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TURBIDITES IN THE UPPER BHUBAN MEMBER OF THE SITAKUND ANTICLINE, CHITTAGONG, SOUTHEASTERN BANGLADESH.

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Abstract: The Upper Bhuban Member in the Sitakund anticline, Chittagong, Southeastern Bangladesh is constituted by the light gray, light yellow and greenish gray sandstone and siltstone with dark gray, bluish black and black finely laminated silty shale to shale. The lithofacies of massive sandstone(Sm), turbidite sandstone (ST), flat bedded sandstone-siltstone (Sh), ripple cross laminated sandstone-siltstone (Sr), laminated sandstone-siltstone (Sl), lenticular laminated sandstone-siltstone-shale (Sll), wavy laminated silty shale to shale (Fw), laminated shale (Fl) with sub-facies black shale (F_{lbk}) and blue shale (F_{lb}) and mudstone (Fm) have been delineated in this member. Based on genetic aspects the facies are grouped into (1) turbidity generated - and (2) deep marine basin plain facies association. The medium to fine grained facies Sm and ST with or without Sh, Sr, Sl Sll Fw and Fm facies constitutes the turbidity generated facie association. The deep marine basin plain facies association is characterized by the monotonous hemi-pelagic bluish black shale (subfacies Flb) and pelagic black shale (subfacies Flbk) with rare to scare silty stringers of facies Sh, Sr, Sl, Sll and Fw. The facies Sm is turbidity channel in the inner part of medial fan and the complete ST sequence indicates channelized forms, while incomplete ones have been identified as channel or interchannel deposits in medial to distal fan. The facies F_{lb} and F_{lbk} denote deep marine environments above and below the carbonate compensation depth, where the lithofacies facies Sh, Sr, Sl, Sll and Fw were deposited as distal turbidites. The facies sequence of medial to distal fan and deep marine basin plain were repeated and randomly juxtaposed one upon other due to instability of basin probably by faulting along Dauki and adjoining area accompanied by sea level change. The paleoflow pattern indicates that the dominant source of detrius was the Shillong plateau along with minor contribution from the Himalayas and Arakan Yoma Folded Belt.

Keywords: Turbidites, Upper Bhuban Member, Sitakund anticline, SE Bangladesh.

mvivsk: evsjv‡`‡ki `w¶Yce As‡ki PÆMÖg AÂ‡ji mxZvKÊ D×fv‡Ri (GwÛUKvBb) D× feb †g¤vi nvjKv ami, nvjKv nj` I meRfve ami, †e‡jcv_i Ges cwjcv_i Øviv MwVZ, hvi g‡a¨ Mvp ami, meRvf Kv‡jv I Kv‡jv m² ¯iwqZ KYvh³ †mj cv_i/K`g wkjv Øviv MwVZ| MVYwenxb †e‡j cv_i (GmGg), cwi¼jZv †mvZ MwVZ †e‡j cv_i (GmwU), mgZj ¯iwqZ †e‡j cv_iÐcwjcv_i (GmGBP), jnix µm ¯iwqZ †e‡j cv_iÐcwj cv_i (GmAvi), ¯iwqZ †e‡j cv_i (GmGj), †jÝ AvKwZi ¯iwqZ †e‡j cv_iÐcwjcv_iÐK`g cv_i (GmGjGj), †XD †Lj‡bv ¯iwqZ cwjh³ K`g cv_iÐm× cv_i (GdWwewjI), ¯iwqZ K`g cv_i (GdGj) Gi mwnZ DcÐewnivKwZi Kv‡jv K`g cv_i (GdGjwe‡K), bxj K`g †g‡U cv_i (GdGjwe) Ges MVbwenxb †g‡U cv_i (GdGg) Gi kxjv ewnivKwZ¸‡jvi Dcw¯Z GB †g¤v‡i mbv³ Kiv n‡q‡Q| DrcwËi Dci wfwË K‡i GB wkjv ewnivKwZ¸‡jv‡K cwi¼jZv †mvZ móRvZ Ges Mfxi mg` †ewmb mgfwgRvZ msN, GB `fvM Kiv n‡q‡Q| ga¨ †_‡K ¶` KYwewkó MVb wenxb †e‡jcv_i (GmGg) Ges cwi¼jZv †mvZ MwVZ †e‡j cv_i (GmwU) cwi¼jZv †mvZRvZ ewnivKwZ msN MVb K‡i‡Q, hvi g‡a¨ GmGBP, Gm Avi , GmGj, GdWwewjI Ges GdGg _vK‡Z I cv‡i ev bvI _vK‡Z cv‡i| Mfxi mg‡`i wkjv ewnivKwZ msN ˆewPÎnxb Aamg` ˆReZjvbx h³ bxjvf K`g cv_i (GdGjwe) Ges ˆReZjvbx Kv‡jv K`g cv_i (GdGjwe‡K) Øviv ˆewkó¨cY, hvi g‡a¨ Aí ev LeB Aí cwigv‡b GmGBP, GmAvi, GmGj, GmGjGj Ges GdWwewjI Av‡Q| MVbwenxb †e‡j cv_i n‡jv cwi¼jZv †mvZ wewkó Lvox b`x ev mg‡`i g‡a¨ †d‡bi wfZ‡ii As‡k Aew¯Z Ges m¤cY cwi¼jZv †mvZ MwVZ †e‡j cv_‡ii mgwó cwi¼jZv †mvZ Lvox wb‡`k K‡i, ‡mLv‡b Am¤cY GB cv_‡ii mgwó mg‡`i bx‡Pi ga¨ n‡Z `ieZx †d‡bi b`xLvox ev `B b`xi g‡a¨w¯Z mg`xK Zjvbx wb‡`k K‡i| bxj K`g cv_i Ges Kv‡jv K`g cv_‡ii DcewnivKwZ h_vµ‡g Kv‡ev‡bU †LmviZgjK MfxiZvi Dci Ges bx‡Pi mg` cwi‡ek wb‡`k K‡i †hLv‡b GmGBP, GmGj, GmGjGj Ges GdWwewjI wkjv ewnivKwZ¸wj `ieZx cwi¼jZv †mvZ mó mg‡`i Zjvbx wn‡m‡e wPwýZ| ga¨ †_‡K `ieZx †db Ges Mfxi mg‡`i †ewmb mgfwgi wkjv ewnivKwZ mgwó¸wj evi evi AewZZ n‡q‡Q Ges wew¶ßfv‡e G‡Ki Dci Ab¨wU e‡m‡Q, hv †ewm‡bi Aw¯iZvi Rb¨ ¯vqx| †mwU m¤eZt †ewm‡bi wbKUeZx WvIwK PrwZi Rb¨ N‡U‡Q hvi m‡½ mg`có cwieZb m¤cwKZ | cvPxb †mv‡Zi cev‡ni cwZKwZ n‡Z Rvbv hvq †h, D³ †g¤v‡ii wewfb cv_i mg‡ni cavb Drm wmjs gvjfwg Ges wKQ Ask wngvjq Ges AvivKvb BIgv fvR ceZgvjv †_‡K G‡m‡Q|

Introduction

Recent alluvial sediments are exposed all over Bangladesh but Tertiary sediments are common in the districts of Chittagong and Chittagong Hill Tracts and Sylhet. The study area is delineated by the latitude 22°34′ N to 22°41′ N and longitude 91°38′ E to 91°42′ E and is situated in the northwestern part of Chittagong district covering an area of about 135sq.km within the Sitakund Hill Range in the Sitakund Upazilla, Chittagong, Bangladesh (Fig. 1). The rocks of the Upper Bhuban Member of Miocene age forms the cliff forming central part of the Sitakund Hill Range and also in the other hill ranges in the exposed folded areas of the Bengal Basin, which are exposed only in road cut, foot path and tributary sections and these are not easily accessible (Khan 1991; Reimann 1993, Mominullah 1978). Dark gray, bluish gray, bluish black and black finely laminated

