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Mid Holocene Marine Transgression at Eastern Coastal Margin of Bangladesh—Implications for Past Sea Level Change

Md. Golam Kibria, S.K. Saha*, Md. Hussain Monsur, Tohida Rashid[1] and Md. Zillur Rahman

Department of Geology, University of Dhaka, Dhaka 1000, Bangladesh
[1]Department of Geography and Environment, University of Dhaka, Dhaka 1000, Bangladesh
✉ sahask03@gmail.com

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Abstract: Sedimentological, palynological data indicate that mangrove community developed under transgressive condition in and around Maheskhali and Kutubdia Island areas during Mid Holocene time (7000 to 5500 years BP) leading to the locally wide spread deposition of organic-rich sediments. During Holocene time global rise and fall of eustatic sea level played an important role not only on the depositional environment but in creating a geomorphic feature on the island. Recurrent occurence of freshwater and mangrove pollen in Maheskhali and Kutubdia Island area indicate that these areas have undergone cyclic marine and non-marine influence. Since the Last Glacial Maximum (about 20,000 years ago), sea level has risen by over 120 m at locations far from present and former ice sheets, as a result of loss of mass from these ice sheets. There was a rapid rise between 15,000 and 6,000 years ago at an average rate of 10 mm/yr. Based on geological data, global average sea level may have risen at an average rate of about 0.5 mm/yr over the last 6000 years and at an average rate of 0.1 to 0.2 mm/yr over the last 3000 years. Vertical land movements are still occurring today as a result of these large transfers of mass from the ice sheets to the ocean. During the last 6000 years, global average sea level variations on time-scales of a few hundred years and longer are likely to have been less than 0.3 to 0.5 m. First transgression was noticed around 6000-5500 cal BP and then a subsequent regression of the bay had been observed from around 5500 cal BP. This was again followed by another small scale transgression episode occurred around 2500—2000 cal BP. So the palynomorph assemblages from the Holocene sediment sample indicate that Maheskhali and Kutubdia Island and its surrounding area was an intertidal environment occupied by mangrove community.

Keywords: Sea level; Vulnerability; Coastal community; Palynology; Transgression.

Introduction

Regionally the study area includes the S-E coastal margin of Bangladesh having the complex nature of physico-chemical condition which deals with the day-to-day life style of the region. But to get a clear overview of the sea level change, land use and surface geology, vulnerability assessment in detail, emphasis has been given to the data of Maheskhali (21°46´ N and 91°59´ E) and Kutubdia (21°49′00″ N 91°51′30″ E/21.8167° N 91.8583° E) Island of Cox's Bazar district.

The shoreline of the Bay of Bengal has been observed not to be static in relation to previous geological events (Umitsu, 1987, 1993; Kudrass et al., 1999; Goodbred and Kuehl, 2000; Islam 2001). During the peak of the last glaciations (18 kyr BP) the Bengal lowland

*Corresponding Author

experienced dry climatic conditions and sea level was 100 metre or more lowered than the present sea level (Umitsu, 1987). At about 12 kyr BP, south-west monsoon became prominent which caused heavy rain fall and sea level started rising very rapidly (Monsur, 1995). This amplified monsoon water plus deglaciated meltwater from the Himalayas flowed over the Bengal Lowland and the initial Madhupur and Barind surface were highly dissected, creating some local pools and depressions (Monsur, 1990). It seems that the coastal processes and climate had a significant control on the topography of this region during late Pleistocene time. The Indian summer monsoon (ISM) during early to middle Holocene was generally stronger than today, with peaks identified at 8.5, 6.4 and 2.7 kyr BP detected in numerous ISM records (Fleitmann et al., 2003; Gasse et al., 1991; Van Campo et al., 1996; Wang et al., 2005) but weaker than today between 5000-1200 yrs BP (Naidu, 2004). Umitsu (1993), Kudrass et al. (1999) and Goodbred and Kuehl (2000) stated that during the Mid Holocene, sea level of the Bay was slightly higher, the climate was warmer, and rivers of this region discharged up to two and half times more than in present times. It has generally been accepted that around 6000 years BP, eustatic sea level was higher than the present sea level.

