CHAPTER 4
LITHOFACIES SEQUENCE OF MORPHOSTRATIGRAPHIC UNITS

4.1 Introduction

A sedimentary facies is defined as a sum of all the primary characteristics of a sedimentary unit. Although the term ‘facies’ has been used in many different senses, a sedimentary facies is a result of deposition in a given environment (Reineck and Singh, 1980). Moore (1949) defined sedimentary facies as any areally restricted part of a designated stratigraphic unit which exhibits characters significantly different from those of other parts of the unit. The word is now used in both a descriptive or an interpretative sense and the word itself may have either a singular or plural meaning. The prefix ‘litho’ is used in the term lithofacies to denote specifically the lithological characters of sedimentary unit. An individual lithofacies is a rock unit defined on the basis of its distinctive lithologic features, including composition, grain size, bedding characteristics and sedimentary structures (Miall, 1990). So each lithofacies represents an individual depositional event.

Study of facies includes changes in horizontal direction (space), as well as changes in vertical direction (time). If genetically related facies overlie each other, they can be grouped into sequences. Thus the assemblage of some related lithofacies types in certain combinations may be indicative of a specific type of environment of deposition. It is, therefore, possible to erect certain environmentally sensitive model, based on the study of modern sediments in which sedimentation processes involved and conditions of deposition are precisely known.
The identification of a lithofacies type is usually based on both textural and structural aspects. Of these two aspects, structure is rather found to be more environmentally sensitive due to its diverse environmental settings and is, therefore, sometimes very deceptive too. Nevertheless, the combination of both these aspects in identifying and grouping lithofacies types can yield more realistic information in the construction of environmentally sensitive sequences.

In construction of facies models one has to be extremely cautious and should be free from any biasness. Reineck and Singh (1980) have cautioned that the presence or absence of individual features cannot generally be used as a positive sign in environmental interpretation. Most of the structures, for instance, occur in several environments. It is generally the spectrum of sedimentary structures and their presence in certain combinations that provide direct clues in environmental interpretation. Certain associations of sedimentary structures and certain lithological associations are typical for certain specific environment. Study of present-day environments provides vast information, on the basis of which environmental models can be constructed. Such models can be based on actual information of sedimentary structures, grain size, etc. In the present-day environment of a given area, process-response models can be constructed emphasizing the sequence of sedimentary structures and relating them to the processes responsible for their formation. Information of investigations in different geographic areas of a given environment may be put together to build up a generalized model for a given environment. These models, however, should be considered no more than ‘models’, because many variations in the deposits of similar environments are possible. So, it can be said that no one sedimentary sequence is exactly identical to another.
However, despite their deposition in varying conditions, certain basic patterns are always similar in deposits of a given environment. This makes their recognition of depositional environments, even in geological record, possible with some certainty (Reineck and Singh, 1980). Most depositional environments can be characterised by distinctive associations of lithofacies; the vertical lithofacies association (vertical sequence) is particularly diagnostic.

4.2 Lithofacies Relationship and Association

In the present study, total 48 vertical profile sections have been excavated at different morphostratigraphic units at different locations out of which 11 sections in gravel bar, 9 sections in terrace, 16 sections in channel bar, 8 sections in levee and 4 sections in flood plain. In order to study the relationship and association of various lithofacies types of the different morphostratigraphic units, the vertical profile sections are grouped into two categories, viz., gravelly sections of gravel bar and terrace and sandy sections of levee, flood plain and channel bar. It has been observed that gravel bar and terrace consist of only one type of lithofacies comprising matrix supported gravel ($G_{ms}$) and it is not associated with other lithofacies types. In case of sandy profile sections of levee, flood plain and channel bar, different types of lithofacies are observed and they are associated with one another. The variations of lithofacies types both in respect of time and space for all sandy vertical profile sections are diagrammatically illustrated in Figs. 4.1 to 4.10.

