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PALAEOENVIRONMENTS DURING HOLOCENE TIME IN BENGAL BASIN, INDIA AS REFLECTED BY PALYNOSTRATIGRAPHY

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ABSTRACT

This study incorporates the results of pollen analyses of one profile each from Kolara, Barrackpore, Namkhana and Chaltiya in the Bengal Basin. The pollen diagrams have been translated in terms of past vegetation and on the basis of changes in the plant communities, the biostratigraphical zonation could be possible. The palaeotemperatures, subsidence and/or submergence of forest between 7,000-5,000 years b.p. have been concluded.

Radiocarbon dating has revealed that the process of peatification in the basin took place between 5,000-2,000 years b.p. The lithostratigraphic evidences have further revealed that the maximum peatification took place in the west and east of Calcutta. The peat beds had begun to reduce towards north and south of Calcutta and ultimately disappeared in the extreme north and south, indicating the environs being not conducive for peatification.

Key-words — Palynostratigraphy, Palaeoenvironments, Holocene, West Bengal, India.

साराँश

बंगाल बेसिन, भारत में परागाणुस्तरिकी द्वारा प्रक्षिप्त होलोसीन कालीन पुरावातावरण – हरिपाल गुप्त

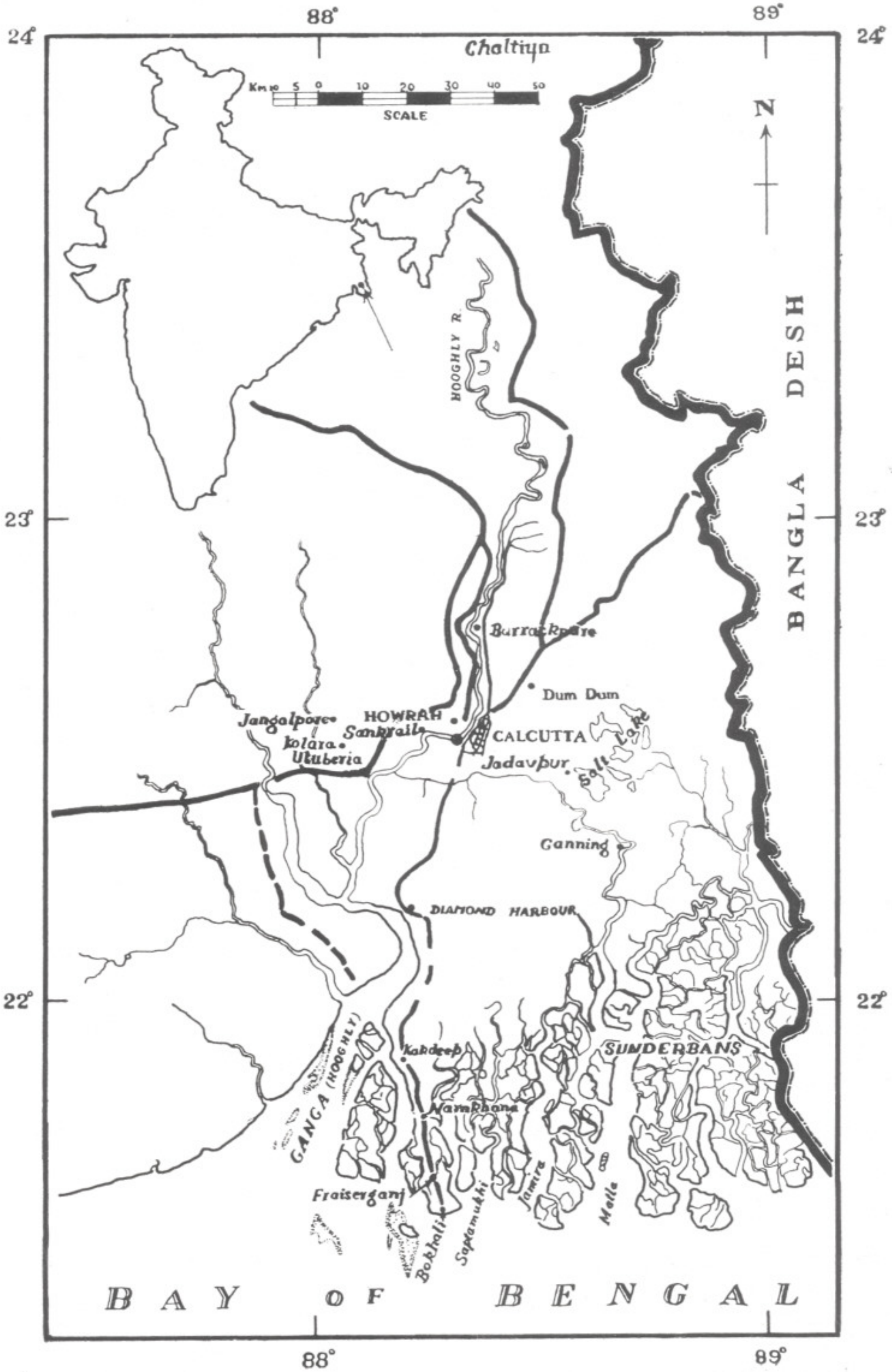
प्रस्तुत अध्ययन में बंगाल बेसिन में स्थित कोलारा, बेरकपुर, नामखाना एवं चलतिया से प्रत्येक की एक-एक परिच्छेदिका के परागकण-विश्लेषणों के परिणामों को प्रस्तुत किया गया है। परागकण-चित्रों को विशेष ढंग से अतीतकालीन वनस्पति के रूप में प्रदर्शित किया गया है तथा पादप समुदायों के आधार पर ही जीव-स्तरिकीय मंडलन संभव हो सका है। पुरातापक्रम, धँसाव तथा 7,000 से 5,000 वर्ष पूर्व की अवधि में जलप्लावन को उपसंहृत किया गया है।

रेडियोकार्बन कालनिर्धारण से यह व्यक्त हुआ कि इस बेसिन में पीट-संघटन का प्रक्रम 5,000 से 2,000 वर्ष पूर्व की अवधि में हुआ था। इसके अतिरिक्त अश्म-स्तरिकीय प्रमाण व्यक्त करते हैं कि अधिकतम् पीट-संघटन कलकत्ता के पूव एवं पश्चिम में हुआ था। कलकत्ता के उत्तर एवं दक्षिण में पीट संस्तर कम होने लगे तथा अन्त में बाह्यतम् उत्तर एवं दक्षिण दिशा में बिल्कुल विलीन हो गये। इससे यह इंगित हुआ कि इन दो दिशाओं के वातावरण पीट संघटन हेतु सहायक नहीं थे।

INTRODUCTION

THE present study deals with the pollen analyses of one profile each from Kolara (22°33′N 88°5′E), Barrackpore (22°50′N 88°18′E), Namkhana (21°45′N 88°15′E) and Chaltiya (24°2′N 88°4′E; Map 1). Kolara lies near the bank of Hooghly River about 35 km west of Calcutta and the area is occasionally flooded by the back flow of water during the high tides. Barrackpore lies about 40 km north-east of Calcutta and is rarely flooded by river water. Chaltiya is situated at the higher ground on the northern flank of Calcutta. Analysis of Chaltiya profile has proved that it is palynologically barren. Namkhana lies within the Sunderbans and is about 20 km inland from the sea-shore. A channel known as Hityani River, passes across the Namkhana. The area is regularly flooded by tidal waters.

The heavy pressure of human activities has adversely affected the indigenous vegetation in Bengal Basin. Kolara, Barrackpore and Namkhana are left bare lands as


88°
89°
24°
23°
22°
Chaltiya
Km 10 5 0 10 20 30 40 50
SCALE
N
HOOGHLY R.
BANGLA DESH
Barrackpore
Dum Dum
HOWRAH
Jangalpore
Sankrail
Kolara
Uluberia
CALCUTTA
Jadavpur
Salt Lake
Canning
DIAMOND HARBOUR
Kakdeep
SUNDERBANS
GANGA (HOOGHLY)
Namkhana
Fraiserganj
Bokhali
Saptamukhi
Jamira
Matla
BAY OF BENGAL

MAP 1

a result of recent deforestation. However, the scattered plantation of *Cocos nucifera*, *Phoenix* sp. and a few legumes constitute the arboreal vegetation. *Casuarina* plantation along the sea-shore has been recently introduced to check the soil erosion. Around Chaltiya, the plantation of mango, litchi, bamboo, babool and coconut is quite common.

The pollen analyses of Holocene sediments in and around Calcutta were earlier carried out by Das (1961), Mallik (1969), Chanda and Mukherjee (1969), Gupta (1970, 1978), Vishnu-Mittre and Gupta (1972), Mukherjee (1972a, b), and Chanda (1974). The results of the above data have been collectively discussed in the discussion part.

Geology — Bengal is characterized by a large alluvial basin floored with Quaternary sediments deposited by Ganges and Brahmaputra rivers and their numerous distributaries. The development of Quaternary terrain was first discussed by Bagchi (1944) in certain portions of deltaic regions of West Bengal. The structural activities, primarily faulting, has significantly influenced the Quaternary geology of Bengal Basin. Oldham (1859), Spate (1954) and Rizvi (1955) have suggested that the older alluvium of Bengal is the Pleistocene terrace material. Wadia (1966), however, distinguished Bengal alluvial plains into two groups, viz., (i) older alluvium (*Bhangar*) corresponding to the Middle Pleistocene occupying the higher grounds forming small plateaus which are too high to be flooded by rising rivers, and (ii) younger alluvium (*Khadar*) being recent in age, occupies the lower levels. The active flood plains comprising mainly clay and peat sediments in Bengal Basin are known since more than one hundred years (East, 1818; Smith, 1841). Morgan and McIntire (1959) have opined that four major areas of older alluvium exist in Bengal Basin, one east of Rajmahal Hills and one west of folded Tripura Hills. The other two areas lie within the basin and are known as Barind and Madhupur jungles. Banerjee (1964) has classified West Bengal into a number of morphological units without giving the details of genetic synthesis. Sen Gupta (1966) has also made a brief geological and geophysical study in western part of Bengal Basin. Based on lithology, structure and tectonics Niyogi *et al.* (1970) have recognized two geomorphic provinces (Pleistocene & Recent) during Quaternary period in West Bengal. They have emphatically suggested that all the landforms belong to Middle-Upper Pleistocene whereas the coastal plains belong to Recent age.

The existence of 0·90-1·20 m thick peat bands at varying depths in and around Calcutta are known since long (Oldham, 1893). An array of C14 dates has revealed that the process of peatification at different places in the basin did not take place at one and the same time rather it ranged between 5,000 to 2,000 years b.p. The occurrence of wood stumps and roots *in situ* is the most significant feature of the peat bands (Oldham, 1893; Ghosh, 1941, 1964; Ghosh, 1957; Ghosh & Negi, 1958; Mukherjee, 1969). Presently the author has discovered wood stumps *in situ* from the underneath clay zone at Kolara and these stumps have been identified as *Heritiera* and *Sonneratia* woods (Pl. 2, fig. 3). The position of these stumps is vertical, horizontal and also slant in the sediments. The vertical position of *Heritiera* stumps with attached knee roots (Pl. 2, fig. 4) afford the evidence of submergence of forest in the basin.

