1		
4950-5080	450	479	137	19	33	2	2	0	88	6	1	1	23	1241	1	2		
5080-5170	485	368	218	51	62	11	6	0	195	3	3	6	25	1433	0	0		
5170-5260	820	602	369	116	72	13	6	1	333	10	1	7	67	2417	1	0		
5260-5310	665	640	310	83	89	5	17	2	286	6	1	16	47	2167	0	2		
5310-5400	230	208	66	29	35	9	5	0	64	5	3	1	23	678	0	2		
5400-5490	485	424	199	37	85	6	12	1	185	14	3	3	27	1481	1	0		2.4 Ma (5470 feet)

Table 2: Continued

Sample depth (feet)	Total mangrove	Total savanna	Total freshwater	Total brackish	Total lowland	Total montane	Total palmae	Total beach	Total algae	Total dinoflagellates	Total other pollen	Total other spores	Total miscellaneous	Grand total	Maximum Polysphaeridium zoharyi	Operculodinium centrocarpum	flooding surface	Sequence boundary
5490-5580	395	323	120	22	37	3	3	0	219	5	2	1	25	1155	0	0		
5580-5670	780	740	326	67	86	7	15	0	298	8	4	6	54	2391	2	0		
5670-5760	550	465	287	68	94	11	15	3	184	8	2	9	64	1760	0	0		
5760-5850	880	757	249	38	75	7	11	1	242	17	2	9	65	2353	0	1	2.7 Ma (5830 feet)	
5850-5940	185	335	143	13	37	6	3	0	65	4	1	4	20	816	0	1		
5940-6030	340	559	113	23	44	8	5	0	80	11	0	3	43	1229	0	1		
6030-6120	245	437	93	17	35	1	3	1	97	0	1	1	32	963	0	0		
6120-6210	185	457	65	15	22	3	0	0	59	0	0	1	16	823	0	0		3.0 Ma (6150 feet)
6210-6300	235	208	81	30	25	6	3	0	65	1	0	2	15	671	0	0		
6300-6390	225	127	29	7	16	5	3	0	52	0	2	2	13	481	0	0	3.4 Ma (6350 feet)	
6390-6480	205	153	56	11	25	1	3	0	93	2	0	0	18	567	0	0		
6480-6570	130	265	52	10	22	3	4	1	55	1	0	1	8	552	0	0		
6570-6660	320	549	152	34	49	23	13	1	158	2	2	3	25	1331	0	0		
6660-6750	225	427	115	21	61	9	10	0	78	6	3	3	28	986	0	2		3.8 Ma
6750-6840	650	546	169	29	58	13	5	0	186	3	0	6	29	1694	0	0		(6660 feet)
6840-6930	685	578	290	56	61	23	7	1	208	4	1	8	28	1950	0	1		
6930-7020	645	895	341	64	82	15	16	1	298	8	0	3	40	2408	0	0		
7020-7110	390	561	220	40	45	8	15	1	129	0	3	5	38	1455	0	0		
7110-7200	235	330	151	22	27	3	0	0	78	5	1	0	9	861	0	2		
7200-7290	390	269	72	17	39	4	5	4	77	6	1	0	23	907	1	1	4.0 Ma (7270 feet)	
7290-7380	375	209	130	29	31	3	5	1	96	8	1	2	18	908	2	0		
7380-7470	685	467	263	58	68	0	13	2	120	10	4	4	52	1746	2	0		
7470-7560	320	214	148	38	51	3	5	0	145	4	0	5	17	950	0	0		
7560-7650	465	346	277	56	64	0	8	1	229	1	3	4	44	1498	0	0		
7650-7740	390	277	111	29	41	2	6	0	110	16	3	1	24	1010	1	1		
7740-7830	385	151	93	24	21	0	6	1	76	6	1	3	15	782	0	1		
7830-7920	285	192	84	15	23	0	4		91	4	2	0	13	713	0	0		
7920-8010	460	237	172	36	36	0	5	0	66	1	2	2	24	1041	1	0		4.2 Ma
8010-8100	365	204	89	28	29	0	4	0	123	4	1	1	20	868	0	1		(8000 feet)
8100-8190	465	372	255	49	54	0	10	0	137	3	4	6	28	1383	0	0		
8190-8280	380	204	141	31	38	0	6	0	243	1	2	5	13	1064	0	0		
8280-8370	230	157	88	16	41	1	3	0	150	0	2	4	21	713	0	0		
8370-8460	245	154	106	19	30	1	3	0	61	4	0	2	21	646	1	1		
8460-8550	280	138	187	18	34	1	5	2	71	3	0	6	25	770	0	0		
8550-8640	145	101	126	17	34	2	7	0	89	8	0	2	18	549	0	0		
8640-8730	125	86	116	26	38	0	6	0	77	6	0	6	21	507	1	1		
8760-8850	110	86	79	12	25	1	3	0	54	1	1	1	12	385	0	0		
8850-8940	95	87	98	14	27	1	1	0	102	3	0	2	7	437	0	0	5.0 Ma (8915 feet)	
8940-9030	145	110	70	23	28	0	8	0	86	5	3	2	14	494	1	0		
9030-9120	180	92	61	21	32	2	5	0	43	2	0	2	8	448	1	0		
9120-9210	55	151	69	21	60	1	5	0	64	3	0	4	18	451	0	1		5.5 Ma
9210-9300	80	221	149	36	83	2	9	0	108	5	1	5	31	730	0	2		(9173 feet)
9300-9390	150	272	144	29	65	0	10	0	111	2	3	1	27	814	0	0		
9390-9480	115	229	98	30	48	0	8	1	111	0	2	5	18	665	0	0		
9480-9570	65	158	66	16	27	0	3	0	56	0	0	0	17	408	0	0		
9570-9660	55	135	78	21	51	0	5	0	71	2	1	4	10	433	1	0		
9660-9750	55	139	80	14	26	2	3	0	87	3	1	2	14	426	0	0	5.8 Ma (9720 feet)	
9750-9840	70	182	47	14	16	1	4	0	45	1	0	1	9	390	0	0		
9840-9860	110	234	76	25	34	0	3	1	65	1	0	4	17	570	0	0		
Total	30220	34702	12557	2767	4218	701	521	52	11075	511	154	318	2455	100251	24	32		

