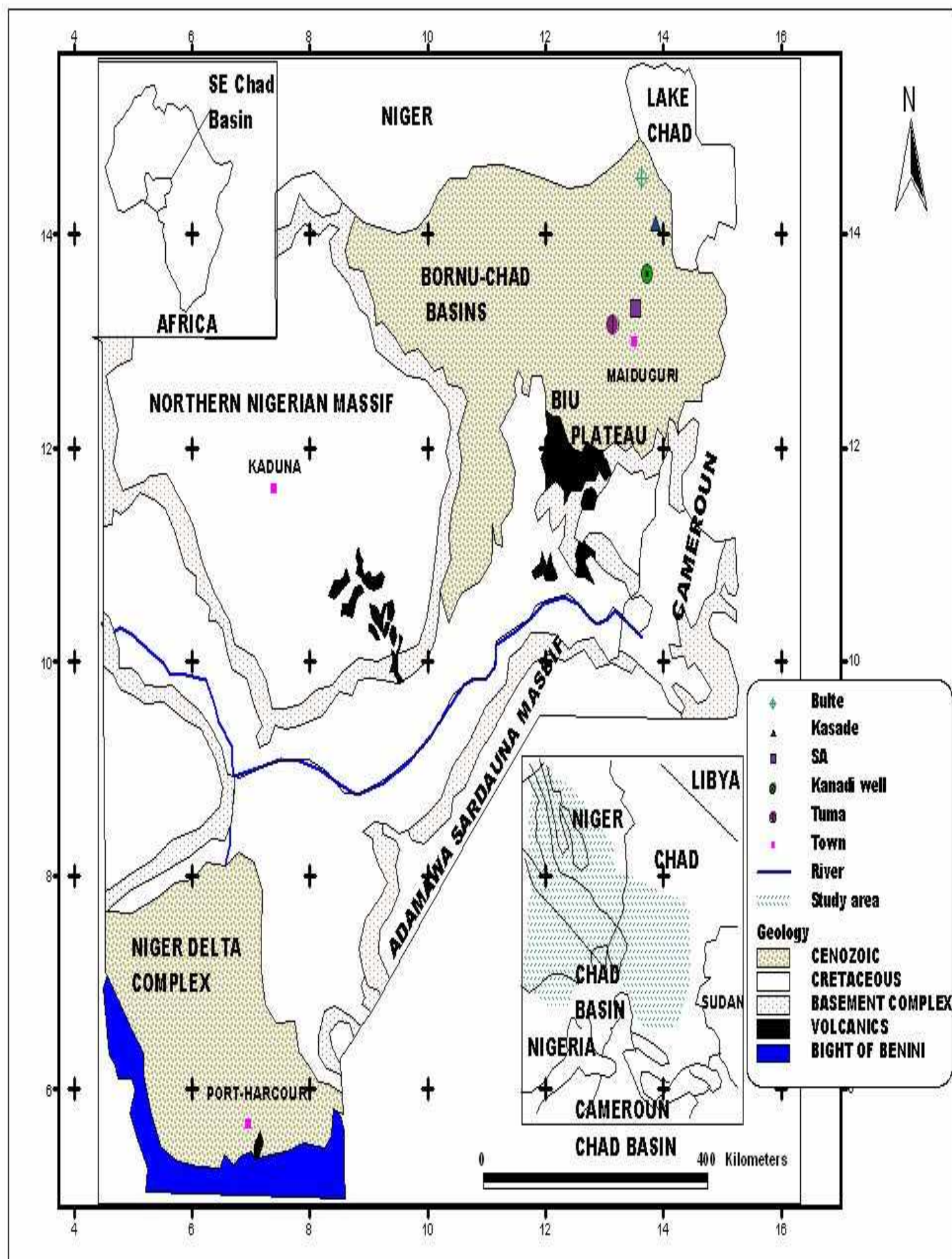




Late Albian - Eocene palynological biostratigraphy of three wells in the Nigerian sector of Chad (Bornu) Basin

Olugbenga Ademola BOBOYE

Department of Geology, University of Ibadan, Ibadan-Nigeria.

oa.boboye@mail.ui.edu.ng; boboyegbenga@yahoo.com

Abstract

Palynological, biostratigraphic and paleoenvironmental analyses were employed on ditch cutting retrieved from Bima, Gongila, Fika Shale and Chad formations in the Tuma, Kasade and Bulte wells, covering total depth of 3,628m, 1,465m and 1,605m respectively. They are located along the NE-SW transect of the Bornu Basin. The aim was to determine the subdivision of the sequences penetrated into zones and the paleoenvironment of the diverse lithofacies.

The study involved the analysis of pollen, spores, dinoflagellate cysts, microforaminiferal test linings and fungal remains. The palynomorph assemblages recovered from these wells are moderately rich and poorly preserved. The informal palynological zones are *Afropollis jadinus* (Late Albian - Middle Cenomanian), *Classopollis brasiliensis* (Late Cenomanian), *Hexaporticolpites emelianovi* (Late Cenomanian - Early Turonian), *Triorites africaensis* (Early Turonian), *Cretacaeiporites scabratus* (Late Turonian), *Droseridites senonicus* (Coniacian - Santonian), *Longapertites* spp. (Campanian - Early Maastrichtian), *Spinizonocolpites baculatus* (Late Maastrichtian) and *Proxapertites operculatus* (Paleocene) Zones. These are assemblage zones which are similar and correlatable to other Cretaceous palynologic zones in the West African, northern southern America and Eurasian basins.

An attempt was made to place the K-T boundary at the last appearance datum of *Proxapertites operculatus*, a Paleocene taxon in the uppermost part of the Fika Formation. The palynomorphs recovered are moderately rich and preserved, mainly monospecific, facies-controlled and long ranging with only few moderately preserved age diagnostic species.

The sedimentological characteristics show that the facies were deposited in a low to high energy shallow marine setting under anoxic and/or suboxic bottom waters. The spore-pollen assemblages from the wells provide insights into the paleoclimatic and paleogeographic settings during the Albian-Cenomanian transition in the basin.

Introduction

The Bornu Basin is a subunit of the large and connected chain of interior cratonic basins in Africa, whose origin is closely connected to the separation of the African and South American plates during the Cretaceous. According to workers which include Clots (1939), Furon (1963), Faure (1966), Louis (1970), Burke and Wilson (1972), Burke and Dewey (1974), Burke (1976), Petters (1979, 1981), Fairhead (1986), Fairhead and Binks (1991), Binks and Fairhead (1992), Guiraud and Maurin (1992), Guiraud et al. (1992), Wilson and Guiraud (1992), Genik (1992), Hartley and Allen (1994), the consensus is that the Chad Basin is the product of rifting, subsidence and sedimentation that accompanied the separation of the African and South American continents. Several authors however assigned important roles to magmatism or "hot spot" theory (Burke and Wilson, 1972; Burke and Dewey, 1974; Wilson and Guiraud, 1992), mantle plume or convection current (Pavoni, 1992; Hartley and Allen, 1994) and crustal extension and subsequent subsidence (Fairhead and Binks, 1991; Binks and Fairhead, 1992; Guiraud et al., 1992) to the origin of the basin.

Pioneer studies, mainly on the geology and hydrogeology of the Bornu Basin include Falconer

(1911), Raeburn and Brynmor (1934), Barber (1965) and Barber and Jones (1960). Carter et al. (1963) gave detailed descriptions of selected sections and boreholes. They also correlated the stratigraphic succession in the Nigerian sector of the Chad Basin with the Upper Benue Trough. Servant (1970) presented stratigraphic data on the Quaternary and Recent sediments northeast of Lake Chad. Burke et al. (1970, 1972) gave a detailed geologic history of parts of Adamawa, Bauchi and Bornu Provinces in northeastern Nigeria with accompanying geological maps. Reymont (1965) correlated the ammonite biostratigraphy of the Benue Trough with the Chad Basin. The palynological study of Adegoke et al. (1978) assigned a Paleocene age to the Kerri-Kerri Formation and shed light on the areal extent of the Kerri-Kerri and Gombe Formations.

Petters (1978) presented the stratigraphic evolution of the Benue Trough as it relates to the Upper Cretaceous palaeogeography of West Africa. In Petters (1979, 1981) the regional correlation of sediments in the Western African Cratonic basins (Chad, Iullemeden, Taoudeni) were presented, covering stratigraphic unit of basins not only in Nigeria but in the neighboring Chad and Niger Republics and Mali.

Lawal and Moullade (1986) worked on Cretaceous sediments and presented further evidence for the existence of marine Cenomanian, Lower Turonian and Maastrichtian in the Upper Benue Trough of Nigeria where lateral equivalents of the Gongila and the Fika Shale Formations of the Chad Basin were reported. They also drew attention, to the possibility of a Cenomanian portion of the Gongila Formation. Okosun (1992, 1995), presented the systematics of ostracods occurring in the Bornu Basin. Popoff et al. (1986) investigated the ammonite assemblages in the Upper Cretaceous Gongila and Pindiga Formations in

northeastern Nigeria, recognizing seven ammonite zones of the Upper Cenomanian, Lower and Middle Turonian ages. According to them, these are correlatable with the Mid-Cretaceous ammonite zonations of the western and eastern Mediterranean. This study is aimed at shedding light on the palynological zonations of the Tuma, Bulte and Kasade wells located within longitudes 130°E and 140°E and latitudes 13°18'28"N and 14°13'N (Fig.1) of the Bornu Basin. It is studied to establish the age, palynozones of the formations penetrated and the paleoenvironmental conditions of their deposition.

Fig. 1: Geological map of Nigeria showing the location of the Nigerian sector of the Chad Basin (Bornu Basin) and the studied wells (modified after Whiteman, 1982 and Genik, 1992).

Geology and Stratigraphy of the Chad Basin

The Nigerian sector of the Chad Basin is the southwestern arm of the larger Chad Basin, which is otherwise referred to as the Bornu Basin. It is a broad intracratonic depression in Central West Africa containing buried rifts in the Niger Republic, and extending into Cameroon, Central Africa Republic, Sudan, Algeria and most of the Chad Republic. The Bornu - Benue Trough is the failed arm of a triple-junction rift system which formed in the Early Cretaceous along with the separation of the African and South American continents. During the Late Cenomanian to Early Turonian a widespread marine transgression affected the Chad Basin (Burke et al., 1970; Furon, 1963). It is genetically linked with the Benue Trough and shows evidence of a rift origin without any strong indication of a fault bounded margin. Bornu Basin sediments are continental, poorly sorted, medium to coarse grained, sandstones (Bima Formation). They directly overlie the basement (Table 1) and mainly intercalations of shale as reported by Carter et al., (1963) and Avbovbo et al. (1986). Overlying the Bima Formation is the Gongila Formation that is composed of sandstones and shales

deposited in a shallow marine environment. These deposits mark the onset of marine transgression into the basin which reached its peak in the Turonian and continue into Senonian after which a regressive phase of deposition occurred.

In the Maastrichtian, estuarine and/or deltaic conditions prevailed which led to the deposition of the Gombe Sandstone. The formation constitutes intercalated shales, siltstones and ironstones. An extensional deformation occurred in the Late Maastrichtian, which lasted, to the end of the Cretaceous. The sub-basin that succeeded this deformation created space for the deposition of the Tertiary Kerri-Kerri Formation, which overlies unconformably, the Cretaceous sediments (Carter et al., 1963). In the Pleistocene to Pliocene, the continental Chad Formation was unconformably deposited upon the Kerri-Kerri Formation. Towards the end of the Tertiary up to the Recent, there was widespread intrusive volcanic activity in the southern part of the basin (Grant et al., 1972; Burke, 1976). The lithostratigraphic descriptions of the studied wells are presented in Figures 2, 3 and 4.

Table 1: Stratigraphic succession for the Bornu Basin in Nigeria (adapted from Carter et al., 1963)

AGE	FORMATION	LITHOLOGY	AVERAGE THICKNESS (m) This study	THICKNESS (m) Olugbemiro (1997)	THICKNESS FROM SEISMIC DATA (m) Avbovbo <i>et al.</i> (1986)	AVERAGE THICKNESS (m) Carter <i>et al.</i> (1963)	DEPOSITIONAL ENVIRONMENT
Pliocene, Pleistocene	Chad Formation	Clay, Sand	979	717 - 1695		400	Lacustrine
-----	-----	---unconformity---	-----	-----	----- 800 -----	-----	-----
Palaeocene (?)	Kerri-Kerri Formation	Coarse Sandstones, Claystone, Sandstone	Not Present	Not Investigated		- 130	Continental
-----	-----	--(unconformity)--	-----	-----	-----	-----	-----
Maastrichtian	Gombe Sandstone	Shale, Sandstone, Siltstone	Not Present	Not Investigated	0 - 1000	- 135	Deltaic, Estuarine
Turonian - Santonian	Fika Shale	Blue - black Shale	971	840 - 1450	0 - 900	430	Marine
Turonian	Gongila Formation	Shales, Sandstone, Limestone	135	162 - 420	0 - 800	420	Marine, Estuarine
Albian (?) - Cenomanian	Bima Formation	Sandstone, Shales, Limestone	509	716 - 850	2000	3050	Continental
Albian	Pre - Bima	Sandstone, Shale		995 (?)	Variable		Paralic - Marine
-----	-----	--(unconformity)--	-----	-----	-----	-----	-----
Pre - Cambrian				Crystalline	Basement		

