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Exploration Targets with Speculative Petroleum System in Different Arc Setups of Andaman Basin, India

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Summary

Globally deepwater remains relatively unknown frontier, and Andaman sea area is one of those. In island arc tectonic setup like Andaman Basin, high heat flow regime is prevalent in fore arc part and even more so in back arc region due to its proximity to spreading centre. This kind of set up is responsible for enhanced maturation and in turn hydrocarbon generation. Exploration history of adjoining producing basins in Myanmar and North Sumatra basin of Indonesia has indicated the fact. A number of prospects have already been identified with the existing 2D and 3D seismic data set in all the three major tectonic set ups (Fore Arc, Volcanic Arc and Back Arc) of Andaman basin. Prospects / Plays like Carbonate platform, Miocene carbonate buildup, fault aided anticline, Pliocene high amplitude channel fan features and basal Miocene structural inversion are very interesting in the ponded lows between accretionary prism of fore arc system. In the volcanic arc setup plays like turbidite fan system within mid Miocene, structural closure due to inversion over paleogene and Miocene faulted anticline look prospective within intravolcanic lows. Back arc setup of Andaman is characterized by the prospects like Miocene faulted anticline and CLC in Mio-Pliocene. Attempt has been made to bring out the possible petroleum system in the operating areas of Andaman basin by interpreting and integrating all available geoscientific data in conjunction with North Sumatra and Myanmar areas for better understanding of hydrocarbon generation, migration and entrapment processes for future exploration. Petroleum system analysis in Andaman Basin indicates presence of major thermogenic, induced thermogenic system. Although biogenic activity related pools cannot be ruled out for the shallower level.

Introduction

Industry's ability to identify hydrocarbon bearing sediments beneath the ocean's floor at extreme water depths continues to improve. In recent years the industry has been successfully making discoveries, and developing those that can pass the rigorous tests necessary to justify high cost deepwater projects. India has not been exception to this global phenomenon. With the introduction of New Exploration Licensing Policy (NELP) by the Government of India in 1997, the country has seen the entry of multiple players into the deep water sedimentary basins of eastern coast of India and Andaman sea in particular. With the state-of-the-art seismic data acquisition-processing-

interpretation, it is becoming certain that further exploration potential exists in deepwater depositional complexes of eastern coast of India and Andaman sea.

The Andaman basin is situated towards southeastern part of Bay of Bengal around Andaman-Nicobar chain of islands (between 60°N to 140°N Lat and 91°E to 96°E Long.), covers an area of more than 2.5 lac sq km. The basin has more than 7.5km thick late Cretaceous to Recent sediments. It is surrounded by the Myanmar Irrawadi delta (Neogene age) in the north, Malayan Mesozoic orogen to the east, Sumatra (Indonesian) plutons in the south and Java trench to the west (Fig.1). Regional tectonic elements from west to east are- trench/ Island arc, fore arc, volcanic arc, and



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back arc (Fig.2), associated with converging plate boundaries. Adjoining Myanmar blocks have gas producer fields-Yadana and Yetagun and North Sumatra blocks have Arun gas field with known petroleum systems. The basin has been tectonically very mobile and different sub-basins have differential mobility and sedimentation pattern. Tectono-sedimentation studies suggest that Andaman sediments were deposited under complex succession of tectonic episodes. Tectonic events have rather dominating role over global eustatic changes causing relative sea level (base level) changes.



Fig.1. Regional map showing the location of Andaman Basin

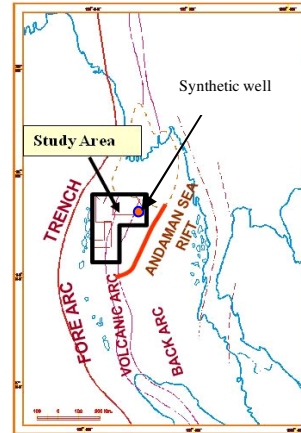


Fig.2: Tectonic map of Andaman Basin showing different tectonic elements with study area

Regional tectonic setting and sedimentation

The evolution of the Andaman Basin relates to Late Cretaceous to Recent subduction of an easterly drifting Indian oceanic plate below Eurasian plate. With the consumption of the oceanic plate by under-thrusting along the Benioff zone, the overlying deep water pelagic sediments and part of Eurasian crust accreted as north-south trending prisms by the process of reverse faulting, thrusting and folding. This resulted into the formation of early arc basin, which accommodated pelagic, turbidities and locally derived fan sediment due to base level changes. These sedimentary successions constitute a major Sequence.

