Mangroves of India: History and palynostratigraphy of Chilka Lake, Orissa

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Fine resolution palynostratigraphy centred on Chilka Lake is aimed at the reconstruction of history of mangrove vegetation in tidal flat, salt marsh and fresh water wetland environments. Pollen analyses of air catches, lake water, lake bottom mud and surface soil samples have been collectively used to quantify the dispersal and preservation of pollen in relation to the modern vegetation. Pollen analysis of a 5.50 m deep profile from Balugaon at the western flank of the lake in prograded delta zone has been done which provides information about the changes in vegetation and depositional environments from approximately 3,100 radiocarbon years B.P. to the present. The results obtained suggest that (i) air catches are devoid of mangrove taxa instead seasonal non-arboreals and planted trees dominate, (ii) lake water, surface sediments and lake bottom mud samples have recorded the occurrence of both core mangroves and mangrove associates to the extent of 10-33 and 50-83 per cent, respectively, and (iii) Balugaon profile portrays the existence of marine, brackish and fresh water bioassemblages. On the basis of subtle changes in the vegetation, various depositional environments, transgressive and regressive facies have been determined.

Key-words—Mangroves, Palynostratigraphy, Palaeoenvironment, Chilka Lake, Quaternary (India).

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सारॉंश

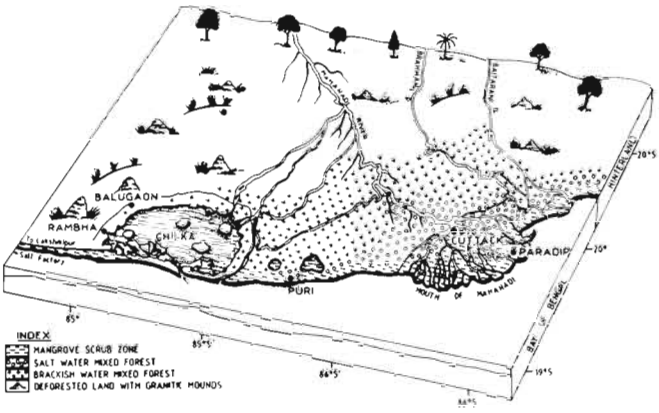
भारत के मैंग्रोव : उड़ीसा में चिल्का झील का इतिहास एवं परागाणुस्तरविन्यास

हरीपाल गुप्ता एवं आशा खंडेलवाल

ज्वारीय मैदान, खारी कच्छभूमि एवं स्वच्छ जलीय वातावरणों में पाई जाने वाली मैंग्रोव वनस्पति के इतिहास की संरचना हेतु चिल्का झील का परागाणविक विश्लेषण किया गया है। वर्तमान वनस्पति के सन्दर्भ में परागकणों के विकीरण एवं परिरक्षण का परिमाण अन्वेषित करने हेतु वायवीय परागकण-नमूनों, झील के पानी, झील की तली की कीचड़ तथा सतही मिट्टी के नमूनों का परागकण-विश्लेषण किया गया। झील के पश्चिम में बालुगांव से 5.50 मीटर गहरी परिच्छेदिका के परागकण-विश्लेषण से लगभग 3,100 रेडियोकार्बन वर्ष पूर्व से आज तक के निक्षेपणीय वातावरण एवं वनस्पति में हुए परिवर्तनों पर महत्वपूर्ण जानकारी मिली है। उपलब्ध परिणामों से प्रस्तावित होता है कि (i) वायवीय-परागकण नमूनों में मौसमी अवृक्षीयों की अपेक्षाकृत मैंग्रोव वर्गक अनुपस्थित हैं तथा लगाये गये वृक्षों के परागकणों की बाहुल्यता है, (ii) मैंग्रोव एवं इनके साहचर्य में पाये जाने वाले पौधे क्रमशः 10-33 प्रतिशत तथा 50-83 प्रतिशत मात्रा में उपस्थित हैं, तथा (iii) बालुगांव परिच्छेदिका समुद्री, खारे एवं स्वच्छ जल समुच्चयों की उपस्थिति इंगित करती है। वनस्पति में हुए परिवर्तनों के आधार पर विभिन्न निक्षेपणीय वातावरण तथा अपसारी एवं अभिसारी संलक्षणी सुनिश्चित की गई हैं।

CHILKA LAKE (Lat. 19°5′-20°, Long. 85°6′) south-west of Puri, is an open lagoon and measures to about 65 km NE-SW and 20 km E-W at the widest point. The word Chilka denotes the birds' paradise. Chilka lagoon is connected with bay of Bengal through narrow channel at its eastern flank; there is regular sea water entry into the lake particularly during storm surges and hurricanes. Several distributaries of Mahanadi River, prominent amongst them is Bhargavi, pour into the lake at its northern flank. Thus, the salinity of the lake fluctuates periodically depending upon the incoming of water from sea or rivers. The salinity effect is more south-eastward and decreases north-westward causing floral, faunal and depositional distinctions. It is a shallow water eutrophic lake and provides an abode to the life to dwell in.

Two types of islands are common in Chilka Lake



Text-figure 1—Panoramic view of Chilka Lake, Mahanadi Delta, Orissa.

(i) rocky granitic mounds up to a height of 15 m which are perhaps the result of orogenic trend of base rock, and (ii) muddy islands which are the later emergence of land after recession of sea water, generally inundated during rainy season (Text-fig. 1). Prominent amongst muddy islands is the Nalabana (10 sq km) on the south-eastern flank located almost in the centre of the lake. There are a number of small and big mud islands, collectively known as 'Parikud' island.

GEOLOGY AND GEOMORPHOLOGY

General topography of coastal region in Mahanadi delta is marked by mangrove swamps abutting the shore but towards inland it is a plain country traversed by distributaries of Mahanadi. The land surface along north-east and east of Chilka lake is low plain but north-western and south-western ends of the lake abound in rocky projections. In all probabilities Chilka Lake represents an embayment in the local shoreline and the formation of sand spits at the mouth of Chilka Lake has begotten a protected body of water where sedimentation could be marked immediately on the lee of the spit. This geomorphological feature is one of the important aspects which might have caused the origin of this brackish water lake (Ahmad, 1972).

The alluvial islands within the lake and at its mouth are the depositional features. This line of islands is faced leeward by 40 km long spit which is remarkably straight and only a few meters wide. Behind this spit there is a belt of small islands (2-3 km wide), and bordered seaward by a narrow creek between the spit and alluvial belt of islands. Laterally the alluvial belt has been breached by numerous transverse creeks that connect Chilka Lake with sea and provide passage for the ebb and flow of tidal water.

The islands off the mouth of Mahanadi are composed of newer alluvium. The geology of rocky islands near north-western flank of Chilka Lake is the same as that of adjoining area consisting of Khondalites, the richly garnitiferous gneisses and schists containing graphite and marked by an abundance of sillimanite (Ahmad, 1972, p. 33).

As regards the age of deltas, the Chandbali Formation, an ancient shoreline in Brahmani-Baitarni deltaic complex, was formed during the last 6,000 years synchronizing last global rise of sea level (Mallick *et al.*, 1972). Niyogi (1971) delineated the ancient shorelines at the Orissa coast and recognised various geomorphic features such as (i) rocky shoreline near Ganjam (48 km), (ii) sandy spit near Chilka Lake (64 km), (iii) deltaic shoreline from Brahmagiri to Talpada (304 km), and (iv) sandy shoreline near Balasore (64 km). Earlier, it has been thought that the development of Orissa shoreline was initiated nearly 5,000 years B.P., the period when depressed sea level was restored to the original level or nearly so (Coleman & Smith, 1964). The ancient shoreline after full restoration of a sea level has been plotted across Ganjam to Balasore covering the ebb of Chilka Lake and Cuttack (Niyogi, 1971). Thereafter, Mahanadi and Brahmani rivers

PLATE 1 →

(All, × 1000)

1. Caryophyllaceae
2,3. *Casuarina*
4. Trilete fern spore
5. Unidentified pollen
6. Fern spore
7. Unidentified pollen
8,9. *Avicennia*
10,11. *Borassus*
12,13. *Lagerstroemia*
14,15. Unidentified pollen
16,17. Acanthaceae
18. Palmae
19. *Phoenix*
20. Fabaceae
21. Fern spore
22. Unidentified pollen
23. Cyperaceae
24. Palmae
25. *Acacia*
26. Unidentified spore

