Petroleum and Coal

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EOCENE–MIOCENE STRATIGRAPHY OF THE SURMA TROUGH, BENGAL BASIN: A SEQUENCE STRATIGRAPHIC APPROACH

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Received January 3, 2019; Accepted February 28, 2019

Abstract

The Bengal Basin is the thickest sedimentary basin in the world; however, little work has been carried out on establishing sequence stratigraphic boundaries within the basin. The stratigraphic framework of the exposed Eocene to Miocene sediments in the Jaintiapur and surrounding areas, northeastern Sylhet, Bangladesh, was constructed from surface sedimentological studies together with sequence stratigraphic modeling of the Sylhet trough. In this study, the exposed Eocene to Miocene sediments having conventional names like Jaintia, Barail and Surma Group have been reinterpreted and renamed as of Dauki Allogroup, Tamabil Alloformation, and Surma Allogroup. The Tamabil Allogroup has been regarded as an undifferentiated unit. Both the Jaintiapur Alloformation and the Afifanagar Alloformation are well developed in the study area. In this work, the parasequences, systems tracts, bounding surfaces and sedimentary sequences of the exposed Eocene to Miocene sedimentary deposits of the study area have been redefined and are recognized as representing responses to changes in relative sea level, sediment influx, and paleogeography.

Keywords: *Sylhet trough; parasequences; system tracts; sequences; depositional environment.*

1. Introduction

Sequence stratigraphy has been defined as the "study of the rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition, or their correlative conformities" [1]. The key attributes of the sequence stratigraphic approach have been a delineation of discontinuity surfaces and the relation of these surfaces with relative sea-level changes [2-3]. Bengal Basin is one of the largest basins in the world; however, little work has been carried out to establish sequence stratigraphic boundaries in the basin as a whole. The Paleogene and Neogene sequence of the Sylhet Trough and the surrounding area was studied by several authors [4-6], but there is currently a lack of detailed sedimentological and sequence stratigraphic information on the Sylhet Trough.

Analysis of facies and facies associations is an appropriate technique for understanding depositional environments. This method was used in the present study for environmental interpretation using the available sedimentological data. The sequence stratigraphy of the exposed Eocene to Miocene sediments of Jaintiapur and surrounding areas of northeastern

Sylhet, Bangladesh, was assessed to obtain a sequence stratigraphic framework for the area. The results of this study will aid future academic and exploration activities in the basin.

2. Study area

The selected study region is the Jaintiapur–Tamabil–Jaflong area in the northeastern part of Sylhet district, northeastern Bangladesh. The northern border of the area forms the international border between Bangladesh to the south and the Indian State of Meghalaya to the north. The study area (Fig. 1) is a hilly region with low hillocks in the west and high hills in the east. The boundary between the two countries in this region is marked by a fault zone, the Dauki Fault zone. This fault zone is filled by the flood plains and channels of many hilly rivers issuing from the Shillong Plateau of Meghalaya. The southern part of the study area is also plain-land, forming the large flood plains of the Meghalayan and Jaintia rivers [7].

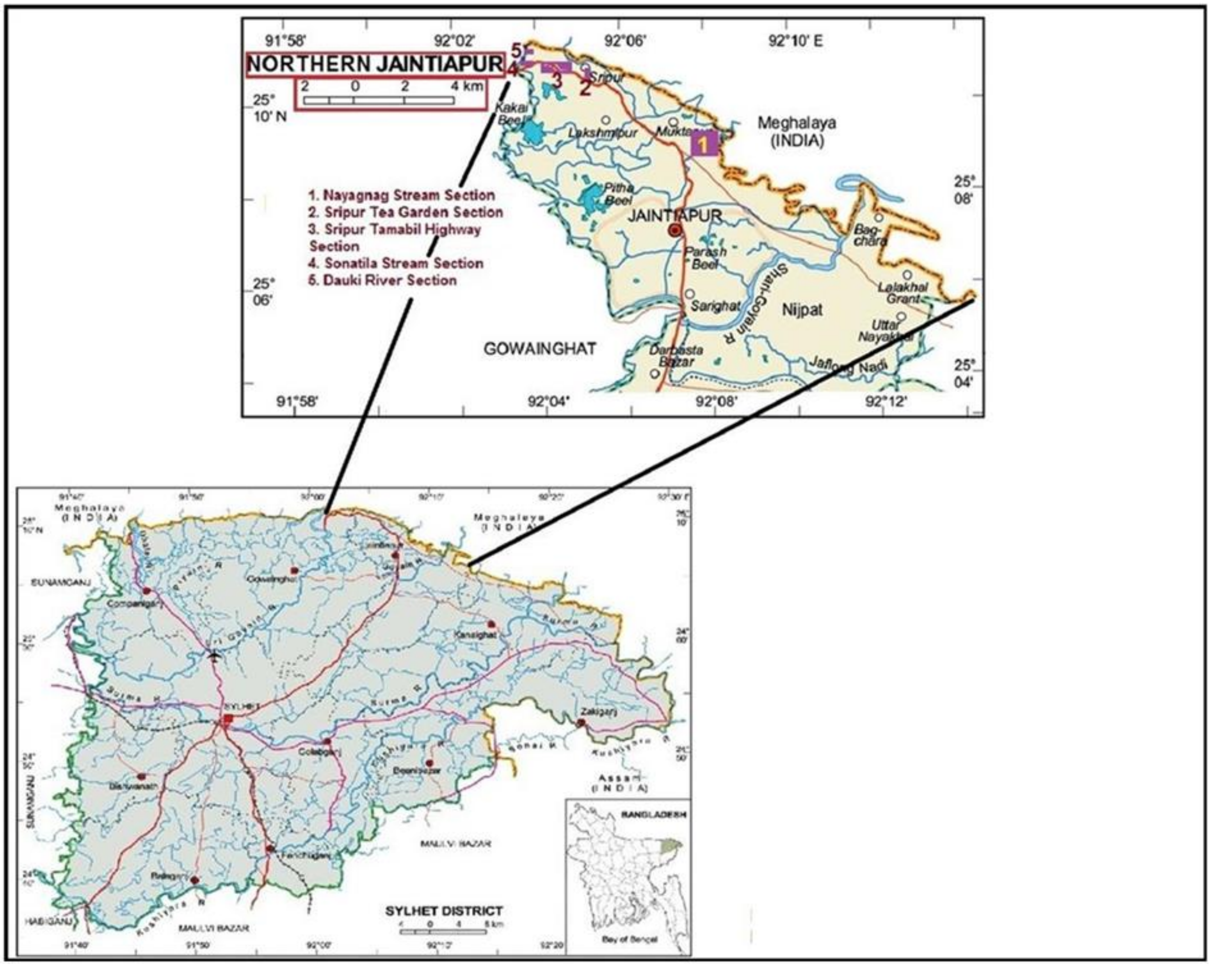

Fig.1. Local map of the study area in Sylhet *(Modified after Khan FH. [20])*

The most important stream within this country is Sonatila Chara in Jaflong. This area was selected for study because good exposures of the Dauki Allogroup (conventional Jaintia Group), Tamabil Allogroup (conventional Barail Group) and Surma Allogroup (conventional Surma Group) are available; unique Allogroup names have been proposed in this study that are all taken from local type sections based on local stratigraphic boundaries and available lithofacies; earlier formation names being taken from Indian type sections. Another important reason is that little work has been carried out using the sequence stratigraphic approach in the area, although the Surma Allogroup has been well studied [8].

3. Geological setting of the Bengal Basin

The Sylhet Trough is located in the northeastern part of the Bengal Basin, which in turn is adjacent to the northern part of the southeastern corner of the Indian Shield where the shield narrows, and can be considered to be the horn of the Indian Shield. The Indian Shield continues toward the northeast as far as the Mishmi Hills. In terms of paleotectonics and paleoenvironment, the Bengal Basin can be regarded as the southwestern continuation of the Assam Basin [9]. As a result, there are many similarities between these two geographically separated basins, and so the stratigraphic nomenclature of the Assam Basin has been applied to the Bengal Basin. Thus, the stratigraphy used has been highly generalized and oversimplified in the Bengal Basin region, at least for the Miocene rocks [8].

The northeastern horn of the Indian Shield is very important in the tectonic history of this region. It has got some pop up blocks such as the Mishmi Hills in the northeast [4], the Shillog and Mikir massifs in the southwest. In the northern half of the Indoburman Range, the orogenic cycle is complete, and the basin is now undergoing thrusting instead of folding. In the southern side of the range, the orogenic cycle is continuing to the west in the Bengal Basin [10].

