Scope of Future Exploration in Andaman Basin, Genetically Linked with Producing Provinces of South-East Asia.

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Summary
In Andaman Sea basin though gaseous hydrocarbon has flowed in two wells, one each in the fore arc and outer structural high (shallow water), commercial hydrocarbon pool is still eluding. Exploration for hydrocarbons in a basin is driven by understanding of its evolution through geological times and linked with its sedimentation history and tectonics. Newly acquired seismic data in Andaman back arc areas provided new insight in understanding. The tectonics and geological history of the Andaman Sea cannot be separated from the tectonics and geological histories of Myanmar (Burma) on the north, and Sumatra on the south. Hydrocarbon occurrences in the North Sumatra and Mergui Basins typically exhibit rift-related petroleum systems which are proven to be quite prolific in parts. Since the East Andaman Basin is a virgin exploration area with no well control, this paper looks at the possibilities of future exploration in the potential syn-rift sequence of Andaman back-arc setup, which is genetically linked with the producing Mergui and North Sumatra basin.

Introduction
The Andaman Sea Basin is still considered to be a frontier area with respect to hydrocarbon exploration due to paucity of drilled data, complex geology, remote location and operational constraints (water depth hovering around 2500m or more). 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 seemingly similar geological setup. In last ten years, a lot of work has been done to understand the tectono-sedimentation model, sequence stratigraphy, petroleum system and hydrocarbon potential of the basin. Since 2011, additional seismic data has been acquired in the NELP Blocks and seven deepwater wells have been drilled, six in forearc and one in backarc. Andaman basin extends from Myanmar in the north to Sumatra, Indonesia in the south and from Thailand and Malaysia in the east to Andaman and Nicobar group of Islands in the west (Fig-1). Tertiary sediments are exposed on the Andaman-Nicobar Islands and preserve a record of the tectonic evolution of the Basin as a whole including the evolution and closure of the Tethys Ocean.

However, main Andaman Basin is a North-South elongated depression narrowing to the south against the tip of Sumatra Pluton—an elevated Paleozoic-Mesozoic arc massif. The basin is surrounded by prolific hydrocarbon producing fields like North Sumatra Basin towards south, Mergui Basin in the east and Moattamma/Irrawaddy-Delta in the north (Fig-1). The basin is segmented into many sub basins due to presence of several prominent morpho-tectonic elements. In a west to east transect, the main tectonic zones are the subduction zone i.e. trench, the Accretionary complex, forearc subbasin, magmatic/volcanic arc, Central Andaman sub Basin (CAB) and the back arc basin (Fig-2). The Andaman basin has two major depo-centres. One is in the fore-arc ponded low part and another is in the main back arc part. There are two volcanic Seamounts namely Alcock and Sewell within the back-arc basin and that were probably segmented later. East Andaman Basin in the backarc, bordering Mergui Ridge is time equivalent of nearby petroliferous North Sumatra and Mergui Basins and exhibits similarity in basin evolution and tectono-stratigraphy. A probable petroleum system in rift-related play model (like North Sumatra) is expected in the East Andaman Basin.
Regional tectono-sedimentation model of Forearc suggests that Cretaceous to Early Paleogene sedimentation took place in deepwater open marine condition, which is unfavorable for preservation of organic matter. Another key issue in the forearc prospectivity is paucity of reservoir. As per the sedimentation model main source of sediments in forearc is Irrawaddy delta which mainly contributed finer clastics. However, clastic input in forearc has also been provided by Andaman Island itself (Andaman flysch). Hence it is likely to have reservoirs close to and all along the eastern Margin of the Andaman Islands. Therefore, exploration for Neogene reservoir and suitable entrapment close to the island may be thought of. Drilled result show that the early post-rift (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, contrary to the Yadana field of Myanmar (Fig.3).