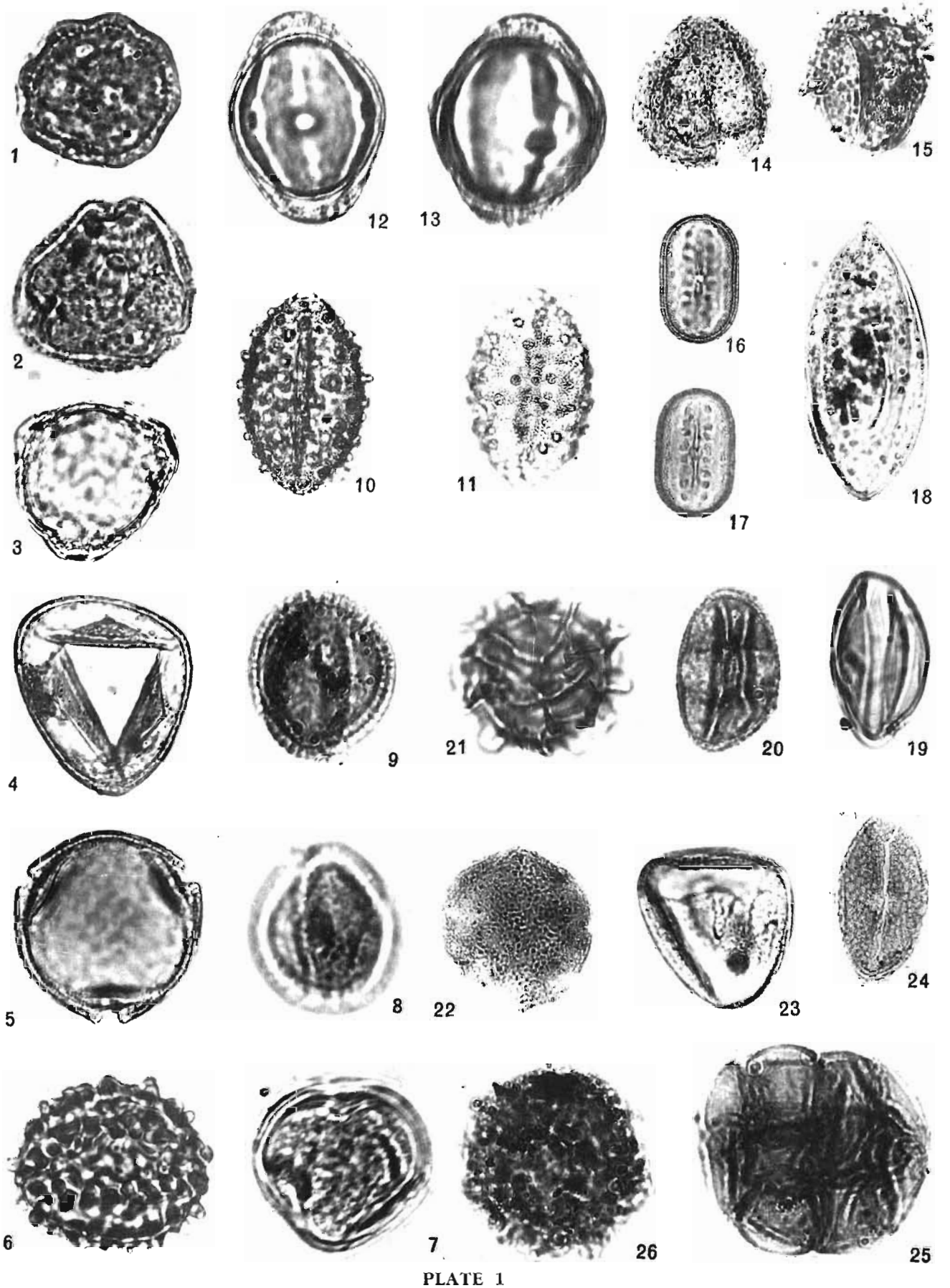


PLATE 1

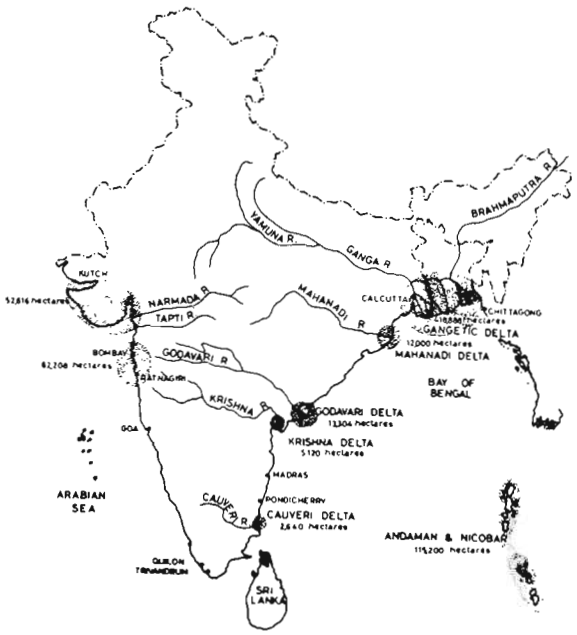
started pouring deltaic sediments into the structurally controlled bay and quickly built forward an arcuate delta. Sediments shed by the fast eroding spurs near Ganjam were moved north-east by littoral currents and a spit was thrown from Ganjam. This spit ultimately connected with the rapidly building delta and in this process formed the Chilka lagoon.

VEGETATION AND ECOZONES

Mangrove vegetation in the recent past had been wide spread all along the coastline of India with characteristic flora varying from one coast to another. But with the advent of biotic pressure, large areas of mangrove forest are denuded (Rao, 1959). Mangrove vegetation has been an important factor in the earth's history since communities of plant first colonized the land surface. It is picturesque to observe mangrove system wherein real biosphere and ecosystem is conserved (Text-fig. 2).

Since the early nineteenth century, many eminent botanists and ecologists were attracted to this flora and contributed a lot to the enigmatic system of mangrove biology and ecology. But the momentum in this direction was generated when foresters met at Calcutta during October, 1957 to consider the economic and technical potential of mangroves. The term 'mangrove forest' does not necessarily denote a forest cover rather it could be any kind of vegetation formation, viz., arborescent, bushy, herbaceous or even entirely denuded in the saline coastal surface (Blasco, 1975).

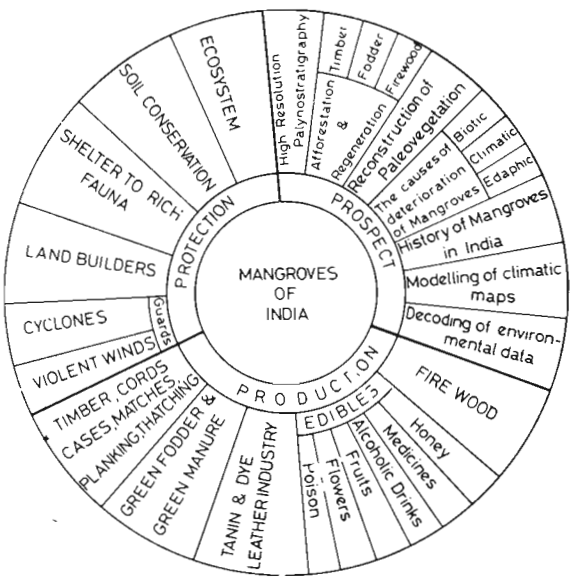
Sidhu (1963) presumed that the mangroves in India were widely distributed covering an area of about 7,000 sq km and the regional distribution was unequal (Map 1). Furthermore, about 60 per cent of the total mangroves of India were distributed in Bengal alone and 17 per cent in Andaman and Nicobar islands. In other places mangrove spread is relatively less and is found in narrow strips of bushy and degraded vegetation.