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to thinly bedded shale and sandy shale, light gray, light yellow and greenish gray sandstone and siltstone compose the rock sequence of the Upper Bhuban Member in the area. So far, a few attempts have been made in the recognition of thin-bedded as well as mostly fine-grained turbidite sequence and marine sediments in the Bhuban Formation of the southeastern folded part of the Bengal Basin, especially in Chittagong Hill Tracts (Hoque 1962; Rahman 1973; Sinha and Sastri 1973; Roy 1974; Akhter and Bhuiyan 1998; Gani and Alam 1999; Rayhan and Mustafa 1999; Huq *et al.* 2000; Alam *et al.* 2003). The Miocene marine fan is believed to extend up to the Dauki Fault along the Sylhet-Meghalaya of India-Bangladesh border **(**DasGupta and Nandy 1995; Akhter and Bhuiyan 1998; Gani and Alam 1999; Haque 2001; Roy *et al*. 2006). No detail work has yet been done for delineation of turbidite as well as deep marine sediments within the Bhuban Formation of the Sitakund anticline. This paper describes both the fine-grained turbidite and deep marine fine grained facies along with paleographic set up within the Early Miocene Upper Bhuban Member from different sections of the central part of the Sitakund anticline, Chittagong, southeastern Bangladesh. Analyses of sedimentary facies, facies association and paleo current have been done and facies - and paleogeographic models have constructed to decipher the depositional setting.

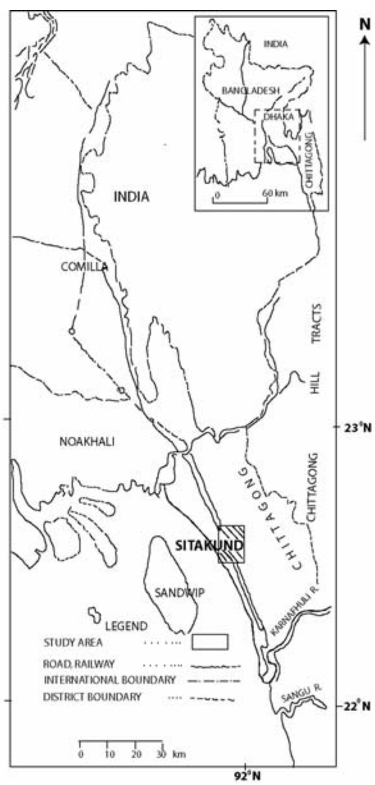

Fig. 1. Location map of the study area.

Materials and Methods

Fieldwork has been carried out along the four east- west transverse sections within the central part of the Sitakund Hill Range by compass-clinometer traverse method. The sections are the Bariyadhala, Sashasradhara, Chandranath Temple and Barabkunda from north to south (Fig. 2). The rocks of the Bhuban Formation are well exposed in the footpath, half metal road and tributaty sections, which are studied in detail and noted for data on lithology, sedimentary facies and paleocurrent. Grain size, shape and sorting of the sediments are visually estimated by comparing these with a pocket reckoner developed by the Dept. of Geological Sciences, Jadavpur University, India following Folk and Ward (1957) and pocket lense. Lithologies of different stations were studied by necked eye and pocket lenses and the cementing materials by observing color and hardness and using HCl and all the information were clearly recorded in the field notebook. The rocks are identified by the color, texture, and composition following Blatt *et al*. 1980; Pettijohn 1984; Walker 1984 and Reading 1986. The sedimentary structures are recognized following Reineck and Singh, 1980 and Collinson and Thompson, 1982. Thickness and attitude of beds and sedimentary structures along with plaeocurrent data are measured by measuring tape and clinometer. Attitude of beds and paleocurrents (azimuth of foreset dip of plannar cross strata, lee side of ripples, plunge of axes of trough cross-sets and plunge of axes of channels) were measured by compass-clinometer. Channel width and depth were measured by measuring tape. Photographs of important features were taken by camera. Thirty five rock samples were collected and sixty one paleoflow data were measured. paleocurent data are analyzed following the scheme of Potter and Pettijohn 1977. Systematic mapping, sampling and photography have been carried out in the field. Relevant publications, literatures and existing geological maps are collected and interpreted to produce background database for present work. The acquired data are later on analysed in the laboratory for detail study. Datail lithologs of the four studied sections along with delineated facies (Figs. 3-5) and pleoflow directions are prepared, on the basis of which facies model (Fig. 6), paleocurrent rose diagram and paleogeographic model (Fig.7) have been constructed.

Results and Discussion

Geology: Geologically the Stitakund hill range is an anticline, which is one of the most prominent structures of the Bengal Basin. It is situated in the Bengal Fore deep portion of the Bengal Basin, located in the northwestern part of Chittagong district. The Bengal Fore deep has two parts namely western platform Flank and the eastern Folded Flank. The eastern Folded Flank is again sub-divided into two zones namely the eastern zone and the western zone. The Sitakund anticline has the position in the western sub zone of the Folded flank, which is considered to be the western most continuation of the Arkan-Yoma folded belt. It is originated from the deformation by the relative movement of the Indian plate and Burmese sub plate, since the Sitakund anticline is trending in NNW-SSE direction (Bakhtine 1966; Guha 1975; Mominulla 1978; Reimann 1993). Most part of the western flank of the anticline is faulted regionally, the alignment of which runs parallel to the NNW-SSE trending regional strike (Fig. 2). The rock sequences of the Bhuban-, Boka Bill-, Tipam Sandstone-, Girujan Clay-, Dupi Tilla-, and Dihing Formation are exposed in this anticline (Mominulla 1978; Reimann 1993; Kabir 2006). The formation has an average strike of N 22°W-S22°E with a higher amount of dip (16°-35°) in the western flank than in the eastern flank (11°-18°).

Stratigraphy: Good exposures of the Bhuban Formation were identified along the roadcut , footpath, hillcut and tributary sections of the banks of the Bariyadhala, Sashasradhara, Chandranath Temple and Barabkunda sections. On the basis of color, gross lithology, geomorpholgy and genetic inference, litho-stratigraphically the Bhuban Formation can be divided into three members: lower, middle and upper. The lower member is sandstone- siltstone dominated with significant amount of shale, middle member is shale dominated with small portion of siltstone and sandstone and upper member is sandstone- siltstone dominated with significant amount of shale (Mominulla 1978; Roy 1975; Rahman 1974; Reimann 1993). The Lower member is not exposed in this anticline. The thickness of the Middle Member and Upper Member varies from 22 to 29m and 56 to 230m respectively (Figs. 3-5). The Upper Member is conformably underlain by the Middle Bhuban Member and overlain conformably by the Boka Bill Formation in the study area and chiefly composed of sandstone and siltstone with subordinate or significantly dominant shale and silty shale. The stratigraphic succession of the study area is given in the Table 2. Seven litho-logs have been constructed from base to top to show the lithology and facies of each section in detail.

Facies Analysis: A facies is a body of rock with specified characteristics where sedimentary rocks can be handled at outcrop or from boreholes, it is defined on the basis of color, composition, texture, fossils and sedimentary structures (Reading, 1986; Teichert, 1958). A facies should ideally be a distinctive rock that forms under certain condition of environment reflecting a particular sedimentary process (Middleton 1973; Cant and Walker 1976; Miall 1978, 1985, 1988, 1990, 1993; Rust 1978; Walker 1984) and the facies in the work has been used in the genetic as well as descriptive sense. The purpose of the facies analysis is to erect a simplified a facies scheme and one facies model that would aid the interpretation and discrimination of the depositional environment of the Upper Bhuban Member in the study area.

The rock sequences of the Sitakund anticline have been studied from the Bariyadhala section in north with Sahasradhara and Chandranath temple sections in the middle to Barabkund section in south, which yield a simplified facies scheme that is arranged in order of grain size from coarse to fine (Table 1). The lithofacies code consists of two parts, a capital letters for model grain size and a small letters chosen as subscript of a distinctive sedimentary structure of lithofacies. The facies are identified, delineated and described following Miall (1978, 1985, 1988), Reineck and Singh (1980), Stow (1986), Walker (1984), Jenkyns (1986), Bouma (1962) and Roy *et al.* (2006).

