CHAPTER 4

The Ganga-Brahmaputra delta: Quaternary evolution

4.1 EVENTS OF THE HOLOCENE

Earth became tied to ice ages since the Early Proterozoic ‘Huronian’ event, 2.6–2.3 Ga BP. Another four episodes were recorded since then: the Late Proterozoic event (1.2–0.5 Ga BP), the Late Ordovician ‘Eocambrian’ event, the Permo-Carboniferous event (230–360 Ma BP) and the Pleistocene Ice Age. Starting from 2 Ma BP, the Pleistocene event may still continue, with our civilisation passing through one of its interglacials (Brian, 1977). Global temperature fluctuations in an ice age bring in cool glacial stages and warm interglacial stages that intervene them. In Europe, the Pleistocene Ice Age is divided into four main glacial epochs: Gunz, Riss, Mindel and Würm. Most mid-latitude continents have their equivalent names for these four glacial epochs but the above identities are also in common usage. The Würm glaciation ended about 12–14 ka BP, and the earth started to get warmer establishing the onset of Holocene. All the world’s deltas evolved during the Holocene. Therefore, events of the Holocene deserve a detailed treatment in the context of this thesis.

4.1.1 Sea-level of the Last Glaciation and the Mid-Holocene transgression

Ollier (1981:223) suggested −130 m PSL (present sea level) to be the ‘best estimation’ among the various figures available on secular sea level lowering during the Last Glacial maximum, about 15 ka BP. This agrees identically with the figures obtained by using oxygen isotopic measurements in deep-sea sediment cores (Peltier, 1992). However, as Bloom (1983) showed, the range of estimates on the Last Glacial lowstand in fact varies as much as from −60 m to −120 m PSL. Pugh (2004:176), in a recent review, stated that at locations far from present and former ice sheets, a of −120 PSL is most likely.

In their generalised form, the Holocene secular sea level/time curves (Fig 4.1), as provided by Shepard (1963), Jelgersma (1966), Mörner (1969, in Mörner, 1971), Tooley (1978 in Goudie, 1992) and Fairbanks (1989) among others, indicate a quick rise at approximately 10 mm a⁻¹ at the beginning, which slowed down to 0.2–2.3 mm a⁻¹ at about 7–5 ka BP (Pethick, 1984). Pugh (2004) summarised that between 15 ka and 6 ka sea level rose at 10 mm a⁻¹ and during the last 6 ka & 3 ka increased at 0.5 & 0.1–0.2 mm a⁻¹ respectively. This means that the sea level had almost reached its present position at 6 ka BP after which it is rising slowly. This fast rate of sea level rise during early Holocene caused worldwide inundation of low-lying coastal areas during the Mid-Holocene and often referred to as Flandrian transgression based on similar occurrences in the North Sea coasts.

By analysing global tide gauge records of approximately the last 100 a, Lambeck and Nakiboglu (1984), Pirazzoli (1989) and Peltier (1992) independently estimated the rate of current secular sea level rise at 1.3 mm a⁻¹ (c. 1900–1980), 0.4–0.6 mm a⁻¹ and c. 1.9
mm a\(^{-1}\) respectively. Pirazzoli (1996:146), based on tide gauge estimates of 21 authors, showed that between 1807 and 1992, global average sea level rise estimates vary between ‘indeterminable’ (four authors) to 3.0 mm a\(^{-1}\) (one author); most estimates range between 1.1 and 1.3 mm a\(^{-1}\) (7 authors). This roughly agrees with Pugh’s (2004) assessment that the world tide gauge data denote a rise of global sea level in the range of 1–2 mm a\(^{-1}\) with a central value of 1.5 mm a\(^{-1}\).

**Figure 4.1:** Holocene sea level curve of different workers.

These secular estimations of sea level/time curves and sea level fluctuations, however, have little value for any particular region. This is because *firstly*, as geoidal eustasy has shown, eustatic changes are simply not ‘world-wide and simultaneous’ (Mörner, 1983:73) and *secondly*, the tectonic or isostatic movement of the coastal zone, makes the actual estimation of sea level fluctuations (rise/fall) extremely varied from one region to another. Thus, more important for a specific region is the studies on relative sea level (RSL), that apply to that particular region. Clark *et al.* (1978), Clark and Linge (1979) and Peltier (1989) suggested six zones of world coastlines, each of which can be identified with a characteristic pattern of sea level fluctuation. According to this classification, the GBD, along with the whole of South Asia, falls in a zone which is typified by an uninterrupted sea level rise of 1–2 m for the last 5 ka. In this area, sea level was at –6 m PSL at 6 ka.