The lithofacies types of the levee, flood plain and channel bar sections of the present study reach have been analysed for the purpose of their variation and occurrences. It has been observed that levee sections show association of 9 different
types of lithofacies ($F_r$, $F_l$, $F_m$, $S_{r2}$, $S_h$, $S_m$, $S_{r1}$, $S_{p1}$ and $S_{p2}$). The $F_r$ facies is found to be present at the top of all the vertical profile sections. The lithofacies $S_{p2}$ is found towards the lower part in all the sections except the Section No. M.2.2 (Fig. 4.3). The $S_m$ facies is another common type of facies present in all the sections except Section No. S.2.1 (Fig. 4.1). The facies $S_h$ is associated mainly with $S_{p2}$ and is absent at Madhupur. The $F_l$, $S_{p1}$ and $S_{r1}$ are the minor facies and occasionally found in some sections. The $F_l$ is found to be present in Section No. S.2.1 (Fig. 4.1). The $S_{r2}$ facies is present only in the Section No. M.2.1 (Fig. 4.3) and shows repetition. The $S_{p1}$ facies is found to be associated with facies of higher flow regime. The $S_{r2}$ facies occurs primarily in association with $F_m$ facies except in Section No. M.2.1 (Fig. 4.3), where it occurs in between $S_{p2}$ and $S_m$. Most of the levee sections show the presence of $F_m$ facies at the upper part. In case of Section No. S.2.1, $F_m$ is found to be present at the bottom also (Fig. 4.1). The presence of $F_m$ facies, deposited during receding flood, implies periods of quiescence and hence, marks the end of a flood event. The incomplete flood sequences indicate simultaneous erosion and deposition by repetitive flood waves. The vertical distribution of lithofacies of the levee sections suggests deposition of two or more flood sequences. The individual flood sequences are, however, found to be less well developed in some cases. It has also been observed that downstream part of the channel, viz., sections at Pundibari and Madhupur, shows less variety of lithofacies types. The distribution of the frequency percentage of number of occurrences of these 9 different types of lithofacies of the levee sections and percentage of their total vertical profile length show (Fig. 4.11) that $S_{p2}$ facies is the most dominant type of lithofacies whereas of $F_l$ is the least abundant. The frequency percentage and vertical length percentage of the lithofacies types are proportional to each other except $S_h$, $S_{r2}$ and $S_{p2}$. It is also
noticed that the abundance of these 9 types of lithofacies varies with respect to frequency percentage and percentage of total vertical profile length of all the sections (Table- 4.1).

The vertical distribution of lithofacies of the flood plain sections shows association of 8 different types of lithofacies ($F_r$, $F_b$, $F_s$, $S_{r2}$, $S_m$, $S_n$, $S_m$ and $S_{r2}$). The $F_r$ and $S_{r2}$ facies are most common types of facies and found to be present at the top and bottom respectively in all the four flood plain sections. The $S_{r2}$ is also a common variety and present towards the upper part of the vertical sections (except Section No. S.5.1; Fig. 4.4). This facies is associated with low flow regime of either $F_r$ or $F_b$ facies (Section Nos. S.5.2, M.1.1 and M.1.2; Figs. 4.4 and 4.5). The $F_b$, $S_n$ and $S_{mb}$ are the minor facies and occasionally found to occur in certain vertical profile sections (Section Nos. M.1.1 and M.1.2; Fig. 4.5). The $S_m$ lithofacies occurs in association with both high and low energy facies and present only in flood plain sections at Sil Torsa (Section Nos. S.5.1 and S.5.2; Fig. 4.4). The lenticular bedded sand ($F_s$) is found only in flood plains towards the upper part of the sections indicating preservation of incomplete ripples under fluctuating flow conditions. The vertical distribution of lithofacies types does not show the presence of any $F_m$ facies. Though the flood plains are experienced by flood waves, however, the end of a specific flood event may not always be marked by deposition of mud unit. Regular and uniform variations in structures and texture may be indicative of individual flood cycle. The downstream part of the channel shows slightly more variety of lithofacies. Fig. 4.12 represents distribution of the frequency percentage and vertical length percentage of different lithofacies types of flood plain sections. The $F_b$ lithofacies is the least abundant in both frequency percentage and vertical length
percentage whereas S_{r2} and S_{p2} are the most abundant in frequency percentage and percentage of total vertical profile length of all the sections respectively (Table- 4.1).

