Aspects and appraisal of Late Quaternary vegetation of Lower Bengal Basin

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Available information, including the latest ones, on palynological investigations of Late Quaternary deposits of Lower Bengal Basin revealed the existence of brackish water swamp forest similar to the present day mangrove forest of Sundarbans in four different periods, viz., ca. 32,000, ca. 22,000, ca. 14,5000 and ca. 7000 yrs BP, established by radiocarbon dating. Consideration of present day environment of mangroves of the Sundarbans reflects their intertidal habitat. Sea-level changes in the Lower Bengal Basin demonstrates recurrent mangrove forest through the Late Quaternary using pollen analytical method and study of logs of woods in semidecomposed state. Attempts have been made here to collocate the fossil data with Carbon 14 datings.

Key-words—Palynology, Vegetation, Mangrove, Late Quaternary, Bengal Basin.

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साराँश

अधरि बंगाल द्रोणी की अनंतिम चतुर्थक युगीन वनस्पति के उद्देश्य एवं दृष्टिकोण

सुनीरमल चन्दा एवं अर्ध्य के. हैत

अधरि बंगाल द्रोणी के अनंतिम चतुर्थक निक्षेपों के परागाणविक अन्वेषणों पर उपलब्ध जानकारी से यह व्यक्त हुआ है कि वर्तमान सुन्दरबन के मैंग्रोव वनों की तरह इस क्षेत्र में खारे पानी एवं दलदली वन चार विभिन्न कालों-लगभग 32000, लगभग 22000, लगभग 14,500 एवं लगभग 7000 वर्ष, में विकसित हुए हैं, ऐसी रेडियोकार्बन आयु के आंकड़ों से पुष्टी हुई है। सुन्दरबन की वर्तमान स्थिति के आधार पर यह प्रदर्शित होता है कि ये अन्तरज्वारीय परिस्थिति में विकसित हुए हैं। अधरि बंगाल द्रोणी में समुद्र के तल में परिवर्तन से इस क्षेत्र में पुनः इसी प्रकार के वनों का होना इंगित होता है। इसी संबंध में कार्बन 14 आयु सहित पादपाश्मों के आँकड़े एकत्र करने के प्रयास किये गये हैं।

THE Lower Bengal Basin is characterised by having the largest mangrove complex of the world, formed by the flow of Ganga, Brahmaputra, Meghna and their numerous tributaries. Geomorphologically Agarwal and Mitra (1991) divided this part into four geomorphic units, viz., Palaeo-, Subaerial-, Transitional- and Marine Delta, out of which the last three, i.e., Subaerial-, Transitional- and Marine units constitute the Lower Bengal Delta complex (Text-figure 1). Studies on palaeovegetation of the Lower Bengal Delta during last two decades have recognised the existence of brackish water forest similar to the present day mangrove forest of the Sundarbans. The present paper deals with the significance of palaeovegetational phenomena with available data. Characteristics of the present day mangroves have been critically considered to understand their palaeoanalog.

The vegetational mapping of the basin (Dasgupta, 1975) records following four forest types:

I. Tropical dry deciduous forest in the western part
II. Tropical moist deciduous forest
III. Tropical semi-evergreen forest scattered in patches, and
IV. Littoral and swamp forest in the southern part.

This littoral and swamp forest in the deltaic south Bengal is known as mangrove forest of the Sundarbans. This mangrove vegetation has been surveyed ecofloristically by several workers like Prain (1903), Curtis (1933), Champion (1936), Puri (1960), Champion and Seth (1968), Rao and Sastry (1974), Naskar (1983), Blasco (1975), Chanda (1977), Chanda and Datta (1986), Naskar and Guha Bakshi (1987), Naskar (1993) and Choudhuri and Choudhury (1994).