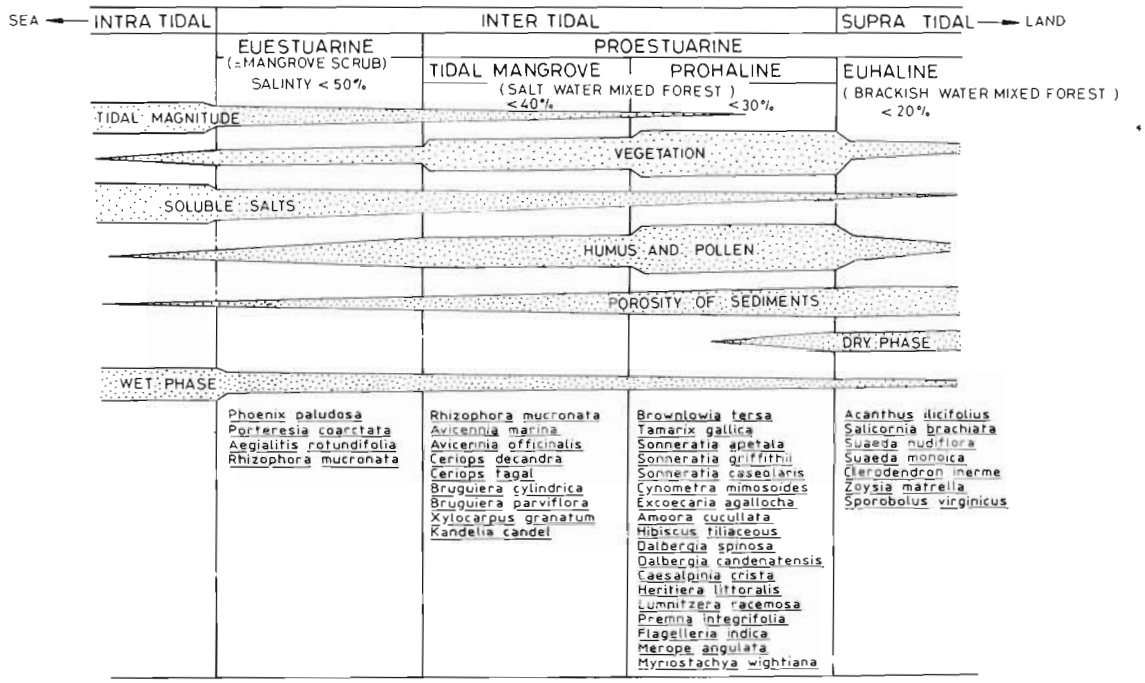
Map 1—Distribution of mangroves in India.

The ecology and distribution of mangrove forest along the Indian coast have been periodically worked out. Champion (1936) considered the whole coastal vegetation as 'tidal swamp forest' which includes four subtypes, viz., (i) low mangrove forest, (ii) tree mangrove forest, (iii) salt water *Heritiera* forest, and (iv) fresh water *Heritiera* forest. In the revised survey, Champion and Seth (1968) maintained the same collective title with five subdivisions, namely (i) mangrove scrubs, (ii) mangrove forest, (iii) salt water mixed *Heritiera* forest, (iv) brackish water *Heritiera* forest, and (v) palm swamp. Later, the whole coastland vegetation has been grouped under estuarine vegetation and depending upon the soil/vegetation types, euestuarine and proestuarine zones have been created (Rao & Sastry, 1974; Rao *et al.*, 1973). Euestuarine includes the plants growing on a muddy relief under the constant influence of successive tides. Proestuarine is a complex zone which includes three subzones: tidal mangroves, euhaline and prohaline which would be determined on the basis of tidal magnitude and degree of salinity.

Thus, the taxa have been encountered in different zones with particular reference to



Text-figure 2—Aspects and prospects of mangroves.



Text-figure 3—Overview of deltaic complex in India with special reference to Mahanadi Delta, Orissa.

Mahanadi delta showing a great degree of fidelity to their respective zones (Chowdhury, 1984; Banerjee & Rao, 1985; Banerjee, 1987). The taxa encountered from different zones in estuarine complex are mentioned in Text-figure 3.

Banerjee (1987) has identified two broad based sections in Mahanadi delta, an outer funnel-shaped estuary along the river mouth and a narrow inner estuary behind the river mouth corresponding to euestuarine and proestuarine, respectively. He considered effective wave action development of stranded beach ridges on tidal flats and absence of *Rhizophora* to delimit outer estuary from the inner estuary. The outer estuarine zone covers mostly tidal flats and is dominated by *Avicennia marina* except for newly exposed areas which are inhabited with saline grass, such as *Porteresia coarctata* and the upper units are covered by *Sonneratia griffithii, S. alba, Bruguiera cylindrica, B. parviflora, Avicennia alba, Lumnitzera racemosa, Ceriops tagal, Aegialitis rotundifolia* and occasionally *Phoenix paludosa*. In the inner estuary, on the basis of soil/salinity and vegetation fraternity, three ecozones are identified, viz., (i) a zone of typical mangrove habitat with members of Rhizophoraceae adapted by means of vivipary and stilt roots, (ii) a zone of less pronounced mangrove habitat grouping different taxa and adapted by means of pneumatophores and buttresses, and (iii) a zone of transition between mangrove and upland taxa.

MATERIAL AND METHOD

During the survey of Chilka Lake, covering a distance of about 20 nautical miles starting from the western flank of lake near Barkul Panth Niwas to Parikud island in the south, around 13 modern samples of surface soil, lake bottom mud and lake water were collected and analysed in order to have the pollen/spore display, and actuo-pollen/vegetation relationship. In addition, a 5.5 m deep soil profile from Balugaon, about 4 km north west of Barkul, was procured and studied palynologically to reconstruct palaeofloristics.

Lithostratigraphically, sediments could be broadly classified as sticky clay with silt and sand in different denominations up to a depth of about 3 m from the surface. Thereafter, sediments become more compressed and composed of blackish grey, sticky clay with abundance of fish scales. In addition, interbedded bands of black organic mud are also recorded at places. The details of lithostratigraphy are as follows:

0.0-1.0 m	— Brownish-grey clay with coarse sand. Organic matter negligible.
1.01-1.50 m	— Brownish-grey clay with medium to coarse sand. Organic matter negligible.
1.51-2.50 m	— Grey sticky clay with silt and fine sand, with 1-2 cm thick sand band at 2.20 m depth.
2.51-3.00 m	— Blackish-grey, sticky clay with silt and organic matter.