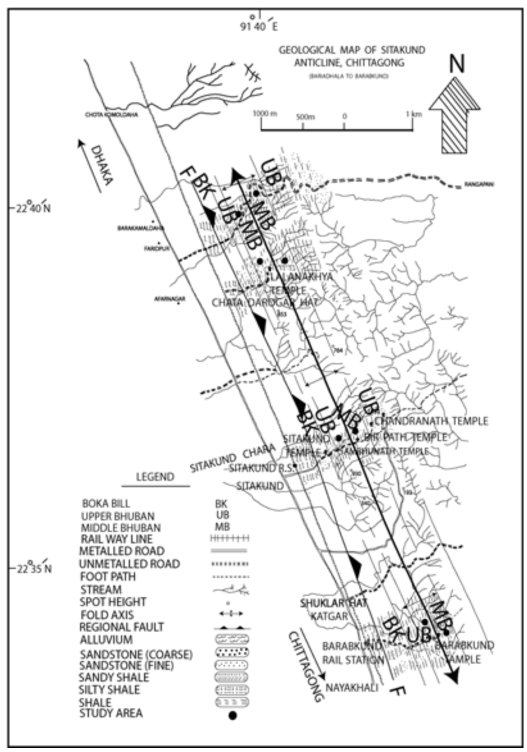

Fig. 2. Geologic map of the study area of the Sitakund anticline with exposures of the Tertiary sediments.

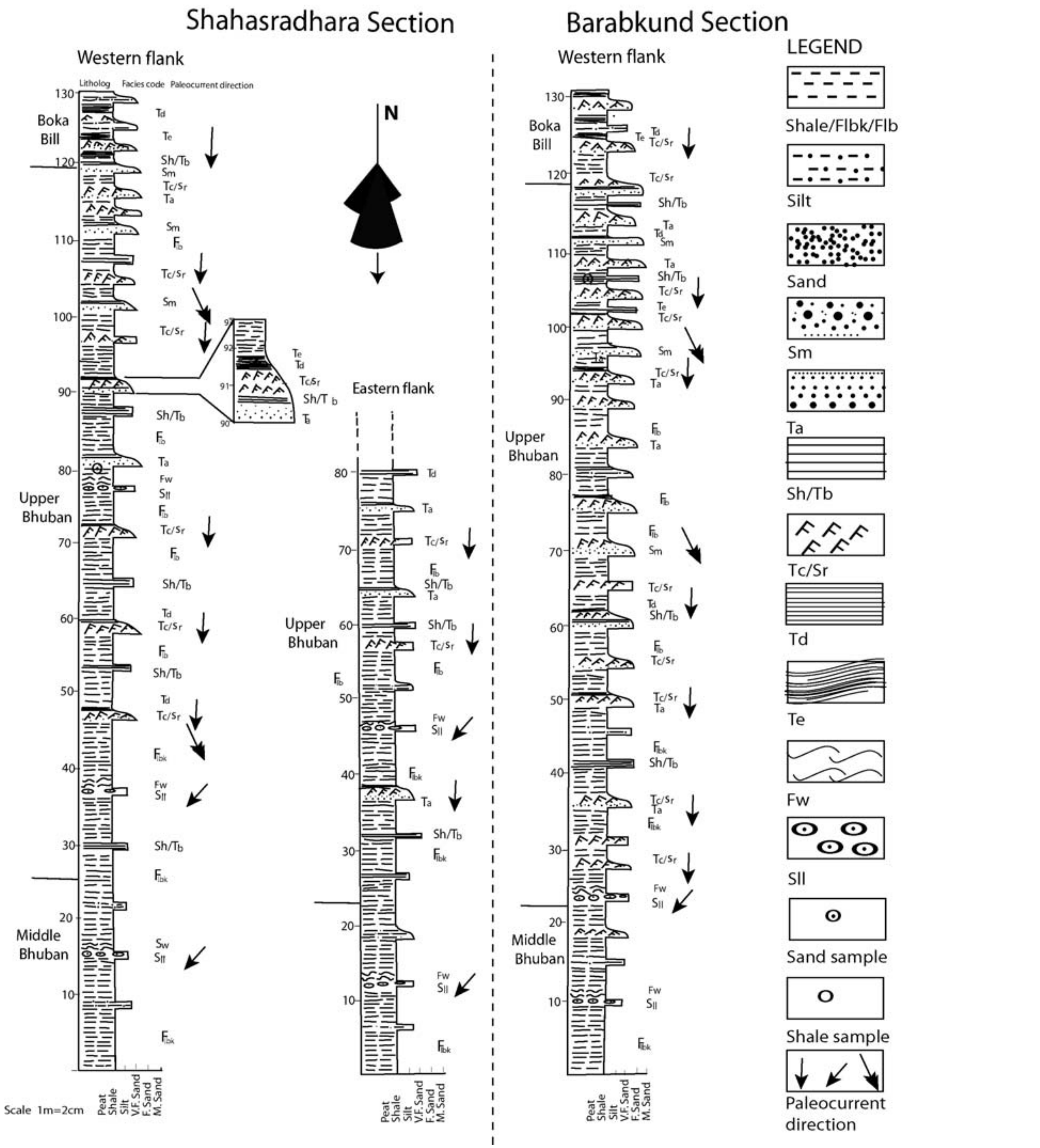

Fig. 3. Lithologic along with facies and paleocurrent of the exposed lithostratigraphic units, Shahasradhara and Barabkund sections, Sitakund anticline, Southeast Bangladesh.

