



Sequence Stratigraphy and Depositional Environment of the Kopili Formation in the Area Between Borholla and Khoraghat, Dhansiri Valley, South Assam Shelf

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Summary

The Middle to Late Eocene Kopili formation is an important source and reservoir for hydrocarbons in the Dhansiri Valley area of South Assam Shelf. Isopach and sand shale ratio maps suggest the development of good reservoir facies sandstones in the lower Kopilis and fair to moderately well developed reservoir facies in the upper Kopilis in an estuarine setting in the study area between Borholla and Khoraghat structures. Correlation of base level fluctuations has revealed the presence of at least two complete sequence stratigraphic cycles, of which the first (Cycle-I or Sequence-I) extends from the onset of forced regression above the Pre-Cambrian basement to the onset of the next forced regression at the beginning of the hiatus towards the end of the deposition of the Barail Group (the Oligocene unconformity). This cycle of base level changes includes the Tura, Sylhet, Kopili formations and the Barail Group of sediments and is constituted of fluvial to shoreface LST, TST and HST deposits. The Kopili formation has been deposited in a dominantly transgressive set up and includes the Maximum Flooding Surface for the first sequence stratigraphic cycle, which is followed by a period of normal regression during which the delta front and delta plain sediments of the Barail Group were deposited. The Sylhet-Kopili and the Kopili-Barail transitions transition appear to be within sequence surfaces whereas the BMS-BCS transition within the Barail Group appears to be a Within Trend Normal Regressive Surface within the HST phase of Cycle-I.

Introduction

The study area is bounded by latitudes 26 deg 00 min in the south and 26 deg 40 min in the north and longitudes 93 deg 50 min 30 sec in west and 94 deg 10 min in the east (Fig. 1). It lies between the producing Borholla field in the north and the Khoraghat and Nambar fields in the south.

On the west it is bounded by the granitic Mikir massif and in the east by the Naga Thrust. The Middle to Upper Eocene Kopili Formation overlies the Lower to Middle Eocene Sylhet Limestone in the entire South Assam Shelf and is dominantly argillaceous in character. It is overlain by the Upper Eocene to Oligocene sediments of the Barail Group (Fig 2).

With the discovery of commercial hydrocarbons within the Kopilis in Borholla field and the occurrence of several hydrocarbon shows in drilled wells within the study area, the need for an analysis of the micro-environment of deposition of the Kopilis using modern sequence stratigraphic concepts for deriving predictive facies models has achieved considerable significance. In this paper, an effort has been made to understand the depositional history of the Kopilis by correlating its various units to a curve of

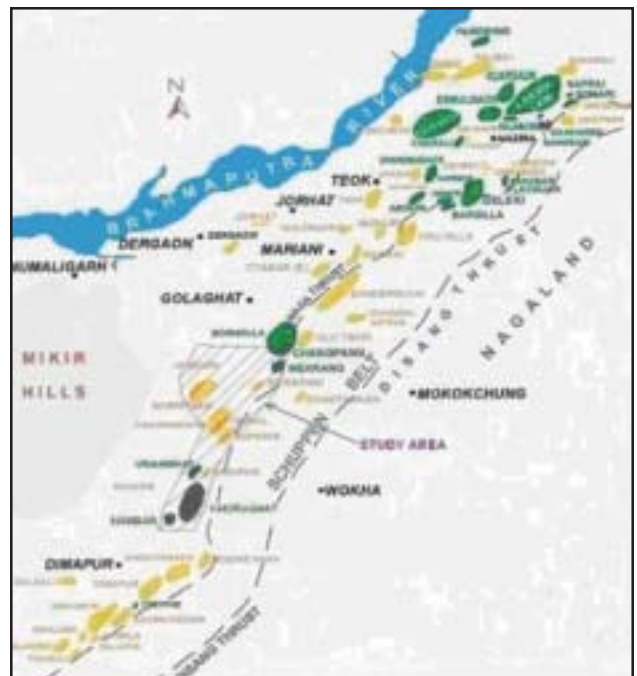


Fig. 1 : Prospect Map Of Dhansiri Valley Showing The Study Area

base level shifts for the sedimentary succession from the Paleocene to Lower Eocene Tura formation resting unconformably above the Pre-Cambrian basement to the

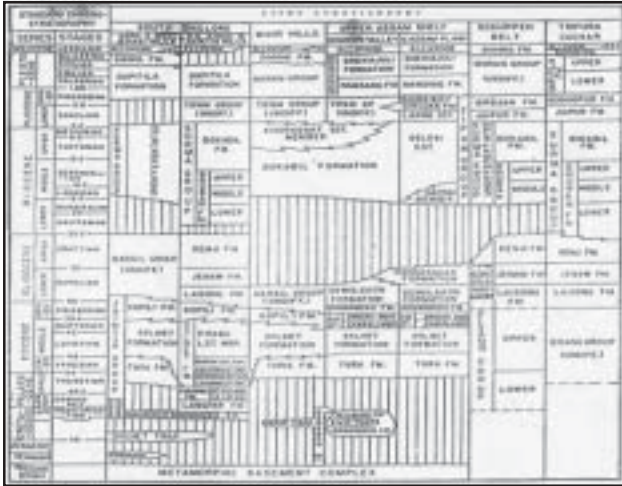


Fig.2 : Lithostratigraphy of Assam-Arakan Basin (After Deshpande et.al. 1993)

Oligocene unconformity at the top of Barail. Cretaceous and Permian sediments may or may not be present below the Paleocene Turas. The nature of the Kopili/Barail and the Sylhet/Kopili transition has also been examined in the light of sequence stratigraphy.