A limited number of detailed studies have been made in the last few decades to reconstruct the Holocene sea level change of the Bengal Lowland, including those of Umitsu (1987, 1993), Banerjee and Sen (1987) and Islam (2001). These past attempts to reconstruct Holocene sea level history have been based on bore hole samples. The study, the first of its type in the Bengal basin, presents a detailed description with faunal succession of pollen which yields the maximum information about the paleoenvironment to know the relative sea level history of Bangladesh during Holocene period.

The ongoing research reviews the sea level rise impacts on the coastal zone of Bangladesh, on the basis of primary and available secondary sources. In the study, the emphasis was placed on assessing the impacts rather than measuring the rate of sea level rise or its cause of global warming, i.e. climate change debate.

Field and Laboratory Investigation

The Maheshkhali island (Figure 1) is subdivided into two equal morphological halves: Eastern and Western halves, by a N-S elongated ancient (about 6000 yrs BP) coastline which runs parallel to the North Nalbila-Gorakghata (Adinath bazaar) road. The eastern half is still retaining the initial undulated morphology with some minor hillocks of Neogene sediments (Table 1). The western half represents a coastal plain with saltmarsh (Supratidal flat), tidal flat, tidal channels and creeks and coastal lagoons (Monsur and Kamal, 1994). Maheshkhali hills (occupying an area of about 76 km^2) as a whole is an extension of the northern part of “Baragi Taung Range”. The continuation of the range has been disrupted by “Maheshkhali channel” at present. This half-oval shaped unit is quite abrupt along the Maheshkhali channel (Monsur and Kamal, 1994) with a high elevation at the middle. On the other hand, the southern and northern parts of the unit comprises low hillocks. Topography is matured and the rounded hills follow the structural trend i.e. NNW-SSE. In the southeastern part of the hilly area, the hills have been grooved by Mudircharrakhal and resulted into a fecund wide valley. The hills slope steeply towards south and south-east and with a low angle towards north and north-east. Elevation of this unit ranges from approximately 12 metres to 70 metres above MSL.

Kutubdia Island (Figure 2) is represented by unconsolidated muddy sediments of Holocene coastal plain deposits. Holocene coastal plain sediments are underlain by a peat layer which is called basal peat layer also called inter fingering or intercalated peat (Table 1). The morphological features of Kutubdia Island can be subdivided into following zones: Supratidal, Intertidal and Subtidal.

Locations of each section were recorded with GPS (Magellan GPS 315). The brackish water sediments were needed to examine in order to find the evidence of relative sea-level change. In addition, to give a new idea about the origin of the Maheskhali and Kutubdia Island, the brackish water sediments were essential to explore. On the basis of reconnaissance survey and availability of exposed dig pit in the six outcrops on the fringe of the island, such as Kutubdia streamer ghat, Kaiyar Bil, South Dhurung, Ajimuddin Sikdar Para from Kutubdia Island and Haramkhali bill section from Maheskhali Island were selected. Facies identifications and interpretation was based on detailed examination of composition, sedimentary structure, bedding, characteristics, sediment grain-size and colour on the exposed outcrops were dug up to the desired level and cleaned the selected faces to retrieve samples and make sketches (Miail, 1984). The interpretation was also based on an examination of vertical facies associations (Walker, 1984). Rock samples were processed for

