GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 4 NO. 2 2006 : 85 - 101
 ISSN 1596 - 6798

THE GEOLOGICAL HISTORY OF SEDIMENTATION IN THE SUB-BASINS OF THE CALABAR FLANK, SOUTHEASTERN NIGERIA: PALYNOLOGICAL EVIDENCE FROM THE IKONO- 1 WELL

O. P. UMEJI

(Received 17 January, 2006; Revision Accepted 14 February, 2006)

ABSTRACT

The oldest sediments overlying basement on Ituk High in Ikono-1 Well are **Late Albian-Late Cenomanian** estuarine and marine shales from which the following index sporomorphs were recovered: *Triorites africaensis*, *Classopollis brasiliensis*, *Sofrepites legouxae*, *Elateropollenites jardinei*, *Cretacaeiporites polygonalis*, *Trilites* S.C.I 124 Jardiné & Magloire 1965, *Auraucariacites australis* and *Inaperturopollenites dubius* Fresh water algal remains, acritarchs, and dinoflagellate cysts, *Chytroesphaeridia* sp.; *Cyclonephelium* sp. together with microforaminifer linings were also recovered.
Palynological data was used to interpret depositional history in the two sub basins of the Calabar Flank, the Ikang Trough and Ituk Basin. **Neocomian-Aptian** terrigenous Awi Formation and marine **Aptian-Albian** reported from Ikang Trough were not encountered in Ituk sub basin. The Ituk sub basin subsided only in the Late Albian and again in the Santonian.
Sedimentation ended in both sub-basins during the **Coniacian-Santonian** uplift. Resumed deposition occurred in Ituk sub basin in the **Campanian**. The **Coniacian** is absent in the two sub-basins. Sedimentation continued into the Tertiary with progradation into the Niger Delta. In discussing the geology of the Calabar Flank, distinction should to be made between the two sub basins

KEYWORDS: Calabar Flank, sub-basins, palynomorphs, sedimentation

INTRODUCTION

The Calabar Flank sedimentary basin is located on the southeastern extremity of Nigeria (**Fig 1a**). It is bounded on the NW by the Ikpe Platform; on the north by the Oban Hills, on the western border is the Cameroon volcanic line, and to the south lies the Calabar hinge line. The terms **Calabar** and **Benin Flanks** were first used by Murat (1972) to denote down-faulted margins flanking the Niger Delta on the northeastern and northwestern sides respectively. The Calabar Flank consists of NW-SE striking horsts, the Oban Massif and Ituk High, separated by a graben, the Ikang Trough (**Fig 1a**). The other marginal basins of Africa are similarly characterized by horsts and graben originating from the Africa-South America continental break-up and the opening of the South Atlantic Ocean. The down-faulted zones guided the transgressions and consequent sedimentation into the inland basins just as in the other sedimentary basins of Nigeria, Reyment (1965)
But for the strike of these boundary faults which in the Calabar Flank are NW-SE while in the Benue Trough are NE-SW, the Calabar Flank shares much with the Abakaliki Basin in the depositional history in pre-Santonian, and with the Afikpo Syncline during the later times. Ikono-1 was among the five exploration wells drilled on Ituk High on OML 12 in the 1950s and 1960s by SPDC Nigeria Ltd. The others are Ituk-2, Uruan-1, Anua-1, Ikono-1 and Ikpe-1, from SE to NW.

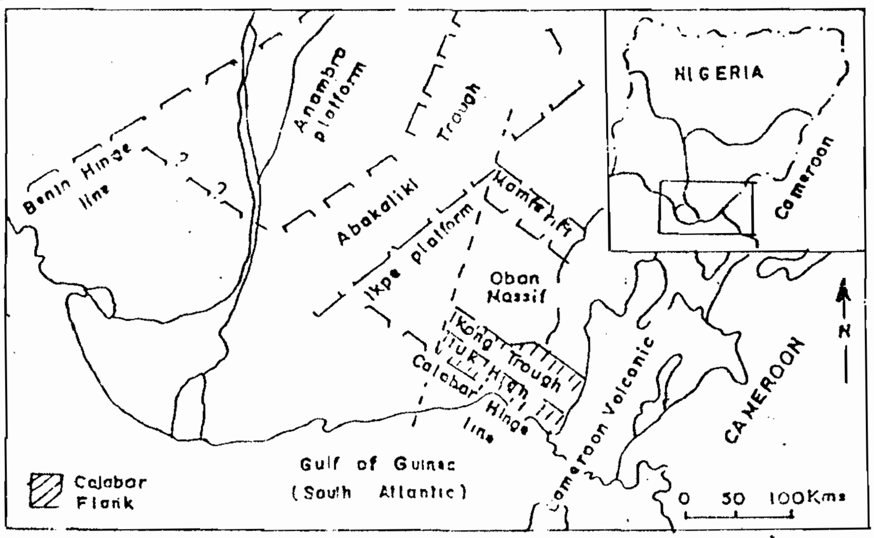


Fig. 1a.. Structural elements of the Calabar Flank and adjacent areas (after Murat 1972)

O. P. Umeji, Department of Geology, University of Nigeria, Nsukka, Enugu State Nigeria.

GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 4 NO. 2 2006 : 85 - 101
COPYRIGHT© BACHUDO SCIENCE CO. LTD PRINTED IN NIGERIA. ISSN 1596 - 6798

THE GEOLOGICAL HISTORY OF SEDIMENTATION IN THE SUB-BASINS OF THE CALABAR FLANK, SOUTHEASTERN NIGERIA: PALYNOLOGICAL EVIDENCE FROM THE IKONO-1 WELL

O. P. UMEJI

(Received 17 January, 2006; Revision Accepted 14 February, 2006)

ABSTRACT

The oldest sediments overlying basement on Ituk High in Ikono-1 Well are **Late Albian-Late Cenomanian** estuarine and marine shales from which the following index sporomorphs were recovered: *Triorites africaensis*, *Classopollis brasiliensis*, *Sofrepites legouxae*, *Elateropollenites jardinei*, *Cretacaeiporites polygonalis*, *Trilites* S.C.I. 124 Jardiné & Magloire 1965, *Auraucariacites australis* and *Inaperturopollenites dubius*. Fresh water algal remains, acritarchs, and dinoflagellate cysts, *Chytroesphaeridia* sp.; *Cyclonephelium* sp. together with microforaminifer linings were also recovered.
Palynological data was used to interpret depositional history in the two sub basins of the Calabar Flank, the Ikang Trough and Ituk Basin. **Neocomian-Aptian** terrigenous Awi Formation and marine **Aptian-Albian** reported from Ikang Trough were not encountered in Ituk sub basin. The Ituk sub basin subsided only in the Late Albian and again in the Santonian.
Sedimentation ended in both sub-basins during the **Coniacian-Santonian** uplift. Resumed deposition occurred in Ituk sub basin in the **Campanian**. The **Coniacian** is absent in the two sub-basins. Sedimentation continued into the Tertiary with progradation into the Niger Delta. In discussing the geology of the Calabar Flank, distinction should to be made between the two sub basins.

KEYWORDS: Calabar Flank, sub-basins, palynomorphs, sedimentation.

INTRODUCTION

The Calabar Flank sedimentary basin is located on the southeastern extremity of Nigeria (**Fig 1a**). It is bounded on the NW by the Ikpe Platform; on the north by the Oban Hills, on the western border is the Cameroon volcanic line, and to the south lies the Calabar hinge line. The terms **Calabar** and **Benin Flanks** were first used by Murat (1972) to denote down-faulted margins flanking the Niger Delta on the northeastern and northwestern sides respectively. The Calabar Flank consists of NW-SE striking horsts, the Oban Massif and Ituk High, separated by a graben, the Ikang Trough (**Fig 1a**). The other marginal basins of Africa are similarly characterized by horsts and graben originating from the Africa-South America continental break-up and the opening of the South Atlantic Ocean. The down-faulted zones guided the transgressions and consequent sedimentation into the inland basins just as in the other sedimentary basins of Nigeria, Reyment (1965).
But for the strike of these boundary faults which in the Calabar Flank are NW-SE while in the Benue Trough are NE-SW, the Calabar Flank shares much with the Abakaliki Basin in the depositional history in pre-Santonian, and with the Afikpo Syncline during the later times. Ikono-1 was among the five exploration wells drilled on Ituk High on OML 12 in the 1950s and 1960s by SPDC Nigeria Ltd. The others are Ituk-2, Uruan-1, Anua-1, Ikono-1 and Ikpe-1, from SE to NW.

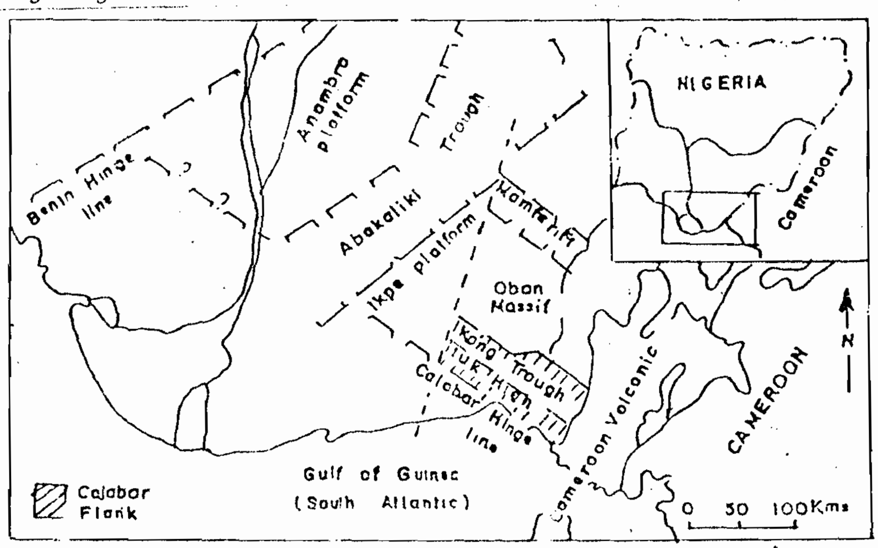


Fig. 1a.. Structural elements of the Calabar Flank and adjacent areas (after Murat 1972)