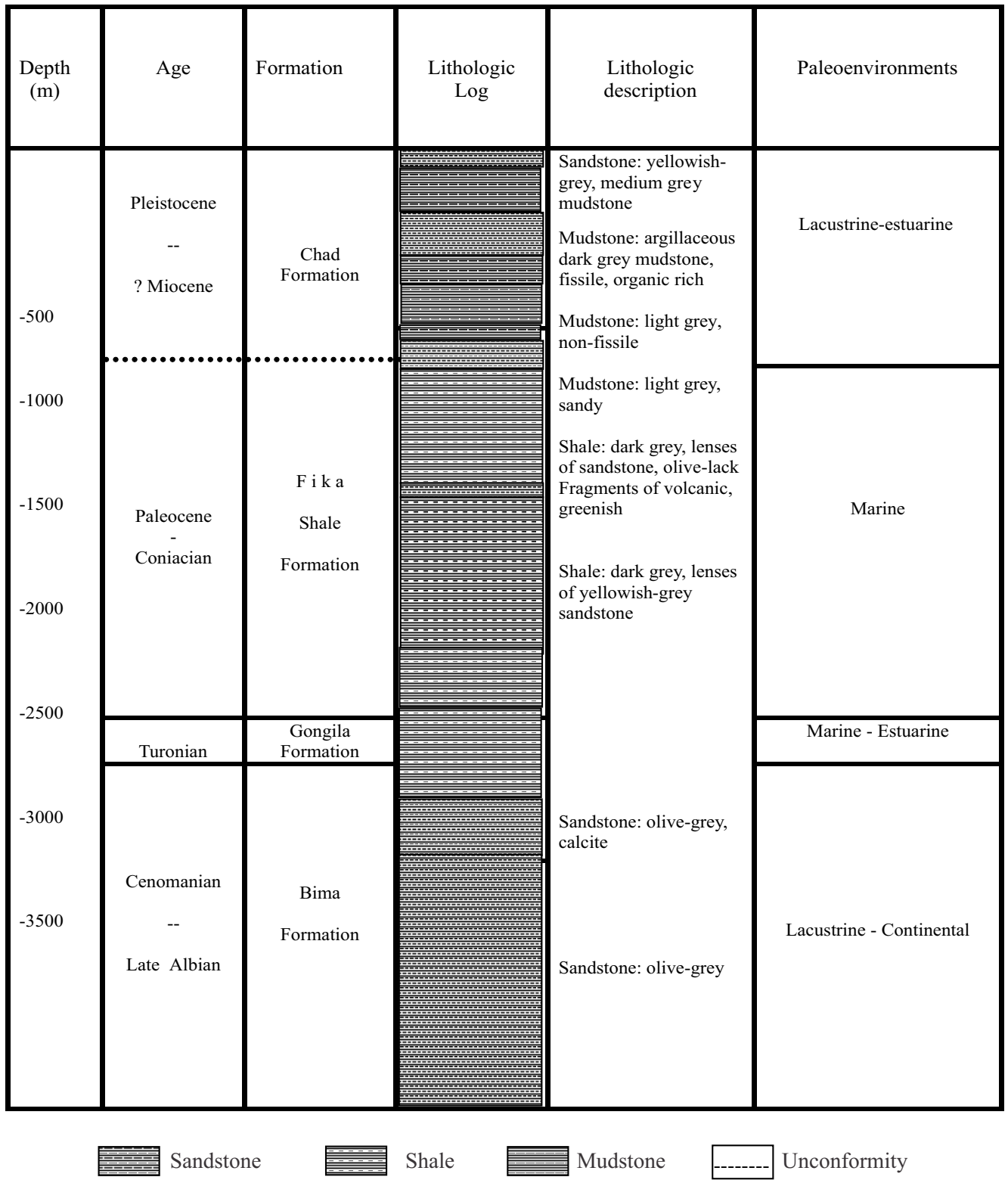


Fig. 2: Lithological profile for Tuma – Well

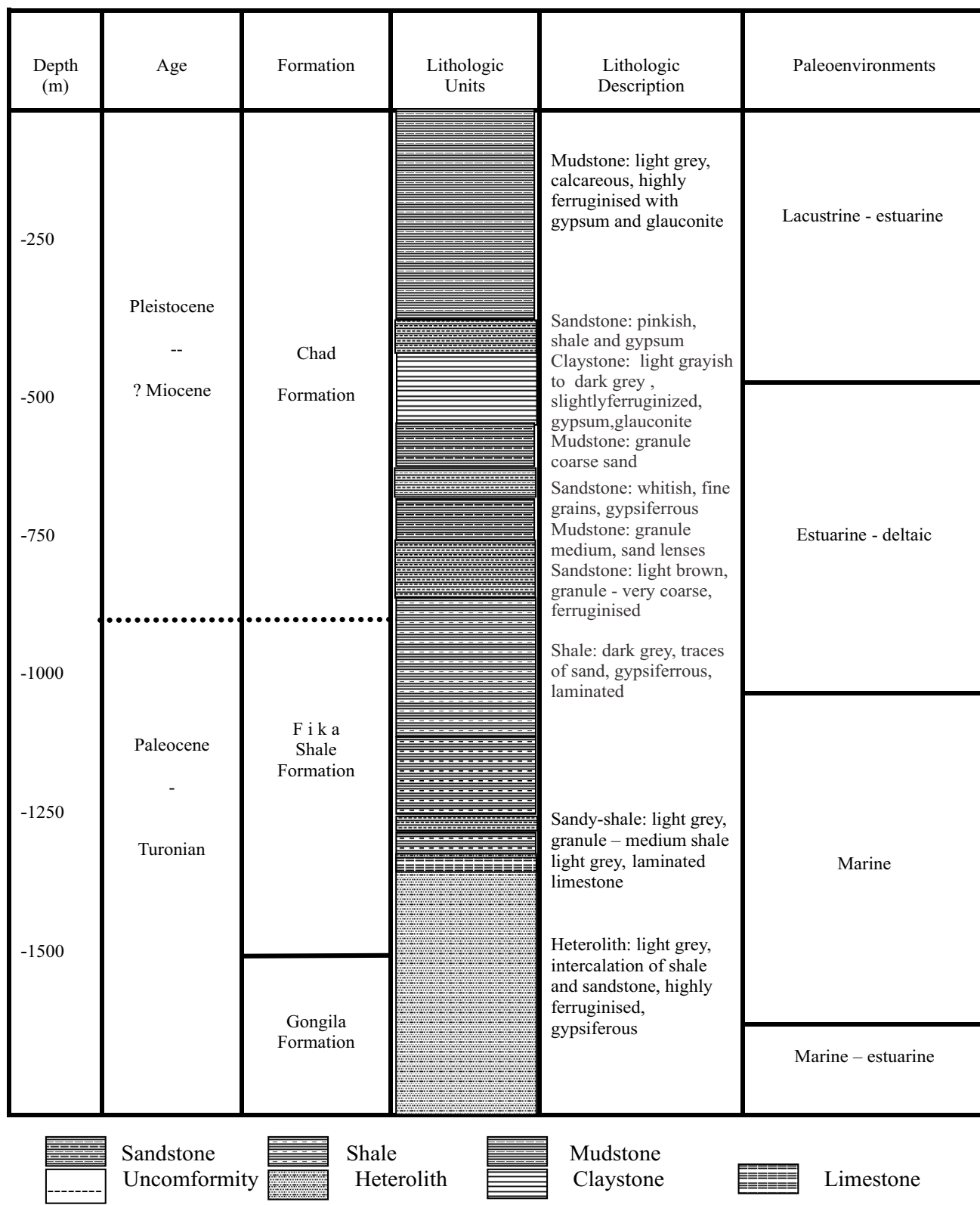


Fig. 3: Lithological profile for Kasade - Well

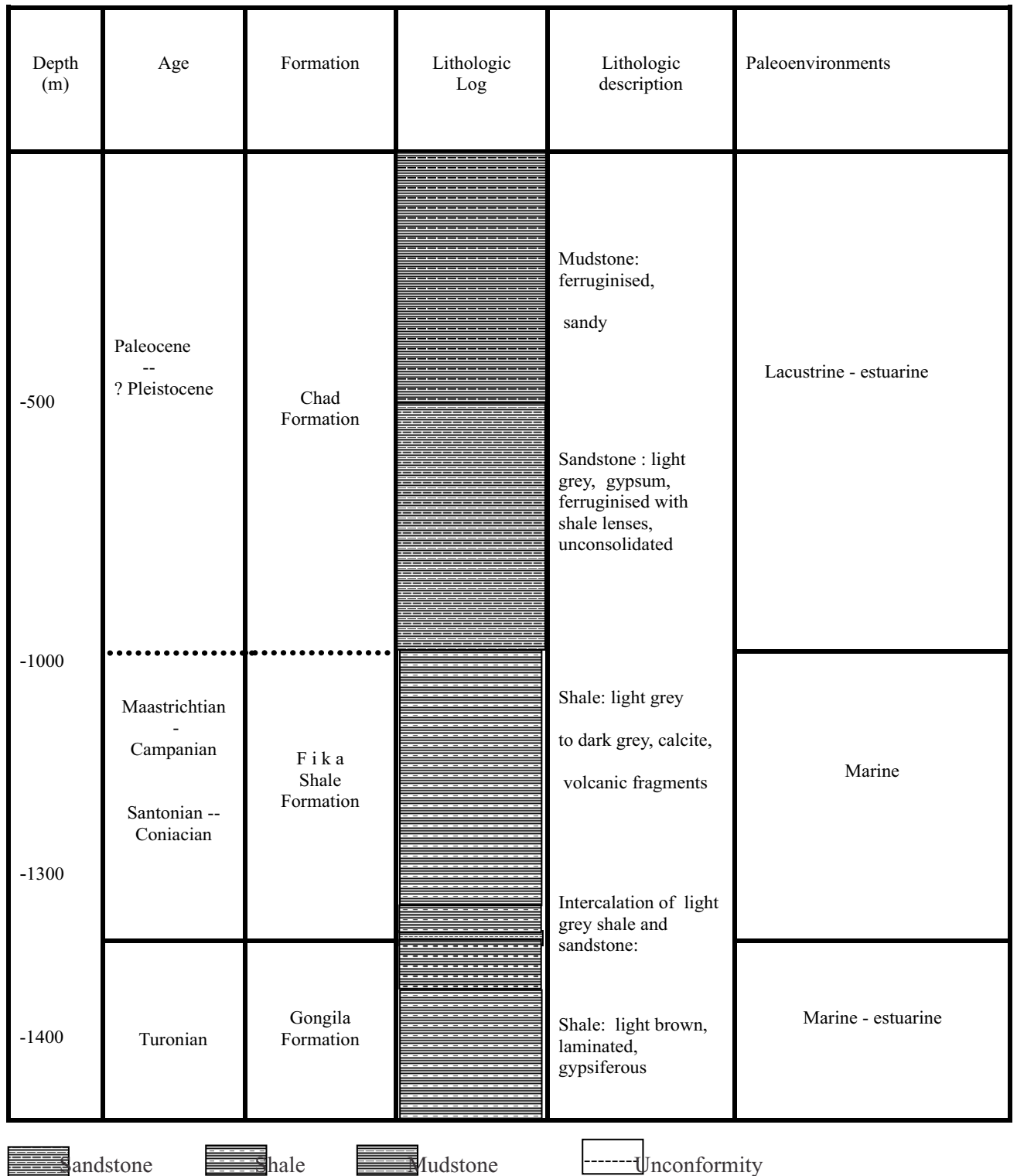


Fig. 4: Lithological profile for Bulte - Well

Materials and Methods

Samples from the Tuma, Kasade and Bulte wells were collected from the Geological Survey of Nigeria Agency (GSNA) in Kaduna through the Management and staff of the National Petroleum Investment Management Services (NAPIMS), a subsidiary of the Nigerian National Petroleum Corporation (NNPC). The samples were thoroughly processed (washed) using standard procedures.

Sampling of the well was done at 5m interval. The samples were separated into two parts; one part was logged in the sedimentological laboratory while the other part was thoroughly washed with distilled water through a 10 μ m polyester sieve to remove drilling mud contaminants and then dried for 24 hours at 50°C for palynological analysis. Ten grams of each sample were digested with 30ml of 10% HCl to remove CaCO₃. It was then digested with 30ml of 40% HF for 24hrs to remove silica, sieve- washed (10 μ m) with water, oxidized in Schulze solution (mixture of nitric acid and potassium chlorate) for 30minutes, washed with 10% potassium hydroxide and centrifuged. The aliquot was dispersed with polyvinyl alcohol, dried and then mounted in DPX. The biostratigraphic study involved the analysis of pollen, spores, dinoflagellates and algae.

RESULTS

Lithostratigraphic Description

The lithologic units observed in the studied wells are shown in Figures 2, 3 and 4. The Tuma well penetrated the Bima, Gongila, Fika, Gombe and Chad formations with a total depth of 3,628m while the Kasade and Bulte wells penetrated the Gongila, Fika, Gombe and Chad with total depths of 1,465m and 1,605m respectively. Samples were analysed and logged for textural characteristics. Lithologic description was carried out under binocular microscope by comparing the sediment characteristics with the standard comparative chart of Western Atlas International Core Laboratories. The lithologic units identified were:

Unit I

This unit consists mainly of greyish terrigenous mudstones with thin interbedded sandstones (<2m) at 265m-305m (Tuma), 50m-475m (Kasade) and 30m-935m (Bulte). The sandstone in the Tuma well is

whitish with greyish-black organic-rich mudstone (495m-550m). Argillaceous sandstones occur with thin bed of mudstone towards the top of the unit. Two upward fining cycles from sandstone to argillaceous sandstone were recorded (710m-705m and 690m-675m), which is an indication of waning depositional energies. The mudstone in the Kasade well is highly ferruginised with traces of gypsum while in the Bulte well, is light grey to yellowish grey, ferruginised sandy mudstones with specks of gypsum with some fissility. The basal part of this unit also consists of volcanic fragments.

Unit II

This unit in the Tuma well is composed of variable sandstone (argillaceous), sporadic occurrences of light grey sandstone and mudstones (<5m). The 1,590m to 2,055m intervals are mainly dark-grey mudstones with moderately well sorted subordinate siltstone. Thin greenish igneous intrusive intervals were recorded at 1,405m to 1,495m, 1590m and 1,715m (dolerite, gabbro and granodiorite). In the Kasade well, this unit range from 475m-865m and is dominated by highly glauconitic with traces of gypsum grey ferruginised claystone. In the Bulte well, the materials consists mainly of light to dark grey calcareous fissile shale with thin interbeds of sand at 1,310m-1,315m.

Unit III

In Tuma well, this unit is dominated by dark grey carbonaceous mudstone (2,115m-2,220m) with subordinate siltstones and lenses of sandstones, Kasade (735m-865m), is characterized by light brown, fine to medium grained sandstone. Bulte exhibits an intercalated light grey sandstone and shale, with coarse grain clasts of calcite (1,335m-1,365m).

Unit IV

This unit (Kasade; 865m-1265m and Bulte; 1,365m-1,465m), consist of partially laminated light – dark grey gypsiferous calcareous shale, while it constitutes the majority of dark grey mudstones in Tuma well (2,220m-2,704m) with intercalated intervals dominated by yellowish grey sandstones, siltstone and argillaceous sandstone. The interval 2,295m to 2,380m (Tuma) consists mainly of mudclasts, which

consists of moderate to unsorted, subangular grains while intervals 2,380m to 2,480m consist of moderate to moderately well sorted, subrounded yellowish grey sandstones. The interval 2,480m to 2,704m is composed of moderately well sorted, subrounded fine grains of mudstones. Intervals 2,625m to 2,698m are poorly sorted and subangular sandstones.

Unit V

This unit in Tuma well is dominated by olive grey sandstones, which are locally argillaceous and contain minor thin beds of mudstone (2,698m-3,628m). At the interval of 2,698m to 2,745m, is the occurrence of mudstones very close to the top of the interval. An upward fining (2,765m) and coarsening units (2,835m) were also recorded.

The dominant lithology at 3,037m-3,625m interval is sandstone. It consists of moderately sorted, subrounded, very fine to coarse grains. This unit in Kasade (1265m-1,375m) is dominantly greyish laminated shale, intercalation of granules to fine sand grained, rounded to angular grained sandstone, poorly sorted and associated poor porosity while is made up of light grey calcareous shale with sand and limestone at the basal part of the unit at 1,375m to 1,415m. At 1,415m to 1,605m, it is light grey in colour, ferruginised traces of shale and limestone intercalation.

