Organodebris analysis of Chilka Lake, Orissa, India : An assessment of depositional environment

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This paper presents the results of organic matter analysis from Chilka Lake, Orissa, India. A coordinated attempt has been made to classify and interpret total organic matter (TOM) in relation to the depositional environment. Organodebris analysis dated back to *ca* 3,200 years B.P. has provided clues that ponding environment gave rise to reducing (anaerobic) conditions which probably accelerated microbial activity, transforming the palynodebris into first semi-amorphous/amorphous and then into fine organic matter. Various phases of mangrove vegetation development, the factors responsible for degrading mangals and land denudation have also been discussed in the light of multivariate methods of data analysis.

Key-words—Organodebris analysis, Palynology, Taphonomy, Depositional environment, Chilka Lake (India).

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साराँश

उड़ीसा (भारत) में चिल्का झील से प्राप्त कार्बनिक पदार्थ का विश्लेषण : निक्षेपणीय वातावरण का मूल्याँकन

आशा खंडेलवाल एवं हरीपाल गुप्ता

इस शोध-पत्र में उड़ीसा (भारत) में चिल्का झील से प्राप्त कार्बनिक पदार्थ के विश्लेषण के परिणाम प्रस्तुत किये गये हैं। निक्षेपणीय वातावरण से सम्बद्ध समग्र कार्बनिक पदार्थ को वर्गीकृत एवं इसकी व्याख्या करने का प्रयास किया गया है। लगभग 3,200 वर्ष पूर्व के कालनिर्धारित कार्बनिक पदार्थ विश्लेषण से पता चला है कि सरोवरी वातावरण के फलस्वरूप आक्सीजन विहीन अवकारक परिस्थितियाँ उत्पन्न हो गई थीं और सम्भवतया इन्हीं के कारण तेज सूक्ष्मजैविकीय गतिविधि हुई जिससे परागाणु-पदार्थ का पहले अर्ध-आकारहीन/आकारहीन तथा अन्त में बारीक कार्बनिक पदार्थ में परिवर्तन हुआ। मैंग्रोव वनस्पति के विकास की विभिन्न अवस्थायें तथा मगलों एवं भूमि अनाच्छादन के ह्रास हेतु आवश्यक कारकों की भी विस्तृत विवेचना की गई है।

ORGANODEBRIS analysis provides a postmortem history of the biota, such as its transportation, burial and decay. This study attempts to determine various taphonomical factors intervening between the living biota and their fossilization. The orientation and degree of decomposition of fossil plant debris, its relative abundance and characteristics, present in the sediments, indicate how and where it was buried and what may have altered it after burial.

There is an evidence that the terrigenous organic matter carried by rivers, etc. is buried in a marine environment, but the bulk of such material is supposedly confined to the close proximity of continents. It has been estimated that two-thirds of the particulate organic matter (POM) carried by rivers, mostly associated with clay and other minerals, is resistant to degradation and is buried in the marine environment (Deuser, 1988).

Is all organic matter buried in a marine environment of terrestrial origin? If not, where does all the terrigenous matter go? Does it reach the ocean and oxidise there? If not, do the marine sediments preserve mostly terrestrial matter? These are some of the basic principles which have to be understood in order to reckon the potential of this study. Estuaries and shelves are by far the most important depositories because the supply of organic matter is high both from land and marine realms. High sedimentation rate and oxygen demand in water lead to quick removal of material from the oxidation zone.

Riverine organic matter chiefly consists of labile (metabolizable) and residual (non-metabolizable) fractions. The labile fraction may be oxidized or lost within the rivers, estuaries and/or in the marine environment. Thus, the degraded fraction of organic matter could represent a significant source of organic carbon accumulating in marine sediments (Ittekkot, 1988). Oceanographers now recognize two distinct classes of particles in sea water 'suspended' and 'sinking'. Particulate organic matter in open sea exhibits a nonlinear decrease with increasing water depth and more than 75 per cent of particulate organic matter loss (POML) occurs in the upper 500 m of the water column (Karl *et al.*, 1988). Since sinking particles contain viable, metabolically active micro-organisms, the process of microbial decomposition is considered to be an important mechanism controlling particulate organic matter flux.

