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Title: Geological Model of Tura in North Assam Shelf using T- R Sequence mapping

Authors:- Soumitri Sankar Dash[#] , C.P.S. Rawat* , Apoorva Sahoo* ,Radha Krishna*, Priyanka Bhardwaj*, A.K. Parakh* , Shipra S. Bhagwani*

Address: # Western Offshore Basin, INTEG, GEOPIC, ONGC Ltd., Dehradun-248001,Uttarakhand,India

*BRG, KDMIPE, ONGC Ltd., Dehradun-248001, Uttarakhand,India

***Presenting author E-Mail**: soumitri123@rediffmail.com, dash_soumitrisankar@ongc.co.in apoorvas.2003@gmail.com*

Abstract:

Over the years, Sequence stratigraphy has developed into the fundamental approach for understanding and predicting the distribution of sedimentary bodies. The stratal stacking pattern evolves in response to the interplay of accommodation available for sediments to fill, shoreline trajectories, base level changes and sediment load.

In the present work, the T-R (Transgressive – Regressive) sequence model has been adopted for lower order sequence stratigraphic mapping of the 2nd order Paleocene – Middle Eocene Passive Margin depositional sequence, where sedimentation is related to shoreline shift. Deeper wells, which have penetrated Tura in entire North Assam Shelf (from Holongapar field in SW to Banamali in north-east), were considered. Sedimentological analyses, petrography of core reports, electrologs, paleo-bathymetry, fossils evidences and available G & G data are analysed to decipher the depositional environment prevailing over the entire North Assam Shelf area for Tura.

A total of four T-R sequences were identified within Tura-Sylhet Formations. Each of these T-R sequences comprise of Regressive and Transgressive Systems Tracts (RST and TST), separated by MFS, while the sequence boundaries are marked by MRS.

T-R 1 which corresponds to Kuargaon member/Lower part of Tura was deposited in distal alluvial fan channel to braided channel environment. The T-R 2 equivalent of Lakhmani member/Upper part of Tura was deposited in a strand plain/barrier bar environment oriented towards NE. The TST sands of T-R 3 which corresponds to topmost part of Tura was deposited in tidal/estuarine channel environment.

RST part of T-R 3 and whole of T-R 4 correspond to Sylhet Formation.

It is observed that TST sands of T-R3 and RST sands of T-R2 sequence are the potential reservoirs within Tura and found to be hydrocarbon bearing in ONGC operated acreages, a time equivalent of prolific Lakadong member in OIL India acreages. So far, RST sands of T-R 1 sequence, time equivalent of Langpar member of OIL India acreage, too are hydrocarbon bearing reservoirs in only few wells of ONGC operated acreages.

Introduction:

The sequence stratigraphic approach was adopted to study the Passive margin depositional sequences of North Assam Shelf. It is a modern tool for stratigraphic analysis and modelling of sedimentary record within a chrono-stratigraphic framework. Sequence stratigraphy has developed into the fundamental approach for understanding and predicting the distribution of sedimentary bodies. The stratal stacking pattern evolves in response to the interplay of accommodation available for sediments to fill, shoreline trajectories, base level changes and sediment load. Sequence stratigraphy also helps to define the genetic characters of different types of stratigraphic surfaces in time and space. (**Fig.1**)

The study covers entire North Assam Shelf from Holongapar field in SW to Banamali in north-east.

Geology and Tectonics of the area:

The Assam & Assam-Arakan Basin is tectonically differentiated into north-easterly plunging linear ridges and depressions to the north of the Dauki-Naga faults and oriented in NE-SW directions. The E-W trending Jorhat fault separates Assam shelf into North Assam Shelf and South Assam Shelf (Bawana.P.R. et al. , 2003).

The Upper Assam shelf, where most hydrocarbon discoveries have been made, lies between two major, counter dipping thrust systems, the Himalayan Front to the north-northwest and the Naga overthrust Belt to the southeast. These thrust system converge to the northeast of the basin in the Mishmi hills. In the south west, the Upper Assam Shelf terminates against Jorhat fault, outcropping at the surface in the Mikir Hills and

Shillong Plateau. Some of the prominent and producing fields in upper Assam Shelf include Geleki, Lakwa-Lakhmani, Rudrasagar etc. (Roychaudhury,S.C and Mukherjee (2011).