The base level cycle

Depositional systems are the sedimentary products of associated depositional environments. They grade laterally into coeval systems, forming logical associations of geomorphic elements, i.e. systems tracts. From the viewpoint of sequence stratigraphy, the terms "systems tract" and "sequence" are linked to changes in base level (Catuneanu, 2003, p. 9).

The base level is generally regarded as a global reference surface towards which continental denudation and marine aggradation tend to proceed. It is usually approximated with the sea level (Schumm, 1993). The base level is dynamic, and constantly shifts its position in time. A rise in base level creates accommodation. Sedimentation may take place at lower or higher rates relative to the rate of creation of accommodation. In the case where the rate of sedimentation is lower than the rate of creation of accommodation, the net effect is water deepening and retrogradation of the shoreline. In case sedimentation rates exceed the rate of creation of accommodation, the net result is water shallowing and progradation of the shoreline. A fall in base level will invariably result in water shallowing irrespective of the depositional process. Base level changes are independent of sedimentation, being controlled by tectonics and eustatic changes in sea level, whereas changes in water depth are dependent on sedimentation.

Transgressions and normal regressions occur during base level rise, and the predominance of one over the other is a function of the balance between creation and consumption of accommodation. In the former, creation predominates over consumption of accommodation. In the latter, accommodation is consumed faster than it is created. During forced regression, the shoreline is forced to prograde seaward, irrespective of the rate of sedimentation, because of fall in base level.

The succession of transgressive and regressive shoreline shifts can be represented by a sinusoidal curve of base level shifts (Fig. 3) and constitute the elements of a complete stratigraphic cycle (Catuneanu p 29-30, 2003). A base level cycle begins with the onset of forced regression and ends with the onset of the next forced regression, passing through normal regressive and transgressive phases in between. Periods characterized by forced regression are represented by subaerial unconformities or their correlative conformities.

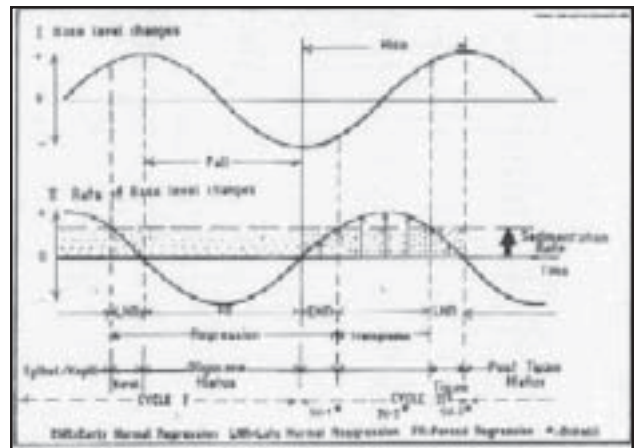


Fig.3 : Sinusoidal curve of base-level shifts showing probable periods of deposition of Sylhet, Kopili, Barail and Bokabil formations in Dhansiri Valley. (after Catuneanu, 2003)

Sequences and system tracts can be defined with respect to the curve of base-level shifts. Fig 4 depicts a complete cycle of base level shifts, the events associated with it at its various stages and also catalogs the typical sequence-stratigraphic surfaces generated during the cycle.

A base level cycle may begin with a short LST phase, followed by a more persistent TST phase deposited during transgression and may be capped by HST phase deposits (Cateneanu, 2003) . Such a relatively conformable genetic sequence of strata bounded by unconformities or their correlative conformities is known as a 'sequence' (Sloss, 1949, Mitchum, 1977).

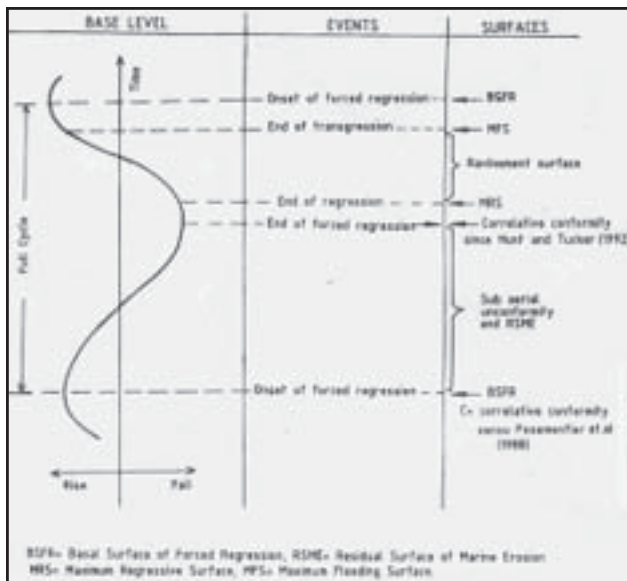


Fig.4 : Timing of sequence stratigraphic surfaces relative to the main events of the base level cycle (modified from Catuneanu, 2003)

Early normal regression (ENR) occurs at the end of the forced regressive phase and just before transgression is about to begin. It is characterized by increasing rates of base level rise (Fig. 3) and progradation of the shoreline. During ENR, Lowstand Systems Tract (LST) deposits form beyond the shelf edge as submarine fans and lowstand wedges as a consequence of sedimentary bypass on the shelf. Some shoreface LST deposits may form close to the shoreline, coeval with deposition of LST phase sediments beyond the shelf edge (Catuneanu, 2003).

