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Electro-facies analysis of the Late Cenozoic sediments of the Sylhet Trough, Bengal Basin (Bangladesh): Implications for interpretation of depositional sequences

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Abstract

The Sylhet Trough of the Bengal Basin is situated in northeast of the Indian plate and is comprised of Eocene to Recent sedimentary successions. The stratigraphy of the Cenozoic Sylhet Trough is poorly studied. The area is regarded as the potential province for hydrocarbon accumulation, targeting the Miocene Surma Group sandstones as the key reservoir rocks. The present study is concerned with sedimentation and depositional environment of the Late Cenozoic (Miocene to Recent) succession of the Sylhet Trough based on electro-facies analysis. Based on the overall GR log motifs, geometry and vertical relationships of electro-facies, four depositional sequences have been interpreted that are separated by unconformities. The lower three sequences (1 to 3) are grouped into Megasequence 1 and is equivalent to undifferentiated Miocene Surma Group sediments, representing tide-dominated marine to coastal (deltaic) depositional systems with evidence of cyclic marine regression and transgression. Within this megasequence, the lower most Sequence 1 is dominated by finer sediments and showing an overall coarsening upward succession, possibly representing an offshore to shelfal facies. The Sequence 2 broadly showing another coarsening upward trend with minor internal variations, which is interpreted as a deltaic succession. The overlying Sequence 3 is also showing coarsening upward succession, which is representing estuary deposits. The topmost Sequence 4 belongs to Megasequence 2 that corresponds to undifferentiated Tipam Group and Dupi Tila Group. This Sequence 4 represents stacked braided river sand bars and gradually changes into meandering river deposits in the upper sequence. Our stratigraphic framework of the subsurface Late Cenozoic sediments of the Sylhet Trough represents a basinward progradation of deltaic to continental-fluvial environments and correspond to retrogradation, progradation and aggradation stacking patterns (from the bottom).

Keywords: Sylhet Trough; Electro-facies; Log motifs; Late Cenozoic successions; Fluvio-deltaic setting

Introduction

The Sylhet Trough of the Bengal Basin is located in the eastern part of the Indian

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subcontinent. The trough occupies a vital geographic position at the junction of three interacting plates, namely, the Indian, Burmese and Eurasian plates (Fig. 1a) and accommodates an approximately 17 km thick clastic sedimentary rocks (except the Sylhet Limestone at the lower part) from Eocene to Recent (HILLER & ELAHI 1984). Sedimentation in the Bengal Basin (including Sylhet Trough) has been controlled by the uplift and erosion of the Himalayas and the Indo-Burman Ranges which were formed due to the collision of the Indian plate with the Eurasian and Burmese plates (ALAM 1989).

