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Stable isotope record of Late Quaternary sediments from northwestern Bengal Basin, Bangladesh

H. M. Zakir Hossain[1,2], Md. Sultan-Ul-Islam[3], Mst. Fahima Ferdousy[3], John S. Armstrong-Altrin[4], Alcides N. Sial[5], Ismail Hossain[3,6,]*, Quazi Hasna Hossain[7]

[1]*Atmosphere and Ocean Research Institute, the University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa, Chiba 277-8564, Japan*
[2]*Department of Petroleum and Mining Engineering, Jessore University of Science and Technology, Jessore 7408, Bangladesh*
[3]*Department of Geology and Mining, University of Rajshahi, Rajshahi 6205, Bangladesh*
[4]*Instituto de Ciencias del Mar y Limnología, Unidad de Procesos Oceánicos y costeros, s, Circuito Exterior s/n, 04510, Mexico DF, Mexico*
[5]*Nucleo de Estudos Geoquímicos e Laboratório de Isótopos Estáveis (NEG-LABISE), Departmento de Geologia, Universidade Federal de Pernambuco, Caixa Posta 7852, 50670-000 Recife, PE, Brazil*
[6]*Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki 305-8572, Japan*
[7]*Department of Geoscience, Shimane University, 1060 Nishikawatsu, Matsue 690-8504, Japan*

**Corresponding author. Tel.: +88-0721-750974; fax: +88-0721-750064*
E-mail address: ismail_gm@ru.ac.bd (Ismail Hossain).

Abstract

Carbon and oxygen isotope compositions of nine sediment samples from the Late Quaternary sequence of the northwestern Bengal Basin, Bangladesh have been examined to infer their paleoenvironment and paleoclimatic conditions. The sediments are predominantly clay to sandy- or silty-clay topsoil. The carbon isotope values are negative at the bottom (-0.95‰ and -0.56‰) and positive at the topmost section (BH-1 = 1.45‰) of the drill core. These negative $\delta^{13}C$ values are considered to be the effect of diagenesis by meteoric water and the positive $\delta^{13}C$ value indicates the influence of a sub-areal exposure horizon. A gradual enrichment in $\delta^{18}O$ values from the bottom to the topmost section (from -12.11‰ to -5.57‰) of the BH-1 core suggests that the paleoclimate was probably humid initially and successively shifted to arid condition due to enhanced evaporation. Strong positive correlation (r = 0.95, n = 9) between $\delta^{13}C$ and $\delta^{18}O$ indicates the sediments were largely altered by diagenesis. The negative $\delta^{13}C$ and $\delta^{18}O$ values are likely to be controlled by post-depositional oxidation of organic matter when the sediments are subjected to oxic or meteoric water diagenesis associated with sea-level fluctuations. The negative $\delta^{13}C$ values in the core sections studied are dominantly controlled by the distribution of C_4 plants rather than C_3 plants.

Keywords: Carbon isotope; Oxygen isotope; Quaternary sediment; Bengal Basin; Bangladesh

Introduction

Stable isotopes are commonly used to evaluate the diagenetic environment and paleoclimatic changes occurred during deposition of sediments (e.g., Cerling, 1984; Marshall, 1992; Quade et al., 1995; Leng and Marshall, 2004; Armstrong-Altrin et al., 2011; Hossain et al., 2013; Heidari et al., 2015). The stable carbon isotope ratio ($^{13}C/^{12}C$) in carbonate sediments and sedimentary rocks, expressed as $\delta^{13}C$ is used in paleooceanography studies as a proxy for changes in production, burial as well as preservation of organic matter (Gischler et al., 2009). Carbon isotopic compositions of pedogenic soil carbonates are also expressed as changes in atmospheric pCO_2 levels over geologic timescale (Cerling, 1991), which in turn used to predict future global warming (Gischler et al., 2009). However, changes in the $\delta^{13}C$ of carbonate sediments through geological time have been interpreted to represent variations in the rate of organic carbon production relative to organic carbon burial and preservation (Hayes et al., 1999). Natalicchio et al. (2012) documented that carbonate precipitation in the shallow subsurface primarily controlled by the result of three microbially-driven processes such as sulphate reduction, methanogenesis, and anaerobic oxidation of methane. Oxygen isotopic compositions of carbonates are highly prone to alteration during diagenesis and/or post-depositional modifications (Hudson, 1977; Hossain et al., 2013; Fan et al., 2014).

This study presents new insights obtained from stable carbon and oxygen isotope results of Late Quaternary bulk sediments analyzed within two drill core sections of the northwestern Bengal Basin, Bangladesh. The $\delta^{13}C$ from bulk sediment (especially in pelagic deposits) is widely used as a stratigraphic tool to evaluate ancient shallow water carbonate settings of ramps and carbonate platforms (Scholle and Arthur, 1980; Grötsch et al., 1998; Gischler et al., 2009), and also to provide information on reworking paleoenvironmental evidences (Cerling, 1984). Stable isotope study of sediments in the Bengal Basin of Bangladesh is limitedly provided (France-Lanord and Derry, 1994; Alam et al., 1997; Hossain et al., 2013). However, the Late Quaternary paleoclimatic variation in the northwestern Bengal Basin is still largely unclear due to inadequate numbers of long-sequenced sedimentary core (184 m) paleoclimatic records. The aim of this study focuses on diagenetic alterations of carbonate remained in core sediments and the consequences for the paleoenvironmental, paleotemperature and paleoclimatic interpretation using stable isotopes.

