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Reservoir Characterisation, Lithofacies Classification and Hydrocarbon Accumulation Pattern of Tura Formation in North Assam Shelf of Assam & Assam-Arakan Basin

Abstract

The Tura Formation of Paleocene-Early Eocene consisting of clastic sediments is playing a major role in contribution of hydrocarbon in Assam Shelf. Major oil fields producing from Paleocene-Eocene are aligned along the NE-SW trending Brahmaputra Arch which is almost parallel to the southern part of present day Brahmaputra River. In general, the reservoir properties of wells of north-eastern oil fields located in OIL acreages are better in comparison to oil wells located in ONGC acreages.

Based on log characteristics and lithology, Tura Formation can be divided into two units; from bottom, Lower Tura and Upper Tura (divided into two parts viz. the bottom unit is termed as **Upper Tura-II** and the top unit is termed as **Upper Tura-I**). Good porosity development observed in Upper Tura-I and in most of the cases this zone contributes hydrocarbon. Clay mineralogy percentage map indicates that in general, Charing-Charali-Disangmukh area the average percentages of Kaolinite is less and Chlorite is higher with respect to Panidihing-Lakwa-Mahakuti-Demulgaon area. Mixed successes in Tura Exploration in the ONGC acreages can be attributed mainly to structure, entrapment, charging and reservoir coupled with diagenesis.

Introduction

In 1937 Fox used the term “Tura Sandstone” after Tura village while mapping the sedimentary sequence in the western Garo hills for the coal bearing, poorly sorted sandstone, disconformably overlying the Mahadeo rocks of unconformably overlying the basement rocks. Fuloria (1976) named the clastic sequence overlying basement and underlying Sylhet Limestone in Upper Assam subsurface as basal Sandstone, whereas the same unit was referred to as Teok Sandstone by Bhandari et.al. (1973).

In the Assam Shelf, Tura Formation unconformably overlies either the Basement Complex, Mikir Trap, Moabund or Mahadeo Formation and conformably overlain by Sylhet Formation with gradational contact. Tura Formation is present in entire Assam Shelf except in the northern bank of Brahmaputra as observed from the drilled wells. Outcrops are observed in the South Shillong Plateau, along the fringes of Mikir Hills and in the intervening Kopili valley.

The ONGC acreage is contiguous to OIL in the north east where the HC potential of Pre Barail sediments has been established. The time equivalent of Tura Formation in OIL (Langpar+Therria+Lower part of the Lakadong Formation) is a major producer. In general, the prolific oil producers from Paleocene-Eocene sequence of OIL having excellent reservoir characteristics with average porosity of 24% and permeability ranges upto 5 darcy. However, the equivalent reservoir facies is found to be deteriorated in general, towards SW of the Assam Shelf. The study area covers about 1008 skm encompassing the North Assam Shelf area. In this work attempt has been made to characterise reservoir properties, role of clay mineralogy in porosity distribution as well as hydrocarbon accumulation pattern of Tura Formation in North Assam Shelf.