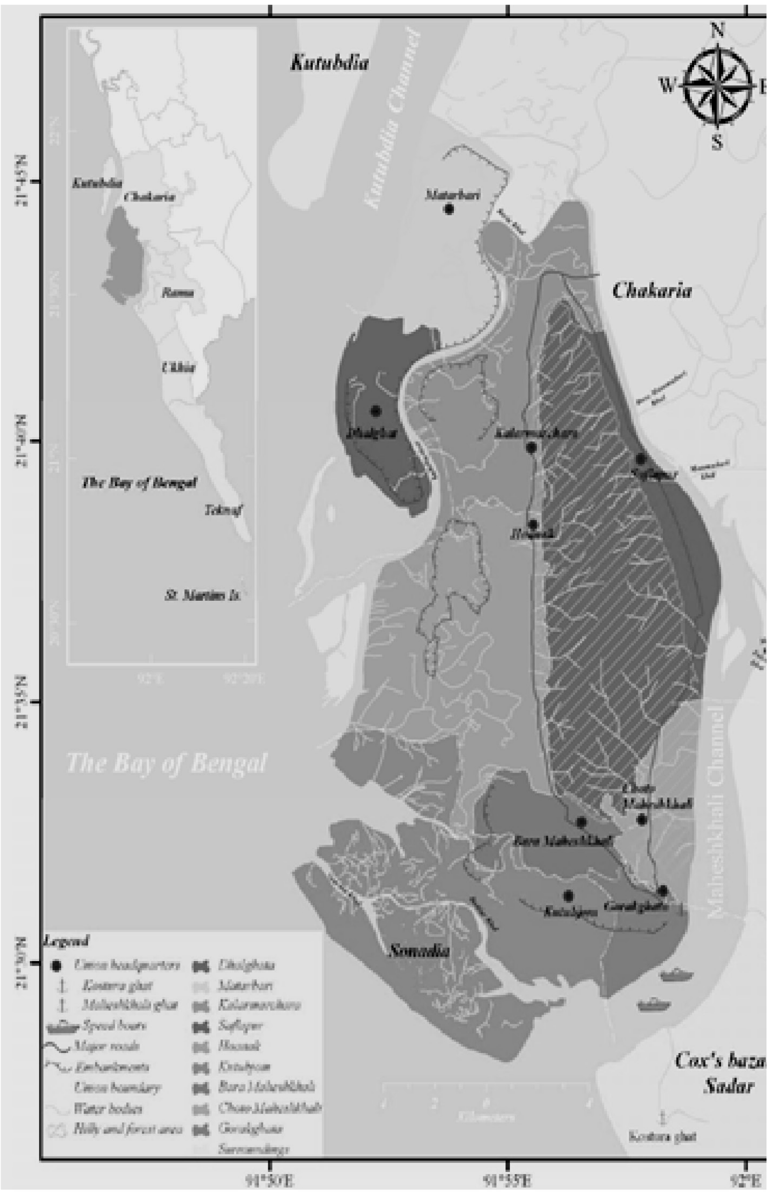


Figure 1: Location map of the Maheskhali Island.

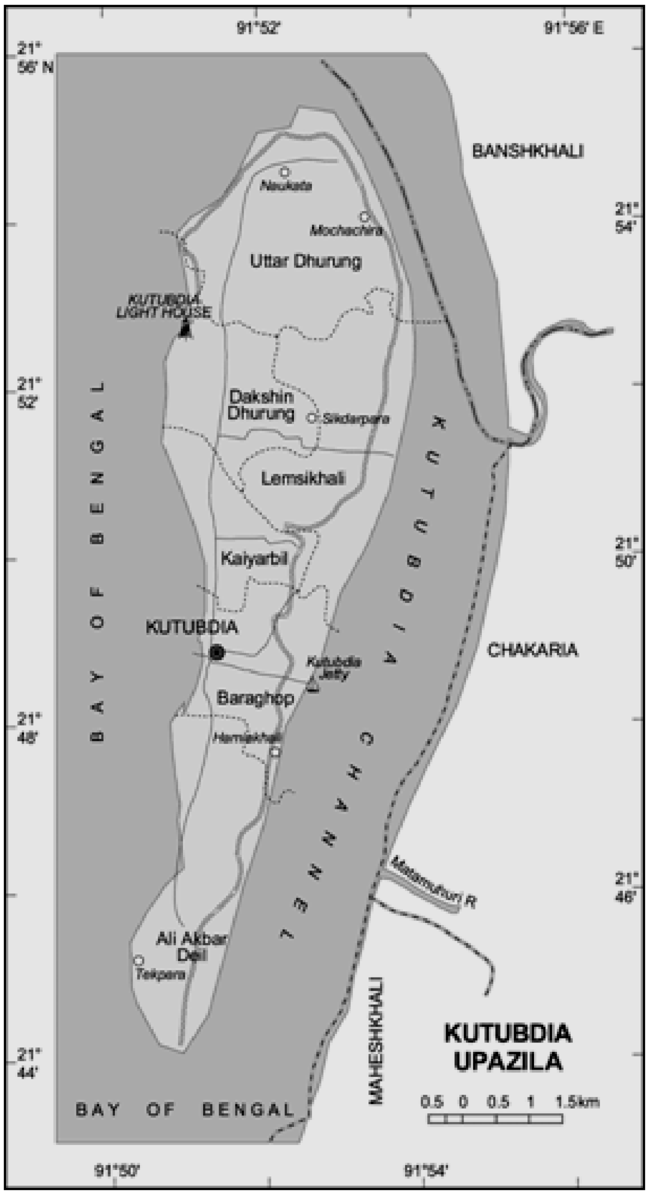


Figure 2: Location map of Kutubdia Island.