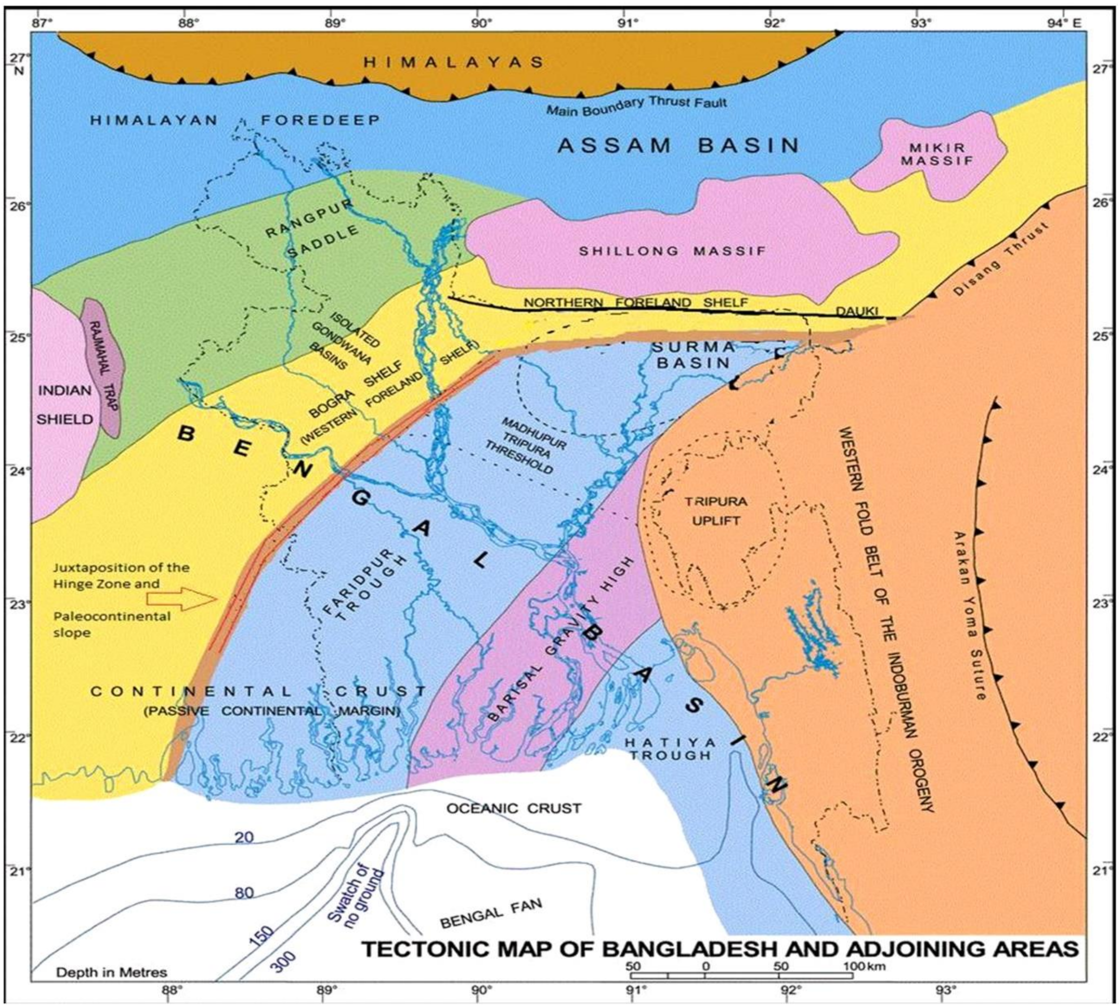

Fig.2. Tectonics map of Bengal Basin to show the juxtaposition of the Hinge Zone and paleo-continental slope

Knowledge of the geology of the Bengal Basin and its basin-fill history has been based to a large extent on seismic evidence from the subsurface, because basin-fill sediments are exposed in only a small part of the country [9, 11]. Two important tectonic elements are located on the western margin of the Bengal Basin. The first tectonic element is the hinge zone, i.e., the close spacing of 300 to 700 m NE–SW contours in the middle of the basin, indicating a sharp slope toward the basin: this zone is a geological structure but is tectonically important. The other tectonic element is the continent–ocean crust boundary. The basin configuration has been studied using gravity and magnetic anomaly data, in which the hinge zone (Fig. 2), the continental shelf, the continental rise, and the continent–ocean boundary are not well demarcated. The hinge zone is normally thought to terminate at the Shillong Plateau in the north; however, the contours are more widely spaced in the north, and the slope is gentler. Movement along the hinge zone has caused the Bengal Basin to undergo a tremendous amount of subsidence, allowing a great thickness of sediments to be accumulated. In the Sylhet Trough, the subsidence was initiated after the Miocene as a result of uplift of the Shillong Plateau by isostatic compensation and subduction of Indian oceanic crust beneath the Burmese Plate.

The Bengal Basin has experienced a series of evolutionary phases since the Permian. The basin did not exist prior to the Cretaceous Period. Instead its current position was occupied by the continental blocks (Fig. 3) of Gondwanaland.

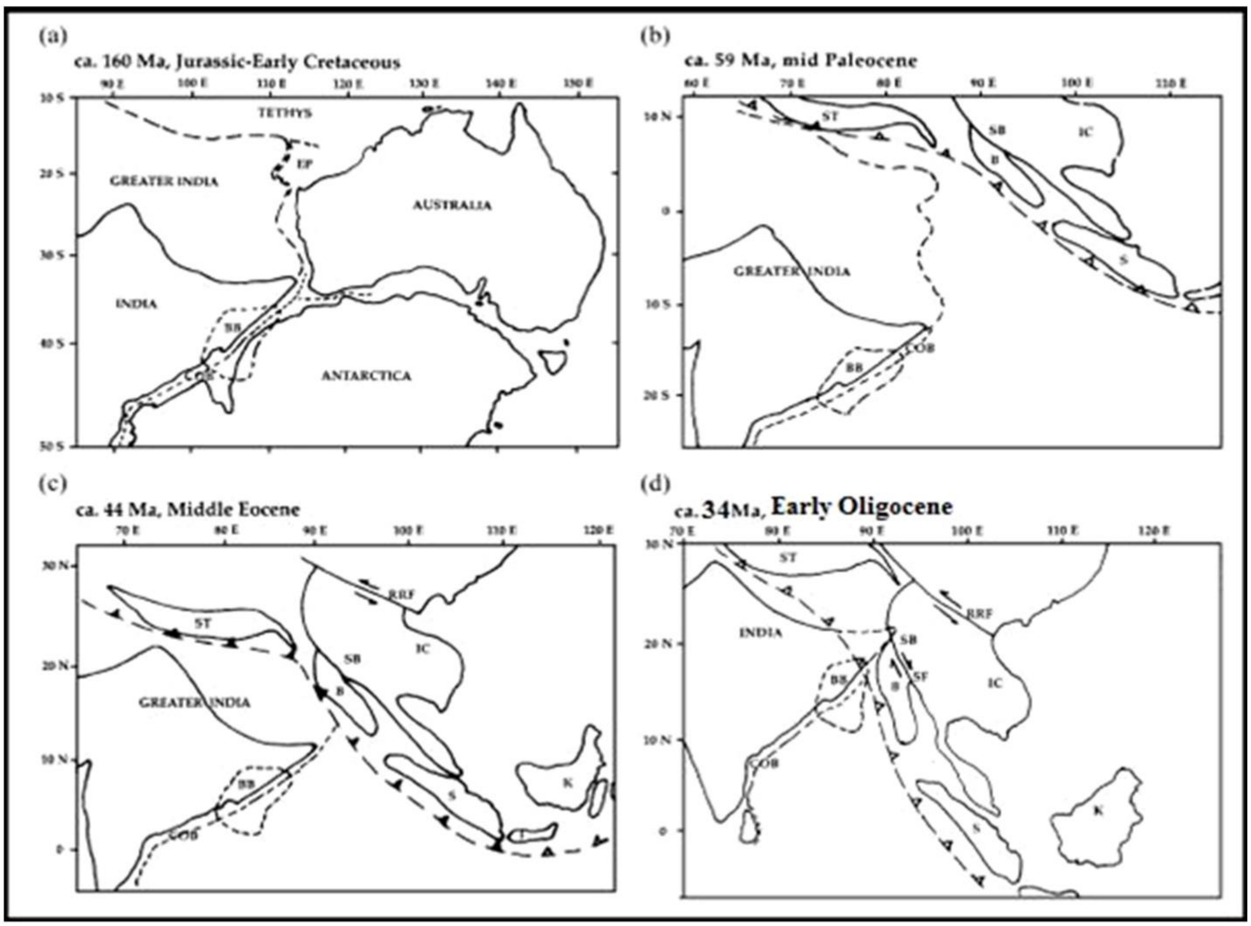

Fig.3. Plate reconstructions of the regional tectonic areas. EP= Exmouth Plateau; COB= continent ocean boundary; ST = South Tibet; B = Burma Block or IBA (Indo, Burma, Andaman); SB = SIBUMASU (Siam, Burma, Malaysia, Sumatra); IC = Indochina; S = Sumatra; BB = Bengal Basin; K= Kalimantan; J = Java; RRF = Red River Fault; SF = Sagaing Fault. (a) Eastern Gondwana fit of the margins of "Greater India", Australia and Antarctica. (b) Plate reconstruction at about 59 Ma, Mid-Paleocene, the start of "soft collision" between India and Southeast Asia. (c) About 44 Ma, Middle Eocene, the start of "hard collision" between India and South Asia. (d) About 34 Ma, Early Oligocene, a time of major collision between India and South Tibet in the north and India and Burma in the east *(Modified from Alam [6])*

The breakup of Gondwanaland began with rifting along the edges of continental India, Australia, Africa, and South America. This is rifting allowed development of the Bengal Basin along the northeastern border of the Indian continental plate margin. Thus the Bengal Basin started off as a rift basin: the rifting is marked by Permian Gondwanan half-grabens on the Precambrian basement. After separation from Gondwanaland, India drifted northward, and the southwestern fringe of the Bengal Basin was a pericratonic basin on a stable shelf over a passive continental margin. An oceanic basin occupied the place of the present Bengal Basin and existed until the Paleogene Himalayan orogeny when the eastern half of the basin was destroyed as a result of subduction of the Indian Oceanic Plate beneath the Burmese Plate during the Neogene [7]. As a result, the basin was left in the very early Neogene as a remnant ocean basin [6] and continued with this status until the end of the Miocene Epoch. The stratigraphic development of the region south of the horn of the Indian Shield began as early as the onset of the breakup of Gondwanaland when the Australian, South American, African, and the Indian Plates separated from the Antarctic Plate, as discussed in detail by previous authors [6, 9].

