
History of mangrove vegetation in Paradip and Jambu islands, Orissa for the past 500 years B.P.: A palynological assessment

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Modern surface samples from Paradip and Jambu islands, Orissa have provided clues of modern pollen deposition, reconstruction of palaeovegetation and to interpret with greater precision the pollen data recovered from the sediments. Pollen composition of modern surface samples coheres with the type of vegetation growing today within the area of 10 sq km and facilitates the comparison of past vegetation with the modern analogues. Pollen diagram constructed from Paradip profile has revealed the history of mangrove vegetation for the past 500 years B.P., wherein four zones of vegetational developments have been recorded. The decline of mangrove vegetation at the top of the diagram going back to about 35 years B.P. could be correlated with a record date around early nineteen-hundred-sixties, when the construction of Paradip Port came into existence. This feature suggests the excessive human pressure over the surrounding vegetation resulting into the ruthless damages to the mangrove and the same has been depicted in the pollen diagram. The plantation of *Casuarina* along the coastline in the recent past has also been recorded in pollen diagram.

Key-words—Palynology, Mangrove, Paradip and Jambu Islands, Orissa (India).

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सारांश

पिछले 500 वर्षों में उड़ीसा में पैरादीप एवं जम्बू द्वीपों की मैंग्रोव वनस्पति का इतिहास : एक परागाणविक मूल्यांकन

हरीपाल गुप्ता एवं राम रतन यादव

उड़ीसा में पैरादीप एवं जम्बू द्वीपों के वर्तमान सतही नमूनों के परागाणविक अध्ययन से परागकण निक्षेपण, पुरावनस्पति की संरचना तथा परागकण विश्लेषण संबंधी ऐसे आँकड़े उपलब्ध हुए हैं जिनसे अच्छे परिणाम उपलब्ध हुए हैं। इन नमूनों से उपलब्ध परागकण इस क्षेत्र में 10 किलोमीटर के क्षेत्रफल में पाई जाने वाली वनस्पति से सामंजस्यता प्रदर्शित करते हैं। पैरादीप परिच्छेदिका के परागकण चित्र से 500 वर्ष पूर्व की मैंग्रोव वनस्पति का इतिहास व्यक्त हुआ है, जिसमें चार वनस्पतिक मंडल अभिलिखित किये गये हैं। परागकण चित्र में ऊपर की ओर मैंग्रोव वनस्पति का ह्रास 1960 के आस-पास के एक अभिलेख से सम्बद्ध किया जा सकता है जिस समय कि पैरादीप बंदरगाह का निर्माण हुआ था। इससे यह प्रस्तावित होता है कि इस क्षेत्र की वनस्पति पर वहाँ आस-पास रहने वाले लोगों का अत्यधिक दबाव पड़ा है और जिसके कारण मैंग्रोव वनों की कटाई हुई है। कुछ वर्षों पूर्व समुद्र तट के साथ-साथ कैजुएराइना के लगाये गये पौधों के प्रभाव को भी परागकण चित्र में प्रदर्शित किया गया है।

MAHANADI River in combination with Brahmani, Baitarani, Dharma and Devi rivers forms an extensive delta around Bay of Bengal which stretches from Chilka Lake in the south to Bhadrak in the north covering approximately 170 km long and 60 km wide area (Lat. 20° 15' : 20° 55' N; Long. 86° 40' : 87° E). This deltaic complex constituted the second largest mangal formation and today a major part of the mangal zone is a bare land.

Palynostratigraphical analysis of the sediments from this deltaic complex was undertaken to study on various aspects of mangal developments and causes of its deterioration in time and lateral extent. To begin with, Paradip was chosen and its 3 m deep soil profile was investigated which is dated ca 500 year B.P. A combined study of modern surface samples and soil profile has been conducted. The palynological information of the estuaries is mainly

from the Gangetic-Sunderban deltaic complex (Das, 1961; Mallik, 1969; Gupta, 1970, 1978, 1981, Chanda & Mukherjee, 1969; Mukherjee, 1972a, b; Vishnu-Mittre & Gupta, 1972; Banerjee & Sen, 1986a, b). Gupta (1981) has investigated one profile each from all the four flanks of the basin and found metachroneity in the development of mangrove vegetation. In addition, several features of interest, such as—submergence and subsidence of forest, nature and extent of peat deposits, have also been worked out in detail. The other pollen analytical studies on the coastal sediments in India are from Bombay (Agrawal & Guzder, 1974; Vishnu-Mittre & Guzder, 1975), Gujarat (Vishnu-Mittre & Sharma, 1975), Pichavaram, Tamil Nadu (Blasco & Caratini, 1973; Caratini *et al.*, 1973; Tissot, 1980); and Brahmani Delta, Orissa (Caratini *et al.*, 1980). A review of the coastal palynology and ecology was made by Thanikaimoni (1987).

GEOLOGY AND GEOMORPHOLOGY

Mahanadi delta occupies shallow, rigid peninsular shield in largely an erosional basin. The basin roughly coincides with an Early Permian rift valley, but at the head of the delta the Upper Gondwana (Athgarh Sandstone) is found all over to north of Puri and extend up to Cuttack and Athgarh (Ahmad, 1972).

It is a tripple delta where the sediments of Mahanadi, Baitarani and Brahmani join to form a protuberant shore. The extensive alluvial tracts are found from Chilka Lake in the south to Bhadrak in the north. The delta projection (about 60 km) indicates the abundance of sediment-discharge from a large catchment of rugged terrain marked by heavy torrential rains. The various distributaries in deltaic region are characterised by an estuarine inlet of the sea near their mouth.

