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RESEARCH ARTICLE

PRINCIPAL COMPONENT AND CLUSTER ANALYSES OF PALYNODEBRIS FROM OUTCROPS OF THE LATE CRETACEOUS SEDIMENTARY STRATAS IN PARTS OF SOUTHEASTERN NIGERIA AND THEIR ENVIRONMENTAL SIGNIFICANCE

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ABSTRACT

Ten types of dispersed organic matter and palynomorphs were identified from outcrop samples of the Nkporo, Mamu and Nsukka formations including spores and fungi (SP), pollen (PO), freshwater algae (FWA), microforaminiferal inner linings (FL), dinoflagellates (DFL), structured phytoclasts (STPH) (wood, cuticles, parenchyma), unstructured phytoclasts (UNPH) (communited and degraded fragments), black debris (BD) and amorphous organic matter (AOM). The identified palynofacies were analyzed using principal component and cluster analysis (PCA). From the scatter plot, three groups are recognized as indicated by loops namely group A (SP and PO) group B (UNPH, STPH and BD), group C (AOM, FL, ACR and FWA). The heatmap dendogram enabled the definition of four main palyno-ecological groups forming the 1st order cluster namely Cluster 1A comprising (SP and PO). Cluster 1B comprise of (UNPH, STPH, BD). Cluster 1C comprise of (AOM and FWA). Cluster 1D comprise of (FL, DFL and ACR). The palyno-ecological clusters were grouped according to their environmental significance, Subcluster 1A palyno-ecology is comprised of Pollen (PO) and Spores (SP) while subcluster 1C is made up of Amorphous organic matter (AOM) and Fresh water algae (FWA) These two sub clusters implicated the rainforest and savanna palyno-ecologies as the major prevalent ecologies during the time of sediments deposition. The 1B subcluster indicates palynofacies typical of swamp constituted by structured and unstructured phytoclast and black debris (STPH, UNPH and BD) which was pronounced in Mamu Formation. Cluster 1D comprising of Dinoflagellate (DFL), Foram linings (FL) and Acritarch (ACR) indicated marine palyno-ecologies. Dinoflagellates constitutes a major part of the modern oceanic planktonic distribution. The presence of a wide variety of palynomorphs indicated that the environment supported a rich and diverse tropical flora. Furthermore, the pattern represented on the heatmap pointed to an alternation of ecologies from one with a greater marine influence to swamp/forest and Savanna Palyno-ecological Communities. Moreover, the observed progressive decrease in the abundance of spores and fungi, and the steady increase in the abundance of foraminiferal lining, dinocysts and marine indicator palynomorphs (acritarchs and dinoflagellates) up the stratigraphic column from Nkporo to Nsukka Formation points to greater marine influence and a deepening basin with paludal conditions more evident in Mamu Formation.

KEYWORDS

Palynofacies, Principal component Analysis, Ecological environment, Late Cretaceous basin, Southeastern, Nigeria

1. INTRODUCTION

The earliest recorded observations of pollen using a microscope probably occurred in the 1640s by the English botanist Nehemiah Grew, (Bradbury, 1967) who described pollen and the stamen, and deduced that pollen is essential for sexual reproduction in flowering plants. By the late 1870s, as optical microscopes became more advanced and the principles of stratigraphy were , well established, Robert Kidston and P. Reinsh worked out the underlying concepts. Reinsch were able to investigate the presence of fossil spores in the Devonian and Carboniferous coal seams and make comparisons between the living spores and the ancient fossil spores (Jansonius and McGregor, 1996). Combaz introduced the concept of palynofacies, which encompasses suites of palynodebris (Combaz, 1964). Batten, applied the concept to studying the origin of sediments and the link between palynodebris and hydrocarbon deposits (Batten, 2003; 2007). The utility of this technique for environmental interpretations has been illustrated by multiple researchers (Fisher, 2005., van der Zwan, 1990., Davies et al., 2001., Oboh-Ikuenobe et al., 2005). Studies of palynodebris have yielded a wide range of classifications, which can be seen in (Bujak et al., 2008; Habib, 1978; Venkatachala, 1981).Quantitative methods in palynology have been in use since the 1930s.

The science of geology has been used by geologists to reconstruct paleoclimate and as a dating method for bog stratigraphy (Birks, 2019). Since the 1950s, the proxy role of pollen grains has allowed scientists to comprehend the spatio-temporal dynamics of past vegetation as well as the impact of human activity on land cover (Faegri and Iversen, 1964). Faegri and Iversen's book emphasized the ecological significance of reconstructing past vegetation by closely identifying individual pollen grains taxonomically, and also acknowledged the statistical value of

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counting the total number of pollen grains, which is known as "the pollen count" (Birks and Berglund, 2018). In a laboratory setting, conducting a typical palynological analysis is a challenging and time-consuming process that also carries a significant amount of bias: a trained observer, with expertise in the taxonomy of the local pollen, can identify a greater variety of species, whereas an inexperienced observer may overlook or inaccurately identify several taxonomic groups. To establish an optimal standard for the study, a minimum pollen count is crucial, and it plays a significant role in ensuring the accuracy of reconstruction using proxy data, specifically pollen as a proxy for vegetation. Numerous studies conducted thus far have aimed to determine the count required for reliable palynological analysis, including the works (Erdtman, 1952; 1954; Faegri and Iversen, 1950; Moore et al., 1991; Djamali and Cilleros, 2020; Pardoe et al., 2021).

Big data sets are becoming more prevalent across numerous fields of study. To make sense of datasets of this nature, techniques must be developed that significantly lower their dimensionality, doing so in a manner that is comprehensible and retains the vast majority of the information contained within the data. One of the oldest and most commonly employed methods for this purpose is principal component analysis (PCA). Despite its frequent use and periodic reinvention, the underlying essence of this technique remains statistical and has been primarily developed by statisticians.

Translating the goal of preserving variability means identifying new variables as linear combinations of existing ones, which successively maximize variance while being uncorrelated. Reducing the search to new variables, the principal components (PCs), equates to solving an eigenvalue/eigenvector problem. Literature on PCA dates from but PCA was not practically utilisable on large datasets until electronic computers became widely available in the decades that followed. Following this milestone, its use has expanded rapidly and numerous variants have been created in various fields (Pearson, 1901; Hotelling, 1933).

