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Upper Assam Basin and its basinal depositional history

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Summary

The Upper Assam Basin is a poly history basin from where hydrocarbons are being produced for more than a century. The first commercial oil discovery of this part of the world came from this basin in the form of Digboi oilfield in 1889. Thereafter, the basin witnessed significant oil and gas discoveries. Exploration work, aimed at different plays, is still continuing in this basin. In present day context, tectonically, the basin can be sub-divided into two parts viz. Assam Shelf fore-land and Thrust fold / Schuppen Belt (Himalayan orogenic belt). The geologic formations in the basin primarily comprise of sand & shale alterations of the sediments from Paleocene/Eocene to Recent age. Recent basin modelling study (carried out by Oil India Limited) integrating drilling data and other geo-scientific data to update the regional geologic model in context of basin evolution and its depositional history propounds that the basin was dipping towards south and south-east after collision of Indian plate (Assam Shelf) with Burmese plate and the sediments came primarily from north and northeast. In the late Miocene and Pliocene period, the Indian Plate (northern side of Assam Shelf) docked with Asian plate and gradually the basin got tilted towards north and northeast; and in the process the basin was locked from three sides i.e. in north, east and south direction. In the recent times the basin has been receiving sediments almost equally from all sides followed by subsequent subductions and this situation is still being continued. In this paper, dynamic evolution of this basin and its basinal depositional history is tried to be explained by regional seismic sections recorded at different parts of the basin.

***Keywords**: Upper Assam Basin*

Introduction

The Upper Assam Basin is bounded by three major thrust faults viz. Himalayan orogenic belt in the north, Mishmi Thrust in the east and Schuppen Belt in south. Sediment thickness in this basin varies from around 3.0 km to 10.0 km. Topographically, the Assam Shelf fore-land basin part is a normal flood plain area of the River Brahmaputra and its tributaries The Upper Assam Basin is continuously being explored since discovery in Digboi primarily by Oil India Limited (OIL) and Oil and Natural Gas Corporation Limited (ONGCL). Till date, lot of wells have been drilled by these two organizations in quest of hydrocarbon exploration, and all these drilling data & other related geo-scientific information are integrated together in different studies in order to unfold the dynamic evolution and depositional history of this basin. Results of those studies are made available in public domain in form of various publications. This basin has got extensive seismic coverage of various vintages which provide immense information about dynamic evaluation of the basin.

In the recent past, OIL carried out basin modelling study integrating all the drilling data and other geo-scientific data to update the regional geologic model in context of basin evolution and its depositional history. The study used data covering mostly eastern part (east of Jorhat) of the basin, wherein the basin is bounded from three sides (Tipi Thrust in north, Mismi Thrust in east and Naga thrust in south) by the major thrust faults. All these data provide significant information for evaluation of Upper Assam Basin and its basinal depositional history. The eastern part of the basin is subducting in three sides as a results of collision with Indo-Sinian plate and Eurasian plate. The tectonic setup of the basin was changed time to time in different ways due to these collisions, and accordingly depositional environment got influenced. Formation densities & compactness are influenced by depositional environment of the basin throughout the history of deposition (Mandal K.L. et al, SEG-2011 Annual Meeting, San Antonio, USA). Structural and depositional patterns of different formations starting from oldest to recent provide supportive evidences to reveal depositional history as well as dynamic evolution of the

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basin. Structural configuration of geologic beds and their depositional pattern are nicely captured in seismic images in terms of reflection events and reflection patterns.

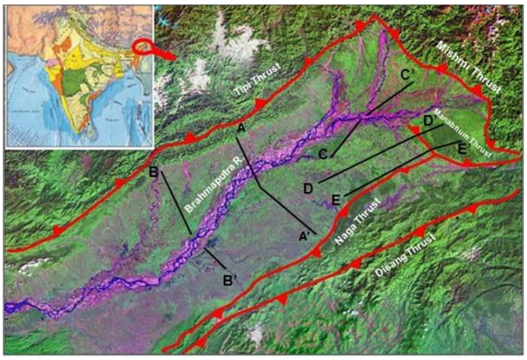

Fig.1: Shows satellite picture of Upper Assam Basin. The basin is bounded by thrust faults from three sides. Geographic positions of the seismic profiles taken into study are also indicated.

