Lower Bengal basin, India witnessing Sea Level change and change of Coastline during Holocene

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Abstract

The present study aims to understand the trend of sea level and coast line change in Lower Bengal basin during Holocene through the evidence of mangrove peat, mangrove wood, wood fragments, estuarine clay and organic rich mud. The biological remains of distinct ecofacies recovered from the measured sections and chronologically dated sediments in nine locations viz., Kumirmari, Dakshin Harishpur, Taldi, Canning, Namkhana, Bakkhali, Diamond Harbour, Raidighi and Gangasagar are used as evidences for the reconstruction of Holocene sea-level curve. The sections are studied up to maximum depth of 41 m from surface. The sea level curve reveals that during 17726±485 cal yr BP to 10720±330 cal yr BP very slow sea level rise was occurred at the depth of -26 m to -21.5 m below present mean sea level (MSL). After 10720±330 cal yr BP onwards up to 10452±70 cal yr BP rapid rise of sea level takes place (transgressional phase) at the depth of -21.5 m to -3.65 m below present MSL. The environment of deposition of the area during that period was mixed brackish water and fresh water tidal mangrove vegetation (Phase-I). The very next phase of deposition in the study area is tidal mangrove vegetation (Phase-II) prevalent during 10452±70 cal yr BP to 8481±44 cal yr BP when there was more or less no sea level change since 1971 yrs. at the depth of -3.65 m to -3.25 m below present MSL. The rapid fall of sea level (-3.25 m to -39 m below present MSL) occurred during 8481±44 cal yr BP - 7034±223 cal yr BP resulting regression in the study area that causes *Phoenix* dominated mangrove upland (Phase-III). Rapid rise of sea level (transgression) was also initiated during this phase and rose at maximum height from the depth of -39 m to -4.3 m below present MSL in the next phase. The bioassemblage of the next phase of deposition (Phase-IV) with abundance of mangrove pollen grains reveals swampy mangrove vegetation in the study area during 5099±214 cal yr BP – c. 3779 cal yr BP. In this phase the sea level rise at the depth of -4.3 m to -0.75 m below present MSL. It appears from the sea level curve that the sediment of brackish water mixed fresh water *Heritiera* forest phase (Phase-V) was deposited within a relatively short time span compared to other phases during c. 3779 – c. 3198 cal yr BP when the sea level existed adjacent to present MSL. The fresh water grey clay with sand deposits dated between c. 3200 cal yr BP to present occur at the depth of present MSL to +1 m (surface) and the assemblage indicate existence of a fresh water grassland (Phase-VI) in and around the area of deposition.

Keywords

Sea level change; Holocene; Present Mean Sea Level; Lower Bengal basin; Environment of deposition

1. Introduction

The relationship between palaeomangrove deposits and Relative Sea Level (RSL) change was determined by Schaeffer-Novelli et al. (1990), who proposed a complex interplay among type, size, and frequency of occurrence of available mangrove landforms as a function of the particular mix of fluvial, tidal, and wave energies in a region. The transitional zone between marine and lacustrine fluvial facies is represented by the estuarine facies that are indicators of the coast line and sea level. Sea level change is defined as a variation of the level of the sea compared to land, triggered by either fluctuations of water volume in ocean basins or vertical movement of landmass (Lambeck, 2002). Biological forms that are bound to certain tide levels can be reliable indicators of sea level changes (Kelletat, 1988). Mangroves (littoral forest) play an important role to preserve the imprint of sea level fluctuations related to climate, eustasy or tectonic movements (Ellison, 1989). Mangroves are designated as indicators of coastal change or sea level rise (Woodroffe, 1990; Blasco et al., 1996).

Several attempts have been made to synthesize data and accurately reconstruct Holocene sea level trends through the evidence of biological remains in different parts of the world viz. Strait of Malacca (Geyh et al., 1979), Australia (Thom and Chappell, 1975; Thom and Roy, 1983, 1985; Hopley, 1987; Bryant, 1992; Woodroffe, 1995; Young et al., 1993, Sloss et al., 2007; Engel et al., 2012; Lewis et al., 2012), America (Suguio et al., 1985; Tomazelli, 1990; Rull et al., 1999; Angulo et. al., 1999; Cohen et al., 2005; Vedel et al., 2006; McKee et al., 2007; Angulo et al., 2008; Soares, 2009; Behling and Göttingen, 2011; Suguio et al., 2013), Thailand (Scheffers et al., 2012), Pacific high islands of Micronesia (Krauss et al., 2010), Indo-Pacific (Woodroffe and Horton, 2005), Asia (Umitsu, 1987; Islam and Tooley, 1999; Hori and Saito, 2007) and in India (Banerjee and Sen, 1987; Farooqui and Vaz, 2000; Ramaiah et al., 2004; Hameed et al., 2006; Bardhan et al., 2011).

In the present study, this is being a first attempt to understand the trend of sea level and coast line change in Lower Bengal basin during Holocene through the evidence of mangrove peat, mangrove wood, wood fragments, estuarine clay and organic rich mud (Figs. 1-3).