Various workers have studied the various sediments of the Late Cretaceous basins and sub-basins of southeastern Nigeria and came forward with documentations concerning its age, lithology, environment, structure, resources etc. (Reyment, 1965; Murat, 1970., Okoro, 1995., Oboh-Ikuenobe et al., 2005., Onyekuru et al., 2019., Opara, 2021a,b., Onyekuru et al., 2025). The study area is located between Longitudes 7°16′E and 8°00′E and Latitudes 5°36′N and 6°15′N (Figure 1) The study area includes the following towns in southeastern Nigeria: Umuahia, Ohafia, Uturu, Okigwe, and Afikpo.

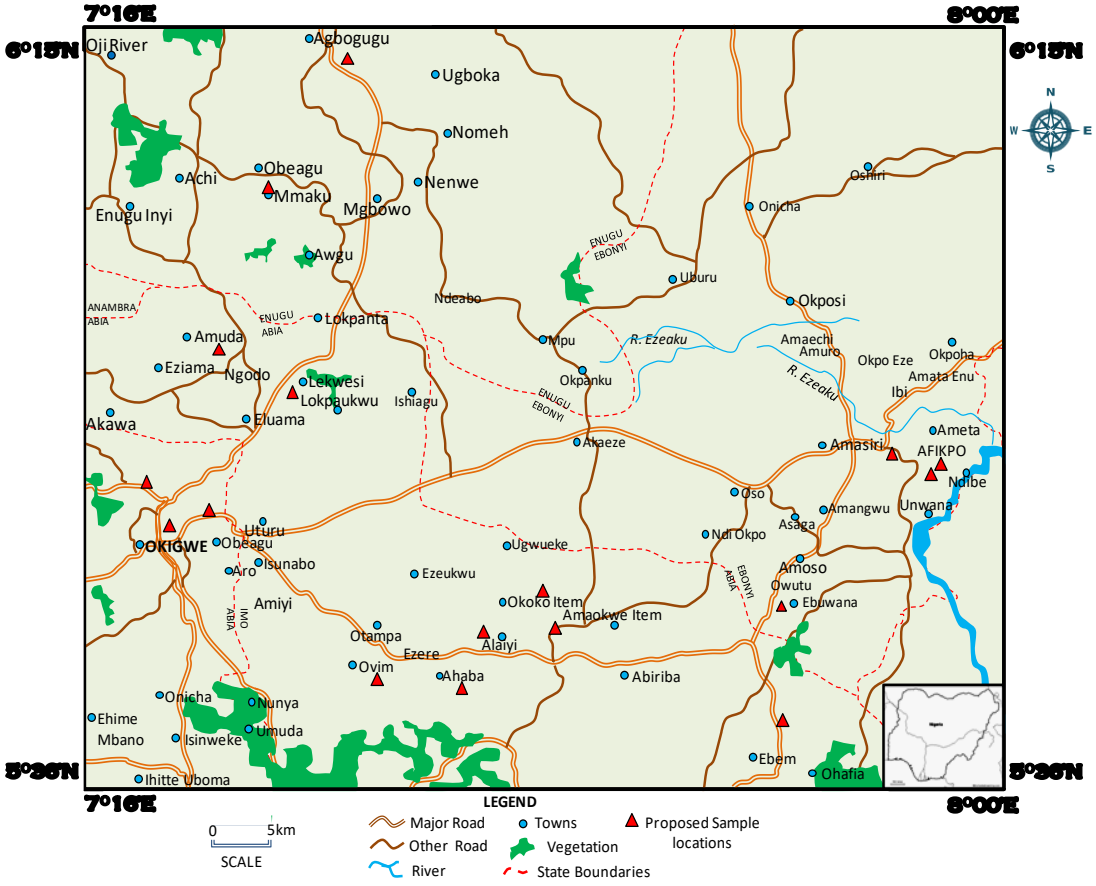

Figure 1: Location map of the study area showing sample locations (adapted from NGSA, 2015)

2. Geological Setting

The formation of Southeastern Nigerian sedimentary basins may be traced back to the late Jurassic following the separation of the South American and African continents in the Early Cretaceous, with the resultant Benue Trough as a failed arm of RRR Triple junction (Murat, 1972; Burke, 1996). Various lines of geomorphologic, structural, stratigraphic and palaeontologic evidence have been presented to support a rift model (Burke 1996; Guiraud and Bellion, 1995; Salako, 2014., Garba et al., 2024). Some researcher summarized the tectonic evolution in chronological order of origin and development starting with the formation a graben-like depression formed by crustal extension followed by rifting, with broad lip adjourning the western margin of the trough (Anambra platform) and a smaller lip on the southern edge (the Afikpo platform) (Figure 2) (Nwajide and Hoque, 1984). The trough stage was characterized by the first marine transgression that took place in Albian (or Aptian) times causing the trough to widen and deepened.

There was a mild deformational episode during the Cenomanian which restricted deposition only in southern part of the trough. The Cenomanian deformation was perhaps very local and may have originated due to reactivation of the basin along basement faults (Burke, 1976). The deformation Stage was initiated when the accumulation of thick sediments in the trough led to the development of instability at the base of faulted crustal blocks which culminated in large-scale folding with fold axes parallel to the trend of the trough. The lips of the trough began to sag to form the Anambra Basin and the Afikpo Syncline. Large-scale alkaline basaltic volcanism took place. (Igwe et al., 2013). The deformed and uplifted (Benue-Abakaliki) trough became a positive element to shed detritus; the depressed platforms of Anambra and Afikpo became the major depocenters. In environments ranging from marine to parallic to fluvial, about 4000m of Post-Santonian sediments were deposited in the Anambra and Afikpo basins. They are largely undeformed, but broadly upwarped with a few degree of dip towards the cratonic margin of the trough.