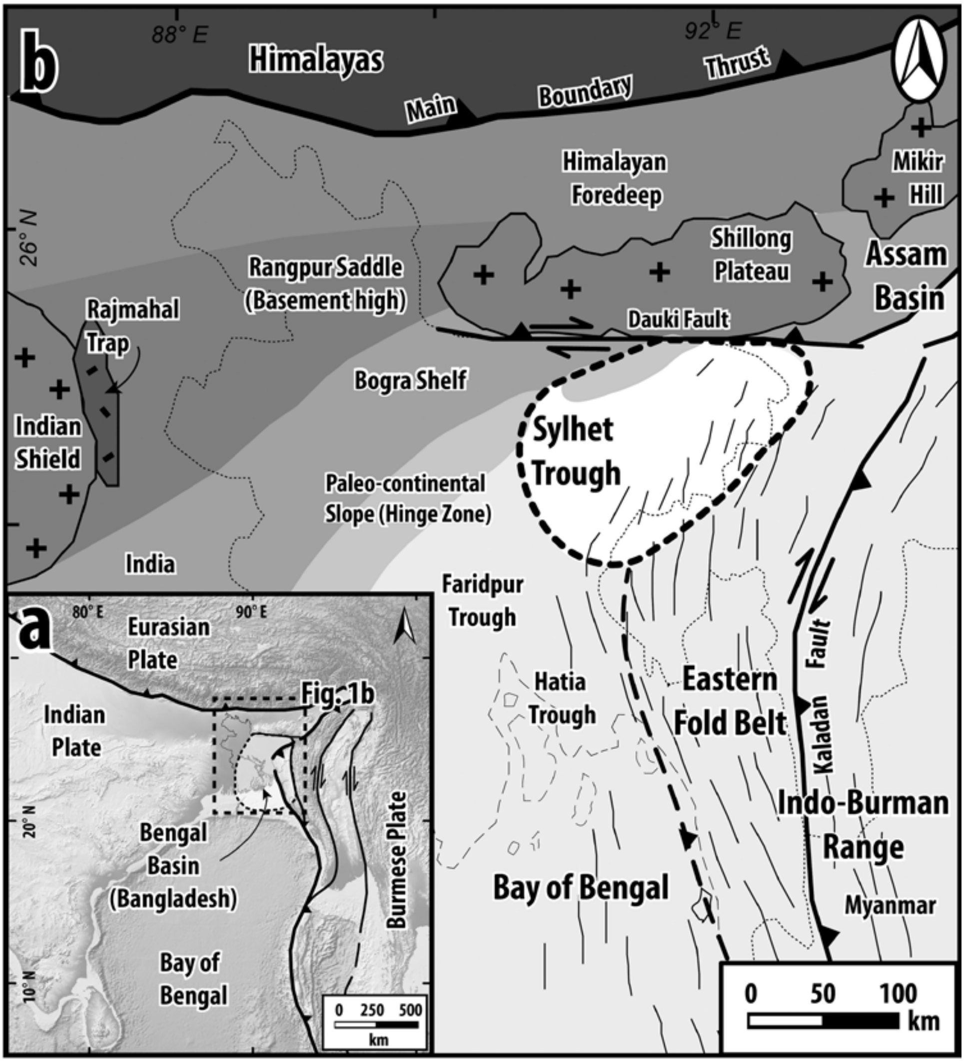

Fig. 1. (a) Map showing the location of the Bengal Basin in the regional context, (b) Regional tectonic frameworks of the Sylhet Trough in the Bengal Basin and its adjoining areas (modified after ALAM *et al.* 2003; ABDULLAH *et al.* 2015).

The Sylhet Trough carries a great economic value as being gas prone. Unfortunately, the most part of the trough is covered with younger alluvium, and has been previously studied from discrete drill hole information. Moreover, the stratigraphy of the basin is not well established and has been correlated with the stratigraphy of Assam region (EVANS 1932) which has different tectonic history. In addition, a continuous core logging of the subsurface has not been done. Thus, sedimentation pattern and depositional sequence analysis based on electro-facies analysis holds much promise in understanding hydrocarbon play concepts within the Sylhet Trough, leading to both renewed interest and exploration.

The aim of this paper is to provide a better understanding of the depositional environment based on wireline log interpretation. Based on the log motifs and their relationships major depositional sequences and possible unconformable surfaces have been identified and then correlated among the boreholes to establish the stratigraphic frameworks of the Sylhet Trough in a regional scale.

Geological Setting

The Sylhet Trough of the Bengal Basin (Figs. 1 & 2a) is bordered by the fold belt of the Indo-Burman Ranges to the east and southeast. The western margin of the basin is limited by the Indian Shield Platform (Fig. 1a). A continental-scale E-W-trending reverse fault with a component of dextral motion (i.e. the Dauki Fault; Figs. 1b and 2a) marks the northern boundary between the Sylhet Trough and Shillong Plateau (HILLER & ELAHI 1984; JOHNSON & ALAM 1991; BISWAS & GRASEMANN 2005). Structurally, the Sylhet Trough is a large oval shaped depression (Fig. 1b) with a series of N-S trending anticlinal structures that are associated with reverse faults (JOHNSON & ALAM 1991; MONDAL & WOOBAIDULLAH 2006).

Tectonic evolution and sedimentation within the Bengal Basin (including the Sylhet Trough) was initiated during the late Mesozoic Gondwana break-up (ALAM 1989). Three main tectonic phases are: (1) Late Mesozoic to Early Cenozoic rifting and drifting (Fig. 2c) (POWELL 1979; SHAMSUDDIN & ABDULLAH 1997), (2) Early soft collision between India and south Tibet, followed by hard collision during the Middle Eocene, and (3) Early Miocene oblique subduction of the Indian plate beneath the Burmese plate and development of remnant ocean basin (ALAM *et al.* 2003). The collision of the Indian plate with the Burmese and the Eurasian plates during the Middle Eocene to Early Miocene resulted in a major switch in sedimentation pattern over the Bengal Basin. During this time, a rapid influx of clastic sediments from the Himalayas and the Indo-Burma Range were deposited into the basin and was followed by an increase in the rate of subsidence of the basin (ALAM *et al.* 2003).