O. P. Umeji, Department of Geology, University of Nigeria, Nsukka, Enugu State Nigeria.

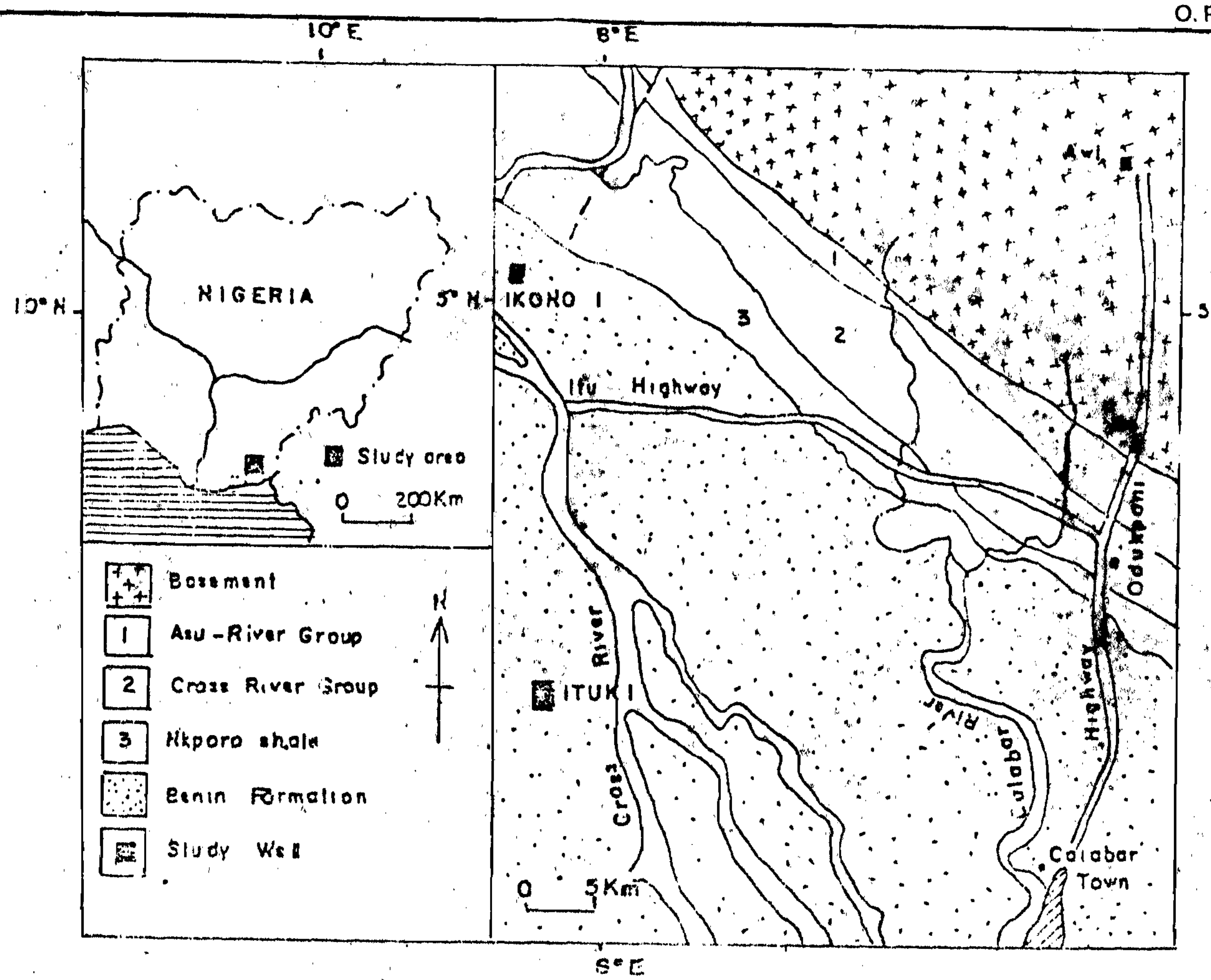


Fig. 1 b: Geological map of Calabar area showing location of Ikono-1 well (after Petters 1980)

Review of stratigraphy

The oldest sedimentary deposit outcropping in the Calabar Flank was named Odukpani Formation by Reyment (1965). It comprises basal arkosic sandstones and conglomerates up to 50 m thick overlain by Cenomanian marine limestones and shales.

Adeleye and Fayose (1978) erected the name Awi Formation for the basal beds and retained the name Odukpani Formation for the rest of the overlying marine Albian-Turonian successions (Fig 2).

Murat (1970) recognized the Neocomian age of the basal grits while Ramanathan and Kumaran (1981) confirmed the age using the palynomorphs from these basal beds in the CALCEMCO Core M-1 Well south of Mfamosing.

The limestones and calcareous sandstones overlying the grits were deposited under paralic conditions. The upper part was laid under open marine conditions. This upper part was dated Aptian-Albian, Ramanathan and Kumaran (1981) and correlates to the Gboko Limestone. This is first Cretaceous marine transgression in the Southern Benue Trough, which obviously skirted the eastern basement massif from south to north following the Ikang Trough. At this time the Ituk High was still a platform.

The Odukpani Formation, as designated by Reyment (1965), contains beds of various ages. These are, the basal grits (the Awi Formation) of Neocomian age (Murat 1972, Ramanathan and Kumaran 1981); Late Aptian - Late Albian shales of the Asu River Group of Reyment (1965) Early-Late Cenomanian limesrones and shales of Nkalagu Formation (Petters and Ekweozor, 1982) as well as shales of Late Cenomanian-Turonian Ekenkpon Shale, (Petters et al., 1995 and Nyong, 1995) (Figs. 2 & 3).

The 1: 250,000 geological map compiled by SPDC Nigeria Ltd for the Geological Survey of Nigeria (1957), referred to the Asu River, Eze-Aku Shale, and Nkporo Shale as groups. This system was followed by Murat (op. cit.). It was Reyment (1965) that reduced the latter two to formational ranks.

LITHOLOGICAL DESCRIPTIONS

The Ikono-1 Well is 3368 m (11,050 ft) deep, terminating on the basement. The lithological descriptions are shown in Fig 3.

The published reports from Ikang Trough used in this work were drawn from (Reyment, 1965; Nton, 1999; Ramanathan and Kumaran, 1981 and other articles synthesized from company files, Reijers (1996). siltstone and subsidiary conglomerate. The base is not exposed at the type section but at Km 26 along the same road, a sharp contact with the basement outcrops, Nton (1999).

This conglomeratic and sandy basal unit of Awi Formation was not encountered in Ikono-1Well where the basal beds are fissile grey shales.

SAMPLING /ANALYTICAL TECHNIQUES

For the purpose of this work, twelve samples were taken from the well cuttings between the depths, **2432-3359 m** at the following depths: 2432, 2456, 2932, 2993, 3042, 3054, 3145, 3176, 3213, 3249, 3286, 3359 m

10 g of each sample were processed by the standard palynological techniques described by Gray (1965): In Kummel and Raup (1965), using HF to remove the silicates. Half of the sample (5 g) was stored for reference, and from which a drop was mounted for non-quantitative kerogen studies, while the

Fig. 2 Lithostratigraphic chart of the Calabar Flank according to the given authors

Age	Petters et al. (1995)		Nyong (1995)		Petters (1995)		Petters&Ekweozor (1982)	
Campanian								
Coniacian	ODUKPANI GROUP	Mbrebu Marl Fm	L. Coniacian		ODUKPANI GROUP	Ekenkpon Shale	Nkalagu Fm	
			E Conacian	New Netim Marl Fm				
Turonian		Ekenkpon Shale Fm	Turonian	Ekenkpon Shale Fm				
Cenomanian			Cenomanian					
Albian		Mfamosing Lst Fm.	L. Albian	Mfamosing Lst Fm		Mfamosing Lst Fm	ASU RIVER GP	Awe Fm
			M Albian					Abakaliki Shale
	ASU RIVER GP	Awi Fm	E. Albian to ? Aptian	Awi Fm	Awi Fm			Awi Fm/Mamfe Fm
Hau-Aptian								

other half was subjected to oxidation using HNO_3 to remove organic matter, 2% Na OH to remove humic matter, and washing at each stage with 10µ nylon mesh. Samples were stained with Safranin O, dispersed in polyvinyl alcohol and mounted in DPX. Five slides were made for each sample (i.e. 1 g/ slide) from which a minimum of 200 grains were counted. One slide was made from the unoxidized portion of each sample for kerogen studies. Kerogen classification is based on Goodall et al. (1992).