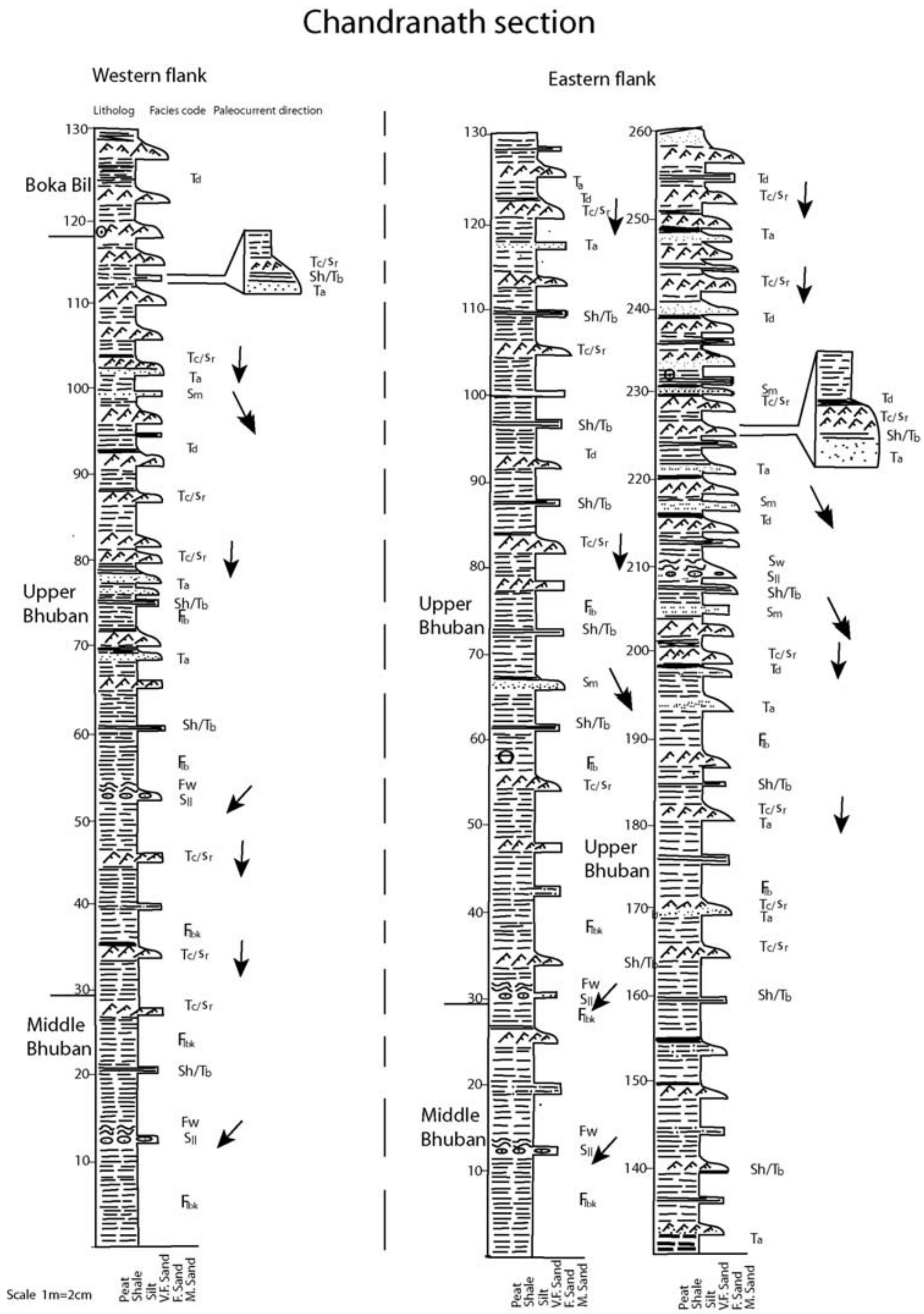

Fig. 4. Lithologic along with facies and paleocurrent of the exposed lithostratigraphic units, Chandranath section, Sitakund anticline, Southeast Bangladesh.

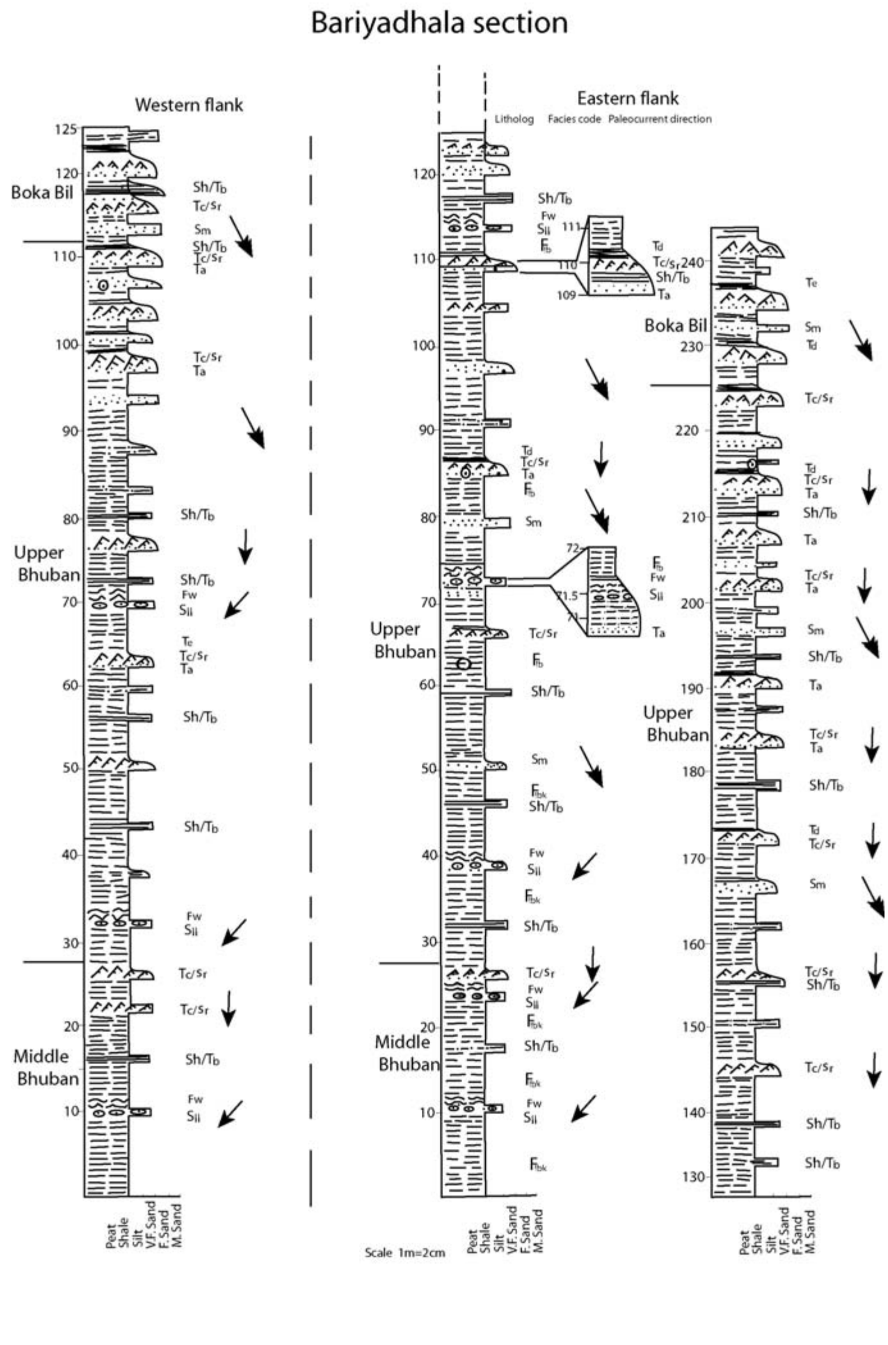

Fig. 5. Lithologic along with facies and paleocurrent of the exposed lithostratigraphic units, Bariadhala section, Sitakund anticline, Southeast Bangladesh.

Table 1. Lithofacies scheme of the study area.

Sl. No.	Facies code	Sub-facies code	Lithofacies	Texture	Sedimentary structure	Contact	Occurrence	Interpretation
I	Fm		Mudstone	Clay	Massive with occasionally trace fossils	Gradational	Topmost part of turbidite deposits	Product of no bed movement in calm and quiet water stage, when turbidity current dies out.
H	Fl	F_{lb}	Blue shale	Clay	Lamination	Sharp	Deep marine pelagic environment	Suspension fall out in deep marine environment above CCD
		F_{lbk}	Black shale	Clay with few very fine silt	Lamination	Sharp	In both below and above CCD and abyssal plain	Suspension fall out in deep marine environment below CCD
G	Fw		Wavy laminated silty shale to shale	Clay with silt	wavy lamination due to draping of occasional silty lense	Sharp	Deep marine shale with infrequent distal turbidite of silt material	Deep marine environment with occasional rhythms of distal turbidite
F	Sll		Lenticular laminated sandstone-siltstone-shale	Very fine sand to silt within clay	Lenticular lamination	Sharp	Starved ripple in a mud dominated environment	Product of ripple movement alternating with mud deposition in deep marine environment
E	Sl		Laminated sandstone-siltstone	Medium to fine sand,silt and clay	l Parallel lamination	Sharp	Medial to distal fan in marine environment	Lower flow regime plane bed condition in marine environment as turbidite Td divition
D	Sr		Ripple cross laminated sandstone-siltstone	Fine sand to silt	Ripple lamination, current generated	Sharp	abandoned part of channel, shallow and crevasse channel, in medial to distal marine environment	Small scale 2D and 3D ripple in lower flow regime condition
C	Sh		Flat bedded sandstone-siltstone	Medium to fine sand and silt	Flat laminaltion/ bedding with straition/ coarse-fine segregation in bedding plane.	Sharp	Upper flow regime plane bed condition	Levee or shallow channel of turbidity current flow in medial to distal fan
B	ST		Turbidite sandstone	Medium to fine sand	Graded- flat – ripple-parallel bedding/ lamination, complete or incomplete	Erosive and sharp	Channel fill, shallow scour fill and flat based turbidites in medial to distal marine fan	Complete/incomplete Bouma sequence as product of turbidity current aided by gravity
A	Sm		Massive sandstone	Medium to fine sand	No bedding or faint dish structure.	Erosive to sharp	Channel fill and shallow scour fill turbidites in medial fan in marine environment	High velocity tractive current flow below the continetal slope.

