PAPER ID: 2012014

A Relook into the Tectono-Sedimentation Model and Hydrocarbon Prospectivity of Andaman Basin

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Abstract

Andaman Basin is a frontier area for hydrocarbon exploration yet it is interesting due to its proximity to mature hydrocarbon provinces in the region viz. North Sumatra, Mergui and Irrawaddy. In last ten years basin has witnessed increased exploration activities by various operators. Since 2011, ONGC has drilled seven deepwater wells and acquired additional seismic data in the area. The present study aimed at refinement of tectono-sedimentation model and evaluation of hydrocarbon prospectivity of the basin in the light of new data.

A regional tectono-sedimentation model of the Andaman Sea region has been presented to understand sedimentation pattern in the Andaman forearc and backarc areas. The study brings out that Cretaceous to Early Paleogene sedimentation in the outer high and forearc areas took place in deepwater, open marine condition which is unfavorable for preservation of organic matter. Source rock studies also suggest that Eocene and older sediments, in general, have marginal organic matter richness. Neogene sedimentation in the forearc took place in somewhat restricted environment due to the rise of Andaman Islands and volcanic arc by this time. As a result, Neogene sediments have better organic matter richness. In one of the deepwater wells drilled in the forearc, TOC of Late Miocene sediment was reported to be in the range of 4.3%. But the sediments are immature due to low heat flow in the region because of the presence of accreted crust. Paucity of reservoir is another constraint in the area as sedimentation mainly took place in deepwater setting.

The study brought out that the East Andaman Basin in the backarc is time equivalent of nearby North Sumatra and Mergui Basins and exhibits similarity in basin evolution and tectono-stratigraphy. These basins opened during Eocene to Early Oligocene and display syn-rift, early post-rift and late post-rift sedimentation. The syn-rift is characterized by fluvio-lacustrine/fluvio-marine sedimentation, early post-rift (Late Oligocene to Early Miocene) by shallow marine/shelfal and the late post-rift phase (Late Miocene to Recent) is represented by deepwater sedimentation. In the northern part of the backarc, Paleogene sediments appear interesting as per the sedimentological data of a well drilled in the area and in view of the high geothermal gradient recorded in the drilled section.

The study suggests that East Andaman Basin, situated between Sewell Rise and Mergui Ridge, could be the potential area for future exploration because a probable petroleum system in rift-related play model like North Sumatra is expected in this part of the basin. In addition to this, Paleogene prospects in the northern part of backarc may also be interesting for exploration.

Key words: Forearc, Backarc, East Andaman Basin, Central Andaman Basin

1. Introduction

Andaman Basin is located in the southeastern part of the Bay of Bengal (Fig.1) and forms a part of Island Arc System which extends from Myanmar in the north to Indonesia in the south. From hydrocarbon exploration point of view, the Andaman Basin is a frontier area but the basin has always attracted focus due to its proximity to mature hydrocarbon provinces in the region viz. North Sumatra, Mergui and Irrawaddy. In last ten years, the basin has witnessed increased exploration activities by various operators viz. ONGC and ENI. Since 2011, ONGC has acquired additional seismic data and drilled seven deepwater wells, six in forearc and one in backarc. Present work aimed at bringing about refinement in the tectono-sedimentation model of the basin and analyzing its hydrocarbon prospectivity in the light of new data.

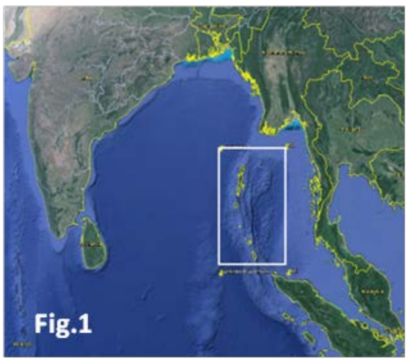
Fig.1

2. Regional geology and stratigraphy

The Andaman Basin has evolved through a complex history of tectonics associated with the convergent plate boundaries (Indian and Burmese Plates) since Cretaceous time. The basin is part of a large geotectonic unit which from west to east includes Andaman trench, outer high, forearc, volcanic arc and backarc.