4. Sedimentological and sequence stratigraphic analyses

4.1. Dauki Allogroup (Jaintia Group)

4.1.1. Sylhet Limestone Formation

The Sylhet Limestone Formation is well exposed along the eastern flank of the Dauki River near Jaflong town; however, the base of this unit is not exposed in Jaflong area but is found in Takerghat to the west of the studied area along Bangladesh-Maghalaya border. The formation is overlain by the Jaflong Shale Alloformation (Fig. 4). The total thickness of the Sylhet Limestone Formation is still unknown, but the few exposed sections are approximately 15–17 m thick. This unit is mainly composed of fossiliferous and non-fossiliferous limestone. Common fossils present in the formation include *Nummulites*, *Discocyclina* and *Alveolina*.

Fig.4. Contact between Sylhet Limestone and Jaflong Shale

Sedimentary facies analysis is one of the initial stages of understanding the sequence stratigraphy of a formation. Appraisal of the bounding surfaces allows reconstruction of the physical extent and time duration of the sedimentation patterns.

Two distinct facies have been recognized in the study area of the Sylhet Limestone Formation.

a. Crystalline limestone facies (Lc)

b. Fossiliferous limestone facies (Lf)

Based on sequence stratigraphic analyses, two parasequences were found in the section, forming a Shelf Margin Systems Tract (SMST). The SMST was formed at a time when sea level was falling relatively slowly, and the location of deposition remained at the edge of the continental shelf. This SMST consists of fossiliferous and crystalline shelf carbonates in an aggradational stacking pattern. The abundance of foraminifera indicates a shallow, warm-water shelf environment. The Sylhet Limestone Formation appears in outcrop as a complete sequence (Fig. 5). The upper boundary of the formation is its contact with the Jaflong Shale (Kopili), which is a type II sequence boundary. This is unconformable with the Tura Formation; this contact is also a Type II sequence boundary.

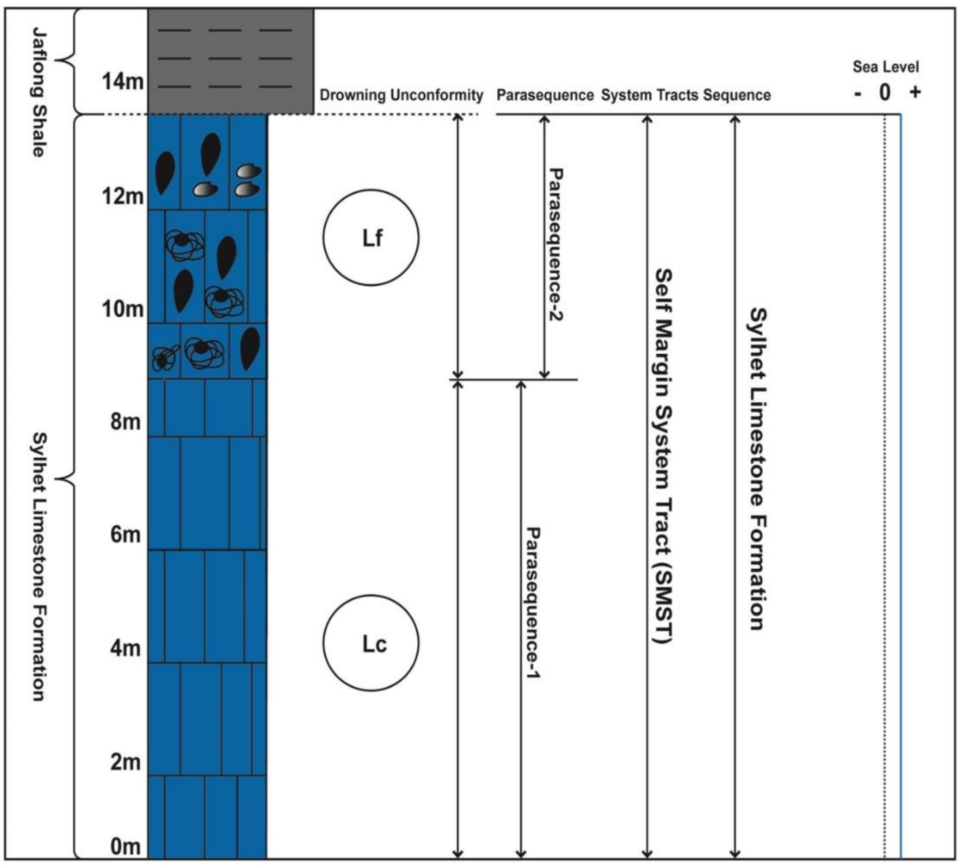

Fig.5. Sequence Stratigraphy of Sylhet Limestone

The Sylhet Limestone Formation was clearly formed in a carbonate depositional setting. In terms of carbonate buildup, the carbonate production (carbonate factory) is controlled by climatic variations, water circulation, nutrient supply, and water depth. Carbonate sediment was precipitated and produced from organic skeletal remains. The sediments were formed by the build-up of more rigid resistant features, such as coral reefs or sandy shoals. The carbonate sediments that have been accumulated display a wide range of platform morphologies often with slopes exceeding the angle of repose [12]. The epeiric carbonate platform was subsequently transformed into a rimmed shelf as a result of relative sea-level rise during the carbonate build-up in the upper part of the Sylhet Limestone Formation. A rimmed shelf with high carbonate production typically develops ramps, which may have a localized distribution around the edge of the platform [13].

4.1.2. Jaflong Shale Alloformation (Kopili Shale)

The Jaflong Shale Alloformation, which conformably overlies the Sylhet Limestone Formation, has been identified as late Eocene in age. This formation is exposed in the same section of the Dauki River as described above. That outcrop and the Tamabil Road section are the only exposures of the Jaflong Shale Formation within Bangladesh. This exposure is composed of dark gray to black shales. The lower contact of the formation is conformable and apparently fault-bounded. The contact between Jaflong Shale Alloformation and the Tamabil Allogroup (Barail) is unconformable.

The Jaflong Shale Alloformation contains the following lithofacies.

a. *Parallel-laminated siltstone (Sh)*
b. *Gypsum facies (Fg)*
c. *Laminated black shale (Fb)*
d. *Red shale (FRc)*
e. *Limestone (Lsc)*

The Jaflong Shale Alloformation contains three parasequences that form a Highstand Systems Tract (HST). The base is a Maximum Flooding Surface (MFS) that unconformably overlies the Sylhet Limestone Formation. The formation of the HST is associated with the creation of accommodation space at a lower rate than that of sediment supply. This accommodation space was created by a rapid sea level rise during deposition of the Jaflong sediments. The sediment supply was negligible in comparison to the much larger accommodation space closer to the coastal area, where sediment was abundant. The black shale and interbedded turbidites indicate a deep-water marine environment of deposition for the HST with an aggradational stacking pattern. The sediments forming the turbidite-related sandstone and siltstones were transported from an eroded orogenic provenance under sub-humid climatic condition [14].

The Jaflong Shale Formation is a siliciclastic sequence. The sediment dispersal system appears to have included submarine turbidity currents that generated small channels in the distal fan area, as well as hemipelagic to pelagic sediment suspension in abyssal to bathyal plains (Fig. 6). The presence of minerals such as glauconite and chert within the interlaminated sandstone and siltstones is typical of this type of depositional setting [13].

