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Sequence Stratigraphy and Depositional Systems for Mid - to Late Eocene Kopili Alloformation, Assam Shelf, Northeastern India

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ABSTRACT : Assam-Arakan basin - a classic polyhistory basin in Northeastern India evolved as a passive margin and later developed into a foreland basin in a peripheral position with respect to the major Naga schuppen belt and the contiguous Indo-Burma orogenic front. The present study is an attempt to establish and understand the Mid - to Late Eocene depositional systems of Kopili Alloformation in terms of the sequence stratigraphic framework of this region. Well-log sequences and seismic stratigraphic analysis coupled with the biostratigraphic studies has been integrated to define various orders of depositional sequences, which are later mapped to bring out the regional depositional pattern and paleogeographic reconstruction. Ten sequences (I-X) four within Paleogene (I-IV) and six within Neogene (V-X) have been identified. Seq. II repsents a major part of Kopili Formation. A framework of estuarine environment, i.e. bay-lagoon-inlet-tidal flat and marsh were significantly involved during the deposition of Seq-II sediments in a coastal set up. The flat coastal gradient of the stable Assam passive margin, a relative sea level rise and a reduced clastic supply from the mature Indian craton in W/NW were probably the favourable factors for the growth of a long and voluminous estuary during the entire Seq-II sedimentation.

INTRODUCTION

Over the years, stratigraphic analysis in Northeastern India is mainly based on the classical concepts of lithostratigarphy, biostratigraphy and the lateral correlation of their associated facies. These traditional approaches to stratigraphic analysis have some limitations in interpreting the paleogeography and geological history of the region. Stratigraphic analysis based on the concepts of sequence stratigraphy integrating out-crop, well-log and seismic data, provide a new correlation tool to derive a model for the geological response of the depositional and erosional processes to cyclic base-level changes, which identifies and defines the genetic character of different types of physical surfaces and stratigraphic intervals within the rock record. The present study is an attempt to establish and understand the Mid- to Late Eocene depositional systems of Kopili Alloformation in terms of the sequence stratigraphic framework of the region. The paper brings out the spatio-temporal relationship between the Kopili sediments and the time equivalent Disang Group in terms of the evolving paleogeography of the area.

REGIONAL GEOLOGY AN OVERVIEW

Northeastern India represents the northern part of the Assam-Arakan basin which extends westward beyond Bangladesh and West Bengal to Orissa and includes parts of Myanmar in the east and south (Fig. 1). Being bounded by eastern Himalayan fold belts on the north and Naga-Patkai fold belts on the east-southeast, it constitutes a vast intermontane basin. Most of its geological features are concealed by the Recent alluvial cover.

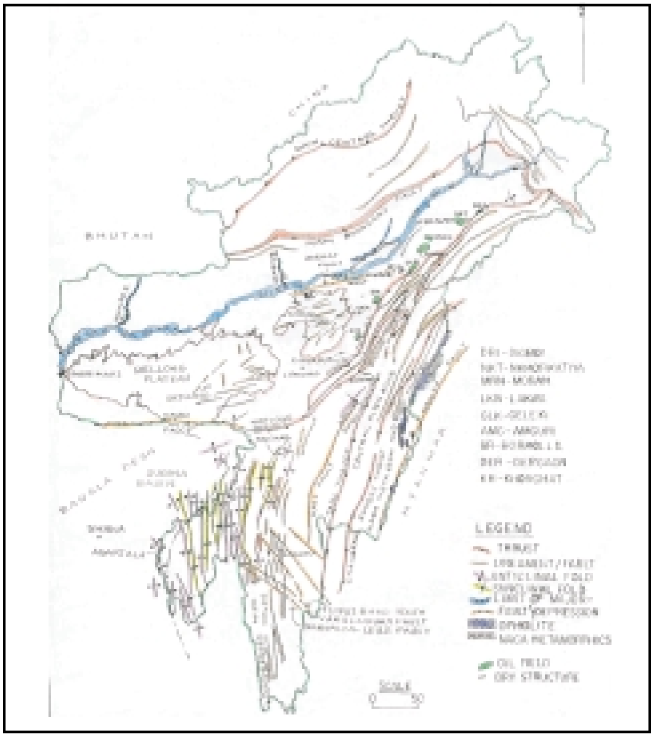

Figure 1 : Tectonic map of Assam-Arakan Basin.

Tertiary rocks rest directly over the granite gneiss and is divisible into two Supergroups (Bhandari et al., 1973). The older Naga Supergroup of Paleogene age is further divided into Jaintia and Barail groups. These Paleogene sediments are mostly deposited in shallow marine to transitional environment. Thickness of these sediments increases from northwest to southeast suggesting the basinal system towards southeast (Raju, 1968; Bhandari et al., 1973; Murty, 1983; Rao, 1983). The overlying Neogene sediments constitute the Brahmaputra Supergroup (Bhandari et al., 1973) was deposited extensively in fluvial environment except the initial shallow marine condition in Dhansiri and Surma Valley which was later replaced by brackish, deltaic and fluviatile condition of deposition (Surma Formation).

Tectonic evolution of northeastern India is intricately linked with the movement of the Indian plate and its relationship with the tectono-chronology of the Himalayan Orogeny and is discussed in terms of the 'Oblique Collision and Tectonic Wedging Model' (Naik, 1994, 1997). Prior to collision and overriding, the northeastern India was almost certainly a passive margin and fronted by Mesozoic Oceanic lithosphere that was continuous with today's eastern coast passive margin. Subsequent to the Thrust loading, flexural sag i.e. the foreland basin was initiated latest by Late Eocene. In the Naga-Patkai Range the inner Thrust were emplaced at that time involving the Eocene and Oligocene sediments.