The basin holds a thick succession of marine sediments (6000m+) from Late Cretaceous to Recent over a Cretaceous ophiolitic basement. The Paleogene and older sediments were deposited in the trench setting and as a result of subduction, they were folded and thrusted and plastered to the Burmese plate with ongoing subduction. The Andaman trench at the commencement of subduction was located at the present day forearc. Later on, with subsequent accretion it moved westwards. The Paleogene and older sequences were uplifted during Oligocene as Andaman and Nicobar Islands with prominent down faulting of the eastern margin to form forearc basin. Neogene sediments are relatively less disturbed and are characterized by shifting depocentres, wrench movements, episodic volcanism and shale diapirism (Roy and Sharma, 1993).

3. Data and Methodology

Increased exploration activities in the basin during last decade resulted in generation of a large volume of good quality seismic data. In the present work, all available 2D sections and some of the 3D sections have been used. Well data of seven deepwater wells (six in forearc and one in the backarc) drilled in the area in recent years have been incorporated. In addition to this, the biostrtigraphic and sedimentological data of recently drilled deepwater wells have also been integrated.

In the present work, a regional tectono-sedimentation model of the Andaman Sea region has been brought out in order to understand the sedimentation pattern in the Andaman Basin by synthesizing the results of south-east Asian tectonic reconstruction (Curray 2004), gravity, seismic, sedimentological, paleontological and source rock studies. Together with this, petroleum geology of the basin has been analyzed vis-a-vis analogue petroliferous basins of the region (i.e. North Sumatra and Irrawaddy) to understand its hydrocarbon prospectivity.

4. Tectono-sedimentation Model

The Andaman Basin evolved as a result of subduction of Indian plate below the south-east Asian plate. Subduction along the eastern Asian margin had started by Cretaceous time when the Gondwana continent was breaking up and India separated from Australia and Antarctica. Initial subduction took place at the site of present day forearc.

The North eastern corner of “Greater India” hit this subduction zone at about 59 ma (Paleocene soft collision) and Indian plate under-went some counter clockwise rotation from about 59 to 55 ma. During this time and until Early Pliocene (4 Ma) India was indenting the SE Asian margin and rotated the Sunda subduction zone in a clockwise direction. With this rotation the direction of convergence became increasingly more oblique which caused apparent increase in the rate of strike slip motion in the basin. As a consequence, the structural evolution of the Andaman Basin is quite complex with phases of extension, inversion and subsidence which controlled sedimentation pattern in the area. Broadly, five major tectono-sedimentation events can be recognized in the Andaman Sea region.

1. **Early Subduction Phase (Cretaceous to Early Eocene, 44 Ma): T**he eastern margin of the Andaman Sea region was probably in passive margin setting prior to the development of Sunda subduction zone. Sedimentation took place in inner shelf to upper bathyal conditions, SIBUMASU Blocks supplied sediments into the basin. Mergui Ridge acted as barrier that prevented sediment supply from Malay Peninsula and Sunda shelf to western part of the basin (Fig.2a).

   In the western margin, Cretaceous sediments have been reported in the outcrops in Andaman Islands as well as in three wells drilled in the outer forearc area. In the outcrop, they consist of pink coloured radiolarian cherts, red jasper and quartzitic and serpentinized marbles. Radiolarian cherts are generally associated with deep water sedimentation over trench. In one of the drilled wells, tectonic mélange has been identified in the cuttings and cores of the Cretaceous section. This chaotic rock mass is thought to have formed part of the sediments covering the initial Indian oceanic crust that got accreted to the SE- Asian plate on initial