Geological setting

The Bengal Basin of Bangladesh is located at a triple junction of lithospheric plates, i.e., the Indian plate, the Eurasian plate and the Burmese sub-plate (Alam et al., 2003). It comprises three geotectonic provinces, such as the stable shelf, the central deep basin (extending from the Sylhet trough in the northeast towards the Hatia trough in the south), and the Chittagong-Tripura fold belt (Alam et al., 2003). The basin fill history of these provinces varied considerably, and comprises a thick sedimentary record (~22 km) of dominantly continental to marine clastic sediments and small carbonate rocks (Alam et al., 2003; Hossain et al., 2010).

The present study area lies on the Stable Shelf geotectonic province (Alam et al., 2003), and is closed to Precambrian Indian Shield Platform (Fig. 1). The area is a part of the Nawabganj-Gaibandha Intracratonic High, and comprises a tiny linear feature trending NE-SW direction (Alam et al., 1997). A total of ~158 m thick Late Quaternary sediments are encountered in Chapai Nawabganj district, northwestern Bangladesh. The studied sedimentary sequences BH-1 (53 m) and BH-2 (40 m) are placed in the Rajarampur and Chanlai area, respectively, of the Chapai Nawabganj district, northwestern Bengal Basin of Bangladesh. The Neogene sediments lie directly over the Precambrian basement rocks instead of the Permian Gondwana rocks as it is in other part of the Stable Platform. Geomorphologically, the area is located on the lower Mahananda-Ganges floodplain. It is a corridor of the mighty Ganges River bounded by Precambrian Indian Platform-Late Jurassic to Early Cretaceous Rajmahal Volcanics on the west and the uplifted Pleistocene Barind Tracts in the east. It is an area of gravity high and Permian Gondwana is missing due to upliftment and/or non-deposition. Even Pleistocene Barind Tract sediments are also absent most probably due to erosion during northeastward journey of the Ganges River. From 40 m in BH-2 and 53 m in BH-1 gray, dark gray to yellowish gray carbonated mud layer with silty and sandy intervals started, which containing molluscan shells with different types of organic remains and thin veins of peat. This carbonated mud layer contains marine microfossils (foraminifera, ostracoda) of mainly Holocene age (Ferdousy, 2011) and indicating tidal mudflat, lagoon, marsh, low saline to brackish water environments. The sequence is not dated by any radiometric methods but this type of thick mud unit (max. 25 m) with peat, mangrove woods and marine microfossils (10-7 ka years) are present in the West Bengal part of the Ganges-Brahmaputra delta (Sarkar et al., 2009). Radiocarbon dating of the active Bengal delta sediments from a depth of 25 to 30 m below surface records an age of 8400 years BP (Goodbred and Kuehl, 2000). Boreholes log in the coastal region of Bangladesh indicate Holocene fine-grained sediments several tens of meters thick associated with major compaction allied subsidence (~5 mm/year) (Goodbred and Kuehl, 2000).

The stratigraphic succession of the northwestern Bengal Basin is summarized in Table 1. Summarized lithofacies log of the BH-1 and BH-2 are illustrated in Fig. 2. The Late Quaternary sedimentary sequence consists predominantly of clay with subordinate sandy- or silty-clay with occasionally coarse sand and conglomerate/gravel. The uppermost part of both sections is characterized by brownish silty-clay topsoil.

Materials and methods

Nine calcareous bulk sediment samples were collected from two drill cores in the Rajarampur (BH-1) and Chanlai (BH-2) areas of Chapai Nawabganj district, northwestern Bengal Basin, Bangladesh.

Stable carbon and oxygen isotope analyses were carried out at the Stable Isotope Laboratory (LABISE) of the Federal University of Pernambuco, Brazil. For determination of carbon and oxygen isotopes, CO_2 was removed from powdered carbonates in a high vacuum

