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Sequence Stratigraphic Analysis of Passive Margin and Foreland Sequences of Lakwa-Lakhmani and Satellite Areas

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Abstract

Petroleum System Sequence Stratigraphic study has been carried out in the Passive margin and Foreland depositional sequences of Lakwa-Lakhmani and adjoining satellite fields The Transgressive-Regressive(T/R) model, intrinsically related to the shoreline shift has been adopted to map high frequency surfaces within the passive margin sequences. Ten T/R sequences have been mapped in the 2nd order Paleocene-Oligocene sequence from PI 10 (Pre-Cambrian Basement Top) to CI 40 (Oligocene Top) unconformities. Low Accommodation System Tract (LAST) and High Accommodation system tracts (HAST) based on progradational and aggradational pattern has been adopted in the Foreland part. In the 2nd order Miocene sequence between CI 40 and CII 100(Lower Clay Marker top) five LAST sequences and in 2nd order Pliocene sequence between CII 100 and LAST-HAST Pliocene (Lakwa Sandstone top) four LAST sequences have been identified, separated by intervening flood plain deposits (HAST).

Introduction

Sequence stratigraphy is a modern tool for stratigraphic analysis and modelling of geological and depositional processes related to base level changes. This method also helps to define the genetic characters of different types of stratigraphic surfaces in time and space . The T/R sequence stratigraphic mapping was carried out in the Passive margin of Lakwa-Lakhmani field and adjoining Satellite areas viz. Demulgaon, Mahakuti, Kaurgaon, Laiplingaon, Tiphuk, Banmali, Sonari and Safrai areas of Upper Assam Shelf.T/R 1 corresponds to Tura, T/R 3 & 4 represents Sylhet, T/R 5,6 & 7 represents Kopili and T/R 8,9 and 10 corresponds to Barail Formation. . LAST represented by Safrai and Geleki sandstone corresponding to TS-5 and TS-6 and HAST (TS-4 sand) is represented by LCM . The Lakwa Sandstone represent the LAST and the conformably overlying Girujan Clay corresponds to the HAST. The channel sands represent the informal pays TS-1, TS-2 and TS-3.

Depositional sequences

The first 1st order sequence was deposited over the basement (**PI 10**). In subsurface, it's occurrence is reported from wells in south Assam shelf. However, the sequence has not been encountered in the study area. The second 1st order Rift Fill sequence was deposited as a result of accommodation created during Early Cretaceous rifting when India separated from Antarctica. This sequence is penetrated in several wells in south Assam shelf (Barpathar-1, Jamuguri-1, Dergaon-1, East Lakhibari-1, Yampa-1, Furkating-1&2, Gamariguri-1) **.** The sequence is spread over the south Assam shelf only and occurrence is localized over the areas of graben fill sediments. This sequence has also not been encountered in the subsurface of the Lakwa field.The third 1st order Passive Margin sequence was deposited when Indian plate was in drift phase. This sequence is bounded between the unconformities **C I 40** above and **P I 10** (Granitic basement)..The sequence is further divided into two 2nd order sequences based on the presence of an unconformity **C II 10** (K/T boundary).The Late Cretaceous 2nd order sequence is bounded between unconformity **M I 80** (at the top of rift fill**)** below and C **II 10** (KTB) above. The hiatus over the rift fill sequence is of ~39.5 Ma duration. Elsewhere, it directly overlies **P I 10** (basement). The sequence was deposited over the rift fill sequence (Sylhet trap) when transgression first entered into the Shillong plateau in Garo, Khasi and Jaintia hills during the drift phase in Late Cretaceous.The younger 2nd order sequence of Passive margin is bounded by the unconformity **C II 10** (KTB) below and **C I 40** (base Miocene unconformity). The sequence ranges from Paleocene to Oligocene with no interruption in sedimentation. The initial transgressive deposits of Early Paleogene over the base Tertiary unconformity C **II 10**, represent the TST of the sequence. The deposition continued till it reached highest base level marking the drowning of the carbonate platform in the Late Eocene (~37.2Ma). Subsequently, the sedimentation continued in HST with concomitant rise in provenance. Normal regression continued from Late Eocene (37.2 Ma) to Late Oligocene (26.2 Ma). A huge delta system developed during the Oligocene, which culminated in a major eustatic sea level fall, coupled with flexural rebound, enforcing widespread subaerial erosion, marking the Base Miocene unconformity **C I 40**. The event is linked with Himalayan orogeny and continent- continent collision. A 2nd order MFS separates the Transgressive Systems Tract (TST) below from Highstand Systems Tract (HST) above. The TST of the sequence is represented by the Tura and Sylhet formations. The Maximum Flooding Surface (MFS) of the sequence coincides with the top of Sylhet Formation, representing culmination of carbonate sedimentation (Drowning unconformity) in the basin. The HST corresponds to the Kopili and Barail formations, with top of Barail marking the upper sequence boundary (**C I 40**).