With further increase in rates of base-level rise and creation of accommodation at greater rates than sedimentation, early normal regression gives way to transgression, in which retrogradation of the shoreline towards land along with formation of transgressive systems tract (TST) deposits such as estuaries and backstepping beaches takes place.

The end of transgression is followed by a period of late normal regression (LNR, Fig 3.), in which the rate of base level rise decreases and gradually approaches still stand. During the initial phases of late normal regression, when the rate of base level rise is still considerably high, delta front deposits may form at river mouths along with progradation of the shoreline. Later, as the rates of base level rise approach zero (i.e. stillstand), progradation gives way to aggradation and marshy and lagoonal deposits of the delta plain, characterized by alternations of coal, shale and minor sandstone.

Late normal regression (LNR) is succeeded by forced regression, in which the base level is forced to fall as a consequence of tectonism and/or eustasy regardless of the effects of sedimentation and accommodation. Forced regression typically gives rise to sub-aerial unconformities and their correlative conformities further basinward. The onset of this forced regression marks the end of the previous base-level cycle and the beginning of the next base-level cycle. A complete base-level cycle generates a typical sequence stratigraphic cycle (i.e. a sequence) above the shelf edge and is comprised of the shoreface LST phase, which, if present, occurs only at the basin margin, a TST phase and an HST phase which is capped by a subaerial unconformity defining the end of the cycle.

Within the study area, the stratigraphic succession is characterized by prominent subaerial unconformities above the basement, at the top of Barail (Early Oligocene) and the unconformity below Namsang Formation (Fig. 2), besides the unconformity below the Recent alluvium deposits. The bulk of the stratigraphic succession from 57 MYBP to 3.5 MYBP including the intervening hiatuses can be represented by two sinusoidal curves representing base level shifts at the shoreline. These two base-level cycles have been represented in this paper as “Cycle-1” and “Cycle-2” (Fig. 5).

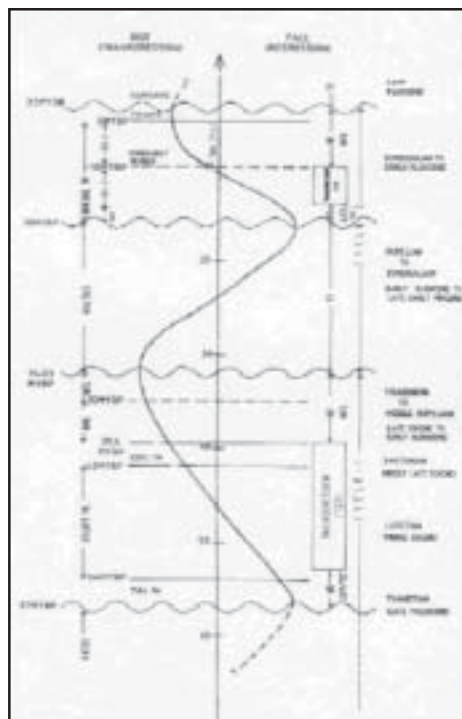


Fig.5 : Representative cycle of base level changes from late Palaeocene to Early Pliocene, Borholla - Khoraghat area.

Depositional environment

The Kopilis have been subdivided, on the basis of lithologic attributes, into seven different sub-units labeled KSU-I to KSU-VII from bottom (Figs. 6, 7 and 8). While sub-units KSU-V to VII are extremely restricted in areal extent, being developed only close to the depocenter around wells MRAC and GM-1, sub-units KSU-I through IV occur throughout the area of study. Sub-units KSU-II and KSU-IV correspond roughly to the Charali and Amguri members respectively of the Kopili Formation.

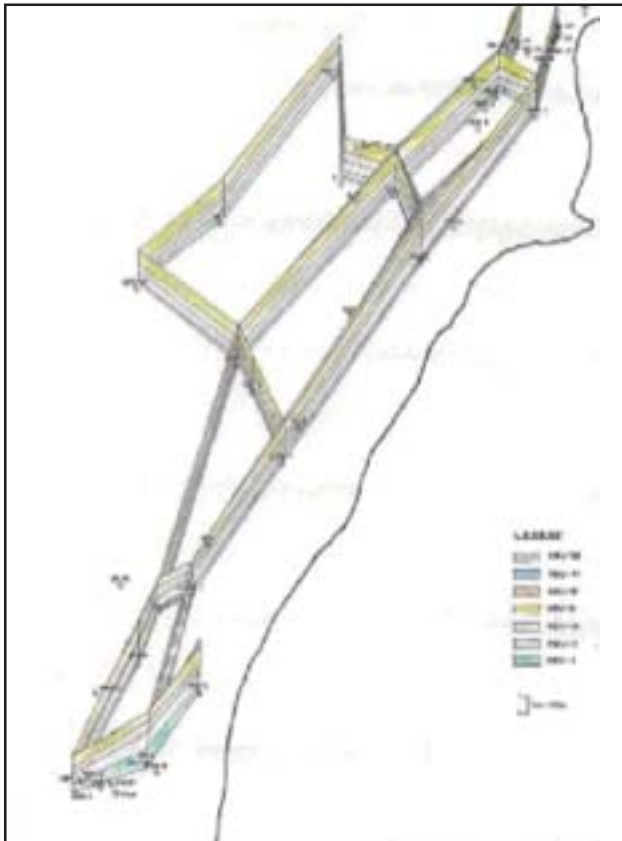


Fig. 6 : Fence diagram for the Kopili formation showing distribution of subunits.