Fig. 1: Mangrove Peat

Fig. 2: Mangrove Wood

Fig. 3: Wood fragment

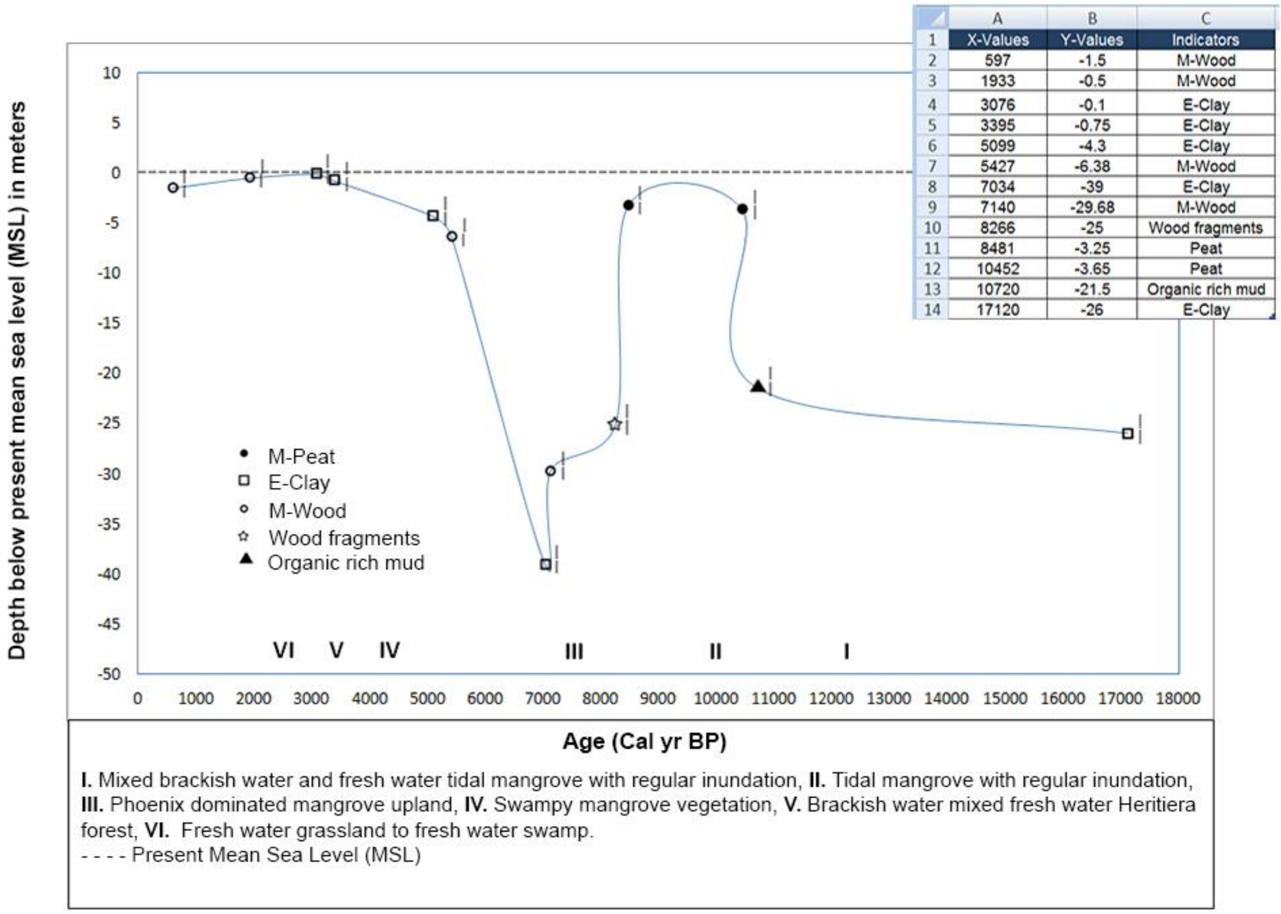
2. Material and Method

The biological remains used as evidences for the reconstruction of Holocene sea-level curve are of distinct ecofacies and recovered from the measured sections and chronologically dated sediments (Plate 1, Plate 2. Plate 3) in nine locations viz., Kumirmari ($22^0$12’18.5148”N Lat., $88^0$56’11.7528”E Long.), Dakshin Harishpur ($22^0$13’3.3204” N Lat. $88^0$49’11.1468” E long.), Taldi ($22^0$19’52.7” N Lat. $88^0$35’59.0” E Long.), Canning ($22^0$18' 37.3422" N Lat. 88^0 39' 28.4292" E Long.), Namkhana ($21^0$46’11.8164”N Lat. $88^0$13’53.4468” E Long.), Bakkhali ($21^0$33’47.268”N Lat. $88^0$15’34.2072”E Long.), Diamond Harbour ($22^0$12’5.562”N Lat. $88^0$12’30.5568”E Long.), Raidighi ($22^0$0’4.302”N Lat. $88^0$26’7.296”E Long.) and Gangasagar ($21^0$38’56.4792”N Lat. $88^0$4’31.5084”E Long.) (Text fig. 1) are. The sections are studied up to maximum depth of 41 m from surface.

Text fig. 1: Area of Interest for the present study

In total 13 radiocarbon ages, each with distinct nature of the dated material and stratigraphic relationship to Present Mean Sea Level (PMSL) are calibrated to Calendar years. All radiocarbon ages included are on materials collected between Canning and Bakkhali (about 100 Km; Text fig. 2, Table 1). The localities for the present study are situated about 20 to 60 Km inland from present coast line (Text fig. 1) and ±1 m above mean sea level and rarely flooded by river water.

Radiocarbon ages are calibrated to Calendar years using Calib 7.0 software and CalPal online Radiocarbon Calibration program QUICKCAL 2007 VER.1.5 and are referred to as conventional ages, Cal BP (before present; 1950).



	A	B	C
1	X-Values	Y-Values	Indicators
2	597	-1.5	M-Wood
3	1933	-0.5	M-Wood
4	3076	-0.1	E-Clay
5	3395	-0.75	E-Clay
6	5099	-4.3	E-Clay
7	5427	-6.38	M-Wood
8	7034	-39	E-Clay
9	7140	-29.68	M-Wood
10	8266	-25	Wood fragments
11	8481	-3.25	Peat
12	10452	-3.65	Peat
13	10720	-21.5	Organic rich mud
14	17120	-26	E-Clay

Text fig. 2 Diagrammatic representation of the trend of Holocene sea level change in Lower Bengal basin, India and corresponding change of environment

Table 1: C^{14} data recorded from Holocene sediments of Lower Bengal basin, India

Location	Geographical coordinates		Sample No.	Nature of the dated material	Depth from Surface (cm.)	^{14}C Age (Yr. B.P. ± error)	References
Kumirmari	22^{0}12’18.5148”N	88^{0}56’11.7528”E	BS-3435	E- Clay	325	810±70	Data from present study
Kumirmari	22^{0}12’18.5148”N	88^{0}56’11.7528”E	BS-3449	M-Wood	150	1970±80	Data from present study
Dakshin Harishpur	22^{0}13’3.3204”N	88^{0}49’11.1468”E	BS-3434	E- Clay	530	4450±170	Data from present study
Dakshin - Harishpur	22^{0}13’3.3204”N	88^{0}49’11.1468”E	BS-3430	E- Clay	410	410±70	Data from present study
Dakshin Harishpur	22^{0}13’3.3204”N	88^{0}49’11.1468”E	BS-3443	M-Wood	250	590±70	Data from present study
Taldi	22^{0}19’52.7”N	88^{0}35’59.0”E	BB-1	M- Peat	465	9271±41	Data from present study
Taldi	22^{0}19’52.7”N	88^{0}35’59.0”E	BB-2	M- Peat	425	7687±38	Data from present study
Namkhana	21^{0}46’11.8164”N	88^{0}13’53.4468”E	GrN7137	E- Clay	175	3170±70	Gupta 1981
Bakkhali	21^{0}33’47.268”N	88^{0}15’34.2072”E	BS-1159	M-Wood	838	4710±12	Chanda and Hait 1996
Bakkhali	21^{0}33’47.268”N	88^{0}15’34.2072”E	BS-1191	E- Clay	4100	6165±195	Chanda and Hait 1996
Diamond Harbour	22^{0}12’5.562”N	88^{0}12’30.5568E	PRL 1779	E- Clay	2800	14460±350	Chanda and Hait 1996
Canning	22^{0}18’37.3422”	88^{0}39’28.4292”E	BS-1160	M- wood	3168	6250±140	Chanda and Hait 1996
Pakhiralaya	22^{0}8’6.8568’N	88^{0}24’5.7744”E	BS-1156	Wood fragments	2230	7530±100	Chanda and Hait 1996
Pakhiralaya	22^{0}8’6.8568’N	88^{0}24’5.7744”E	BS-1190	Organic rich mud	4980	8800±135	Chanda and Hait 1996
Pakhiralaya	22^{0}8’6.8568’N	88^{0}24’5.7744”E	OS-17287	Wood fragments	490	4250±40	Stanley and Hait 2000
Pakhiralaya	22^{0}8’6.8568’N	88^{0}24’5.7744”E	OS-18427	Wood fragments	2115	7150±70	Stanley and Hait 2000
Pakhiralaya	22^{0}8’6.8568’N	88^{0}24’5.7744”E	OS-17064	Wood fragments	4130	8250±60	Stanley and Hait 2000
Raidighi	22^{0}0’4.302”N	88^{0}26’7.296’E	OS-17063	Wood fragments	2173	7260±50	Stanley and Hait 2000