South and east of Disang thrust, the Miocene and the younger series are not represented. The flexural process continued with migration of the basin towards NW in a classical Piggyback style.

SEQUENCE STRATIGRAPHY: AN INTEGRATED ANALYSIS

Sequence stratigraphic analysis in Assam –Arakan basin *sensu stricto* has not been attempted by any of the earlier workers. In the present work, well-log sequence and seismic stratigraphic analysis coupled with the biostratigraphic studies has been attempted and finally integrated following the standard sequence stratigraphic interpretation procedure (Vail & Warnardt, 1990). Various orders of depositional sequences have been defined and later mapped to bring out the regional depositional pattern and paleogeographic scenario of the region. Though, on well-logs and also in biostratigraphic studies, cycles of higher orders (fourth even fifth order) are recognised, they are not well defined on seismic sections. Therefore, sequence boundaries which are defined seismically and further calibrated using other co-lateral data, have been correlated regionally.

Well-log Sequence Analysis: Multi-well studies using a suite of wire-line logs, provide invaluable information to sequence analysis and help developing an architectural and space-time reconstruction of the Formation. Besides defining the different system tracts, well logs are used for identifying the unconformity which in turns defines the sequence boundary. Fig. 2 & 3 show the different criteria used for unconformity identification in well logs. Using all these criteria, sequence boundary SB-II has been defined in the present study on the top of a correlatable coarsening up unit and is considered as an unconformity (Fig. 4). However, unlike lithostratigraphic boundary, the sequence boundary has been taken on the top of the HST (Fig 4).

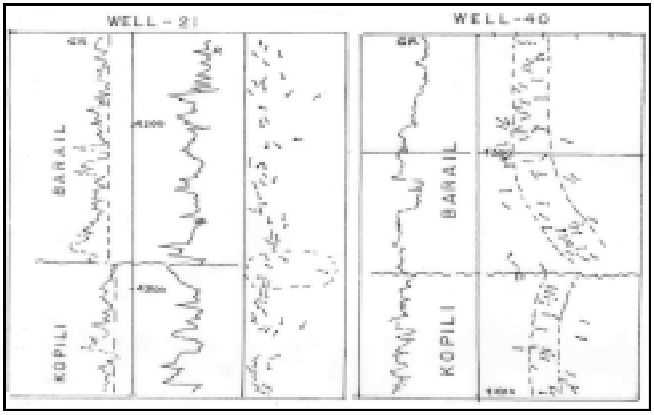

Figure 2 : Dipmeter pattern depicting unconformity in well 21 and 40.

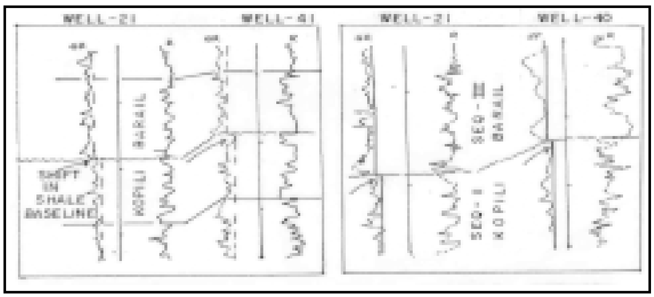

Figure 3 : Shale Baseline shift depicting unconformity

Various System tracts identified on well logs following the criteria suggested by Vail et al., (1990) are used for regional correlation in a grid pattern. Micropaleontological studies and the established stratigraphic boundaries are also incorporated to make the informal correlation (rather matching) more formal and stratigraphically meaningful (Fig.4).

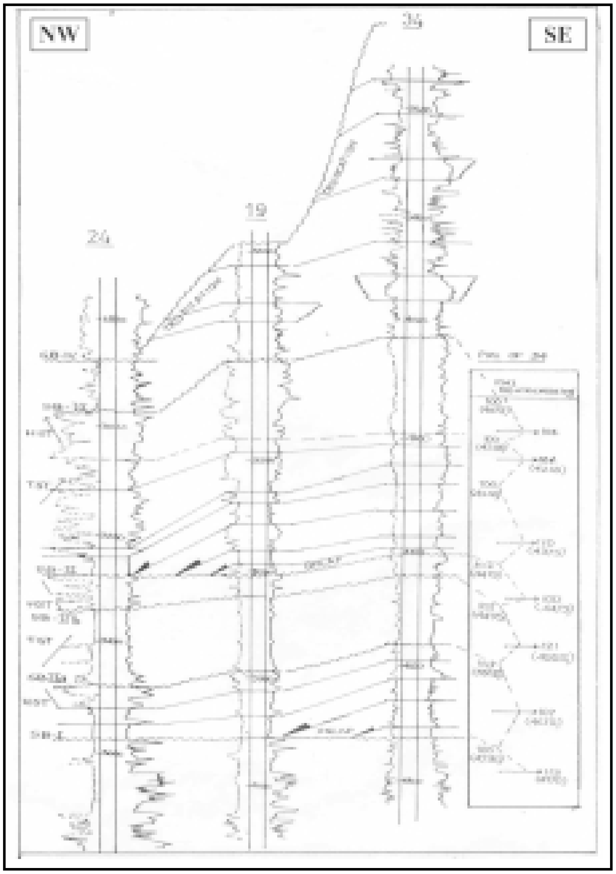

Figure4 : Regional electrolog correlation showing various sequences and their associated system tracts, onlap, truncation on the top of SB-I and SB-III (datum – Sylhet) . Profile a-a'