1st order Foredeep sequence (Miocene-Recent) The fourth 1st order sequence was deposited in the foreland tectonic setting in response to advancing Himalayan thrust. The sequence is deposited over the base Miocene unconformity (**C I 40**) after a hiatus of 4.3 million years.. Three 2nd order foredeep sequences are identified in Miocene to Pliocene, while the fourth one is currently under deposition.2nd order sequence (Miocene) sequence was deposited over the base Miocene unconformity **C I 40** and **C II 100.T**he upper boundary corresponds to the boundary between Geleki Sandstone below and Lakwa Sandstone above separated by the regional Clay marker (LCM) . TS-4 pay sand is embedded within LCM.

2nd order Foredeep sequence (Pliocene): The second 2nd order foredeep sequence was deposited over the Base Pliocene unconformity **C II 100** and its upper boundary is marked by Late Pliocene to Early Pleistocene unconformity **C II 110.** During the period the third phase of Himalayan orogeny commenced resulting into major upheaval, excessive sedimentation and forebulge shift closer to HFT (Himalayan Frontal Thrust). The accommodation was filled with high-energy braided channel deposits (Lakwa Sandstone) followed by flood plains deposits (Girujan Clay).

2^{nd} order sequence (Late Pliocene - Pleistocene): The sequence was deposited over **C II 110** and its top is limited by **C II 120.** This unit is represented by Upper Sandstone/ Nazira Sandstone. This was followed by the deposition of low energy, wide flood plains equivalent of the argillaceous Namsang Formation.

2^{nd} order sequence (Pleistocene - Recent): This 2^{nd} order sequence is currently under deposition during the superposing phase of Himalayan foreland system over the Naga foreland system. Deposition commenced over the unconformity **C II 120** (~ 1.81 Ma) above the underlying 2nd order sequence.

Transgressive-Regressive Sequences

Transgressive/Regressive (T/R) sequence model of Embry and Johannessen (1992) has been adopted for Passive margin depositional sequence whereas in the Foreland sequences Low Accommodation and High Accommodation System Tract Model has been employed in Lakwa-Lakhmani and adjacent satellite fields.

The T-R sequence model of Embry and Johannessen (1992) l offers an alternative way of packaging strata into sequences, with an objective to attain high resolution chrono correlation at reservoir level. The T-R sequence is divided into two systems tracts: a Transgressive Systems Tract (TST) bounded by the sequence boundary below and the MFS above and a Regressive Systems Tract (RST) bounded by the MFS below and the sequence boundary above. Thus, the MFS in this model subdivides the 'T-R sequence' into transgressive and regressive systems tracts. The model limits the "sequence" boundary at the top of RST. In T-R model, the key sequence stratigraphic surfaces are MFS and MRS, which separate the TST and RST, thus avoiding the problem of having subaerial unconformity within the sequence.

In the present work in Lakwa-Lakhmani and Satellite field, the T/R sequence model has been adopted for lower order sequence stratigraphic mapping of the 2^{nd} order Paleocene-Oligocene depositional sequence, where sedimentation is related to shoreline shift .Ten T/R sequences have been identified. The lower four of these T/R sequences are part of 2^{nd} order TST and the overlying six are part of the 2^{nd} order HST. The Maximum Flooding Surface (MFS) of the 2^{nd} order depositional sequence coincides with the MFS of the 4^{th} T/R sequence. This MFS coincides with the top of Sylhet Formation, representing culmination of carbonate sedimentation ('Drowning unconformity') in the basin (Fig 1). In the overlying 2^{nd} order Miocene and Pliocene Foredeep Sequences which are away from the changes of base level fluctuations, Low Accommodation and High Accommodation System Tract have been used. The 2^{nd} order Miocene sequence is further divided into five LAST sequences separated by HAST. The 2^{nd} order Pliocene sequence is divisible into four LAST sequences separated by HAST..

2^{nd} order sequence (Paleocene-Oligocene):

T/R sequence-1: This sequence is the first sequence of the ten T/R sequences marked which were identified in the 2^{nd} order Paleocene –Oligocene Passive Margin depositional sequence. It is bounded by PI 10 unconformity at the base and MRS-1 at the top. The flooding surface MFS-1 of this sequence divides TST and RST. This T/R sequence corresponds to the lower part of Tura Formation deposited by alluvial fans deposits, fluvial dominated channels. (FIG.1)

T/R sequence-2 corresponds to the upper part of Tura Formation and comprises of mainly sand with shale intercalation.The sand entry is from N,NW and NNW.