Raidighi	22^{0}0’4.302”N	88^{0}26’7.296’E	BS-1394	Organic rich mud	2340	7960±170	Stanley and Hait 2000
Raidighi	22^{0}0’4.302”N	88^{0}26’7.296’E	BS-1389	Organic rich mud	2350	9420±235	Stanley and Hait 2000
Raidighi	22^{0}0’4.302”N	88^{0}26’7.296’E	OS-17283	Wood fragments	2700	7430±45	Stanley and Hait 2000
Ganga Sagar	21^{0}38’56.4792”N	88^{0}4’31.5084”E	-------	E- Clay	90	2920±20	Chakraborty 1991

(M= Mangrove, E=Estuarine)
Notes: C^{14} dating Laboratory- BS = Birbal Sahni Institute of Palaeobotany, Lucknow, India, BB = Bengal Basin (Geological Survey of India, Kolkata, India), PRL = Physical Research Laboratory, Ahmedabad, India, GrN – Groningen, The Netherlands and OS = Study by Stanley and Hait, 2000

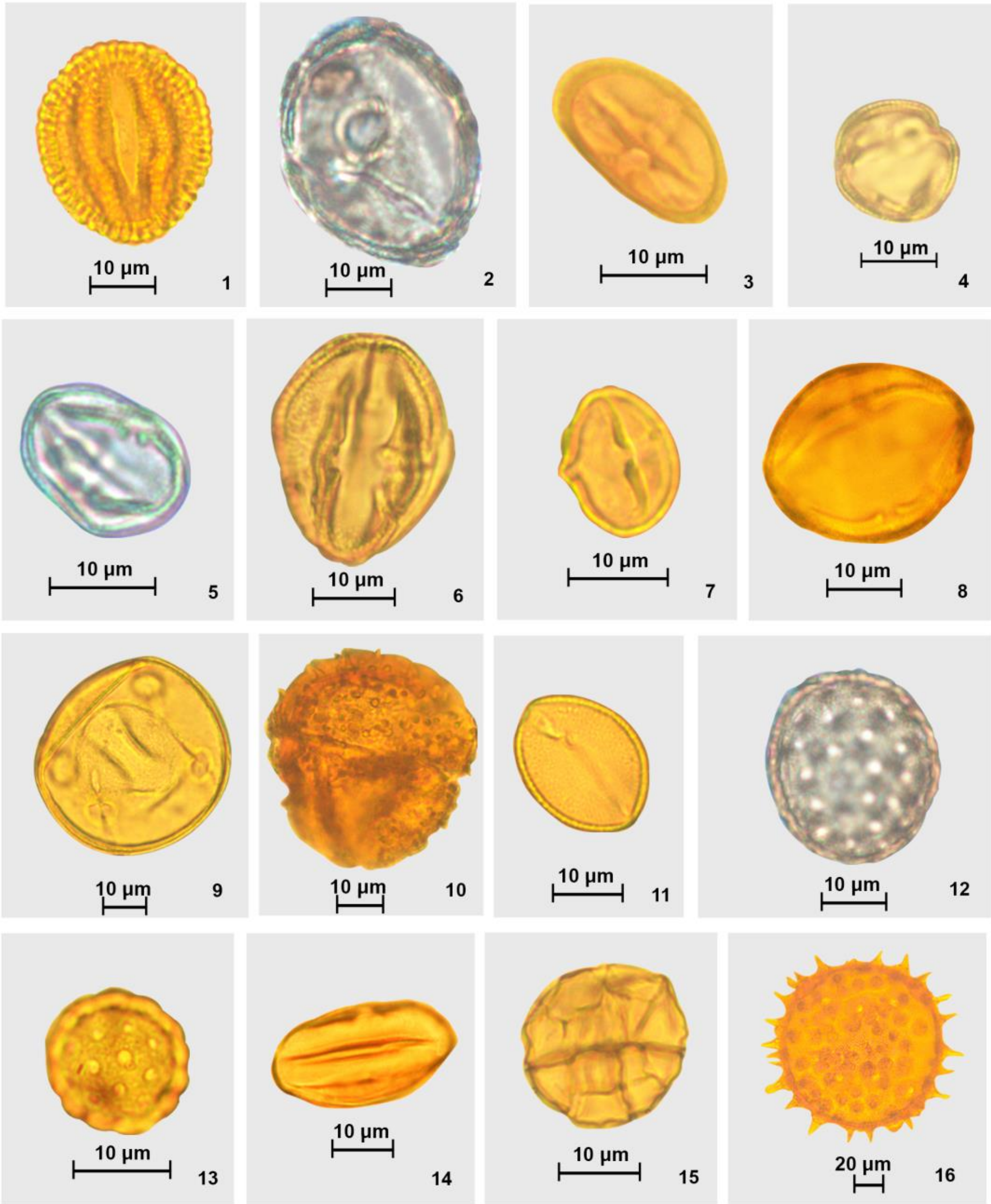


Plate 1

Fig. 1 Pollen grain of *Avicennia* sp.
Fig. 2 Pollen grain of *Sonneratia* sp.
Fig. 3 Pollen grain of *Rhizophora* sp.
Fig. 4 Pollen grain of *Ceriops* sp.
Fig. 5 Pollen grain of *Bruguiera* sp.
Fig. 6 Pollen grain of *Excoecaria* sp.
Fig. 7 Pollen grain of *Aegiceras* sp.
Fig. 8 Pollen grain of *Heritiera* sp.
Fig. 9 Pollen grain of *Xylocarpus* sp.
Fig. 10 Pollen grain of *Nypa fruticans*.
Fig. 11 Pollen grain of *Phoenix paludosa*.
Fig. 12,13 Pollen grains of Cheno-Amaranthus type.
Fig. 14 Pollen grain of *Heliotropium* sp.
Fig. 15 Pollen grain of Leguminosae.
Fig. 16 Pollen grain of Malvaceae.