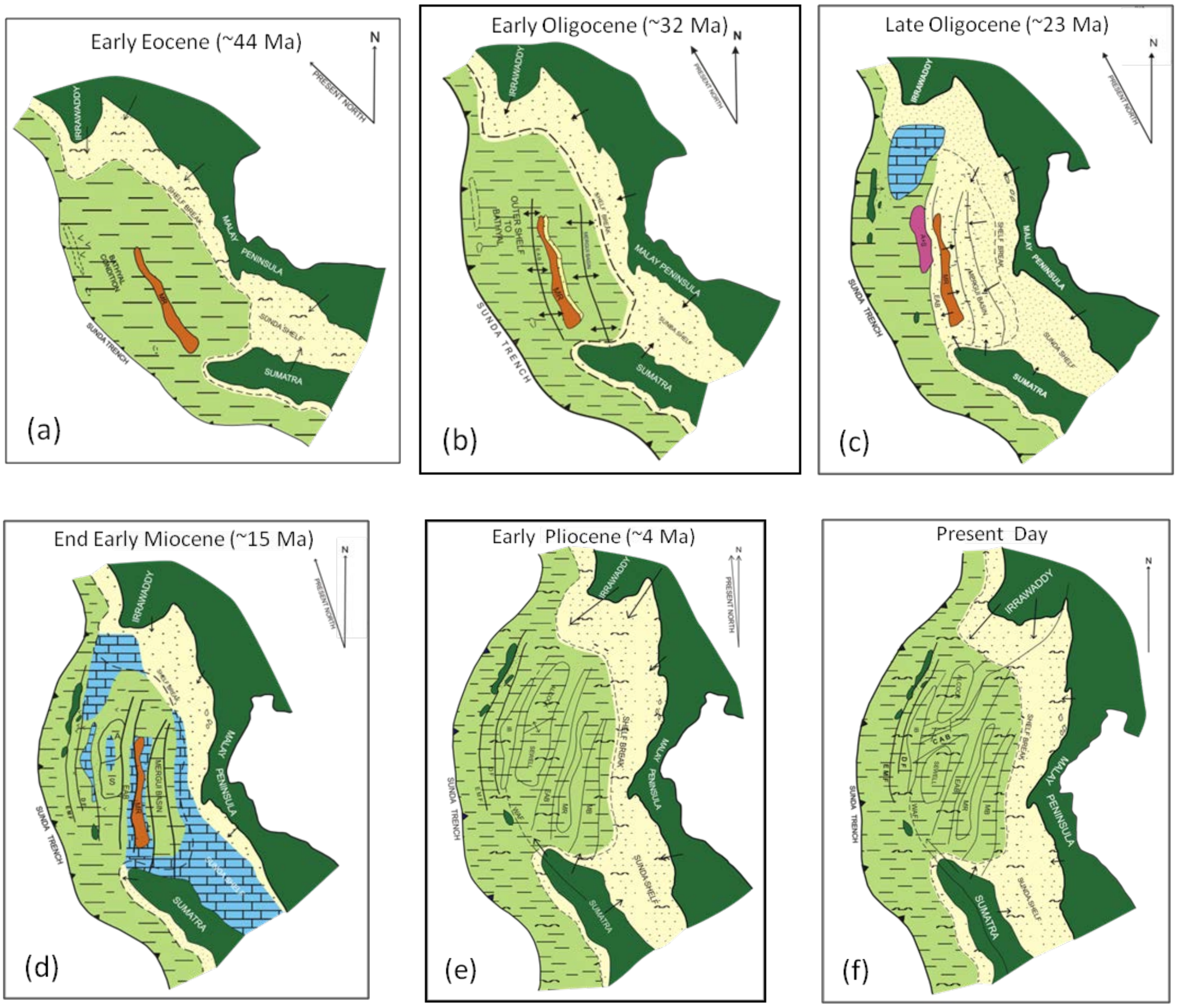

Fig. 2 (a - f): Tectono-sedimentation model from Early Eocene to Present Day. Abbreviations: MR-Mergui Ridge, EAB-East Andaman Basin, A+S-Conjoined Alcock and Sewell seamounts, EMF-Eastern Margin Fault, DF-Diligent Fault, A-Alcock, S-Sewell, IB-Invisible Bank, WAF- West Andaman Fault, MB-Mergui Basin, CAB-Central Andaman Basin.

subduction and formed fold packets. This type of mélange sequence is usually found only in subduction zones.