In this paper, the conceived model for evolution of the Upper Assam Basin & basinal depositional history on basis of available geo-scientific data would be discussed first, and thereafter regional seismic sections would be presented as supportive evidences. Although the seismic lines presented here are very sparse, but they provides a fair overall idea about the basin.

Geologic setting of Assam-Arakan basin

The broad geology and dynamic evolutions of this basin inferred from available geo-scientific data (Oil India Ltd., July 2002, final report on Integrated Basin Modeling of Upper Assam Basin. Major formations of this basin are Sylhet group (Eocene), Kopili (Late Eocene - Oligocene), Barail (Oligocene- Miocene), Tipam (Miocene), Girujan (Miocene), Namsang (Pliocene) and Siwalik/Dhekiajuli (Recent). Thickness of these formations varies in N-S direction (i.e. across the basin) whereas the thickness variations are less in NE-SW direction (i.e. in basinal strike direction). Girujan, Tipam and Barail formations are thickening towards south and south-east. These formations are northwardly dipping in northern side of the axis of central basement high. Sand developments in these formations are better towards north. Girujan Formation witnessed massive erosion in late Miocene period near central basement high. At places Tipam also got eroded to some extent. Namsang formation has 'divergent' type depositional pattern and is thickening to towards north and as well as towards the eastern side of the basin. Siwalik/ Dhekiajuli have gentle-dipping beds throughout the basin.

During the deposition of all the formations from Oligocene to Late Miocene (Kopili to Girujan), the basin got tilted towards south and south-east as a result of collision of Assam Shelf (of Indian Plate) with Indo-Sinian Plate. In this set up, the basin witnessed deposition of Kopili, Barail, Tipam and Girujan formations in shallow marine, deltaic, braided & meandering and waterlogged flood plain environment respectively. During the entire period, the sediment influx varied between north to south and northeast to southeast (**Fig.2**). Consequently, the beds are mainly south to southeast dipping (**Fig.2A**).

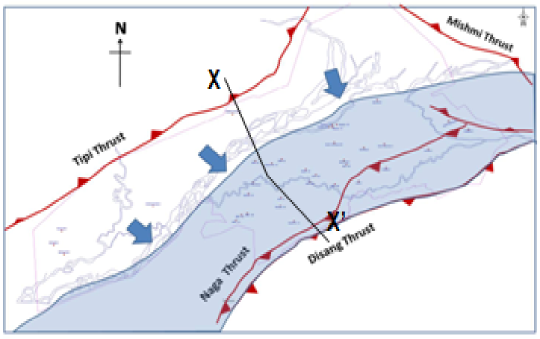

Fig.2 : Showing southward tilted basin and sediment influx from northern side in Oligocene to Pliocene. Highlighted area is tilted area of the basin.

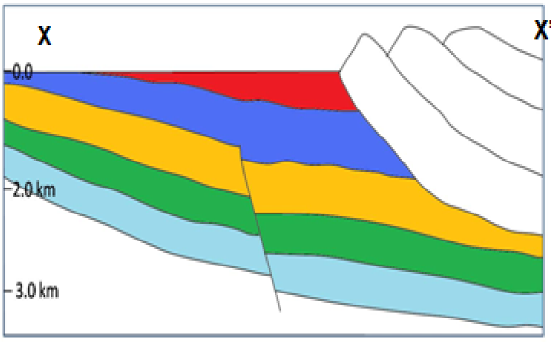

Fig.2A: Showing formations (Eocene Group to Girujan) in context of tectono-sedimentary environment along profile AA' shown in **Fig.3**.

In Late Miocene period, the basin witnessed bulging and formation of basement high at the central part of the basin as a result of collision between Indian and Eurasian Plate. This consequently led to a regional unconformity over Girujan formation and severe erosion thereafter. This also led to tilting of the basin towards north and northeast direction (Fig.3). Namsang formation (Late Miocene to Pliocene) was deposited in this condition in fluvial environment. In this time basin was locked from three sides i.e. south, east and north that led to its subduction simultaneously in these three directions. Sediment influx was mainly from south to southwest direction to fill up the depression and consequently, the formations are north to northeast and east dipping (Fig.3A). In later period while the depression was being filled up by sediments to form Namsang formation, gradually the ground level became gentle and sediments started coming towards middle from north, east and south direction and the basin began to go downwards.