EXTANT MANGROVES OF SUNDARBANS AND THEIR ENVIRONMENT : A MODERN ANALOG OF LATE QUATERNARY VEGETATION

The Indian Sundarbans located (Lat. 21°32'-22°40' North and 88°85'-89°00' East) within District 24-Pargana (north & south) of West Bengal enjoy humid tropical maritime climate due to its proximity to the Bay. The region is characterised by heavy rainfall and high humidity. The annual rainfall is about 1650 to 1800 mm in central and northern areas and 2790 mm on the outer coast. The summer is hot and sultry due to higher atmospheric humidity (> 80%). The mean maximum temperature during June-July is 29°C. The winter is quite pleasant due to maritime influence. The mean minimum temperature during December-January is 20°C. Climatic hazards in the form of cyclonic storms accompanied by tidal waves up to 5-8 m height often break over the mangroves during a cyclonic depression which is a regular feature of this region during pre-monsoon and post-monsoon months. This phenomenon is considered as the single disruptive source of repeated setbacks to the existing vegetation.

The ecology, forest type and phytosuccession of mangrove forest of Sundarbans have been extensively studied. Prain (1903) considered the Sundarban Delta forest and divided into three main zones, viz.,

(i) Southern coastal strip and southwestern part, with some dominant mangrove species
(ii) Central zone of *Heritiera*, and
(iii) North-eastern part with Savanah type of vegetation.

Curtis (1933) divided the Sunderbans into three main zones on the basis of salinity, viz.,

(i) Salt water forest
(ii) Moderately salt water forest, and
(iii) Fresh water forest

Champion and Seth (1968) considered the Sundarbans as tidal swamp forest which included five sub-divisions, viz.,

(i) Mangrove scrub
(ii) Mangrove forests
(iii) Salt water mixed *Heritiera* forest
(iv) Brackish water mixed *Heritiera* forest and
(v) Palm swamps.

Rao and Sastry (1974) grouped Sundarban mangroves under estuarine vegetation subdividing into: (i) Euestuarine, (ii) Tidal mangrove, (iii) Prohaline, and (iv) Euhaline, depending upon the tidal magnitude and salinity.

Blasco (1975) divided the mangroves into (i) Back mangrove with the physiognomy of low thickets, (ii) Dense mangroves, (iii) Tall and dense mangroves dominated by *Heritiera fomes*, (iv) Tall mangroves dominated by *Rhizophora* and *Heritiera*, and (v) *Phoenix paludosa* formation.

Naskar and Guha Bakshi (1987) identified five ecological successions of the Sundarban mangrove swamps based on tidal magnitude, viz., (i) Phase I swampy mangrove or intertidal mangrove zones, (ii) Phase II Tidal mangrove, (iii) Phase III True mangrove decline, (iv) Phase IV colonization of non-littoral species, and (v) Phase V xerophytic non-mangrove and dry evergreen forest.

A detail floristic study of the Sundarbans in the deltaic West Bengal (Naskar & Guha Bakshi, 1987; Naskar, 1993) recorded thirty five true mangroves, viz., *Acanthus ilicifolius, Heritiera fomes, Phoenix paludosa, Avicennia alba, A. marina, A. officinalis, Excoecaria agallocha, E. bicolor, Cynometra ramiflora, Derris scandens, D. trifoliata, D. umbellatum, Hibiscus tortusus, Thespesia lampus, Amoora cuculata, Xylocarpus granatum, X. molucensis, Aegiceras corniculatum, Aegialitis rotundifolia, Proteresia coarctata, Bruguiera cylindrica, B. gymnorhiza, B. parviflora, B. sexangula, Ceriops decandra, C. tagal, Kandelia candel, Rhizophora apiculata, R. mucronata, Sonneratia apetala, S. caseolaris, H. littoralis, Brownlowia lanceolata*; twenty five mangrove associates, viz., *Acanthus volubilis, Cerbera odollam, Nerium indicum, Thevetia peruviana, Hoya parasitica, Dolichandrone spathacea, Heliotropium curassavicum, Ipomoea pescaprae, Cyperus exaltatus, Fimbristylis sub-bispicata, Scirpus triquetra, Caesalpinia crista, C. nuga, Canavalia cathartica, Dalbergia spinosa, Derris indica, Viscum orientale, Thespesia populnea, Pandanus fascicularis, Aeluropus lagopoides, Leersia hexandra, Phragmites kakra, Tamarix dioica, T. gallica, Clerodendrum inerme, Premna integrifolia* and seven obligate mangroves, viz., *Sesuvium portulacastrum, Aerva lanata, Sarcolobus carinatus, Salicornia brachiata, Suaeda maritima, S. nudiflora* and *Ammonia baccifera*.