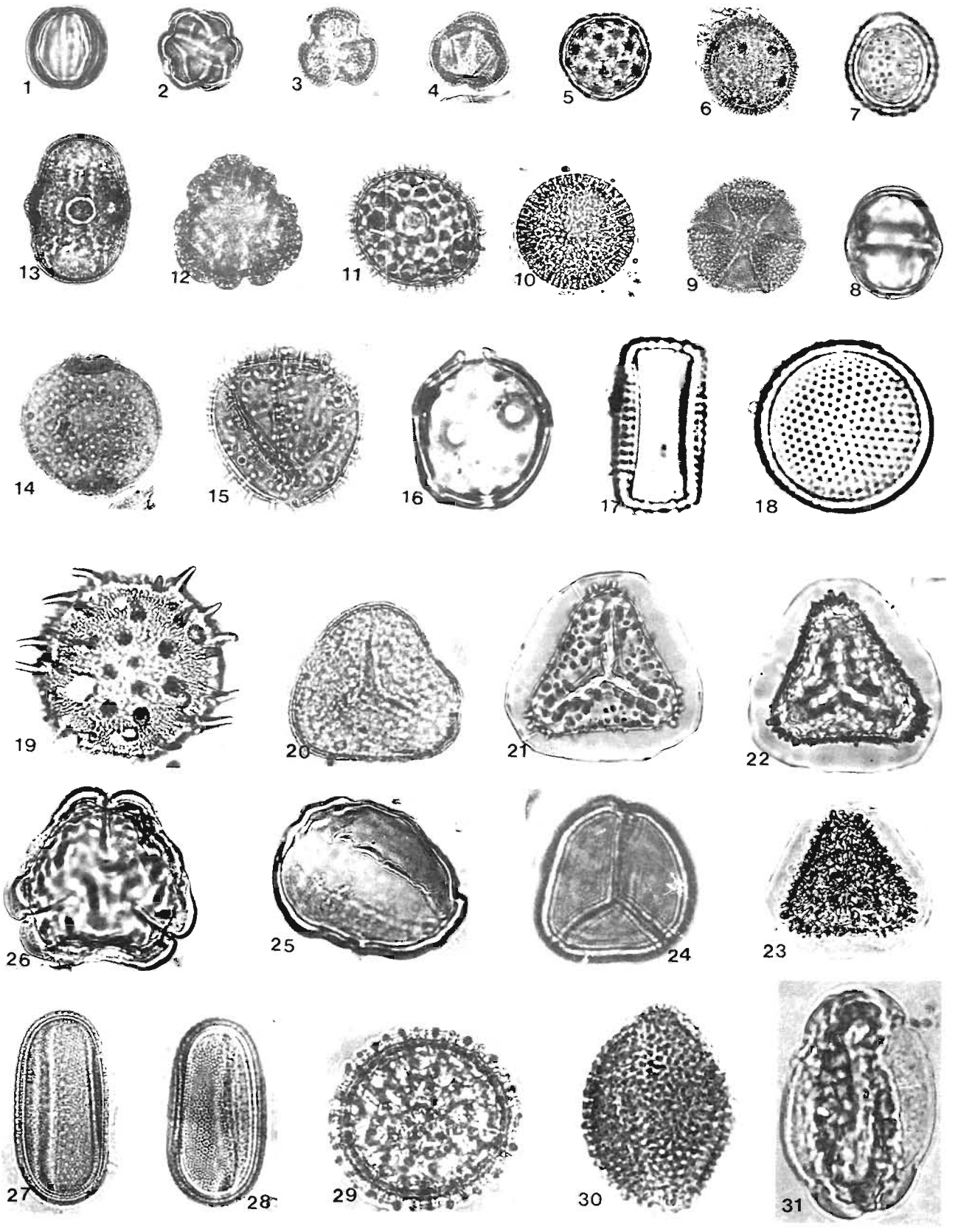

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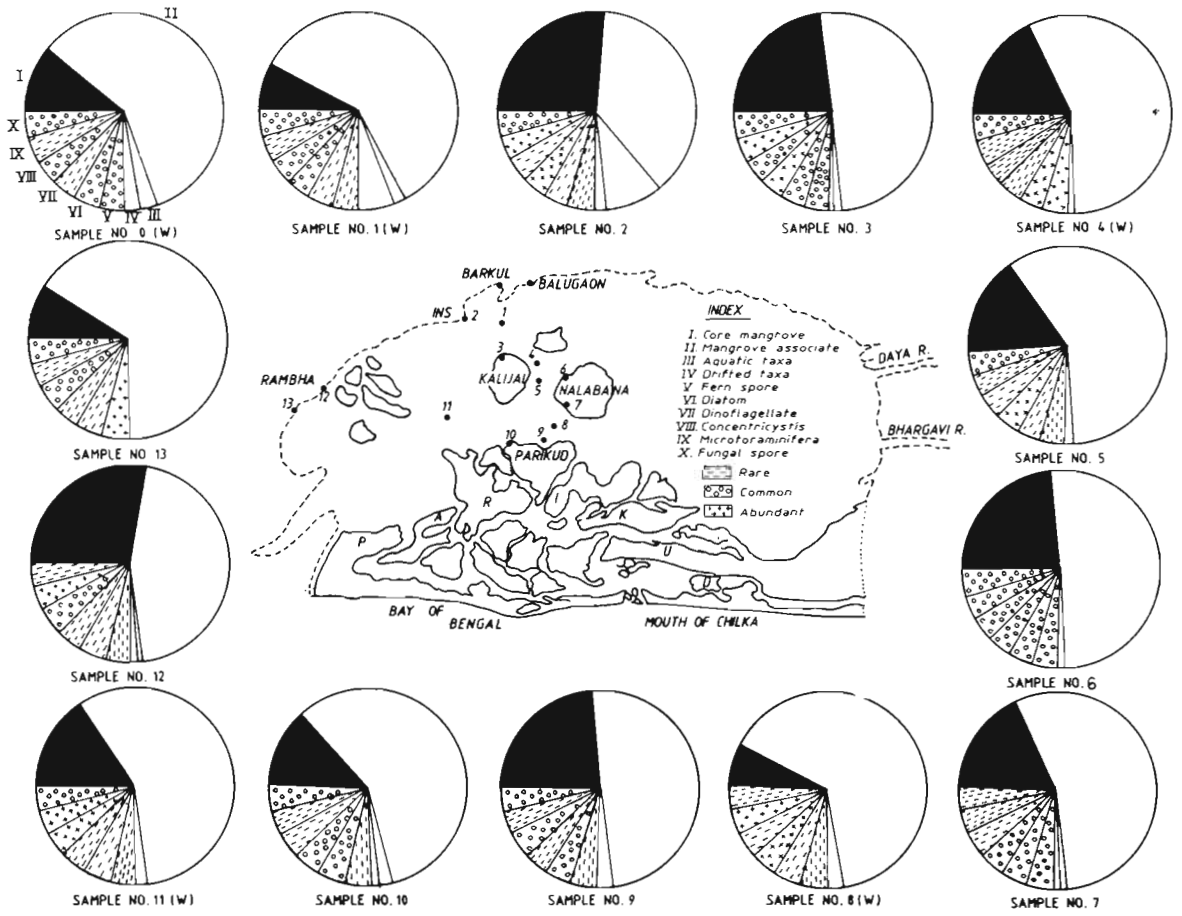
PLATE 2



Text-figure 4—Pollen deposition model at Chilka Lake.

3.01-4.00 m — Blackish-grey, sticky clay with gyttja and 0.5 1 cm thick bands of black organic mud one each at 3.50 m, 3.70 m and 4.0 m levels.

4.01-5.50 m — Blackish-grey, sticky clay admixed with black organic mud and gyttja with abundant fish scales.

POLLEN DEPOSITION MODEL AND MODERN VEGETATION

To evolve the pollen deposition model (Text-fig. 4) at Chilka Lake and to work out the modern pollen/vegetation relationship, a variety of samples such as air catches (Text-fig. 5) lake water, lake bottom mud and surface soil (Text-fig. 6), has been investigated. An area of about 20 nautical miles from Barkul at the western flank of the Chilka to the Parikud island at the south-east and further south-west at Rambha has been covered. Core mangroves, mangrove associates, aquatics and long distance drifted taxa have been put together for understanding their relative frequencies. For fern spores, diatom frustules, dinoflagellate cysts,

←

PLATE 2

1-2. *Terminalia*, × 500.
3-4. *Avicennia*, × 500.
5. Chenopodiaceae, × 500.
6. Unidentified pollen, × 500.
7. *Pandanus*, × 500.
8. Rhizophoraceae, × 1000.
9. *Caesalpinia*, × 500.
10. *Jatropha*, × 500.
11. *Abutilon*, × 500.
12. Unidentified pollen, × 500.
13. *Sonneratia*, × 500.
14. Unidentified pollen, × 500.
15. *Nypa fruticans*, × 500.
16. Apocynaceae, × 500.
17,18. *Coscinodiscus*, × 1000 (Girdle and valve views).
19. Malvaceae, × 500.
20-24. Trilete fern spores, × 500.
25. Cocos nucifera, × 500.
26. Unidentified pollen, × 500.
27,28. *Acanthus ilicifolius*, × 500.
29. *Polygonum*, × 500.
30. Unidentified pollen, × 1000.
31. *Barringtonia*, × 500.

concentricystis cysts, microforaminiferal inner linings and fungal spores, the qualitative system of relative abundance has been adopted (Andrews, 1966). Each taxon is, thus, rated as follows:

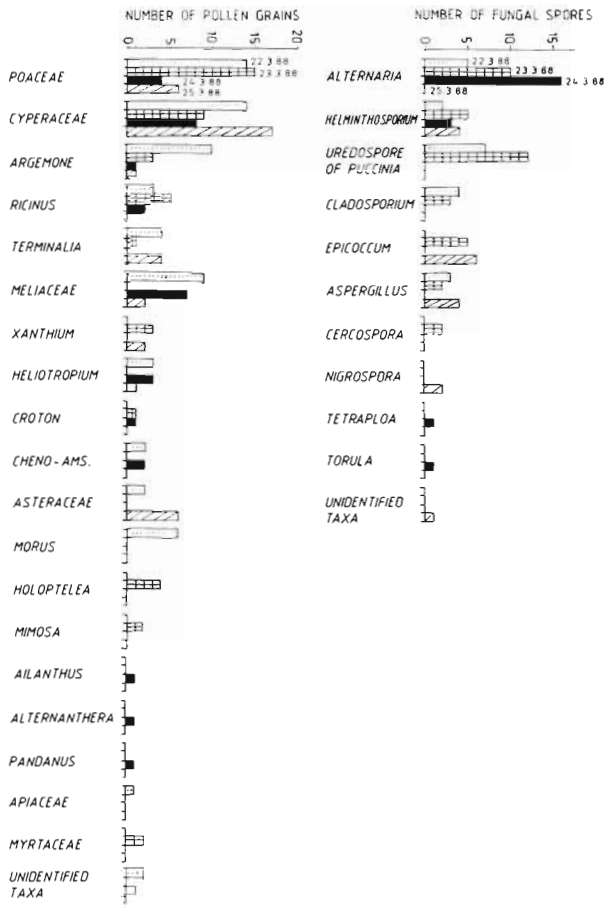
Abundant—Atleast one specimen in all fields of view.

Common—Atleast one specimen in many fields of view.

Rare—One or two specimens in entire slide.

