Abstract: Sedimentation in a fluvial system leads to the formation of bars with varied morphology, bedform features and internal stratification. These features bear imprints of the hydrodynamic conditions which had prevailed during bar formation and development. The Brahmaputra River of north-east India represents a sandy braided river with very large bedforms and frequent channel migration, switching and avulsion. This study examines the lithofacies types and their associations which had developed in different parts of a Unit Bar of the Brahmaputra River near Dibrugarh, Assam. The study indicates that lithofacies associations in a braided river deposit may show frequent variations due to changes in the prevailing hydrodynamic conditions in the area.

Keywords: Lithofacies, Unit Bar, Brahmaputra River, Assam

Introduction: A close relationship exists between water flow, sedimentation and bedform development in a river channel (Hjulstrom, 1939; Sundborg, 1967; Shields, 1936; Miller et al., 1977 ). In a fluvial system, sediments derived through erosion are transported away from the source as bedload or suspended load and subsequently get deposited in regions where the kinetic energy of the transporting media drops. Subsequently sedimentation takes place through initiation and development of “bars” (Cant and Walker, 1978), many of which may continuously undergo modification through the process of sedimentation to form unit bars (Smith, 1974). Also, adjacent bars may merge together to form bar assemblages (Bristow, 1987). The bars develop varied bedform features and internal stratification, whose characteristics are the reflection of the hydrodynamic conditions prevailing during the time of their deposition.

In north-east India, the Brahmaputra River represents an antecedent snowfed river (Sarma, 2004) which is thought to have existed before the origin of the Eastern Himalayas and which had formed a part of the ancient Indo-Brahm River (Pascoe, 1919) or the Siwalik River (Pilgrim, 1919). In this region it flows through the states of Arunachal Pradesh and Assam for a length of approximately 950 km before it finally debouches its sediment load into the Bay of Bengal (Fig.1a). It is a sandy braided river with very large bedforms (Coleman, 1969) and marked by frequent channel migration, switching and avulsion. Also, there is rapid change in rate of sedimentation during the falling stages of flood cycles.

Near Dibrugarh in Assam, the thalweg of the main channel shifts northwards towards the northern bank of the river and a large crescent shaped compound bar is found between the thalweg and the southern bank of the river (Fig.1b). This compound bar is further incised by 2nd to 4th order channels. Many portions of this bar have become stabilized over time, while there still remains many portions marked by annual bar-pattern changes after the end of a flood cycle.
This study focuses on the occurrence of different lithofacies types and their association in a unit bar of a 2nd order channel of the Brahmaputra river near Dibrugarh, Assam (Fig.1c). The study also attempts to decipher the channel flow characteristics in the associated channel of the unit bar.

**Methodology:**
The unit bar had emerged post-monsoon within the 2nd order river channel in year 2014. Subsequently, all prominent surface bedform features which had developed on the unit bar surface were identified, described and their dimensions systematically recorded. Trenches were dug at the downstream and upstream portion, as well as in the central portion of the left and right flanks of the unit bar. These trenches were used for identification of types and various other aspects of internal stratification. The lithofacies types were identified following the lithofacies scheme for fluvial deposits by Miall, 1978. Internal stratification attitude, thickness and textural characteristics were measured with the help of a Brunton Eclipse Pro Compass and a Flexible Geoscience Degree (University of Leicester). Representative sediment samples from various lithofacies units were collected for laboratory textural analysis.

Post monsoon hydrologic and bathymetric measurements along the 2nd order channel of the Brahmaputra river between Nagaguli Ghat and Spur No.1 (near Paltan Bazar) was also undertaken along three traverses aligned normal to the flow in the channel. Water current velocity at various predetermined locations and depths was measured with the help of a micro-computer based water velocity recorder which was connected to a cup-type current meter. Current velocity data recorded at various depths and locations was used in deciphering spatial variations in current velocity in the study area.

Markov Chain Analysis is a statistical tool which has been successfully utilized in examining cyclicity in sedimentation (Miall, 1973, Harbaugh & Bonham-Carter, 1970). The single-dependency method has been used in this study to investigate the sedimentation cyclicity. The details of the methodology has been described elsewhere in many texts (Lindholm, 1987; Miall, 1990).

