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Palynostratigraphy, palaeoenvironments and kerogen assessment of Mid-Cretaceous Ezeaku Shales succession from River Obey in Umudi-Lokpanta, Abia State, Southeastern Nigeria

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ABSTRACT

There have been disparities about the age of the Eze-Aku Formation, Anambra Basin south-eastern Nigeria. Eleven surface samples of the Eze-Aku Shales from the River Obey in Umudi village, Lokpanta Abia state, were subjected to standard palynological, palynofacies, kerogen preparation and analysis. A diversified palynoflora with preponderance of typical Late Cenomanian to Early Turonian diagnostic palynomorphs were recovered. Common taxa were *Elaterosporites protensus*, cf. *Elateropollenites jardinei, Steevesipollenites binodosus, Steevesipollenites grambasti, Gnetaceaepollenites barghoornii, G. diversus, G. clathratus, Galeocornea causea, Classopollis* spp., *Podocarpidites herbstii*, *Fraxionoipollenites venustus*, *Cretaceaporites mulleri*, *Cicatricosisporites venustus,* and the dinoflagellate cysts *Callaiosphaeridium trycherium, Oligosphaeridium pulcherrimum, O. complex, O. albertense, Pseudoceratium pelliferum, Florentinia resex, Heterosphaeridium difficile*, *Surculosphaeridium longifurcatum*, *Cribroperidinium orthoceras*, and different species of *Dinogymnium*. Angiosperm pollens were scarce while gymnosperms were moderate due to the evolutionary trend of the flowering plants in the early Cretaceous. Structured phytoclasts with sparse amorphous organic matter which indicated deposition in nearshore to marginal marine environments dominated the palynofacies. The sporomorph colour indicated mature oil and gas generation potentials.

***Keywords*:** Palynomorphs, phytoclasts, kerogen; Eze-Aku Formation, Anambara Basin, elaterates province

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1. INTRODUCTION

Few published palynological studies have been carried out on the Benue Trough, as well as other inland basins of Nigeria compared to the petroliferous Niger Delta. Besides, there are conflicting informations on the age of the Eze-Aku Formation which is part of the Lower Benue Trough. Salard-Cheboldaeff (1990), while reviewing the palynology of Nigeria, had associated the Eze-Aku Formation with the Lower Turonian "Nkalagu quarry". Other researchers (Short and Stauble, 1967; Oboh-Ikuenobe *et al.*, 2005; Ukaegbu and Akpabio, 2009; Uzoegbu and Okon 2017; Didei and Okumoko, 2017; Akpofure and Didei 2018; Soronnadi-Ononiwu and Didei, 2018) had all assigned a Turonian age to the Eze-Aku Group/Formation. On the contrary, Ehinola (2010) had dated it as Upper Cenomanian to Middle Turonian, while Lawal (1991) had dated the basal black shales of the Eze-Aku Formation as Late Cenomanian. Furthermore, Chiadikaobi *et al*., (2018) in their stratigraphic table of Southeastern Nigeria, which was modified after Reyment (1965) and Ojoh (1992), had given the range of the Eze-Aku shale Group as Late Cenomanian to Middle Turonian. Finally, in recent times, Nigeria has made concerted efforts to increase her hydrocarbon reserves. To realize this, the government had allocated some acreage in the Inland Basins, hence due to the need to assess the hydrocarbon potentials of these Basins.

2. GEOLOGICAL SETTING AND STRATIGRAPHY

The Benue Trough Nigeria (**Fig. 1**) comprises the Upper, Middle and Lower Benue sub-basins which arose from a "pull apart" basin associated with the opening of the Atlantic Ocean which ended in the Early Tertiary with the development of the Tertiary Niger Delta (Petters and Ekweozor, 1982; Ekweozor and Unomah, 1990). The Benue Trough was subjected to four depositional cycles which were all associated with transgressions and regressions of the sea. The first sedimentary cycle which is associated with the deposition of the Asu River Group lasted from the Middle Albian to Late Albian. It is laterally equivalent to the Bima Sandstones in the Upper Benue Trough and the Awe/Arufu/Uomba Formations of the Middle Benue (Wozny and Kogbe, 1983; Reyment and Dingle, 1987). The second sedimentary phase occurred between the Upper Cenomanian and Middle Turonian and it was during this period that the Eze-Aku shales herein studied were deposited (**Table 1**).

The lateral equivalents are the Amasiri and Makurdi sandstones in the Afikpo Basin and Middle Benue Trough, respectively. Furthermore, the Gongila, Jessu and Dukul Formations are their lateral equivalents in the Upper Benue Trough (Ehinola, 2010). Again, the third sedimentary phase which ranged from the Upper Turonian to the Lower Santonian is associated with the deposition of the Awgu shale and Agbani sandstones which are lateral equivalents of the Fika and Sekunle shales in the Upper Benue Trough. Finally, the fourth sedimentary cycle, which ranged from the Campanian –Maastrichtian, was marked by the deposition of the Nkporo shales, Owelli sandstones, Afikpo sandstones and Enugu shales coupled with the deposition of the Mamu Formation, Ajali sandstones and the Nsukka Formations with their Upper Benue Trough lateral equivalents as the Numanha shale and Gombe sandstone (Ehinola *et al*., 2005; Reyment, 1965). The lithostratigraphic units of the Lower Benue Trough are broadly divided into the Abakiliki, Eze-Aku and Awgu shales with ages ranging from Albian to Coniacian (Table 1).

Table 1. Table of Formations, Niger Delta Area (after Short and Stauble (1967))

SUBSURFACE			SURFACE OUTCROPS		
Youngest Known Age		Oldest Known Age	Youngest Known Age		Oldest Known Age
Recent	Benin Formation (Afan Clay Member)	Oligocene	Plio/Pleistocene	Benin Formation	Miocene
Recent	Agbada Formation	Eocene	Miocene Eocene	Ogwashi-Asaba Formation Ameki Formation	Oligocene Eocene
Recent	Akata Formation	Eocene	L. Eocene	Imo Shale Formation	Paleocene
			Paleocene	Nsukka Formation	Maestrichtian
			Maestrichtian Campanian Campanian/ Maestrichtian	Ajali Formation Mamu Formation Nkporo Shale	Maestrichtian Campanian Santonian
EQUIVALENTS NOT KNOWN			Coniacian/ Santonian Turonian Albian	Awgu Shale Eze Aku Shale Asu River Group	Turonian Turonian Albian

For better understanding of the geological records of the different inland basins in Nigeria, exhaustive paleontological studies need to be undertaken. The few published palynological studies include those of Ojoh (1992) in the southern Benue Trough; Edet and Nyong (1993) in the Calabar Flank; Lawal and Moullade (1986); Ojo and Akande (2001) in the Upper Benue Trough; Ola-Braimoh and Boboye (2011) in the Bornu Basin; Ojo and Akande (2004) and Abubakar *et al.* (2011) in the Gongola Basin, among others. Again, in the Benue Trough most of the other investigations were based on foraminifera none of them had incorporated palynology and sporomorph colour analysis. The present palynological investigation of eleven surface samples from River Obey in Lokpanta, Abia State Nigeria (Lat. 06°00′.353″ N, Long. 007°27′.723″E), is aimed at shedding more light into the Early Cretaceous microflora from Nigeria, ascertain the age of the Eze-Aku Shales based on the occurrence of diagnostic palynomorphs, as well as characterizing the palynofacies from the particulate organic matter and sporomorph colour index to infer the paleoenvironmental conditions and petroleum generating potential of the Eze-Aku Shales.