CLIMATE

The entire region of Mahanadi delta enjoys oceanic tropical humid climate which is equable throughout the year and humidity recorded is 75 per cent and 82 per cent for the driest and wettest months, respectively. April is the hottest month with 36°C and 21°C maximum and minimum temperatures, respectively. July-August receive torrential rains with 1,585 mm as an annual average. With the onset of monsoon, the wind velocity increases to 40 km/h and reduces to 15-25 km/h during the winter. The weather is disturbed during post monsoon and early part of eastern monsoon when the depression and storms originate in the Bay

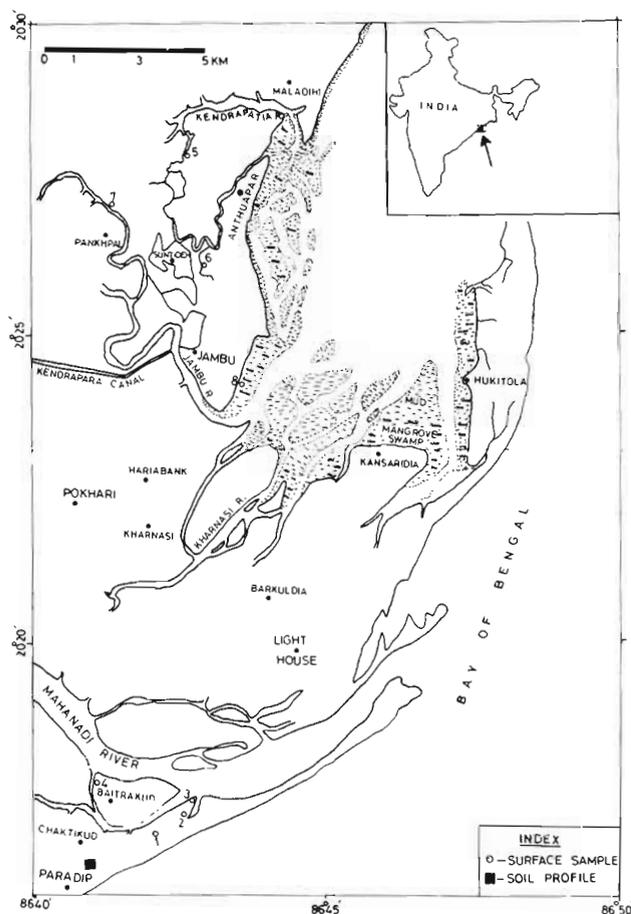
of Bengal. Some of these depressions intensify and develop violent cyclones and storms with a speed of 180-220 km/h causing heavy damages to the plant and animal life.

VEGETATION

The vegetation of Mahanadi delta has been investigated alongwith its ecological aspects by Haines (1961), Rao and Mukherjee (1972), Choudhury (1984) and Banerjee and Rao (1985). Banerjee (1987a, b) has recognised three vegetation zones, viz., (a) zone of typical mangrove habitat with the preponderance of Rhizophoraceae members adapted by means of stilt roots and vivipary, e.g., *Rhizophora* spp., *Ceriops* sp., *Bruguiera gymnorhiza*, *Kandelia* sp., *Aegiceras* sp., etc.; (b) zone of less pronounced mangrove habitat associated with different groupings of taxa adapted by means of pneumatophores and buttresses, e.g., *Sonneratia* spp., *Heritiera fomes*, *Avicennia* sp., *Excoecaria* sp., etc.; (c) zone of midland and hinterland mangrove with the mingling of upland flora due to sudden change of habitat, e.g., *Brownlowia tersa*, *Dalbergia horrida*, *Pongamia pinnata*, *Cynometra iripa*, *Caesalpinia bonducella*, *Aglaia cucullata*, *Cerbera manghas*, *Bruguiera sexangula*, *Heritiera littoralis*, *Phoenix paludosa*, *Crinum asiaticum*, *Thespesia populnea*, *Clerodendrum inerme*, *Syzygium* sp., *Carissa spinarum*, *Diospyros* spp., etc.

The mangrove vegetation of Mahanadi delta, particularly in and around Paradip, is on decline. The increasing human pressure, unplanned development ignoring long term repercussions, and its problem of deforestation, plantation of cash crops, urbanization and industrialization have taken a heavy toll of the mangrove forest. As a result, forests are reducing fast, ecological balance is disturbed and cyclones are becoming worse. Erosion of top soil is on way maring the chance for regeneration of mangrove. The vegetation around Paradip has been ruthlessly damaged in the recent past with the construction of port. Paradip port has maritime tradition, going back to 16th and 17th century A.D., and since then the mangroves are being exploited.

At present, mangroves could be seen in the creeks and channels along the upper part of the inner estuarine zone with degraded mosaic. Hardly any mangrove taxon is found near Paradip as the topography has been considerably disturbed. A few scattered bushes and stands of *Avicennia alba* and *Excoecaria agallocha*, respectively, are seen. Nevertheless, entire deforested area is succeeded by



Map 1—Sites of samples investigated.

Acanthus ilicifolius bordering watery places. The reason for its existence is mainly two-fold: (i) these are vegetatively propagated and hence form extensive thickets, and (ii) it is not preferred by browsing animals and are of no economic potential. *Phoenix paludosa* forms pure formations at places in the flood plain area and *Borassus* is found isolated as midland vegetation. The fern commonly occurring in this area is *Acrostichum aureum*.

MATERIAL AND METHOD

Eight surface samples from different places along various creeks were collected to study the modern pollen/vegetation relationship. A three metre deep profile was also collected from Paradip, near Mahanadi mouth (Map 1). The material for pollen analysis and radiocarbon assay were collected from different borings using Hiller's peat auger. The sediments are composed of soft clayey silt with rich organic matter.

The method employed for extraction of pollen and spores from the matrix is the same as suggested

by Erdtman (1943). The relative frequencies for all taxa (Pl. 1, figs 1-29; Pl. 2, figs 1-19) encountered from the sediments have been calculated in terms of total land plants and the pollen spectra have been constructed highlighting ecological groups. The plus sign (+) in the pollen spectra and diagram denotes values below one per cent.