T/R sequence-3 is represented by upper part of Tura Formation and lower part of Sylhet formation.. Alternation of shale and limestone suggests shallowing and deepening of the basin.

T/R sequence-4 is represented by upper part of Sylhet and the lower part of Kopili Formation, the flooding surface of T/R 4 corresponds to 2nd order MFS of the 2nd order Passive Margin sequence, which is drowning event on top of underlying carbonate cycle.

T/R sequence-5 The sequence represents lower to middle part of Kopili Formation of Late Eocene chronospan. The sand isolith map shows the orientation of the sand bars in NE-SW to ENE-WSW direction. Presence of sand bars parallel to each other depicts a number of transgressive and regressive events. This sequence corresponds to a part of Kopili Formation(Fig-36).

T/R sequence-6 is the second sequence deposited in Late Eocene and earliest part of Early Oligocene corresponding to the upper part of Kopili Formation. The sand isolith map suggests orientation of barrier bars and long shore bars in NE-SW and NNE-SSW direction. T/R sequence-7 corresponds to the uppermost part of Kopili. This sequence has been deposited in fluctuated coast line with basinal slope towards south and south-east and deposited as barrier bars and beach sands oriented in NE-SW and NNE-SSW direction This sequence corresponds to the lower part of BMS.

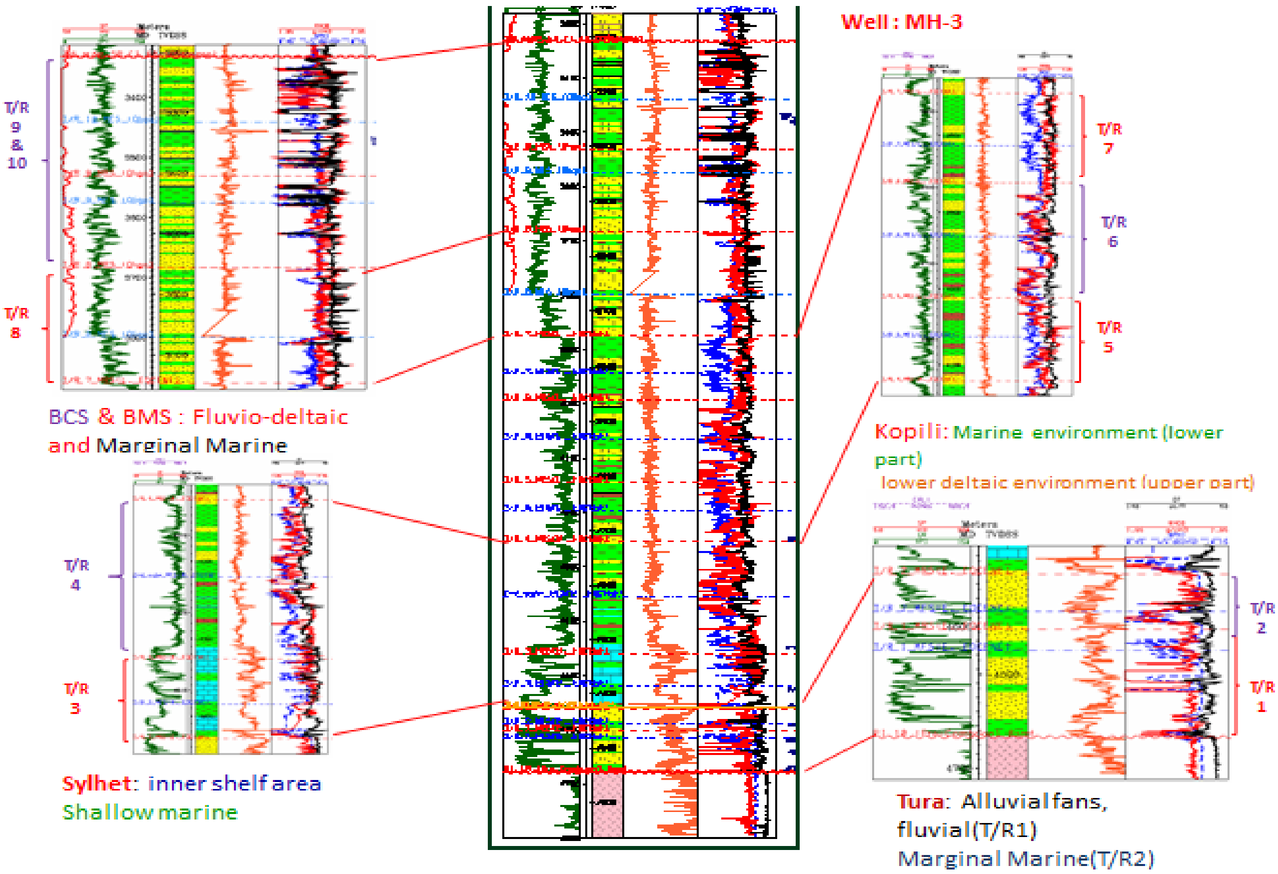

FIG:1: Showing T/R Sequences

T/R sequence-8 corresponds to the upper part of the BMS and lower part of the Barail Coal Shale (BCS) units of Barail Group. The sequence covers major part of Early Oligocene chronospan. The sand isolith map suggests major sand entry points from NNW except in Banmali area where it is from N. The. LBS-I,II and BMS are the main oil producing sand in this sequence(Fig-39).

T/R sequence-9 corresponds to the Barail Coal Shale (BCS) covering the chronospan of Late Oligocene. The major pays of the sequence include LBS II and III

T/R sequence-10 is dominated by marshes and constrained channels as well as crevasse splays developed in the inter distributary area which is the part of the lower delta plain**.** The sequence corresponds to upper BCS unit of Barail Group and covers the Late Oligocene chronospan. Sand entry is from NNW to NW. This sequence is represented by LBS-IV, V,VI.

Low- and High Accommodation Systems Tracts:

The identification of all Regressive and Transgressive systems tracts, discussed above is based on shoreline shifts. In case of overfilled basins or in portions of sedimentary basins that are not influenced by down stream control (shore line shift) and are influenced by upstream control (Climate,source area tectonism, glaciation/de-glaciation etc), the concept of Low Accommodation Systems Tract (LAST) and High Accommodation Systems Tract (HAST) is employed .(FIG.2)

