

2D Petroleum Systems Modeling of Offshore Extension of Ariyalur-Pondicherry Sub basin, Cauvery Basin

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Keywords:

Petroleum Systems Modeling (PSM), Source Rock, Kinetics, Transformation Ratio, Critical Moment.

Abstract

Cauvery Basin, a peri-cratonic rift basin, located at the eastern coast of India, with 8-9 km of sediment deposits, has a significant/proven hydrocarbon deposit in its Onland fields, producing not only from the conventional Cretaceous and Tertiary reservoirs but also from unconventional Fractured Basement reservoir. Apart from the Onland fields, numerous HC discoveries have been made in the shallow offshore areas like PY-1 and PY-3 fields, currently the efforts are focused towards exploration of these plays into further offshore areas of Deep and Ultra-Deepwater areas of Cauvery Basin. In this paper, a 2D Petroleum Systems Modeling (PSM) for the offshore extension of Ariyalur-Pondicherry sub basin is attempted to study its hydrocarbon generation, expulsion and the associated migration pathways. Temperature, Maturity and Boundary conditions of the model were calibrated from the 1D PSM generated for a well located in proximity to the profile. Scenario testing with opening and closing of faults were performed to determine their behavior. The simulated model was used for analyzing the maturity of the late Jurassic, Barremian, Mid-Aptian, Aptian, Albian and Turonian source rocks, the timing of expulsion along with migration pathways of the generated hydrocarbon.

Introduction

Cauvery Basin, located along the Eastern Continental Margin of India (ECMI), is a rift basin which evolved as a result of continental drifting between India, Antarctica, and Australia during breakup of Eastern Gondwana Land and subsequent sea floor spreading (Powell et al., 1988). It is the largest Category-I basin of India, spread across 2,50,000 sq. km. including both onland and offshore areas with established

production of hydrocarbons. Exploration in this basin started over 5 decades ago and resulted in discovery of several oil and gas fields.

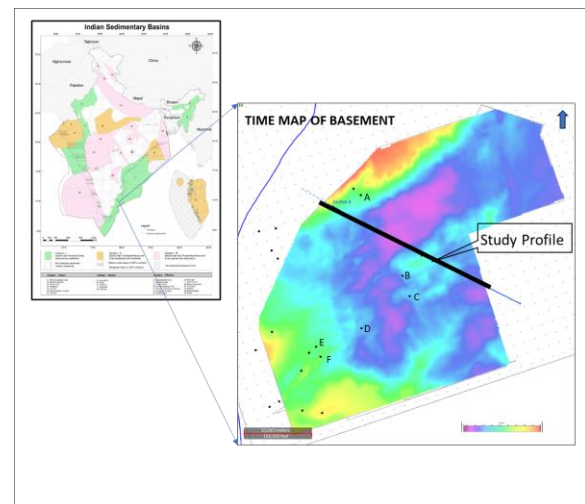


Fig 1. Location of the Study Area showing Time map of Basement.

Initial exploration in Cauvery offshore paved the path for the HC discovery in the PY-1 structure (from Fractured Basement & Eocene sands) in 1980 & PY-3 structure (from lower Nannilam sands) surrounding the Portonovo High in 1983 off the coast of Pondicherry along with PH-9 in the Palk Bay area in 1981, followed by the discovery of Ganesha Field (Fan-A) in the Cretaceous fan slope of Ariyalur - Pondicherry sub basin (offshore) in 2007. Subsequently, several discoveries were made by RIL in the Deep offshore blocks within Synrift, Turonian & late Cretaceous sediments (Source: NDR, DGH India). Well A and D in Fig.1 were gas discoveries from Turonian and Synrift sediments respectively whereas well F was gas and condensate discovery

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from Late Cretaceous sediments. Well B was dry due to poor reservoir facies and Well C was gas bearing (non-commercial) from Synrift sediments. A thorough analysis of the petroleum systems emerging in the Deep & Ultra deep offshore areas of Cauvery Basin for the discovered plays is essential for venturing into newer areas.