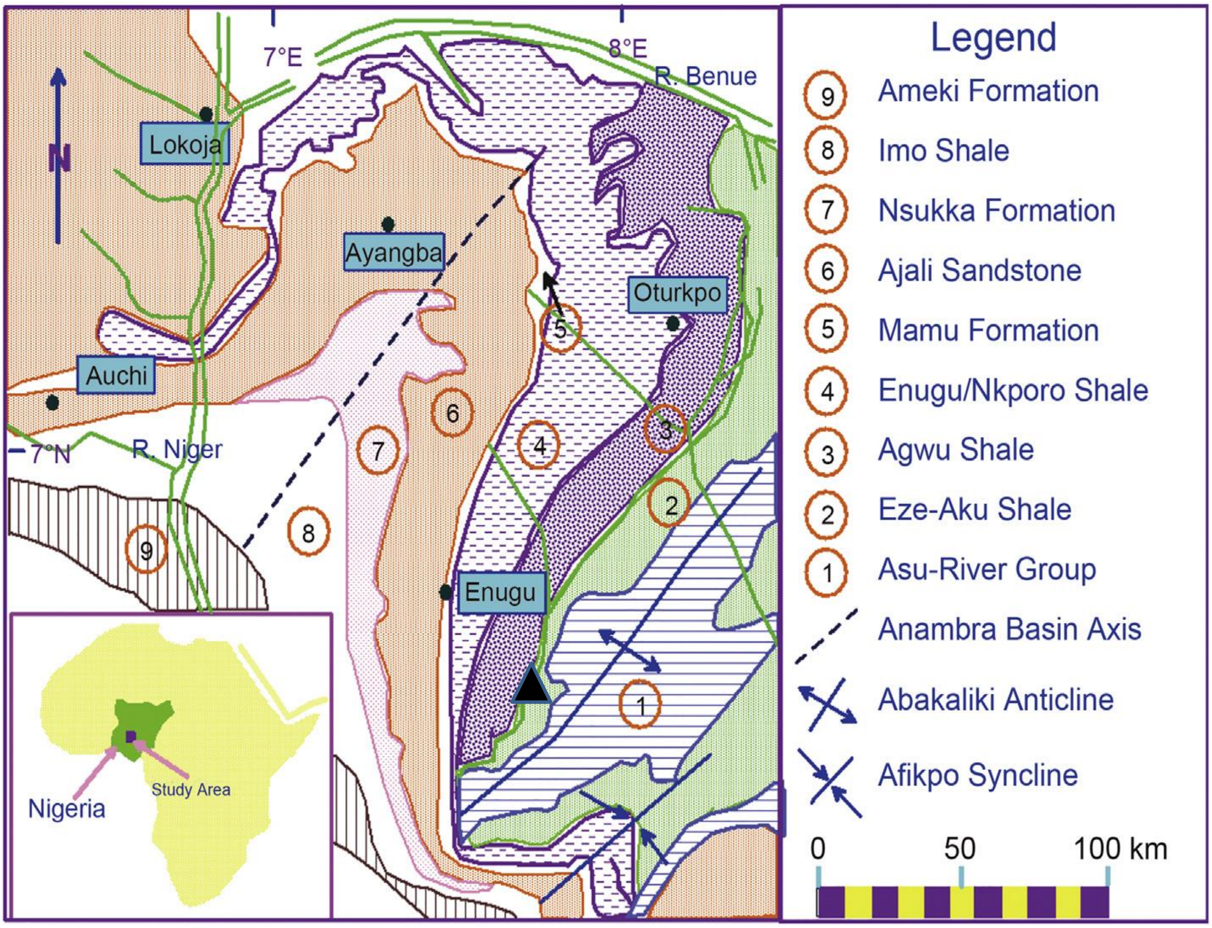


Fig. 1. Geological map of the Anambra Basin triangle showing location of study site (modified after Nton and Bankole, 2013)

3. MATERIALS AND METHODS

Eleven (11) surface samples were collected at 50-cm vertical intervals from the bank of River Obey in Umudi village in Lokpanta, Abia State. The surfaces of the samples were scrapped to remove surface contaminants. The samples were collected in sterile polyethylene bags and taken to the laboratory prior to preparation. Thirty grams of each sample were subjected to standard palynological preparation techniques of disaggregation and removal of carbonates and silicates with hydrochloric acid and hydrofluoric acid under a fume cupboard (Faegri and Iversen, 1989). The samples were then treated with hot Hydrochloric acid (HCl) and wet – sieved over a 5-micro mesh polypropylene sieve. The Branson Sonifier 250 was further employed during sieving to facilitate a complete removal of silt and clay particles. The residues for palynomorphs were oxidized using concentrated nitric acid (HNO_3), while those for palynofacies and kerogen analysis were not oxidized in order to retain the original nature and colours of the different palynomorphs and phytoclasts.The residues were prepared for study as strewn mounts using Loctite. The slides were analyzed and all the palynomorphs present (pollen, spores, dinoflagellate cysts, algae, foraminiferal linings, and fungal remains) were recorded and the totals and percentages of the different groups calculated (**Table 2**).

Table 2. The total counts and percentages of the different palynomorph groups recovered from the Eze-Aku shales

Palynomorph Group	Total counts	% occurrence
Gymnosperms	230	14.98
Angiosperms	120	7.82
Spores	66	4.3
Dinoflagellate cysts	836	54.46
Microforaminiferal wall linings	13	0.85
Acritarch	19	1.24
Algae	43	2.8
Miscellaneous	208	13.55
	1535	100

The relative abundance plot of the different palynomorph groups per sample and the relative abundances of gymnosperms and angiosperms per sample were plotted on Microsoft Excel 2010 (**Figs. 2**, **3** microscope with an attached Axiocam 1Cc 1 Camera at the Palynology laboratory of the Evoluti. 2, 3). Photomicrographs of index palynomorph species (**Figs. 4-7**) were taken with a Zeiss Axioskop onary Studies Institute, University of the Witwatersrand, Johannesburg, South Africa. Different palynological reports of similar ages from Africa and South America facilitated the identification of the different palynomorphs. Here, dinoflagellates and other marine elements were identified based on the monographs of (Williams and Bujak, 1977; Below, 1984, Powell, 1992; Fauconnier *et al*., 2004). The different *Dinogymnium* species were differentiated with the aid of (May, 1977; Herngreen, 1975; Lentin and Vozzhhennikova 1990). The nomenclature follows Fensome and Williams (2004). The different dispersed organic matter and palynomorph groups identified were pollen and spores, fungal remains, freshwater algae, marine palynomorphs, structured phytoclasts (wood, cuticles, parenchyma), unstructured phytoclasts (resins, comminuted and degraded fragments, black debris, and amorphous organic matter (Batten, 1982; Oboh- Ikuenobe *et al*., 2005, 2012; Durugbo, 2016). Visual colour analyses were carried out using *Deltoidospora/Cyathidites* as the standards (Ibrahim *et al*., 1997, Makled *et al*., 2013; Atta Peters and Achaegakwo, 2016) based on comparison with the Munsell colour standards (Pearson, 1984) in Pross *et al*. 2007. The slides, residues, unprocessed samples, and duplicate prints are housed in the palynological collections of the Biological Sciences Department, Redeemer's University, Ede, Osun State, Nigeria.

4. RESULTS AND DISCUSSION

4. 1. *Palynomorph distribution*

A total palynomorphs abundance of 1535 were recorded (**Table 2**). The most diverse group were the dinoflagellate cysts composed of thirty seven genera with fifty nine species and total count of 836. *Dinogymnium* species especially *Dinogymnium westralium*, *D. undulosum*, *D. nelsoense*, dominated the whole assemblage. Others were *Heterosphaeridium difficile*, *Hystrichosphaerina schweindolfii*, *Oligosphaeridium dicuculum*, *O. albertense*, *O. pulcherrimum*, *Pseudoceratium pelliferum*, *Surculosphaeridium longifurcatum*, *Cribroperidinium orthoceras*, *Florentinia resex*, *F. deanei*, *Cyclonephelium chabaca*, *Nelsoniella acreas*, *Exochosphaeridium phragmites*, *Exochosphaeridium* sp., *Coronifera* sp., *Spiniferites ramosus*, *Spiniferites* spp. Gymnosperms were twenty species with total count of 230; angiosperms were twenty species with total count of 120, and fungal elements were 189.

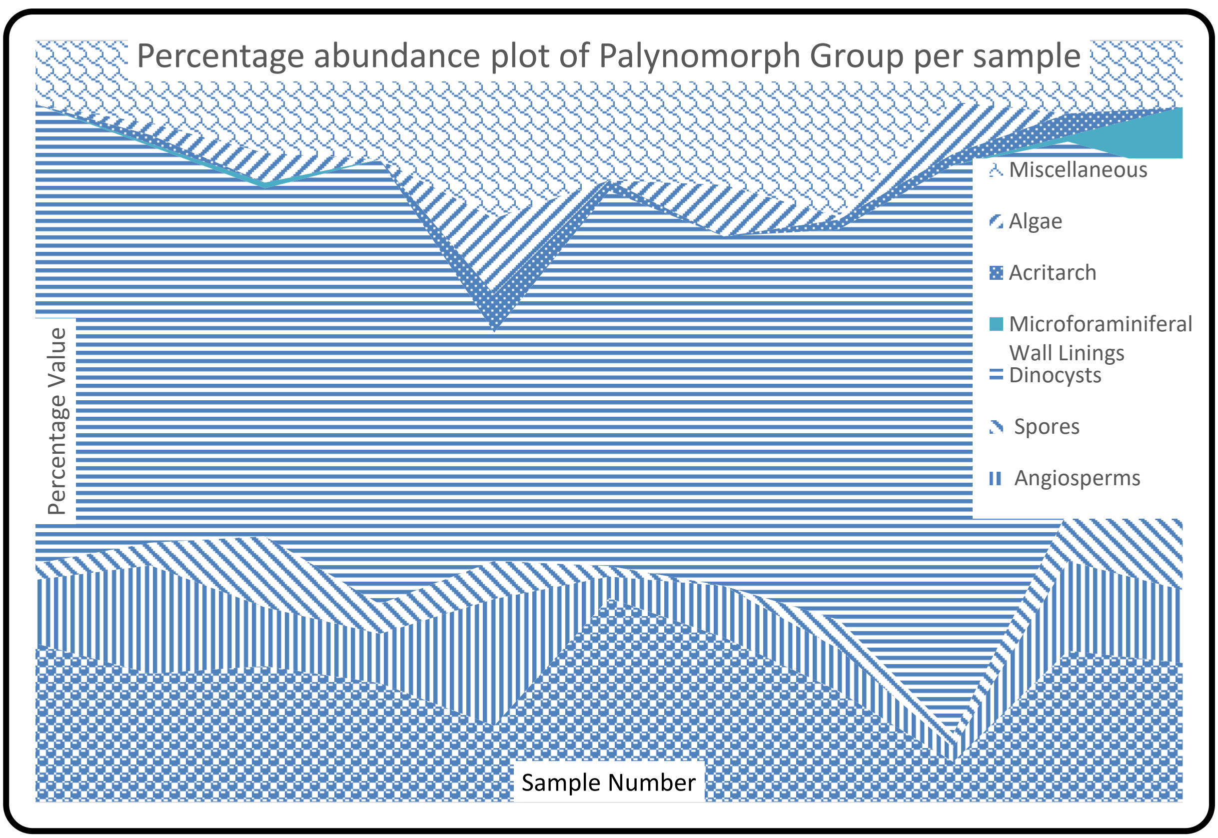


Fig. 2. The relative abundance plot of the recovered palynomorphs groups per sample in the Eze-Aku shales