Plate 1: Images of few biological remains (Pollen grains and Spores)

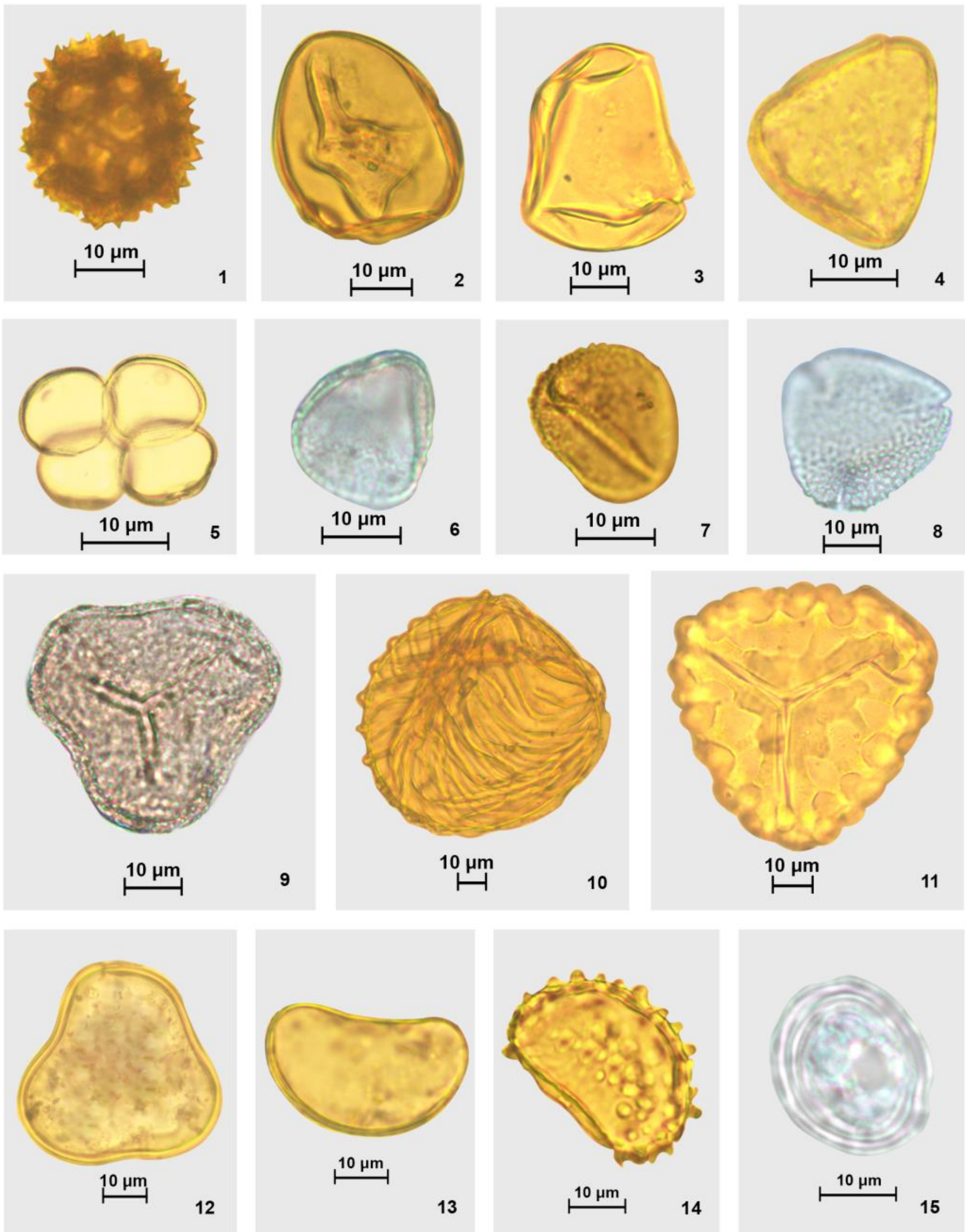


Plate 2

Fig. 1 Pollen grain of Compositae.
Fig. 2 Pollen grain of Poaceae.
Fig. 3 Pollen grain of Poaceae.
Fig. 4 Pollen grain of Cyperaceae.
Fig. 5 Pollen grain of *Typha* sp.
Fig. 6 Pollen grain of *Typha* sp.
Fig. 7 Pollen grain of *Potamogeton* sp.
Fig. 8 Pollen grain of *Nymphoides* sp.
Fig. 9 Spore of *Acrostichum* sp.
Fig. 10 Spore of *Ceratopteris* sp.
Fig. 11 Spore of *Lygodium* sp.
Fig. 12 Spore of Trilete psilate.
Fig. 13 Spore of Monolete psilate.
Fig. 14 Spore of Monolete verrucate.
Fig. 15 *Concentricystes rubinus* (splitted half).

Plate 2: Images of few biological remains (Pollen grains and Spores)