Table 1: Generalized lithostratigraphic successions of Maheskhali and Kutubdia Island

Age	*Formation*	*Lithology*
Holocene	Beach sand	Medium grained, sub-rounded, containing heavy minerals.
	Alluvium	Silt and clay
	Peaty and swampy deposits	Black clay with plant roots and twigs
Plio-Pleistocene	Dupi Tila	Whitish and gray medium grained massive sandstone with clay and shale. Poorly sorted
Pliocene	Girujan clay	Bluish gray clay with subordinate shale, siltstone and sandstone
	Tipam sandstone	Yellow, massive, ferruginous sandstone, alternating with shale, claystone. Cross-bedding, ripple marks and fossil wood present
Mio-Pliocene	Boka Bil (Base not seen)	Alternation of sandstone and bluish gray shale with subordinate siltstone and calcareous sandstone

palynological studies following standard procedures (Faegri and Iversen, 1989).

Results and Discussion

Sea Level Fluctuations in the Geologic Past by Pollen Studies

As a result of transgression along with the rise of relative sea-level, freshwater vegetation would be replaced by brackish-water mangrove species (Islam, 2001). Mangrove pollen is thus a very useful indicator, of relative movements of sea-level in the tropical environments (Belprio, 1979; Ellison, 1989), as well as the principal technique for reconstructing the Quaternary' environment (Birks and Birks, 1980). Qualitative and quantitative analyses of the palynological assemblages recorded from the various formations of the Quaternary sediments of Maheskhali and Kutubdia Island and its surroundings. The palynological data comprises 27 species belonging to 35 genera. Out of these, 11 species belong to five genera of Pteridophyta, 22 species under 14 genera belong to Angiosperms, while one genus with one species have an affinity with Gymnosperms. Algae are represented by nine species of seven genera and six species of four genera belong to fungi.

Pollen Record of Maheskhali Section

Pollen samples were collected as M-l and M-2 which represent the depositional sequences of the section. Fifteen slides of the samples have been studied and 50 pollen were identified of different species. Of them *Spiniferites* sp, *Todisporites plicatus, Tricolpatespinose, Palmipollenites ocaenicus, Palmidites plicatus, Monosulsites* sp, Lygodiumsporites *eocaenicus,* Phoenix *sylvestris, Avicenniasp, Lirasporisintergranifer,* and *Striatriletes* sp are especially remarkable (Figure 3). Pollen collected from M-l sample *(Palmidites plicatus Zone)* represents palm type vegetation and shows intertidal zone of paleoenvironment (Table 2). Moreover, this zone is represented by abundant algal body, fungal tubes and pteridophytic spores that reflect that the area was not permanently submerged. M-2 is dominated by mangrove pollen such as *Avicennia* sp, *Phoenix sylvestris.* It interprets that the environment of *Phoenixsylvesiris* Zone was suitable for mangrove vegetation and a shift of coast line towards land, during the transgression phase.

Pollen Record of Kutubdia Section

Pollen assemblage has been studied for Kayar Bill K-2, K-3 which belonged to Kutubdia section Kayar Bill contains both fresh water pollen and mangrove pollen. Pollen that are available are *Prosopisgrandis, Tsugapollenites* sp, *Inapertusporites* sp, *Bruguieragym norhizha, Lygopodium sporitglobatus, Sonneratiopollis* sp, *Lygodium sporiteseocaenicus, Nototbyrite spadappakarensis, Callimothalus* sp, *Fungal spore* (Figure 4) and represented as *Inapertusporites* sp Zone (Table 3).