Paleobathymetry data shows progressive shallowing of sea during Paleogene and major uplift at the end of Late Oligocene resulting in emergence of Andaman-Nicobar chain of Islands. As a result Oligocene fore arc sag formed in the eastern side, which accommodated more than 2000m of arc derived younger flysch sediments, constituting a distinct major sequence. In the back arc extensional forces generated North Sumatra, Murgui and east Andaman basins; which received younger sediments from Sumatra



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pluton (south) and Malaya orogeny (east). Rise of volcanic arc in east created a fore arc ponded low, which accommodated thick Neogene sediments. During Late Neogene, intra volcanic arc rifting due to NW-SE extension and local cauldron subsidence accommodated fan and pelagic sediments. Further in the upper part, sediments deposited under deepening bathymetry due to Andaman sea rift. Fore-arc sub-basins in east of Middle Andaman and in ponded low accommodated 3-5 Km of Neogene sediments supplied from local accretionary arc and Irrawadi delta – fan system. The basin architecture is defined by six major geotectonic elements as identified from detailed seismic profiles (Pandey et.al 1993). From west to east they are: Trench, inner slope, outer high, fore arc, volcanic arc and back arc (fig.3)

Petroleum System Analysis:

Source:

Baratang Formation (Eocene) is considered to be the main source, which shows lithological similarities with Launghe shale, which is main source in Myanmar. Baratang Formation is comprised of shale/ carbonaceous shale deposited in bathyal to shallow marine environment. Depositional system of source rock is visualized to consist of turbidity fans / fans, which are related to supply from southern Sumatra plutons & eastern Malay orogen. Pro-delta to deltaic clastic intercalations in shale in the north indicate Proto Irrawadi river system in Burmese plate. Due to deltaic influence Baratang formation is more arenaceous in northern fore arc. Starved shelf margin possibly experienced limestone deposition, as indicated by presence of calcareous material/ limestone within Baratang Formation. The Oligocene Port Blair formation, which is mainly littoral flysch deposit in the western part is shallow marine to bathyal shale/ carbonaceous shale in the eastern part, may also act as source rock. During Oligocene time, elevation of Andaman Island resulted into shallow water to littoral environment as indicated by conglomerate and grit beds (Port Blair Formation). These are poor source rock. However, in the fore arc basin, shelf to bathyal depositional

environment prevailed, which possibly led to better organic content preservation. The upper part of Oligocene have been eroded due to upliftment and aerial exposure. However, some lows, developed due to extension/ wrench, accommodated 2000m+ of sediments; may possibly act as source kitchen. The Oligocene formation has been eroded over the volcanic arc. Paleogene source facies is present to the west of Diligent Fault in fore arc basin.

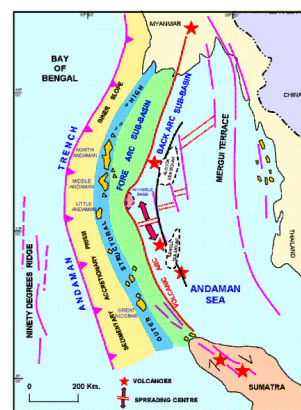


Fig.3: Tectonic map showing Trench, inner slope, outer high, fore arc, volcanic arc and back arc from west to east.