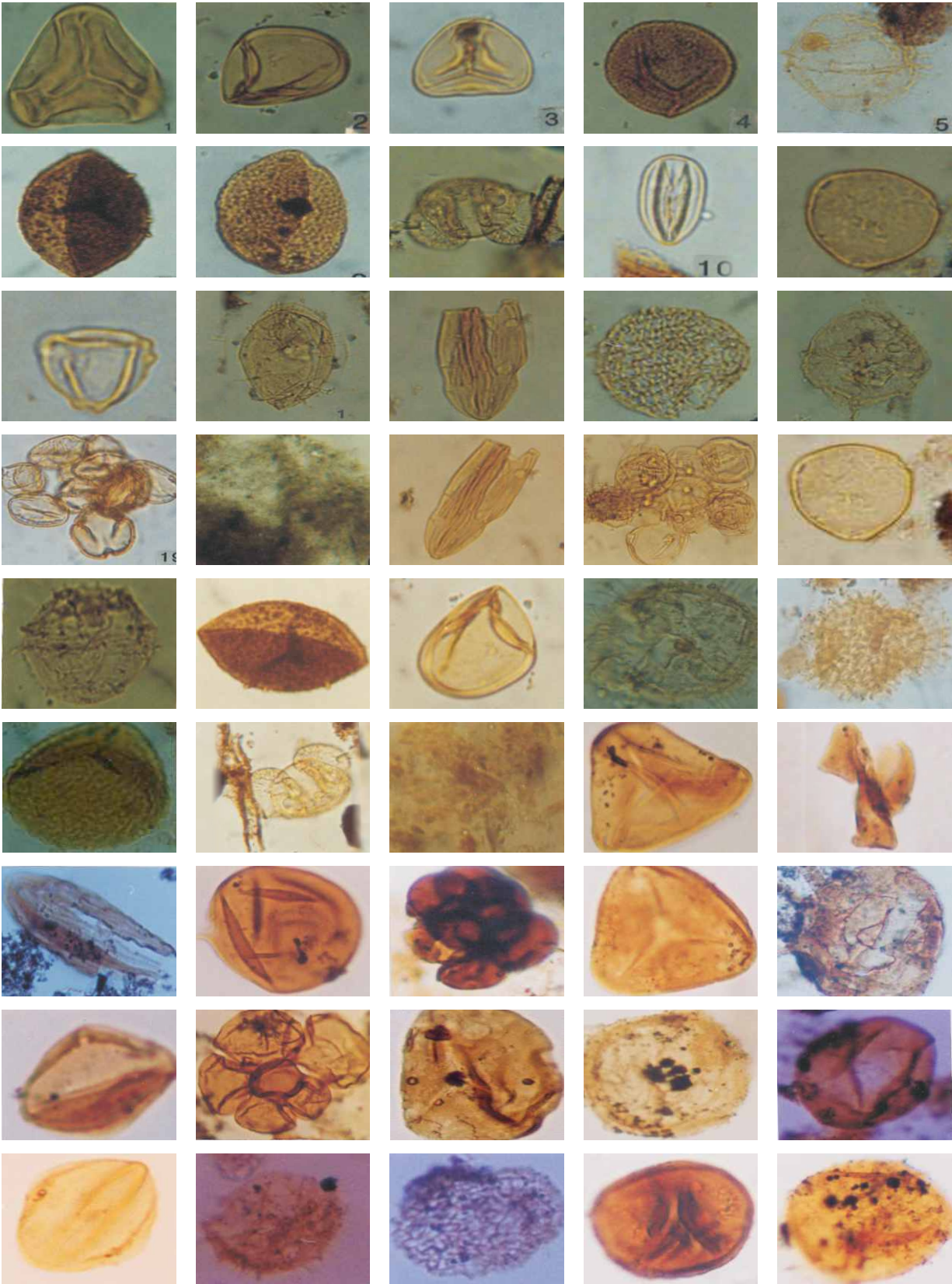
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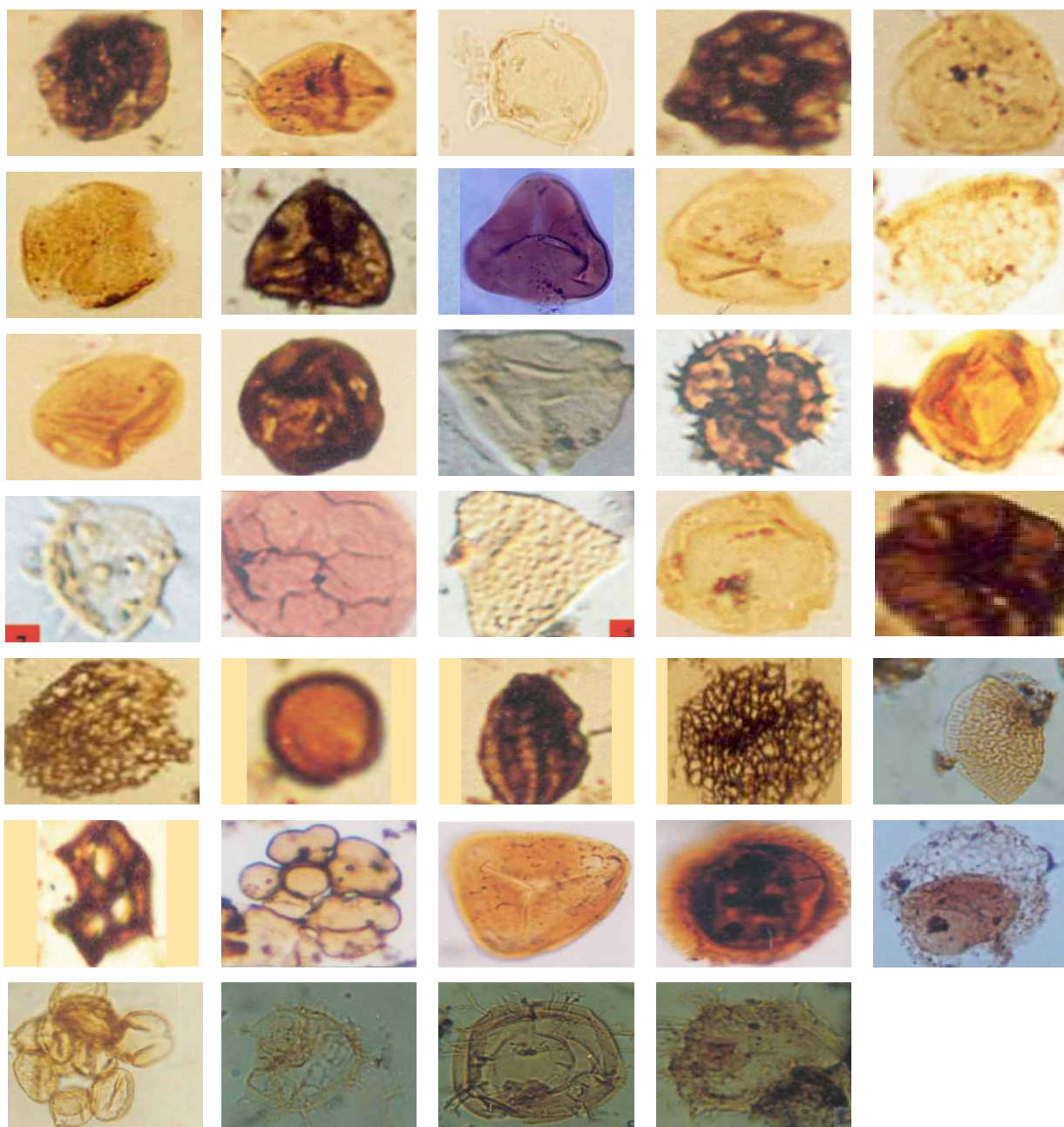
Selected palynomorphs recovered from the studied wells.

1	-	<i>Deltoidospora juncta</i>	Wilson & Webster, 1964 (x1000)
2	-	<i>Laevigatosporites</i> sp.	(x400)
3	-	<i>Cyathidites minor</i>	Couper, 1953 (x400)
4	-	<i>Cicatricosisporites</i> sp.	Regali <i>et. al.</i> , 1974 (x400)
5	-	<i>Alisocyta reticulata</i>	(x400)
6	-	<i>Longapertites vanendenburgi</i>	Van Hoeken-Klinkenberg, 1964 (x400)
7	-	<i>Echimonocolpites major</i>	(x400)
8	-	<i>Proxaperpites</i> sp.	(x400)
9	-	<i>Podocarpidites cf. ellipticus</i>	Cookson, 1947 (x800)
10	-	<i>Psilatricolpites</i> sp.	(x400)
11, 13 & 23	-	<i>Psilatiriporites</i> spp.	(x400)
12	-	<i>Cleistosphaeridium</i> sp.	(x400)
14	-	<i>Spiniferites ramosus</i> .	(x400)
15	-	<i>Ephedripites multicostatus</i>	Brenner, 1963 (x400)
16 & 36	-	<i>Afropollis jardinus</i> (Brenner, 1963) Doyle <i>et al.</i> 1982	(x400), (x800)
17	-	<i>Impagidium</i> sp.	(x400)
18	-	<i>Oligosphaeridium pulcherrimum</i>	(White, 1849), Davey & William, 1966 (x400)
19	-	<i>Retitricolporites</i> sp.	Van Der. Hammen, 1954 (x400)
20	-	Amorphous organic matter	(x400)
21	-	<i>Psilatricolpites</i> sp.	(x400)
22	-	<i>Retitricolporites</i> sp.	Van Der. Hammen, 1954 (x400)
24	-	<i>Areoligera</i> sp.	(x400)
25	-	<i>Areoligera senomensis</i>	(x400)
26	-	<i>Echimonocolpites major</i>	(x400)
27	-	<i>Laevigatosporites</i> sp.	(x400)
28	-	<i>Cleistosphaeridium</i> sp.	(x800)
29	-	<i>Cyclonephelium</i> sp. 3	Cookson and Eisenack,

		1962 (sensu Schrank & Ibrahim, 1995) (x400)	
30	-	<i>Retibrevitricolporites</i> sp. (x800)	
31	-	<i>Concavissimisporites</i> sp. (x400)	
32	-	<i>Pachydermites diderixi</i> (x400)	
33	-	Amorphous organic matter (x400)	
34	-	<i>Cyathidites</i> sp. (x400)	
35	-	<i>Tricolpites giganteus</i> Jardiné & Magloire, 1965 (x800)	
36	-	<i>Afropollis jardinus</i> (Brenner) Doyle <i>et. al.</i> 1982 (x800)	
37	-	<i>Ephedripites cf. multicosatus</i> Brenner, 1963 (x800)	
38	-	<i>Araucariacites australis</i> Cookson, 1947 (x400)	
39	-	<i>Cretacaeiporites polygonalis</i> (Jardiné & Magloire) Herngreen, 1973 (x800)	
40	-	Smooth <i>Trilete</i> spore (x800)	
41	-	<i>Elaterosporites klaszii</i> Jardiné & Magloire, 1965 (x800)	
42	-	<i>Cingulatisporites ornatus</i> Van Hoeken-Klinkenberg, 1964 (x800)	
43	-	<i>Monosulcites</i> sp. (x800)	
44	-	Microforaminiferal wall lining (spiral) (x800)	
45	-	<i>Triorites</i> sp. 3 (x800)	
46	-	Dinocyst (x400)	
47	-	<i>Araucariacites australis</i> Cookson, 1947 (x800)	
48	-	Smooth trilete spore (x800)	
49	-	<i>Tricolpites microstriatus</i> Jardiné & Magloire, 1965 (x800)	
50	-	<i>Cyclonephelium</i> sp. <u>Below, 1981</u> (x800)	
51	-	<i>Afropollis jardinus</i> (Brenner) Doyle <i>et al.</i> , 1982 (x800)	
52	-	<i>Ephedripites</i> sp. 4 Herngreen, 1973 (x800)	
53	-	<i>Inaperturopollenites</i> sp.4 (x800)	
54	-	Microforaminiferal wall lining (spiral) (x800)	
55-58		<i>Triorites</i> sp. (x800)	
59-61		<i>Afropollis jardinus</i> (Brenner) Doyle <i>et al.</i> , 1982 (x800)	
62	-	Forma P0 304 Lawal & Moullade, 1986 (x800)	
63	-	<i>Cretacaeiporites mulleri</i> Herngreen, 1973 (x800)	
64-65	-	<i>Cretacaeiporites polygonalis</i> (Jardiné & Magloire) Herngreen, 1973 (x800)	
66	-	<i>Hexaporitricolpites amelianovi</i> Boltenhagen, 1967 (x800)	
67	-	<i>Incertae sedis</i> Jardiné & Magloire, 1965 (x800)	
68	-	<i>Monosulcites</i> sp. (x800)	
69-72	-	<i>Inaperturopollenites</i> sp. (x800)	
73	-	<i>Cyathidites</i> sp. (x800)	
74&75	-	<i>Araucariacites australis</i> Cookson, 1947 (x800)	
76	-	trilete spores (x800)	
77	-	<i>Cyathidites australis</i> Couper, 1953 (x800)	
78	-	<i>Tricolpites</i> sp. (x800)	
79	-	<i>Spinizonocolpites baculatus</i> Muller, 1968 (x800)	
80	-	<i>Rugulatisporites caperatus</i> (x800)	
81	-	<i>Retibrevitricolpites triangulatus</i> Van Hoeken-Klinkenberg, 1964 (x800)	
82	-	<i>Droseridites senonicus</i> Jardiné & Magloire, 1965 (x800)	
83	-	<i>Zlivisporis blanensis</i> Pacltová, 1961 (x800)	
84	-	<i>Proteacidites</i> sp. Jardiné & Magloire, 1965 (x 800)	

****Note -** ? P300 - P400 forms are highly carbonized hence the photographs could not be presented





Biostratigraphic Age and Correlation

A total count of seven hundred and ninety-seven palynomorph of four species were recorded in the wells. Highly carbonized forms are not presented. Many of the assemblage zones are in proximity of potential biohorizons consisting of last appearance datum (LAD) and the first appearance datum (FAD). *Afropollis jadinus* FAD is named because it coincides with the base of the *Afropollis jadinus* Assemblage Zone and has the potential for long distance correlation. All of the named assemblages' zone taxa are potential range zone markers. The palynological zones were established after Germeraad et al. (1968), Evamy et al. (1978), Lawal and Moullade (1986) and Salard - Cheboldaëff (1979, 1981, 1990). The abundance and diversity plots of the palynomorph for the wells are presented in figures 6, 7 and 8.

Six palynological zones of late Albian to Eocene age have been identified in the studied wells (Figs. 9, 10, 11), and the wells correlation is presented (Fig. 12)

Tuma well palynozones (Fig. 9) are;

Palynological zone : *Afropollis jadinus* Zone

Stratigraphic Interval : 3,628m-2,570m

Suggested age: Late Albian – Cenomanian

Formation: Bima

Definition: The top of this zone is characterized by *Elaterosporites* spp. and continuous occurrence of *Afropollis jadinus* ({Brenner} Doyle et al. 1982) also known as *Reticulatisporites jadinus* (Jardiné and Magloire, 1965).

Discussion: The top of this zone corresponds to the top of the Bima Formation here dated as late Albian - Cenomanian based on the Last Appearance Datum (LAD) of *Afropollis jadinus* and *Elaterosporites klaszii*. Muller (1968), Brenner (1968), Herngreen (1973, 1975), Doyle et al. (1977), De Klasz and Jan du Chêne (1978), Kotova (1978), Salard-Cheboldaëff (1979), Hochulli (1981), Lawal (1982), Schrank (1984) and Lawal and Moullade (1986), all used *Afropollis jadinus* as a Cenomanian marker species. Other species are *Cretacaeiporites polygonalis* (Jardiné and Magloire, 1965), *Monosulcites* sp., *Cretacaeiporites scabratus* (Herngreen, 1973), *Tricolpites redactus*, *Elaterosporites verrucatus*, *Elaterosporites castelainii*

and *Elaterosporites klaszii* (Jardiné and Magloire, 1965) Jardiné 1967 and *Cyclonephelium* sp. (Below, 1981). The base is characterized by species such as *Afropollis jadinus* (Brenner) Doyle et al., 1982, Forma PO 304 (Lawal, 1982), *Monocolpites marginatus* (Van Der Hammen, 1954), and *Cretacaeiporites mulleri*. Foraminiferal test linings and dinocysts also commonly occur. This zone is generally characterized by *Retimonocolpites* sp., *Inaperturopollenites hiatus*, *Classopollis* spp., *Cyathidites* sp., *Galeacornea clavis*, *Galeacornea stoveri* (Elsik, 1968).

Palynological zone : *Hexaporotricolpites emelianovi*/*Classopollis brasilienses* Zone

Stratigraphic Interval : 2,570m-2,235m

Suggested age: Late Cenomanian - Early Turonian

Formation: Gongila

Definition: The base of this is characterized by the First Appearance Datum (FAD) of *Hexaporotricolpites emelianovi* (Boltenhagen, 1967) and *Classopollis brasiliensis* (Herngreen, 1975) in Thusu and Van der Eem, 1985.

Discussion: The zone is co-occurred with *Cretacaeiporites polygonalis* (Jardiné and Magloire) Herngreen, 1973, *Monosulcites* sp., *Galeacornea verrucata* and *Triorites africaensis* assemblages. The zone is dated Cenomanian to Turonian

At the base are occurrences of *Gnetaceaepollenites arealis*, *Elaterosporites klaszii*, *Lycopodium* sp., Forma PO 304 (Lawal, 1982), and *Steevesipollenites binodosus* (Stover, 1964). The top of the zone is defined by the Last Appearance Datum (LAD) of *Hexaporotricolpites emelianovi* (Boltenhagen, 1967) and *Classopollis brasilienses*. Also recoded are the disappearances of *Elaterosporites klaszii*, *Steevesipollenites binodosus* and Forma PO 304 and drastic reduction in the frequencies of *Cretacaeiporites polygonalis*, *Cicatricosisporites dorensis* and *Deltoidospora* sp. The palynomorph assemblage within this zone is poorly preserved and carbonized but moderate numbers were recorded. The assemblage consists mostly of miospores but the occurrences of dinocysts and foraminifera test linings

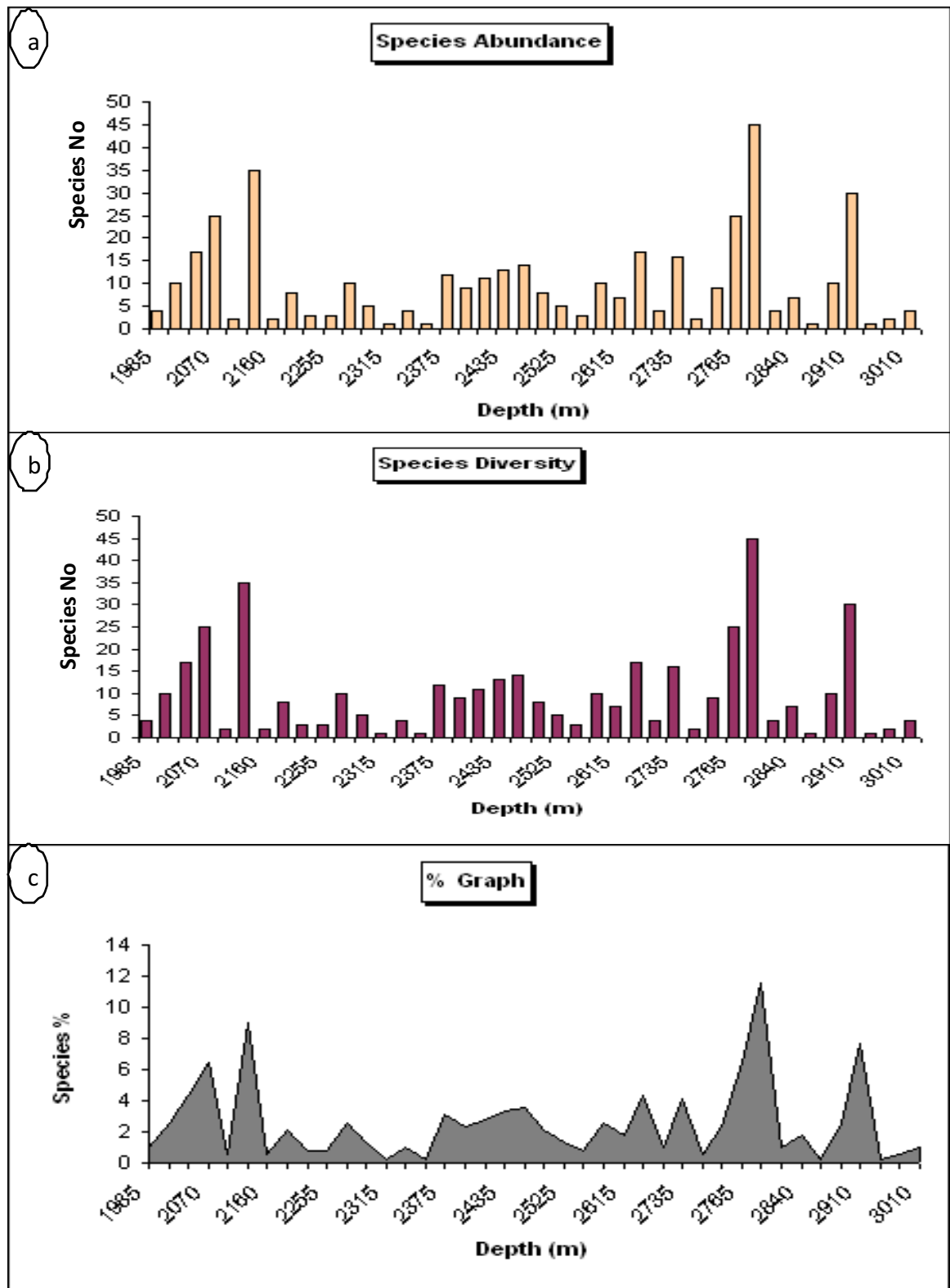


Fig. 6:(a) Species abundance, (b) Species diversity and (c) Percentage graph of total counts showing diverse palynomorph occurrence in Tuma well.