Depositional systems developed during the Kopili period are typically those of the TST phase, such as estuaries and bayhead deltas at river mouths and back-stepping beaches where open shorelines existed. The sandstones within Kopili formation are thin, of limited lateral extent and enclosed in shales. The dominant pattern within Kopilis is fining upward, suggesting transgressive conditions of deposition. Other authors such as Naik et. al. (2001), Kanungo et. al. (2002) have also inferred an estuarine depositional environment during the deposition of the Kopilis. Based on biostratigraphic evidence, Baruah, J

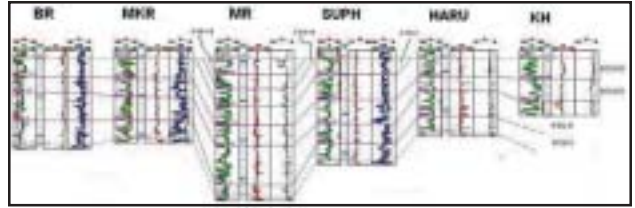


Fig.7 : Well correlation profile of Kopili formation along strike showing sub-units, South Assam Shelf.

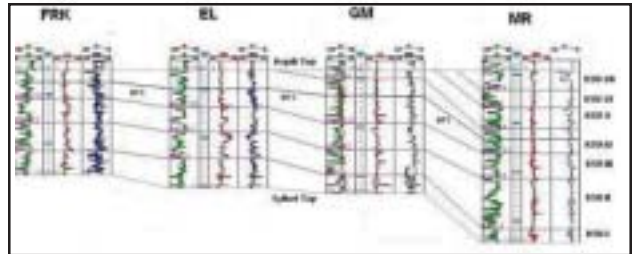


Fig.8 : Well correlation profile of Kopili formation along dip, showing subunits, South Assam Shelf.

(2004) has suggested warm, shallow marine conditions (upto 20 – 30 m bathymetry) during the deposition of the lower Kopilis and very shallow marine conditions (5- 10 m bathymetry) during the deposition of the upper Kopilis.

The curve of base level shifts for the Kopilis indicates dominant transgression (Figs. 5, 9). While the lower Kopilis correspond to the middle stages of transgression (hence greater water depth), the upper Kopilis have been deposited towards the end of the transgressive phase, in lesser water depths. The bathymetric data generated from lab studies are therefore consistent with the generated curve of base level shifts for the Kopilis.

Isopach maps of the Kopili formation and its subunits KSU-II and KSU-IV (Figs. 10, 11, 12) suggest the development of estuaries in the East-Lakhibari – Gamariguri area to the north and in the Khoraghat area to the south. While the estuaries developed during lower Kopili times seem to be incomplete estuaries, the estuary developed in an east-west trend in the Gamariguri - Merapani area during the Upper Kopili period seems to be more complete in character, with the development of an offshore barrier island complex, a tidal ravinement zone and bayhead deltas further to the west, close to river mouths debouching into the sea. Further south, in the Khoraghat area, conditions favourable for the development of incomplete estuaries in Lower Kopilis persisted into the Upper Kopilis.

Incomplete, or drowned estuaries are characterized by greater rates of transgression at the open shore-line than

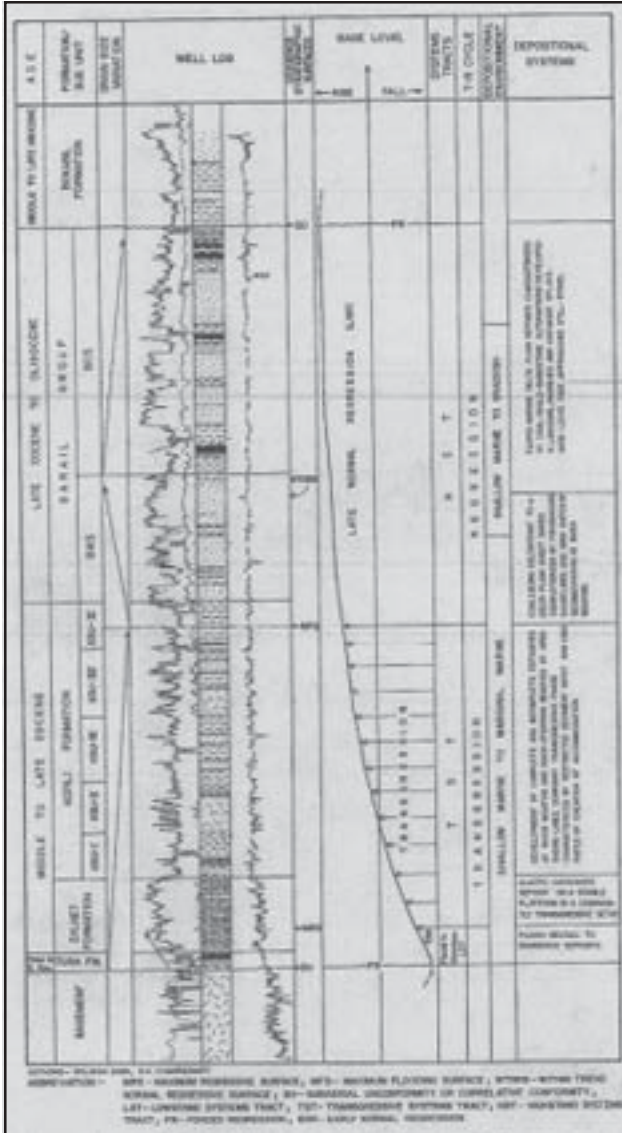


Fig. 9 : Diagram showing Cycle-I (Sequence-I), sequence stratigraphic surfaces developed, base level fluctuations, unconformities and regressive-transgressive phases of deposition.

at the river mouth, leading to the formation of bayhead deltas. Favourable conditions for the development of incomplete (drowned) estuaries include high sediment supply and unincised valleys. Fully developed or *complete* estuaries, on the other hand, are characterized by greater rates of transgression at the river mouth than at the coastline. Conditions favouring the development of complete estuaries are low sediment supply rates and the presence of incised valleys (Fig. 13).

