Facies Analysis of the Neogene Surma Group Succession in the Subsurface of the Surma Basin, Bengal Basin, Bangladesh

DEWAN NAHID SULTANA & M. MUSTAFA ALAM

Abstract

From a geological perspective the Bengal Basin, in the north-eastern part of the Indian subcontinent, is situated at the junction of three interacting plates, namely, the Indian, Burmese and Tibetan plates. This forms a prominent hydrocarbon-bearing sedimentary basin in south-central Asia that contains about 22 km of Tertiary sediments, one of the world's thickest accumulations.

This research work is a sedimentological study of the subsurface Neogene clastic succession within the Surma basin, with special emphasis on detailed facies analysis of the Miocene-Pliocene Surma Group that contains important reservoir sandstones. Core samples from the Fenchuganj-2 and the Kailastilla-2 wells show twelve individual facies types. All the facies types have been grouped together into four facies associations on the basis of the dominant process of formation of each facies, their affinity to occur together, as well as their overall depositional environments. These facies associations are: (I) Offshore to shelf; (II) Tidal flat; (III) Tidal ridge; and (IV) Tidal channel associations. The sediments of the Surma Group within the study wells have been interpreted as representing deposits of shallow marine to tide-dominated coastal depositional settings, characterised by cyclic regressive phases with occasional transgressive incursion of offshore to shelf facies.

Key words: Sedimentology, facies analysis, environments, Surma Group, Surma basin.

Introduction

The Bengal Basin (Fig. 1), in the north-eastern part of the Indian subcontinent, is located at the junction of three interacting plates, namely, the Indian, Burmese and Tibetan plates. This basin represents a prominent hydrocarbon-bearing sedimentary basin in south-central Asia, and is well known for the development of one of the thickest (± 22 km) sedimentary accumulations in the world. The sedimentary-fill within the basin is of Tertiary age, with the Neogene Surma Group succession containing important sandstone reservoirs particularly in the eastern part of the basin, including the Surma basin.

The Surma basin has formed mainly as a consequence of subsidence along the Dauki Fault system, which is thought to have a huge vertical displacement.

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Fig. 1. Regional tectonic setting of the Bengal Basin showing the position of the Surma basin in relation to the surrounding tectonic elements. Hinge zone separates the Indian platform to the west from the central deep basin and Chittagong-Tripura Fold Belt (CTFB) to the east. (Modified from UDDIN & LUNDBERG 1998).

with little or no lateral shear (HILLER & ELahi 1988). The present-day configuration of the Surma basin is confined by the Precambrian basement complex (PASCOE 1973) of the Shillong Plateau to the north, and in the east and south-east by the CTFB. Towards south and south-west the basin is open to and generally ascends towards the 'Hinge Zone' (Fig. 1). The basin is characterised by large, closed, negative gravity anomaly, has minimal topography and contains numerous lakes and swamps and is actively subsiding, showing subsidence rates in the order of 11 m within the last few hundred years (MORGAN & MCIINTIRE 1959).

In the Bengal Basin, a considerable database including geological, geophysical and sedimentological data has been established through hydrocarbon exploration activities during the past few decades. In this regard,

The focus of the present research work is a detailed facies analysis pertaining to the depositional environments and paleogeographic settings for the Neogene clastic succession encountered in drill holes of the Fenchuganj-2 and the Kailastila-2 wells in the Surma basin, north-eastern Bengal Basin (Fig. 2). Special emphasis has been given to the Surma Group sediments because, in most of the gas/condensate fields discovered so far in Bangladesh, hydrocarbon is thought to have been generated from and trapped within the sediments of this Group. Since the basin is an important gas-bearing province, the paleoenvironments of deposition of the Neogene succession within the basin needs to be evaluated and understood in detail for accurate stratigraphic prediction of architecture of the reservoir facies and reservoir pattern.

Thirteen cores (between depth range of 2,190 m and 4,939.3 m) from the Fenchuganj-2 well and thirteen cores (between depth range of 2,270 m and 3,026.3 m) from the Kailastila-2 well have been taken into consideration. A number of individual facies types were identified on the basis of comprehensive logging of the available core samples from the Surma Group succession (Table 1). Based on detailed facies analysis of the core samples from the wells, an attempt has been made in this study to interpret the depositional environments of the Surma Group sediments within the Surma basin.