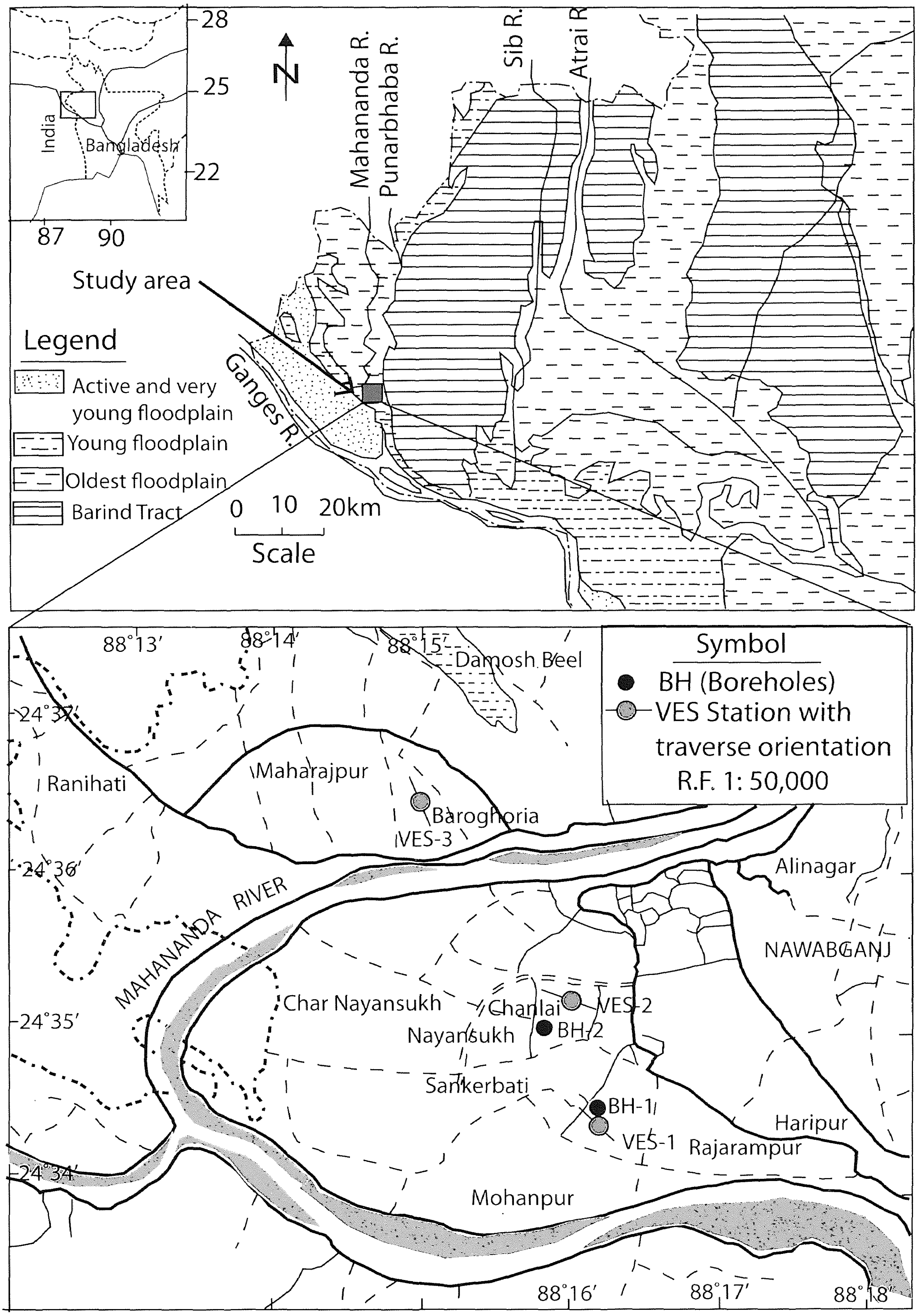

Fig. 1 Geological map showing location of the study area, sampling points, and major rock types in the northwestern Bengal Basin, Bangladesh (after Alam et al., 1997).

Table 1. Stratigraphic succession of the northwestern Bengal Basin, Bangladesh (modified after Alam et al., 2003; Najman et al., 2008).

Age	Group	Formation	Lithology	Depositional environment
Holocene		Alluvium	Sand, silt, clay and organic matters	Fluvial and coastal
Pleistocene		Barind Clay	Red clay	Fluvial
Plio-Pleistocene	Dupi Tila	Dupi Tila	Sandstones, mudstones	Fluvial
Miocene	Surma	Surma	Sandstones, mudstones	Deltaic
L. Eocene		Kopili Shale	Shales, few limestone	Shallow marine
E. to M. Eocene	Jaintia	Sylhet Limestone	Limestone	Shallow marine
Paleocene-E. Eocene		Tura Sandstone	Quartz arenites	Shallow marine