Description of Lithofacies Types

a) Massive sandstone facies (Sm): The massive sandstone facies is occasionally exposed in the Upper Bhuban Member of the Sitakund Anticline, the color of which varies from grayish white to greenish gray and occurs as channel shaped bodies. These are medium to fine grain sandstone and individual sandstone beds range in thickness from 20cm to 45cm that are embedded within shale.

Interpretation: Channeling is common and amalgamation is not commonly observed. Faint indication of ‘dish’ structure indicates fluid escape during deposition of sandstone. Massive sandstone also indicates rapid deposition of a large amount of sand from fluidized flow. A turbidity current which normally maintain its sand load in suspension by fluid turbulence can pass through stage of fluidized flow during the final few moments (second or minute) of flow immediately preceding deposition. Massive sandstones are well represented in many of the Cretaceous and Tertiary sequence of USA (Chan and Dott, 1983; Linket al., 1981).

b)Turbidite sandstone (ST): This sandstone facies is well exposed in the study area. The sandstone is grayish white in color and grain size ranges from medium to fine sand. It is characterized by graded bedding, flat bedding, ripple cross lamination with occasionally parallel lamination from base to top, which are embedded as channels of different size and shape within shale. Sandstone bodies have sharp base and tend to grade upward into finer silt and mud. Within the sandstone bodies combination of graded bedding, ripple cross lamination and occasionally parallel lamination are observed locally. The channelized sandstone bodies of this turbidite facies are separately from each other by hemipelagic to pelagic bluish black to black shale (Plates 1-6).

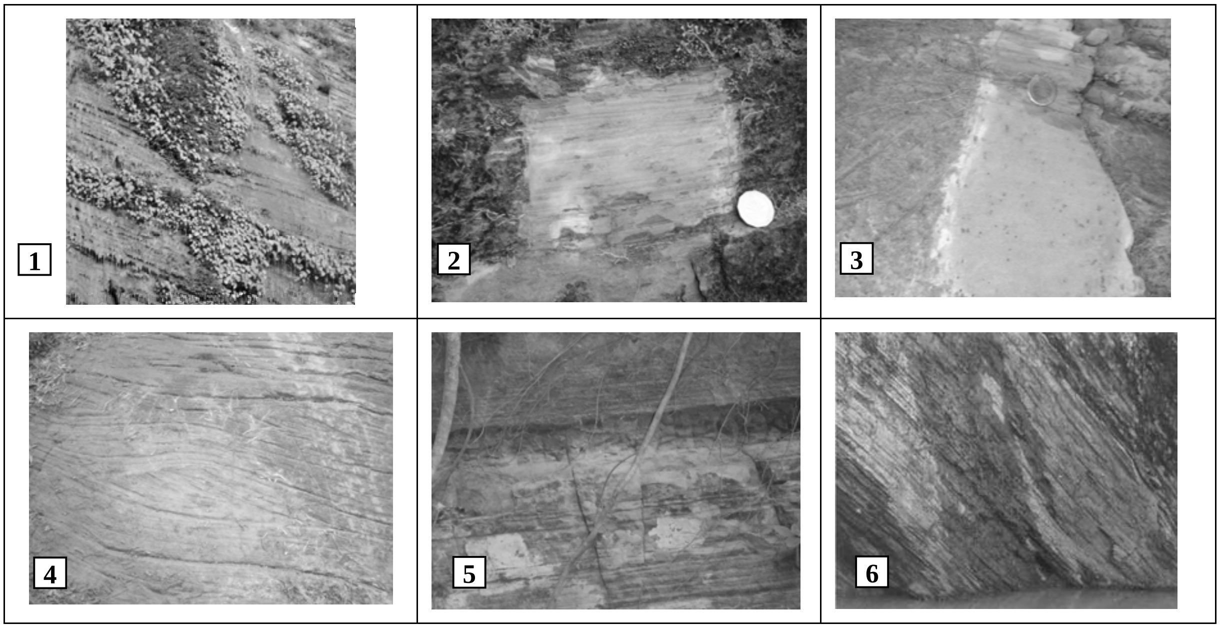

Plate 1. A veritcal clip section of Shaharadhara water fall consisting of ripple laminated very hard Sandstone (Tc division) alternated with black shale (less than 20%) of the Upper Bhuban Member, Shaharadhara section, Sitakund anticline, Chittagong. **Plate 2.** Alternation of gray to light yellow flat bedded sandstone (Tb division) and bluish black shale (hemipelagites) of the upper Bhuban Member Bariyadhala section, Sitakund anticline, Chittagong. **Plate 3.** A mega Channel of turbidite (2.2 m deep) infilled with graded bedded Sandstone (Ta division) and flat bedding (Tb division) within bluish black shale (hemipelagites) of the Upper Bhuban Member, Barabkund section, Sitakund anticline, Chittagong. **Plate 4.** A turbidite channel filled by ripple laminated light yellow sandstone (Tc division) and gray to light yellow parallel laminated sandstone (Td division) alternated with black shale (as negative relief) of the Upper Bhuban Member, Chandranath temple section, Sitakund anticline, Chittagong. **Plate 5.** Channels (partial view) of light yellow turbidite sandstones structured by flat bedding (Tb division) alternated with deep marine dark shale of the Upper Bhuban Member, Chandranath temple section, Sitakund anticline, Chittagong. **Plate 6.** A classical view of laminated black shale with stringers of light color sandstone –siltstone as turbidites within the deep marine basin plain facies association, Upper Bhuban Member Bariyadhala section, Sitakund anticline Chittagong.

Interpretation: Sandstone bodies structured by graded bedding, flat bedding, ripple cross laminations graded upward into parallel laminated silt and mud have been reported by many authors. Bouma (1962) proposed an excellent facies model for this type of sandstone known as Bouma sequence for classical turbidites (Stow 1986; Walker 1984). The facies shows a deposition by turbidite current in marine condition below the continental slope. If there is a high rate of deposition from suspension during rippling, climbing ripple cross lamination will form (Reineck and Singh 1980).

(c) Flat bedded sandstone-siltstone facies (Sh): This facies is constituted by the gray to bluish gray fine sandstone and siltstone (Plates 2, 4 & 5). The bedding shows characteristics striation or coarse and fine grain segregation. Normally this occurs above the graded bedded Ta turbidite division in the turbidite sandstone facies where it is marked as Tb division. But when is occurs as individual layer within the black shale it is termed as Sh facies, which is not much common.

Interpretation: The characteristic bedding appearance with characteristics striation or coarse and fine grain segregation suggests their origin under high flow regime plane bed condition when turbidity current aided by gravity action flows shiftly in unidirection below continental slope in deep marine environment (Bourgeois 1980; Walker 1984; Mutti 1977).

(d) Ripple laminated sandstone –siltstone facies (Sr): This facies is also a dominant lithofacies in the study area, which as lenticular body within dark shale (Plate 4). It is to note that Sr occurs within yellowish to gray to brownish yellow siltstone to very fine sandstone. Ripples are asymmetric in profiles and sinuous crested, mostly linguid and lunate in nature. Ripple symmetry indices (RSI) ranges from 3 to 3.92 and ripple indices (RI) from 15 to 18.25. The internal architectures of foresets are

simple with respect to wave formed ripples, where paleocurrent is in single direction. The lithofacies ranges in thickness varying from few cm to 1m.