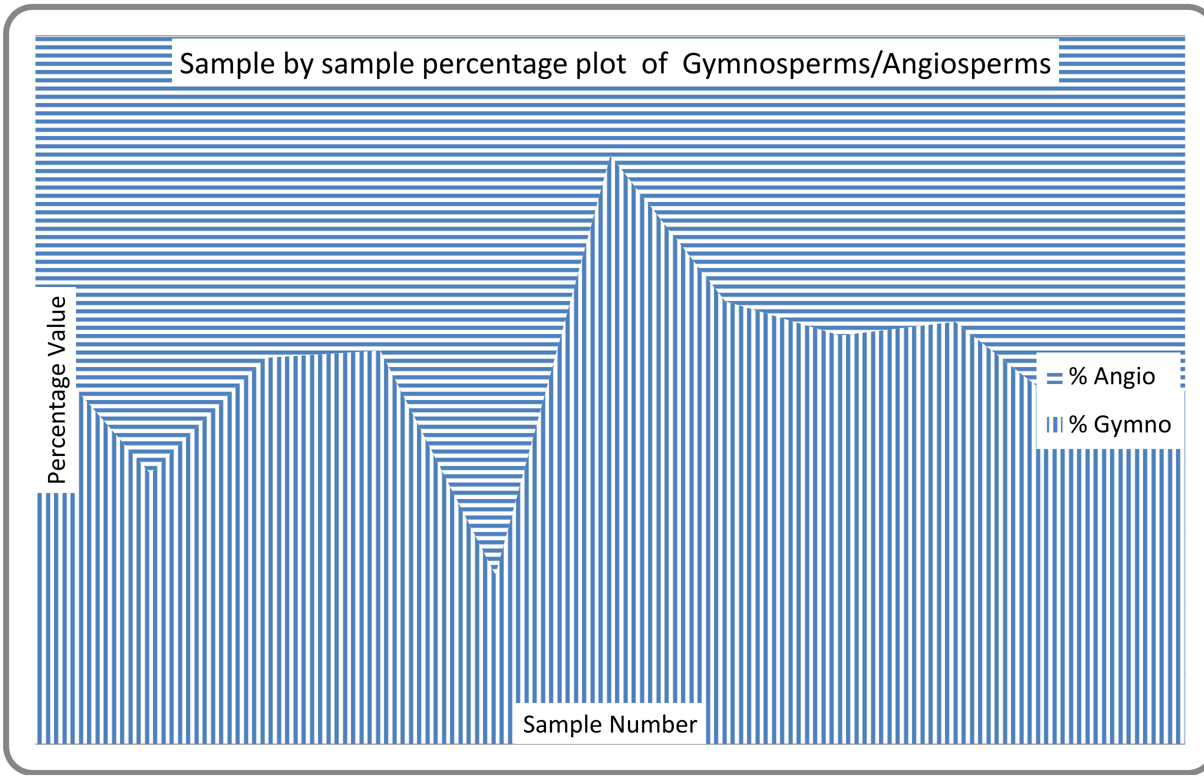


Fig. 3. The sample by sample relative abundance plot of the recovered Gymnosperms and Angiosperms

There were fourteen genera and seventeen species of spores with the total count of 66; freshwater algae (*Botryococcus* sp.) were 42 with a spot occurrence of *Concentricytes* sp.; Acritarchs 19; Microforaminiferal wall linings (13); and other miscellaneous palynomorphs (diatom frustules and incertae sedis) were 19. Among the gymnosperms *Araucariacites australis*, *Cycadopites* sp., and *Napites* sp., dominated. However, the *Ephedripites*, *Gnetaceaepollenites*, and *Classopollis*, genera were the most diverse. Furthermore, *Cretaceaporites mulleri*, *Hexaporocolpites emelianovi*, *Triorites* sp., and *Tricolpites* sp., were the commonest angiosperms. Appreciable amounts of freshwater algae *Botryococcus* sp., and spot occurrence of *Concentricytes* sp. were also recovered (Fig. 2).

4. 2. Lithological results

The samples were composed mainly of mudstones, especially in samples 1, 2, 3, 6, 7, 8, 9, 10, 11, while samples 4, 5 were dominantly sandy.

4. 3. Results of Palynofacies and Kerogen analysis

Terrestrial, medium sized structured brown and black woody particles with terrestrial Amorphous Organic Matter (AOM) and rare cuticles dominated the palynofacies assemblage, especially in samples 1, 2, 3, 7, 8, 9 and 10. Marine derived amorphous organic matter was sparse especially in the samples with abundant marine elements (samples 2, 3, 4, 9, 10).

These structured phytoclasts in association with terrestrial Amorphous Organic Matter dominated the palynofacies suggest deposition in nearshore marine environments. Again, the preponderance of orange brown to mid brown sporomorph colours of *Deltoidospora/ Cyathidites* which correlates with SCI of 7-8, indicated mature oil generation potentials [(zone of peak oil generation/early zone of condensate generation, Matchete-Downes, 2009; Pearson, 1984; Atta-Peters and Achaegakwo, 2016)].

4. 4. Age Determination

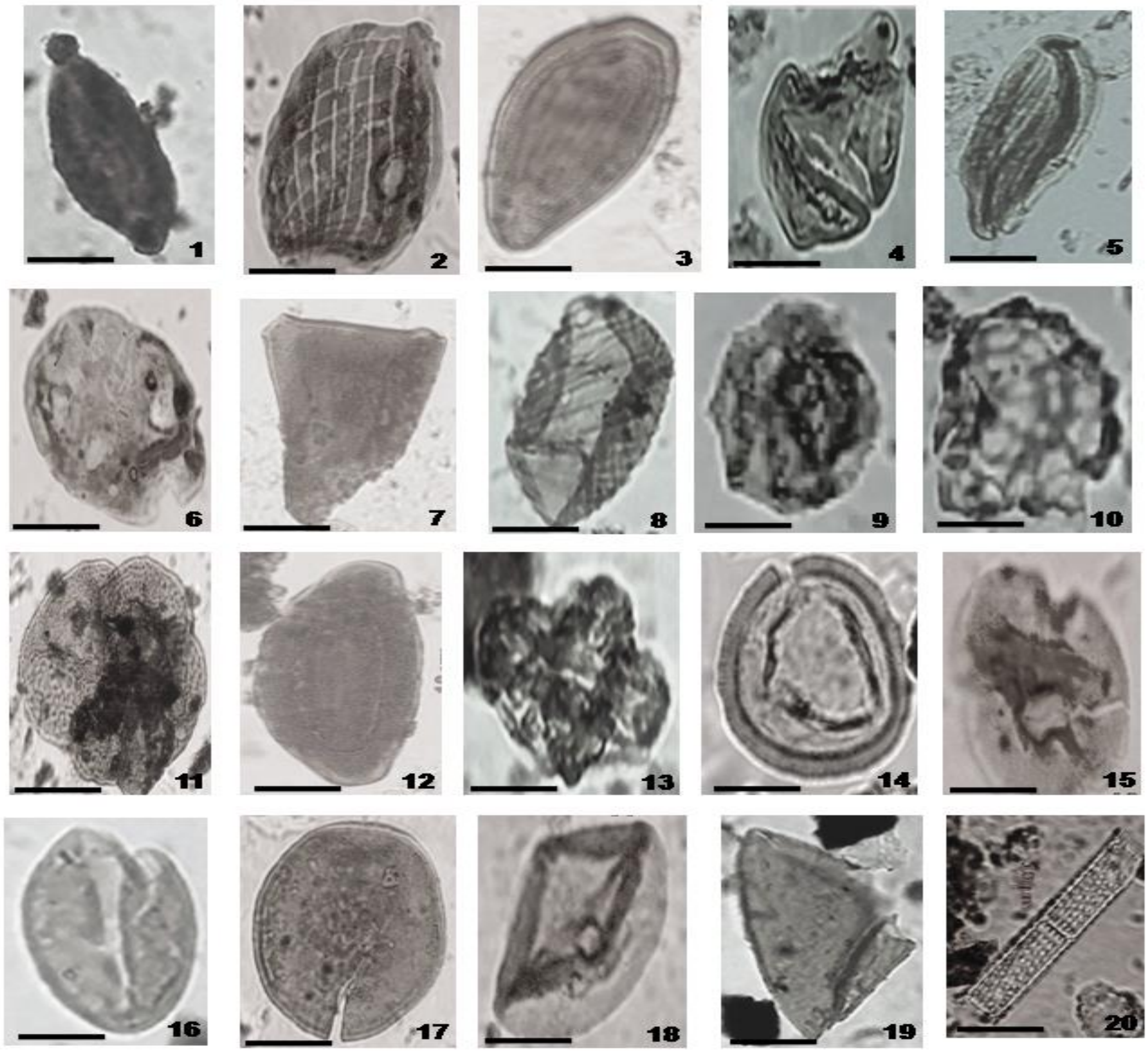
The majority of the recovered palynomorphs have been previously reported from sediments of similar age from different parts of Africa and South America, especially Brazil, Cameroon, Côte d' Ivoire, Senegal, Sudan, Gabon, etc. A late Cenomanian to Early Turonian age is inferred for the studied section, especially the basal samples based on the presence of relics of *Elaterosporites protensus*, cf. *Elateropollenites jardinei,* with common records of *Classopollis* sp., *Steevesipollenites binodosus, Steevesipollenites grambasti, Ephedripites barghoornii, Gnetaceaepollenites diversus, G. clathratus, Triorites africaensis, Cretaceaporites mulleri, Cicatricosisporites venustus, Trifossapollenites rugosa, Ephedripites montanensis,* and the dinoflagellate cysts *Callaiosphaeridium trycherium, Florentinia resex, Oligosphaeridium albertense, O. dicuculum, O. buciniferum, O. pulcherrimum, O. complex, Surculosphaeridium longifurcatum, Pseudoceratium pelliferum, Pareodinia ceratophora, Cribroperidinium orthoceras, Cyclonephelium chabaca, Heterosphaeridium difficile,* and different species of *Dinogymnium* (Masure *et al.*, 1998).