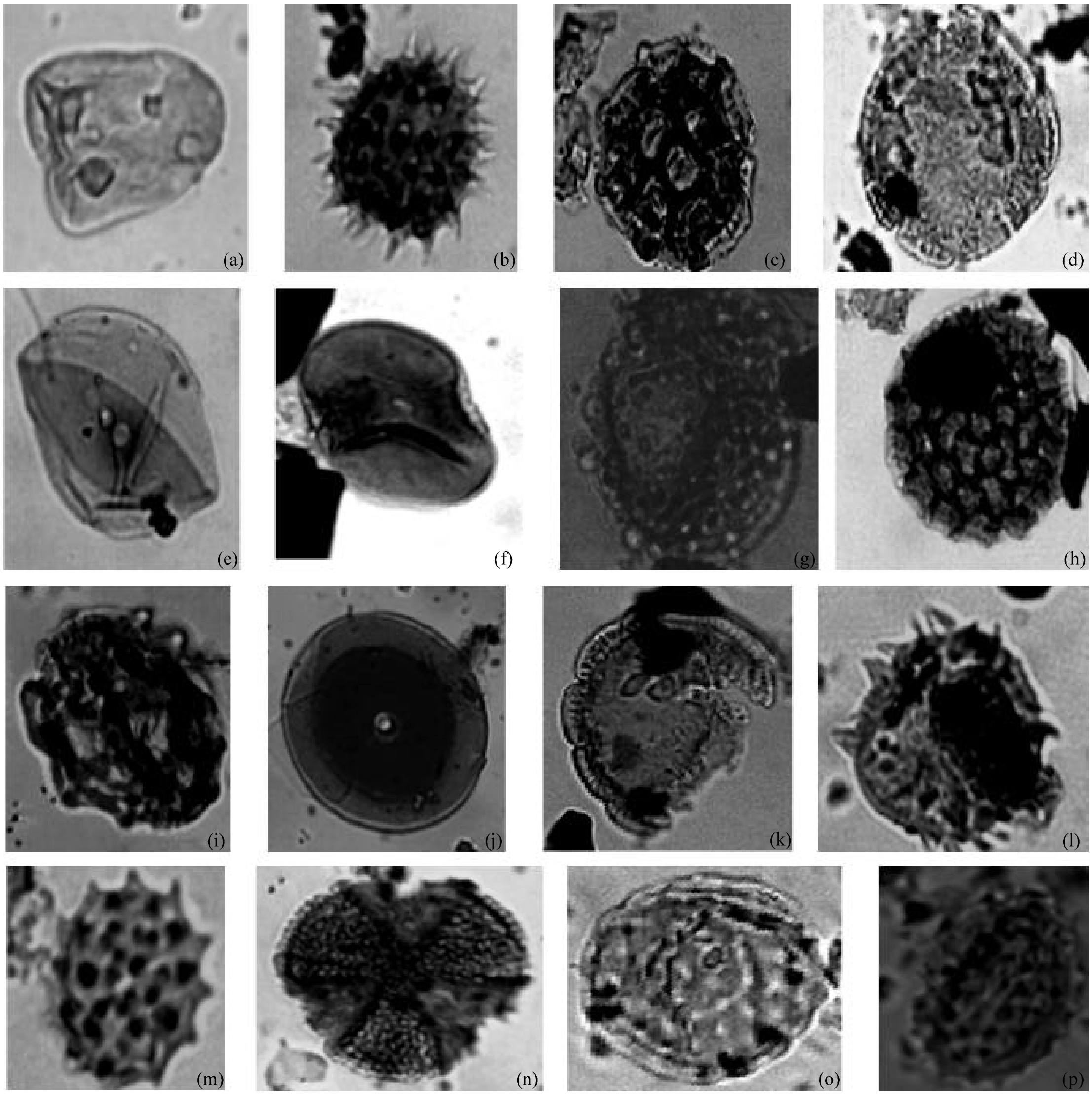

Fig. 2: Photomicrographs of some recovered Savanna pollen species from well A and B with corresponding well, sample and England finder location. (a) *Cyperaceaepollis* sp. Well B (8640-8730) G33/2, (b) *Echitricolporites spinosus* well A (7350-7440) G30/0, (c) *Fenestrites spinosus* well B (4590 - 4680) V39/ 1, (d) *Retistephanocolpites gracilis* well B (7740-7830) T19/2, (e) *Monoporites annulatus* well A (1980-2040) M24/3, (f) *Multiareolites formosus* well A (5010-5100) G24/1, (g) *Gardenia imperialis* well A (5010-5100) P35/2, (h) *Polygonum* sp. Well A (6720- 6810) N42/2, (i) *Peregrinipollis nigericus* well B (3690-3780) T52, (j) *Numulipollis neogenicus* well B (5170-5260) O34/1, (k) *Retistephanocolpites gracilis* well B (5170-5260) K24/3, (l) *Echistephanoporites echinatus* well B (2790-2880) T33/4, (m) *Tubifloridites antipodica* Cookson, 1947; well A (7530 -7620) M41 (n) *Margocolporites vanwijhei* well B (7650-7740) S39/1, (o) *Chenopodipollis* sp. (Chenopodiaceae) well B (7740-7830) T18/1 and (p) *Tubifloridites antipodica* well B (5400-5490) K24/3

Presentation of results: The analysis sheets (data sheets) were inputed on STARTABUGS, from which distribution charts showing the palynomorph species arranged by stratigraphic appearances and disappearances against increasing depth in the wells were generated, with the log and systems tracts by the side. The marker species were plotted separate from other species. This facilitated the picking of the palynological zonal boundaries easily.