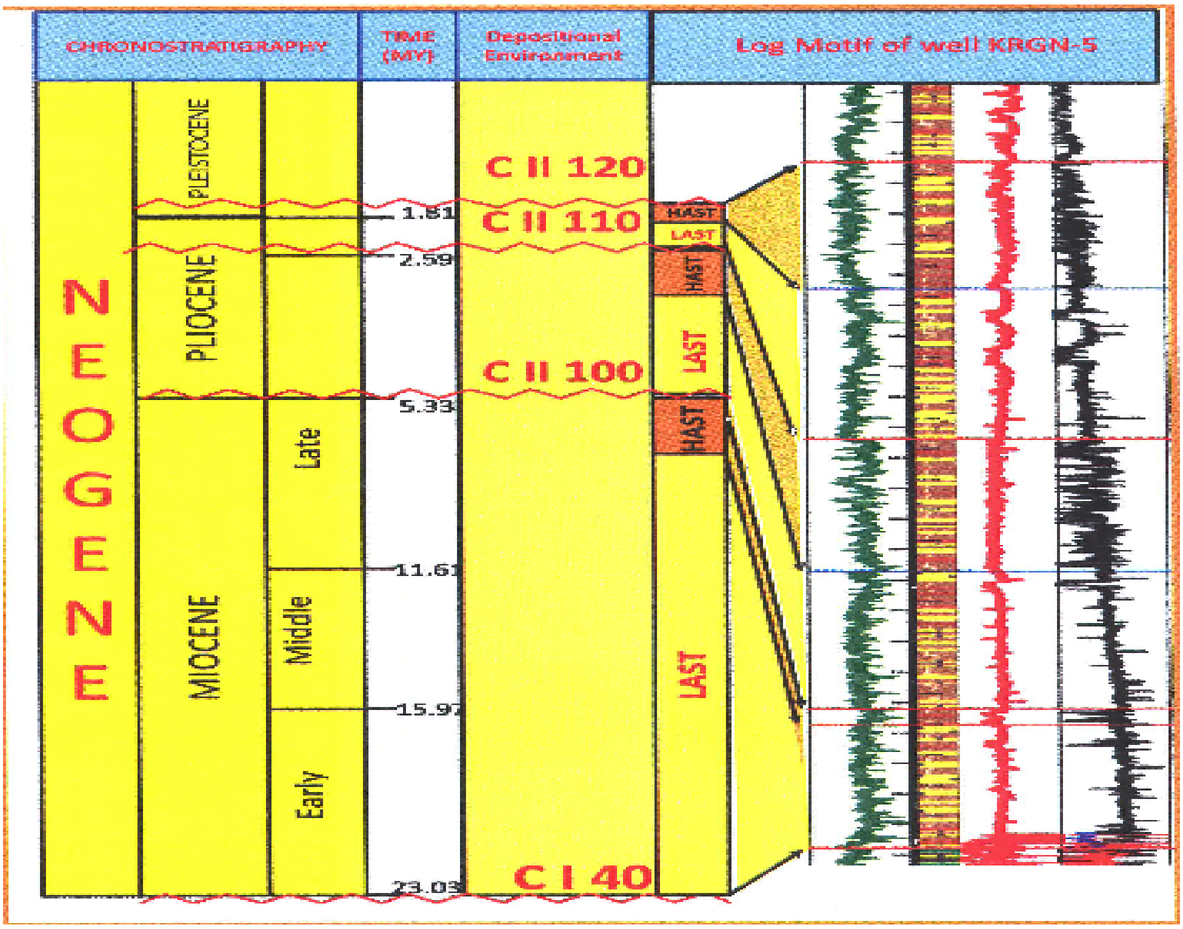

FIG.2: Showing LAST/HAST Sequences

The LAST/HAST concept provides solution to the sedimentary basins that are dominated by non-marine surface processes (e.g. over filled basins) or where only non-marine facies are preserved, with practically no connection to shoreline shift. They signify certain amount of accommodation available during deposition, which is based on subsidence pattern within a given tectonic setting.

In the 2nd order Miocene depositional sequence, five LAST sequences, separated by HAST have been identified. LAST represented by Safrai and Geleki sandstone corresponding to TS-5 and TS-6 and HAST (TS-4 sand) represented by LCM . In the 2nd order Pliocene depositional sequence four LAST sequences separated by HAST have been identified.The sequence corresponds to Lakwa Sandstone and overlying Girujan Clay. The Lakwa Sandstone represent the LAST and the conformably overlying Girujan Clay corresponds to the HAST. The channel sands represent the informal pays TS-1, TS-2 and TS-3. The 2nd order sequence (Late Pliocene- Pleistocene) is represented by Upper Sandstone/Nazira Sandstone and Namsang Formation.The 2nd order sequence (Pleistocene-Recent) is currently under deposition.

Structural Interpretation

Structural analysis of the area clearly brings out two dominant fault pattern viz. ENE-WSW,NE-SW longitudinal faults and NW-SE trending transverse/cross faults.The major faults ENE-WSW and NE-SW are having a southerly hade, These faults have reactivated and form entrapment for both shallow as well as deeper hydrocarbon plays.In Kaurgaon area,a four way closure with faulted entrapment is observed close to Tura top.To the north of Lakwa wedge out structure with fault is observed close to Tura top.In Demulgaon area four way structural closure is observed at Tura level.