Reviewing the literature on Quaternary sea level in India, Merh (1987:248) found that they are suggestive of up to +10 m PSL during the Holocene ‘almost all over the Indian coastline’. This, of course, does not agree with the ideas of Clark *et al.* (1978) and, since the glacio-eustatic sea level estimations allow little more than 0 PSL for the Holocene (Fig-4.1), this extra 10 m will have to be explained using tectonic eustasy or geoidal eustasy. Merh (1987:248) found it desirable ‘to explore the likelihood of a glacio-eustatic rise of 6 to 10 m (in combination with isostatic adjustments) at least along the Indian coast line’. But, it seems more rational to re-investigate the evidences and see whether they can belong to a previous highstand. Examples of reinterpreting earlier ideas after re-investigations of similar kind are not uncommon in the literature (Goudie, 1992).
Figure 4.2: Plot of $^{14}$C dates against depth of organic samples from Ganga-Brahmaputra delta. Subsidence and tectonic instability is a major concern for accuracy and standardisation of results. Plots joined by a line come from same borehole (after Goodbred and Kuehl, 2000a with data of Islam, 2001 incorporated).

Specifically for the southwestern sector of the GBD (Indian part), Banerjee and Sen (1987) suggested an RSL rise from −7 m PSL at about 7 ka BP to 0 PSL at 5 ka BP in six transgressive phases through analysis of palyno-plankton stratigraphy and proxydata on bio-remain assemblage. In a later publication they (Sen and Banerjee, 1990) slightly modified the ages ascribed to the various phases and held that the Ammonia transgression in the Bengal basin between 7 and 6.4 ka BP coincides with the global Mid-Holocene transgression (Fig. 4.2). The sample and proxydata sites of these studies are spread over about 5,500 km$^2$ and their conclusions are dependant on the stratigraphic position of the materials that yield $^{14}$C dates (i.e., the samples’ depth from the ground level, in turn indicating their height/depth from the PSL). Based on $^{14}$C dating of woods and organic matter samples and position of shells from coastal Bangladesh, Umitsu (1987) envisaged a sea level of −47 m PSL at 12.3 ka BP, after which it steadily increased by 5.5 mm a$^{-1}$ up to 6.4 ka (−15 m PSL) and by 2.3 mm a$^{-1}$ thereafter to reach the PSL. Hait et al. (1996), based on $^{14}$C dating of five core samples in a traverse across the lower delta of West Bengal from Haora through Canning and Bakkhali, suggested a sea level at −47 m PSL about 9.8 ka BP, that rose to −4.9 m PSL at about 5 ka BP, indicating an average rise rate of 8.8 mm a$^{-1}$ during early Holocene. Conversely, samples at Bakkhali suggested 0.7 mm a$^{-1}$ rate of rise for the later part of the Holocene between 6.2 and 4.7 ka (Hait et al., 1996). It may be pointed out here that, since land subsidence is a common phenomenon in the southern GBD and since these studies have not taken this fact into consideration, their results may not be quite accurate. Their findings, however, have been widely referred to in many recent works (e.g., Goodbred and Kuehl, 2000a; Allison et al., 2003; Goodbred et al., 2003 etc).
Goodbred and Kuehl (2000a) used the above works and their own findings out of 13 samples from different localities of Bangladesh to determine the sea level curve during the Holocene. Adjusted to the delta's sediment compaction rates, this study indicated that the sea level of the GBD was 60–70 m, 22–35 m and 17–29 m lower than the PSL at 10 ka BP, 7 ka BP and 6 ka BP respectively (Fig. 4.2).

Islam (2001), based on pollen and diatom analysis of sediment cores from two localities close to Dhaka and Khulna and their $^{14}$C dating, suggested an average rate of 1.07 mm a$^{-1}$ rise in the Holocene secular sea level in the GBD. He inferred occurrence of five transgression-regression cycles for the area during the last 9 ka. The maximum rate of rise was 3.65 mm a$^{-1}$, observed between 6.3 and 5.9 ka BP (Khulna site) and the minimum rate of rise was 0.81 mm a$^{-1}$ (Dhaka site), seen between 4.4 and 2.3 ka. All these results were corrected for known subsidence rates for the sampling sites. This means, at about 7 ka BP, the sea level of the delta stood at ~7.5 m PSL. This value agrees closely with Banerjee and Sen’s suggestion. The data of Islam (2001) is incorporated in Fig. 4.2 to facilitate comparison.