The stratigraphic successions of the various tectonic settings of the Bengal Basin (KHAN & MUMINULLAH 1986) are not adequately known and suffer from over simplification and over generalisation. The stratigraphic subdivision of the Surma basin was initially established by lithostratigraphic correlation with the type sections in the Assam Basin, north-eastern India (EVANS 1932). This subdivision was fundamentally based on the sandstone-shale ratio, especially, in the subdivision of the Surma Group. Due to the tectonic complexity within the Bengal Basin, and also the lack of marker horizons, diachronism of formations and the spatial changes in lithology, which commonly occur in prograding shoreline to delta sequences, it is not rational and realistic to correlate lithologically certain formations between different parts of the basin or even between two different basins as adopted in the past and as practiced at present. However, for the purpose of this study a somewhat updated Cenozoic lithostratigraphic succession for the Surma basin and adjoining areas has been followed, which is summarised in Table 1 (HILLER & ELAHI 1988).
Table 1. Lithostratigraphic succession of the Surma basin showing the seismic markers and thickness of the stratigraphic units (modified from HILLER & ELahi, 1988).

<table>
<thead>
<tr>
<th>Age (approx.)</th>
<th>Group</th>
<th>Formation</th>
<th>Seismic Marker</th>
<th>Thickness (max.) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holocene</td>
<td>DIHING</td>
<td>Alluvium</td>
<td></td>
<td>3,350</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dihing</td>
<td>Yellow</td>
<td></td>
</tr>
<tr>
<td>Pleistocene</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Pliocene</td>
<td>DUPI TILA</td>
<td>Upper Dupi Tila</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Lower Dupi Tila</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Pliocene</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Miocene</td>
<td>TIPAM</td>
<td>Girijan Clay</td>
<td>Brown</td>
<td>3,500</td>
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<td></td>
<td></td>
<td>Tipam Sandstone</td>
<td></td>
<td></td>
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<tr>
<td>Miocene</td>
<td>SURMA</td>
<td>Upper Marine Shale</td>
<td>Red</td>
<td>3,900</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Oligocene</td>
<td>BARAIL</td>
<td>Renji</td>
<td>Violet</td>
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<tr>
<td></td>
<td></td>
<td>Jenam</td>
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<td></td>
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<td>Laisong</td>
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<td></td>
</tr>
<tr>
<td>Paleocene-Eocene</td>
<td>JAITIA</td>
<td>Kopili Shale</td>
<td>Blue</td>
<td>7,200</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Paleocene</td>
<td></td>
<td>Undifferentiated sedimentary rocks (with some volcanics ?) on the continental basement complex</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Facies Analysis

In this study twelve distinct facies types have been identified, which were grouped into four facies associations on the basis of their formative processes, affinity to occur together, and their overall depositional environments. These facies and facies associations occur in various proportions throughout the Surma Group succession in the study wells. On the basis of detailed analysis pertaining to depositional processes, the relationships between individual facies within each of the facies associations have been documented, and the environments of deposition of the Surma Group sediments have been interpreted in relation to the paleogeographic settings. The facies types within each facies associations are first described and then interpreted below.

Offshore to Shelf Facies Association

Types of facies within this facies association include shale/mudstone and sand/silt-streaked shale.
Description

*Shale/Mudstone Facies:*

This facies consists of predominantly grey to bluish-grey; very thin to evenly laminated shale and minor massive mudstone, which is occasionally silty. Shale is mainly grey to blackish-grey in colour, with bed thickness ranging from a few centimetres to a few tens of centimetres, whereas, the mudstone is dark grey to black in colour (Fig. 3A). This type of facies is very common in the cores 4, 11, 12, 14 and 16 of the Fenchuganj-2 well, and in the cores 11, 12 and 13 of the Kallastila-2 well.

*Sand/Silt-Streaked Shale Facies:*

The most prominent facies type in the study cores is shale with sand/silt-streaks (Fig. 3A). Bed thickness of this facies varies from a few to a few tens of centimetres. The facies is grey to blackish-grey in colour, while the sand/silt-streaks within this facies are light grey in colour. Sand is fine-grained and silt ranges from coarse to fine in size. The streaks are less than 1 mm to a few
millimetres in thickness, with flat to slightly undulatory upper and lower contacts, and are continuous to discontinuous; sometimes bioturbated intervals with minor burrows have been observed. Occasional soft-sediment deformation intervals are also present. This facies is common in the cores 11, 12, 14 and 16 of the Fenchuganj-2 well.