VEGETATIONAL HISTORY OF LOWER BENGAL BASIN

Palaeobotanical evidence

Ghosh (1941) recorded several tree trunks, identified as *Heritiera fomes*, from a depth of around 9 m below ground level in Calcutta. The trunks were found vertically standings which proves that they were not drifted but *in situ* and probably indicate subsidence of an extensive mangrove forest. Ghosh (1957) recorded buried logs of *Heritiera* and Ghosh and Negi (1958) identified *Carapa* from subsurface sediments of Dum Dum.

Palynological evidence

Palynological investigations of peat and peat bearing sediments were conducted to identify the vegetational history and palaeoenvironment of Bengal Basin. Pollen analysis of Holocene sediments of Garia recorded palynomorphs and diatoms (Das, 1961). Diatoms are the member of algae Bacilariophyceae. Total absence of mangrove pollen grains and climatic changes in the Lower Bengal Basin was reported by Mallick (1969), who recorded the presence of pollen grains of *Eugenia, Eriodendron,* Palmae, *Pandanus,* Malvaceae, *Amaranthus, Heliotropium, Suaeda maritima, Trema orientalis, Ixora, Eclipta alba, Artemisia,* Graminae, Cyperaceae and spores of pteridophytes from the lower layer of Calcutta peat (2.0 to 2.5 m bgl). Chanda and Mukherjee (1969) were the first to apply C14 dating accompanied by pollen analysis from sediments of Salt Lake and Bagirhat. The fossil pollen originated from arboreal *Heritiera, Excoecaria, Rhizophora, Sonneratia, Bruguiera, Bauhinia, Terminalia, Dipterocarpus* and non-arboreal like Poaceae, Cyperaceae, Polygonaceae, Liliaceae, *Acanthus ilicifolius, Pandanus, Lippia, Euphorbia, Crotalaria, Clerodendrum, Capparis, Plantago, Epilobium,* together with hydrophytes like *Typha, Limnanthemum* and *Hydrocera*. These floristic compositions indicate the existence of a typical swamp type of vegetation along with mangrove in and around Calcutta similar to the present day vegetation of the Sundarbans. Pollen diagramatic representation of the vegetational history as revealed from sediments of Salt Lake, Baidyabati, Belgachhia and Bagirhat were made by Mukherjee (1972), the vegetation was found to be dominated by mangrove elements about 5000 yr BP. The change in the river courses along with high rate of siltation and increasing biotic interference were reported to be responsible for the change of vegetation.

Gupta (1970) recorded fungal spores for the first time with three saprophytic fungi, viz., *Amellophora, Entophlyctis* and *Tetraploa* from Calcutta peat. Later Gupta (1978) noticed diagenetic change in trilete fern spores from Holocene of Lower Bengal Basin. Vishnu- Mittre and Gupta (1972) investigated the Holocene sediments of Jangalpur and Sankrail palynologically. The pollen grains of *Rhizophora* and *Heritiera* were recorded in significant quantities in these sediments along with sporadic occurrence of *Bruguiera, Avicennia, Ceriops* and *Excoecaria*. The pollen grains of aquatic plants, viz., *Potamogeton, Lemna, Typha* and *Myriophyllum* were also recorded. The vegetational scenario pointed towards the existence of a brackish water mixed *Heritiera* forest during Holocene. However, the record of pollen grains of *Rhizophora* in large quantities was interpreted as a result of transport from other localities. Records of diatoms, assignable to fresh water types from the Holocene sediments of Sankrail supported the existence of a fresh water environment in Sankrail area (Gupta & Khandelwal, 1984).