Ukpong and Ekhalialu (2018) had used the occurrences of *Steevesipollenites binodosus, Ephedripites jansonii, Cretacaeiporites mulleri, Triorites africaensis, Galeacornea clavis, Classopollis classoides, Classopollis annulatus, Cretacaeiporites polygonalis, Ephedripites* sp., *Leiotriletes* sp., and *Classopollis* sp., to date the Mbarakpa wells from the Calabar Flank as Cenomanian –Turonian.

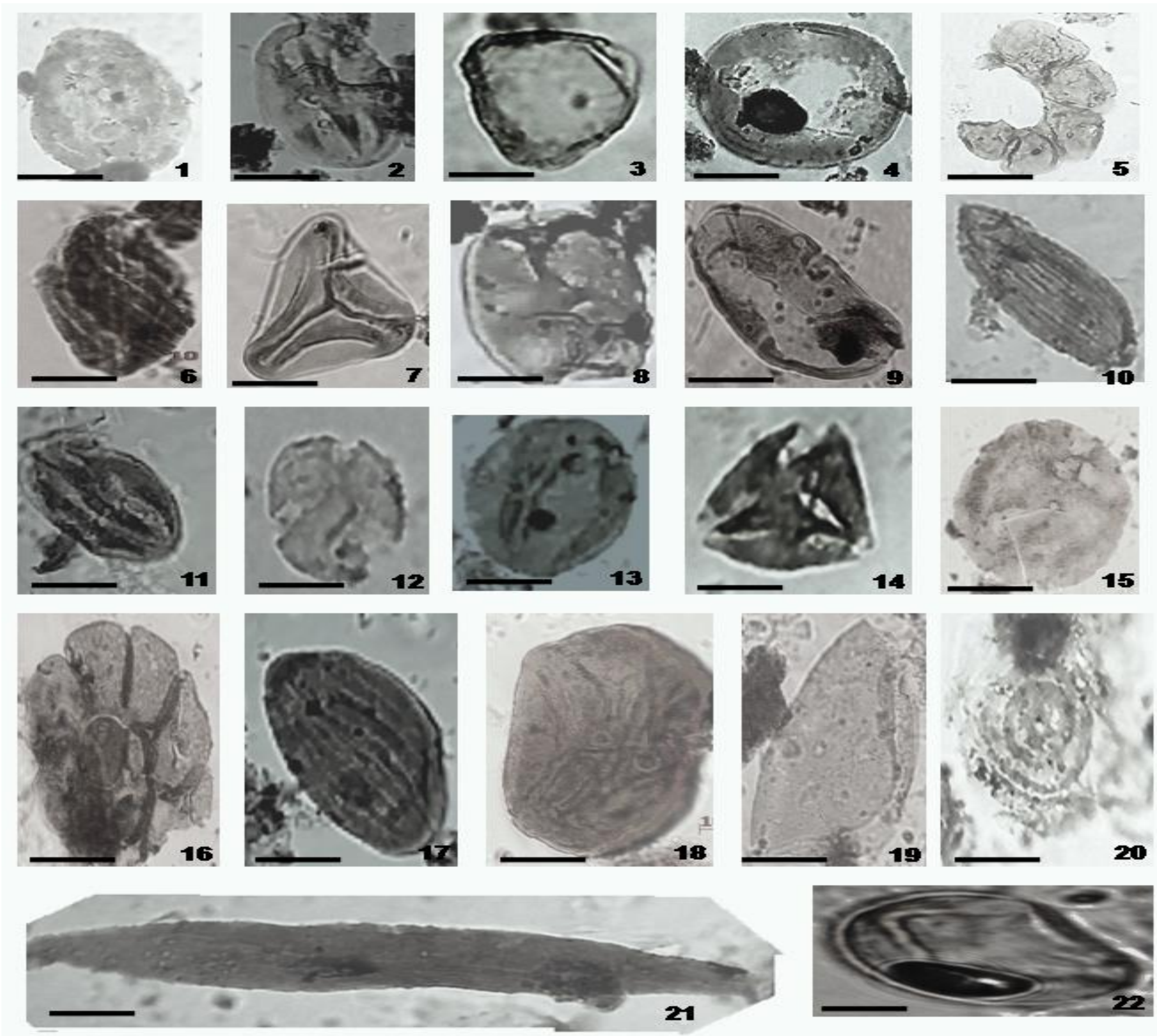
Lawal (1991) had recovered *G. diversus, G. clathratus Galeacornea causea, G. clavis, Triorites africaensis, Classopollis brasiliensis,Perotrilites pannuceus, Cretacaeiporites scabratus, Elaterocolpites castelaini,* in association with the dinoflagellate cysts *Florentinia lacinata, F. mantelli, Subtilisphaera pirnaensis, Xiphophorodium alatum, Odontochitina costata, Cyclonephelium vannophorum* among others from the basal black shales of the Eze-Aku shales some of which were recorded in the present study.

The studied section showed close affinity with the Cenomanian *Triorites africaensis* Taxon –range Zone 8 of Muller *et al*. (1987) whose base is defined by the Top occurrence of *Afropollis jardinus* and basal occurrence of *Triorites africaensis,* while the top is characterized by the Top occurrence of *Classopollis* sp., and *T. africaensis*.

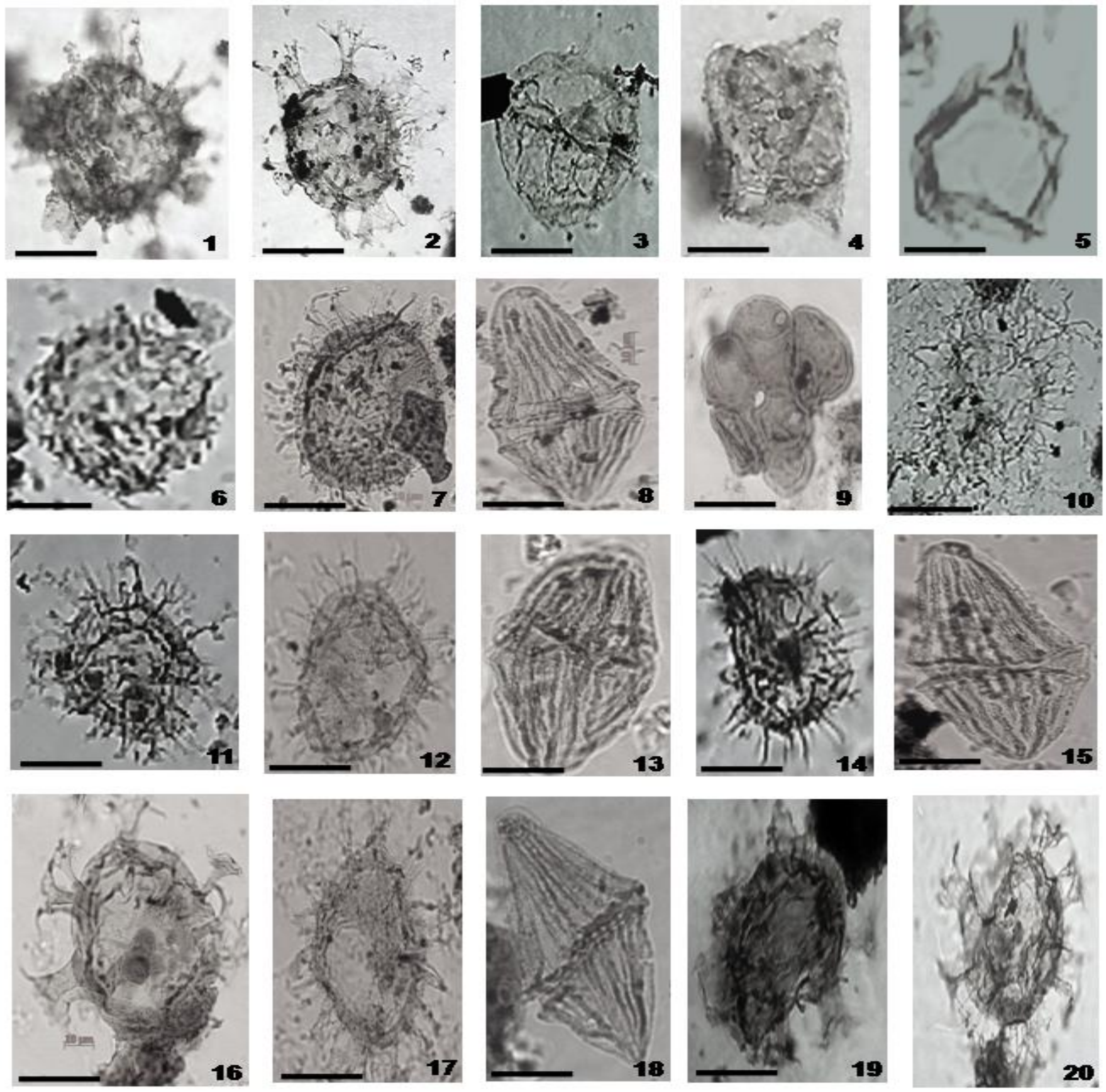
The additional characteristics include the presence of *Ephedripites* complex, *Gnetaceaepollenites* complex, *Cicatricosisporites venustus* and elaterates (Singh, 1971). The absence of *A. jardinus* coupled with the presence of *Classopollis* sp., *T. africaensis,* species of *Ephedripites*, and *Gnetaceaepollenites* in the studied samples confirms this assertion. Again, Lawal and Moullade (1986), working with sediments from the Upper Benue Trough Northeast Nigeria, had assigned an upper Cenomanian to basal Turonian age to their Zone II (*T. africaensis*) Assemblage zone. The base is defined by the simultaneous base occurrences of *T. africaensis* and *Gnetaceaepollenites* sp. 1, with the base occurrence of *Classopollis brasiliensis* slightly below. However, the top boundary is delineated by the disappearance of *T. africaensis, C. brasiliensis* and *Gnetaceaepollenites* sp. 1.