The channel bar sections show more variety in lithofacies types than levee and flood plain sections. A total 11 different lithofacies types are found (F_r, F_l, F_m, S_{rp}, S_{r1}, S_{r2}, S_{h1}, S_{m}, S_{p1}, S_{p2} and S_{r3}) to be present. The frequency percentage shows that the most dominant type is S_m and the least dominant is F_r facies while S_{p2} covers the maximum percentage of the total vertical profile length (Table- 4.1; Fig. 4.13). The F_r, F_l and S_{r1} facies are found occasionally in some sections. The F_r and S_{r1} facies are found at the top of the vertical sections (Section Nos. S.4.1, M.3.2, C.1 and C.4; Figs. 4.6, 4.7, 4.9 and 4.10). Most of the S_{rp} units are present towards the upper part of the sections and interbedded with high and low flow regime facies. S_{r2} is also found towards the upper part. The S_{p2} facies is associated with either S_{h} or S_{m} towards the lower part of the sections. The occurrence of S_{r1}, S_{p1} and F_m is very less as compared to S_{h}, S_{m} and S_{p2}. The presence of F_m in two sections, deposited during receding flood, implies periods of quiescence and hence, marks the end of flood event. However, the end of a specific flood event may not always be marked by deposition of mud unit. Regular and uniform variations in structures and texture may be indicative of individual flood cycle. The variety of lithofacies varies at different locations. The deposition along the river channel appears to have taken place in phase. The planar and trough cross-beded sand, massive bedded sand and horizontal bedded sand must have been deposited during flood stage. The planar and trough cross-beded units originate as a consequence of migration of bars and 3-D ripples respectively, whereas the horizontal bedded sand must have been deposited in the plane bed phase in the upper flow regime. The massive bedded sand units
have been deposited from the rapid sedimentation. The facies constituted of finer sediments like ripple laminated sand and finely laminated silt and clay were deposited during falling or receding phase of flood waves due to reduced discharge followed finally by the deposition of mud facies, thus making the end of a flood event. However, not all flood events may be recorded in the sequences, because sometimes successive high energy flood waves might erode the deposits of the preceding ones.

4.3 Textural Variations in Vertical Sequence

The textural variations of four size parameters (\(M_2\), \(\sigma_s\), \(Sk_3\) and \(K_G\)) with the lithofacies types have been prepared for each vertical profile section (Figs. 4.1 to 4.10). Fluvial deposits are known for fining upward sequence. The levee, flood plain and channel bar deposits of the present study reach show overall fining upward trend with some variations in between the vertical sequences. In some of the sections [Section Nos. S.2.1 (L), M.2.2 (L), S.4.1 (CB), S.4.2 (CB), P.2.1 (CB) and P.2.3 (CB); Figs. 4.1, 4.3, 4.6 and 4.7], the fining upward tendency is observed where after an initial fining trend, the grain size seems to be gradually increases upward from the middle of the sequence and then finally shows a fining upward trend. This behavior is perhaps due to the composite nature of the sequence which reflects the deposition from two or three superimposed flood phases. During the first flood phase, the deposition took place with usual fining upward tendency but before finally waning out the flood waves, the second phase was gradually brought in the site of deposition resulting yet another flood sequence with gradual fining upward tendency. The two flood plain sections at Sil Torsa (Section Nos. S.5.1 and S.5.2; Fig. 4.4) and one channel bar section (Section No. S.4.2; Fig. 4.6) also show similar
trend, but this is because of the presence of granules in the sections. The vertical
distribution of lithofacies of the levee sections suggests deposition of two or more
complete flood sequence. The individual flood sequences are, however, found to be
less well developed in some cases.

Sorting of the sediments also shows some definite relationship with the grain
size, which is clearly reflected by the close conformity between the mean size ($M_z$)
and standard deviation ($\sigma_t$) curves. The trend of standard deviation curves indicates
a gradual increase of its values towards up implying thereby the sorting becomes
poorer towards the upper part of the sequences except Section Nos. S.5.2 (FP), S.4.1
(CB), S.4.2 (CB), M.3.2 (CB) and M.3.5 (CB) (Figs. 4.4, 4.6 and 4.9). Skewness
($Sk_t$) and kurtosis ($K_G$) do not show any marked variations on relationships as far as
their distribution in vertical sequence is concerned; but the distribution of skewness
shows an upward increase [except Section Nos. S.4.1 (CB), M.3.1 (CB) and M.3.3
(CB); Figs. 4.6, 4.8 and 4.9] in the asymmetry of the sediments. The association of
frequency curves (Figs. 2.10 to 2.13) crudely supports this view point. This indicates
that with decreasing in grain size upward, the finer modes sediment are being added
in increasing proportions and thereby reduces the symmetry and increase the
modality of the sediments.