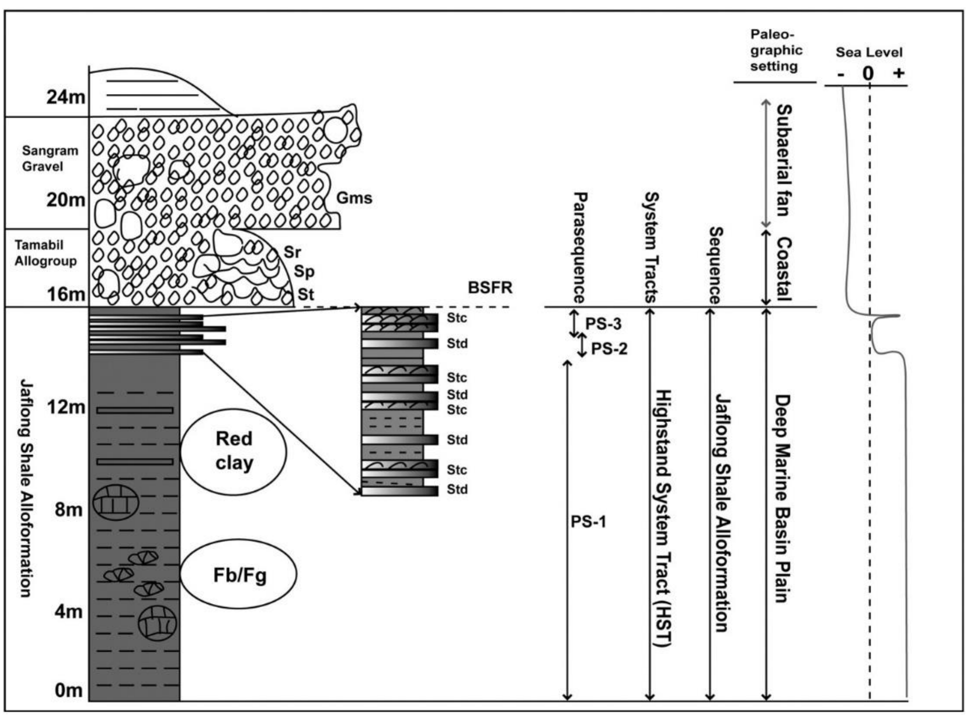

Fig.6. Sequence Stratigraphic Settings of the Jaflong Shale Allo formation

4.2. Tamabil Allogroup (Undifferentiated Barail)

The Tamabil Allogroup is the new name for the Barail Group. This unit largely represents the Oligocene sediments of the Sylhet Trough and the adjacent Assam Basin. The Tamabil Allogroup occupies a large area of the northeast of the Haflong–Disang Thrust that covers areas in Eastern Sylhet and Southwest Assam. The unit is well developed in the Surma Valley, North Kachar and the Garo–Khasia–Jaintia Hills [9-10]. The Tamabil sandstone is light gray, light brown and pink in color and very-fine- to fine-grained with thin- to medium-sized beds. Although the Tamabil Allogroup consists of three formations, it is considered to be "undifferentiated" in the present study in the exposures within the Sylhet Trough. The rocks of the Tamabil Allogroup show lateral and vertical lithological variations.

Alam [5, 8] suggested that the Tamabil Allogroup (Barail) succession in the Jaintiapur–Tamabil–Sangram bazaar areas of the northeastern Sylhet trough consists of shallow-marine deposits. However, the group has also been interpreted as a sequence of coastal, deltaic to shallow marine deposits [7]. The predominant lithology includes conglomerates, sandstones, siltstones, shales and mudstones. Channels, cross-bedding, intercalations, carbonaceous shale and lenses of coal indicate a probable swampy deltaic environment of deposition under tropical climatic conditions.

On the basis of the lithology and facies association, the Tamabil Sandstone Allogroup has been divided into three units as described below.

The lowermost member (130 m in thickness) of the formation is dominated by sandstone with minor amounts of shale. The sandstones are pink and brick-red in color, medium- to coarse-grained and cross-bedded with evidence of ripple cross-lamination. The beds are not well compacted and friable but in some places are very hard because of the presence of ferruginous cement. Splintery, black to grayish-black shales and yellowish-brown siltstones are also present in minor quantities. Intraformational conglomerates occur within the sandstone: these are well exposed along a road-cut and the tributary section from Tamabil through Sonatila Stream (Fig. 7).

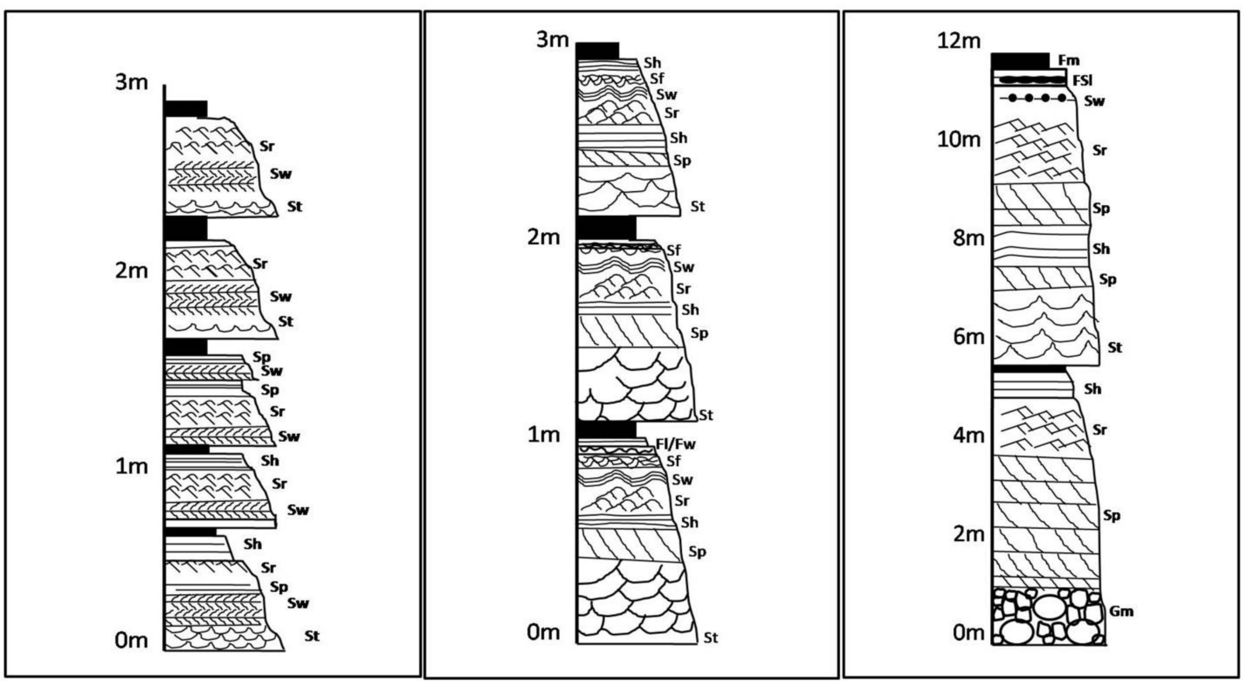

Fig.7. Litho-stratigraphic Log Model of the Tamabil Allogroup

The middle member (65 m in thickness) of the formation is a pink to yellowish-brown sandstone. The rock is fine- to medium-grained, ripple-laminated to ripple cross-laminated and planar cross-bedded with bidirectional cross-bedding. Thinly bedded shales are also present within sandstone beds. The sandstones are lenticular, wavy and sometimes flaser-laminated with abundant mud clasts in the lower part. Several channels are identifiable in this subunit with widths of several centimeters. The middle part of the allogroup is best exposed in the section from Tamabil BGB camp to Noljhuri camp.

The uppermost and thickest member (450 m thick) of the formation is dominantly sandstone with minor amounts of shale and siltstone. The sandstones are pink to brick-red in color and are unconsolidated showing massive, trough-cross-bedded and planar cross-bedded sandstones.

The best-developed sections are located between the Sripur Tea Garden and the Nayagang BGB Camp and in the Assampara–Rangapani river section. All deposits are exposed as channel and over-bank deposits on relatively flat terraces.

The facies and facies associations are classified according to their origin and sedimentological structures.

a. Clast-supported conglomerate facies (Ccg)
b. Trough cross-stratified sandstone facies (St)
c. Planar cross-stratified sandstone facies (Sp)
d. Horizontal-laminated sandstone–siltstone facies (Sh)
e. Ripple cross-laminated sandstone–siltstone facies (Sr)
f. Wavy-laminated very-fine-grained sandstone facies (Sw)
g. Flaser-bedded and laminated sandstone–siltstone facies (Sf)
h. Lenticular-laminated sandstone–siltstone facies (Fsl)
i. Mudstone facies (Fm)

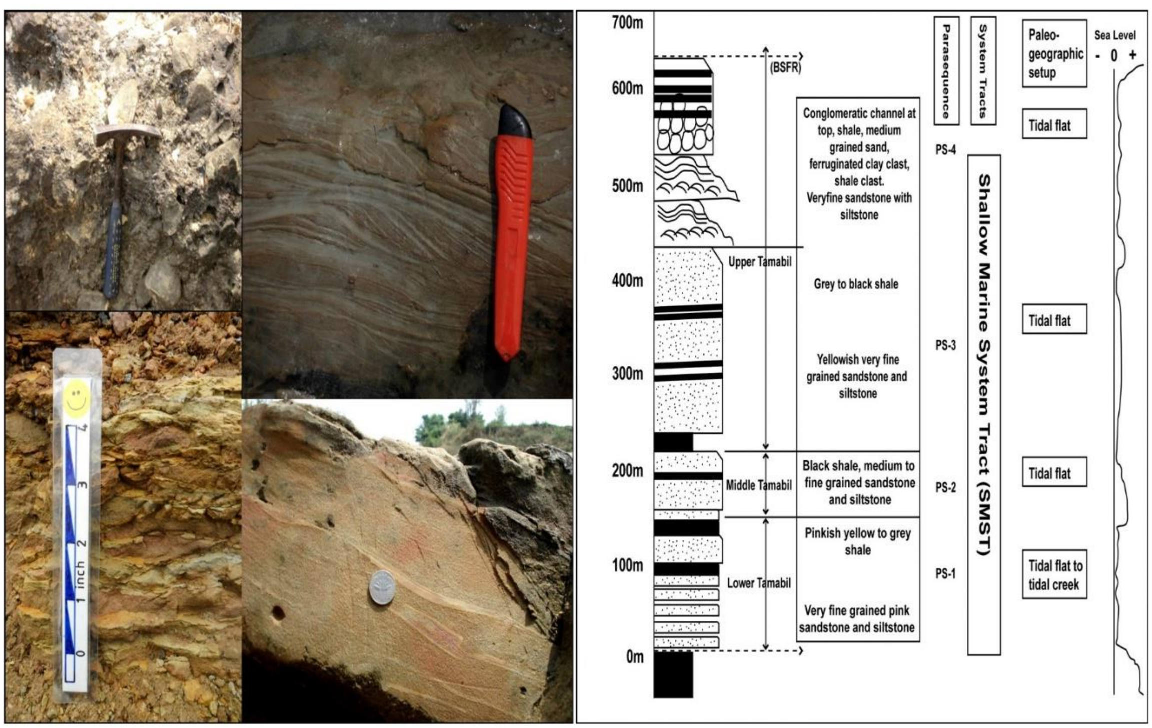

Fig.8. Clast-supported conglomeratic bed, trough cross-stratified sandstone facies, heterolithics of the Tamabil Allogroup, mud interclasts within the Tamabil Sandstone Allogroup and the sequence stratigraphic setting of the Tamabil Allogroup