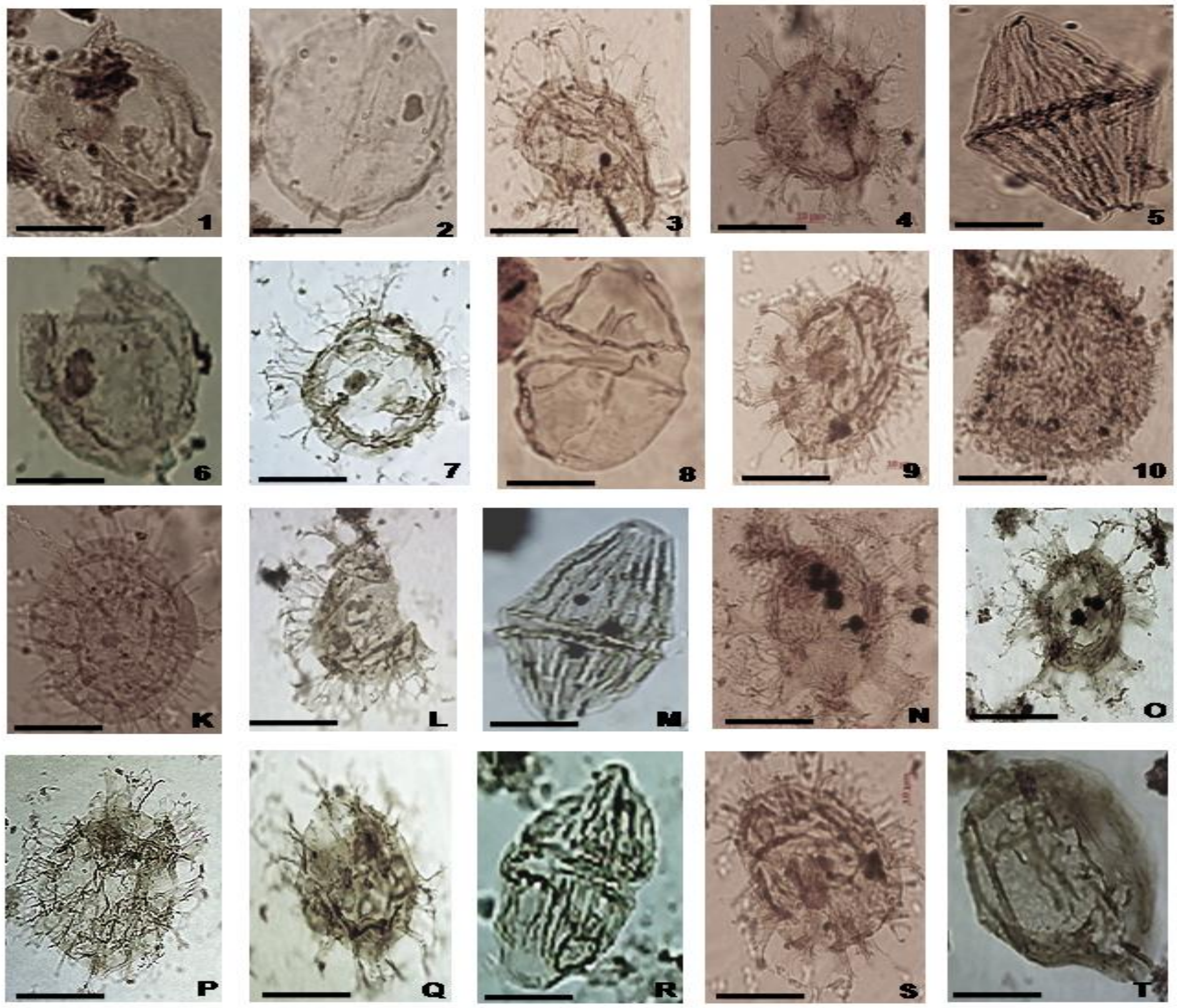
Explanations to **Fig. 4**. 1. *Steevesipollenites binodosus* Stover, 1964 Sample 10 (N39/4); 2. *Gnetaceaepollenites barghoornii* Herngreen, 1973 Sample 8 (P35/2); 3. *Steevesipollenites* sp. Sample 2 (P42/3). 4. *Cf. Elateropollenites jardinei* Herngreen, 1973 Sample 1 (N50/3). 5. *Steevesipollenites grambasti* Azéma and Boltenhagen, 1974 Sample 2 M34/3). 6. *Cretaceaporites mulleri* Herngreen, 1975 Sample 10 (E47/0).7. *Triorites africaensis* Jardine and Magloire, 1965 Sample 10 (N48/0). 8. *Cicatricosisporites venustus* Deak, 1963 Sample 4 (R41/3). 9. *Hexaporotricolpites emelianovi* Boltenhagen, 1967 Sample 10 (R38/2). 10. *Klukisporites* sp. Sample 8 (S49/4). 11. *Classopollis torosus* (Reissinger) Balme, 1957 Sample 3 (H44/1).12. *Steevesipollenites* sp. Sample 10 (R42/3). 13. *cf. Podocarpidites herbstii* Berger, 1963 Sample 10 (P30/4). 14. *Classopollis compacta* Klaus, 1960 Sample 10 (L33/4). 15. *Tricolpites reticulatus* Cookson 1947 ex Couper, 1953 Sample 10 (W53/3).16. *Cycadopites sp.* Sample 2 (J49/2). 17. *Classopollis* sp. Sample 10 (M43/2). 18. *Trifossapollenites rugosa* Rouse, 1959 Sample 8 (T48/1).19. *Retimonocolpites* sp. Sample 10 (T38/1). 20. Diatom frustule Sample 1 (N43/3). Scale bars represent 20 μm.



Explanations to **Fig. 5.** 1. *Araucariacites australis* Cookson, 1947 Sample 3 (H23/4). 2. *Trifossapollenites rugosa* Rouse, 1959 Sample 7 (F33/1). 3. *Triorites africaensis* Jardine and Magloire, 1965 Sample 10 (O39/2). 4. *Classopollis cf. klausi* Boltenhagen, 1973 Sample 5 (L31/1). 5. *Microforaminiferal wall Linings* Sample 1 (T32/4). 6. *Ephedripites torosus jansonii* (Pocock) Muller, 1973 Sample 1(N28/3). 7. *Deltoidospora* sp. Sample 1 (P35/2). 8. *Cretaceaporites mulleri* Herngreen, 1973 Sample 7 (R36/4). 9. *Retimonocolpites* sp. Sample 10 (T38/1). 10. *Ephedripites montanensis* Brenner, 1968 Sample 10 (S48/3). 11. *Trifossapollenites rugosa* Rouse, 1959 Sample 8 (T48/1). 12. *Tricolpites sagax* Norris, 1967 Sample 11 (E37/0). 13. *Eucomiidites* sp. Sample 10 (W53/3). 14. *? Syncolporites boltenhageni* Jan du Chene, Sample 7 (O26/0). 15. *Inaperturopollenites* sp. Sample 10 (S54/4). 16. *Microforaminiferal wall Linings* Sample 1 (M34/3). 17. *Ephedripites* sp. Sample 2 (F38/1). 18. *Matonisporites* sp. Sample 3 (P50/0). 19. *Longapertites* sp. Sample 7 (O26/0). 20. *Gabonisporis vigourouxii* Boltenhagen, 1967 Sample 1 (S34/2). 21. *Cycadopites* sp. Sample 3 (T43/4). 22. *Laevigatosporites gracilis* Wilson and Webster, 1946 Sample 4 (Q41/0). Scale bars represent 20 µm.