Table 2. Lithologic succession of the central part of Sitakund anticline, Chittagong**.**

Formation		Lithologic description	Thickness (m)
Boka Bill		Gray to light gray fine grained well sorted sandstone with sandy shale and siltstone. Lenticular bedding, micro cross lamination, ripple marks and concretion are present.	17+
		Conformable	
Bhuban	*Upper	Alternation of sandstone, silty shale and shale. Grayish white to grayish gray through yellowish gray medium to fine grained hard sandstone and siltstone which are massive as well as variously structured by graded bedding, flat bedding, ripple lamination and lenticular lamination. Bluish black thinly laminated silty shale to shale. Blue to black laminated and exfoliated weathered shale with massive mudstone.	117
	Middle	Mainly shale with subordinate sandstone and siltstone. Black thinly laminated shale with lenses of sandstone and siltstone, which are grayish white. Bluish gray to gray massive and variously stratified sandstone. Matrix supported conglomerate locally present.	25+
		Base Not Se	

*This is the study area.

Interpretation: On the basis of RI and RSI these ripples are observed as mixed in origin (Tanner 1967; Boersma 1970; Reineck and Wunderlich 1968). The ripple index (RI) value of 15 to 18.25 and ripple symmetry index (RSI) value of 3 to 3.92 with internal unidirectional foreset suggest that these ripples might have produced by the action of current in shallow or deeper environmental set up. The ripples in black shales are distal turbidites (Walker 1984).

(e) Laminated sandstone-siltstone facies (Sl): It is not a common lithofacies in the study area. It is composed of gray to light bluish gray, light yellowish gray and even dark gray fine to very fine sandstone and siltstone and occasionally silty-shale. Lamination is parallel to sub parallel with very low degree of inclination, i.e., nearly flat without any signature of parting lineation. Occasionally muscovite and biotite are present in the lamination plane. Convolutions are present in this facies which is 3 to 12cm thick.

Interpretation: The facies without parting lineation suggests its origin either from suspension or slow moving current under lower flow regime condition (Herms *et al.* 1982). Parallel laminations are the product of deposition of suspension clouds due to decrease in turbulence of fluctuation in current velocity (Reineck and Singh 1980). Parallel lamination may be the product of turbidite channel deposits (Kumar and Sanders 1974). Convolute lamination develops from deformation of the structure either due to rapid deposition or liquefaction of underlain sediments (Alam 1990) This may also represent a varied depositional environment like flood plain of fluvial environment (McKee *et.al.* 1967; Alam 1992); estuary (Cooper 1993; Dalrymple *et al.* 1992); tidal flat (Barwis 1976; Davis 1978) and deep sea fan (Pickering and Hiscolt 1985; Hesse 1985). But its association with black shale suggests deep marine environment.

(f) Lenticular laminated sandstone-siltstone-silty shale facies (Sll): This facies is constituted by yellowish gray to grayish white, sometimes brown colored very fine sandstone to siltstone embedded within shale or mudstone layers. Virtually these lenses are ripples, mostly current generated and lenses are few mm to few cm thick and shale-mudstone layers surround these lenses. This facies is observed in shale- mudstone dominated part of heterolithic lithosuccession as starved ripples. It is in fact made up of sand lenses within the black shale alternating with clay layer repeatedly over a longer distance in space and time. The facies is occasionally highly bioturbated and occurs in the study area.

Interpretation: The origin of lenticular lamination requires conditions of current or wave action depositing very fine sand to silt alternating with slack water condition when mud is deposited (Reineck and Singh, 1980). These sand-silt layer or lenses are made of foreset laminae of current ripple or wavy ripple. It also indicates the absence of abundant supply of coarser clastic to form continuous lamination. Thus, the main environment of the formation of the facies is subtidal to intertidal zone (Reineck, 1960; Reineck and Wunderlich, 1968) and deep sea. Their occurrence within black shale as lenses indicate distal turbidite deposits within anoxic pelagic environment.

(g) Wavy laminated silty shale to shale (Fw): These facies is characterized by dark gray to blakish gray siltyshale to shale having wavy laminated sedimentary structures. The bed contact is more or less sharp and it normally overlies lenticular laminated sandstone-siltstone facies Sll).

Interpretation: The forward and backward motion of the wave/ current in fine grained sandy silty sub-strata forms ripple and lenses and wavy laminations are produced by the draping of the underlying ripples or lenses (Reincek and Sigh 1980; Reading and Collinson 1996). This facies indicates slack water condition in which mud can also deposit along with sand-silt. So in submarine distal fan environment, when distal turbidites as ripples and lenses are draped by pelagic or hemipelagic mud (Stow 1986; Roy *et al*. 2006).

(h) Laminated shale facies (Fl): The laminated shale facies is exposed most abundantly throughout the Bhuban Formation containing 60% of the lithocolumn**.** Occasionally shale and mudstone are brecciated showing irregularly boxlike and concoidal fracture. Moreover, spheroidal type of weathering is some time common. This facies includes two subfacies, which are black shale (F_{lbk}) and blue shale sub facies (F_{lb}) (Plates 5&6).

(1) Subfacies black shale (F_{lbk}): The black shale sub facies is well exposed in study area. The shale is laminated and fissile and contains few very fine grain lenses of sand and silt. Occasionally shale is bioturbated .

Interpretation: The calcareous a well a non-calcareous natures of black shale suggest that it was deposited both below and above carbonate composition depth (CCD), a depth below which carbonates are completely dissolved (Hesse 1975). The presence of glauconite, dolomite and chert, graywacke nature of interbedded sandstones and (?) nereites type trace fossils (Monir 2004) and black to dark color of shales suggests that the shales are pelagic and hemipelagic in type, which were deposited in deep marine environment, particularly in bathyal and abyssal plain (Bouma 1962; Mutti 1977; Hesse 1975; Jenkyns 1986). The coarse (interbedded very fine grain clastics as facies Sl, Sll, Sh) and fine (shale as Fl facies) alteration over a considerable vertical distance is characteristic of fine grain turbidite and hemipelagite- pelagite sequence (Stow 1986).

(2) Subfacies blue shale (F_{lb}): The color of this facies is blue to bluish gray. Calcareous concretionary bodies are observed locally within this subfacies.

Interpretation: It denotes a calm and quiet condition, which is deep marine environment. The blue color may indicate much shallow depth than the black shale, might be above the CCD and calcareous band might have originated from decomposition of fossils, which acted as cement. The presence of glauconite, dolomite and chert along with terregineous silty and muddy materials within shale indicates hemipelagic nature of the blue shales (Stow 1986; Rayhan and Mostafa 1999).

(i) Massive mudstone facies (Fm): Massive mudstone facies found as minor constituent in the study area. The color of this facies is gray. Normally it occurs as uppermost part of the turbidite sandstone facies (ST) above Td division when there presents complete Bouma sequence. The mudstones are occasionally biochurned with vertical and inclined trace fossils.

Interpretation: It indicates calm and quite environments where flow velocity is practically nill. It may represents suspension fallout of the finest terrigenous deposit as mud blanket when turbidity current dies out in deep marine environment below continental slope (Hesse 1975; Boume 1962).

Facies Association of the Upper Bhuban Member: Facies association is a group of facies that occur together and are considered to be genetically or environmentally related, thereby making more information than a facies in isolation from its neighbors (Walther 1894 cf. Reading 1986; Blatt *et al*. 1980; Reading 1986, Miall 1988). So, the analysis of facies is thus the fundamentals to all environmental interpretations and paleogeographic reconstruction (Brombley 1991; Miall 1986, 1990, 1991). Based on the grain size, sedimentary structures and genesis of individual facies, the facies can be grouped as two facies associations of the study area. These are namely the turbidity generated facies association and deep marine basin plain facies association.

(1) Turbidity generated facies association: This facies association is constituted by the medium to fine grained facies Sm and ST with or without Sh, Sr, Sl Sll Fw and Fm facies. This facies association is well exposed in more or less all the studied litho-successions of the Upper Bhuban Member in the Sitakund anticline, Chittagong. The lower contact of this facies association is erosive as well as flat bottomed. The upper contact is sharp, which is occasionally gradational with steel gray/ black shale. This facies association is dominated by the incomplete and complete Bouma sequence of turbidite along with less frequent Sm, Sh, Sr, Sl Sll, Fw and Fm facies. It is locally characterized from base to top by graded bedding (Ta), flat bedding (Tb), ripple cross lamination (Tc), with faint parallel lamination (Td) and finally mud (Te)/ Fm when the complete Bouma sequence is preserved.

