Mannar Sub-Basin, Cauvery Basin - Characteristics & Opportunities for Hydrocarbon Accumulations

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Abstract

Cauvery Basin evolved during taphrogenic fragmentation of the East Gondwanaland initiated in Mid-Late Jurassic. Mannar sub-basin which is the southernmost graben of Cauvery Basin, however is typically different from other parts of Cauvery Basin in its genesis, configuration, volcanism and Neogene inversion tectonics. It is characterized by a unique structure representing predominantly a sag type of basin with thin (2-3km) of rift sediments overlain by thick marine sag systems (>4km). The other sub-basins in Cauvery have rift-sag type configuration with thick rift sequences (> 5-6km) in half graben setup and a thin overlying sag system (~3km) deposited during the drift phase. The sub-basin is large, symmetrical and structureless in most part of the area while faulted rift systems are localized and seen along the margins representing predominantly a Marine Sag basin. Sedimentary systems in a sag basin are largely controlled by gravity driven flows in deep water rather than the tectonic driven sedimentary systems in a rift basin. Mannar sub-basin is also characterized by the presence of igneous bodies in forms of sills, dykes and extrusive lava flows at various stratigraphic levels influencing the thermal maturation of source rocks, reservoir quality & entrapment mechanisms. Neogene inversion structures are another characteristic feature observed in Mannar area representing an inverted passive margin setup. Based on these differences, the hydrocarbon accumulation and distribution patterns could possibly be different from rest of the Cauvery Basin. This paper is focused in understanding the possible hydrocarbon play and strati-structural traps in Mannar area based on the global analogy to marine sag basins, inverted passive margin basins & volcanic rift basins.

Key words: Rift-Sag, Sag basin, Passive Continental Margin basin, Inverted Passive Margin.

Introduction

Cauvery Basin is one of the petroliferous rich passive continental margin basin situated along the East Coast of India. The rifted continental margin of Cauvery basin is divided into several horst and graben structures and overlain by thick passive margin sequences developed during drift phases of basin evolution. Hydrocarbon habitat is proven by the development of widespread Jurassic, Barremian, Albian-Aptian effective source rocks charging reservoirs of synrift & post rift sequences through the migration pathways like faults & unconformity layers.