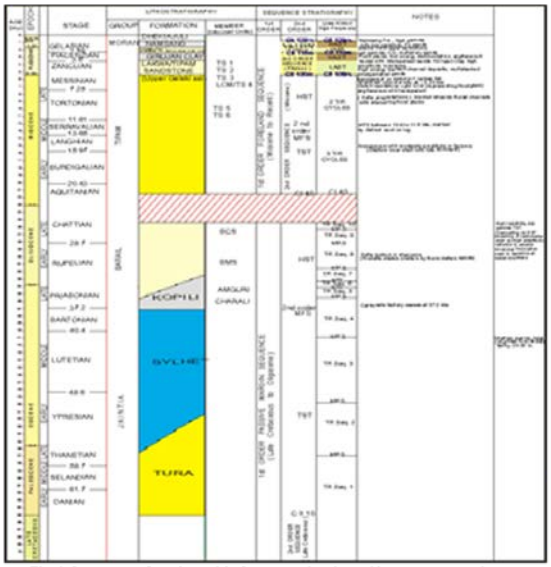

Fig.1:Sequence Stratigraphic framework adoped in present study

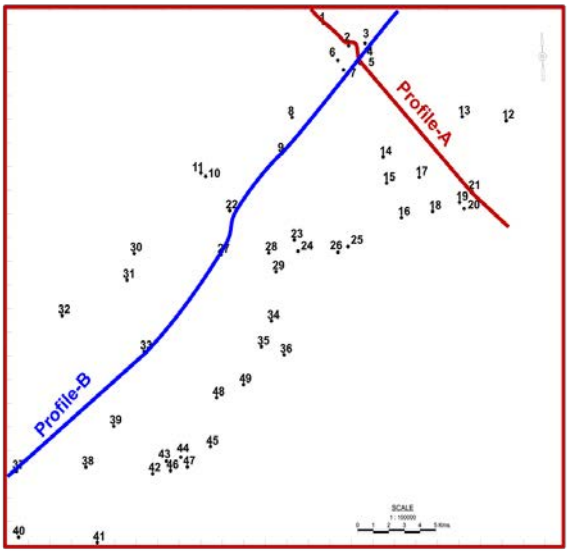

Fig.2: Base Map of North Assam Shelf

Sequence Stratigraphic Concept:

The T-R model is related to shoreline shifts and base level changes; this can easily be related to the depositional sequences. Another significant feature of this approach is that the lower order, high frequency cycles describe the internal architecture of the larger sequence, which can be of more practical utility at reservoir level. These high frequency sequences are more 'local' and realistic as they represent short timing and duration of base level changes.A total of approximately 49 deep wells were taken into consideration while constructing log correlation profiles along both dip and strike across the North Assam Shelf **(Fig.2)**. 9 dip (NW-SE) and 4 strike (NNE-SSW) profiles were generated using T-R sequence model out of which, profile –A (dip) and profile-B(strike) is shown (**Figs.3 & 4)**. The above log correlation profiles along dip and strike direction are attempted to correlate prominent sequence boundaries and pay sands as well as other potential reservoirs within Tura in North Assam Shelf. The NW-SE dip log correlation profiles from Panidihing to Lakwa areas depict the regional structural disposition. The basinal slope was from NW to SE and hence, basement is at shallower level towards NW. The individual isopach of deeper units like Tura is expected to increase towards SE.