Paleocene and Eocene sediments have been reported in outcrops as well as in four wells drilled in the outer forearc. During this period, finer clastics deposited under bathyal conditions in open marine setting as per the sedimentological and paleontological studies.

Pre-rift passive margin phase of sedimentation is not reported in North Sumatra and Mergui basins as these basins opened during Late Eocene/ Oligocene period in response to the backarc extension.

2. **Backarc Extension Phase (Early Oligocene, 32 Ma):** Further subduction during Late Eocene/Early Oligocene time led to the rise of SE-Asian plate and shallowing of Andaman Sea resulting in deposition of shale, silt and sand under bathyal to outer shelf environment. In the east shelf progradation took place. Simultaneously, syn-sedimentary tectonics added new accretionary slices towards the westward shifting trench. Regional paleo-tectonic studies indicate sediment input from Sumatra and Malay Peninsula and overall deepening of the region towards Myanmar Central Basin.

   The Late Eocene–Early Oligocene backarc extension resulted in opening of intracratonic North Sumatra and Mergui Basins and peri-cratonic East Andaman Basin (Fig.2b). The Mergui Ridge acted as separator horst between intracratonic and peri-cratonic basins except in the northern and southern plunging edges where the basins were probably connected with each other (Jha et al., 2010).

3. **Andaman Rise Phase (Late Oligocene, 23 Ma):** During Late Oligocene, Andaman-Nicobar Islands rose above the sea level due to thrusting. Shallow water sand, silt and shale were deposited over Andaman Island areas; however bathyal claystone, silt and limestone were deposited in the forearc. Excessive sand input during Oligocene may be related to further rise of Asian plate and marine regression. Top of Oligocene is a regional unconformity, which suggests a large area surrounding Andaman-Nicobar and basin margin was aerially exposed. Rise of Andaman Island contributed coarser flysch sediments towards west and east. This phase also marks the initiation of carbonate deposition in the northern part of the forearc.

   In the North Sumatra and Mergui Basins sedimentation was typically marked by thick sand prone alluvial and fluvio- lacustrine deposits in the proximal setup with gradual fluvio-marine facies development towards the basinal areas. Andaman rise phase is also marked by initiation of emergence of conjoined Alcock and Sewell seamounts (Fig.2c).

4. **Forearc Extension Phase (End Early Miocene, 15 Ma):** During Early Miocene, thermal subsidence caused regional marine transgression which reduced clastic input in the Andaman Sea; this is evidenced by the widespread carbonate deposition on the structural highs and basin margins. The basinal areas were filled with mixed sediments viz. shale, mud, marl etc. (Fig.2d).

   Up-thrusting of Andaman Islands during Late Oligocene led to back thrust extension which caused major faulting to the east. East Andaman and Diligent Faults came into existence during this time. Down thrown side of these faults formed forearc basins which received reworked Andaman fan sediments and Neogene Irrawaddy fan sediments, inter-bedded with volcano-clasts and carbonate beds.

   Rise of volcanic/magmatic arc in the eastern part was another major event during this phase. This led to the exposure and erosion of older Paleogene section. The eroded sediments were deposited in the adjoining lows in forearc basins. As per the drilled well data, volcanic activities in the basin commenced around 23 Ma (Early Miocene) and culminated at 11.5 Ma (Mid-Miocene). Peak volcanic activity ranges from 21.8 to 17.6 Ma (Early Miocene).

5. **Backarc Spreading Phase (Early Pliocene, 4 Ma):** This phase is characterized by opening of Central Andaman Basin since 4 Ma (Fig.2e) which resulted in separation of Alcock and Sewell seamounts. The backarc spreading caused further deepening of Andaman Sea and renewal of clastics sedimentation all over the area (Fig.2f). Active delta progradation were again in place in Irrawaddy , North Sumatra and Mergui shelves bringing enough clastics from existing highs into the system. During this phase the main source of sediments in forearc and backarc basins was Irrawaddy delta.

