Petroleum Systems of Upper Assam Shelf, India

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SUMMARY

Upper Assam Shelf, a southeast dipping shelf over thrust by the Naga Hills is a foreland part of Assam-Arakan Basin. The present study aims to identify the elements and processes making up the petroleum system of upper Assam shelf to assist in prioritizing future exploration effort. Source rocks mainly in Barail, Kopili and Sylhet/Tura formations of the Schuppen belt have charged reservoirs in upper Assam shelf since Late Miocene. Reactivation of structures and developing folds in the foreland possibly created impedance to lateral migration from the Schuppen Belt since Pleistocene. Migration is primarily updip to the northwest along the northeast- trending slope and occurs through reactivated basement-rooted faults. In Nazira low and adjoining area, hydrocarbon charge from local Sylhet/Tura, Kopili and Barail source rocks of the foreland has caused diversity in oil characteristics. In Dhanasiri valley, uniformity in oil characteristics is due to lack of local generation. Two oil groups are evident; one predominantly matching to source rocks of Oligocene and Late Eocene sequences, another matching to source rocks of middle Eocene to Paleocene sequences.

Two petroleum systems (PS) have been identified, one is Paleocene to Middle Eocene- Paleocene to Middle Eocene (Tura and Sylhet - Tura and Sylhet) (!) with four Assessment units (AU'S) defining sub-systems operating in the basin, another Late Eocene to Oligocene - Oligocene (Kopili and Barail - Barail) (!) with six AU'S. Best targets for future exploration are fault blocks north west of Nazira low and the crestal highs for strati-structural play in Tura-Sylhet sequence, Geleki structure for Basal clastics and fractured basement and retrogradational HST sands in Khoraghat to Mekrang for stratigraphic play in Bokabil sequence.

Introduction

The upper Assam shelf, a southeast dipping shelf is the foreland part of Assam-Arakan Basin. It is bounded by the shield of Mikir hills towards its west and Mishmi hills along its northeastern boundary. The upper Assam shelf contains about 7000m thick sediments of mostly Tertiary and Quaternary age. Our study area is the lease area of ONGC (Fig. 1). Worldwide, > 56% of conventional oil reserves, excluding the heavy oil reserves, are in foreland basins (Hunt, 1996). Such basins accumulate huge amounts of hydrocarbon by lateral secondary migration from large drainage areas. Although, production from fields of Assam have continued for more than a century but the volume of hydrocarbon produced is not significant. Continuous production from Digboi field however, is an evidence of active hydrocarbon generation and charging at present. The abundance of petroleum in a basin is dependant upon the existence of all the elements and processes necessary for a world-class petroleum system in time and space.

This study is a integrated geologic, geophysical, and geochemical investigation of the elements and processes making up the petroleum system of upper Assam shelf..

In addition, geochemical results of large number of sediment cuttings, oil, and gas samples from various exploratory wells are discussed. The objective is to identify and charecterise the key elements which have contributed to the establishment of prolific petroleum system in Assam

Geology, Tectonics and stratigraphy of Assam Basin

Assam geologic province is the first known hydrocarbon province in India. The upper Assam Shelf consists of a portion of the Paleocene to Eocene continental shelf of the Indian plate which became emergent and which is being over-thrust by the Himalayas on the north-northwest and by the Naga hills on the southeast. The present-day Assam Basin, a cratonic margin, reflects three distinct tectonic phases. The earliest was Late Cretaceous to Eocene block faulting and development of a southeasterly dipping shelf. During the second phase, in Oligocene time, uplift and erosion