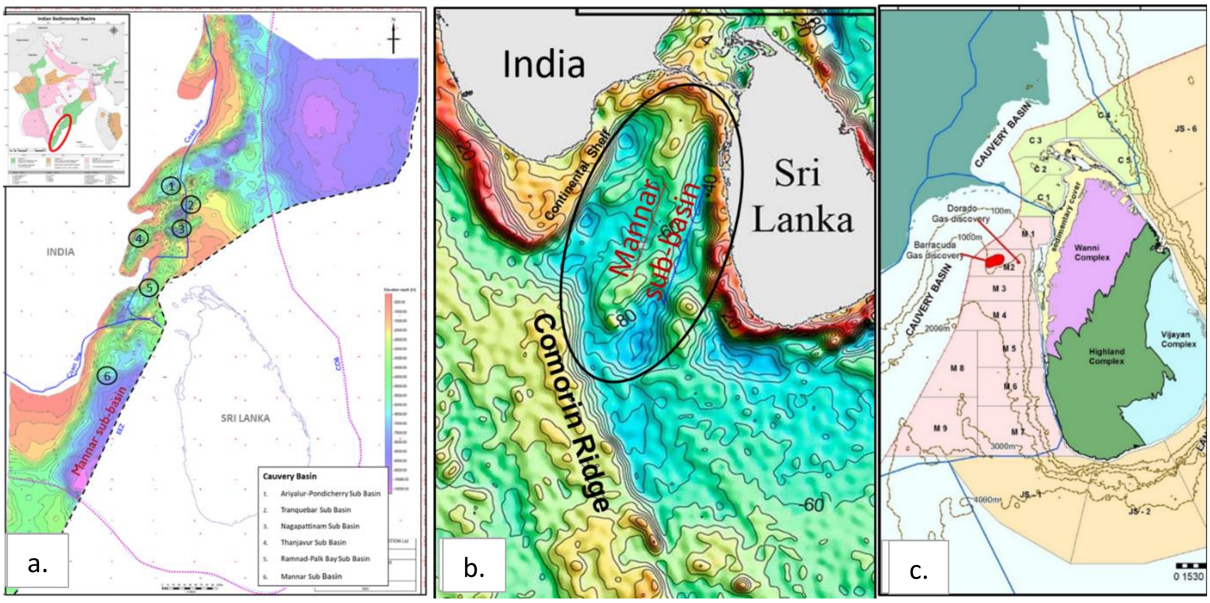

Fig. 1a Location Map of Mannar sub-basin b. Map showing tectonic limits of Mannar sub-basin. c.Map showing the two hydrocarbon discovery in the Sri Lankan territory of Mannar sub-basin.

Mannar sub-basin is located in the southern part of Cauvery Basin between SE coast of India and West coast of Sri Lanka (Fig. 1a). It extends over an area of 85,000 sq.km in water depths ranging from 20m to >3000m. Out of the total area, an area of 59000 sq.km falls under Indian jurisdiction and the rest under Sri Lankan jurisdiction. In Mannar sub-basin, a sedimentary column of more than 10km in the main depocentre is inferred based on the seismic data. Mannar sub-basin is relatively unexplored. Eleven exploratory wells were drilled in the Indian side so far without any success. The exploration success is limited to two gas discoveries viz., Barracuda and Dorado wells by Carin Energy Ltd. in the Sri Lankan deep waters along the eastern flank of Mannar sub-basin. These Gas discoveries and Satellite seep studies over Mannar offshore have identified the presence of atleast one active petroleum system within the Mannar sub-basin (Baillie et. al., 2004).

Geological Setting & Tectonic Evolution

Mannar sub-basin is considered as a southern most part of Cauvery basin co-evolved during the rift – drift phase of Cauvery basin. The tectono-sedimentation limit of Mannar Sub-Basin in West and Northwest is marked by continental shelf of India, to South Southwest by Cape Comorin ridge and to the east and south east by continental shelf of Sri Lanka (Fig.1b.).

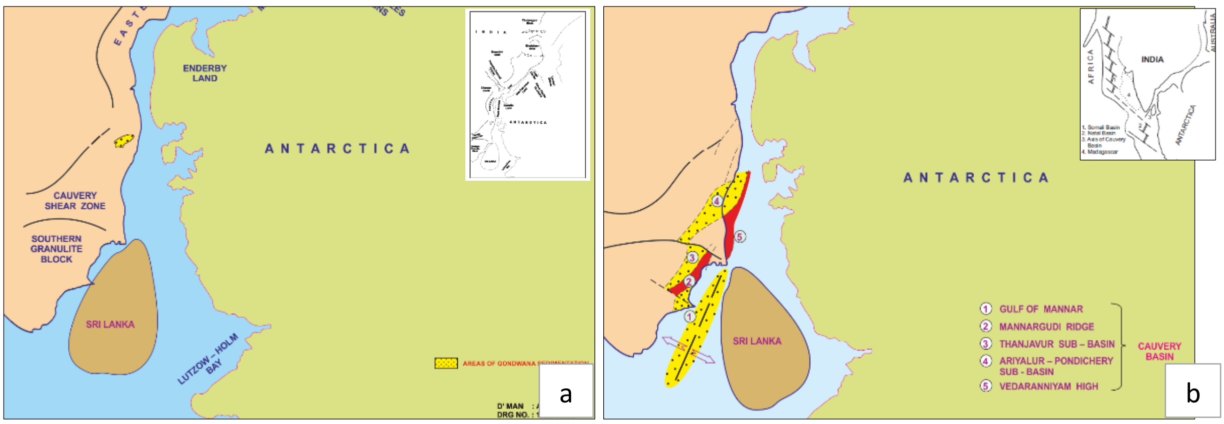

Fig. 2 a. Paleo-reconstruction of India – Sri Lanka - Antarctica during Pre-rift in Early Jurassic, b. Paleo- reconstruction of India –Sri Lanka-Antarctica during the rift initiation in Mid-Late Jurassic. Crustal extension resulted between India and Srilanka due to counter clockwise rotation of Srilanka (Lal et al., 2009).