Source rock maturity and hydrocarbon generation:

Source rock Palynological studies of Paleogene Shale in a drilled well in fore arc setting suggest sapropelic- Humic-Charcoal facies with fair to moderate rich in organic matter content (TOC 4%, HI 30-250). In the well Y the total organic matter is generally moderate to rich in Paleogene shale. This indicates gas and oil generating source layers may be possibly present in low-lying areas and in deeper undrilled horizons. Drilling of Baratang Formation (wells A, B and C) has shown presence of 2-6 % gas in sand and shale, which indicate presence of thermogenic gas. It is summarized that the Paleogene depocentre in fore arc and back arc contains 2400m of Baratang source rock, which has moderately rich organic facies- Sapropelic Humic-



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Charcoal and Humic Sapropelic-Wood, indicating gas generating potential.

Areas of tectonic subsidence (ponded fore-arc and back arc) have deeply buried source rock causing thermal maturity. Late Neogene igneous intrusive bodies in fore-arc low may have accelerated maturity in some Paleogene and Neogene sediments.

Geothermal gradient varies from 1.5°C in forearc to 4.5°C in backarc setup. Burial studies in a synthetic well (fig.2) in Back arc indicate that paleogene source sediments attained onset of oil generation at around 20 my and Neogene at 8 my. Peak hydrocarbon generation for paleogene source started around 11 my and continues to present.

Migration:

Although short and long distance migration may occur in many ways, but in Andaman Arc Basin dominantly short distance vertical migration is visualized due to compartmentalization of basin due to tectonic activity and lack of water drive system. Deeply buried kitchen, which is confined to north south extending ponded low has been segmented or compartmentalized into isolated lows due to number of east west cross trends. This set up favors short distance, vertical migration through deep seated faults/fractures within ponded low. Turbidity channel levee system may provide some lateral migration.

Entrapment:

Likely entrapment mechanisms are stratigraphic carbonate pods over tectonic & magmatic shoal and structural highs / inversion in lows. Apart from these mud and volcanic diapers, Paleogene wedge out and erosional pinch out may entrap hydrocarbon at suitable locales.

Reservoir rock

Rise of Andaman Islands at the close of Oligocene caused formation of N-S trending Diligent fault and rise of

volcanic arc resulted in W-Andaman fault. Movement of these faults created space to accommodate Irrawadi fan in Northern ponded fill (in Fore arc) and Andaman Flysch in South and Middle fore arc part. These sediments may contain fan/ delta fan clastic reservoir rocks.

Neogene back arc extension caused formation of number of younger grabens in the volcanic arc. These grabens received Irrawadi fan clastics, particularly in the North Andaman Basin; however shoulder of these younger rifts experienced shallow water carbonate deposition. These clastic and carbonates in the volcanic arc are visualized as main reservoir rock. Well data in the fore arc indicate presence of Miocene limestone reservoir facies over the shallow magmatic shoal and tectonic highs, and clay/calcareous clay in lows. Developments of carbonate platform and few build ups in forearc setup are also good reservoirs for entrapment.

Besides Thermogenic Petroleum System, a possible Biogenic Petroleum System also exist in Andaman Basin (Fig.4). The rapidly buried Mio-Pliocene fluvial to deltaic and marine sediments in Gulf of Martaban have been proved having a biogenic hydrocarbon system.

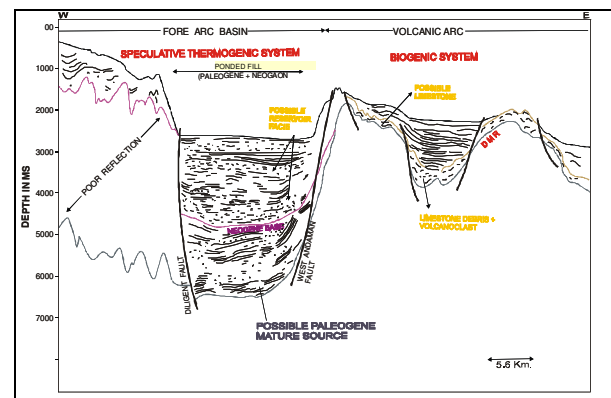


Fig.4. Envisaged petroleum systems along seismo-geological section



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Exploration targets

Fore arc

Developments of carbonate platform and few build ups in fore arc ponded low are prospective from exploration point of view. Possible Miocene platfomal carbonate feature over pre-existing basement high (fig.5 has high amplitude anomaly with 150ms vertical closure. The total sediment thickness is likely to be over 2000m above the structural high. The anticipated area of the prospect is 100 Sq. Km. Presence of Yadana Gas Field with 5 TCF reserve at 200 Km north of the prospect gives a thrust to the prospectivity perception of the block (Fig.6).