Palynological investigations of Holocene sediments from Kolara, Barrackpur, Namkhana and Chaltiya revealed differences in the development of vegetation in all the four parts of Lower Bengal Basin (Gupta, 1981). He (Gupta, 1981) further recorded four phases of deposition on the basis of vegetational history from west and east of Lower Bengal Basin. In phase I (ca 7000 yrs BP) warm, humid, fresh water environment with feeble brackish water influence prevailed which was evidenced by pollen of *Heritiera, Phoenix paludosa,* Leguminosae and fern spore of *Acrostichum aureum.* In succeeding phase II (ca, 5300 yrs BP) higher magnitude of tidal influx was noticed by high frequency of core mangrove taxa like *Rhizophora, Ceriops, Sonneratia.* The phase III (ca 5000) was marked by higher representation of salt tolerant fresh water taxa, viz., *Sonneratia, Acanthus ilicifolius, Suaeda,* etc., which indicated the reduction of the inflow of tidal water. Phase IV (4990-1710 yrs BP) indicated the disappearance of *Sonneratia, Acanthus* and abundant presence of *Heritiera* and *Ceriops.* The overall assemblage pattern, according to him, indicated a fresh water lake environment except for the presence of *Ceriops* which could not be accommodated in the fresh water plant community.

Palynological studies of Calcutta peat, collected from Metro Railway excavations, were extensively worked out by Barui and Chanda (1979, 1982, 1984, 1992; Barui *et al.*, 1986). Based on palynoassemblage pattern of three successive peat layers, eleven palynozones were proposed and recognized since 7030±150 yr BP to 2640±150 yr BP (Barui & Chanda 1992). The dominant fossil pollen types recovered from the samples were *Heritiera* along with *Suaeda, Aegiceras, Bruguiera, Sonneratia, Barringtonia, Excoecaria, Phoenix, Nipa, Acanthus,* etc., most of which originated from typical mangroves. The lower peat layer (ca 7000-6400 yrs BP) were palynologically divided into four palynozones with *Heritiera, Excoecaria, Phoenix* with grasses as main components. The pollen diagram depicted a rather flat vegetational sequence from bottom upwards with insignificant fluctuations of climate and vegetation. The middle peat layer (ca. 6350-6200 yr BP) with five palynozones were formed by a mixed type of forest vegetation as depicted by the presence of *Heritiera, Barringtonia, Excoecaria* and *Phoenix*. In the lower part of middle peat layer a marshy habitat was inferred on the basis of records of fern spores, but their absence in the upper part probably indicated formation of a relatively dry condition. The upper peat layer (ca. 2650 yrs BP) was divisible into two palynozones. The lower part of the upper peat layer indicated dominance of grass pollen grains along with *Heritiera*. The presence of a number of fern spores probably pointed towards the formation of terrestrial vegetation. *Heritiera* was the dominant element in the upper part. As amelioration of climatic condition from the previous one was thus inferred. The overall fossil pollen assemblages indicated the existence of a swampy halophytic vegetation more or less similar to the present day vegetation of Sundarbans in all the three peat layers depicting a low lying topography frequently inundated by sea water and mixing of sea water with fresh water from northern streams. On the basis of the record of a large number of pollen of mangrove taxa, Barui and Chanda (1992) concluded that the origin of Calcutta peat was not drifted.

