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## Sequence stratigraphic study of Passive Margin and Foreland sequences and impact of post Barail tectonics on the structuration and hydrocarbon potential of Geleki and satellite fields of Upper Assam.

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### Summary

*Sequence stratigraphy is a modern tool for stratigraphic analysis and modelling of geological and depositional processes related to base level changes which also helps to define the genetic characters of different types of stratigraphic surfaces in time and space. In the current study, Petroleum System Sequence Stratigraphy approach was adopted to study the Passive margin and Foreland depositional sequences of Geleki field and adjoining Satellite areas viz. Mekeypore, Bihubar, Laxmijan in the East to North-East, Namti Borsilla in SW of Upper Assam, covering the frontal thrust corridor of Naga Schuppen belt and adjoining fore deep part of Nazira Low.*

*Structure and thickness maps of depositional sequences were prepared to understand regional depositional setting. Isopach maps and sand facies distribution maps of T/R sequences were prepared to bring out reservoir facies distribution and depositional highs and lows.*

*The post Barail upliftment, an important tectonic event, resulted change in basin architecture due to cross faulting, uplift and inversion which has influenced the sedimentation pattern of the area at different stratigraphic levels. During Miocene the environment of deposition varies from shallow inner shelf to braided streams fluvial channels with intervening flood plains. Low and High accommodation systems tracts were mapped based on progradational and aggradational log patterns. LAST/HAST sequence boundary is a conformable contact, created due to differential intensity of sedimentation and lithological variation, which has been mapped on logs and calibrated on seismic in the Foreland setup.*

*Prospectivity of the study area has been analysed by integrating the effect of post Barail tectonics on structure, facies, hydrocarbon occurrences and supported with attribute studies to identify the areas of exploration interest. To bring out the priority areas for further exploration, the study area was divided into four sectors viz Namti - Borsilla, South West Geleki, North Geleki-Mekeypore and Laxmijan-Bihubar area. Transgressive/Regressive sequence based stratigraphic and sedimentation model for the study area will be useful to delineate the remaining hydrocarbon potential of the area.*

**Keywords:** volcanics, Marl, Tight reservoir

### Introduction

Over the years, interpretation and analysis of basin stratigraphy was mainly based on the traditional methods. The recent developments in applications of sequence stratigraphy (Catuneanu, O. (2006) have brought about the major changes in the stratigraphic analysis, which resulted in Petroleum System Sequence Stratigraphy i.e. PS Cube studies in Indian petroliferous basins. The above approach was adopted to study the Passive margin and Foreland

depositional sequences of Geleki field and adjoining Satellite areas of Upper Assam Shelf of Assam. It 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 study covers entire Geleki acreage, in addition to the Satellite fields viz. Mekeypore, Bihubar, Laxmijan in the East to North-East, Borsilla, Namti in SW of Geleki and Napamua in the North-West. Though the

presence of hydrocarbons has been wide spread in the study area, the entrapment and distribution pattern of sediments and reservoir facies is yet to be completely understood.

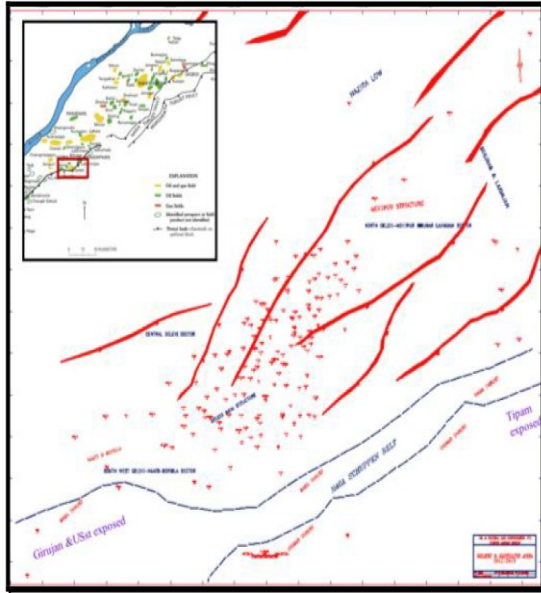


Fig. 1: Study area with tectonic elements.