Sand-shale ratio for the lower Kopilis (unit KSU-II; Fig. 14) suggest greater clastic input sand-shale ratios

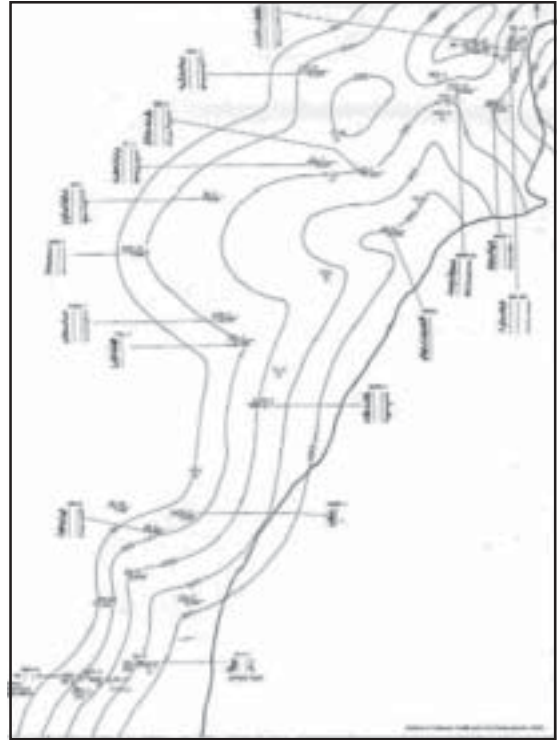


Fig.10: Isopach map of Kopili formation between Borholla and Khoraghat, South Assam Shelf.

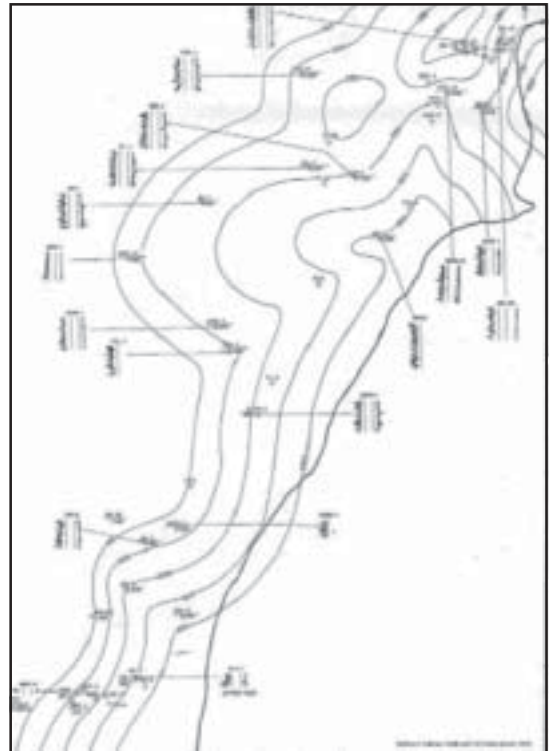


Fig. 11 : Isopach map of Kopili sub-unit II (KSU-II) between Borholla and Khoraghat, South Assam Shelf.

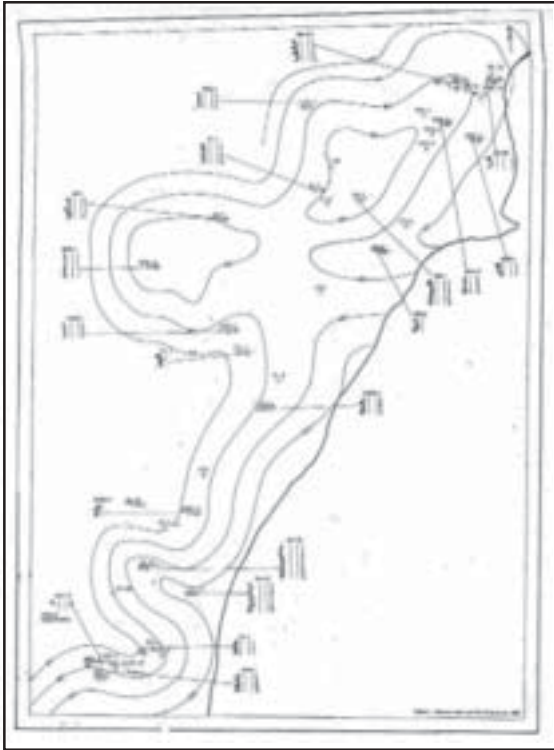


Fig. 12 : Isopach map of Kopili sub-unit IV (KSU-IV) between Borholla and Khoraghat, South Assam Shelf.