Tectono-stratigraphic evolution of the Mannar sub-basin can be broadly divided into four phases comprising of synrift (Middle Jurassic to Early Aptian), post rift sag (Early Aptian to Turonian), Pre collision passive margin (Coniacian to Paleocene) and post collision passive margin (Early Eocene to Recent). Rifting of Cauvery Basin was initiated during Mid-Late Jurassic, in response to development of Natal Basin between Africa – Greater India and Antarctica. This crustal extension resulted in counter clockwise movement of Sri Lanka. This is followed by rifting between India and Antarctica-Australia, in the Early Cretaceous, causing more extension and continued till Early Aptian (Fig. 2a & 2b). Rift transition (or post-rift) is considered with thermal sag phase during the Late Cretaceous. From the Late Cretaceous to the Tertiary, the sub-basin remained a passive margin with an inversion episode during the Oligocene and Miocene Epochs (Shaw 2002; Kularathna et. al., 2015)

Basin Configuration

Mannar sub-basin appears to have a unique configuration representing predominantly a sag-type passive continental margin basin characterized by a small rift system which is comparatively small (2-3km) compared to the post rift sag system. Typical synrift sequences bounded by faults are deep & localized along the margin of the sub-basin and the sag system is thick (> 4km) (Fig. 3b). The other sub-basins of Cauvery Basin are rift-sag type passive continental margin where a major portion of sediment fill is represented by rift sequences (generally more than 5-6km in the depocenter) followed by thin sag phase (generally less than 4km in the depocenter) deposited in passive margin setup. Sediment fill is dominated by synrift sequences bounded by tensional faults formed during the rift phase of evolution, exhibiting horst-graben and half graben structures (Fig. 3a).