Fig. 3. Lithologic section of Ikono-1 well

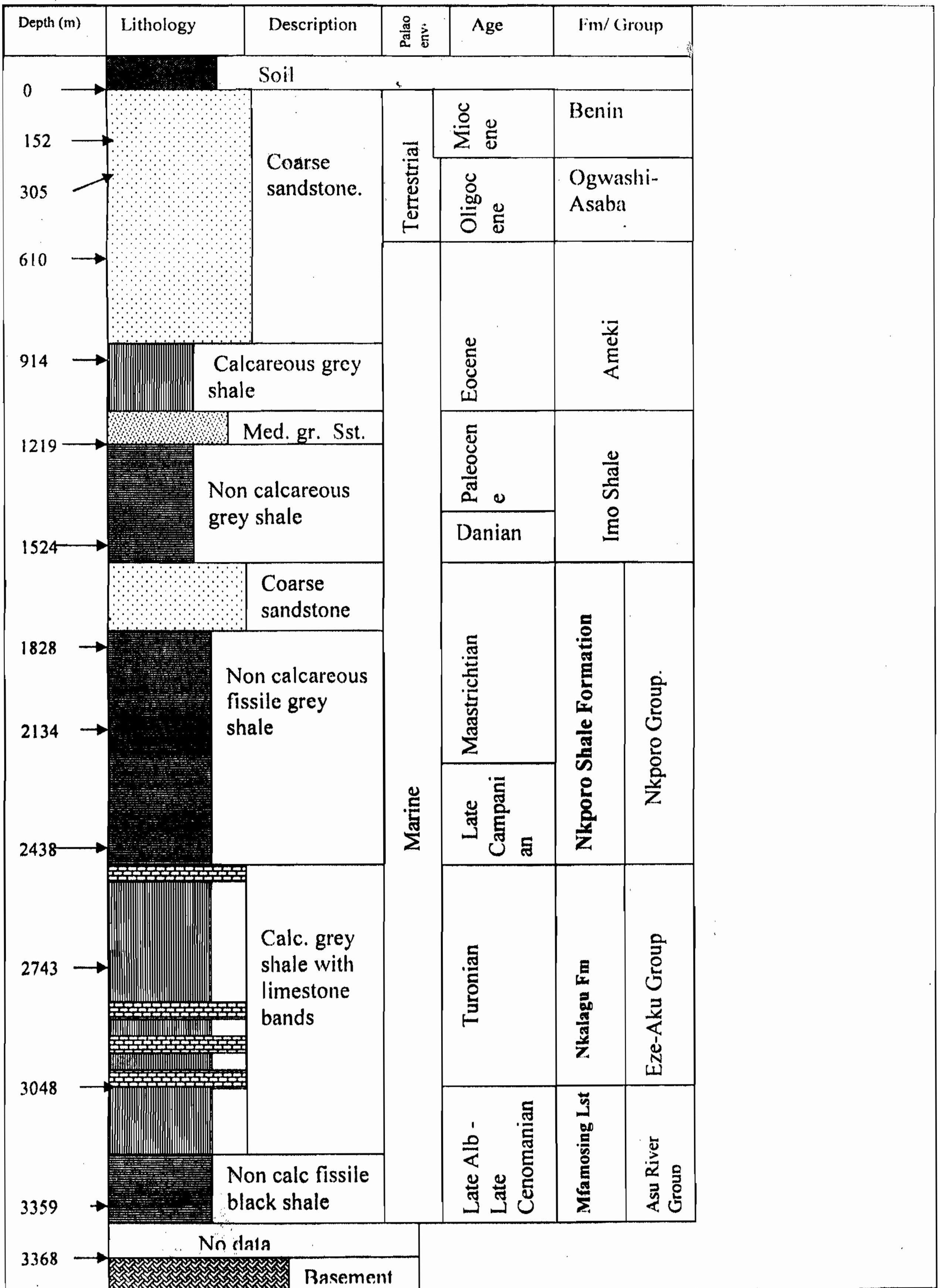


Fig 4 Lithologic log of Ikono-1 well (2225-3359 m) showing sample locations

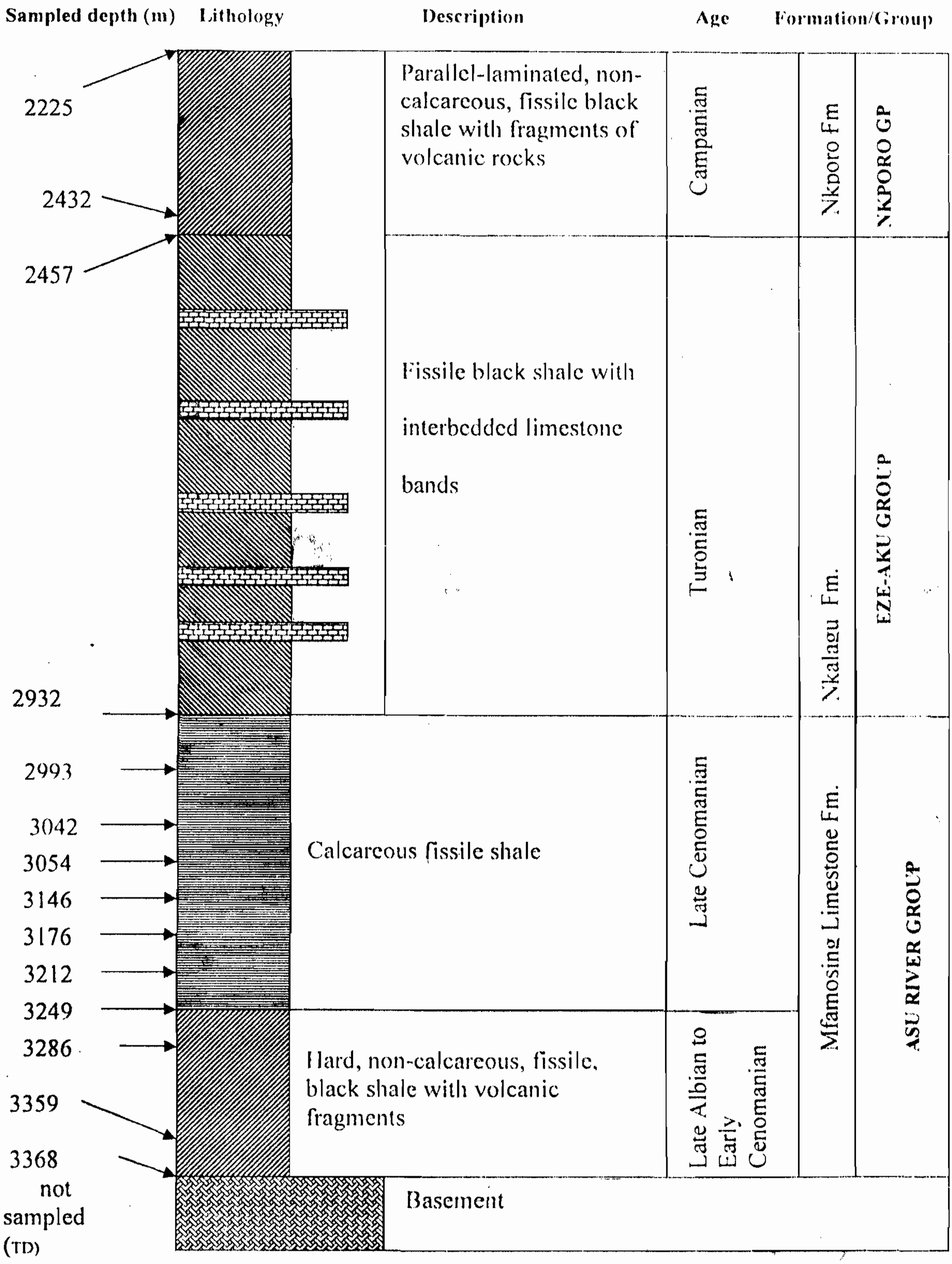


Fig. 5 Biofacies distribution in Ikono -1 Well

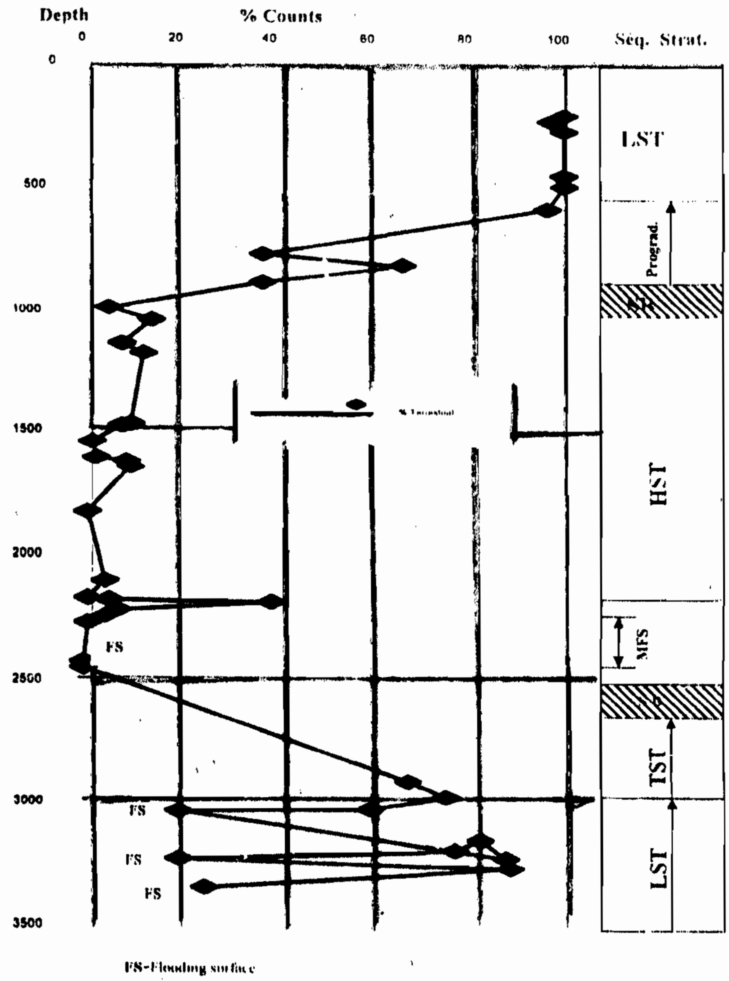


Fig 6 Distribution of particulate organic matter with depth

Particulate organic matter (%)	Depth (m) 3359	3042	2932
Pollen	3	4	1
Microforaminifer linings	12	5	2
Dinoflagellate cysts	2	3	0
Tracheids	4	5	1
Cuticles	12	6	0
Structureless organic matter	65	77	95
Marine source	75	22	81
Terrigenous source	25	79	19

Fig 7. Distribution of species diversity with depth

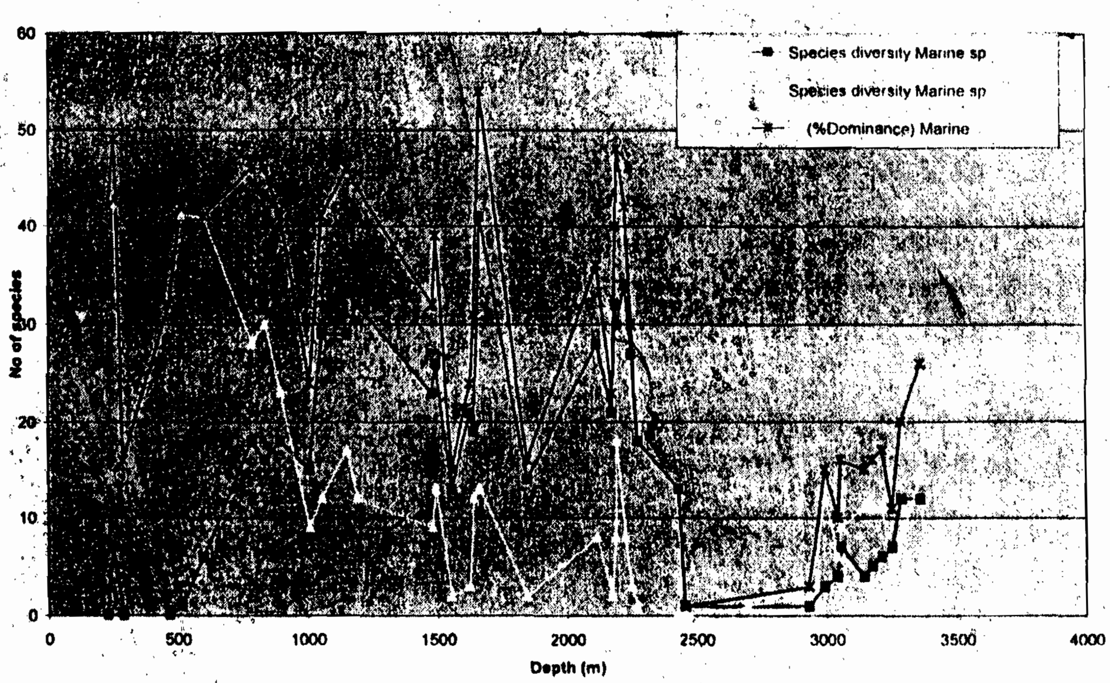


Fig. 8 Biostratigraphic distribution of sporomorphs from the basal sections of the Ikono- well