Explanations to **Fig. 6.** 1. *Florentinia resex* Sample 4 (W42/2). 2. *Oligosphaeridium pulcherrimum* Davey and Williams, 1966 Sample 3 (L36/3).3. *Cribroperidinium orthoceras* (Eisenack) Sarjeant, 1985 Sample 7 (R26/3). 4. *Paleoperidium cretaceum* Singh, 1971 Sample 3 (V37/1). 5. *Pareodinia ceratophora* Deflandre, 1947 Sample 3 (V37/1). 6. *Cyclonephelium cf compactum* Sample 3 (P45/2). 7. *Exochosphaeridium truncigerum* Sample 3 (P45/2). 8. *Dinogymnium undulosum* Cookson and Eisenack, 1970, Sample 1 (M28/3). 9. *Microforaminiferal wall Linings* Sample 9 (P32/4). 10. *Adnatosphaeridium ? tutulosum* (Cookson & Eisenack 1960) Morgan 1980, Sample 1 (G52/4). 11. *Spiniferites ramosus* (Ehrenberg) Mantell 1854 Sample 3 (V40/1). 12. *Exochosphaeridium* sp. Sample 3 (D28/3). 13. *Dinogymnium vozzhennikovae* Lentin and *Vozzhennikova*, 1990 Sample 3 (H39/3). 14. *Cleistosphaeridium* sp. Sample 10 (G28/0). 15. *Dinogymnium westralium* Cookson, 1956 Sample 10 (U31/1). 16. *Oligosphaeridium albertense* Sample 4 (L52/4). 17. *Hystrichodinium* sp. Sample 3 (G32/1). 18. *Dinogymnium westralium* Cookson, 1956 Sample 10 (U31/1). 19. *Florentinia deanei* Davey and Williams 1966 Sample 3 M52/2. 20. *Hystrichosphaerina schindewolfii* Alberti 1964 Sample 4 (L52/4). Scale bars represent 20 μm.



Explanations to **Fig. 7.** 1. *Apteodinium cf reticulatum* Singh 1971 Sample 3 (E49/4). 2. *Subtilisphaera* sp. Sample 4 (S50/2). 3. *Adnatosphaeridium* sp. Sample 1 (G52/4). 4. *Florentinia* sp. Sample 4 (S22/4). 5. *Dinogymnium westralium* Cookson, 1956 Sample 4 (S22/4). 6. *Kallosphaeridium* sp. Sample 10 (Q50/0). 7. *Oligosphaeridium buciniferum* Corradini 1973 Sample 2 (K48/2). 8. *Amphigymnium* sp. Sample 10 (U31/1). 9. *Dinogymnium undulosum* Cookson and Eisenack, 1970, Sample 1 (M36/3). 10. *Coronifera* sp. Sample 5 (G28/2). 11. Cf. *Callaiosphaeridium trycherium* Duxbury, 1980 Sample 1 (N54/3). 12. *Cyclonephelium chabaca* Below, 1981 Sample 3 (F39/3). 13. *Exochosphaeridium* sp. Sample 3 (V29/4). 14. *Systematophora* sp. Sample 2 (J24/2). 15. *Dinogymnium undulosum* Cookson and Eisenack, 1970 Sample 10 (U31/1). 14. *Achomosphaera alcicornu* (Eisenack, 1954) Davey and Williams 1966 Sample 3 (S33/2). 15. *Callaiosphaeridium trycherium* Dixbury 1980 Sample 1 (N54/2). 16. *Heterosphaeridium difficile* (Manum and Cookson, 1964) Joannides, 1986 Sample 2 (P29/4). 17. *Surculosphaeridium longifurcatum* (Firtion, 1952) Davey, Downie, Sarjeant and Williams, 1966 Sample 2 (J24/2). 18. *Dinogymnium cretaceum* Delandre, 1935, Evitt *et al*., 1967 Sample 4 (Q37/4). 19. *Exochosphaeridium* sp. Sample 3 (U47/2). 20. *Batiacasphaera* sp. Sample 2 (B43/4). Scale bars represent 20 μm.

Other associated forms were *Cretacaeiporites mulleri, C. scabratus, Galeocornea clavis, Hexaporotricolpites emelianovi,* and *Tricolpites microstriatus*.

Furthermore, Salard-Cheboldaeff (1990) had listed the characteristic palynomorphs of the different formations in the Upper Benue Trough Nigeria, as reported by Lawal and Moullade (1986). For the marine Yolde Formation dated Late Albian to early Cenomanian, there was a consistent occurrence of *Classopollis jardinei, Gnetaceaepollenites jansonii/ barghoornii,* while *G. clathratus, Cretacaeiporites polygonalis* characterized the Pindiga Formation, the base of which is defined by the presence of *Crybelosporites pannuceus* and *Ephedripites* sp. 5 of Herngreen, while the top occurrences of *Steevesipollenites binodosus,* and *Galeocornea clavis* defined the top. Furthermore, Batten and Uwins (1985) had listed *Florentinia mantellii, F. radiculata, F. laciniata, Florentinia* sp., *Coronifera cf. C. tubulosa, Palaeohystrichophora infusorioides* co-occurring with common tricolpate pollen and spores among Cenomanian palynomorphs from northeast Libya.

Likewise, Foad and Lashin (2012) had also reported the presence of *O. pulcherrimum, Florentinia* sp., and *Cyclonephelium* spp., from the Late Cenomanian through Turonian of El-Waha-1 well southern western part of the Western Desert Egypt. *Spiniferites* sp., *Classopollis brasiliensis, Araucaricites australis, Cretaceaporites scabratus,* were common in the Cenomanian together with *Afropollis jardinus, A. kahramanensis* which did not range into the late Cenomanian.

Conclusively, the age of the studied section of the Eze Aku shale is not older than Late Cenomanian based on the presence of relicts of the *Elaterosporites/Galeacornea* complex which absence typifies the middle Albian to early Cenomanian of Gondwana (Heimhofer and Hochuli, 2010; Herngreen and Jimenez, 1990; Dino *et al*., 1999; Batten, 2007).

However, these contrast the reports of some earlier workers who had dated the Eze -Aku shales as Turonian (Short and Stauble, 1967; Ekweozor and Unomah, 1990; Oboh-Ikuenobe *et al.* 2005; Ukaegbu and Akpabio, 2009; Uzoegbu and Okon 2017; Akpofure and Didei 2018; Soronnadi-Ononiwu and Didei, 2018). This Late Cenomanian to Early Turonian age further agrees with some earlier reports (Lawal and Moullade, 1986; Lawal, 1991; Ehinola, 2010). Some of the recovered palynomorphs have been associated with the Albian –Cenomanian elaterates province (Muller 1968; Kaska 1989; Herngreen *et al*., 1996; El Beialy *et al*., 2010; Ojo and Akande, 2001). The scarcity of pteridophyte spores and *Classopollis* sp. which Dino *et al.* (1999) had opined, characterizes the late Cenomanian as compared to Albian and Early Cenomanian was clearly demonstrated in the studied samples.

4. 5. Implication of Dinogymnium species

The total dinoflagellate cysts suite, including the presence of *Dinogymnium* species, is typical of Cenomanian-Turonian age (Powell, 1992). Morgan (1978) had earlier commented that *Dinogymnium* species range from Santonian to Maastrichtian in the Northern hemisphere, although they occur sporadically in the Turonian, rarely had they been found in Cenomanian sediments. Moreover, Herngreen (1975) had also recovered different species of *Dinogymnium* from the Upper Cretaceous sediments in Brazil and he further reported pre-Senonian species, such as *D. vozzhennikovae, D. digitus* and *D. mitratum,* which had been recovered in the U.S.S.R. Their common records in the Eze Aku shales seem to suggest an older age or the recovery of some new species. This could further support Jardine's claim of recovering these *Dinogymnium* species in African sediments older than Santonian, as reported by Morgan (1978). Furthermore, Emelyanova *et al.* (1996) had recovered much older species *D. aerticum* and *D. vergonsense* from the Lower Cretaceous (Hauterivian) surface sections from Northwestern Tethyan area of Western Switzerland and Southeast France. They further highlighted the earlier reports of Riley and Fenton (1984) who had indicated in situ occurrences of *Dinogymnium* species in Upper Berriasian, Valanginian and Hauterivian sections from DSDP Site 535 in the Gulf of Mexico. Moreover, El Beialy *et al*. (2010) had erected and dated their *Dinogymnium. vozzhennikovae* Interval zone from the North Western Desert Egypt as Cenomanian which supports their presence in the studied Cenomanian section of the studied Eze Aku shales. Again, Londeix *et al.* (1996) had also reported in-situ occurrence of *Dinogymnium* species in Hauterivian ammonite-dated sediments from the northwestern Tethyan area, Châtel-Saint-Denis (western Switzerland) and Vergons (southeast France in Upper Berriasian, Valanginian and Hauterivian sediments from re-examination of the samples earlier studied by Riley and Fenton (1984) from DSDP Site 535 in the Gulf of Mexico. They erected two new species viz *Dinogymnium aerlicum* and *Dinogymnium vergonsense*. Finally, Jain (1975) in his stratigraphic remarks had opined that the genus *Dinogymnium* evolved during the Albian with the form referred to as *Dinogymnium* sp. A. In addition, *D. westralium* is common in the Cenomanian while three species are from western Siberia U.S.SR., represented the Turonian. Furthermore, *D. heterocostatum* is associated with the Coniacian, while *D. albertii*, *D. microgranulosum* and *D. acuminatum* all indicate Santonian and younger ages.