MODERN POLLEN/VEGETATION RELATIONSHIP

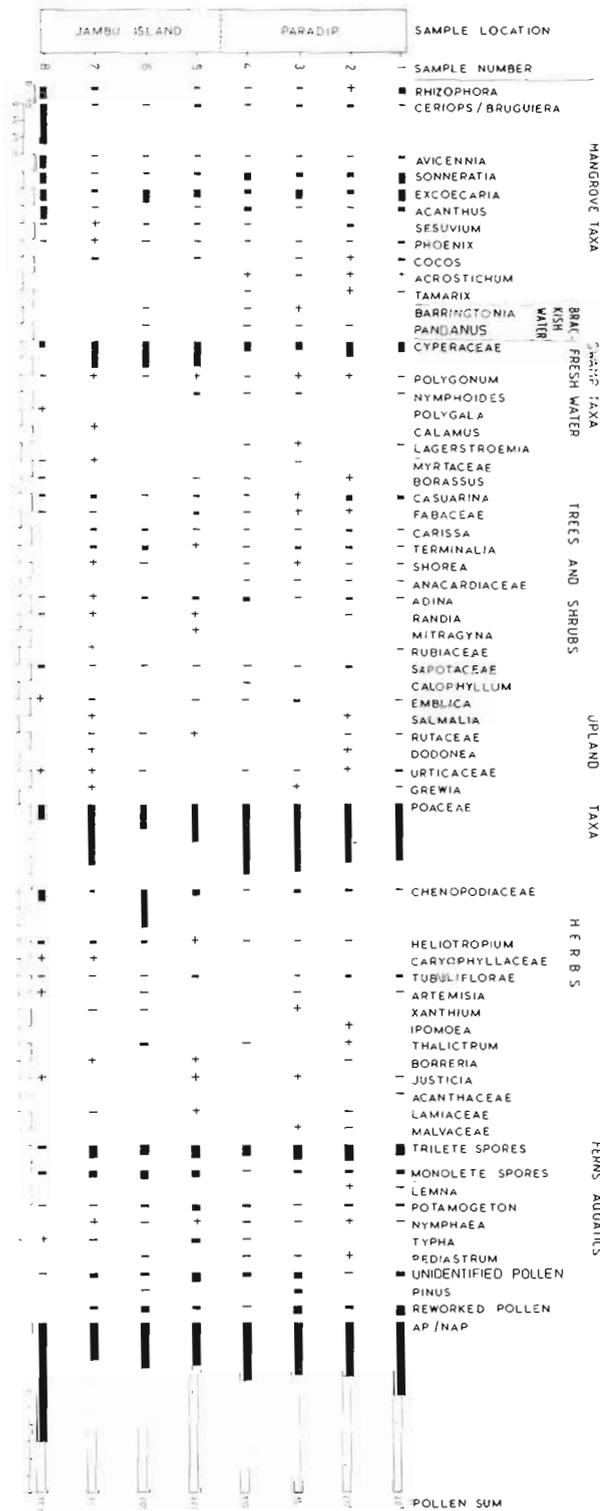
Surface sample nos. 1-3 were collected at the mouth of Mahanadi River and sample no. 4 from Baitrakud in Paradip (Text-fig. 1).

The study of these samples has revealed poor occurrence of mangrove taxa which match with the present day condition of mangrove degradation. Nevertheless, core constituents of mangrove recorded are *Excoecaria* (7%) and *Sonneratia* (3-7%) followed by *Acanthus* and *Avicennia* (1-3% each), *Rhizophora* (up to 4%) and *Ceriops/Bruguiera* (1-2%). The peripheral mangrove taxa recorded are *Sesuvium* and *Phoenix* (1-2% each), *Acrostichum aureum* and *Tamarix* (1% each). The brackish water swamp taxa, such as *Barringtonia* and *Pandanus*, are sporadic. Cyperaceae (6-9%) are dominant amongst fresh-water swamp taxa. The upland arboreal taxa are represented by *Casuarina* (up to 4%), *Carissa*, *Terminalia*, *Adina*, Sapotaceae, *Emblia* (1-2% each). Poaceae (34-42%) dominates the herbaceous vegetation; its high values are related to the increasing open-land all around. Ferns, represented by both trilete (7-10%) and monolete (1-3%) spores, are quite high and suggestive of enhanced atmospheric humidity. *Potamogeton* (1-2%) and *Nymphaea* (1%) are the two fresh-water taxa present in this environment.

Reworked bisaccate pollen grains (1-6%) have been found in all the samples; they are more concentrated near the mouth of Mahanadi River indicating a transportation of sediment from the nearby coal-bearing strata of Lower Gondwana.

Surface sample nos. 5-7 were procured from Barpal, Pankhpal and Suntideh in Jambu, respectively. This area, too, is under heavy biotic pressure, as the major forest cover has been cleared for paddy cultivation. The vegetation growing today comprises *Acanthus ilicifolius*, *Excoecaria agallocha*, *Dalbergia spinosa*, *Derris trifoliata*, *Phoenix paludosa*, *Tamarix troupii*, *Cocos nucifera* and *Borassus flabellifer*. Recently, the forest department has introduced the afforestation scheme on waste lands by planting *Casuarina equisetifolia* and *Eucalyptus* sp. Around Pankhpal, *Suaeda maritima* forms dense thickets.

Pollen analysis of the above samples exhibits



the dominance of *Excoecaria agallocha* (2-8%). The other mangrove taxa are represented by *Rhizophora* (up to 3%), *Ceriops/Bruguiera* (1-2%), *Sonneratia* (3-5%), *Acanthus* (1-5%), *Avicennia* (1-2%) and *Sesuvium* (1-2%).