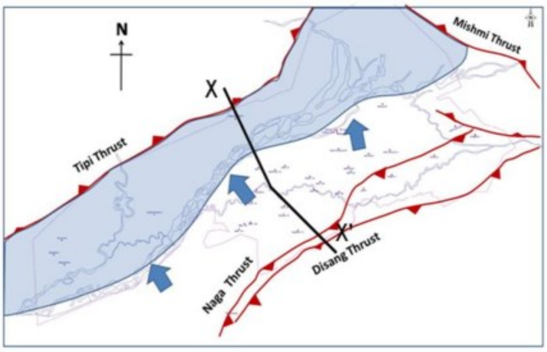

Fig.3 : Showing northward tilted basin and sediment influx coming from southern side in Pliocene to Pleistocene. Highlighted area is the tilted portion of the basin.

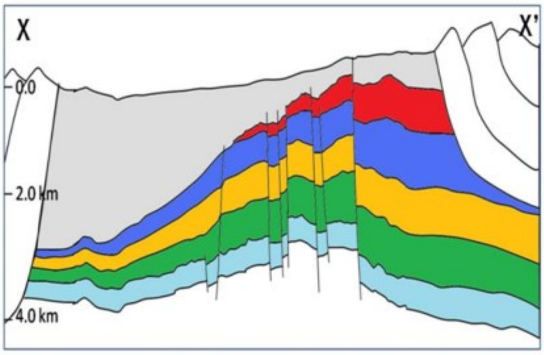

Fig.3A : Showing formations (Eocene Group to Namsang in conntext of tectono – sedimentary environment along profile AA' shown in **Fig.4**.

Subsequently, sedimentation were continued from all sides i.e. north, south, west and east on gentle ground level of the basin, and the basin kept sinking due to continuous sediment load. In this process, Dhekiajuli/ Siwalik group of formation was formed. The beds are gentle and more or less parallel (**Fig.4 & Fig.4A**). This situation is still continuing to present time.

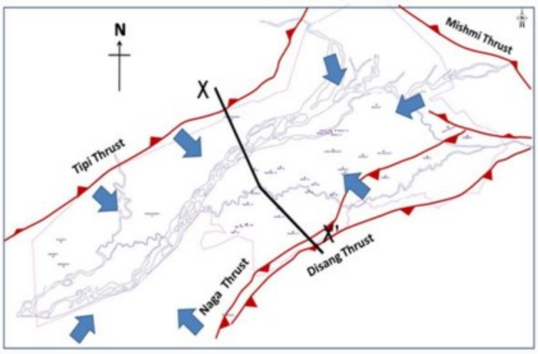

Fig.4 : Showing the present day situation, sediment influx are coming from all sides.

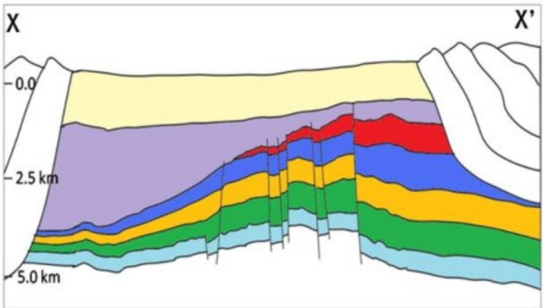

Fig.4A: Showing formations (Eocene Group to Dhekiajuli) in context of tectono-sedimentary environment along profile AA' shown in **Fig.5**.

Method & Approach

Most part of the basin is covered by 2D & 3D seismic survey of different vintages starting from 1977. For this study, 2D seismic profiles are chosen to represent different parts of the basin. These 2D seismic profiles are taken from seismic data archive. These data were processed by different industry standard processing software at different periods of time. Though these seismic sections are not having same ranges of amplitude scale (of reflection events) still they are quite adequate for the present study. The horizons pertaining to boundaries of major formations like Siwalik/ Dhekiajuli, Namsang, Girujan, Tipam, Barail, Eocene and Basement are marked in seismic sections in correlation with drilled wells. There are some data gaps due to River Brahmaputra - interpolation is done for formation boundaries in such gap areas. In this way, broad depositional patterns of major formations along these seismic profiles have been delineated.