4.4 Summary Sequences of Morphostratigraphic Units of the Torsa
River

In the present study, an attempt has been made to sum up the significant
structural and textural characteristics of the lithofacies with respect to their
arrangement in the vertical sequence of different morphostratigraphic units, viz.,
levee, flood plain and channel bar. The gravel bar and terrace units have been kept separately because they do not show any structural or textural variations in their vertical sequences. Finally, summary sequences (Harms et al., 1982) for each of the morphostratigraphic unit have been constructed on the basis of the average length of each of the lithofacies units in terms of the cumulative total length from all the vertical profile sections of the particular morphostratigraphic unit in question as well as the observed sequential tendency of their vertical associations.

The lower part of the levee sections is dominantly occupied by the large-scale planar cross-beded sand ($S_{p2}$) followed by either horizontal laminated sand ($S_h$) or massive bedded sand ($S_m$). The minor facies large-scale trough cross-beded sand ($S_{t1}$) is occasionally found to be present (Section No. M.2.1; Fig. 4.3) along with large-scale planar cross-stratified sand ($S_{p2}$). Small-scale planar cross-beded sand ($S_{p1}$) is another minor facies associated with low energy lithofacies of climbing ripple laminated sand Type-2 ($S_{r2}$) and massive bedded silt and clay with roots and bioturbation ($F_r$) (Section Nos. S.2.1 and S.3.1: Fig. 4.1) except Section No. P.1.1 (Fig. 4.2). Another low energy minor facies finely laminated silt and clay ($F_l$) is present only in one section at Sil Torsa (Section S.2.1; Fig. 4.1) interbedded with $S_{p2}$ and $S_h$. The top most part of all the levee sections is capped by the lithofacies $F_r$.

The facies $S_{r2}$ is overlain by massive bedded silt and clay ($F_m$) and found to be present towards the upper part of the vertical sequences (Section Nos. S.2.1, S.3.2 and M.2.1; Figs. 4.1 and 4.3). It is observed that lower part of the sequences is occupied by the high energy facies whereas upper part is occupied by low energy facies. The levee sequence of the present study indicates that fluvial sedimentation is cyclic in nature. This is particularly manifested by the clay bands. To sum up the
sequence of the lithofacies types of levee sections, a summary sequence for the levee unit has been constructed (Fig. 4.14a and Fig. 4.15) in terms of their position and with respect to their abundance.

The flood plain sections show less variation in lithofacies types than levee. It has been noticed that lithofacies $S_{p2}$ covers the lower most part of all the flood plain sections and is overlying by high energy facies either $S_m$ or $S_h$ followed by low energy facies except Section No. M.1.1 (Fig. 4.5) at Madhupur. The minor facies $S_h$ is found to be present only in one section (Section- M.1.2; Fig. 4.5). The facies $F_1$ is found locally at Madhupur (Section No. M.1.1; Fig. 4.5). Most of the upper part of the sections is presented by low energy facies like $S_{r2}$ and $F_p$. It has been observed that the downstream sequence shows relatively more variations and dominated by the smaller dimension structures than the upstream sequence. The top most part of all the sections are covered by $F_p$. To sum up the sequence of the lithofacies types of flood plain sections, a summary sequence for the flood plain unit has been constructed (Fig. 4.14b and Fig. 4.15) in terms of their position and with respect to their abundance.