The undifferentiated Tamabil Allogroup as exposed in the study area is mostly arenaceous and consists of approximately 650 m of thick sandstone, siltstone, silty shale, shale, and mudstones. This indicates a tidal flat–estuarine environment in a marginal-marine setting. The depositional environments are interpreted as tidal channels, tidal creeks, and intertidal flats. From the sequence stratigraphic point of view, the depositional site remained stationary relative to sea level and basin floor movement. These conditions were created after the retreat of the deep-marine conditions of the Jaflong Shale Formation that was encased in a HST. The boundary between the Jaflong Shale Formation and the Tamabil Allogroup is considered to be a Type I sequence boundary. Subsequently, during the marine regression at the beginning of the Oligocene, the Tamabil Allogroup was deposited in a marginal-marine to the estuarine–tidal flat environment [15]. Thus the Tamabil Allogroup can be interpreted as an SMST that was repeated several times (Fig. 8).

4.3. Surma Allogroup

4.3.1. Jaintiapur Alloformation (Bhuban)

The Jaintiapur Alloformation of the Surma Allogroup, which is of Miocene age, contains three sequences deposited in tide-dominated (nearshore), storm-dominated (shelf) and continental slope environments. Tide-dominated facies are exposed in the Jalhas–Guabaria area, storm-dominated shelf facies occur in the Nayagang section, and marine facies are exposed along the Hari River. The general interpretation of the Jaintiapur Alloformation suggests that the unit is of marine origin [16-17].

The Jaintiapur Alloformation has been measured as approximately 1000 m thick. The unit is characterized by bluish to black shale with subordinate light yellow to green sandstone, grayish-white siltstone, dark gray mudstone and conglomerate. Pebbly sandstone and medium-grained massive sandstone and conglomerate are present only in the lower part of the formation. The exposed lower boundary of the formation with the Tamabil (Undifferentiated) Group is represented by a marked unconformity and consists of conglomeratic laterite. The upper contact with the Afifanagar Alloformation of the Surma Allogroup is also unconformable but not distinct and is exposed at the Lalakhal Tea Garden section.

Fifteen lithofacies were identified within the Jaintiapur Alloformation. Each of these is characterized by a unique combination of lithology, texture and sedimentary structures and represent deposition in a specific subenvironment within a submarine fan complex.

a. *Conglomerate facies (Gm)*
b. *Pebbly sandstone facies (Ps)*
c. *Massive sandstone facies (Sm)*
d. *Fine-grained sandstone facies (ST)*
e. *Planar c-stratified sandstone facies (Sp)*
f. *Hummocky cross-stratified sandstone (SH)*
g. *Swaley cross-stratified sandstone (Ss)*
h. *Parallel-bedded sandstone–siltstone facies (Sh)*
i. *Rippled and ripple cross-laminated sandstone–siltstone facies (Sr)*
j. *Flaser-laminated sandstone–siltstone facies (Sf)*
k. *Laminated sandstone–siltstone and silty claystone facies (Sl)*
l. *Lenticular-laminated sandstone–siltstone facies (Sll)*
m. *Wavy laminated silty shale to shale (Fw)*
n. *Bluish-black to black shale facies (Fl)*
o. *Massive mudstone facies (Fm)*

Analysis of the vertical distribution of facies is based on grain size, bed thickness and facies changes that appear to be characteristic of specific morphological elements. The facies model for the Jaintiapur Alloformation was determined on the basis of the facies, depositional environments and fluid flow movement. Facies models of the Jaintiapur Alloformation are illustrated in Fig. 9.

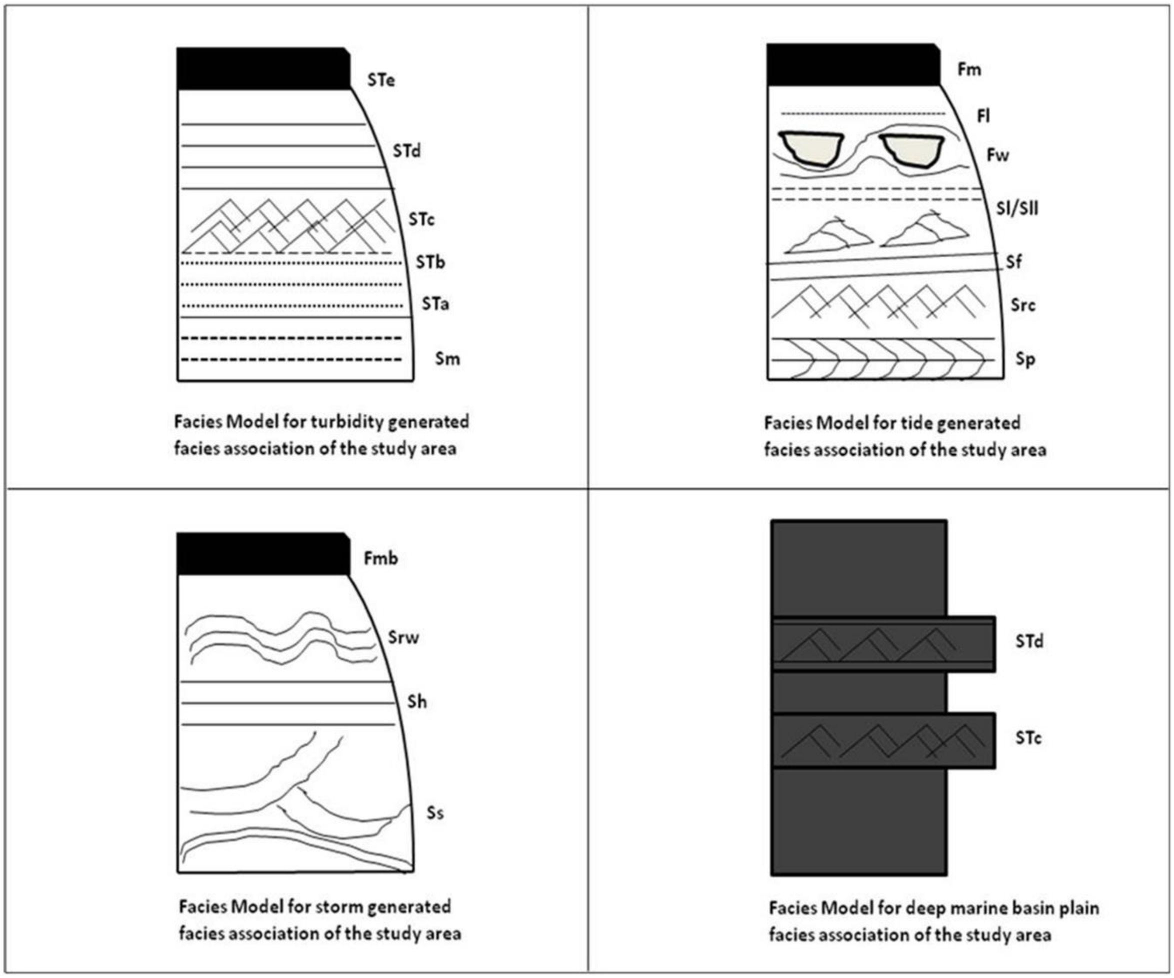

Fig.9. Facies models of the different studied sections in the Jaintiapur Alloformation

From the study of facies analysis and lithology of the Jaintiapur Alloformation (Fig. 10), fifteen parasequences with at least three distinct systems tracts were identified in the Jaintiapur area of the Sylhet Trough. Sedimentation in the Jaintiapur Alloformation began on the exposed coastal areas of the upper Tamabil Allogroup. This exposed surface is an unconformity filled by conglomerate that may have been an incised valley fill. The sedimentary sequence began with a Lowstand Systems Tract (LST). Faulting during a later period changed the environment into a deep-marine basinal plain forming an HST as a result of rapid sea level rise. The overall depositional pattern of the Jaintiapur Alloformation contains repeated HSTs and SMSTs ending with a basal surface of forced regression (BSFR) formed in a shallow environment. Thus, the upper bounding surface is also an unconformity. The entire lithological succession of the Jaintiapur Alloformation represents a sequence. Sea level changes have resulted in a stacking pattern of the systems tracts related to third- to fourth-order cycles of sea level change.