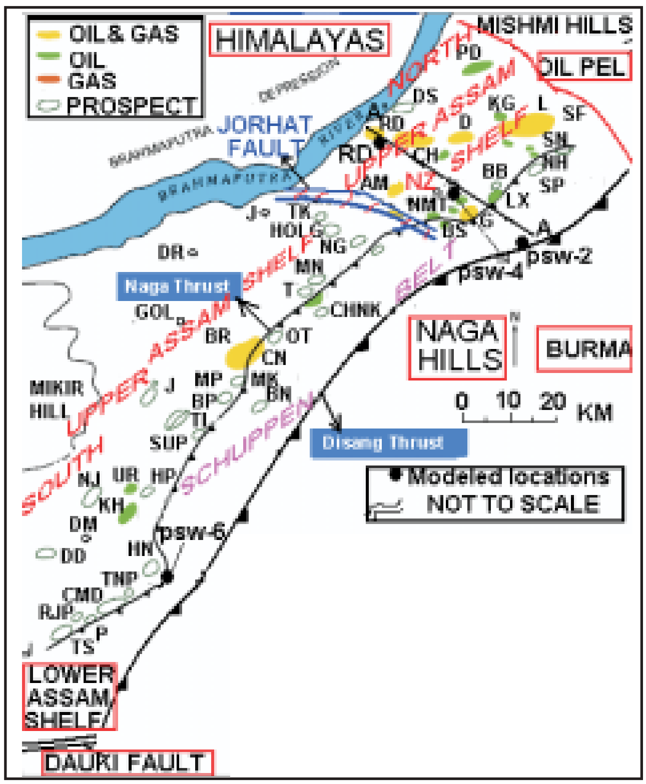

Fig. 1. Study area

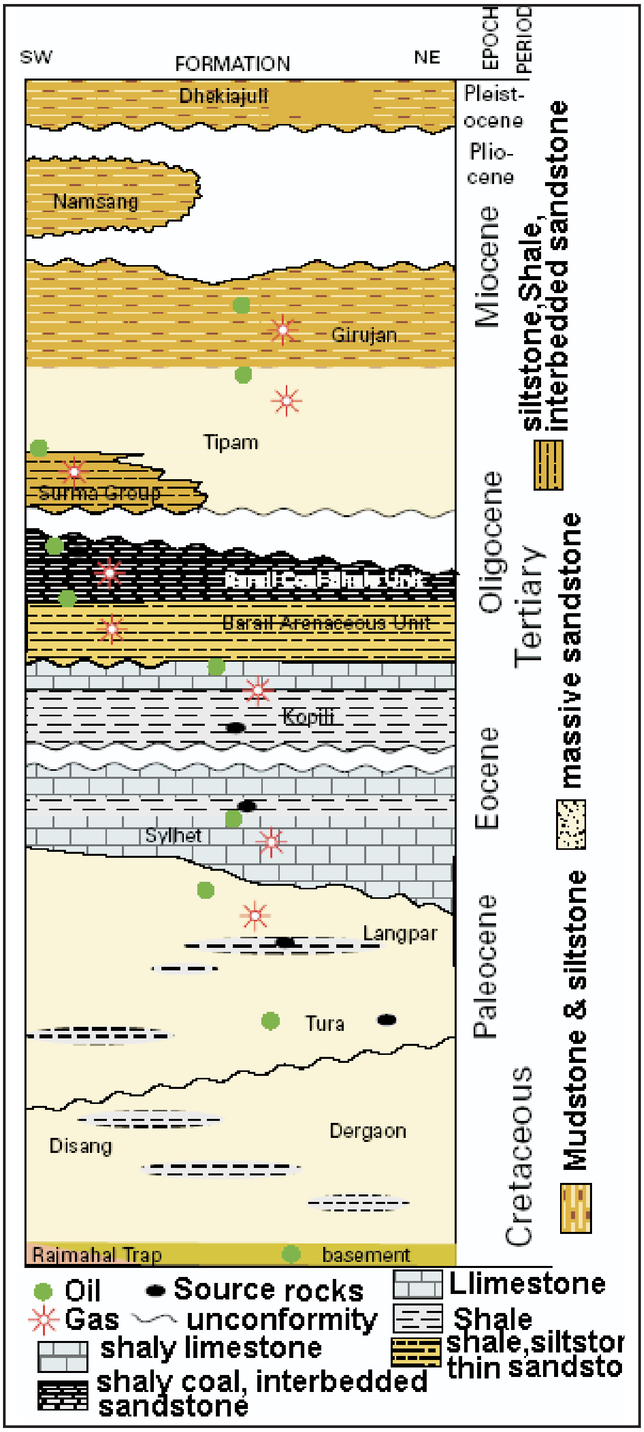

Fig. 2. Generlised Startigraphy

occurred north of the Dukai fault (Fig. 1); many basement faults were reactivated; and many basement-controlled structures became prominent (Naidu and Panda, 1997). Late Miocene through Pliocene extensive alluvial deposition followed Oligocene uplift and erosion. The general stratigraphy and generalized northeast –southwest (NE-SW) cross section (line A-A‘, Fig. 1) showing development of Assam Shelf are shown in Fig. 2 and 3 respectively.

Samples and Methods

Seismic and well log data have been used for

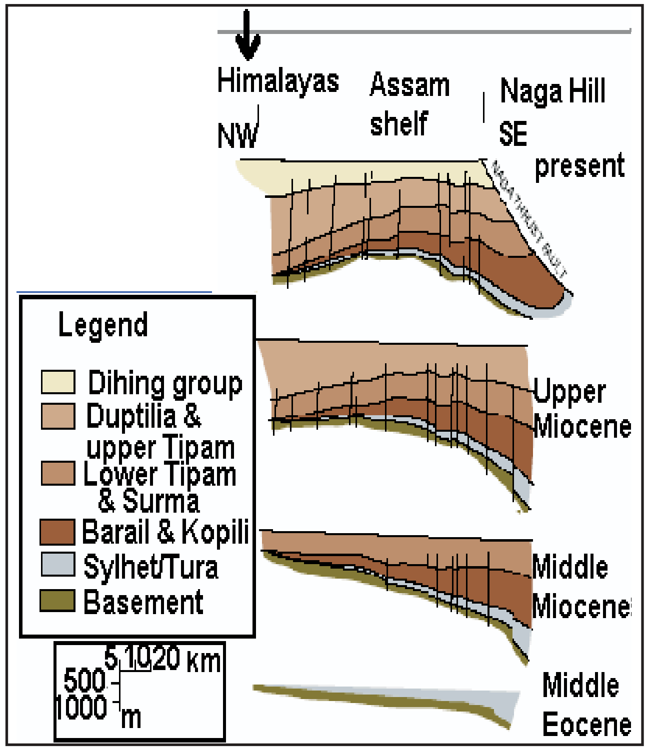

Fig. 3. Development of Assam Basin

identification of sequence boundary, reservoir, seal, traps and migration. Source Rock screening data of 106 wells has been used for identification of hydrocarbon generating centers. TOC and Rock Eval analyses were carried out using a LECO analyser and a Rock Eval II respectively using standard methods (Peters, 1986). A Leitz MPV3 microscope was employed for vitrinite reflectance measurements (Stach, 1982). Bitumen extraction from ground whole rock was carried out using chloroform. Gas chromatographic analyses were carried out on OV-1 (25mm x 0.32mm) column. GC-MSD analysis was carried out with GC-6890 and MSD597. Carbon isotopic analysis was carried out on VGSRA-II ratio recording Mass spectrometer. Genex software has been used for maturity and hydrocarbon generation modeling. Compositional, Biomarker and isotopic data of 12 oil and 67 sediment samples has been used for oil grouping and oil to source correlation.