Seismic Sequence Analysis: Sequence boundaries on seismic sections are identified based on changes in time/ thickness, reflection termination associated with time/ thickness change, termination pattern (onlap, downlap, toplap and truncations), etc. Validating with the well data, the entire stratigraphic section of Assam has been divided into ten sequences (I-X) (Naik, et, al, 2001), within each sequence, some higher order sequences are also identified on well logs. Since, their recognition in the seismic sections is beyond the vertical resolution, they are not correlated and mapped. Widespread smaller scale cycles or subsequences that themselves resemble depositional sequences except for absence of significant erosional relief and their bounding discontinuities have been identified within SEQ-II. The tops of the two subsequences, i.e., SEQ. IIa and SEQ. IIb, correspond close to the relative sea level fall around 44 Ma and 39.4 Ma as inferred by palynological data and also depicted by low PMI (Palynological Marine Index) (Fig.4). However, they are not separable in seismic sections and therefore, only SEQ-II as a whole has been correlated and mapped. Seismically seq-II is mostly transparent with low amplitude, moderate frequency, discontinuous to patchy reflections. SEQ-II is discussed in detail below.

General Features of SEQ-II: Bounded below by sequence boundary SB-1 and above by SB-II, representing a major part of Kopili Formation.

Sedimentary facies: Lithologically, Seq-II is dominantly an argillaceous unit with thin sand beds and marl streaks. Coal and other carbonaceous matters are in negligible amount. The shales are mostly gray to dark gray, splintery with a few marl streaks. Pyrites are often seen in shales. The sands are quartzitic, fine grained, clean, fairly well sorted and sugary in nature. Glauconites are quite common. Sands are generally current bedded. Both festoon and tabular types are present. Sometimes, the sands are bioturbated. The shales also exhibit tidal flat bedding. Flaser and lenticular bedding are observed in some cores. All these sedimentary structures indicate tidal influence during the deposition of these sediments (Rao, 1983).

Biofacies: Biostratigraphically, Seq-II is characterized by the presence of calcareous forams. The overall faunal frequency and the size of the forams decrease towards the upper part. A few arenaceous forams like "*Trochammines*" and "*Haplophragmoides*" (normal growth) are also seen. The diminutive calcareous forms and the presence of the above arenaceous forams suggest the possible deposition in estuarine condition (Mohan et.al, 1970).

Log Correlation and Regional Extent: Regional well log correlation suggests two subsequences within Seq-II (Seq. IIa and Seq. IIb), which are more or less consistent through out the area and can be traced confidently from one well to other (Fig. 5, 6 & 7). The uniformity in litho-association and traceability over large areas, suggest a stable and calm environment of deposition (Serra, 1986).

Sand/Shale Ratio Map: The sand/shale ratio map prepared on the basis of well-logs suggests relatively higher sand/shale ratio in the west-northwest side. The values in general decrease towards east-southeast with corresponding increase in the finer clastics (Fig. 8).

Electrofacies: Within Seq-II, blocky, funnel and bell shaped, simple spike and tapered spikes are seen. Serrated shapes are also common. Logs adjoining the isopach maxima are mostly serrate blocky to funnel shape. Logs outside the isopach

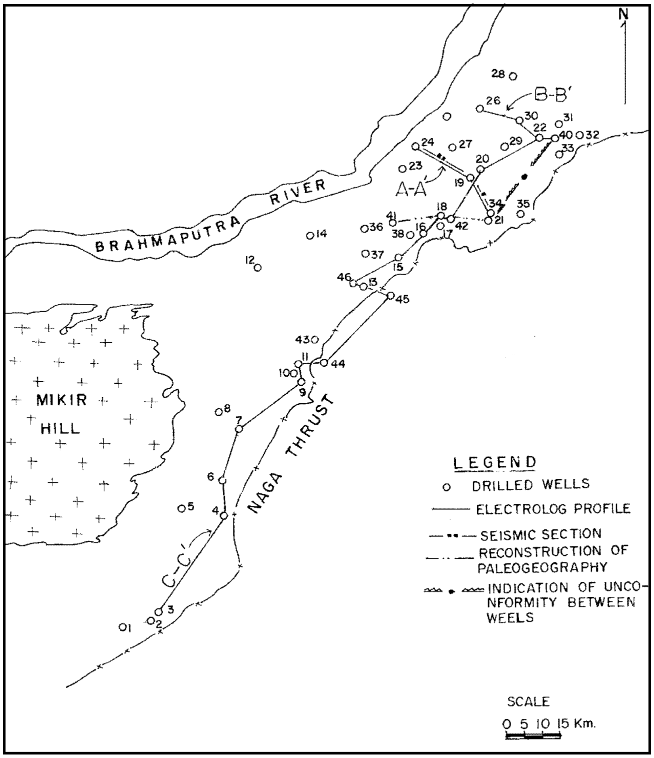

Figure5 : Index map showing electrolog profiles, seismic sections etc.

