Structural and Sedimentary Evolution of Upper Assam Basin, India and Implications on Hydrocarbon Prospectivity*

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Abstract

The Upper Assam Basin is a composite foreland basin which is located between the eastern Himalayan foot hills and the Assam - Arakan thrust belt. The basin is terminated to the northeast by the Mishimi Hills block and to the southwest it is partly disrupted by the Shillong plateau basement uplift. The stratigraphic record of upper Assam foreland basin is controlled by three variables: eustasy, tectonic subsidence, and sediment supply. The sediment supply feeds the foreland basin either from NW side of Himalayan Mountains or from SE side of overriding thrust belt. The eustasy and sediment supply control the short term stratigraphic framework that superimposed over the tectonic sequences that are formed due to asymmetric slope of the basin and position of forebulge. The basal unconformity is formed due to erosion of progressively migrating forebulge and upper unconformity is formed due to tectonic effects. The sedimentary record of the basin was formed during passive margin setting in Paleogene time during drifting phase of Indian Plate after detachment from Antarctica Plate. Fluvial to marine coarse clastic sediments deposited in Paleocene to lower Eocene period there after widespread transgression leading to deposition of carbonate sediments in middle Eocene period and shale is dominated in upper Eocene time. During Oligocene and Miocene increased proportion of coarse clastics is attributed to the tectonic uplifts in the provenance as well as falling sea level. Successive basin wide compressive orogenic phase during late Miocene to Pliocene resulting emergence of landforms and subsequent erosion are marked by unconformable relations between Tipams and overlying sediments of Moran Group.

Structural Evolution of Upper Assam Basin

The general view inferred from seismic surveys is that the Assam plains form a broad arch at the basement level with its apex in the region of the present Brahmaputra River and sloping towards the Himalayan foot hills in north and Naga Hills in the south. This arch is dissected by a number of faults with a general strike of NE-SW or ENE-WSW parallel to the fault pattern observed in the Mikir

Hills metamorphic complex (Roy et.al., 1975) and also parallel to thrust pattern in Naga Hills. The structural pattern in the sedimentary cover is controlled by the irregularities in the basement surfaces known from gravity survey and differential movement along faults. There is good correspondence between gravity high in the basement and structures in the sedimentary cover. The structures are platform type, either gentle domes or elongated gently anticlinal folds dissected by numerous faults (Figure 5). The outcrop data of Naga and Mikir Hills and well data in Kuargaon, Lakwa, and Disangmukh areas indicate southeastward thickening Tertiary sequences. These are deposited under shallow marine to fluvial facies and prograded southwards. Seismic reflectors in the foreland part exhibit a monoclinally dipping attitude from NNW to SSE and are cut by a number of faults. Mainly two sets of faults have been interpreted: (1) faults heading towards Naga Hills – are fore thrusts and reactivated normal faults with reverse movement i.e. inverted normal faults (2) low angle reverse faults heading towards Mikir Hills and are known as back thrusts (Sahoo and Gogoi, 2008). The area between the outer most thrust sheet and the back thrust form the triangle zone. Both the back thrust and fore thrust exhibit parallelism to Naga thrust. Normal faults are interpreted as basin forming faults which were active during the deposition of Barails (Oligocene) and with decreasing intensity during deposition of Tipams (Miocene-Pliocene). The reverse movement along these faults is interpreted to have taken place during Pliocene-Pleistocene time (Figure 1).

Evolution of Depositional Sequences

Depositional sequences are bounded by unconformities and their correlative conformities. There are four depositional sequences identified based on the identification of surfaces or discontinuities based on seismic reflection configuration of sedimentary units. These seismic sequence boundaries are tied to wells using synthetic seismograms. The unconformities are designated by their stratigraphic ages and are P1, P2 (Paleogene unconformity), N1 (Neogene unconformity) and Q1 (Quaternary unconformity) surfaces. The four depositional sequences are identified on the well logs and stratigraphic sections and are described below (Figure 2).

