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## Understanding the Deep Syn-Rift Petroleum Systems of Cauvery Basin: A 2D Case Study from Ramnad Basin

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### Summary

Ramnad basin is a proven province producing from siliciclastic reservoirs of upper Cretaceous Nannilam and Bhuvanagiri formations. The source rocks of late Jurassic age are fully mature and are well within the gas window. Numerous structural and stratigraphic traps have been interpreted in the past. The deeper syn-rift sequences hosting good quality sandstone sequences have not been targeted for exploration so far. 2D petroleum systems modelling carried out on a NW-SE section aims to increase the understanding of the behaviour of deeper petroleum systems in the area.

**Keywords:** Petroleum Systems Modelling, Ramnad Basin, Cauvery Basin, Petroleum Migration, Source rock Maturity

### Introduction

Petroleum systems modeling is a vital additional component in assessing exploration risk before drilling, as risks can be associated with reservoir location, structural or stratigraphical traps, source rock maturation or regional level seals holding hydrocarbons in place. By integrating geological, geophysical, petrophysical and well data one can model the evolution of basin and petroleum systems with time.

Petroleum systems modelling helps to predict which traps are most likely to contain hydrocarbons, as well as the type of expected hydrocarbons and their properties.

Till date most of the exploration has targeted shallow reservoirs such as the Bhuvanagiri, Nannilam and Kamlapuram sandstones in the Ramnad sub-basin. This case study aims to understand the petroleum systems elements and their influence on hydrocarbon generation, expulsion, migration and accumulation through geological time.

### Geological Settings of Cauvery Basin

The Cauvery basin forms the southwestern margin of the Jurassic rift of the east coast of India (Figure 1). The Cauvery Basin is an intra-cratonic rift basin, divided into a number of sub-parallel horsts and graben, trending in NE-

SW direction (Vasudevan et al, 1998). The basin formed during the fragmentation of Gondwana land during the drifting of the India-Sri Lanka landmass away from the Antarctica/Australia continental plate during Late Jurassic to Early Cretaceous time. The Ramnad sub-basin is bounded by the Pattukottai high in the northwest and in the southeast by the Mandapam-Delft ridge. The sub basin holds sediments over 6000 m in thickness, ranging in age from late Jurassic to Recent.

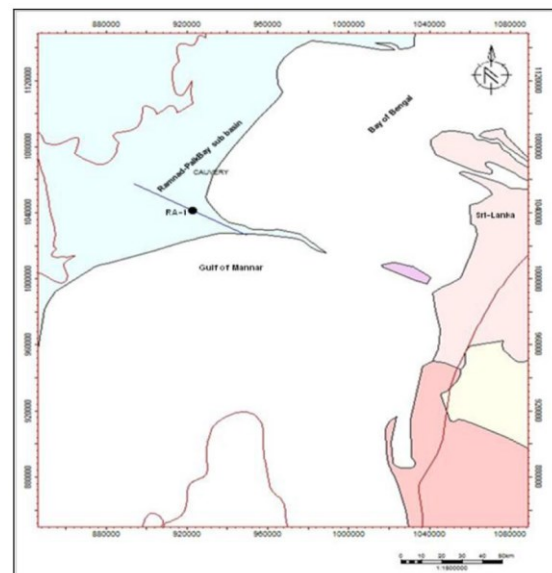


Figure 1: Location map showing the cross section location

## Petroleum Systems of Ramnad Sub-Basin

Exploration in the Ramnad sub-basin has provided a good insight into the petroleum systems of the area. Known reservoirs in the area are the middle Cretaceous Bhuvnagiri sandstones, upper Cretaceous Nannilam sandstones and Kamlapuram sands of Paleocene age (Chandra et al, 2006). The syn-rift sequences of the Andimadam formation are still not well understood in terms of source and reservoir distribution. With the majority of production coming from the Nannilam reservoirs, deeper reservoir formations of Andimadam sequence are likely to be a next potential target for hydrocarbon exploration.

The known source facies are established in the lower Cretaceous Andimadam formation. Alternate streaks of shale sequences in deeper parts are known to have good source rock potential. These shales are typically the main source rock encountered in the study area. The source rocks are typically a mixture of type II-III facies (Vasudevan et al, 2008). The area has good seals in place, with shale sequences of Cenomanian, Santonian, and Maastrichtian being the major regional seals (Figure 2).