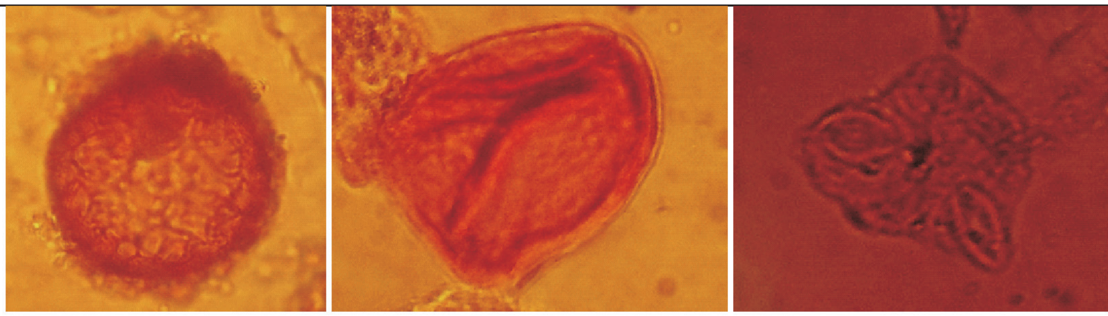
K-2 is dominated by Pteridophyte palm pollen such as *Lygopodium sporiteglobatus, Lygodium sporiteseocaenicus* (Figure 4) and it represents the swampy environment.

K-3 is dominated by mangrove pollen such as *Prospisgrandis, Bruguieragym norhizha*, and *Sonneratopollis* sp. Mangrove pollen is the signature of the paleoenvironment of transgressive phase and represented as *Prosopisgrandis* Zone (Table 3).

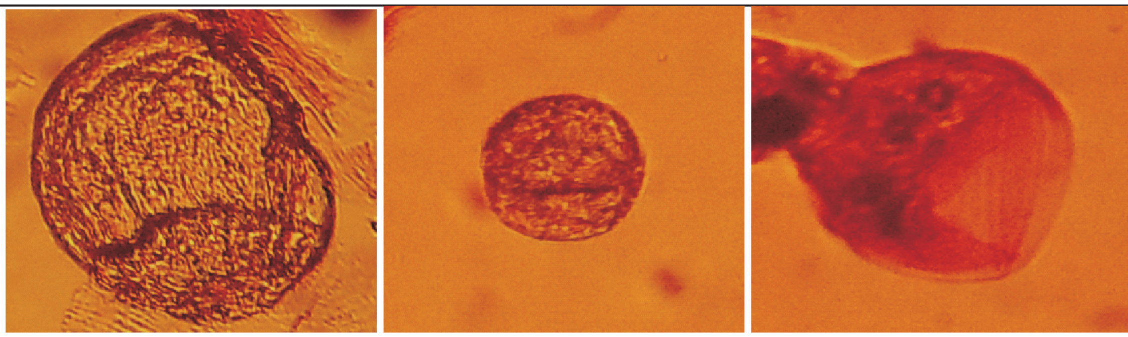
The pollen assemblage has been performed for South Dhurong as SD-1 and SD-2. Most of the representative pollen is fresh water tropical pollen. Pollen species that are available in this area are *Palmidites major, Palmidites minor, Palmiditesplicatus, Monosulcites rectangularis, Plimidites* sp. A few mangrove species *Bruguiera gymnorhizha* was identified in this section. The pollen assemblage has been performed for Ajimuddtn Skidder Para as AJ-1 and A-2. Most of the representative pollen is fresh water tropical pollen. Pollen species that are available in this area are *Palmidites major, Palmidites minor, Palmiditesplicatus,*