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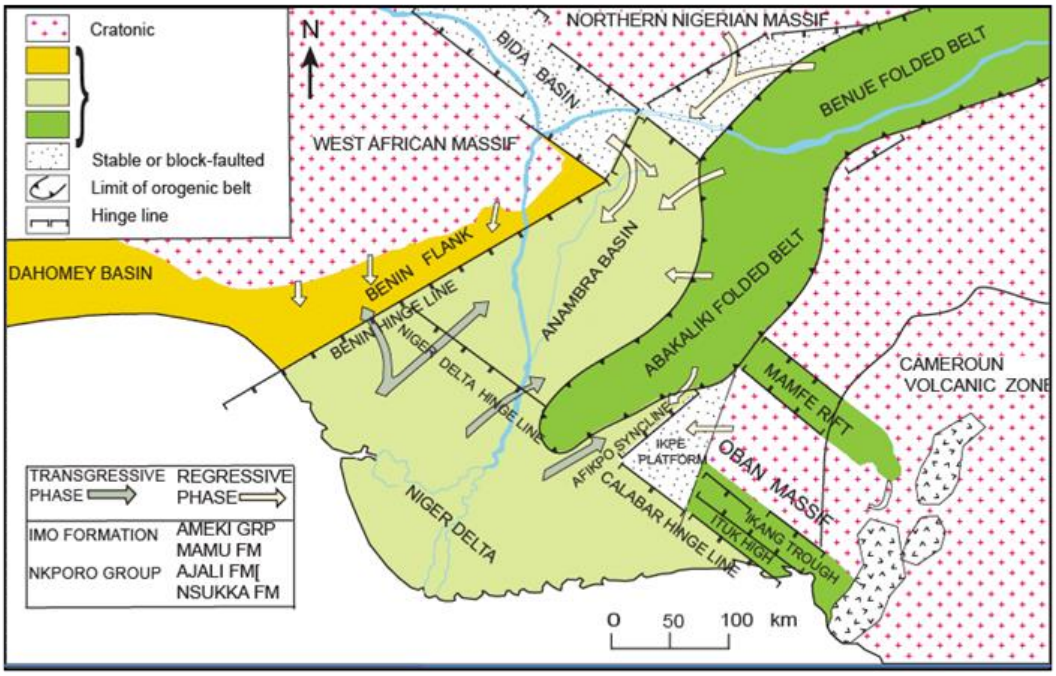

Figure 2: Tectonic Map of South-East Nigeria, from the Albian to Santonian Ages. (B). Tectonic Map of South-East Nigeria during the Campanian to Eocene (redrawn and modified after Murat, 1970).

The stratigraphic history of the region (Table 1) is characterized by three sedimentary phases (Short and Stauble, 1967; Murat, 1972; Obi et al., 2001). These three phases were: (a) the Abakaliki-Benue Phase (Aptian-Santonian) characterized by the deposition of the Asu River Group, Ezeaku Group, Awgu Formation, (b) the Anambra-Benin phase (Campanian-Mid Eocene) marked by the Nkporo Group, Mamu, Ajali, Nsukka, Imo formations, Ameki Group and Ogwashi-Asaba Formation, and (c) the Niger Delta phase (late Eocene-Pliocene) marked by the Akata, Agbada and Benin formations.

Table 1: Correlation Chart for Early Cretaceous to Tertiary Strata in the Southeastern Nigeria. (Nwajide, 1990).

Age		Abakalili-Anambra Basin	Afikpo Basin
(Ma) 30	Oligocene	Ogwashi-Asaba Formation Ameki/Nanka Formation/	Ogwashi-Asaba Formation
54.9	Eocene	Nsugbe Sandstone (Ameki Group)	Ameki Formation
65	Paleocene	Imo Formation Nsukka Formation	Imo Formation Nsukka Formation
73	Maastritchian	Aja li Formation Mamu Formation	Aja li Formation Mamu Formation
83	Campanian	Nkporo Owelli Formation/Enugu Shale	Nkporo Shale Afikpo Sandstone
87.5	Santonian	Agba ni Sa ndstone/Awgu Shale	Non-de position
88.5	Coniacian		
93	Turonian	Eze Aku Group	Eze Aku Group (including Amas iri Sst)
100	Cenomanian Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unamed Group	
Precambrian		BASEMENT COMPLEX	

3. METHODOLOGY

3.1 Palynological Study

Seventeen (17) shale, mudstone and clayey sandstones samples were collected from outcrops described on road-cuts, river channels, erosion sites, quarries/sand mining burrow pits and processed for their palynological contents. Sample preparation was carried out using the conventional method as follows:

The samples are subjected to treatment with dilute hydrochloric acid (HCl) to remove any available carbonate in the sample. Followed by dissolution of silicates which was achieved by the use of hydrofluoric acid (HF) on samples. The samples are then stirred at regular intervals with nickel rod and then left overnight in a fume cupboard. After decanting the HF, samples are then thoroughly washed with distilled water. Samples were then treated with warm 36% HCl, then cold HCl to remove fluoride gels followed by washing with 0.5% HCl and then the samples are transferred into small 15cm^{3}centrifuge tubes. After centrifuging, the floating top part consisting of organic material was gently decanted into another tube. The organic material is then thoroughly washed with water. The organic residue is then transferred into a porcelain basins, and concentrated Nitric acid (HNO_3) is gently added. The mixture is warmed for a few minutes and stirred properly with a glass rod, later centrifuged and the Nitric acid decanted, and the residue thoroughly washed with distilled water. This was followed by neutralization of acid with warm potassium hydroxide (KOH), then centrifuged and KOH decanted. The residues are preserved by adding a drop of glycerol/glycerin to each of the properly labelled phials.

Finally a small quantity of glycerin jelly is put on the centre of the clean slide and a small quantity of organic residue added and warmed. The mixture is spread out evenly, covered with cover slip, and the slide was labeled. Slides were made from the samples and examined under the transmitted light microspcopy. Photomicrographs were taken with leica III binocular microscope.

3.2 Principal Component and Cluster Analysis

The identified Palynofacies were analyzed using principal component and cluster analysis. Principal component analysis, or PCA, is a statistical procedure that allows one to summarize the information content in large data tables by means of a smaller set of "summary indices" that can be more easily visualized and analyzed. It uses an orthogonal transformation

to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components.