Cyperaceae (15-16%) is common. The upland tree taxa, such as *Casuarina*, Fabaceae (1-3%) each, *Carissa*, Sapotaceae (1-2% each), *Terminalia* (up to 3%), *Adina* (up to 2%) and Rutaceae (1%), are present in low frequencies, whereas herbaceous taxa of ubiquitous ecology are represented by Poaceae (15-36%), Chenopodiaceae (2-23%), *Heliotropium* (up to 2%) and Tubuliflorae (1-2%). Fern spores, both triletes (6-8%) and monoletes (4-5%), are present in good values. The fresh-water elements present are *Potamogeton* (1-4%), *Typha* (1-3%), *Nymphaea* (1%) and *Pediastrum* (1%). Bisaccate reworked pollen are common in all the samples.

The pollen spectra is incoherent with the present day vegetation statistics. For example, *Acanthus ilicifolius* and *Excoecaria agallocha* are not adequately represented in the pollen spectra. *Avicennia* and *Rhizophora* pollen seem to be drifted from the adjacent mangrove zone. High pollen frequency of Chenopodiaceae from Pankhpal sample corroborates the common occurrence of *Suaeda maritima* in the area.

Sample no. 8 is collected from near Jambu Village. The biotic pressure is also operational in this area but still there are some patches of undisturbed nature where both core and peripheral mangrove exist in natural ecology. The pollen spectrum is dominated by mangrove taxa, like *Ceriops/Bruguiera* (24%) followed by *Avicennia* and *Acanthus* (8% each), *Rhizophora*, *Sonneratia* and *Excoecaria* (7% each). *Sesuvium* and *Phoenix* are present in low values.

Fresh water swamp taxa, such as Cyperaceae (4%) *Nymphaeoides* (1%) and *Polygala* (1%), are relatively low. The upland taxa, including both arboreals and non-arboreals, are either poor or sporadic. Such taxa recorded are *Casuarina*, *Myrtaceae*, *Borassus*, *Adina*, *Randia*, Fabaceae, Sapotaceae, *Emblica*, Urticaceae, Poaceae,

Text-figure 1—Modern pollen spectra from Paradip and Jambu islands in Mahanadi Delta, Cuttack, Orissa.

PLATE 1

(All figures, × 1000)

- 1-3. *Rhizophora* sp., equatorial view.
- 4-6. *Avicennia* sp., polar view and equatorial view.
- 7,8. *Heritiera* sp., equatorial view.
- 9-11. *Aegiceras* sp., equatorial view.
- 12,13. *Adina* sp., equatorial view.

- 14-16. *Emblica* sp., polar view and equatorial view.
- 17-21. *Excoecaria agallocha*, polar view and equatorial view.
- 22,23. *Sonneratia* sp., equatorial view.
- 24-26. *Acanthus ilicifolius*, equatorial view.
- 27. Chenopodiaceae pollen.
- 28. *Barringtonia* sp., equatorial view.
- 29. Chenopodiaceae.

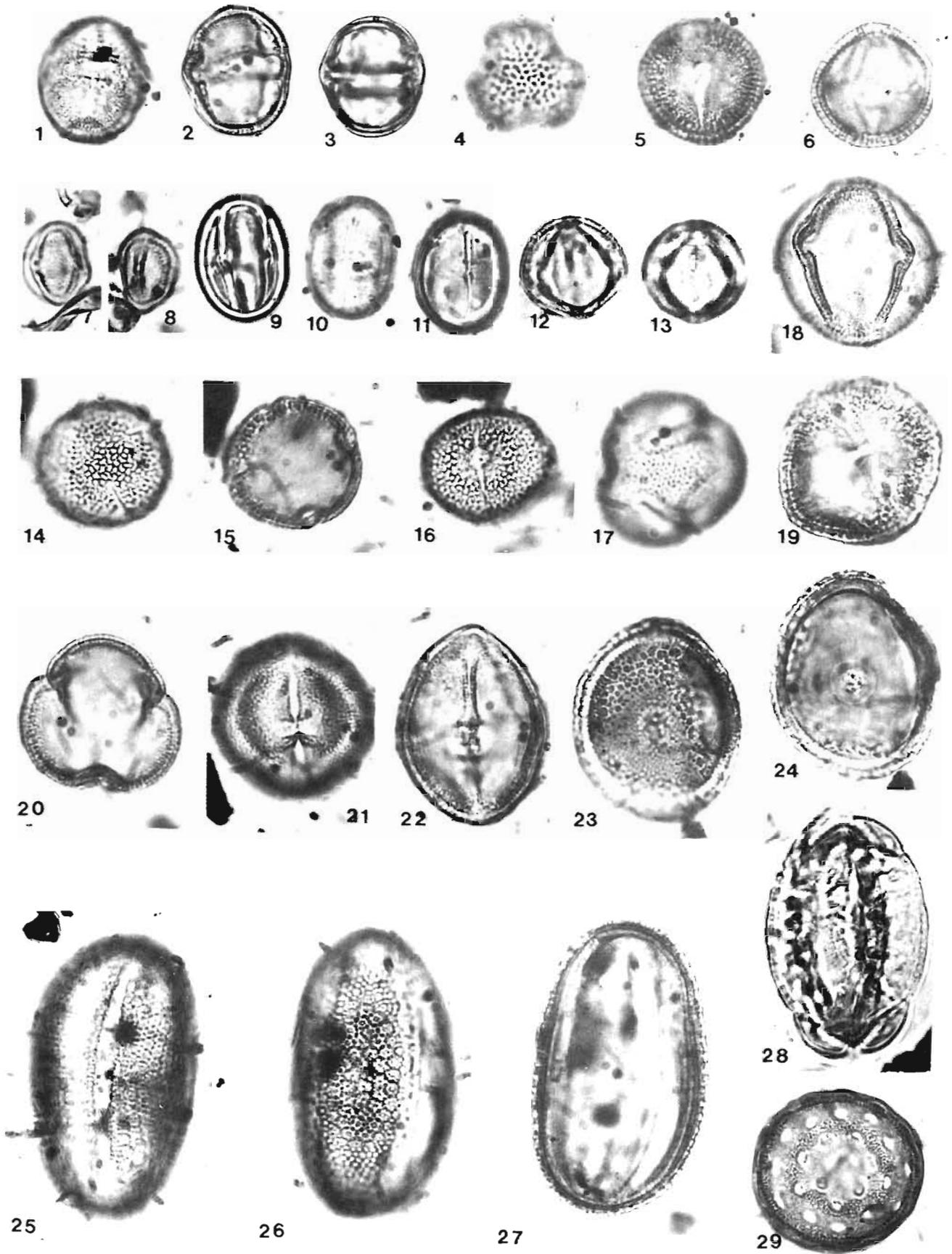


PLATE 1

Chenopodiaceae. *Heliotropium*, Tubuliflorae, Caryophyllaceae, *Artemisia* and *Justicia*. Ferns and aquatic taxa are poorly represented.