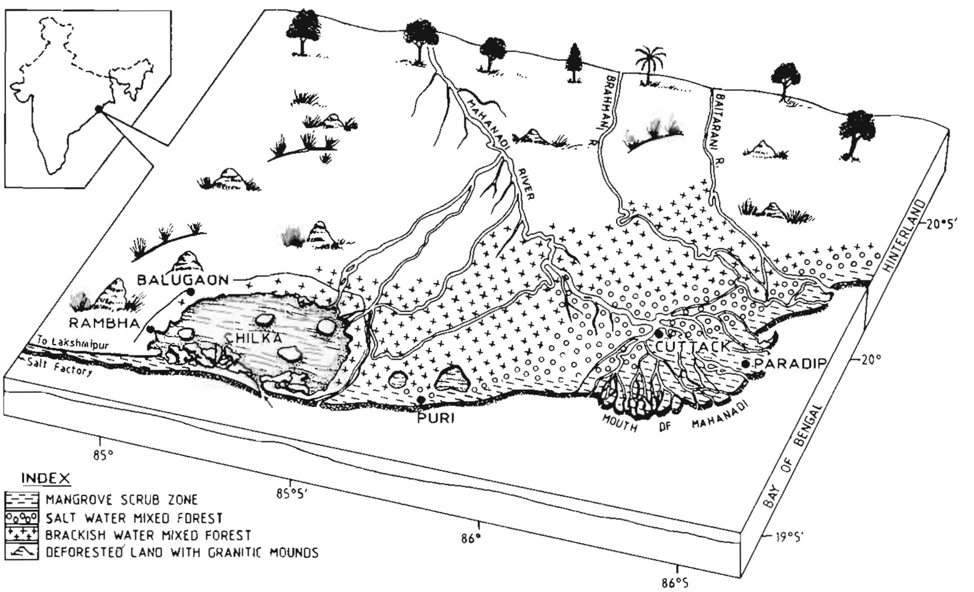
Although opinions are divided, the mechanism of organic matter decomposition is an important feature in the study of elemental dynamics. Cho and Azam (1988) believe that decomposition by attached bacteria may explain only a trivial fraction and have demonstrated that heterotrophic bacteria are instrumental in the decomposition of rapidly sinking particles within and below euphotic zone.

Total organic matter study envisages the basic concept for the total biomass potential and its provenance in the sediments. The importance of this study is unequivocal and realized for the hydrocarbon research (Correia, 1971; Venkatachala, 1981). The impact of different types of organic matter on the types of hydrocarbons generated is the result of contributions made by scavengers, fungi, bacteria, etc. to the organic debris (Frederiksen *et al.*, 1982). The identification, quantification and origin of key components among the organic matter could also be used as an important parameter in palynofloral mapping and palaeoenvironmental reconstruction and could, in turn, be fruitfully exploited in facies correlation (Pocock *et al.*, 1987-88). In India, a beginning has been made using samples from the Konal Ar Basin, Palni Hills, south India and the palynodebris characteristics of each zone in a 2.30 m deep profile worked out palynologically (Vasanthy *et al.*, 1980) has been distinguished.

Chilka Lake is an eutrophic open lagoon, measuring about 65 km north-south and 22 km east-west. The object of the particulate organic matter analysis is to investigate macerate variables and thereby improve palaeoenvironmental deductions. The study has given us a new insight in understanding various phenomena of biotic degradation (Gupta, 1978). Besides, it also proved helpful to examine physical, chemical and biological conditions responsible for the transformation of organic matter enabling to recognise the depositional environment and the degree of decomposition of sediments. The fungi are of primary importance as the bio-degrading agents, while bacteria are the main decomposing agents of organic matter in the marine environment (Sieburth, 1979).

MATERIAL AND METHOD

The organodebris analysis of samples from a 5.5 m deep profile from Chilka Lake at Balugaon (Lat. 19°5'-20°; Long. 86°6') in the Mahanadi delta of Orissa (Text-figure 1) has been carried out. This profile was also investigated palynologically and the base was radiometrically dated to 3,100 ± 270 years B.P. -BS-804 (Gupta & Khandelwal, 1990). The matrix was deflocculated with 10 per cent aqueous solution of KOH and sieved through 50, 100 and 150 mesh successively, in order to check any pollen/spores loss through filtrate. The residue was washed with distilled water thoroughly and strew organic matter slides were prepared and studied under Olympus BH-2 microscope



Text-figure 1—Panorama of Chilka Lake.

using × 40 objective. Percentages impression based diagram, using ten replications for each sample was prepared showing relative values of nine biotypes recovered from the sediments in vertical sequence (Text-figure 2; Table 1). The ternary diagram (Text-figure 3; Table 2) shows collective values for structured, amorphous and fungal materials. All the macerate groups according to their degree of decomposition have also been illustrated.

Several classification schemes for particulate organic matter have been proposed earlier by Staplin (1969), Burgess (1974), Robert (1979), Pocock and Vasanthy (1982), and Massoud and Kinghorn (1985). However, Hart (1986) is of the view that the above schemes for organic matter classification, being derived mainly from coal petrology, lack an integrated approach and neglect the great importance of the depositional environment acting upon the biological characteristics as preservable particles and thus proposed the classification based on POM characteristics. The classifications both of Masran and Pocock (1980) and Hart (1986) have been followed here.