Sediments examined in the basin consist of clay, organic mud (amorphous peat), silt and sand. The grain-size and mineral analyses of these sediments have revealed that the Pleistocene sediments are identical with those of recent flood plains deposits (Morgan & McIntire, 1959). Pleistocene and Recent sediments do not differ in maximum grain-size but an excess of very fine-grained material is found in Pleistocene sediments though this could also be due to weathering and/or pedogenesis. Recent sediments are darker in colour and loosely compact with high water contents whereas Pleistocene sediments are oxidized, reddish-brown in colour, mottled and contain calcareous nodules with low water contents.

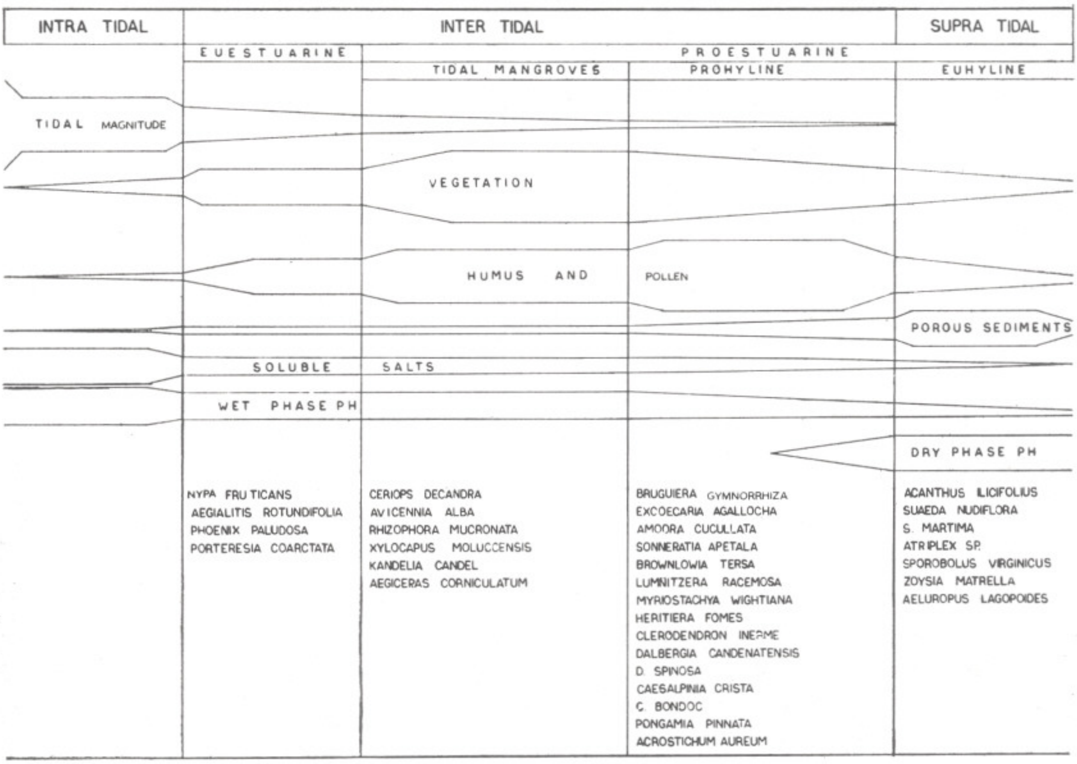
The preliminary petrological analysis of Namkhana sample (at 1·8 m depth) has revealed pH=8, $CaCO_3$ (mostly calcite) =0·50% and organic carbon=0·609% and no siderite could be detected whereas Kolara sample (at 4 m depth) has revealed pH=3·3, traces of $CaCO_3$ and organic carbon= 6·93% (personal communication from Dr S. N. Rajaguru of Deccan College, Pune).

Vegetation — The aboriginal vegetation has been exterminated from a large area of the basin as a result of intensive human interference. *Heritiera littoralis*, once abundantly growing in western parts of Bengal Basin, is absent today. Nevertheless, patchy occurrence of mangroves is seen protected in extreme south abutting on the Bay of Bengal. Champion and Seth (1968) have described vegetation type of Bengal as Tidal Swamp Forest under which four major subtypes such as mangrove scrubs, mangrove forest, salt-water mixed *Heritiera* forest and brackish-water mixed *Heritiera* forest have been recognized more or less in an ecological sequence from sea to inland. The palm swamp has been separately dealt within the salt water mangrove scrubs, occupying the dry nitches.

Rao and Sastry (1974) have given a very useful account of the ecology of the Gangetic-Sunderbans complex with Hooghly-Haria-bhanga estuarine system. They have considered tidal swamp forest sensu Champion and Seth, 1968 as estuarine complex and based on soil types, the vegetation has been categorized into two types, viz., Euestuarine — nearer the sea and Proestuarine — farther the sea (Text-fig. 1).

Euestuarine — In this soil type the indicator plants grow on muddy relief which is under constant influence of tides. Plants show high degree of fidelity and sociability with a shallow area under tidal influx or elevated dry nitches bordering the estuarine water and land. The characteristic vegetation of this type consists of *Nypa fruticans* (on protected streams), *Phoenix paludosa* (on elevated dry fringes), *Aegialitis rotundifolia* (nearer the sea) and *Porteresia coarctata* (on newly formed areas along the bank).

Proestuarine — This composite vegetation is further divisible into three subtypes, viz., (i) Tidal Mangroves — characterized by the luxuriant growth of scrubs and tree species of mangroves such as *Ceriops decandra, Avicennia alba, Rhizophora mucronata, Xylo-*



TEXT-FIG. 1 — Gangetic-sunderbans estuarine complex, West Bengal (after Rao & Sastri, 1974: A modified sketch).

carpus (*Carapa*) *moluccensis*, *Kandelia candel* and *Aegiceras corniculatum*, (ii) Prohyline — marked by brackish water conditions which is favourable for the growth of salt tolerant fresh water plants such as *Bruguiera gymnorhiza*, *Excoecaria agallocha*, *Amoora cucullata*, *Sonneratia apetala*, *Brownlowia tersa*, *Lumintzera racemosa*, *Myriostachya wightiana*, *Heritiera fomes*, *Clerodendrum inerme*, *Dalbergia candenatensis*, *D. spinosa*, *Caesalpinia crista*, *C. bonduc*, *Pongamia pinnata* and *Acrostichum aureum* — an indicator of secondary conditions (Rao *et al.*, 1973), and (iii) Euhyline — marked by highly salt tolerant fresh water plants which grow under conditions of apparent wetness or dryness, viz., *Acanthus ilicifolius*, *Suaeda nudiflora*, *S. maritima*, *Atriplex* sp., *Sporobolus virginicus*, *Zoysia matrella* and *Aeluropus lagopoides*, etc.

MATERIAL AND METHOD

The material for pollen analyses was collected from freshly dug out pits. Before procuring the samples the wall surface of the pit was properly scrapped out to avoid any external contamination. Thereafter, the inner core of sediments was picked up at a desired depth in the measured section and stored in the sample tubes and sealed with paraffin wax. Samples for radio-carbon dating were collected in lump (approx. 1/2 kg each) at the measured depth at the junction of lithostratigraphic change and also from similar deposition.

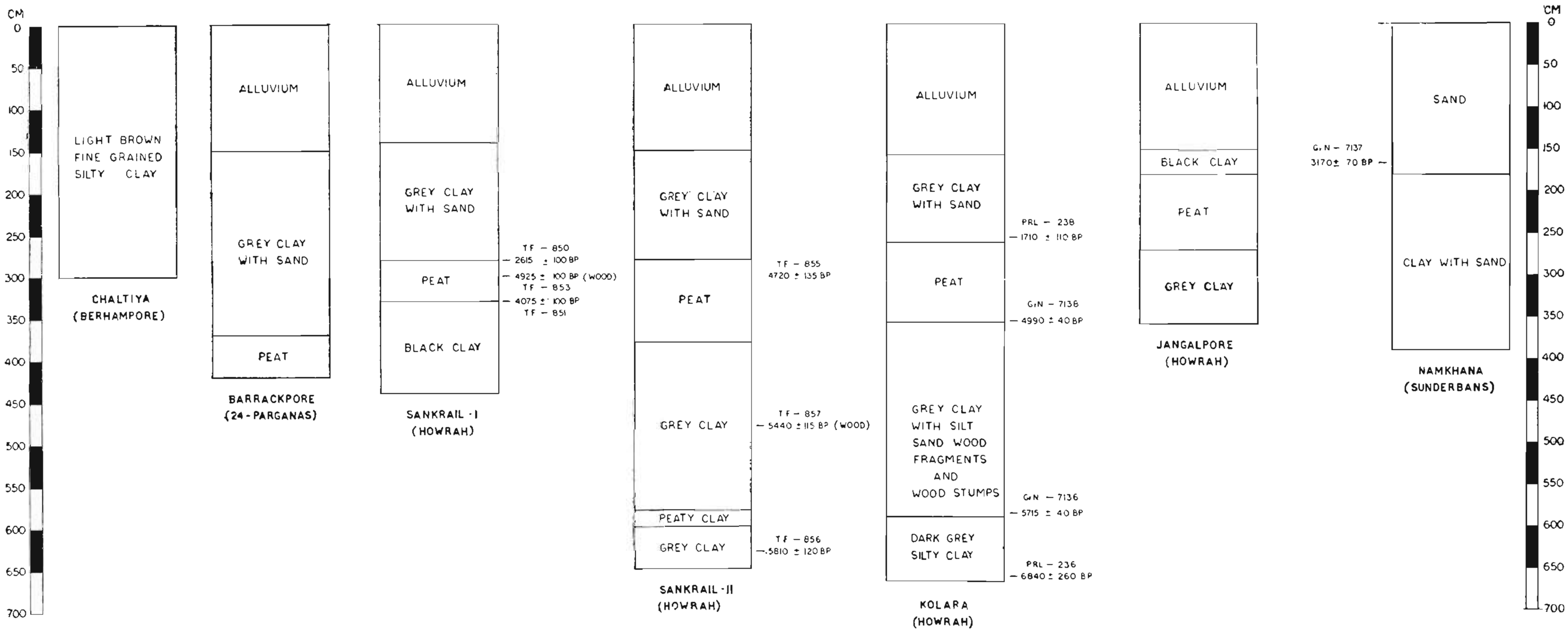
Twenty gram of the material from each sample was gently ground and treated with concentrated HCl to remove the carbonates and then these were boiled with 10% aqueous solution of KOH in order to deflocculate the matrix and to liberate the pollen and spores. Thereafter, the whole sample was sieved through 200 mesh. The residue was examined for macroscopic plant remains. The filterate after centrifuge was subjected to HF treatment for about 48 hrs and then processed through usual technique of acetolysis (Erdtman, 1943, 1952). Finally the material was preserved in 50% aqueous solution of glycerine plus a few drops of phenol. The percentages for all taxa have been calculated in terms of total counts. The resolved pollen diagrams have been constructed. The + sign in the pollen diagram denotes values less than one per cent.