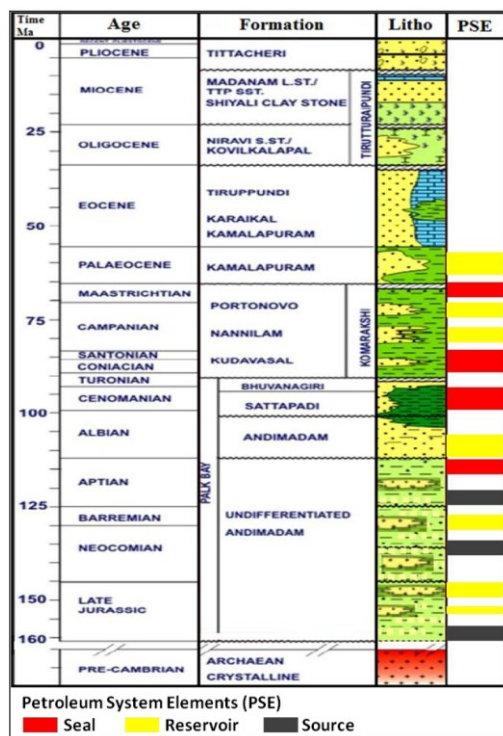


Figure 2: Generalized stratigraphy of Cauvery Basin with indications of the different petroleum system elements considered in the present study. (Modified after Chaudhuri et al., 2009)

## Petroleum Systems Modelling Input

A 2D numerical model was constructed using a present day, depth converted cross section from Ramnad sub-basin (Chaudhuri et al, 2008). The cross section with multiple horizons and faults was digitized to define physical layers between the horizons (Figure 3). Each layer was assigned with different lithological properties and was given a stratigraphical age. Using public domain data, identified layers were assigned to different petroleum system elements such as source, reservoir, seal and overburden. Kinetic input parameters for type III source rock developed by (Pepper & Corvi, 1995) were used for kinetic modelling. Other input parameters such as lithology, TOC, HI and erosion inputs were also defined for the numerical model. Necessary input parameters such as Paleo Water Depth (PWD), Heat Flow (HF) and Sediment Water Interface Temperature (SWIT) were also defined for the model as boundary conditions. The model was simulated and thermally calibrated to understand the basin and petroleum systems evolution through geological time scale.

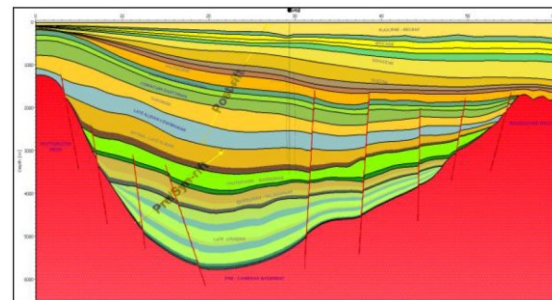


Figure 3: Depth Cross section from Ramnad basin, showing different layers and sub-division of layers along with faults.

## Thermal Calibration

The simulated model was thermally calibrated against the present day temperature and measured vitrinite reflectance values, obtained from well RA-1, which is located on the geological cross section used for modelling (Figure 4).

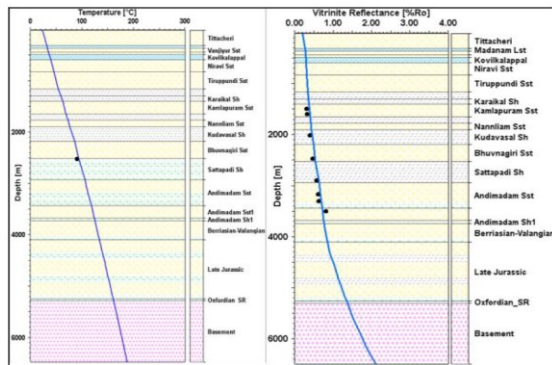


Figure 4: Modelled temperature curve is calibrated against the present day temperature and vitrinite reflectance value from well RA-1.