Analogous Prospectivity comparisons with adjoining producing Fields of Asia/South East Asia

Fore Arc Prospectivity:

![Tectonic map of Andaman Basin showing different tectonic elements with study area.](image)

![Carbonate build-ups drilled in Fore-Arc Basin without any hydrocarbon show in tight lime stones of Miocene age. The bottom section shows the analogous Multi TCF Yadana Field of Myanmar producing from carbonate platform.](image)
The identification of suitable reservoir facies remained the main emphasis of carrying out exploratory activities in fore arc setup. But so far our exploration has been restricted only up to upper part of Neogene. Petroleum system analysis on the basis of 2D modeling also suggests the presence of the thermogenic petroleum system in the fore arc basin in the deepest part of the fore arc i.e in the ponded lows (Fig.6). Prospective structural and stratigraphic plays within these ponded lows at a comparatively deeper stratigraphic level than the already drilled plays at shallow level are the potential targets for future exploration.

Back Arc Prospectivity:

Back Arc of East Andaman Basin is time equivalent of nearby petroliferous North Sumatra and Mergui Basins and exhibits similarity in basin evolution and tectono-stratigraphy. Although the available geoscientific data of northern part of Andaman Sea does not show any pronounced rift related play, but drilled well in the northern part of back arc can be compared with the adjacent Shwepyithy gas field of Myanmar located in Andaman Sea. The objective of the drilled well was to probe the Miocene targets characterized by strong seismic amplitudes along with clear inversion features. But due to very high bottom hole temperature (indicating high geothermal gradient) identified objects could not be tested. Hydrocarbon show (MLU gas data) was observed at places during drilling, and considerable clastic facies have been encountered (Fig.7).

In Myanmar offshore of Andaman Sea, the multi-TCF gas fields of Yadana in a limestone reservoir and Yetagun in a deltaic sand reservoir are two mature hydrocarbon
provinces. These trends can be extrapolated into backarc Andaman region because of the similar geological setup. G & G analysis shows that thicker sedimentary sequence is present in the deeper parts of back-arc sub-basin which might have acted as source for effective hydrocarbon generation analogous to nearby Myanmar basin (Fig.8). The seismic data reveals a thick Cenozoic rift package within the Central Andaman Basin which will have implications on basin modeling and direct impact on the petroleum systems of the deep water Myanmar and Indian-Andaman blocks (Fig.8B). Petroleum system analysis based on 2D modelling also suggests presence of major thermogenic, induced thermogenic system in back arc region. Because, in island arc tectonic setup like Andaman Sea, high geothermal gradient (Fig.9B) with high heat flow regime is prevalent in back arc region due to its proximity to spreading centre. This kind of set up is responsible for enhanced maturation (Fig.9A) and in turn hydrocarbon generation. Exploration history of adjoining producing basins in Myanmar and North Sumatra basin of Indonesia has indicated the fact.

Fig.8 (A) Structural cross section from Yadana field to Yetagun field of Myanmar. The huge low in between the two fields is the kitchen area for both the producing fields. (B)Thick sediment-filled (> 4 Km) graben shows the similar setup in Andaman back arc basin which is expected to be the source pod.

In the southern part of Andaman, recent G & G interpreted seismic data revealed the presence of a completely unexplored rift set-up, similar to the nearby North Sumatra and Mergui rift basins situated on the eastern side of Mergui Ridge (Fig.10). Therefore, a probable petroleum system in rift-related play model (like Mergui & North Sumatra) is expected in the East Andaman Basin, where early synrift sequences of lacustrine to marine shales provide the source.

Fig.10 Regional Section through East Andaman and Mergui Basin clearly depicts presence of Syn-rift play in East Andaman basin genetically related with Mergui basin.
Due to greater depth of burial and proximity to the volcanic arc and spreading center the area will have better thermal regime favouring maturity compared to Mergui basin. Fluvial coarser clastics within early synrift phase and basin margin deltas of late synrift phase provide the reservoirs. Transgressive shales of late synrift/early postrift phase are acting as regional seal (Fig.11).