The zonation of pollen diagrams is independent of other areas and is based on the recognition of biostratigraphic units (pollen assemblage zones) from the palynostratigraphy of each of the profiles studied. The zonations of pollen diagrams are not dependent on each other and thereby they are considered as local pollen zones. These are prefixed with the site initials, e.g. KO (Kolara), BA (Barrackpore), NA (Namkhana) and numbered in chronological order. An attempt has also been made to synchronize different pollen sequences on the basis of vegetational shifts and C14 dates of individual profile investigated. For the purpose of regional parallelism, other profiles investigated earlier from Bengal Basin have also been taken into consideration. The profiles which have not received C14 dates, have been compared with the well-dated profiles elsewhere in the basin. The assemblage zones made here are strictly in accordance with the code of International Subcommission on Stratigraphic Classification (Hedberg, 1976). The name of assemblage-zone has been derived from two or more of the prominent and diagnostic constituents of the pollen assemblage. Some of the pollen assemblage zones have been divided into subpollen zones to express finer biostratigraphic details.

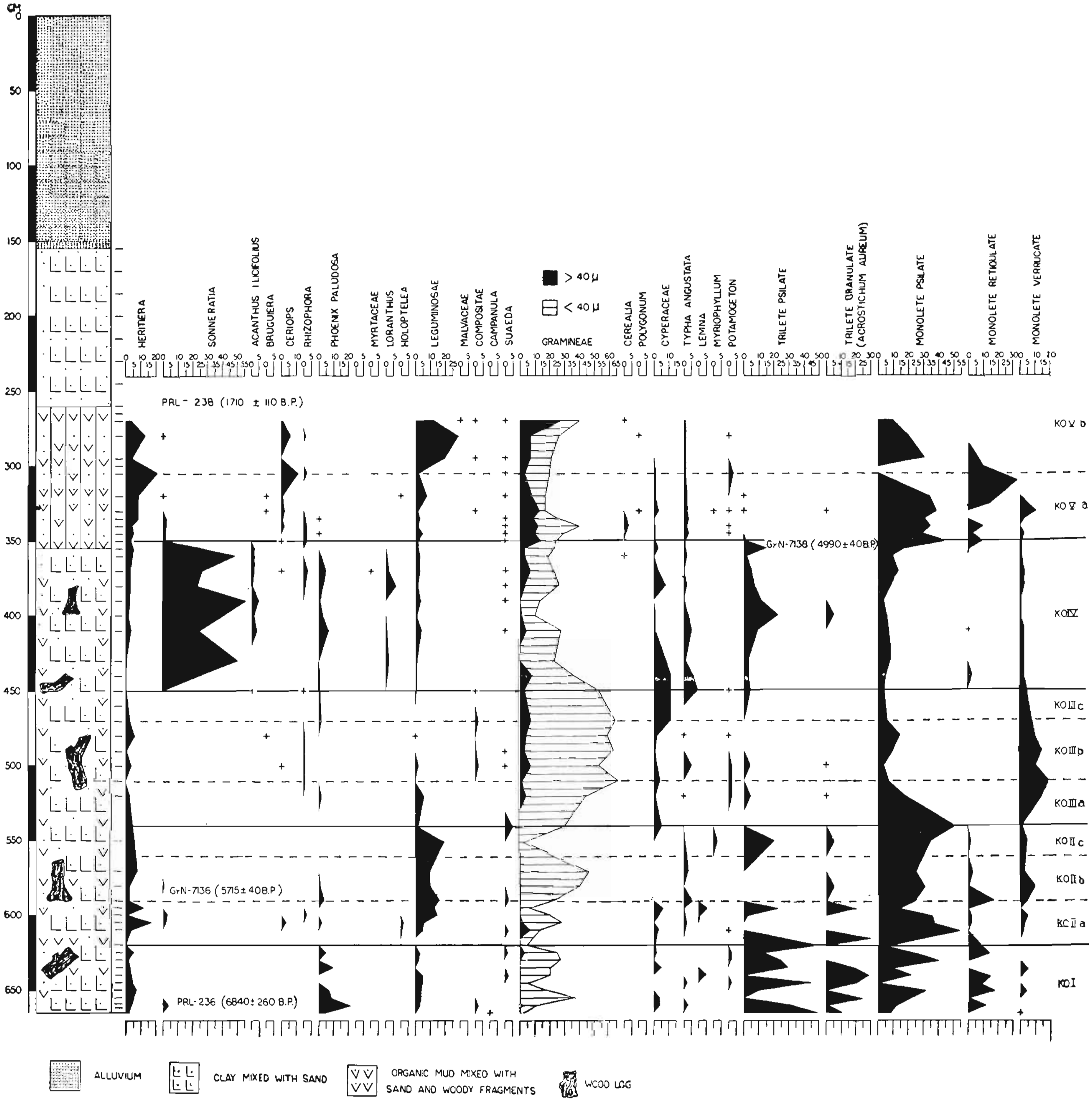
STRATIGRAPHY

The Holocene stratigraphy of Bengal Basin (Text-fig. 2) is characterized by the occurrence of light-dark grey clays, peat, interbedded with clay beds. Peat beds are generally thin ranging from 50-100 cm in thickness. Peat is amorphous in nature and quickly cracks when exposed to atmosphere. Mud, silt and sand constitute the upper part of lithostratigraphy and ranges from 140-160 cm in thickness (Pl. 1, figs 1, 2; Pl. 2, fig. 3).

In general, the deposition of sand, silt and clay seems to be fluviatile in nature. The clay was probably deposited under swampy conditions which was often inundated by back flow of river water. The peat might have been formed by ponding of water under quiet conditions and this probably suggest the cessation in inundation. The Namkhana profile (Sunderbans), south of Calcutta, is about 4 m deep but does



TEXT-FIG. 2 — Stratigraphy of Bengal Basin.



TEXT-FIG. 3 — Pollen diagram from Kolara, West Bengal (Percentages calculated in terms of total counts).

not possess peat and instead it possesses coarse brown sand with little clay and more soluble salts. Similarly Chaltiya profile, extreme north of Calcutta, is about 3 m deep and is devoid of peat but the sediments are comprised of an excessive fine-grained material.

The lithostratigraphy of the present profiles studied and the earlier from Sankrail and Jangalpore (Vishnu-Mittre & Gupta, 1972), Bagirhat, Baidyabati, Belagachia and Salt lakes (Mukherjee, 1972b) has revealed that the maximum peatification took place in the west and east of Calcutta. The peat beds tend to reduce towards north and south of Calcutta and ultimately the peat beds disappeared towards extreme north (Chaltiya) and extreme south (Namkhana) indicating environs not conducive for peatification.

Kolara Profile — It is the thickest amongst all profiles studied. An array of C14 dates has revealed that the rate of sedimentation was not uniform throughout. The 75 cm thick bottom sediments of underneath clay zone was deposited in 1125 years at the rate of 1 cm per 15 years. These data enable the author to believe that the rate of deposition was slow and took place under less disturbed conditions. The top 230 cm sediments of underneath clay zone was deposited in 725 years at the rate of 1 cm per 3 years. This indicates a rapid deposition as a result of flooding episodes by rising and advancing currents. The peat formation took place under lacustrine conditions at a very slow rate. The one metre thick peat bed was deposited in 3280 years at the rate of 1 cm per 33 years. The deposition of upper clay and sand took place in 1710 years at the rate of 1 cm per 6·5 years. Thus, the Kolara lithostratigraphy reveals that the deposits are mainly of two kinds, viz., lacustrine and fluviatile laid down more or less in alternating fashion. Details of lithostratigraphy are given below:

0-155 cm — Alluvium with coarse sand and silt.
155-260 cm — Grey clay with sand and silt.
260-358 cm — Black amorphous peat with abundance of woody fragments.
358-590 cm — Grey clay with sand and silt. Woody fragments and wood stumps quite common.
590-665 cm — Dark grey clay with very fine silt. Woody fragments less frequent.

Barrackpore Profile — In the absence of C14 dates for this profile, it is thought worthwhile to correlate it with Kolara profile. Two profiles are more or less akin to each other and hence the top of the peat bed could be synchronous. The metachroniety exists only in overlain clay zone which is double the thickness in Barrackpore profile. Details of stratigraphy are given below:

0-150 cm — Coarse sand and silt.
150-370 cm — Grey clay with sand and silt.
370-420 cm — Black amorphous peat.

Namkhana Profile — The sediments throughout the Namkhana profile are divisible into two parts mainly on the basis of sand contents, viz., top sand with clay (170 cm thick) and bottom sandy clay (220 cm thick). The sediments at the depth of 165 cm have been radiometrically dated to 3170 ± 70 years b.p. and the age for the base of the profile could be extrapolated to *ca.* 7000 years b.p. The deposition was laid down at the rate of 1 cm per 19 years indicating slow rate of sedimentation throughout the profile. Thus, the bottom sediments being sandy clay might have been deposited under lagoonal condition. But the top sediments, being mostly sandy in nature, reflect that the deposition might have been taken place under tidal flat conditions. The sedimentation in the tidal flats is generally controlled by the contemporaneous deposition and erosion resulting into a slow rate of deposition. Details of lithostratigraphy are given below.

0-170 cm — Brown sand with clay. Soluble salts excessively present.
170-390 cm — Dark brown sandy clay with lesser amount of soluble salts.

POLLEN DIAGRAMS AND THEIR COMPOSITION

KOLARA POLLEN DIAGRAM

The whole pollen diagram (Text-fig. 3) has been divided into five local pollen zones and the zones II and III have been further divided into three subzones whereas zone V has been divided into two subzones. This has been done to express finer biostratigraphic details and to elaborate the significant events during Holocene epoch.

Zone KO-I (665-620 cm)— This zone is characterized by the occurrence of *Heritiera* and *Phoenix* pollen grains in good frequencies right from the base of pollen diagram. *Sonneratia* pollen grains are seen at the base and top respectively. Leguminosae is well-represented throughout this zone. Small-sized graminoid pollen occur in good frequencies (up to 37%) throughout the zone whereas large-sized graminoid pollen appeared only at the upper zone limit. *Suaeda* pollen is seen up to 2% from about the middle of the zone. Compositae (2%) and a single pollen of *Campanula* could be seen at the lower zone limit. Cyperaceae registers discontinuously high values throughout this zone. *Typha angustata* and *Potamogeton* are sporadically present in the upper and lower zone limits respectively. *Lemna* appeared in good frequencies (5%) only in the middle of this zone. Fern spores including *Acrostichum aureum* are present abundantly.