The prospect is overlain by fine clastic sequences of late Miocene age which may act as a good seal over the carbonate prospect. The fine clastic sequence is overlain by about 150m thick bed of chaotic reflection, which possibly indicate coarse clastics / volcano-clasts / debris flow. The bed is following the up warping shape with marked vertical closure and may also act as good reservoir. The bed of chaotic reflection is overlain by thick fine clastic sequences. There is a marked unconformity on top of this sequence. Above the unconformity, there seems to be deepwater environment right from Pliocene to Recent. Under deepwater environment, during Pliocene time, there is a good development of channel fan complex which can also be explored as secondary target.

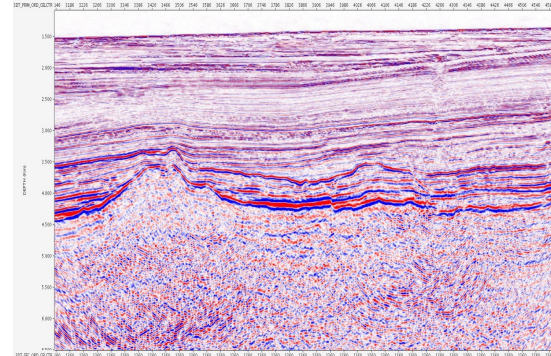


Fig.5. Miocene Carbonate platformal feature on top of basement

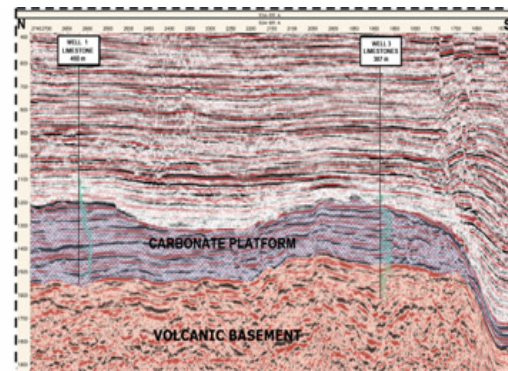


Fig.6. A seismic line passing through Yadana gas field of Myanmar

Pliocene high amplitude anomalies are basically CLC, which are well demonstrated in attribute maps. These shallow reservoirs have both the probability to contain hydrocarbon of biogenic and/or thermogenic origin. These are the additional targets for exploration when stacked with the deeper objects (fig.7).



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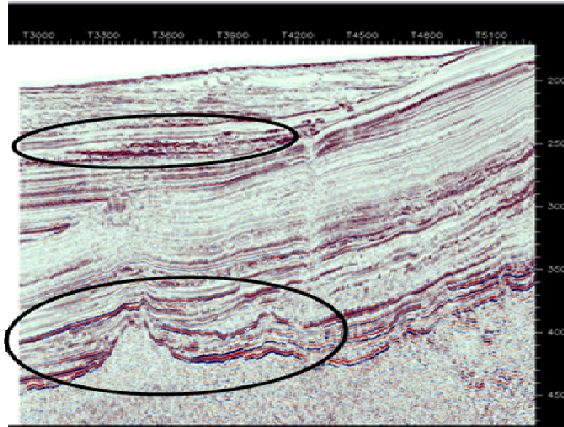


Fig.7. Pliocene high amplitude anomalies (CLC)

Volcanic arc

The volcanic arc contain about 3 km thick Neogene sediments since most of the older sediments are eroded. Seismic data shows number of inversion structure at Miocene level adjacent to diligent fault & West Andaman Fault in ponded low (Fig.8). Mostly these structures, results in nosing of strata, which occasionally are orthogonal to channel/ fan trends, hence may cause possible entrapment. These inverted structure and domal feature with transparent top could be the favorable exploration targets in volcanic arc. But features with high amplitude, close to the basement highs may be talus, derived from the nearby intrusive highs hence not favorable from exploration point of view (Fig.9).