The T-R sequences, sequence stratigraphic surfaces and systems tracts are recognized by their characteristic log signatures (**Fig.4**). The transgressive marine facies association is identified by an overall increase in gamma log/fining up sequence or positive SP log response exhibiting retrogradational reflection configuration. The regressive infilling facies is recognized by an overall decrease in gamma ray/coarsening up or a change to more negative SP log pattern exhibiting a progradational reflection configuration(**Fig.4).**

T-R cycle mapping using Sequence stratigraphic concept was judiciously adopted along with integration of all the available electro-logs, source rock data & lab data (Paleontological, sedimentological, palynofossils & paleo-bathymetry data etc.) to understand Tura reservoirs which is the oldest sedimentation over the undulating Pre-Cambrian granite Basement . Regional study on the basis of Sequence stratigraphy and facies distribution of Paleocene to Middle Eocene sediments in entire North Assam Shelf has brought out four correlatable TR sequences, namely TR-1, TR-2, TR-3 and TR-4 litho-stratigraphically within Lower unit/Kuargaon member of Tura, within Upper unit/Lakhmani member of Tura, within Sylhet Formation and close to Lower Kopili base sands respectively. (**Figs. 3 & 5**)

While correlating the different sequence stratigraphic surfaces, it is observed that T-R 4 MFS appears to be the maximum flooding surfaces within the two Ist order sequences i.e. P1 10 (Pre-Cambrian Basement) at base and C1 40 Oligocene Barail unconformity at the top and hence known as 2^{nd} order MFS from here onwards. This 2^{nd} order MFS marks the culmination of carbonate deposits and known as drowning

unconformity within the Basin. This surface is regionally correlatable across the Shelf .All the wells have been correlated by flattening at 2nd order MFS which may be regional time marker observed near the top of Sylhet Formation litho-stratigraphically

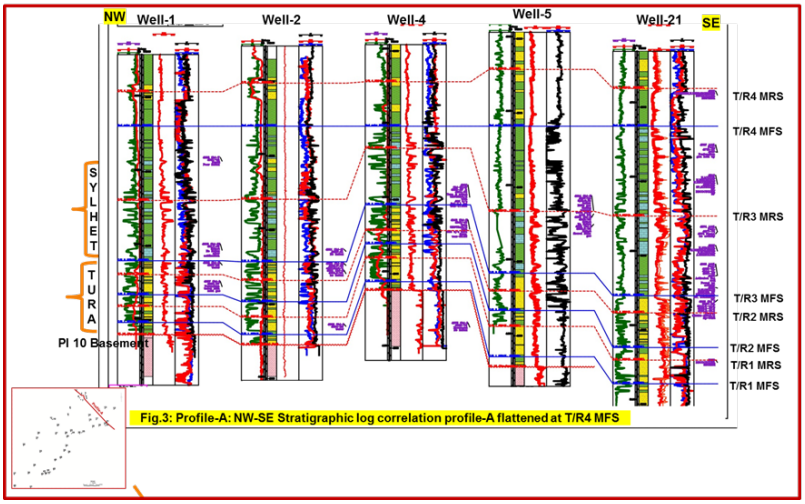

Fig.3: Profile-A: NW-SE Stratigraphic log correlation profile-A flattened at T/R4 MFS