Tectonic and Geologic Setting

Cauvery basin was formed as a consequence of a basin evolution during the Late Jurassic-Early Cretaceous period. The rifting resulted in formation of alternate horsts and grabens, leading to the formation of several sub basins. The basin architecture consists of asymmetric half-grabens separated by basement horsts. The rift axes of the sub-basins are observed to be NE-SW which is substantiated by the dominant basement trends.

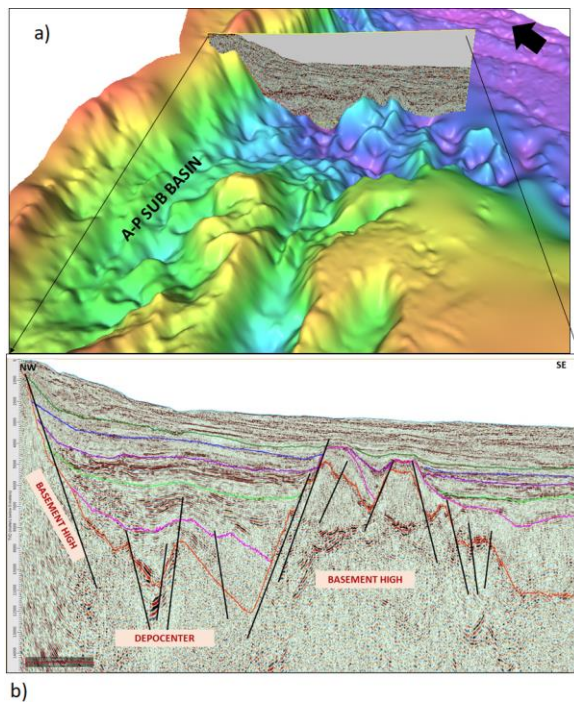


Fig. 2.a) Architecture of A-P & Tranquebar sub basin (onland & offshore); b) Interpreted 2D Seismic Depth Section.

Methodology

Petroleum systems modeling aims at reconstructing the history of the sedimentary basins by providing knowledge of the petroleum system elements and associated processes (Hantschel and Kauerauf 2009). PSM also aims at predicting the distribution of source rocks, its maturity, transformation ratio, critical moments and migration pathways of the generated hydrocarbons. A 2D PS Modeling was carried out along a NW-SE Regional line (Fig.1) across the offshore extension of Ariyalur Pondicherry sub basin for analyzing the Petroleum generation, migration, and its entrapment. The role of the faults was also considered for depicting the potential fluid migration pathways and distribution of the hydrocarbon along the profile.

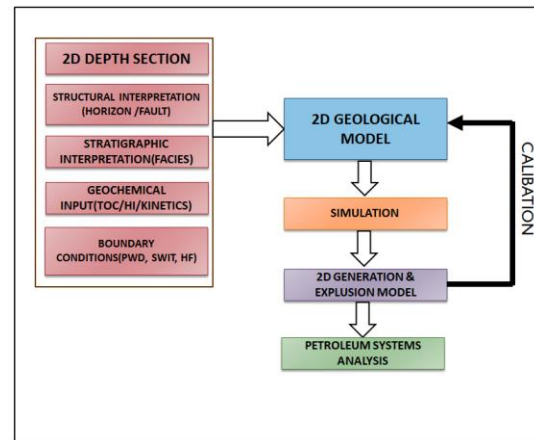


Fig. 3. 2D PSM Workflow

The EASy%Ro algorithm was used to calculate vitrinite reflectance from temperature histories (Sweeny and Burnham 1990). Thermal and maturity calibration of the source rocks were carried out through 1D modeling of the nearby well. As there aren't any wells drilled into this graben and therefore the TOC and HI values of the deeper source rocks were speculatively assigned considering them to be analogous with their onland counterparts.

