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Relative sea-level changes during the Holocene in Bangladesh

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ABSTRACT

This paper presents a reconstruction of the Holocene paleo-environment in the central part of Bangladesh in relation to relative sea-level changes 200 km north of the present coastline. Lithofacies characteristics, *mangal* peat, diatoms and paleophysiographical evidence were considered to reconstruct the past position and C-14 ages were used to determine the time of formation of the relative sea level during the Holocene. With standard reference datum, the required m.s.l. at the surface of five sections was calculated. The relative sea-level (RSL) curve suggests that Bangladesh experienced two mid-Holocene RSL transgressions punctuated by regressions. The curve shows an RSL highstand at approximately 7500 cal BP, although the height of this highstand could not be determined because the transgressive phase was observed in a bioturbated sand flat facies. The curve shows a regression of approximately 6500 cal BP, and the RSL was considerably lower, perhaps 1–2 m, than the present m.s.l. The abundant marine diatoms and mangrove pollens indicate the highest RSL transgression in Bangladesh at approximately 6000 cal BP, being at least 4.5 to 5 m higher than the modern m.s.l. After this phase, the relative sea level started to fall, and consequently, a freshwater peat developed at approximately 5980–5700 cal BP. The abundant mangrove pollens in the salt-marsh succession shows the regression at approximately 5500 cal BP, when it was 1–2 m higher than the modern sea level. The curve indicates that at approximately 5000 cal BP and onwards, the RSL started to fall towards its present position, and the present shoreline of Bangladesh was established at approximately 1500 cal BP and has not noticeably migrated inland since.

1. Introduction

Sea-level change is the product of many interrelated processes and is an integrated measure of environmental phenomena in terms of both causes and consequences. The composition of coastal sediments, coupled with any biological components they contain, represents a rich source of information on past changes of relative sea level (Godwin, 1943, 1945; Godwin, 1940; Antony, 2001).

Several kinds of sea-level indicators can be used to reconstruct sea-level curves. The most reliable indicators are considered to be organic remains in their growth position, preferably *in situ* peat. Mangrove peats, which precisely indicate former sea levels have been applied as sea-level indicators in many studies (Geyh et al., 1979; Woodroffe, 1981; Woodroffe et al., 1985; Grindord, 1985; Cohen et al., 2005). The mangrove ecosystem is considered to be highly susceptible to sea-level changes (Gornitz, 1991), and the sediments deposited beneath mangrove vegetation can provide useful indications of former sea levels (Scholl, 1964; Woodroffe, 1981; Van de Plassche, 1986). Mangrove peats are generally deposited intertidally and may be directly relative to the position of the sea at their time of deposition. Also, the sediments of these peats contain large amounts of organic carbon suitable for radiocarbon dating (Woodroffe, 1981). In reconstructing historical sea levels, several studies (Scholl, 1964; Bryant et al., 1992; Chappell, 1993; Fujimoto and Miyagi, 1993; Beaman et al., 1994; Fujimoto et al., 1996) have departed from the assumption that mangroves develop at approximately the mean sea level. It is known that erosion, accretion or other disturbances may cause variation on the order of ±1 m (Bunt et al., 1985). In Grand Cayman (West Indies), the substrate of the marine mangrove is generally 15–30 cm above the mean sea level (Woodroffe, 1981), and in Florida is 0–12 cm above m.s.l. (Scholl and Stuiver, 1967). In the coastal plain of Townsville (Australia), mangroves are found from 1.5 to 3.0 m amsl (Belperio, 1979), while in Coral and Cocoa creek, northern Australia, the lower part of the mangrove forest is between 0 and 1 m amsl (Aucan and Ridd, 2000).

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The global mid-Holocene highstand broadly dated between 8 and 4 Ka, occurred in a considerably large portion of the world (Ingolfsson and Hjort, 1999), including South America, Africa, Antarctica, Australia, and the Pacific and Indian Oceans. Being a coastal region, it was thought that there should have some evidence of the mid-Holocene marine transgression in the central part of Bangladesh, i.e., that the mid-Holocene highstand occurred in Bangladesh. A limited number of detailed studies have been conducted in the last few decades reconstructing the Holocene sea-level change of Bangladesh, including those of Umitsu (1987, 1993), Banerjee (2000) and Islam (2001). These past attempts have been based on borehole samples, and their study sites were at low-lying deltaic regions. These regions are not suitable for sea-level research because they are susceptible to long-term subsidence due to anthropogenic activities, which may lead to miscalculation of the altitude of the m.s.l. These authors obtained pollen, diatom, and molluscan fossil shells to construct the RSL curves. The present study, the first of its type in Bangladesh, shows a detailed description of the sedimentary facies and discusses the vertical changes of these facies successions along with faunal analyses of pollen and diatoms, which yield the maximum information about paleo-environmental changes. The present study attempts to reconstruct the Holocene paleo-environment by focusing on relative sea-level changes. An RSL curve and an approximate paleo-coastline in Bangladesh during the Holocene will also be constructed.