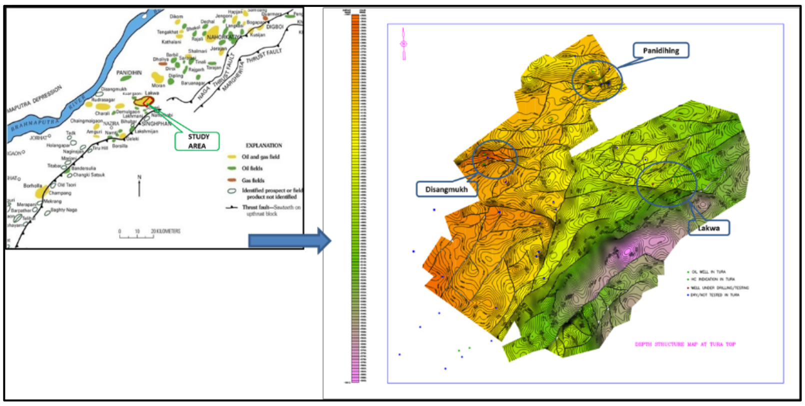


Figure-1. Map showing the study area and Structure Map on top of Tura

Tectonic Setting

The Assam & Assam Arakan Basin is bounded by the Eastern Himalayan fold belt in the North, the Mishmi hills in the North East and the Patkai – Arakan fold belt in the East. It is a typical poly-history basin having more than one phase of tectonics and sedimentation. The evolution of the basin is essentially influenced by the Northward movement of the Indian plate towards the Eurasian and Burmese plates. The extensional tectonics prevailed fault trend in the area is NE-SW transacted by the younger E-W to NW-SE trend creating a number of fault blocks. Till Oligocene the tectonic regime changed to compressional environment during the major phase of Himalayan orogeny. This resulted in reactivation along faults, resulting in reverse faults and inverted structures. It is established that during Paleogene to Early Neogene time, the basinal slope of Assam Shelf was towards the East and South East direction and sedimentary thickness increases toward Naga Schuppen area. During Pliocene time, basinal slope reversal took place during the deposition of Namsang sediments.

Depositional Regime

The onset of sedimentation in the Upper Assam Shelf - North part of the basin started during Paleocene to Early Eocene time in a fluvial to marginal marine to shallow marine environment in which Tura formation was deposited over Basement in a passive margin set-up. End of Tura sedimentation, witnessed a widespread transgression during which carbonate dominated Sylhet Formation and marine pro-delta Kopili Formation were deposited. Regression was observed after deposition of Kopili Formation which is overlained by delta front sandstone of Demulgaon Formation or BMS (Barail Main Sand) succeeded by delta plain interbedded shale and sandstone with thin layers of coal of Rudrasagar Formation or BCS (Barail Coal Shale). These delta plain BCS deposits are unconformably overlained by a thick sequence of high energy (braided) fluvial sandstone of Tipam Group.

Lithology

The Tura formation consists mainly of sandstone, siltstone and shale with occasional coal streaks. Time to time, earlier workers subdivided this sedimentary sequence in three/four units on the basis of lithofacies assemblages, electrolog characters and envisaged depositional environments.

Saikia et al. (1995) divided Tura Formation into four informal lithounits. The bottommost unit is the ferruginous coarse grained poorly sorted sandstone with carbonaceous streaks. Overlying unit comprises of fine to medium grained kaolinitic sandstone. The third unit contains calcareous sandstone with glauconite and fossil tests deposited in tidal channel environment. The topmost litho-unit comprises of sugary sandstone at the bottom and thin calcareous sandstone at the top **(Fig.2).** On the basis of characteristic log pattern in integration with different laboratory data, Gupte & Morang (2010) divided the Tura sediments into two parts, viz., Tura Lower and Tura Upper.