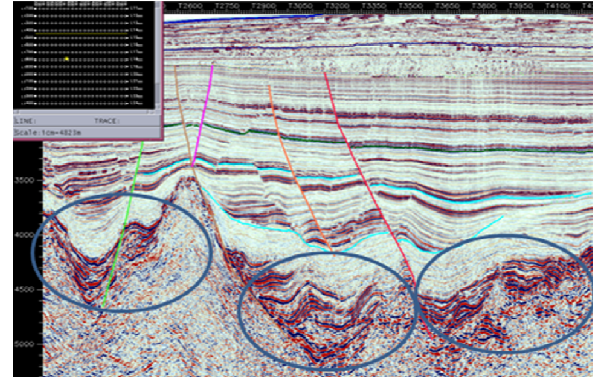


Fig.8. inversion structure at Miocene level in volcanic arc

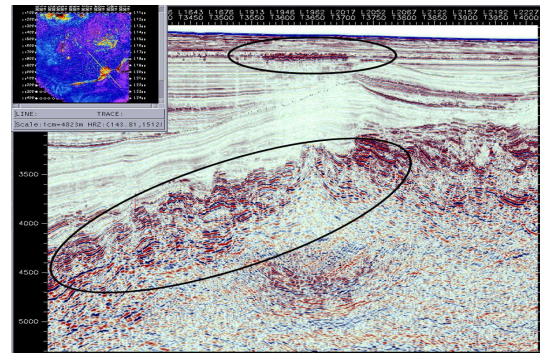


Fig.9. Features with high amplitude, close to the basement highs may be talus, derived from the nearby intrusive highs

Under deepwater environment, during Pliocene time, there is a good development of channel fan complex which can be seen at several places (Fig. 10)



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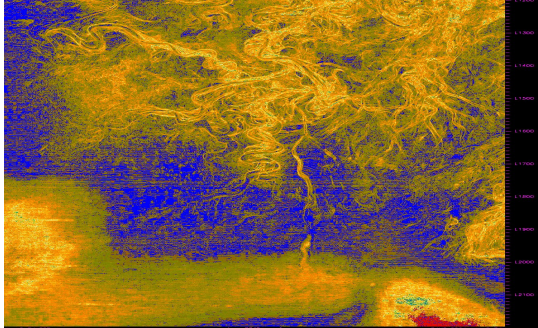


Fig.10. Pliocene – Pliostocene channel-fan complex.

A stratigraphic feature (possible turbidite fan) is indicated by high amplitude anomaly. The feature has around 40 m thickness and is probably Mid Miocene age. The feature is interpreted as deepwater turbidite fan and expected to have coarser clastics with favourable reservoir facies (fig.11). The total sedimentary thickness is likely to be around 1340m above the prospect. The stratigraphic feature is dissected by a fault.

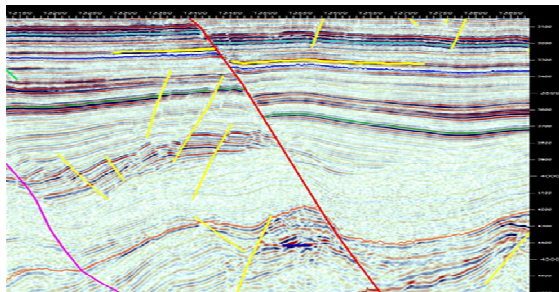


Fig.11. High amplitude stratigraphic feature (possible turbidite fan).

Back arc

ONGC operated area having back-arc setup is surrounded by prolific hydrocarbon provinces. 3D area is partly covered with paleo-high/volcanic high and partly by grabenal low.

