International Journal of Geosciences, 2016, 7, 615-629
Published Online April 2016 in SciRes. http://www.scirp.org/journal/ijg
http://dx.doi.org/10.4236/ijg.2016.74047

# Holocene Biostratigraphic Zones Corresponding Litho-Chronostratigraphy, Environment of Deposition and Successive Changes in the Geomorphology of Bengal Basin, India during Last 10,000 Years

**Prasanta Kumar Sen[1], Manju Banerjee[2*]**

[1]Department of Botany, Bankim Sardar College, South 24 Parganas, West Bengal, India
[2]Department of Botany, University of Calcutta, Kolkata, India
Email: prasanta_kr_sen7@yahoo.co.in

Received 26 February 2016; accepted 25 April 2016; published 28 April 2016



## Abstract

**Biostratigraphic Zones Bb. Bz. H. I-V distinguished in $C^{14}$ dated Peat, peaty clay sediments above arid, Barren zone have identified distinct environment of deposition as fresh water mixed brackish water to shallow marine to brackish water mangrove swamp, brackish water mixed fresh water swamp followed by colonization of non-littoral species to fresh water swamp during Holocene in the Bengal basin, India in chronological succession. The successive phases of depositional environment have identified the events of sea level rise, marine transgression and sea ward movement of the sea. The unique database has explored successive changes in the geomorphology of South Bengal from upland dry to marine deltaic environment to fresh water upland condition.**

## Keywords

**Holocene, Biostratigraphy, Flandrian Transgression, Geomorphology, Bengal Basin**

## 1. Introduction

Late Quaternary research has attracted considerable attention of the scientists since late 20th century to acquire

*Prof. Manju Banerjee is a senior retd.-professor of University of Calcutta.

**How to cite this paper:** Sen, P.K. and Banerjee, M. (2016) Holocene Biostratigraphic Zones Corresponding Litho-Chronostratigraphy, Environment of Deposition and Successive Changes in the Geomorphology of Bengal Basin, India during Last 10,000 Years. *International Journal of Geosciences*, **7**, 615-629. http://dx.doi.org/10.4236/ijg.2016.74047

maximum data base on the recent past global environment primarily to apprehend the likely changes of environment in near future and also to assess the past environment [1]-[10]. Lately reference [11] has utilized evidences of mangrove vegetation in response to environmental changes during late Quaternary along west coast of India and southern China. In the present paper, multidisciplinary study of diverse biological remains of diverse eco-system including mangrove in the $c^{14}$ dated Holocene sediments has generated rich data revealing the ecological changes that occurred in the Bengal basin, India during last ten thousand years. The change in the environment of deposition identified through analysis of Biostratigraphic zones Bb. Bz.I-V above Bb.Bz. Barren zone is discussed taking into consideration the litho-stratigraphic and chrono-stratigraphic succession. The biostratigraphic zones have revealed the successive changes in the geomorphology of the south Bengal basin during last 10,000 years.

## 2. Study Area

The locations of study viz., Calcutta, Dum Dum, Barrackpore, Kolaghat lie between 22˚N to 23˚N 87˚30'E to 88˚30'E in the southern part of West Bengal, India at about 80 to 120 km inland from present coastline (**Figure 1**).

### Geological Setting of Study Area

Sedimentary sequences of Bengal basin lie unconformable over Pre-Cambrian basement with history of deposition since Upper Carboniferous-Permian-Jurassic-Cretaceous to Holocene [12] [13]. In recent years the geological setting of the Quaternary sediments occupying most of the flood plain areas of West Bengal, India and Bangladesh and in the shelf and Deep basin zones with easterly dip towards Bangladesh in the southeast of the N-S trending Eocene Hinge zone have been discussed [14]. The south eastern part of the basin is covered by older alluvium while southern part has cover of younger alluvium and deltaic sediments.

## 3. Material and Methods

The Materials are from excavations upto 13 m. depth from surface for Metro Railway, Calcutta (Section CV), Thermal power project at Kolaghat (Section K1), local brick industries at Dumdum (Section D1) and Barrackpore (Section B1). Among these sections CV section at Bhabanipur Netaji Subhas Station, Calcutta (Section CV) is the type section (**Figure 2**). All the sediment types exposed in the lithologically distinguished layers are identified according to nomenclature proposed by [15] [16].