### Work flow

The identification of sequence stratigraphic surfaces was based on fining up and coarsening up patterns on GR logs supplemented by SP and resistivity logs and overall stratal stacking patterns. In the next stage, the higher frequency Transgressive/ Regressive sequences and lower order MRS and MFS were mapped within the 2nd order depositional sequences. Besides the log pattern, the stratal stacking (progradational, retrogradational and aggradational) of the strata were also considered for firming up the higher frequency surfaces although they were not observed on the seismic. These surfaces were then correlated across the study area for their lateral continuity and for mapping the internal architecture of the System tracts. In the Foreland setup, Low and High Accommodation System tracts were mapped based on progradational and aggradational log patterns. The identified sequence boundaries and major flooding surfaces were calibrated on seismic for further validation (Fig.2).

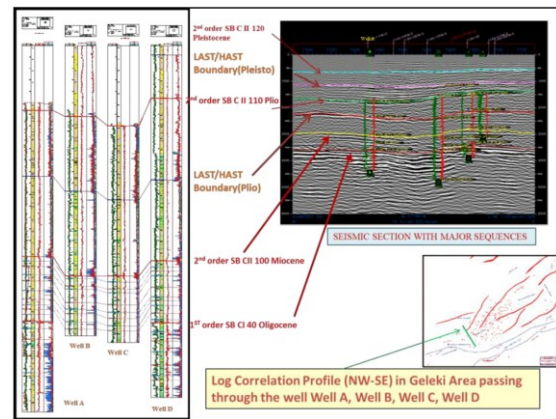


Fig. 2: Log correlation profile in Geleki area and its calibration on seismic.

### 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 Mukherjea (2011)).

Geleki field is situated in the close vicinity of Naga Thrust belt. Many NE-SW trending normal faults and E-W cross faults divide the field in to the several faults blocks (Sastri et al. 1989) confined to the northern part of Upper Assam shelf comprising of prolific Geleki structure and isolated satellite structures viz Mekeypore-Bihubar-Laxmijan areas in the N/NE, Borsilla-Namti prospects in SW, Napamua structure in NW. Nazira-Sonari low is situated in downstream area with respect to Geleki structure towards the N/NW, which separates the Geleki structure from Rudrasagar and Lakwa fields in north east. A NE-SW trending belt of imbricate thrusts known as Naga

Schuppen Belt lies all along the study area in NE/E/SW. Several smaller isolated structures in the vicinity of Geleki Field are also drilled. However the complex geological set up, combined with non-commercial hydrocarbon occurrences till now and possibly the logistic constrains in the satellite area, exploration input has not been extended as required of these satellite acreages. The Schuppen belt constitutes part of mobile belt of Assam-Arakan Basin is an imbricate thrust zone exposing Tertiary sediments along different thrust planes/slices (Das Gupta,A.B, Biswas A.K. 2000). Some of the prominent thrust encountered in the study area of Geleki and satellite fields are Disang thrust, Naga thrust and Cholimsen thrust. Naga thrust forms the NW limit the Shuppen belt. The surface trace of it closely follows the boundary between the alluvium and Naga foot hills.

The sediments in the study area were deposited in varying environments during different time periods (Ahmed et al. 1993). In the 1st order Oligocene and 2nd order Miocene sequence environment of deposition varies from marine-prodelta to fluvio-deltaic environment and from shallow inner shelf to braided streams, fluvial channels with intervening flood plains respectively. LAST/HAST (Pliocene and Pleistocene) is a conformable contact, created due to differential intensity of sedimentation and lithological variation and were mapped based on progradational and aggradational log patterns in the Foreland setup (Fig. 3).