The comparison of pollen sums of the taxa recorded in the pollen spectra and their actual frequency in the modern vegetation composition of the area reveals that certain taxa, like—*Rhizophora*, *Ceriops/Bruguiera* and *Sonneratia*, are over-represented while *Avicennia*, *Excoecaria* and *Acanthus* are under-represented in the pollen spectra.

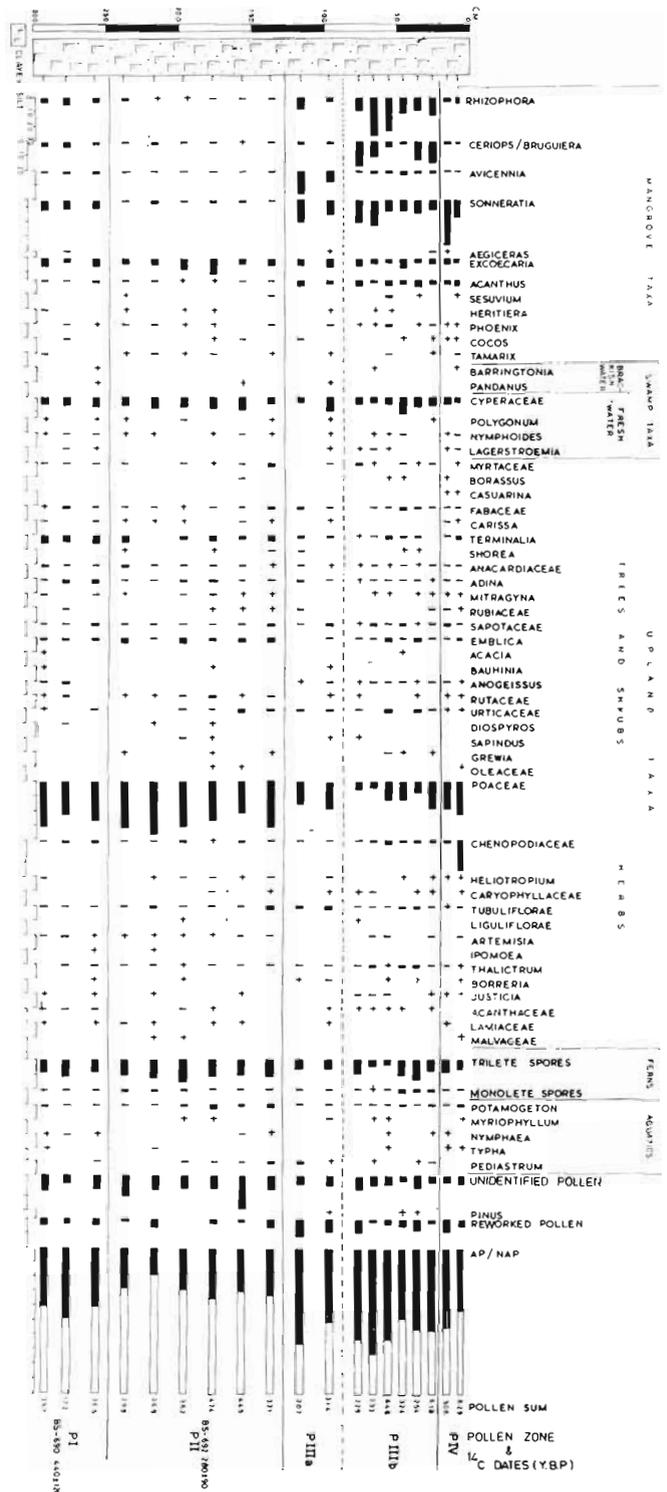
POLLEN DIAGRAM AND ITS COMPOSITION

The pollen diagram (Text-fig. 2) from Paradip has been graded into four zones in chronological order and prefixed with the site initial, e.g. P-I-IV.

Zone P-I (3.0-2.5 m)—This zone is characterised by moderate values of core mangrove taxa, out of which *Sonneratia* and *Excoecaria* attain relatively higher values as compared to *Rhizophora* and *Ceriops/Bruguiera*. *Avicennia* and *Acanthus* are present in consistently low values whereas *Heritiera*, *Phoenix*, *Cocos* and *Tamarix* are sporadically low throughout the zone.

Fresh water swamp taxa are mainly represented by *Cyperaceae* while *Polygonum*, *Nymphoides*, *Lagerstroemia*, etc., are recorded in low values, not exceeding one per cent. The midland and upland vegetation, however, is dominated by *Terminalia*, *Adina*, *Fabaceae*, *Anacardiaceae*, *Sapotaceae*, *Emblia*, etc. *Poaceae* is present in high values attaining up to 35 per cent of the total vegetation. This taxon cannot be relied upon for interpretation of the depositional environments since its members grow in marine, brackish water and fresh water environments and also difficult to be differentiated palynologically. Ferns are quite high in frequency in this zone but the fresh water taxa, such as *Potamogeton*, *Nymphaea*, *Typha* and *Pediastrum*, are present in low values. The pollen of unknown affinities as well as the reworked pollen are present in high values. These features indicate a drifting of the reworked pollen and fresh-water aquatic pollen taxa through rivers and rivulets.