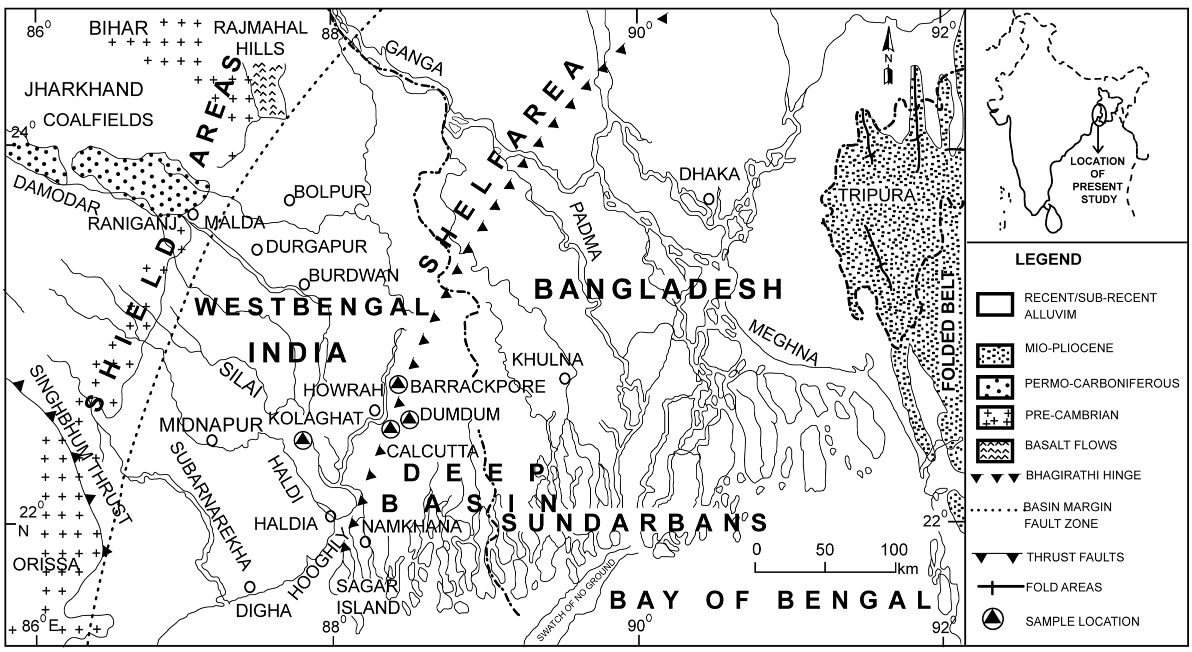

**Figure 1.** Map of southern part of Bengal basin showing study areas.

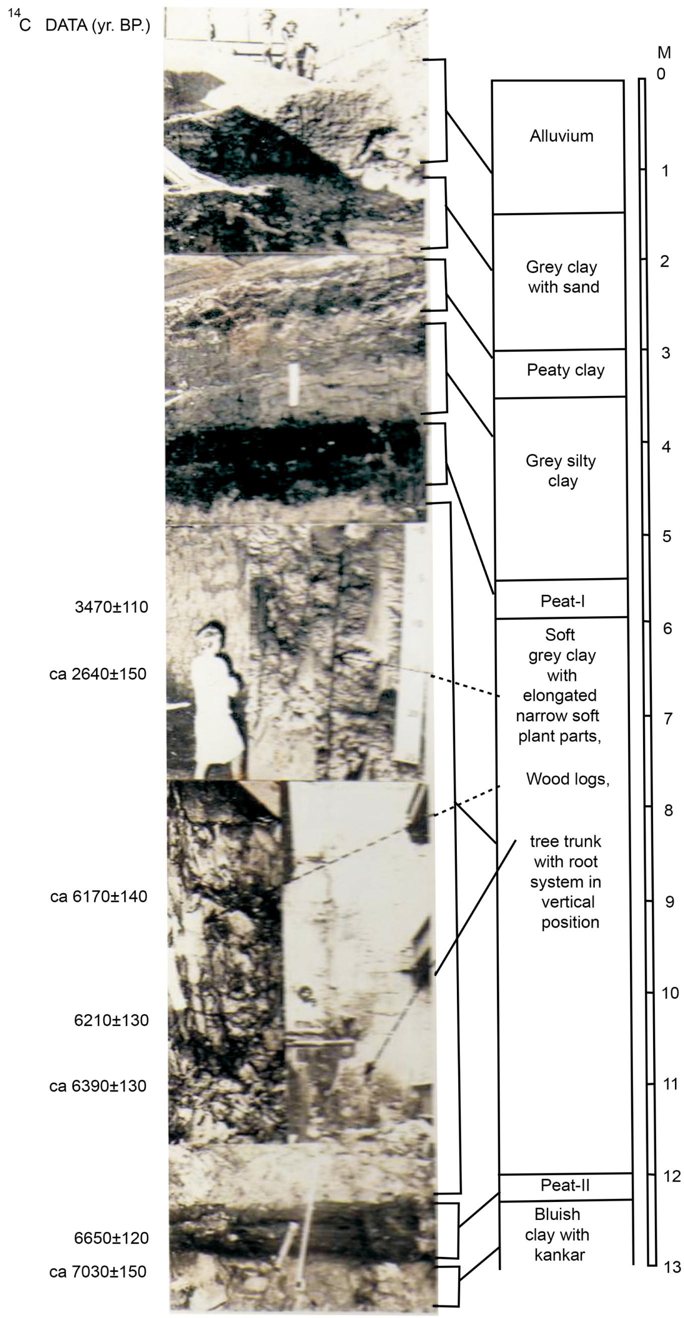


**Figure 2.** Succession in section CV at Calcutta (type section).

Appropriate techniques have been employed to recover the diverse types of biological remains. Samples have been collected at close intervals of 25 cm. from four sections at Calcutta, Dum Dum, Kolaghat and Barrackpore. $C^{14}$ dating of the suitable sediments and *in situ* bioforms collected from measured sections of each of the exposures has been made. The biological remains have been utilized as proxy data evidences. The chronological succession has been considered with the help of $C^{14}$ data accumulated from the study area (**Table 1**). The record of each proxy data in the lithosuccession, together with the $C^{14}$ dates and environment are enlisted in **Table 2** and **Figures 3-6**. Bioforms collected from measured sections at each location have been critically considered for environment analysis through specific methodologies of study that include pollen, spores, other micro plant remains, microforam, megascopic plant, animal and ichno remains (**Figures 7-10**).