Statistical analysis: Mean, standard deviation, student T-test, one way Analysis of Variance (ANOVA) and correlation analysis were performed on the different

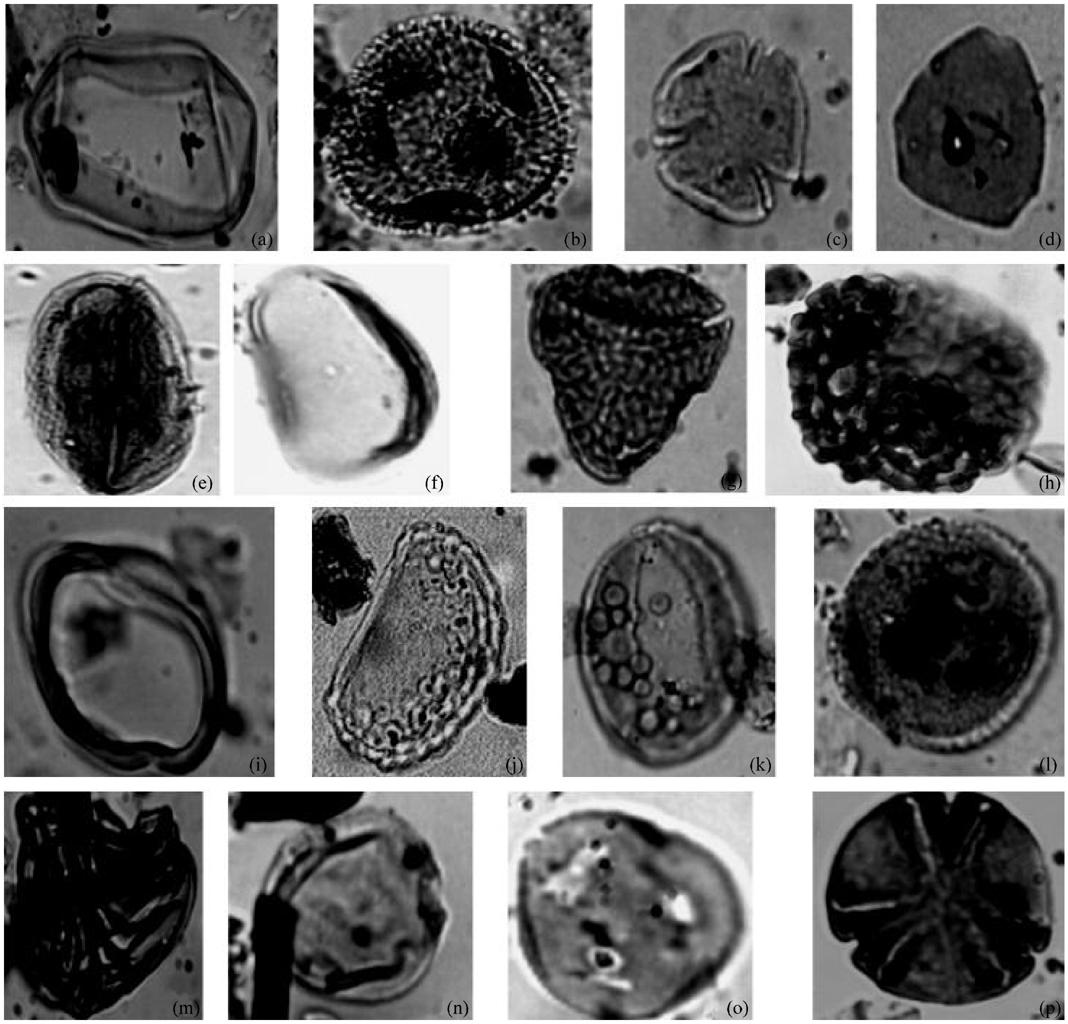

Fig. 3: Photomicrographs of some Freshwater swamp species recovered from wells A and B with corresponding well, sample and England Finder location. (a) *Nympheaepollis clarus* well B (2790 -2880) M22/2, (b) *Retitricolporites irregularis* well A (2130 -2220) Q48/4, (c) *Psilatricolporites operculatus* well A(2310 -2400) V36/3, (d) *Momipites* sp. Well A (7260-7350) G35/1, (e) *Striatricolpites catatumbus* well B(5400-5490)W26/1, (f) *Laevigatosporites* sp. Well A (1980-2040) L28/2, (g) *Lycopodium* sp. Well A (1980-2040) K42/4, (h) *Crassoretitriletes vanraadshooveni* well B (3330-3420) D27/2, (i) *Nympheaepollis clarus* well B (4590-4680) R38/2, (j) *Verrucatosporites* sp. Well A (4590-4680) R38/2, (k) *Gemmamonoporites* sp. well B (8370-8460) R22/2, (l) *Retibrevitricolporites obodoensis* well B (5400-5490) U19/3, (m) *Magnastriatites howardi* well A (2490-2580) S42/1, (n) *Anthocleista vogelii* well B (3780-3870) S38/4, (o) *Anacolosidites cf. luteoides* well A (5400-5490)P28/2 and (p) *Rauwolfia vomitora* well A (5400-5490) S35/3

ecological groups using the Prism version 5.00 computer software programme (GraphPad Software, San Diego, CA). Significant limits were set at the 95% confidence interval.

RESULTS

Palynostratigraphy

Pollen, spores and algae: Ninety six and eighty nine samples of wells A and well B between (1980-10570 feet) and (1920-9860 feet) were analyzed. The palynomorphs recovered were abundant and diverse in most of the horizons studied. The assemblages were dominated by land derived sporomorphs particularly *Monoporites annulatus, Zonocostites ramonae, Podocarpus milanjianus, Stereisporites* sp., *Cyperaceaepollis* sp., *Sapotaceoidaepollenites* sp., *Retistephanocolpites gracilis* (*aff. Borreria verticillata*), *Podocarpidites* sp., *Verrucatosporites* sp., *Laevigatosporites* sp.,