4. 6. Regional and intercontinental age correlation

Dino *et al.* (1999) had defined the Albian-Cenomanian Africa –South America Elaterates province (ASA) which occurred within a few degrees latitude of the palaeoequator. Though *Senegalosporites* and *Pentapsis* species were not recovered in the 11 samples analyzed, the presence of *Elaterosporites protensus*, *Sofrepites legouxiae*, and *Galeacornea causea* confirms the penetration of the Africa–South America Elaterates province. In their range chart, *Sofrepites* species had ranged from Middle Albian to Middle Cenomanian, while *Galeacornea* species range up to Late Cenomanian. Herngreen (1973, 1975) had defined three zones and six sub-zones in the early Albian to Late Cenomanian of the Barreirinhas and Sergipe Basins of Brazil in which the recovered palynomorphs show close affinity with those of the Eze-Aku shales. Moreover, working on Middle Cretaceous samples from Northeastern Peru, Brenner (1968) had posited that provincial affinities existed between Peru and West Africa as revealed by the presence of palynomorphs such as *Triorites africaensis*, *Afropoliis jardinus*, *Proteacidites longispinosus*, similar to those described by Jardine and Magloire (1965).

4. 7. Kerogen and spore colour inferences

Visual colour analyses were carried out using *Deltoidospora/Cyathidites* as the standards (Ibrahim *et al*., 1997, Makled *et al*., 2013; Atta Peters and Achaegakwo, 2016). The orange brown to mid-brown sporomorph colour correlative with (Sporomorph Colour Index) SCI of 7-8, based on comparison with the Munsell colour standards (Pearson, 1984) in Pross *et al.* 2007 indicated matured oil and gas generation potentials from the present study. This concurs with the reports of Ehinola (2010) who opined that the Eze-Aku shales are matured.

4. 8. Paleoenvironmental and palaeoclimatic interpretation

The scarcity of pteridophyte spores, rare bisaccate pollen, with common ephedroid, cycadophyte, angiosperms, and *Classopollis* species suggests a hot and semi- arid climate

(Salard and Dejax, 1991). Barreda and Archangelsky (2006) had reported the development of a warm global climate inferred from oxygen isotope during the Late Albian – Late Cenomanian. These results suggest that the sampled area belongs to the tropical northern Gondwana province of Brenner (1968) rather than its Southern counterpart characterized by common bisaccate pollen and scarce ephedroid pollen (Mclachlan and Pieterse, 1978). The total counts of the gymnosperms were generally higher than those of the angiosperms possibly due to the evolutionary history of angiosperms which became more widespread during the Middle Cretaceous (Salard-Cheboldaeff and Dejax, 1991). Spores and acritarchs were rare.

4. 9. Environments of Deposition

The high concentration of terrestrially derived organic matter in the Eze Aku shales suggest proximity to the paleoshoreline (Ukaegbu and Akpabio (2009), while a high concentration of marine derived AOM is indicative of a distal location (Oboh-Ikuenobe *et al*., 1998). The commonest accessory minerals were ferruginous materials with carbonaceous matter suggesting deposition in low energy (near shore) environments. The common record of *Dinogymnium* species, together with abundant structured brown wood, fewer black wood, and some freshwater algae indicates sediment deposition in a nearshore low salinity environment. This concurs with the earlier reports of Ukaegbu and Akpabio (2009) that the predominance of sandstones in the Eze Aku Formation together with abundance of burrowing organisms, widely distributed pebbles and cobbles, predominance of calcareous sandstones, massive beddings and cross stratification, all suggested shallow marine conditions. The transgressive/regressive phases they reported were clearly demonstrated in the studied samples by the dinoflagellates /sporomorph ratio. Edet and Nyong (1993) had attributed higher dinocyst/sporomorph ratios to more marine conditions while the opposite indicates nearshore environments of deposition. Nwajide (1990) had also inferred shallow water depositional environments for the Eze-Aku Formation.

5. CONCLUSIONS

Though most reports in the past had dated the Eze-Aku Formation to be of Turonian or basal Turonian age (Oboh-Ikuenobe *et al*., 2005; Kogbe, 1976; Ekweozor and Unomah, 1990; Ukaegbu and Akpabio, 2009), this present work upholds the Late Cenomanian to Turonian age for the Eze-Aku Formation earlier proposed by (Ehinola, 2010; Ojo *et al*., 2010; Akande and Erdtmann, 1998). The floral composition concurs with the Albian-Cenomania elaterates provinve (ASA). The kerogen assessment revealed phytoclasts which are mature for oil and gas generation. The inferred shallow water environment of deposition inferred from dinoflagellate suite dominated by *Dinogymnium* species, common terrestrially derived organic matter, the preponderance of ferrugineous materials and carbonaceous matter also concurs with the results of earlier workers.

Supplementary data

Note: Cf. *Elateropollenites jardinei* shows no resemblance to any other form in all literature consulted, except the *E. jardinei* in Plate IV Figures 5-8 of Herngreen 1973; Plate XIV Figure 6 of Dino *et al*. (1999), especially the striations and Plate 1 Figure 15 of Herngreen 1974.

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Supplementary data

Stratigraphic Distribution of the different Palynomorph Groups recovered per sample in the Eze-Aku shales

	TAXON	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Total
	Gymnosperms												
1	Alisporites similis	0	0	0	0	1	0	0	0	0	0	0	1
2	Araucariacites australis	2	5	9	7	4	7	3	1	4	7	2	51
3	Classopollis spp.	2	1	0	4	0	1	0	2	2	2	0	14
4	Classopollis compacta	0	0	0	0	1	0	0	0	0	2	0	3
5	Classopollis cf. klausi	1	0	0	0	1	0	0	0	1	1	0	4
6	Classopollis cf. torosus	1	0	0	1	3	0	0	0	0	0	0	5
7	Clavatipollenites hughesi	0	1	0	0	0	0	0	0	0	0	0	1
8	Cycadopites spp.	2	8	2	2	1	2	0	0	3	9	1	30
9	Ephedripites jansonni	1	0	0	0	0	0	0	1	0	0	0	2
10	Ephedripites irregularis	0	0	0	1	0	0	0	0	0	0	0	1
11	Ephedripites minimus	0	0	1	2	1	3	0	1	2	2	1	13
12	Ephedripites montanensis	0	1	1	4	0	2	0	1	2	5	2	18
13	Ephedripites multicostatus	1	2	0	0	0	0	3	1	2	1	2	12
14	Eucomiidites cf debilis	0	0	0	0	0	0	0	0	0	2	0	2
15	Eucomiidites spp.	3	1	1	0	2	0	0	1	2	1	0	11
16	Gnetaceaepollenites barghornii	0	0	0	0	0	0	0	1	0	1	0	2
17	Gnetaceaepollenites clathratus	0	0	0	0	0	0	0	1	1	1	1	4
18	Gnetaceaepollenites diversus	0	0	1	2	0	0	0	0	0	2	0	5
19	Inaperturopollenites spp.	2	2	1	5	0	2	0	0	2	0	1	15

20	Monosulcites spp.	1	2	0	0	0	0	0	0	0	0	0	3
21	Napites spp.	4	3	0	4	2	1	0	0	0	7	0	21
22	Podocarpidites cf canadensis	0	0	0	0	0	0	0	1	0	0	0	1
23	Podocarpidites herbestii	0	0	1	0	0	0	0	1	1	1	0	4
24	Steevesipollenites binodosus	0	0	0	0	0	0	0	0	1	1	0	2
25	Steevesipollenites grambasti	0	1	0	0	0	0	0	0	0	0	0	1
26	Spermatites spp.	1	0	0	2	0	1	0	0	0	0	0	4
		21	27	17	34	16	19	6	12	23	45	10	230
	Angiosperms												
1	Cretaceaporites mulleri	1	0	0	0	1	0	2	1	1	3	1	10
2	?Elateropollenites jardinei	1	0	0	0	0	0	0	0	0	1	0	2
3	Ericipites spp.	1	0	0	0	0	0	0	0	0	0	0	1
4	Fraxinoipollenites venustus	0	0	0	0	0	1	0	0	1	2	0	4
5	Hexaporocolpites emelianovi	0	1	0	2	1	1	0	1	1	4	0	11
6	Hexaporocolpites potonei	0	0	0	0	0	0	0	0	0	1	0	1
7	Inaperturopollenites spp.	2	2	0	5	0	0	0	0	0	0	0	9
8	Longapertites sp.	0	1	0	0	0	0	1	0	0	0	0	2
9	Monocolpites spp.	0	1	1	0	0	0	0	0	0	0	0	2
10	Psilamonocolpites sp.	1	0	0	0	0	0	0	0	0	0	0	1
11	Psilatricolpites spp.	0	0	0	4	0	0	0	0	0	2	0	6
12	Retimonocolpites sp.	1	1	1	0	0	0	0	0	0	2	0	5
13	Retitricolpites ellipticus	0	1	0	0	0	0	0	2	1	2	0	6
14	Retitricolpites spp.	0	1	0	0	0	0	0	0	0	3	1	5
15	Retitricolporites vulgaris	0	0	0	0	1	0	0	0	1	1	0	3
16	Syncolporites cf. boltenhagii	0	0	0	0	1	0	1	0	0	0	0	2