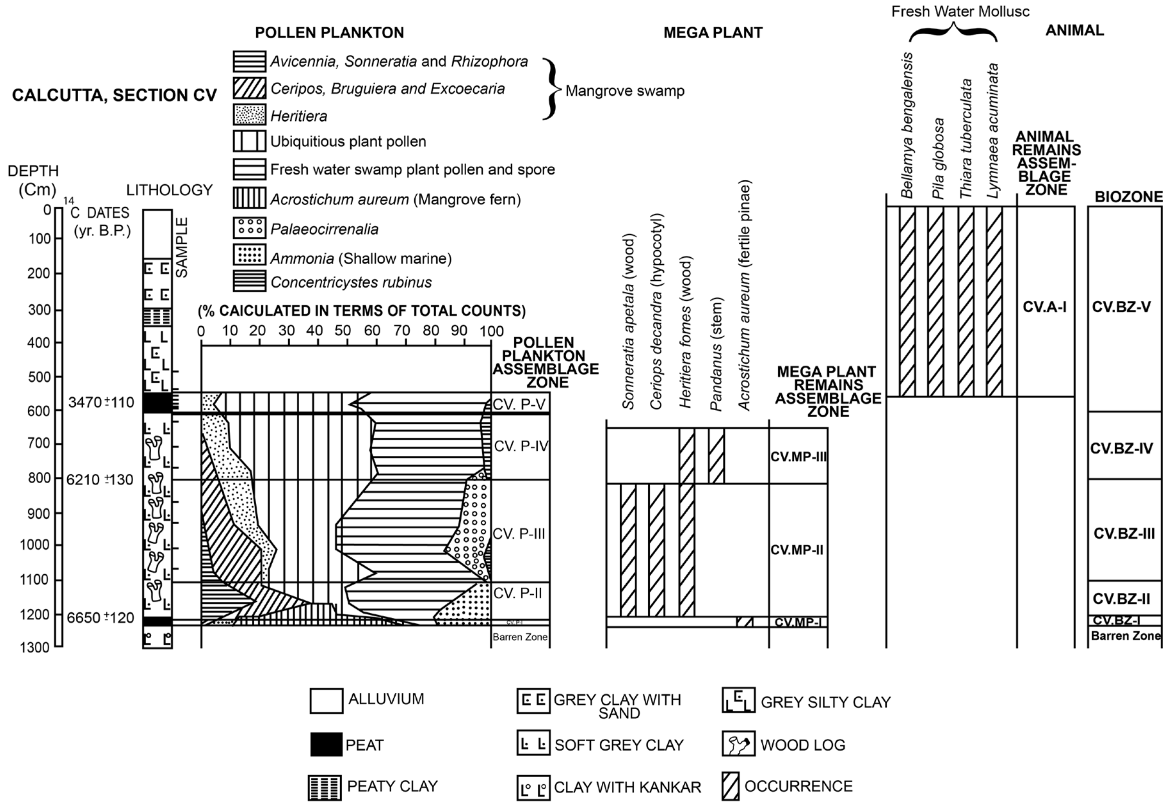


**Figure 3.** Biozones of type section CV, Calcutta.

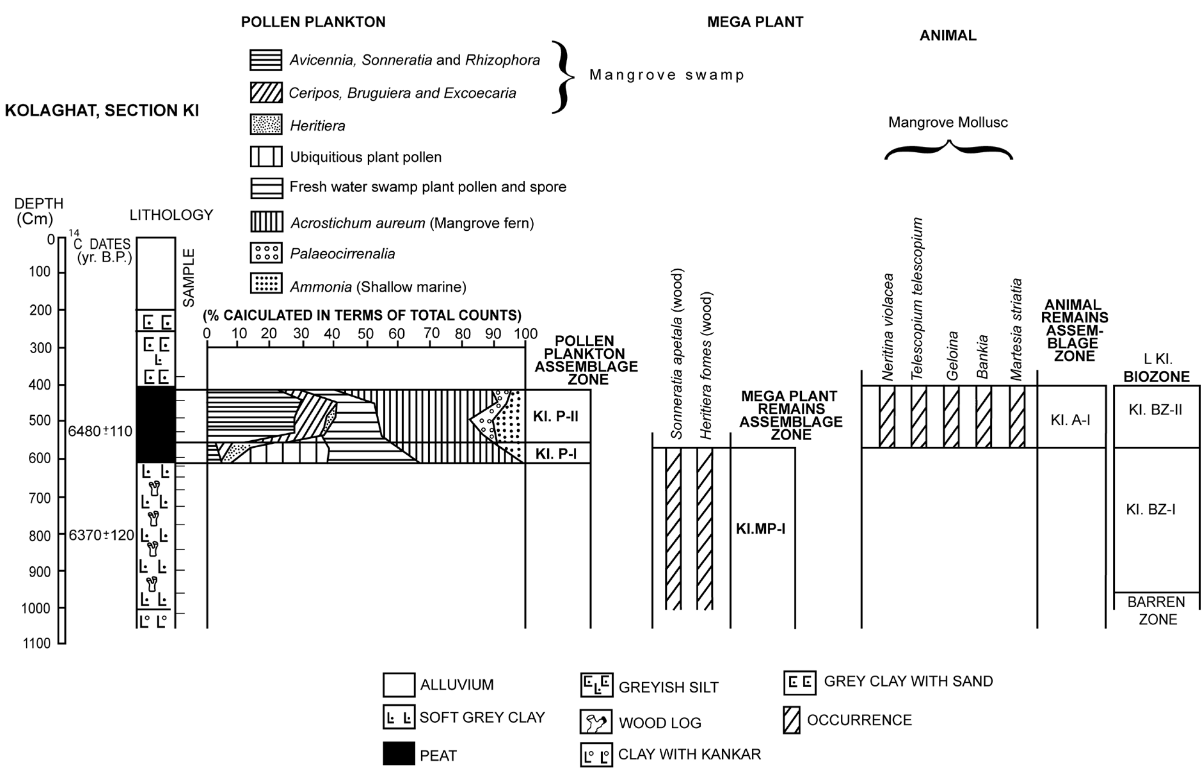


**Figure 4.** Biozones of section KI, Kolaghat.

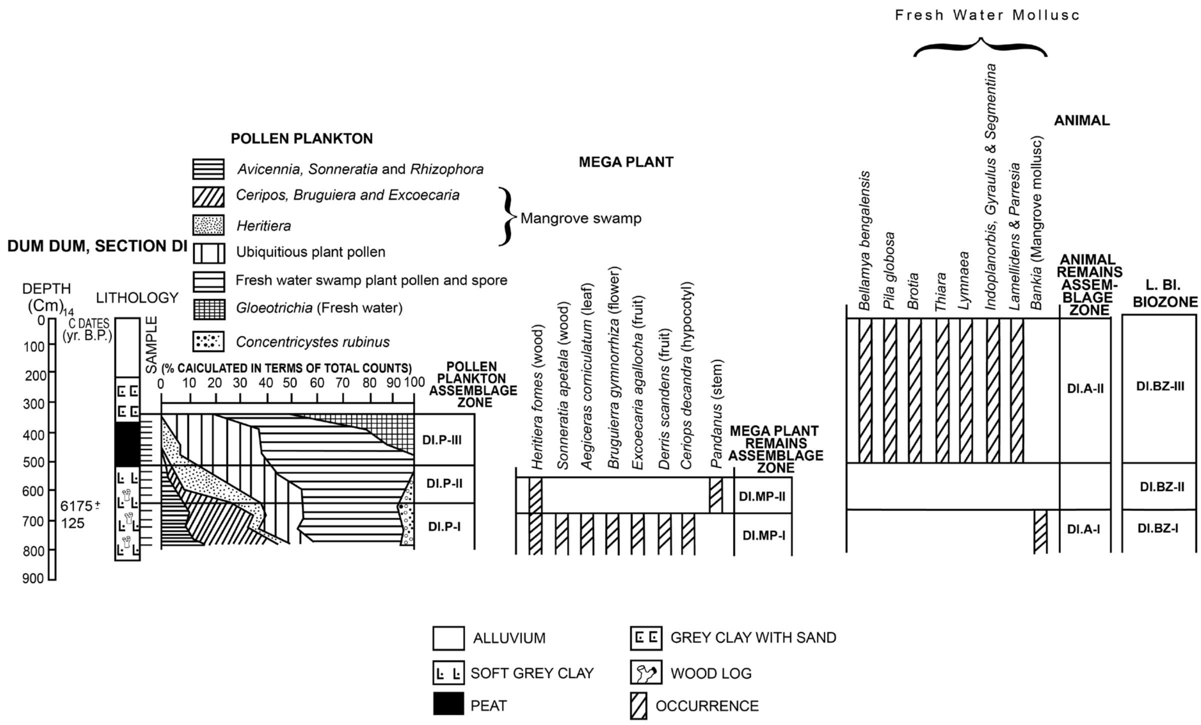


**Figure 5.** Biozones of section DI, Dum Dum.

**Table 1.** $C^{14}$ dates from Holocene sediments of Bengal basin, India.

| Location | Lab. sample No. | Nature of Sample | Depth from Surface (cm) | Depth from MSL (cm) (Altitude) | $^{14}$CAge (Year BP ± error) | References | Calendar age (Cal yr.BP) |
|---|---|---|---|---|---|---|---|
| Calcutta I | BS 544 | F-Peat | 600 | 0 | 3470 ± 110 | [17] | 3747 ± 138 |
| Calcutta I | BS545 | M-Wood | 800 | −200 | 6210 ± 130 | [17] | 7099 ± 153 |
| Calcutta I | BS521 | M-Peat | 1210 | -610 | 6650 ± 120 | [17] | 7536 ± 90 |
| Calcutta II | BS252 | Peat | 650 | −50 | 2640 ± 150 | [18] | 2718 ± 203 |
| Calcutta II | BS258 | M-Peat | 880 | −280 | 6170 ± 140 | [18] | 7059 ± 154 |
| Calcutta II | BS253 | M-Peat | 1000 | −400 | 6360 ± 120 | [18] | 7265 ± 132 |
| Calcutta II | BS259 | M-Peat | 1120 | −520 | 6390 ± 130 | [18] | 7295 ± 124 |
| Calcutta II | BS255 | M-Peat | 1260 | −660 | 7030 ± 150 | [18] | 7859 ± 137 |
| Dum Dum | TF 443 | M-Wood | 650 | −150 | 6175 ± 125 | [19] | 7059 ± 154 |
| Barrackpore | BS 531 | F-Peat | 610 | −10 | 3030 ± 100 | [17] | 3208 ± 131 |
| Kolaghat I | BS 520 | M-Wood | 525 | −25 | 6480 ± 110 | [17] | 7391 ± 96 |
| Kolaghat I | BS 533 | M-Wood | 800 | −300 | 6370 ± 120 | [17] | 7282 ± 121 |
| Kolaghat II | PRL 178 | M-Peat | 700 | −200 | 6900 ± 70 | [20] | 7751 ± 69 |
| Namkhana | GrN7137 | Clay | 175 | 225 | 3170 ± 70 | [21] | 3395 ± 72 |
| Bakkhali | BS 1159 | M-Wood | 838 | −438 | 4710 ± 120 | [20] | 5427 ± 136 |

(Explanation: M = Mangrove, E = Estuarine, F = Freshwater).

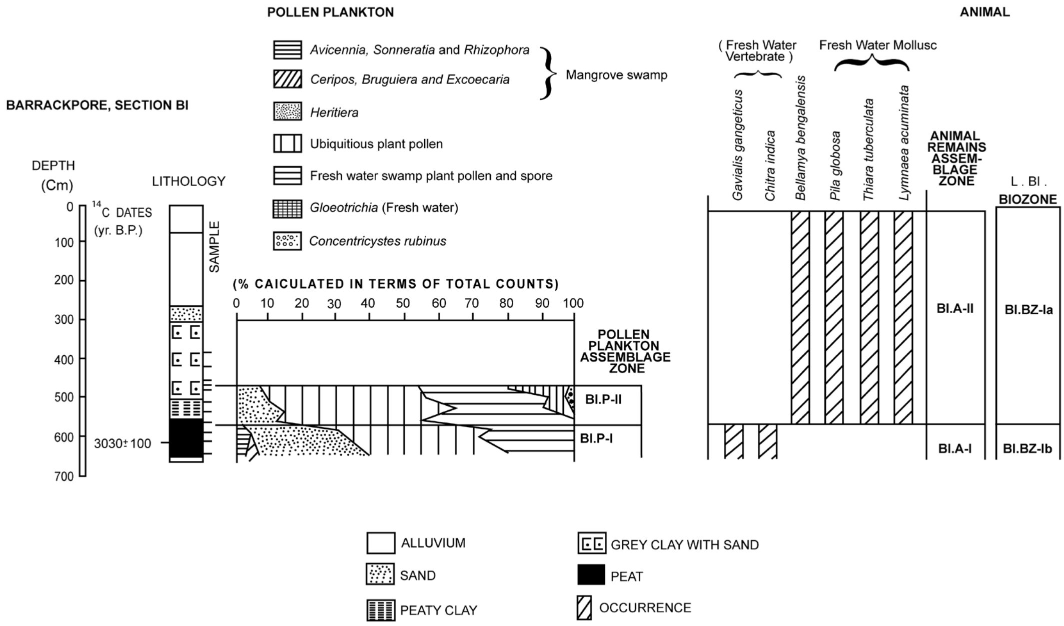


**Figure 6.** Biozones of section BI, Barrackpore.

**Table 2.** Bengal basin Holocene Biostratigraphic Zones (BBH.BZ), corresponding environment of deposition, geomorphic change and delta evolution.