AP/NAP ratio indicates little higher values of non-arboreal vegetation as compared to the arboreals. The vegetational picture evolved in zone P-I, after considering the information perceived from the modern pollen vegetation relationship, indicates that *Sonneratia* and *Excoecaria* were the two dominant taxa suggesting the contact point nearer to the fresh-water sources with higher turbidity. The



Text-figure 2—Pollen diagram from Paradip in Mahanadi Delta, Cuttack, Orissa.

other mangrove taxa, such as *Rhizophora*, *Ceriops/Bruguiera*, etc., relatively lower in values, are derived from the inner estuary line with comparatively deeper parts along the creeks and slopes.

Zone P-II (2.5-1.20 m)—This zone denotes open conditions as non-arboreal vegetation dominates over the arboreals. There is an overall depression in the mangrove tree taxa as compared to the preceding zone. The values for *Excoecaria*, however, remained static although the zone, whereas other taxa enumerated in the preceding zone continued in exceedingly low values. Fresh water swamp taxa have improved slightly than before. The notable difference in this zone is marked by an overall spurt in the values of midland and upland taxa, particularly the non-arborescent taxa, such as Poaceae, Caryophyllaceae, *Heliotropium*, etc. The ferns and fresh water aquatics, such as *Potamogeton* and *Pediastrum* improved considerably and so also the reworked pollen. This is indicative of a high magnitude flow in the channels. The vegetational picture obtained in zone P-II depicts recession in the tidal magnitude as a result of which the fresh water discharge increased encouraging the influx of salt-tolerant, fresh water and the upland taxa.

Zone P-III (1.20-0.20 m)—This zone, on the basis of marked variations in the mangrove taxa, has been subdivided into two subzones, viz., P-III a and b.

Subzone P-III a (1.20-0.85 m)—This subzone records high values of *Avicennia* and *Sonneratia*, followed by *Excoecaria*, *Acanthus*, *Rhizophora* and *Ceriops/Bruguiera* indicating most conducive environment for the luxuriant growth of mangrove vegetation. *Avicennia* sp. cf. *A. marina* is adapted to exceedingly high salinity condition as they possess salt glands in their leaves for exuding excess of salts. On the other hand, *Sonneratia* has a preference for lesser saline conditions. This association of the two taxa suggests the depositional environment to be typical of marine nature subject to high turbidity and silt deposition.

The other elements of the mangrove zone with greater salt tolerance, such as *Heritiera*, *Phoenix*, *Cocos*, etc., are present in low frequencies. Cyperaceae is present with still higher values at the close of this subzone. There is also a general reduction in the values of upland tree taxa. Poaceae has declined considerably as compared to the preceding zone. There is also a depression in the overall values of ferns and fresh-water aquatics. AP/NAP ratio has revealed improvement in the arboreal vegetation.

Subzone P-III b (0.85-0.20 m)—Subzone P-III b is recognised by high values of *Rhizophora*, *Ceriops/Bruguiera* and *Sonneratia* wherein *Avicennia* experiences a setback and *Excoecaria* continued to be moderate. All other mangrove taxa

with a preference of low salinity are present either in extremely low values or are sporadically dispersed. This zone covers a time span of about 150 years and the mangrove vegetation thrived well and established. The other taxa recorded in high frequencies are Cyperaceae, Poaceae, Chenopodiaceae, *Heritiera*, *Sesuvium*, *Phoenix*, *Cocos*, *Tamarix*, etc. Upland tree taxa continue as before, however, with a slight depression. Chenopodiaceae and *Acrostichum aureum* have improved considerably indicating high salinity. The general picture of the Zone P-III has revealed a favourable environment for the luxuriant growth of mangrove vegetation with an increased salinity, giving pace to front-line estuary mangroves to thrive.

Zone P-IV (0.20-0.00 m)—In this zone, mangrove taxa declined sharply except for *Sonneratia* which flourished at the cost of suppression in the values of Rhizophoraceae. *Excoecaria* and *Acanthus* remain static. The other mangrove taxa, like *Aegiceras*, *Sesuvium*, *Phoenix*, *Cocos* and *Tamarix* have gained a little. Cyperaceae has reduced considerably whereas other swamp taxa have improved a little than before. The upland tree taxa continue with more or less same values. Nevertheless, Poaceae and Chenopodiaceae have registered marked improvement while other herbaceous elements are present in reduced values than before. Ferns, aquatics, etc., continue in almost same values as before. The picture obtained from this zone has revealed a steep fall in the values of mangrove taxa in general and Rhizophoraceae members in particular. *Sonneratia*, being high pollen producer, increased considerably in the beginning but dwindled in the later half of this zone. This decrease in the value of mangrove elements can be assigned to the activity of man as the total time span for this zone is around thirty-five years and could be well correlated with record date around early nineteen hundred sixties when the construction of Paradip Port came into being.

DISCUSSION AND CONCLUSION

The results permeated from the pollen analytical study of surface samples are variable. At places it has been recorded that the pollen composition of the surface samples is coherent with the existing vegetation of the area. For instance, sample nos. 1-4 collected from near the mouth of Mahanadi River at Paradip have brought about a close relationship between the pollen assemblage and modern vegetation. However, sample nos. 5-7 but for no. 8, collected from Jambu Island, have shown a partial relationship between the pollen

assemblage and modern vegetation. The analysis of all the surface samples reveals that some of the taxa are over-represented and a few are under-represented. The members of Rhizophoraceae and *Sonneratia* are over-represented. The members of Rhizophoraceae are high pollen-producers in the mangrove complex and are provided with all contrivances for their transportation and spread. This feature had already been observed by several earlier workers (Muller, 1959; Caratini *et al.*, 1973; Vishnu-Mittre & Gupta, 1972; Ratan & Chandra, 1983, 1984; Grindrod & Rhodes, 1984; Grindrod, 1988). As regards *Sonneratia*, it is also a high pollen producing taxon but generally does not represent its high frequency in the sediments. Similar observations have also been made by Caratini *et al.* (1973). Nevertheless, *Sonneratia* pollen may present in low values or even absent in the sediments owing to the fact that bats feed on its pollen (Tomlinson, 1986).