The lower limit of zone KO-I is radiometrically dated to 6840 ± 260 years b.p. (PRL-236). The pollen assemblage of this zone depicts a picture of brackish water mixed *Heritiera* forest with a sprinkling of *Sonneratia*, Leguminosae and *Suaeda*, etc. *Phoenix paludosa* is the co-dominant constituent of this zone which might have occupied the dry elevated fringes. *Acrostichum aureum*, alongwith other monolete and trilete fern spores, is abundantly found and indicates the fresh water conditions. The occurrence of *Potamogeton*, alongwith *Lemna*, *Typha angustata* and Cyperaceae further confirms the fresh-water environments.

Zone KO-II (620-540 cm)— This zone is defined by high pollen frequencies of *Heritiera* and Leguminosae and a sprinkling of *Sonneratia*, *Ceriops*, *Rhizophora*, *Phoenix paludosa*, *Holoptelea* and *Suaeda*. Small-sized graminoid pollen register increased values than the preceding zone. The large-sized graminoid pollen record high values in the beginning and thereafter disappeared. Cyperaceae is discontinuously high and *Potamogeton* more or less disappears. *Typha angustata* has increased frequencies than before but *Lemna* and *Myriophyllum* are locally high. *Acrostichum aureum* shows gradual decline upwards. Trilete psilate fern spores form a discontinuously high curve. The values for monolete psilate fern spores have risen tremendously recording two summits of 54% and 52% at the lower and upper zone limits respectively. Monolete reticulate fern spores, after attaining a peak (18%) a little below the middle of zone, declined upwards. Monolete verrucate fern spores have registered continuously high values than the preceding zone. The zone is divisible into three subzones.

Subzone KO-IIa (620-590 cm)— There is a sudden rise in the values of *Heritiera*. The values for *Phoenix paludosa* fall. The values for Leguminosae slightly improved showing steep rise in the upper half of this subzone. *Sonneratia*, *Ceriops*, *Rhizophora* and *Holoptelea* are locally high in the upper half of this subzone. *Suaeda* is sporadically high throughout. Small-sized graminoid pollen are fluctuatingly high in the middle whereas large-sized graminoid pollen attain a peak (7%) in the lower half of this subzone and thereafter disappeared. Cyperaceae is lowly present throughout showing upward increase and *Typha angustata* appeared in the middle showing upward increase. *Lemna* (6%) is locally high towards the upper limit of this subzone whereas a single pollen of *Potamogeton* could be encountered a little below the middle of this subzone. *Acrostichum aureum* attains two summits of 30% and 20% at lower and upper subzone limits respectively and trilete psilate fern spores have reduced to nil except that it regains high values (23%) at the upper limit. The monolete psilate fern spores show a steep rise in the middle and steep fall at the boundaries whereas monolete reticulate fern spores are abundant at the boundaries and low in the middle. Monolete verrucate fern spores commence a little below the middle showing fluctuatingly high values towards the upper subzone limit.

There is a definite increase in the values of fresh-water salt resistant taxa such as *Heritiera* and *Sonneratia*. The appearance of *Ceriops* and *Rhizophora* pollen grains in this subzone is attributed as drifted from the Tidal Mangroves Zone as a result of aggradation. This composition of vegetation in this zone suggests the prevalence of fresh-water conditions with a slight mixture of brackish water.

Subzone KO-IIb (590-560 cm)— There is a fall in the values of *Heritiera* and Leguminosae except they rose slightly towards the upper subzone limit. The curves for *Phoenix paludosa* and *Suaeda* show steep decline. The curve for small-sized graminoid pollen has, however, rose tremendously. The high values for Gramineae here could be assigned to *Porteresia coarctata* since it colonizes the newly formed areas under tidal influx. The curve for *Typha angustata* record high values than before and there is complete break in the curves for Cyperaceae, *Lemna*, *Myriophyllum*, *Potamogeton* and trilete psilate fern spores. The values for *Acrostichum aureum* have extremely dwindled down and ultimately its curve ceases in the upper half of this subzone. The curves for all the monolete fern spores are fluctuatingly low.

The total disappearance of fresh-water aquatic plants, reduction in the values of *Heritiera*, ferns and Leguminosae and the tremendous increase in the curve for Gramineae (*Porteresia coarctata*) have revealed a great degree of tidal influx in the prevailing fresh water environments. The lithology of this zone remains $\pm$ same as before and has provided the evidences to deduce that the rate of deposition was very fast. The lower subzone boundary has been radiocarbon dated at 5715 ± 40 years b.p. (GrN-7136).

Subzone KO-IIc (560-540 cm) — The beginning of this subzone is marked by steep fall in the curve of Gramineae and the rise in Leguminosae. *Heritiera* records a gradual decline in its curve throughout the subzone. *Suaeda* and Cyperaceae appeared in high values just at the upper boundary in contrast to the sharp decline in the curve of Leguminosae. *Typha angustata* declined upwards but *Myriophyllum* with good values appeared in the middle of this subzone. The values for *Acrostichum aureum* alongwith other monolete and trilete fern spores improved well in the middle.

The vegetational development of the subzone KO-IIc suggests that the conditions remained almost the same as in the preceding subzone except for the short-phased cessation in the tidal water indicating the dry pH phase.

Zone KO-III (540-450 cm) — The zone is determined by the maximum development of Gramineae (*Porteresia coarctata*) and the maximum fall in the values of fern spores except for the monolete verrucate fern spores. The tree pollen frequencies have been highly reduced. The Cyperaceae pollen curve continues to be low except its values shoot up towards the upper part of the zone.

The dates for lower and upper limits of zone KO-III are not known. The rate of deposition is $\pm$ uniform throughout since the times of subzone KO-IIb to zone KO-IV and therefore, the date for lower and upper limits of zone KO-III could be extrapolated at *ca.* 5600 and 5300 years b.p. respectively. This zone is divisible into three subzones.

Subzone KO-IIIa (540-510 cm)— The pollen curve for *Heritiera* registers a gradual decline whereas Leguminosae shows a steep decline. The values for *Phoenix paludosa* became sporadic and *Rhizophora* just commenced at the upper boundary. The Gramineae attains high values showing a gradual rise upward. Cyperaceae is lowly present and *Typha angustata* is sporadic. *Potamogeton* appeared in the upper half of this zone and maintained low curve. *Acrostichum aureum* has reduced to almost nil and other fern spores register steep decline in their curves except for monolete verrucate fern spores which experienced high values showing gradual increase upward.

Subzone KO-IIIb (510-470 cm) — This subzone does not significantly differ from the preceding subzone except that the values for Gramineae (*Porteresia coarctata*) further rose and large-sized graminoid pollen are also higher than before. There is also some improvement in the values of *Heritiera*. *Bruguiera* and *Ceriops* are marked by one pollen grain each. *Rhizophora* maintains a low curve throughout. Leguminosae is further reduced and ultimately became sporadic in the upper half of this subzone. Cyperaceae maintains a low but continuous curve whereas *Typha angustata* is discontinuously high. *Potamogeton* and *Acrostichum aureum* are sporadic. The fern spores show an overall decrease in their values.

Subzone KO-IIIc (470-450 cm) — The general pattern of vegetation is very much similar with the preceding subzones except that the values for Gramineae declined and Cyperaceae increased. Single pollen of *Acanthus ilicifolius* is also encountered at the upper boundary.

The general vegetation pattern of the zone KO-III has revealed that the area was frequently inundated by the river water. It may be recalled here that because of the induced brackish water conditions most of the fresh-water elements such as *Lemna*, *Myriophyllum* and *Potamogeton*, etc. have either vanished or became very sporadic.

Zone KO-IV (450-350 cm)— This zone is determined by exceedingly high values of *Sonneratia* which attains three summits of 50%, 55% and 48% at the lower, middle and upper zone limits respectively. *Acanthus ilicifolius* maintains good frequency pollen curve in the upper two-third of this zone. The values for *Heritiera* have reduced considerably but the values for *Phoenix paludosa* have increased proportionately. *Ceriops* and *Rhizophora* are sporadic and low respectively in the upper zone limit. *Loranthus* commenced right at the beginning of this zone in low frequencies but improved its values in the upper half of this zone. Leguminosae maintains a low but continuous curve throughout the zone. Myrtaceae is attested by the presence of one pollen grain only. *Suaeda* is sporadically present throughout the upper half of this zone. Small-sized graminoid pollen (*Porteresia coarctata*) experienced a steep decline whereas large-sized graminoid pollen remained static. Cyperaceae and *Typha angustata* attained high values in the beginning and thereafter continued in low values throughout the zone. *Lemna*, *Myriophyllum* and *Potamogeton* are totally absent from this zone. *Acrostichum aureum* is also absent but for an appearance in the middle of the zone. The fern spores on the whole reduced but for trilete psilate spores which registered high values.

The upper boundary of this zone is dated to 4990±40 years b.p. (GrN-7138). The lithostratigraphy continues to be the same as in the preceding zones. The total period taken for the development of this zone is about 300 years. From the above account of the vegetation it is deduced that the velocity of tidal water was reduced and ± dry pH phase was developed being favourable for the growth of salt tolerant fresh-water plants such as *Sonneratia*, *Acanthus ilicifolius* and *Suaeda*.

Zone KO-V (350-260 cm)— This zone is marked by steep decline in the values of *Sonneratia* which ultimately became sporadic. The values for *Heritiera* and Leguminosae have improved more than the preceding zone. *Ceriops* also shows tremendously high values. Small-sized graminoid pollen grains (*Porteresia coarctata*) have reduced but large-sized graminoid pollen grains improved. There is a general improvement in the fresh-water aquatic pollen grains. Trilete fern spores have reduced to nil whereas monolete fern spores register high frequencies in general.

This zone is also characterized by a change in the lithostratigraphy, i.e. from clay zone to peat zone. The lower and upper zone limits have been radiocarbon dated at 4990±40 years b.p. (GrN-7138) and 1710±110 years b.p. (PRL-238) respectively. Thus the time taken for the establishment of this zone is 3180 years. This zone is divisible into two subzones.

Subzone KO-Va (350-305 cm)— This subzone records very low values for *Sonneratia* till the lower half and soon after it disappeared. *Heritiera* records gradual increase attaining a maximum of 21% at the upper subzone boundary. *Bruguiera* and *Phoenix paludosa* are sporadic whereas *Rhizophora* maintains discontinuously low values. *Ceriops* commences in low values right at the beginning of this subzone attaining a maximum of 11% at the upper subzone boundary coinciding the peak point of *Heritiera*. *Holoptelea* and Compositae are represented by one pollen each. Leguminosae maintains low but continuous curve showing upward rising trend. *Suaeda* is sporadically abundant. Gramineae in general remains the same as in the preceding zone except for the increase in the large-sized graminoid pollen curve. A few cerealia type of pollen (60 μm) have been encountered in the beginning and thereafter they diminished. Cyperaceae and *Typha angustata* maintain low curves throughout whereas *Polygonum*, *Myriophyllum* and *Potamogeton* are sporadically abundant. Trilete fern spores declined to sporadic values but the monolete fern spores have proportionately increased.