Banerjee and Sengupta (1992) and Sengupta (1993) studied clues like slope and relief features, oolitic sediments and palaeontological indicators for evidences of Pleistocene/Holocene lowstand in the Swatch of No Ground (SNG) area off the western GBD (Appendix-1). They found that these features do occur at depths like ~150m, ~100 m and ~50 to ~90 m: connoting lower sea levels. Among these, the features between ~50 and ~90m were correlated with a palaeoshoreline. But it cannot be correlated with any sea level time curve as no age data was provided by them.

4.2 THE GANGA BRAHMAPUTRA DELTA (GBD) : QUATERNARY SEDIMENTATION AND DRAINAGE EVOLUTION

Oldham (1893:444) speculated that the Indus valley might have been the original outlet for the drainage that developed along the Himalayan foredeep to the north of the Indian continent and that the RGG and the GBD evolved in a ‘geologically recent date’ (see Sec. 3.3). Subsequently Pascoe (1919), Pilgrim (1919) and Wadia (1932) elaborated and refined his ideas and suggested the existence of a west-flowing ‘Indobrahm’ (Pascoe, 1919) or ‘Siwalik’ (Pilgrim, 1919) river in the Early or Middle Pleistocene which was later (in the Middle to late Pleistocene according to Deb, 1956) dismembered into two separate streams due to earth movements. The one to the east partly reversed its flow and was captured by two headward eroding rivers (or two different tributaries of the same river) that were draining into the Bay of Bengal—the proto-Ganga and the proto-Brahmaputra. This event evolved the middle and lower reaches of the modern Ganga and Brahmaputra systems. Wadia (1932:92) felt that ‘differential earth-movements’ was the ‘chief contributory cause’ for the capturing. Biswas and Agarwal (1992), however, suggested that the proto-Brahmaputra was originally draining into the Bengal basin from the RGG. In effect, the Bengal basin was transformed into the depocentre of two of the world’s mightiest rivers and the Ganga-Brahmaputra delta was born. A rapid infilling of the basin followed and it gradually shifted the position of the coastline from NE-SW to approximately ENE-WSW by the end of the Quaternary (Biswas and Agrawal, 1992).

The Quaternary is also characterised by the global fluctuations of sea level related to the Pleistocene ice age, and, in some parts of the basin, by tectonic upliftment and subsidence. These had complicated an apparently simple picture as can be seen in the next sections.
Figure 4.3: Major morphological features of the Ganga Brahmaputra delta. Barind tract and Madhupur terrace are uplifted blocks with remnant Pleistocene surfaces that separate the delta into different compartments and hinder free swinging of rivers across the delta surface. Morphostratigraphically equivalent surfaces are also seen bordering the Chhotoanagpur plateau. The hinge zone is a flexure of the subsurface continental shelf to the deeper basin areas. Base image prepared from IRS-1D WIFS data of 3 March 1998.

4.2.1 The broad geomorphic provinces of the GBD

The present GBD is a composite one which has been contributed by the Ganga, Brahmaputra and their many important active or decayed distributaries apart from the small to medium-sized peripheral streams coming from the surrounding uplands. The current orientation of the Ganga-Padma-Lower Meghna river has diagonally divided the delta into two halves (Fig. 4.3). The part in the SW was primarily contributed by the Ganga system and the rest by the Brahmaputra and Meghna systems. The former has
often been termed as the 'more deltaic' part of the GBD (Bagchi, 1944, 1972b; Basu and Chakraborty, 1972; F. Khan, 1991).

As appears from Fig. 4.3 the present Bhagirathi-Hugli river forms the approximate boundary between the central part of the western delta, contributed mainly by the distributaries of the Ganga and the western sub-deltaic lobes accreted by the rivers emerging from the Chhotanagpur plateau. Therefore, the southwestern region of the delta can again be divided into two sections: (i) The zone to the west of the Ganga (upstream of Jangipur) and Bhagirathi-Hugli (beyond Jangipur), mainly accreted by the west-bank tributaries of the Ganga and Bhagirathi-Hugli rivers and (ii) the zone to the east of the Ganga and Bhagirathi-Hugli, contributed mainly by the distributaries of the Ganga.

However, the overall deltaic accretion in the basin during most of the Quaternary was contributed by three categories of streams:

(i) The small and medium-sized streams coming from the Meghalaya plateau in the north and from the mobile belts in the east. Approximate highland catchment area: $44.9 \times 10^3$ km$^2$.

(ii) The small and medium-sized streams emanating from the Indian subcontinent in the west. Approximate highland catchment area: $41.1 \times 10^3$ km$^2$.

(iii) The very large rivers of the Ganga and Brahmaputra systems. Approximate catchment area: $1,480 \times 10^3$ km$^2$.