Depositional Sequence 1

This is the youngest sequence and is represented by intervals with subparallel discontinuous reflections with low interval velocities (Figure 2).

Depositional Sequence 2

The depositional sequence is corresponding with Moran Group and bounded by distinct unconformities N1 and Q1. These sediments show an angular unconformity with Tipam sediments near Naga thrust. There is shift in basinal slope during the post Tipam tectonic episode. The slope was towards northeast and east during the Tipam times and changes its direction to the north and northwest.

Depositional Sequence 3

This depositional sequence comprises mainly continental sediments deposited in prograding environment. The different units are classified on the basis of their stratal relations and lithologies. The depositional sequence bounded by two unconformities P1 and N1 and comprises sediments of Tipam Group. The basal incised valley fill deposits are coarse clastics and are represented as reflection free surfaces. The Girujan Clay Formation appears as moderate amplitude and serrated log motifs. In the sequence six main sands are identified over the Upper Assam Valley and the thickness varies from 50 to 300m. The sandstones are characterized by good reservoir properties having porosities varying from 20 to 30%. The regional cap rock for oil gas pools in the sequence is Girujan Clay. In the down-dip part of the sequence, the lithofacies of the sediments grade into favorable source rocks deposited in deltaic environments. Therefore it is obvious that the hydrocarbon migration was effective laterally before the development of faulted blocks.

Depositional Sequence 4

This depositional sequence comprises distinct high amplitude and frequency, continuous reflections in seismic. The upper part of the depositional sequence is progradational in nature with weak, discontinuous reflections and bounded by Type-II sequence boundaries correspond to P2 unconformity (Figure 2). The basal sandstones overlying the basement grading to weathered basement in the lower part and are oil bearing. The possible seals are the overlying transgressive Sylhet Limestone - Kopili Shale sequence. The Sylhet Limestone Formation marked by first marine transgression all over North Assam Shelf and is characterized by limestones interbedded with layer sandstones. The Kopili Shale consists largely of sand-shale alternation with dominantly argillaceous component. The source character and trapping conditions appear to be common for Sylhet and Kopili Formation. The stratigraphic traps and fault controlled structural type of traps are observed in both the formations.

Structural Controls on Sedimentary Processes

The structural growth and intensity of deformation was varying with time. The tectonic deformation was syn-sedimentary in nature (Goswami and Goswami, 2008). The intensity of deformation and structural growth was higher in basinal direction than basin margin. The seismic section as shown in Figure 4 suggests presence of older down to basin normal faults related to basin forming processes. Some of these faults have controlled sedimentation as evidenced by drastic thickness variation across the fault. The reduced sedimentary thickness over paleo-highs suggests that older fault systems have been modified in the basin evolution process. The E-W trending fault zones have been initiated during Miocene-Pliocene time. The normal faults are interpreted as basin forming faults which were active during the deposition of Barails (Oligocene) and with decreasing intensity during deposition of Tipams (Miocene-Pliocene). The reverse movement along these faults is interpreted to have taken place during Pliocene-Pleistocene time. Naharkatiya, Moran, and Rudrasagar are structures developed on the basement highs and located near the Brahmaputra Arch. The Lakwa and

Geleki structures in the pericraton area formed during Oligocene and Miocene times and have been modified due to intermittent activity of fault bounding structures. The Boroholla structure formed due to basement tectonics and is shallower than towards northeast. The structures appear to be controlled by local highs and the faults developed in the granitic basement have considerable control on sedimentation pattern on the basin and is described below:

Sedimentation vis a vis Fault growth

When the sediment supply is higher than the accommodation space created due to tectonic subsidence then sedimentation with fault growth is developed. The basin topography remained flat and fault growth with sedimentation is developed during basin forming and modifying stage (Figure 3). The basal sandstone, Sylhet, Kopili, Tipam, and post Miocene sediments are deposited in this stage. The basal sandstone, Sylhet and Kopili Formations are deposited in very long time span suggesting mild fault growth, whereas the Tipam and post Miocene sediments are deposited in small time period with rapid sedimentation and fault growth. The change from Kopili sedimentation to Barail is marked by increase in the proportion of coarser clastics. This increase can be attributed to the tectonic uplifts in the provenance as well as falling sea level. At the end of Oligocene, the shelf was uplifted along Dauki hinge line resulting in erosion of platform sediments. Subsequently, in Late Miocene to Early Pliocene times most areas of Assam – Arakan Basin gradually came under fluvial depositional conditions due to sea retreat towards south and southwest. The Tipams are the products of the braided channel systems giving rise to composite sand bodies formed by lateral coalescence.