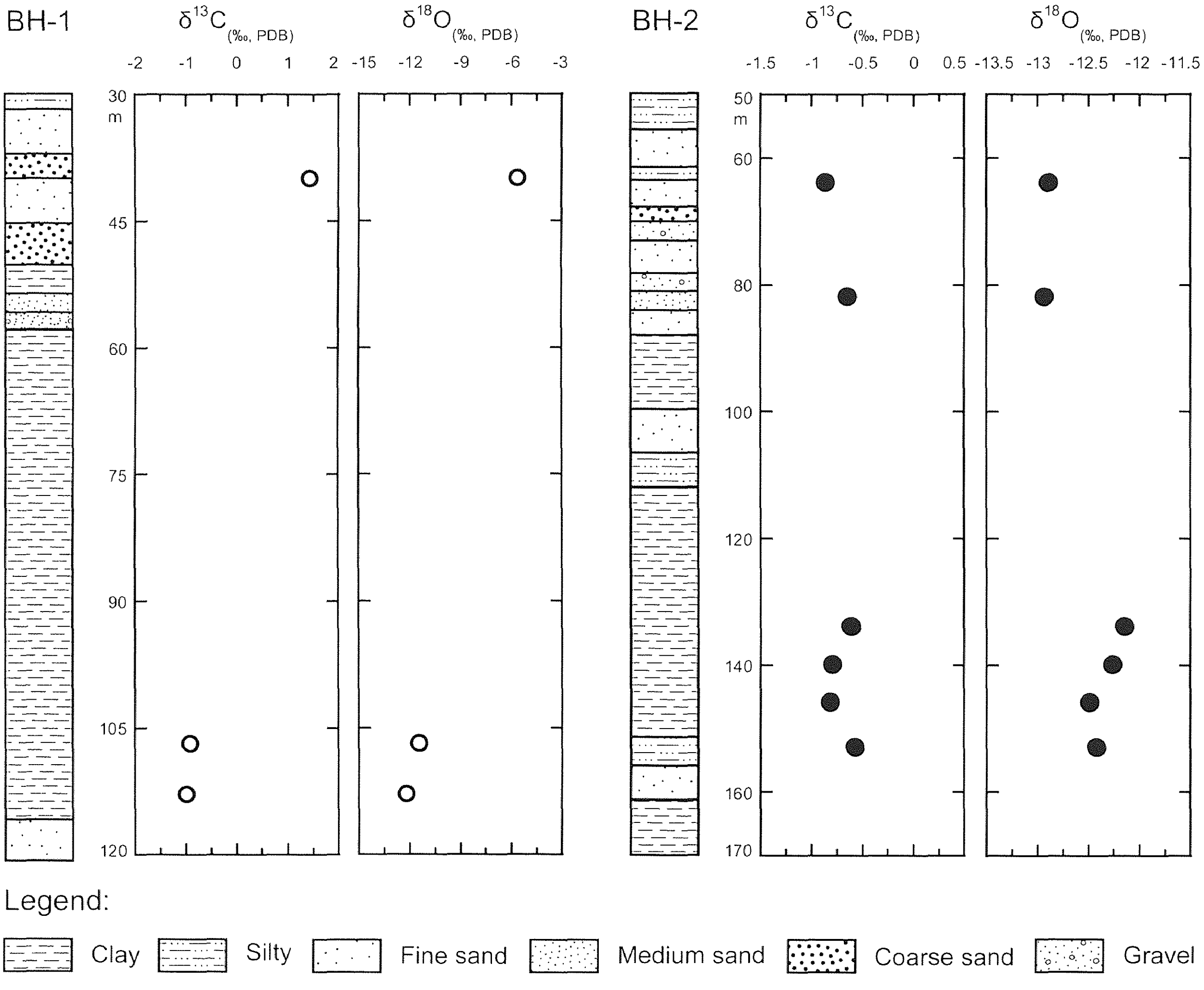

Fig. 2 Vertical distribution of $\delta^{13}C_{(‰, PDB)}$ and $\delta^{18}O_{(‰, PDB)}$ of the Late Quaternary sediments, northwestern Bengal Basin, Bangladesh.

line after reaction with H_3PO_4 at 25 °C, and cryogenically cleaned based on the technique explained by Craig (1957). CO_2 gas released by this method was analyzed for carbon and oxygen isotopes in a double inlet, triple collector SIRA II mass spectrometer, using the reference gas BSC (Borborema Skarn Calcite) calibrated against NBS-18, NBS-19, and NBS-20, has a value of-8.58‰ PDB for $\delta^{13}C$ and -11.28‰ PDB for $\delta^{18}O$ (Armstrong-Altrin et al., 2011). Isotopic results for both carbon and oxygen are reported using standard per mil (‰) notation with respect to Vienna Peedee Belemnite (VPDB). The SMOW (Standard Mean Ocean Water) conversion values to PDB standard were carried out using the following equation $\delta^{18}O_{calcite}$ (SMOW) = 1.03086 $\delta^{18}O_{calcite}$ (PDB) + 30.86 (Friedman and O'Neil, 1997). The uncertainties of the isotope measurements were

0.1‰ for C and 0.2‰ for O, based on multiple analyses of an internal laboratory standard (BSC).

Results

The carbon and oxygen isotopic compositions of calcareous sediments in the Late Quaternary core sections are given in Table 2. The $\delta^{13}C$ values range from -0.89‰ to 1.45‰ PDB in Rajarampur section (BH-1), and -0.85‰ to -0.56‰ PDB in Chanlai section (BH-2). Similarly, $\delta^{18}O$ values vary from -12.11‰ to -5.57‰ PDB and -12.14‰ to -12.92‰ PDB in Rajarampur and Chanlai sections, respectively. The $\delta^{13}C$ values show relatively coherent variations, and fluctuate between positive values of nearly 1.45‰ PDB in the uppermost BH-1 section and negative values of about -0.95‰ PDB in the lowermost BH-1 section. Consequently, all samples from the BH-2 display negative $\delta^{13}C$ excursions with maximum values in the top sample (S. No. BH-2.1) and minimum values at the bottom sample (S. No. BH-2.6) (Table 2). On the other hand, the $\delta^{13}O$ values are mostly identical throughout the core section BH-2 (av. -12.51‰ PDB), whereas the low negative value is identified in the top section of the core BH-1 (BH-1.1 = -5.57‰ PDB).

Discussion

Carbon isotopes

Carbon isotope signatures provide useful information about the exchangeable surface oceanic carbon reservoirs (Farquhar et al., 1989). Variation in $\delta^{13}C$ in marine carbonates can reflect changes in the carbon cycle that can be associated with changes in oceanic productivity and atmospheric greenhouse gases (Marshall, 1992). Carbon isotope values are relatively more stable during post-depositional diagenetic alteration than oxygen isotope values, however, shifts can be significant where organogenic carbon is incorporated (Marshall, 1992). The $\delta^{13}C$ values for recent marine carbonates range between 0‰ and 4‰ (Hudson, 1977). The $\delta^{13}C$ compositions of the studied bulk sediments are confined to a narrow range, ranging from -0.95‰ to -0.56‰ PDB, while one sample (BH-1.1) has positive $\delta^{13}C$ value up to 1.45‰ PDB (Table 2). The low negative $\delta^{13}C$ values in the sediments reflect the effects of pedogenic modification of carbonates (Bellanca et al., 1995) that possibly control diagenesis by meteoric water and/or changes in relative sea-level (Allan and Matthews, 1982). The more positive $\delta^{13}C$ values (1.45‰) occurred at 40 m depth in BH-1 likely reflect sea-level fluctuations, increasing fresh water conditions and/or strong influence of warmer climates. A carbonated mud layer (~5 m thick) contains molluscs shells and charophytes in the borehole BH-1 around 40 m depth (Ferdousy, 2011). Presence of molluscs and charophytes in the upper core suggest deposition associated with a freshwater environment (Sanjuan et al., 2012) and/or fluctuation between saline and freshwater conditions. However, upper part of the BH-1 is characterized by fine grained sand, silt and silty-clay (Fig. 2). The thick clay- or silty-clay layer in both cores (~50 m) contains