With the firm establishment of the monsoon circulation since the Miocene (Parrish, 1987; Wang, 1990), their share in sediment contribution was dependent on factors like catchment area, resistance of catchment materials and regional upliftment of the catchment apart from fluctuations in the monsoon regime (Williams, 1985; COHMAP, 1988). For example, a gradually increasing rate of sediment inflow is envisaged for the third category rivers in view of the rapid upliftment of the Himalaya and the Tibetan plateau during the later part of the Pleistocene (Hsu 1973; Ollier, 1981; Gansser, 1982, 1988).

Thus, at the inception of the Quaternary, while the main delta was gradually being accreted by the Ganga and the Brahmaputra from the North and along the central sections, smaller peripheral streams were simultaneously filling up the fringe areas all along the basin boundary. Despite the fact that the depth of the Mi-Pliocene surface does not vary appreciably along the same latitude between the eastern and western edges of the basin (A. Khan, 1991), deltaic progradation had probably been more prominent in the western basin margin, compared to the east owing to the comparatively larger size of the rivers.

4.2.2 Quaternary evolution of the GBD

A great deal of research, carried out in the last 15 years, established a fair understanding of the Quaternary evolution of the Ganga delta proper, of which the present study area forms a part. The Quaternary evolution of the GBD depended on three main factors: climatic change, eustasy, tectonics and sediment supply (Goodbred et al., 2003).

The Holocene sequence in Bengal basin varies form about 15 m over the Indian platform to some 90 m in the deeper basin areas (Allison, et al., 2003). At least 30 boreholes have penetrated the entire sequence during the last 15 years (Umitesu, 1993; Hait et al., 1996; Stanley and Hait, 2000; Goodbred and Kuehl, 2000a) and the broad
framework of evolution of the GBD became fairly clear. This is outlined in the following sections based mainly on Goodbred and Kuehl (2000a).

4.2.2.1 The lowstand scenario: 18 ka BP

Glacial lowstand was at its extreme. Exposed laterised uplands and incised valleys, often containing lag gravels, were widespread. River discharges were low—probably insignificant compared to the present. Sea level was some 100 m lower than the PSL, exposing wide areas of the continental shelf to subaerial processes. Niyogi (1972) stated that during this time, approximately an 80-km wide stretch of continental shelf became exposed in Orissa and West Bengal. Alam (1989) put this at over 100 km off the GBD. Cochran (1990) on the other hand, suggested that the entire continental shelf adjacent to the GBD might have been exposed during the maximum lowstand, with the rivers directly emptying their load to the continental slope. Existence of cut and fill channels on the shelf area (Saxena et al., 1982) seems to support this observation. In a scenario like this, the SNG, with its floor at −65 to −1,300 m, probably formed a large and deep estuary.

In the southern GBD, occurrence of gneissic pebble (gravel) horizons in the subsurface (c. 50 m bgl and deeper) were reported from quite a long time (Oldham, 1893; Chatterjee et al., 1964; Pascoe, 1964). Gravel horizons are also common in the southern extreme of the delta like Sagar island (CGWB, 1982a-d). The origin of these pebbles were linked by some early workers to things like 'rocky hills' that might exist in the subsurface in places like Calcutta (Oldham, 1893; Pascoe, 1964: 1987-8, Ahmad, 1972) and the Nilgiri hills of coastal Orissa from where they were supposed to be 'transported north eastwards by some kind of coastal drift' (Chakraborty, 1970:20) However, these were actually lag deposits of rejuvenated streams during the last glacial lowstand. Chatterjee et al. (1964) suggested that a part of these could have been contributed by the Chhotanagpur plateau to the west of the GBD. They also felt that the upward-fining sedimentation sequence that exists on the top of each of the gravel horizons in the southwestern GBD is a connotation of their link with sea level fluctuations.

4.2.2.2 Onset of warming: 15 ka BP

The upper Bengal fan started receiving fresh sediment input, denoting onset of climatic warming and increase in precipitation and discharge levels.

4.2.2.3 Delta development commenced: 11.5–10 ka BP

By 11.5 ka BP, Intensity of SW monsoon was at stronger-than-present levels that shot up sediment discharge at least 2.5-times of their present amounts (which is ~1 × 10⁹ t a⁻¹). The incised river valleys started to fill-up with sand (Goodbred and Kuehl, 2000b). However, peak sedimentation rate at the Bengal fan indicate that the incipient delta was incapable of accommodating a large part of the load it received.