Table 2: The biozonation and associated paleoenvironment of Maheskhali Island

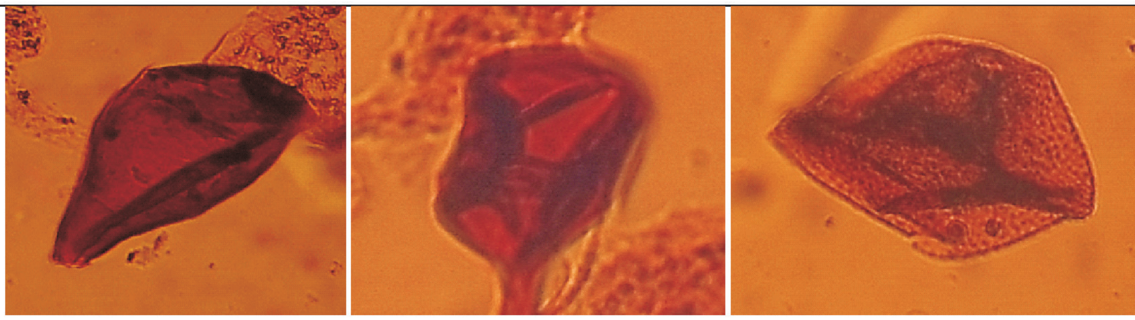
Sampling point and depth	*GPS location*	*Representative pollen*	*Bio zone*	*Vegetal nature*	*Paleoenvironment*
M-1	21.54493°N	*Palmidites plicatus*	*Palmidites plicatus* Zone	Palm	Near Shore
	91.91945°E	*Lyoodiumsporites eocaenicus*			
13 ft		*Monosulsites* sp.			(Regression)
M-2	21.54408°N	Avicennia sp,	*Phoenix sylvesiris* Zone	Mangrove	Tidal-Marine
	91.91941°E	Phoenix sylvestris			(Transgression)
11.5 ft					



Spiniferites sp | *Todisporites plicatus* | *Tricolpatespinose*



Lirasporisintergranifer | *Lirasporisintergranifer* | *Striatriletes* sp



Lygodiumsporites eocaenicus | *Phoenix sylvestris* | *Avicennia* sp

Palmipollenites eocaenicus | *Palmiditesplicatus* | *Monosulsites* sp

Figure 3: Microphotographs of selected index pollen from peat layers of Maheskhali Island.