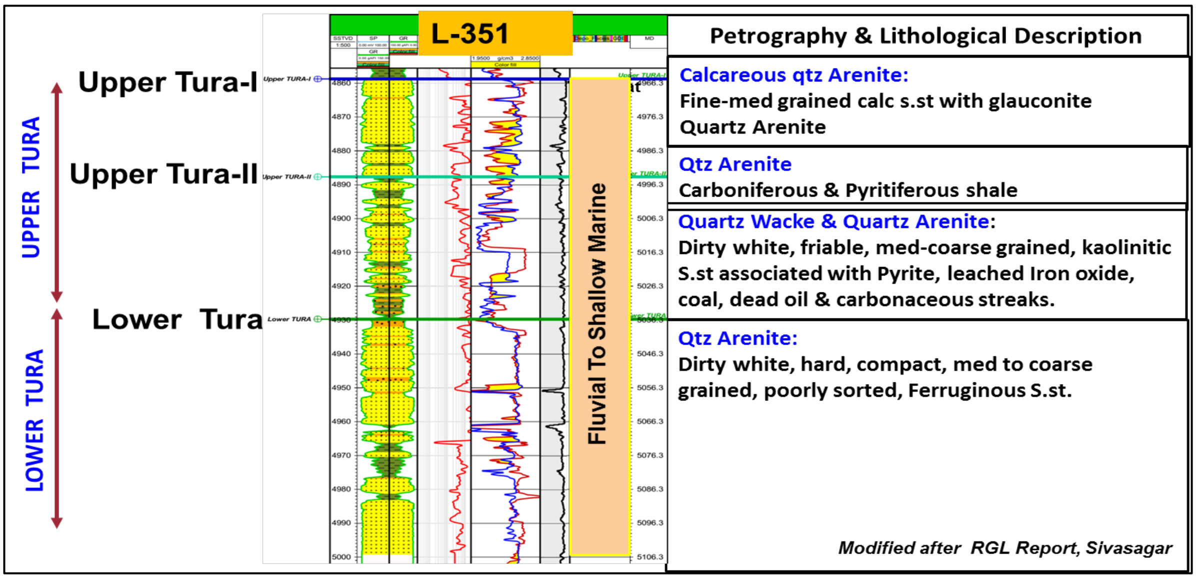


Figure-2. Representative well showing subdivision of Tura Formation into different litho-units

On the basis of microfauna, Paleocene age has been assigned to **Lower Tura** unit and the sediments have been interpreted to be deposited under fluvial environment and Early Eocene age has been assigned to the **Upper Tura** unit and shallow to marginal marine environment of deposition has been interpreted. The sedimentological and paleontological studies of some cores of Tura indicate the sedimentation in a near shore to inner shelf environment of deposition in a Tidal delta. Most of the cores of the wells in this area show flaser and lenticular bedding and are highly bioturbated indicating a very shallow, quiet environment of deposition.

Sedimentological & Petrographic Studies

The sedimentological studies carried out at RGL, Sivasagar (2018), indicates that the **Lower Tura** contains whitish grey, light brown to reddish brown, coarse to medium, occasionally very coarse, poorly to moderately sorted, sandstone associated with very hard & compact, non-calcareous claystone bands, occasional coal and carbonaceous shale. Poorly sorted loose quartz, mica, abundant feldspar (fresh as well as altered to kaolinite) present. Shale is light grey to grey, hard, fissile and non-calcareous. The sands of **Upper Tura** are grey to greenish grey, occasionally whitish grey, medium to coarse grained, at places fine grained to silty, glauconitic, calcareous sandstones and contain shell fragments while the shales are grey, hard and compact, pyretic with disseminated organic matter and silty lenses. Glauconite, mica and pyrite are commonly present.

Petrographic study of core and cuttings indicate that Lower Tura consists of quartz wacke and feldspathic quartz arenite microfacies and the Upper Tura is predominantly calcareous quartz arenite and quartz arenite. Calcareous quartz arenite consists of fine to medium, occasionally coarse grained, moderately to poorly sorted quartz grains with glauconite pellets cemented by intense calcite.

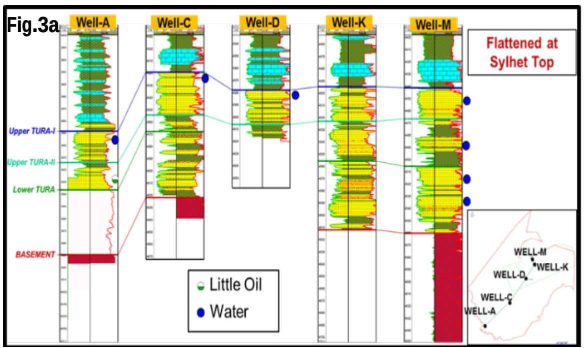
Megascopic and Petrographic study also indicates that in general, the Tura sediments are mainly sandstone with intercalations of shale, siltstone and volcanic tuff. The volcaniclastics are embedded with terrigenous clastic sediments of Tura Formation**.** In general, Lower Tura sequence is dominated by volcaniclastics whereas Upper Tura is dominated by clastics (Kataki et.al, RGL Report, 2015). However, it is very difficult to differentiate between volcaniclastics and clastics with the help of conventional electrologs.