A couple of wood fragments and a shell, found by Umitsu (1993) below and −10 m above the low-stand laterite horizon, were dated ~14 ka BP and ~ 9.9 ka BP. This indicated that the delta growth must had started at about 10–11 ka BP. At 11 ka BP, fan sedimentation recorded a sharp decline indicating shift of the depocentre to on-shore localities. Sea level rose to −45 m, transgressed a large part of lower basin and started to trap sediments that initiated the development of the GBD system. In southern basin, fine Lower Delta Mud facies covered most of the lowstand oxidised surfaces and alluvial sands in a near-shore mangrove-dominated depositional environment. In northern parts of the basin, sand sequences continued to be deposited in the central valleys and also to the Sylhet basin.
4.2.2.4 Delta development during rapid rise of sea level: 11–9/7.5 ka BP

The above scenario persisted as the sea level rose to ~15 or ~10 m at the end of this period (~10 mm a⁻¹). Deposition of Fine Mud facies in the northeastern Sylhet basin started only after 9 ka BP, indicating that after this time the Brahmaputra was following its western course (Avulsion-I: W⇌E; see Fig. 4.3 for identification of the Old Brahmaputra course) and discharging its sediments directly to the sea, until about 7.5 ka BP. This, although starved the subsiding Sylhet basin from sands, supported the maintenance of shoreline stability of the delta front at the time of rapid rise in eustatic levels.

4.2.2.5 Maximum Holocene transgression and delta progradation thereafter: 7.5–5 ka BP

The rate of sea level rise slowed around this time and the maximum landward limit of inundation was achieved in the western part of the basin. The delta transformed from an aggradational (on-lapping, vertically accreting) to progradational (off-lapping, horizontally accreting) system and the main depocentre migrated seaward (Goswami and Chakraborty, 1987; Chakraborty, 1987). Extensive dispersal of sands started on the coastal plain as the upstream alluvial valleys were topped up. This laid Muddy Sand deposits onto the mangrove-dominated coastal plains. A muddy submarine delta began to take shape at about 7.5 ka BP as well and that made GBD a compound entity with clearly defined subaerial and sub-aqueous components. The Muddy Sand deposits can be viewed as the topset beds to both the components. The growth of the delta clinoform continued and the western delta approached its present extent by ~5 ka BP. This also heralded the formation of coastal peat layers and abandonment and eastward migration of the active Ganga distributaries.

The Middle Holocene strand line: The rapid rise in sea level up to the Middle Holocene, according to Alam (1989: 137), had ‘brought the shore in line with an arc that swung across from south of Calcutta almost to Dhaka and then more closely followed the present coast to the southeast.’ For the southwestern GBD (Indian part), Banerjee and Sen (1987) have deduced that the maximum transgression took place some time in 7-6.5 ka BP and, at that time, the palaeocoastlines trended SW-NE through localities like Kolaghat, Kolara, Sankrail, Calcutta and Dumdum-which are some 80-120 km inland from the present strandline.

Between 7.5 ka and 6 ka BP, the Brahmaputra returned to its eastern course (Avulsion-II: W⇌E) to the Sylhet basin that started to rapidly fill up at > 20 mm a⁻¹. This was also the time when maximum Holocene transgression was achieved in the eastern delta, some 1 to 2 ka after the eastern part. Between 6 ka and 5 ka BP, as the Sylhet basin sediments indicate, the Brahmaputra switched its course again and returned west (Avulsion-III: W⇌E). With this change, the river probably joined the Ganga, now migrated eastward, for the first time in Holocene.

4.2.2.6 Eastward younging of the coastal delta: 5–0 ka BP

During this time, the delta development shifted its focus mainly towards the east and the eastern coastline gradually swung southward to its present position.
Figure 4.4: Panels representing salient features of Late Quaternary evolution of the Ganga-Brahmaputra delta. See text for explanation. Br, Md and SNG stand for Barind tract, Madhupur terrace and Swatch of No Ground submarine canyon respectively. Cf. Fig. 4.3 (after Goodbred and Kuehl, 2000a).
At least another avulsion of the Brahmaputra occurred (Avulsion-IV: W→E) after which it finally abandoned its course through the Sylhet basin about 150 a ago to its modern channel (Avulsion-V: W→E).

Based on epidote/garnet ratio and relative abundances of clay-minerals like illite, smectite and kaolinite in modern bedloads of the Ganga and Brahmaputra, Heroy et al. (2003) attempted to determine whether core-sample sediments from different parts of the delta were deposited by either of these two rivers. They found four of their six borehole samples (driven to 90 m) indicated two to six switchings between Ganga and Brahmaputra. This connotes that paths of these two rivers swung across the central part of the delta for a major part of the Holocene.