Evidences in seismic profiles recorded in different parts of the basin

North-South profiles (Profile AA' and Profile BB'): Profile AA' and Profile BB' are along the dip direction of the basin (**Fig.5 and Fig.6** respectively). These seismic sections show that Oligocene and Miocene formations like Kopili, Barail, Tipam and Girujans are thickening towards Naga Thrust in south direction confirming sedimentations came from the north or north-east direction when basin was tilted to south and it is explained by **Fig.2 & Fig.2A**. In the both profiles, it is seen that Namsang, the Pliocene formation, is thickening towards the North and has divergent type of sequences - this indicates Namsang deposition took place when basin was tilted in North direction (explained by **Fig.3 & Fig.3A**). Divergent type deposition patterns were formed due to prolong tilting of basin and gradual filling up of depression. Analogy may be taken from Bengal basin for divergent type deposition patterns in between Pandua top and Hooghly top where basinal slope was towards the seafront and sediment came from land side (**Fig.7** to **Fig.9**). Recent formation like Dhekiajuli/ Siwalik is seen almost horizontal and this indicates that deposition took place when basinal slope became gentle after filling up depression, and the sediments came from all sides. The basin subsided due to constant sediment loading (resemble situation explained in **Fig.4** & **Fig.4A**). **East-west profiles (Profile EE', Profile DD'):** Profile EE' (**Fig.10**) is near the Naga Thrust and extending up to Manabum Thrust. Oligocene-Miocene formations viz. Kopili, Barail, Tipam and Girujans are thickening towards east indicating the fact that basinal slope was towards east in Oligocene-Miocene period due to subduction of Indian plate under Indo-Sinian Plate. Thickening of Namsang indicates that this dipping of the basin towards east continued in post Miocene period also- divergence type reflection pattern reveals gradual filling up of the depression by sediments coming from western side of the basin. During the end of Namsang deposition, the basin already became gentle and Dhekiajuli/ Siwalik formations were deposited. Horizontal beds of Dhekiajuli/ Siwalik reveal continuous subsidence of the basin due to sediment loading and this condition continued till recent time.

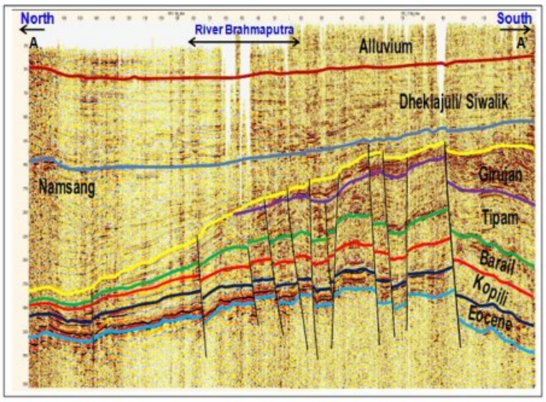

Fig.5: Shows seismic section of profile **AA'** extending from north to south across the Basin. 'Divergent' pattern of sedimentations are seen in Namsang formation.

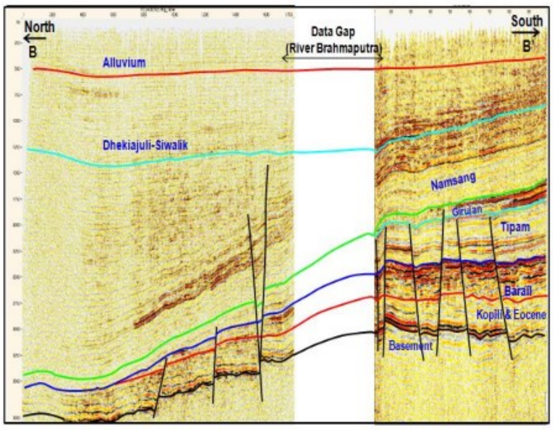

Fig.6: Shows seismic section of profile **BB'** extending from north to south across the Basin. 'Divergent' pattern sedimentation is seen in Namsang formation.