Stratigraphy of the Sylhet Trough has been studied mainly through discrete well data and limited exposures that occurs in the northeastern corner of Bangladesh (Fig. 2a). The stratigraphic framework of the Sylhet Trough was initially established by lithostratigraphic correlation to the type sections in the Assam Basin of the northeastern India (EVANS 1932; HOLTROP & KEIZER 1970; KHAN & MUMINULLAH 1980; JOHNSON & ALAM 1991; REIMAN 1993; SHAMSUDDIN & ABDULLAH 1997; ALAM *et al.* 2003). However, the Bengal Basin and the Assam Basin are two separate basins with different tectonic and geomorphic histories. Sedimentary packages that fill these two basins differ in thickness, composition, and inherent flow directions. Based on this correlation, the stratigraphic units (from younger to older) of the Sylhet Trough are the Dihing Formation, the Dupi Tila Group, the Tipam Group (Girujan Clay and Tipam Sandstone formations), the Surma Group (Bokabil and Bhuban formations), the Barail Group (Renji Formation) and the Jaintia Group (Kopili Shale and the Sylhet Limestone formations) (EVANS 1932; HOLTROP & KEIZER 1970; JOHNSON & ALAM 1991; REIMAN 1993; SHAMSUDDIN *et al.* 2001).

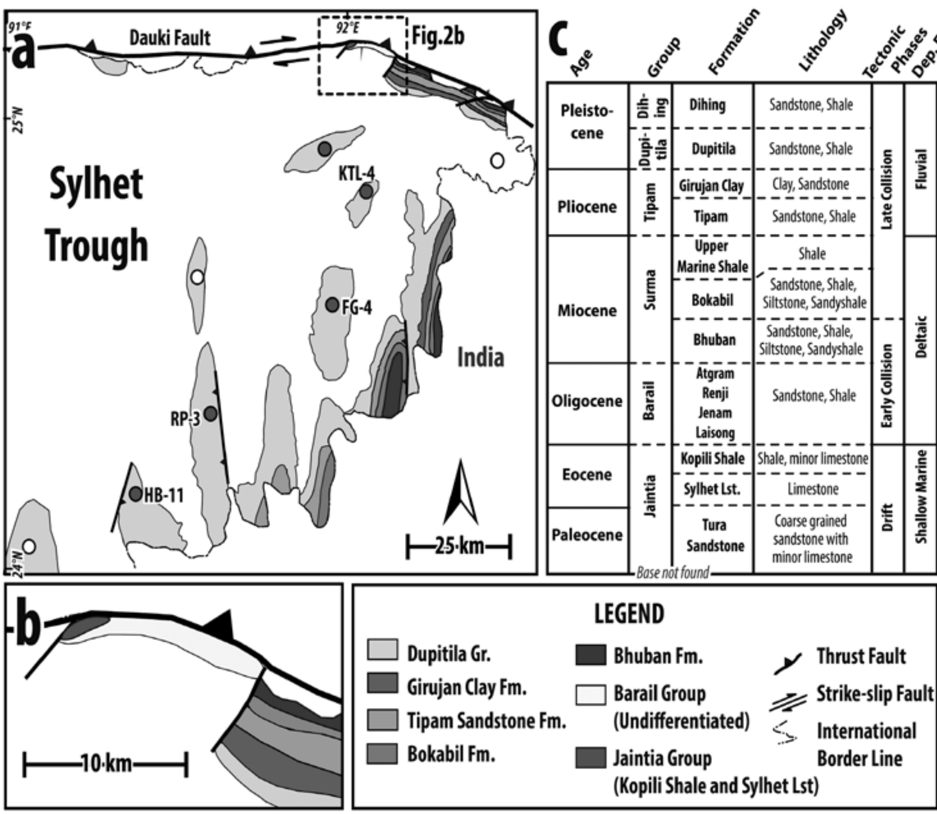

Fig. 2. Geological map showing the distribution of the traditional stratigraphic units that are exposed in (a) the Sylhet Trough, Bangladesh (modified after ALAM *et al.* 1990) and (b) in the Jaintiapur-Tamabil and adjacent area in the Sylhet District, northeastern Bangladesh. (c) Summary of the stratigraphic units, tectonic phases and depositional environment of the Cenozoic succession of the Sylhet Trough, Bengal Basin [Abbreviation for the wells: KTL: Kailashtila; FG: Fenchuganj; RP: Rashidpur; HB: Hobiganj].

Methods

In order to construct the depositional architecture and stratigraphic framework of the Late Cenozoic successions of the Sylhet Trough, a detailed documentation of log-motifs has been carried out using gamma-ray logs. Distinctive shapes of gamma ray log curve (Fig. 3) for each cycle are indicative of different facies cycles, depositional sequences, megasequences and uniformities or bounding discontinuities. On the basis of the gamma-ray log shape and stacking of vertical profile lithology identification, facies analysis using wireline-facies was conducted to make various environmental interpretations (SERRA 1985; CANT 1992; POSAMENTIER & ALLEN 1999; MARTINIUS *et al.* 2002; CHOW *et al.* 2005).