Focussing on the coastal GBD, Allison et al. (2003) collected over 30 core samples up to a depth of 4–6 m from various localities in Bangladesh and used data from a previous study by Stanley and Hait (2000) in Indian Sundarban to examine clay mineralogy, elemental traces and $^{14}C$ chronology. They found that the sediments displayed a younging trend towards the east in three overlapping phases. The westernmost part of the coastal delta—comprising whole of the Indian Sundarban—was accreted during 5–2.5 ka BP. This observation is consistent with $^{14}C$ dating of samples from Namkhana (+ 2.25 MSL) and Gangasagar (0.9 m bgl) that indicated dates of 3,170±70 a (Gupta, 1981) and 2,900±20 a (Chakrabarti, 1991a) respectively. It also agrees with suggestions that the evolution of the Sundarban part of the GBD commenced after 5 ka BP (Uimitsu, 1987) or during 4.5–3.2 ka BP (Banerjee and Sen, 1987).

The delta growth then shifted east in phases that lasted 4–1.8 ka BP, <4–0.2 ka BP and 0.2–0 ka BP, corresponding to G2, G3 and GB1 respectively in Fig. 4.6. Among these, only the last phase, which represents modern discharge from the Meghna estuary, contains any significant share of Brahmaputra sediments. This means that for the majority of the last 5 ka, Brahmaputra was draining through the secluded Sylhet basin and/or into the Meghna estuary. In other words, it did not shift westward of its present course, otherwise its signature would have been visible in the western delta sediments. Allison et al.’s study also indicated that the sediment source to the coastal delta was linear rather than originating from a point. They also observed that the older delta lobes, despite abandonment, did not face appreciable erosion probably due to sediment reworking in a macrotidal environment. One notable exception to this is the
westernmost part of the delta that eroded few kilometres in some places in the last 200 years (Bandyopadhyay and Bandyopadhyay, 1996; Allison, 1997).

![Map](image)

**Figure 4.6** Schematic representation of phases of late Holocene growth of the Ganga-Brahmaputra delta, associated with progressive shifts of Ganga (G1, G2 and G3), Brahmaputra (B2) and combined Ganga-Brahmaputra (GB-1) discharges (after Allison et al., 2003).

### 4.3.1 Holocene formations

#### 4.3.1.1 General stratigraphy

Umitsu (1987) divided the Latest Pleistocene and Holocene sedimentary units of the southern GBD into three parts:

(i) The bottom gravel horizon, deposited during the maximum of the Last Glaciation.

(ii) The middle lower member, deposited between the Last Glacial maximum and 12 ka BP, when the sea level was ~45m PSL.

(iii) The top upper member, deposited between 10–8 ka and 6–5 ka BP. A fall of sea level between c. 12 ka and 10 ka BP, setting in a minor erosional phase between the lower and the upper members, was also suggested. From c. 5 ka BP onwards, according to Umitsu, peatlands and wetlands started to develop.

Goodbred and Kuehl (2000a) proposed the following classification of Holocene facies of the delta based on borehole samples (Table 4.1). Among the five Holocene facies identified by them, one is exclusive to the Sylhet basin. The GBD proper, therefore, consists of four major Holocene layers deposited on an oxidised, low-stand base. From bottom to top, these are Sands, Lower Delta Mud, Muddy Sand and Thin Mud. The Sundarban formation obviously belongs to the Thin Mud facies. Goodbred and Kuehl (2001a) did not include the low-stand lag gravels in their scheme. These may also be classified as Pre-Holocene and put alongside the oxidised surface.
### Table 4.1: Summary of stratigraphic facies of the Ganga-Brahmaputra delta (after Goodbred and Kuehl, 2000a)