Table 2. Stable carbon and oxygen isotopic composition of Late Quaternary sediments, northwestern Bengal Basin, Bangladesh

Sample no	Depth (m)	$\delta^{13}C$ (‰ PDB)	$\delta^{18}O$ (‰ PDB)	$\delta^{18}O_{calcite}$ (SMOW)[b]	$\delta^{18}O_{water}$ (SMOW)[c]	
					20°C	25°C
BH-1.1	40	1.45	-5.57	25.12	-4.64	-3.57
BH-1.2	107	-0.89	-11.34	19.17	-10.42	-9.35
BH-1.3	113	-0.95	-12.11	18.38	-11.19	-10.12
BH-2.1	64	-0.85	-12.88	17.58	-11.96	-10.89
BH-2.2	82	-0.63	-12.92	17.54	-12.00	-10.93
BH-2.3	134	-0.60	-12.14	18.35	-11.22	-10.15
BH-2.4	140	-0.78	-12.25	18.23	-11.33	-10.26
BH-2.5	146	-0.80	-12.48	18.00	-11.56	-10.49
BH-2.6	153	-0.56	-12.41	18.07	-11.49	-10.42
Mean ± one standard deviation (n = 9)[a]		-0.51 ± 0.7	-11.57 ± 2.2	18.9 ± 2.2	-10.5 ± 2.2	-9.58 ± 2.2

[a] n = number of samples; the isotope data were checked for discordant outliers before computing mean and standard deviation values using discordancy tests for normal samples using new critical values at 99% confidence level (Verma and Quiroz-Ruiz, 2006a, b). No discordant data were observed.

[b] $\delta^{18}O_{calcite}$ (SMOW) = 1.03086 $\delta^{18}O_{calcite}$ (PDB) + 30.86 (Friedman and O'Neil, 1977).

[c] These values are calculated by assuming a paleotemperature of precipitation of 20 and 25 °C (e.g., Wright, 1987) and using the calcite paleothermometer of Friedman and O'Neil (1977).

abundant fresh water organic materials and peat remains (Ferdousy, 2011). Rashid et al. (2013) noted that the highest relative sea-level transgression occurred in Bangladesh at ~6000 cal BP based on abundant marine diatoms and mangrove pollens. However, the paleo-coastline started to retreat towards south from the central Bangladesh before 4870-4780 cal BP (Rashid et al., 2013), and a fresh water peat-swamp environment was developed in the region. The positive $\delta^{13}C$ values in BH-1 (~40 m) are considered to be relative sea-level changes with relatively fresh water conditions prevailed during sedimentation at approximately 5000 cal BP (Rashid et al., 2013). The glaciation/deglaciation of the Himalaya is likely to have had a marked effect on the high sedimentation rates and relative sea-level changes in the Bengal Basin (Islam and Tooley, 1999). High humid period prevailed in the Indian Sub-continent between 11,000 and 10,000 yr BP when valley cutting by the rivers of the Bengal Basin was predominant (Van Campo, 1986). The studied down-core sediments relatively more declined $\delta^{13}C$ values (up to -0.95‰) reflecting strengthens humid paleoclimatic conditions prevailed during deposition. The isotope values are strongly controlled by higher climatic variability during intensified monsoon precipitation. Strengthened of South Asian monsoon was initiated during Late to Middle Holocene (ca. 9-4 ka) (Bookhagen et al., 2005). Regional precipitation predominate the fractionation of carbon isotopes at moderate temperature and under wet conditions (Zhang et al., 2011). Diefendorf et al. (2010) reported that the variation of carbon isotopes between CO_2 and modern C_3 plants, and is negatively correlated to precipitation, representing that more negative $\delta^{13}C_{org}$ excursion corresponds to more precipitation. This result is supported by the study of Hall et al. (2009) and concluded that rainfall largely controls the $\delta^{13}C$ ratios of higher plants in the KwaZulu-Natal, South Africa. Allan and Matthews (1982) noted that the $\delta^{13}C_{TDIC}$ values in ground waters and river waters are typically low; generally range between −10‰ and −15‰ from plant respiration and production of CO_2 in the catchment soils. Fisher et al. (2005) suggested that oxidation of organic matter can play an important role to lowering both carbon and oxygen isotope values during short/long term exposure of the sediments to meteoric water in sea-level fall. Vertical distributions of $\delta^{13}C$ in the BH-1 and BH-2 core sections of the Late Quaternary sediments are shown in Fig. 2. In BH-1 core, changes drastically up section to positive $\delta^{13}C$ values reflect anaerobic oxidation of methane in anoxic marine and fresh water sediments (Natalicchio et al., 2012). Budai et al. (2002) suggested that methanogenic carbonates are characterized by positive $\delta^{13}C$ excursions due to precipitation from a ^{13}C-enriched carbon pool. However, during methanogenesis, ^{12}C is preferentially incorporated in methane, while the residual pore water becomes enriched in ^{13}C during methanogenesis (Boehme et al., 1996; Natalicchio et al., 2012). The $\delta^{13}C$ of carbonate is always showing a wide range of variation that is more related to plant photosynthetic pathways (Cerling, 1984; Cerling et al., 1989; Alam et al., 1997). The $\delta^{13}C$ values in terrestrial plant are sensitive to changes in atmospheric CO_2 (Nguyen Tu et al., 2004). The intensification of water stress, as a result of larger CO_2-forced warming causing an increase in available moisture driving greater isotopic discrimination caused rapid decreasing ^{13}C values of terrestrial plants (Bowen et al., 2004). The elevated algal population and photosynthetic activity in the shallow marginal marine environment can give positive $\delta^{13}C$ values (Milliman and Muller, 1977; Armstrong-Altrin et al., 2011).