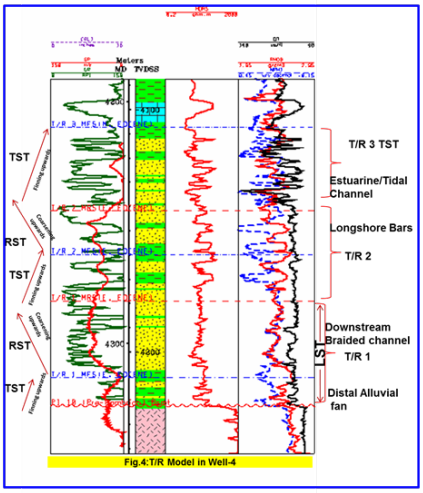

Fig.4:T/R Model in Well-4

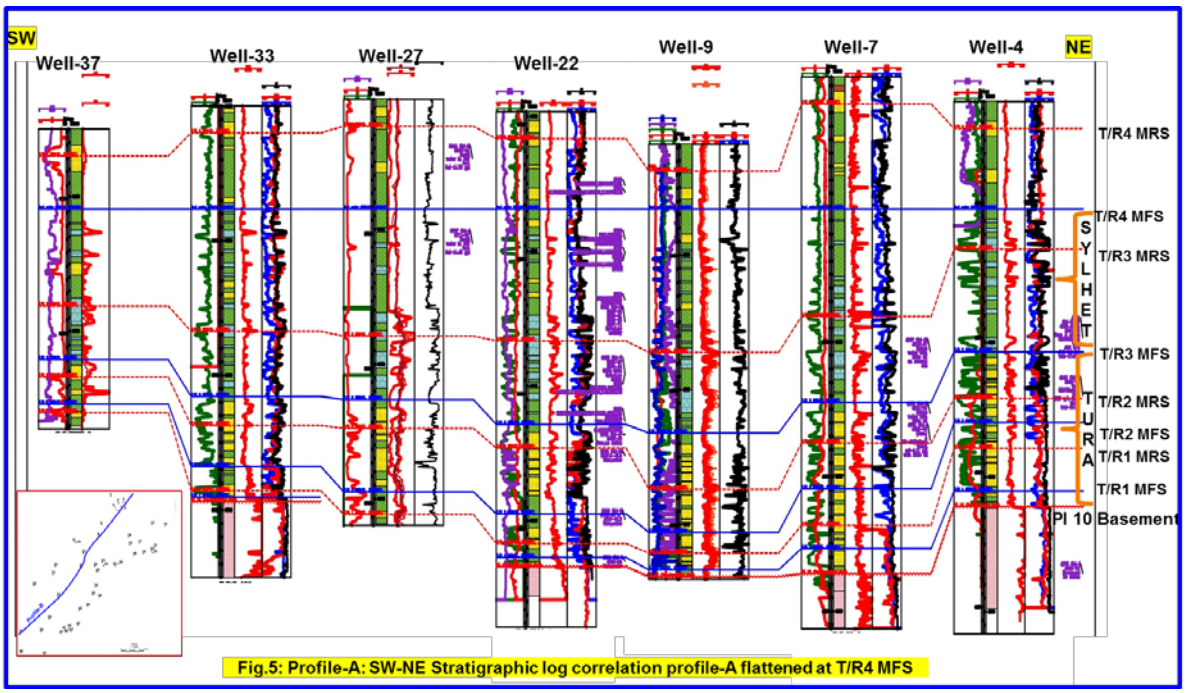

Fig.5: Profile-A: SW-NE Stratigraphic log correlation profile-A flattened at T/R4 MFS

Each of these T-R sequences comprise of Regressive and Transgressive Systems Tracts (RST and TST), separated by MFS, while the sequence boundaries are marked by MRS (**Fig.5).** Four of these T-R sequences are part of 2nd order TST . The Maximum Flooding Surface (MFS) of the 2nd order depositional sequence coincides with the MFS of the 4th T-R sequence. In the next stage, the higher frequency Transgressive/ Regressive sequences and lower order MRS and MFS were mapped within the 2nd order depositional sequences. These surfaces were then correlated across the study area for their lateral continuity and for mapping the internal architecture of the System tracts. The identified sequence boundaries and major flooding surfaces were calibrated on seismic for further validation (**Fig.6**).

Discussion and Analysis:

2nd order sequence (Paleocene- Late Eocene):

T-R sequence-1: This is the first sequence of the four T-R sequences marked which were identified in the 2nd order Paleocene – Late Eocene Passive Margin depositional sequence in North Assam Shelf. 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 lower part as TST and upper part as RST units.This unit is basically termed as low stand system tract (LST) as this is deposited during the stage of early-rise normal regression (Hunt & Tucker, 1992). Low stand deposits typically consist of the coarsest fraction of both nonmarine and shallow marine sections i.e. the lower part of a fining upward profile in nonmarine strata. Lowstand fluvial deposits typically accumulate on an uneven, immature topography .This T-R sequence corresponds litho-stratigraphically to the lower part of Tura Formation and marks the onset of clastic sedimentation over basement. This comprises of mainly high-gamma coarse grained to gritty, micaceous/feldspathic sandstones (arkoses) and thin sandy claystones and grey shales at the bottom and fine grained sandstones & siltstones at the top.