2. Study area

2.1. General geography of the study site

Bangladesh is mostly covered with Quaternary sediments. The geological evolution is basically related to the uplift of the Himalayan Mountains and the outbuilding of deltaic and floodplain landmasses by the major river systems of Ganges–Brahmaputra–Meghna originating in the uplifted Himalayas. Physiographically, the Bengal basin can be divided into two major units, the Pleistocene uplands and Holocene sediments. The Pleistocene uplands include the Barind tract and the Madhupur tract. The Holocene sediments include the alluvial fans in the foot hills of the Himalayas, the uplands such as the Tippera surface, the deep tectonic basin (Sylhet basin), and the Ganges–Brahmaputra–Meghna flood and delta plain, the most extensive unit of the basin Mukherjee et al. (2009). The flood and delta plain consists of clastic fluvial deposits with elevations no more than 15 m above MSL in most areas. Radiocarbon dating of sediments from the plain yields an age of generally less than 10,000 years to a depth of 30 m below land surface in most areas (Mukherjee et al., 2009).

During the peak of the last glaciation (18,000 yrs BP), the Bengal Lowland experienced dry climatic conditions and sea-level was 100 m or much lower than the present sea level (Umitsu, 1987). At about 12,000 yrs BP, south-west monsoon became prominent which caused heavy rainfall and sea-level started rising very rapidly (Monsur, 1995). This amplified monsoon water plus deglaciated melted water from the Himalayas flowed over the Bengal Lowland, thus the initial Madhupur and Barind surfaces were highly dissected and created some local pools and depressions (Monsur, 1995). The Indian Summer Monsoon (ISM) during early to middle Holocene was generally stronger than today, with peaks identified at 8500, 6400, and 3600 yrs BP detected in numerous ISM records (Fleitmann et al., 2003; Gasse et al., 1991; Van Campo et al., 1996; Wang et al., 2005). Umitsu (1993), Kudrass et al. (1999) and Goodbred and Kuehl (2000) stated that during the mid-Holocene sea level was slightly higher, the climate was warmer, and rivers of this region discharged up to two and half times more than in present times. Thus the most of Bangladesh had low elevation throughout its geologic history that made it very much sensitive to the relative sea-level changes which influenced geologic processes of weathering, erosion and deposition of sediments rather than tectonic control.

The study area, Dhaka, is located in the central part of Bangladesh, and is composed of the Pleistocene Madhupur tract and the Holocene floodplain along the rivers (Fig. 1a). To find evidence of a relative sea-level change, it is essential to explore the mangrove peat beds, which were formed in an intertidal zone. To fulfill this objective the southern part of the Madhupur tract was selected as the study area. The present study area is located in the G–B–M flood plain which has not been disturbed by subsidence caused by pumping and tectonic activities either. The layer of Holocene sediment in the study area is thin (30 m), so it may show a slight artificial subsidence. The tract of the present study area is drained by the Dhaleshwari, Buriganga, Bangshi, Banar, and Shitalakshya rivers of the Brahmaputra–Jamuna River system (Fig. 1a). All these rivers flow southeast and discharge freshwater into the vast Meghna River (Fig. 1a).

The area is annually inundated with floodwater during the monsoon period and after flooding, it receives a small increment of fluvial sediments. The tract is 1–10 m higher than the adjacent floodplain areas (Fig. 1b).

To obtain an accurate relative sea-level curve, five outcrops were chosen in the same geological framework (Holocene overlies the Pleistocene basement). The area is approximately 36 km long and is elongated the east–west direction. The five hand-excavated outcrops are Sony (studied by Rashid et al., 2009), Vatpara, Nayanipara, Dobadia and Chatbari. The locations of each outcrop were recorded with GPS. At present, the study area is characterised by fresh water terrestrial vegetation, including deciduous trees such as *gewa* and *sa*l and is not subject to any marine or tidal influence. The normal tidal range is about 3 m in the west coast and becomes higher to the east coast to about 5 m near at the mouth of the Meghna estuary (Hoque, 1991). The present study area does not show any evidence of tectonic signature (Monsur, 1995; Rashid et al., 2009) and appears to be the most stable part in Bangladesh.

2.2. Geology of the study site

The area is divided into two major lithostratigraphic units in the following ascending order: the Madhupur Clay Formation (Monsur and Paepe, 1994) of Pleistocene age and the Bashabo Silty-clay Formation of Holocene (Recent) age (Monsur and Paepe, 1994). The Madhupur Clay and Sand Formation is the oldest deposit exposed in the study area. The upper part of the Madhupur Formation consists of highly weathered reddish-brown mottled clay, whereas the lower part is composed of micaceous sand exhibiting some ripple cross-lamination and cross-bedded primary sedimentary structures. The Holocene deposit covers the bottom of the floodplains and tract valleys. The Holocene Series in the type locality at Bashabo is called the Bashabo Silty-clay Formation (Monsur and Paepe, 1994). The Bashabo Formation consists of yellowish-brown to bluish-grey sand to clay and is extensively distributed in the central Bangladesh floodplain. The five outcrops are very close to Bashabo, and the lithology of the Holocene succession of the sites is similar. Hence, the deposits exposed at all sites are considered to be part of the Bashabo Formation. The lithology of each site is described as follows.

The iron concretions, wood, and cracks indicate strong weathering in the Madhupur Clay and Sand Formation. Due to weathering, the Madhupur tract eroded away and cut the tract, forming a valley. A sharp and clear boundary between the Madhupur weathered soil and the Holocene deposits is prominent in this succession. The mud balls and fragments indicate that weathering also acted during its deposition. The rootlets coated with lignite indicate that the