### Simulation Output: Burial History

A 1D profile extracted along the well RA-1 shows that the source rocks from late Jurassic to Aptian show different source rock transformation ratios with increasing depth (Figure 5). At present day all the source rocks with the exception of the shales in upper Andimadam sequence, show more than 50% transformation from kerogene to hydrocarbons. From the burial history it can be inferred that deeper source rocks show signs of maturity as early as lower Cretaceous. The shallower source sequences however still have good potential to be converted into hydrocarbons.

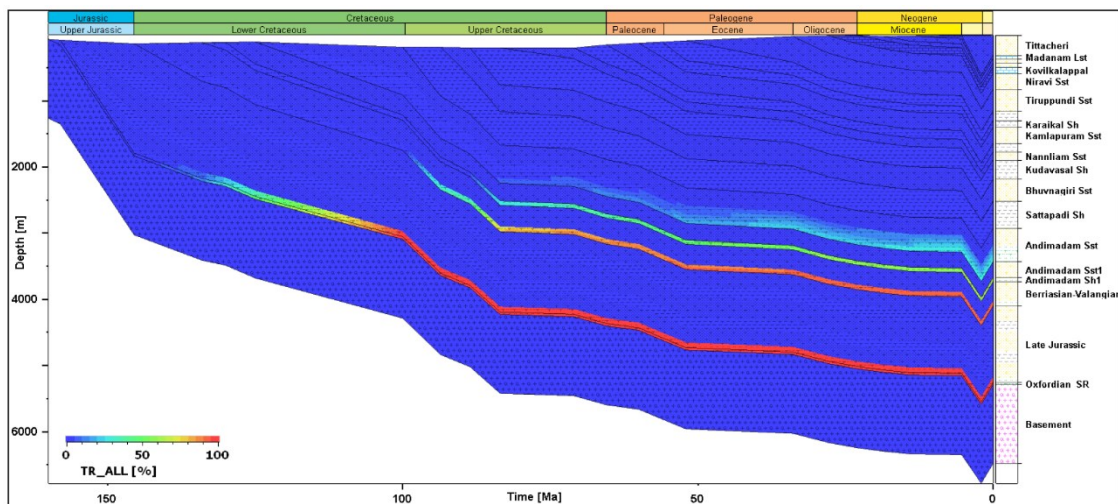


Figure 5: Burial history curve showing transformation ratio of the known and assumed source rock sequences within Andimadam formation of late Jurassic to early Cretaceous.

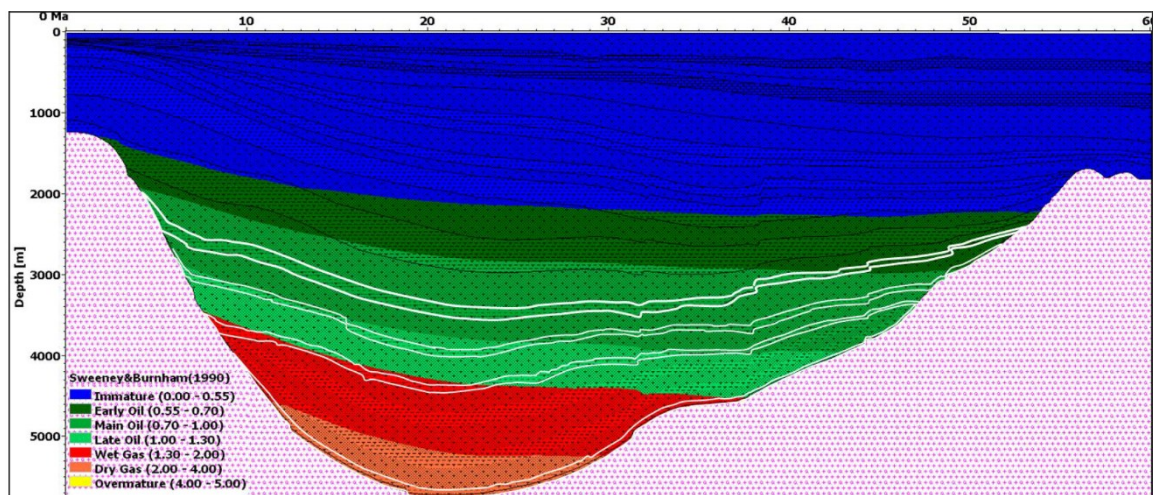


Figure 6: Sweeney & Burnham maturity overlay showing maturity window for all the source rocks (white borders) considered in the petroleum systems model.