Hydrocarbon Prospectivity

Good plays occur where source rock, hydrocarbon migration pathways, reservoir rocks, and seals are developed in conjunction (Lambiase and Morley, 1999). The study deciphers that the structural evolution in the basin exerted a major influence not only on stratigraphic development but also on petroleum occurrence as well. All the exploratory activities mostly confined to south of Brahmaputra River. The structures of Moran and Rudrasagar have oil in Oligocene reservoirs and are developed on the basement highs, located nearer to Brahmaputra Arch. The latter developed structures Lakwa and Geleki in the pericraton area have oil accumulations in Oligocene and Miocene reservoirs. The reservoirs in Borholla structures in fractured basement, Paleocene, Eocene, and Miocene ages are related to basement tectonics. Hydrocarbon generation in the area occurred at a time when compressional forces had modified the preexisting structures. As a result, the structures formed by these forces have ideal locales for entrapment of migrating hydrocarbons. The hydrocarbon started migrating from Sylhet and Kopili source rocks about 10-12 million years, when all the structures had already formed. The hydrocarbon expulsion is believed to be in the Schuppen Belt, where numbers of fault conduits are developed to bring hydrocarbon charge to shallow reservoirs. The migration is primarily up dip to the northwest along northeast trending slope of the shelf. The vertical migration occurring through reactivated basement rooted faults associated with plate collision. Active thrust tectonics by the end of Pliocene had resulted in reactivation of the structures in the foreland. The subsidence during deposition of youngest stratigraphic units of Pliocene-Pleistocene age is related to tectonic loading of advancing thrust sheet from the south. This youngest phase of compressional tectonics which determined the present configuration of structures is suitable for the entrapment of hydrocarbons. In the frontal belt Digboi, Kharsong, Geleki, Amguri, Namti-Borsila, Laxmijan-Bihubar, Meyckepore, Borhola-Champang areas, the main play types are upthrust tip line fold, snakehead anticlines, subthrust monoclines and fault closures. In Khoraghat, relict features related to Barail-Bokabil unconformity forms the hydrocarbon play. In Geleki Field the Tipam plays are primarily structural and Barail plays are stratigraphic-structural and stratigraphic in nature associated with both Paleogene extension tectonic regime and Late Neogene compressional tectonics controlled by major NE-SW trending faults. Thick argillaceous units of Girujan Formation serve as regional vertical seal for Tipam reservoirs and, similarly, the coal-shales of BCS unit forms the regional seal for Barail Main Sand reservoirs. Additionally, shale horizons developed at LCM and within Barails provide the local seal vertical seal (Figure 5). In foreland bulge belt Naorkatiya, Moran, Dikom, Lakwa-Lakhmani, Rudrasagar, Laiplingaon, Kuargaon-Demulgaon, Charali-Changmaigaon areas have accumulations in Tipam-Barail reservoirs and the main entrapment style is constituted by rotated fault blocks with late stage inversions.