Further palynological and palaeontological studies of surface and subsurface samples from Metro Railway excavations in Calcutta, Dum Dum, Kolaghat, Barrackpur, Luthian and Prentice Islands in the Sundarbans depicted distinct depositional environment in the Holocene of Lower Bengal Basin (Sen & Banerjee, 1984, 1990; Banerjee *et al.*, 1989). Sen and Banerjee (1984) recorded remains of gharial (*Gavialis gangeticus*) and tortoise (*Chitra indica*) of fresh water origin from the peat sediments exposed at Barrackpur reflecting its fresh water origin. A few surface and subsurface sediments studied from Prentice and Luthian islands of the Sundarbans recorded both terrestrial and marine elements in the bioassemblage (Banerjee *et al.*, 1989). Six different depositional environments were explored in Calcutta, Dum Dum, Kolaghat and Barrackpur areas during ca. 7000-2000 yrs BP based on palyno-plankton records (Sen & Banerjee, 1990). Phase I (>7000 yrs BP) was found to be barren of any biological remains and the presence of 'kankar' in the sediments indicated arid environment of deposition. Phase II (7000-6650 yrs BP) and Phase III (6650-6400 yrs BP) had experienced saline environment. The vegetational composition of Phase II and III consisted of *Acrostichum aureum, Heritiera, Avicennia, Sonneratia, Bruguiera,* microforaminifera (cf. *Ammonia*) and fungal spores identified as originating from *Palaeocirrenalia*. Phase IV (6400-6175 yrs BP) was represented by the pollen grains of *Ceriops, Excoecaria, Bruguiera,* Poaceae, Cyperaceae and *Typha*. Occurrence of Cyperaceae and *Typha* pollen in significant frequencies in this phase indicated a change of ecosystem from brackish water environment to brackish water mixed fresh water environment. The mangrove taxa declined in Phase V (6,175-5000 yrs BP) because of reduction in salinity. Predominance of *Heritiera* pollen along with Poaceae, Cheno-Amaranthaceae pollen marked this phase. Fresh water environment of deposition reflected by high value of *Potamogeton,* algal remains of *Gloeotrichia* and total extermination of mangrove except *Heritiera* marked Phase VI (5000-2000 yrs BP). Further palaeoenvironmental studies of subsurface cored sediments up to a depth of 30 m collected from Digha, Haldia and Kolaghat of South Bengal revealed shifts in the depositional environment in these regions (Hait *et al.*, 1994a, 1994b, 1995). Palynological and micropalaeontological studies of Digha bore hole recorded three broad ecological phases (Hait *et al.*, 1994a) and Haldia recorded four ecological phases (Hait *et al.*, 1994b) within a single climatic phase, i.e., tropical mode of deposition. The Kolaghat bore hole recorded eight ecological phases having essentially tropical climatic condition with one sub-phase, which was arid in nature (Hait *et al.*, 1995).

On the basis of dominance of some ecologically significant taxa, three distinct and different ecological

Table 1—Radio-carbon dates from the Lower Bengal Delta

Location	Geographical coordinates		Depth (in m)	[a]Material	Lab. No.	Conventional radio carbon age	Ref.
•Calcutta							
Bhawanipur	22°34'	88°24'	12.10	M-Peat	BS 521	6650 ± 120	b
Bhawanipur	22°34'	88°24'	8.0	M-Wood	BS 545	6210 ± 130	b
Bhawanipur	22°34'	88°24'	6.0	F-Peat	BS 544	3470 ± 110	b
Elgin Road	22°34'	88°24'	12.60	M-Peat	BS 255	7030 ± 150	c
Elgin Road	22°34'	88°24'	11.20	M-Peat	BS 259	6390 ± 130	c
Elgin Road	22°34'	88°24'	10.00	M-Peat	BS 253	6360 ± 120	c
Elgin Road	22°34'	88°24'	8.80	M-Peat	BS 258	6170 ± 140	c
Elgin Road	22°34'	88°24'	6.50	Peat	BS 252	2640 ± 150	c
Salt Lake	22°35'	88°30'	8.50	M-Wood	T 729	4930 ± 120	d
Salt Lake	22°34'	88°28'	4.25	Peat	PRL 1776	3990 ± 70	e
•24-Parganas(S)							
Dum Dum	22°40'	88°25'	6.50	M-Wood	TF 443	6175 ± 125	f
Barrackpur	22°48'	88°22'	6.10	F-Peat	BS 531	3030 ± 100	b
•Howrah							
Kolara	22°33'	88°5'	6.50	E-Clay	PRL 236	6840 ± 260	g
Kolara	22°33'	88°5'	5.75	M-Wood	GrN 7136	5715 ± 40	g
Kolara	22°33'	88°5'	3.50	F-Peat	GrN 7138	4990 ± 40	g
Kolara	22°33'	88°5'	2.50	F-Clay	PRL 238	1710 ± 110	g
Sankrail	22°36'	88°15'	3.30	F-Peat	TF 851	4075 ± 100	h
Sankrail	22°36'	88°15'	3.00	F-Peat	TF 853	4925 ± 100	h
Sankrail	22°36'	88°15'	2.75	F-Peat	TF 850	2615 ± 100	h
Sankrail	22°36'	88°15'	6.25	Clay	TF 856	5810 ± 120	h
Sankrail	22°36'	88°15'	4.87	M-Wood	TF 857	5440 ± 115	h
Sankrail	22°36'	88°15'	3.04	Peat	TF 855	4720 ± 135	h
•Midnapur							
Kolaghat	22°24'	87°54'	8.00	M-Wood	BS 533	6370 ± 120	b
Kolaghat	22°24'	87°54'	5.25	M-Wood	BS 520	6480 ± 110	b
Kolaghat	22°27'	87°55'	7.00	M-Peat	PRL 1781	6900 ± 70	e
Kolaghat	22°27'	87°55'	26.60	E-Clay	BS 1192	31750± 2030	e
Digha	21°37'	87°32'	24.50	E-Clay	PRL 1777	22360± 450-420	e
Haldia	22°3'	87°59'	30.00	E-Clay	BS 1179	7800 ± 410	e
Madhabpur	21°47'	87°36'	2.40	E-Clay	-	2900 ± 160	i
Brajaballavpur	21°55'	87°38'	2.50	E-Clay	-	5760 ± 160	i
•Hooghly							
Dankuni	22°42'	88°18'	7.60	M-Peat	BS 1158	6030 ± 140	e
Janai Road	22°45'	88°9'	4.50	F-Peat	BS 524	4080 ± 110	b
•24-Parganas (S)							
Namkhana	21°45'	88°15'	1.75	Clay	GrN 7137	3170 ± 70	g
Bakkhali	21°37'	88°18'	8.38	M-Wood	BS 1159	4710 ± 120	e
Bakkhali	21°37'	88°18'	41.00	E-Clay	BS 1191	6165 ± 100	e
Diamond Harbour	22°13'	88°10'	28.00	E-Clay	PRL 1779	14460 ± 350-330	e
Bagirhat	22°24'	88°25'	5.50	M-Wood	T 730	5080 ± 110	d
Canning	22°48'	88°40'	31.68	M-Wood	BS 1160	6250 ± 140	e
Pakhiralaya	22°14'	88°47'	22.30	M-Wood	BS 1156	7530 ± 100	e
Pakhiralaya	22°14'	88°47'	49.80	E-Clay	BS 1190	8800 ± 135	e
Ganga Sagar	21°39'	88°7'	0.90	E-Clay	-	2920 ± 20	i