In the cores 11 and 12 of the Kailastila-2 well, the sand/silt-streaks within this facies are usually greyish-brown to light brown in colour. The streaks are commonly discontinuous and rarely continuous; and characterised by nearly flat to undulatory contacts within the shale. Bed thickness of the sand/silt-streaked shale facies ranges from a few cm to few tens of cm; and the facies lacks burrows and bioturbated intervals unlike in the cores from the Fenchuganj-2 well.

Interpretation

The offshore to shelf facies association mainly reflects laminated grey to bluish grey shale with occasional sand/silt-streaks, lens and/or interlaminae and subordinate mudstone/shale. The association is interpreted as representing quite water depositional environment of the shelfal to offshore settings, with water depth of more than 50 m, where the sand/silt-streaks have been deposited during high tides and/or storm. Shale facies is occasionally bioturbated and contain burrows filled with fine sand and silt indicating occasional sand/silt influx to the shelf area.

Tidal-Flat-Facies Association

The facies types within this association include shale with lenticles (lenticular bedding), wavy-bedded sand/mud, flaser-bedded sandstone and ripple-laminated sandstone with mud drapes.

Description

Lenticular-Bedded Facies:

This type of facies occurs most commonly in the cores 7, 8 and 10 of the Fenchuganj-2 well and in the middle portion of the core 9 of the Kailastila-2 well. The colour of shale in this facies ranges from grey to bluish-grey; and the lenses within the shale are light grey in colour. The lenses are rippled and appear as either isolated or weakly connected (Fig. 3B). They are composed of fine-sand and coarse- to fine-silt showing internal micro cross-lamination commonly referred to as 'starved ripples' (Reineck & Singh 1980) when they occur as isolated lenses. The ripples are commonly asymmetrical in nature, but occasional symmetrical types have also been encountered. Vertically adjacent rippled lenses may show opposite current orientation (Fig. 4A). Soft-sediment
deformation structures and deformed nature of lenticles have occasionally been observed; and only in the Fenchuganj cores intensely convoluted beds with micro folds and/or faults were seen. A few bioturbated horizons with worm burrows are also present.

Wavy-Bedded Sand/Mud Facies:

Wavy-bedded facies is represented by straight to wavy intercalation of sand/mud units that are a few mm to a few cm in thickness. Grey coloured mud and light grey coloured ripple-laminated sandy siltstone and sandstone characterise these intercalations (Fig. 4A). The mud layers overlie the ripple crests and more or less fill the ripple troughs, so that the surface of mud layers only slightly follow the concave or convex curvature of the underlying ripples. Ripples are mainly asymmetrical, showing bi-directional orientation (Fig. 4B) with relatively flat bases. Worm burrows, small-scale folds and faults, loading, soft-sediment deformation (Fig. 4) and ball-and-pillow structures along with mud injections have been observed in several cores.
Fig. 4. (A) Lenticular- to wavy-bedded facies (facies association II) showing isolated or connected,
cross-laminated lenticles in core 10 (3,615 m - 3,624 m) of the Fenchugang-2 well. Note
dehformed nature of the lenticles. (Coin is 2 cm in diameter). (B) Wavy-bedded facies of facies
association II in core 7 (3,135 m - 3,143 m) of the Fenchugan-2 well showing silty to sandy
layers, which are ripple-laminated with bi-directional orientation. Note small-scale loading
structure and injection of mud. (Coin is 2 cm in diameter).

**Flaser-Bedded Facies:**

This type of facies is characterised by light grey to greyish-brown, fine- to
medium-grained sandstones with thin and dark grey mud flasers and occasional
mud intraclasts. Mud flasers usually occur on the ripple troughs and sometimes
continue on lower part of the ripple foreset laminae. This facies has an increased
content of sand with minor mud as flakes. In the study cores a gradation usually
occurs from the flaser-bedded facies to wavy-bedded facies (Fig. 5A). Thickness
of individual beds of this facies ranges from 10 to 30 cm. Reactivation surfaces
and intersecting trough-shaped ripple-laminations are apparent in most of the
study cores (Fig. 5B). Thin mud drapes commonly occur along the ripple
foreset in several cores. Ripple-laminations in this facies indicate their formation
by migration of asymmetrical ripples. Flaser thickness ranges from 1 to 4 cm
and its width varies from a few millimetres to a few tens of centimetres. Ripple-
laminae sets are sometimes bi-directional in orientation. Similar facies types have
been described by Alam (1995a) from the Baraichari Shale formation of the
Surma Group succession in the Sitapahar anticline in south-eastern fold belt of
Tucker (1989) and many others have also described the flaser-bedded facies from both modern and ancient sediments. This facies has been commonly encountered in the cores 7, 8, and 10 of the Fenchuganj-2 well.