The overall picture of the subzone KO-Va depicts a cessation in the flooding episode and the quiet conditions prevailed which enabled the peat formation in ponding water. The curves for all the taxa in this subzone are very much in accordance with the ecological behaviours except for the *Ceriops* which is quite abundant and a misfit in the prevailing fresh-water environments. However, at the moment *Ceriops* pollen grains could be interpreted as transported through the agency of wind and/or water.

Subzone KO-Vb (305-260 cm)— This is characterized by the decline in the values of *Heritiera* and *Ceriops* and an abrupt rise in Leguminosae curve. *Sonneratia*, *Rhizophora*, Compositae, Malvaceae, *Suaeda*, *Polygonum*, *Potamogeton* and cerealia pollen remain sporadic. *Typha angustata* is present in low values throughout the subzone. Gramineae (both small & large-sized) has improved further. Fern spores on the whole reduced to nil except for monolete psilate fern spores which record quite good values throughout.

This subzone does not significantly differ from the preceding subzone both lithologically and palynologically except for local changes in the pollen values. Thus climatologically it is almost in continuance of the previous one.

Barrackpore Pollen Diagram

In this profile the peat bed is devoid of fossil pollen and spore contents before the successive pollen zones and thereby this complete thickness of peat is considered as barren interzone and referred to informally by reference to the adjacent pollen zone for example BA-I.

Zone BA-I (375-310 cm)— This zone is delineated by the high values of *Heritiera* throughout. *Bruguiera* registers localized high values slightly below the middle of this zone. The values for *Holoptelea* commenced in good frequencies right at the beginning of the zone and thereafter declined to nil in the middle but regained high values at the upper zone boundary. *Pinus* pollen are locally abundant. The Gramineae pollen curve is found in low frequencies except it attains very high values at the upper zone boundary. *Suaeda* is present throughout maintaining a fluctuatingly good pollen curve. *Campanula*, Cyperaceae and *Typha angustata* are confined only in the lower half of the zone in good frequencies. *Potamogeton* maintains a fluctuatingly high pollen curve attaining two summits (30%) one each at the lower and the middle of the zone but shows a steep decline at the upper zone boundary. A few diatoms (pennate forms) could also be encountered at the lower part of the zone coinciding with the peak of *Potamogeton* pollen curve. The fern spores are present almost throughout the zone in good frequencies.

At the moment there is no evidence plausibly good to be assigned for the absence of pollen and spores from the peat band. However, the differential pollen preservation due to extensive chemical reaction, i.e. oxidation and microbiological activities over the pollen and spores could be the possible explanation for the absence of pollen grains from peat.

The face value analysis of each pollen curve of Zone BA-I depicts that the deposition took place under quiet environments when fresh-water conditions prevailed. Hardly any lithological or biological evidence has been noticed that supports the tidal influence and hence the area was far away from the reach of tidal water.

Pinus pollen grains in this zone are the results of long distance transportation from hillside. The high frequency of *Holoptelea* pollen grains does testify the dry tropical climate registering a rise in temperature.

Zone BA-II (310-235 cm)— This zone is characterized by the maximum development of *Holoptelea*. It would not be erroneous to name it as *Holoptelea* Acme-zone since no other taxon of the preceding zone BA-I continues in this zone except for the sporadic occurrence of *Heritiera*, *Pinus* and *Typha angustata*.

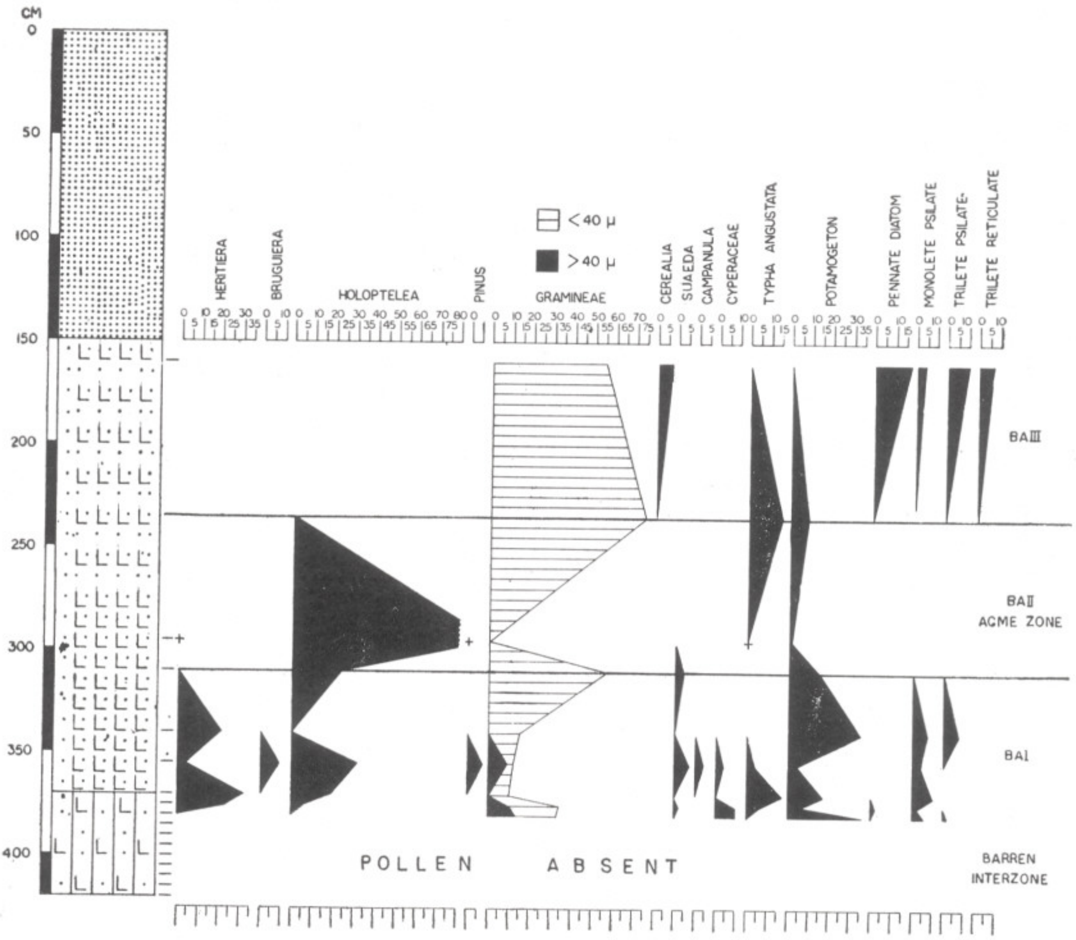
Nevertheless, 100% values for *Holoptelea* and sudden disappearance of aquatic elements alongwith ferns and *Heritiera*, enables to conclude that due to further rise in temperature the evaporation increased resulting into the drying up of ponds, etc.

Zone BA-III (235-140 cm)— In this zone the arboreals disappeared and Gramineae rose suddenly maintaining high values. Cerealia type pollen appeared in low frequency in the beginning but gradually improved upwards. *Typha angustata* and *Potamogeton* appeared in high values in the beginning and thereafter declined upwards. Fern spores are present in high frequencies towards the upper zone limit.

The overall picture of Zone BA-III reveals that the area was beyond the reach of tides but the localized damp conditions were restored owing to rains, etc.

Namkhana Pollen Diagram

Zone NA-I (390-370 cm)— The pollen sequence of this zone is characterized by steep rise of *Ceriops* (45%) and *Rhizophora* (7%) pollen curves in the middle. *Bruguiera*, *Acanthus ilicifolius*, *Sonneratia* and *Pongamia* are present in comparatively much low

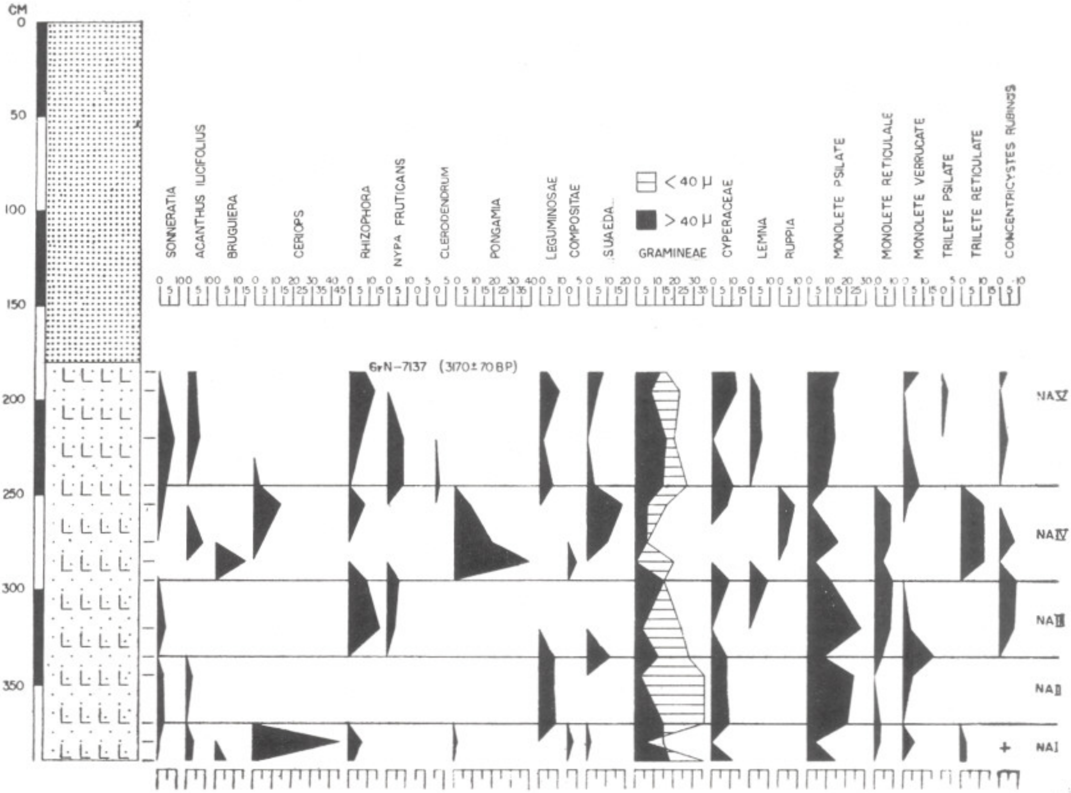


TEXT-FIG. 4 — Pollen diagram from Barrackpore, West Bengal (Percentages calculated in terms of total counts).

values. Amongst non-arboreals *Suaeda* and Compositae are lowly present whereas Gramineae, Cyperaceae and monolete psilate fern spores are abundantly high in the lower and upper zone limits showing steep decline in the middle of the zone. The other fern spores are lowly present. Single remain of *Concentricystes rubinus* has been encountered.