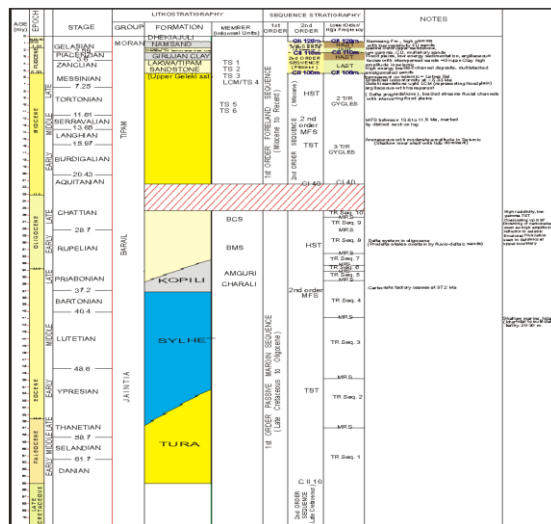


Fig. 3: The Sequence stratigraphic framework adopted in the present

### Post Barail Uplift/Tectonics

It is an important tectonic event resulting in the structural dissection of the entire basement in the north east along the major tectonic trends viz., E-W, NW-SE and NE-SW. The differential block movement has also influenced sedimentation and preservation of subsequent sediments particularly Girujan Clay which is a critical element in the petroleum system of the area (Naik.G.C. et.al, 2001). The post Barail upliftment resulted change in basin architecture due to cross faulting, uplift and inversion which has influenced the sedimentation pattern of the area at different stratigraphic levels. During the Late Eocene time, possibly due to falling sea level and the tectonic activity in the provenance, there was an increase in sediment supply. This process resulted in discrete sandstone body deposited as tidal sand in the upper part of Eocene, corresponding to Kopili. At the end of Late Eocene /Kopili, an orogenic phase uplifted the Indo Burma orogen separating the Assam- Arakan from Burmese Basin. Barail sediments mark the sudden increase in sediment input to the basin. This uplift and sedimentation process established the delta system. The change from Kopili sedimentation to Barail is marked by increase in the proportion of coarser clastics and this can be attributed to the tectonic uplift in the provenance as well as falling sea level. The uplifts during end Oligocene coincided with a global sea level fall and collision-subduction-uplift in north east India. Reversal of basal slope was observed by flattening the horizons at different levels on seismic (Fig.4)

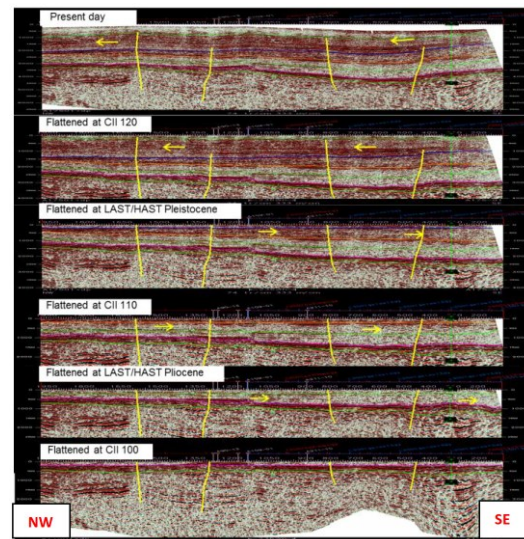


Fig. 4: Flattening of horizons showing the reversal

The Miocene marked a new phase of sedimentation in changed basin architecture. The basin floor in most platform areas has been rendered uneven and structurally dissected. Girujan Clays conformably overlying the Tipam in the large part of Upper Assam shelf and Naga hills and has a critical role in Petroleum entrapment/accumulation. The effect of post Barail tectonics is observed at different stratigraphic levels as shown in the figure (Fig. 5).

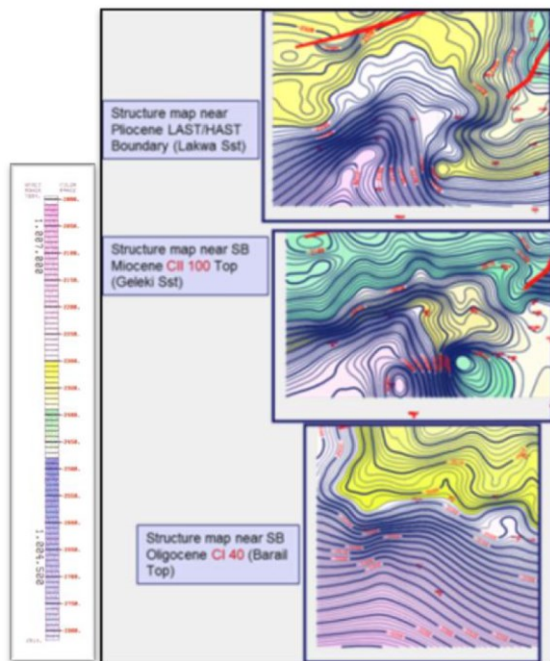


Fig. 5: Effect of post Barail tectonics.