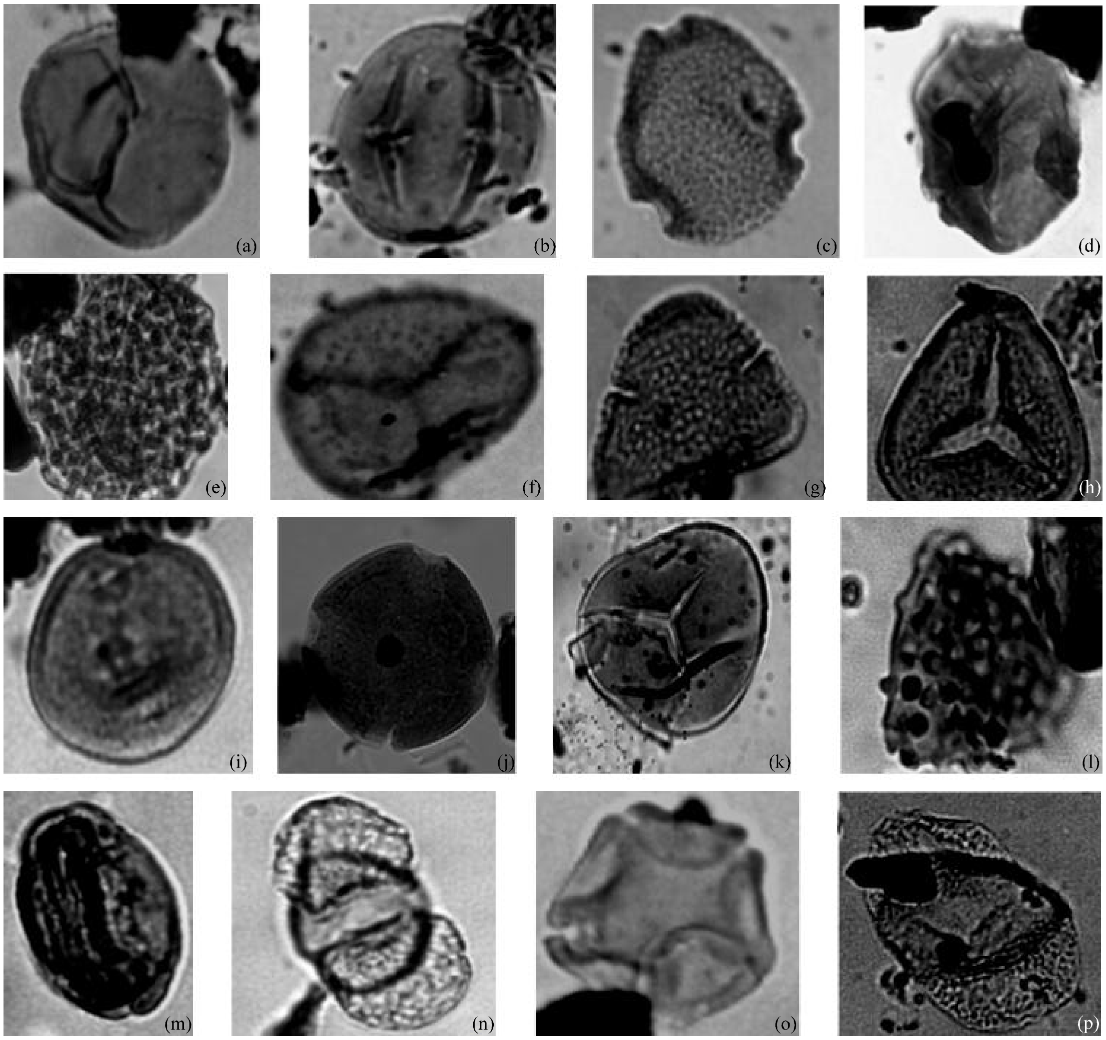

Fig. 4: Photomicrographs of some Lowland Rainforest species recovered in well A and B, with the corresponding well, sample and England Finder liocation. (a) *Stereisporites* sp. (Smooth) well B (2880-2970)H33/4, (b) *Sapotaceoidaepollenites* sp. Well B (5400-5490) S32/1, (c) *Canthium* sp. well B (5760-5850) X17/3, (d) *Corsinipollenites jussiaensis* well A (10400-10490) J41/1, (e) *Spirosyncolpites bruni* well B (6750-6840) S45/2, (f) *Sterisporites* sp. (Rough) well B (2700 -2790) X48/2, (g) *Bombacidites bellus* well A (7800 -7890) N38/4, (h) *Polypodiaceoisporites* sp. well B (2700 -2790) M43/3, (i) *Psilatricolporites crassus* well A (5640 -5730) T34/3, (j) *Pachydermites diederixi* well A(4470 -4560) N36/3, (k) *Acrostichum aureum* well A (9590 -9680) N36/3, (l) *Echitriporites trianguliformis* well B (3420 -3510) H27/3, (m) *Marginipollis concinnus* well B (2700 -2790) X48/2, (n) *Podocarpus milanjianus* well A (6000-6090)T35/3, (o) *Alnipollenites verus* well A (6000-6090)T35/3 and (p) *Podocarpidites* sp. well A (2220-2310) J30/1

Polypodiaceoisporites sp. and *Acrostichum aureum.* Two hundred and thirty palynomorph species were recorded in well A, while well B yielded one hundred and seventy-three species.

Dinoflagellates/marine elements: Abundant records of dinoflagellate cysts which peaked at some horizons characterized the well A. The dominant species were *Polysphaeridium zoharyi*, *Operculodinium centrocarpum*, *Spiniferites ramosus*, *Achomosphaera ramulifera*, *Tuberculodinium vancampoae*, *Hystrichokolpoma rigaudiae*, *Spiniferites* sp. (*S. membranaceus*, *S. mirabilis*, *S. delicatus*, *S. bulloideus*, *S. elongatus*, *S. bentorii* and *S. hyperacanthus)*, *Selenopemphix nephroides*, *Achomosphaera andalousiensis*, *Achomosphaera* sp., *Selenopemphix* sp.