In general, the *Ceriops-Rhizophora* vegetation dominated during zone NA-I, indicating tidal mangrove forest. On the margins of the tidal mangroves, *Bruguiera*, *Acanthus ilicifolius*, *Sonneratia* and *Pongamia* grew. Thus the overall picture of vegetation with the appearance of an animal remain (*Concentricystes rubinus*) characteristic of marine environments strongly suggest that the area was under the constant influence of tides during this zone and the date for this zone is extrapolated between *ca* 6500-7000 years b.p. from the one C14 date 3170 ± 70 years b.p. (GrN-7137).

Zone NA-II (*370-330 cm*)— This zone is characterized by the sudden disappearance of *Ceriops* and *Rhizophora*. The curve for Leguminosae (*Dalbergia* spp.) suddenly appeared and maintained high values (9%) throughout the zone. The curves for *Sonneratia* and *Acanthus ilicifolius* continued throughout with a slight rise in their values. *Suaeda* (12%) is locally high at the upper zone boundary. Gramineae, Cyperaceae and monolete fern spores maintain high pollen curves throughout the zone. The other fern spores continue to be low.



TEXT-FIG. 5 — Pollen diagram from Namkhana (Sunderbans), West Bengal (Percentages calculated in terms of total counts).

The disappearance of *Ceriops*, *Rhizophora* and *Concentricystes rubinus* from this zone reveals the regression in the tides which enabled the salt-tolerant fresh-water plants such as *Sonneratia*, *Acanthus ilicifolius*, etc. to colonize the area. Further, the abundance of *Suaeda* and fall in Cyperaceae and monolete psilate fern spores at the upper zone boundary reveals the short period of dry pH phase. The date for this zone is extrapolated between *ca* 5800-6500 years b.p.

Zone NA-III (330-295 cm)— It is marked by the reversal of high values of *Rhizophora* alongwith *Nypa fruticans*. *Acanthus ilicifolius* is absent in this zone but *Sonneratia* continues in low frequencies throughout. *Concentricystes rubinus* makes a sudden appearance and maintains high frequencies (10%) throughout the zone. Gramineae and Cyperaceae declined considerably. Monolete fern spores on the whole attain high values in the beginning and thereafter tend to decline upwards. *Lemna* pollen grains are encountered in high percentages at the upper zone boundary.

The overall picture of the vegetation depicts that the salt-water mangrove scrubs existed during this zone and after a gap of about 700 years the area was again within the encroachment of the sea and under the constant influence of tides. The occurrence of high pollen frequencies of *Nypa fruticans* suggests that they preferred the protected streams. This conclusion is further corroborated by the high frequencies of *Concentricystes rubinus*. The high pollen frequency of *Lemna* at the upper zone limit could be due to its cosmopolite nature. The date for this zone could be extrapolated between *ca* 5000-5800 years b.p.

Zone NA-IV (295-245 cm)— This zone comprises an admixture of both types of forests such as Tidal Mangroves and Prohyline Vegetation. *Bruguiera*, *Acanthus ilicifolius*, and *Pongamia* are abundant in the lower half whereas *Ceriops*, and *Rhizophora* are abundant in the upper half of this zone. *Sonneratia* shows a considerable decline. The pollen curve for *Suaeda* is quite high attaining a summit (18%) towards the upper zone limit. *Clerodendrum* has made its appearance for the first time in the upper half of this zone. Gramineae shows a general decline throughout but Cyperaceae has reduced to nil except it regained its values towards the upper zone limit. *Ruppia* pollen is first seen a little below the middle of zone and thereafter maintains high frequencies reaching to a maximum of 9% towards the upper zone limit. The monolete fern spores are fluctuatingly high but trilete reticulate fern spores are abundantly present throughout this zone. The curve for *Concentricystes rubinus* is discontinuously high attaining maximum values a little below the middle of zone.

The foregoing account of vegetation of this zone does not give a very clear picture as to which forest type it belongs since there is an admixture of both tidal mangroves and prohyline vegetation. However, the occurrence of *Ruppia* and *Concentricystes rubinus* alongwith *Ceriops* and *Rhizophora* has confirmed that ecologically it is the continuation of the preceding zone, i.e. the area was under the tidal influx and *Bruguiera*, *Acanthus ilicifolius*, *Pongamia* and *Suaeda* grew on the elevated dry nitches bordering the estuarine water and land. The date for this zone has been extrapolated between *ca* 4000-5000 years b.p.

Zone NA-V (245-185 cm)— The curve for *Sonneratia* and *Acanthus ilicifolius* improved and maintained high values throughout the zone. *Ceriops* pollen curve disappeared but *Rhizophora* pollen curve shows a gradual upward rise attaining high values towards the close of this zone. *Nypa fruticans* maintained high values throughout the lower half and soon after declined to nil in the upper half of this zone. The curve for *Clerodendrum* remained low in the lower half of the zone and thereafter diminished. *Pongamia* is absent but Leguminosae (*Dalbergia* spp.) reappeared right at the beginning and maintained fluctuatingly high pollen curve. *Suaeda* has reduced to nil in the middle, showing increased tendency upward. Gramineae has risen more than before maintaining high values throughout the zone. Cyperaceae pollen curve is high at the lower and upper zone limits except it experiences a sudden setback in the middle of the zone. *Lemna* is present in high frequencies throughout but *Ruppia* is altogether absent in this zone. Monolete psilate fern spores are abundant throughout whereas other fern spores are very lowly present. The curve for *Concentricystes rubinus* is low but continuously present throughout the zone.

A glance over the vegetational development of this zone reveals that the magnitude of tides in this area was much reduced as a result of that the salt tolerant fresh-water constituents increased and encroached the area in contrast to the tidal mangrove constituents. The upper limit of this zone has been dated to 3170 ± 70 years b.p. (GrN-7137).

CORRELATION OF LOCAL POLLEN ZONES AND FORMULATION OF REGIONAL POLLEN ASSEMBLAGE ZONES

The local pollen zones delineated in the pollen diagrams from Kolara, Sankrail, Jangalpore and Barrackpore in the west and east of Calcutta are more or less identical both lithologically and palynologically and the minor differences encountered in them may be referred to as local variations. Thus, on the basis of synchroneity amongst the local pollen zones in different pollen diagrams, a number of regional pollen assemblage zones have been recognized. Since the profile from Kolara depicts $\pm$ a perfect picture of lithostratigraphy, palynostratigraphy and chronostratigraphy, its pollen diagram has been considered as the basis for the purpose of regional zonation. The Namkhana profile extreme south of Calcutta, has been dealt with separately as it shares no affinities with the Kolara profile. The regional pollen assemblage zones for west and east of Bengal Basin are as defined below:

HERITIERA-PHOENIX PALUDOSA-LEGUMINOSAE-GRAMINEAE-FERNS ASSEMBLAGE ZONE

Type Site — Kolara, District Howrah, local zone KO-I and II, depth between 665-540 cm.

Zone Diagnosis — The arboreals such as *Heritiera* and *Phoenix paludosa* are the predominant pollen types. The Leguminosae amongst non-arboreals is by far the most dominant pollen type. Gramineae and ferns are fluctuatingly high.

Contacts — This zone is the lowest in the sequence. The upper zone limit is marked where the curves of *Heritiera*, Leguminosae and ferns begin to fall and the curve for Gramineae rises consistently.

Age — The date for lower boundary as extrapolated from one radiocarbon date immediately above the lower zone boundary at Kolara (PRL-236) is *ca* 7000 years b.p. and the date for upper zone boundary is extrapolated from one radiocarbon date immediately below the upper zone boundary at Kolara (GrN-7136) is *ca* 5600 years b.p.

Gramineae-Cyperaceae-Heritiera-Ferns Assemblage Zone

Type Site — Kolara, district Howrah, local zone KO-III, depth between 540-450 cm.

Zone Diagnosis — This zone is marked by the maximum development of grasses and reduction in the arboreals except for *Heritiera* which continues in low values throughout. Cyperaceae is found in comparatively good frequencies and ferns in low frequencies in comparison to the preceding zone.

Contacts — The upper boundary is marked where the Gramineae curve begins to decline and *Heritiera* reduced almost to nil.

Age — The date for the upper boundary, as extrapolated from the two extramural radiocarbon dates (GrN-7136 & GrN-7138) falls at *ca* 5300 years b.p.

Sonneratia-Acanthus Ilicifolius Phoenix Paludosa-Loranthus-Typha Angustata Assemblage Zone

Type Site — Kolara, district Howrah, local zone KO-IV, depth between 450-350 cm.

Zone Diagnosis — This zone is characterized by over all dominance of arboreals. *Sonneratia* has exceedingly high values throughout the zone. *Heritiera*, *Phoenix paludosa*, *Loranthus*, Leguminosae maintain low but continuous curves throughout the zone. *Acanthus ilicifolius* is represented by fairly good frequencies but only in the upper half of this zone. *Typha angustata* is fairly frequent. Grasses are much reduced.

Contacts — The lower zone boundary is marked where the pollen of *Sonneratia* first appeared and the upper zone boundary is marked where the values of *Sonneratia* are reduced almost to nil.

Age — The upper zone boundary is dated to 4990 ± 40 years b.p. (GrN-7138).

Heritiera-Ceriops-Leguminosae-Gramineae-Ferns Assemblage Zone

Type Site — Kolara, district Howrah, local zone KO-V, depth between 350-250 cm.

Contacts — The lower zone boundary is marked by the resumption of *Heritiera*.

Zone Diagnosis — It is characterized by high values of *Heritiera*, *Ceriops*, Leguminosae, Gramineae and fern spores.

Other known sites — This assemblage zone, but for local differences, is also found at Sankrail, Jangalpore and Barrackpore pollen diagrams. At Sankrail and Jangalpore the values for *Rhizophora* pollen curve are much higher than the type site. At Barrackpore the *Holoptelea* pollen curve predominated the arboreal vegetation which is absent from the type site.

Age — The upper zone boundary has been radiocarbon dated to 1710 ± 110 years b.p. (PRL 238).

The regional pollen assemblage zone for south of Bengal Basin (Namkhana) are defined as below:

Ceriops-Rhizophora-Leguminosae-Concentricystes Rubinus-Gramineae-Cyperaceae and Ferns Assemblage Zone

Type Site — Namkhana (Sunderbans), Bengal, local zones NA-I, II and III, depth between 390-295 cm.

Zone Diagnosis — It is characterized by the localized high values of *Ceriops*, *Rhizophora*, *Concentricystes rubinus* and Leguminosae. Gramineae, Cyperaceae and fern spores maintain continuously high values throughout.

Contacts — This zone is the lowest in sequence of pollen bearing sediments. The upper zone limit is placed where the *Rhizophora* declines and *Pongamia* commences.

Age — No radiocarbon dates for this zone are available. However, on the basis of one available date (GrN-7137) and keeping in view the rate of sedimentation the age for the base of this zone is interpolated at *ca* 7000 years b.p. and the age for upper zone boundary falls at *ca* 5500 years b.p.