## Source Rock Maturity

Petroleum systems modelling indicates that all the known source sequences from late Jurassic to pre Albian times are mature and are in oil and gas windows. The deeper source rocks of late Jurassic sequence are in dry gas window and all other Cretaceous source rocks are in the oil window (Figure 6). While the lower Jurassic formations had entered late oil window, lower Cretaceous source rock within Aptian and pre Aptian formations entered the main oil window during Santonian – Campanian. Modelling thus confirms the trends which have been previously established by Phaye et. al., 2011.

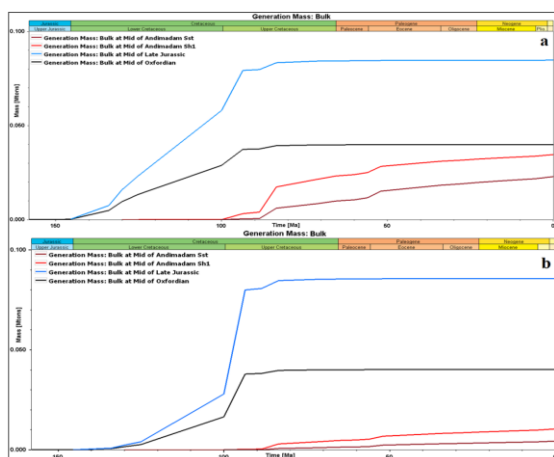


Figure 7: Plot showing the generation potential (in Mtons) of different source rocks for a) Pepper & Corvi type III kinetic reaction b) Tissot in Waples type III kinetic reaction.

## Hydrocarbon Generation

Most of the hydrocarbons which have been generated in the Ramnad basin are thermogenic in nature (Vasudevan et al, 2008). The source rocks of late Jurassic formations achieved peak generation during late Cretaceous time. Also, the deeper Oxfordian source rocks show a similar trend but have generated lesser hydrocarbon masses. Within the Cretaceous sequence, the source rocks show lesser generation potential of hydrocarbons. Both the source layers within the Andimadam formations are still showing increasing trend of hydrocarbon generation potential. Due to shallow burial depth the generation potential of these source layers are lower (Figure 7a). A sensitivity analysis was done by applying another thermogenic kinetic reaction developed by Tissot and Waples (1992) for type III kerogen. Application of Tissot and Waples (1992) indicates that the source rocks show different behaviour with respect to hydrocarbon

generation. More rapid and sudden attainment of peak generation is achieved for deeper source rocks within late Jurassic and Early Cretaceous (Figure 7b). It is likely that the expulsion for deeper source rocks could have been around late Cretaceous to early Tertiary times. Vasudevan et al (2008) also discussed the possibility of the source rocks reaching their expulsion stages during the same time. Thus kinetic reaction is a key to understand hydrocarbon generation and expulsion from the source rocks, but uncertainties must be taken into account.

## Hydrocarbon Migration & Accumulation

Migration modelling has indicated that most of the sandstone sequences encountered in Andimadam can serve as a good reservoir, and that hydrocarbons can potentially accumulate (Figure 8). Both structural and stratigraphic traps were in place during the evolution of basin at different times. Migration routes within the area are mostly vertical due to buoyancy. At some places, faults can also be seen acting as a conduit for fluid migration. The model considers the effect of open and close faults for understanding the hydrocarbon migration, which takes place during different time steps of basin evolution (Figure 8). The stratigraphical and structural traps present within the Andimadam formation can be a good target for deeper exploration in future (Figure 9).

## Conclusions

- Petroleum systems modelling of Ramnad Basin has provided a new insight with respect to hydrocarbon generation, expulsion, migration and accumulation within the syn-rift sequences of Andimadam formation.
- The early syn-rift sequences, having source facies are fully mature and are within the gas window. The upper sequences which are potential source rocks fall within the oil window during present day.
- Deeper source rocks in Andimadam formation show a transformation ratio of more than 80% while the potential source rocks in upper Andimadam formations show an attainment of more than 50%.
- Thermal calibration for well RA-1 was achieved against the temperature and VRO values.
- The generation potential of deeper source rocks remains unchanged but shows a steep rise which depicts from the sensitivity analysis of thermogenic kinetics.
- Hydrocarbon generation in Ramnad basin starts during lower Cretaceous and attains peak during

upper Cretaceous time. The shallow sources started generating hydrocarbon from mid Cretaceous time and have not attained their peak generation capacity.