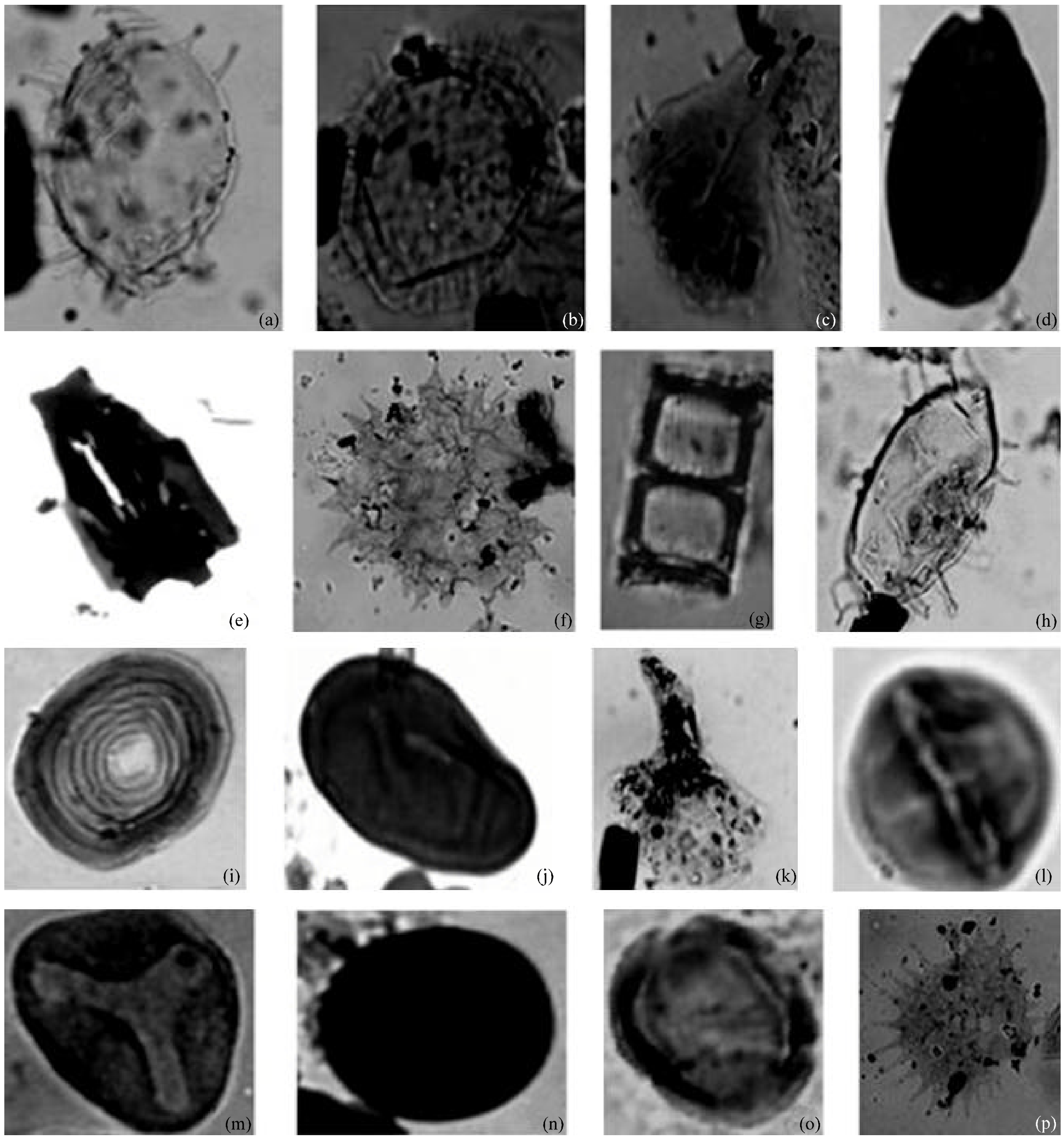

Fig. 5: Photomicrographs of some dinoflagellate cycts and accessories recovered from wells A and B, with the corresponding well, sample and England Finder location. (a) *Polysphaeridium zoharyi* well A (2880-2970) H33/4, (b) *Operculodinium centrocarpum* well B (3690- 3780) O35/1, (c) *Botryococcus braunii* well B (4860-4950) K38/4, (d) *Fungal spore*. well B (5760-5850) O38/2, (e) *Charred Graminae Cuticle* well A (2130-2220) X36/1, (f) *Pediastrum* sp. Well B (8370-8460) W38/1, (g) Diatom Frustule well B (4680-4770) K20/2, (h) *Polysphaeridium zoharyi* well A (2880-2970) H33/4, (i) *Concentricytes circulus* well B (4680-4770) K20/2, (j) *Fungal spore* well A (10400-10490) V18/2, (k) *Botryococcus braunii* well B (3690-3780)K24/2, (l) *Zonocostites ramonae* well B (3690-3780) L24/3, (m) *Elaeis guineensis* well A (7260- 7350) T12/1, (n) *Fungal spore* well A (3510-3600) M37/4, (o) *Zonocostites ramonae* well B (3780-3870) K24/1 and (p) *Pediastrum* sp. well B (5760-5850) K38/4

and the acritarch *Leiosphaeridia* sp. The recoveries were moderate in well B, with *Polysphaeridium zoharyi*, *Spiniferites ramosus*, *Operculodinium centrocarpum*, *Protoperidinium* sp. (*Pteridinium* sp. of Wall *et al*., 1977), *Selenopemphix nephroides*, *Hystrichokolpoma rigaudiae*, *Spiniferites* sp., *Achomosphaera* sp., *Selenopemphix* sp., *Brigantedinium* sp., *Tectatodinium* sp. and the acritarch *Leiosphaeridia* sp. as the commonest species. Deepening at some intervals was indicated by the records of *Impagidinium* sp., *Nematosphaeropsis labyrinthus* and *N. lemniscata*. The spot records of *Dinogymnium euclaense*, *Muderongia* sp. and *Odontochitina* sp., which are Maastrichtian and older dinocysts at 6000 and 8160 feet, in the well A, together with such older palynomorphs as *Monocolpopollenites sphaeroidites*, *Ephedripites* sp., *Gnetaceaepollenites* sp., *Foveotriletes margaritae, Proteacidites longipinosus*, *Psilamonocolpites marginatus*, *Cinctiperiporites mulleri*, *Corsinipollenites jussiaeensis, Retimonocolpites obaensis* all suggest the reworking of older sediments onto younger horizons.

The preponderance of the paleoenvironmental indicators dinoflagellate cysts, microforaminiferal wall linings and freshwater algae *Botryococcus braunii and Pediastrum* sp., in the studied sections of the wells suggests sediment deposition in a shallow marine environment with frequent freshwater incursions.