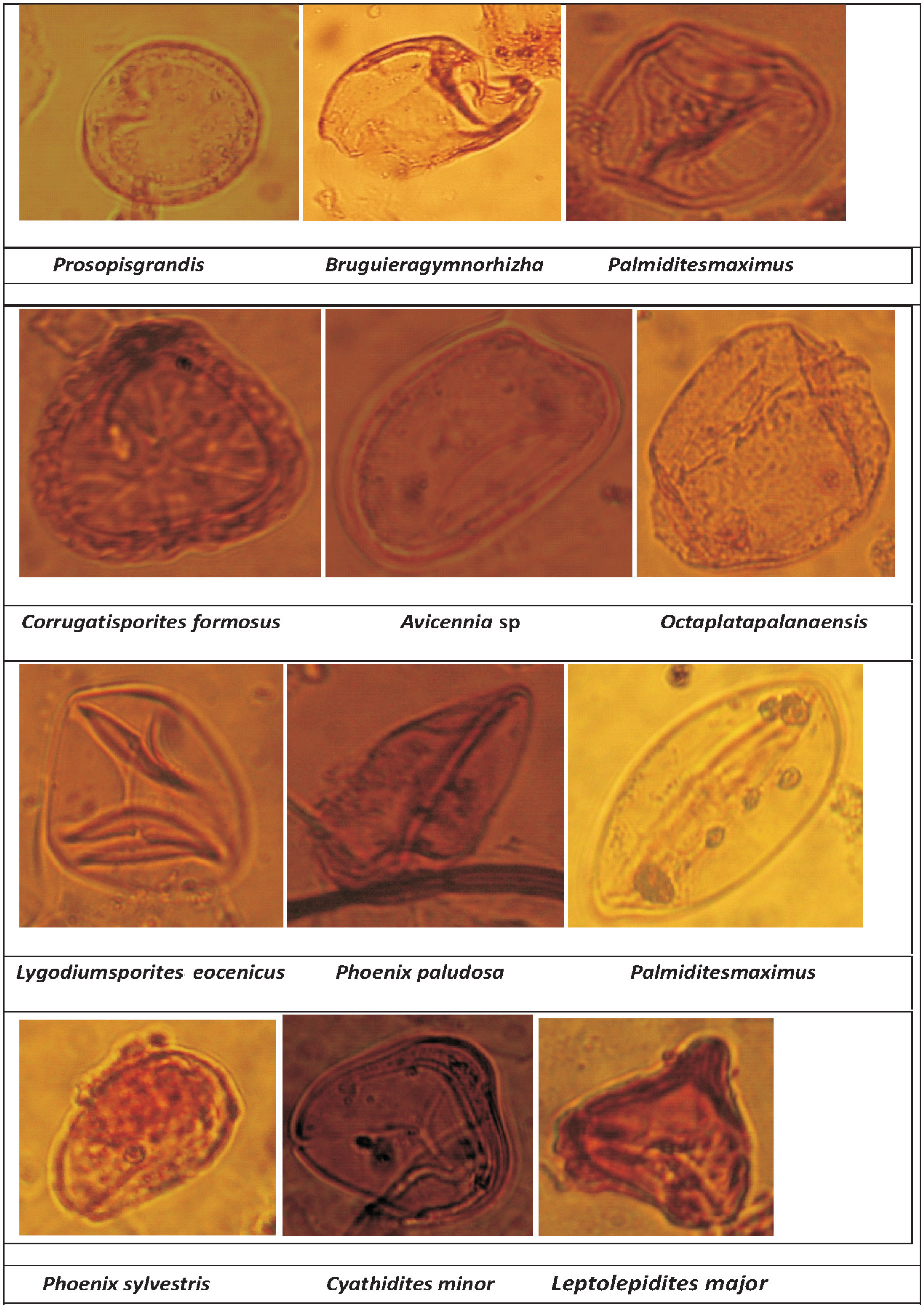


Figure 4: Microphotographs of selected index pollen recovered from peat layers of Kutubdia Island.

Table 3: Biozonation and associated paleoenvironment of Kutubdia Island

Sampling point and depth	*GPS location*	*Representative pollen*	*Bio-zone*	*Vegetal nature*	*Age (C-14) (After Monsur, 1999)*	*Paleo-environment*
K-1 9 ft	21.83822°N 91.85887°E	*Inapertusporites* sp, *Fungaltube, Palmidites assamicus*	*Inapertusporites* sp Zone	Palm	1110 $\pm$90	Near Shore
K-2 and K-3 11-11.5 ft	21.84407°N 91.85416°E	*Prosopisgrandis, Sonneratiopollis* sp	*Prosopisgrandis* Zone	Mangrove	2370 $\pm$90	Tidal-Marine

Monosulcites retangularis, Corrugatisporites sp, and a few mangrove species were identified and they are *Prosopisgrandis, Sonneratiopollis* sp, and *Palmidites maximus* (Table 3).

Conclusion

The study areas are covered with Quaternary tidal flat deposits. Regular sequential sedimentary succession is absent in the area; rather it shows a heterogeneous mixture of clay, silt and sand. However based on lithological characteristics up to a depth of 60 feet (18 m) from the land surface, the lithological section can be subdivided into four lithostratigraphic units. From bottom to the top, these units are a fine sands unit, silty sand unit, clayey silt unit and silty clay unit.

Paleo-climatic conditions and depositional environment of the coastal Bangladesh can be discussed in two aspects; one is before 18000 years BP and the other is after 18000 years. An excellent account of paleogeography and depositional history can be found in Mikhailov and Dotsenko (2007). Before 18000 years, a maximum of glacial ocean regression occurred, slopes of water surface and current velocities were high, and evacuation of coarse sediments (boulders, pebble, and gravel) occurred. Deep downcut channels formed on the Pleistocene surface of the Bengal basin, deposition of coarse sediments and formation of delta occurred at the mouth of erosional down cutting.

During the Last Glacial Maximum (LGM) (about 18000 years ago), the ocean level was nearly 120 m lower than the present-day level (Mikhailov and Dotsenko, 2007). At that time, the coastlines at the mouth of the Ganges and Brahmaputra rivers were farther south of the modern outer shelf. The entire Bengal basin represented a Pleistocene area downcut by branches of the old Ganges and Brahmaputra rivers and, in fact, it was a *sculptural*, or *downcut* delta. The land and shelf surface was no less than 60 m lower than the present surface. Most likely, water and sediments of both rivers entered the ocean in the form of a combined flow through the erosional channel inherited by the present Swatch of No Ground Canyon. It is assumed that the river flow of that time was much lower than the present flow (Goodbred and Kuehl, 2000) because of the weakened southwestern monsoon and arid conditions in the mountains of Tibet and Himalayas; this, in particular, caused the increase of water salinity in the Bay of Bengal. The sediment runoff passed in transit through branches of the down cut delta and through the ocean in the area of the present deep-water place exceeding 100 m. Slopes and current velocities in the branches and erosional down cutting were increased. Transported coarse river sediments (boulders, pebble, gravel and coarse sand) settled at the seaside and formed shoals and other accumulative forms of relief. These accumulative forms spatially separated from the old downcut delta and the erosion downcutting (canyon) at the mouth can be considered as the active delta of the Ganges and Brahmaputra rivers during the Last Glacial epoch.