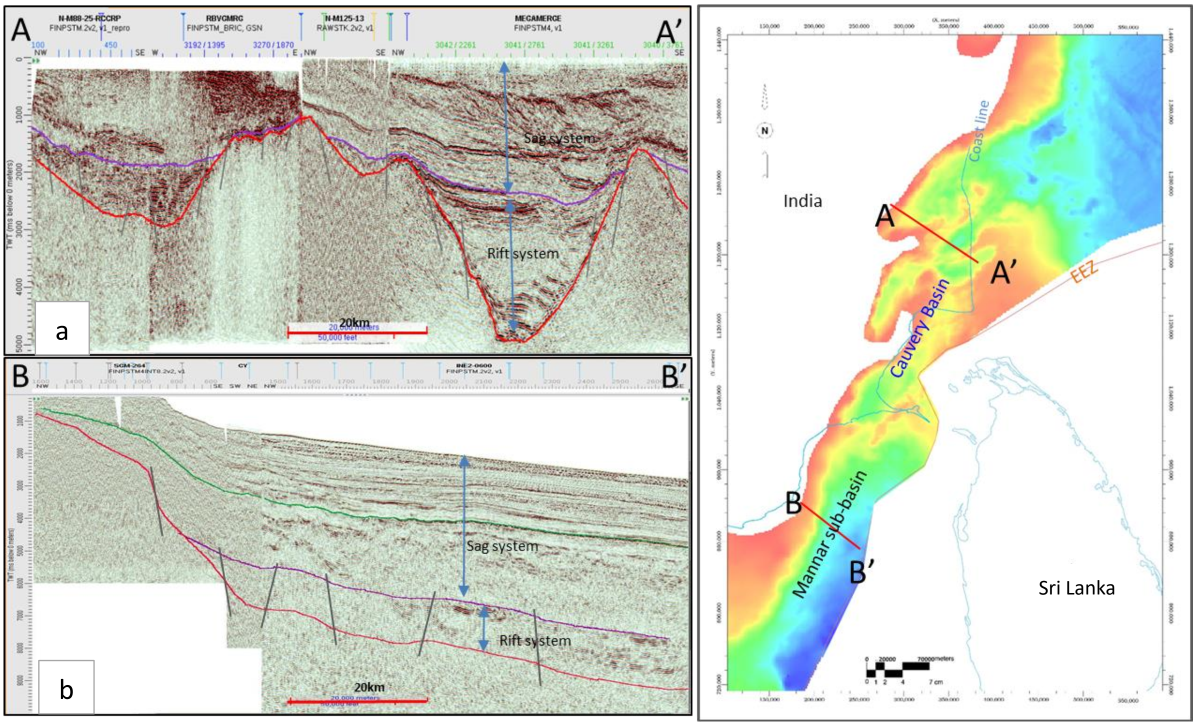

Fig.3a.Seismic transect in Cauvery Basin showing Rift-Sag type passive margin basin depicting the fault bounded horst and graben structure, b. Seismic transect in Mannar area showing the sag type of passive margin basin.

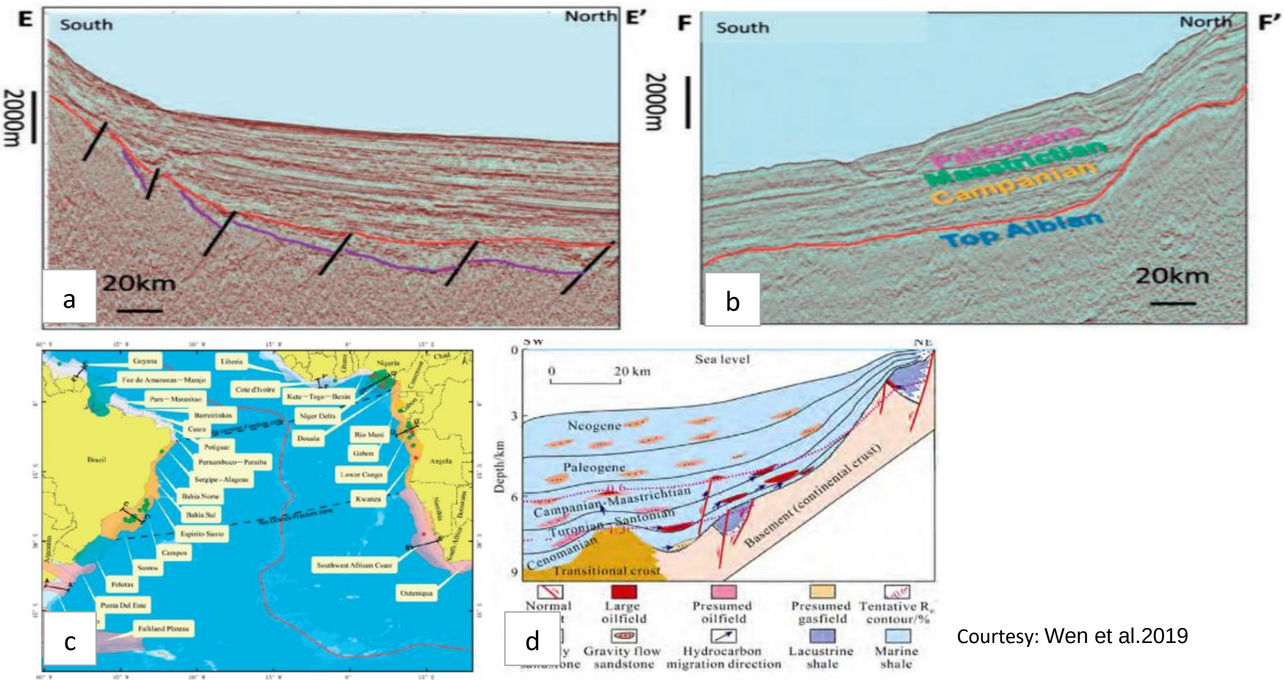

Fig. 4 Seismic section showing the sag-type passive margin basins in the northern segment of the South Atlantic margins, 4a. S-N oriented EE' seismic section is located in the Guyana basin, 4b. S-N oriented FF' seismic section is located in the Cote d'Ivoire basin, 4c. Location of these seismic sections, 4d. Geological model showing the petroleum accumulations in sag-type basins (Wen et al.2019).