Age: The wells A and B sequences fell within the broad pan-tropical *Echitricolporites spinosus* zone of Germeraad *et al.* (1968) and the P800-P900 zones of Evamy *et al.* (1978). The sequence also correlated with the J2-J3 Zones of Legoux (1978). The ages of the studied sections of the wells ranged from Late Miocene (P860) at the base to Early Pleistocene (P900) subzone at the top. This is attributed to the Quantitative Base and Base Occurrences of the Niger Delta palynological Miocene/Pliocene boundary marker species *Retistephanocolpites gracilis (aff. Borreria verticillata)* at 8520 and 9030 feet respectively in wells A and B (Evamy *et al*., 1978). Again the 5.0 Ma MFS's were delineated at 8545 feet and 8915 feet in wells A and B, defined by the FDO's of *Cyclammina minima, Eggerella scabra* and LDO of *Globorotalia tumida* as well as the marked influx of Arenaceous foraminifera. These events further indicated the penetration of Late Miocene below these depths. The uppermost part of the wells are dated Lower Pleistocene based on the first peak abundance of *Podocarpus milanjianus* at 2040 feet and the presence of *Spiniferites elongatus, Spiniferites bulloideus* and *Spiniferites hyperacanthus* (Powell, 1992; Rochon *et al*., 1999), coupled with the FDO: *Globorotalia miocenica* dated 2.0 Ma at 4680 and 4650 feet, respectively for wells A and B.

Ecological group assessment: The ecological group trends in the two wells appeared similar with the savanna dominating over mangrove and the other ecological groups especially in well A (Fig. 6 and 7; Table 1 and 2). The least were beach, other pollen, other spores and *Palmae*. The abundance of freshwater algae especially *Botryococcus braunii* is in agreement with Morley (1995), who recognized its abundance in the Pliocene-Pleistocene of the Niger Delta. There were clear crests and troughs in the microfloral abundance, suggesting alternations of dry and wet climates.

The statistical tests revealed significant relationships between all the ecological groups (at 95%) confidence interval except the marine elements in the well A. A comparison of the wells A and B showed that the means of the ecological groups were significantly different and the Bartlett's test for equal variances depicted significant differences. An entirely different scenario was observed in the well B, there were significant relationships between the mangrove, savanna, montane and marine elements while none existed for the freshwater, brackishwater,

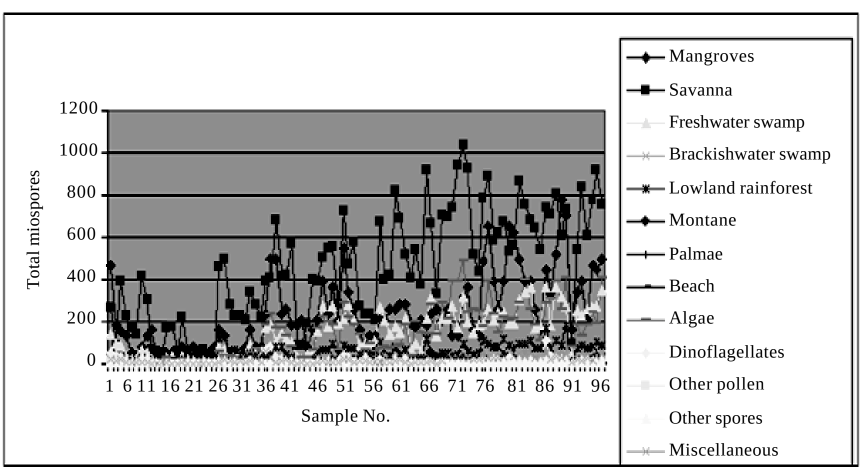

Fig. 6: Well A ecological groups abundance plot

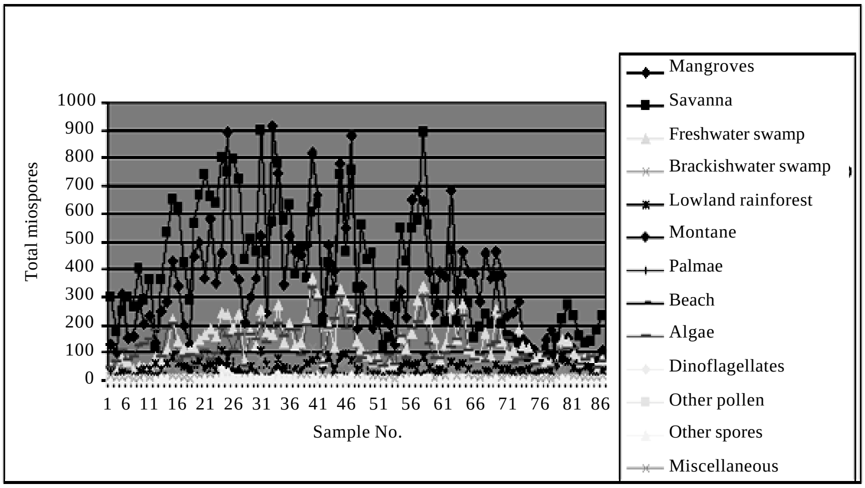

Fig. 7: Well B ecological groups abundance plot

lowland rainforest, palmae, beach, algae and other spores. This shows that though the two wells were from the same field, their miospore associations are slightly different.

Dinoflagellate stratigraphy: The dominant dinoflagellate cysts in well A were *Operculodinium centrocarpum* and *Polysphaeridium zoharyi* accounting for 11.15 and 10.14% respectively (Fig. 5). The dominance of these two species which were concentrated at some points could have resulted from lowered sea levels following glacial maxima (Mozardec-Kerfourn, 1988, 1992a, b). A critical evaluation of well B, revealed the dominant dinoflagellate cysts to be *Operculodinium centrocarpum, Polysphaeridium zoharyi, Protoperidinium* sp. *(Peridinium* sp. of Wall *et al.*, 1977), *Spiniferites ramosus, Invertocysta* sp. and the acritarch species *Leiosphaeridia* sp.

Evidence of climatic variations, sea level changes and contributions to the global glacial history: As highlighted earlier the chronostratigraphic ages for the sediments were provided by diagnostic foraminifera which enabled correlation to worldwide chronostratigraphy. The MFS's were used as the zonal boundaries for convenience. The recognized SB's were dated by comparison with the Global Sequence Cycle Chart of Haq *et al.* (1988) as revised by Berggren *et al.* (1995) and updated by Grandstein *et al.* (2004).

Early pleistocene (c.a 1.3-2.0 Ma): Top defined by the FDO of *Globorotalia truncatulinoides* and *Hyalinea balthica*. This horizon corresponds to the 1.3 Ma MFS. The zonal base is defined by the 2.0 Ma MFS marked by the FDO of *Globorotalia miocenica* and the LDO's of *Pulleniatina obliquiloculata* and *Pulleniatina finalis*. Well A: (2070-4680 feet) and Well B: (2040-3750 feet) Early Pleistocene.