MACERATE ANALYSIS

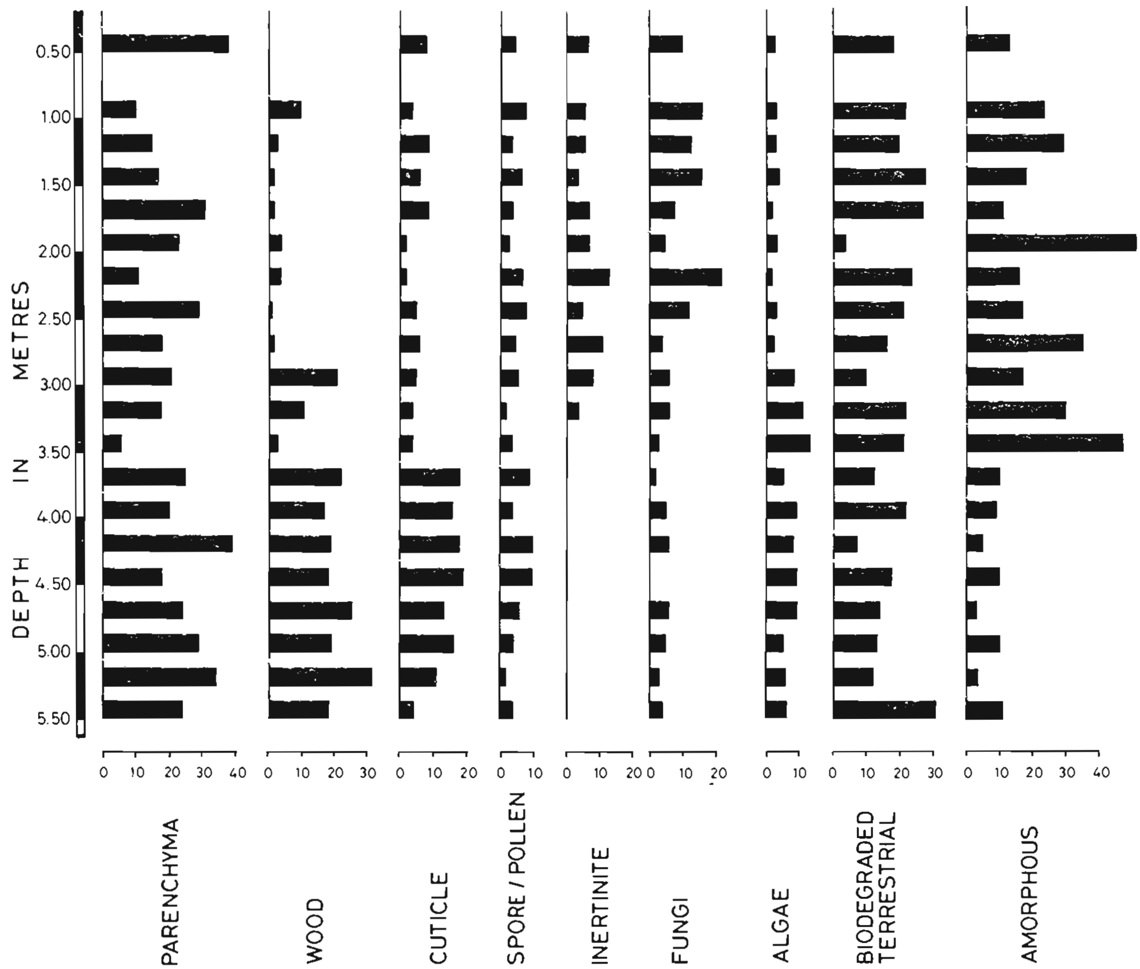
Macerate material, found dispersed in sediments, comprises both biological as well as abiological components. The organic matter in sediments represents a very small proportion of the total sediments. Correia (1971) has recognized three types of organic matter in the sediments, viz., (i) organic matter having definite morphological shape, (ii) organic matter with distorted morphology, and (iii) organic matter with no biological affinity.

CLASSIFICATION OF ORGANIC MATTER

1. Structured terrigenous materials

These materials comprise organic matter with either well or less well-defined morphology of more or less known biological affinities.

Parenchyma (Telinite)—A large number of parenchymatous tissues, belonging to leaf, stem and root were encountered. These tissues are fully or partially



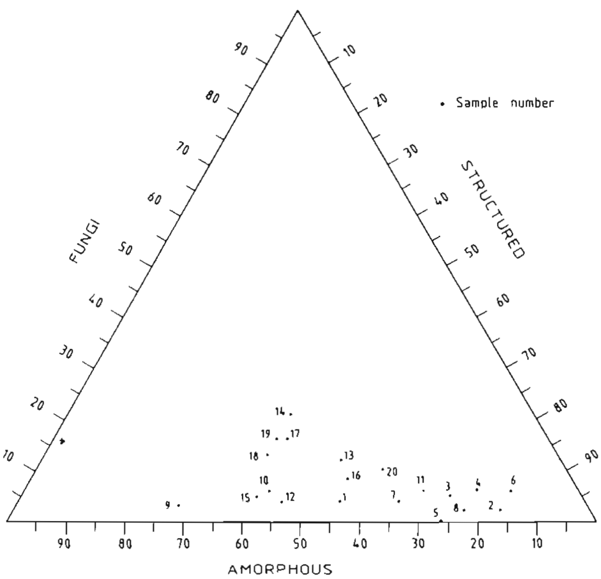
Text-figure 2—Diagram showing relative values of dispersed particulate organic matter.