| $^{14}$C Dates (yr BP) | Location, Local (L) Biozone, Depth from MSL (cm) | Biostratigraphic Zones | Environment of Deposition | Geomorphic Changes and Evolution of Bengal Delta |
|---|---|---|---|---|
| 5000-3000 to present | Calcutta (L) CVBZ V Depth +600 to 00 DumDum (L) D1BZIII Depth +500 to 00 Barrackpore (L) B1BZ1a Depth +600 to+65 Barrackpore (L) B1BZ1b Depth +65 to −50 | **BBH. BZ. V**: *Heritiera-Potamogeton-Typha*-Fern-*Concentricystes rubinus* (Type-II) *Gloetrichia-Gavialis-Chitra-Bellamya-Pila Thiara-Lymnaea* | Freshwater with Brackish Water Influence to Fresh Water | Delta Top to Inland |
| 6175 - 5000 | Calcutta (L)CVBZIV Depth 00 to −200 DumDum (L) D1BZII Depth 00 to −150 | **BBH. BZ. IV**: *Heritiera-Bruguiera-Pandanus-Cheno-Amaranthus*-Poaceae-*Typha*-Fern-*Concentricystes rubinus* (Type I) | Brackish Water Mixed Fresh Water | Delta Top |
| 6400 - 6175 | Calcutta (L) CV BZIII Depth −200 to −500 DumDum (L) D1BZI Depth −150 to −300 | **BBH. BZ. III**: *Ceriops-Bruguiera-Excoecaria-Avicennia-Sonneratia Rhizophora-Heritiera-Typha-palaeocirrenalia-Callimothallus-Concentricystes* rubinus (TypeI)-*Bankia* | Estuarine Mangrove with High Precipitation | Tidal mudflat |
| 6500 - 6400 | Calcutta (L) CV BZII Depth −500 to −610 Kolaghat (L)K1 BZII Depth +100 to −50 | **BBH. BZ. II**: *Avicennia-Sonneratia-Rhizophora-Ceriops-Bruguiera-Excoecaria-Heritiera*-Fern-*Ammonia-Neritina-Telescopium-Geloina-Bankia-Martesia* | Shallow Marine to Swampy Mangrove | Shallow marine to Delta Front |
| 7000 - 6500 | Calcutta (L) CV BZI Depth −610 to −625 Kolaghat (L)K1 BZI Depth −50 to −100 to −500 | **BBH. BZ. I**: *Heritiera-Bruguiera-Acrostichum*-Fern-*Ammonia* | Marine Inundation (Flandrian Transgression) in Freshwater Condition | Estuarine to Shallow Marine |
| >7000 | Calcutta CV (L) Barren Zone Depth −625 to −700 Kolaghat K1(L) Barren Zone Depth −500 to −550 | **BBH.BZ Barren zone** of Kankar nodules | Arid | Dry, Upland |

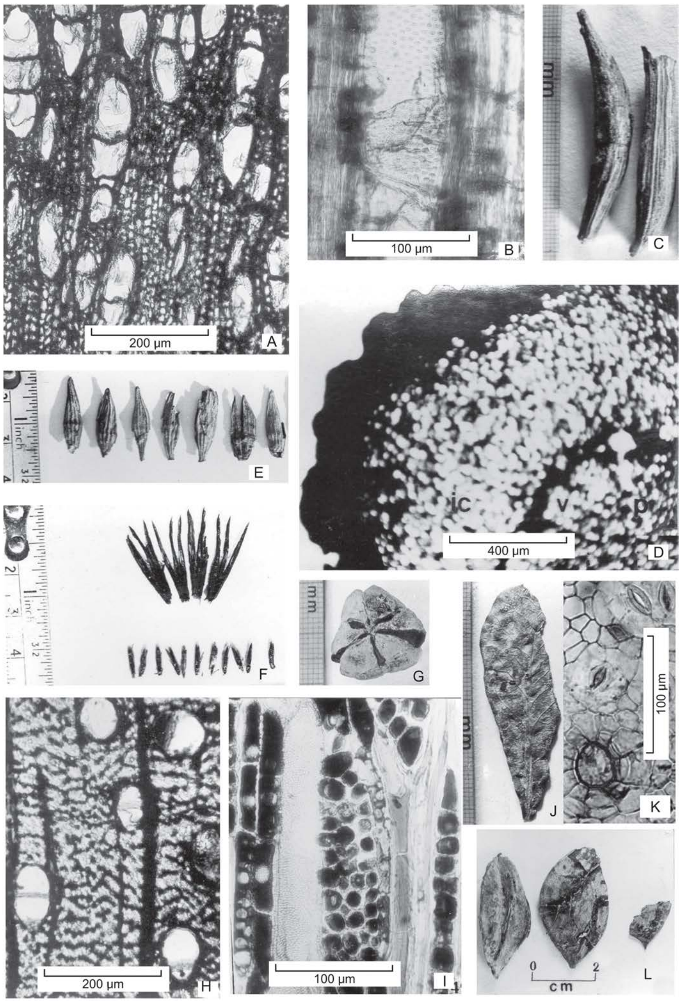


**Figure 7.** (A) Cross section of subfossil *Sonneratia apetala* wood; (B) Tangential longitudinal section of subfossil *Sonneratia apetala* wood; (C) Sobfossil hypocotyls fragments of *Ceriops decandra*; (D) Transvers section of subfossil hypocotyl of *C. decandra*; (E) Subfossil flowers of *Bruguiera gymnorrhiza*; (F) A subfossil flower showing calyx lobes and petals of *B. gymnorrhiza*; (G) Subfossil fruit of *Excoecaria agallocha*; (H) Cross section of subfossil *Heritiera fomes* wood; (I) Tangential longitudinal section of subfossil *H. fomes* wood; (J) Subfossil leaf of *Aegiceras corniculatum*; (K) Lower epidermis of subfossil *A. corniculatum* leaf; (L) Subfossil pods of *Derris scandans*.

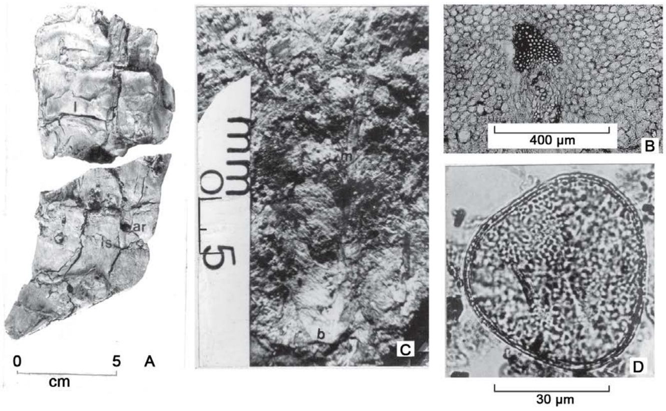


**Figure 8.** (A) Subfossil stems of *pandanus* sp. with leaf scars; (B) Vascular bundle of subfossil leaf *pandanus* sp.; (C) Fertile pinnae of Acrostichum aureum with sporangia; (D) Trilete spore of *A. aureum*.