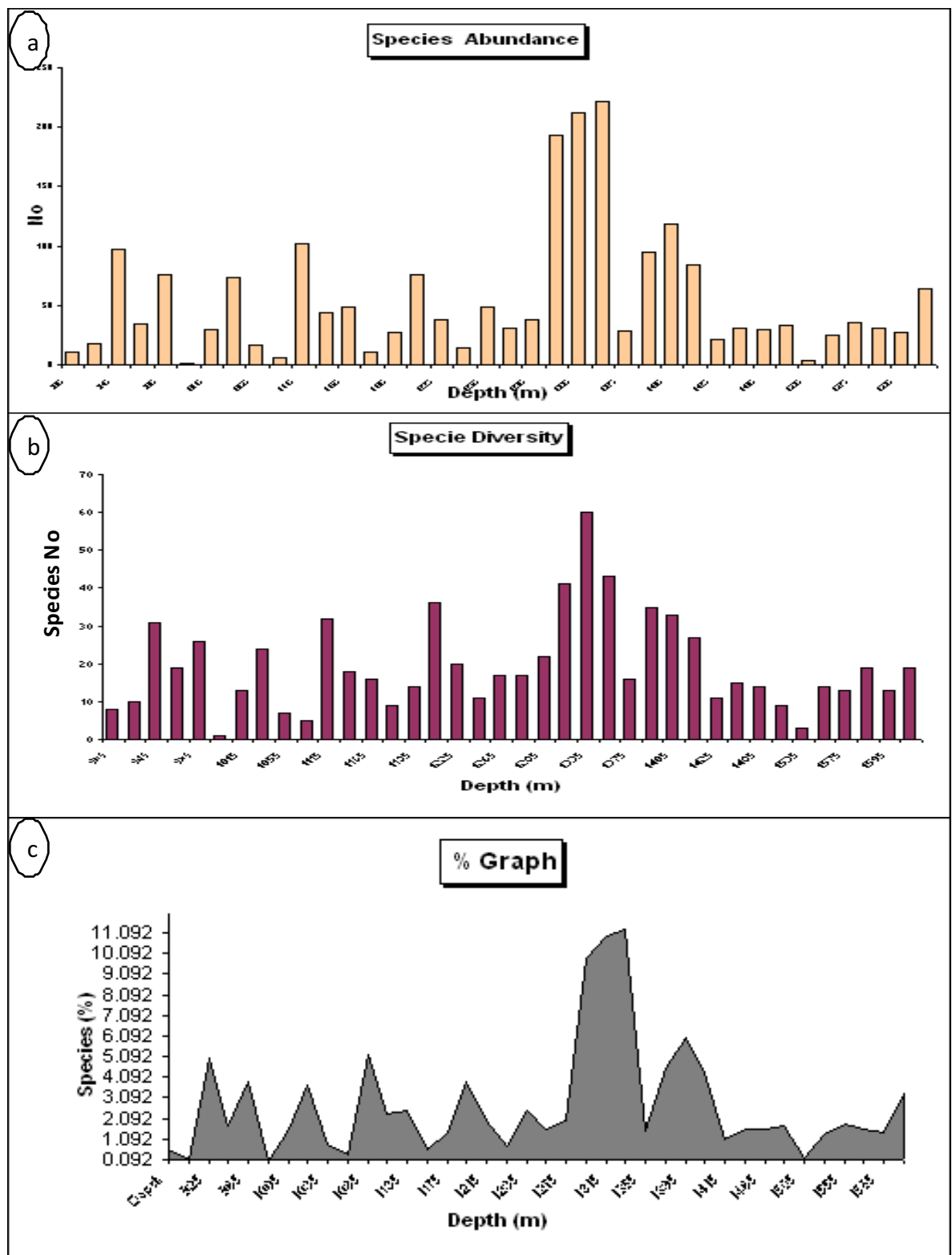


Fig. 7:(a) Species abundance, (b) Species diversity and (c) Percentage graph of total counts showing diverse palynomorph occurrence in Kasade well.

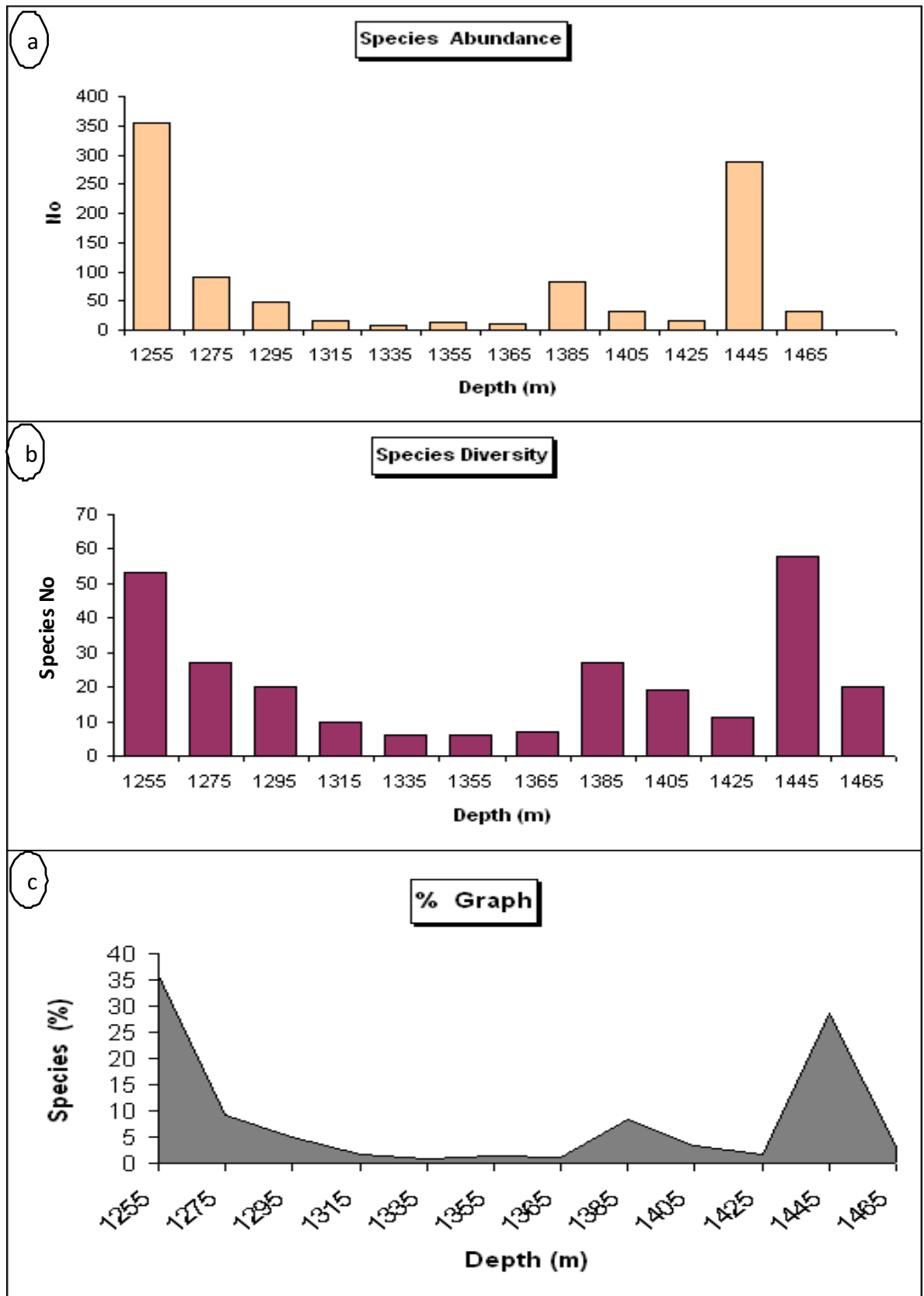


Fig. 8 : (a) Species abundance, (b) Species diversity and (c) Percentage graph of total counts showing diverse palynomorph occurrence in Bulte well.

are found within the interval.

Palynological zone : *Triorites africaensis* Zone

Stratigraphic Interval : 2,235m-2,120m

Suggested age: Lowermost Turonian

Formation: Gongila

Definition: The zone is characterized by the occurrence of *Triorites africaensis* (Jardiné and Magloire, 1965), within this interval.

Discussion: This zone is contrary to the late Cenomanian guide species earlier reported from the Cretaceous sediment (Jardiné and Magloire, 1965), Lawal and Moullade (1986)). This species is still found even in the Turonian (Early).

Assemblages within this interval consist principally of low diversity miospores, together with rare dinocysts and moderate numbers of foraminiferal test linings.

Palynological zone : *Cretaceaiporites scabratus* Zone

Stratigraphic Interval: 2,120m-1,605m

Suggested age: Late Turonian

Formation: Fika

Definition: The top of this zone is defined by the FAD of *Cretaceaiporites scabratus* (Herngreen, 1973) and the base the LAD of *Droseridites senonicus* (Jardiné and Magloire (1965).

Discussion: The abundance of *Gnetaceaepollenites* sp. occurred at 2,175m while *Subtilisphaera* sp. exhibits a marked reduction in abundance. Dinocyst assemblages show a general decrease in diversity. Generally, miospores exhibit an increase in representation, although assemblages are of low diversity dominated by *Araucariacites australis* Cookson, 1947, together with foraminiferal test linings.

Palynological zone: *Droseridites senonicus* Zone

Stratigraphic Interval : 1,605m-1,220m

Suggested age: Coniacian – Santonian

Formation: Fika

Definition: The zone is defined by the LAD occurrence of *Proxapertites operculatus* (Van Der Hammen, 1956) and the FAD occurrence of

Droseridites senonicus and *Emmetrocyta* sp. (Jardiné and Magloire, 1965; Jan Du Chêne et al. 1978; Lawal and Moullade 1986).

Discussion: The disappearance of *Pediastrum* sp., which could also be as a result of facies change marks the beginning of *Emmetrocyta* sp. subzone, which is positioned at the highest occurrence of *Emmetrocyta* sp. at the depth of 1,230m.

There is co-occurrence of *Droseridites senonicus* and *Subtilisphaera* spp. at the depth of 1,605m with marked increase in abundance. Miospores abundance is low within this zone, and dinocysts are also abundant and moderately diverse in distribution.

Palynological zone : *Proxapertites operculatus* Zone

Stratigraphic Interval : 1,235m-720m

Suggested age: Paleocene

Formation: Fika

Definition: The zone is characterized by the FAD occurrence of *Proxapertites operculatus* (Van Der Hammen, 1956).

Discussion: It occurs in association with *Spiniferites* sp. and *Subtilisphaera cheit* at the interval below 725m. Common *Deltoidospora* sp. and *Granulatisporites* sp. characterize the miospore assemblages below the 1,090m depth. Numerous specimens and species attributable to the genus *Spiniferites* were identified. Also recorded in this zone are *Monocolpites marginatus* (Van Der Hammen, 1956), *Foveotriletes margaritae*, *Buttinia andreevi* (Boltenhagen, 1967) and *Tricolpites* spp. with rare occurrence of *Mauritidites crassiexinus* species.

Kasade well Palynozones (Fig 10) are;

Palynological zone: *Triorites africaensis* Zone

Stratigraphic Interval: 1,605m-1,505m

Suggested age: Late Cenomanian - Early Turonian

Formation: Gongila

Definition: The base of the interval is characterized by the FAD of *Triorites africaensis* (Jardiné and Magloire, 1965) with co-occurrence *Classopollis brasiliensis*, *Afropollis jardinus*, *Steevesipollenites* sp. *Galeacornea causea* (Stover, 1963) and *Gnetaceaepollenites* sp.

Discussion: The interval is marked by increase in the frequency of *Cretacaeiporites* sp. and the LAD of *Triorites africaensis*. The disappearance of *Classopollis brasiliensis*, *Afropollis jardinus*, *Steevesipollenites* and *Gnetaceaepollenites* sp. were recorded. The interval is characterized by the occurrence of *Cretacaeiporites mulleri*, *Cretacaeiporites polygonalis*, *Trifossapollenites* sp., *Tricolporopollenites* sp., S.CI. 428, S.CI. 215 (Jardiné and Magloire, 1965), *Tricolporopollenites* sp., *Hexaporotricolpites emelianovi* and *Monocolpopollenites* sp.

Palynological zone: *Cretacaeiporites scabratus* Zone

Stratigraphic Interval: 1,505m-1,405m

Suggested age: Late Turonian

Formation: Fika

Definition: The base of the interval is defined by the occurrence of *Cretacaeiporites* spp. which increases both in frequency and diversity.

Discussion: There is concurrent disappearance of *Triorites africaensis*, *Classopollis brasiliensis*, *Afropollis jardinus*, *Steevesipollenites* sp., *Gnetaceaepollenites* sp.1 (Lawal and Moullade, 1986) and *Bacutricolpites* sp.1. The top of the interval is marked by occurrence of *Droseridites senonicus* and increase in the frequency of gymnosperms. The interval is characterized by the increase in the diversity and abundance of *Cretacaeiporites* spp. such as *Cretacaeiporites scabratus*, *Cretacaeiporites mulleri*, *Cretacaeiporites infrabaculatus* and *Punctioratipollis krutchii*. Low diversity and abundance of gymnosperms and microflora abundance and diversity, further characterize the interval compared with the lower and overlying zones.

Palynological zone: *Droseridites senonicus* Assemblage Zone

Stratigraphic Interval: 1,405m-1,285m

Suggested age: Coniacian – Santonian

Formation: Fika

Definition: The base of the zone is marked by the occurrence of *Droseridites senonicus* and *Zlvisporites blanensis*. This is strongly associated with basal increase in the frequencies of *Tricolporopollenites* sp.,

S.CI 428, S.CI 215(Jardiné and Magloire, 1965), T.S 152, T.S 299, *Tricolpites* sp., S.CI 260 and *Monocolpopollenites* sp.

Discussion: The base of this interval is further characterized by the appearances of *Proteacidites* sp., *Tubistephanocolpites cylindricus*, *Cingulatisporites ornatus*, *Rugulatisporites caperatus*, *Aquilapollenites alveolatus* and spontaneous increase in the abundance of *Cyathidites* sp. The top of the interval is placed at the disappearance of *Tricolporopollenites* sp., S.CI. 428, 260, S.CI. 215, 152, 299 and *Tricolpites* sp. The interval is characterized by the new appearance of *Aquilapollenites* sp., *Rugulatisporites* sp., *Syncolporites marginatus* and *S. subtilis*. Many pollen forms also disappeared in this zone such as *Cretacaeiporites* spp., *Tricolpites giganteus*, *Tricolpites gigantoreticulatus* and *Hexaporotricolpites emelianovi*. Very high microflora population and diversity further characterize the interval. The gymnosperms and *Cyathidites* sp. show maximum development and it is strongly associated with high abundance of microforaminiferal wall linings and dinoflagellate cysts.