In the Jaintiapur Alloformation, the siliciclastic depositional systems of tides, storms and turbidity currents below the continental slope and deep-marine pelagic to hemipelagic suspension contain definite areas of sediment accumulation. The paleogeographic setting of the formation varies from the estuary to tidal flat and tidally dominated shallow-marine shelf through storm-dominated deeper shelf and submarine proximal distal fan with turbidity currents. The sequence is also indicative of a deep-marine anoxic basin plain with pelagic sedimentation caused by relative sea level change (Fig. 11) and tectonic settings.

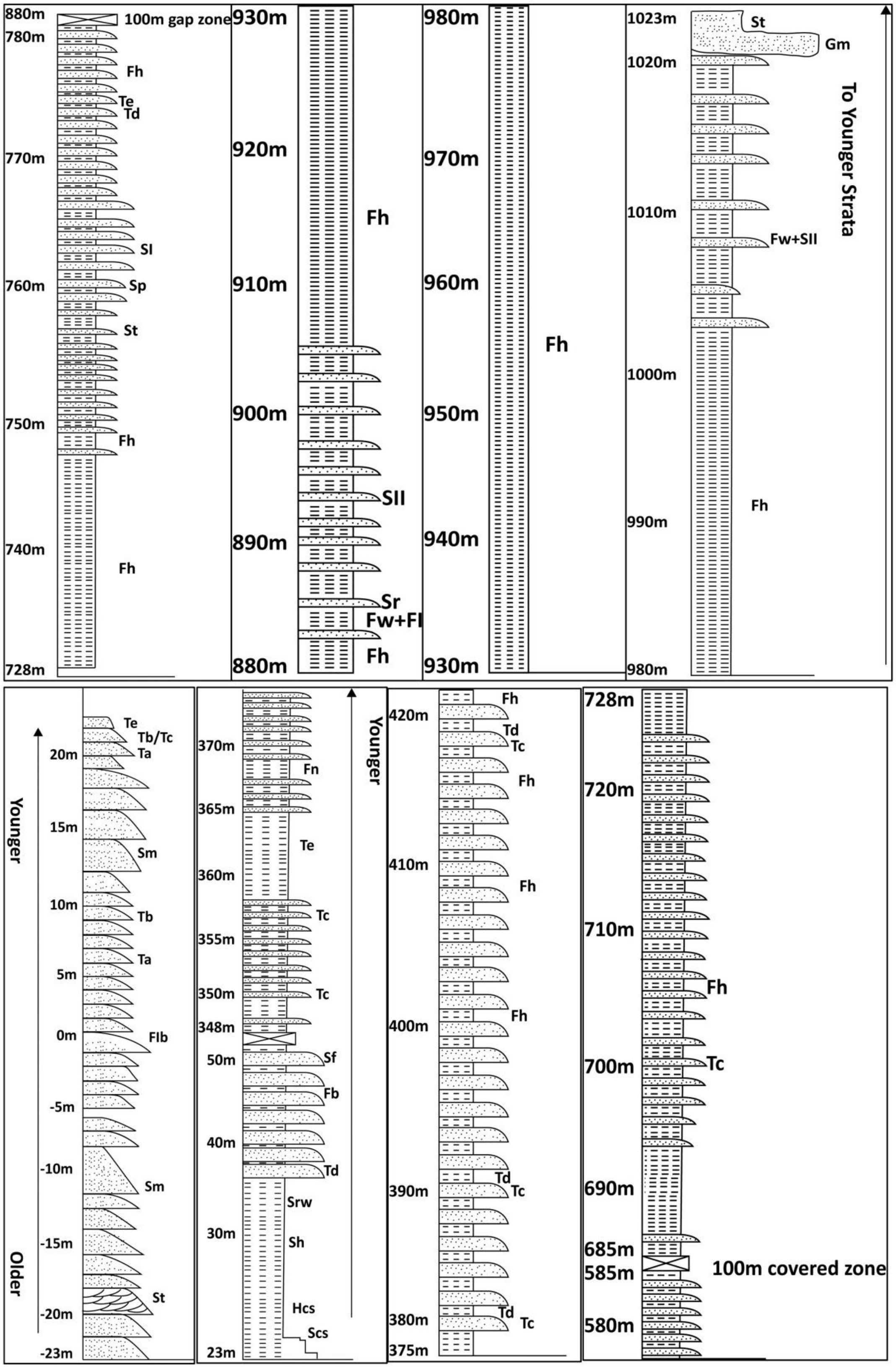

Fig.10. Sedimentary litholog of the Jaintiapur Alloformation

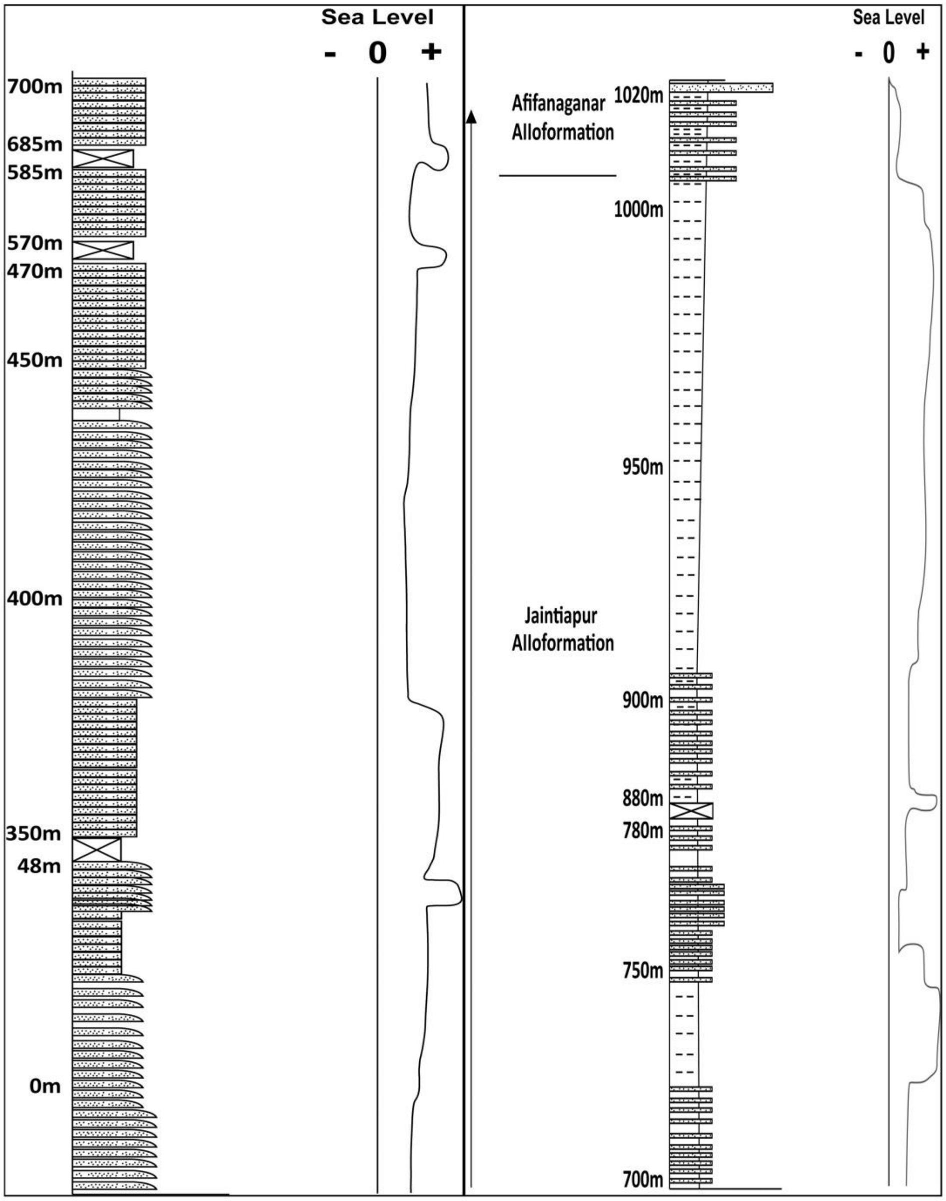

Fig.11. Interpreted sea level curve for the Jaintiapur Alloformation, Sylhet

4.3.2. Afifanagar Alloformation (Bokabil)

The Afifanagar Alloformation is the youngest unit of the Surma Allogroup and is well exposed along the banks of the Hari River, in the Lalakhal area and in the Tetulghat area of Jaintiapur, Sylhet. The objective of the study of Afifanagar Alloformation is to delineate better the facies and facies associations to generate a depositional model for the paleoenvironmental interpretation during deposition of the unit in the Miocene Epoch, which will ultimately help to obtain a sequence stratigraphic model of the formation.