The isopach and isolith map **(Figs.6 & 7)** of the initial deposits of TST sequence have been generated. It is observed that the entire T-R sequence is pinched out towards south-western part which is clearly seen in well no 40. The initial deposition might have been derived from the erosion of high ridges and might have deposited in the lows. At that time, the underlying basement configurations might have influenced the deposition of initial sedimentary fill thickness. The TST deposit is represented by weathered granite and fluvial dominated sediments with little or no marine influence. The TST sands deposited over the Basement probably represents the distal alluvial fan (?) as has been depicted from the isopach /sand isolith map of this unit.
The TST sand is devoid of fauna. These transgressive deposits are represented by fining upward log motif.
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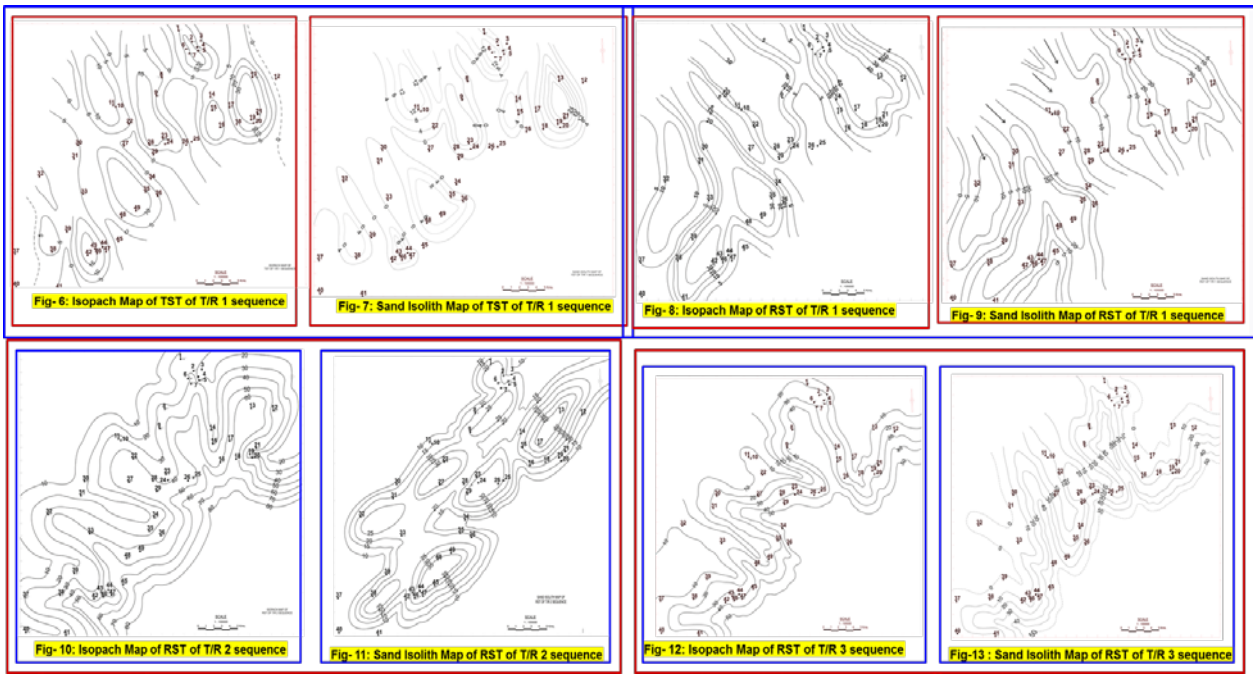
The RST sands of T-R1 sequence consists of massive sandstones units mainly unfossiliferous. These possess poor to fair reservoir characteristics and have little exploratory success till now. The high rate of sedimentation 67 to 115m/Ma coupled with its sedimentological characteristics depicts to have been deposited in a sub-ordinate fluvial channel set up. This RST unit corresponds to Kuargaon Member of Tura Formation in ONGC acreage and it is time equivalent of top part of Langpar Formation of OIL India acreage where some residual oil has been reported by OIL. Based on integration of G&G data at the end of T-R1, the approximate paleo strand line is drawn in the study area. (**Fig.14**)



Laboratory studies corroborate the clastic facies to be of feldspathic and ferruginous in nature and might have been deposited under high energy fluvial condition. Occasional pyrite and ferruginous sandstones suggest the existence of oxidizing conditions and dominance of kaolinitic clay within this TST-RST sands clearly depicts a terrestrial source. The RST sands are probably deposited in a subordinate braided channel facies.**(Figs.8 & 9)** Sedimentological and biostratigraphical studies have been carried out in well no.15. Based on bio-stratigraphical studies, the age is interpreted to be from Late Paleocene to Early Eocene.