Source Rocks

The Gondwana graben fill sequence has a limited aerial extent and with sedimentary thickness varying from 400-500m. There is no source rock potential in this sequence based on available data. The Rift fill sequences of early Cretaceous have limited data with good quality, immature to marginally mature organic matter in wells J-1, F-2 and EL-1 with source potential (TOC: 1.61 to 7.3, S2: 2.5 to 29.68) but does not establish source rock in this sequence regionally. The sediments within Tura and Sylhet possess fair to good mature source rock characteristics. Kopili sediments also possess fair to good source rock characteristics and are marginally mature. Fig. 4 shows a geochemical log from selected wells of Upper Assam shelf. The Barail sediments are found to be highly organic rich among all the sequences

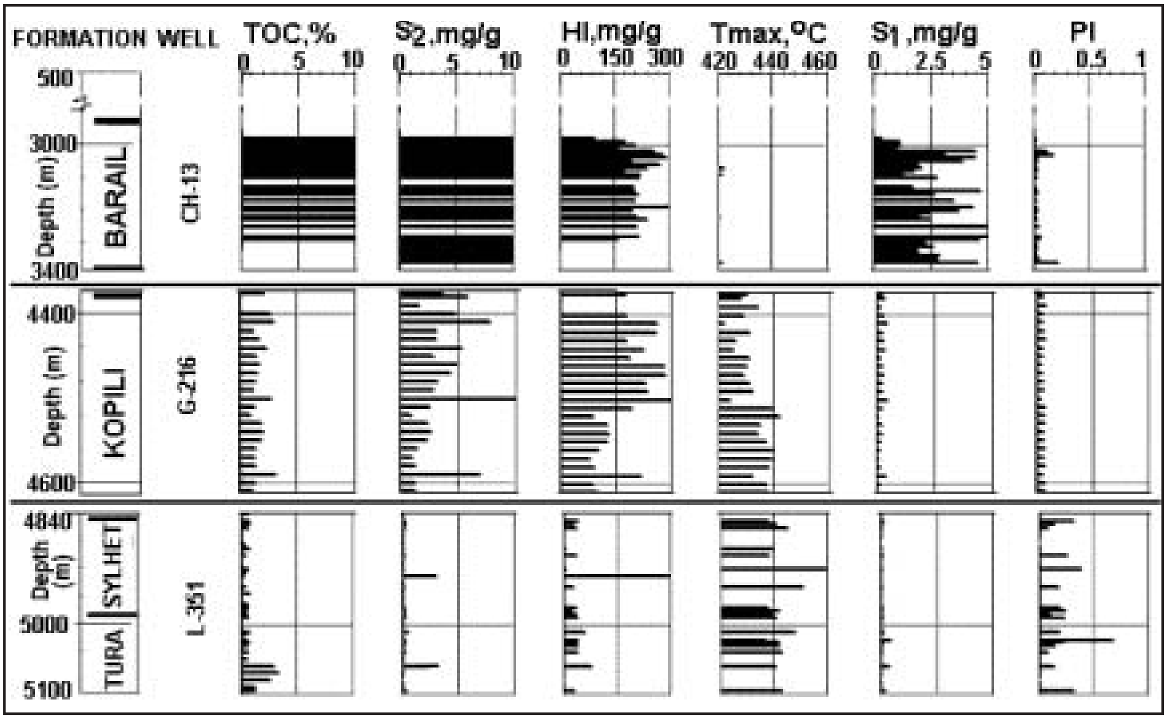

Fig. 4. Geochemical log from selected wells of upper Assam shelf

but immature, as indicated by conventional maturity parameters like vitrinite reflectance (VRo), Rock Eval Tmax, biomarker ratios and production index (PI) values in shelf area. Southern parts of upper Assam Shelf do not have high organic richness as compare to north in all sequences. Source rocks within these sediments contain types II and III Kerogen. Kopili sediments possess poor to fair oil-prone OM in Lakwa-Sonari area and good to very good oil-prone layers in Geleki area. In Barail sequence organic-rich layers are more abundant in Lakwa-Sonari and Rudrasagar-charali-Demulgaon area as compared to Geleki-Nazira low.

Reservoir Rocks, Seals, Traps and Migration

The graben fill sequences of early Permian age form good reservoir facies but no hydrocarbon occurrences are seen. Thin reservoirs are embedded within early cretaceous shales, show presence of hydrocarbons in the wells Der-1 and EL-1. Due to the proximity of fractured basement rocks to the source rocks of Paleocene-Oligocene sequences in the sub thrust area, the fractures formed an ideal reservoir. Reservoir rocks also include the Sylhet Formation limestones, Kopili Formation interbedded sandstones, Tura (basal) marine sandstones and Surma Group alluvial sandstone reservoirs in the upper Assam Shelf. The most productive reservoirs are the Barail main pay sands and the Tipam Group massive sandstones. Channel sands within upper Tipam and Girujan have minor gas accumulations in North Assam shelf and South Assam shelf respectively. The seals are available as shelfal shales near the flooding surfaces at both the beginning and close of RST and TST cycles from Paleocene to Lower Oligocene. The shales within Oligocene fluvial and marshy flood plains provide the good seals to the constrained channels present in the inter distributory area. In Bokabil sequence of the foreland system in south Assam shelf seal is provided by the transgressive shales which encase the relict features, retrogradational sands and tide/ storm derived sands. Seals also include Miocene shales and clays in North Assam shelf. The thick clays of the Pliocene Gurjan Group provide the regional seal and is present in most part of the Assam shelf. Thus the Girujan acts as the regional seal in North Assam shelf area and Bokabil acts as regional cap in the South Assam shelf areas and most of the commercial hydrocarbon occurrences are seen below these sequences.