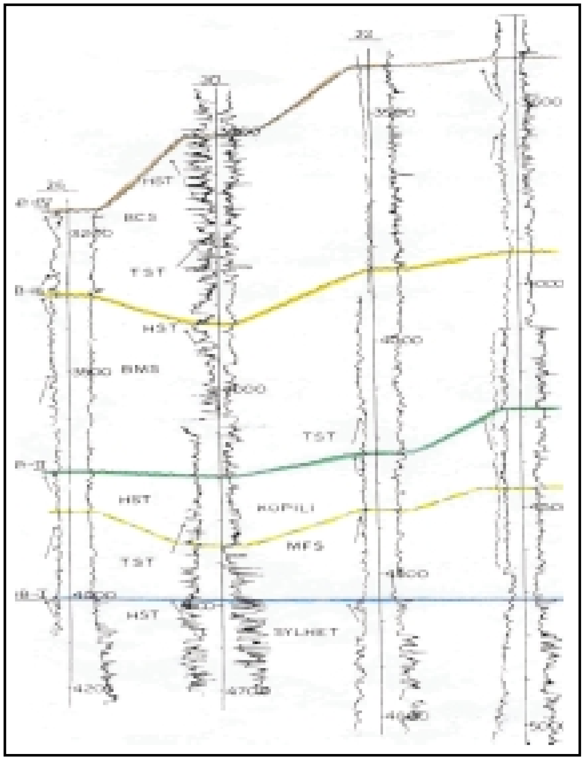

Figure 6 : Electrolog correlation.

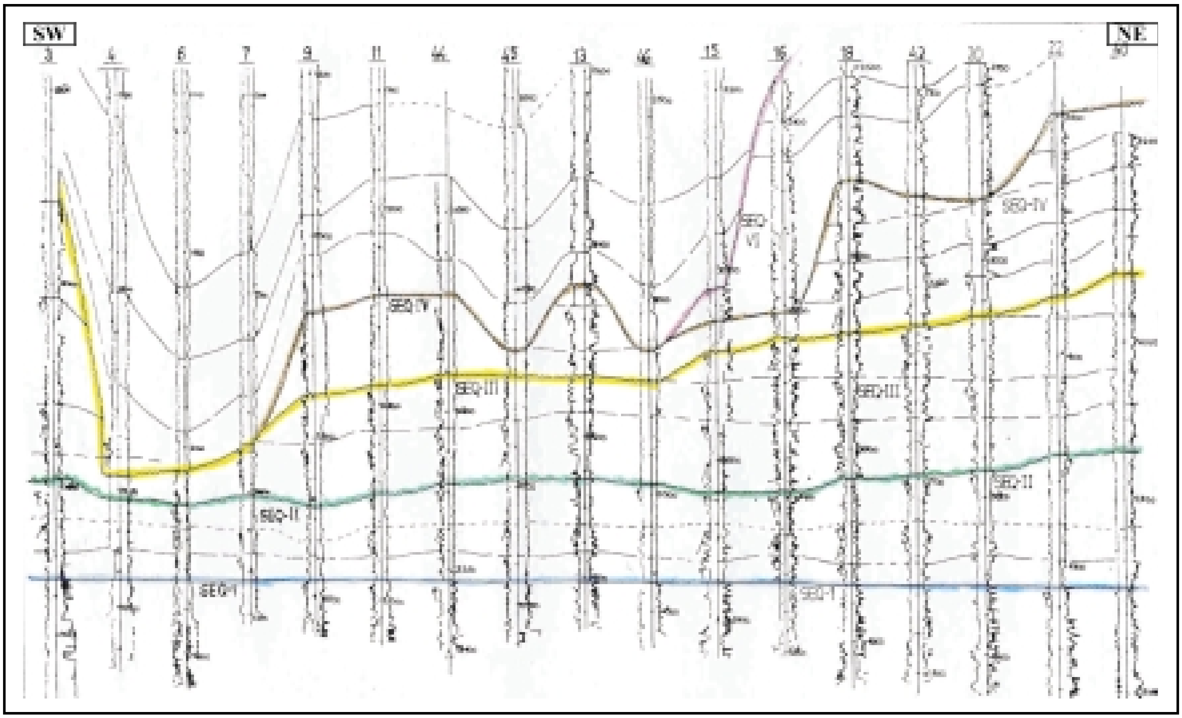

Figure 7 : Electrolog correlation

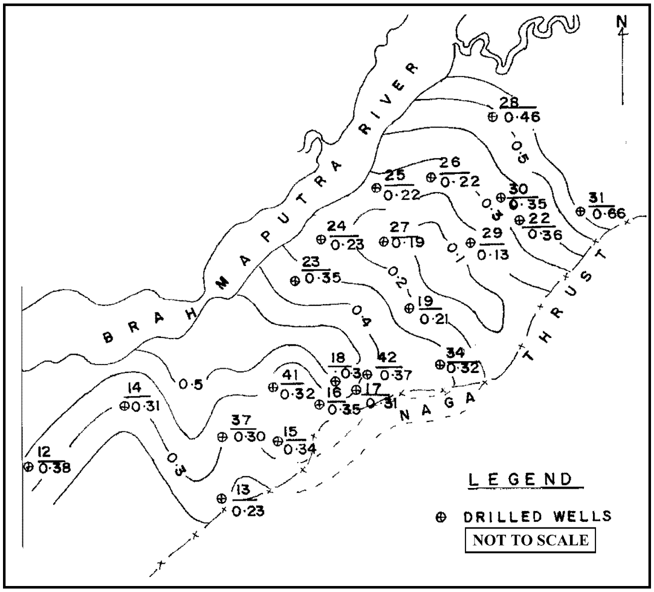

Figure 8 : Sand/shale ratio map SEQ-II (Kopili).

maxima show simple spike, tapered spike and also bell shaped nature (Fig. 6 & 7).