Conclusion

The Transgressive-Regressive model, intrinsically related to the shoreline shift has been adopted to map high frequency surfaces within passive margin sequences. Low Accommodation and High Accommodation system tracts (LAST/HAST) based on progradational and aggradational pattern is adopted in Foreland part. Within the two 1st order sequences i.e. from PI 10 (Pre-Cambrian Basement Top) to CI 40 (Oligocene Top) unconformity, a total of 10 T/R sequences have been mapped from Paleocene to Oligocene Passive Margin setup. T/R 1 and T/R 2 corresponds to Tura Formation, T/R 1 have been deposited as alluvial fans and braided channels whereas T/R 2 deposited as offshore bars. T/R 3 and T/R 4 representing Sylhet Formation deposited in shallow marine environment. T/R 5, T/R 6 and T/R 7 correspond to Kopili Formation and have been deposited in deeper bathymetry. T/R 8, T/R 9 and T/R 10 represent Barail Formation and have been deposited in fluvio-deltaic setup.In 2nd order Miocene Sequence five LAST sequences have been identified separated by HAST. LAST-1 represents Safrai member, LAST-2 & LAST-3 corresponds to TS-6 sand, LAST 4 & LAST 5 represents TS-5 sand. The Lower Clay marker (LCM) represents the HAST and TS-4 sand within it.The 2nd order Pliocene Sequence has been divided into four LAST sequences separated by HAST. LAST Pliocene represents Lakwa sandstone (TS-1,2 and 3) and HAST represents Girujan Clay Formation.The 2nd order Late Pliocene-Pleistocene sequence is divided into LAST & HAST corresponding to Nazira sandstone and Namsang formation respectively.Structural analysis shows three types of fault pattern viz. ENE-WSW, NE-SW and NW-SE. and the paleotectonic analysis suggests reversal of paleoslope from SE to NW during Pliocene.