In sag basins, though effective source rocks are developed in the rift systems, they are relatively thin and localized. In Mannar sub-basin, knowledge of source rocks is limited as none of the wells drilled have penetrated the early synrift sequences in the basinal side. As with typical sag basins, in Mannar sub-basin, no significant structural traps are developed in the basinal area except along the margins. High risk is envisaged in migration & charging of the shallow reservoirs from the effective source rock developed in rift systems. Globally these type of basins are less explored. However, a few discoveries in sag type basin developed along South Atlantic offshore margins are reported like Jubilee oilfield in Tano sub-basin & deep water Liza discovery in the Guyana Basin (Fig. 4a). These discoveries were made in gravity-flow fans in early postrift sequences (Wen et al.2019). Play analysis of these discoveries suggest that in sag-type basins, the upper sag system formed during the drift period is very thick and mainly consists of clastic sediments, and the gravity flow sediments are widely developed. In the drift stage, the deep water marine system was deposited quickly and was very thick. Apart from the known effective source rocks in synrift sequences, early post rift marine shales can enter hydrocarbon maturity window and directly charge the deep marine turbidite sandstones in the same sag sequence formed in the drift stage. Gravity-flow fans in early post rift sequences are the most favorable hydrocarbon plays in the sag type passive continental margin basins (Wen et al.2019).

Volcanism

Mannar sub-basin has witnessed volcanic activity in several phases. Evidences of volcanism in Mannar area clearly seen in seismic and wells drilled. This phenomenon is unique to this sub-basin and adjacent Ramnad sub-basin. Volcanic bodies are seen as high amplitude seismic signatures occurring as continuous and discontinuous/saucer shaped bodies on seismic. In Mannar area, the volcanic bodies in the form of sills and dyke intrusions are noticed in the periphery of the sub-basin, while in the central part it is seen as continuous sheet representing a volcanic flow. These sills are found to occur at different stratigraphic levels especially in the Turonian & older sediments while, the extensive flood basalt type volcanic body is observed stratigraphically close to K-T boundary and are encountered in drilled wells (Fig. 5). Geochronolocial studies on cuttings samples & cores of the igneous rocks could not bring a consensus on the age of these volcanic rocks.

Based on the stratigraphic relation and morphology, broadly two phases of volcanic activity is envisaged in the area much later to the rifting episode of Mannar sub-basin, the oldest volcanic activity is related to Marion hot plume during 89Ma which occurs as intrusive sills & dykes in the periphery of the basin. While the youngest volcanic activity probably the effect of Reunion hot spot is seen in large area as extrusive volcanic flows of thickness more than 700m close to K-T during 65 Ma.

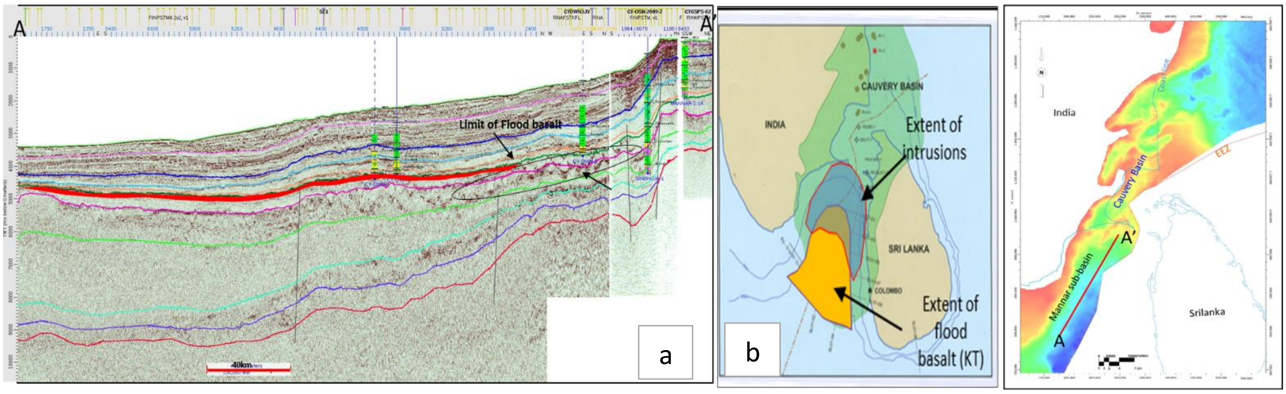

Fig. 5a Seismic section in N-S across Mannar area depicting the extent of flood basalt close to K-T boundary and the extension of intrusive rocks in Turonian sequences b. map showing the extension of volcanic rocks in Mannar sub-basin.