Seismic facies: Continuous with varying amplitude reflections are seen. Amplitude becomes higher towards Mikir Hill. In some areas reflections abruptly terminate due to erosional effect. The entire section therefore, is relatively reflection free with intermittent reflection of varying amplitude and frequency (Fig. 9). In general the reflection configurations are parallel to sub-parallel suggesting uniform rates of deposition on a uniformly subsiding shelf or stable basin plain setting (Vail et al., 1977).

SEDIMENTATION MODEL FOR Seq-II.: The Estuarine-Embayment Fill Model

Since the paleo-shelf break is not obvious in Assam region, it is logical to infer that the sediments deposited in the shallow marine to transitional set-up in this part may either represent transgressive or highstand or shelf margin system tracts formed landward to the depositional shelf break. The depositional model for Seq-II has to account for the following observations.

-Slow rate of deposition indicated by the presence of marl streaks and glauconites (Galloway, 1989).

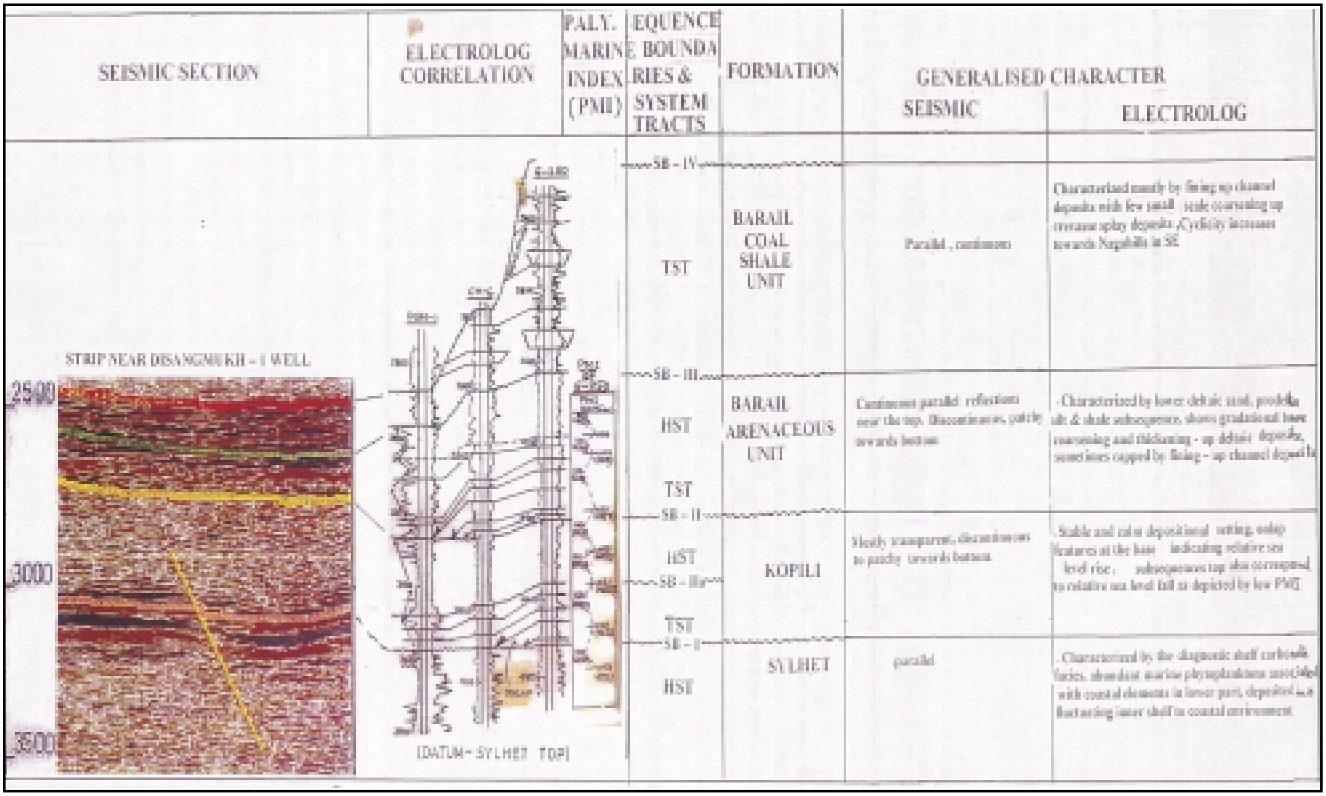

Figure 9 : Generalised characters of Paleogene Sequences.