Explanation: [a]Prefixes: M = Mangrove, E= Estuarine, F=Freshwater,
[b]Sen and Banerjee 1990
[c]Barui *et al.*, 1986
[d]Chanda and Mukherjee 1969
[e]The present study
[f]Agarwal and Kusumgar 1967
[g]Gupta 1981
[h]Vishnu-Mittre and Gupta 1972
[i]Chakrabarty 1991
•District

phases were demarcated from Digha (Hait *et al.*, 1994a). Phase I (25.0-21.0) was deposited under deltaic environment as reflected by palynological and foraminiferal analysis. *Sonneratia* was the main pollen type of this phase. Radiometrically this phase was dated as 22,360±450 yrs BP (PRL 1777, Table 1). The Phase II (20.0-3.0 m) was characterised by having a number of foraminiferal taxa of open shallow marine ecology suggesting the existence of marine environment. In phase III (3.0-0.0m) reappearance of some plants of brackish water ecology and abundance of foraminifera of restricted marginal marine environment marked this phase.

In Haldia (Hait *et al.*, 1994b) Phase I (30.0-22.0 m) is dominated by mangrove palynomorphs with *Sonneratia* and *Rhizophora* having been the dominant elements. The presence of microthyraceous fruiting body, acritarch like *Concentricystes,* fungal spores of *Cirrenalia* and foraminiferal inner lining (cf. *Ammonia*) formed a characteristic association and have bearing on the paleoecology. This phase was deposited during 7800±410 yrs BP (BS 1179, Table 1). The Phase II (22.0-6.0 m) was characterised by the presence of a number of foraminiferal taxa which were possibly deposited in a shallow marine environment. Absence of foraminifera, higher representation of fresh water palynomorphs and reappearance of mangroves, although in lesser frequency marked Phase III (6.0-5.5 m). The regression of the sea caused the mangrove to come back accompanied by higher frequency of fresh water elements, viz., *Typha, Potamogeton*, etc. The Phase IV (5.5-3.0 m) was marked by complete absence of the mangroves and dominance of fresh water palynomorphs.