Anticlines and faulted anticlinal structures, subparal-lel to and associated with the northeast-trending Naga thrust fault, are the primary traps. Subthrust traps are probably present below the Naga thrust sheet. Two major tectonic grains are imprinted on the Assam shelf. NE-SW is the older grain where as east north east- west south west (ENE-WSW) is the younger one. These trends have been reactivated during foreland tectonic phase. ENE-WSW fault show differentiation as well as strike slips movement. The basement inversions in north Assam shelf and south Assam shelf started forming subsequent to Tipam deposition. The major trap formation has happened during the close of Girujan deposition nearly 1.8Ma. During this time differentiation and sinistral movement across Jorhat fault detached the Mikir forebulge separating north and south Assam shelf. Thereafter north and south Assam behaved differently across Jorhat fault during the superposing phase of the Himalayan foreland. In north Assam, the slope reverses to NW, which is a causative factor for basement arching, where as in south Assam Mikir upliftment continued causing differentiation across most of the faults dividing the area into fault blocks. The compensating antithetic fault along major faults provided

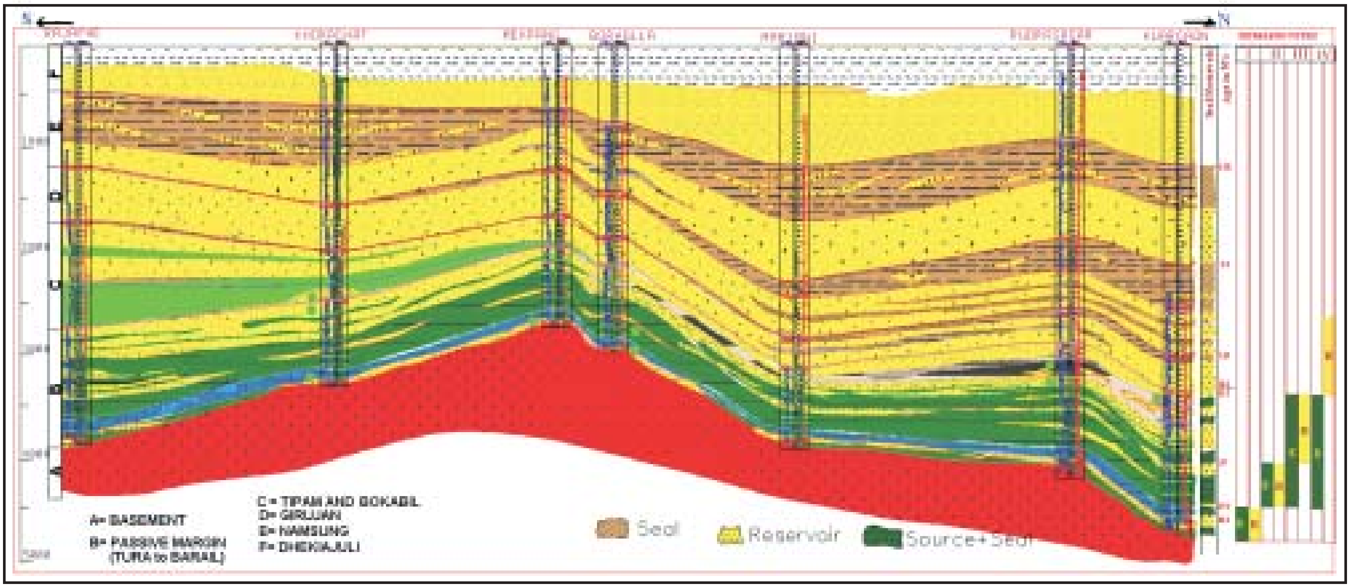

Fig. 5. Geological cross section across upper Assam shelf showing source, reservoir, seal, trap and existing petroleum system

trapping mechanism. Some of these major faults have acted as conduits for the vertical migration.

Early Eocene shales and Paleocene-early Eocene sands are likely to have formed the seal-reservoir 'doublets' for long distance lateral migration of Paleocene - early Eocene oils. Shore face sands within Barail main sand (BMS), are likely to have acted as carrier beds for lateral migration of oils generated in the Schuppen belt areas. Vertical migration is envisaged along the NE-SW trending faults and ENE-WSW cross trends. Reactivation of structures and developing folds in the foreland possibly created impedance to lateral migration from the Schuppen Belt since Pleistocene. The geological cross sections constructed along the strike from Kuargaon to Rajaphe show a distribution of reservoir, seal and source facies present in the Assam shelf area (Fig. 5).

Maturity and hydrocarbon generation

Thermal maturity values range from Ro 0.5 to 0.62 percent in both the Sylhet/Tura and Kopili Formations. Maturity is expected to increase with depth to the southeast toward the Naga thrust fault and be even higher in the sub thrust. In Barail Group, source rock maturities are generally low, varying from Ro 0.4 to 0.5 percent. It is quite likely that the vitrinite reflectance values might have been suppressed due to presence of hydrogen rich organic matter. Maturity and hydrocarbon generation modeling was done at three pseudo locations (PSW-2, PSW-4 and PSW-6). Burial diagram and maturity window of these locations are shown in Fig. 6. In PSW-2 location in Schuppen Belt, bottom of Barail coal shale (BCS)/top of BMS and Kopili sediments are in peak oil zone (≥ 0.7% VRo) since 2 and 4 Ma respectively, whereas top of Sylhet and Tura sediments has attained condensate and wet gas zone maturity (≥ 1.3%VRo) recently. Top of BMS, Kopili, Sylhet and Tura sediments in this location has attained 0.5%VRo at 5, 26, 27 and 28 Ma respectively. In Nazira low (PSW-4), BMS sediments are in oil zone (≥ 0.5%, <0.7% VRo) since 1-2 Ma and Kopili, Sylhet and Tura sediments are in peak oil generation zone (≥ 0.7%VRo) since 2 Ma. In this location, top of Tura, Sylhet and Kopili has attained 0.5%VRo at 22, 17 and 4 Ma respectively. In Dimapur low (PSW-3), top of BMS, Kopili Sylhet sediments are in oil zone (≥ 0.5%, <0.7% VRo) since 12, 8 and 5 Ma respectively and Tura sediments are in peak oil generation zone (≥ 0.7%VRo) recently.