Oxygen isotopes

The oxygen isotope composition of carbonate rocks is controlled by a temperature dependent fractionation of oxygen among the precipitating water and the minerals (e.g. calcite/dolomite) or precipitation/evaporation ratios (Leng and Marshall, 2004). Oxygen isotope is more susceptible than carbon isotope during diagenesis and/or burial temperature (Fisher et al., 2005). Diagenesis occurs on the sea floor, near-surface meteoric and shallow or deep burial environment (Swei and Tucker, 2012). However, the oxygen isotope composition of soil CO_2 is also controlled by oxygen isotope exchange between soil CO_2 and soil water adding to the production and diffusion of CO_2 (Cerling, 1984; Breecker et al., 2009). The $\delta^{18}O$ values of bulk sediments for core sections BH-1 and BH-2 range from -12.11‰ to -5.57‰ PDB and -12.92‰ to -12.14‰ PDB, respectively (Fig. 2 and Table 2). This small variation in $\delta^{18}O$ for BH-2 may be the result of sea-water surface temperature effect, whereas large variation in BH-1 is attributed to fluctuations in ^{18}O by evaporation (Budd and Land, 1990) and/or sea-level fluctuations. Umitsu (1987, 1993) documented that a strong early Holocene marine influence throughout the southern parts of the Bengal Basin, while the northern parts were under fluvial influences. The peak relative sea-level transgression occurred in Bangladesh at approximately 6000 cal BP, being at least 4.5 to 5 m higher than the modern mean sea-level (Rashid et al., 2013). Thereafter, the relative sea-level started to fall, and consequently, a freshwater peat developed at approximately 5980–5700 cal BP.

Marine carbonates with $\delta^{18}O$ value range from -10 to -5‰ can be considered to retain primary oxygen isotope signatures (Hall and Veizer, 1996; Chakrabarti et al., 2011). The negative $\delta^{18}O$ excursions are also associated with high rainfall and wet seasonal climatic conditions (Dettman et al., 2001). Fisher et al. (2005) noted that an increase of ocean temperatures of ~6 °C as the $\delta^{18}O$ values decrease from -3.5‰ to -5‰ using a standard temperature equation based on Anderson and Arthur (1983). For the equilibrium precipitation of carbonates, the mineral isotope composition declines by ~0.24% for every 1 °C increase in temperature (Craig, 1965). The oxygen isotopes are known to be more susceptible to diagenesis than the more robust carbon isotopes (Fisher et al., 2005). The negative $\delta^{18}O$ can be interpreted as post-depositional changes within the sediments during burial, or meteoric water diagenesis (Keith and Weber, 1964). In addition, the negative $\delta^{18}O$ values reflect humid paleoclimatic conditions (Dettman et al., 2001) and positive $\delta^{18}O$ values suggest an increased in evaporation rate due to the incidence of arid conditions (Fisher et al., 2005; Fan et al., 2014). The Bengal Basin sediments were derived from tectonic uplift and erosion of the Himalayan orogeny (Hossain et al., 2010). Variations in the $\delta^{18}O$ in the sediments were mainly the effect of Himalayan monsoon precipitation together glacial activity and sea-level change. Umitsu (1987) demonstrated that lowland area of the Bengal Basin of Bangladesh has experienced dry climatic conditions during the last glaciations (18,000 yrs BP) and the relative sea-level was 100 m or lower than the present sea-level. Strong South Asian monsoon was initiated during ~12,000 yrs BP and rapidly rising sea-level owing to heavy rainfall together deglaciated melting water in the area. The warmer climatic condition was prevailed during the middle Holocene time in the Bengal Basin of Bangladesh (Umitsu, 1993). The low $\delta^{18}O$ values and rapid fluctuations observed in the BH-1 core pointed to diagenesis of sediments as well as an increase in sea-surface temperature. The little negative $\delta^{18}O$ values (-5.57‰) in the up-core section of BH-1 than more negative values (-12.11‰) in the down-core might be resulted from the strong evaporation and then elevated the heavier isotopes in the investigated area (Fan et al., 2014). The marked positive correlation ($r = 0.95$, $n = 9$; critical t value for 99% confidence level is 0.735; Verma, 2005) between $\delta^{13}C$ and $\delta^{18}O$ (Fig. 3) suggests that the Late Quaternary sediments were affected primarily by meteoric diagenesis shifting the primary signal to more negative values towards the bottom core section (Marshall, 1992). The light carbon (^{12}C) and oxygen (^{16}O) are likely to be incorporated into re-precipitated calcite during diagenetic environments, leading to negative excursions on the $\delta^{13}C$ and $\delta^{18}O$ values (Fisher et al., 2005).