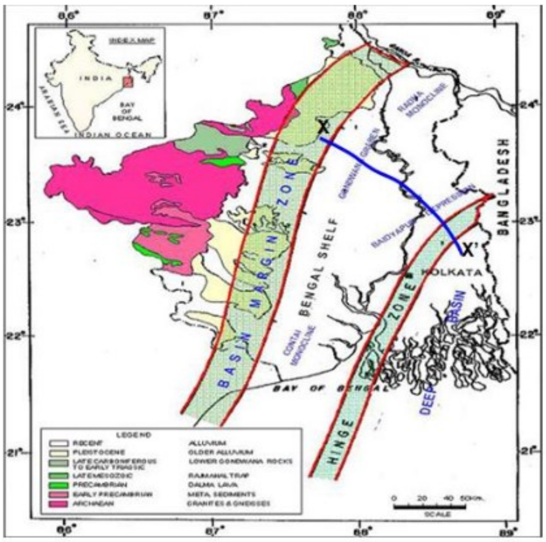

Fig.7: Shows tectonic setup of Bengal Basin in south part of West Bengal.

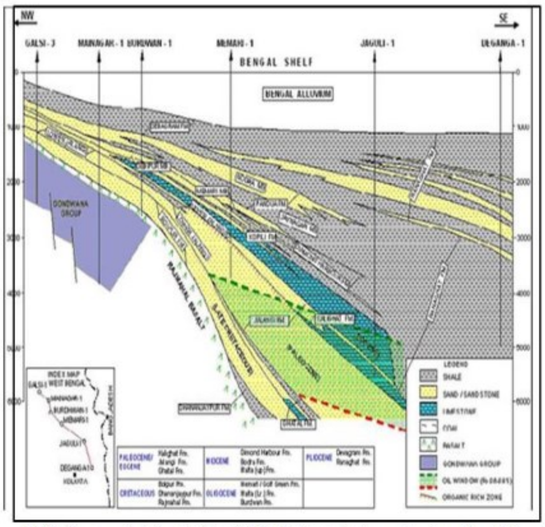

Fig.8: Shows a geological section (of profile **XX'** of **Fig.7**) extending from northwest to southeast in Bengal Basin. The section is constructed based drilled wells. Sediments are thickening towards seafronts and have 'divergent pattern' of deposition

Profile DD' (**Fig.11**) is close to profile EE' and is extending into Manabhum Thrust in east (**Fig.1**). Unlike profile EE' the thicknesses of Kopili, Barail, Tipam and Girujans in profile DD' are not increasing towards east. Beds are dipping towards east with consistent thickness. All these signify that the profile is close to tilting axis of the basin.

Profile CC': Profile CC' (**Fig.12**) is passing through Sadiya shown in the map (**Fig.1**). This profile is in north of profile DD'. Most significant feature is that Girujan sediment is missing and Barail is thinning towards down dips. These indicate that the basinal dip was towards south till late Miocene (Girujan deposition) and geographic position of this profile was in higher side in comparison to that of profile DD' and profile EE'. Namsang formation has diverging reflection pattern and is thickening towards east. This reveals that during Namsang deposition the basin was tilted towards the north & north-east. Dhekiajuli/ Siwalik formation beds are gentle and thickness is almost uniform. This suggests that Dhekiajuli/ Siwaliks were deposited when the basin became gentle after gradual filling up of the depression (due to basin tilting) by Namsang sediments primarily coming from south and south-west.

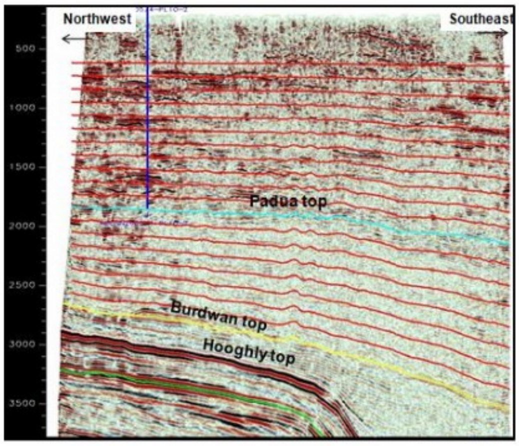

Fig.9: Shows seismic profile extending from northwest to southeast near the profile **XX'** in Bengal Basin. Sediments are thickening towards seafront and 'divergent pattern' reflection (i.e. 'divergent pattern' sediment deposition) are seen in between Pandua top and Hooghly top.