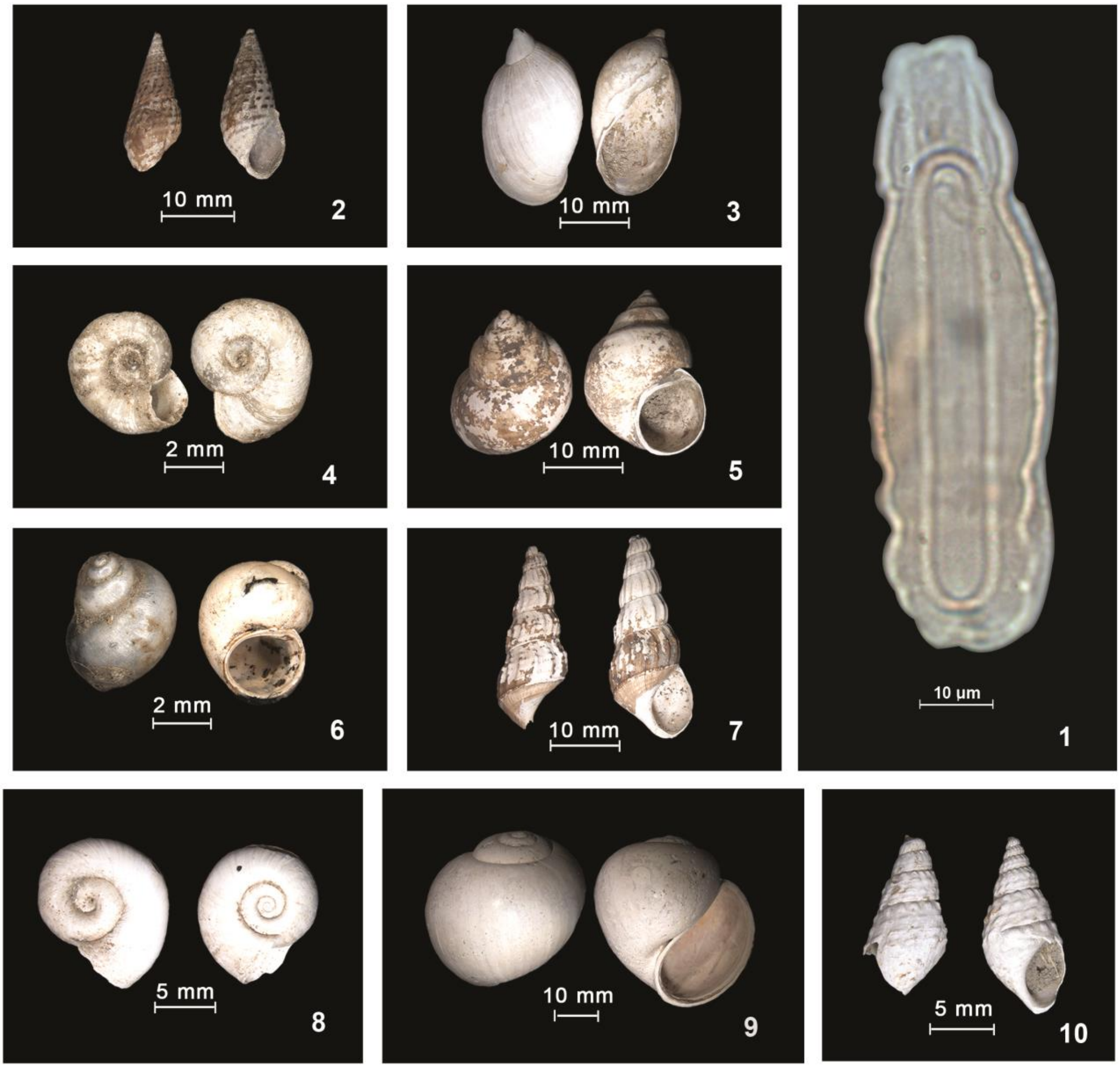


Plate 3

Fig. 1 Algal filaments of *Gloeotrichia* sp.
Fig. 2 Dorsal and ventral view of mollusc shells of *Tarebia lineata.*
Fig. 3 Dorsal and ventral view of mollusc shells of *Lymnea acuminata* f. *patula.*
Fig. 4 Dorsal and ventral view of mollusc shells of *Gyraulus convexiusculus.*
Fig. 5 Dorsal and ventral view of mollusc shells of *Bellamya bengalensis.*
Fig. 6 Dorsal and ventral view of mollusc shells of *Gabbia orcula.*
Fig. 7 Dorsal and ventral view of mollusc shells of *Brotia costula.*
Fig. 8 Dorsal and ventral view of mollusc shells of *Indoplanorbis exustus.*
Fig. 9 Dorsal and ventral view of mollusc shells of *Pila globasa.*
Fig. 10 Dorsal and ventral view of mollusc shells of *Tarebia granifera.*

Plate 3: Images of few biological remains (Fresh water alga and mollusc shells)

2.1 Sea level indicators

In order to reconstruct sea level change using mangrove sediments, it is necessary to know the altitudinal range within which the mangrove species occur as this represents the indicative range of the sea level index point. Mangrove sediment, mangrove peat, mangrove wood, peat with fresh water diatom, mangrove pollen, marine and estuarine mollusc gastropod shells, bivalves, *in situ* freshwater hardwood stumps, *in situ* mangrove root, coral reef, lagoonal mud, coastal marsh, organic clay etc. have been used as sea level indicators by several workers time to time throughout the globe (Geyh et al., 1979; Banerjee and Sen, 1987; Blasco et al., 1996; Farooqui and Vaz, 2000; Ramaiah et al., 2004; Cohen et al., 2005; Horton et al., 2005; Woodroffe and Horton, 2005; Hameed et al., 2006; Vedel et al., 2006; McKee et al., 2007; Sloss et al., 2007; Soares, 2009; Bardhan et al., 2011; Behling and Göttingen, 2011; Engel et al., 2012; Lewis et al., 2012; Punwong, 2013; Suguio et al., 2013).

3. Trend of Sea level and Coast line change in Lower Bengal Basin, India during Holocene

The sea level curve (Text fig. 2) reveals that during 17726±485 cal yr. B.P. to 10720±330 cal yr BP very slow sea level rise was occurred at the depth of -26 m to -21.5 m below present mean sea level (MSL). After 10720±330 cal yr BP onwards up to 10452±70 cal yr BP rapid rise of sea level takes place (transgressional phase) at the depth of -21.5 m to -3.65 m below present MSL. The environment of deposition of the area during that period was mixed brackish water and fresh water tidal mangrove vegetation (Phase-I) as evidenced from the occurrence of mangrove pollen grains of *Heritiera*, *Nypa*, *Bruguiera*, *Excoecaria* and fern spores. The very next phase of deposition in the study area is tidal mangrove vegetation (Phase-II) marked by the occurrence of mangrove pollen grains viz. *Sonneratia*, *Xylocarpus*, *Bruguiera*, *Heritiera* and fern spores. This phase was prevalent during c. 11,506 cal yr BP to 8481±44 cal yr BP when there was more or less no sea level change since 1971 yrs. at the depth of -3.65 m to -3.25 m below present MSL.

The rapid fall of sea level (-3.25 m to -39 m below present MSL) occurred during 8481±44 cal yr BP - 7034±223 cal yr BP resulting regression in the study area that causes *Phoenix* dominated mangrove upland (Phase-III) with the maximum development of pollen of mangrove palm *Phoenix* along with high abundance of *Heritiera*, low values of mangrove pollen *Xylocarpus*, *Sonneratia*, *Bruguiera* and high frequency of Asteraceae, Poaceae, Malvaceae, Cyperaceae pollen and fern spores. Rapid rise of sea level (transgression) was also initiated during this phase and rose at maximum height from the depth of -39 m to -4.3 m below present MSL in the next phase.

The bioassemblage of the next phase of deposition (Phase-IV) with abundance of mangrove pollen grains of *Sonneratia*, *Avicennia*, *Ceriops*, low value for *Bruguiera* pollen and fresh water loving mangrove plant *Heritiera* reveals a swampy mangrove vegetation in the study area during 5099±214 cal yr BP – c. 3779 cal yr BP. In this phase the sea level rise at the depth of -4.3 m to -0.75 m below present MSL.

It appears from the sea level curve that the sediment of brackish water mixed fresh water *Heritiera* forest phase (Phase-V) was deposited within a relatively short time span compared to other phases during c. 3779 – c. 3198 cal yr BP when the sea level existed adjacent to present MSL.

The fresh water grey clay with sand deposits dated between c. 3198 cal yr BP to present occur at the depth of present MSL to +1 m (surface). Diverse and frequent fresh water plant pollen grains of *Suaeda* (Cheno-Amaranthus type), *Typha*, *Nymphoides*, Asteraceae, Malvaceae, Cyperaceae, Poaceae and *Acrostichum aureum*, *Ceratopteris*, *Lygodium* spore, fresh water alga *Gloeotrichia*, fresh water mollusc shells recovered in the assemblage of the sediment indicate existence of a fresh water grassland (Phase-VI) in and around the area of deposition.

4. Depositional facies and C^{14} records of Holocene sediments in Lower Bengal Basin, India

Depositional facies (Plate 4)

Distinct change in the depositional environment from (I) mixed brackish water and fresh water tidal mangrove vegetation with regular inundation to (II) tidal mangrove environmental phases of deposition with regular inundation, (III) environment constituted with *Phoenix* dominated and occasionally inundated mangrove upland associated fern, (IV) the swampy mangrove to tidal mangrove vegetational environment in a tropical warm and humid climate condition, (V) environment of brackish water mixed fresh water *Heritiera* forest with initiation of non-littoral taxa to (VI) the fresh water grassland to fresh water swamp condition in quiet environment with high precipitation and humidity have been explored through palaeobiological evidence from chronologically dated sediments during c.11, 000 – 1970±80 yr BP in the Lower Bengal basin.

The nature of the dated material recovered from C^{14} dated sediments, depth of the dated material in relation with present mean sea level (MSL) and the depositional facies during Holocene in the study area plotted in Text fig. 2 has been made through following analysis:

1. The environmental factor analysis of the estuarine and fresh water plant and animal bioforms recovered during the present study has been critically worked out.
2. In the present study mangrove peat, mangrove wood, wood fragments, estuarine clay and organic rich mud preserved in Holocene deposits have been used as indicators to place finite limits on the timing and maximum height attained by the sea-level.