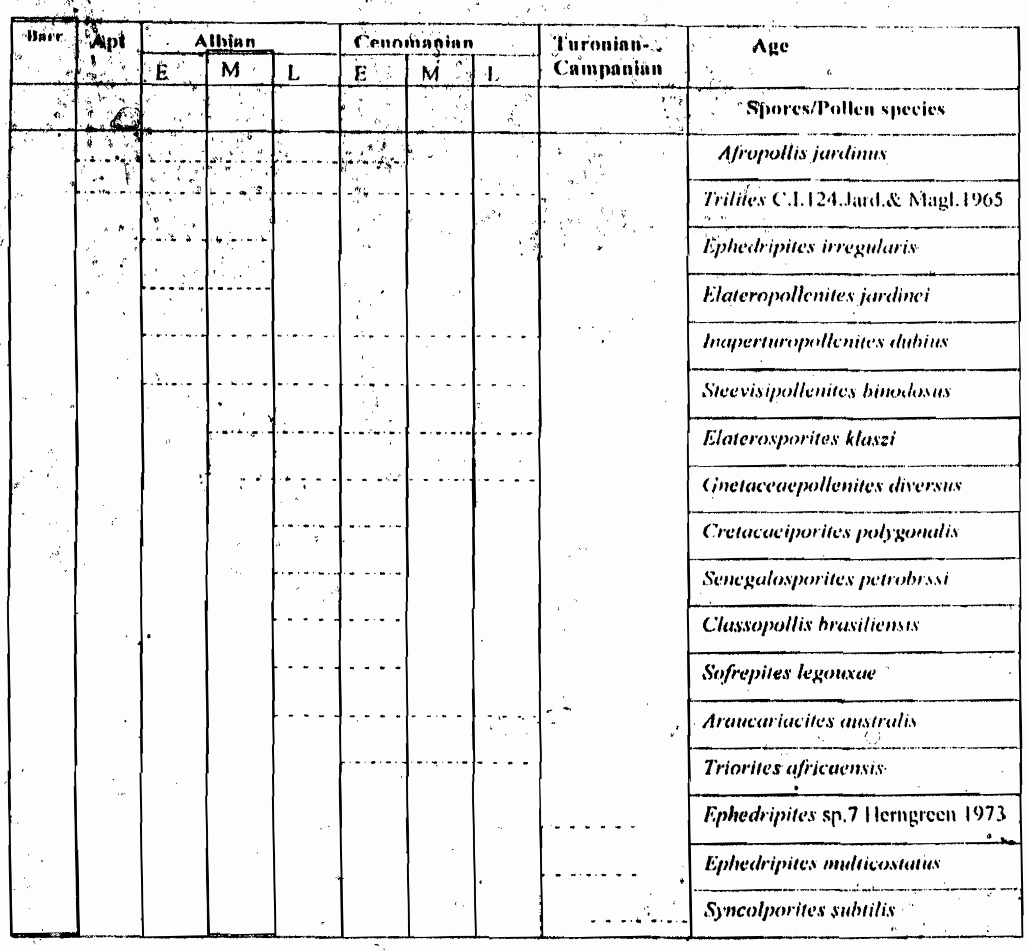
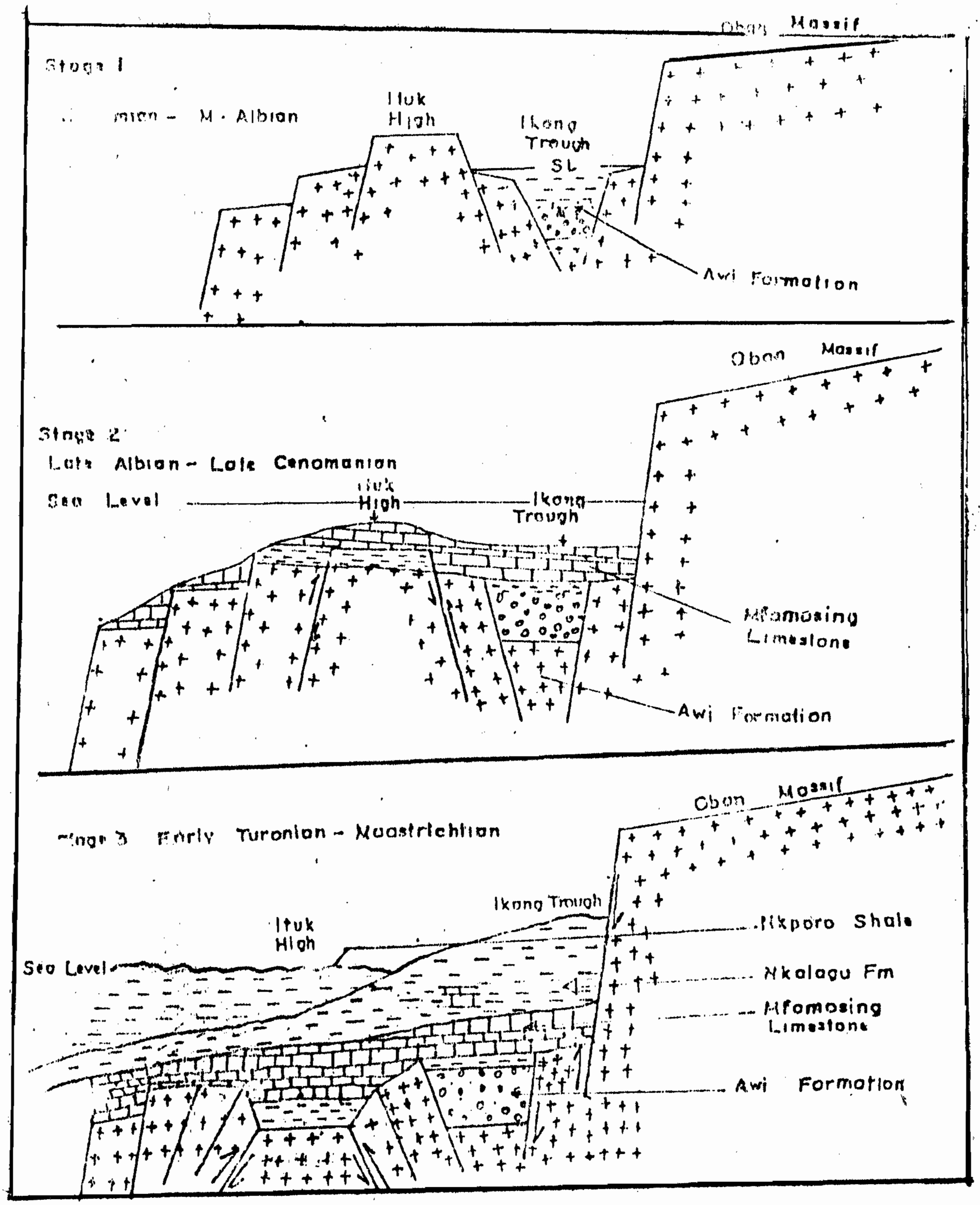


Fig. 9: Schematic diagram of cretaceous paleogeographic and sedimentation history of the Calabar Flank



RESULTS

The samples were very poor in palynomorphs at the lower horizons. Rarely could up to 200 grains be recovered, probably as a result of thermal destruction which also gave rise to the observed blackness of organic matter e.g. **Fig. 11** nos. 12-14.

3249-3359m. Hard, non-calcareous fissile black shale (Late Albian-Late Cenomanian)

Terrigenous species: *Leiotriletes* sp., *Cyathidites austrialis*, *Trilites* S.C. I. 124 Jardine and Magloire 1965, *Inaperturopollenites australis*, *Cycadopites* sp, *Ephedripites multicostatus*, *Elateropollenites jardinei*, *Sofrepites legouxae*, *Classopollis brasiliensis*, *Triorites africaensis*, and *Schizosporis* Sp 1.

Only two grains of doubtful *Afropollis jardinus* were encountered. The absence of *Afropollis jardinus* in the Calabar Flank observed by Doyle et al. (1982) is still not conclusive from this work.

Marine species: *Leiosphaeridia* sp. species including, large and small, laevigate and scabrate forms Fig 12, nos. 13-17. Also present are *Pterospermopsis* sp., *Palaeocystomocystis apiculata*, *Cyclonephelium* sp., *Batiacasphaera* sp., unidentifiable gonyaulacacean (Fig. 12, nos1 & 2) and peridiniacean (Fig. 11, no.3) dinoflagellate cysts and microforaminifer linings.

Combaz (1964) classified unoxidized acid-insoluble organic matter into palynomorphs, phytoclasts and amorphous organic matter. The simple grouping scheme is followed here.

Kerogen

The kerogen of sample 3359 m depth from the non-calcareous shale has the following distribution, Fig. 6:

Palynomorphs consist of ephedroid pollen, microforaminifer linings, and dinoflagellate cysts. Phytoclasts consist of wood tracheids, cuticles, and fungal remains. Amorphous Organic Matter consists of transparent, yellow- brown, black- brown and black forms. Rest includes mainly of amorphous sheets and fluffy organic matter

3249-2932 m. Calcareous shale (Late Cenomanian Mfamosing Limestone Formation)

Terrigenous species: . *Schizosporis* Sp 1, 2, 3, *Cyathidites minor*, *Trilites* S C. I. 124 Jardine & Magloire 1965, *Araucariacites australis*, *Podocarpidites* sp. *Classopollis brasiliensis*, *Ephedripites multicostatus*, *Ephedripites* sp. *Ephedripites irregularis*, *Triorites africaensis*. *Gnetaceaepollenites diversus*, *Elateropollenites jardinei*, *Syncolporites subtilis*, *Cretacaeiporites polygonalis*, *Senegalosporites petrobrasi* and *Steevisipollenites binodosus*.

Marine species: *Coronifera oceanica*, *Cleistosphaeridium polypes*, *Chytroesphaeridia spinosa*, *Cyclonephelium deckonincki*, *C. distinctum*, *Pterodinium cingulatum*, *Leiosphaeridia* sp., crustacean limbs and microforaminifer linings.

Classopollis brasiliensis disappears at the top, marking the end of the Cenomanian

Kerogen: The distribution of kerogen from 3042 m. is shown in Fig. 6.

2932-2456m Calcareous grey shale with limestone bands (Ekenkpon Shale -Late Turonian)

The samples at this depth are very poor in species count and preservation.

Palaeoenvironment of deposition			
Depth (m)	Fm	Biofacies	Palaeonvironment
1493 1628	Imo Shale	*Batiacasphaera compta, Palaeocystodinium, Ceratiopsis, Cyclonephelium, Spiniferites* Peridinoids < gonyaulacoids	Spiniferites- Cleistosphaeridium-Areoligera association of **open marine conditions** transgressive, deepening basin
1628 2225	Nkporo Shale	*Brackish water palms, Mauritidites & Proxapertites*, *Schizosporis*, *Leiosphaeridia* sp. 1, 2 & 3. Peridinoids < gonyaulacoids. **Dinogymnium peak.**	*Cyclonephelium-Spiniferites-Areoligera* Association **Brackish water-nearshore marine**
2225 2456	Nkporo Shale	Peridinoids < gonyaulacoids, Brackish-water palms, *Proxapertites, Mauritidites & Retistephanocolpites, Pediastrum, Gorgonisphaeridium, Leiosphaeridia, Cleistisphaeridium.*	*Leiosphaeridium-Cleistosphaeridium* association **Low salinity, brackish water environment**
2456 2932	Ekenkpon Sh.	Foraminifer linings, crustacean and coralline remains, *Schizosporis*. AOM = 95%	**Open marine environment**
2932 3249	Mfamosing	Foram linings, peridinoids < gonyaulacoids, *Schizosporis*. crustacean remains, *Tasmanites sp* AOM = 65%.	**Nearshore marine**
3340[illegible] 3359	Mfamosig	Foram linings, peridinoid < gonyaulacoids cysts, *Schizosporis*, cuticles. A O M = 50 %	*Tasmanites-Protoleiosphaeridium-Leiosphaeridium* association-Low salinity environment **Estuarine**