Conclusions

The study demonstrates that the migration of basin bounding fault has profound controls on development of potential plays in the basin. The interaction between thrusting, eustasy, and mode of subsidence is the factors to sedimentation patterns. The Eocene sediments are deposited in a passive margin setup when the Indian Plate detached completely from Antarctica and entered the drift phase which continued until collision of Indian Plate with Eurasian and Burmese Plates and thereafter foreland phase of the basin began. On the passive margin setting, the shelf sedimentation patterns controlled by sea level and have distinct system tracts that are widely recognized on seismic lines, well logs, and well log cross sections. The sequences thus developed on account of accommodation were created due to slow subsidence along longitudinal extensional faults to compensate the load. During this period there is continuous sedimentation and controlled by block movements of basement faults and the platform merges gradually into thrust and fold belt marked by steepening basement slope towards southeast. The basement dips more steeply into foredeep towards southeast with successive faulting and an increase in thickness of sediments in this direction. Peripheral upwrapping occurs at the distal margin of the foreland basin and produces an arch called Brahmaputra Arch or Forebulge. The hydrocarbon expulsion is believed to be more efficient in Schuppen and the number of fault conduits is developed to bring the hydrocarbon charge to shallow reservoirs. The migration is primarily up dip to the northwest along the northeast-trending slope of the shelf, with vertical migration occurring through reactivated basement-rooted faults associated with the plate collision.

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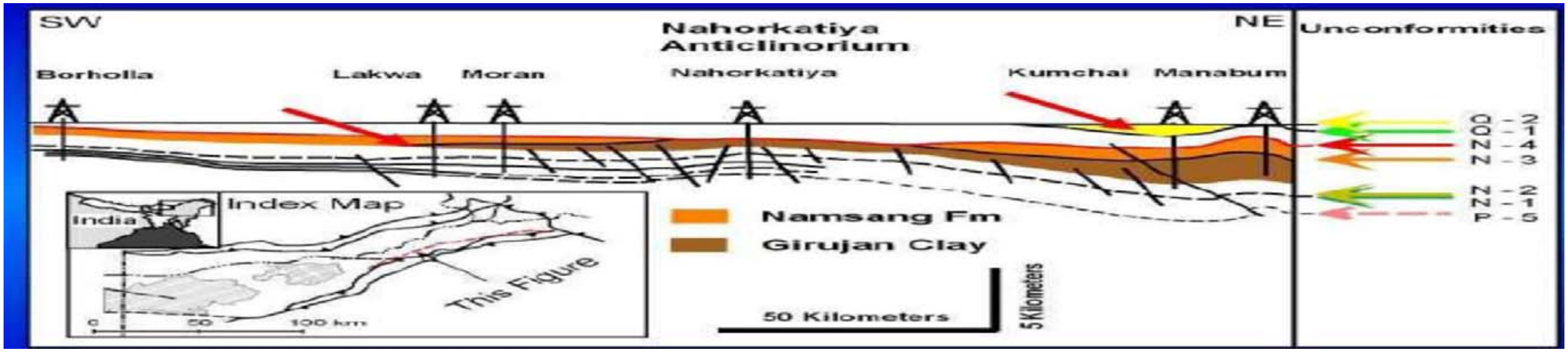


Figure 1. Geological cross section showing stratigraphic extent and major faults along NNW-SSE and SW- NE direction.