Air catches—Pollen calendar from the air catches prepared at the bank of Chilka Lake near Barkul during the later half of March, 1988, a blooming time for most of the trees, has depicted that none of the taxon belonging to core mangrove or mangrove associate has been recorded. The pollen taxa recorded in the air catches belong mainly to the ground vegetation. Nevertheless, arboreal pollen encountered in this assemblage belong to *Morus, Ailanthus, Holoptelea*, Myrtaceae, Meliaceae, *Pandanus, Terminalia*, etc. which are either drifted from hinterland zone or planted in the near vicinity. In addition, a large number of fungal spores have been encountered and important amongst them are *Alternaria, Helminthosporium, Cladosporium* and uredospores of *Puccinia*.

Lake water—The study of samples 0, 1, 4, 8 and 11 of Chilka Lake water amounting 500 cc each has revealed that the quantitative pollen potential of core mangrove and mangrove associate taxa is low. However, pollen spectra obtained from each sample depict the dominance of mangrove associates followed by core mangrove taxa, but the values for these taxa are inconsistent. For example, core mangroves are better represented in samples 4 and 11 whereas mangrove associates are rich in samples 0 and 1. *Holoptelea* has exceedingly high values in samples 8 and 11. *Casuarina* pollen is higher (12%) in sample 0 but much reduced in samples 8 and 11 and absent from samples 1 and 4. The ubiquitous taxa like Poaceae, Cyperaceae and Chenopodiaceae are present in greater values in all the samples. Amongst aquatic taxa, *Potamogeton* and *Typha* are richly present in samples 0 and 1 only. Long distance drifted pollen are represented in good frequency in all the samples. The core constituents of mangrove



Text-figure 5—Air catches at the western flank of Chilka Lake, Barkul, Orissa.

forest recorded in the modern samples are *Rhizophoraceae, Aegialitis, Heritiera, Sonneratia, Nypa fruticans, Acanthus ilicifolius, Xylocarpus, Excoecaria*, etc. whereas mangrove associates are represented by *Cocos, Borassus, Pandanus, Lumnitzera, Anacardium, Barringtonia*, Palmae and several herbaceous elements including grasses, sedges, ferns and chenopods.

Lake bottom mud—Samples 2, 3, 5 and 6 were collected from the bottom mud of Chilka Lake. The pollen analysis has revealed the expansion of core mangrove taxa and reduction of mangrove associates

PLATE 3 →

1-2. Unidentified bodies, × 1000.
3. *Pediastrum*, × 500.
4. Microthyrioid structure, × 1000.
5,6. *Pinnularia*, × 500.
7. Fungal spore, × 1000.
8,9. *Ammonia*, × 500
10. *Pediastrum*, × 500.
11,12. Fungal spores, × 500
13. *Tetraploa*, × 500.
14-19. Dinoflagellate cyst, × 1000.
20,21. Fungal spores, × 1000.
22. *Tetraploa*, × 1000.
23. Fungal hyphae, × 1000.

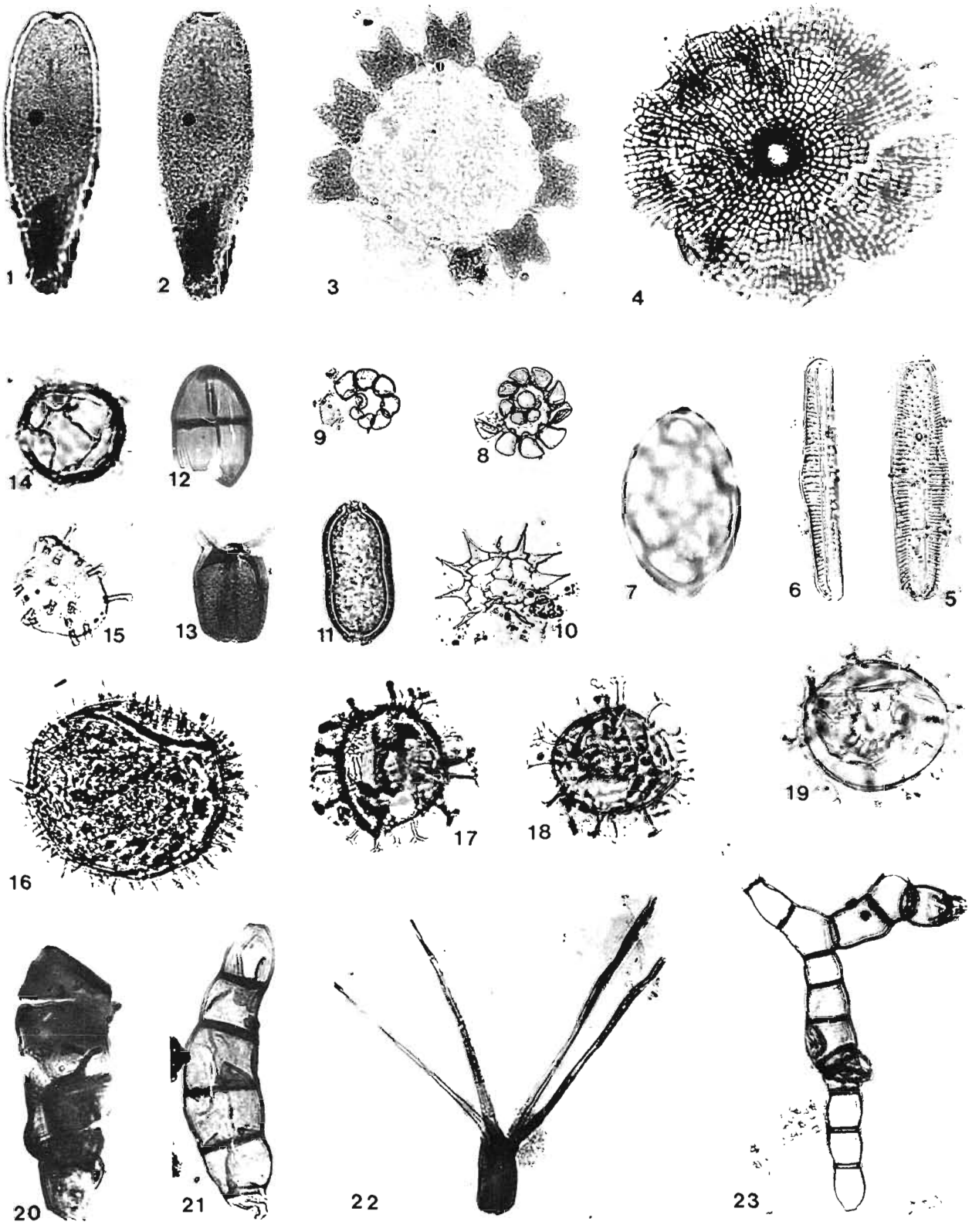
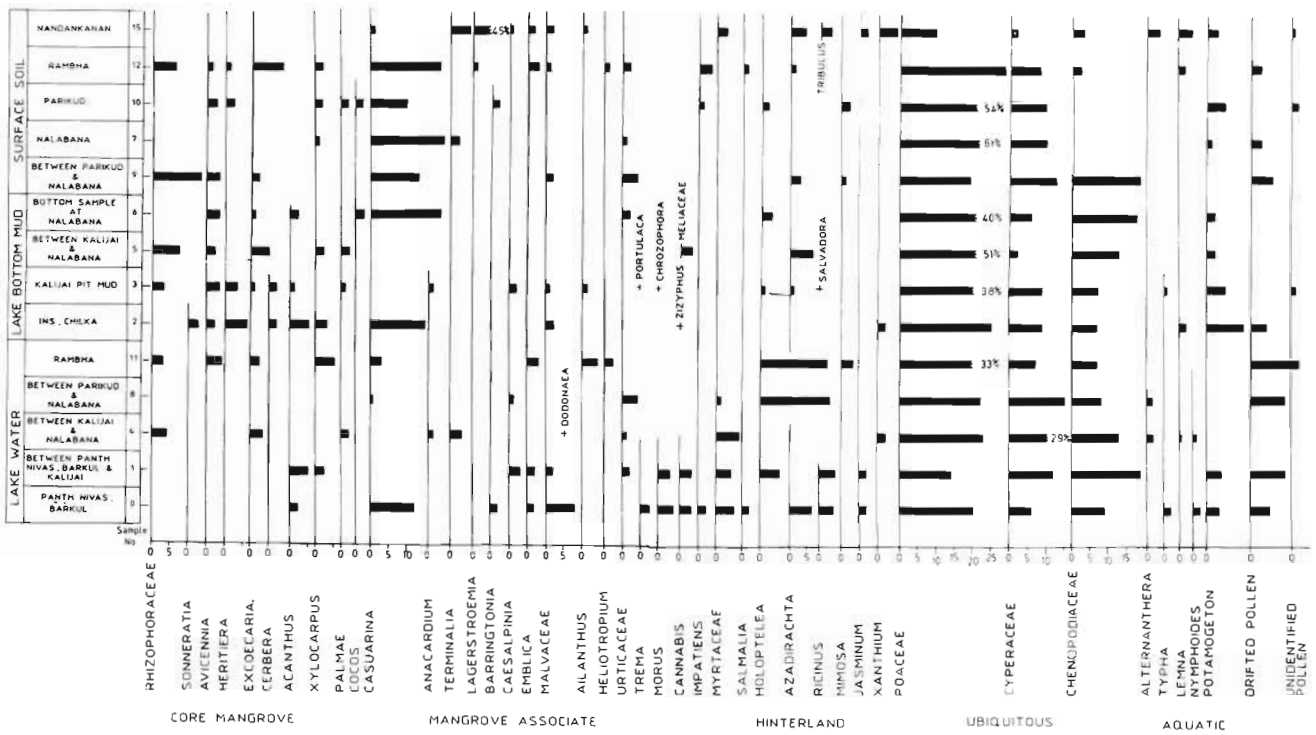