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Model Inputs

A 2D PSM has been carried out along a depth seismic profile across offshore extension of A-P Sub Basin bounded by Basement high from North and South with 8-9km of sediment thickness which ranges from Late Jurassic to recent age (Fig.2.a). The depocenter observed in the 2D profile is oriented along the rift axis (NE-SW) of A-P sub basin. 8 Major horizons representing the paleo-topography along with faults were interpreted in the seismic section vividly depicting the architecture of Synrift sediments, overlain by the late Cretaceous and Tertiary deposits (Fig.2.b). The workflow adopted for the study is illustrated in Fig.3. The thickness, age and lithologies of the respective formations are based on information from the proximally drilled offshore wells and from the established 3D PS Model of Onland Part of the A-P & Tranquebar sub basin (Wagh et al., 2022). The lithological variations observed in the nearby wells were approximated to obtain a gross picture of the PS elements. The model attempted to emulate the lateral variation in facies for different formation by assigning lithological parameters derived from the adjacent established plays (Fig 4.a). Although several erosional events are evident in the seismic section, only the major erosive events during the basin fill have been considered for the simplification of the model. This may lead to slight underestimation of the burial history but its effect on the maturity will be negligible. In this model, source rocks have been assigned at the bottom of rift fill and during the major transgressive events occurring through the evolution of the basin.

Due to lack of geochemical data for the deeper source rocks, the authors had to speculatively assign TOC, HI values & Kerogen type based on the regional understanding (Janardhan et. al. 2013) and analysis of the depositional environments (Fig.4b&c), whereas the Late Cretaceous and Tertiary source rocks parameters were derived from the nearby drilled wells. Out of the 6 identified source rocks, Barremian and Mid Aptian SR were assigned Type II (Burnham 1990) kinetics whereas Late Jurassic, Aptian, Albian and Turonian SRs were assigned Type III (Pepper-Corvi, 1995) kinetics.

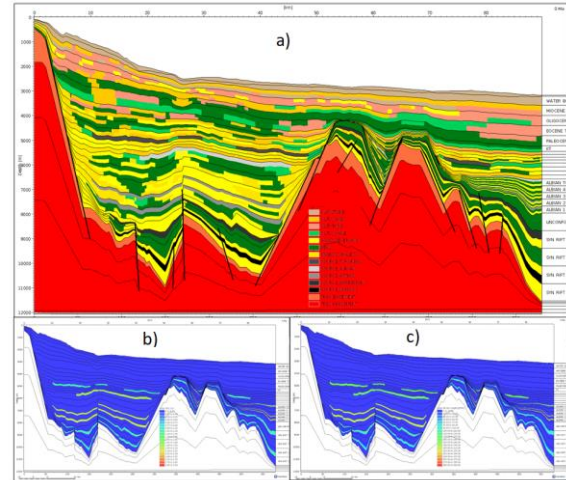


Fig. 4.a). 2D geological Model, b) Initial TOC, c) Initial HI.

Boundary Conditions

2D Paleo-bathymetry variations were generated for 7 levels viz, Jurassic, Albian, Turonian, Santonian, Paleocene, Eocene, and Miocene levels by integrating the understandings of recently carried out paleogeographic studies with the existing regional Paleo-bathymetry Maps of Cauvery basin. The Regional Heat flow maps of Cauvery Basin were utilized to prepare the Basal Heat flow variation corresponding to major tectonic events such as rift initiation, climax etc. Additionally, Sediment/Water Interface Temperature (SWIT) which is a function of the surface temperature and water depth, was calculated from the integrated auto-SWIT tool of Petromod. The boundary conditions of the 2D model were calibrated through 1D PSM (Fig.5). The 2D Model was simulated using the Petromod's inbuilt Combined (Invasion Percolation & Darcy) migration algorithm. Multiple Scenarios were generated using opening and closing of faults to demonstrate sealing and non- sealing conditions and subsequently timing of faults was assigned.