Fig. 5. (A) Photograph showing ripple-cross-laminated sandstone facies (facies association III) passing upward into flaser-bedded facies then into lenticular-bedded facies (facies association II). Note herringbone cross-lamination encountered in core 8 (3,260 m - 3,269 m) of the Fenchuganj-2 well. (Pencil is 14 cm long). (B) Ripple-laminated sandstone facies passing upward into wavy-bedded facies and then into lenticular-bedded facies of facies association II in core 10 (3,615 m - 3,624 m) of the Fenchuganj-2 well. This core demonstrates a fining-upward sequence produced by tidal flat progradation. The lenticles are connected or isolated, internally cross-laminated showing bi-directional orientation. (Hammer is 4.8 cm long).

Ripple-Laminated Sandstone Facies:

This facies is characterised by light brown to brownish-grey sandstones and sandy siltstone, containing mud drapes along the foresets of cross-lamina (Fig. 5A & B). This facies is continuously rippled, fine-to medium-grained where the ripples are mainly asymmetrical, but occasionally symmetrical in nature. Individual bed thickness of this facies varies from 4 to 15 cm. The ripple-lamination sometimes shows bi-directional orientation indicating reversal of the depositing current. The ripple-laminated facies has been commonly encountered in the cores 8 and 9 of the Kailastila-2 well, and also in the cores 8, 9, 10, and 15 of the Fenchuganj-2 well. Sporadically distributed worm burrows are abundant in cores of the Fenchuganj well in comparison with cores of the Kailastila well.
Interpretation

In facies association II, the wavy-bedded facies is interpreted to have been deposited under low to moderate energy conditions in the middle part of the intertidal zone, whereas, the flaser-bedded facies and ripple-laminated facies with mud drapes are thought to be the characteristic deposits of the lower intertidal to upper subtidal zone (De Raaf & Boersma 1971). In these sub-environments sedimentation occur during moderate energy conditions and is apparently dominated by suspension fall out of mud in the form of drapes and flakes, associated with the slack water periods between ebb and flood tides. The lenticular-bedded facies in which the lenticles are internally micro cross-laminated, indicate weak current in a low energy condition. This facies indicates deposition in the upper intertidal to supratidal zones, where sedimentation mainly occurs from suspension. All the internal sedimentary structures within the facies in facies association II represents the continuum of tidal structures of Reineck & Wunderlich (1968); and are commonly thought to have been generated by the progradation of tidal flats within the intertidal zone of the tidal depositional setting.

Tidal-Ridge Facies Association

Cross-laminated sandstone, parallel-laminated sandstone, trough cross-bedded sandstone and planar cross-bedded sandstone comprise this facies association.

Description

Cross-Laminated Sandstone Facies:

This type of facies consists of fine- to medium-grained cross-laminated sandstone, which is light grey to brownish-grey in colour and lacks any significant mud drapes and mud clasts. Bed thickness of cross-laminated facies, on an average exceeds 25 cm in cores of the Kailastila-2 well, and varies from 20 cm to more than 50 cm in cores of the Fenchuganj-2 well. Ripples are mainly asymmetrical in nature having amplitudes of few cm. Vertically adjacent sets of cross-laminated sandstone facies show opposite dip directions producing herringbone cross-stratification (Fig. 5A). This type of facies is common in the cores 8, 9, 10, 13 and 15 of the Fenchuganj-2 well and the cores 5 and 9 of the Kailastila-2 well.

Parallel-Laminated Sandstone Facies:

This facies constitutes only a minor part of the Surma Group succession in the study wells. The facies is characterised by fine- to coarse-grained, light to dark grey coloured sandstone with average bed thickness of 20 cm, and displays both textural and mineralogical differentiation of the horizontal to nearly horizontal-lamination (Fig. 6A). The facies is common in the cores 9 and 10 of
the Fenchuganj-2 well and in the cores 1, 3, and 8 of the Kailastila-2 well, where usually there is an upward transition from cross-laminated sandstone facies to parallel-laminated facies.