   Mangrove bioassemblage is already established as direct indicator of the tidal zone between Mean High Water Neap (MHWN) and Mean High Water Spring (MHWS) which is at present 1.36 m at Sundarbans (Surveyor General of India, Tide table of the Hugli River, 1985; Banerjee and Sen, 1987).
3. With the aid of different biological evidences, the sea level change, transgression or regression of the sea during late Quaternary has been understood by various workers throughout the world viz. in Florida (Spackman et al., 1966), Western Australia (Thom et al., 1975), Strait of Malacca (Geyh et al., 1979), New South Wales South coast, Australia (Thom and Roy, 1983, 1985; Young et al., 1993), Gulf of Mexico coast (Blum et al., 2002) and New South Wales Southeast coast, Australia (Sloss et al., 2007).

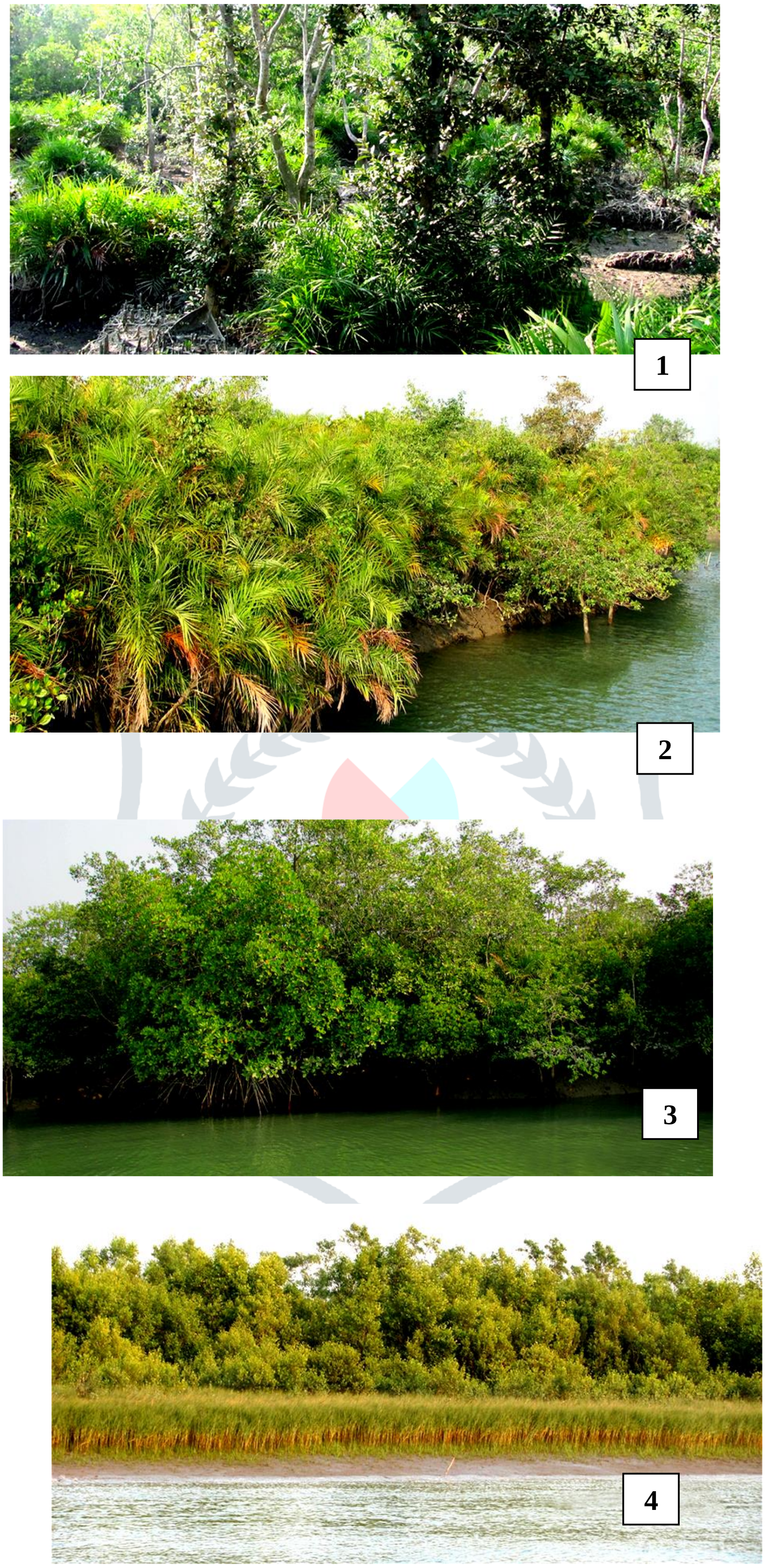


Plate 4

Present day Mangrove vegetation of Lower Bengal basin, India
Fig. 1 Brackish water mixed fresh water Heritiera forest
Fig. 2 Phoenix dominated mangrove upland
Fig. 3 Tidal mangrove with regular inundation
Fig. 4 Mixed Brackish water and fresh water tidal mangrove with regular inundation

5. Discussion

The trend of sea level and coastline changes in the area of present study, revealed through palaeobiological evidence from Holocene sediments of Lower Bengal basin (Text fig. 2), has been enumerated in Table 2. The coastline ecosystem refers to the typical mangrove association in modern or ancient assemblages.

Table 2: Trend of sea level and coastline change with phases of deposition of C^{14} dated sediments in Lower Bengal basin, India during Holocene

Phases of deposition	Chronological date Yr. B.P.	 Cal. Yr. B.P.	Sea level fluctuations (from Present Mean Sea Level)	Sea level elevation and rate of sea level movement (rise/fall)	Displacement of coast line
VI. Freshwater grassland	3000 to 1970	3198 to 1933	Sea level reached almost its present level	-0.5 m (0.25in 1462 yrs = 0.0002 m/yr rise)	Coastline approached its present position about 2000 yrs. B.P.
V. Brackish water mixed fresh water *Heritiera* forest	3500 to 3000	3779 to 3198	Sea level rose very slowly for minimum height	0.75 m (3.55 m in 1704 yrs = 0.002 m/yr rise)	Seaward extension of coastline was continuing due to siltation.
IV. Swampy mangrove vegetation	4450 to 3500	5099 to 3779	Rapid sea level rose at maximum height up to -4.3 m	-4.3 m (34.7m in 1935 yrs = 0.02 m/yr rise)	Due to regression the swampy mangrove vegetation shifted at the area of present study (Kumirmari and Dakshin Harishpur) which is 10-20 Km inland from the present position of the coastline and 40-50 Km seawards from the earlier position.
III. *Phoenix* dominated mangrove upland	7687 to 6000	8481 to 6847	Gradual and rapid fall of sea level and lowest phase of sea level during Holocene and 2nd phase of transgression initiated	-39 m (35.75m in 1447 yrs = 0.02 m/yr fall gradually)	Regression of sea occurred, coastline moved seawards and delta advanced seawards.
II. Tidal mangrove vegetation	10000 to 7687	11506 to 8481	Initial phase of rapid rise of sea level and then remained stable for 1971 years	-3.65 (17.85 m in 268 yrs = 0.07 m/yr rise), then for 1971 yrs sea level was stable and reached at -3.25m	Coast line reached 60 Km inland from the present position and transgression of sea occurred (transgression phase).
I. Mixed brackish water and fresh water tidal mangrove	11000 to 10000	12914 to 11506	Sea level attained this position since more than 5000 yrs back	-21.5 m	The area of present study (Taldi and Canning) perhaps was located near tidal mangrove swamp.