Fig.14 : Sand-Shale ratio map of Kopili sub-unit II (KSU-II), Borholla - Khoraghat area , South - Assam Shelf. than during the upper Kopilis (KSU-IV, Fig. 15); in the East-Lakhibari-Gamariguri area,



Fig. 13 :Diagram showing the development of complete and drowned estuaries (after Catuneanu, 2003).



Fig.15: Sand-Shale ratio map of Kopili sub-unit IV (KSU-IV), Borholla-Khoraghat area, South Assam Shelf.

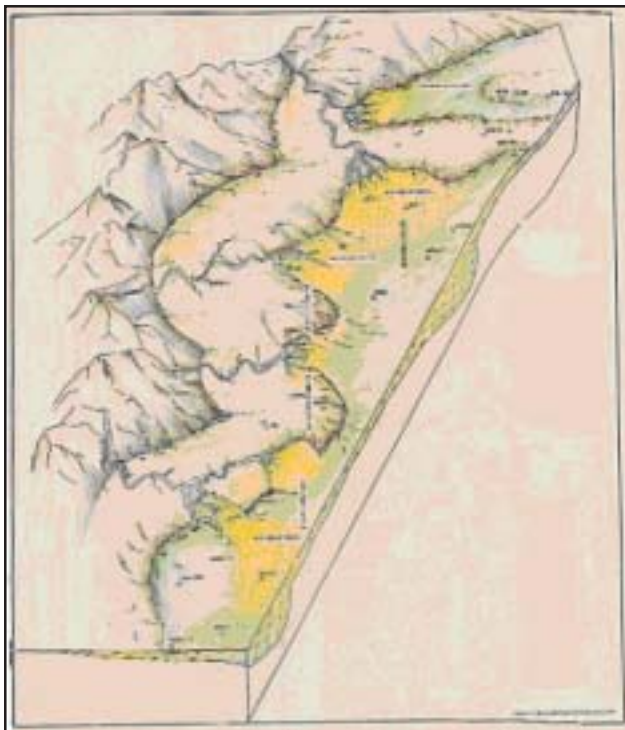


Fig.16 : Depositional model for Kopili sub-unit II (KSU-II), Borholla-Khoraghat area, South Assam Shelf.

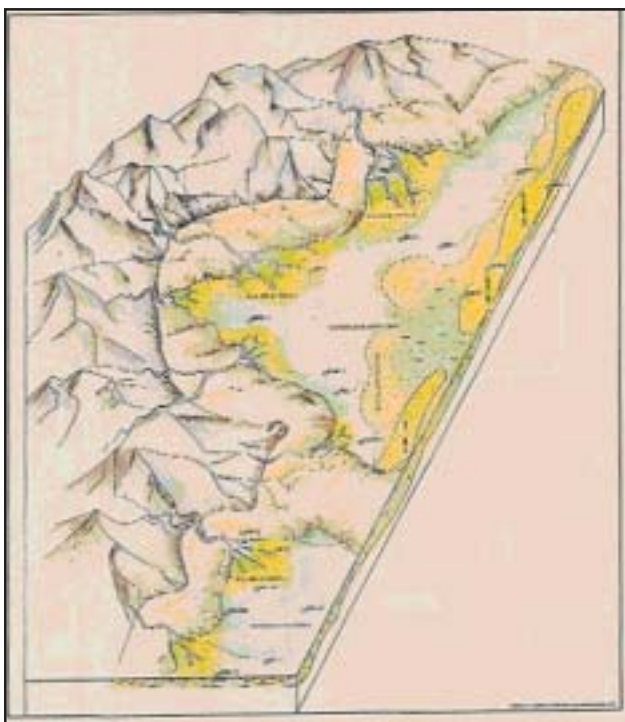


Fig.17 : Depositional model for Kopili sub-unit IV (KSU-IV), Borholla-Khoraghat area, South Assam Shelf.

are the lowest for both units KSU-II and KSU-IV, thus suggesting a greater probability of development of complete estuaries in the northern part of the study area. In the central part of the study area, however, close to the Telihal and Suphayam structures, clastic input from debouching streams and rivers during both lower and upper Kopili periods was minimal, leading to the formation of back-stepping beaches in an overall transgressive set-up. The general isopachous trend is NE-SW with basinward thickening towards east and southeast and a general veering of strike to east-west near Barpathar – East-Lakhbari-Gamariguri-MRAC. This east west veering of strike could probably be due to superimposition of a younger east-west fault trend in the area. Such younger east-west fault trends are observable on remote sensing satellite maps and extend into the Mikir Hills (Dotiwala et. al., 1999). Estuarine depositional environments and systems tracts developed during the lower and upper Kopilis are depicted in 3-D models for KSU-II and KSU-IV in the study area (Figs. 16, 17).

Discussion

Analysis of the depositional environment of the Kopilis from a sequence stratigraphic point of view is of particular interest for generating predictive facies models in view of commercial production of hydrocarbons from various pays within Kopilis from the Borholla Field and sporadic hydrocarbon shows in wells drilled in the rest of the study area.