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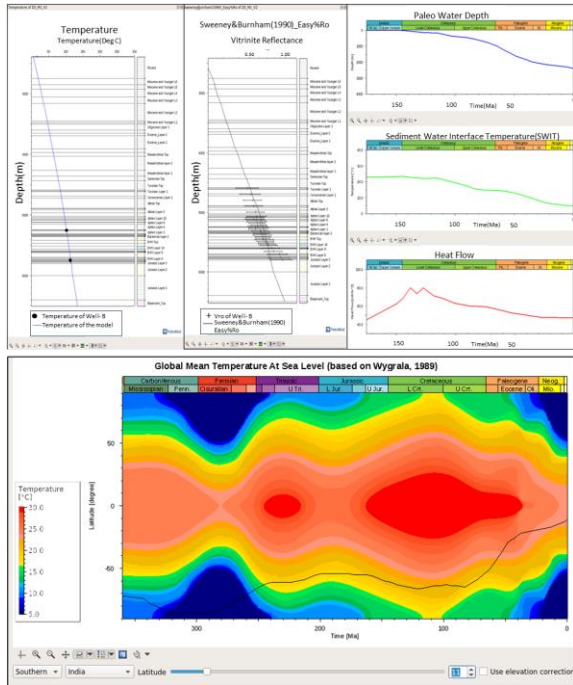


Fig. 5: Temperature & Vro and Boundary condition calibration through 1D PSM of the nearby well-B.

Results and Discussion

On simulation of the 2D model, Thermal maturity along the profile was generated with Transformation Ratio (TR) and Critical Moments (CM) of the identified Source Rocks (Fig.6. a, b & c). The study depicts that the Jurassic SR falls in dry gas window whereas Barremian SR falls across dry & wet gas window and rest of the source rocks from Mid Aptian to Turonian fall with early to late oil window.

The model illustrates that all the source rocks from Jurassic to Albian within the depocenter have transformed most of its organic matter into Hydrocarbon while the Turonian SR has just begun to transform. The model further shows that the depocenter in the South Eastern part of the area has transformed significant amount of its kerogen. These areas were not only prone to very high heat flows during the Rifting of Cauvery Basin but also had huge sedimentation giving rise to high overburden pressure which can be accounted for maximum transformation of organic matter within the sub

basins. The Critical Moment along with their TR % are represented in Table 1 below.

Source Rock	Kinetics	TR(%)	CM(Ma)
Jurassic	Pepper-Corvi T-III	96-98	100-83
Barremian	Burnham T-II	93-99	92-77
Mid-Aptian	Burnham T-II	85-100	89-78
Aptian	Pepper-Corvi T-III	90-96	81-79
Albian	Pepper-Corvi T-III	90-98	60-65
Turonian	Pepper-Corvi T-III	20-25	NA

Table 1: Transformation Ratio & Critical Moment of Source rocks.

The simulated model attempts to reproduce the migration pathways of the HC generated from the source to the nearby Cretaceous and Tertiary reservoirs (Fig. 7). Although significant amount of HC is observed to have escaped outside the system through faults, unconformities and vertically, it is to be noticed that some of the HC has been accumulated where structural or stratigraphic traps were present. Although, these entrapments corroborate with nearby proven accumulations to a certain extent and they seem to be encouraging but trap prediction through a 2D PS model is highly uncertain. For better understanding, a 3D calibrated model with complex lithological variation should be utilized to infer the true distribution and accumulation of Hydrocarbons.