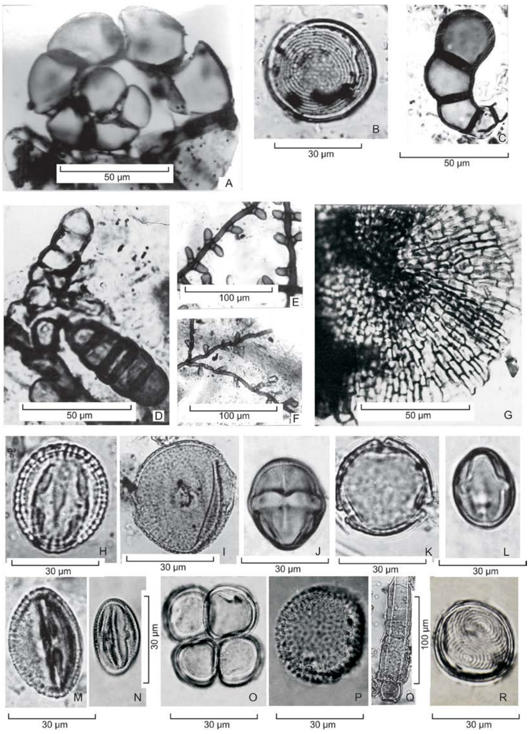

**Figure 9.** (A) Marine to brackish water benthonic microforaminifera, *Ammonia* sp.; (B) *Concentricystes rubinus* type I split half; (C) Fungal spore of *Palaeocirrenallia* sp.; (D) Germinating spores of *Meliolinites anfracta*; (E) Hyphae and hyphopodias of *Meliolinites spinkii*; (F) Hyphae and hyphopodias of *Meliolinites anfracta*; (G) *Callimothallus* sp. Stomata; (H) Pollen grain of *Avicennia* sp.; (I) Pollen grain of *Sonneratia* sp.; (J) Pollen grain of *Rhizophora* sp., (K) Pollen grain of *Ceriops* sp.; (L) Pollen grain of *Bruguiera* sp.; M: Pollen grain of *Excoecaria* sp.; (N) Pollen grain of *Heritiera* sp.; (O) Pollen grain of *Typha* sp.; (P) Pollen grain of *Potamogeton* sp.; (Q) Trichome of *gloeotrichia* sp.; (R) *Concentricystes rubinus*, type 11, with two identical halves.

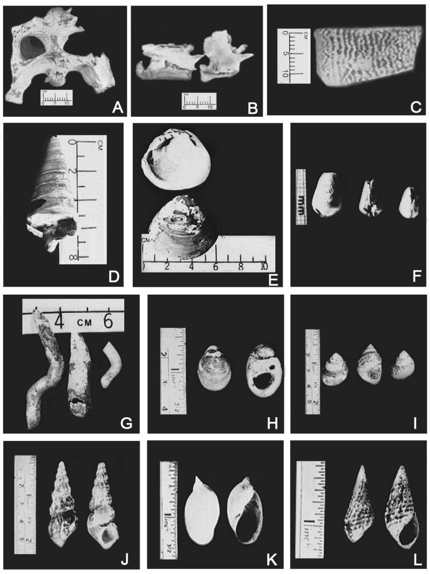

**Figure 10.** (A) Dorsal view of skull of *Gavialis gangeticus*; (B) Vertebrae showing ball and socket joint between successsive vertebrae of *G. gangeticus*; (C) Dorsal view of costal carapace plate of *Chitra indica*; (D) Molluse shell of *Telescopium telescopium*; (E) Mollusc shells of *Geloina* sp.; (F) Mollusc shels of *Martesia striata*; (G) Tubes of *Bankia* sp.; (H) Mollusc shells of *Neritina violaceae*; (I) Mollusc shells of *Bellamya bengalensis*; (J) Molusc shells of *Thiara tuberculata*; (K) Mollusc shells of *Lymnaea acuminate*; (L) Mollusc shells of *Thiara lineate*.

## 4. Biostratigraphic Zones

The Holocene biostratigraphic zones are identified as Bb.Bz.H (Bb.Bz = Bengal basin Biostratigraphic zone; H = Holocene). Biostratigraphic zonations of $C^{14}$ dated Holocene sediments have been made through correlation of bioassemblage zones (local zones) of four sections viz. the Type section CV, Calcutta (**Figure 2** and **Figure 3**), Kolaghat (**Figure 4**), Dumdum (**Figure 5**) and Barrackpore (**Figure 6**). The sample position in each section has been plotted in consideration with the present day Mean Sea Level (MSL) as per Survey of India records. Plant remains assemblage zones and Animal remains assemblage zones above Barren zone of Kankar layer at base Bb.Bz.H Barren zone have been considered in the Bengal basin Holocene Biostratigraphic zonation. Correlation of the Bioassemblage zones of each section (local zones) with the Type Section CV (**Figure 3**) has distinguished five Biostratigraphic zones viz; Bb.Bz.H I-V (**Table 3**).

### 4.1. Bio and Litho Facies Change Pattern

Finer resolution of Biozones Bb.Bz.H.I-V recovered from $C^{14}$ dated continuous succession of different types of sediments exposed from surface upto 13 m. depth viz. Silty clay, Peat I, Soft Grey clay with wood logs, Peat II, Bluish Grey Clay and Clay with "Kankar" layer (**Figure 3**) has revealed changes in the biofacies pattern related to ecological changes. The ecologically characteristic bioassemblage of each section correlate with the chronologically identical horizons while corresponding lithological correlation disagree due to variation in the lithofacies characteristics (**Figure 11**). The lithofacies reveal a overall coarsening upward trend. The Biostratigraphic zones Bb.Bz.H.I-V of typical fresh water to marine ecological assemblage (**Table 3**) have identified the "Time Stratigraphic Event" of Flandrian Transgression. The biozones have revealed the gradual changes in the geomorphology of the basin through time in accordance with the ecological changes.

### 4.2. Identification of "Time Stratigraphic Event" of Flandrian Transgression

The sediments immediately above the Bluish Grey Clay layer with "Kankar" Bb.Bz.H Barren zone have record of bioassemblage of brackish water mixed fresh water plant viz. in situ fertile frond together with dispersed spores of *Acrostichum*, pollen of *Heritiera* and microforaminifera *Ammonia* with lesser to abundant (bottom upward) frequency (Bb.Bz.H.I). The biozone (Bb.Bz.H.II) with diverse delta front swampy mangrove plant, animal remains with frequent occurrence of *Ammonia* suggest a shallow marine environment. The Bb Bz.H.I

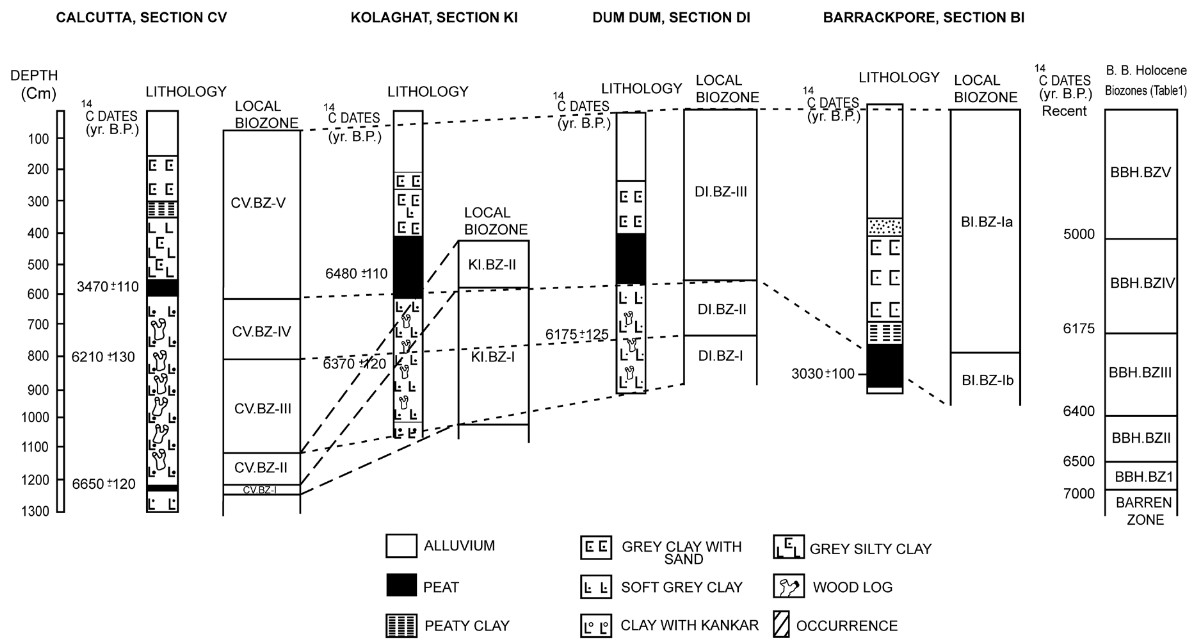


**Figure 11.** Correlation of local biozones and holocene biostratigraphic zones of Bengal basin with corresponding litho and chronostratigraphy.