**Trough Cross-Bedded Sandstone Facies:**

This facies consists of distinct sets of cross-beds with troughs (Fig. 6B). The troughs in core samples have been identified on the basis of the tangential nature of cross-strata. The facies is light grey to grey in colour, medium- to coarse-grained, and having the cross-strata tangential to the bottomset and at an angle to the topset. In this facies elongate and platy granule with some fine pebbles (Fig. 6B) usually concentrates along the foreset laminae, sometimes in the basal part of the bed. Reactivation surfaces, commonly mud drapes is observed in this facies. Sometimes closely spaced clay drapes, deposited by subordinate current is found to develop couplets enclosing bundles. Herringbone cross-stratification, which is marked by opposed dip directions in vertically adjacent sets of cross-bedding, have also been encountered in this facies. Similar structure has been described by Alam (1995a) from the Surma Group sediments of the Sitapahar.

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Fig. 6. (A) Photograph showing parallel-laminated sandstone facies (facies association III) overlying low angle cross-laminated sandstone facies in core B (2,926 m -2,935 m) of the Kailastila-2 well. (Coin is 2.7 cm in diameter). (B) Trough cross-bedded sandstone facies (facies association III) with well rounded and elongated mud clasts along foreset laminae observed in core 3 (2,296 m - 2,305 m) of the Kailastila-2 well. (Hammer is 4.8 cm long).
anticline in the south-eastern fold belt of Bangladesh. This facies has been commonly encountered in the cores 9, 10, 13 and 15 of the Fenchuganj-2 well and in the cores 3, 5, and 9 of the Kailastila-2 well.

Planar Cross-Bedded Sandstone Facies:

Planar cross-bedded sandstone facies is characterised by sets of planar-tabular cross-beds (Fig. 7A) that occur as a single set or cosets. Top of the tabular sets shows flat truncation surface with the cross-strata that are inclined at a sharp angle with both the topset and bottomset. This facies is more abundant than trough cross-bedded sandstone facies. Many sandstone beds are apparently massive which may reveal faint internal cross-stratification and highly indurated calcite cemented horizons occur within this facies. Alam (1993) showed that similar apparently massive sandstone unit of the Fenchuganj and Beanibazar cores revealed cross stratification in X-ray radiographs. The planar cross-bedded sandstone facies are common in the cores 9, 10, 13 and 15 of the Fenchuganj-2 well and in the cores 2, 3, 4, 9 and 10 of the Kailastila-2 well.

Interpretation

The facies association III is characterised by low-angle planar and trough cross-bedding (sometimes with lag deposits), parallel and cross-lamination, mudstone rip-up clasts. These features indicate sediment transport by strong traction currents. Internal sedimentary structures strongly suggest that the associated features of the sandstone units are of shoreline/coastal marine process. Bi-directional orientation in several sandstone units indicate reversal of flow of the depositing currents. Presence of herringbone cross-stratification in many of these sandstone units suggests an unequivocal tidal current origin. Tidal bundles (Smith 1988), reactivation surfaces veneered by mud drapes and mud couplets are characteristics of dominantly tidal processes. Visser (1980) proposed that the mud couplets commonly develop in the subtidal channel during a complete ebb/flood tidal cycle; and these features have similarities to those described from the cores of this study. The mud couplets represent deposition during two slack water periods and forming a bundled structure as the sand layer deposited during dominant current stage is thicker than the sand layer of the subordinate current stage (Smith 1988 and Tucker 1989).

Tidal-Channel Facies Association:

Cross-bedded sandstone with pebble/granule lag and sandy-matrix supported conglomerate constitute the facies types within this association.
Description

**Cross-Beded Sandstone Facies (with Pebble/Granule Lag):**

This facies is composed of pebbly sandstones where the clasts range from granule to pebble in size and platy to slightly rounded in shape. The sandstone of this facies is light grey in colour, and is coarse to medium grained. The pebble/granule lag is commonly confined to the base of this facies, which are common in the cores 3, 5, 10 and 13 of the Kailastila-2 well.

**Sandy Matrix-Supported Conglomerate Facies:**

This facies is devoid of internal stratification and is similar to gravelly sand facies of Ghiaudo's (1992) classification scheme. Clasts in this facies are subangular to subrounded with 5 to 10 mm in size, and are of sandy matrix supported lacking any preferred orientation. Beds of this facies maintain slightly erosional contacts with the underlying beds. The sandy matrix-supported conglomerate facies is restricted to the cores 10 and 13 of the Kailastila-2 well. Bivalve shell fragments are also found within this facies (Fig. 7B).