The Miocene Afifanagar Alloformation unconformably overlies the Jaintiapur Alloformation and is overlain by the Mio–Pliocene Lalakhal Sandstone Alloformation with an erosional unconformity. The unit is mainly composed of silty shale, shale, siltstone, and sandstone. The silty shale is gray to bluish-gray in color, laminated to thinly bedded, moderately compact and highly jointed. The shale is greenish-gray, very-fine-grained, thinly to thickly laminated and intercalated with silty shale. The sandstone is light gray, medium- to very-fine-grained, moderately compacted and contains trough, planar and ripple cross-stratification and parallel to flaser and lenticular lamination.

In total, eleven lithofacies were identified within the Afifanagar Alloformation.

a. *Clast-supported conglomerate facies (Gm)*
b. *Trough cross-stratified facies (St)*
c. *Planar cross-stratified sandstone facies (Sp)*
d. *Fine-grained sandstone–siltstone facies (STc–STd)*
e. *Parallel-laminated sandstone–siltstone facies (Sl)*
f. *Ripple cross-laminated sandstone–siltstone facies (Sr)*
g. *Flaser-laminated sandstone–siltstone facies (Sf)*
h. *Lenticular-laminated sandstone–siltstone facies (Sll)*
i. *Wavy-laminated shale facies (Flw)*
j. *Parallel-laminated shale facies (Fl)*
k. *Mudstone facies (Fm)*

A vertical facies model is defined as a general summary of a specific sedimentary environment; the relationships of the facies in a stratigraphic sense can be understood by the construction of a facies model. Facies models for the lower, middle and upper parts of the Afifanagar Alloformation are illustrated in Fig. 12. An overall facies model of the Afifanagar Alloformation exposed along the Hari River section is also described below.

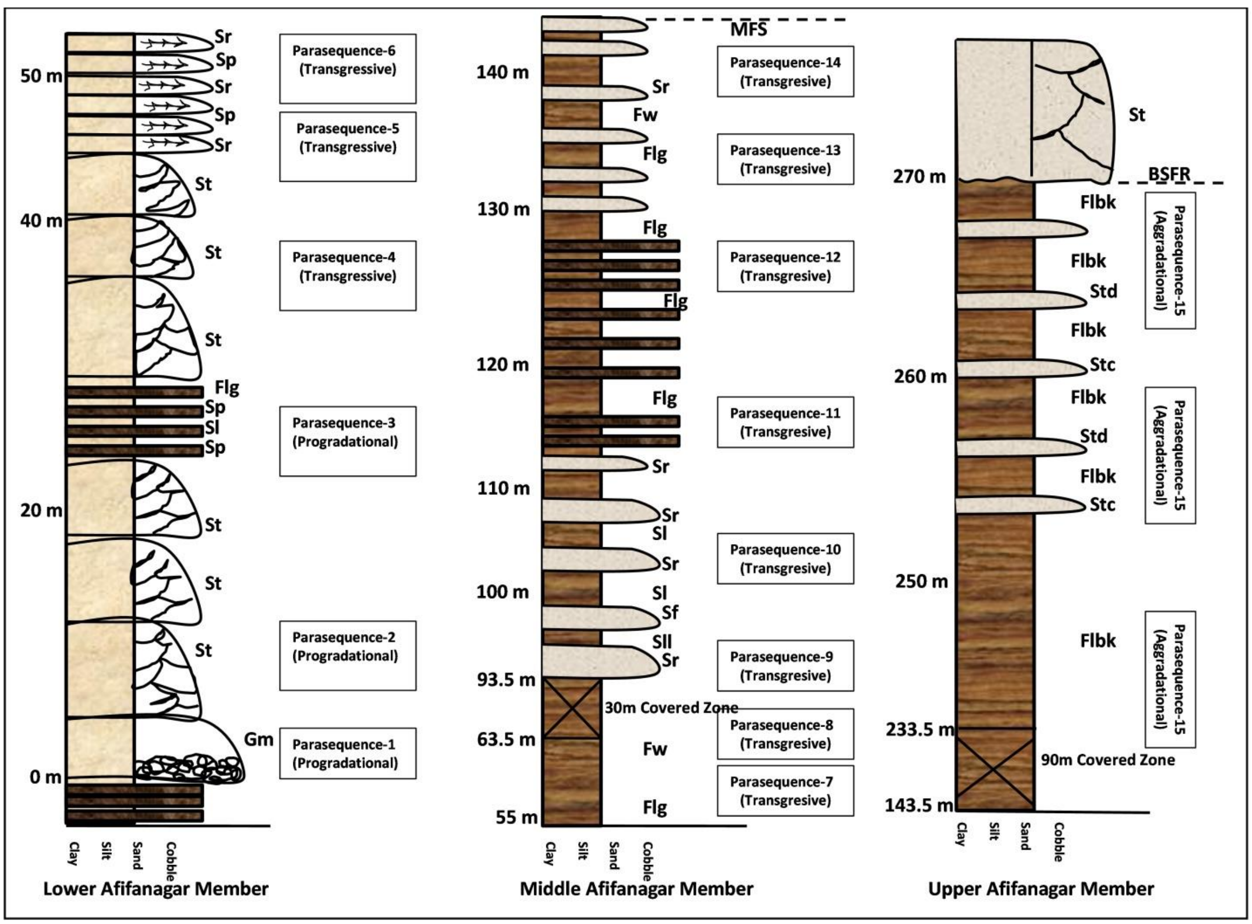

Fig.12. Sedimentary log and sequence stratigraphy of the Afifanagar Alloformation

The Afifanagar Alloformation can be grouped into three facies associations on the basis of paleoenvironments. The fluvial facies association (FFA) represents incised valley, braided channel and overbank deposition, the tidal facies association (TFA) was formed in the estuary, tidal creek and tidal flat environments, and the marine facies association (MFA) was the result of deep marine hemipelagic sedimentation some distal turbidite progradation. The FFA consists of facies Gm and Stf, Spf, Slf, Flg subfacies and the Lower Afifanagar Member is composed of Fmf facies, the TFA is constituted by facies and subfacies of Stt, Spt, Slt, Sr, Sll, Sf Flb and Fmt forming the Middle Afifanagar Member. MFA is constituted of facies and subfacies of STc, STd, Flb, and Flbk represent the Upper Afifanagar Member.

From the analysis of the facies, facies association, and lithological succession, a total of seventeen parasequences were identified within the Afifanagar Alloformation from base to the top within the studied area. These parasequences can be classified into three types of system tracts on the basis of the stratigraphy, facies associations, and depositional environments.

The basal deposit of the studied area is a conglomerate, which is located above the shelf deposit of the uppermost part of the Jaintiapur Alloformation. The conglomerate represents sedimentation in an incised valley and is included in Parasequence 1. Such incised valleys were formed as a result of rapid sea-level fall or local tectonic uplift. The incised valley over the exposed Upper Jaintiapur shelf and the clasts within the conglomerates are mainly composed of shale from the shelf. This conglomerate is followed by a comparatively large thickness of Parasequence 2, i.e., channelized areneous deposits. The sediments are coarse-grained trough-cross-stratified sandstone (St) of braided fluvial origin. Parasequence 3 contains very fine sandstone to siltstone alternating with parallel-laminated gray shale. These rocks are moderately hard and sometimes calcareous. The parasequences in this systems tract are usually stacked to form a progradational pattern. The progradational geometry was formed by lateral building out to form a gently sloping depositional surface. This type of geometry is generated in conditions of stable sea level with a high sediment supply.

The parasequences in this system tract were deposited during a rapid sea level regression from the depositional site of the Upper Jantiapur shelf, and the earlier depositional site was exposed and eroded. Formation of the falling stage system tract (FSST) was associated with progressive destruction of accommodation space caused by a fall in relative sea level [1, 18]. The low sea level caused subaerial exposure of the shelf, and rivers become incised and bypassed the shelf to deposit sediments directly on the slope and basin floor. The incised valley between the Upper Jaintiapur Alloformation and the Lower Afifanagar Alloformation marks the sequence boundary and is termed the BSFR. The top of this systems tract is bounded by a conformable transgressive surface (CTS).

In the Hari River section, the TST includes about half of the total lithological succession of the Afifanagar Alloformation. PS 4 to PS 8 constitute the transgressive systems tract. These parasequences are related to each other, and the environment of deposition varied because of slight variations in sea level and tectonic activity. The basal part of this systems tract consists of Parasequence 4, which is approximately 15 m thick and contains trough-cross-stratified, medium- to fine-grained, moderately sorted sandstone bodies that are channelized. Shale shingles are occasionally present within the sandstone (St) of the channels. The presence of mud and occasional bidirectional paleocurrents in the St facies of the channels indicate tidal action within estuarine channels. This was followed by a transgression in the depositional area after waning of fluvial activity.

Above PS 4, silty tidal flat deposits of PS 5 are present, followed by medium- to fine-grained, planar cross-stratified to ripple-laminated small channel-fill sandstone deposits. These channel features constitute PS 6 and contain bidirectional paleocurrent patterns indicative of tidal action. These are small estuarine channel fills. PS 5 and PS 6 alternate with each other and the thickness of this zone is about 10 m.