The Upper Bhuban Member under investigation is characterized by more incomplete Bouma sequence than complete ones (Figs. 3-5). Sandstone bodies with a division of Bauma sequence suggest very rapid setting of grains from suspension, possibly in such quantities and at such a rate that is rapidly expelled upward, and momentarily the grain water mixture becomes fluidized, which destroy any possibly sedimentary structure except graded bedding (Ta). The second phase of deposition involves traction of grains on the bed representing the upper flow regime plane bed (Tb) (Harms *et al*, 1982). The third phase is made up of sand and silty sediments showing small-scale current ripple bedding (Tc). Some times convolute laminations are present with piled-up ripple. The contact with lower flat laminated Tb division is rather sharp. If there is high rate of deposition from suspension during rippling climbing ripple lamination will form. The upper interval of very fine sand to silty clay shows parallel lamination where the contact is distinct (Td). Finally as flow dies away, turbidity current mud (Te) or Fm will blanket the bed followed by hemipelagic mud E(h).

The incomplete Bouma sequence has a different hydrodynamic interpretation. The sandstone bed with Tc division within black shale may probably predict that this was deposited from slower turbidity current, perhaps in a more distal geographic setting, than bed starting with Ta division. This may be proximal levee deposit, laterally adjacent to bed beginning with division Ta in a nearby turbidity channel. The upper plan bed passes directly into Tc ripple bed if the grain size is finer then 0.15mm (Southard 1975; Reineck and Singh 1980). The facies Sm denotes channeling in the medial to distal submarine fan. The Sll or Sh is regarded as distal turbidities within submarine basin plain.

(2) Deep-marine basin plain facies association: The deep-marine basin plain facies association is characterized by the monotonous steel gray to black laminated shale (facies Fl) with a regular arrangement of hemi-pelagic (subfacies Flb)and pelagic shale/mudstone (subfacies Flbk) with some silty stringers. The rare to scare individual constituents facies of this association are flat bedded sandstone- siltstone facies (Sh), riple laminated sandstone-siltstone (Sr), laminated sandstone- siltstone facies (Sl), lenticular laminated sandstone-siltstone-silty shale facies (Sll) and wavy laminated silty shale to shale (Fw). The shale/mudstone are mostly suspension fall out in submarine basin plain as hemipelagites and pelagites in very calm and quiet environment, where as facies Sh, Sr, Sl and Sll are stringers as distal turbidities carried by turbidity current in distal paleogeographic setup.

Facies model: Facies in the litho-successions of the studied sections are genetically grouped into facies association for obtaining information on paleoenvironments. The facies and facies association help to reconstruct two types of facies model in the investigated Upper Bhuban Member, which are repeated through out the litho-successions. The first one is dominantly formed by medium to fine grained sand stone and silt stone consisting of complete or incomplete turbidity generated facies sequence with little amount of blue to black shale (Fig. 6a). The second facies model is for deep marine basin plain sediments, mostly suspension fallout pelagites and hemipelagites, which embedded some distal turbidites (Fig. 6b). This is more or less equally persistent with the turbidite dominated facies model in the Upper Bhuban Member in the study area. It reveals from the litho-successions that the coarse and fine alternation of the turbidity- and deep marine basin basin facies association are repeated through out during the life span of the deposition of the member demonstrating progradation and receeding phases of submarine fan development within the deep marine basin plain environment due to instability of the basin floor and relative sea level change (Posamentier *et al.* 1988).

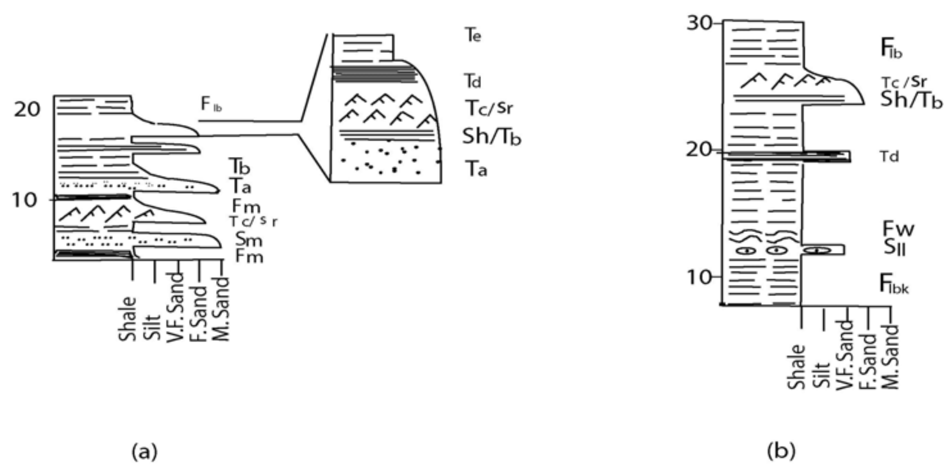

Fig. 6. (a) Facies model for turbidity generated sediments; (b) Facies model for deep marine basin plain sediment

Environment of deposition: The Upper Bhuban Member is inter-bedded with the medium to fine grain turbidity generated facies associated of massive sandstone (Sm) and turbidity sandstone (ST) with or without Sh, Sr, Sl and or Sll/ Fm facies and deep marine basin plain facies association of thinly laminated black- blue (Fl) and wavy laminated silty shale to shale(Fw) with insignificant distal turbidites as Sh, Sr, Sl, Sll. The incomplete sequences are represented by T_{a-c}, T_{b-d} and T_{a-b-e} T_{b-c}, T_c, T_d, T_{a-b}, T_b, $T_{a-b-c-e}$ and $T_{a-b-d-e}$, of which T_{a-c}, T_{b-d} and T_{a-b-e} are most common and T_{a-b-e} and T_{a-b-c} sequences are rare. The Sm facies represents turbidity channel in inner part of the medial submarine fan. The complete Bouma sequences represent channelized forms of sandstone, while incomplete ones have been identified as channel or interchannel sandstones. Bed thickness variation in each bundle consisting of T_{a-d} sand and T_e mud possibly indicate different stages channel activity and/or different geographical positions within the submarine fan with respect to main feeder or distributary channel. The shallowing nature of some channels indicate their origin from overtopping and crevassing on the nearly levee. Sand/shale ratio, sandstone bed thickness, grain size and erosive features decrease from medial to distal part of fan. The less distinct Sh, Sr Sl and Sll in shale dominated marine basin plain facies association indicates turbidity generated rhythms in the deep marine environment. The shales of fine grain facies association are both calcareous and non-calcareous and composed of glauconite, chlorite, illite, dolomite, chert, quartz, mica and felspar suggesting their deposition in deep marine anoxic bathyl and abyssal plain environment, both above and below the carbonate compensation (Link and Nilsen 1980; Frey and Pemberton 1984; Jenkyns 1986, Walker 1984). The dark and greenish gray color indicates a reducing environment and paper-thin laminated shale indicates the calm and quite environment i.e. unit was deposited in the deep marine environment (Roy *et al.* 2006; Haque 2001, Stow 1986). The graywacke nature of the interbedded sandstone also indicates marine environment (Pettojhon *et al.* 1972). The Sm facies denotes channel in proximal to medial position submarine fan set up. The facies ST (complete orincomplete) along with Sh, Sr, Sl and Sll indicate their deposition by turbidity current in more distant medial to distal fan environment (Stow 1986; Shanmugam 1980; Alam *et al*. 2003; Roy *et al.* 2006). All of these information suggest that the depositional environment during the deposition of the Upper Bhuban Member in the study area was deep marine with progradation and receding phases of submarine fan development below the continental slope, which were alternated by shale dominated deep marine basin plain deposits due to relative sea level change and tectonic activity with short temporal and spatial sense**.**