5. Hydrocarbon Prospectivity:

Forearc: As per the tectono-sedimentation model, Cretaceous sediments are tectonic mélange in the forearc. Paleogene sequences were deposited in deep water open marine setting, unfavorable for preservation and development of source and reservoir facies. Geochemical data also indicates that organic matter richness is marginal in Cretaceous and Paleogene sediments. Neogene sequences may have good organic matter richness (as indicated by the source rock study of a deepwater well) because by that time somewhat restricted circulation had developed in the forearc particularly in the ponded low; but the maturity of the sediments is low as per available data.

Neogene sedimentation took place over an accreted crust which is a tectonic mélange of Cretaceous-Paleogene sediments and ophiolite. The heat flow in this type of crust is usually low. This is evidenced by low geothermal gradient observed in the wells drilled in the forearc as compared to the backarc well. This could be the reason for lower maturity of Neogene sediments in the forearc. In the eastern part of the ponded low, Neogene sediments may be relatively more mature because of higher heat flow from the volcanic arc.

The key issue in the forearc prospectivity is paucity of reservoir. As per the tectono-sedimentation model main source of sediments in forearc is Irrawaddy delta which mainly contributed finer clastics. The Early to Mid-Miocene carbonate build-ups may not be interesting in the area as they were never exposed to sub-aerial conditions for development of secondary porosity. In view of the above the hydrocarbon prospectivity of forearc appears to be marginal.

Backarc: As per the model the East Andaman Basin in the backarc, situated between Sewell rise and Mergui Ridge, is time equivalent of petroliferous North Sumatra and Mergui Basins. The basin exhibits similarity in basin evolution and tectono-stratigraphy. In the North Sumatra and Mergui Basins, the initial syn-rift fluvio-lacustrine and fluvio-marine sedimentation grades into shallow marine/shelfal in late syn-rift/ early post-rift then finally enters deepwater phase in the late post-rift (Jha et al.2010). Similar sedimentation pattern is seen in the East Andaman Basin (Fig.3).