Table 1—Showing relative values of dispersed particulate organic matter

Sample No.	Depth in metres	Parenchyma	Wood	Cuticle	Spore/ pollen	Inertinite	Fungi	Algae	Bio-degraded terrestrial	Amorphous
1	0.50	38.0	—	7.5	4.5	6.5	9.5	3.0	18.0	13.0
2	1.00	10.0	10.0	3.5	7.5	5.5	15.5	2.5	21.5	24.0
3	1.30	15.0	3.0	8.5	3.5	6.0	12.5	2.5	20.0	29.0
4	1.50	17.0	2.0	6.0	6.5	3.5	15.5	4.0	27.5	18.0
5	1.80	31.0	2.0	8.5	4.0	7.0	8.0	1.5	27.0	11.0
6	2.00	23.0	3.5	2.0	3.0	6.5	4.5	2.5	4.0	51.0
7	2.30	10.5	3.8	2.2	6.6	13.3	21.5	1.6	24.4	16.1
8	2.50	28.7	1.0	5.3	7.5	5.1	12.1	3.3	20.5	16.5
9	2.80	17.8	2.3	6.2	5.0	11.4	4.4	2.4	16.0	34.5
10	3.00	21.0	21.0	5.0	5.5	7.5	5.5	7.5	10.0	17.0
11	3.20	10.8	11.2	3.9	2.0	3.5	6.2	10.5	22.0	29.9
12	3.50	5.1	2.6	3.6	4.3	—	3.2	12.8	21.4	47.0
13	3.70	24.5	21.5	17.5	8.5	—	2.0	4.5	12.0	9.5
14	4.00	20.0	17.0	15.5	4.0	—	4.5	8.5	21.5	9.0
15	4.20	28.5	19.0	17.5	10.0	—	6.0	8.0	6.5	4.5
16	4.50	18.0	17.5	19.0	10.0	—	—	9.0	16.5	10.0
17	4.70	24.0	25.0	13.0	6.0	—	6.0	9.0	14.0	3.0
18	5.00	29.0	19.0	16.0	4.0	—	5.0	4.5	12.5	10.0
19	5.20	34.0	31.0	11.0	1.5	—	2.5	5.5	11.5	3.0
20	5.50	24.0	18.2	3.5	3.6	—	3.8	5.9	30.5	10.5

identifiable by the presence of chloroplast, pallisade tissues, stomata, etc. Parenchymatous tissues are generally derived from the terrestrial domain in a high energy environment and deposited in the deltaic zone where oxidation ceases. The survival of parenchymatous tissues, the initial stages of degradation, is largely controlled by physical factors followed by chemical/biological agencies (Plate 3). The initial stages observed are (i) flattening of cell wall, (ii) dissolution of cell wall, and (iii) shrinkage and loss of protoplasmic contents.

The values for parenchymatous tissues have been plotted along the stratigraphy column (Text-figure 2).



Text-figure 3—Ternary diagram presenting total values for structured, amorphous matter and fungi.

Table 2—Showing total values for structured, amorphous matter and fungi

Sample	Depth	Fungi	Structured	Amorphous
1	0.50	9.5	59.5	31.0
2	1.00	15.5	39.0	45.0
3	1.30	12.5	38.3	49.0
4	1.50	15.5	39.0	45.0
5	1.80	8.0	54.0	38.0
6	2.00	4.5	40.5	55.0
7	2.30	21.5	38.0	40.5
8	2.50	12.1	50.9	37.0
9	2.80	4.4	45.1	50.5
10	3.00	5.5	67.5	27.0
11	3.20	6.2	41.9	51.9
12	3.50	3.2	28.4	68.4
13	3.70	2.0	76.5	21.5
14	4.00	4.5	65.0	30.5
15	4.20	6.0	83.0	11.0
16	4.50	—	73.5	26.5
17	4.70	6.0	77.0	17.0
18	5.00	5.0	72.5	22.5
19	5.20	2.5	83.0	14.5
20	5.50	3.8	55.2	41.0

The maximum values occur between 5.50-3.70 m and 3.00-1.80 m in depths. There is another peak at the top of the profile. The curve suggests high terrestrial influxes at the depths mentioned above.

Wood—This group comprises the cellular remains of vessels/tracheids and may be either brown in colour (lignified) or colourless (non-lignified). Small woody fragments generally dark-brown in colour are abundant. Lignified woody material is relatively more resistant to physical, chemical and microbial degradation. However, some wood fragments show degradation in the form of circular pits.

The wood curve maintained parity with the parenchyma curve up to 3.70 m level and then declined at 3.50 m level achieving high values once again with the parenchyma until the 3.00 m level. Thereafter the