In order to build-up the relationship between individual log motifs or electro-facies in a regional section across the Sylhet Trough, four wells Kailashtila-4; Fenchuganj-4; Rashidpur-3; Hobiganj-11; (Fig. 2) have been selected from previously published literature (ISLAM & HOSSAIN 2002; KABIR & HOSSAIN 2009; KAMRUZZAMAN 2017; KHAN *et al.* 2013; RAHMAN *et al.* 2012; PARVIN & WOOBAIDULLAH 2019; PARVIN *et al.* 2019a,b), then digitized and re-interpreted using Petrel.

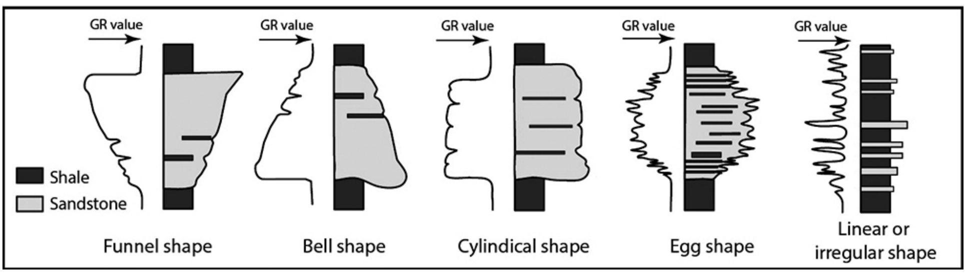

Fig. 3. Basic gamma ray (GR) log motifs and their interpretations.

Electro-facies analysis

On the basis of gamma-ray (GR) log motifs or shapes of the studied wells from the Sylhet Trough (Table 1 and Fig. 4), electro-facies have been grouped into five broad categories named bell shaped, funnel shaped, cylindrical shaped, linear shaped, and egg shaped motifs. Each of the log motifs are representative of major and minor cycles of sedimentation which are summarized in Table 1 and described in the following section.

Bell shaped log facies (Figs. 4 & 5; Table 1) indicates an increase in GR value, corresponds an increase in clay content in upward direction. This electro-facies is suggesting overall fining-upward successions with a transitional upper, but abrupt lower boundaries (Figs. 4 & 5). This shape suggests retrograding distributary and tidal channel, also found in alluvium fan, fluvial channel, point bar and deltaic channel environment (CHOW *et al.* 2005).

Table 1. Gamma-ray (GR) log motifs identified in the wells from the Sylhet Trough (note that depths are in meters).

GR log motifs	Kailashtila-4	Fenchuganj-4	Rashidpur-3	Hobiganj-11
Bell shaped	1100-1010, 1270-1100, 2750-2660	1490-1450, 1580-1490, 2200-1900, 2375-2200	1375-1215, 1770-1700 (Fig. 5a), 1850-1770 (Fig. 5a), 1960-1850 (Fig. 5a), 2040-1960	1180-980
Funnel shaped	2220-2100, 3005-2920, 3110-3005, 3110-3005, 3220-3110	2800-2680 (Fig. 5b), 2950-2800, 3175-2950, 3390-3175, 3550-3390	1215-1080, 1470-1375, 2370-2120, 2550-2370, 2700-2550, 2750-2700, 2820-2750, 2900-2820	1920-1620, 2100-2050, 2190-2100 2270-2190, 2500-2270
Linear shaped	-	-	-	3100-2500, 2050-1920 (Fig. 5c)
Egg shaped	1500-1270, 2920-2750 (Fig. 5d)	2680-2375	2120-2040, 1080-1005	-
Cylindrical shaped	1010-325, 2100-1500, 2660-2220	1910-1580	450-0, 1005-450, 1700-1470 (Fig. 5e)	1620-1180, 980-190

Funnel shaped log facies (Figs. 4 & 5; Table 1) shows an upward decrease in GR values, possibly indicating a coarsening-upward sedimentary succession. This funnel shape indicates sediment deposition in a regressive shallow marine bar in prograding deltaic or an alluvial fan environment (POSAMENTIER & ALLEN 1999; CHOW *et al.* 2005).

Linear shape is characterized by irregular shape in GR log (Figs. 4 & 5; Table 1) and corresponds to thick mudstone, claystone with interbedded sandstone or siltstone, marsh coals or shales that might indicate calm and quite condition. The linear shape reflects shallow marine, inter-distributary bay, lagoon, flood plain and marsh sub-environments (CHOW *et al.* 2005).