The principal component analysis (PCA) was done in order to make a qualitative assessment of the relationships between the various palyno-ecological communities. The procedure involves a two step approach: (a) scaling and (b) clustering, First the mean variable is subtracted from individual variable by so doing the data is centered around zero. Samples with relatively high transcription gets positive values while those with relatively low transcription gets negative values. Next each data point is divided by the standard deviation (SD). Regardless of the variation of the original data, this procedure ensures that it is tightly grouped as the spread of the data is now narrowed. This procedure is important in the heatmap dendogram to limit the shades of colour to fewer shades and be able to discern the transcription of the samples.

4. RESULTS

4.1 Results of Palynological analysis

Several types of dispersed organic matter and palynomorphs were identified including spores and pollen, fungal remains, freshwater algae, microforaminiferal inner linings, structured phytoclasts (wood, cuticles, parenchyma), unstructured phytoclasts (communited and degraded fragments), black debris and amorphous organic matter. Representative photomicrographs are shown fig 3 and 4.

4.1.1 Ndibe Station

The palynomorphs recovered in this sample include majorly both terrestrial species namely: *Longapertites marginatus, Acrostium aureum. Leitriletes adrienennis, Milfordia jardinei, Laevigatosporites discordatus, Forveotriletes margarifae, Mauritiidites crassibaculatus and Proxapertites operatatus*. Marine species include: , *Dinocyst indeterminate, Acritarch sp, foram linnings*

4.1.2 Leru Station

Species recovered include: *Longapertites marginatus, Butina andreevi, Leitriletes adrienennis, Longapertites, Zlivisporis blanensis and Gleicheniidites senonicus.* Marine dinoflagellates include *Dinocyst indeterminate and Foram linings.*

4.1.3 Agbogugu Station

This sample is dominated by terrestrial species namely: *Longapertites marginatus, Butina andreevi, Longapertites sp, Zlivisporis blanensis, Cingulatisporites ornatus and Distaverrusporites simplex,*

4.1.4 Ebuwana Station

Species recovered are *Longapertites marginatus, Acrostium aureum, Acrostium aureum, Dinocyst indeterminate, Laevigatosporites discordatu, Butina andreevi, Retidisporites sp, Zlivisporis blanensis, Distaverrusporites simplex and Ephedripites regularis. Azolla cretacea* constituted the only fresh water algae with *Dinoflagelate indeterminate* as the only marine species.

4.1.5 Nguzu Edda Station

Recovered species include: *Longapertites marginatus , Ariadnaesporites spinosus, Zlivisporis blanensis, Fungal spore, Cingulatisporites ornate, Foram lining*

4.1.6 Umunneoche Station

Species recovered include: *Longapertites marginatus, Acrostium aureum, Butina andreevi, Ariadnaesporites, Rettidisporite echinatu, Longapertites sp, Laevigatosporites discordatus, Zlivisporis blanensis, Fungal spore and Ephedripites regularis, Mauritiidites crassibaculatus, Proxapertites operatatus*

4.1.7 Km 74

The sample is very rich in terrestrial species namely*: Longapertites marginatus , Butina andreevi, Ariadnaesporites spinosus, Cycadopites sp, Rettidisporite echinatus, Leitriletes adrienennis*, *Longapertites sp, Zlivisporis blanensis, Ephedripites regularis, Syndemicolpites typhicus*

4.1.8 Uturu Station

Recovered forms are *Longapertites marginatus Acrostium aureum, Dinocyst indeterminate, Butina Andreev, Longapertites sp, Laevigatosporites discordatus, Ephedripites regularis, Syndemicolpites typhicus*

4.1.9 Umuasua 1

This sample is marine species dominant including: *Carpatella cornuta, Cordosphaeridium varians, Fibrocysta licia, Spiniferites spp*, *Cordosphaeridium inordes*, *Fibrocysta spp., Cyclonephelium deckonincki*, *Fibrocysta spp., Danea abbreviate* and *Carpatella septata.* Terrestrial species include *Ariadnaesporites spinosus,, Damassadinium californicum and Cythadites australi*

4.1.10 Umuasua II

Also this sample sparse on terrestrial species. recovered species include: *Longapertites marginatus , Ariadnaesporites, Damassadinium californicum, Marine palynomorphs include: Spiniferites spp, Cordosphaeridium inordes, Fibrocysta spp., Cyclonephelium deckonincki, Fibrocysta spp., Danea abbreviate, Carpatella septata, Carpatella cornuta, Cordosphaeridium varians, Fibrocysta licia.* and *Carpatella septata*

4.1.11 Amaba

Recovered species include: *Acrostium aureum, Laevigatosporites discordatu, Spinodemicolpites sp, Cordosphaeridium varians, Proxapertites*

4.1.12 Ahaba-Imenyi

Recovered species are *Longapertites marginatus Acrostium aureumoperatatus, Distaverrusporites simplex, Ariadnaesporites spinosus, Pollentricolpate echinatu, Laevigatosporites discordatus*

4.1.13 Ikpankwu

Terrestrial species include; *Longapertites marginatus, Butina andreevi,* marine palynomorphs include; *Spiniferites spp., Cordosphaeridium inordes, Acritarch sp and Fibrocysta sp.*

4.1.14 Ihube

There is a preponderance of terrestrial species in this sample. *Longapertites marginatus*, *Ariadnaesporite, Tectatodinium rugulatum, Butina Andreev, Longapertites sp, Damassadinium californicum , Mauritiidites crassibaculatus, Longapertites microfoveolatus, Retiidiporite magdalensis, Zlivisporis blanensis, Monocolpopollenite, Ephedripites regularis and Gleicheniidites senonicus.* The only marine species recovered is *Spiniferites sp.*

4.1.15 Umulolo

Terrestrial species recovered include: *Mauritiidites crassibaculatus ,Longapertites marginatus Proxapertites operatatus, Mauritiidites crassibaculatus, Leitriletes adrienennis, Butina Andreev, Gleicheniidites senonicus, Retidisporites sp,* while Marine palynomorphs include: *Cordosphaeridium inordes, Fibrocysta spp* and *Spiniferites spp*

4.2 Subjecting the data to Principal Component Analysis

Ten types of dispersed organic matter and palynomorphs were identified including spores and fungi (SP), pollen (PO), freshwater algae (FWA), microforaminiferal inner linings (FL), dinoflagellates (DFL), structured phytoclasts (STPH) (wood, cuticles, parenchyma), unstructured phytoclasts (UNPH) (communited and degraded fragments), black debris (BD) and amorphous organic matter (AOM) (Table 2).