Pongamia-Ceriops-Bruguiera-Suaeda Ruppia-Concentricystes Rubinus Assemblage Zone

Type Site — Namkhana (Sunderbans), Bengal, local zone NA-IV, depth between 295-245 cm.

Zone Diagnosis — It is characterized by exceedingly high values of *Pongamia* pollen. *Ceriops*, *Bruguiera*, *Ruppia*, *Suaeda* and *Concentricystes rubinus* are locally high. The values of Gramineae and Cyperaceae are reduced.

Contacts — The lower and upper zone boundaries are marked where *Pongamia* pollen curve commences and declines respectively.

Age — The age for upper zone boundary extrapolated from the one available radiocarbon date (GrN-7137) falls at *ca* 4500 years b.p.

Sonneratia Acanthus Ilicifolius-Nypa Fruticans Assemblage Zone

Type Site — Namkhana (Sunderbans), Bengal, local zones NA-V, depth between 245-185 cm.

Zone Diagnosis — It is marked by high values of *Sonneratia* and *Acanthus ilicifolius* and the disappearance of the *Ceriops*.

Contacts — The lower zone boundary is marked where *Sonneratia* and *Acanthus ilicifolius* improve and *Rhizophora* decreases.

Age — The upper zone boundary is radiocarbon dated to 3170 ± 70 years b.p. (GrN-7137).

DISCUSSION AND CONCLUSION

Re-evaluation of the Previous Work

While discussing the vegetation and palaeoenvirons of the Bengal Basin as revealed by the present investigations, it is deemed necessary to discuss the previous palynological analyses, which are mainly confined to the west and east of Hooghly River. Das (1961) has reported some of the pollen and diatoms from the recent sediments of a pond near Garia whereas Mallik (1969) has preliminarily enumerated a list of microfloristics of Calcutta peat from different localities pioneering in the field of pollen analyses of Holocene sediments in Bengal Basin. Chanda and Mukherjee (1969), while making a brief report of taxa recovered from Bagirhat and Salt Lake profiles, have concluded the human settlement and agricultural practices. It is evidently based on the large quantity of cerealia pollen and the associated weed like *Plantago*. This conclusion would have definitely been altered if the existence of autogamy amongst the cereals and the autiquity of wheat in Bengal Basin would have been well considered. The wheat is known to be introduced in Bengal during 1000 years B.C. (Vishnu-Mittre, 1968) and *Plantago* is an associated weed of wheat and not of rice. Mukherjee (1972a), while elaborating the prehistoric steading, has chosen the size as the only criterion for establishment of steading which was in fact suggested by Firbas (1937) for European countries in the absence of other criteria available about half a century ago. This is not the safe criterion particularly for Indian subcontinents where large number of gasses are found to occur. Thus, owing to size overlap in wild and cultivated grasses it is not feasible to draw a demarcation line between wild and cultivated grass pollen. In the present communication I have classified grass pollen into three categories on the basis of size alone, viz., less than 40 μm, between 40-60 μm, and more than 60 μm. The pollen grains of 60 μm and above, whom I consider as cerealia type, are very less and do not occur till the last zone. Thus the events of farming as inferred by Chanda and Mukherjee (1969) and Mukherjee (1972a) need to be re-established. Mukherjee (1972b) has pollen analysed the peat profiles from Bagirhat, Belgachia, Salt lakes and Baidyabati of the east-west flanks of the Bengal Basin. However, the work deserves a few comments, viz., (i) the pollen diagrams lack clarity and comparability. The construction of resolved pollen diagrams would have been of paramount importance for the legibility of the taxa instead of giving composite pollen diagrams alone, (ii) Mukherjee has recognized I-VI pollen zones in all the pollen diagrams but the object and basis for the zonation remains obscure. The validity of the zonation of pollen diagrams would have been accepted if it had been in accordance with the code of stratigraphic nomenclature of India (1971), and (iii) the recognition of pollen taxa from sediments need re-evaluation as below:

— The pollen of *Anacardium* is recognized right from the base of the profile vide zone I, p. 365 but surprisingly enough it is a native of South America and recently introduced in India along the coasts (Brandis, 1906; Santapau & Henry, 1973).

— The *Xanthium* is a common annual weed (Santapau & Henry, 1973) and not an associated weed of cultivation as pointed out on page 145.

— The two statements, viz., *Suaeda* is a swampy plant vide zone I, p. 361 and the presence of Chenopodiaceae pollen indicates the initial stage of reclamation vide zone I, p. 366 are self contradictory. Nevertheless, chenopods do not occur in swamps instead they prefer dry alkaline soils.

— Nearly 50% vegetation was constituted by *Heritiera* vide zone I, p. 369 then how Chanda and Mukherjee (1969) presumed of a typical mangrove throve existed in and around Calcutta *ca* 5000 years b.p. vide para 2, p. 2.

— *Melaleuca leucandendron* is an Australian species and planted as hedge in Indian gardens (Brandis, 1906; Santapau & Henry, 1973). Therefore, the identification of *Melaleuca* pollen is yet to be confirmed.

— *Aegle marmelos* grows in dry regions of Indian subcontinents (Santapau & Henry, 1973) and not in swamps as pointed out by Mukherjee.

— The 12 species of the genus *Terminalia* occur in India and none has been reported to occur in coastal regions particularly in Bengal (Brandis, 1906, p. 311). Thus, the pollen identified from the sediments are yet to be confirmed.

— The *Capparis* spp. are mostly confined to arid regions (Brandis, 1906) and not to the swamps or as indicator of cultivation.

The report of saprophytic fungi and their attack on pollen and spores from Bengal Basin (Gupta, 1970, 1978) leading to the degradation of pollen and spores, is one of the factors controlling the preservation of pollen and spores. The results obtained from pollen analytical investigation of Sankrail and Jangalpore profiles (Vishnu-Mittre & Gupta, 1972) corroborate with the present work except the former differs in having excessive pollen of *Rhizophora*.

Vegetation and Environments

The vegetation history is metachronous throughout the Bengal Basin. Therefore, the vegetation of east, west and south of Bengal Basin has been separately dealt with.

West and East of Bengal Basin — The vegetation has been defined under the following four phases.

Phase I — In the western and eastern parts of Bengal Basin the vegetational history commences with the brackish water mixed *Heritiera* forest in which *Phoenix paludosa* and Leguminosae grew in quite good frequencies. *Sonneratia* pollen are sporadic. The ground vegetation during this phase was largely inhabitated by ferns including *Acrostichum aureum*. Gramineae occurred in good frequencies except for a sharp decline in its values at the close of this phase. The other herbage is represented by the stray occurrence of Compositae, *Suaeda* and *Campanula*. *Potamogeton*, *Lemna*, *Typha angustata* and Cyperaceae are the sole representatives of the aquatic environments. The frequencies of the above taxa are low and discontinuous. From the aforesaid account of vegetation of phase-I, it is deduced that the fresh-water environments with a little mixing up of brackish water existed in and around Kolara *ca* 7000 years b.p. The climate might have been warm and humid.

Phase II — During Phase II *Heritiera* shows an overall increase in its values whereas *Phoenix paludosa* has reduced tremendously and finally disappears. Leguminosae curve has increased right in the beginning and attained high values in the later part. The lower part of this phase is also characterized by stray occurrence of brackish water elements such as *Rhizophora*, *Ceriops* and *Sonneratia*. A few pollen of *Holoptelea* are also noticed which had been probably drifted from the adjacent warm and dry zones. Gramineae curve registered much higher values than the preceding phase. The values for *Suaeda* and *Typha angustata* have improved whereas Cyperaceae and other hydrophytes have declined. Ferns are overall increased except for *Acrostichum aureum* which have considerably declined during upper part of this phase. However, the environments during lower part of phase II appear to have been similar to the preceding phase but during upper part of phase II they vastly differ in having a great degree of tidal influx in the prevailing fresh-water environments.

Phase III — It is determined by exceedingly high values of *Sonneratia*. *Acanthus ilicifolius*, *Phoenix paludosa* and *Loranthus* are the co-dominant arboreal taxa. *Heritiera* curve is highly reduced. Small-sized graminoid pollen are much reduced in contrast to large-sized graminoid pollen. Indeed, there is an overall decrease in the ground vegetation. This phase is also marked by the occurrence of cerealia type pollen at the close which has been radio-carbon dated to 4990 ± 40 years b.p. (GrN-7138). The composition of vegetation during this phase is suggestive of either reduction in the magnitude of tidal water or cessation in the tide suitable for the luxuriant growth of salt tolerant fresh-water taxa such as *Sonneratia* and *Acanthus ilicifolius*.

Phase IV — This phase is marked by the disappearance of *Sonneratia* and *Acanthus ilicifolius*. The values for *Heritiera*, *Ceriops* and Leguminosae show a gradual upward increase. Small-sized graminoid pollen have reduced whereas large-sized graminoid pollen have increased correspondingly. There is a general improvement in hydrophytes and ferns except for trilete ferns which are almost absent in this phase. There is a change in the lithostratigraphy from preceding phases, i.e. from clay to peat. The overall picture of this phase depicts a cessation in the flooding episode and the quiet conditions prevailed which enabled the peat formation in ponding water.

Comparison with other Pollen Diagrams — At Barrackpore there are no radiocarbon dates so far available from the profile, but it is evident to assume that the pollen sequence is not older than *ca* 1500 years b.p. as determined on the basis of radiocarbon dates available from Kolara profile. Lithologically this profile resembles with the upper part of Kolara profile, i.e. sediments above peat zone. Zone BA-I is analogus with the top of Kolara pollen sequence where it exhibits the predominance of *Heritiera*, ferns and large-sized graminoid pollen. But in the subsequent zones BA-II and III, the vegetation is dominated by the *Holoptelea* and Gramineae depicting warm and dry climatic environs which largely differ from Kolara profile.

The pollen sequences from Sankrail and Jangalpur are quite analogous with the zone KO-V of the Kolara profile except that Sankrail and Jangalpur pollen diagrams record higher percentages of *Rhizophora* pollen.

Submergence and/or Subsidence of Forest — It is reasonable to assume the submergence and also the subsidence of forest from Kolara profile. This assumption is strengthened by the fact that lithology and chronology of Kolara profile provide the clues of the rate of sedimentation, viz., (i) the bottom 75 cm thick sediments of the underneath clay zone was deposited at the rate of 1 cm per 15 years indicating the normal rate of deposition, (ii) the top 230 cm sediments of the underneath clay zone was deposited at the rate of 1 cm per 3 years indicating a very rapid deposition, and (iii) the peat deposition took place at the rate of 1 cm per 33 years indicating a very slow rate of deposition. The upper alluvium was deposited at the rate of 1 cm per 6·5 years which seems to be aeolian in origin. The lithostratigraphy also affords the evidence of tree stumps in the underneath clay zone. These woods have been identified as *Heritiera* and *Sonneratia*. The position of these stumps is vertical, horizontal and slant as well. The vertical position of *Heritiera* wood stumps with intact knee roots afford the evidence of subsidence owing to submergence of land as a result of diastrophic activities.