Palynological zone: *Longapertites* spp. Zone

Stratigraphic Interval : 1,285m-1,185m)

Suggested age: Campanian- Early Maastrichtian

Formation: Fiak

Definition: The base of the interval is defined by *Droseridites senonicus* and *Zlvisporites blanensis*, and the FAD occurrence of *Longapertites microfoveolatus* and a considerable decrease in *Rugulatisporites caperatus*.

Discussion: The top of the interval is marked by the high frequency occurrence of *Monocolpites marginatus* and the first occurrence of *Echitriporites trianguliformis*. It is also associated with the abrupt decrease in the frequency of *Cyathidites minor* and continuous occurrence of *Longapertites* spp. The interval is characterized by the appearance of new forms such as *Milfordia* sp., *Milfordia* sp.2, *Milfordia* sp. 4 and *Longapertites* sp. The upper part of the interval at 1,225m probably marks the top of the Campanian and the base of Early Maastrichtian age

and it is characterized by the appearance of *Buttinia andreevi*, *Retidiporites*, *magdalenensis*, reappearance of gymnosperms such as *Tricolpopollenites* sp., S.CI. 152 and S.CI. 428 (Jardiné and Magloire).

Palynological zone: *Spinizonocolpites baculatus* Zone

Stratigraphic Interval: 1,185m-1,115m

Suggested age: Late Maastrichtian

Formation: Fika

Definition: The high occurrence of *Monocolpites marginatus*, the appearance of *Echitriporites trianguliformis* (Van Hoeken-Klinkenberg, 1964) and the FAD occurrence of *Spinizonocolpites baculatus* mark the base of the zone. *Spinizonocolpites* (Nypa) is mangrove pollen, which is common in coeval West African coastal basins.

Discussion: The top of the interval is characterized by the low frequencies of *Auriculiidites* sp., *Periretisyncolpites* sp. (Van Hoeken-Klinkenberg, 1964), *Droseridites senonicus* and high frequencies of *Monoporites annulatus* (Jardiné and Magloire, 1965), continuous occurrence of *Longapertites marginatus* (Van Hoeken-Klinkenberg, 1964) and *Buttinia andreevi* with maximum development of *Zlivisporites blanensis* and *Auriculiidites* sp. Other floras that show continuous appearance in the zone are *Retimonocolpites* sp., and *Rugulatisporites caperatus* that are absent in the Paleocene (Van Hoeken-Klinkenberg, 1964). However, forms that show appearances include *Distaverrusporites simplex*, *Cingulatisporites ornatus* (Van Hoeken-Klinkenberg, 1964), *Stephanocolporate* grains and *Gemmazonocolpites* sp. The assemblage of this zone corresponds to the *Proteacidites dehaani* Zone established by Germeraad et al. (1968) for tropical areas and is dated Late Maastrichtian age.

Palynological zone: *Proxapertites operculatus* /? P200 - P400 Zones

Stratigraphic Interval: 1,115m-905m

Suggested age: Paleocene -? Eocene

Formation: Fika

Definition: The base of the interval in this formation is marked by the FAD of *Proxapertites operculatus*.

Discussion: The top of the interval recorded high frequencies with maximum species associated with the occurrence of *Psilatricolporites crassus* and *Gemmamonocolpites* sp., *Grimsdalea magnaclavata*, *Psilastephanocolpites fissilis* and *Psilatricolporites crassus*. The interval is further characterized by the occurrence of *Proxapertites* sp., *Retimonocolpites* sp., *Anacolosidites* cf. *luteoides*, *Triporites* sp., *Ctenolophonidites costatus*, *Proteacidites* sp., *Tricolpites* sp. and *Buttinia andreevi*. Microfloras present are angiosperm pollen grains such as *Proxapertites cursus*, *Syncolporites* sp. and *Retitriporites* cf. *clarensis*.

Grimsdalea magnaclavata has its basal occurrence in P300 Zone but does not appear beyond P400 Zone (Evamy et al., 1978). Others forms include *Spinizonocolpites echinatus*, last appearance of *Periretisyncolpites* sp., *Auriculiidites* spp., *Longapertites* sp., *Retidiporites magdalensis* and *Syncolporites marginatus*. At the base are the occurrences of *Verrucatosporites usmensis* and *Peregrinipollis nigericus*, which are restricted to P400 Zone (Evamy et al. 1978), *Monocolpites marginatus*, *Mauritiidites crassibaculatus*, *Retibrevitricolporites triangulates*, *Pteris* sp., *Retibrevitricolporites distinctus*, *Echitriporites trianguliformis*, *Striamonocolpites* sp. and *Zlivisporis blanensis*, similar to palynomorph assemblages of P300 and P400 Zones of Evamy et al. (1978). It also corresponds to the floral assemblages reported by Salard - Cheboldaef (1981) in Akinbo and Ameki Formations in the southern Nigeria and by the base of the Gwandu Formation in the Northwestern Nigeria.

Bulte well Palynozone (Fig. 11) are

Palynological zone: *Triorites africaensis* Zone

Stratigraphic Interval: 1,465m – 1,385m

Suggested age: Late Cenomanian - Early Turonian

Formation: Gongila

Definition: The base is characterized by the co-occurrences of *Classopollis brasiliensis*, *Afropollis jardinus*, *Elaterosporites klaszii*, *Cretacaeiporites mulleri*, *Ephedripites* sp. and the LAD of *Triorites africaensis*.

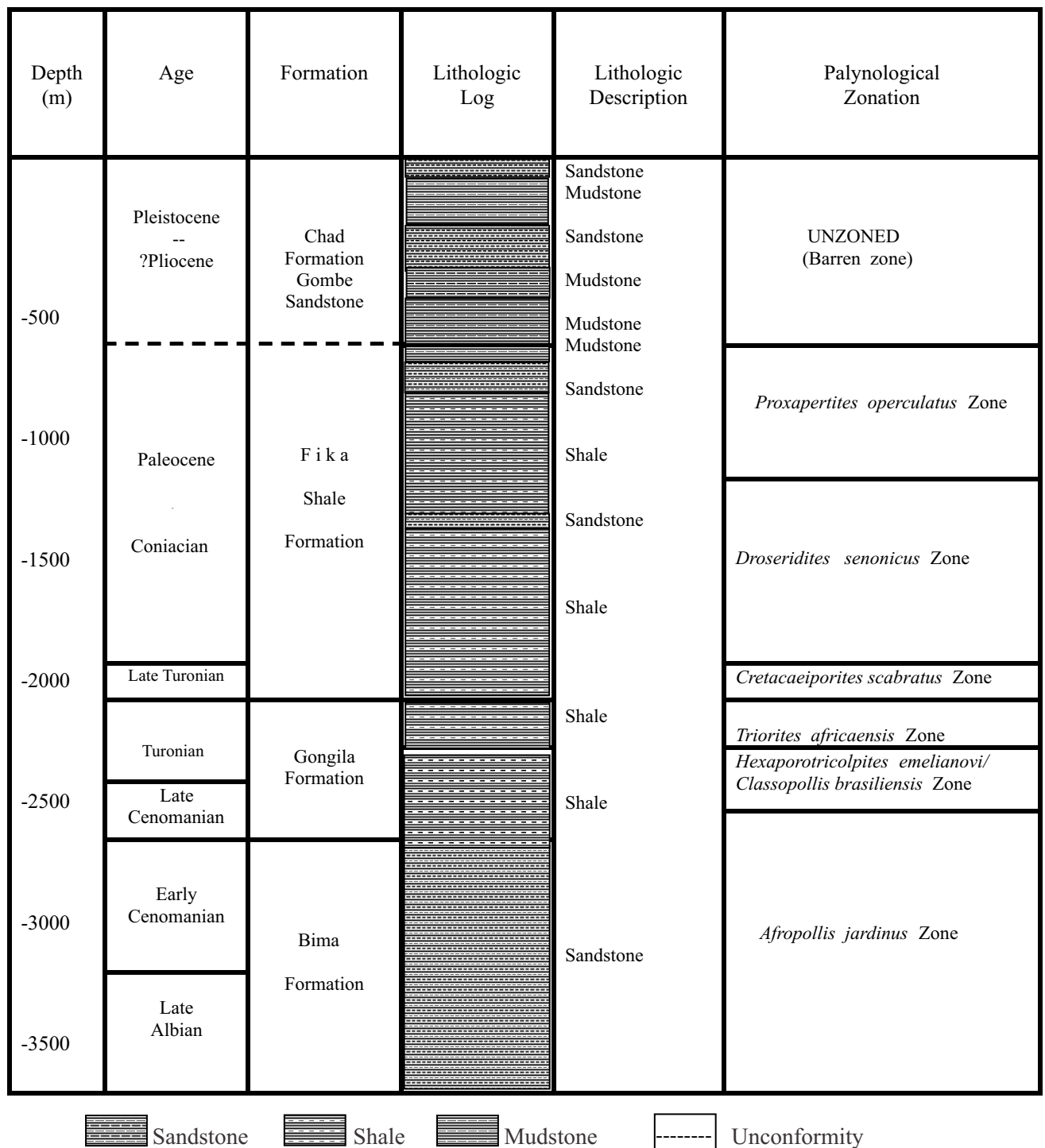


Fig. 9: Palyno- stratigraphic profile for Tuma – Well

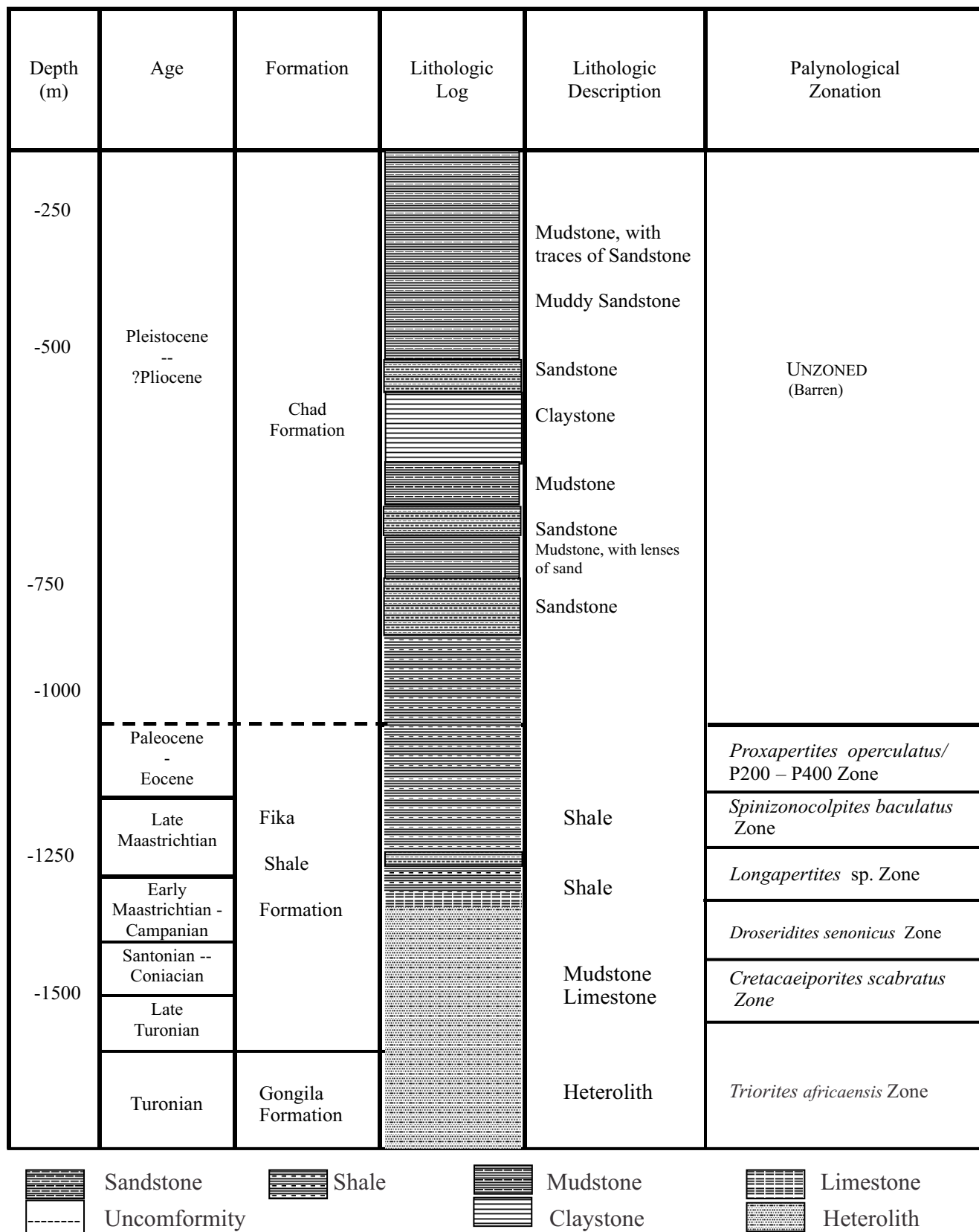
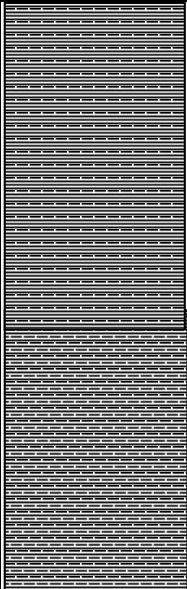
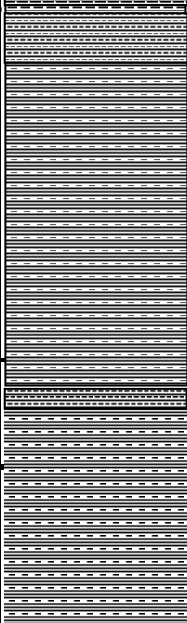


Fig. 10: Palyno- stratigraphic profile for Kasade - Well

Depth (m)	Age	Formation	Lithologic Log	Lithologic Description	Palynological Zonation
-500	Pleistocene -- ?Pliocene	Chad Formation		Mudstone, siltstone traces Sandstone Sandstone, with lenses of shale fragments of volcanic	Unzoned (Barren)
-1000	Paleocene	F i k a Shale Formation		Shale	<i>Proxapertites operculatus</i> Zone
-1250	Late Maastrichtian				<i>Spinizonocolpites baculatus</i> Zone
	Early Maastrichtian –Campanian				<i>Longapertites vanendenburgi</i> Zone
	Santonian – Coniacian				<i>Droseridites senonicus</i> Zone
	Turonian	Gongila Formation			<i>Cretacaeiporites scabratus</i> Zone
					<i>Triorites africaensis</i> Zone

 Sandstone
  Shale
  Mudstone
  Unconformity

Fig. 11: Palyno- stratigraphic profile for Bulte - Well

Discussion: The top of the zone is marked by the disappearance of *Classopollis brasiliensis*, *Afropollis jardinus*, *Gnetaceaepollenites* sp., and concurrent appearance of *Hexaporotricolpites emelianovi* and *Tricolpites giganteus*. The interval is characterized by the occurrence of *Galeacornea causea*, *Galeacornea clavis*, *Liliacidites* sp., *Concavissimisporites variegates* (Delcourt and Sprumont, 1963), *Cretacaeiporites scabratus*, and *Ephedripites multicostatus*.

Palynological zone: *Cretacaeiporites scabratus* Zone

Stratigraphic Interval: 1,385m-1,275m

Suggested age: Turonian

Formation: Fika

Definition: The base of the zone coincides with the disappearance of *Triorites africaensis*, *Classopollis brasiliensis*, *Gnetaceaepollenites* sp., *Afropollis jardinus* and the appearance of *Tricolpites giganteus*, increase in the frequency of *Cretacaeiporites scabratus* and *Cretacaeiporites mulleri*.

Discussion: This interval range zone is characterized by low microfloral abundance in compared to the lower and upper zones. The top of this zone is characterized by the increase in diversity of the angiosperm such *Tricolporopollenites* sp., S.CI. 107, S.CI. 152, S.CI. 428 (Jardiné and Magloire, 1965) and *Monocolpopollenites* sp., very low floral population and diversity. Others are charred Graminae and microflorals such as *Hexaporotricolpites emelianovi*, *Tricolporopollenites* sp., and *Syncolporites subtilis* are reported to be very common in the Turonian but rare in the Senonian (Jardiné and Magloire, 1965; Boltenhagen, 1967). However, *Cretacaeiporites scabratus* and *C. mulleri* have their maximum abundance in the Turonian. (Boltenhagen, 1980). Jan du Chêne (2000) also dated *Classopollis* sp. from Cenomanian to Turonian. This zone is dated Turonian on the basis of the quantitative occurrence of *Cretacaeiporites scabratus* and rare occurrence of *Triorites africaensis* and the disappearance of *Bacutricolpites* sp.1, *Gnetaceaepollenites* sp.1, and *Classopollis brasiliensis* (Kotova, 1978).