Grouping of oil and gas and their source correlation

Assam oils are normal gravity (range: 15-58°API, av. 300) with significant wax content (0.11-22%, av. 11.5%), low sulphur content and are generally moderately mature. Based on bulk geochemical characteristics the Assam oils are characterized to be of two major groups, (i) naphthenic-aromatic and (ii) paraffinic. The former have 15-320 API gravity owing to their coal source while the latter group of 30-580 API. Mainly two types of n-Alkane distribution pattern are found in oils of Assam shelf. One is typical of higher plant lipids and cuticular waxes with the presence of high concentration of hydrocarbons in C23 to C35 range. Contribution from algal and marine precursors is manifested in bimodal distribution giving maxima around C19 and C29 in another one. This pattern is observed in majority of oils. Biodegradation of various degrees is observed by partial or total removal of n-alkanes in some of the oils of north Assam shelf. Pr/Ph ratios in the studied oils are generally greater than 3.0 varying from 2.3- 7.5 indicating thereby terrestrial influence with rather oxidizing environment. In Borholla-Chanpang and Khoraghat-Tenephy areas, the Eocene and fractured basement oils have the typical terrestrial pattern and seem to be similar except Bokabil oils. In the northern part of upper assam shelf - around Nazira low and adjoing area many oils do not have n-alkane beyond C25. Although

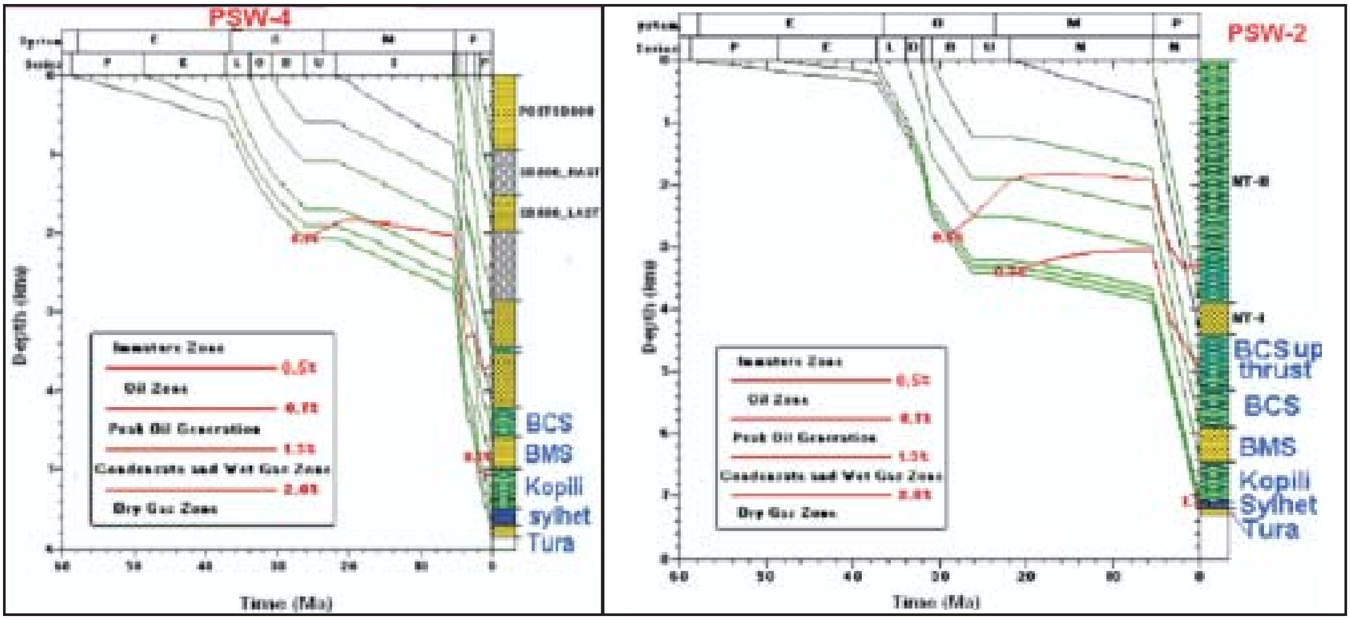

Fig. 6. Subsidence diagram and maturity window at location Nazira low (PSW-4) and Schuppen belt (PSW-6)