The area seems to be initially represented by a coastal deltaic plain with normal deposition which has later on affected by the floodings, causing the subsidence in the area resulting into the formation of lake basins suitable for the formation of peat. Thus the Holocene sedimentation in the eastern and western parts of Bengal Basin passed through three different phases, viz., in deltaic plain under normal conditions, in deltaic plain, affected by the frequent floods and lacustrine. The second phase was dominated by severe aggradational activities.

South of Bengal Basin — The vegetation has been defined under the following five phases.

Phase I — In the southern part of the Bengal Basin the vegetational history commences with the *Ceriops*-*Rhizophora* complex indicating the tidal mangrove conditions.

On the periphery and dry nitches *Bruguiera*, *Acanthus ilicifolius*, *Sonneratia* and *Pongamia* occurred.

Phase II — It is marked by the sudden disappearance of *Ceriops* and *Rhizophora* and appearance of Leguminosae in good frequencies. The curves for *Sonneratia* and *Acanthus ilicifolius* continued throughout with a slight rise in their values. The overall picture of vegetation reveals that there was a short period of cessation in the tides.

Phase III — This phase is characterized by the reversal of *Rhizophora* in high values alongwith *Nypa fruticans* and disappearance of *Acanthus ilicifolius*. The appearance of an animal remain (*Concentricystes rubinus*) in good frequencies, characteristic of marine environs, is suggestive of consistency in the tides. Therefore, it is congenial to believe that between *ca* 5000-5800 years b.p. the area was within the encroachment of sea.

Phase IV — This phase signifies the admixture of both tidal mangroves and prohyline vegetation. *Bruguiera*, *Acanthus ilicifolius*, *Pongamia*, *Ceriops* and *Rhizophora* are abundant in the lower and upper halves of this phase respectively. *Ruppia* and *Concentricystes rubinus* are both abundant during this phase. Thus the occurrence of *Ruppia* pollen and *Concentricystes rubinus* alongwith *Ceriops* and *Rhizophora* depict that ecologically this phase is the continuation of the preceding phase as the area was under the direct tidal influx. The occurrence of *Bruguiera*, *Acanthus ilicifolius*, *Pongamia* and *Suaeda* shows that they grew on the elevated dry nitches bordering the estuarine water and land.

Phase V — This phase records a change in the pattern of vegetation from the preceding phase, i.e. the improvement in the values of salt tolerant fresh-water constituents such as *Sonneratia*, *Acanthus ilicifolius*, *Nypa fruticans* and Leguminosae has been noticed whereas the values for *Ceriops*, *Rhizophora* and *Pongamia* have considerably reduced. Therefore, on account of the vegetation it is deduced that the magnitude of tides during this phase reduced considerably encouraging the salt tolerant freshwater taxa to flourish.

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EXPLANATION OF PLATES

PLATE 1

1. A general view of the site Kolara, West Bengal.
2. Profile showing peat, clay and alluvium at Kolara, West Bengal.

PLATE 2

3. Profile showing stratigraphical details, embedded wood stumps in underneath clay zone are clearly seen at Kolara, West Bengal.
4. Showing almost complete tree trunk with intact knee roots of *Heritiera* lying in vertical position at Kolara, West Bengal.

1

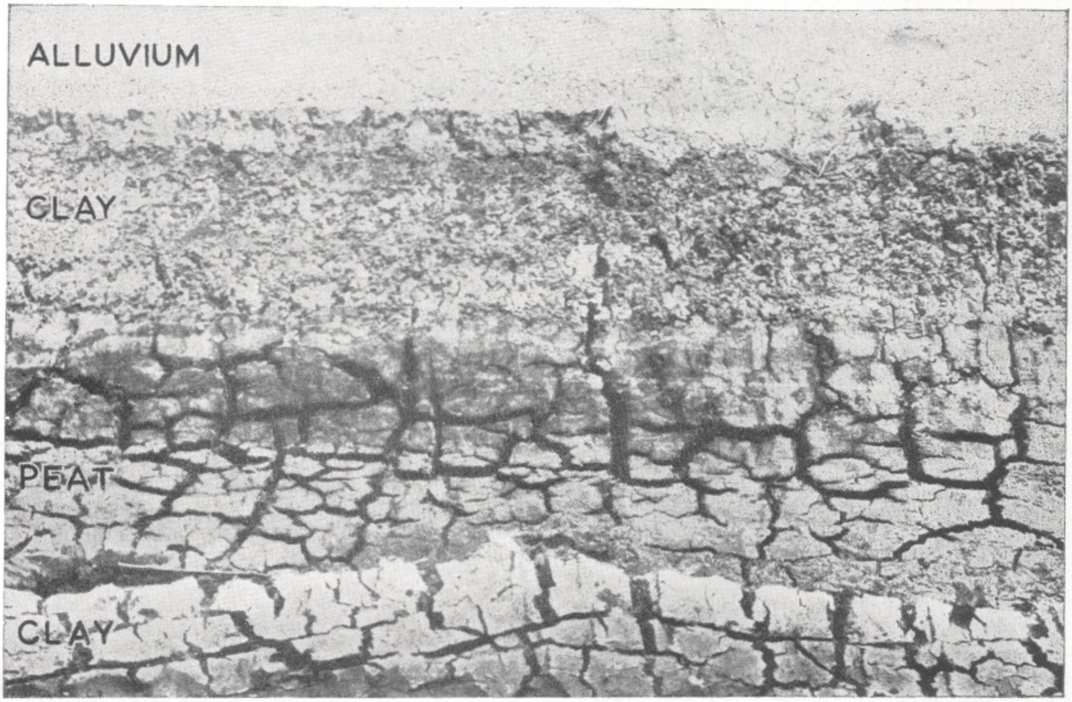
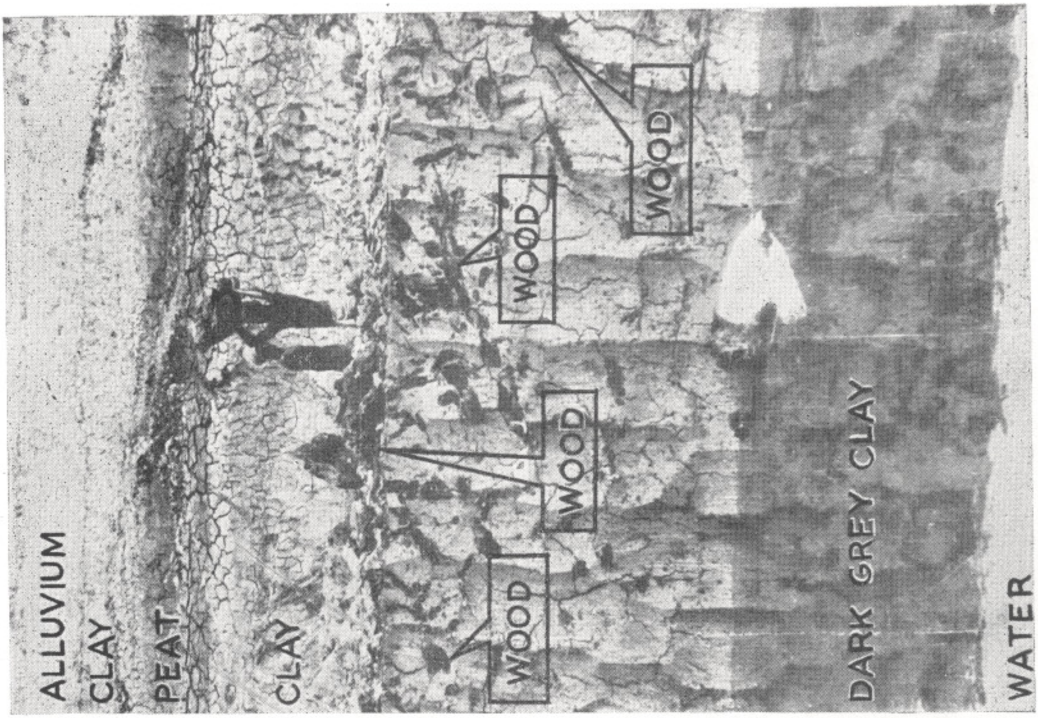

2


PLATE 1


ALLUVIUM
CLAY
PEAT
CLAY
WOOD
WOOD
WOOD
WOOD
DARK GREY CLAY
WATER

3

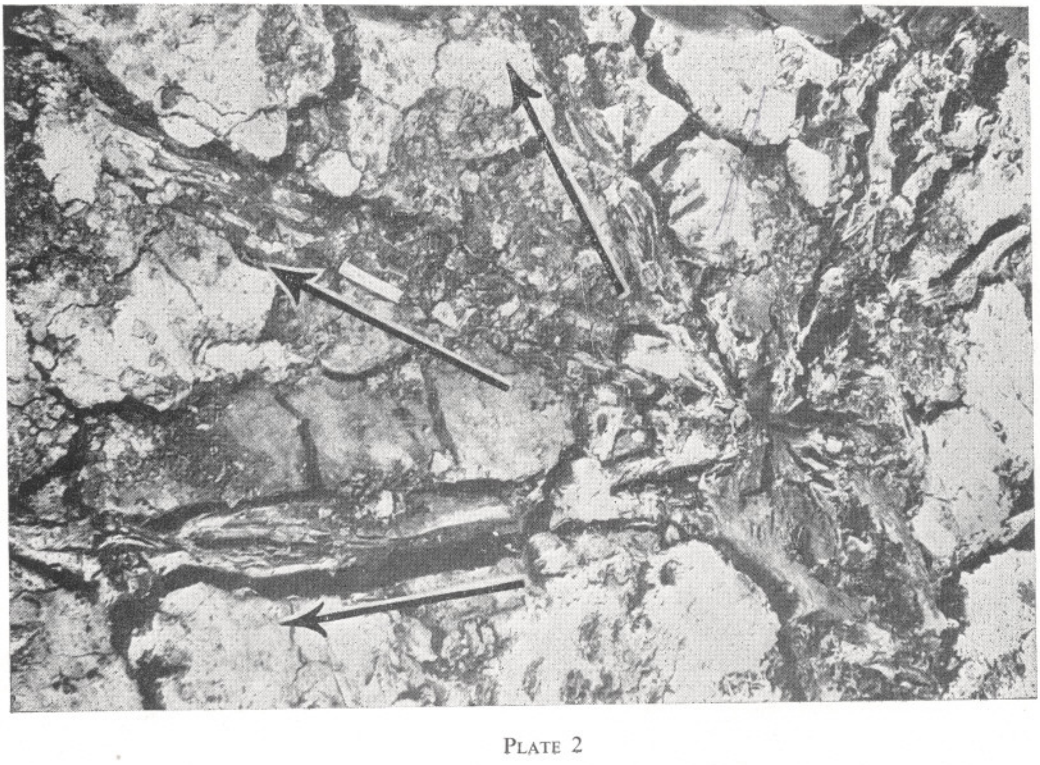


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PLATE 2