-Deposition in a stable and calm set up suggested by the regional traceability of the correlation lines irrespective of direction. (Serra, 1972) -The observed isopach/isochronopach (Fig. 10 & 11) maxima along the Teok-Amguri-Charali- Demulgaon area corresponding to the sand maxima axis and transverse to the strike of the basin. Geleki-Lakwa area also shows good development of sand parallel to the strike

- *Low sand-shale ratio.*
- *Distribution of various electrofacies*
- *Presence of pyrites and glauconite.*
- *Foraminiferal association suggesting brackish water estuarine condition.*

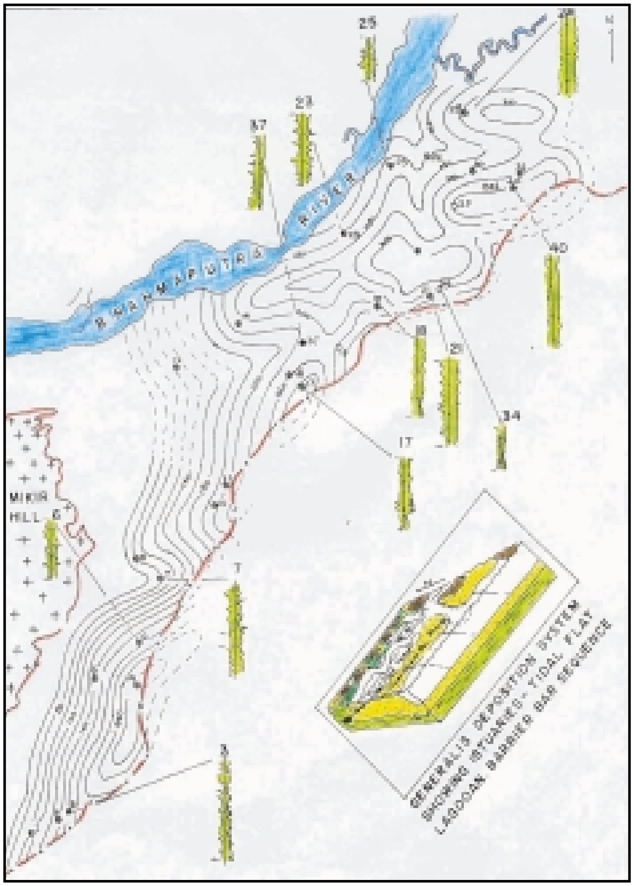

Figure 10 : Isopach map of SEQ-II (Kopili)

On the basis of all these criteria, an estuary-embayment fill model (Fig. 10) seems more probable environment of deposition for these sediments. It is believed that a framework of estuarine environment, i.e. bay-lagoon-inlet-tidal flat and marsh were significantly involved during

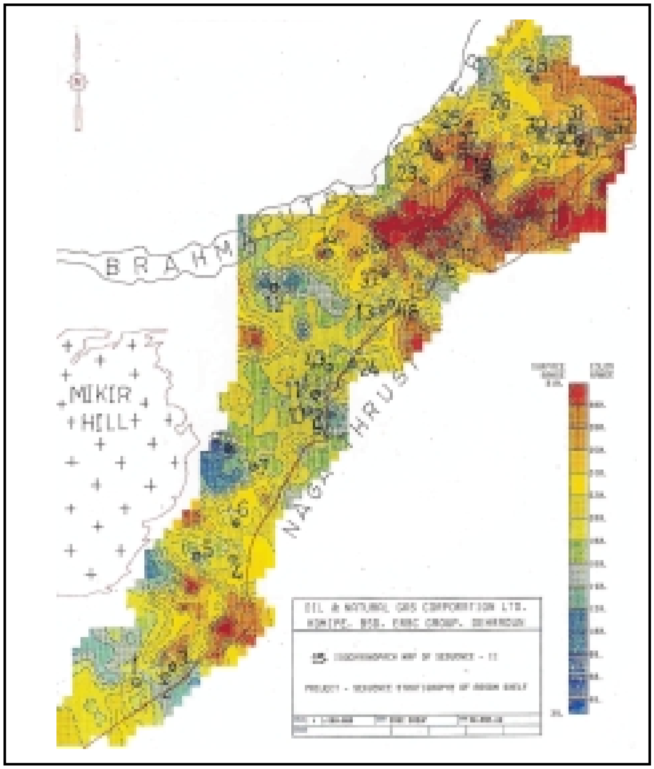

Figure11 : Isochronopach map of SEQ-II (Kopili).

the deposition of Seq-II sediments in a coastal set up. With relative rise in sea level coupled with renewed clastic supply, the carbonate platform of Seq-I was given up. This led to the deposition of lower unit of Seq-II in a shallow open marine shelf embayment as Transgressive System Tract (TST) (Fig. 12).

Relative lowering of sea level or increase in rate of sediment supply reverses the transgression to cause depositional regression (Curray, 1964) or normal regression of Posamentier et al.,1992. This resulted in the incision of fluvial drainage and seaward accretion of littoral sediments as barrier bars and deposition of Sandy middle unit (Seq-IIa).

The sharp upper contact of the SEQ-IIa. unit indicates the marine flooding surface (MFS) which recorded rapid deepening . Subsequent rise in sea level resulted into rapid accommodation development and the sediments were again trapped along the estuarine-embayment shelf. The gross sandstone thickness decreases smoothly from a maximum in the Teok-Amguri-Charali- Demulgaon area to a minimum at the edges. In Dhansiri Valley NE-SW oriented thickness maxima may represent axial trend of the barrier bar (Fig. 10).