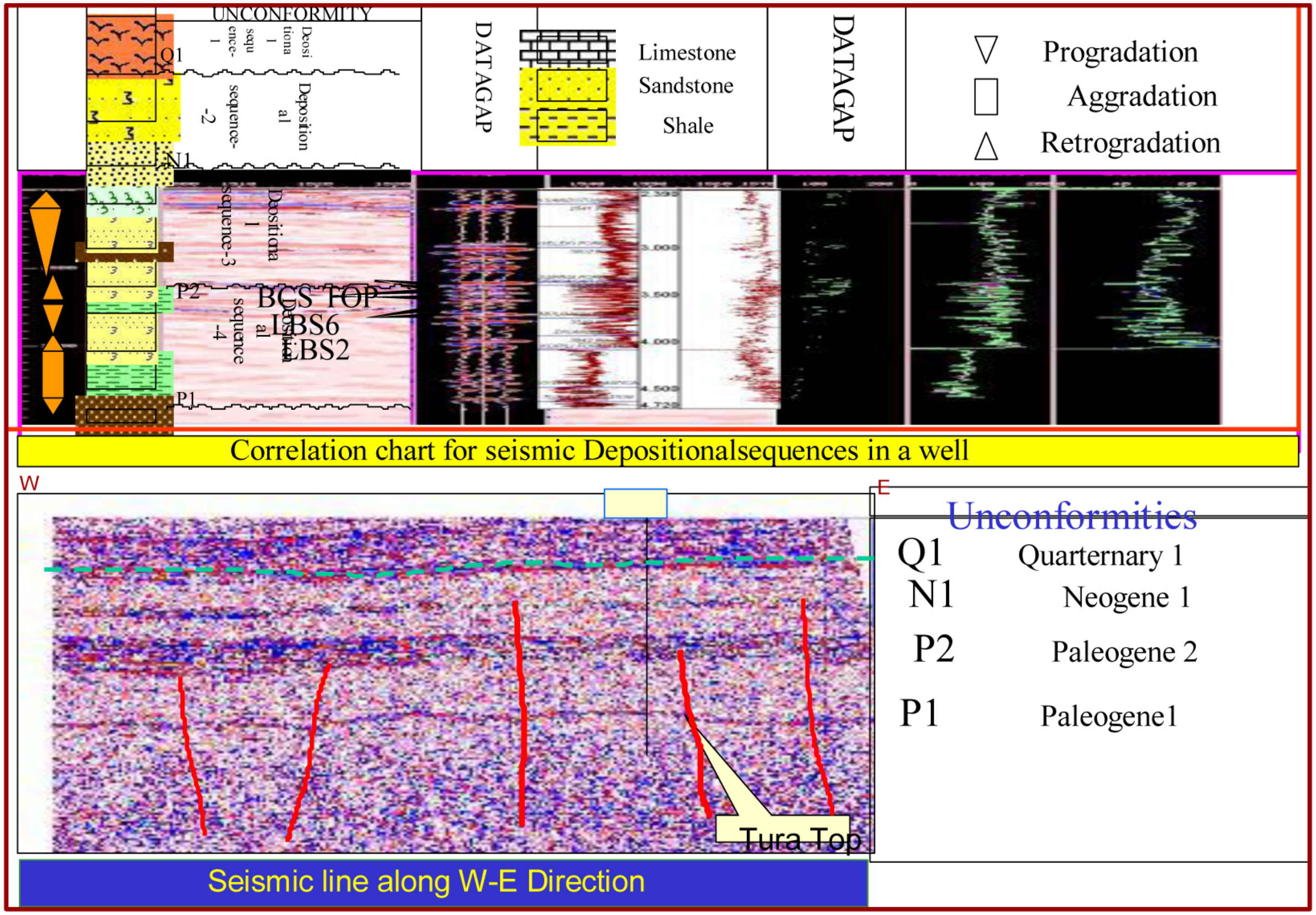


Figure 2. Correlation chart for seismic depositional sequences and major unconformities with W-E seismic section.