Log characteristics & Correlation

On the log the Upper Tura can be distinguished from the overlying Sylhet Formation by sudden increase in resistivity, change of neutron-density pattern and break in sonic logs which are well correlatable across the North Assam Shelf area. In general, a shale layer at the bottom of the Sylhet Formation separates the Tura Formation. Lithologically, a high resistivity sandstone layer and in few cases high resistivity shale layer separates the Upper and Lower Tura. Again there is a distinct change of neutron-density pattern with break of sonic log between Upper and Lower Tura. In Panidihing-Disangmukh area the boundary falls mostly on the shale layer, however in Lakwa-Lakhmani area it falls on the sandstone layer**.**

So far, in the entire North Assam Shelf area, only 7 wells have produced oil from Tura. All the wells are contributing from Upper Tura only and hence is focus of exploration. In general, top portion up to 15-25m of Upper Tura is tight & highly calcareous and below this zone, good porosity development is observed. In most of the cases this zone contributes hydrocarbon. On the basis of log characteristics and lithological characters the Upper Tura can also be divided into two parts, viz. the bottom unit is termed as **Upper Tura-II** and the top unit is termed as **Upper Tura-I**. The Upper Tura-II is mainly sand-shale sequence and the Upper Tura-I is dominantly sandstone sequence **(Fig.3a & Fig.3b).**

Isopach map of Tura Formation indicates that thickness increases gradually from NW to SE in the basinal dip direction. The thickness varies from 57m to 167m with sediment entry from NW-NNW **(Fig.4a).** Isopach of Upper Tura also indicates thickening of sediments towards SE and thickness ranges from 35-80m. The sand isolith prepared for Upper Tura (15-52m) indicates two sand maxima axis with input from NW & NNW (**Fig.4b**). The pack thickness of Upper Tura -I ranges from 16m to 40m.



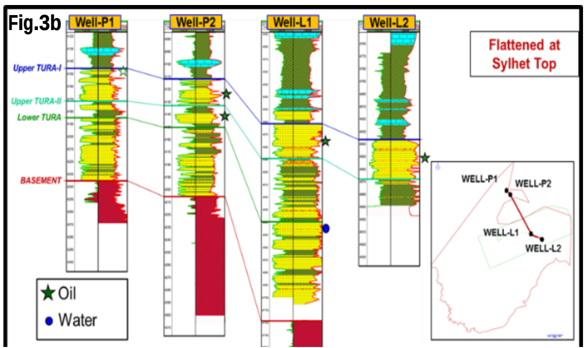


Figure-3a & 3b. Stratigraphic log correlation profiles in Strike & Dip directions

Fig.4a

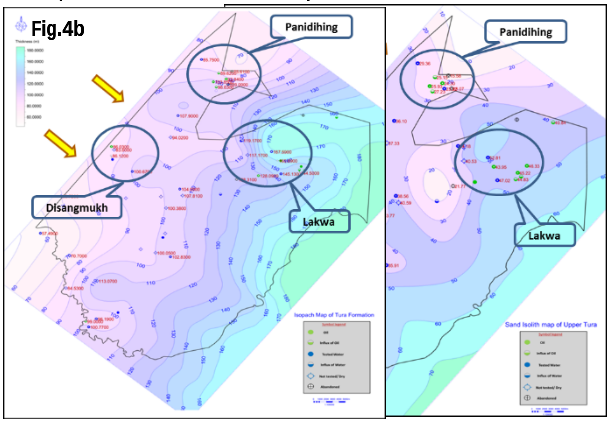


Figure-4a & 4b. Isopach of Tura & Sand Isolith of Upper Tura

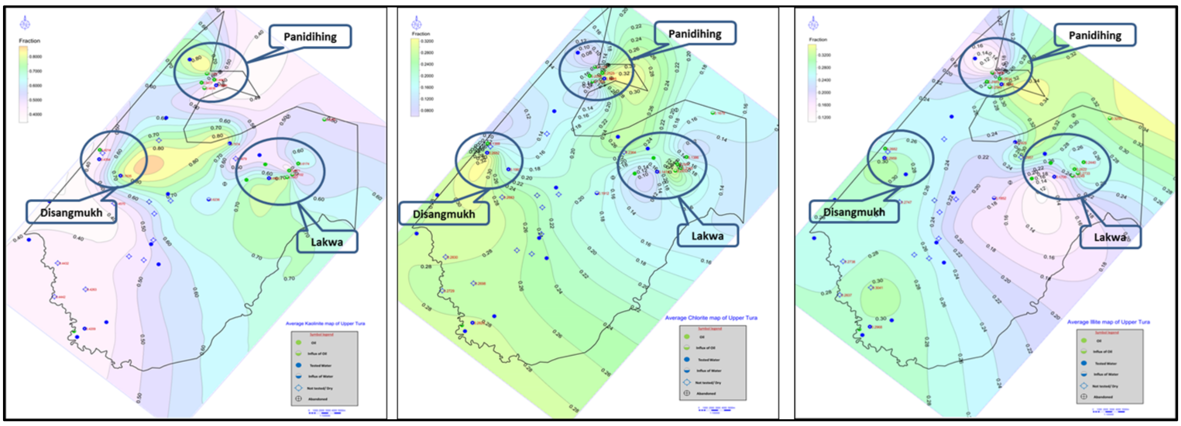
Clay Mineralogy & its Effect on Porosity