In the well A, except at few points where the counts of *Zonocostites ramonae* exceeded *Monoporites annulatus*, (Table 1) the microfloral assemblage is dominated by *Monoporites annulatus* and other savanna species. This trend occurred with common records of the dinocysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* between 1980-2670 feet suggesting a marked dry climate possibly associated with lowered sea level (glacial maximum) around this period in the Niger Delta. This event is demonstrated again around the 2.0Ma MFS at 4680, where *Polysphaeridium zoharyi*, occurred regularly from 4560-5190 feet in association with abundant savanna species. In the well B (Table 2), around the 2.0Ma MFS at 3750 feet are clusters of the dinocysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* between 3510-3870 feet. The few mangrove peaks at (2070 and 3780 feet) show possible wet periods sandwiched in-between an extremely dry climate.

Early-late pliocene (c.a 5.0-2.0 Ma): The top of this Zone is defined by the FDO of *Globorotalia miocenica* and the LDO's of *Pulleniatina obliquiloculata* and *Pulleniatina finalis* which coincided with the 2.0 Ma MFS. The base is defined by the FDO's of *Cyclammina minima, Eggerella scabra* and LDO of *Globorotalia tumida*. The horizon coincides with the 5.0 Ma MFS. It also lies close to the Base Occurrence/Quantitative Occurrence of the savanna pollen specie *Retistephanocolpites gracilis (aff. Borreria* sp.), which is the index Pliocene /Miocene boundary marker in the Niger Delta (Evamy *et al.*, 1978).

0-2.7 Ma: The top of this Zone is defined by the FDO of *Globorotalia miocenica* and the LDO's of *Pulleniatina obliquiloculata* and *Pulleniatina finalis* which coincide with the 2.0 Ma MFS. The base is defined by the FDO's of *Bulimina marginata* and *Cyclammina cancellata* as well as the LDO of *Sphaeroidenella dehiscens*, which is dated 2.7 Ma.

2.0-2.7 Ma Well A: (4680-5580 feet); Well B: (3750-5490 feet): Savanna species dominated the well A microfloral assemblage within this time (2.0-2.7 Ma) except at 5190-5370 feet where mangrove peaked, showing a possible wet period in-between an extremely dry climate. The wet period is supported by common freshwater swamp species. The common records of *Polysphaeridium zoharyi* from 5550-6180 feet, revealed a well defined dry climate around the 2.7 Ma.

Within this time lapse in well B, there were peaks of mangrove at (4500 and 4860 feet) and a longer wet period between 5080-5850 feet. A marked drier period supported by common records of *Polysphaeridium zoharyi* occurred between 4860-5080 feet.

2.7-3.4 Ma: The top is defined by the FDO's of *Bulimina marginata* and *Cyclammina cancellata* as well as the LDO of *Sphaeroidenella dehiscens*, which are dated 2.7 Ma. The base of the Zone is defined by the FDO's of *Rectuvigerina multicostata, Amphistegina lessonii, Globigerinoides bollii, Globorotalia margaritae* and *Globorotalia pseudomiocenica,* which is correlated with the 3.4 Ma MFS.

Well A: (5580-6900 feet) and well B: (5490-6390 feet): In well A, savanna species dominated the microfloral assemblages, the common freshwater swamp species suggests possible climatic fluctuations. *Polysphaeridium zoharyi* became common from 6900-7170 feet, *Operculodinium centrocarpum* was common between 5820-6180 and 6990-7260 feet. This indicates a possible glacial maxima and lowered sea level around 2.7 Ma. On the other hand in well B, there were peaks of mangrove between 5490-5850 feet and 6210-6390), in-between savanna dominated microflora. The dinocysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* occurred in spots around 5310-6030 feet.

3.4-4.0 Ma: The top of this Zone is defined by the FDO's of *Rectuvigerina multicostata, Amphistegina lessonii, Globigerinoides bollii, Globorotalia margaritae* and *Globorotalia pseudomiocenica,* which is correlated with the 3.4 Ma MFS. Its base coinciding with the 4.0 Ma MFS is defined by the FDO's of *Marginulina costata, Haplophragmoides compressa* and *Globigerina nepenthes.*

3.4-4.0 Ma-well A: (6900-7980 feet) and well B: (6390-7170 feet): Abundant savanna species dominated the microfloral assemblage. *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* were common between 6900-7170 and 6990-7350 feet, respectively. The assemblagein well A indicates an extremely dry climate. While in well B, the microfloral assemblage was dominated by savanna species. The dinocyst *Polysphaeridium zoharyi* was absent, while *Operculodinium centrocarpum* occurred in spots around 6660-6930 feet. This suggests an extremely dry climate and agrees with the results from well A.

4.0-5.0 Ma: The top of this Zone is defined by the FDO's of *Marginulina costata* and *Globigerina nepenthes.* It coincides with the 4.0 Ma MFS. The base is defined by the FDO's of *Cyclammina minima, Eggerella scabra* and LDO of *Globorotalia tumida.*

Well A: (7980-8570 feet) and well B: (7170-8880 feet): This interval is characterized by extremely high records of savanna pollen and common *Retistephanocolpites gracilis* (*aff. Borreria* sp.). The records of the dinocysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* were sparse in well A, while mangrove pollen, in association with common freshwater swamp, brackish water swamp species dominated the microfloral assemblage in well B. The dinocyst *Polysphaeridium zoharyi* was common between 7200-7470 feet and later occurred in spots within this section. *Operculodinium centrocarpum* occurred in spots all through. This suggests a period of climatic fluctuations with brief dry periods and fllowered sea levels.

Late miocene: 5.0-5.8 Ma: The top is defined by the FDO's of *Cyclammina minima, Eggerella scabra* and LDO of *Globorotalia tumida.* The base of this Zone dated 5.8 Ma MFS is defined by the FDO's of *Haplophragmoides narivaensis* and *Globoquadrina dehiscens.*

Well A: 5.0-5.8 Ma(8570-9380 feet) and well B: (8880-9720 feet): This section is of Late Miocene age, savanna species still dominated the assemblage in well A. This occurred with common freshwater swamp species, mangrove peaked between 9770-10040 feet, indicating a possible wet inter-phase between a dominantly dry climate. This section is characterized by abundant records of savanna species, mangrove just peaked between 8940-9120 feet in well B. The dinocysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* were sparse in occurrence.