**Observation and Interpretation:**
The portion of the 2nd order channel under investigation exhibits a slightly sinuous trend. The unit bar considered for the present study lies within the 2nd order channel, and has a roughly trapezoidal planform with a length of approximately 1500 m and maximum width of 570 m. Its presence leads to bifurcation of the flow in the channel, with the southern channel remaining active for a longer duration than its northern counterpart. The bar margins show water-level cut marks formed due to erosion by gradually receding water level after the post-flood emergence of the bar. Undulatory and linguoidal ripples (Fig.2a.) have formed in subaqueous sediments which are currently being deposited along the bar periphery. The bar-tops contain dunes with sinusoidal crestlines, wind generated ripples (Fig.2b.), raindrop imprints, worm trails and bird footmarks.

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**Fig. 2. Bedform structures found in the area.**

2a. Undulatory to lingoidal ripples. *Flow from back to front.*

2b. Wind generated ripples. *Flow from front to back.*

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The hydrological and bathymetric measurements in the river channel reveal that the maximum depth of water in the channel varies between 3 m in the upstream portion to 3.5 m in the downstream portion. Also there is a widening of the channel from 40 m in the upstream portion to 60 m in the downstream portion of the area. The cross sectional profiles of the river-bed indicate a shift of the thalweg from the right bank towards the left bank (Fig.3). Water current velocities recorded from
Fig 3: Cross-sectional profiles of the 2nd order channel showing variations of water-current velocity at various depths within the channel.

The upstream portion:
The upstream portion of the unit bar is composed of medium and fine sands (Mz 1.97φ – 2.32φ) and comprises of four lithofacies varieties, namely massive sand (Sm), planar cross-stratified sand (Sp), trough cross-stratified sand (St) and rippled sand (Sr) (Fig.4; Trench-1). Sm is devoid of internal stratification and contain large drifted wood pieces with smoothened edges and surface.

different depths indicate highest flow velocity in the central portion of the upstream part of the channel, where it attains a velocity of 1.4m/sec. The maximum velocity recorded from the central portion of the channel is 1.2m/sec. The maximum flow velocity drops further to 1.0m/sec in the downstream portion of the channel, where its width widens out to 60m.
This smoothening is due to their abrasion and long distance of transport by sediment-laden water. The unit is overlain by Sp along a 33° down-current sloping surface. The internal laminae of Sp also dip at the same angle ( = 33°), and are formed by the avalanching down of sediments along the slope surface. The surface represents the lee side of a large dune. Here lithofacies Sp is overlain by lithofacies St. The foreset laminae show alternations of mud-rich and mud-deficit layers with thickness ranging between 7 and 12 mm. The foreset angle vary between 26 and 34°. The lowest portion of the sequence is composed of large-scale trough cross stratified sand (St) with maximum coset thickness of 31 cm. The dimensions of St diminish gradually towards the upper portion of this unit, where it ultimately attains an average coset thickness of 14 cm. There is also a corresponding reduction in average thickness of foreset laminae to about 5 mm.

Facies St is overlain by repetitions of small trough (coset length 7-13 cm.) cross stratified sand and ripple bedded sand (Sr), which formed in sediments deposited in a scoured channel which had incised the bar surface. Two repetitions of St and Sr are discernable in the sequence.

The lithofacies sequence indicates prevalence of low flow regime condition with a gradual reduction in stream power in this portion of the unit bar.

The flanks:

The middle portion of the northern flank of the unit bar exhibits a 1.16 m thick sandy sequence comprising of low angle trough cross-stratified sand (St), massive mud (Fm) and horizontal laminated sand (Sh) facies (Fig.4; Trench-4). Lithofacies St and Fm comprise the lower portion of the sequence. Above them, the facies changes to Sh with thin layers of Fm. Facies Sh is composed of thin (average thickness 3 mm.) alternations of mud-rich and mud-poor layers of sand, and have a total thickness of 27 cm. Facies Fm is composed of thin bedded dark grey coloured mud (average thickness of beds 2 cm).

Trough cross stratified sand (St) with partially developed sigmoidal foresets are found towards the top of the sequence. The cosets decrease in dimension from bottom towards top of the unit. The average thickness of the internal laminae vary between 3 and 5 mm. The foreset angle dip between 3° and 14° downstream.