### Low and High Accommodation Systems Tracts

Sedimentary deposits of nonmarine surface processes, which are independent of marine and lacustrine influence, cannot be justifiably analysed using traditional systems tracts which are controlled by shoreline shifts. To interpret and analyze these deposits, specifically fluvial one where relationship with coeval shoreline shift is difficult to establish, use of low- and high-accommodation systems tracts are widely in use.

Low-accommodation systems tract (LAST) within fluvial successions represented by an incised-valley-fill type of stratigraphic architecture dominated by multistacked channel fills without any significant floodplain deposits (Fig.5). LAST deposits are progradational (coarsening upward) and accompanied by low rates of aggradation,

similar to Low Stand Systems Tract (LST). LAST typically form on top of subaerial unconformities where the amount of available fluvial accommodation is still low. This low amount of available accommodation also controls high channel fill-to-overbank deposit ratio, the absence or poor development of coal seams and the presence of well-developed paleosols.

High-accommodation systems tract (HAST) deposits infers higher rates of creation of fluvial accommodation resulting in a simpler fluvial stratigraphic architecture that includes a higher percentage of finer grained overbank deposits, similar in style to the transgressive and highstand systems tracts (TST and HST). The depositional style is aggradational and HAST is characterized by a lower energy regime, and the overall deposition of fine grained sediments. The accumulation of fluvial facies in HAST continues during declining depositional energy through time, which results in an overall fining-upward profile.

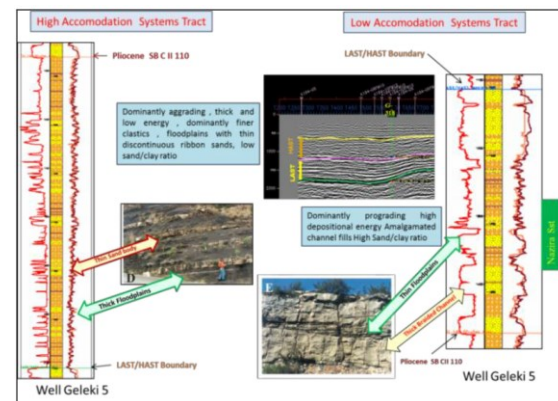


Fig. 5: Log pattern of LAST & HAST and its seismic signatures

LAST and HAST are most relevant in overfilled basins or in portions of sedimentary basins that are beyond the influence of marine base-level changes. The change from LAST to HAST is gradational rather than abrupt. In LAST and HAST, the best petroleum reservoirs are related to LAST where the channel fills tend to be amalgamated and hence there is a good connectivity between individual sandstone bodies. In HAST reservoirs will be in the form of isolated point bars, channel fills, or crevasse splays within finer-grained floodplain facies. The sand input direction is from NE to SSW (Fig. 6 & 7).