Table 2: Percentage abundances of palyno-ecological communities.

FM	SAMPLE ID	Playnofacies									
		PO	SP	DFL	FWA	FL	ACR	STPH	UNPH	BD	AOM
NKPORO FM	NK-P1	30.8	46.2	5.1	0.0	5.1	0.0	0.0	0.0	0.0	12.8
	NK-P2	21.1	42.1	5.3	0.0	5.3	0.0	5.3	10.5	0.0	10.5
	NK-P3	16.7	58.3	0.0	0.0	0.0	0.0	4.2	4.2	0.0	16.7
MAMU FM	MA-P1	13.4	39.0	1.2	4.9	0.0	0.0	12.2	23.2	6.1	0.0
	MA-P2	9.3	29.6	0.0	0.0	0.0	0.0	22.2	11.1	27.8	0.0

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Table 2 (Cont): Percentage abundances of palyno-ecological communities.

FM	SAMPLE ID	Playnofacies									
		PO	SP	DFL	FWA	FL	ACR	STPH	UNPH	BD	AOM
	MA-P3	15.9	17.5	1.6	0.0	0.0	0.0	23.8	25.4	15.9	0.0
	MA-P4	0.0	53.8	3.8	3.8	0.0	0.0	7.7	19.2	11.5	0.0
	MA-P5	24.1	62.0	1.3	0.0	0.0	6.3	3.8	2.5	0.0	0.0
	MA-P6	15.4	71.2	0.0	0.0	0.0	0.0	7.7	0.0	5.8	0.0
	MA-P7	20.5	35.9	5.1	0.0	0.0	0.0	15.4	2.6	20.5	0.0
NSUKKA FM	NS-P1	3.7	3.7	64.8	0.0	16.7	5.6	0.0	0.0	0.0	5.6
	NS-P2	0.0	2.3	79.5	0.0	4.5	4.5	0.0	0.0	0.0	9.1
	NS-P3	26.7	73.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NS-P4	19.2	73.1	0.0	0.0	3.8	0.0	3.8	0.0	0.0	0.0
	NS-P5	7.5	45.0	35.0	0.0	5.0	0.0	0.0	7.5	0.0	0.0
	NS-P6	28.6	34.3	8.6	0.0	11.4	11.4	0.0	5.7	0.0	0.0
	NS-P7	7.4	44.4	25.9	0.0	22.2	0.0	0.0	0.0	0.0	0.0

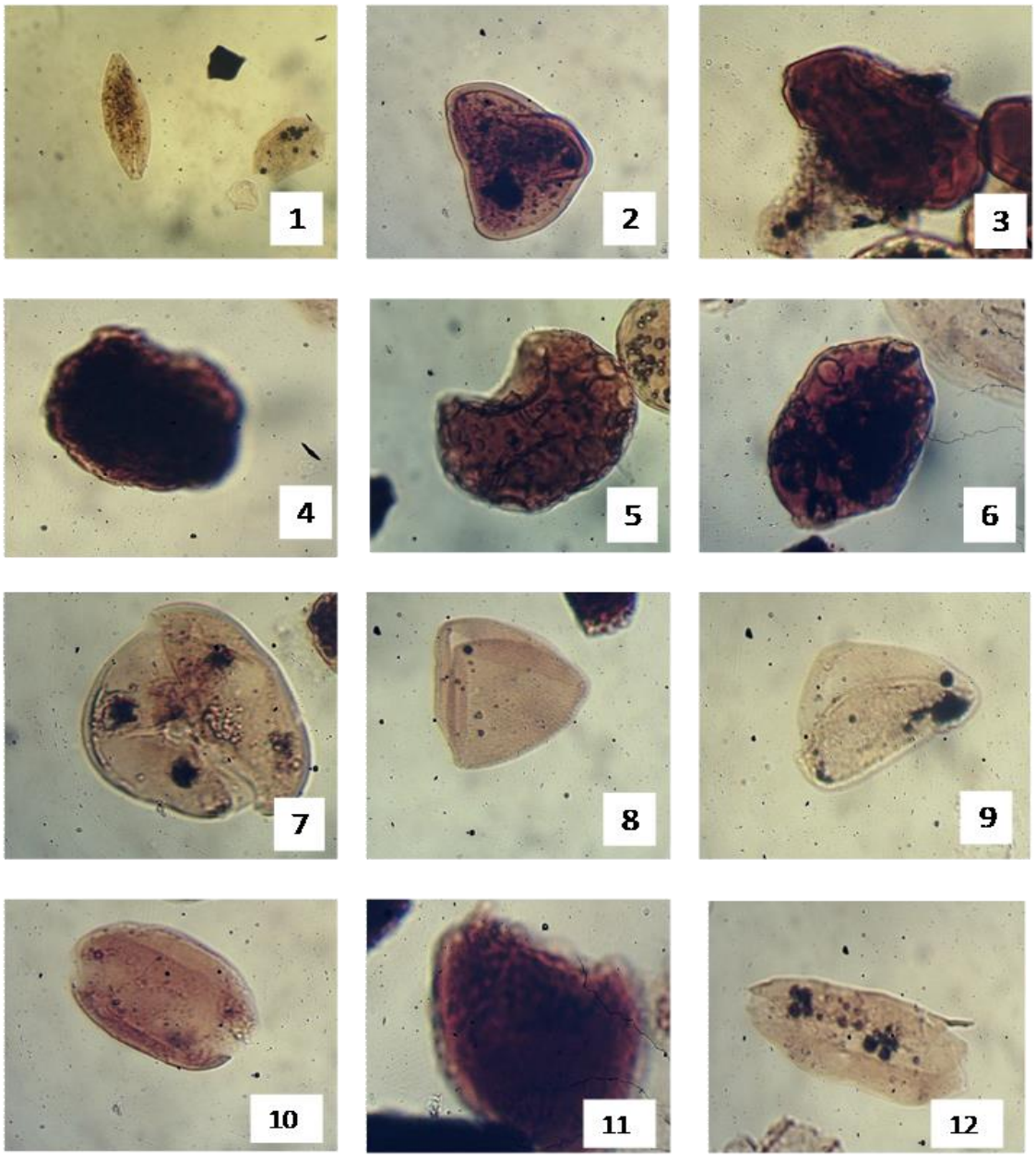

Figure 3: Photomicrograph of representative palynomorphs in the study area.(x200)