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Fig. 7. (A) Photograph showing planar cross-beded sandstone facies in core 3 (2,296 m - 2,305 m) of the Kailastila-2 well. (Pencil is 17 cm long). (B) Sandy matrix-supported conglomerate facies with elongated shelly particles (white in colour) encountered in core 13 (2987.6 m - 3026.3 m) of the Kailastila-2 well.
Interpretation

In this facies association, sandy matrix-supported conglomerate facies commonly underlies the cross-bedded sandstone facies. Cross-bedded sandstone facies with basal lag indicates deposition within the tidal channels. The angular to subrounded shape of the clasts in the sandy matrix-supported conglomerate facies indicates that the sediments have been transported into tidal channel from nearby source of high relief, or they could be rip-up mud clasts indicating high energy conditions within the channel that is capable of eroding the underlying mud bed. This type of strong current activity within the tidal channel may be associated with seasonal flooding in the nearby upstream alluvial systems.

It should be mentioned that virtually all the individual facies of facies associations II and III might also occasionally occur within the tidal channel facies association.

Discussion

On the basis of gross lithological changes, generally continental-transitional to deltaic environments have been suggested for the Surma Group sediments in the Surma basin (HOLTROP & KEIZER 1970 and KHAN et al. 1988). According to JOHNSON & ALAM (1991) the Surma Group strata are prodelta to delta front deposits of a large mud-rich delta system. ALAM (1993 & 1995b) envisaged macrotidal coastal depositional settings with extensive development of the deposits of predominantly intertidal and subtidal subenvironments within the Surma Group sequence encountered in the Beanibazar, Bakhralab, Fenchuganj, Kailastila and Rashidpur structures in the Surma basin. Tidal signatures have been recorded in the outcrop sections of the Surma Group sequence in the Sitapahar anticline (ALAM 1995a and ALAM & FERDOUS 1995) and also in the Mirinja anticline (ALAM & KARIM 1997) in the south-eastern fold belt of the Bengal Basin. The Surma Group strata exposed in the Mirinja anticline has been interpreted as a transition from a shallow marine muddy shelf to tide dominated coastal settings (ALAM & KARIM 1997). On the basis of recent work in the Sitapahar and Mirinja anticlines, GANI & ALAM (1999) suggested that the Surma Group succession represents an overall basinward progradation from deep marine to coastal marine depositional settings. However, it is important to note that the Surma Group strata in the Surma basin and CTFB may represent clastic succession deposited in two different tectonic settings; the former (Surma basin) representing a settings proximal to a passive to collision margin, whereas, the latter overlies a subduction margin setting.

Sedimentological analysis of the Surma Group sediments in the subsurface structures of the Surma basin suggests an overall shallow marine shelf to tide-
dominated transitional/coastal paleoenvironmental settings characterised by alternating transgressive and regressive phases as a result of subsidence as well as relative sea-level changes (SULTANA 2000). Tidal systems are potentially sensitive to sea-level change because tidal resonance which favour tidal sedimentation is a sensitive function of basin geometry which in turn may be dramatically altered by small changes in sea level. Thus tide-dominated conditions may be turned on and off in a geological instance because of sea-level rise or fall (WALKER & JAMES 1992).

In the present study, transitions from shallow marine muddy shelf to tide-dominated coastal depositional environments have been documented on the basis of core analysis and their environmental interpretation. In order to reconstruct the paleoenvironments and depositional history of the Surma Group sediment of the study wells, this group of sediment has been interpreted to belong to two basic gross setting – muddy shelf and sandy nearshore/coastal environments. Nearshore to coastal sandy environments may further be subdivided into three subenvironments, such as, tidal flats (intertidal), tidal sand ridge and tidal channel (both subtidal and subaerial). The depositional settings may have been characterised by repetitive transgressive and regressive phases.

From the general sedimentological log of the Surma Group sediments encountered in cores of the Fenchuganj-2 well (Fig. 8), it can be envisioned that sedimentation has taken place in a regressive setting with occasional transgressive phases. The overall depositional environment of the sediment is laterally interpreted by illustrating in a block diagram (Fig. 9) showing the major sub-environments within the proto-Surma basin embayment. The main source of sediment influx into this embayment is thought to have been derived from the active fluvial system prograding towards south and south-west of the basin and forming an overall prograding depositional system. Here the depositional scenario is described stratigraphically from older to younger. The shelfal mud interbedded with sand/silt-streaked shale unit (Core 16) was deposited during a transgressive phase basinward from the subtidal zone. The mud contains several bioturbated horizons and burrows filled with sand, indicating occasional sand transport into the muddy shelf. Coarse-grained sediments supplied by the fluvial system were then reworked into several sand ridges parallel to the tidal current direction in several vertically stacked tidal-creek sub-environments. The fining-upward cycles (Core 15) with a sharp or slightly pebble/ granule erosional base are thought to have developed by deposition during the regressive phases.