In Kolaghat, the thirty m thick sedimentary succession was divisible into eight phases (Phase I-VIII) from bottom upwards on the basis of palynological, micropalaeontological and sedimentological characteristics (Hait *et al.,* communicates). In Phase I (30.0-26.6 m), fluvial environment prevailed which was evidenced by textural analysis of sediments. Biologically this phase was found to be barren in nature. The Phase II (26.6- 23.8 m) was characterised by the appearance of mangrove palynomorphs, viz., *Sonneratia, Avicennia, Rhizophora, Bruguiera, Heritiera,* etc., along with grasses which indicated that the plain was transformed into intertidal zone promoting some typical mangroves to grow during 31,750±2030 yrs BP (BS 1192, Table 1). The succeeding Phase III (23.8-20.8 m) was dominated by some core mangrove taxa indicating the existence of more tidal influx. The Phase IV (20.6-17.0 m) was characterised by the total absence of palynomorphs but showing abundance of shallow marine inner shelf foraminifera, viz, *Ammonia, Globigerina, Bolivina, Neogloboquadrina, Elphidium, Glabratella, Uvigerina, Nonion, Fissulina* and *Triloculina.* The Phase V (16.5-11.5 m) and Phase VI (11.4-7.3 m) were barren of biological remains. Sedimentologically they were found to be deposited under fluvial environment. In addition, Phase VI contained 'Kankar' probably formed under a relatively arid condition, suggesting existence of hot and dry condition for a prolonged period. In Phase VII (7.0-5.4 m) the mangrove palynomorphs reappeared for the second time in the 30.0 m thick sedimentary sequence. The fern *Acrostichum* was the main palynological element accompanied by *Sonneratia* and *Heritiera.* The presence of mangrove palynomorphs in the pollen assemblage and textural analysis of sediments suggested reappearance of tidal influence, thus revealing transgression of the sea for the second time during 6900±70 yrs BP (PRL 1781, Table 1). The next phase, i.e., Phase VIII (5.3-0.0 m) was biologically barren. Sedimentological study revealed fluvial condition signifying regression of the sea for the second time.

RADIO CARBON DATING

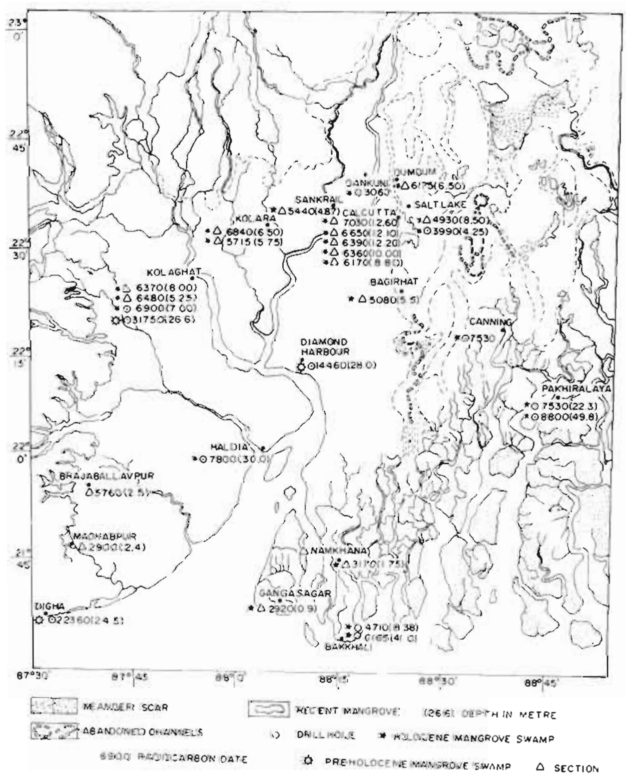
A considerable amount of data have been obtained from published records on C14 datings of Late Quaternary sediments of Lower Bengal Basin in the last two decades (Table 1) which have helped to understand the biostratigraphical ages. The correlative use of radiometric datings under a palaeoenvironmental framework has helped in highlighting the importance of that ages of Late Quaternary sediments as a basic component of palaeoenvironmental research. Almost all the carbon-14 dates from Lower Bengal Basin have been found to be younger than 10,000 yrs BP, i.e., all within the limit of Holocene Period. However, dates of three organic rich clay sediments from Digha (24.5 m), Kolaghat (26.6 m) and Diamond Harbour (28.0 m) were measured as 22,360±450/420, 31,750±2,030 and 14,460± 350/330 respectively, thus indicating that the sediments consisting of mangrove palynomorphs were deposited during Late Pleistocene, before that last glacial maximum.