The trend in the rise of sea level in the Lower Bengal basin during Holocene, as analysed in the present paper, supports the view of Shepard, 1964 and Shephard et al., 1967. They expressed the view that sea level was never above the present MSL; it was also supported by the data obtained from thirty three islands in Micronesia, central pacific that there was no oscillation in the rise of sea level during Quaternary. On the other hand, Fairbridge (1961) suggested 3-6 m rise of sea level from the present MSL during 7000 to 5000 yrs BP (Atlantic stage).

In the present study existence of sea level at -21.5 m below present MSL during 12914 to 11506 cal yr BP and the rise of sea level from -21.5 m to -3.65 m below present MSL between 11506 to 8481 cal yr BP. During this period, after the initial rapid rise, the sea level remained stable for 1971 years. After that, gradual and rapid fall of sea level occurred up to -39 m below present MSL during 8481 to 6847 cal yr BP and it was the lowest phase of sea level during Holocene. During 5099 to 3779 cal yr BP rapid rise of sea level occurred and reached at -4.3 m below present MSL. Then very slow sea level rise occurred at -0.75 m below present MSL during 3779 to 3198 cal yr BP. The sea level reached almost its present level at -0.5 m below present MSL between 3198 to 1933 cal yr BP.

The palaeobiological evidences reported by Hait and Behling, 2009 suggest the disappearance of the early Holocene mangrove forest due to the changes in the sea level (transgression) after 9240 cal yr BP, reappearance as a result of the stabilization of the sea level at the study site around 7560 cal yr BP and its less rapid increase from about 5000 cal yr BP onwards. This incidence had a great impact on the present study site where due to the transgression reported by Hait and Behling, 2009 and the change of the coastline, the mangrove vegetation shifted to the study area resulting tidal mangrove vegetation in this area during 10,000 – 7687±38 yr BP. Reappearance of mangrove during about 8420-7560 cal yr. B.P according to Hait and Behling, 2009 supports the time-span during 10,000 – 7687±38 yr BP in the present study site. The evidences also indicate towards the reappearance of intertidal habitat after 4800 cal yr BP which was disappeared between 7560 and 4800 cal yr BP because of the accumulation of a huge quantity of sediment from the sea level regression, accompanied by a high rate of fluvial sedimentation. The regression occurred during 7560-4800 cal yr BP in this zone had sharply affected the present study site where the regression caused again seaward change of coastline resulting mangrove upland with significant decline of tidal mangrove vegetation. Lastly, the incidence of reappearance of intertidal habitat in this zone after 4800 cal yr BP is highly comparable to the occurrence of swampy and tidal mangrove vegetation in the present study area at seaward site of Lower Bengal basin during 4450±170 – c. 3500 yr BP and c. 3500 – c.3000 yr BP respectively.

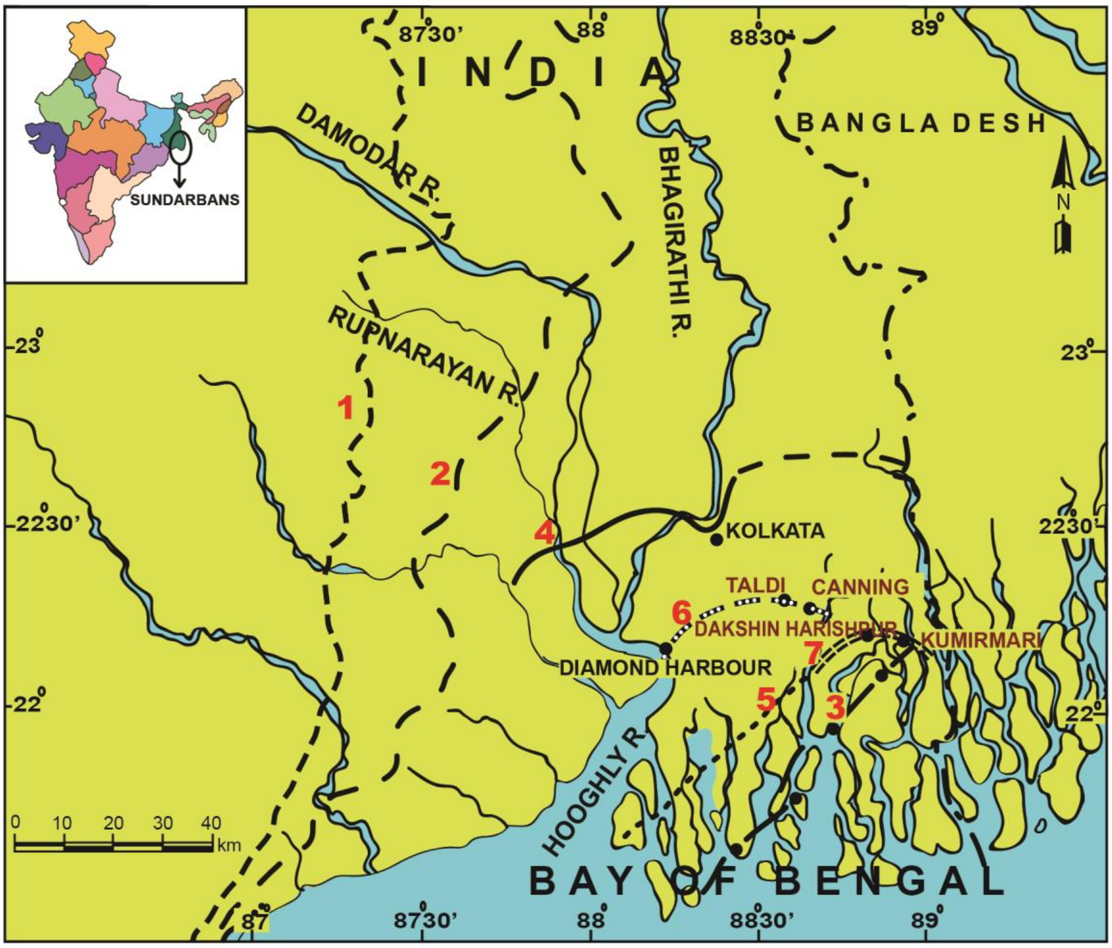
Similar types of mid Holocene coastal progradation are reported from different areas of the world viz., in northern Australia (Woodroffe et al., 1985), Nile delta in Egypt (Stanley and Warne, 1993, 1994), Bangladesh (Umitsu, 1993; Islam and Tooley, 1999), Okains Bay, Banks Peninsula, Canterbury, New Zealand (Stephenson and Shulmeister, 1999), Changjiang (Yangtze) delta, China (Hori et al., 2001), Philippines (Berdin et al., 2003), Indonesia (Yulianto et al., 2004), east coast of Korea (Choi et al., 2014).