Palynological zone: *Droseridites senonicus* Zone

Stratigraphic Interval: 1,275m-1,215m

Suggested age: Coniacian – Santonian

Formation: Fika

Definition: It is defined by the FAD of *Droseridites senonicus*. The base of the zone is marked by increase in diversity of the angiosperm such as *Tricolporopollenites* sp., S.CI. 107, S.CI. 152 (Jardiné and Magloire, 1965), and S.CI. 428 (Jardiné and Magloire, 1965). Discussion: The appearances of *Zlavisporis blanensis*, *Cingulatisporites ornatus*, *Rugulatisporites caperatus*, *Tubistephanocolpites cylindricus*, *Monosulcites* sp. (Jardiné and Magloire, 1965; Jan Du Chêne et al. 1978; Lawal and Moullade 1986) near the base characterized this interval. The top of the zone is placed at the basal occurrence of *Longapertites* sp. and high microflora population and diversity characterize the interval. *Cyathidites* sp. has maximum development here and strongly associated with lining and dinoflagellate cysts.

Palynological zone : *Longapertites vanendenburgi* Zone

Stratigraphic Interval: 1,215m-1,115m

Suggested age: Campanian - Early Maastrichtian

Formation: Fika

Definition: The base of the zone is placed at the final disappearance of *Tricolporopollenites* sp., S.CI. 428 (Jardiné and Magloire, 1965), S.SI. 152, S.CI. 107, *Tricolpites* sp. and the continuous appearance of *Longapertites* sp.

Discussion: The microflora abundance and diversity in this zone is lower compared to the underlying zone. Further characterized by rare occurrences of *Rugulatisporites caperatus*, abrupt decrease in the abundance of *Cyathidites* sp. and least abundant level of dinoflagellate cysts. The top of the zone is marked by high frequencies of *Monocolpites marginatus* and base occurrence of *Spinizonocolpites echinatus*. The upper unit from 1,155m-1,115m is characterized by re-emergence of angiosperm.

Palynological zone : *Spinizonocolpites baculatus* Zone

Stratigraphic Interval: 1,115m-995m

Suggested age: Late Maastrichtian

Formation: Fika

Definition: The zone is marked by FAD of

Spinizonocolpites echinatus (Muller, 1968) and the appearance of *Proxapertites operculatus*.

Discussion: This interval range zone is characterized and marked by high frequency of *Foveotriletes margaritae*, *Aquilapollenites* sp., *Monoporites* sp., *Retibrevitricolpites triangulatus*, *Verrucatosporites usmensis* and *Monosulcites* sp. The microflora assemblage corresponds to the *Proteacidites dehaani* Zone established by Germeraad et al., 1968.

Palynological zone : *Proxapertites operculatus* Zone

Stratigraphic Interval: 995m - 395m)

Suggested age: Paleocene - ?Eocene

Formation : Fika

Definition: The zone is defined by the FAD of *Proxapertites operculatus*.

Discussion: The co-occurrence *Verrucatosporites usmensis*, *Monoporites* sp., *Retibrevitricolpites triangulatus*, *Foveotriletes margaritae*, *Tricolporopollenites* sp. and *Arecipites* sp. were recorded. The top is deficient of diagnostic forms. The interval can further be characterized by the occurrence of *Grimsdalea magnaclavata* and *Doualaidites* sp.

DISCUSSION

The fossil assemblage that characterize the *Afropollis jardinus* Zone are *Afropollis jardinus*, Forma PO 304 (Lawal and Moullade, 1986), *Elaterosporites klaszii*, *Cretacaeiporites scabratus*, *C. polygonalis*, *C. mulleri*, *Classopollis brasiliensis*, *Tricolporopollinites* sp., *Hexaporotricolpites emelianovi* and *Galeacornea clavis*.

Afropollis jardinus is the main species that marks the base of the Tuma well and it shows a continuous regular occurrence. The top of Cenomanian marks the zone where *Afropollis jardinus* disappears in the stratigraphic interval studied.

This species was recognised in the Aptian to Cenomanian of Senegal, Albian to Cenomanian of Nigeria, Aptian and Cenomanian of Gabon and Congo (Jardiné et al., 1974); Albian to Cenomanian of Brazil (Herngreen, 1973) and Peru (Brenner, 1963). *Classopollis brasiliensis* is one of the two guide species for the *Triorites africaensis* (Late Cenomanian) Zone

of Lawal and Moullade, (1986) been species occurred sporadically in the studied intervals of the wells, but is described from sediments in Senegal of Lower Cenomanian age. While frequency and continuous occurrence has been used to date sediment as lowermost Turonian to Cenomanian (Jan du Chêne, 2000) while some of the taxa such as *Ephedripites* sp., *Tricolpites* sp., and *Cretacaeiporites mulleri* have been recorded in the Lower Senonian of the Senegal Basin (Jardiné and Magloire, 1965; Azema and Boltenhagen, 1974). The pollen and spores assemblage recorded is similar to that described in Sequence VII of Senegal (Jardiné and Magloire, 1965); Cenozoene "1" (Boltenhagen, 1967, 1975), Zone V in Gabon (Moussavou, 1980) and Zone III in Benue Trough, Nigeria (Lawal and Moullade, 1986), all dated Turonian age.

In West Africa and South America, tricolpate pollen first appeared at the Cretaceous (Jardiné and Magloire 1965; Muller 1968; Herngreen 1973). *Tricolporopollenites* were reported first from sediments not earlier than Late Albian and sometimes only from the Cenomanian (Muller, 1968). Its first appearance in West Africa and Brazil was reported by Jardiné and Magloire (1965) and Herngreen (1973).

Galeacornea spp. were recovered from the studied samples. The stratigraphic range of *G. clavis* (Stover, 1963) lies within the Cenomanian to Turonian age interval (Lawal and Moullade, 1986).

Elaterosporites sp. characterized the basal units in the studied section. *Elatere* bearing forms are reported in Albian to Cenomanian of Brazil, Senegal, Ivory Coast, Nigeria, Gabon and Algeria by a great genetic diversity (Kotova, 1978).

Other genera unique to this assemblage are *Hexaporotricolpites emelianovi*, *Triorites africaensis* and *Cretacaeiporites scabratus*, *Hexaporotricolpites* sp., *Hexaporotricolpites* and *Triorites* sp. were defined by Jardiné and Magloire (1965) in the Upper Albian to Lower Cenomanian deposits of the Senegal and Ivory Coast. *Hexaporotricolpites* also appear in the Upper Albian to Lower Cenomanian in Brazil (Herngreen, 1973). The grain was reported from the Upper Albian to Cenomanian in West Africa. However, *Triorites africaensis* was described from the Upper Ceromanian of Senegal and Brazil (Jardiné et

al., 1972).

Jardiné and Magloire (1965) used *Droseridites senonicus* as an index species of Coniacian to Santonian age. It was first described from the Lower Senonian of Senegal and Ivory Coast (Jardiné and Magloire, 1965) and also in southwestern Nigeria (Jan du Chêne et al., 1978) all dated Lower Senonian.

In Nigerian basins, this taxa became extinct at the upper boundary of the Coniacian - Santonian. A comparison of this type of palynomorph assemblage shows similarity with *Proxapertites operculatus* zone established by Gemeraad et al. (1968), it also corresponds to P200 Zone established by Evamy et al. (1978), and the work reported by Salard-Cheboua (1981) on the Ewekoro and Ebenebe Imo formations in the southern Nigeria. This zone marks the K/T boundary in this basin with the high frequency of *Longapertites vanendenburgi* of Late Maastrichtian and the appearance of *Syncolporites marginatus*, which disappeared above the boundary. *Proxapertites operculatus* appeared above the K/T boundary in the Paleocene, this is evident in the work of Van Hoeken-Klinkenberg (1966).

Paleoenvironment of Deposition

Lacustrine, estuarine to shallow marine deposits were recorded for the wells and the depositional characteristics of these stratigraphic intervals are based on the associated palynomorph assemblages that correlate with the sedimentological interpretations. The formations that characterized these wells were deposited under diverse depositional milieu. (Figs. 2, 3, 4 and 13).

The lithology that characterized the lower unit (Tuma: 3,628m to 2,115m) intervals were deposited from suspension in low energy environments (Reineck and Singh, 1980). The intercalated sand beds intervals are mineralogically immature and texturally submature based on the textural parameter which indicated absence of reworking at the site of deposition and a relatively short period of transportation (Folk, 1974), except for the sands at 2115m-2220m intervals of which the sorting and shapes suggests they could have been reworked after deposition and abraded during transportation to the point of deposition (Reineck and

Singh, 1980; Friedman and Sanders, 1978). The diversity in grain sizes suggests low to high energy environments. The intercalated nature of the sands could be interpreted as mainly point bar deposits of a laterally migrating high sinuosity river channel or overbank floodplain (Reineck and Singh, 1980). The muds are interpreted as abandoned river channels and/or as overbank floodplain sediments, their preservation (sediments) implies rapid basin subsidence triggered by periodical avulsion of the river channels. The abundance of terrestrially derived palynomorphs, miospores, and sporadic occurrence of *Pediastrum bifidites* suggests a freshwater depositional milieu. The presence of ubiquitous miospores, low diversity of dinocyst assemblages (2600m) is dominated by the presence of *Subtilisphaera* spp. and abundant foraminifera test lining (2220m to 2115m), suggests deposition in a very shallow, low salinity, brackish lake and /or marginal marine depositional environment. (Gemeraad et al., 1968).

The low diversity of dinocyst assemblage at 2,600m is dominated by *Subtilisphaera* spp. The presence of this dinocyst suggests deposition in a restricted marine setting possibly brackish lagoon and/or inland sea (Gemeraad et al., 1968).

The upper units is characterized by the presence of miospores, high frequency of foraminifera test linings, low diversity of dinocysts, and the association often consists of species tolerant of salinity changes. This characterized the wells except for 1605m to 1220m (Tuma), 1405m to 1285m (Kasade), 1275m to 1215m (Bulte) depths, suggesting very shallow, low salinity, brackish lagoon and/or marginal marine depositional environment. In the restricted marine facies assemblages, most importantly the halophyte pollen of *Classopollis* is a characteristic feature that indicates that their parent plants (derived from *Fenelopsis alata*, *Cheirolepidiaceae*, Hluštík and Konzalozá, 1976) were important components of the coastal marshes (Batten, 1975). Batten (1982) found a direct correlation between increased numbers of cheirolepidiacean pollen and transgressive phases. Marine coastal to shallow environments yield dinocysts from the neritic (*Spiniferites*, *Oligosphaeridium* and *Florentinia*) (Wilpshaar and

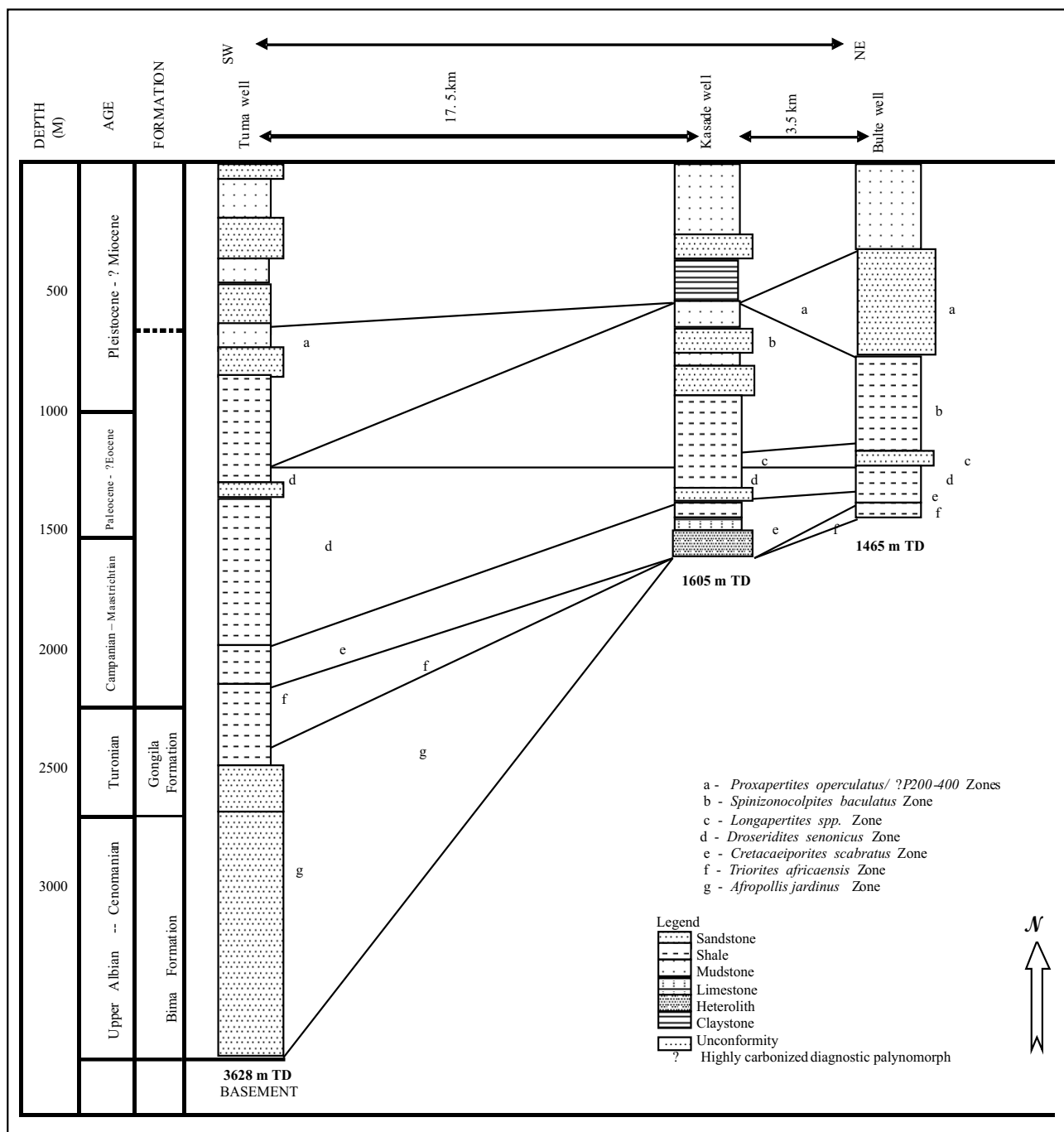


Fig. 12: Palyno- stratigraphic cross- section of the wells.

Leereveld, 1994, 1995). The relative abundance of ceratiacean (*Odontochitina*), gonyaulacacean (*Oligosphaeridium*) groups indicates proximity to the shore and is a useful salinity index. The increase in gonyaulacacean dinocysts is associated with offshore, open marine conditions (Davey, 1970, Harland, 1973 and Batten, 1979). The records of gymnosperm pollen *Ephedripites* and *Araucariacites* in the wells (Tuma: 2120-1605m; Kasade: 1465-1385m) is an indicator of arid/semiarid environments (Ibrahim and Schranck, 1996).

The intervals 1,605m-1,505m (Kasade) and 1385m (Bulte) shared the same textural characteristics with the underlying units with continuous increase in shale content with depth. The lithologies and the relatively high assemblage population are suggesting a deposition in a deltaic setting but strongly influenced by high fluvial energy transporting medium associated with marine incursion, this correspond to the top and base of Gongila and Fika Formations.

The intervals 1,505m-935m depth constitutes muds that were possibly deposited from suspension in low energy settings and it is characterized by low to moderate diversity of dinocyst assemblages with terrestrially derived miospores, which suggest an influx of terrigenous materials into the marine setting as evident from the assemblages. The intercalated thin clean sands that occurred throughout this interval suggest a high energy outer shelf environment (Reineck and Singh, 1980).

The assemblages within the 1,435m-1,025m intervals yielded medium to highly diverse assemblages that are overwhelmingly dominated by marine dinocysts suggesting deeper water, normal salinity, and open marine environment (Lawal, 1982). The terrestrially derived miospores suggest transport into an extensive open marine setting. Freshwater alga *Pediastrum* spp. suggests lower salinity brackish setting to locally freshwater depositional environment (Gemeraad et al., 1968). However, it is suggested that, the muds (1,575m-1,435m) were deposited in an extensive siliciclastic sediment- starved low salinity lake and/or marginal marine basin turbidite (Reading, 1972; Pettijohn, 1975; Reineck and Singh, 1980).

New appearances in the upper part include *Balteocysta perforata*, *Oligosphaeridium* sp.3 and cf.