PLATE 3



Text-figure 6—Modern pollen spectra at Chilka Lake.

in general. *Casuarina* (14%) is considerably high in samples 2 and 6 but absent from samples 3 and 5. Poaceae is constantly high in all the samples. Cyperaceae and Chenopodiaceae remained moderately high in samples 2 and 3 but Cyperaceae declined and Chenopodiaceae improved proportionately in samples 5 and 6. Amongst aquatic taxa, *Potamogeton* is higher in sample 2 but subsequently declined in rest of the samples. *Lemna* and *Typha* are present in low values in samples 2 and 3 respectively. Long distance drifted pollen are absent except for sample 2.

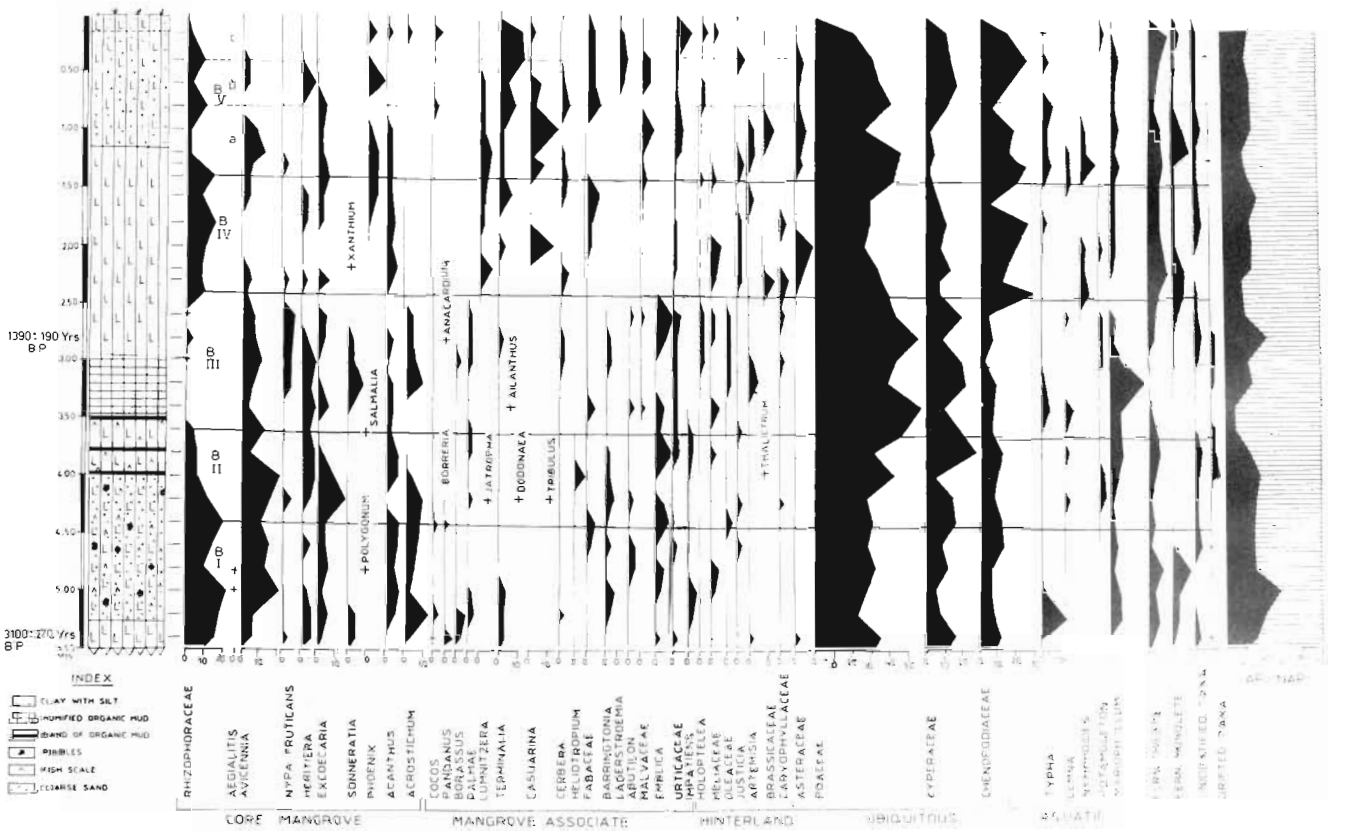
Surface soil—Samples 7, 9, 10 and 12 were collected from the surface sediments from in and around the lake and sample 15 was collected from Nandankanan, a wild life sanctuary near Bhubaneshwar, away from marine influence and shall be dealt with separately. Sample 9 records highest values for Rhizophoraceae followed by *Avicennia* and *Excoecaria*. Rhizophoraceae has considerably reduced but *Excoecaria* has shown remarkable increase in sample 12. Rhizophoraceae is absent from samples 7 and 10. Mangrove associates on the whole are scatteredly moderate. *Casuarina* pollen record exceedingly high values in all the samples. Poaceae and Cyperaceae continued to be in higher values but Chenopodiaceae pollen are absent from samples 7 and 10 and low in sample 12. Aquatics and long distance drifted taxa have registered low frequencies.

No mangrove taxa was recorded from sample no. 15 though it has good representation of taxa like *Terminalia, Lagerstroemia* and *Azadirachta*. Poaceae, Cyperaceae and Chenopodiaceae are present in low values. Aquatic taxa are represented in good frequencies as the sample was procured from the bank of an artificial lake.

The analysis of all the samples has revealed that except *Casuarina* and ubiquitous taxa, the mangrove associates dominated and core mangroves co-dominated the vegetation. This pattern of pollen spectra is incoherent with the present day vegetation mosaic in and around Chilka Lake. Present day condition of mangrove degradation is wide spread all over the area. In view of prevailing contrast features between the present day vegetation mosaic and pollen record of the surface samples, it could be deduced that the core mangrove pollen taxa are derived from nearby mangrove forest abutting the sea shore. Owing to the fact that several contrivances are present in the mangrove taxa, their pollen transportation from far off places can not be ruled out. The mangrove associates may have derived from midland as well as upland vegetation zones.

POLLEN DIAGRAM AND PALAEOFLORISTIC COMPOSITION

Based on pollen statistics in a vertical profile from Balugaon covering a time span of 3,100 ± 270



Text-figure 7—Pollen diagram from Balugaon, Orissa.

years B.P., a pollen diagram (Text-fig. 7) has been prepared and relative frequencies of each pollen/spore taxon have been plotted. In all, five pollen assemblage zones have been proposed in ascending order and prefixed with the site initial, e.g., B-I to B-V and the zone B-V has been further subdivided into three zonules, viz., a, b, c. This has been done to express biostratigraphic units in terms of palaeovegetation and to translate significant events and episodes since the time of deposition of Balugaon sediments. Each zone has been separately discussed.