The Tura Formation shows heterogeneity in reservoir quality. Recent study carried out at RGL, Sivasagar indicates that in Upper Tura primary porosity is partly preserved and in most of the cases, burial compaction and silica cement occluded the porosity. Sometimes calcite, kaolinite and siderite cement reduces the porosity. Quartz arenite in the Upper Tura shows better development of secondary porosity compared to quartz wacke that are predominant in Lower Tura.

In the Upper part of Tura Formation, extensive calcite cementation has deteriorated the reservoir quality. Moreover, this part is also affected by clay and ferruginous matter. The better reservoirs are associated with upper part of stacked tidal channel facies and tidal sand flat environment. The good reservoir facies is sandwiched between overlying and underlying impermeable calcite cemented sandstone or shale layers.

Clay minerals observed in the Tura Formation are: Kaolinite, Chlorite, Illite, Montmorillonite and mixed layer. With increasing depth Illite is dominant over Montmorillonite. The SEM study indicates that porosity is badly affected by the presence of feldspar, biotite, chlorite and detrital clay. Calcite cement and quartz overgrowth have further deteriorated the porosity. Feldspar and calcite dissolution, formation of kaolinite, chlorite and smectite are observed as important late stage diagenetic features.

Chlorite coatings preserve primary pore spaces in the sandstones by inhibiting the nucleation of quartz cements on grain surfaces. With the burial depth increasing, smectite and kaolinite tended to be transformed into chlorite. Kaolinite occurs as blocky crystals forming booklets in the pores. These booklets reduce porosity. Illite forms fur like coatings on grains which bridges the pore throats causing drastic reduction in permeability.



Figures-5a, 5b & 5c. Map showing average percentages of Kaolinite, Chlorite & Illite Upper Tura

Clay mineralogy percentage maps of Chlorite, Kaolinite & Illite for Upper Tura have been prepared for the Upper Tura by taking the average value from the data generated from the XRD analysis (Table-1 & Figures. 5a, 5b & 5c).

Table-1.

Clay Mineral	Area & Distribution of Average Clay %		
	Charing-Charali-Disangmukh	Panidihing	Lakwa-Demulgaon-Mahakuti
Kaolinite	42-45	39-72	46-75
Chlorite	20-26	11-28	13-29
Illite	27-30	16-31	17-28

Property Modelling

Facies Modelling: Three types of facies namely sandstone, siltstone and shale were interpreted in the wells on the basis of logs. It has been upscaled by using "most of" average method. Variogram analysis of each facies have been carried out for the zones Upper Tura-I to Upper Tura-II & Lower Tura to Basement. Subsequent to data analysis, facies modelling was carried out for both the pay sands using Sequential Indicator Simulation method.

Petrophysical Modeling: Porosity (PHIE) values of 11 wells were upscaled using "arithmetic" average method. Subsequent to upscaling, data analysis was carried out biasing with modeled facies. Variogram analysis was done considering normal scored data. The spherical variogram model was used to assign range in major, minor and vertical direction. The variogram results obtained from data analysis were used for petrophysical modeling of upscaled porosity data. Petrophysical modelling was thus carried out by using "Sequential Gaussian Simulation Method".

