De-risking of Kamalapuram Play in Nagapattinam sub-basin, Cauvery Basin: A Play Fairway Approach

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Summary

Geological risk mapping through 3D Seismic based Play Fairway approach is carried out for the prospectivity of Paleocene-Eocene Kamalapuram play in Nagapattinam sub-basin, Cauvery Basin. 3D Structural model with high resolution lithofacies model is utilized to generate a calibrated petroleum system model with hydrocarbon flow vectors. Composite Chance of Success Map (COS), also known as common risk segment maps for Kamalapuram Play in study area is prepared by integrating COS maps of Reservoir, source, seal and charge, which are the outputs of Petroleum System Model. The COS maps are highly helpful for chalking out future exploration areas and measures the risk associated.

Introduction

A Play is group of discovered and undiscovered pools of petroleum that share a common gross reservoir, top seal and petroleum charge systems (Allen and Allen, 2013). Play fairway is the geographical area over which the play is believed to extend. Play fairway analysis is the evaluation of a Play by mapping the risk component of a play in the area of interest (Fig. 1).

Figure 1: Play fairway analysis approach.

It is becoming standard practice in oil industry as huge investments are dependent on risk factor. This approach creates Composite COS map (Chance of Success) by integrating COS maps of elements of Petroleum System (Reservoir, Source, Seal and charging). It provides pathways to identify the prospective areas of basin and ranks them into low, medium and high risk categories (Fig. 1). Low risk means all the four elements of petroleum system are present and risk increases these components are missing.

Cauvery basin is the southernmost petroliferous basin of India (Fig. 2). It is a pericratonic rift basin evolved during Late Jurassic break up of Gondwanaland and developed into a passive margin setup by the end of Cretaceous (Rangaraju et al., 1993). The basin is evolved as several horsts and graben due to the interaction cross-trends and drifting. Nagapattinam is one the prolific hydrocarbon producing sub-basin of Cauvery basin. Late Jurassic-Albian Synrift Andimadam shales are effective mature source rocks in this basin (Fig. 3). Commercial hydrocarbon is established throughout geological column right from Proterozoic fractured basement to Oligocene Neravy sands.

Figure 2: Tectonic map of Cauvery basin (left) and study area showing Nagapattinam sub-basin (right).
K/T boundary in Cauvery basin is a known pronounced unconformity (having a range of ~8Ma hiatus), where the huge thickness Companian-Maastrichtian sediments (Fig. 5). This erosion has led to the progressive development of submarine canyon known as Kamalapuram canyon. The Kamalapuram sands are deposited as channel fills and debris flows in this K/T cut during Paleocene and as slope fans, debris flow and turbidites during lower Eocene (Prabhakaran et al 2007). These sands commercial oil and gas producers from several fields along the canyon. The present study aims to identify other potential areas in Nagapattinam sub-basin for the Kamalapuram play by the play fairway approach.

Methodology
The workflow followed in present study is schematically shown in Fig. 4.

Play Fairway Analysis (PFA) at basin scale is generally carried out at basin scale (mostly on 2D lines) by integrating regional maps of all four petroleum system elements. The more scientific approach is to carry out petroleum system modelling (PSM) followed by PFA. In the present study, this method is followed by preparing a detailed reservoir model and PFA is carried out after PSM simulations.

The study area is covering Nagapattinam sub-basin is having an area of ~2500skm where 1600 skm is covered by megamerge 3D PSTM data while the remaining area is covered by 2D lines. After lithological interpretations and log correlation, major regional horizons and faults are interpreted (Fig. 5) and structural model is built in depth domain (Fig. 7). The Nagapattinam sub-basin is bounded by Pattukottai-Mannargudi high to the west and Vedaranniam high to the east and Karaikal high to the northeast and separated from northern Tranquebar by Tiruvarur-Pallivaramangalam spurs which join with Karaikal high (Fig. 2, 6 & 7). The time relief maps at K/T boundary portrays the E-W trending canyon (Fig. 6a). The other minor cut canyons can be seen at west of Nannilam area, west and south of Karaikal high. The time relief at level close to Kamalapuram top (lower Eocene) shows basin deepening towards east (fig. 6b). Structuring is seen in the canyon part and also at the northern part of Vedaranniam area.
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faults (bounding the canyon) (Fig. 7b). These faults play critical role in charging the Tertiary sands.

Kamalapuram has formation spans from Paleocene and Lower Eocene and the mode of sand deposition is different in both phases. The Paleocene Kamalapuram sands are mostly cut fill deposits while the Lower Eocene sands are deposited as both slope fans, channels and turbidites in an well established shelf-slope system. The sand isolith maps are prepared utilizing the well data, isopach maps and net acoustic impedance attribute slices and refined manually. These maps show that Paleocene sands are restricted to cut areas, while the Lower Eocene sands are more wide spread and also showing the E-W channel trends (Fig. 9).

The cross-plots of NPHI vs P-Impedance for Kamalapuram sands (Fig. 8) show a broad separation of sand-shales in P-impedance with slight overlap. The sands have higher impedance than that of shales. Post-stack inversion has been carried out and P-impedance volume is generated, which is useful for facies discrimination.