Following the regressive phases, shelfal mud (Core 14) appears with the rise of relative sea level that passes upward into a single sand ridge progradation followed by tidal flat deposition (Core 13) developed during a normal regressive phase. At the time of highstand sea level, a predominantly muddy sequence (Core 12 & 11) having random intercalations of silt/sand-streaked shale and
lenticles with micro cross-lamination have been deposited. These types of facies mainly represent quite water environment in the offshore to shelfal settings with occasional incursion of sand/silt-laden current during high tides and/or storm events. Therefore, the thin sand units may be termed as tempestite as they may have also been storm generated. No evidence of channelling was observed within this sequence.

The transgressive phase is followed by progradation of tidal ridge and tidal flat (Core 10) at the time of the next regressive phase. A huge thickness of
interbedded tidal flat and subtidal dune deposits (Core 9 & 7) have been developed under slowly shifting coastline. The tidal flat deposits with lenticular-, wavy- and flaser-bedding are thought to have been deposited in a mixed-flat environment with slight progradation. This deposit is overlain by vertically stacked tidal-channel sands (Core 5) which lack mud drapes but contain mud clasts along foreset laminae. Sandstone units within the channels are usually thick, apparently massive containing faint low-angle cross-lamination with mud clasts along foresets and as erosional lag deposits. Finally, deposition of the shelf muds (Core 4) above the sandy deposits of the shoreline setting took place in a very low energy condition following a rise of the relative sea level.

In the Kailastila-2 well, deposition of the Surma Group sediments is described from older to younger sequences in terms of detailed interpretation of the sedimentological log (Fig. 10). From Fig. 10, it is apparent that the lowermost horizon (lower part of Core 13) probably represents either an inner estuary channel or incised fluvial channel deposited at the time of lowstand sea level. The sands within the deposits are characterised by parallel to low-angle cross-
lamination, the top of which is marked by thin transgressive lag deposits. This lag is a chaotic mixture of mudstone, siltstone and sandstone clasts with shell fragments that are calcite cemented. A huge thickness of muddy sequence (upper part of Core 13, Core 12 & 11) characterised by dark grey to black fissile shale/mudstone with occasional silt laminae, has been deposited during the ensuing transgressive phase in a shelf environment. Finally, this phase is followed by a great thickness of interbedded tidal ridge/bar and tidal channel deposits (Cores 10 to 1), which have been deposited during an overall regressive phase.
Notably tidal flat facies is very rare in this phase of deposition. Tidal ridge deposits are marked by the presence of herring-bone cross-lamination, ripple-lamination that are bi-directional in character, trough cross-bedded unit with rare pebbly/granule erosional base, and mud drapes cross-bedded units with mud clasts along foreset laminae. On the other hand, the deposits of tidal channel sub-environment are marked by the presence of cross-bedded sandstone facies with erosional basal lag, and sandy matrix-supported conglomerate facies. The sandstone units in tidal channels are sometimes amalgamated, indicating several vertically stacked channels. The depositional environments of the Surma Group sediments in the Kailastila structure is illustrated in the block diagram (Fig. 11) showing the lateral relationship of major sub-environments within the paleo-embayment of the Surma basin.

![Block diagram showing the lateral relationships between the major depositional environments and sub-environments of the sediments encountered in the Kailastila-2 well of the Surma basin.](image)

Fig. 11. Block diagram showing the lateral relationships between the major depositional environments and sub-environments of the sediments encountered in the Kailastila-2 well of the Surma basin.

**Conclusions**

A detailed subsurface lithofacies analysis has been carried out using the conventional core samples from the Fenchuganj-2 and Kailastila-2 well in the Surma basin. Twelve distinct facies have been identified, which were then
grouped into four facies associations with genetic significance, namely, offshore to shelf facies association (containing shale/mudstone facies, and sand/silt-streaked shale facies), tidal-flat facies association (lenticular-bedded facies, wavy-bedded sand/mud facies, flaser-bedded facies, and ripple-laminated sandstone facies), tidal-ridge facies association (cross-laminated sandstone facies, parallel-laminated sandstone facies, trough cross-bedded sandstone facies, and planar cross-bedded sandstone facies), and tidal-channel facies association (cross-bedded sandstone facies with pebble/granule lag, and sandy matrix-supported conglomerate facies).