<table>
<thead>
<tr>
<th>Facies</th>
<th>Period of Deposition</th>
<th>Distribution</th>
<th>Lithology</th>
<th>Colour</th>
<th>Width</th>
<th>Depth to top</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI: Thin MUD</td>
<td>c. 5-0ka BP</td>
<td>Floodplain environments throughout, absent near fluvial channels</td>
<td>Variable soft, muddy sediments with occasional fine sands</td>
<td>Brown to grey-brown</td>
<td>2-7 m</td>
<td>Surface; locally 20-40 m</td>
<td>Abandoned floodplain and overbank deposits</td>
</tr>
<tr>
<td>V: Sylhet Basin MUD</td>
<td>c. 10-0 ka BP</td>
<td>Sylhet basin, also along the Brahmaputra channel</td>
<td>Variable silt-dominated sediments with 0-70% sand and 5-90% clay</td>
<td>Brown-gray to blue-gray</td>
<td>60-80 m</td>
<td>3-5 m</td>
<td>Tectonic floodplain deposits</td>
</tr>
<tr>
<td>IV: Muddy Sand</td>
<td>c. 8-3.5 ka BP</td>
<td>South-central delta</td>
<td>Variable fine sand-dominated sediments with 25-80% muds</td>
<td>Brownish grey</td>
<td>30-35 m</td>
<td>4-7 m</td>
<td>Estuarine distributary-mouth channel deposits</td>
</tr>
<tr>
<td>III: Lower Delta MUD</td>
<td>c. 12-7.5 ka BP</td>
<td>South-central delta tidally influenced area</td>
<td>Silt-dominated sediments with 15-35% clay and 0-35% fine sand</td>
<td>Brownish grey</td>
<td>20-25 m</td>
<td>16-40 m</td>
<td>Coastal plain and delta front deposits (likely mangrove)</td>
</tr>
<tr>
<td>II: Sand</td>
<td>After c. 12ka BP</td>
<td>Widespread except in central Sylhet basin. Present as basal unit where oxidised facies are absent</td>
<td>Fine, medium, and generally 'fining upward' coarse sands with abundant micas and heavy-minerals</td>
<td>Grey</td>
<td>15-80 m</td>
<td>5-65 m</td>
<td>Alluvial valley and river channel fill</td>
</tr>
<tr>
<td>I: Oxidised</td>
<td>Pre-Holocene</td>
<td>Locally throughout, particularly adjacent to exposed uplands</td>
<td>Generally stiff muds underlain by medium quartzose sands</td>
<td>Yellow-brown to orange</td>
<td>5-10 m</td>
<td>Surface to c.45 m</td>
<td>Lateritic uplands of lowestand exposure</td>
</tr>
</tbody>
</table>

The western face of the GBD currently forms the frontier region of the off-lapping accretionary wedge belonging to the Sundarban formation.

#### 4.3.2 The geomorphic divisions of the GBD

Bagchi (1944) made a widely accepted 3-part division of the southwestern GBD, which is drained by the distributaries of the Ganga. This classification of the delta includes:

(i) The ineffectual moribund portion to the north of the Calcutta-Khulna-Madhumati river line. In this region, land-building activity no longer functions.

(ii) The semi-active mature portion extending up to Sundarban from the south of the moribund delta. Here land is being raised along the stretches close to the rivers. The so-called subsidence-caused marshes of the lower Bengal are found in the south-central part of this region. These marshes have been described as efficient silt trappers.

(iii) The active portion, occupied by the Sundarban mangroves. The general elevation of this part is below the highest tidal level and the land-building processes are being actively carried out here.

In a later work, Bagchi and Mukherjee (1978:15) recognised that, since Bagchi's (1944) study, the 'natural hydrological changes as well as human interference obviously induced modifications' to his 'classical' scheme. The most important of these, they felt, is the premature reclamation of the active sector of the delta that rendered characteristics of maturity to it.

Chattopadhyay (1985:213), in a separate classification scheme of the ZEBH, also emphasised the anthropogenic modification of the active delta ('fluvo-estuarine deposition zone' in his classification) and identified the central marshes (the 'marshy chain') as the transitional zone between the northern fluvial and the southern fluvio-
4.3.3 Ideas on the Ganga distributaries and the growth of the delta: A historical perspective

Among its distributaries, the westernmost Bhagirathi channel was identified as the original outlet of the Ganga water by the early workers (Sherwill, 1858; Fergusson, 1863; Oldham, 1870; Reaks, 1919; Fox, 1938; Mukerjee, 1938; Bhattasali, 1941; Majumdar, 1942; Bagchi, 1944). Suggestions of it being a canal (Willcocks, 1930) or a canalised river (Basu and Chakraborty, 1972) notwithstanding, this view is accepted almost unanimously. (At least one exception is Chowdhury (1964) who suggested the Padma as a precursor to the Bhagirathi.) Principal evidence for the antiquity of the Bhagirathi comes from its traditional link with religion and civilisation (Sherwill' 1858; Hunter, 1876b; Bhattasali, 1941; Chatterjee, 1972).

Some workers (Oldham, 1870; Reaks, 1919; Fox 1938; Niyogi et al., 1970; Bakr, 1971; Basu and Chakraborty, 1972; Niyogi 1975, 1989; Choudhury, 1978; Chattopadhyay, 1985; Rudra, 1986, 1987) have generally suggested that the portion of the delta contributed by the Ganga distributaries has gradually built east / southeastwards by throwing successive overlapping deltaic lobes relating to the different distributaries that came into prominence and then lost importance one after another. Bagchi (1944), though has accepted a general southeastward migration of the delta face, has also maintained that no absolute chronology for the development and dissipation of the distributaries should be deduced from this.