Egg shaped log facies (Figs. 4 & 5; Table 1) are comprised of decrease and then increase of GR values. The serrated egg shape profiles have coarsening- and then fining-upward successions. This trend is usually the result of progradation and retrogradation (CHOW *et al.* 2005).

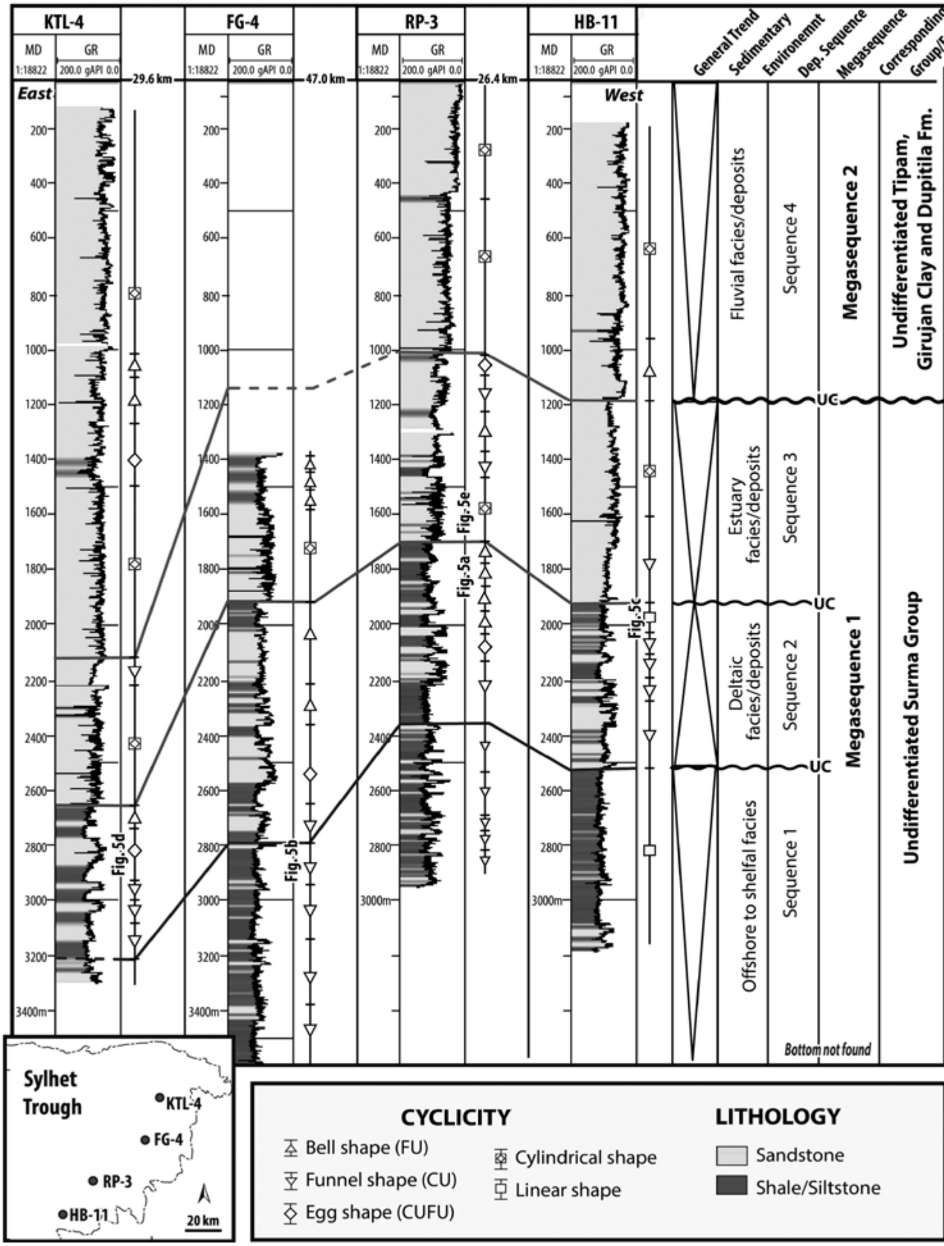

Fig. 4. Regional stratigraphic seetin section based on gamma-ray log interpretation is showing distribution and correlation of the Late Cenozoic successions across the Sylhet Trough. Based on gamma ray log response, four depositional sequences have been identified in the KTL-4, FG-4, RP-3 and HB-11 wells. The small map at the bottom left hand side is showing the location of the wells. Note that examples of different log motifs are highlighted in the following figure. [Abbreviations: UC: Unconformity Surface; KTL: Kailashtila; FG: Fenchuganj; RP: Rashidpur; HB: Hobiganj].