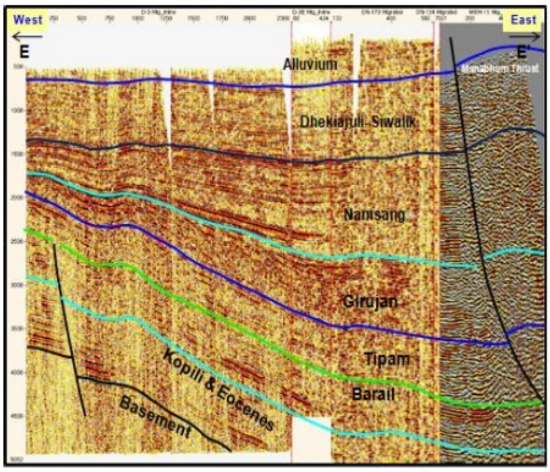

Fig.10: Shows seismic profile EE' extending from west to east.

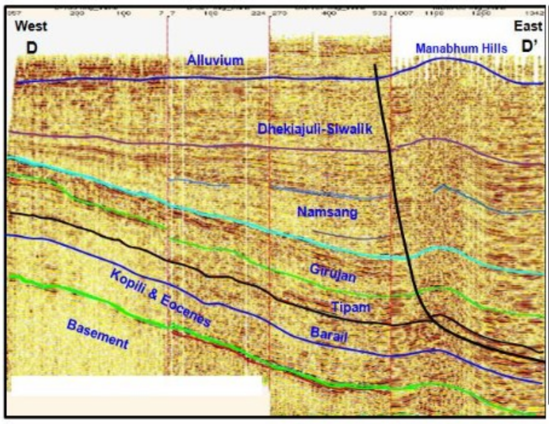

Fig.11: Shows seismic profile **DD'** extending from west to east.

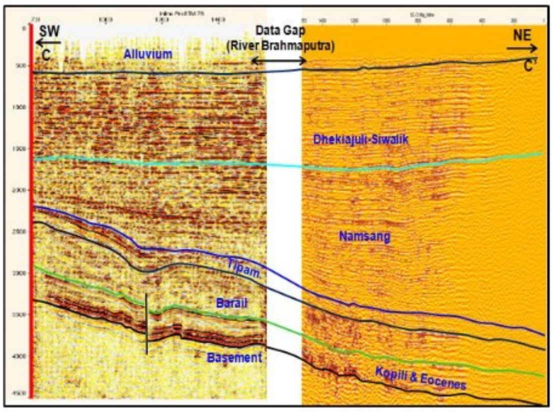

Fig.12: Shows seismic profile **CC'** extending from southwest to northeast. 'Divergent' pattern sedimentation is seen in Namsang formation.

Discussion

OIL carried out basin modelling study integrating all the drilling data and other geo-scientific data to update the regional geologic model in context of basin evolution and its depositional history in quest of redefining its hydrocarbon exploration program. The primary objective of the study was to address hydrocarbon GME (generation, migration & entrapment) model in Upper Assam Basin. It is an unpublished report and is treated as classified data of OIL. Here, only the very key points of the basin (Upper Assam Basin) evolution are presented (from **Fig.2** to **Fig.4A)** based on the findings of the said basin modelling study report of OIL. The study reconfirms the existing basin evolution model published in USGS open file report (Wandrey C.J. et al, 2004) and other publication (Balan K.C. et al, 1997).

Under this study, for the first time, several seismic profiles taken from different parts of the basin are presented in order to explain the complete phases of evolution & depositional history of the Upper Assam Basin from the past to recent. The seismic profiles provide pictures of subsurface geologic configuration in north, south and east of the basin. Depositional patterns of major formations depicted in seismic images reveal how the sediment deposition took place in north, south and east part of the basin during three different stages of evolution (viz. Eocene to late Miocene, late Miocene to Pliocene and Pliocene to recent). These seismic images cater the supporting evidences to the dynamic evolution model in north, south and east part of the basin.