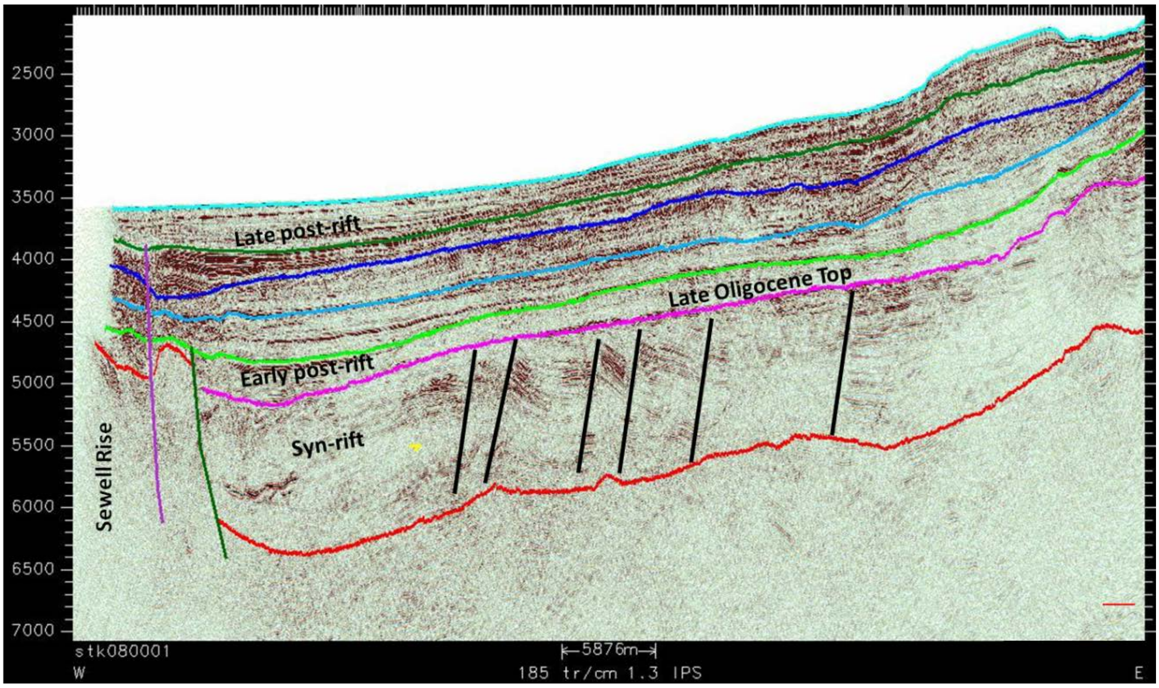

Fig.3: E-W line in the East Andaman Basin between Sewell Rise and Mergui Ridge showing syn-rift, early post-rift and late post-rift sequences.

In the northern part of the backarc Paleogene may be interesting as suggested by the data of a drilled well. The sedimentological studies of cores and cuttings of the well indicate good reservoir development and presence of organic matter in the probable Late Oligocene sequence (Fig.4a, 4b). The geothermal gradient is also high in this part of the basin. Considering these facts, the East Andaman Basin and northern part of the backarc could be the potential areas for future exploration.

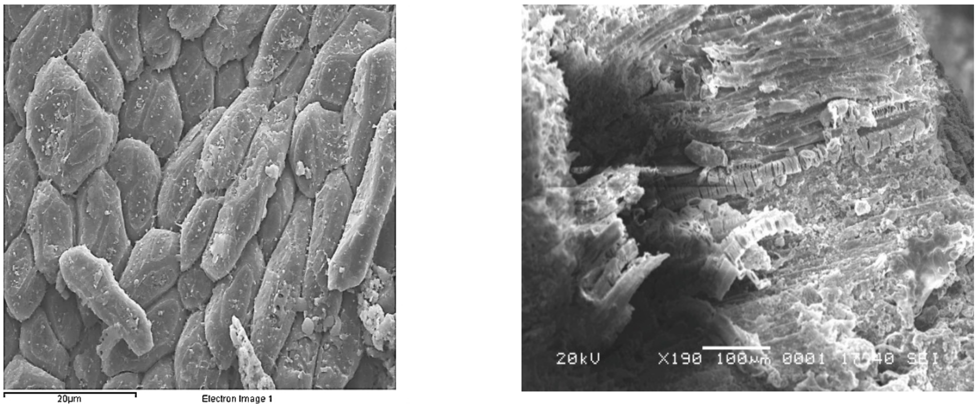

Fig.4 (a & b): SEM image showing kerogen/woody matter within probable Late Oligocene sequence.

6. Conclusions:

1. The study brings out that the hydrocarbon prospectivity of forearc and outer high is marginal. Cretaceous sediments in this part are mostly tectonic mélange and the Paleogene sequences were deposited in deep water open marine setting, unfavourable for preservation and development of source and reservoir facies.

2. Neogene sequences may have good organic matter richness in the forearc; but the maturity of the sediments is low due to low heat flow in the region because of the presence of accreted crust. Paucity of reservoir is another constraint in the area as sedimentation mainly took place in deepwater setting.

3. As per the tectono-sedimentation model, East Andaman Basin bordering Mergui Ridge in the backarc is time equivalent of nearby petroliferous North Sumatra and Mergui Basins. The basin exhibits similarity in basin evolution and tectono-stratigraphy. This area appears interesting for future exploration as a probable petroleum system in rift-related play model (like North Sumatra) is expected in this part of the basin.

4. In the northern part of the backarc, Paleogene targets may be promising as suggested by the data of a drilled well. The sedimentological studies of cores and cuttings of the well indicate good reservoir development and presence of organic matter in the probable Late Oligocene sequence.

Acknowledgements:

The authors would like to thank ONGC management for the permission to publish this paper. They are grateful to the colleagues at KDMIPE for useful discussions and comments.

The views expressed in the paper are solely of the authors and not necessarily of the organization to which they belong.

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