The stratigraphic succession from the basement to the base of Namsang formation in the study area is demarcated by three prominent sub-aerial unconformities viz. above basement, the Oligocene unconformity above Barail and the unconformity at 3.5 MYBP at the base of the Namsang Formation (Fig 2). The Oligocene unconformity divides the stratigraphic succession into two major sequence stratigraphic cycles (viz. Cycle – 1 or Sequence – 1 and Cycle – 2 or Sequence – 2, Fig. 5). As the generation of sub-aerial unconformities typically takes place during forced regression (Catuneanu, 2003. p 47, Helland-Hansen and Martinsen, 1996), the period of hiatus of the Oligocene unconformity as well as the hiatus above basement have been correlated with periods of forced regression characterized by regional fall in base level. The onset of forced regression denoting the start of Cycle – 1 (i.e. Sequence – 1) could begin as late as Middle Cretaceous in the study area, and is demarcated by the occurrence of the Mikir Traps of Middle Cretaceous age in well Barpathar-1. Dasgupta et.al. (2000, p.87) has also indicated a large break in sedimentation spanning over 60m.y. from the middle

Cretaceous to the late Paleocene or Eocene in well Barpathar-I. The end of Cycle-1 is demarcated by the onset of forced regression at the end of deposition of the Barail Group and is represented by the Oligocene unconformity. Cycle – I includes the Paleogene depositional systems and systems tracts of the Tura, Sylhet and Kopili formations and the regressive delta front and delta plain deposits of the Barail Group.

The second sequence stratigraphic cycle (Cycle-2 or Sequence - 2) begins with the onset of forced regression at the close of Barail and continues till the onset of the next forced regression at the end of Tipam. It includes the major part of the sediments of the Surma Group and the undifferentiated Tipams. This is marked by the sub-aerial unconformity below Namsang formation. The present discussion is confined to the first cycle (Cycle 1). Fig. 5 depicts the base level rises and falls during both Cycle – 1 (i.e. Sequence – 1) and Cycle – 2 (i.e. Sequence – 2). The curves shown are only representative and do not indicate any quantitative changes in base level.

Deposition in the study area during the first cycle begins with the end of forced regression at around 57 MYBP and is represented by the laying down of the Tura formation over the basement. This cycle is characterized by the deposition of the continental to shoreface LST deposits of the Tura (and early Sylhet?) Formation, followed by the TST deposits of the Sylhet and Kopili formations and ends with the HST phase deposits of the BMS and the BCS (Barail Group; Fig 9). The entire period of deposition is characterized by a base level rise. The shoreface LST phase was deposited during Early Normal Regression and is characterized by the continental to fluvio-marine deposits of Tura Formation and perhaps the early part of Sylhet formation. This period is of short duration and is characterized by a progradation of the shoreline and a coarsening upward grain size variation pattern.

With increasing rates of base level rise and restriction in sediment supply, early normal regression gave way to full-scale transgression. The transition from early normal regression to transgression is marked by the end of the initial coarsening upward phase, and the beginning of the fining upward phase; it is designated as the Maximum Regressive Surface (MRS). It marks the change from progradation to retrogradation. It is also known as the transgressive surface (Posamentier et.al 1988). This MRS lies close to the Tura/Sylhet lithostratigraphic boundary but may occur within the early part of the Sylhet; Fig. 9)

An extended period of transgression follows the MRS and continues upto the Maximum Flooding Surface (MFS) close to the top of the Kopili Formation. This transgressive period is marked by fining upward grain-size variation pattern and demarcates the TST phase deposits of the Sylhet and the Kopili formations. The bulk of the Sylhet formation was laid down as carbonate deposits on a stable platform. Sediment influx was higher towards the later part of the transgressive phase during the Kopili period, resulting in the development of estuaries at river mouths and back-stepping beaches at open shorelines. The MFS marks the end of shoreline transgression and is characterized by fining upward sediments below and coarsening upward sediments above it; it is overlain by coarsening upward HST deposits of the Barail Main Sand unit (BMS).

The deposition of the Kopili formation is followed by the coarsening upward, coalescing delta front sheet sands of the BMS during a phase of late normal regression characterized by decreasing rates of base-level rise and progradation of the shoreline with increasing influx of clastic material. As the rates of base level rise approached still-stand towards the end of late normal regression, rhythmic alternations of shale, sandstone and coal developed in a fluvial to fluvio-marine delta-plain setting, forming the Barail Coal Shale (BCS) unit of the Barail Group.

This was followed by the onset of forced regression and the development of a major hiatus during the Oligocene period. Erosion during this period was quite extensive; resulting in the removal of considerable sections of the BCS, the BMS and at places even the Kopilis.

The transition from the Eocene Kopilis to the overlying Barails has been described by Deshpande et.al. (1993) as a lateral gradation in the Dhansiri Valley area, although Dasgupta et. al. (2000, p.87) has postulated a local break in sedimentation at the Kopili/Barail boundary spanning about 10 m.y. in the Garo Hills area. In the West Bengal Shelf, a minor diastem spanning about 3 m.y. has been recorded at the equivalent stratigraphic position. Seismic sections along dip and strike within the study area also do not reveal a distinct Kopili-Barail boundary and cannot be demarcated without log support (Figs. 18 ,19).

The transition from the Sylhet to the Kopilis has also been described as laterally gradational (Deshpande et.al. 1993). Microfaunal evidence (Dasgupta et.al. 2000, p 56) also do not suggest major breaks in sedimentation at the Sylhet-Kopili and the Kopili-Barail boundaries.