Thalassiphora sp. from the mangrove swamp, the pollen association comprises mostly palms like *Longapertites* spp., *Proxaperturates*, *Verrutricolporites* sp. and other taxa. The appearances of fungal spores, *Botryococcus* sp. and charred Gramineae cuticle associated with sandy gypsiferous shale are indicative of fluvial influence and suggestive of inner neritic to marginal marine. The occurrence of Gramineae pollen, mainly in the Neogene, indicates the development of grassy areas in a seasonally dry climate (Gemeraad et al., 1968; Lawal, 1982; Reading, 1972; Pettijohn, 1975; Reineck and Singh, 1980).

The upper parts of the wells (935m-0) are thought to have been influenced by fresh water incursion tending towards marine environment. The assemblages are relatively moderate in terms of population and diversity. They consist of admixtures of both land and marine derived forms. Some of the dinoflagellates present are *Phelodinium boloniese*, *Andalusiella polymorpha?*, *Genulacta longicollis*, *Batioladinium jaegar*, *Odontochitina costata* and *Crebroperidinium orthoceras*. Others include *Trichodinium castaneum*, *Florentinia* sp., *Senegalinium* sp.5, *Batiacasphaera* sp., *Eucladinium* cf. *medisense*, *Senegalinium* sp., *Oligosphaeridium* sp., *Senegalinium* sp.4, *Dinogymnium euclaensis* and *Spiniferites* sp. which are thought to be deeper in depth considering the high dinoflagellate population, diversity and microforaminiferal wall linings. These marine forms suggest the possible connection between the Tethyan Sea and Atlantic Ocean (Okosun, 1995; Petters, 1978; Reymont and Dingle, 1987).

CONCLUSIONS

The palynological and lithofacies analyses of the samples available for study have resulted in the development of palynozonation scheme for the Bornu (Chad) Basin. The zonations established are characterized by a particular appearance, evolution and extinction of the microfloras, these are;

Tuma well:

- a) *Afropollis jadinus* Zone (Late Albian-Cenomanian),
- b) *Hexaporoetricolpites emelianovi*/Classopollis

- brasiliensis Zone (Late Cenomanian – Early Turonian),
- c) *Triorites africaensis* Zone (Early Turonian),
 - d) *Cretacaeiporites scabratus* Zone (Late Turonian),
 - e) *Droseridites senonicus* Zone (Coniacian - Santonian), and
 - f) *Proxapertites operculatus* Zone (Paleocene)
- Bulte and Kasade well:
- a) *Triorites africaensis* Zone (Late Cenomanian - Early Turonian),
 - b) *Cretacaeiporites scabratus* Zone (Turonian; Kasade – Late Turonian),
 - c) *Droseridites senonicus* Zone (Coniacian-Santonian),
 - d) *Longapertites* spp. Zone (Campanian - Early Maastrichtian),
 - e) *Spinizonocolpites baculatus* Zone (Late Maastrichtian),
 - f) *Proxapertites operculatus*/P200-P400 Zone (Paleocene -? Eocene).

These zones are correlated to synchronous spore-pollen assemblages of West African, Eurasian and northern South American basins. The major unconformity in the Fika Formation is characterized by the LAD of the Paleocene assemblages such as *Proxapertites* spp. and other taxa which characterized the upper part of the Fika Formation. The palynological evidence indicates Late Albian to Late Eocene in the studied samples.

The development of this zonation demonstrates the understanding of palynomorph distribution and will provide an age control for the interpretation and modeling of the petroleum geology of the Bornu (Chad) Basin.

The sedimentary units in the studied wells showed an overall transgression and regression character from lacustrine through estuarine, and up to inner shelf environment. The transgression and regression character of the sedimentary sequence was interpreted according to the succession of the lithofacies assemblages and flora distribution in the samples.

The depositional environments recognized base on the lithofacies assemblages (which is controlled by climate variations in the basin) are fluvial facies, estuarine-deltaic facies and brackish shallow inner to marginal marine facies under anoxic and/or suboxic bottom waters.

Detailed records of spore-pollen assemblages from the three wells located in the Bornu (Chad) Basin provide new insights into the paleoclimatic and paleogeographic settings during the Albian-Cenomanian transition in the basin (southwestern Chad). Palynological taxa such as *Afropollis jadinus* (Doyle, et al. 1982), *Elaterosporites klaszii* (Jardiné and Magloire) Jardiné, 1967 and the dinoflagellate cyst *Cyclonephelium* sp. (Below, 1981) indicate a latest Albian age for this unit. Abundance of Gondwanan elements such as *Afropollis* (Doyle, et al. 1982) and *Elaterosporites* (Jardiné, 1967) indicates a northward extension of the paleogeographic distributions of those taxa during this time. Comparison between the studied microflora of the Bornu (Chad) Basin and microfloras from Tethyan and Gondwanan realms allows better understanding of the Tethyan paleogeographic setting.

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**Variability of Late Pleistocene-Holocene Niger River
Discharge into the Gulf of Guinea:
Foraminiferal Isotopic evidence from Niger Deepsea Fan Sediments**

Adesina T. Adegbie

Nigerian Institute for Oceanography and Marine Research (NIOMR)
P.M.B. 80108, Victoria Island, Lagos, Nigeria

Abstract

Stable oxygen isotope ($\delta^{18}\text{O}$) ratios of planktonic foraminifera *Globigerinoides ruber* (pink) and *Globigerinoides sacculifer* from Niger deep sea fan sediments have revealed the variability of the Niger River discharge into the Gulf of Guinea for the last 245,000 years. Analysis of Meteor core GeoB 4901-8 (02°40.7'N, 006°43.2'E: water depth 2184 m), showed glacial and interglacial climatic oscillations in the Late Quaternary over the tropical eastern Atlantic. During glacial periods the oxygen isotope values are high; in contrast, they are very low during interglacials. Highly negative $\delta^{18}\text{O}$ values of *G. ruber* (pink) up to -3.2‰ were recorded in these sediments; these values are very low when compared with the $\delta^{18}\text{O}$ (*G. ruber* (pink) record from the Congo fan (-1.8‰). Similarly, low values up to -2‰ during interglacials were recorded in the difference between the oxygen isotope values ($\Delta\delta^{18}\text{O}$) of the shallow-dwelling planktonic foraminifera *G. ruber* (pink) and *G. sacculifer* and suggest seasonal temperature variations. In addition to indicating oscillating climatic temperature conditions in the Late Quaternary, very low values of $\delta^{18}\text{O}$ ratios of *G. ruber* (pink) also record periods of surface ocean freshening. The $\Delta\delta^{18}\text{O}$ (*G. ruber* - *G. sacculifer*) record gives credence to the fact that there was significant increase in the Niger River discharge during warm periods.

Keywords: Deep sea fan sediment, Stable oxygen isotope, planktonic foraminifera, Africa climate change, monsoon precipitation, paleohydrology.

Introduction

Paleoenvironmental conditions over Africa have been a subject of interest among earth scientists, Barker et al., (2004). Many studies have been conducted to unravel what the African climate was like especially in the Quaternary. Continental studies on lake levels (Street and Grove, 1976), sand dunes (Sarnthein, 1978) and also on marine sediments (Pastouret et al., 1978; Schneider et al., 1997; Hooghiemstra, 1988; Zabel et al., 2001; Adegbie et al., 2003; Marret et al., 2008) have all shown that the African climate and paleoenvironment are influenced and may be controlled by a suite of complex processes. It is known that the African monsoon strongly influences the African terrestrial climate on one hand and also the surface water hydrography of the surrounding marine realm on the other hand. These are recorded in paleoceanographic and paleoenvironmental proxies such as oxygen, nitrogen and carbon isotopes, alkenones, foraminiferal, pollen-spore and dinoflagellate cyst assemblages. Unfortunately although some progress has been made using

palynological proxies (Marret et al., 2008; Kholeif and Mudie, 2009). However, much more must be done in correlating the African monsoons and precipitation changes. More studies are therefore needed in order to correlate between the African monsoonal precipitation changes during glacial and interglacial periods.

Such correlations can better be done with the study of deep-sea cores close to the continent that could provide continuous record for several thousand year (kyr) cycles. The Niger deep sea core GeoB4901-8 provides such data. Oxygen isotopes of planktonic foraminifera from the Niger deep sea fan sediments were analysed to provide paleoenvironmental information that allows reconstruction of precipitation changes and sea surface hydrography in the basin. This paper will further discuss the history of the Niger River discharge into the tropical east Atlantic surface ocean under the influence of varying climatic conditions during the past 245, 000 years.

Study Area

The hydrography of the Gulf of Guinea where the Niger Delta fan is located is tightly coupled to the atmospheric circulation of the region and could be best described in relation to the general atmospheric conditions of the eastern equatorial South Atlantic. Peterson and Stramma (1991) and Wefer et al., (1996) described in detail the hydrography of surface and subsurface waters of the South Atlantic. In the tropical east Atlantic, the surface warm currents comprise the Guinea Current (GC) which runs parallel to the west coast of Africa, the south equatorial current (SEC) which runs in the opposite direction, and the Angola current (AC) which runs southwards along the southeastern margin of the Atlantic (Fig. 1). The cold surface waters are the Benguela Coastal Current (BCC) and the Benguela Oceanic Current (BOC). They respectively transport cold nutrient-rich waters coming from the low latitudes of Antarctica, southern Africa and the Indian Ocean towards the southeastern coast and the open central gyre. Other currents are the subsurface South Equatorial Counter Current (SECC) and the Equatorial Under-Current (EUC). The

combination of local and remote wind forcing is said to be responsible for the large variability of the surface currents in the south Atlantic (Richardson and Walsh, 1986). Owing to the Coriolis force, air moving from the subtropical high pressure area to the equatorial low pressure zone is diverted to the northeast of the equator. Thus, the SE-trades emerge. The EUC is a fast-flowing undercurrent extending between 5°N and 5°S parallel to the equator in water depths of 50-125 m (Peterson and Stramma, 1991). The current runs year-round and is present throughout the entire equatorial Atlantic.

The interactions of these currents coupled with the strong influence of the southeast trade winds as already mentioned above might cause the shoaling of the thermocline and the nutricline and sometimes result in oceanic upwelling (Schneider et al., 1994). Coastal upwelling signals have been well documented in the Angola basin (Voituriez and Herbland, 1981) so also are seasonal upwelling cells reported along the coast of West Africa and near the coast of Gabon (Diedhiou et al., 1998).

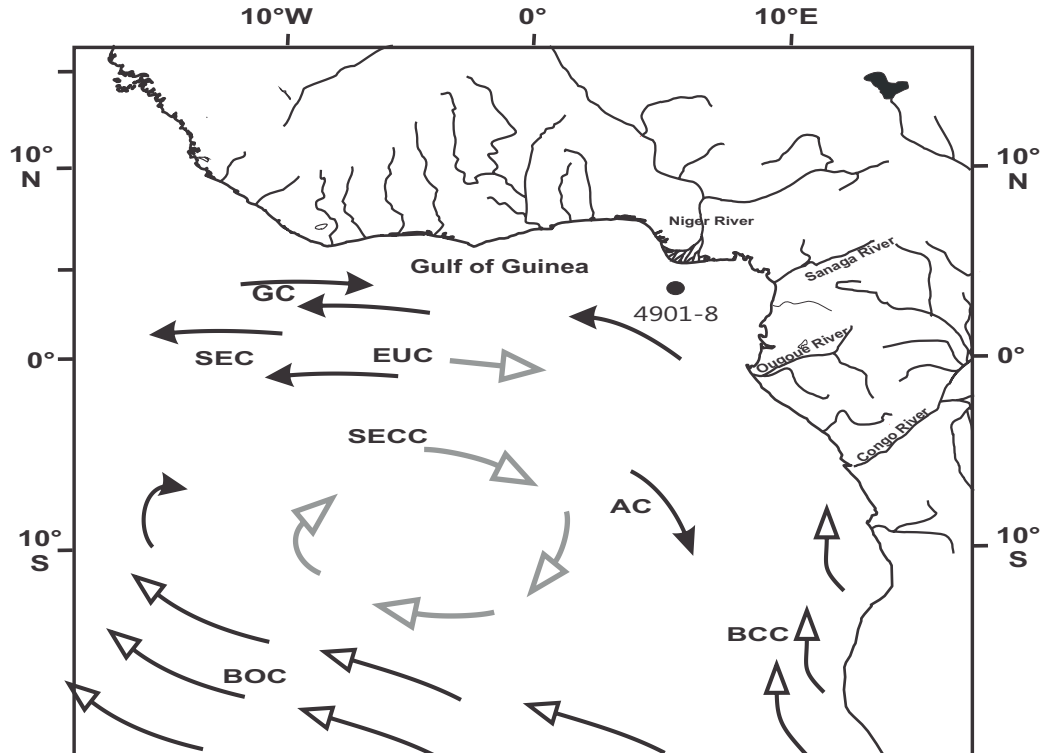


Figure 1. Location of gravity core GeoB 4901-8 and the current pattern in the Gulf of Guinea and Southeastern Atlantic ocean (black arrows warm; white cold, grey subsurface currents).

MATERIALS AND METHODS

Sediment samples from gravity core GeoB 4901-8 (02°40.7'N, 006°43.2'E) at water depth of 2184 m, taken from the Niger deep sea fan were analysed. The core was retrieved during the first leg of RV Meteor Cruise Nr. 41 (M41/1). Core recovery technique is well described in Schulz et al., (1998).

The 20.28m core was sampled on board at 5 cm intervals producing a total of 406 samples. During sampling, 10 cm³ syringe samples were taken. The core samples were taken to the University of Bremen geological laboratory and were wet-sieved over a sieve combination of 150 and 63m mesh sizes and dried overnight at 50°C in the oven. The dried weights of each sieve (> 150 and 63 m) were taken. For each sample, an average of thirty specimens of *Globigerinoides ruber* (pink), twelve specimens of *Globigerinoides sacculifer* (without final chamber) between the sizes of 350 and 400 m and six specimens

of *Cibicides wuellerstorfi* of sizes > 250 m were picked. Only undamaged tests were selected for isotope measurements.

The stable oxygen isotope ($\delta^{18}\text{O}$) record of epibenthic foraminifera *Cibicides wuellerstorfi* was used for the reconstruction of the age model (Fig. 2a) because it correlates better with the SPECMAP (Fig. 2b) than the $\delta^{18}\text{O}$ records of *G. ruber* and *G. sacculifer*. Although the $\delta^{18}\text{O}$ records of *G. ruber* and *G. sacculifer* show typical Late Quaternary patterns of alternating glacial-interglacial heavier and lighter values, they also strongly record local changes in surface water temperature and/or salinity especially in the last interglacial (Schneider et al., 1997). This made the $\delta^{18}\text{O}$ record of *C. wuellerstorfi* the best choice for establishing the age model. Using the AnalySeries 1.1 software programme (Paillard et al., 1996), the $\delta^{18}\text{O}$ record of *C. wuellerstorfi* was correlated with the widely used marine isotope stages (MIS) of the SPECMAP $\delta^{18}\text{O}$ stack (Table 1; Imbrie et