**Table 3.** Local (L) biozones identified in the four sections; each biozone represents the dominant and ecologically characteristic bioassemblage; lithology, radiocarbon dates, and position of the sediments from surface and present day MSL are given. Two peat layers at different depths and chronology in the type section are identified as Peat I and Peat II layers.

| **Sections studied → Particulars of the sections↓** | **Section CV-Calcutta (Figure 3)** | **Section K1-Kolaghat (Figure 4)** | **Section D1-DumDum (Figure 5)** | **Section B1-Barrackpore (Figure 6)** |
|---|---|---|---|---|
| Local (L) Zone | L. Biozone CV.BZ.V | L. Biozone | L. Biozone D1.BZ.III | L. Biozone B1.BZ.Ia |
| Bioassemblage | *Potamogeton-Typha*-Poaceae-Fern-*Concentricystes Rubinus* (Type II-ribs smooth, surface psilate) *Bellamya-Pila-Thiara-Lymnaea* (Fresh water mollusc | | *Heritiera-Potamogeton-Typha*-Poaceae-Fern-*Gloeotrichia-Concentricystes rubinus* (TypeII) *Bellamya-Pila-Thiara-Lymanea*-(Fresh Water Mollusc) | *Heritiera- Potamogeton-Typha-Gloeotrichia*-Poaceae-Fern-*Concentricystes rubinus* (Type *Bellamya-Pila-Thiara-Lymnaea* (Fresh Water Mollusc) |
| Depth from Surface (cm) Depth from Present MSL (cm) | Surface to 550 - 600 +600 to 00.00 | | Surface to500 +500 to 00 | Surface to 535 +600 to +65 |
| Lithology | Peaty Clay, Grey Silty Clay, Peat I | | Clay, Peat | Clay, Peaty Clay, Peat |
| $^{14}$C Date | Recent to 3470 to ca 5000 yr BP | | Recent to 3470 yr BP to Ca 5000 | Recent to ca2000 to 3030 yr BP |
| Local (L) Zone | L. Biozone CV.BZ.IV | | L. Biozone D1.BZ.II | L. Biozone B1.BZ.Ib |
| Bioassemblage | *Heritiera-Bruguiera-Pandanus-Cheno-Amaranthus*-Poaceae-*Typha*-Fern-*Concentricystes rubinus* (Type-I) Ribs Rough, Foveolate, Ornamentation at Polar Regions | | *Heritiera-Sonneratia-Pandanus Cheno-Amaranthus-Heliotropium-Typha*-Fern-*Concentricystes rubinus* (Type-I) | *Heritiera*-Poaceae-*Typha-Alternanthera*-Fern-*Gavialis gangeticus Chitra indica* (Vertebrate Remains) |
| Depth from surface (cm) | 600 - 800 | | 500 - 650 | 535 - 650 |
| Depth from Present Day MSL (Cm) | 00 to −200 | | 00 to −150 | +55 to −50 |
| Lithology | Soft Grey Clay With Wood Logs | | Soft Grey Clay with Wood Logs | Peat |
| $^{14}$C Date | ca 5000 - 6210 yr BP | | ca 5000 to 6175 yr BP | 3030 yr BP to ca 4000 yr BP |
| Lithology | Soft Grey Clay with Wood logs | | Soft Grey Clay with Wood logs | |
| $^{14}$C Date | 6210 yr BP to ca 6400 | | 6175 -ca 6500 yr BP | |
| Local (L) Zone | L.Biozone CV.BZ.II | L.BiozoneK1.BZ.II | | |
| Bioassemblage | *Avicennia-Sonneratia-Rhizophora-Ceriops-Bruguiera-Excoecaria Heritiera*-Fern-*Ammonia* | *Avicennia-Sonneratia-Rhizophora-Ceriops-Bruguiera-Palaeocirrenalia* Fern-*Ammonia-Neritina violacea-Telescopium-telescopium-Geloina-Bankia-Martesia striata* (Brackish water mollusc) | | |
| Depth from Surface (cm) | 1100 - 1210 | 400 - 550 | | |
| Depth from Present Day MSL (cm) | −500 to −610 | +100 to −50 | | |

**Continued**

| | | |
|---|---|---|
| Lithology | Soft Grey Clay and Peat II | Peat |
| $^{14}$C Date | ca 6400 - 6650yr BP | Ca 6200 - 6480 yr BP |
| Local (L) Zone | L.Biozone CV.BZ.I | Biozone K1.BZ.I |
| Bioassemblage | *Heritiera-Bruguiera-Acrostichum aureum-* Fern-*Ammonia* | *Heritiera-Sonneratia-Acrostichum aureum - Cheno-Amaranthus-Heliotropium*-Poaceae-Fern-*Ammonia* |
| Depth from surface ( cm) | 1210 - 1225 | 550 - 600,<br>600 - 1000 |
| Depth from Present Day MSL (cm) | −610 to −625 | −502 to −100<br>−100 to −500 |
| Lithology | Peat II | Peat and Soft grey Clay with Wood Logs |
| $^{14}$C Date | 6650 - 7000 yr BP | 6480 yr BP - ca 7000yrBP |
| Local (L) Zone<br>Depth from surface (cm) | CV Barren Zone<br>1225 – 1300 | K1 Barren Zone<br>1000 - 1050 |
| Depth from Present Day MSL (cm) | −625 to −700 | −500 to −550 |
| Lithology | Bluish Grey Clay with Kankar Nodules | Bluish Grey Clay with Kankar Nodules |

and II are $C^{14}$ dated as 7000 to 6500 and 6500 to 6400 yr. B.P. respectively thus evidently explore for the first time the global "Time Stratigraphic Event" of Flandrian Transgression (*Ammonia*) in Bengal basin, India [17]. Influence of marine facies decrease thereafter and fresh water influence increase in the following biozones viz., Bb.Bz.HIII (6400 to 6175 yr. B.P.), Bb.Bz.H.IV (6175 to 5000 yr. B.P.) and Bb.Bz.H.V (5000 yr. BP to recent) effectively change the geomorphology of the area.

### 4.3. Successive Geomorphological Changes in the South Bengal during Holocene

Geomorphological changes that have occurred in the areas 80 to 120 km Inland and upto present coastline in the southern part of Bengal basin, India during last 10 ka are clearly understood through interpretation of the Biostratigraphic zones Bb.Bz.H.I-V recovered from the various litho-units. The stages in the successive geomorphological changes (**Figure 12**) and corresponding chronological data are enumerated below:

A) Bb.Bz.H. (Barren zone: >7000 yr. BP)

The locations were arid, upland before 7000 years with the shoreline existing towards south; the environment allowed formation of "Kankar" nodules in and around the locations between Calcutta, Kolaghat lying at a distance of about 60 km. (**Figure 1**; **Figure 12**).

B) Bb.Bz.H.I (7000 - 6500 yr BP)

Gradual landward migration of the sea due to Flandrian sea level rise initiated brackish water influence in the fresh water condition of the area; primary invasion of a brackish water mixed fresh water forest of *Acrostichum*, *Heritiera* with moderate to high frequency of microforaminifera *Ammonia* are the evidences in support of the environment; the *in situ* occurrence of fertile pinna of *Acrostichum aureum* in the basal part of Peat II reveals the slow rate of deposition of the existent *Acrostichum* dominated forest in the areas. High frequency of *Ammonia* in the brackish water mixed fresh water forest reveals marine transgression which has been identified as the global Flandrian (*Ammonia*) Transgression of 7000 - 6500 yr. BP. Geomorphology of the area thus changed from upland, arid condition to the delta initiating forest with marine inundation.