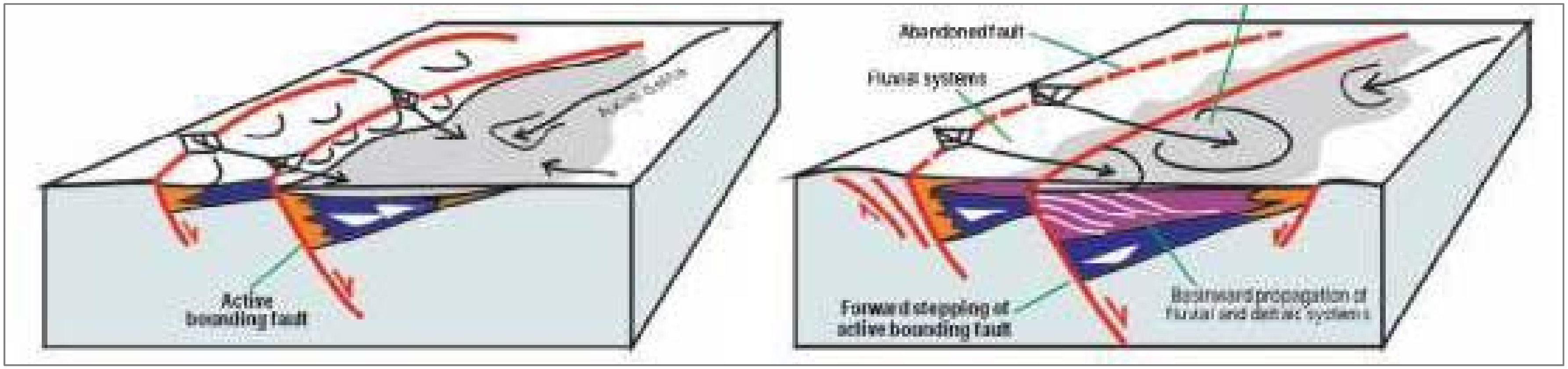


Figure 3. Schematic figure showing basin bounding fault and sedimentation patterns proximal and distal region of the basin.