Fig.12 shows structural cross section from Yadana field (west) to Yetagun field (east) of Myanmar. The huge low in between is the kitchen area for both the producing fields. The back arc basin of ONGC operating area shows the similar setup, where relatively thicker sedimentary sequence is expected 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.13)

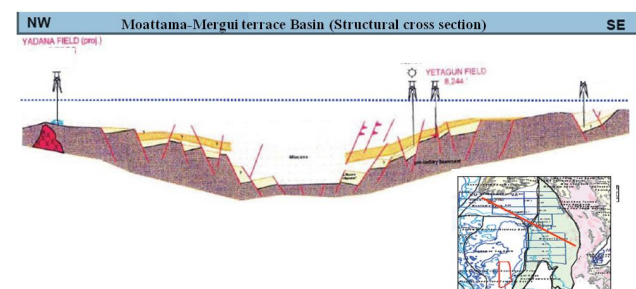


Fig.12. Structural cross section from Yadana field (west) to Yetagun field (east) of Myanmar

Structural closure due to inversion in Miocene over the huge paleogene package, which is thought to be the source rock (fig. 14). A number of faults connecting the source act as conduits. Anticipated area for the prospect is 50 – 60 skm

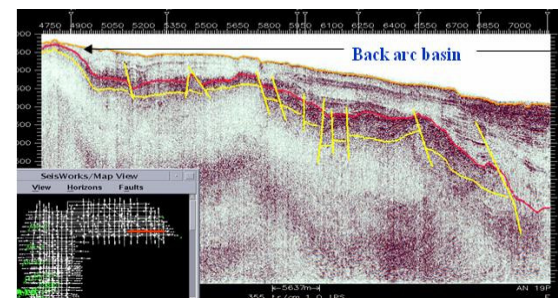


Fig.13. Thicker sedimentary sequence expected in the grabenal parts of back-arc sub-basin



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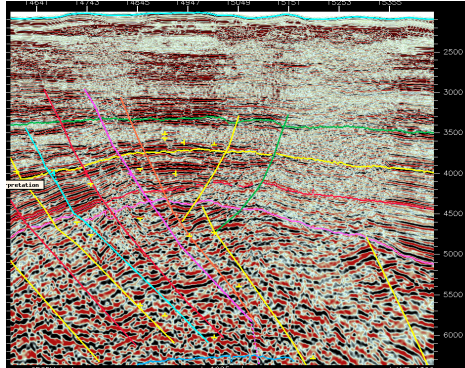


Fig.14. Miocene closure (inversion) in back arc of Andaman sea

In the shallow level distinct CLC with significant amplitude are the probable reservoirs. Deep seated faults connecting the source and reservoir act as migration path for hydrocarbon. (Fig.15). Analogous producing field in the similar back arc setup of Trinidad with known petroleum system supports the prospectivity of this structure (fig.16).

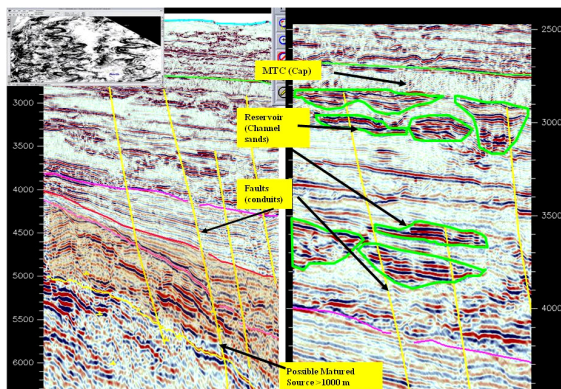
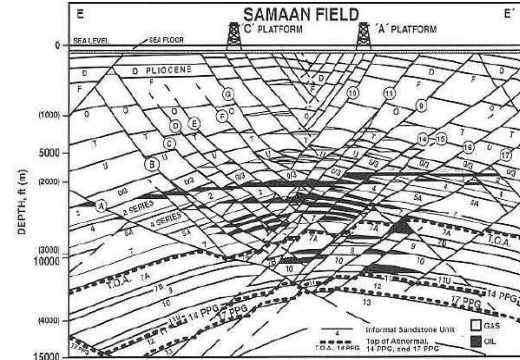


Fig.15. Envisaged petroleum system in back arc system





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