On the basis of detailed facies analysis, the Surma Group sediments encountered in the study wells is interpreted to have been deposited in shallow marine muddy shelfal to tide-dominated coastal depositional settings. Tidal signatures within these sediments are strongly demonstrated by numerous internal sedimentary structures that are produced predominantly by tidal current processes. This interpretation is based on detailed analysis of the internal structures within the various facies and their occurrence in the facies associations.

The vertical relationships of the facies and facies associations of the Neogene clastic succession within the study wells suggest their deposition in a repetitive transgressive and regressive phases controlled by relative sea-level fluctuations. On the other hand, the small-scale cyclic patterns observed within major allocyclic sequences have been developed as a result of lateral migration of the subenvironments within the proto-Surma basin embayment system.

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বাংলাদেশে বক্তৃতায় বেসিনের সুরমা খাদের অভ্যন্তরীন নিওজিন সুরমা ফ্রেঞ্চ শিলাস্তা রের ফেসিস বিশেষ্য

লেওয়ান নাহিদ সুলতানা ও যু. মুফতিয়া আলাম

সাবসংক্ষেপ

ভূতাত্ত্বিক দৃষ্টিকোণ থেকে বক্তৃতায় বেসিন ভারত, বাংলা ও চিতুর এই দুইটি প্লেটের ত্রি-সংযোগ শুলে একটি খুঁড়ুই ওরূপ পৃথিবী ক্ষুদ্র করে আছে। ভূ-অবস্থার কি তথ্য থেকে এই দুইটি ভারত উপমহাদেশের উত্তর-পূর্ব কোণে অবস্থিত। দক্ষিণ-মধ্য এশিয়ায় ভূতাত্ত্বিক বেসিন একটি বিখ্যাত হাইড্রোকার্বন-সমূহ বৈশিষ্ট্য হিসাবে প্রকাশিত; এই হাইড্রোকার্বন সমূহ জুড়ে ছড়িয়ে আছে - যা পৃষ্ঠরেখা থেকে বিপরিলিঙ্গ পালিঙ্গ বেসিন অঞ্চলের মধ্যে অনাবৃত। ফেসিস বিশেষ্যের মাধ্যমে এই প্লাজম্যাটিক শিলাস্তারের ভূতাত্ত্বিক ইতিহাস এবং এই দুই ধার বক্তৃতায় বেসিনের সাবসংক্ষেপ এবং পৃথিবী-আচ্ছাদিত বিষয়কের দ্বারা নিরূপণ করা ও তোলা সব বলে ধারণা করা যায়।

বর্তমান গবেষণার কার্যটি পরিচালিত হয়েছে মূলতঃ সুরমা খাদের শিলাশ্রেণীর উপর ভিত্তি করে। সুরমা খাদের বক্তৃতা দেশের উত্তর-পূর্ব অঞ্চলে এবং এটি কৃত্রিম ও পর্যায়ক্রমে অবস্থিত এবং এটি কৃত্রিম ও নির্মাণ প্রকল্পের একটি শিলাশ্রেণী। প্রাকৃতিক ও প্রাকৃতিক প্রকল্পের একটি শিলাশ্রেণী হিসাবে প্রকাশিত; এই শিলাশ্রেণী প্রকল্পের বিষয়ে বক্তৃতায় বেসিনের মধ্যে অনাবৃত। ফেসিস বিশেষ্যের মাধ্যমে এই প্লাজম্যাটিক শিলাস্তারের ভূতাত্ত্বিক ইতিহাস এবং এই দুই ধার বক্তৃতায় বেসিনের সাবসম্পর্কে এবং পৃথিবী-আচ্ছাদিত বিষয়কের দ্বারা নিরূপণ করা ও তোলা সব বলে ধারণা করা যায়।

ফেসিস বিশেষ্যের বিপরীতে বক্তৃতা থেকে অনুমান করা যায় যে, উল্লেখ্য বক্তৃতায় বেসিনের এই দুই ধার বক্তৃতা পৃথিবী সমন্বয়ের মধ্যে প্রকাশিত হয়েছ। এই বক্তৃতা প্রকল্পের এই দুই ধার বক্তৃতা পৃথিবী সমন্বয়ের মধ্যে প্রকাশিত হয়েছ।