Parasequence 7 overlies this zone and consists of parallel- to wavy-laminated grayish shale. This parasequence alternates with PS 8. The ripples of these two parasequences are bidirectional, indicating a small tidal flat deposit. The parallel- to wavy-laminated shale together with the presence of the lenticular-laminated siltstone suggest a tidal flat environment. The depth of the tidal channel deepens and the grain size changes from very-fine-grained sandstone–

siltstone to shale in the upper part of the succession, i.e., mud-dominated deposition. Tidal creek siltstone indicates high-energy conditions, i.e., probably spring tide and a fluctuating energy level in the shale-dominated zone. After the 10-m-thick alternating zone of muddy tidal flats with small tidal creek deposits, an approximately 30-m covered zone is present in the lithological succession. After this, 18 m thickness of small estuarine sediments of PS 9 alternate with the tidal-flat sediments of PS 10. There is a possibility that a slight fall in sea level occurred at this time. Another 15-m-thick alternating zone of PS 11 and PS 12 is present above the comparatively coarser-grained lower horizon of PS 9 and PS 10. The final zone of this systems tract consists of alternations of two parasequences, PS 13 (muddy tidal flat deposits) and PS 14 (tidal creek deposits).

The overall deposition of this transgressive tract occurred in conditions with fluctuating energy levels. As a result, a marginal marine depositional environment was formed. Thick channel fills indicating high-energy conditions later diminished to form a sandy–silty–muddy tidal flat that characterizes the basal part of the systems tract. The thicknesses of the sand, silt, and shale units are variable throughout the whole system tract, which also indicates negligible fluctuations in sea level. The parasequences of this tract show a retrogradational geometry characterized by back-stepping over the basal incised valley. The formation of the transgressive system tract was associated with the creation of accommodation space at a rate faster than the rate of sediment supply. Consequently, a retrogradational parasequence set was developed.

The boundary between the TST and the HST of the Upper Afifanagar Member is marked by a fault in the field area, which might be syndepositional in nature. As a result, abrupt alterations in the environment of deposition were observed, i.e., coastal deposits overlain by deep-marine basin plain deposits. This is the uppermost part of the Afifanagar Alloformation, which is about 116 m thick. At the base of the deposit, an approximately 90-m covered zone (superficial cover) is marked by the presence of a tributary of the Hari River, which is oriented at a right-angle to the Hari River and parallel to the strike of the strata.

After the 90-m gap in the succession, there is a unit of dark blue shale that is highly splintered, weathered and occasionally convoluted. These shales are deep-marine pelagites and make up Parasequence 15. These shales are occasionally embedded within ripple-laminated, very-fine-grained turbiditic sandstone–siltstone (Tc) and parallel-laminated (Td) sandstone, the bases of which have channel-like morphologies. These are small distal turbidite channels. The presence of dark blue shale containing calcium carbonate suggests that this unit was formed above the carbonate compensation depth. Above this, PS 17 occurs, which consists of black shale and contains occasional pyrite.

The contact between the Afifanagar Alloformation and the overlying Lalakhal Sandstone Alloformation is erosional and unconformable and acts as a type I sequence boundary. This boundary is identified as the BSFR, which may have formed as a result of rapid sea-level fall enhanced by uplift of the depositional surface. The parasequences of this system show aggradational to progradational geometry characterized by uniform progradation of sediments from shelf to slope to deep marine basin plain. Instead of rapid sea level rise caused by down-faulting of the depositional site, the sediment supply was low because the depositional site was far away from the shore. The faulted surface acts as a maximum flooding surface and the upper boundary, which is with the Lalakhal Sandstone Alloformation, is forced-regressive. Hence the HST of the Upper Afifanagar Member lies below the forced regression surface and above the maximum flooding surface.

The Afifanagar Alloformation as a whole contains a FSST in the lower part, a TST in the middle part and an HST in the upper part. The formation as a whole is bounded at the base by a type I sequence boundary with the Jaintiapur Alloformation and at the top by a type I sequence boundary with the Lalakhal Sandstone Alloformation.

The paleogeography of an ancient sedimentary basin at a particular time can be reconstructed from the sedimentary succession by studying the set of depositional systems tracts that existed contemporaneously in the basin [18]. The lithological succession of the Afifanagar

Alloformation in the study area contains siliciclastic deposits. The Afifanagar Alloformation in the study area contains fluvial, marginal-marine, shallow–marine and deep-marine sedimentary systems.

5. Proposed stratigraphy of the Sylhet Trough

The stratigraphic nomenclature used currently to describe the Sylhet Trough and the overall Bengal Basin has its roots in the famous work by Evans [19]. The complete stratigraphic column with the type sections (in Assam, India) has been mostly obtained from that work. After Evans, many other sedimentologists have worked on the Sylhet Trough: of these, the works of Alam [4-6, 8] are the most notable.

On the basis of previous studies and on the field data collected in this study, a new stratigraphic nomenclature is proposed for the Eocene–Miocene sediments of the Sylhet Trough. A detailed sequence stratigraphic model is constructed, which includes a renewed sea-level model based on the global sea level curve, demarcation of each of the sequence stratigraphic surfaces identified and an overall model of the Sylhet Trough (Fig. 13).

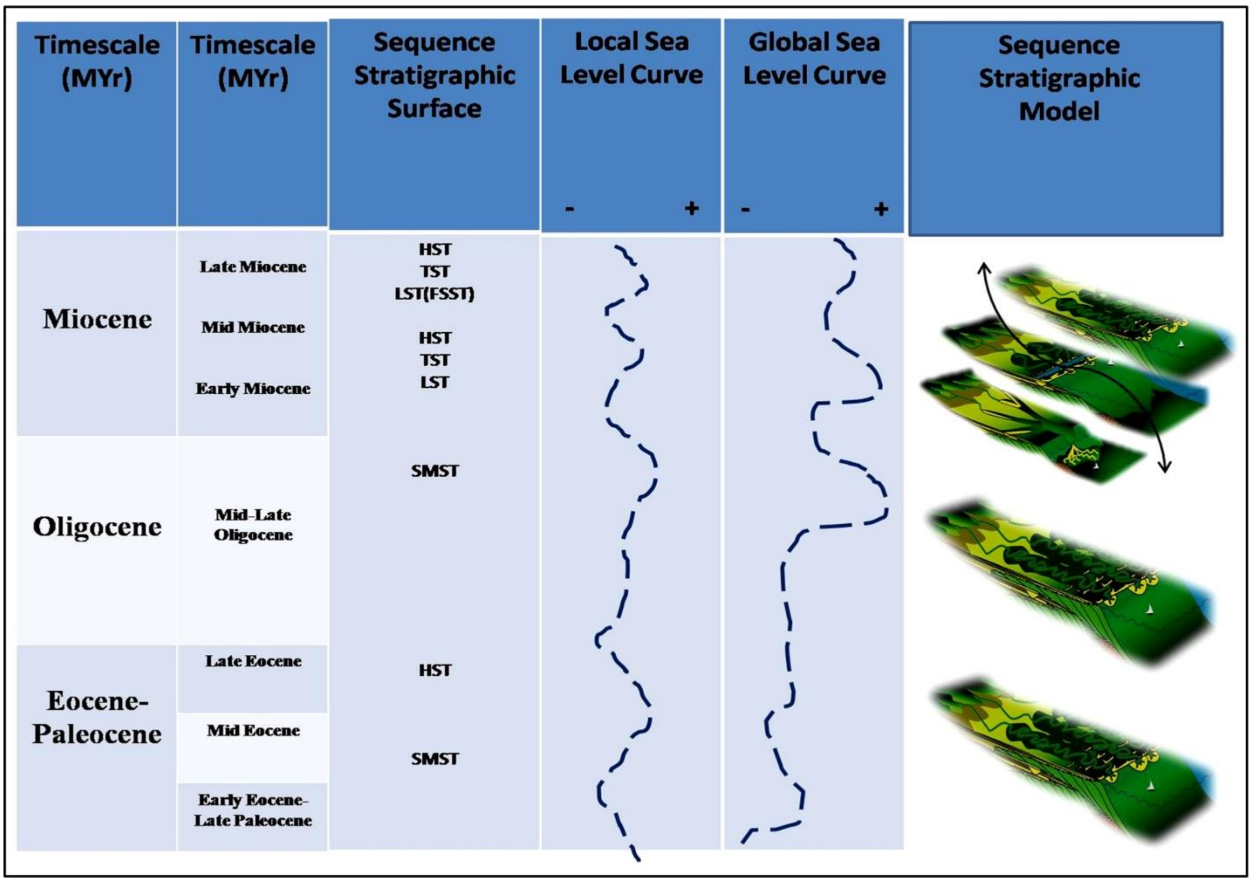

Fig.13. Stratigraphic model of the Sylhet Trough, Exxon-Vail Curve (modified)

6. Conclusions

Observations on the surface exposures of the formations from the Sylhet Limestone to the Afifanagar Alloformation of the Surma Allogroup (Eocene to Miocene periods) have revealed new sequence boundaries based on the broad sequence stratigraphic characteristics of the study area and local type section names replaced with previous stratigraphic nomenclatures. By using classical sequence stratigraphic approaches, the stacking patterns of the parasequences have been well understood and interpreted. The results of this study will aid future surface and subsurface studies on the Sylhet Trough from the sequence stratigraphic point of view.

6. Acknowledgements

The first author would like to express his deepest gratitude to the Govt. of Brunei and UBD for supporting the research. The authors would also like to thank Phua Eng Siong for his technical support with the drawings. The authors are also thankful to Dr. Badrul Imam for his critical suggestions on the paper.

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