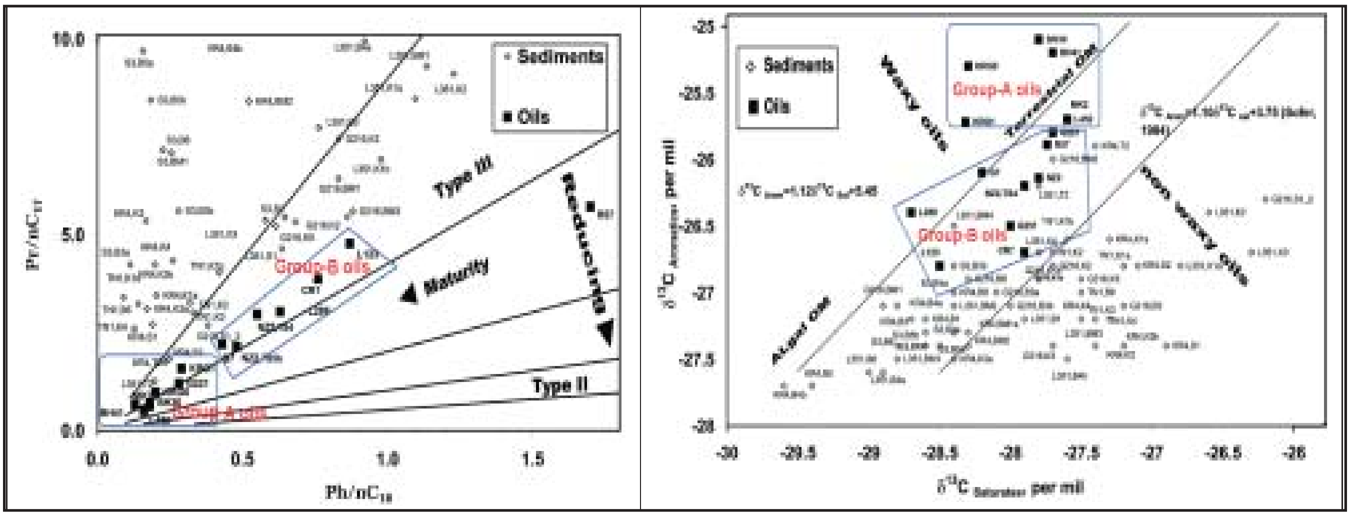

Fig. 7. Cross plot of Pr/nC17 vs Ph/nC18 and 13Csat vs 13Carom showing two oil groups

having similar Pr/Ph values as the typical oils, these oils have Cmax at C15, C17, C19, or C23 indicating either effect of maturity or marine OM input. Biomarker data indicate that oils in the Barail, Kopili and Tipam reservoirs are genetically correlated across the Lakwa, Geleki, Rudrasagar, Safrai and Charali fields. However, sylhet oils of Panidihing area and the Tura oil of L-452 are distinctly different and do not correlate to other oils in this area. Various cross plot for Assam oils (Fig. 7 and 8) shows Late Eocene oils of Borholla-Chanpang, Sylhet, Tura and Fractured basement oils form one group and Kopili oil of north Assam shelf, Barail, Tipam and Bokabil oils form another group. Oil group marked A have typical terrestrial OM n-alkane signature with C33 or higher n-alkane present and Cmax at C25 or more. The group B oils, on the other hand, have n-alkane pattern suggesting mixed OM input. Terrestrial OM input in the crudes is evidenced by the presence of oleanane and bicadinanes in all the samples studied. n- alkane distribution , sterane and triterpane fingerprints for two oil groups are shown in Fig.9. Oil-source correlation study shows that group A oils predominantly correlate to very few source rocks of Sylhet-Tura and group B to Kopili-Barail source rocks– dominated by mixed organic matter.

The study of Asaam gases reveals that they are of thermogenic origin and generated from a source within oil window. Gases are generally enriched in C2+ hydrocarbons, suggesting association with liquid hydrocarbons. Gases from Kopili, Barail and Tipam reservoirs from Lakwa, Geleki, Demulgaon, Changmaigaon, and Banmali fields are genetically related and have been generated from a source of low to moderate maturity (methane δ^{13}c, -45.0 to -48.0 $^{0}/_{00}$). Mixing of bacterial gas is prevalent in Rudrasagar, Safrai, Charali and Amguri fields (methane δ^{13}C in Rudrasagar ranging from -59.4 to -52.4 $\%_0$). Lighter ethane isotope compositions in many