CONCLUSION

1. The Late Quaternary climate of Lower Bengal Basin was essentially wet humid and tropical as

was proclaimed by the palynological evidence. However, the presence of Kankar in a couple of cases, viz., Kolaghat and Salt Lake, indicated arid subphase within the broad tropical wet phase of deposition.

2. A typical brackish water swamp condition dominated by mangroves as far north as Dankuni (Lat. 22° 42': Long. 88° 18') and as far south as Bakkhali (Lat. 21° 37': Long. 88° 18') strongly suggested the existence of an extensive swamp during ca. 7000-5000 yrs BP (Text-figure 1) in South Bengal Basin. Intertidal coastal vegetation consisting of mangroves grew in the zone between mean sea level and mean high water spring tides. Probably this large swamp got developed due to stabilisation of sea during mid Holocene. Pollen analysis of the sediments depicted dominance of *Heritiera* along with *Sonneratia, Rhizophora* and *Acrostichum.*
3. The mangrove bearing estuarine sequence was found to be overlain by fresh water sequence represented mainly by *Typha-Potamogeton*, etc. The sea started retreating after 5000 yrs BP leading to the establishment of the modern terrain.



Text-figure 1—The Lower Bengal coastal estuarine and alluvial plains showing locations which encountered Holocene and Pre-Holocene mangrove facies.

4. The occurrence of *Heritiera* in the western part of Sundarbans is in a dwindling state among the mangroves (in Indian part). Due to various physical factors the supply of fresh water to river Hooghly has been considerably depleted resulting into slow extermination of *Heritiera* (Chanda, 1977; Chanda & Dutta, 1986; Banerjee, 1987; Choudhuri & Choudhury, 1994). But almost all vegetational historical surveys of the Holocene sediments of Lower Bengal Delta show abundant presence of pollen of this taxon in fossil state along with other typical mangrove palynomorphs; in some cases also logs of wood in semi-decomposed state. But extant *Heritiera* occurs in large quantities in the eastern part of Sundarbans in Bangladesh (Hussain & Acharya, 1994).
5. Finding of Holocene mangrove bearing horizons in much lower depths at Pakhiralaya (8000±135 yrs BP, D=49.8 m & 7530± 180 yrs BP, D = 22.3 m), Bakkhali (6165± 190 yrs BP, D=41.0 m), Canning (6250± 140 yrs BP, D=31.68 m) and Haldia (7800± 410, D=30.0 m) reflects fluctuation of the sea level during early to mid Holocene time in these areas (Table 1). The fluctuation might have been due to rapid sea level rise coupled with subsidence or some other strictly local factors.
6. Records of Pre-Holocene mangrove swamp at Digha (22,000± 450/420 yrs BP, D = 24.5 m), Kolaghat (31,750± 2,030 yrs BP, D = 26.6 m) and Diamond Harbour (14,460±350/330 yrs BP, D=30.0 m) appears to be of special significance, because during those times the global sea levels were at least 125 m, 55 m and 120 m lower than of present mean sea level respectively (Chappel & Shackleton, 1986) thus a vertical upliftment during the respective times might have taken place.
7. In all the cases peat/wood/clay containing mangrove elements have been recorded at depths well below the present day mean sea level, indicating that the sea never arose above the present day level. These data are in accordance with the recorded world sea level curve during the Late Quaternary (Chappel & Shackleton, 1986).

8. The pattern of sea level fluctuations during the Late Quaternary had controlled the evolution and formation of Lower Bengal Basin. The fluctuations were almost the same throughout the concerned area during the development of extensive swamp phase during mid Holocene (7000-5000 yrs BP). However, great variations are noticed at a local level during Early Holocene time. More multi-and inter-disciplinary studies on form, process and interaction of the depositional systems are needed to demonstrate the complexity at a local scale.

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