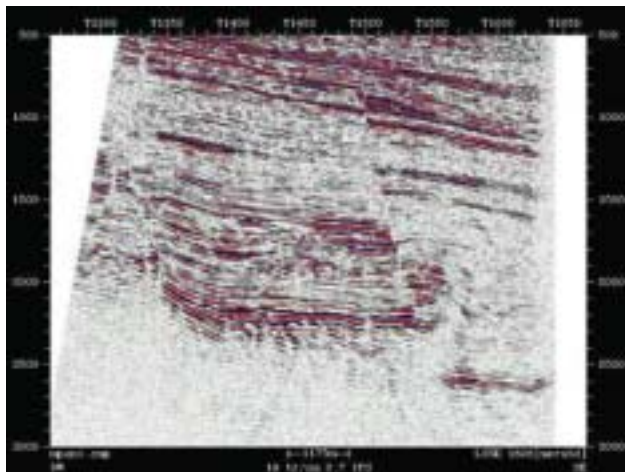


Fig.18 : Uninterpreted seismic section along dip, Merapani block, South Assam Shelf.

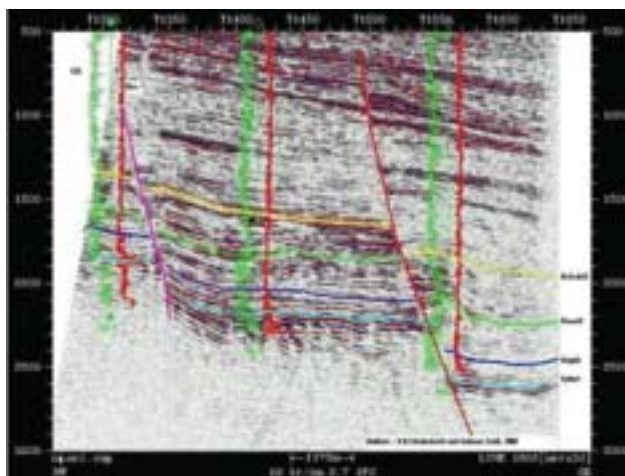


Fig.19 : Interpreted seismic section along dip, Merapani block, South Assam Shelf

It therefore follows from the above that the Tura-Sylhet, Sylhet-Kopili and the Kopili-Barail transitions are not sequence boundaries but merely lithostratigraphic facies boundaries within Cycle – I (Sequence-I). The closest sequence surface to the Tura-Sylhet transition is the Maximum Regressive Surface and the closest sequence surface to the Kopili-Barail transition is the Maximum Flooding Surface of Cycle-I (Sequence – I). These sequence stratigraphic surface seem to demarcate systems tracts within Cycle-I (Sequence- I) rather than sequence boundaries. The BMS/ BCS transition also appears to be a within sequence transition within the HST phase, demarcating the transition from delta front to delta plain, and is thus strictly not a sequence boundary. It has been designated here as a Within Trend Normal Regressive Surface (WTNRS; Catuneanu 2003 p 148; Fig. 9, Fig. 20).

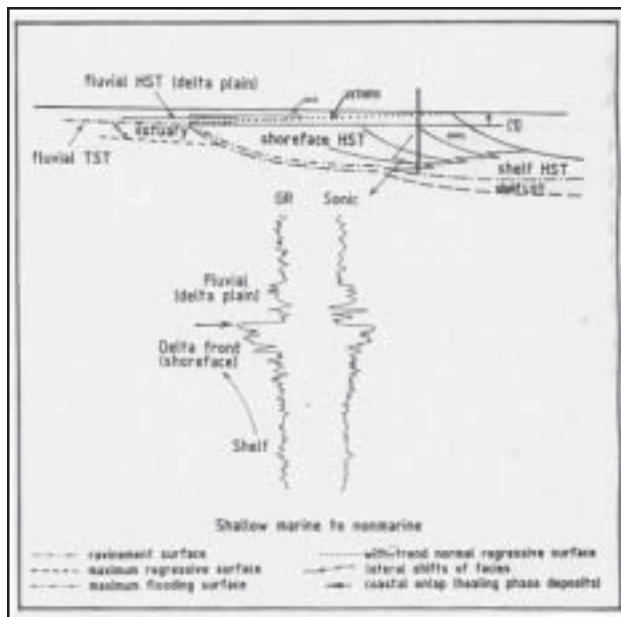


Fig.20 : Diagram illustrating development of a Within Trend Normal Regressive Surface (WTNRS; after Catuneanu, 2003)

Conclusions

- 1> The stratigraphic sequence from the Tura Formation to the end of Tipams in the study area can be divided into two sequence stratigraphic cycles viz. Cycle – 1 (composed of Paleogene sediments) and Cycle – 2 (composed of Neogene sediments) on the basis of base level fluctuations near the shoreline. The present study is restricted to Cycle – 1.
- 2> The Sylhet/Kopili and Kopili/Barail transitions are within sequence surfaces and not sequence boundaries.
- 3> The Turas were deposited as continental to shoreface LST sediments during a short early normal regressive phase. The end of this early normal regressive phase is marked by the Maximum Regressive Surface (MRS).
- 4> TST phase carbonates of the Sylhet Formation and the estuarine sediments of the Kopili Formation were laid down above the MRS.
- 5> Estuarine conditions prevailed at river mouths during the deposition of the Kopilis. Back-stepping beaches developed at open shorelines where clastic input was restricted.
- 6> The end of transgression was marked by the Maximum Flooding Surface (MFS) close to the top of Kopili Formation. This was followed by the deltaic deposits of the Barail group laid down in the HST phase during late normal regression.
- 7> The BMS/BCS transition is a within trend normal regressive surface (WTNRS) within the HST phase of

Cycle- I and is not strictly a sequence boundary.

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