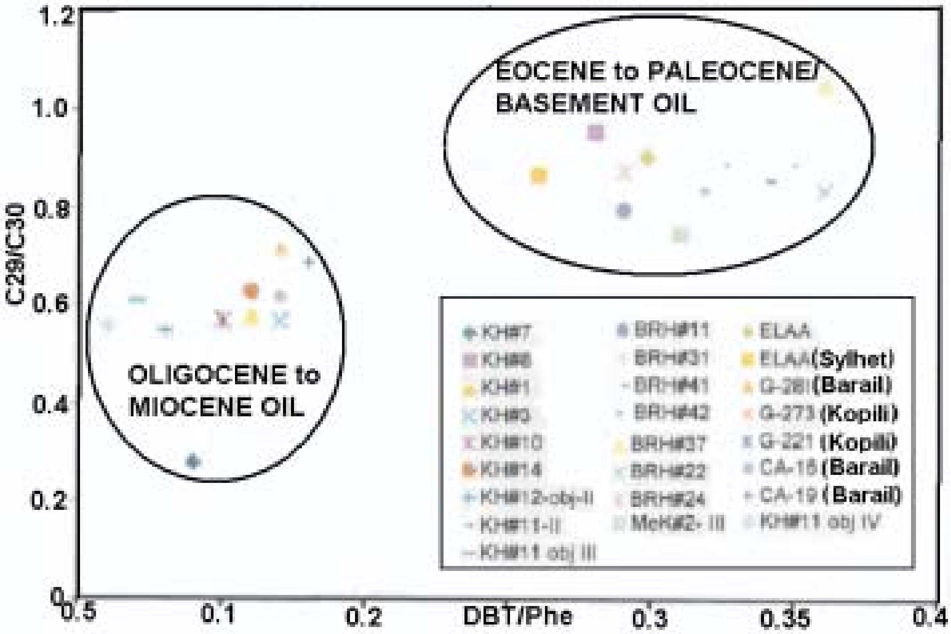

Fig. 8. Cross plot of DBT/Phe vs C29/C30 showing two oil groups

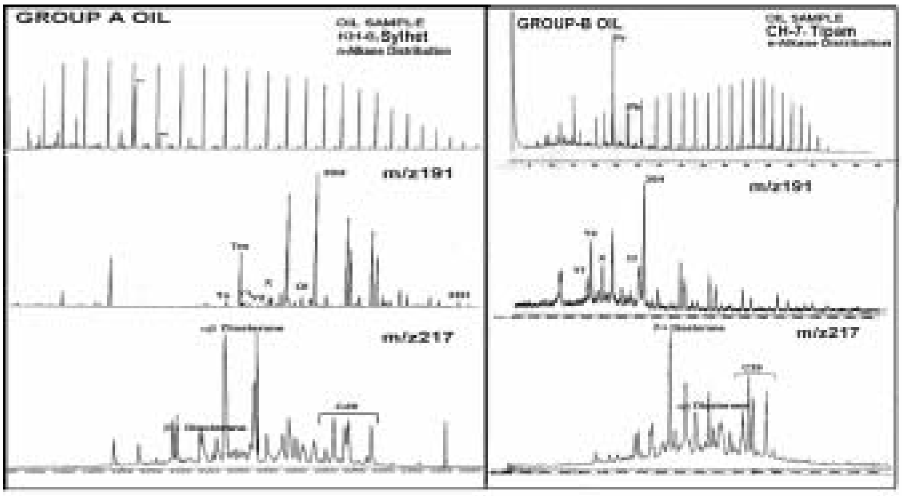

Fig. 9. n- alkane distribution, sterane and triterpane fingerprints for two oil groups

gases from Rudrasagar field point towards contribution from local immature/early mature sources in this area. Gases from Borholla- Changpang and Khoraghat field in South Assam Shelf, on the other hand exhibit much heavier methane isotopic compositions (δ^{13}C methane (-36.0 to -38.0 $\%_0$) suggesting a more mature source different from the gases of Lakwa, Geleki and Rudrasagar fields of Upper Assam Basin. The Bokabil gases in Khoraghat and Nambar area in South Assam Shelf, however, are similar to Kopili, Barail and Tipam reservoir gases from Upper Assam Valley fields and suggest generation from a similar source at lower maturity. Fig.10 shows gas grouping of Assam. of ONGC. Upper and lower Tipam sands contribute 69% of oils produced by ONGC from Assam and Arakan Basin and Barail Formation adds another 30%. Thus Tipam and Barail together account for 99% of the production. Commercial hydrocarbons are also known from Kopili and Sylhet Formations of Eocene age and fractured basement, but they constitute only 1% of total production. Most hydrocarbon production is northwest of, and parallel to, the Naga thrust fault. Oil seeps are also reported in the Schuppen Belt area. Mainly two PS have been identified in the Assam shelf area: (I). Paleocene to Middle Eocene- Paleocene to Middle Eocene (!) and (II). Late Eocene to Oligocene – Oligocene (!).

Each PS further consists of number of assessment units (AU) defining sub-systems operating in the basin. The Paleocene to Middle Eocene- Paleocene to Middle Eocene (!) PS consists of following sub-systems: (I A). Paleocene to Middle Eocene– Fractured Basement (!), (I B). Paleocene to Middle Eocene – Paleocene to Middle Eocene (!), (I C). Paleocene to Middle Eocene – Late Eocene (!), and I D. Paleocene to Middle Eocene – Late Pliocene to Pliestocene (!). Another PS Late Eocene to Oligocene - Oligocene (!) consists of following sub-systems: (II A). Late Eocene to Oligocene – Late Eocene (!), (II B). Late Eocene to Oligocene – Oligocene (!), (II C). Late Eocene to

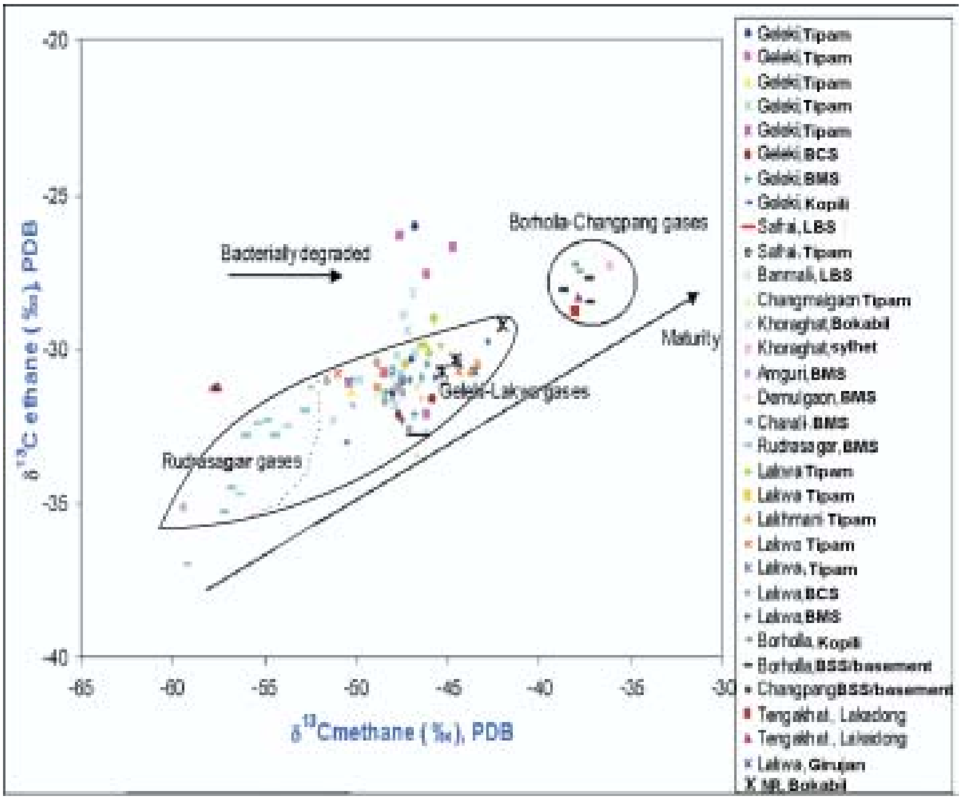

Fig. 10. Cross plot of 13Cmethane (0/00), PDB vs 13Cethane (0/00), PDB showing gas grouping of Assam