Acanthus, *Avicennia* and *Excoecaria* are under-represented in the pollen assemblage in contrast to its position in the vegetation. This could be well explained due to the entomophily coupled with low pollen production. Nevertheless, in Pichavaram mangroves in Tamil Nadu, *Acanthus ilicifolius* has been recorded to its expected values (Caratini *et al.*, 1973). In Sample no. 8, collected from near Jambu Village where undisturbed patches of mangroves are present, the pollen spectrum recorded the predominance of core mangrove taxa followed by peripheral mangrove taxa. All surface samples contain reworked pollen indicating a high influx of water transportation from far of distances.

The surface sample study has enabled to understand that *Rhizophora*, *Ceriops/Bruguiera* and *Sonneratia* are over-represented whereas *Avicennia*, *Excoecaria* and *Acanthus* are under represented in the pollen assemblage as compared to their actual occurrence in the forest.

The pollen diagram constructed from Paradip profile has been phased into four zones in chronological order. In Zone I, which covered a time span of less than 100 years, the core mangrove taxa

except for *Sonneratia* and *Excoecaria* were poorly developed whereas midland and upland vegetation was dominated by *Terminalia*, *Adina*, Fabaceae, Anacardiaceae, Sapotaceae, *Emblica*, etc. This zone indicates that mangrove vegetation, which perhaps thrived earlier, has been damaged due to either climatic or biotic influence. But the high values of *Sonneratia* and *Excoecaria* do not exclusively support the biotic factor; instead these two taxa have liking for the increased fresh water conditions and colonize the contact point near the fresh water discharge with greater turbidity. Thus, the fresh water discharge with greater magnitude in the delatic complex can not be ruled out. Zone II, which lasted for about 200 years, has recorded further depression in almost all the mangrove taxa whereas the fresh-water swamp taxa including aquatics have risen successively. The overall values of Zone II depicts recession in the tidal magnitude and more fresh water discharge from the rivers and rivulets. In addition, the biotic factor remained operational and the open conditions developed.

Zone III, in general, is a period for luxuriant growth of mangrove vegetation. However, the vegetation composition in the lower and upper parts is incoherent and hence it has been subdivided into two for the convenience of describing the biostratigraphic units in terms of vegetation. Zone IIIa lasted for about 50 years and is marked by high values of *Avicennia* and *Sonneratia*. The core mangrove taxa, particularly Rhizophoraceae members, are lowly present. *Avicennia* is adapted to exceedingly high salinity conditions, whereas *Sonneratia* has liking for lesser salinity. This association of two heterogeneous taxa is suggestive of typical marine condition with high turbidity and salt deposition. Zone IIIb lasted for about 150 years. It is marked by the establishment of core mangroves, such as *Rhizophora*, *Ceriops/Bruguiera* and *Sonneratia*; all other taxa with a preference of low salinity and those with fresh water inclination have declined considerably. Chenopodiaceae and *Acrostichum aureum* have improved significantly.

The results obtained from this zone have

PLATE 2



(All figures unless otherwise stated are, $\times 1000$)

1. *Byttneria berbacea*, polar view.
- 2,3. Unidentified 3-porate, equatorial view
4. *Brownlowia* sp., polar view.
- 5-7. Unidentified 4-parasyncolpate pollen.
8. *Polygala* sp., equatorial view.
- 9,10. *Gardenia* sp. pollen tetrad
- 11,12. *Xylocarpus* sp., polar view and equatorial view.
13. *Acacia* sp.
14. *Ceratopteris thalictroides*, $\times 500$.
15. Monolete spore, $\times 500$.
- 16-19 Reworked Permian pollen, $\times 500$; 16. *Plicatipollenites* sp., 17. *Crescentipollenites* sp., 18. *Labirites* sp., 19. *Verticipollenites* sp.