Fig.10 Table showing Palaeoenvironments of Deposition

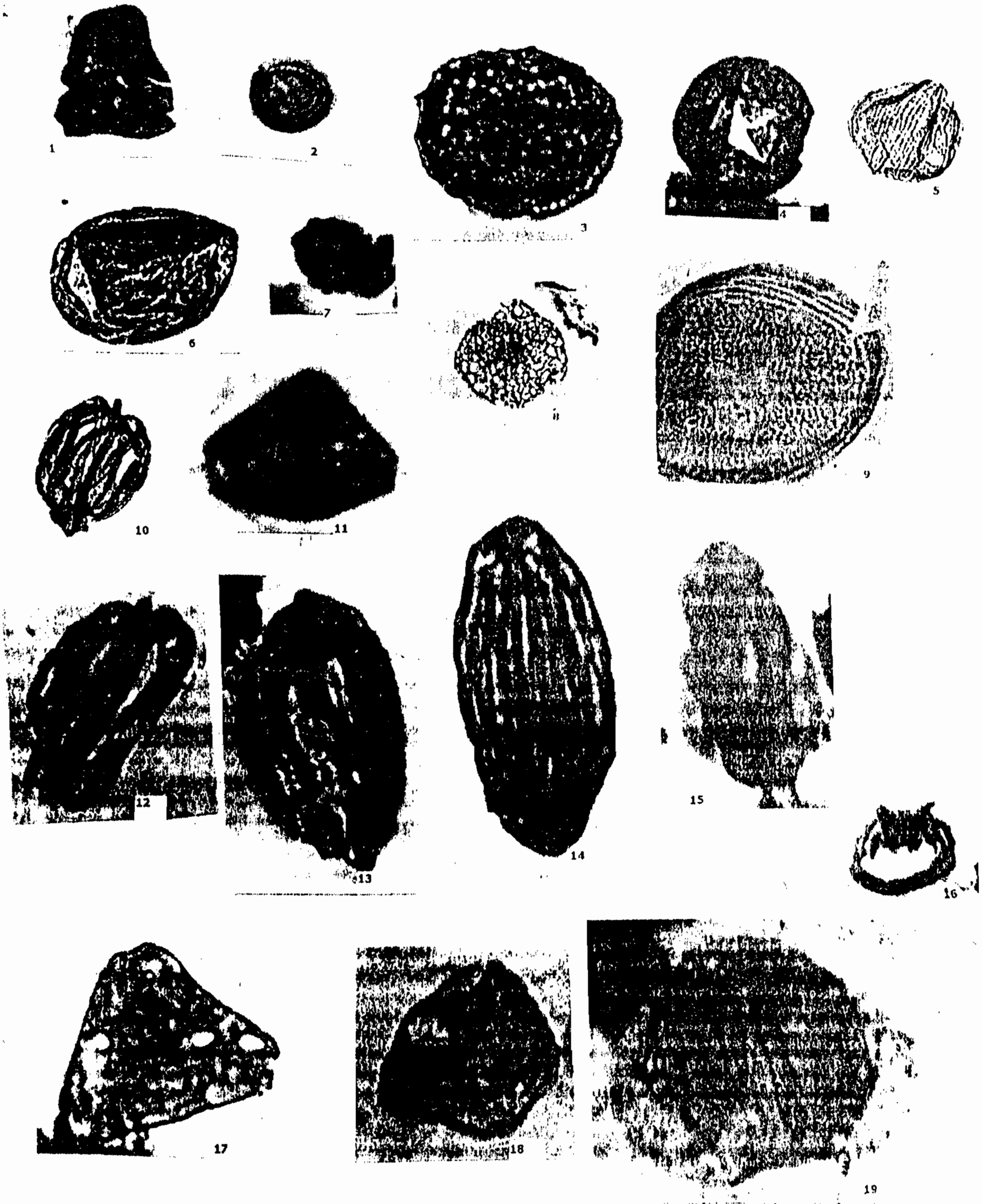


Fig 11 Sporomorphs from Ikono-1 well (2432-3359 m)

Magnification: Nos 1-3, 4, 6 -7 and 9 (X 400); others (X 1000)
1. *Cyathidites minor* Couper 1953
2. *Trilites* S. C. I. 124 Jardiné and Magloire 1965
3. *Cingutriletes* sp.
4. *Lycopodiumsporites* sp.
5. *Gnetaceaepollenites diversus* Stover 1964
6. *Inaperturopollenites dubius*
7. *Trilites* S.C, I. 124 Jardiné and Magloire 1965
8. *Afropollis jardinus* Doyle, Jardiné and Doerenkamp 1982
9. *Classopollis brasiliensis* Herngreen 1975
10. *Senegalosporites petrobrasi* Herngreen 1973
11. *Elateropollenited jardinei* Herngreen 1973
12. *Senegalopollenites petrobrasi* Herngreen 1973
13. *Steevisipollenites binodosus* Stover 1964
14. *Ephedripites multicostatus* Brenner 1963
15. *Ephedripites irregularis* Herngreen 1973
16. *Galaeacornea clavis* Stover 1964
17. *Triorites africaensis* Jardiné and Magloire 1965
18. *Cretacaeiporites polygonalis* (Jardiné and Magloire 1965) Herngreen 1973
19. *Podocarpidites* sp.

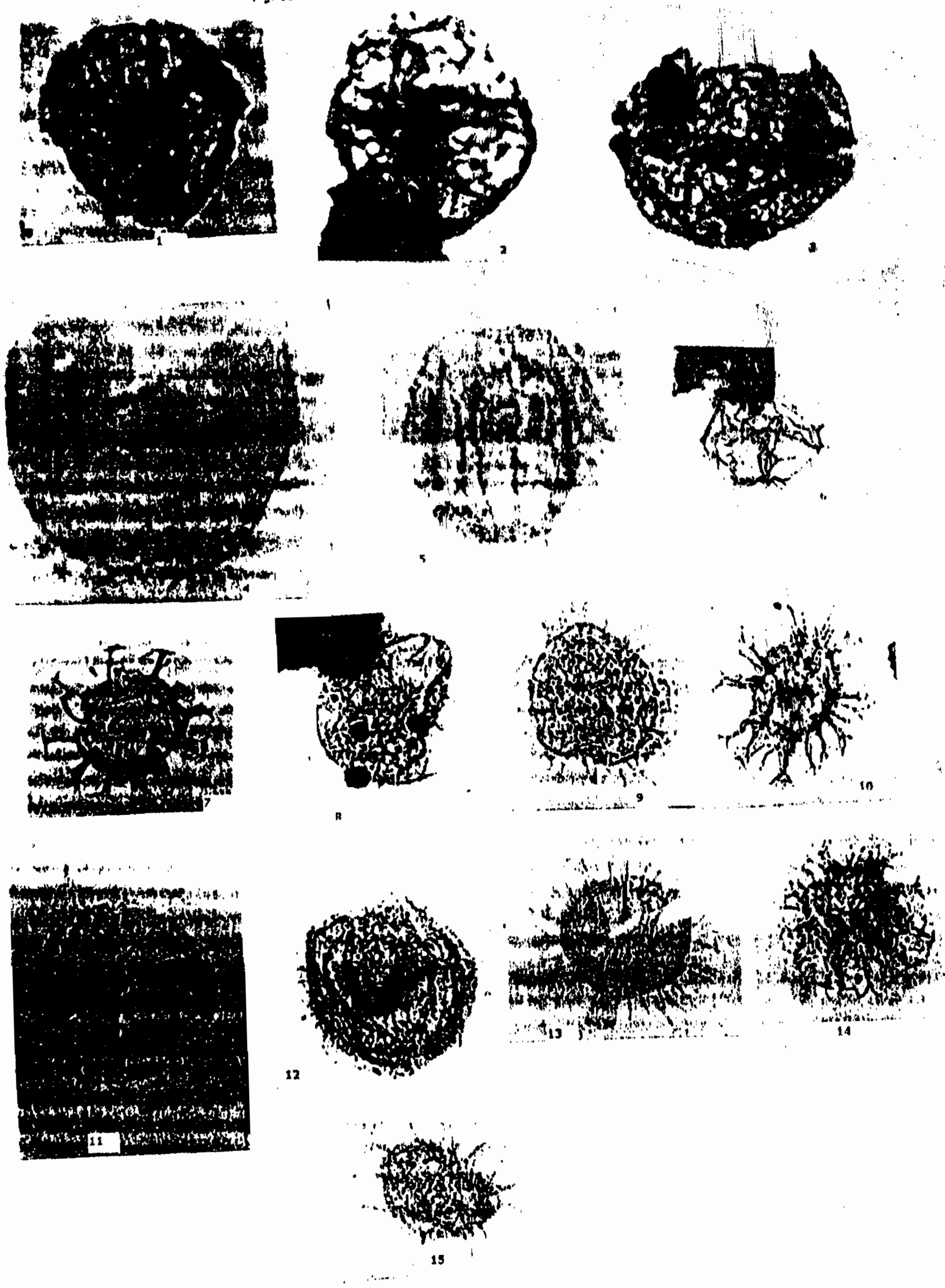


Figure 12 Dinoflagellate cysts from Ikono-1 well

Magnification No. 7, 8, 9, 13 and 15 X 400; others X1000

1. Peridinoid indet
2. Peridinoid indet
3. Gonyaulacoid cyst indet
4. *Batiacasphaera eutyches* (Davey 1969) Davey 1979
5. *Microdinium setosum* Sarjeant 1966
6. *Pterodinium cingulatum* (O Wetzel 1933) Below 1981
7. *Hystrichsphaeridium tubiferum* (Ehrenberg 1938) Davey and Williams 1966
8. *Exochosphaeridium bifidum* (Clarke and Verdier 1967) Clarke, Davey, Sarjeant and Verdier 1968
9. *Polysphaeridium subtile* Davey and Williams 1966
10. *Spiniferites ramosus ramosus* (Ehrenberg 1938) Loeblich and Loeblich 1966
11. *Subtilisphaera pirnaensis* Jain and Millipied 1973
12. *Cyclonephelium vannoforum* Davey 1969
13. *Coronifera oceanica* Cookson and Eisenack 1958
14. *Spiniferites ramosus gracilis* (Davey and Williams 1966) Lentin and Williams 1973
15. *Cleistosphaeridium ?aciculare* Davey 1969