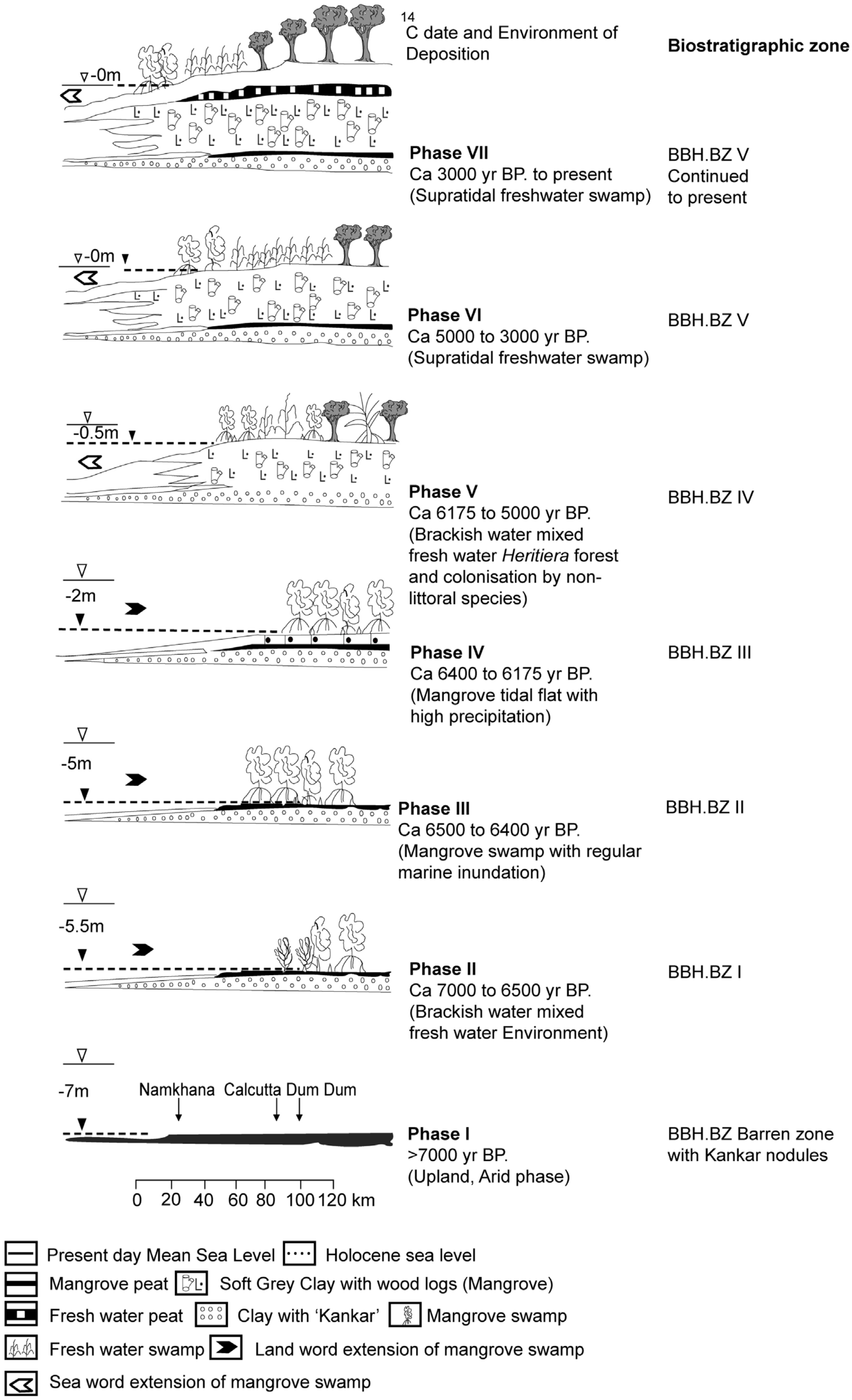


**Figure 12.** Biostartigraphic zones, corresponding environment of deposition, successive phases of geomorphic changes and evolution of Bengal basin during Holocene.

C) Bb.Bz.H.II: (6500 - 6400 ± yr.BP)

Geomorphology of the area rapidly changed towards a luxuriant delta front swampy mangrove forest of tropical, humid climate; shallow marine condition in and around the locations prevailed as revealed from the occurrence of bio remains of *Avicennia*, *Rhizophora*, *Sonneratia*, *Geloina*, *Neritina* and *Bankia* (ichno remain) along with abundant frequency of *Ammonia*. The evidences suggest that shoreline position existed in the areas during 6500 - 6400 yr. B.P. and Peat II was deposited at this phase of shallow marine environment.

D) Bb.Bz.H.III: (6400 - 6175 ± yr. BP)

Influence of marine transgression, however, decreased within a short time and the seaward migration of the shoreline started since 6400± yr. B.P. Ecosuccession of the mangrove forest changed and the geomorphology also changed due to reduced extent of tidal activity. Swampy mangrove of delta front ecosystem changed to tidal mudflat forest and introduction of back mangroves like *Aegiceras*, *Excoecaria*, *Derris* and *Typha* occurred along with the swampy mangrove taxa *Sonneratia* and *Bruguiera*.

The uppermost part of Peat II and basal part of ‘Soft Grey Clay with wood logs’ layer were deposited during this time. The basal part of Soft Grey Clay layer with wood logs has also records of in *situ* upright stem and roots with extensive branches of *Heritiera*.

E) Bb.Bz.H.IV: (6175-ca 5000 yr. BP)

Soft Grey Clay with high frequency of occurrence of pieces of woods entangled in the clay layer deposited at this phase led to the nomenclature of this layer as Soft Grey Clay with wood logs [22]. The deposition of high frequency of pieces of wood logs entangled in clay layer suggests severe storm effect at this phase of deposition. Peat I layer started to get deposited during ca 5000 yr. BP. The bioremains recovered from this layer are *Pandanus*, *Heritiera*, *Bruguiera*, Cheno-Amaranthus, Poaceae, *Typha* etc. The assemblage suggests colonization of non-littoral species at this time. Rapid seaward migration of the shoreline changed the geomorphology of the locations of study from “marine”, “delta front”, “Tidal mudflat” to “Delta Top” condition.

F) Bb.Bz.H.V: (ca 5000 yr BP to ca 3000 ± yr BP)

The predominantly fresh water forest with some supralittoral taxa which initiated during ca 5000 ± yr BP continued for a long time and typical supralittoral geomorphological features enabled deposition of thick layer of peat (Peat I). This Peat I above the clay sediments with wood logs was deposited in an extensive area of Bengal basin both in India and Bangladesh. By 4500 - 3000 ± yr BP the shoreline and delta front geomorphology migrated to Namkhana about 90 to 60 km south of the locations of study and about 30 to 20 km. inland from present coastline (**Figure 1**).

G) Bb.Bz.H.V-Recent: (ca 3000 ± to Recent)

The geomorphology of the locations changed to more fresh water condition with the abundant fresh water supply through a number of important rivers like Hooghly and Rupnarayan. By ca 3000 yr BP the areas had supply of enormous amount of sediments of Silty Clay which was deposited as the younger alluvial sequence. Since 3000 ± yr BP to Recent the coastline migrated to present position. Recent fresh water dominated locations of Calcutta, Dumdum, Barrackpore, Kolaghat have younger alluvium as the Holocene cover and the subsurface Holocene deposits has Silty clay, Peat I, Soft Grey Clay with wood logs, Peat II and Bluish Grey Clay with ‘Kankar’ ranging in age from ±10 ka to Recent. The southern part has recent geomorphological features of delta top to delta front succession of the basin (**Figure 12**).