Zone B-I (5.50-4.40 m)

This zone is marked by an overall dominance of core mangrove taxa. All the four taxa, viz., *Rhizophora, Ceriops, Bruguiera* and *Kandelia* are clubbed together under Rhizophoraceae. It predominated the vegetation and attained maximum values in the first half, attaining a peak of about 20 per cent. Thereafter, it declined and later attained another peak at the close of the zone. *Avicennia* and *Acrostichum* made the humble beginning but improved later and attained peaks coinciding with the Rhizophoraceae. *Avicennia* has preference for brackish water conditions and is characteristic of lagoons with fluctuating water levels. It is also said that it can withstand salinity of up to 90 per cent albeit in dwarf condition (Branes, 1980). *Excoecaria* is consistently moderate throughout the zone. *Heritiera* is present in moderately good values in the first half of the zone and later vanished at the point of peak formation of Rhizophoraceae. *Avicennia* reappeared at top of the zone. *Nypa fruticans* and *Sonneratia*, inhabitants of high nitches, appeared in good frequencies in the bottom samples but vanished from rest of the zone

Mangrove associate taxa in this zone are inconsistent and sporadically high at places. For example *Cocos, Pandanus, Borassus*, Palmae, *Cerbera, Terminalia*, etc. and Fabaceae, *Barringtonia, Lagerstroemia, Abutilon, Emblica*, etc. are recorded from the upper and lower parts of the zone respectively. Hinterland vegetation is sporadic and scarce. The taxa belonging to upland vegetation are Meliaceae, *Justicia* and *Artemisia*. Poaceae, Cyperaceae and Chenopodiaceae are grouped under ubiquitous taxa in view of the fact that their members occur in all possible habitats and palynology does not help much in discriminating

the mangrove taxa from the taxa of other habitats. Nevertheless, the symphonic behaviour with the mangrove taxa could help in evaluating them for further interpretations. Aquatic taxa are represented by *Myriophyllum* in good values throughout but declined at the close of the zone. *Typha* is locally high in the lower half of the zone. Both monolete and trilete fern spores are abundant.

The palaeofloristic picture of zone B-I suggests that the arborescents were quite high attaining a peak of 60 per cent in the middle of the zone. It has also revealed that Rhizophoraceae, *Avicennia, Acanthus* and *Acrostichum* were the dominant, followed by *Excoecaria, Heritiera* and *Sonneratia* as co-dominant taxa. This feature of the vegetation depicts that the typical deltaic conditions prevailed during this phase encouraging widespread of core mangrove taxa.

Zone B-II (4.39-3.60 m)

It records the overall supression in the values of Rhizophoraceae as compared to the preceding zone. This supression in Rhizophoraceae is dotted with phenomenal rise in *Excoecaria* and *Heritiera*. *Acanthus* and *Acrostichum* continued almost in the same values as before except that the former experienced depression in the lower half and disappeared from the upper half of this zone.

Amongst the mangrove associates, some of the taxa such as *Barringtonia* and *Emblica* have achieved consistency. And rest of the taxa enumerated in the preceding zone remained sporadically high. However, some taxa like *Terminalia* and *Cerbera* are absent from this zone, and *Heliotropium* which was absent before, is locally high. Hinterland taxa maintain more or less same status as in Zone B-I. Poaceae, Cyperaceae and Chenopodiaceae show high values throughout, in the upper half of the zone.

Amongst aquatic taxa *Myriophyllum* continued in almost the same value but *Typha* disappeared. *Lemna* and *Potamogeton* are sporadically high. Trilete fern spores continued in reduced values while monolete fern spores disappeared. The long distance drifted taxa belonging to coniferae are recorded in greater values in the upper half of this zone which were otherwise sporadic in zone B-I.

The vegetation mosaic in Zone B-II differs slightly from the preceding zone. There is an overall impoverishment in the arborescent vegetation and the values do not exceed more than 30 per cent of the total counts. The supression in Rhizophoraceae and significant rise in *Avicennia, Excoecaria* and *Heritiera* supports the view that this phase experienced slight recession in the tidal magnitude and at the same time fresh water discharge increased proportionately encouraging the influx of salt tolerant taxa to withstand.

Zone B-III (3.59-2.40 m)

This zone has witnessed the total disappearance of Rhizophoraceae and significant improvement in *Nypa fruticans, Heritiera* and *Sonneratia* values. *Avicennia, Excoecaria* and *Acanthus* are present in reduced frequencies.

An overall spurt in the values of mangrove associate taxa has been recorded, albeit different taxa have shown different behaviour. Palmae, *Cerbera, Barringtonia* and *Emblica* maintained higher values in the upper half of this zone, whereas Urticaceae retained consistently good values throughout. Taxa like *Borassus, Terminalia*, Fabaceae, *Abutilon* and Malvaceae remained sporadically high. Likewise hinterland taxa in general have improved. The values for *Holoptelea*, Meliaceae, Oleaceae, *Artemisia* and Caryophyllaceae are more or less consistent. Poaceae and Cyperaceae have improved further maintaining considerably high values throughout the zone but two are not compatible. *Myriophyllum* is a dominant taxon amongst the aquatic taxa and maintains considerably high value throughout forming a peak of 22 per cent in the middle of the zone. *Typha, Lemna*, and *Potamogeton* are sporadically high in the lower and upper halves of this zone respectively. Both trilete and monolete ferns have almost disappeared except for they reappeared at the close of the zone.

Zone B-III is marked by considerable decline in the total values of arboreals in the beginning though it improved later scaling a peak in the middle of the zone and thereafter again declines. Disappearance of Rhizophoraceae alongwith significant suppression in *Avicennia* and corresponding rise in *Nypa fruticans, Heritiera* and *Sonneratia* suggest the cessation in the tidal magnitude giving pace to limnobios to thrive. *Nypa* is a palm of quiet estuaries or shallow lagoons in which fresh water runs. It prefers brackish water and does not occur on shores exposed to much wave action and never in hypersaline condition (Tomlinson, 1966). Likewise, *Heritiera* and *Sonneratia* also favour brackish water fringing the swamp forest and make their expansion in pure stands in the habitat with greater amount of fresh water discharge.

Zone B-IV (2.39-1.35 m)

There is significant change over in the vegetation mosaic from B-III to B-IV. Rhizophoraceae which disappeared in the preceding zone has reappeared in high frequencies and

continued throughout this zone. However, *Avicennia, Nypa fruticans, Heritiera* and *Excoecaria* have either reduced considerably or they became sporadically high. *Sonneratia* and *Acrostichum* have vanished but *Acanthus* maintained its consistency throughout.

Mangrove associates, in general, have recorded an improvement. *Lumnitzera, Terminalia*, Fabaceae and Urticaceae are found in greater values than preceding zone. *Casuarina*, supposedly an exotic tree, has earmarked in the middle of the zone and the date for this event could be extrapolated to around 800 years B.P. Hinterland taxa too, have improved and are marked by sporadically high values of Meliaceae, *Justicia*, Brassicaceae and Caryophyllaceae. *Holoptelea*, Oleaceae, etc. which were present earlier are absent in this zone. Poaceae and Cyperaceae have reduced but Chenopodiaceae has gained tremendously. Asteraceae has appeared and continued in good frequency in the first half and thereafter, declined from rest of the phase. Aquatic taxa have dwindled except for *Myriophyllum* which continued in low potential than before. *Nymphoides* has appeared in this zone and gained high percentage in the beginning but vanished later. Ferns have regained prominence and are present throughout the zone in considerably high values. This zone displays the overall dominance of Rhizophoraceae and Chenopodiaceae depicting the high magnitude of tides. Chenopods are tolerant of submersion and can colonise the shallows and even extend into the fresh water influenced zone.

Zone B-V (1.34-0.0 m)

On the basis of subtle but significant changes in the mangrove taxa and also being an important phase of human holocaust covering a time span of about 600-700 yrs B.P. has been subdivided into three subzones, viz., B-V, a, b, c.

Subzone B-V a (1.34-0.80 m)—It records high values of *Avicennia* followed by *Phoenix, Excoecaria, Lumnitzera* and *Terminalia*. *Casuarina* is on its climax maintaining significantly high values throughout. The other taxa of significant values are Malvaceae, Urticaceae, *Justicia, Artemisia*, Brassicaceae and Asteraceae.

Poaceae and Chenopodiaceae are present in their maxima but Cyperaceae has considerably reduced. There is an overall spurt in aquatic taxa in this subzone. *Typha* and *Myriophyllum* are represented throughout in moderate values whereas *Lemna* and *Nymphoides*, though confined in the lower half of this subzone, are present in high frequencies. Both monolete and trilete ferns have improved than before. The total arboreal constituents are low as compared to non-arboreals and do not exceed 20 per cent of the total vegetation.

Subzone B-V b (0.79-0.45 m)—This subzone is dotted by overall reduction exclusively in mangrove components. Rhizophoraceae and *Avicennia* have reduced drastically but *Heritiera* and *Phoenix* improved proportionately. *Terminalia* and Fabaceae have gained values. *Lumnitzera, Cerbera, Lagerstroemia*, Malvaceae, Urticaceae and Asteraceae are represented by good frequencies but most of them are not consistent.