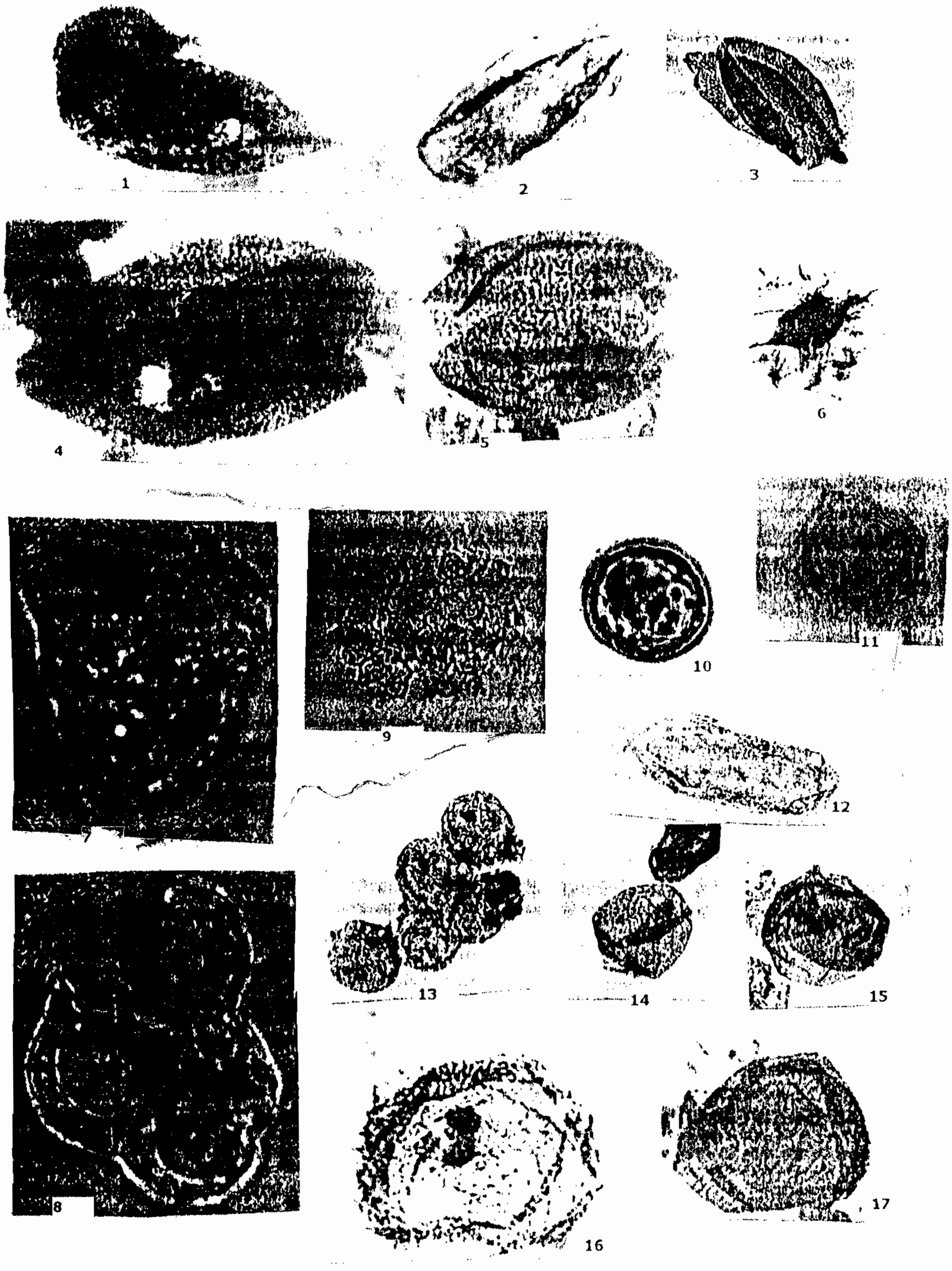


Figure 13 Other palynomorphs from Ikono-1 well

Magnification: All figures X 40

1. *Schizosporis* sp.
2. *Schizophacus parvus* (Cookson and Dettmann1959) Pierce 1976
3. *Schizosporis reticulatus* Cookson and Dettmann 1959
4. *Spermatites* sp
5. *Schizosporis spriggi* (Cookson and Dettmann 1959) Pierce 1976
6. *Pterospermopsis* cf. *helios* Sarjeant
7. Biserial foraminifer lining
8. Trochospiral foraminifer lining
9. *Pediastrum* sp. cf. *P. botryanum* (Turpin) Meneghini 1840
10. *Maculatasporites amplus* Segroves 1967
11. *Pterospermopsis aureolata* Cookson and Eisenack 1958
12. *Deusilites tentus* Hemer and Nygreen 1967
13. *Leiosphaeridia* sp. 4
14. *Leiosphaeridia* sp. 2
15. *Leiosphaeridia* sp. 3
17. *Leiosphaeridia* sp. 3

Terrigenous species: Fresh water algae, *Schizosporis spriggi* and *Maranhites brasiliensis* Brito.
Marine species: *Microdinium setosum*, *Hysrichosphaeridium tubiferum*, and *Polysphaeridium pumilum*. Others include microforaminifer linings, crustacean and coralline remains.
The age assignment is also based on the absence of the marker species such as the Late Cenomanian *Classopollis brasiliensis* at the base and of the Lower Senonian *Droseridites senonicus* at the top.

Kerogen: The calcareous grey shale with limestone bands and volcanic ash was sampled at 3042 and 2932 m depth, (Fig. **12 c & d** respectively). The 3042 m sample is from shale and the 2932 m sample, from the ash.
The results from the shale are distributed as follows (**Fig. 6**). The phytoclasts consist of tracheids only. The sample from the volcanic ash is barren as shown in Fig. 14 d.

2457-2225 m Parallel-laminated, non-calcareous, black shale (Nkporo Shale-Late Campanian)
Terrigenous species: The spore *Verrucatosporites usmensis*, and pollens *Proxapertites cursus*, *Proxapertites magnus*, *Proxapertites operculatus*, *Mauritidites crassibaculatus*, *Aquilapollenites senegalensis* and *Echitricolporites spinosus* were recovered. Others are the fresh water algae, *Crassosphaera bellus*, *Gorgonisphaeridium magnum* and *Pediastrum* cf *P. botryanum*.
Marine species: *Palaeocystodinium australinum*, *Phelodinium gaditanum*, *P. granulostriatum*, *Andalusiella polymorpha*, *Ceratiopsis diebelii*, *Ceratiopsis leptoderma*, *Cleistosphaeridium aciculare*, *Florentinia mantelli*, *Areoligera senoniensis*, *Exochosphaeridium bifidum*, *Polysphaeridium subtile*, *Cordosphaeridium varians*, *Achomosphaera ramulifera*, *Spiniferites ramosus ramosus*, *Spiniferites ramosus gracilis*, *Trichodinium castaneum*, *Leptodinium subtile*, and *Batiacasphaera compta*.

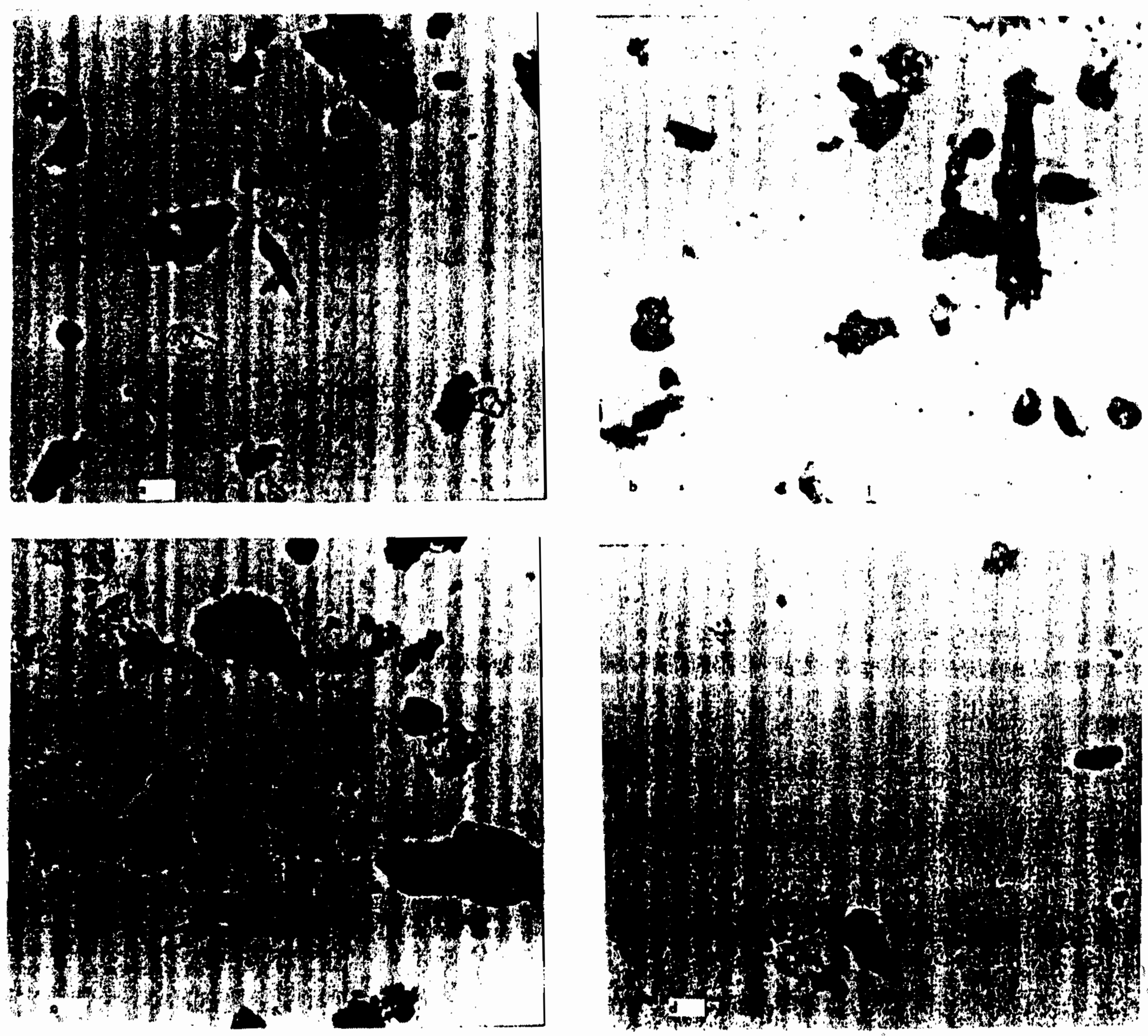


Figure 14 Photomicrographs of the Kerogens from Ikono 1 Well

Magnification X 400

a. Mfamosing Limestone Formation at 3359 metre depth (Non calcareous fissile shale)

b. Mfamosing Limestone Formation at 3249 metre depth (Calcareous fissile shale)

c. Nkalagu Formation at 3042 metre depth (Shale interbedded with limestone)

d. Nkalagu Formation at 2932 metre depth (the interbebbed volcanic ash bed)

Also recovered were the acritarchs, *Leiosphaeridia* sp. *Pterospermopsis radiata*, *Cymatiosphaera radiata*, *Leiovalia crassa*, and microforaminifer linings (Fig. 11). This assemblage falls within the **Leiosphaeridia-Cleistosphaeridium Association** of Downie et al. (1971) which are restricted to brackish water low- salinity environments.

2225-1628 m Non-calcareous black shale (Nkporo Shale-Maastrichtian)

Terrigenous: The same sporomorphs content as in the underlying Late Campanian occurs with *Proxapertites magnus* and *Schizosporis parvus* in addition.