In Mannar sub-basin, high risk is perceived in terms of source rock maturity and reservoir quality due to heating effects of these volcanic episodes. Volcanic extrusive rocks in the centre of the basin, is a major impediment in targeting the Mesozoic sequences and seismic imaging of deeper sequences. 1D Petroleum system modelling carried out considering intrusive & extrusive volcanic rocks and their corresponding heat flows suggest that intrusive rocks can have local effect on maturation of the source rock lying close to the magmatic aureole while extrusive rocks have a negligible effect on the maturation of source rock. In Mannar sub-basin since the intrusive rocks are seen mostly confined to Turonian sequences along the northern periphery of the sub-basin, risk of over maturation of Cenomanian-Turonian source rock is envisaged in the local pockets close to the intrusives, However, the flood basalt occurring near K-T boundary, does not seem to disturb the normal geothermal gradients and maturation of source rocks. Seismic analysis suggest the narrow corridor along the margin of the basin with less density of the volcanic bodies as suggested by the seismic character can be a potential area for exploring deeper sequences. The forced fold structures due to the intrusion activities and stratigraphic traps in intra-basaltic layers as seen in Barracuda & Dorado discoveries is an additional entrapment features in the area.

Neogene Inversion Tectonics

Mannar sub-basin remained as a passive margin basin after rifting episode ended in Early Aptian. However Neogene compressional structures are noticed in the seismic data in Mannar area, which are not seen in other sub-basins of Cauvery Basin (Fig. 6b). Though these structures are formed much later to get charged from the envisaged effective source rock sequences, global analogy of the similar type of inverted passive continental margin basins with inversion in the Neogene, especially in the Miocene are proved to be hydrocarbon bearing. In the Levant basin in East Mediterranean, for example, hydrocarbons were generated at rifting stage of Triassic and early depression stage of Jurassic, but the large gas fields that are currently discovered are all located in the Miocene anticline traps which were inverted in the Cenozoic (Fig. 6a, Zhixin Wen et al.2019). The Hysteria basin in the Gulf of South Mexico also presents the same hydrocarbon accumulation characteristics. In these discoveries, differently, its hydrocarbon migrates vertically (or is redistributed) through inverted faults. (Wen et al.2019).