In addition, volcanic activities in Paleogene time supplied additional heat in the basin. In the southern part, Andaman back arc basin is bounded in the west by Sewell Rise and in the east by Mergui ridge which separates it from Mergui basin further east (Fig.10). Mergui basin is the north ward continuation of the North Sumatra basin which is a typical back arc basin. Mergui basin can be considered as a part of the Andaman back arc basin. The typical syn-rift architecture found in Mergui basin are well pronounced in southern part of Andaman back arc (Fig.13, 14, 15).

Nature of crust has got an important role in the basal heat flow of any basin which in turn determines the geothermal gradient in a basin to a great extent. Analyzing all the tectonic aspects of Andaman basin it appears that a major part (Fore Arc & Volcanic Arc) of Andaman Basin has oceanic crust at bottom. Many workers (Metcalfe.I, 2006, Longley, Ian, 1997, Bird.P, 2003) have shown this in their tectono stratigraphic models (Fig.4). Continental crust covers a portion of the southern part of Andaman backarc basin (Fig.12), which is marked by higher geothermal gradient (Fig.9B).

Mergui and North Sumatra Basins are known to hold significant hydrocarbon reserves in its rift related plays. This in fact adds confidence about the presence of a plausible working petroleum system in East Andaman Basin in a similar rift-related play model.
In the Mergui Basin (offshore Thailand) the mid-Miocene interval overlying the limestone has a low TOC (<1%) but, according to published sources, is prognosed to be the source that has charged the successful oil and gas wells in that basin. By analogy, the same source could be present in the back-arc of the Andaman Sea Basin; where TOC is 1.5 to 2.0 (Fig.16).

Extensive work has been done on the tectono-stratigraphy and evolution of backarc basins of Indonesia including North Sumatra basin (Doust and Nobel, 2008). The Andaman back arc basin experienced more or less similar polyphase tectonic history. Though no well has been drilled in the southern part of the Andaman back arc basin, on the basis of the seismic data and analogy to North Sumatra and Mergui basin, it can be said that 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 with different clastic plays, 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 form of channel-fan system (Fig.17).

2D Petroleum system analysis suggests hydrocarbon generation probably started as early as latest Oligocene in Andaman back arc basin and hydrocarbon expulsion started in Early Miocene and continued till recent (Fig.18).

Many indirect hydrocarbon indicators have been either reported as being present in Andaman Sea area or interpreted from the reprocessed seismic data by different authors. Available satellite seep surveys indicate that a number of hydrocarbon seeps are recognized and catalogued over the Andaman area, some reputedly appearing near or on some seismic lines. Other hydrocarbon indications include sea-floor pock marks and vent mounds, gas clouds or chimneys, bright spots and flat spots (high amplitude reflector lengths and/or flat anomalous features) and bottom simulating reflectors.
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(BSRs), generally accepted to be caused by the presence of gas hydrates in the sedimentary section (Fig.19). All of these strongly favors the presence of hydrocarbon in east Andaman Basin.

Fig.19 Sections of East Andaman basin showing strong Bottom simulating reflectors (BSRs).

Conclusion
East Andaman Basin with its different morpho-tectonic units is a part of the Andaman-Sumatra subduction mega complex. Recently acquired seismic data in Andaman back arc areas provided new insight in understanding; depicting the fact that the basin in every possible way is time-equivalent to the well explored, mature hydrocarbon provinces of North Sumatra and Mergui Basins. 2D & 3D seismic data interpretation convincingly point out a close resemblance of tectono-stratigraphy amongst them. Presence of a completely unexplored rift set-up in the southern part of East Andaman basin, similar to genetically related North Sumatra and Mergui rift basin is emerging as a hotspot for future exploration. Presence of Continental crust similar to North Sumatra and Mergui basin increases the chance for entrapment of Potential amount of hydrocarbons in strati-structural combinations within this rift play of Andaman back arc and destined to become a major focus for future exploration.

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