17	Tricolpites microminus	0	0	1	0	0	0	1	0	0	0	0	2
18	Tricolpites parvus	1	3	0	0	0	0	0	0	2	0	1	7
19	Tricolpites spp.	1	3	0	0	0	0	0	0	0	6	0	10
20	Trifossapollenites rugosa	1	0	0	1	0	0	1	1	0	2	1	7
21	Triorites africaensis	0	1	1	0	0	0	0	0	0	2	0	4
22	Triorites spp.	0	0	2	1	1	0	1	0	3	7	0	15
23	Indeterminate pollen	1	1	0	0	0	0	3	0	0	0	0	5
		11	16	6	13	5	2	10	5	10	38	4	120
	Spores												
1	Cicatricosisporites cf. abacus	0	1	0	0	0	0	0	0	0	0	0	1
2	Cicatricosisporites sp.	0	0	0	0	0	0	1	1	1	1	0	4
3	Cicatricosisporites venustus	0	1	0	0	0	0	0	0	0	0	0	1
4	Concavissimisporites sp.	0	0	0	1	0	0	0	0	0	0	0	1
5	Cyathidites minor	5	3	1	0	0	0	1	1	5	3	1	20
6	Cyathidites australis	1	0	0	0	0	1	0	0	4	1	0	7
7	Elaterosporites protensus	0	1	0	0	0	0	0	0	0	0	0	1
8	Deltoidospora sp.	5	2	0	0	0	0	0	0	0	0	0	7
9	Gabonisporites vigourouxii	1	0	0	0	0	0	0	0	0	0	0	1
10	Galeocornea causea	0	1	1	0	0	0	0	0	0	1	0	3
11	Gleicheniidites sp.	0	0	1	1	0	0	0	0	1	0	0	3
12	Klukisporites sp.	0	0	0	0	0	0	0	1	0	0	0	1
13	Laevigatosporitess sp.	1	0	1	1	0	0	0	0	0	0	0	3
14	Lycopodiumsporites sp.	0	0	0	1	0	0	0	0	0	0	0	1
15	Matonisporites spp.	0	0	1	0	0	0	0	0	0	0	0	1
16	Polypodiaceoisporites sp.	0	0	1	0	0	0	0	0	0	0	0	1
17	Triporoletes sp.	1	0	0	0	0	0	0	0	0	0	0	1

18	Indeterminate spores	0	0	0	4	0	0	1	0	0	0	0	5
19	Trilete spore	0	0	0	1	0	0	0	0	1	2	0	4
		14	9	6	9	0	1	3	3	12	8	1	66
	Dinoflagellate cysts												
1	Achomosphaera ramulifera	0	0	2	0	1	0	1	0	0	0	0	4
2	Achomosphaera sp.	0	1	2	0	0	0	0	0	0	1	0	4
3	Adnatosphaeridium	0	0	0	0	0	0	0	0	0	0	0	0
4	Alisogymnium dowolio	0	0	0	0	0	0	0	0	0	2	0	2
5	Alisogymnium sp.	0	0	0	0	0	0	0	0	1	0	0	1
6	Apteodinium cf reticulatum	0	0	0	0	0	0	0	0	0	0	0	0
7	Batiacasphaera sp.	0	1	0	2	0	0	0	0	0	0	0	3
8	Cf. Callaisphaeridium trycherium.	1	1	0	0	0	0	0	0	0	0	0	2
9	Canningia sp.	0	0	13	3	3	3	1	0	4	3	3	33
10	Chatanginella sp.	0	0	0	1	0	0	0	0	0	0	0	1
11	Circulodinium sp.	1	0	0	0	0	0	0	0	0	0	0	1
12	Cleistosphaeridium sp.	0	8	20	1	0	0	0	0	2	1	1	33
13	Coronifera spp.	0	1	4	0	0	0	0	0	0	0	0	5
14	Cribroperidinium orthoceras	0	0	0	0	0	0	1	0	0	0	0	1
15	Cyclonephelium chabaca	0	3	2	0	0	1	0	0	0	0	0	6
16	Cyclonephelium compactum	2	5	0	2	3	1	0	2	2	5	1	23
17	Dingodinium sp.	1	0	0	0	0	0	0	0	0	0	0	1
18	Dinogymnium cretaceum	0	0	5	10	0	2	2	0	5	5	0	29
19	Dinogymnium denticulatum	0	0	1	0	0	2	0	6	3	5	1	8
20	Dinogymnium nelsoense	0	8	19	10	3	3	2	8	10	14	5	70
21	Dinogymnium pustulicostatum	0	0	10	15	4	6	0	1	8	23	0	67

22	Dinogymnium undulosum	3	0	27	16	1	3	1	9	8	45	1	114
23	Dinogymnium cf. vozzhennikovae	2	3	13	20	1	4	0	4	1	0	0	47
24	Dinogymnium westralium	0	0	40	25	3	5	4	0	8	25	9	119
25	Dinogymnium sp.	0	0	3	6	0	1	0	3	0	6	4	23
26	Epelliosphaeridia spinosa	0	1	0	0	0	0	0	0	0	0	0	1
27	Exochosphaeridium sp.	2	3	5	3	1	0	0	0	0	0	0	14
28	Exochosphaeridium phragmites	0	0	11	0	0	0	0	0	0	0	0	11
29	Florentinia deanei	0	0	1	0	0	0	0	0	0	0	0	1
30	Florentinia resex	1	1	2	1	0	0	0	0	0	0	0	5
31	Florentinia sp.	0	0	1	0	0	0	0	0	0	0	0	1
32	Gonyalacacysta sp.	2	5	1	5	3	2	4	5	2	0	2	31
33	Gonyalacacysta cf. tenuiceras	0	0	2	0	1	0	0	0	0	0	0	3
34	Hapsocysta spp.	1	1	0	0	0	0	0	0	0	0	0	2
35	Hystrichodinium sp.	0	0	1	0	0	0	0	0	0	0	0	1
36	Hystrichosphaerina schweindolfii	0	0	0	1	0	0	0	0	0	0	0	1
37	Heterosphaeridium difficile	4	1	7	0	0	0	0	0	0	0	0	12
38	Kallosphaeridium sp.	0	0	0	0	0	0	0	0	1	1	0	2
39	Maduradinium spp.	0	0	0	0	0	0	0	0	0	1	0	1
40	Meiourogonyaulex cf. bulloideus	0	0	1	0	0	0	0	0	0	0	0	1
41	Nelsoniella acreas	1	0	0	0	0	0	0	0	0	0	0	1
42	Oligosphaeridium albertense	2	1	0	0	0	0	0	0	0	0	0	3
43	Oligosphaeridium dicuculum	1	1	0	0	0	0	0	0	0	0	0	2
44	Oligosphaeridium buciniferum	2	1	0	0	0	0	0	0	0	0	0	3
45	Oligosphaeridium complex	0	1	2	0	0	0	0	0	0	1	0	3
46	Oligosphaeridium pulcherrimum	0	1	2	0	0	0	0	0	0	0	0	3

47	Palaecystodinium golzowenze	0	0	1	0	0	0	0	0	0	0	0	1
48	Pareodinia ceratophora	0	0	2	0	0	0	0	0	0	0	0	2
49	? Perisseiasphaeridium pannosum	0	0	1	0	0	0	0	0	0	0	0	1
50	Polysphaeridium sp.	0	0	9	0	0	0	0	0	0	0	0	9
51	Spiniferites fluens	0	0	0	0	0	0	0	0	0	1	0	1
52	Spiniferites multibrevis	1	0	5	0	0	0	0	0	1	0	0	7
53	Spiniferites ramosus	0	0	8	1	2	0	1	1	0	0	1	14
54	Spiniferites sp.	2	2	1	0	0	1	0	0	1	0	0	7
55	Strphrosphaeridium sp.	6	0	0	0	0	0	0	0	0	0	0	6
56	Subtilisphaera sp.	4	4	4	3	5	3	3	6	3	3	1	39
57	Surculosphaeridium longifurcatum	1	2	0	0	0	0	0	0	0	0	0	3
58	Surculosphaeridium sp.	3	0	0	1	0	0	0	0	0	0	0	4
59	Systematophora sp.	3	1	0	0	0	0	0	0	0	0	0	4
60	Indeterminate Dinoflagellate cysts	3	9	14	4	3	0	0	0	3	3	0	39
		49	66	242	120	34	35	18	45	59	139	29	836
1	Foraminiferal Wall Linings	10	1	0	0	0	0	0	0	1	1	0	13
	Acritarch												
	Leiosphaeridia spp.	0	4	5	3	0	1	3	0	0	2	0	18
	Palmages	0	0	0	0	0	0	0	0	0	1	0	1
		0	4	5	3	0	1	3	0	0	3	0	19
	Algae												
1	Botryococcus spp.	0	0	22	0	5	0	6	0	5	4	0	42
2	Concentricytes sp.	0	0	0	1	0	0	0	0	0	0	0	1
		0	0	22	1	5	0	6	0	5	4	0	43

	Others												
1	Diatom frustules	2	1	0	0	0	0	0	0	2	2	0	7
2	Incertae sedis	0	3	2	4	0	0	0	0	1	2	0	12
3	Fungal spores/hypha	8	9	24	50	14	13	14	12	16	25	4	189
		10	13	26	54	14	13	14	12	19	29	4	208