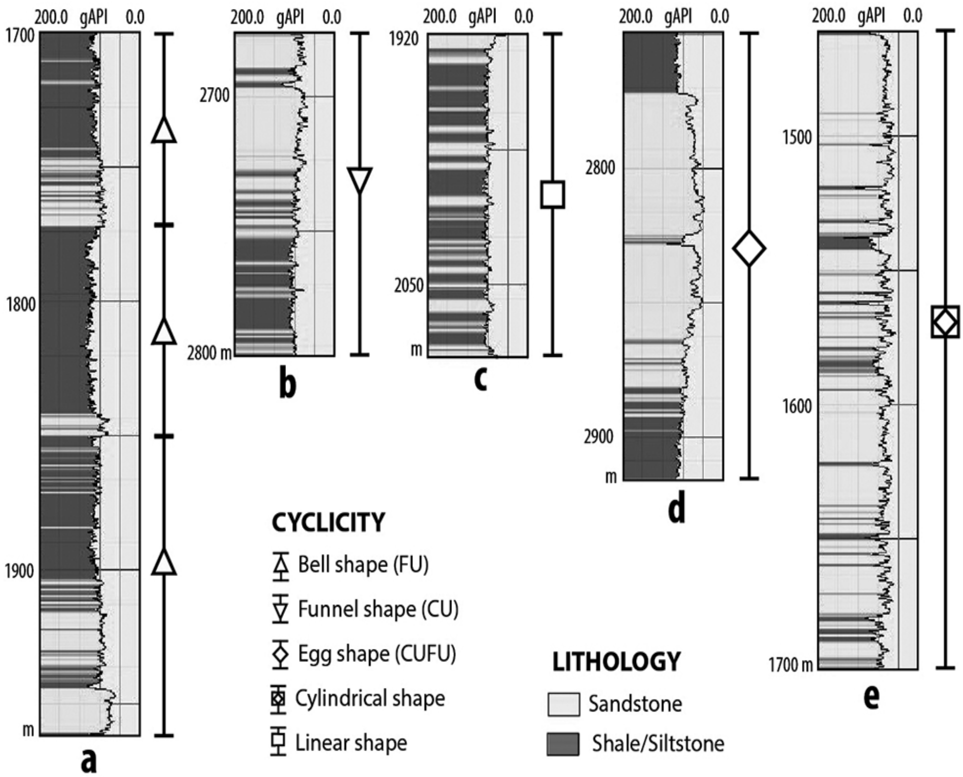

Fig. 5. Interpreted basic gamma-ray log motifs highlighted from the Figure 4.

Cylindrical shaped log motif (Figs. 4 & 5; Table 1) shows a constantly low GR values and represents shale free sand dominating sequence with sharp upper and lower contact. Depositional energy is essentially constant, which may be aggrading fluvial channel, deltaic distributaries and tidal sand (POSAMENTIER & ALLEN 1999; CHOW *et al.* 2005).

Depositional sequences based on log motifs

Four depositional sequences (Sequence 1 to Sequence 4) have been identified based on GR log trend in the KTL-4, FG-4, RP-3 and HB-11 wells (Fig. 4). Sequence-1 shows an irregular trend in GR log (Fig. 4). The base of this sequence is not identified, and the top depths of this sequence are approximately 3220 m, 2800 m, 2375 m and 2520 m of the KTL-4, FG-4, RP-3 and HB-11 wells respectively (Fig. 4). The gamma ray character of this sequence shows a continuous upward transition which may correspond to interbedded shales and siltstone to fine-grained sandstones. The overall irregular cycle and dominance of finer sediments are indicating a possible retrogradational setting within the offshore to shelfal shallow marine environment (Figs. 4 & 5).

A relatively low gamma ray response characterizes the Sequence 2 which is consisting of four parasequence sets (Fig. 4). The lower and middle parts of the sequence show an overall coarsening-upward (CU) funnel shape. The gamma ray log response of this sequence is indicating deltaic facies, relatively stable broad and shallow subtidal channel, interdistributary bay, crevasse splay and prograding channel-tidal flat depositional sub-environments. In general, Sequence 2 is thickening to the west or southwest and can be representative of prograding deltaic deposits (Figs. 4 & 5).