1. Azolla cretacea 2. Laevigatosporites sp 3. Araidnaesporites spinosus 4,11. Cingulatisporites ornatus 5,6. Buttinia andreevi 7. Psiltricolpites sp 8,9. Longapertites marginatus 10,12. Retidiporites magdalenensis

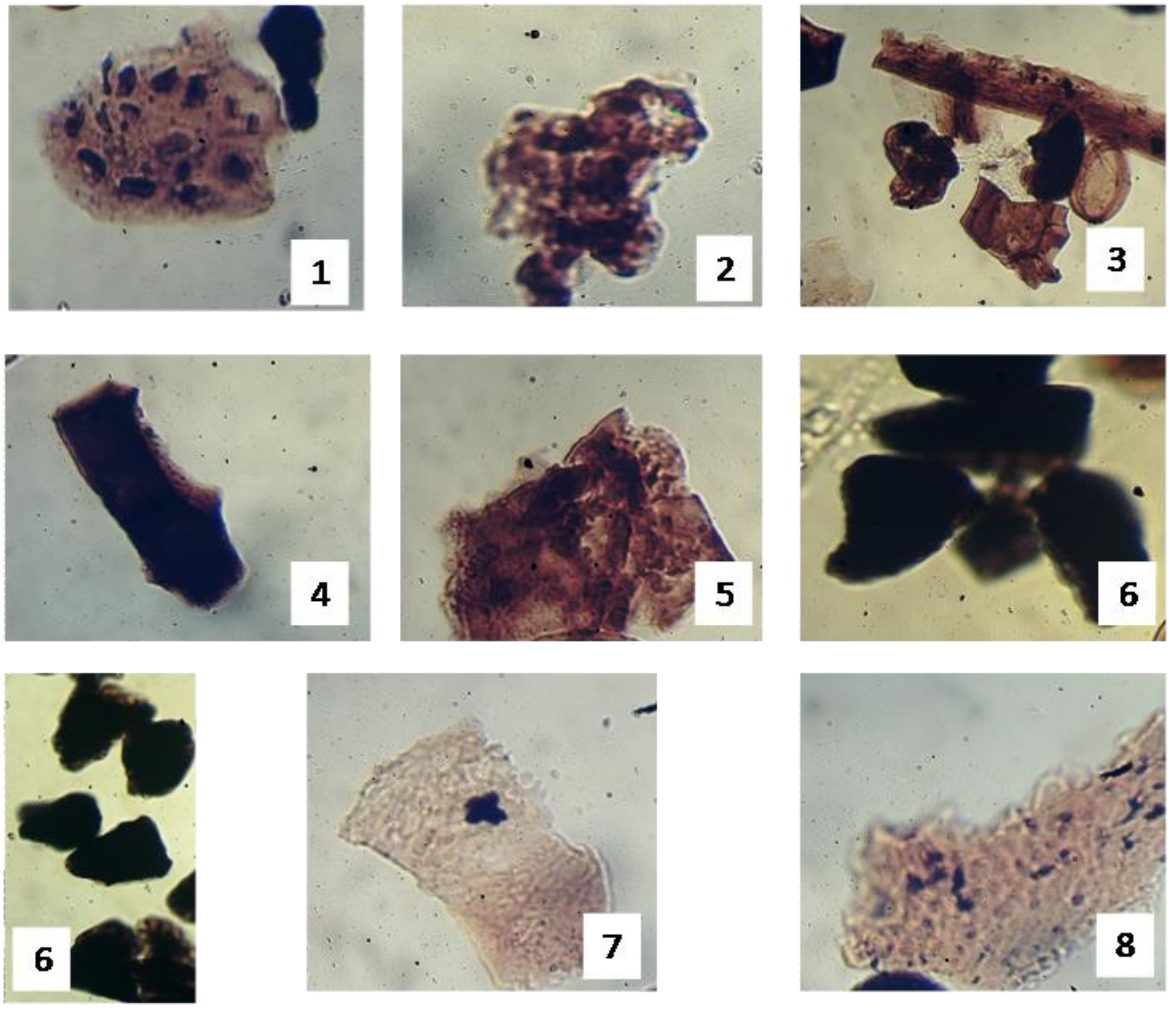

Figure 4: Photomicrographs of dispersed organic debris in the study area.(x200)

1. Pitted wood 2. degraded wood 3. poorly preserved wood fragments 4. Well preserved wood 5. Amorphous organic matter 6,7 Black debris 8. cuticle

In the PCA model with two components, knowledge of which variables are influential, and also how the variables are correlated is given by the principal component loadings.

These loading vectors are called PC1 and PC2 (Table 3 and 4), while visual presentation was done using scatter plots and dendogram heatmap (Figure 5 and 6).

Table 3: Principal components (10 data points in rows, 10 components in columns):

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
PO	-1.82	-0.40	1.06	-1.75	0.36	0.05	0.05	-0.02	0.10	-0.00
SP	-8.95	0.38	0.12	0.62	-0.20	-0.02	0.04	0.01	-0.02	-0.00
DFL	1.20	4.29	-1.54	-0.24	0.07	0.15	0.11	0.01	0.02	0.00
FWA	2.20	-0.36	0.82	0.77	-0.10	-0.00	0.31	0.10	0.31	0.00
FL	1.55	0.96	0.91	0.19	-0.14	-0.82	-0.64	-0.01	-0.00	-0.00
ACR	2.06	0.06	1.07	0.08	-0.10	-0.38	0.56	0.02	-0.26	0.00
STPH	0.65	-1.85	-1.30	-0.24	-0.17	0.11	-0.17	0.34	-0.07	-0.00
UNPH	0.49	-1.47	-1.02	0.43	1.53	-0.10	-0.02	-0.14	-0.01	-0.00
BD	0.93	-1.73	-1.31	-0.18	-1.16	-0.07	0.05	-0.24	0.03	0.00
AOM	1.69	0.13	1.18	0.34	-0.09	1.09	-0.28	-0.06	-0.09	-0.00