The only way to conclusively prove or disprove the eastward younging model were to radiogenically date suitable samples from suitable localities of the ZEBH'. The work of Allison et al. (2003) elaborated in Section 4.2.2.6, did precisely that and established the idea on scientific grounds.

DISSIPATION OF THE BHAGIRATHI: By the beginning of the 19th century, the Bhagirathi started to become seasonably cut off from the Ganga (Colebrooke, 1803; Paddington, 1894) and the Padma had emerged as the most important deltaic distributary of the river. True to the prediction of Sherwill (1858), the Bhagirathi's off-take point from the Ganga at Suti has now degenerated so much that during the low-stage parts of the year, water flows towards the Ganga instead of entering into it (Basu and Chakraborty, 1972). The river's lower course is now mostly maintained by tide water (that enters 290 km upstream from its confluence) apart from contributions from the western plateau rivers and the Farakka barrage scheme that diverts certain amount of water from the Ganga during the lean period between January and May. Cut-off from its original provenance, the sediment load of the Bhagirathi-Hugli is now chiefly provided by its western tributaries.

There is no agreement about the time when the prominence of the Padma at the expense of the Bhagirathi was initiated or established. Some opinions about this are: 12-16th century (Chatterjee and Majumdar, 1972; Maitra, 1972), 14th century (Fox, 1938), Late 15th-Early 16th century (Mookerjea, 1965; Roy, 1969 in Begum, 1987), Early 16th century (Hirst, 1916; Reaks, 1919; Rudra, 1986) and 16th century (Mukerjee, 1938).

In the 1660 map of the GBD by Van den Broucke, the Padma was given a clear prominence over the Bhagirathi-Hugli river. The Bhagirathi entrance at Suti had been recorded to be fordable in the lean season in as early as 1666 (c. 330 a BP) by Tavernier in his Voyages in India (Sherwill, 1858. Exact date of observation. 6 January, 1666),

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which, according to Hunter (1876b:26), is ‘the earliest mention in the history of the silting up of the Bhagirathi’. About 115 years later, Rennell (1783:259) observed that although the Hugli had a comparatively deeper outlet, it ceased to be the principal branch of the Ganga. Discharge through the Hugli was ‘less than in the Ganga other in the proportion one to six’. He also found it ‘almost dry from October to May’ at its headwaters. While these observations do not provide any clue to the timing of the initiation of the decay of the upper Bhagirathi, they do corroborate that the Padma had established its prominence over the Bhagirathi by the middle of the 17th century, if not earlier.

There is also no consensus explanation of this shift. Sherwill (1858:3) had speculated that it occurred because, aided by the general slope of the land toward the SE or the centre of the basin, ‘the water from the Ganges has a greater inclination to proceed straight on ... rather than turn into the Bhagiruthhee’. He had also made sediment loads responsible for ‘filling up’ of the Bhagirathi. Oldham (1870) and Bagchi (1944), however, felt that any changeover from one distributary to another is only a normal part of the delta building process, where a given distributary would always seek a least-gradient outlet as the area around it is accreted and raised. Hirst (1915:19) presumed that the shift was ‘probably directly due to the earthquake of 1505 AD’. Subsequently, Mukerjee (1938) has connected the event to simultaneous rising of the land in the SW, subsidence of the land in the SE as well as deforestation-triggered soil erosion in the Chhotanagpur plateau, clogging the Bhagirathi with sediments.

Although Stevenson-Moor et al. (1919:5) reported that, ‘there is no evidence to justify ... that the gradual process of elevation and subsidence are determining factors in the river development of the delta’, more recent works by Deb (1956) and Coleman (1969) do indicate a tectonic influence behind the event. Morgan and McIntire (1959:319), for instance, made ‘faulting and resultant tilting of fault block’ responsible for the eastward shift of the Ganga distributaries towards the Brahmaputra-Meghna system. Basu and Chakraborty (1972) and Khandelkar (1984) also felt the same. F. Khan (1991) even linked the changeover event to the recent multiple faults along the course of the Padma. All major recent works on the delta equivocally stressed the significance of tectonics on evolution of the delta (Goodbred and Kuehl, 2001; Allison et al. 2003; Goodbred et al., 2003)

Among these, Goodbred and Kuehl (2000a) suggested that the Ganga joined Brahmaputra for first time ~5 ka ago. This shift of the primary discharge form Bhagirathi to the Padma probably started to materialise about 4 ka BP when the eastward growth of the coastal delta started to commence (Allison et al., 2003).