The bar sequences show more variations in lithofacies types than other morphostratigraphic units. A total 12 types of different lithofacies have been encountered. The gravel bar sections from Phuentsholling to Sil Torsa comprise only $G_{ms}$ lithofacies whereas channel bar sections from Sil Torsa to Cooch Behar show 11 types of different lithofacies ($S_{p1}$, $S_{p2}$, $S_{r1}$, $S_{r2}$, $S_{rp}$, $S_{r1}$, $S_m$, $S_h$, $F_1$, $F_m$ and $F_p$). The major high energy facies $S_{p2}$ occurs towards the bottom part of all the sections except in Section No. P.2.3 (Fig. 4.7). This facies is associated with other major
types of high energy facies like $S_m$ or $S_h$ and sometimes they are interbedded with $S_p$. The low energy facies $S_{r2}$ and $S_m$ are found in abundance towards the upper part in the present channel bar sequences. The minor low energy facies $S_{r1}$ is found only at Cooch Behar. The other minor low energy facies $S_{p1}$, $F_m$ and $F_i$ also occupy the upper part of the vertical sequences. The very rare $F_i$ facies occurs only in Section No. S.4.1 (Fig. 4.6) and associated with $F_m$. Most of the sections show that top most part is capped by low energy lithofacies. Occasionally it may be covered by $S_h$ and $S_m$ (Sections Nos. S.4.2 and M.3.1; Figs. 4.6 and 4.8). The channel bar sequence of upstream part is more cyclic in nature than the downstream part. Miall (1977, 1978) defined six (6) types of depositional environment and resultant facies assemblages for low sinuosity, multiple channel braided rivers. Due to the distinct variation between the lithofacies types of gravel bar and channel bar sequences, two types of braided bar sequence, one for the upstream part of the gravelly study reach, i.e., from Phuentsholing to Sil Torsa and another for the downstream part of the sandy study reach, i.e., from Sil Torsa to Cooch Behar can be correlated with the classification suggested by Miall (1977, 1978). On the basis of his classification, the gravel bar sections can be, to some extent, compared to Trollheim type, which is characterised by the presence of major facies $G_{ms}$ and $G_m$ and the less genetic significant minor facies of $S_t$, $S_n$, $F_i$ and $F_m$. However, in case of the gravelly bars of the present study, only a lone facies $G_{ms}$ has been found and the other lithofacies types of Trollheim type of model are found to be absent which may be due to the constraint of limited exposure of the vertical profile sections of ½ m to 1 m length. The channel bar sequences can also be, to some extent, compared to the Platte type. The major lithofacies in the Platte type are $S_p$ and $S_t$ with minor lithofacies of $S_h$, $S_r$, $G_m$, $F_i$ and $F_m$. In the present channel bar sequence, major lithofacies $S_p$ and $S_h$ with
minor presence of F, Fm, and S, are found to be present while massive or crudely bedded gravel (Gm) lithofacies is totally absent. Based on the sequences of lithofacies of 16 vertical profile sections of the channel bars, a summary sequence for the channel bar unit has been constructed (Fig. 4.14c and Fig. 4.15) in terms of their position and with respect to their abundance. No depositional model has been proposed for gravel bar because of the presence of only one type of lithofacies Gm. The terrace, levee and flood plain sequences have not been correlated with the classification of Miall (1977, 1978) as these morphostratigraphic units fall outside the main channel of the river.

The terrace sections of the upstream part of the river between Phuentsholing and Hasimara comprise only Gms facies like gravel bar and no depositional model has been constructed. The presence of same type of lithofacies (Gms) in case of both terrace and gravel bar may be attributed to the fact that the river dynamic system that prevailed earlier is more or less the same with the one that prevail at present, as terrace represents the older river bed. The gravel sheets are composed of open framework of gravels with unfilled voids, which represents channel lag deposits.
Table 4.1: Relative abundance of lithofacies types in different morphostratigraphic units.