The post-glacial ocean level rise, the increase in atmospheric precipitation in the mountains, and the increase in river water flow and sediment runoff contributed to the beginning of intense accumulation of river sediments, first, at the mouth of the erosional downcutting (15000–11000 years ago) and, then, on the surface of the Bengal basin.

About 11000 years ago, the ocean level rose to the elevation of –55 m and the backup began its propagation to the Bengal basin. Simultaneously, the accumulation of deposits and the Holocene delta formation began on its surface. Due to the considerable sediment runoff of rivers, which was twice as much as the present-day runoff (because of the southwestern monsoon activation), the Holocene delta started its formation at the mouth of the Ganges and Brahmaputra rivers several thousand years earlier as compared to the mouths of other large rivers of the world (where deltas originated in bays and lagoons 6000–8000 years ago). Over the period of 11000–7000 years ago, the deposited sediment layer on the Bengal basin surface exceeded 50 m; in the last 7000 years, the layer thickness was more than 15 m (Goodbred and Kuehl, 2000).

At about 5000 years BP the sea level rose to an elevation of as much as five metres above present sea level (Umitsu, 1993). After that the sea level began to fall to its current position at present.

In the Maheskhali Island, the coast line or the beach of 6000 yrs BP was at the foot of the hillocks along the Nalbila-Garakghata road section. Wave action washed out the initial surface of the island.

Environmental changes associated with Quaternary sea level fluctuations have had a profound impact on the distribution of mangrove habitats at both local and regional scale. Mangroves provide the coastal tropical and sub-tropical tidal areas, and as such have a high degree of salinity where mangals occur include estuaries and marginal marine shorelines.

Sedimentological, palynological and radiocarbon data indicate that mangrove community developed under transgressive condition in and around Maheskhali and Kutubdia Island areas during Mid Holocene time (7000 to 5500 years BP) leading to the locally wide spread deposition of organic-rich sediments. During Holocene time global rise and fall of Eustatic Sea Level played an important role not only in the depositional environment but in creating a geomorphic feature in the island. Recurrent occurrence of freshwater and mangrove pollen in Maheskhali and Kutubdia Island area indicate that these areas have undergone cyclic marine and non-marine influence. It shows palm type vegetation indicating near-shore environment. So it is observed that there is a cyclic occurrence of marine and non marine pollen. First transgression was noticed around 6000-5500 cal BP and then a subsequent regression of the bay had been observed from around 5500 cal BP. This was again followed by another small scale transgression episode occurred around 2500—2000 cal BP. So the palynomorph assemblages from the late Pleistocene sediment sample indicate that Maheskhali and Kutubdia Island and its surrounding area was an intertidal environment occupied by mangrove community.

At the last glaciations (about 10,000 yrs BP) monsoon rainfall was quite prominent and the glacier on the Himalayan tops also started melting. The melt water together with the amplified monsoon water flowed over Barind and the Madhupur tracts. This enormous water highly dissected the initial Barind and Madhupur formations and the rivers were overloaded with huge influx of suspended sediments. The gradual rise of Holocene sea level was accompanied by the development of submerged islands due to this influx of sediments. During the maximum high stands of Holocene sea level (about 5500 yrs BP) the top surface of these islands were also raised very close to the high tide level. After 5500 yrs BP Holocene sea level dropped about 1 to 2 metres resulting in the aerial exposition of the surface of the submerged islands, like the Kutubdia, Matarbari, Hatia and Sandwip. This was again followed by another small scale transgression episode occurred around 2500—2000 cal BP. The presence of interfingering peat layers in the Kutubdia Island supports this statement.

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