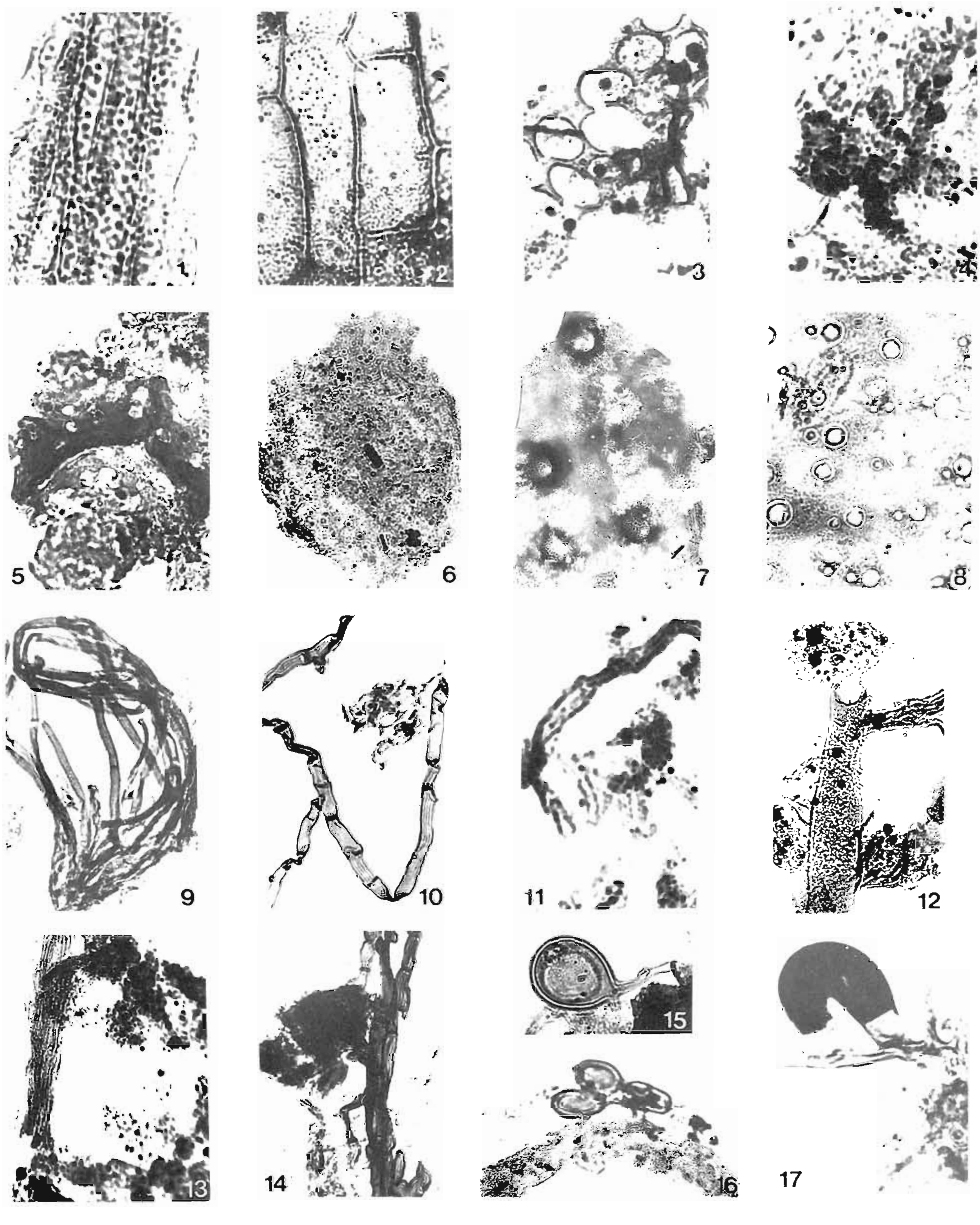


PLATE 1

wood curve remained low, did not exceed more than 4 per cent until 1.0 m level. The variation in accumulation is due to the transportation of terrigenous biotic elements into the deltaic environment under high energy conditions.

Cuticle (Cutinite)—Cuticular material recovered from the sediments is derived from woody as well as herbaceous plants. Cutinite is also considered as exinite and it is generally composed of thin and translucent tissues. The cuticle curve started with lower values than parenchyma and wood. Only between 5.00-3.70 m level its value expands to 19 per cent and behaves in tune with parenchyma and wood. Later, the curve for cuticle declines and continues at extremely low values except between 1.80 to 0.50 m level. The assessment of cuticular material parallels that of woody material and gives similar indications of the depositional environment.

Spores and pollen (Sporinite)—Spores and pollen, in general, are allochthonous in origin but help in the reconstruction of palaeofloristics and interpretation of the depositional environments. By virtue of having resistant outer walls, the spores and pollen deserve better chances of preservation in diverse conditions. However, preservation has been found best in reducing environment.

In general, the spores and pollen show low frequencies throughout the profile contrasting with the other palynodebris. Their values increase slightly to 8-10 per cent at the levels between 5.00 to 3.70 m and 2.50 to 1.00 m. The behaviour of spores and pollen curve is inversely proportionate to the values of other palynodebris.

Inertinite—It is woody material of dark brown to black colour appearing opaque and occasionally translucent. Inertinite has not been encountered in the lower part of the profile. It was first found at 3.20 m level in low amounts and then increased reaching two peaks of 11 and 13 per cent at 2.80 m and 2.30 m levels, respectively. Thereafter, it declined upward.

Fungi (Sclerotinite)

Different types of fungal spores, conidia, mycelia and hyphae have been found. The fungal material plays a primary role in biodegradation of biota, though they are very selective in choosing their hosts. Fungal hyphae can be seen penetrating into the structured material and transforming it into semi-amorphous/amorphous materials (Plate 1). Fungi may attack all types of biological substance including wood parenchyma, pollen/spores, etc. rendering it more susceptible to bacterial attack. They form circular/irregular perforations, scars, wedge-shaped grooves on the exterior surfaces. The entry of hyphae through apertures in pollen/spores has been well demonstrated by Faegri (1971). Nevertheless, the chemistry of the exine determines the susceptibility of pollen/spores to fungal attack and differential biodegradation of biological materials in the same depositional environment can be demonstrated. The fungi are present from the base of profile but in low proportions up to 2.50 m level. Thereafter, there is an upward increase which coincides with the portion of biodegraded material.

Biodegraded material

Both terrigenous and aqueous organic materials have been included in this group. These are mostly insoluble organic materials ranging from grey, light brown to dark brown in colour. They comprise both plant and animal fractions of undefined biological affinity. In most cases, it is rather difficult to trace their ancestry. However, a few could be partially identified to their respective genera and species.