>5.8 Ma well A: (9380-10570 feet) and well B: (9720-9860 feet): Savanna species still dominated the microfloral assemblage within this thin section older than 5.8 Ma. The dinocysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* were sparse to absent.

Paleoclimatic deductions: The dominance of *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* which were concentrated at some points in the two wells could have resulted from lowered sea levels following glacial maxima (Mozardec-Kerfourn, 1988, 1992a, b). The 1.3, 2.0, 2.7, 3.4, 4.0, 5.0 and 5.8 Ma Maximum Flooding Surfaces were respectively dated using diagnostic foraminifera. Close to these MFS's were clusters of *Polysphaeridium zoharyi* and *Operculodinium centrocarpum,* especially around the 2.0-2.7 Ma MFS's in well A (4650-5640 feet) and (3780-5850 feet) in well B (Table 1 and 2). The signature being more pronounced in well A. Furthermore, this trend was slightly repeated between the 2.7-3.4 Ma MFS's (5640-6900 feet) and (5850-6390 feet) in wells A and B, respectively. Further downhole, between the 3.4-4.0 Ma MFS's well A (6900-7900 feet) and well B (6350-7270 feet), were spot records of the two species. The recoveries between the 4.0-5.0 Ma MFS's were similar to the former, while below the 5.0 Ma MFS (Late Miocene) in well B were spot records of these species contrary to well A, in which a remarkable increase in the abundance of the two species especially below the 5.8 Ma MFS down to the last sample analyzed 10570 feet were observed.

DISCUSSION

A predominantly dry climate is inferred for these sediments due to the abundance of *Monoporites annulatus* (Graminae), *Cyperaceaepollis* sp., *Chenopodipollis* sp. and other savanna species. This agrees with the reports of Morley (1995) who inferred from late Miocene data from the Niger Delta which spanned a period of about 1.7 Ma, that the abundance of Gramineae pollen and common mangrove pollen within lowstand fan deposits was consistent with a dry climate and widespread representation of mangroves on the lower delta plain. Possibly this trend continued into the Pliocene and younger ages. Again, Hooghiemstra *et al.* (1986) had also associated the abundance of Gramineae pollen and Chenopodiaceae-Amaranthaceae with the dry conditions of desert and savanna. Moreover, Pocknall *et al.* (2001) in carrying out an integrated paleontological study of Pliocene to Pleistocene sediments of the Orinoco Delta in Eastern Venezuela and Trinidad, had attributed the increase in the abundance of Cyperaceae in the Pleistocene to the same climatic (cooling) event that led to the introduction of *Alnus* into the Andes which they observed coincided with the appearance of *Avicennia* sp. In these studied Niger Delta wells apart from the abundant records of Cyperaceae pollen, the moderate records of *Podocarpus milanjianus* could have arisen from the same cooling event reported by Pocknall and co-workers.

An assessment of the dinoflagellate cysts records further gives credence to a dominantly dry climate coupled with warm temperatures in the Pliocene-Pleistocene of the Niger Delta. Mozardec-Kerfourn (1988, 1992a, b) had associated *Polysphaeridium zoharyi* with dry climate and lowered sea levels, while Udeze and Oboh-Ikuenobe (2005) linked *Operculodinium centrocarpum* with warm climate. These trends were clearly revealed in the well A, around the 2.0 Ma MFS at 4680 feet, where *Polysphaeridium zoharyi,* occurred regularly from 4560-5190 feet in association with abundant savanna species. In the well B, around the 2.0 Ma MFS at 3750 feet were clusters of the dinoflagellate cysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* between 3510-3870 feet. The most pronounced period of glacial maxima and lowered sea level as revealed by the results from the wells A and B are the periods close to and around the 2.0-2.7 Ma MFS. This particular event has been reported by Molnar and Cane (2004) who opined that early to Middle Pliocene global climate was clearly different from those since 2.7 Ma. They further reported that, around 2.7 Ma, the warm equable climates of early and middle Pliocene time (5-2.7 Ma) were replaced by recurring ice ages.

The inferred warm climate and lowered sea levels around the 3.4-2.7 Ma from the studied samples concurs with the earlier reports from Colombia by Hooghiemstra (1993) who suggested warm climatic conditions around the 3.2-2.7 Ma.

Leroy and Dupont (1994) had recognized this event from their study of a 200 m marine pollen record from northwestern Africa. Their study revealed cyclic vegetational and continental climatic fluctuations in this area from 3.7-1.7 Ma. The cycles paralleled oxygen isotope stages. Tropical forests and mangrove swamps got to Cape Blanc about 5°N of the present distribution before 3.5 Ma. Between 3.5 and 2.6 Ma, forests occurred and later disappeared after which a Saharan paleo-river flowed until isotope stage 134 (3.35 Ma). After this period wind transport of pollen grains prevailed over fluvial, as pollen indicators of trade winds increased between 3.3 and 2.5 Ma. They suggested a strong aridification of the Northwestern African climate during isotope stage 130 (3.26 Ma) after which humid conditions got re-established followed by another aridification around 2.7 Ma.

Pocknall *et al.* (2001) had related the dominance and subsequent decline of *Grimsdalea magnaclavata* to a possible climatic warming and cooling which coincided with the major regional lowstand displayed on Haq *et al.* (1987) Global sea level curve at around 2.1 to 2.0 Ma. This same event is clearly revealed in the well A, around the 2.0 Ma MFS at 4680 feet, where *Polysphaeridium zoharyi*, occurred regularly from 4560-5190 feet in association with abundant savanna species. In the well B, around the 2.0 Ma MFS at 3750 feet were clusters of the dinoflagellate cysts *Polysphaeridium zoharyi* and *Operculodinium centrocarpum* between 3510-3870 feet. Furthermore, the cooling events must have encouraged the preponderance of *Podocarpus milanjianus* between 4650-4920 feet in well A and 3510-4230 feet in well B respectively. The few mangrove peaks at (2070 and 3780 feet) in well B indicate possible wet period in-between an extremely dry climate.

CONCLUSION

The 2.0 and 2.7Ma glacial maxima events which had been reported in different parts of the world, has been indicated in Western Niger Delta sediments. The evidence is clearly demonstrated by both marine and terrestrial palynomorphs.

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