## 5. Discussion and Conclusion

The biozones Bb.Bz.H.I-V above Barren zone have revealed the pattern of ecological and geomorphological changes that occurred in the lower part of Bengal basin lying in the western part of the Bhagirathi Hinge (**Figure 1**) during Holocene. Distinct change is revealed in the environment from upland arid condition to marine, deltaic to fresh water condition affecting the change in the geomorphology of south Bengal within last ten thousand years as summarized in the following (**Figure 12**). Prior to 7000 yr BP. MSL which was at –7 m from present day MSL gradually reached the present position by 5000 yr BP. The rate of sea level rise initiated by 7000 yr BP. was slower during first five hundred years between 7000 - 6500 yr BP when Peat II deposition occurred. Since 6500 yr BP rapid rise of sea level along with high rate of sedimentation and slower rate of subsidence changed the geomorphology of the locations. The slow rate of deposition at the time of transgression e.g. 25 cm. during 500 years (7000 to 6500 ± yr BP and higher rate of deposition of 400 cm. in 225 years during 6400 to 6175 ± yr BP are revealed from $c^{14}$ dated subsurface sediment analysis. That later phase of deposition was accompanied with slow rate of subsidence is clearly explored from the geomorphological changes from deltaic to fresh water condition by 5000 yr BP suggesting progradation of the delta. In addition, migration of the coastline at least 90 - 60 km. south of these locations is recorded by 4500 yr BP. The evidences of geomorphological changes during Holocene strongly support the pre-Holocene sedimentological and geomorphological characteristics of Bengal basin, India. Subsurface geological investigation in the West Bengal part of Bengal basin [12] [13] [22] [23] have revealed that the West Bengal geoprovince lying west of Hinge zone has the typical depositional characteristics of "higher rate of sedimentation compared to slower rate of subsidence" with predominantly progradational feature. Almost same progradational deltaic feature has been observed in the East coast of India [24]. The present study on the high resolution Biostratigraphic zones in the Holocene sediments (**Table 2**) has confirmed the trend of sedimentological characteristics of the West Bengal geoprovince, initiated since Neogene period. The observation of 1.5 - 2 cm. subsidence per year and further rise of sea level beyond Flandrian Transgression in the Holocene sediments of Bangladesh part of Bengal basin lie in the Deeper Basinal part. Reference [25] however, does not agree with the present critical biostratigraphic and lithological analysis of Holocene sediments in the West Bengal geoprovince. In this part of the basin, there is no record of further rise of sea level after 5000 yr BP. Early Holocene rapid rise of sea level and higher sea level during mid Holocene (6000 - 4000 yr BP.) and late Holocene regression of sea have been recorded in the Mahi valley, Gujrat coast [8]. Reference [5] [6] have also recorded Holocene sea level rise during 6500 yr. BP followed by regression of sea in South East Asia and Australia.

## Acknowledgements

Grateful thanks are due to late Dr. M. N. Bose, ex-Director and Dr. G. Rajagopaian, ex-Dy. Director, Birbal Sahni Institute of Palaeobotany, Lucknow for help in carbon dating of the samples of present study. Co-operation and help from Metro Railway and Kolaghat Thermal Power Project authorities during collection are gratefully acknowledged. The authors are grateful to late A. G. Dastidar for help and encouragement during sample collection. Cordial thanks to Mr. Argha Sarkar, Dept. of Botany, Bankim Sardar College, South 24 Parganas, West Bengal and Mrs. Chitrita Sarkar for their immense co-operation during preparation of figures.

## References

[1] Antonio, P.P. (1991) World Atlas of Holocene Sea level changes. Elsevier Oceanography Series, 58 UNESCO. Elsevier, Amsterdam.

[2] Mehr, S.S. (1992) Quaternary Sea-Level Changes along Indian Coast. *Indian National Science Academy A*, **58**, 461-472.

[3] Mehr, S.S. (1993) Neogene-Quaternary sequence in Gujarat: A Review. *Journal Geological Society of India*, **41**, 259-276.

[4] Mehr, S.S. and Chamyal, L.S. (1993) The Quaternary Sediments in Gujarat. *Current Science*, **64**, 11-12.

[5] Woodroffe, C.D. (1993) Late Quaternary Evolution of Coastal and Lowland Riverline Plains of South East Asia and Northern Australia: An Overview. *Sedimentary Geology*, **83**, 163-173. http://dx.doi.org/10.1016/0037-0738(93)90010-3

[6] Allen, H. (1994) The Time of the Mangroves: Changes in the Mid-Holocene Estuarine Environments and Subsistence in Australia and Southeast Asia. *Bulletin of Indo-Pacific Prehistory Association*, **14**, 1-16.

[7] Sen, P.K. and Banerjee, M. (1995) Study of Mega Plant Remains from Holocene Sediments of Bengal Basin, India for Biostratigraphic Zonation and Environment Analysis. In: Pant, D.D., Ed., Birbal Sahni Centenary Volume, *Proceedings of International Conference on Global Environment and Diversification of Plant through Geological time Scale Society for Indian Plant Taxonomists*, Allahabad, 395-407.

[8] Rachna, R., Maurya, D.M. and Chamyal, L S. (1998) Late Quarternary Sea Level Changes in Western India: Evidence from Lower Mahi Valley. *Current Science*, **74**, 910-914.

[9] Banerjee, M. (1996) Biological Remains in Tracing Coastal Evolution with Particular Reference to West Bengal Geoprovince of Bengal Basin, India. Integrated Coastal Zone Management—A Manual of Department of Environment, Government of West Bengal, Department of Ocean Development, Government of India, Calcutta, 229-239.

[10] Banerjee, M. (1998) Appraisal of Trend of Coastal Zone Evolution in the Western Geoprovince of Bengal Basin in Relation to Present Day Coastal Zone Problem Considerations. In: Mukherjee, A.D., Datta, K. and Sanyal, P., Eds., *Proceedings of National Workshop on Coastal Zone Problems*, Calcutta, School of Oceanographic Studies, Jadavpur

University (Eds.), 7-35.

[11] Kumaran, K.P.N., Yao, F.Y., Li, C.-S. and Limaye, R.B. (2007) Mangrove Vegetation Response to Environmental Changes during Late Quaternary along West Coast of India and Southern China: A Palynological Appraisal. *Quaternary International*, **167-168**, 223.

[12] Roy Barman, A. (1992) Geological History and Hydrocarbon Exploration in Bengal Basin. *Indian Journal of Geology*, **64**, 235-258.

[13] Ganguly, S., (1997) Petroleum Geology and Exploration History of the Bengal Basin in India and Bangladesh. *Indian Journal of Geology*, **69**, 1-25.

[14] Sarkar, A., Sengupta, S., McArthur, JM., Ravenscroft, P., Bera, M.K., Bhushan, R., Samanta, A. and Agrawal, S. (2009) Evolution of Ganges-Brahmaputra Western Delta Plain: Clues from Sedimentology and Carbon Isotope. *Quaternary Science Review*, **30**, 1-17. http://dx.doi.org/10.1016/j.quascirev.2009.05.016

[15] Dastidar, A.G. and Ghosh, P.K. (1967) A Study of Subsoil Conditions of Calcutta. *Journal of Institute of Engineering*, **48**, 692-714.

[16] Banerjee, M., Sen, P. and Dastidar, A.G. (1984) On the Depositional Condition of the Holocene Sediments of Bengal Basin with Remarks on Environmental Condition of the Soft Grey Clay Deposition in Calcutta. *Proceedings of Indian Geotechnical Conference* 1, Calcutta, 21-23 December 1984, Div. I, 63-69.

[17] Barui, N.C., Chanda, S. and Bhattacharya, K. (1986) Late Quaternary Vegetational History of the Bengal Basin. In: Samanta, B.K., Ed., *Proceedings XI Indian Colloquiu Micropaleontology Stratigraphy*, *Part II*, Bulletin, Geological Mining Metallurgical Society, India 54, Geology Department, University of Calcutta on 16-18 October 1984, 197-201.

[18] Agarwal, D.P. and Kusumgar, S. (1967) Radiocarbon Dates of Some Prehistoric and Pleiostocene Samples. *Current Science*, **36**, 566 -568.

[19] Chanda, S. and Hait, A.K. (1996) Aspects and Appraisal of Late Quaternary Vegetation of Lower Bengal Basin. *Palaeobotanist*, **45**, 117-124.

[20] Gupta, H.P. (1981) Palaeoenvironment during Holocene Time in Bengal Basin India as Reflected by Palynostratigraphy. *Palaeobotanist*, **27**, 138-160.

[21] Banerjee, M. and Sen, P.K. (1987) Palaeobiology in Understanding the Change of Sea Level and Coastline in Bengal Basin during Holocene Period. *Indian Journal of Earth Science*, **14**, 307-320.

[22] Mukherjee, A. and Hazra, S. (1997) Changing Paradigm of Petroleum Exploration in Bengal Basin. *Indian Journal of Geology*, **69**, 41-64.

[23] Das Gupta, A.B. (1997) Geology of the Bengal Basin. *Indian Journal of Geology*, **69**, 161-176.

[24] Vaidyanandhan, R and Ghosh, R.N. (1993) Quaternary of the East Coast of India. *Current Science*, **64**, 804-816.

[25] Milliman, J.D., Broadus, J.M. and Gable, F. (1989) Environmental and Economic Implications of Rising Sea Level and Subsiding Deltas: The Nile and Bengal Examples. *Ambio*, **18**, 340-345.