Small-scale coarsening and fining-upward (CUFU) cycle possibly represent alteration of shale and sandstone litho-facies within the Sequence 3 (Fig. 4). At the lower part of this sequence, small-scale fining-upward (bell shape) possibly indicates sandstone litho-facies at the bottom and shaley litho-facies at the upper part. The bell shape parasequences within this Sequence 3 are possibly indicating retrograding distributary channel deposits. Series of stacked channel sands have characteristic cylindrical log motifs. The thin clay and shale layers represent the abandonment of the individual channels. The overall log motifs of this sequence indicate that this sequence might have been deposited in marginal estuarine influence and that of the upper part in marshy environments or shallow marine to transitional, estuarine tidal channel, interdistributary bay, tidal mudflat environments. This depositional sequence is also showing an overall increase in thickness towards west or southwest and can be a part of prograding deltaic system (Figs. 4 & 5).

The Sequence 4 shows a cylindrical or fining-upward (FU) log motif (possibly represent stacked sand with occasional very thin deposits of clay and may indicate an aggradational setting; Fig. 5). The middle part shows a small-scale fining-upward (FU), coarsening-upward (CU) and cylindrical shaped facies. The overall (cylindrical or fining upward) log motifs of Sequence 4 are characteristic of fluvial deposits.

Depositional framework of the Late Cenozoic (Miocene to Recent) Sylhet Trough

Borehole information (Fig. 4) suggests that the sequences 1 to 3 correspond to undifferentiated Miocene Surma Group sediments. Based on the overall GR log motifs, geometry and vertical relationships of electro-facies, the sequences 1, 2 and 3 can be broadly grouped into Megasequence 1 and have been interpreted as deposited under tide-dominated deltaic depositional setting characterized by alternating transgressive and regressive phases as a result of subsidence as well as relative sea level changes. Previous authors (ALAM 1989; ALAM 1995; ALAM *et al.* 2003; KHANAM *et al.* 2017; RAHMAN *et al.* 2009) has also suggested similar depositional environment for the Surma Group sediments. Our interpretation shows that sequences 2 and 3 gradually become thick to the southwest. This progressive thickening possibly corresponds to prograding delta clinoforms in a deltaic setting (Fig. 6).

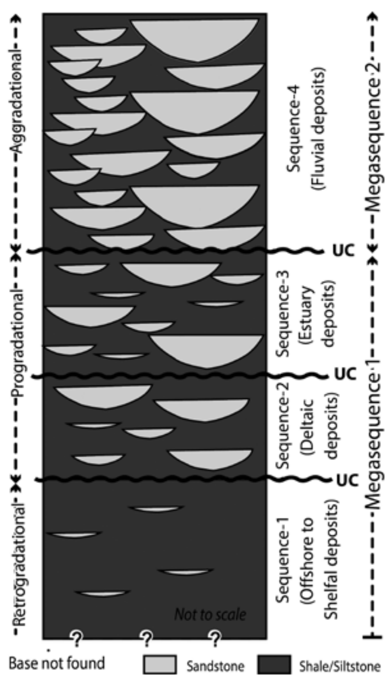

Fig. 6. Conceptual stratigraphic model (based on gamma ray log) illustrating three types of stacking patterns; the retrogradational, progradational and aggradational [Abbreviation: UC - Unconformity].

The overlying sequence 4 corresponds to undifferentiated Tipam Group and Dupi Tila Group of Pliocene to Late Pleistocene age (Fig. 6). This sequence is broadly under Megasequence 2 and has been interpreted as braided to fluvial deposits as previously suggested by others (ALAM 1989; ALAM 1995; ALAM *et al.* 2003; GAZI & ALAM 2004; KHAN 1990; RAHMAN *et al.* 2009). In general, sequence 4 shows variable thickness throughout the basin as it has relatively higher thickness in the synclinal parts and opposite adjacent to anticlinal crests.

Conclusions

A high-resolution electro-facies analysis (based on gamma-ray log motifs) has been carried out to understand the depositional environment of the Late Cenozoic sedimentary successions of the Sylhet Trough. Based on the results, following conclusions can be made -

(1) The subsurface sedimentary successions of the Sylhet Trough can be divided in to four depositional sequences and two megasequences. Sequences 1 to 3 belong to Megasequence 1, which is equivalent to undifferentiated Miocene Surma Group sediments. The topmost depositional sequence (i.e. Sequence 4) is the part

of Megasequence 2 and is correlatable with the undifferentiated Tipam Group and Dupi Tila Group.