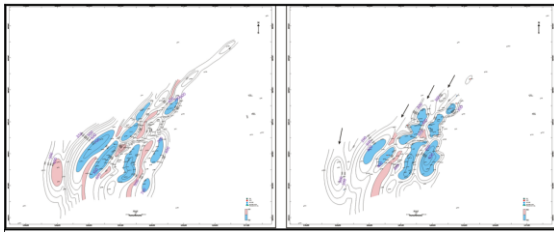


Fig. 6: Isopach and Isolith maps of Pliocene LAST sequence

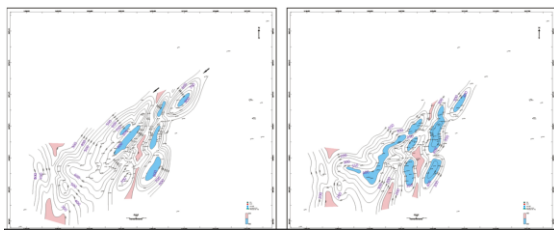


Fig. 7: Isopach and Isolith maps of Pliocene HAST sequence

### Structural mapping interpretation and Prospectivity Analysis.

Structural maps prepared at different levels i.e. CI 40(1<sup>ST</sup> order Oligocene, Barail top), CII 100(2<sup>nd</sup> order Miocene, Geleki Sst), LAST/HAST boundary Pliocene, CII 110(2<sup>nd</sup> order Pliocene, Girujan clay), LAST/HAST boundary Pleistocene, CII 120(2<sup>nd</sup> order Pleistocene, Namsang) has been discussed below. Reflectors corresponding to top of sequence boundaries were picked up from the logs and were calibrated on seismic. The geological sections showing structural configuration of the study area was prepared. A clear understanding of structural and the existing fault patterns was also brought out by analysing the data in the VRC. The data quality in south and south-east deteriorate which can be attributed to the structural complexity owing to the presence of thrusts.

During Paleogene-Early Neogene (Oligocene-Early Miocene) the basinal slope was more towards Naga thrust area whereas the reversal of basinal slope observed at post-Miocene as corresponding sediments shows thickening from SE-NE. The dip gradient in SE flank of the Geleki structure as well as NE plunge has changed substantially and has partially altered the structural picture at younger level (post-Miocene). NE-SW trending fault system constitutes the major structure controlling fault system and hydrocarbon pools are also controlled by the same.

In all the structure maps, Geleki structures with NE-SW trend extends upto MKYP and then takes a swing and

continue further ENE-WSW indicating the presence of several cross trends. The associated cross faults extending upto Nazira low particularly at CI 40 (Oligocene) and CII 100 (Miocene) levels and getting less prominent at younger levels. These cross trends are likely to provide better entrapment conditions in the down plunge area around Geleki and also around Bihubar and Laxmijan area. In the Southwest part of the study area which is logistically constrained (proximity to Nagaland border, hilly terrain and reserved forest in the area), the mapping has been interpolated by using 2D data, and hence mapping ambiguity remains in the depth structure maps at CI 40 (Oligocene) and CII 100 (Miocene) levels, which persists at shallower structure maps also. This ambiguity has been resolved with the structure maps prepared based on well data and electrolog correlations of the wells drilled in the area. The presence of cross trend in the area could not be marked on seismic due to lesser throw of 10-40m. On structure maps, the existence of sharp turn of axis and abrupt ending of faults shows the presence of several cross trends in the area. At younger levels some fault trends are difficult to mark but the effect is clearly visible in the area. Namti-Borsilla structure a separate anticlinal structure which takes a swing from N-S to NE-SW during post Barail upliftment needs to be extensively focused particularly for Tipam, which is placed suitably on structure maps/geological cross section.

South-West Geleki area shows prominent structures separated by low axis, which are likely to be extended to the south of the study area. Well logs and reservoir data indicates that the main Geleki structure is opening up towards south and south west. Isopach and Sand isolith maps show a good thickness at T/R 3 & 4 corresponding to TS-6 & TS-5C respectively of Tipam formation. The SW area forms an interesting sector for further delineation. For the pre-Barail Top of T/R 6(Regressive cycle) and Base of T/R 7(Transgressive cycle) (Kopili) shows the presence of a good sand which can be traced in many wells and has given commercial hydrocarbons in a well (Fig.8).

Sand/Silt Isolith map shows presence of good thickness of reservoir facies towards south. Although this sand has not been tested in any other well but the thin lenticular sands deposited in the prodelta conditions might extend further South-West, the hydrocarbon accumulations cannot be ruled out in these lenticular sands.