Paleogeographic setup: The understanding of the paleogeography of depositional site of the ancient rock sequence is achieved from the study of paleocurrent data as these indicate the paleoflow directions and their flow expansion from inclination of trough cross axes, foreset inclination, lee slope of ripples and plunge of paleochannel axes as preserved in ancient sediments. This type of study provides important information about paleogeographic set up (Potter and Pettijohn 1977; Pettijohn 1984; Nilsen and Abbott 1981; Brombley 1991; Maill 1991, 1993). The directional measurements that are used for paleocurrent analysis of the present study are lenticular laminated sandstone (Sll), ripple laminated sandstone (Sr) and axis of the channels. Sixty one measurements were used for the construction of palocurrent rose diagram following Potter and Pettijohn 1977 (Fig. 7). The overall paleocurrent pattern lies in the southern hemisphere of the streonet with the dominant paleoflow azimuth lying in between 165° to 195°. The distribution is unimodal, which indicates that the source area was in north. A close inspection of the Fig.7 suggests that source areas were dispersed from N35°W to N35°E, where the dominant one was from N15°W to N15°E. From the present geographical point of view the Shillong plateau in the north of the investigated area was the dominant source area as evident from the dominant paleoflow direction. The N35°W azimuth suggests a less significant provenance was the Himalayas. The azimuth of N35°E indicates that the Naga-Lushai-Arakan Yoma folded belt also acted as less dominant locus for the sediment derivation of the study area. The Miocene marine fan is believed to extend up to the Dauki Fault along the Sylhet-Meghalaya of India-Bangladesh border to the present southern limit of the Bengal Basin though the eastern folded belt (DasGupta and Nandy, 1995; Akhter and Bhuiyan 1998; Gani and Alam 1999; Alam *et al.* 2003; Roy *et al.* 2006). The proximal part of submarine fan is not extended up to limit of the investigated area as no conglomeratic and associated facies are found in the litho-succession of the present area (Figs. 3-5). The thin bedded and medium to fine grained turbidite dominated facies model indicates the presence of the middle to distal part of the submarine medial fan (Fig. 7). The deep marine basin plain facies model indicates the paleogeographic set up of the deep marine basin plain, where insignificant amount of turbidites could enter.

The repetition of the two distinct facies association in the litho-successions suggests the progading and receding phases of submarine development within the marine basin plain. The facies associations of medial to distal fan and deep marine basin plain repeat and randomly occur one upon suggesting slope instability along basin margin formed probably by faulting along Dauki in Meghalaya-Sylhet border and adjoining area accompanied by sea level fluctuation.

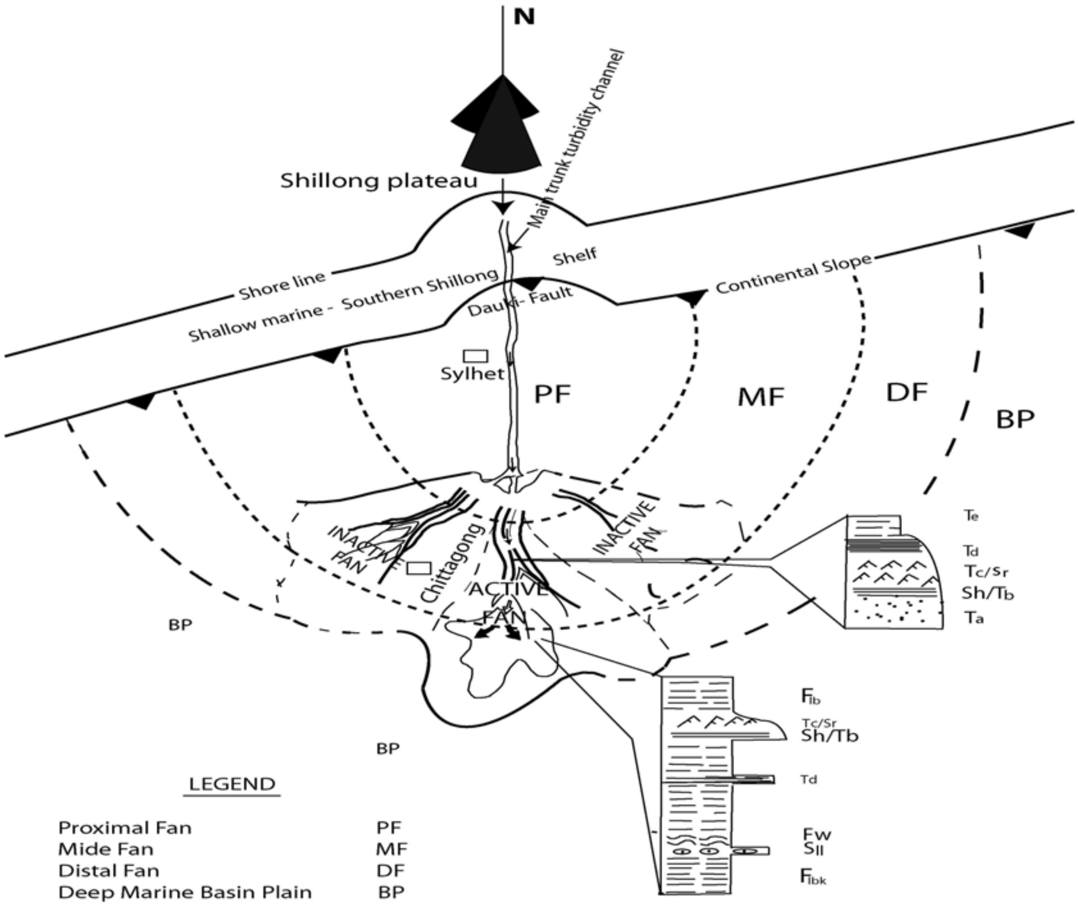

Fig. 7. Paleogeographic model during the deposition of the Lower Miocene Upper Bhuban Member, Sitakund, Southeast Bangladesh (not to scale).

Conclusions

The followings are the conclusions arrived at the present study:

1) Dark gray, bluish gray, bluish black and black finely laminated to thinly bedded shale and sandy shale, light gray, light yellow and greenish gray sandstone and siltstone compose the rock sequence of the Lower Miocene Upper Bhuban Member in axial region of the Sitakund anticline, Chittagong, southeastern Bangladesh, which suggests a fan environment within deep marine environment.

2) The turbidite dominated facies association comprises S_m and classical turbidite S_T (complete and incomplete) along with Sh, Sr, Sl, Sll, Fw and Fm facies indicating medial to distal submarine fan environment.

3) The facies Sm indicates turbidity channel in the inner part of medial fan. The complete Bouma sequence is less common than incomplete sequence. The concave up complete sequences represent channelized forms of sandstone, while incomplete ones have been identified as channel or interchannel sandstones in more distal paleogeographic set up in medial fan. Bed thickness variation in incomplete sequence possibly indicates different stages channel activity and/or different geographical positions within the submarine fan with respect to main feeder or distributary channel.

4) The blue to bluish black hemipelagites (F_{lb} subfacies) and black pelagites (F_{lbk} subfacies) with less distinct turbidity generated base missing sandstone- siltstone-silty shale of facies Sh, Sr, Sl, Sll and Fw constitute the deep marine basin plain facies association, which suggests deep marine basin plain environment in a distal paleogeographic set up.

5) The shales of mud dominated facies association are both calcareous and non-calcareous and composed of glauconite, chlorite, illite, dolomite, chert, quartz, mica and felspar suggesting their deposition in deep marine anoxic bathyl and abyssal plain environment, both above and below the carbonate compensation .The graywacke nature of the interbedded sandstone also indicates marine environment

6) The facies sequence of medial to distal fan and deep marine basin plain were repeated and juxtaposed randomly one upon other, which is thought to be formed due to slope instability along basin margin formed probably by faulting along Dauki and adjoining area accompanied by sea level fluctuation.

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