T-R sequence-2: The lower and the upper boundary of the sequence are marked by MRS-1 and MRS-2 respectively. The flooding surface of this sequence i.e. MFS-2 separates the TST and RST. T-R 2 corresponds to the upper part/Lakhmani member of Tura Formation of ONGC operated acreage where as in

OIL India; this unit corresponds to Lakadong member. This comprises of mainly sand with shale intercalation. Compositionally they are fine to medium grained occasionally coarse grained with thin layers of sugary calcareous sandstone with clay clasts and glauconite and fine to very fine bioturbated sandstone deposited in tidal flat environment (core report of well nos-16 & 15). This sequence has proved to be oil bearing in many wells.
The RST sands show a typical coarsening upward/blocky log motif **(Fig.5)** and compositionally very matured and texturally well sorted and well-rounded quartz arenites with little impurities of calcitic matrix. They may be deposited in beach environment. The porosity of these RST sands developed in north-west around well no-2&4 area are found to be ranging from 17-20% whereas the porosity get reduced to 9-13% towards south and SE area mainly due to the presence of calcareous cement as matrix towards south. The increase of porosity in north-west area is mainly due to the silica as cement in quartz arenite sandstones. The RST sands of T-R2 are correlatable with thick sand group of Lakadong member which is the most prolific reservoir within OIL India acreage.
Sedimentological and bio-stratigraphical studies in well no.15 suggests the sediments have been deposited in inner neritic to transitional depositional environment. Intercalated shales have been deposited in mud flat, the presence of glauconite and clay mineral montmorillonite in sand suggest deposition in shallow marine environment with a probable bathymetry ranging from 10-20m.

The RST deposits of T-R 2 isopach map **(Fig.10)** suggests sand entry from NW and NNW. The rate of sedimentation varies from 14 to 20 m/Ma. Sand isolith map **(Fig.11)** shows the deposition of sands under strand plain environment around well nos.1 & 10. The Isolith map reveals different individual barrier bars representing fluctuations of coast line due to marine transgression .These barrier bars are oriented in NE-SW direction due to the influence of active long shore currents acting within wave base of marine inner shelf area. The different barrier bars are punctuated by tidal inlets in between. These tidal inlets are more or less permanent passages between barrier bars/islands that allow tidal exchange between the open sea and lagoons. Inlet channels are generally deepest between tips of the islands and shoal into tidal delta both landward and seaward. Relatively flat channel margin platforms may occur on one or both sides of the main inlet channel but commonly are best developed on the side adjacent to the barrier that is growing by spit accretion. Based on integration of G&G data at the end of T-R2, the approximate paleo strand line is drawn in the study area. (**Fig.15**)