A structural model of 200mx200mx25m resolution (Vertical resolution of 20m in Kamalapuram Fm) is prepared with horizons from basement to ground level and faults. Around 125 layers have been made to make the vertical resolution. Well lithology and P-impedance is populated into the model and litho-facies model is
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generated by well data and co-krigged with P-impedance (Fig. 10).

Petroleum System Modelling

The following workflow is adopted for the Petroleum system modelling (Fig. 11).

![Methodology for simulation of Petroleum system model.](image)

The prepared geological model with reservoir, faults and facies model is taken to simulator platform. Age assignment to different layers and fault properties are defined in the model as per the geological understanding. Cauvery basin has two effective source layers within Andimadam Formation, viz., Kimmeridgian and Albian. TOC %, HI and Tmax are loaded from well data (Janardhan et al., 2013). Kimmeridgian shales have 1-3% TOC while Albian shales have average TOC of 1.5-3.37% (Fig. 12). Kimmeridgian shales are having restricted extent in this sub-basin.

The other important parameters such as Erosion maps, heat flow, paleo water depths (PWD) maps (ONGC internal data) are loaded into the model. There are five major unconformities recorded in Cauvery basin viz., (1) Middle Miocene Top, (2) Oligocene Top (<200m), (3) Maastrichtian Top (<1500m), (4) Turonian Top (<200m) and (5) Albian Top (<150m) (source: PScube report). Rift duration is considered as 160Ma to 101.5 Ma for heat flow study. Bottom hole temperature data from around 70 wells is loaded. Heat Flow was in the range of ~85 mW/m² during Albian and was gradually decreased with time and present day heat flow observed is ~35-45 mW/m². Sand porosity, Vitrinite reflectance and Bottom-hole pressure data from ~70 wells are loaded to the model which will be used for calibration purposes. The further detailing of PSM is outside the scope of present study.

The simulation is carried out in three steps (thermal, pressure and migration) with calibration at each step which took several iterations. Bottom hole temperature, pressure and Vitrinite reflectance are used for calibration purposes (fig. 12c). Transformation ratio (fig. 12d) suggest that Albian source rock are in early oil to wet gas window while Kimmeridgian source rock are in main oil to dry gas window. The migration simulation is carried out in several iterations and calibrated with field accumulations (Fig. 13). An additional H/C flow migration simulation is run on split mode where independent sub-layers are as used zones. The output is the migration flux which is depicted as flow vectors and it shows the path of migration from source to reservoir (Fig. 14). These flow vectors at Kamalapuram and adjacent field suggest that the migration is from southern depocentre (Fig. 14b).

![TOC % maps of (a) Kimmeridgian and (b) Albian source rocks. (c) Vitrinite Reflectance (VRo) and (d) Transformation ratio maps of Albian source rocks.](image)

The geological event charts are extracted at different places of basin to understand the chronology of generation-migration-accumulation (Fig. 15). The critical point for Kimmeridgian source rock is ~100-79Ma while that for Albian source rock ranges from 67 Ma to 17Ma and trap formation is during Eocene for Kamalapuram play. Here it is to be noted that different parts of sub-basin will have different critical
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points and maturity. It appears that Albian source rock mainly charged the Tertiary plays.

Figure 33: (a) NW-SE section showing transformation ratio of source rocks. (b) Simulation result showing H/C accumulations for Kamalapuram formation.

Figure 14: Results of flow simulation showing H/C flow vectors (on left) and zoom at Kamalapuram area showing calibrated H/C accumulations and flow vectors (on right).

Figure 15(a): Geological Event Chart & Generation balance diagram Extracted from central part of sub-basin.

Figure 15(b): Geological Event Chart & Generation balance diagram Extracted at a pont close to canyon of sub-basin.

Play Fairway Analysis

The final simulated result is used to create play chance maps (also known as CRS- Common risk segment maps) of Kamalapuram play. The source rock COS map is prepared by combining source presence COS (TOC%) and source maturity (combination of VRo & Transformation ratio) (Fig. 16a). The charge map is prepared by the H/C accumulation results from the system and flow paths (Fig. 16b). The reservoir COS map (Fig. 17) is prepared by integrating reservoir presence and quality (porosity).

Figure 16: Chance of Success (COS) maps of (a) Source rock and (b) Charge.

Figure 17: Chance of Success (COS) maps of Reservoir.
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Conclusions

3D seismic based petroleum system modelling is carried out in Nagapattinam sub-basin for Kamalapuram play using high resolution reservoir and structural model. The generated model is calibrated at established H/C fields of Kamalapuram play. Risk mapping by Play fairway approach is carried out using the prepared geological model and the results of PSM to find out the future low risk areas for exploration of Kamalapuram play. The results show some encouraging areas with low to medium risk. The present study has establishes a comprehensive workflow for the risk mapping of any play using 3D seismic volume at sub-basin to prospect level. The present study will provide the pathway for future risk mapping studies for other plays in different sub-basins.

References


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