Table 4: Component loadings (17 dimensions in rows, 10 components in columns):

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
NK-P1	-0.27	0.07	0.26	-0.30	0.00	0.34	-0.21	-0.28	0.32	0.00
NK-P2	-0.29	0.03	0.12	-0.08	0.25	0.29	-0.34	-0.11	-0.09	-0.29
NK-P3	-0.28	0.01	0.16	0.16	-0.02	0.48	-0.14	0.03	-0.43	0.23
MA-P1	-0.26	-0.15	-0.17	0.17	0.46	-0.05	0.13	0.05	0.43	-0.00
MA-P2	-0.19	-0.28	-0.43	-0.07	-0.45	-0.03	-0.10	-0.24	-0.27	-0.04

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Table 4 (Cont): Component loadings (17 dimensions in rows, 10 components in columns):										
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**	**PC9**	**PC10**
MA-P3	-0.13	-0.34	-0.48	-0.32	0.45	-0.02	-0.21	0.27	-0.16	0.10
MA-P4	-0.26	-0.06	-0.20	0.52	0.06	-0.07	0.16	-0.52	-0.10	-0.10
MA-P5	-0.29	0.02	0.13	-0.04	-0.01	-0.05	0.35	0.32	-0.23	-0.32
MA-P6	-0.29	-0.01	0.03	0.14	-0.19	-0.01	0.11	0.37	-0.09	-0.09
MA-P7	-0.26	-0.11	-0.21	-0.38	-0.45	0.04	0.10	-0.04	0.36	0.02
NS-P1	0.04	0.52	-0.28	-0.16	0.02	-0.00	-0.09	0.04	-0.09	-0.63
NS-P2	0.04	0.50	-0.35	-0.12	0.03	0.32	0.26	0.05	-0.08	0.46
NS-P3	-0.29	0.03	0.13	-0.01	-0.06	-0.00	0.18	0.06	0.24	-0.04
NS-P4	-0.29	0.03	0.10	0.11	-0.10	-0.07	0.02	0.36	0.01	0.16
NS-P5	-0.22	0.34	-0.22	0.14	0.11	-0.01	0.17	-0.11	0.14	0.09
NS-P6	-0.25	0.12	0.26	-0.46	0.20	-0.49	0.22	-0.32	-0.34	0.18
NS-P7	-0.22	0.33	-0.03	0.17	-0.13	-0.47	-0.63	0.11	0.08	0.22

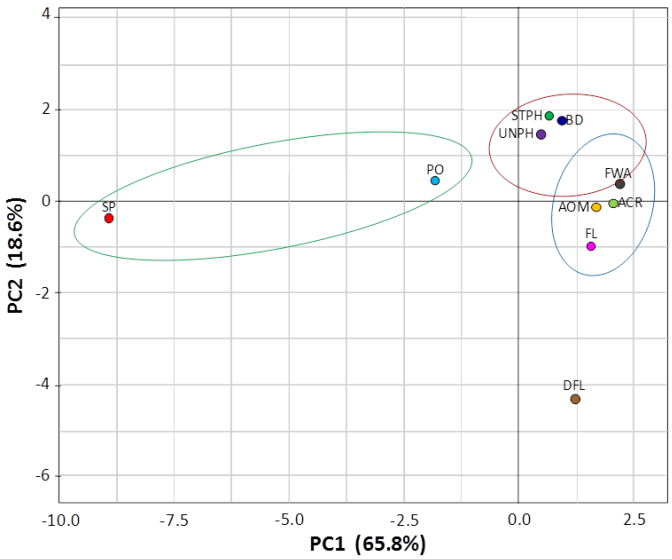

Figure 5: PCA scatter plot showing correlation and clusters of palynofacies in the study area

The PCA biplot displays the relationships between all 10 variables at the same time. When two vectors are close, forming a small angle, the two variables they represent are positively correlated (ie) Variables contributing similar information are grouped together, that is, they are correlated. From the scatter plot, three groups are recognized as indicated by loops namely group A (SP and PO) group B (UNPH, STPH and BD), group C (AOM, FL, ACR and FWA). The implication is that when the numerical value (% abundance) of one of the palynomorphs in a particular group increases or decreases, the numerical value of the other palynomorphs in the group has a tendency to change in the same way.

Loading plots also hint at how variables correlate with one another: a small angle implies positive correlation, a large one suggests negative correlation, and a 90° angle indicates no correlation between two characteristics.

When variables are negatively ("inversely") correlated, they are positioned on opposite sides of the plot origin, in diagonally Opposed quadrants. Here they diverge and form a large angle (close to 180°), they are negative correlated. For instance, Dinoflagellate (DFL) and pollen (PO), spores (SP) are highly inversely correlated, so is SP and FWA. PO and most of Group B cluster as well as FL and most of Group B cluster seems to have no correlation as the angle connecting them approximates 90^0

Furthermore, the distance to the origin also conveys information. The further away from the plot origin a variable lies, the stronger the impact that variable has on the model. From the plot, dinoflagellates (DFL) and spore (SP) suggest strong influence on the PCA model. The palyno-ecological parameters are further compared in the Heatmap Hierarchical cluster dendograms in Fig. 6. For this, the variables that are most similar are defined to form the first order cluster. Hierarchical cluster is accompanied by a dendogram which indicate both the similarity and the order that the cluster were formed.

From the column, the heatmap dendogram enabled the definition of four main palyno-ecological groups forming the 1st order cluster namely Cluster 1A comprising (SP and PO). This cluster showed a high transcription with an almost even representation in all the formations of study as indicated by the white to red colour shades, with the exception of samples NS-P1 and NS-P2 from Nsukka Formation where they showed a slightly low transcription of <0. Cluster 1B comprise of (UNPH, STPH, BD). This cluster is well developed in Mamu Formation at MA-P2, MA-P3 and MA-P7 where they defined a sub-cluster with high transcription as indicated by the white colour shade. Elsewhere, they showed a low transcription <0.5. Cluster 1C comprise of (AOM and FWA). This cluster is characterized generally by low transcription across the formations under study however with pockets of slight high transcription in Nkporo Formation. Cluster 1D comprise of (FL, DFL and ACR). This cluster is least developed in Mamu Formation as indicated by the deep blue colour shade. DFL is best developed in Nsukka Formation forming a cluster with very high transcription at NS-P1 and NS-P2 as indicated by the red colour shade and another subcluster at NS-P5 and NS-P7 indicated by white colour shade. A 2nd order cluster was also identified comprising of clusters 2A (constituted by 1st order clusters 1A and B) and cluster 2B (constituted by 1st order clusters 1C and D).