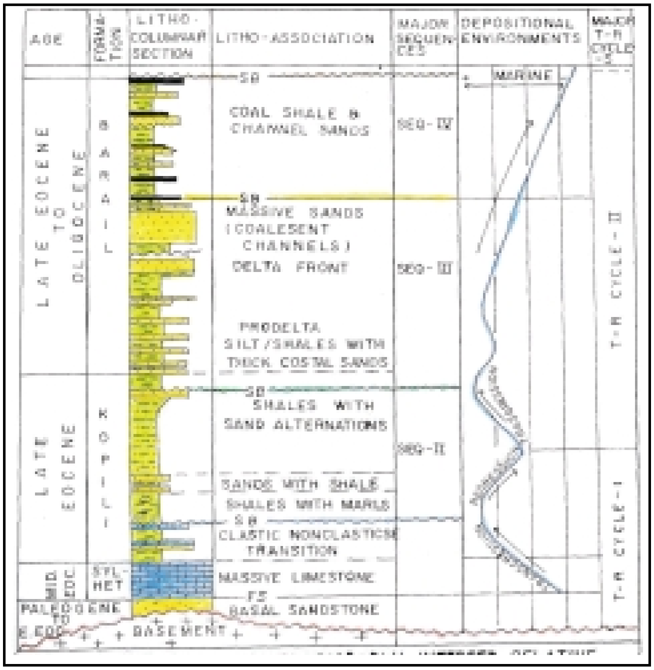

Figure 12 : Generalised lithostratigraphy, inferred relative sea level and sequence stratigraphic interpretation SEQ-I to IV, Upper Assam

This bar might have restricted normal marine circulation creating brackish or lagoonal set up in the landward side in west and northwest. Subsequent relative rise in sea and continued transgression resulted in the deposition of black shales in estuarine condition. The overlying prograding unit was deposited following a relative sea level fall towards late Eocene time. The Teok-Amguri-Charali-Demulgaon was the main embayment area. The main drainage and sediment supply was from the Teok and Disangmukh side. Namti-Geleki-Lakwa area showing broadly NE-SW oriented depositional pattern represents the barrier bar axis.

Thus, the broad environmental setting was that of a vast, shallow water sea floor which was slowly changing from a carbonate platform (Fig. 13 & 14) to a relatively muddy deeper water during a period of relative sea level rise. The flat coastal gradient of the stable Assam passive margin, a relative sea level rise and a reduced clastic supply from the mature cratonic source (Indian shield) were probably the favourable factors for the growth of a long and voluminous estuary during the entire Seq-II sedimentation. The model leads support to the views expressed by previous workers. Mohan and Pandey (1973), based on biostratigraphic analysis inferred a shallow marine to brackish water condition for Kopili sediments. Murty (1983), opined that the pre-Barail

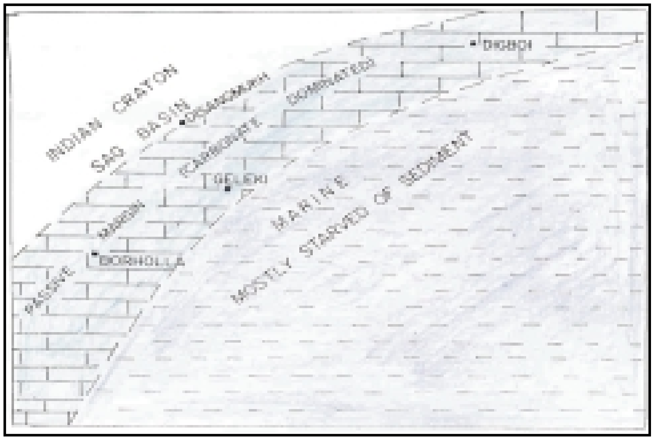

Figure13 : Generalized paleogeographic map of Upper Assam during early to middle Ecocene time showing carbonate platform development (SEQ-I)

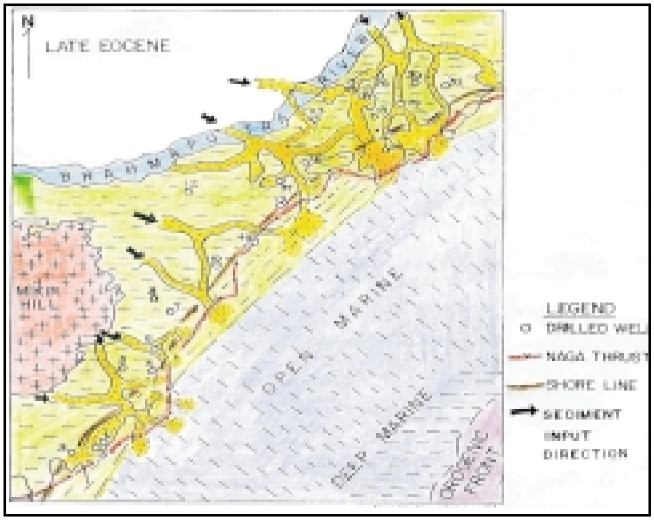

Figure14 : Paleogeography during SEQ-II (Kopili).

sedimentary sequences were associated with a stable to mild unstable shelf littoral to sublittoral environment deposited during a broad transgressive set up. Rao (1983) also viewed the deposition of Kopili in a brackish water tidal flat environment and doubted if any delta began to form in Eocene time.

DISCUSSION

Change in Stratigraphic perception: Lithostratigraphically, the top of the monotonous limestone has been taken as the top of Sylhet Formation (Deshpande et al., 1994). However, following the North American Stratigraphic Code nomenclature, "...... *where a shale unit overlies a unit of* *interbeded limestone and shale, the boundary commonly placed at the top of highest readily traceable limestone bed*", Sylhet Formation top has been taken at top of the first appearance of the correlatable limestone. Therefore, Seq–I top/Seq-II bottom boundary has been taken on the top of the well correlatable limestone peak and is considered as a drowned unconformity.