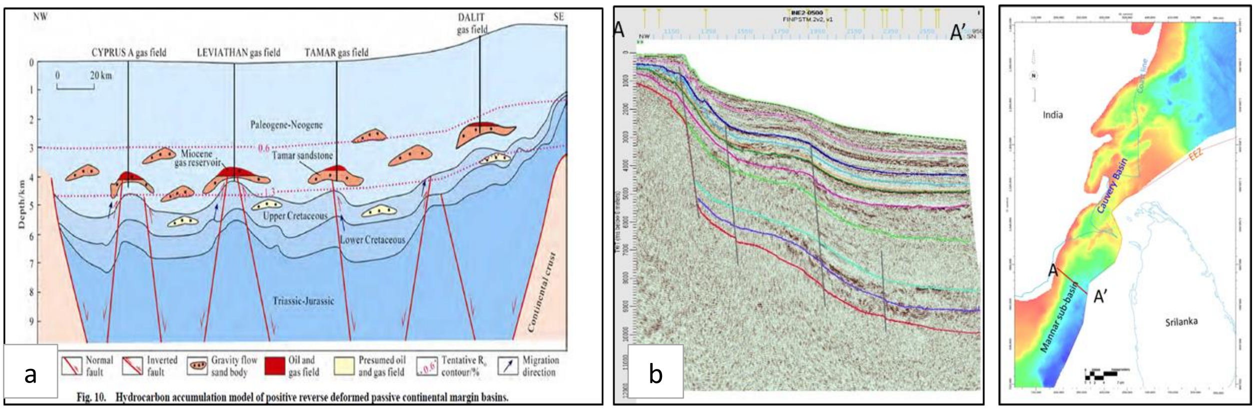

Fig. 6 a Geological Model of inverted passive margin setup in Levant basin in East Mediterranean Courtesy: Wen et al.2019. b. Seismic section across Mannar sub-basin depicting the Neogene compressional structures.

Focus areas for Exploration

The current evaluation of the sub-basin has shown that the Mesozoic sediments which are major hydrocarbon producing reservoirs in Cauvery Basin are not explored in this sub-basin. These sediments have shown the presence of good reservoirs in the northern rising areas of the basin where wells are drilled. A few wells drilled in the basinal part have not penetrated these sediments as they were not drilled beyond K-T lava flows. Global analogy also suggests, the early post rift sequences as the potential plays in similar marine sag basins. It is pertinent to mention that to target these potential reservoirs, wells have to be placed at areas where the lava flows are absent. An understanding of the sub-basin reveals that the western rising flank of the sub-basin is a potential area as the K-T flows are largely restricted along the axial part of the sub-basin. A few fault closures are also present in these areas which can be potential targets. A window of opportunity exists in this sub-basin which is sparsely explored considering its size.

Conclusions

Mannar sub-basin is a frontier area in a Category-I Basin, where deeper stratigraphy is relatively unexplored. Petroleum system in Mannar sub-basin is not clearly understood due to sparse well data & poor seismic imaging in the deeper sequences. Evaluation of play potential in a frontier area due to data constraint is a challenging task. In such a case prediction of possible petroleum system and hydrocarbon plays are highly relied on the analogues basins. For Mannar sub-basin, adjacent sub-basins of Cauvery Basin are considered as analogues in source rock potential and hydrocarbon play distribution as all these sub-basins are co-evolved during the East Gondwana fragmentation. However, certain characteristic differences in configuration and magmatic activity constraints the application of one to one correlation of these sub-basins.

Mannar sub-basin has distinct configuration style representing mostly a sag type of basin with relatively deep and localized rift systems. No significant structural traps are developed in the basinal area except along the margins. High risk is envisaged in migration & charging of the shallow reservoirs from the possible effective source rocks developed in rift system. Global analogy suggests, possibility of development of thick & mature source rocks in early marine sag phase charging the deep water turbidite systems developed during the same sag phase. Stratigraphic features like Wedge out, pinchouts, deep water turbidite fan in the early marine sag sequences could possibly be the major targets for exploration. Neogene compressional structures seen in the area are distinct to Mannar sub-basin, which could also act as a hydrocarbon traps.

However the major impediment in exploration of Mannar sub-basin is the presence of volcanic rocks as intrusive & extrusive rocks at various stratigraphic levels. PSM 1D modelling with various variants of heat flow when considered as intrusive and extrusive volcanic activities was worked out, which actually suggest that intrusive rocks can have local maturation of the source rock when present close to the magmatic aureole while extrusive rocks have a negligible effect on the maturation when developed before or after any volcanic episode. Apart from the stratigraphic features, forced fold structures due to the intrusions and intra-basaltic layers is an additional entrapment features as seen in the Sri Lankan discoveries. An approach based on the global analogy of similar basins when data is limited would help in understanding & targeting the successful geological models, pays and hence reduce the exploration risk.

Acknowledgement

The authors are thankful to Director- Exploration, ONGC for the kind permission to publish the work. They are also indebted to Shri C.B. Yadava, ED-Basin Manager, Cauvery Basin, for approving the paper for publication. Thanks are due to Shri P. Arumugam, GM (G) -Block Manager & Shri K. Velu, GM (Gp-S) for their encouragement and support.

Statement The views expressed in this paper are of authors only and not necessarily reflect the views of ONGC.

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