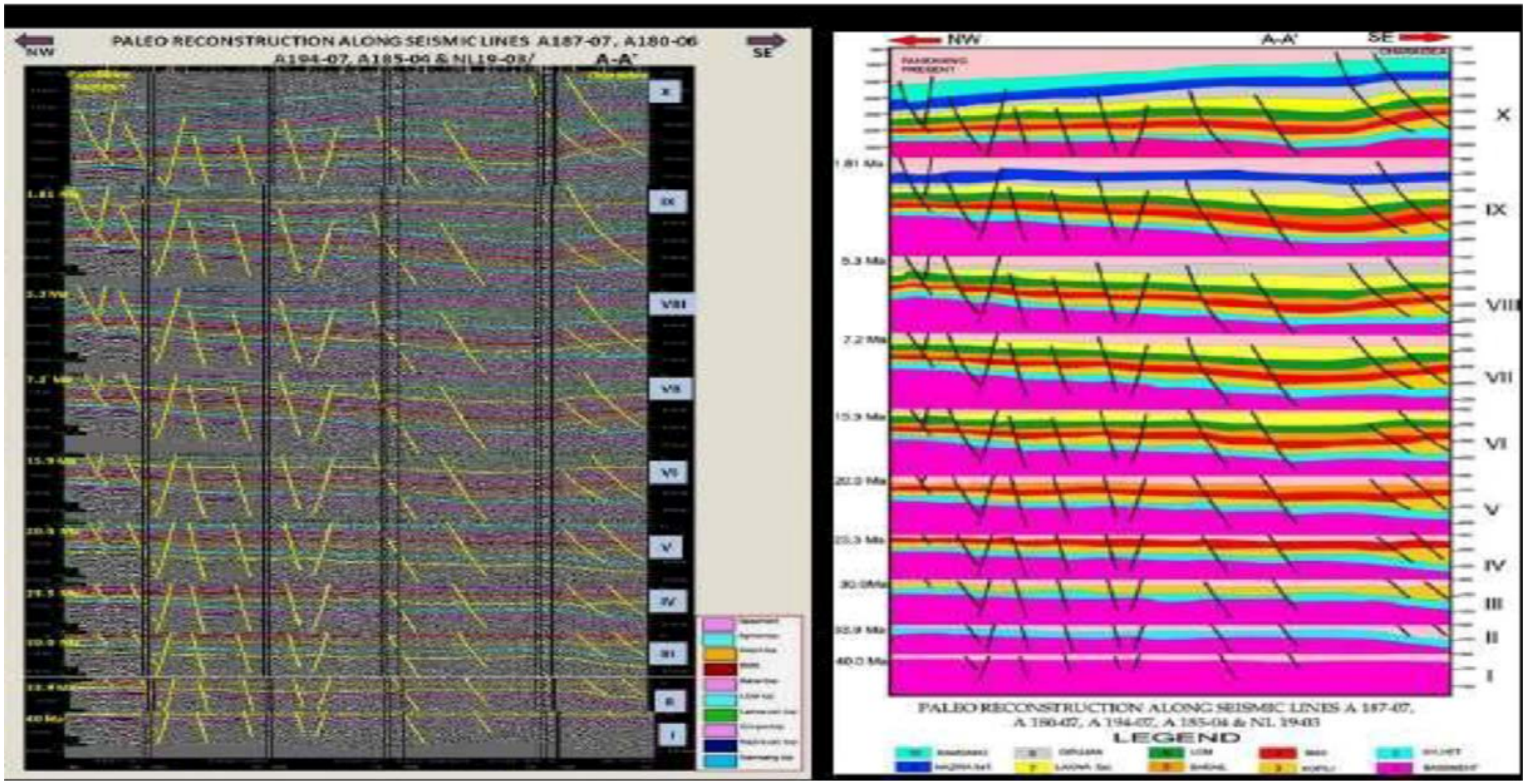
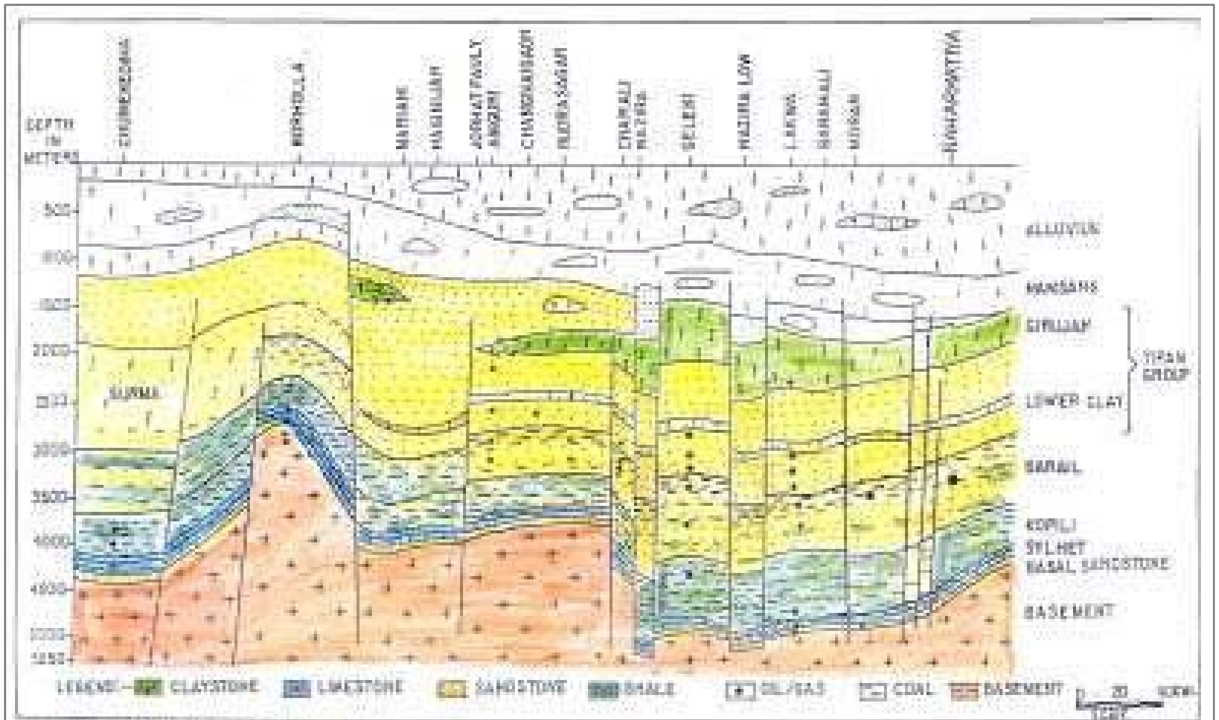


Figure 4. Paleo reconstruction along seismic lines of NW-SE direction of the basin.



SCHEMATIC SECTION ALONG UPPER ASSAM VALLEY SHOWING DISTRIBUTION OF HYDROCARBON ACCUMULATION

Figure 5. Distribution and Accumulation patterns in the Basin.