Profile **AA'** (**Fig.5**) passing through Dikom-Khagorijan area shows abrupt thickness variation in Girujan in the area associated to central basement high part of the basin. This indicates that in some places Girujan was uplifted and severe erosion took place. This is the evidence of bulging of central part of the basin after tilting of the basin towards north as a result of collision of Indian Plate with Eurasian Plate. Bulging of the central part of the basin was happened because of compressional force acted from three sides (north, south and east) as the basin got locked in north (Tipi Thrust), south (Naga Thrust) and east (Mismi Thrust) after collision with Eurasian Plate. This might be the possible reason why there is central basement high in Dibrugarh-Tinsukia-Barekuri-Baghjan area. During this bulging of basement (due to compressional force) many basement faults were reactivated and as a result many basement controlled structures became prominent (**Fig.4A**, **Fig.5** & **Fig.6**). The basin got locked from three sides (Tipi Thrust, Mishmi Thrust and Naga Thrust) and the compressional force (from north, east and south) is still probably active due to relative motion of the plates, and this compressional force influences neotectonics to some extent in the fore-land region. Concept of tilting of the basin towards north (after collision of Indian Plate with Eurasian Plate) also explains why Barail, Tipam and Girujans have northward dipping in northern side of the axis of central basement high (**Fig.3** & **Fig.3A**).

Drilling data reveals that sand developments in Eocene group, Barail, Tipam and Girujans are better in north and north-north-east. It suggests sediment source came into basin from north and north-north-east during Eocene to late Miocene. Deposition patterns seen in north-south seismic profiles also support the same (**Fig.5** & **Fig.6**) Sediments also came from south and southeast after collision with Burmese plate but that part is already been consumed under the Thrust-belt. This may be a reason why evidences of those deposition (sediments) are not seen today.

The study is confined within the area mainly from east of Jorhat to Manabhum Hills & Sadiya. This study has brought a detail picture for the first time with evidences in several seismic profiles regarding dynamic evolution of the major part of the basin especially for the most significant part where the basin got locked from three sides (Tipi Thrust, Mishmi Thrust and Naga Thrust). The conceived basin evolution model explains most of the features of the basin as we are seeing today and all the evidences are captured in seismic profiles.

It would have been better if some seismic profiles across the basin could be arranged from west of Jorhat to infer larger picture of dynamic evaluation of this basin.

Conclusion

- All the above mentioned seismic profiles provide evidences in support of the conceived basin model, which propounds that the basin was dipping towards south and south-east after collision of Indian plate (Assam Shelf) with Burmese plate and the sediments came primarily from north and northeast.
- In the late Miocene and Pliocene period, the Indian Plate (northern side of Assam Shelf) docked with Asian plate and gradually the basin got tilted towards north and northeast; and in the process the basin was locked from three sides i.e. north, east and south. Because of locking from these three sides, compressional force acted from these three sides and as a result the central part of the basin got uplifted (bulging upwards). Central basement high in Dibrugarh-Tinsukia-Baghjan region was formed probably due to this bulging.
- During this bulging, massive erosion of Girujan formation took place and its evidences are seen as very uneven sediment thicknesses in Girujan. Many basement faults were reactivated by the bulging of basement (due to compressional force) and as a result many basement controlled structures became prominent.
- The Namsang was deposited in fluvial environment and during this time the basin was definitely tilted (due to collision of Indian Plate with Eurasian Plate) towards north and northeast. There was a long deposition hiatus between Namsang and Girujans.
- Tilting of the basin towards north (after collision of Indian Plate with Eurasian Plate) made Barail, Tipam and Girujans to have northward dipping in northern side of the axis of central basement high.
- Recent time deposition like Dhekiajuli/ Siwalik and Alluvium are having almost horizontal (gently dipping) beds. This indicates that the basin received sediments almost equally from all sides followed by subsequent subductions and this situation is being continued to recent times.
- The basin is locked from three sides (Tipi Thrust, Mishmi Thrust and Naga Thrust) and the compressional force (from north, east and south) is still probably active due to relative motion of the plates, and this compressional force influences neotectonics to some extent in the fore-land part of the basin.
- The evolution of the basin and its sediment deposition model is described in **Fig.2** to **Fig.4A** and the supporting evidences are presented in the seismic sections. The conceived basin evolution model explains most of the features of the basin as we observe today.

Acknowledgement

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