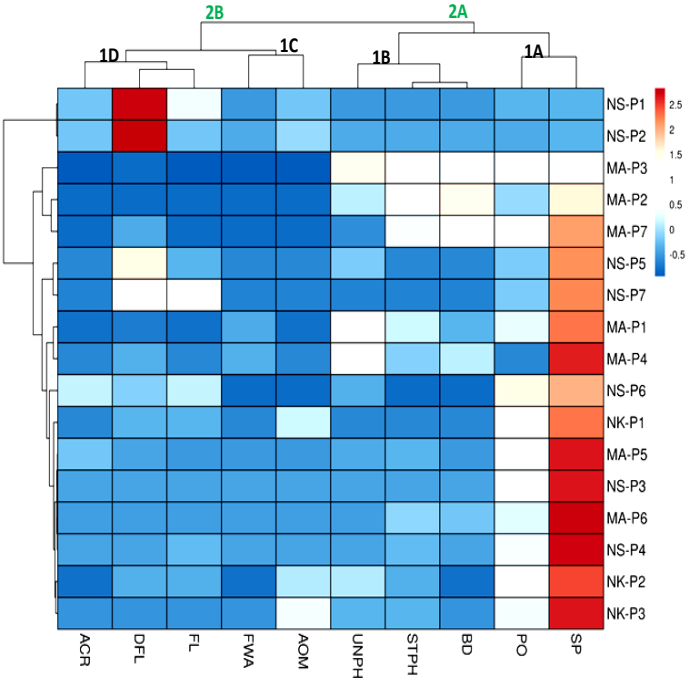

Figure 6: Heatmap dendogram showing palynofacies clusters in the study area

5. Discussion

The palyno-ecological clusters were grouped according to their environmental significance, Subcluster 1A palyno-ecology is comprised of Pollen (PO) and Spores (SP) while subcluster 1C is made up of Amorphous organic matter (AOM) and Fresh water algae (FWA) These two sub clusters implicated the rainforest and savanna palyno-ecologies as the major prevalent ecologies during the time of sediments deposition. The Rainforest communities are characterized by freshwater vegetation such as algae (botryococcus and pediastrum), ferns (Salvinia and sedge), palm, shrub and trees of distinct families. The savanna ecology is characterized by a diversity of vegetation such as Palmae, Caesalpiniaceae and Umbelliferae (White, 1926., Jansonius and McGregor, 1996., Birks, 2019., Djamali, and Cilleros, 2020). The 1B subcluster indicates palynofacies typical of swamp constituted by structured and unstructured phytoclast and black debris (STPH, UNPH and BD) which was pronounced in Mamu Formation.

Cluster 1D comprising of Dinoflagellate (DFL), Foram linings (FL) and Acritarch (ACR) indicated marine palyno-ecologies. Dinoflagellates constitutes a major part of the modern oceanic planktonic distribution representing an important component of food chain in the marine environment (White, 1926; Armstrong and Brasier, 2005). The dinoflagellate cysts are common in marine sediments but generally lacking in non-marine sediments. Acritarchs are the resting stage of certain planktonic algae which are mostly found in marine sediments, with similar ecological characteristics as the dinoflagellates (Armstrong and Brasier, 2005; Adeniran, 2015).

The presence of a wide variety of palynomorphs indicated that the environment supported a rich and diverse tropical flora. The Rainforest community is characterized by freshwater vegetation such as algae (botryococcus and pediastrum), ferns (Salvinia and sedge), palm, shrub and trees of distinct families. The Swamp palyno-ecological communities are characterized by algae (Botryococcus spp.), fern, sedge, vine, shrub, and palms (White, 1926). The marine ecological communities is represented by palynomophs normally found in fluviomarine settings and they include the dinoflagellates, foraminifera and planktonic algae (Eisawi and Schrank, 2008; Olayiwola and Bamford, 2016).

The pattern represented on the heatmap pointed to an alternation of ecologies from one with a greater marine influence to swamp/forest and Savanna Palyno-ecological Communities. Moreover, the observed progressive decrease in the abundance of spores and fungi, and the steady increase in the abundance of foraminiferal lining, dinocysts and marine indicator palynomorphs (acritarchs and dinoflagellates) up the stratigraphic column from Nkporo to Nsukka Formation points to greater marine influence and a deepening basin with paludal conditions more evident in Mamu Formation.

6. Conclusion

From the PCA scatter plot, three groups are recognized as indicated by loops namely group A (SP and PO) group B (UNPH, STPH and BD), group C (AOM, FL, ACR and FWA). The heatmap dendogram enabled the definition of four main palyno-ecological groups forming the 1st order cluster namely Cluster 1A comprising (SP and PO), Cluster 1B comprise of (UNPH, STPH, BD), Cluster 1C comprise of (AOM and FWA) and Cluster 1D comprise of (FL, DFL and ACR). A 2nd order cluster was also identified comprising of clusters 2A (constituted by 1st order clusters 1A and B) and cluster 2B (constituted by 1st order clusters 1C and D).

The palyno-ecological clusters were grouped according to their environmental significance, Subcluster 1A palyno-ecology is comprised of Pollen (PO) and Spores (SP) while subcluster 1C is made up of Amorphous organic matter (AOM) and Fresh water algae (FWA) These two sub clusters implicated the rainforest and savanna palyno-ecologies as the major prevalent ecologies during the time of sediments deposition. Cluster 1D comprising of Dinoflagellate (DFL), Foram linings (FL) and Acritarch (ACR) indicated marine palyno-ecologies. Dinoflagellates constitutes a major part of the modern oceanic planktonic distribution representing an important component of food chain in the marine environment

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