- Migration modelling suggests that most of the migration in Ramnad Basin is vertical and taking place along the faults and resulted into structural traps.
- Generated hydrocarbons mostly consist of gas, which are observed to be accumulated within the reservoir sequences in Andimadam formation.

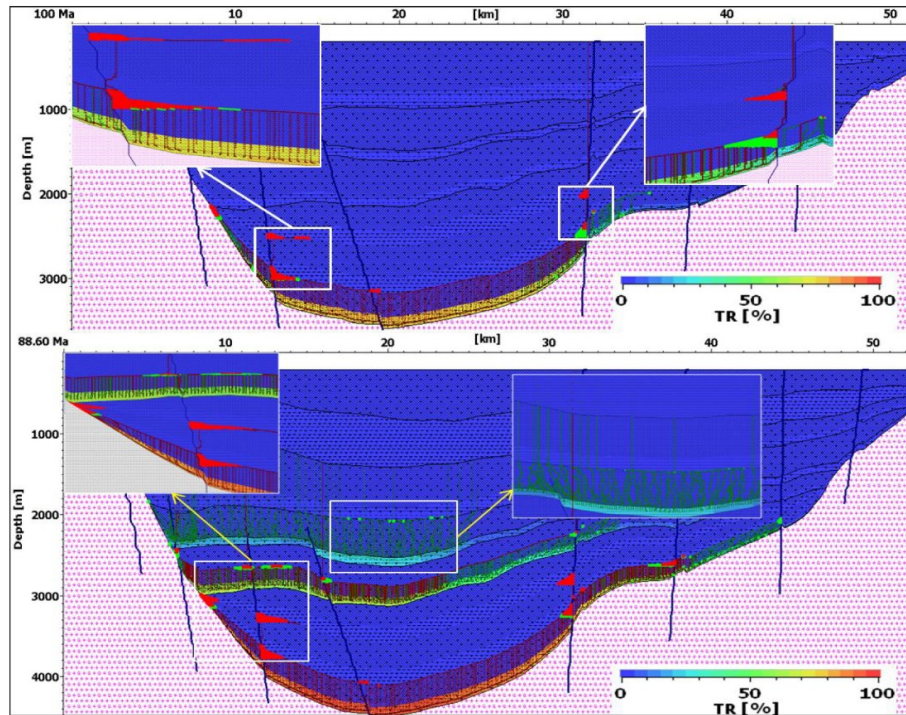


Figure 8: Overlay showing transformation ratio of source rocks and hydrocarbon migration pathways at different times of basin evolution. Most of the migration is vertical due to buoyancy and along the faults.

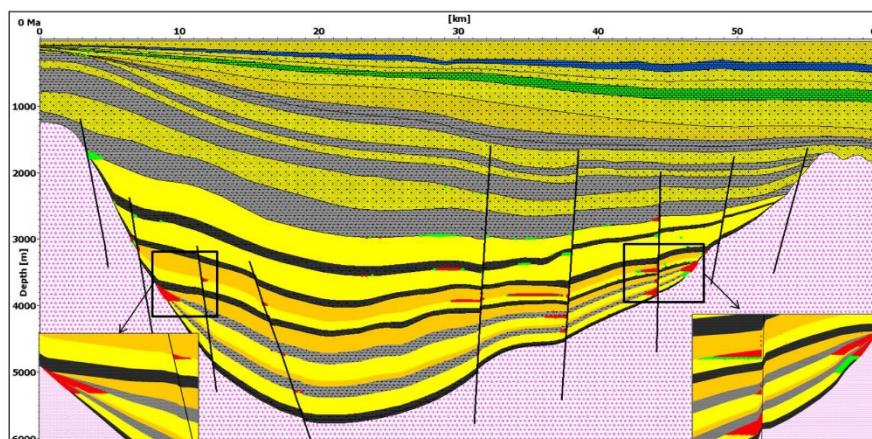


Figure 9: Overlay showing charged prospects within Andimadam sandstone sequences. Most of the sand and shale sequences act as a combination of reservoir and seal. Fault traps within lower Andimadam sandstones are also shown as likely scenarios of migration modelling.



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