The organic matter grouped under biodegraded material is largely terrigenous but a fraction may also belong to sapropelic material probably of algal origin. These are the results of thermal maturation and deem to be the precursor of hydrocarbon generation.

The amount of biodegraded material recorded is quite high throughout the profile. In the lower half of the diagram, the high value is not synchronous with the curve for fungi *vis-a-vis* it behaves concordantly with material of terrestrial origin like parenchyma, wood and cuticle. In the upper half of the profile, high values of fungi correspond with those of biodegraded material indicating that the former is the major source of biodegradation.

←

PLATE 1

(All magnifications × 500)

1,2. Showing chloroplast within the cells and elongation of cell wall.
3. Dissolution of cell wall began.
4. Organic matter loosing morphological shape.
5. Biota lost biological identity.
6. Amorphous organic matter with no biological affinity.
7. Wedge-shaped pattern developed over the biota—An advance stage of biodegradation.
8. Circular pittings could be seen over the surface of biota.
9, 10. Algal/fungal hyphae.
11. Hyphae with less defined morphology.
12-14. Biota lost morphological shape due to fungal attack.
15. Fungi attacking the biota.
16-17. Fungal spores/conidia penetrating their hyphae into the biota.

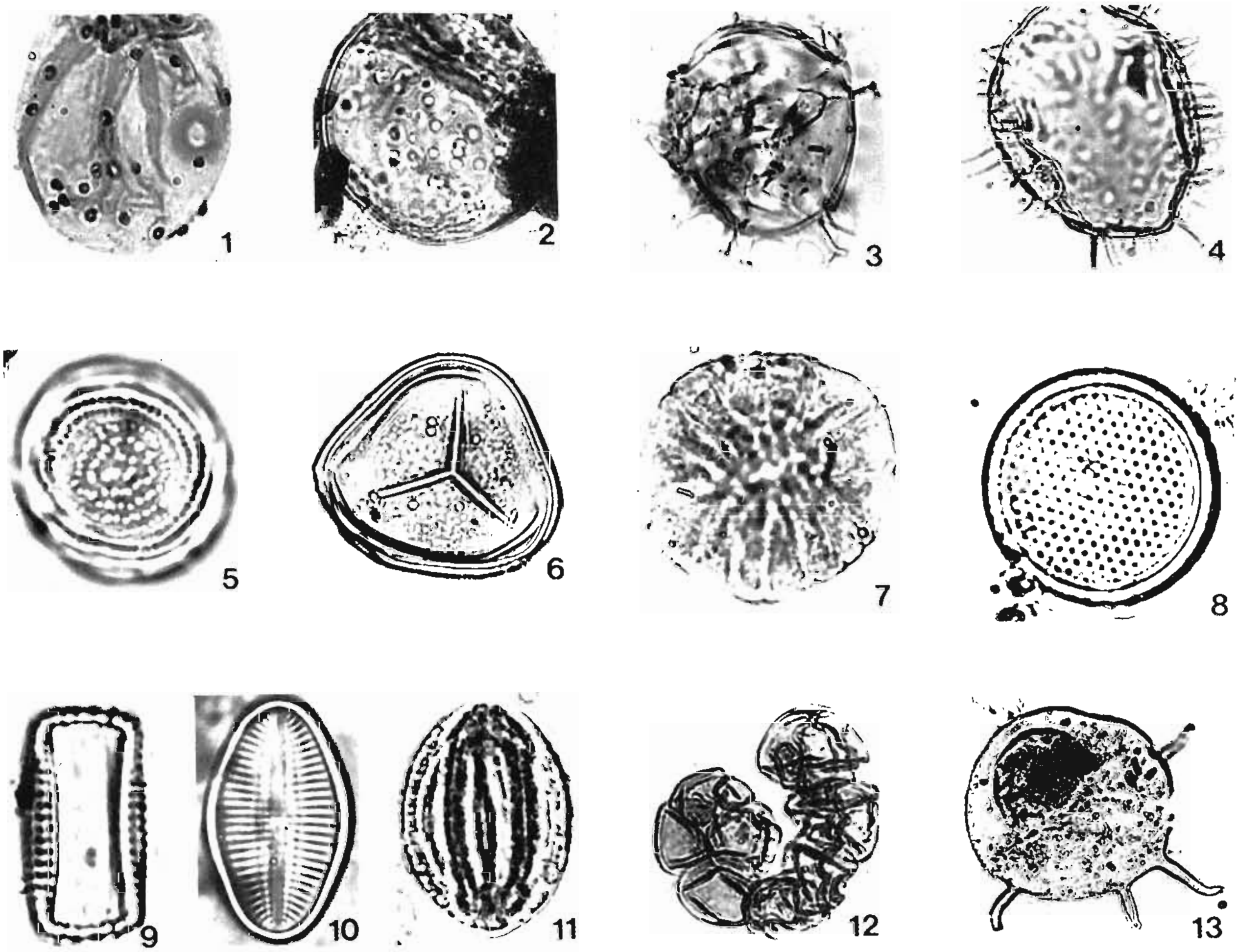


PLATE 2

(All magnifications × 500)

1. Graminoid pollen with circular pittings.
2. Unidentified pollen with partial degradation.
3, 4. Dinoflagellate cysts.
5. *Pseudoschizaea.*
6. Trilete fern spore with circular pittings.
7. Pollen almost lost its identity owing to degradation.
8-10. Diatom frustules.
11 Pollen grain.
12. Microforam.
13. Unidentified object.