(2) Depositional environment for the Sequences 1 to 3 (i.e., Megasequence 1) can be interpreted as offshore to shelfal, deltaic, estuarine sedimentary facies deposits; respectively. The overall GR log motifs, geometry and vertical relationships of electro-facies of these depositional sequences represent a tide-dominated deltaic depositional system with evidence of cyclic marine regression and transgression. In contrast, our interpretation for the overlying depositional sequence within the Megasequence 2 corresponds stacked braided river sand bars that grades into meandering river deposits.

(3) The stratigraphic relationship of the interpreted depositional sequences of the Sylhet Trough corresponds to retrogradation, progradation and aggradation stacking patterns (from the bottom) within a basin-ward prograding deltaic to continental-fluvial environments.

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সিলেট খাদ, বেঙ্গল বেসিন (বাংলাদেশ) এর প্রান্তিক সেনোজোয়িক যুগের পললের ইলেক্ট্রো-ফেসিস বিশ্লেষণ: অবক্ষেপন পর্যায়ক্রম ব্যাখ্যায় এর প্রভাব

ফরিদা খানম, এম. জুল্লে জালালুর রহমান, রাশেদ আবদুল্লাহ ও মু. মুস্তাফা আলম

সারসংক্ষেপ

ইন্ডিয়ান প্লেটের উত্তরপূর্ব কোনের বেঙ্গল বেসিন এর সিলেট খাদ ইয়োসিন হতে বর্তমান সময়ের পলল দ্বারা গঠিত। এই সেনোজোয়িক সিলেট খাদ এর স্তরতত্ত্ব সুপঠিত নয়। এলাকাটি তেল গ্যাস-এ সমৃদ্ধ এবং মায়োসিন সুরমা গ্রুপের বেলেপাথর এই তেল গ্যাসের মূল আধার। সেজন্য বর্তমান গবেষণাকর্মটিতে ইলেকট্রোফেসিস-এর ভিত্তিতে সিলেট খাদের প্রান্তিক সেনোজোয়িক যুগের অর্থাৎ মায়োসিন হতে বর্তমান শিলা সমূহ জমা হওয়ার পরিবেশ নির্ণয় করা হয়েছে। গামা-রে লগ এর ধরন, প্রকৃতি এবং জ্যামিতিক সম্পর্ক এর উপরে ভিত্তি করে চারটি পর্যায়ক্রমিক শিলাস্তর নির্ণয় করা হয়েছে। যা কয়েকটি স্তর ব্যতিক্রম দ্বারা পৃথক করা যায়। নিচের তিনটি পর্যায়ক্রমিক শিলাস্তর (১-৩) কে প্রধান বৃহৎ পর্যায়ক্রমিক শিলাস্তর-১ এ অন্তর্গত করা যেতে পারে, যা মায়োসিন যুগের সুরমা গ্রুপের সমতুল্য। যা সামুদ্রিক হতে উপকূলবর্তী স্থানে জমা হয়েছিল। পর্যায়ক্রমিক শিলাস্তর-১ এর নিম্নভাগ সুক্ষ্ম পলল দ্বারা তৈরী। এটি উপরের দিকে ক্রমেই বড় দানাদার পলল দ্বারা তৈরী যা সম্ভবত সামুদ্রিক হতে মহীসোপান অঞ্চলে জমা হয়েছিল। পর্যায়ক্রমিক শিলাস্তর-২ ও আরেকটি উপরের দিকে ক্রমবর্ধমান বুণনের পলল নির্দেশ করে, যদিও এর মধ্যে কিছুটা অভ্যন্তরিণ ব্যত্যয় হয়েছে। এই পর্যায়ক্রমিক শিলাস্তর-২ ব-দ্বীপ অঞ্চলে জমা হয়েছিল এর উপরের পর্যায়ক্রমিক শিলাস্তর-৩ মোহনাবর্তী স্থানে জমা হওয়া নির্দেশ করে। সবচেয়ে উপরের পর্যায়ক্রমিক শিলাস্তর-৪ বৃহৎ পর্যায়ক্রমিক শিলাস্তর-২ এর অন্তর্গত, যা সামগ্রিকভাবে টিপাম ও ডুপি টিলা গ্রুপের সমতুল্য। এই পর্যায়ক্রমিক শিলাস্তর-৪ এর ম্যধবর্তী স্তুপীকৃত স্যান্ডবার বেনীপ্রবাহ হতে বাঁকবহুল নদীতে পলল জমা হওয়া নির্দেশ করে। সিলেট খাদের প্রান্তিক সেনোজোয়িক যুগের পলল সমূহ বেসিনের দিকে ক্রম অগ্রসর ব-দ্বীপ হতে নদীজাত পরিবেশে পলল জমা হওয়ার সাক্ষ্য বহন করে।