Marine species: *Deflandrea polymorpha*, *Phelodinium pentagonale*, *Phelodinium gaditanum Areoligera senoniensis*, *Trichodinium castaneum*, *Cleistosphaeridium diversispinosum*, *C. polypes*, *Cordosphaeridium varians*,., *Achomosphaera ramulifera*, *Spiniferites ramosus ramosus*, *Danea californica*, *Pterodinium cingulatum*, *Chytroesphaeridia beatica*, *Cyclonephelium densebarbatum*, *Polysphaeridium subtile*, *Spinidinium saggitulum*, *Dinogymnium acuminatum D. euclaense*, and hydroid coral remains. The dinoflafellate cysts belong to the **Cyclonephelium-Areoligera-Spiniferites Association.**

All the species of *Dinogymnium* disappear at the top of this unit and marks the end of the Late Maastrichtian, after reaching their peak abundance at **1628 m** depth. *Phelodinium gaditanum* also disappears at the base of the Danian in Gbekebo-1 well of the Benin Flank, Oloto (1990). The presence of *Fibrocysta axialis*, *Heteraulacacysta pustulata*, *Glaphyrocysta exuberans*, *Apectodinium homomorphum*, *Eocladopyxis paniculata*, *Homotryblum abbreviatum* indicates the beginning of the Danian.

Acritarcha: Included are *Leiovalia crassa*, *Schizosphacus parvus*, *Crassosphaera bellus*, *Pterospermopsis velata* and *Gorgonisphaeridium magnum.*

1628-1493 m Grey shale (Imo Shale - Danian)

Terrigenous species: Only two species of trilete spores, *Cyathidites minor* and *Cyathidites australis* were encountered.

Marine species: The marine species include *Ceratiopsis diebelii*, *Palaeocystodinium golzowense* and *Apectodinium paniculatum*. *Hystrichokolpoma rigaudiae*, *Cyclonephelium deckonincki*, *Spiniferites ramosus gracilis*, *Cordosphaeridium varians*, *Areoligera senoniensis*, *Pterodinium cingulatum*, *Diphyes colligerum*, *Cleistosphaeridium polypes*. This assemblage is referable to the **Spiniferites-Cleistosphaeridium-Cordosphaeridium-Areoligera Association** of Downie et al. (1971).

1493-1189 m Non-calcareous grey to black shale (Imo Shale- Late Paleocene)

This depth is rich both in sporomorphs and marine species. The numerous species constituting the assemblage cannot be given here but suffice it to mention that similar assemblage including *Glaphyrocysta exuberans*, *Cordosphaeridium fibrospinosum*, *Turbiosphaera galeata*, *Nematosphaeropsis balcombiana*, *Muratodinium fimbriatum*, and *Litosphaeridium siphoniphorum* have also been recovered from the Paleocene of the Benin Flank by Jan du Chêne and Adediran (1984).

DISCUSSION

A sketch of the lithostratigraphy and geological history of the Calabar Flank is shown in **Fig. 15.** During the **Late Albian–Early Cenomanian**, the first marine flooding occurred on Ituk High depositing the parallel-laminated, non-calcareous shales over the basement, under estuarine or lagoonal conditions. This is the upper part of the Mfamosing Limestone Formation). The absence of the marine basal beds of Late Aptian-Early Albian age and the occurrence of Late Albian-Late Cenomanian marine shales with volcanic fragments in Ituk sub basin show that its subsidence and sedimentation began much later than that of Ikang Trough and was accompanied by volcanism.

Over-maturation and blackening of the organic matter, shown in the palynomorphs of **Fig. 11**, nos. 12-18; 20-23, is attributed to burial and low grade metamorphism caused by volcanism.

There was building up of carbonate banks and their subsequent destruction through the influx of clastic materials as the sea level continued to rise during the Turonian in Ituk sub-basin. Sedimentation continued on Ituk High till the end of the Turonian (Coniacian-Santonian uplift). The uplift shifted the depositional axis to the south west of Ikang sub-basin. This is similar to that of the Southern Benue Trough where, the Santonian uplift ended sedimentation and the depositional basin shifted westwards to the Anambra Basin.

Turonian beds are overlain by the Campanian with a major sequence boundary, Fig. **5**. Late Campanian microfossils were recovered from the beds overlying the Turonian confirming that the Coniacian and Santonian are absent.

From the foregoing, it is obvious that only the Late Albian-Late Cenomanian marine part of Asu River Group is found in Ikono-1 well, which part is also found in many areas along the Benue Trough. The Nkporo Shale was deposited throughout the Late Campanian and Maastrichtian. Full marine conditions continued on Ituk sub-basin so that the more clastic, nearshore deposits of Mamu, Ajali and Nsukka Formations of Anambra Basin do not occur.

The coarse-grained sandstone at the top of Nkporo Group marks the Cretaceous/Tertiary boundary in Ikono-1 well and the base of the Danian Imo Shale. The Eocene regression continued into the Oligocene and Miocene. The Miocene-Recent Benin Formation has buried the older formations so that they are only encountered in the subsurface.

AGE

The age of the recovered sporomorphs from the basal section is shown in **Fig. 8.**

Triorites africaensis is the index species of the Late Cenomanian of Senegal (Jardiné and Magloire, 1965; Jardiné, 1967) although it has also been identified from the Cenomanian-Albian of Gabon (Boltenhagen 1963, Plate 2, fig. 24). The Zone VII of Jardiné and Magloire, (op. cit.) of Middle-Late Cenomanian, contains the pollens, *Classopollis brasiliensis*, *Triorites africaensis*, and *Galaeacornea clavis*, *Triorites africaensis*, *Creatcaeiporites polygonalis*, *Classopollis brasiliensis*, and *Galaeacornea clavis* occur in the Late Albian-Early Cenomanian palynozone VIII of Jardiné and Magloire (1965); the *Classopollis brasiliensis* Subzone of the *Elaterocolpites-Elateroplicites-Sofrepites* Zone of Herngreen (1975); the Zone 1a (Po-304 i.e. *Afropollis jardinus)* Assemblage Zone of Lawal and Moullade (1986) and the top of the Late Albian-Early Cenomanian Africa-South America Middle Cretaceous geophytological province of Herngreen and Chlonova (1981).

The Albian-Cenomanian boundary is marked by the replacement of *Classopollis classoides* by *C. brasiliensis* and by the appearance of *Triorites africaensis*. The rarity of *Afropollis jardinus* and *Classopollis classiodes* which are abundant in the Late Albian-Early Cenomanian Abakaliki Shale may be ecological. The elaters-bearing pollen are absent in the Turonian.

Muller et al. (1987) and Lawal and Moullade (1986) erected a *Droseridites senonicus* taxon-range zone to cover the Early Senonian. The base is marked by the first appearance of *D. senonicus* and the top by its extinction. It also includes the first appearance at the base of the zone of *Victorisporis*, *Ariadnesporites*-complex, *Gabonisporis vigourouxii* and *Retitricolporites* sp. At the top, the extinction of *Senegalosporites petrobrasi* and *Victorisporis* occurred. This palynozone is known in Gabon (Boltenhagen, 1976). The above species occur in Awgu Shale at Agbogugu road section of the southern Benue Trough. They were not recovered in this work showing that the presence of the Coniacian in Ituk sub basin is doubtful.

Fig. 15 Lithostratigraphy and depositional history of Ikang Trough and Ituk High - the Southern Benue Trough is included for correlation

Age	GROUP	Calabar Flank: Ikang Trough (THIS REPORT)	Calabar Flank: Ituk High (THIS REPORT)	Southern BenuTrough: Abakaliki/Afikpo Area (Modified from Ojoh 1992)
Maastrichtian	NKPORO		Nkporo Shale Fm	Mpu Hills Fm
Campanian	NKPORO		Nkporo Shale Fm	Akpoha-
Santonian				
Coniacian				Ekori Fm
Late-Early Turonian	EZE-AKU	Nkalagu Fm	Nkalagu Fm	Agu-Ojo Nara Shales
Late-Early Cenomanian	ASU RIVER	Upper Mfamosing Limestone Fm	Upper Mfamosing Limestone Fm	Ezillo Fm Agala Fm
Late Albian	ASU RIVER	Upper Mfamosing Limestone Fm	Upper Mfamosing Limestone Fm	Ngbo Fm
Middle Albian	ASU RIVER	Lower Mfa mosing Lime stone Fm		Ekebeligwe Fm
Early Albian	ASU RIVER			
Late Aptian-Neocomian	ASU RIVER	Awi Formation		

Sequence stratigraphy

Gregory and Hart (1992) in a predictive model of the response of palynoflora to sea-level changes showed that the Lowstand Systems Tract (LST) is characterized by terrigenous dominance (> 65 % terrigenous) of the palynoflora. The Transgressive Systems Tract (TST) has marine dominated palynoflora (<50% terrigenous). The Highstand Systems Tract (HST), characterized by progradational to retrogradational electric log stacking patterns, has the progradational intervals dominated by terrigenous microflora while the retrogradational intervals are characterized by *marine* dominance (<50 % terrigenous) to strong marine influence (50-65 % terrigenous).

A plot of the percentage count of terrigenous species versus depth, (**Fig. 5**) shows the response of the palynoflora to sea-level changes. At the base, occurs a wide fluctuation with three peaks of marine dominance indicating flooding surfaces (FS), alternating with three peaks of terrigenous dominance of late Lowstand or early TST. In **Fig. 7** the marine species diversity shows a smoother curve of late progradation or early Lowstand. The benthic microforaminifer linings and cuticles are highest at **3359 m**. The fluctuation continues throughout the Turonian. It is difficult to pick the biofacies pattern owing to the barrenness of the samples within the calcareous units. The kerogen, however, shows 95% structureless organic matter which is attributed to marine source, Goodall et al. (1992). There is no difference in the palynoflora content between the non-calcareous shale with volcanic fragments at the base and the overlying calcareous shale.

Morley (1995) reported that within marine sediments, miospores are most abundantly represented in Lowstand sediments and least represented in those from Maximum Flooding Surfaces at the base of the Highstand. This trend is followed by the results of this analysis, **Fig. 4**. The fluctuating late Lowstand or early TST at the base is shown by low marine species count of (<15 species) around the **3000 m** depth. It builds up to 35 species per sample at the maximum flooding surface at **2500 m** depth, fluctuates between the two values at Highstand and drops to 0-8 species at the Lowstand, at the top of the core around **500 m** depth. The highest total count occurs at the Maximum Flooding Surface.

The kerogen from **3359 m** carries the highest palynomorphs, most of which are microforaminifer linings The oxidized fraction has abundant, large, fresh-water *Schizosporis* fragments, (**Fig 12, no 1**). Among the phytoclasts which also run highest at this depth, (16 %), cuticles are predominant. In general, the trend shows a decrease in phytoclasts and an increase in the amorphous organic matter, indicating a late Lowstand from **3359** to **2457 m**.

Pasley and Hazel (1990) and Pasley et al. (1991) reported dominance of marine organic matter in the Transgressive Systems Tract, much of the terrigenous component of the palynoflora being trapped in the estuarine and near-shore environments. In the offshore environments the marine component of the palynoflora is dominant both in frequency and diversity.

A Sequence Boundary is inferred at **2457 m**, between the Turonian and Campanian. There is a sudden appearance of Late Campanian palynomorphs at this depth which also records the Maximum Flooding Surface and absence of terrigenous kerogen. The Campanian/Maastrichtian boundary, on the other hand, is marked by a sharp increase in terrigenous input, from 7 % to 40% and dropping in like manner to 5%. The **TST** continues into the Early Maastrichtian, culminating in an **HST** throughout the Middle Maastrichtian, Danian and the rest of the Paleocene.