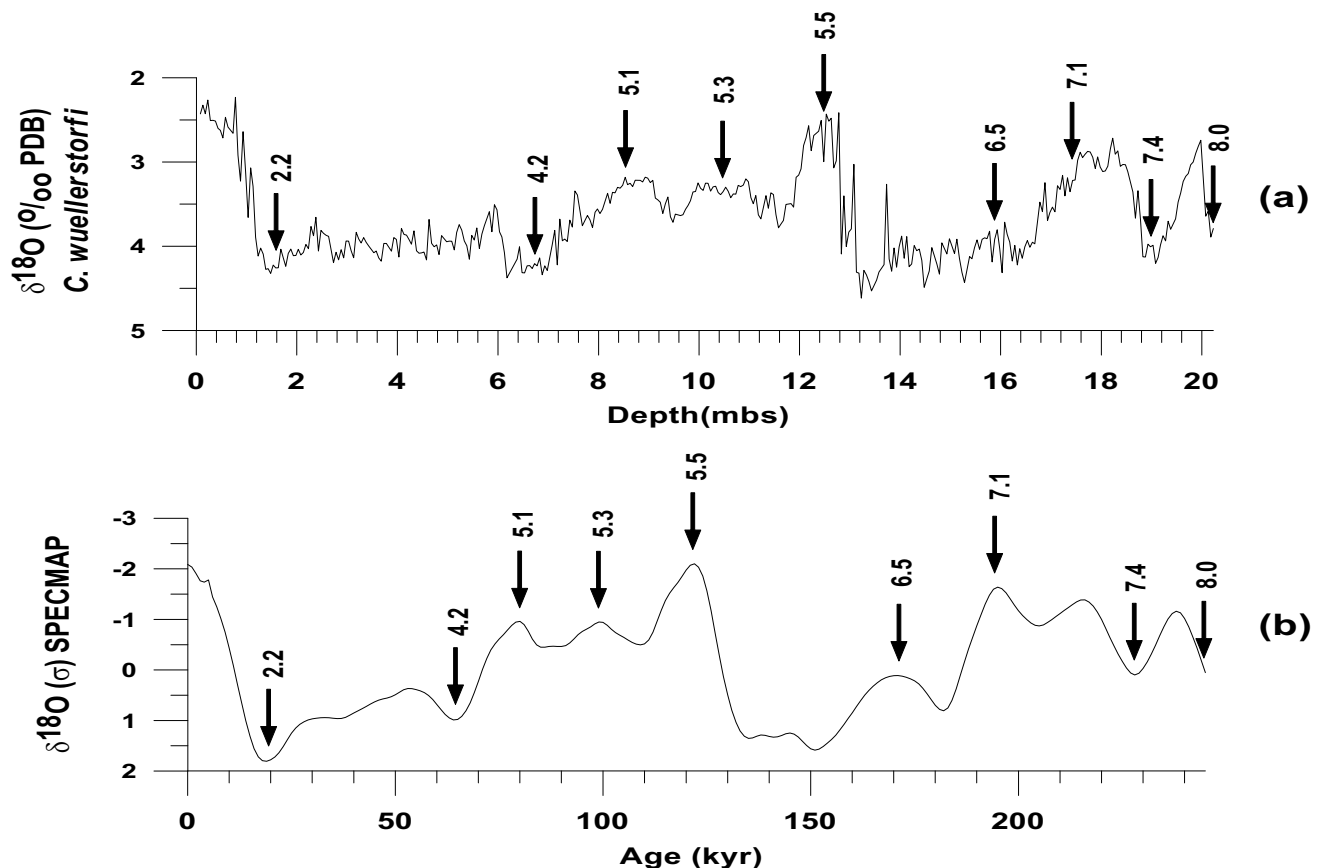


Figure 2. Age model of core GeoB 4901-8. (a). $\delta^{18}\text{O}$ record of *Cibicides wuellerstorfi*, (b). $\delta^{18}\text{O}$ record of the SPECMAP. Arrows show the marine oxygen isotopic events used as stratigraphic control points.

al., 1984). Isotope ratios are measured using a Finnigan MAT 251 micromass spectrometer connected to a Kiel Automated Carbonate Device. The carbonate test is reacted with concentrated orthophosphoric acid at 75°C. Isotopic results are presented in per mil (‰) using the standard isotopic delta notation (δ) relative to the Pee Dee Belemnite (PDB) scale. Conversion to the international PDB scale was done using the NBS-18, NBS-19 and NBS-20 standards. Typical analytical precision of isotopic measurements of calcite at the University of Bremen laboratory is better than ± 0.07 ‰, for $\delta^{18}\text{O}$.

RESULTS

Sediment samples recovered from GeoB 4901-8 are fine-grained hemipelagic mud and of foraminifera ooze with varying amounts of clay and nannofossils. The oxygen isotopic data for the core gives an age

model that dates back to MIS 8.0 with an age of about 245 kyr. before present (Fig. 2 (a, b) and Table 1). Sedimentation rates are moderately high reaching a maximum of 12 cm/1000 years in cold glacial stage conditions and as low as 5 cm/1000 years during interglacials.

Figure 3 shows the results of the stable oxygen isotope records plotted against time. An average of 3‰ and 2.7‰ amplitude change were observed in the records of *G. ruber* (pink) and *G. sacculifer* respectively, representing highly varied hydrographic changes in the Gulf of Guinea for the past 245 kyr. The Holocene and other interglacial periods penetrated by this core show a marked decrease in the $\delta^{18}\text{O}$ values of these two species. High negative $\delta^{18}\text{O}$ values of *G. ruber* (pink) up to -3.2‰ per mil were recorded in these sediments. Also, the $\delta^{18}\text{O}$ record of *G. ruber* (pink) shows unusual distinct four peaks in MIS 5 which might be caused by surface water freshening (Fig. 3).

Table 1. Isotopic events used as stratigraphic control points, obtained from correlation of the timescale of the Spectral Mapping Project (SPECMAP)

* with the stable oxygen isotope $\delta^{18}\text{O}$ curve of the epibenthic foraminiferan *Cibicides wuellerstorfi*.

MIS	Time (kyr)	Depth (m)
Sediment surface	0	0
2.2	19	1.58
4.2	65	6.73
5.1	80	8.53
5.3	99	10.48
5.5	122	12.48
6.5	171	15.88
7.1	194	17.43
7.4	228	19.03
8.0	245	20.23

*SPECMAP is from (Imbrie, et al., 1984).

DISCUSSION

Surface Water Hydrography

Considering the location of core GeoB 4901-8 on the Niger fan (Fig. 1) it is expected that the $\delta^{18}\text{O}$ records of *G. ruber* (pink) will not only respond to global ice volume changes but also to changes in continental rainfall intensity, as recorded by foraminiferal and palynological data from the Congo deep-sea fan for the past 200 Cal kyr. BP (Schneider et al., 1997; Barker et al., 2004; Marret et al., 2008). This species of planktonic foraminifera is well known to inhabit very shallow water depth (10-30m) and could tolerate relatively large changes in temperature, 16-31°C and salinity, 22-49‰ (Hemleben et al., 1989). *G. ruber* is also known to flourish during increased river discharge (Pastouret et al., 1978; Schneider et al., 1997). Zabel et al., (2001) attributed the relatively low carbonate content (0.1-36.1 wt %) of the sediments from the Niger fan core to the dominance of terrigenous materials that are mainly supplied by the Niger River. Peaks of low $\delta^{18}\text{O}$ values of *G. ruber* (pink) up to -3.2 ‰ in the Holocene as well as other interstadial warm periods penetrated by this core apparently indicate

significant hydrographic changes due to fresh water dilution by the Niger river. These values when compared with those observed at the Congo fan (Schneider et al., 1997) and the Niger delta (Pastouret et al., 1978) could be interpreted as periods of large surface water freshening.

Variations in the local hydrography could also be inferred from the measured $\Delta\delta^{18}\text{O}$ ($= \delta^{18}\text{O } G. \text{ ruber} - \delta^{18}\text{O } G. \text{ sacculifer}$). Analysis of plankton tows, core top samples and culture experiments by (Erez and Luz, 1982; Fairbanks et al., 1982; Mulitza et al., 1998) reveal the significance of temperature sensitivity, habitat depth and temporal distribution pattern of these species. Both species are known to be tropical and shallow dwelling living in the upper water column (<50m) and could tolerate wide range of sea surface temperatures and salinities. Nevertheless despite the similarities these species still exhibit differences in isotopic signal down-core (Fig. 3 and 4). Although *G. ruber* (pink) tend to record more negative $\delta^{18}\text{O}$ values than *G. sacculifer*, both are known to record $\delta^{18}\text{O}$ values lower than the average -1.5‰ annual $\delta^{18}\text{O}$ value reported for the Holocene.

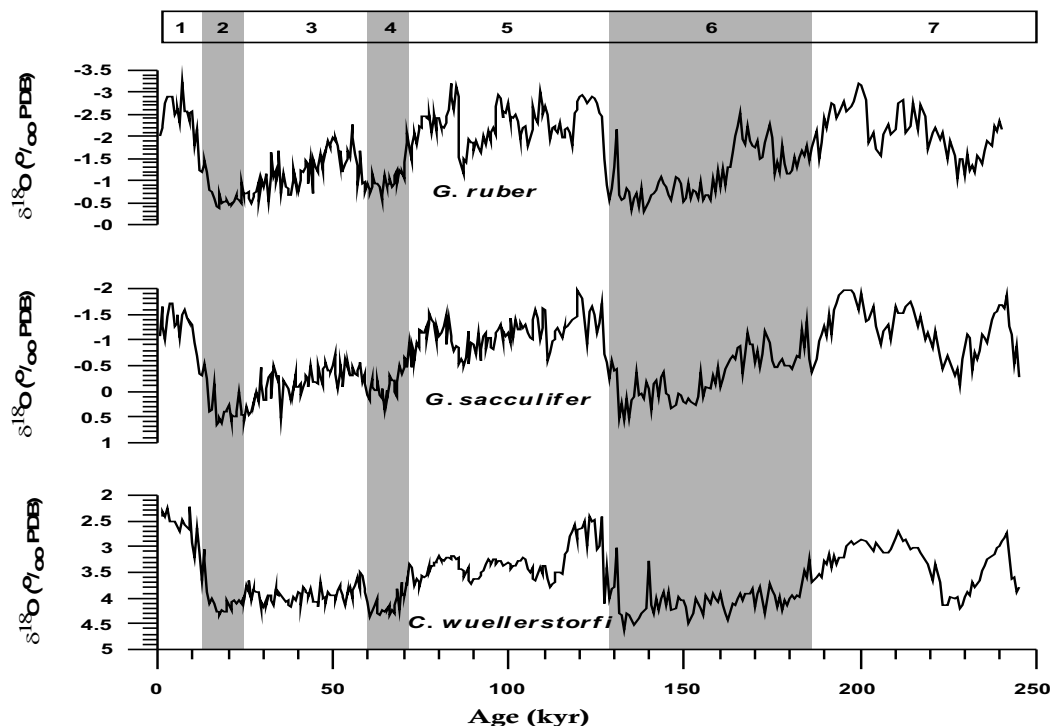


Figure 3. Stable oxygen isotope ($\delta^{18}\text{O}$) values for *Globigerinoides ruber* (pink), *Globigerinoides sacculifer* and *Cibicides wuellerstorfi* plotted on the age scale.

Mulitza et al., (1997) using the $\delta^{18}\text{O}$ difference between shallow and deep-living planktonic foraminifera to decipher surface water stratification, recorded a difference of up to $\sim 3\text{‰}$ in the tropics. Evidence from core-top studies (Duplessy et al., 1991; Mulitza et al., 1998) showed that

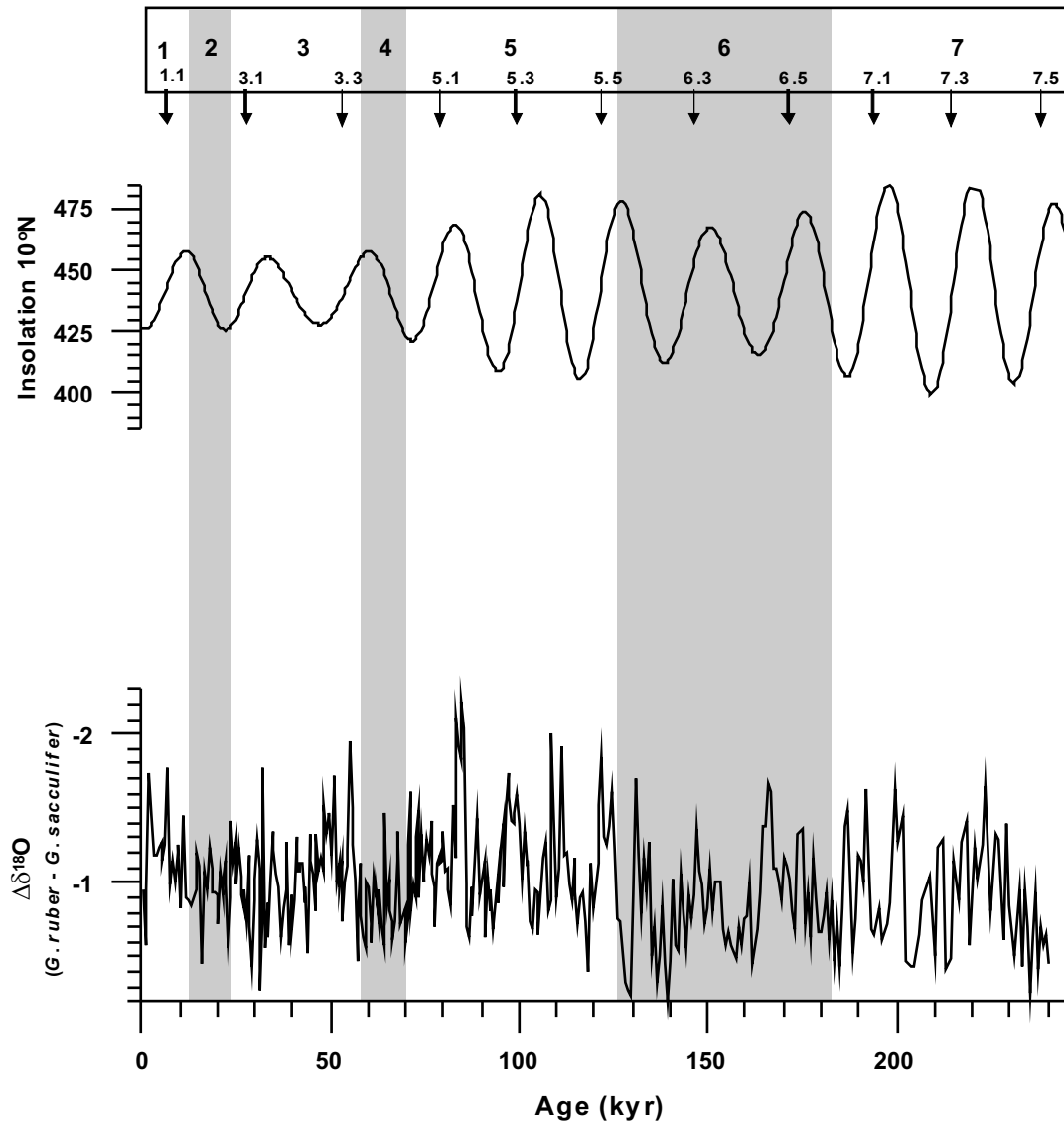


Figure 4. Downcore variations of $\delta^{18}\text{O}$ (*G. ruber*-*G. sacculifer*) and insolation at 10°N.

most of the shell material from *G. ruber* and *G. sacculifer* are secreted in the mixed layer of the ocean. In the Niger fan core, the $\Delta\delta^{18}\text{O}$ values vary between -2.21‰ and -0.16‰ with an average offset of about 2‰ dominantly resulting from temperature and salinity changes in the upper water column. If the global ice volume effect is assumed to be negligible ($\Delta\delta^{18}\text{O}$ for two mixed layer species), on one part, this difference may indicate changes in the seasonal distribution pattern of the species, suggesting that the $\Delta\delta^{18}\text{O}$ values might be a function of seasonal fluctuations in Sea Surface Temperature (SST) (Mulitza et al., 1998). Secondly, due to the location of the core, $\Delta\delta^{18}\text{O}$ signal probably indicate local salinity changes due to surface water freshening by the Niger river discharge. An average of 2‰ $\Delta\delta^{18}\text{O}$ value recorded between these species is not expected to be solely caused by SST changes in a tropical ocean.

CLIMATIC IMPLICATIONS

Comparison of the $\Delta\delta^{18}\text{O}$ signals with orbital insolation at latitude 10°N (Fig. 4), a position where the low pressure cells over central Africa sits during boreal summer shows that at periods of maximum insolation, there are corresponding high spikes in $\Delta\delta^{18}\text{O}$ values. The variation in the intensity of the summer insolation more or less corresponds with amplitude of the $\Delta\delta^{18}\text{O}$ for the late Quaternary. This shows the sensitivity of the surface ocean hydrography to changes in atmospheric conditions on the African continent. During warm climatic conditions for example in MIS 3, 5 and 7, $\Delta\delta^{18}\text{O}$ values are far more negative, sometimes up to -2.3‰ , most likely showing strong surface water freshening due to increased Niger River discharge into the Gulf of Guinea. It is therefore reasonable to say that periods of warm interglacial conditions was accompanied by wet conditions as contrasted with periods of cold and dry glacial climatic periods, as previously demonstrated by changes in the forest pollen data recorded for the Congo delta (Barker et al., 2004).

CONCLUSIONS

Very high negative $\delta^{18}\text{O}$ values up to -3‰ recorded for the shallow dwelling planktonic foraminifera *G. ruber* (pink) apparently indicate large freshwater discharge from the Niger river, as suggested by high precipitation and reduced salinity over the delta area mostly during interglacial periods. Although the absolute amount of change in sea surface temperature and salinity could not be fully established from the $\delta^{18}\text{O}$ (*G. ruber* – *G. sacculifer*) record, the 2.3‰ $\delta^{18}\text{O}$ change between these two mixed layer species is high. Since SST is known to be fairly constant in this tropical part of the ocean (Zabel et al., 2001), the high value of $\delta^{18}\text{O}$ is thereby suggested to be due to increased river input causing surface water freshening. The climate over central and western Africa as recorded in the stable oxygen isotope composition of *G. ruber* and *G. sacculifer* tests when compared with the SPECMAP shows alternating glacial and interglacial climatic conditions averaging 50,000 year duration.

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