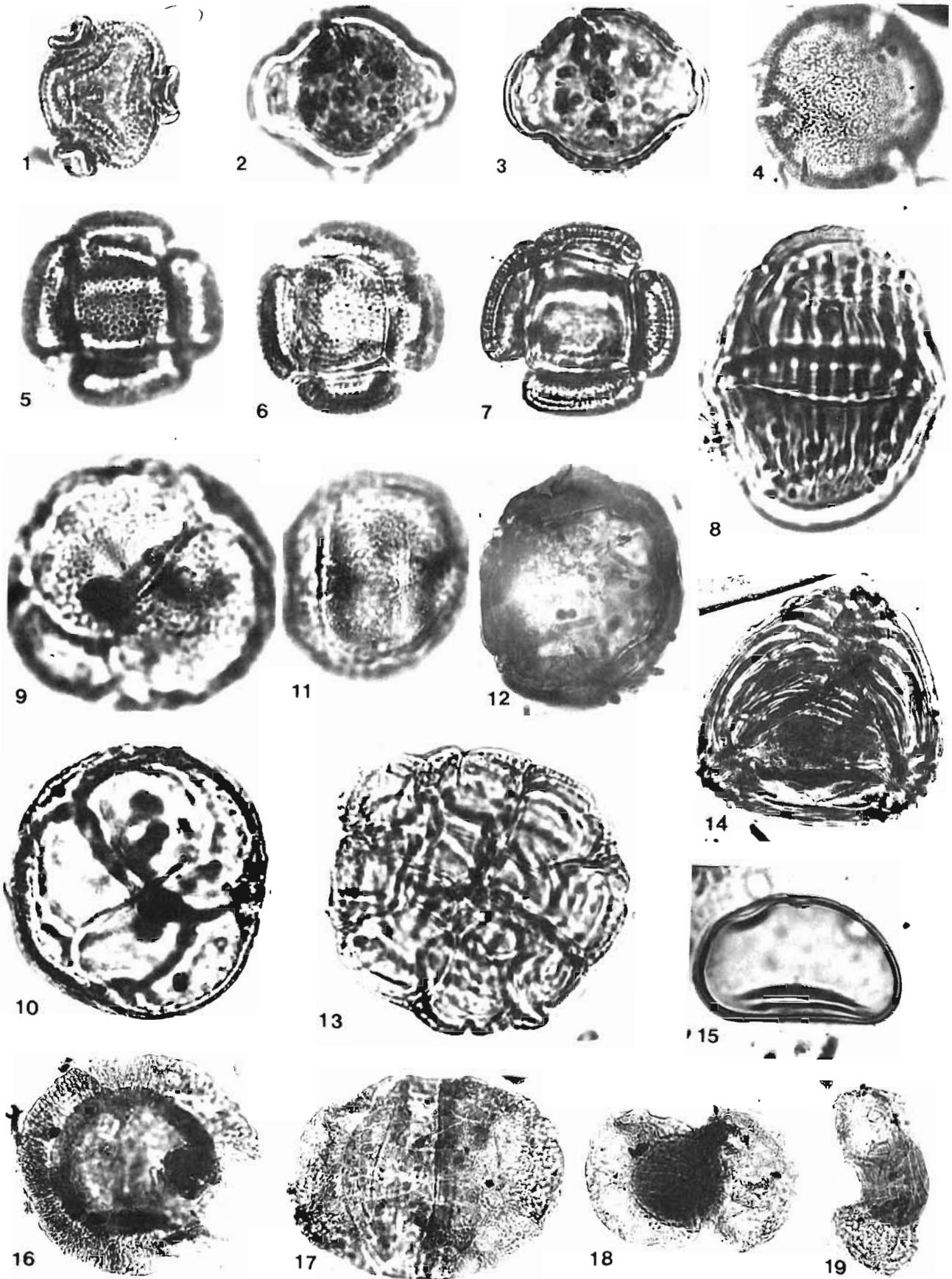
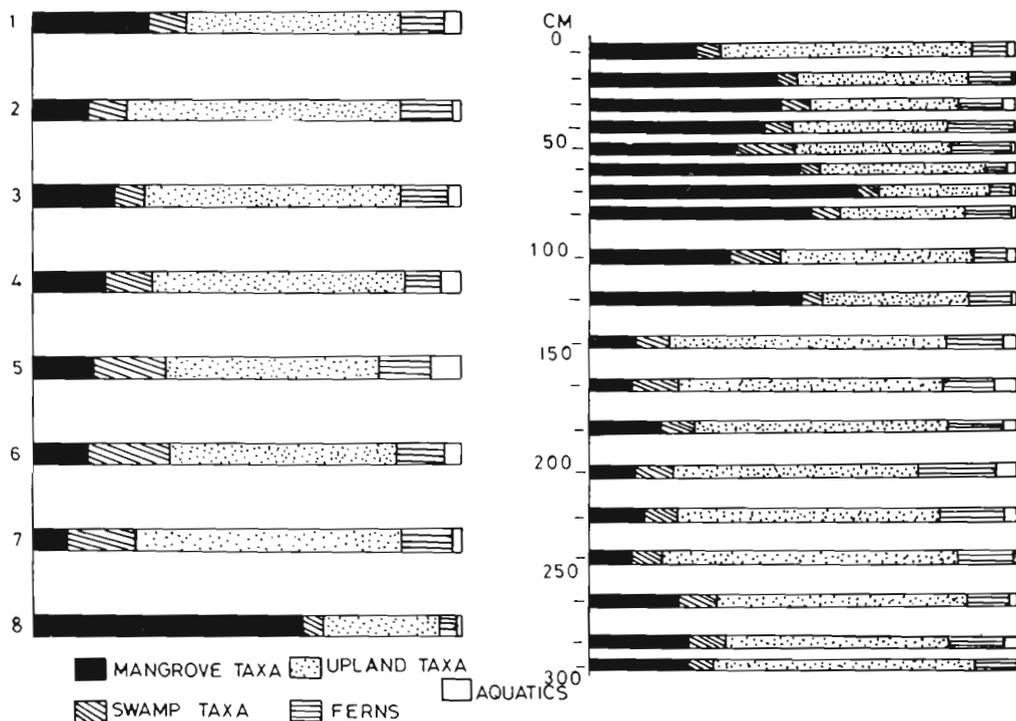


PLATE 2



Text-figure 3—Summary diagram showing collective relative frequencies of various ecologically grouped plant taxa based on Text-figures 1 and 2.

revealed a favourable environment for about 200 years for the successive growth of mangrove vegetation with an increased salinity giving pace to front-line estuary mangroves to flourish. The colonisation of the mangrove system is also indicative of undisturbed conditions and hence it could also be assumed that during this phase the biotic pressure ceased for some time; it may be because of the unfavourable natural condition which perhaps precluded the man's entry into the forest.

During the Zone IV, which has short time-span (not exceeding 35 years), all the mangrove taxa declined sharply, except for *Sonneratia*. This setback in the overall mangrove taxa, particularly members of Rhizophoraceae, could be abused in the hands of man; this loss to the mangrove vegetation could be correlated with record date around 35 years when the construction of Paradip Port came into being and a vast area was deforested.

The reworked Permian pollen have been encountered invariably in all the profile samples, in low values in the bottom samples but their frequencies increased in the top samples. The sediments containing these pollen grains after erosion have been incorporated into the Mahanadi and transported up to its mouth or even farther and deposited along with recent sediments.

The summary diagram (Text-fig. 3) gives a comparative picture of mangrove taxa, swamp taxa,

upland taxa, ferns and fresh water aquatics. This also provides at a glance correlation between the vegetation of surface samples and profile samples. In broader perspective, the mangrove taxa remain lower than the upland taxa in the lower half of the profile and, thereafter, the former improved and the latter declined. It has also been observed that the surface-sample vegetation statistics has helped greatly in the correct interpretation of pollen diagram.

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