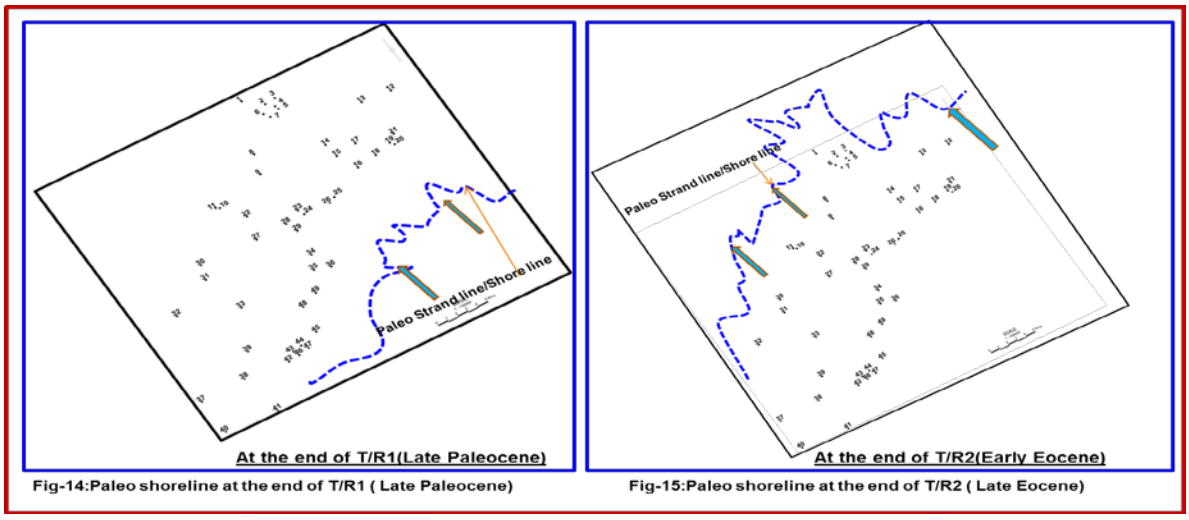


Fig-14:Paleo shoreline at the end of T/R1 (Late Paleocene)
Fig-15:Paleo shoreline at the end of T/R2 (Late Eocene)

T-R sequence-3: This sequence marks the third T-R sequence of the Passive Margin depositional sequence. The lower boundary is MRS-2 within Tura Formation and the upper boundary of this sequence is MRS-3 within carbonates of Sylhet Formation.The MFS-3 separate the RST and TST. The TST is represented by top part of Tura Formation and comprises of mainly sand and thin streaks of shale. This depositional sequence comprises of vertically stacked multiple sandstone reservoir units that together constitute tidal/estuarine channels or marginal marine deposits as has been brought out in Isopach map **(Fig.12)**. They may be deposited in a transgressive river mouth with narrow estuarine channels as observed in sand isolith map **(Fig.13).** The MFS between underlying TST and overlying RST is well correlatable regionally on a basinal scale. The thickness of TST deposits varies from 13m to 51m and their rate of sedimentation ranges from 18 to 25m/Ma. This sequence was deposited over a period of about 3.5 Ma. This transgressive deposit of T-R3 which is equivalent to top part of Tura reservoir may form excellent reservoir rock units whereas the overlying

MFS shale can form the regional seal. The TST sands are represented by a fining upward log motif predominantly and blocky log motif **(Fig.4)** at some places and are characterised by low diversity-low abundance faunal assemblages. This TST correlates to thick sand group of Lakadong member of OIL India and principal producing reservoir of OIL India acreage. This transgressive sand which is part of Lakhmani Member of Tura Formation litho-stratigraphically is oil bearing in well no 17.The RST is represented by lower part of Sylhet formation and comprises of mainly limestone and shale Alternation of shale and limestone suggests shallowing and deepening of the basin. It may be presumed that the paleo strand line/coast line must be lying somewhere further north of the study area.

Conclusion:

- T-R 1 which corresponds to Kuargaon member/Lower part of Tura was deposited in distal alluvial fan channel to braided channel environment. The T-R1 sands are mainly feldspathic, ferruginous sandstone with kaolinitic clay confirming a terrestrial source.
- The T-R 2 equivalent of Lakhmani member/Upper part of Tura was deposited in a strand plain/barrier bar environment oriented towards NE. The RST sands of T-R2 are predominantly quartz arenite with little calcitic cement as matrix .These are well sorted, well rounded texturally indicating a beach environment.
- The TST sands of T-R 3 which corresponds to topmost part of Tura was deposited in tidal/estuarine channel environment. These sands are deposited in an overall fluctuating shallow marine to marginal marine environment with a bathymetry ranging from 10 to 25m. Individual sand units are thick but when stacked vertically they show appreciable thickness.
- The entire Tura is deposited in a distal alluvial fan, coalescing braided, barrier/offshore bars and estuarine /tidal channel complex system in whole of North Assam Shelf.

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