Average effective porosity map prepared for the Upper Tura indicates that the porosity ranges from 3% to 16%. Along Disangmukh-Panidihing NE-SW trend good porosity (8-16%) development is observed. However, in the Lakwa-Kuargaon area moderate to good porosity (8-11%) and in Mahakuti area poor porosity (3%) development is observed **(Figs.6 & 7).**

Fig.7

Fig.6

Fig.8

Figure-6. Average 3D porosity map of Upper Tura; Figure-7 Property Modelling of Tura Formation; Figure-8 Hydrocarbon accumulation pattern in Tura Formation

Risk elements & Hydrocarbon accumulation pattern

So far in UAN block 48 wells have penetrated Tura and out of these only 7 wells in Disangmukh-Panidihing & in Lakwa are oil bearing. About 8 wells gave oil influx during testing. The low success ratio for Tura warrants analysis of the Key risk elements, viz. presence & effectiveness of Reservoir, Trap and HC migration. Based on the structure map at Tura top it is observed that some of the wells located in structurally favourable situation are HC bearing whereas others, though located in the similar or better set-up, are dry (**Fig.1).**

In most of the Tura wells in UAN block area, the Upper Tura-I is the main reservoir contributing to the production. Till date, the best producer from Tura is in Disangmukh and comparatively poor performing wells are in Lakwa area. In general, towards south-eastern side of the block (Lakwa-Lakhmani-Demulgaon) porosity development is relatively poorer. However, localised good reservoir facies are developed. The porosity is badly affected by calcite cementation as well as presence of substantial amount of clay minerals like kaolinite.

A number of wells, however, drilled in the Charali-Changmaigaon-Rudrasagar area went dry despite located in good structural situation with similar order of porosity development (14-15%). Additionally, no hydrocarbon shows reported during drilling of these wells. Thus it can be envisaged that western part of the Block (Charali-Changmaigaon-Rudrasagar area), is devoid of hydrocarbon due to lack of charge migration.

The Disangmukh, Panidihing and Lakwa areas are proven from the HC migration point of view in Tura reservoirs, however, selective charging of traps are observed in the area as not all the probed structures are charged. It is envisaged that earlier formed NE-SW faults and later formed E-W faults played a major role in HC migration and entrapment. It has been observed that Disangmukh-Panidihing oil wells falls on the footwall side of E-W trending normal fault closure. In Lakwa area, except one well, all the other oil wells falls on the NE-SW hanging wall fault closure. Thus both hanging-wall and foot-wall prospects are charged **(Fig.8).**

Mixed successes in Tura Exploration can be attributed mainly to structure, entrapment, charging and reservoir coupled with diagenesis. Hence, future Tura Exploration could be the locales where good structural entrapment along E-W or NE-SW trending fault system coupled with development of good reservoir facies.

Conclusions

The Tura Formation of Paleocene-Early Eocene age has been divided into Lower and Upper Tura based on log characteristics and lithologic assemblages. The thickness of Tura Formation increases towards the basinal slope in SE direction. On the basis of log characteristics and lithological characters the Upper Tura can also be divided into two parts, viz. the bottom unit is termed as **Upper Tura-II** and the top unit is termed as **Upper Tura-I**. The Upper Tura-II is mainly sand-shale sequence and the Upper Tura-I is dominantly sandstone sequence. In most of the Tura wells in UAN block area, the Upper Tura-I is the main reservoir contributing to the production. The pack thickness of Upper Tura -I ranges from 16m to 40m**.**

The wells producing from Tura has porosity in the range of 8-16%. In general towards south-eastern side of the block (Lakwa-Lakhmani-Demulgaon) porosity development is relatively poorer. In most of the Tura wells, the Upper Tura-I is the main reservoir contributing to the production. However, hydrocarbon entrapment in Lower Tura also cannot be ruled out. Clay mineralogy percentage maps indicate that in general the average Kaolinite(%) is higher in Lakwa-Demulgaon-Mahakuti area whereas the dominance of average Chlorite(%) is observed in Charing-North Rudrasagar-Disangmukh area. However, drastic variation of the same is observed in Panidihing area.

Mixed successes in Tura Exploration in the ONGC acreages can be attributed mainly to structure, entrapment, charging and reservoir coupled with diagenesis. Hence, future Tura Exploration could be the locales where good structural entrapment along E-W or NE-SW trending fault system coupled with development of good reservoir facies.

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