Amorphous material

This includes granular and fine organic matter which has lost all biological affinities. It is greyish brown in colour and comprises an irregularly shaped mass comprising organic mineraloid aggregates. It also constitutes a sizeable amount of the sediment in nearshore environments (Sieburth, 1979). It is produced in abundance by bottom feeders and is rich in carbohydrates. The amorphous matter can be produced both under aerobic or anaerobic conditions which can be recognized under the florescence microscopy using colour variations. A pale yellow to deep amber colour is produced under aerobic bacterial activity, whereas grey to dark brown colour with some transparency is indicative of anaerobic bacterial activity.

The amorphous material records low figures in the beginning of the diagram with abrupt rises in 3.50 to 2.00 m levels. Most of the amorphous material encountered in the present study varies from grey to dark-brown in colour. Thus, it is assumed that amorphorisation took place under reducing environment in the nearshore zone.

Algae (Alginite)

Colonial and unicellular algae like diatoms, dinoflagellates and other algal forms of fresh and or marine water habitat have been recovered in it. Most of the algal forms are not degraded (Plate 2). Nevertheless, sometimes amorphous algal masses have been observed which might be the end product of biodegradation.

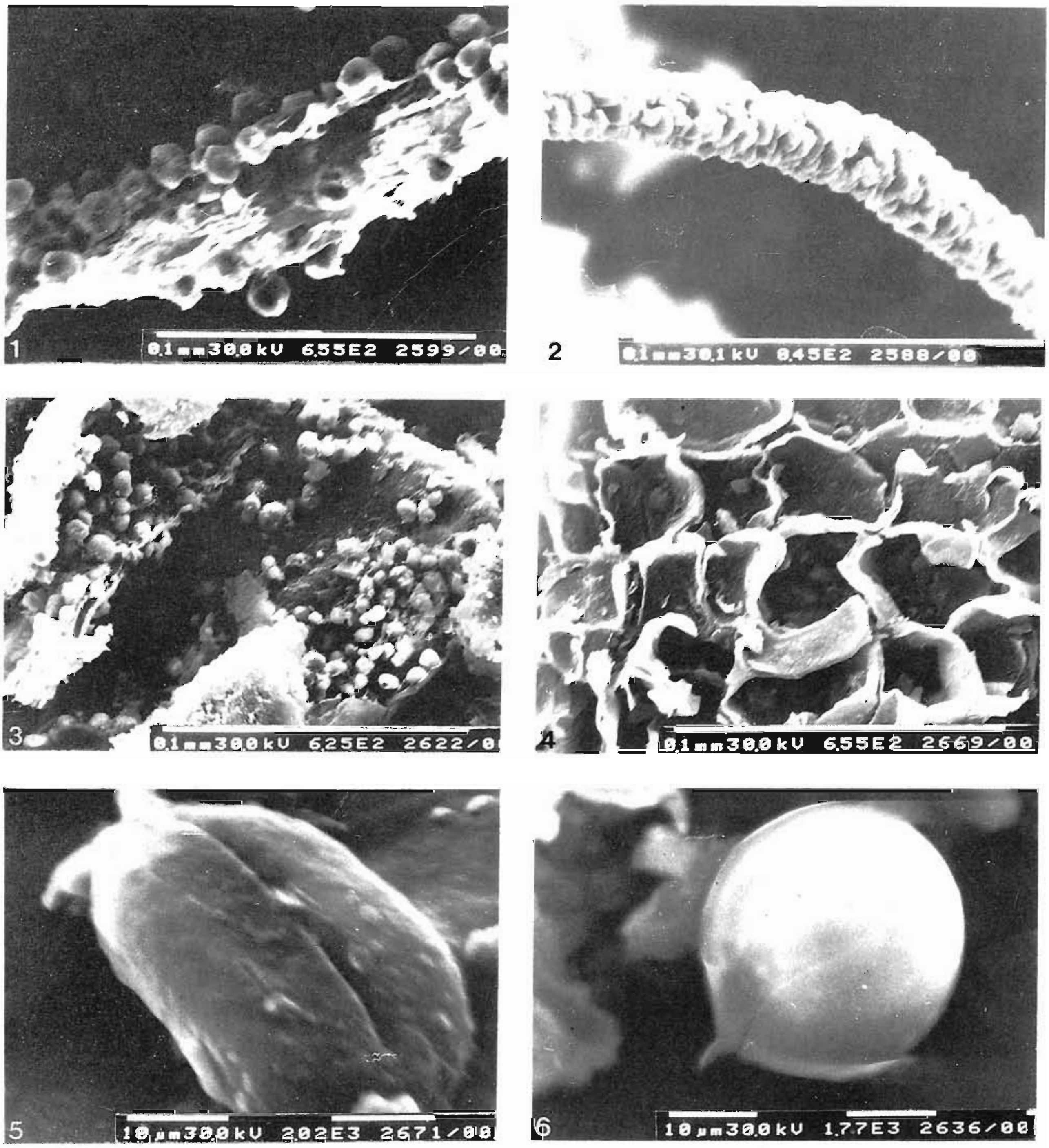


PLATE 3

1. Fungal spores attached to the structured terrestrial plant tissue.
2. Structured terrestrial plant tissue showing ragged surface with fungal infestation.
3. Fungal spores *in situ* in semiamorphous matter.
4. Structured terrestrial tissue with lodged fungal spores and partial dissolution of cell walls.
5. Monosulcate pollen with partial fungal infestation.
6. Single fungal spore with protruding attachment.