Poaceae declined, Cyperaceae improved and Chenopodiaceae maintained constant rise attaining summit at close of the subzone. Aquatic taxa, except for *Myriophyllum*, have either vanished or declined to negligible as compared to the preceding subzone. Fern spores continued to be in lower values.

Subzone B—V c (0.44—0.0 m)—This subzone is marked by total extermination of mangrove constituents. The area is characterized by heathland except for *Terminalia*, Fabaceae, *Cocos, Phoenix* and *Acanthus* which are either sporadic or present in patches.

The evaluation of this zone reveals that the mangrove taxa experienced setback in general and displayed erratic behaviour. The mangrove associate and hinterland taxa have gained considerably. The first phase of this zone is marked by almost extermination of Rhizophoraceae and expansion of *Avicennia*. The midland and upland taxa improved significantly. In the second phase Rhizophoraceae lost stability; *Avicennia* declined; *Heritiera* and *Phoenix* improved. Besides, midland and upland taxa continued to rise. The third subphase is marked by total extermination of mangrove components and improvement in the midland and upland taxa, both quantitatively and qualitatively.

It is obvious from the foregoing account that during this phase covering a time span of 600-700 yrs B.P., the tidal magnitude ceased and incoming of fresh water increased causing considerable loss for the growth of exclusively mangrove components but, at the same time, human holocaust can also not be ruled out as there are legendary records of increasing biotic pressure over the swamp forest in the near past.

DISCUSSION AND CONCLUSION

Investigation of air catches conducted at the western flank of the lake near Barkul Panth Niwas has brought to our knowledge that none of the core mangrove or mangrove associate taxon is encountered in the pollen assemblage; rather,

pollen are mostly derived from heathland vegetation

The analysis of samples from different points within the lake have yielded rich pollen assemblage. Amongst them the taxa belonging to peripheral mangroves or mangrove associates predominate and the core mangroves rank second. However, core mangrove taxa are better represented in sample nos. 4 and 11.

The study of lake bottom mud samples has revealed that the core mangrove taxa are present in higher values as compared to lake water samples and corresponding reduction in the mangrove associate taxa has been noticed

The pollen analysis of surface soil samples from in and around Chilka Lake does not show comparability in all the samples. For instance, sample no. 9 records highest values for core mangrove taxa whereas they are poor in sample nos. 7 and 10.

Thus, the overview of modern samples analysis has brought forward that they do not hold uniformity. In all probabilities, this could be explained as due to the under water channels or canyons which govern the movement of the water both from sea and river into the Chilka Lake and, therefore, depending upon the sampling site, the pollen assemblage may or may not record marine influence. In general, mangrove associates remained dominant and core mangroves co-dominant in the pollen assemblage This assessment is exclusive of *Casuarina*—an introduced plant, and ubiquitous taxa like Poaceae, Cyperaceae and Chenopodiaceae. The pattern of pollen spectra so obtained does not match with the present day vegetation because the prevailing condition of mangrove degradation exists far and wide all around the lake owing to the heavy biotic pressure. In view of the above facts the interplay of pollen from far off distances cannot be ruled out, and this has been considered as an intricate problem for the reconstruction and interpretation of palaeofloristics.

The pollen diagram constructed from Balugaon has been phased into five zones in ascending chronological order and the total time taken in the development of Balugaon sediments is *ca* 3,100 years. While discussing the pollen diagram, we have categorized the whole vegetation as core mangrove, mangrove associate, hinterland, ubiquitous, aquatic and long distance drifted taxa. This has enabled us to assess the vegetation mosaic and also the drift of pollen grains from their provenance. In addition, the information obtained from modern sample study has been considered instrumental for the correct evaluation of vegetal complexes.

Zone B-I took about 700 years for its development and sedimentation is estimated to be laid down at the rate of 1 cm per 7 years. This zone enjoyed the luxuriant growth of core mangroves. Amongst all the taxa encountered, Rhizophoraceae predominated the vegetation in the first half; *Avicennia* and *Acrostichum* came into the prominence in the later half of this zone. *Excoecaria* and *Heritiera* remained moderate. *Nypa fruticans* and *Sonneratia* were encountered during early part of the zone. Mangrove associates and hinterland taxa remained inconsistent and sporadic throughout. The palaeofloristic picture depicts that the deltaic environments prevailed and encouraged reasonably good spread of core mangrove taxa. In view of the vegetal variations in lower and upper parts of this phase, it is clear that during early part there had been more sea water influence which enabled Rhizophoraceae to flourish and advance. It declined in the later half owing to fluctuation in the sea level

Zone B-II spanned for about 500 years and the rate of sedimentation is more or less similar to the preceding phase. This phase is marked by steep depression in Rhizophoraceae and phenomenal rise in *Excoecaria* and *Heritiera*. *Acanthus*, too, reduced and *Acrostichum* disappeared from the second half of this phase. *Barringtonia* and *Emblica* improved and maintained consistency. The reduction in Rhizophoraceae, significant rise in *Avicennia, Excoecaria, Heritiera*, etc. and spurt in mangrove associate taxa suggest that this change over in the vegetational influx might have been due to the recession in the tidal magnitude and at the same time increase in the fresh water discharge.

Zone B-III, in general, is a period for luxuriant growth of mangrove taxa, like *Nypa fruticans, Heritiera* and *Sonneratia*. Nevertheless, Rhizophoraceae is absent all through and *Avicennia, Excoecaria, Acanthus*, etc., have reduced considerably than before. Mangrove associate and hinterland taxa have shown remarkable improvement. Values for aquatic taxa have also improved. This set up in the mangrove vegetation wherein Rhizophoraceae is either absent or sporadic characterises the progradation of delta as a result the exposed land is flooded more with the fresh water rather than sea water. This condition lasted for about 800 years which is the total period taken for the development of this phase.

Rhizophoraceae which vanished in the preceding zone has reappeared and continued in high frequencies throughout the Zone B-IV. *Acanthus* and Chenopodiaceae behaved symphonically with Rhizophoraceae and maintained high consistency throughout. *Avicennia, Nypa*

fruticans, Heritiera, Excoecaria, etc., have either significantly reduced or remained sporadically high. *Sonneratia* and *Acrostichum* have disappeared from this zone. Mangrove associates and hinterland taxa have experienced an improvement. Aquatic taxa have registered a decline and ferns have improved. This phase spanned for about 500 years and is characterised by regular inundation of landmass. In all probabilities, the depressed sea level during the preceding phase was restored to the original level in this phase or else storm surges, hurricanes, etc., produced high water levels creating congenial conditions for Rhizophoraceae members to colonize.

Zone B-V covers a time span of about 600-700 years and is over burdened by immense human pressure. This phase on the basis of subtle but significant changes in the mangrove and hinterland vegetation has been subdivided into three subphases. Subphase 'a' lasting for about 300 years, records good existence of *Avicennia, Excoecaria, Acanthus, Lumnitzera, Terminalia*, etc. *Casuarina* is present in its climax whereas Rhizophoraceae experienced a steep fall in its values. Subphase 'b' is recognised by an overall depression in mangrove components and subphase 'c' is dotted with total extermination of mangrove constituents. This phase, in the history of mangrove vegetation development, is important as it signifies the degraded mangrove vegetation owing to the biotic holocaust. The man entered into the landscape with greater force and better understanding of mangrove wealth causing irrepairable loss to the forest. Similar results are obtained from Sunderban-Gangetic plain, Bengal (Gupta, 1981).

Palynostratigraphical analysis of a 3.0 m deep profile at Paradip Island near the mouth of Mahanadi River has revealed a degraded pattern of mangrove vegetation since the time of sedimentation around 500 yrs B.P. (Gupta & Yadav, 1990). The periodicity and intensity by both pastoralists and arabalists have been assessed in terms of vegetation development step by step. In the last phase of Paradip pollen diagram covering total time span of about fifty years, ruthless damages to the vegetation could be correlated with the record date around 35 years B.P., when construction of Paradip port came into being and a vast land was denuded. The total development at Paradip could be compared with the last phase of Balugaon pollen diagram with minor variations of local importance. However, the notable difference observed between the two, concerns the occurrence of reworked Permian pollen from nearby colliery in Paradip sediments which are absent from Balugaon. The occurrence of reworked pollen at Paradip suggests that there had been faster rate of water flow carrying a huge amount of sediments and depositing at the mouth of river. This feature is noticeable by virtue of quick sedimentation at Paradip which is estimated to be at the rate of 1 cm in less than two years.

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