The $\delta^{18}O$ value of sediment pore water can be used to estimate the $\delta^{18}O$ value of precipitation, which yields insights into atmospheric circulation patterns as well as the paleo-elevation of high landmasses (Amundson et al., 1996; Garzione et al., 2000; Breecker et al., 2009). The $\delta^{18}O$ value is largely controlled by the $\delta^{18}O$ value of soil water and soil temperature (Breecker et al., 2009). The calculated $\delta^{18}O$ value of pore water ranges from -12.00‰ to -10.42‰ (SMOW) at 20° C and -10.93‰ to

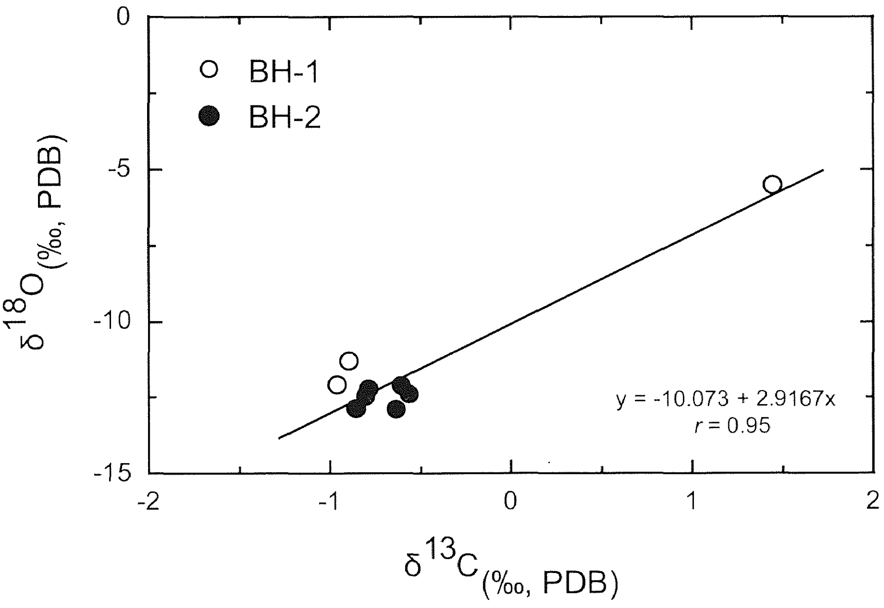

Fig. 3 $\delta^{13}C_{(‰, PDB)}$ versus $\delta^{18}O_{(‰, PDB)}$ plot for Late Quaternary sediments, northwestern Bengal Basin, Bangladesh.

-9.35‰ (SMOW) at 25° C, while at 40 m depth in the BH-1 section sediment is relatively with much higher values (-4.64‰ at 20° C and -3.57‰ at 25° C) (Table 2). Shackleton (1968) and Meyers and Lohmann (1985) reported that the seawater composition is inferred to have varied between -0.5‰ and +0.5‰ SMOW. Stromatolitic dolomite in Vempalle Formation, India is likely to be precipitated in equilibrium with marine waters significantly depleted in oxygen isotopes (-10‰ to -15‰ SMOW) with respect to modern sea water (Chakrabarti et al., 2011). Allan and Matthews (1982) and Marshall (1992) documented that meteoric water has lower $\delta^{18}O$ excursion than marine water and possibly shifted to low $\delta^{13}C$ excursion where the waters contain isotopically light carbon from soil-derived CO_2. Van Geldern et al. (2013) proposed that fresh water with low $\delta^{18}O$ values of -7‰ demonstrates present-day meteoric water, salt water of recent marine origin with $\delta^{18}O$ values of about −0.8‰, and brine with a $\delta^{18}O$ value of −1‰, close to that of seawater. The $\delta^{18}O$ values of pore waters for the sediments are all lower than typical seawater value, inferring the high-influence of meteoric water diagenesis (Armstrong-Altrin et al., 2009). However, the negative $\delta^{13}C$ excursions together with negative $\delta^{18}O$ values in the studied sediments would be controlled by post-depositional oxidation of organic matter in tiny exposure of the sediments to oxic and/or meteoric water diagenesis associated with sea-level fluctuations or tectonic uplift (Allan and Matthews, 1982; Marshall, 1992; Fisher et al., 2005).