The curve for algae has been clearly divided into two halves. The lower half, up to 3.00 m level, exhibits high values coinciding with the amorphous curve, while the upper half shows a considerable decline which is not synchronous with the amorphous curve.

DISCUSSION AND CONCLUSION

A composite diagram, following visual spectrography under light microscope, has been prepared to illustrate the relative values of various components of the particulate organic matter in order to work out the depositional environments. The diagram has been broadly divided into two phases—B-I and B-II.

Phase B-I (5.50-3.50 m) with predominance of parenchyma, wood and cuticles could be labelled as a structured terrestrial organic matter phase. The other components of macerals are either rare or absent.

Phase B-II (3.50-0.50 m) records a decrease in the structured terrestrial organic matter contents and corresponding increase in biodegraded, amorphous and fungal materials. This phase has been subdivided into four subphases.

Subphase B-IIa (3.50-2.80 m) shows a steep fall in parenchyma, cuticles, spore/pollens, etc.; woody material shows increasing tendency. Inertinite maintains moderately high values up to the close of this subphase. Amorphous, biodegraded, fungal and algal materials show rising trend but all decline at the top of subphase.

Subphase B-IIb (2.80-1.50 m) records high but fluctuating values of parenchyma with decreased values for wood and cuticles. Spore/pollen and inertinite increased slightly, while fungal and biodegraded materials increased considerably. Amorphous matter decreased at the close of the subphase. Algal material declined continuously throughout.

Subphase B-IIc (1.50-1.00 m) also shows an increase in parenchyma figures. Wood, cuticles, spore/pollen and inertinite remained at low levels but fungal and biodegraded material increase. The amorphous matter declines, while algae continued at low values as before.

Subphase B-IId (1.00-0.50 m) recorded a large increase in fungal, biodegraded and amorphous materials but parenchyma values fluctuated. Wood, cuticles, spore/pollen and inertinite are present in relatively increased frequencies but algae continued at low figures as before.

Three major categories of particulate organic matter, structured (grouping of parenchyma, wood, cuticles, spore/pollen, etc.), biodegraded/amorphous and fungi have been plotted in a ternary diagram (Text-figure 3) in chronological sequence to work out their distribution in relative abundance. Fungi, the primary source of biodegradation, have been plotted independently. The distribution pattern indicates that structured material is most frequent ranging between 30-80 per cent and fungi 0-30 per cent. However, the fungi are also attacked by bacteria and transformed into biodegraded/amorphous material and therefore, this could be the reason for the low values of fungi.

CORRELATION OF DOM AND POLLEN DIAGRAM

As already mentioned in the text, we have also done palynostratigraphy of the same profile to correlate the two disciplines. The pollen diagram has been classified into five zones (Gupta & Khandelwal, 1990), whereas the dispersed organic matter (DOM) diagram is classified into two phases. Phase II has been further divided into four sub-phases. The pollen diagram suggests that there had been more sea water influx in the deltaic environment during Zone I, which declined in the upper part of the zone and almost ceased in Zone II as the value of Rhizophoraceae depressed considerably. Phase I of the dispersed organic matter diagram covers both the above zones and is marked by the preponderance of terrigenic structured organic matter which includes biodegraded, amorphous and algal matter in moderate frequencies. This feature of organodebris accumulation is indicative of deltaic environments in close proximity to the continent. So, there is an agreement between the palynological and organic matter analyses.

Subphase IIa is marked by steep decline in structured material except for the wood which maintained high values. Biodegraded, amorphous and algal matters showed substantial rises which indicates that ponding conditions prevailed, tidal activity ceased resulting in reducing (anaerobic) environments. This accelerated the microbial activities, transforming organodebris into semi-amorphous/amorphous materials. Thus, this subphase could be analogously correlated with the Zone III of pollen diagram wherein total disappearance of Rhizophoraceae, suppression in *Avicennia*, corresponding rise in *Nypa fruticans*, *Heritiera*, *Sonneratia* and fresh water aquatic taxa has been documented.

Subphase IIb is characterised by fluctuatingly high values for parenchyma, fungi, biodegraded and amorphous organic matter, while algal figures have declined. This feature suggests fluctuations in tidal magnitude disturbing the reducing environments. This subphase parallels Zone IV of the pollen diagram (Gupta & Khandelwal, 1990, p. 389) but the two do not cohere totally owing to the fact that it records dominance of Rhizophoraceae and Chenopodiaceae depicting high magnitude of tidal influx.

Subphases IIc and IId coincide with Zone V of the pollen diagram and record fluctuatingly high values for parenchyma, fungi, biodegraded and amorphous materials. Other groups of palynodebris also registered a rising tendency but algae continued at low values. Restoration of ponding conditions with an intermittent influx of tidal water is suggested which is also supported by pollen evidence wherein Rhizophoraceae, *Avicennia* and other mangrove associated taxa declined till they vanished from top of the profile.

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