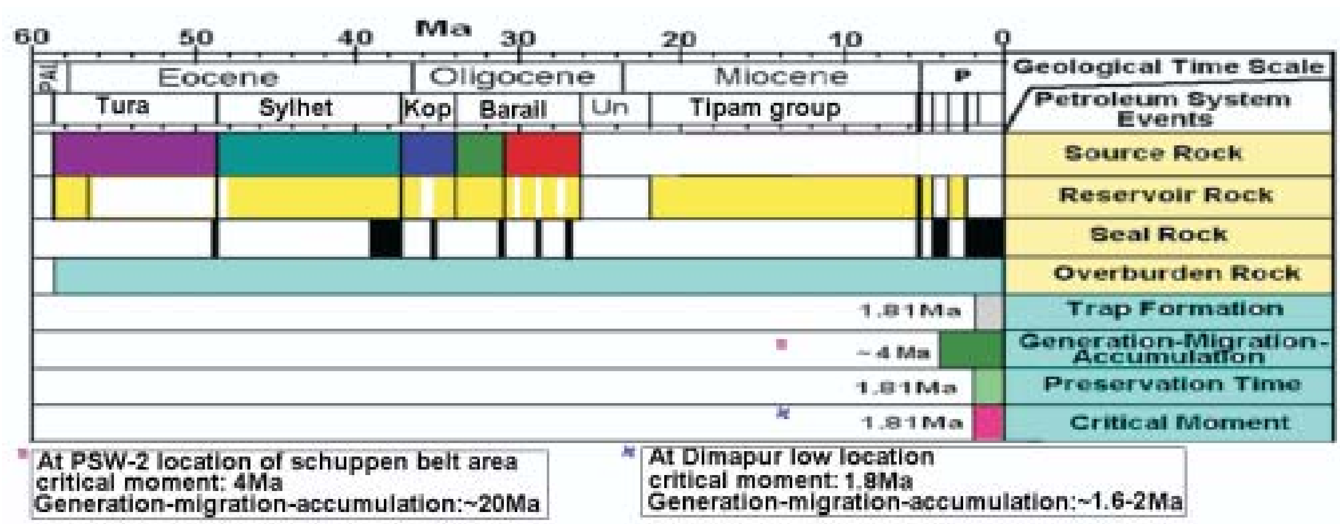

Fig. 11. Event charts for petroleum system in Nazira low of Assam shelf

Oligocene – Early to Middle Miocene (!), (II D). Late Eocene to Oligocene – Late Miocene (!), (II E). Late Eocene to Oligocene – Early Pliocene (!) and (II F). Late Eocene to Oligocene – Early Pliocene (!). The events chart for petroleum system is shown in Fig. 11.

Conclusions and Exploration Implications

All essential petroleum system elements and processes have resulted in prolific upper Assam shelf. These include the following:

- Excellent source rocks in Barail. Although immature in shelf area but likely to be matured in Schuppen Belt.
- Moderately mature to mature Sylhet/Tura sediments have fair source rock characteristics whereas moderately mature Kopili sediments have fair to good source rock characteristics.
- Excellent reservoir rocks include the Barail main pay sands and the Tipam Group massive sandstones beside the Sylhet limestones, Kopili interbedded sandstones, Tura and Langpar (basal) marine sandstones.

- Effective seals include interbedded Oligocene and Miocene shales and clays, and the thick clays of the Pliocene Gurjan Group.
- Anticlines and faulted anticlinal structures subparal-lel to and associated with the northeast-trending Naga thrust fault, are the primary traps. Subthrust traps are probably present below the Naga thrust sheet. The major trap formation has happened during the close of Girujan deposition nearly 1.8Ma.
- The compensating antithetic fault along major faults provided trapping mechanism. Some of these major faults have acted as conduits for the vertical migration. Shore face sands within BMS, are likely to have acted as carrier beds for lateral migration of oils.
- Critical moment for hydrocarbon accumulation is 1.8Ma.

Because of fair organic richness and immature source rocks in the foreland and only moderate maturity in the frontal belt, hydrocarbon charge to the traps in the foreland has been limited. Impedance to lateral migration due to development of folds during Pleistocene to Recent time are other detrimental factor for hydrocarbon charging from Schuppen Belt. Best targets for future exploration are fault blocks NW of Nazira low and the crestal highs for structural play in Tura-Sylhet sequence, Geleki structure for Basal clastics and fractured basement and retrogradational HST sands in Khoraghat to Mekrang for stratigraphic play in Bokabil sequence.

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Points-to-Ponder

In this forum we invite authors to submit thought provoking questions which have short answers and which bring out some important issues in the theory or practice of exploration geophysics. The questions should be submitted, preferably, along with their answers; however, that is not mandatory and the editorial board will make efforts to find correct answers. Selected questions will be published with their answers.

Q : **How does NMO stretch affect seismic data and how can one minimize it?**

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Answers on page 45