Gregory and Hart (1992) also reported that the palynoflora varies at the onset of progradation depending on the proximity to the deltas. Locations more distal to the delta experience continued marine dominance while those in a more proximal position change from marine-dominated to a more mixed palynoflora. The change continues with eventual dominance of terrigenous palynomorphs as progradation continues. This trend was also observed. The Late Albian-Late Cenomanian TST fluctuates between marine- and terrigenous-dominated palynoflora of a proximal setting. The Turonian-Campanian trend resembles an offshore environment with marine-dominated palynoflora but when integrated with the associated dinoflagellate cysts, indicate nearshore, low salinity conditions.

Another Sequence Boundary at **1152 m** at the Paleocene/Eocene boundary was picked by a slight and gradual increase in the terrigenous input. Terrigenous influence increases gradually with progradation up to the **786 m** depth where a sharp rise in terrigenous dominance marks the Oligocene Lowstand.

Palaeonvironment of deposition

Fig. 10 shows the palaeoenvironmental interpretation of Ikono-1 well based on the integration of lithological and biofacies results. The abundance of foraminifer linings, chorate and peridinoid dinoflagellate cysts in the **3359 m** from the non-calcareous shale indicates deposition in a nearshore marine environment, probably in an estuary or lagoon with much influx of fresh water based on the presence of large size freshwater algae, *Schizosporis*.

The association of cuticles (plant leaves) with estuarine and nearshore environments have been reported, (Goodall et al. 1992).

The acritarch, *Leiosphaeridia* is common in samples from **3359-2952 m**. Combaz (1967) presented arguments to show that **Tasmanites-Protoleiosphaeridium-Leiosphaeridium** associations are indicative of abnormal, low salinity environments, where they could form blooms of floating algae. An estuarine environment is accordingly inferred for this depth. Muller (1959) from a laboratory experiment concluded that only the order **Rotallidae** possesses a chitinous inner test. McKee et al. (1959) found much microforaminifer linings (<150 μ) in shallow water, and held that those found in deeper water resulted from the dwarfing of larger forms. In this work, microforaminifer abundance occurs in association with fresh water algae indicating a shallow water origin, rather than dwarfing in deeper water. An open marine environment was established up the sequence during the Cenomanian-Turonian with the increase in transgression during which corals lived. The alternating limestones and shales with volcanic rock fragments are records of magmatism during the basin development.

The Campanian transgression carried the dinoflagellate eco-group, the **Areoligera Association** of Downie et al (1971), dominated by **Cyclonephelium**, **Areoligera** and **Glaphyrocysta** of normal salinity or open sea environment. Goodall (1992) cited Marshall and Batten (1988) that the **Cyclonephelium** group proliferated in low latitude **nearshore** black shales in highly stressed environments during the Cenomanian-Turonian, while the genera **Glaphyrocysta** (and **Areoligera,** *Systematophora placantha, Riculacysta* and *Adnatosphaeridium*) were dominant in transgressive phases during the **deepening** of the basin in stressed environments. The Cenomanian-Turonian oxygen-deficient conditions in the Calabar Flank have been reported by many authors, Nyong and Ramanathan, (1985).

The latest Maastrichtian transgression has the **Spiniferites-Cleistosphaeridium-Cordosphaeridium** dinoflagellate eco-group. Goodall (1992) found *Spiniferites* to be ubiquitous though increasing in abundance within transgressive sequences and declining during regressions. The abundance of *Dinogymnium* indicates low salinity lagoonal or estuarine conditions. The Danian was a period of Highstand and return of the **Areoligera Association**, with *Ceratiopsis diebelii*. The end of Cretaceous transgression was followed by Highstand in the Paleocene, progradation and regression in the Eocene and Lowstand since the Oligocene.

CONCLUSION

Two distinct sedimentary sub basins existed in the Calabar Flank during the Cretaceous, the Ikang Trough and Ituk High. The age of the sedimentary fill of Ikono-1 Well shows that Ituk High sustained different subsidence and depositional histories compared to Ikang Trough. In discussing the geology of the Calabar Flank, distinction should be made between the two sub basins.

Sedimentation began in Ikang Trough during the Late Aptian-Late Albian but on the adjoining Ituk High, deposition did not start until the Late Albian- Early Cenomanian. From the Early Cenomanian onwards, sedimentation was contemporaneous in the two areas thus, the Late Albian- Late Cenomanian marine part of the Asu River Group is found in Ikono-1 Well, which part is also found in many areas along the Benue Trough. The marine conditions continued till the Late Turonian when sedimentation ended in Ikang Trough.

The Coniacian and Santonian sediments were not found. Obviously, the tectonic uplift of the Calabar Flank started about this time. Sedimentation subsequently shifted to Ituk sub basin where the Late Campanian-Late Maastrichtian Nkporo Group overlies the calcareous beds of the Turonian. Nkporo Shale was deposited throughout the Campanian and Maastrichtian under normal marine conditions so that the coarse clastic formations of Mamu, Ajali and Nsukka of Anambra Basin do not occur in the Calabar Flank. The coarse-grained sandstone at the top of Nkporo Group marks the Cretaceous/Tertiary boundary in Ikono-1 well and the base of the Danian Imo Shale. The rest of the Tertiary-Recent was one of Lowstand.

ACKNOWLEDGEMENTS

The well-cuttings for this work were provided by SPDC Nigeria. The Departmental cartographer, Mr. Finan Ugochukwu sketched the figures. Mr Dan Amogu did the sketch of palaeogeological history. I remain indebted to them all.

REFERENCES

Adeleye, D. R. and **Fayose,** E. A. 1978. Stratigraphy of the type section of Awi Formation, Odukpani area, southeastern Nigeria. Nig. J. M. Geol. 15, pp. 33-37.

Amajor, L. C. 1985. The Cenomanian Hiatus in the southern Benue Trough, Nigeria. Geol. Mag. 122: 39-50.

Bostick, N. H.1971. Thermal alteration of clastic organic particles as an indicator of contact and burial metamorphism in sedimentary rocks. Geoscience and Man. 3: 83-92.

Combaz, A. 1964. *Les Palynofacies.* Revue Micropaléontologie, 7, (3) : 205-218.

Combaz, A. 1967. Leiosphaeridaceae Eisenack 1954, et Protoleiosphaeridae Timofev 1959- leurs affinitiées, leur role sédimentologique et géologie. Rev. Palaeobot., Palynol., 1 (1-4): 309-321

Downie, C., **Hussain,** M. A. and **Williams,** G. L. 1971. Dinoflagellate cyst and acritarch associations in the Paleogene of South east England. Geoscience and Man 3, pp. 29-35

Doyle, J. A, **Jardine,** S. and **Doerenkamp,** P. A. 1982. *Afropollis* a new genus of early angiosperm pollen with notes on the Cretaceous palynostratigraphy and palaeoenvironments of Northern Gondwana. Bull. Centre Rech, Explor. Prod. Elf-Aquataine. V. 6: 39-117.

Goodall, J. G. S.1992. Paleocene and Lower Eocene Palynology and Palynofacies of the Viking Graben, North Sea. Unpublished PhD Thesis, University of London.

Goodall, J. G. S., **Coles,** G. P. and **Whitaker,** M. F., 1992. Integrated palynological, palynofacies and micropalaeontological study of the Pre-salt formations of the South Gabon subbasin and the Congo Basin. Geologie Africaine Coll. Geol. Libreville. Recueil des Communic 6-8 May, 1991, p. 365-399.

Gray, J. 1965. Palynological Techniques. In: Kummel B. and Raup D., 1965. Handbook of Paleontological Techniques. W. H. Freeman and Company, San Francisco. 852 pp.

Gregory, W. A. and **Hart,** G. F. 1992. Towards a Predictive Model for the Palynologic response to Sea-Level Changes. PALAIOS, 7: 3-33

Herngreen, G. F. W., 1975. Palynology of Middle and Upper Cretaceous strata in Brazil. Meded. Rijks Geol. Dienst., n.s., 26(3): 39-91.

Herngreen, G. F. W., and **Chlonova,** A. F., 1981. Cretaceous Microfloral Provinces. Pollen et Spores. 23 (3-4): 441- 455.

Iwobi, O. C. 1991. Foraminiferal ages in the southern Benue Trough N. A. P. E Bull. 6 (1): 39-47.

Jan du chene R. E. and **Adediran,** S. A. 1984. Late Paleocene to Early Eocene dinoflagellates from Nigeria. *Cahiers de Micropaleontologie.* 3, pp. 5-39

Jardine, S. and **Magloire,** I., 1965. Palynologie et stratigraphie du Cretace des Bassins du Senegal et de Cote d'Ivoire. Mem. B. R. G. M. Coll. Int. Micropal 32: 287-222

Kogbe, C. A., 1976. Continental Intercalaire in northwestern Nigeria. Nig. J. Min. Geol. 13 (2): 45-50.

Lawal, O. and **Moullade,** M, 1986. Palynological Biostratigraphy of Cretaceous Sediments in the Upper Benue Basin, N. E. Nigeria. Revue de Micropaleontologie, 29, (1): 61-83.

Mckee, E. D., **Chronic,** J., and **Leopold,** E. B., 1959. Sedimentary belts in Lagoon of Kapingamarangi Atoll. Bull. A. A. P. G., 43(3): 501-562.

Morley, R. J. 1995. Biostratigraphic characterization of Systems Tracts in Tertiary sedimentary basins. *Indonesian* Petroleum Association, Proceedings of the International Symposium on Sequence Stratigraphy in SE Asia, May, 1995

Muller, J. 1959. Palynology of Recent Orinoco delta and shelf sediments: reports of the *Orinoco Shelf* Expedition. Volume 5. Micropaleontology, 5: 1-32.

Murat, R. C., 1970. Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In: Dessauvagie, T. F. J. and Whiteman, A. J., (Eds.) African Geology. Univ. of Ibadan Press, pp. 251-266.

Nyong, E. E. and **Ramanathan,** R. M. 1985. A record of oxygen-deficient paleoenvironments in the Cretaceous of the Calabar Flank, S. E. Nigeria. Jour. Afr. Earth Sci. 3 (4): 455-460.

Nton, M. E., 1999. Sedimentology and depositional environment of Awi Formation, Calabar Flank, southeastern Nigeria. Nig. J. Min. Geol. 35 (1): 25-36.

Ojoh, K. A. 1990. Cretaceous Geodynamic evolution of the southern part of the Benue Trough (Nigeria) in the Equatorial domain of the South Atlantic - stratigraphy, basin analysis and paleogeography. Bull. Centres Tech. Explor.-Prod. Elf-Aquitaine, 14(2): 419-442.

Ojoh, K. A. 1992. The southern part of the Benue Trough (Nigeria) Cretaceous Stratigraphy, Basin analysis, Palaeo-oceanography and Geodynamic evolution in the Equatorial domain of the South Atlantic. N A P E. Bull. 7 (2): 131-152.