The observed transition of lithofacies from St through Fm to Sh and finally St (with sigmoidal foresets) reflects initial deposition of sediments in a low flow regime condition and the formation of dunes (Miall, 1987). Subsequent drop in flow velocity during the waning stages of floods led to the deposition of mud layers upon St. The presence of Sh over St indicates prevalence of planar bed flow and a change from lower flow regime conditions to upper flow regime conditions during the time of deposition of Sh. The presence of St with sigmoidal
foreset laminae in the topmost portion of the sequence reflects drop in flow velocity and a subsequent reversal to lower flow regime conditions in the area. The southern flank of the bar contains facies Fm, Sr, Sln (lenticular bedded sand), St and Sm (Fig.4; Trench-3). Each lithofacies unit overlies another with an erosional contact. The sediments comprising the different lithofacies are composed of very fine sand and fine sand ($M_z = 2.4\phi$ – $3.5\phi$). The base of the sequence is characterised by the presence of irregular mudclasts in massive sand (Sm). It is succeeded by massive mud (Fm). A 1.02m thick layer of Sr and Sln overlies Fm. They are subsequently overlain by St. No upward reduction in sizes of cosets are seen within the sequence. The bar top contains linguoidal ripples with a thin mud drape upon them. The lithofacies sequence represents a gradual transition from a flood recession deposit (at the base) towards depositional settings characterising low flow regime condition with gradual increase in stream power.

The downstream portion:
The downstream portion of the bar is composed almost entirely of facies Sh. A thin mud drape (Fm) occurs at the top of the sequence. The individual laminae of Sh have thickness ranging between 2.5 mm and 10 mm (Fig.4; Trench-2). The laminae thickness increase from the bottom towards the top of the sequence. They are composed of medium sand and fine sand ($M_z = 1.95\phi$ – $2.25\phi$). The occurrence of Sh indicates prevalence of upper flow regime conditions in this location. The description of lithofacies types and association indicates that the upstream part of the studied unit bar is composed largely of sediments deposited in a low flow regime condition where conditions for deposition of sediments never calmed down to favour the deposition of mud (i.e., Facies Fm). The lithofacies associations characterising the two flanks exhibit dissimilar features. The northern flank (which lies more closer to the main channel) preserves impressions of prevalence of upper flow regime conditions (facies Sh) for short time intervals. The southern flank on the other hand preserves the impression of a single complete flood cycle. It preserves a complete sequence comprising of Fm, Sr, Slm and St and finally Fm. The downstream end of the unit bar reflects the prevalence of upper flow regime condition for most of the time. The lithofacies is composed of Sh with a thin mud drape at the top of the sequence.

Markov Chain Analysis was attempted to understand cyclicity of sedimentation in the lithofacies associations encountered in trench 3 and 4. The probability matrix and the Facies Relationship Diagram (FRD) for the two associations are given below. The prominent solid lines indicate transitions significant at 0.10 significance level. The FRD for trenches 3 and 4 indicates the difference in facies association occurring in the northern and southern banks of the unit bar.

<table>
<thead>
<tr>
<th></th>
<th>Sm</th>
<th>Fm</th>
<th>Sr</th>
<th>St</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sm</td>
<td>0.00</td>
<td>0.25</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Fm</td>
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<td>0.00</td>
<td>0.33</td>
<td>1.00</td>
</tr>
<tr>
<td>Sr</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.25</td>
</tr>
<tr>
<td>St</td>
<td>0.25</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Probability Matrix for Trench - 3**

<table>
<thead>
<tr>
<th></th>
<th>St</th>
<th>Fm</th>
<th>Sh</th>
</tr>
</thead>
<tbody>
<tr>
<td>St</td>
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<td>0.25</td>
<td>1.00</td>
</tr>
<tr>
<td>Fm</td>
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<td>0.00</td>
<td>0.41</td>
</tr>
<tr>
<td>Sh</td>
<td>1.00</td>
<td>0.25</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Probability Matrix for Trench - 4**

![FRD for Trench-3](image)

**FRD for Trench-3**

![FRD for Trench-4](image)

**FRD for Trench-4**

**Conclusion:**
Braided rivers are characterised by very large bedforms and frequent changes in its channel pattern. There is also rapid change in the rate of sedimentation during the falling stages of a flood cycle. In case of the present unit bar, these changes
are very prominently displayed by the variations in lithofacies associations occurring at different portions of the unit bar. The upstream part of the unit bar reflects deposition of sediments under low flow regime conditions, while the downstream end of the unit bar displays features reflecting deposition under high flow regime conditions. Variations in lithofacies association found in the northern and southern part of the bar are reflected prominently in the corresponding Facies Relationship Diagrams (FRD). Thus, the study indicates that lithofacies associations in a braided river deposit may show frequent variations due to changes in the prevailing hydrodynamic conditions in the area.

References:


Smith, N.D., 1974 Sedimentology and bar formation in the Upper Kicking Horse River, a braided outwash stream. J. Geol., 82, 205-223.