Changing plant communities during Miocene to recent

The carbon isotopic evidence of the Late Quaternary sediments in northwestern Bengal Basin is compared with the stable isotopic composition of soil carbonates in Miocene Siwalik succession in western and central Nepal and Pakistan, Pleistocene palaeosol in northwestern Bangladesh, and Middle-Late Holocene western Ganges-Brahmaputra delta plain sediments in order to tracing the contributions of C_3 and C_4 plants in the Himalayan watersheds. The isotopic composition of soil CO_2 is mostly controlled by the proportion of surface plant biomass using the C_3 (Calvin cycle) or C_4 (Hatch-Slack) photosynthetic pathways (Smith and Epstein, 1971, Cerling, 1984). The C_3 and C_4 photosynthetic pathways fractionate carbon isotopes to variable degrees, while $\delta^{13}C$ values for C_3 and C_4 plants ranging from ~-22‰ to -30‰ and -10‰ to -14‰, respectively (Bender, 1971; Farquhar et al., 1989; Cerling et al., 1997). C_3 grasses are usually restricted to cool climatic conditions and C_4 dominated grassland adapted relatively high irradiance, water stress, and temperature conditions (Ehleringer, 1978; Cerling et al., 1989; Quade et al., 1995). The $\delta^{13}C$ values of soil carbonates in Pakistan range from -12‰ to -9‰ PDB (Quade et al., 1995), consistent with C_4 plants dominated vegetation. Sediments of the Bengal Basin were largely derived from erosion of the Himalayas (France-Lanord and Derry, 1994; Hossain et al., 2010). Miocene sedimentary rocks in the Sylhet Basin, northeastern Bangladesh are very similar to the Miocene Surai Khola and Bakiya Khola sedimentary rocks as evidenced by geochemical studies, suggesting a similar source. France-Lanord and Derry (1994) reported that fine-grained sediments are associated with C_4 plants, whereas coarse-grained sediments are associated with C_3 dominated organic matter. This result is consistent with a study of organic matter by Hossain et al. (2009) and concluded that organic matter in the Tertiary Sylhet succession, northeastern Bengal Basin of Bangladesh were derived from both C_4 and C_3 plants. The $\delta^{13}C$ values in the present study range between -0.95‰ and 1.45‰ PDB, supported mainly predominance of C_4 plants. Mixed C_3 and C_4 plants are well documented in the Middle Holocene western Ganges-Brahmaputra delta plain and return to extensive growth of C_4 plants in the Late Holocene (Sarker et al., 2009). Aucour et al. (2006) documented that the *Phragmites/Saccharum/Imperata* swamp grasslands are widespread in humid regions of the Indo-Gangetic plain and the Brahmaputra valley, whereas the *Dicanthium/Cenchrus/Lasiurus* and *Sehima/Dichanthium* grasslands are spread over the western part of the basin. The $\delta^{13}C$ values in soil carbonates in the Surai Khola and Bakiya Khola Siwalik succession range from -9.3‰ to -12.2‰, with an average -10.4‰ (Quade et al., 1995), and -9.1‰ to -11.3‰, with an average -10.4‰ (Harrison et al., 1993), respectively. The carbon isotopic patterns in the Surai Khola are very similar to Bakiya Khola section in central Nepal, but highly decline carbon isotopic values in the Late Quaternary sediments of Bangladesh (-0.95‰ to 1.45‰ PDB). The pedogenic carbonate concretions from Pleistocene palaeosol sequences on the northwestern Bangladesh have $\delta^{13}C$ values ranging from -11.5‰ to 2.5‰, PDB (Alam et al., 1997), indicating that influence of both C_3 and C_4 plants respiration. C_4 plants have $\delta^{13}C$ values of less than -15‰ PDB, whereas C_3 plants have much higher $\delta^{13}C$ values up to -27.9‰ PDB (Meyers, 1994). These larger fractionations of $\delta^{13}C$ in pedogenic carbonates indicate variable climatic conditions that favor C_3 and C_4 plants. However, the photosynthetic efficiency of C_3 and C_4 grasses is primarily depends on temperature and atmospheric pCO_2 levels such that C_4-dominated ecosystems are favored under low pCO_2

conditions when accompanied by elevated temperature (Cerling et al., 1997). C_4 grasses are abundant in tropical and sub-tropical regions, and C_3 grasses are dominate in high latitude and high altitude regions (Cerling et al., 1989, 1997). The $\delta^{13}C$ of C_3 plants is highly sensitive to humidity or precipitation and is mainly influenced by soil water content and/or precipitation (Sternberg et al., 1984; White et al., 1994). Additionally, C_3 plants respond to changes in atmospheric CO_2 with decreased maximum net photosynthetic rates that are related to lowered CO_2 levels (Ehleringer et al., 1991; Cerling et al., 1997), while C_4 plants are less sensitive to atmospheric CO_2 levels. Changes in pCO_2 level due to rapid continental weathering and tectonically active Himalayan region are likely to be lowering of CO_2 in concomitant to favoring terrestrial C_4 plants photosynthesis than C_3 plants (Cerling et al., 1997; Pagani et al., 2005). These features show that the distribution of $\delta^{13}C$ in the northwestern Bengal Basin are dominantly controlled by the distribution of C_4 plants, and C_3 plants over small in tropical, sub-tropical, and temperate environments.

Conclusions

The stable carbon and oxygen isotope results of nine Late Quaternary sediment samples of two core sections from the Chapai Nawabganj district, northwestern Bengal Basin, Bangladesh were studied. The carbon isotope data show a negative excursion from -0.95‰ to -0.56‰ PDB and a positive excursion at the uppermost BH-1 drill core sample (1.45‰ PDB). These negative $\delta^{13}C$ excursions are considered to be the effect of meteoric water diagenesis and the positive $\delta^{13}C$ values indicate the influence of a sub-areal exposure horizon. The $\delta^{18}O$ values represent marked negative excursions throughout the core sections BH-1 and BH-2, which range from -12.92‰ to -11.34‰ PDB with low negative value at the topmost section (-5.57‰ PDB), suggesting that the paleoclimate was probably humid and gradually shifted to arid condition. The marked positive correlation between $\delta^{13}C$ and $\delta^{18}O$ (r = 0.95, n = 9) indicates that the Late Quaternary sediments are largely altered by meteoric diagenesis. The negative $\delta^{13}C$ and $\delta^{18}O$ excursions are probable controlled by post-depositional oxidation of organic matter in tiny exposure of the sediments to oxic or meteoric water diagenesis associated with sea-level changes. However, the stable isotope results of the present study supports for the dominance of C_4 plants over C_3 plants.

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