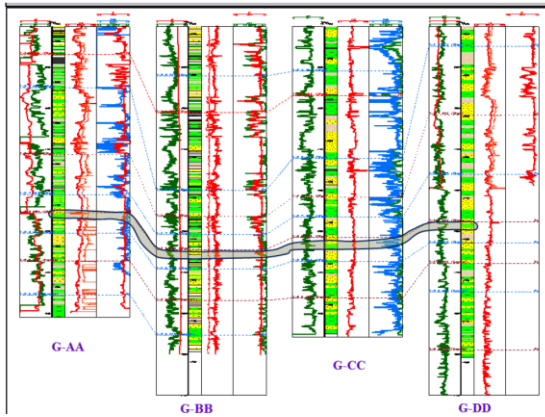


Fig. 8: T/R marked on log correlation profile for pre –Barail

North Geleki-Mekeypore plunging axis shows its continuity toward NE. Structure map analysis shows number of good structures along the plunge axis and on rising flank. Occurrences of hydrocarbons in the area, makes it a promising exploration target all along the plunge.

Bihubar and Laxmijan area although sparsely explored has shown hydrocarbon occurrences at multiple levels. An Isolated structure NW of Laxmijan was observed on seismic which appears to be promising. Attribute analysis demonstrate the sand distribution around the prominent structure in the vicinity.

The prospective areas are shown in Fig. 9.

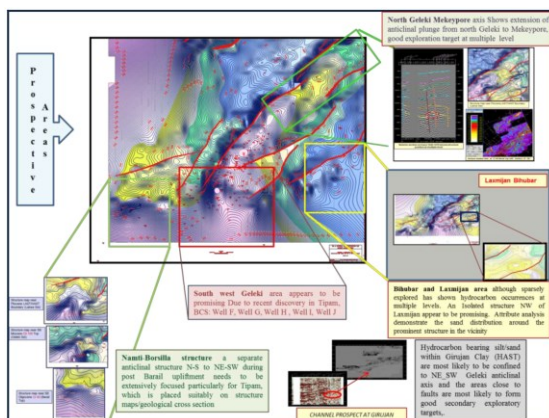


Fig. 9: Prospective areas identified in the study area.

## Conclusion

Prospectivity of the study area has been analysed by integrating structures, facies HC occurrences and supported with attribute studies to identify the areas of exploration interest. To bring out the priority areas for further exploration, the study area was divided into four sectors viz Namti - Borsilla, South West Geleki, North Geleki-Mekeypore and Laxmijan-Bihubar area.

**Namti-Borsilla** structure is an separate anticlinal structure separated from main Geleki structure by Nazira Low. This structure takes a swing from N-S to NE-SW during post Barail upliftment, needs to be extensively focused particularly for Tipam.

**South-West Geleki** area appears to be promising since recently discovery in two wells within Tipam Sand are located at the rising flank of a new independent structure as seen from the study. The structure seems to extend further south and needs to be probed.

**North Geleki-Mekeypore** plunging axis from North Geleki to Mekeypore shows its continuity toward NE. Good structures are observed along the plunge axis and on rising flank at multiple level. **Bihubar and Laxmijan area** structure near top of LAST/HAST boundary Pliocene shows isolated structure and holds better structural position with respect to wells drilled at the flank of the structure which have shown oil indication. Attribute analysis supports development of sand facies within the vicinity.

Hydrocarbon bearing silt/sand within Girujan Clay (HAST) are most likely to be confined to NE\_SW Geleki anticlinal axis and the areas close to faults are most likely to form good secondary exploratory targets.

The Isopach and sand Isolith maps of different T/R levels have shown that the sand input direction was from N and NE during Pre Barail whereas it was dominantly from NE during Post Barail. The geological model has brought out the necessity to review the exploration strategy in the area particularly in south and south-west including the secondary targets like the Prospectivity of Girujan Clay.

Sand/Silt Isolith map of T/R 6(Regressive cycle) and Base of T/R 7(Transgressive cycle) (Kopili) shows presence of good thickness of reservoir facies towards south. This thin



lenticular sands deposited in the prodelta conditions might extend further South-West of the study area.

Petroleum System Sequence Stratigraphy considered to be latest interpretation approach may be extended in other fields of Upper Assam shelf, for stratigraphic analysis and modelling of geological and depositional processes. Transgressive/Regressive sequence based stratigraphic and sedimentation model for the Geleki and satellite area of upper Assam shelf will be useful to delineate the remaining hydrocarbon potential of the area.

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