Similarly, in the present study, Seq-II top (SB-II) is defined by the top of a HST (Fig.4) and mostly marks the top of a prograding sandy unit. Unlike lithostratigraphy, some time equivalent shale unit of Barail Sand has also been included within Seq-III. The sequence boundary SB-II is easily recognizable in areas like Rudrasagar, Dikhomukh, Disangmukh, etc. (i.e., northwestern part of Upper Assam), and in Mariani, Charali, Geleki, Amguri, Lakwa areas, the boundary definition is little difficult and has been considered at different levels by different workers. This is because of the fact that the lower part of the overlying sequence (Seq-III, Barail Formation) in many wells consists of prodelta shales/ silts (Fig.14), which have almost similar log signature as that of Seq.II.

Most of the previous workers consider this boundary as conformable one. However, biostratigraphic studies carried out by Singh et al., 1986, indicate that the top of Kopili Formation in Naojan, Kasomarigaon and Barapathar wells is marked by a prominent erosional unconformity. Banerjee (1980) has also interpreted an unconformity below the Barail Group in Amguri area. Similar unconformity has also been reported in the stratigraphy of Bangladesh (Khan and Hussain, 1980) and other east coast basins of India. In the present study, this boundary has been interpreted as an unconformity.

Paleogeographic Reconstruction: Geologically, as viewed by many workers, the Upper Assam and the Lower Assam show two distinctive geological facies belts, i.e., Upper Assam shelf facies and Lower Assam Geosynclinal facies (Krishnan, 1982, Wadia, 1953, and many others) correspond closely with the shelf or the platform and the geosyncline or the basinal part respectively. This conveys a pseudofilling about the paleo shelf-slope system in this region. Therefore, as inferred in the present study, this division and definition seems illogical and vague. The basinal slope during depositions of Seq-II with shelf–slope system was towards east/southeast. Tectonic evolution of the area suggests that the basin was generated synchronously with the east coast basins of India during Cretaceous time and subsequently developed into a passive margin. The first extensive marine incursion to Upper Assam during Late Paleocene to Early Eocene time changed the region into an eperic sea with deposition of Basal Sandstone as transgressive lag. Subsequently the hinterland was peneplaned and got flattened. Siliciclastic supply was reduced and carbonate growth was favored (Fig.15).

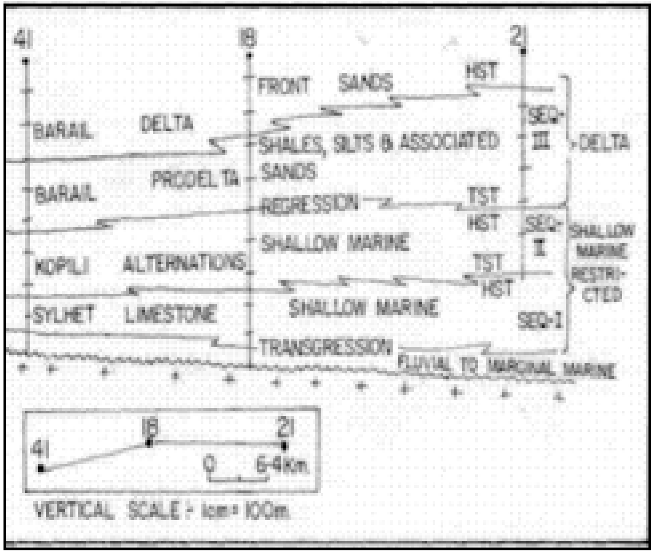

Figure15 : Reconstruction of paleogeography during paleogene time. Upper assam (Modified after Madan Mohan, 1975).

Kopili-Disang Relationship: During Mid to Late Eocene time the area witnessed transgressive- regressive (T-R) (Fig. 12) cycles leading to the deposition of shale and sand alternations of Seq-II. Thus, during Eocene time, the major source for Seq-II sediments was from the west and northwest, i.e. the Indian Craton whereas the source for the equivalent Disang Group of sediments was from the Burmese basin including the volcanic arch and the Ophiolite belt. The effect of the orogenic front was not extended upto the Upper Assam during this time. The apparent facies relationship between these two homotaxial units seems to be due to the closure of the separating seaway at a later phase that brought these facies juxtaposed to each other at present.

CONCLUSION

- Assam-Arakan basin represents a classic example of a polyhistory basin which developed as a passive margin and later changed into a foreland basin in a peripheral position with respect to the major Naga schuppen belt and the contiguous Indo-Burma orogenic front. The oblique collision and the tectonic wedging model has been visualized in the Northeastern India.

- The entire stratigraphic section of Assam has been divided into ten sequences (I-X), out of which four are within Paleogene (I-IV) and the rest are within Neogene (V-X). The Paleogene sequences are well correlatable both in Upper Assam and Dhansiri Valley.
- The major input for the Seq-II, was from west and northwest, i.e., the Indian craton. The apparent facies relationship between these sequences and the time equivalent Disang Group of sediments is due to the closure of the separating seaway at a later phase bringing these facies juxtaposed to each other.

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The views expressed in the paper are solely of the authors and not necessarily of the organization in which they are working.

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