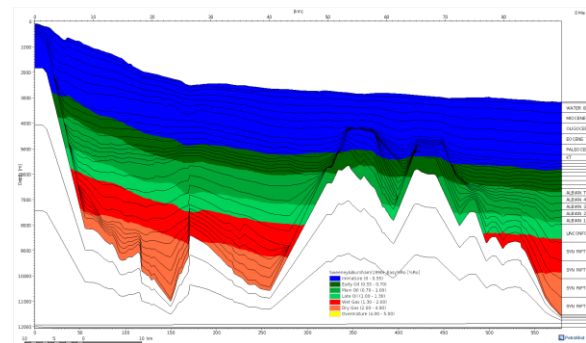


Fig 6.a Thermal Maturity along the Profile



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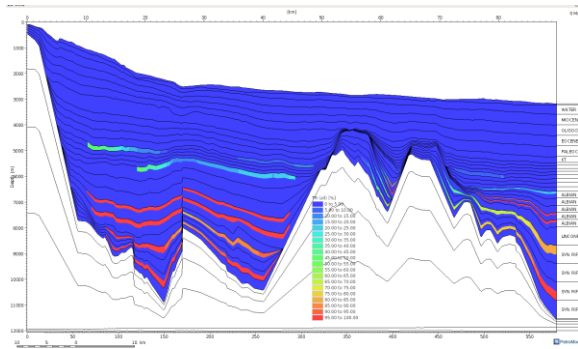


Fig 6.b. Transformation Ratio (%) of Source Rocks along the profile.

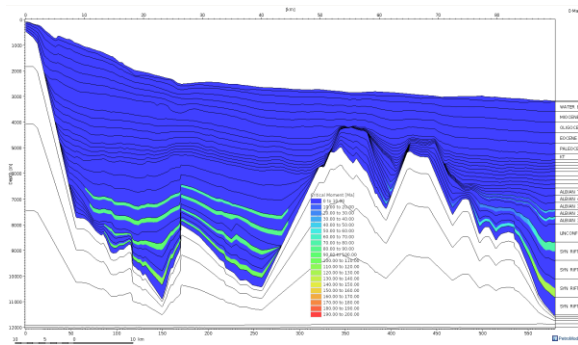


Fig 6.c. Critical Moments (Ma) of Source Rocks.

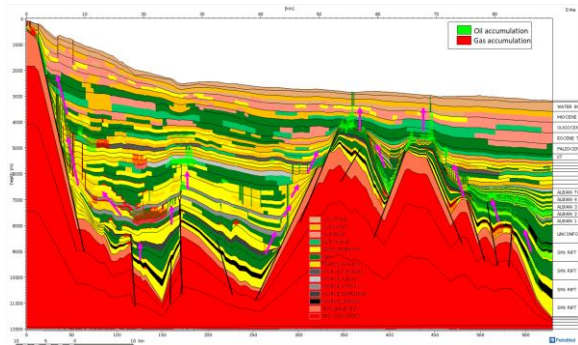


Fig. 7. Hydrocarbon distribution with migration vectors (highlighted through magenta arrows).

Conclusion

A 2D Petroleum Systems Model was generated for the Offshore Extension of Ariyalur -Pondicherry Sub basin along the NW-SE profile. In the grabens, the source rocks from Late Jurassic to Albian, fall mostly within the dry gas to peak oil window whereas

Turonian SR is in early oil window. The sources with TOC values ranging from 1-2% and HI values ranging between 80-200 mgHC/gTOC have been observed to have generated and expelled most of its hydrocarbons within the depocenter with TR values ranging from 85-100% except Turonian SR which has TR in the range of 25-30%. The Peak time of expulsion can be inferred to be within 100 to 80 Ma for Jurassic, Barremian, Aptian and mid Aptian SR while Albian SR attains CM around 60Ma. The distribution of the hydrocarbons within the section corroborates with nearby wells to some extent but it is to be noted that these accumulations are dependent on the lithological variation, structural and stratigraphic traps interpreted within the model. The true distribution and accumulation of hydrocarbons can only be addressed with a detailed 3D PSM.

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Acknowledgements

Authors would like to thank ONGC Ltd for granting permission to publish this work. We express our sincere gratitude to Shri. Shantanu Mukherjee, GGM Basin manager, Cauvery Basin, ONGC for his motivation and guidance. We would also like to thank Shri. P. S. Rautela, CGM, Block-I Manager, Cauvery Basin for his help & support. We would like to thank team RGL, Chennai for their support and cooperation. Views expressed in this paper are those of authors only.