The trend of sea level rise at 7000 to 4000 cal yr BP in Lower Bengal basin is closely comparable to the records obtained from sea level curve drawn by Banerjee and Sen (1987). This is also comparable to the records obtained from Western Australia (Thom et al., 1975), strait of Malacca (Geyh et al., 1979), East China (Yang Huaijen and Xie Zhiren, 1984) and Kouilou estuary valley, Africa (Giresse and Moguedet, 1980).

6. Conclusion

Occurrence of high frequency of mangrove pollen and other palaeobiological remains recovered from the Holocene sediments of Taldi and Canning area radiocarbon dated 11506 to 8481 cal yr BP indicated that the coastline existed in this study area 50-60 Km inland from the present coastal zone during this period. Due to regression, seaward migration of mangrove ecosystem resulted in the change of coastline about 33 Km towards South at Kumirmari and Dakshin Harishpur area 10-20 Km inland from the present estuarine zone during 5099 to 3779 cal yr BP. On the other hand, Hait and Behling (2009) suggested the disappearance of early Holocene mangrove in Pakhiralaya area after 9240 cal yr BP, reappearance of mangrove vegetation in this zone during 8420 to 7560 cal yr BP and again disappearance between 7560 and 4800 cal yr BP because of the accumulation of a huge quantity of sediment from the sea level regression, accompanied by a high rate of fluvial sedimentation. Lastly, the incidence of reappearance of intertidal habitat in this zone after

4800 cal yr BP was clearly evident from their study. Again, occurrence of wood fragments and organic rich mud recovered from the Holocene sediments in Raidighi area indicated the past mangrove vegetation in this area during 8266 to 10720 cal yr BP (Stanley and Hait, 2000). Evidence of Holocene relative sea level movement at two different sites viz. Panigati and Matuail in Bengal basin, Bangladesh was used by Islam and Tooley (1999) to draw two relative sea level curves. The sea level curve from Panigati showed five trangressive episodes since about 9000 cal yr BP and the other sea level curve from Matuail revealed three transgressive episodes since about 7000 cal yr. B.P. According to Banerjee and Sen (1987) and Sen and Banerjee (2016), the coastline extended from south west to north east of Bengal basin between Kolaghat, Kolara, Sankrail, Calcutta, Dum Dum during 7000 to 6175 yr BP (Mid Holocene) due to rapid rise of sea level. The strand line position proposed in the Bengal basin based on geomorphic study through airphoto has suggested strand line position during 2, 15, 000 yr BP and 82, 000 yr BP towards the present lateritic upland in the western Bengal basin, further west of 88^0 E Longitude (Niyogi, 1968). Kamal and Varadarajan (1984) suggested that the strand line during Pleistocene was located almost at the present position through mathematical model. The changing position of coastline during Quaternary period along with the present interpretation is enumerated in Text fig. 3.



1. - - - - - Coastline at 215000 yr. B.P. (Niyogi. 1968)
2. —— —— Coastline at 82000 yr. B. P. (Niyogi. 1968)
3. —●— Pleistocene strand line (ed.Kamal and Varadarajan,1984)
4. ——— Coastline during 7000 to 6000 yr. B.P. (Banerjee and Sen, 1987; Sen and Banerjee, 2016)
5. - - - - - - Coastline during 4500 to 3000 yr. B.P. (Banerjee and Sen, 1987)
6. ▫▫▫ ▫▫▫ ▫▫▫ Coastline during 11,000 to 10,000 yr. B.P. (Present study)
7. ======= Coastline during 4450 to 3500 yr. B.P. (Present study)

Text fig. 3 Coastline changes since Pleistocene in Lower Bengal basin, India

Transgression, regression and sea level fluctuations cause displacement of coastline which is directly related to siltation rate or rate of sedimentation. The progradation of delta is simply proportionate to the rate of sedimentation. The data of rate of sedimentation during Holocene in Lower Bengal basin are plotted in Table 3.

Table 3: C^{14}dates from Holocene i.e. late Quaternary sediments of Lower Bengal basin, India and Rate of sedimentation

Location	Sample No.	Nature of the dated material	Depth from Surface (cm.)	^{14}C Age (yr BP ± error)	References	Thickness (cm.) between consecutive c^{14} dated sediments	Depositional time (Year)	Rate of sedimentation (cm. / year)
Kumirmari	BS-3449	M-Wood	150	1970±80	Data from present study	175	……….	………..
Kumirmari	BS-3435	E- Clay	325	810±70	Data from present study			
Dakshin Harishpur	BS-3430	E- Clay	410	410±70	Data from present study			
Dakshin Harishpur	BS-3443	M-Wood	250	590±70	Data from present study	280	3860	0.07
Dakshin Harishpur	BS-3434	E- Clay	530	4450±170	Data from present study			
Taldi	BB-2	M- Peat	425	7687±38	Data from present study	40	1584	0.03
Taldi	BB-1	M- Peat	465	9271±41	Data from present study			
Namkhana	GrN7137	E- Clay	175	3170±70	Gupta 1981	………	………..	………..
Bakkhali	BS-1159	M-Wood	838	4710±120	Chanda and Hait 1996	3262	1455	2.24
Bakkhali	BS-1191	E- Clay	4100	6165±195	Chanda and Hait 1996			
Diamond Harbour	PRL 1779	E- Clay	2800	14460±350	Chanda and Hait 1996	………	………..	………....
Canning	BS-1160	M- wood	3168	6250±140	Chanda and Hait 1996	………	………..	…………
Pakhiralaya	OS-17287	Wood fragments	490	4250±40	Stanley and Hait 2000	1625	2900	0.56
Pakhiralaya	OS-18427	Wood fragments	2115	7150±70	Stanley and Hait 2000	115	380	0.30
Pakhiralaya	BS-1156	Wood fragments	2230	7530±100	Chanda and Hait 1996	1900	720	2.64
Pakhiralaya	OS-17064	Wood fragments	4130	8250±60	Stanley and Hait 2000	850	550	1.54
Pakhiralaya	BS-1190	Organic rich mud	4980	8800±135	Chanda and Hait 1996			

Location	Sample No.	Nature of the dated material	Depth from Surface (cm.)	^{14}C Age (Yr. B.P. ± error)	References	Thickness (cm.) between consecutive c^{14} dated sediments	Depositional time (Year)	Rate of sedimentation (cm. / year)
Raidighi	OS-17063	Wood fragments	2173	7260±50	Stanley and Hait 2000	167	700	0.24
Raidighi	BS-1394	Organic rich mud	2340	7960±170	Stanley and Hait 2000	10	1460	0.006
Raidighi	BS-1389	Organic rich mud	2350	9420±235	Stanley and Hait 2000	350	………...	………….
Raidighi	OS-17283	Wood fragments	2700	7430±45	Stanley and Hait 2000			
Ganga Sagar	-------	E- Clay	90	2920±20	Chakroborty 1991			

(M= Mangrove, E=Estuarine)

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