<table>
<thead>
<tr>
<th>Abundance (Position)</th>
<th>Lithofacies (Levee)</th>
<th>Lithofacies (Flood Plain)</th>
<th>Lithofacies (Channel Bar)</th>
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<tbody>
<tr>
<td></td>
<td>Frequency %</td>
<td>Length %</td>
<td>Frequency %</td>
</tr>
<tr>
<td>1 (Least)</td>
<td>F₁</td>
<td>F₁</td>
<td>F₁</td>
</tr>
<tr>
<td>2</td>
<td>Sₜ₂</td>
<td>Sₚ₁</td>
<td>Sₜ₂</td>
</tr>
<tr>
<td>3</td>
<td>Sₚ₁</td>
<td>Sₜ₂</td>
<td>Sₚₚ</td>
</tr>
<tr>
<td>4</td>
<td>Sₗ₂</td>
<td>Sₗ₂</td>
<td>Fₛ</td>
</tr>
<tr>
<td>5</td>
<td>Sₙ</td>
<td>F₁</td>
<td>Sₘ</td>
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<td>6</td>
<td>Fₘ</td>
<td>Fₘ₁</td>
<td>F₁</td>
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<tr>
<td>7</td>
<td>F₁</td>
<td>Sₙ</td>
<td>Sₚ₂</td>
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<td>8</td>
<td>Sₘ</td>
<td>Sₘ₁</td>
<td>Sₗ₂</td>
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<tr>
<td>9</td>
<td>Sₚ₂</td>
<td>Sₚ₂</td>
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<tr>
<td>10</td>
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</tr>
<tr>
<td>11 (Most)</td>
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</tbody>
</table>
Fig. 4.1: Vertical sequences of levee at Sil Torsa showing associations of lithofacies and variations of textural parameters.
Fig. 4.1 (contd..): Vertical sequences of levee at Sil Torsa showing associations of lithofacies and variations of textural parameters.
Fig. 4.2: Vertical sequences of levee at Pundibari showing associations of lithofacies and variations of textural parameters.
Fig. 4.3: Vertical sequences of levee at Madhupur showing associations of lithofacies and variations of textural parameters.
Fig. 4.4: Vertical sequences of flood plain at Sil Torsa showing associations of lithofacies and variations of textural parameters.
**Section No. - M.1.1 (FP)**

Fig. 4.5: Vertical sequences of flood plain at Madhupur showing associations of lithofacies and variations of textural parameters.
Section No.- S.4.1 (CB)

Section No.- S.4.2 (CB)

Section No.- P.2.1 (CB)

Fig. 4.6: Vertical sequences of channel bar at Sil Torsa and Pundibari showing associations of lithofacies and variations of textural parameters.
Fig. 4.7: Vertical sequences of channel bar at Pundibari showing associations of lithofacies and variations of textural parameters.
Fig. 4.8: Vertical sequences of channel bar at Pundibari and Madhupur showing associations of lithofacies and variations of textural parameters.
Fig. 4.9: Vertical sequences of channel bar at Madhupur showing associations of lithofacies and variations of textural parameters.
Fig. 4.9 (contd..): Vertical sequences of channel bar at Madhupur showing associations of lithofacies and variations of textural parameters.
**Fig. 4.10:** Vertical sequences of channel bar at Cooch Behar showing associations of lithofacies and variations of textural parameters.
Fig. 4.10 (contd..): Vertical sequences of channel bar at Cooch Behar showing associations of lithofacies and variations of textural parameters.
Fig. 4.11: Distribution of frequency percentage and vertical length percentage of different lithofacies types of the levee sections.

Fig. 4.12: Distribution of frequency percentage and vertical length percentage of different lithofacies types of the flood plain sections.

Fig. 4.13: Distribution of frequency percentage and vertical length percentage of different lithofacies types of the channel bar sections.
Fig. 4.14: Summary sequences of levee (a), flood plain (b) and channel bar (c) of the Torsa River.
Small-scale planar cross-bedded sand ($S_{p1}$)
Large-scale planar cross-bedded sand ($S_{p2}$)
Massive bedded sand ($S_m$)
Horizontal laminated sand ($S_h$)
Climbing ripple laminated sand in drift, type-1 ($S_{r1}$)
Climbing ripple laminated sand in drift, type-2 ($S_{r2}$)
Climbing ripple laminated sand in phase ($S_{rp}$)
Small-scale trough cross-bedded sand ($S_{t1}$)
Large-scale trough cross-bedded sand ($S_{t2}$)
Massive silt and clay with roots and bioturbation ($F_r$)
Massive bedded silt and clay ($F_m$)
Finely laminated silt and clay ($F_i$)
Lenticular bedded sand ($F_s$)

Fig. 4.15: Legends for the different lithofacies types.