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A relook into the Hydrocarbon Prospectivity of Kamalapuram Formation in Cauvery Basin through Play Fairway Analysis

Abstract

Kamalapuram play was established as a stratigraphic canyon play in Nagapattinam sub-basin, but remained elusive in Ariyalur-Pondicherry and Tranquebar sub-basins till 2014. In the year 2014, wells drilled over Madanam high produced hydrocarbons from structural plays in Kamalapuram Formation. The purpose of this study is to map areas with an equal probability of hydrocarbon occurrence within Kamalapuram Formation in Ariyalur-Pondicherry and Tranquebar sub-basins of Cauvery basin. This study involved integration of Geological modeling, Petroleum System Modeling and Play Chance mapping using different software. Play Fairway map demonstrates areas of high probability of hydrocarbon occurrence in relation to the spatial distribution of effective source, reservoir and seal. The study has brought out that the effective source sequences for Kamalapuram play are in the Albian to Late Jurassic sediments. Play Fairway map indicate high probability of hydrocarbon occurrence in Madanam high which is validated by drilled wells wherein the wells flowed oil and gas from Kamalapuram Formation. Also the north-western flanks of Karaikal high, the PYA structure and the north-western edge of Ariyalur-Pondicherry sub-basin indicate good probability of hydrocarbon occurrence.

Introduction

Play Fairway Analysis is the process of identification of areas within the basin where specific geologic attributes necessary for the existence of hydrocarbon accumulation exists. Play fairway maps (also referred to as traffic light maps or common risk segment maps) are used to highlight sweet spots in hydrocarbon exploration and to address matters of prospect risk on a regional or basin-wide scale. Recently, this approach has been more widely employed to rank and compare the prospectivity of large areas, especially in the early part of exploration cycle. Play fairway maps are closely related to the various elements of petroleum systems, viz., source, reservoir and seal. Also, the timing of generation, migration and accumulation of hydrocarbon plays a vital role in Play Fairway analysis.

Cauvery basin, located in the southeastern part of the Indian Peninsula, evolved in Late Jurassic time as a result of rift-drift phenomenon of the then Indian plate from Gondwanaland. Numerous down-to-basin extensional faulting took place in the Cauvery Basin due to rifting. These faults trend parallel to the Pre-Cambrian Eastern Ghats trend (NNE-SSW) giving rise to horst-graben setting. Formation of grabens and horst blocks subdivided the Cauvery Basin into five sub-basins. The present study is confined within the two northern sub-basins viz., the Ariyalur- Pondicherry Sub-basin and the Tranquebar Sub-basin. These two sub-basins are separated by the Kumbakonam-Madanam-Portonovo High (Fig 1).

Oil and gas have been found in different formations ranging from Pre-Cambrian basement to Oligocene in Cauvery basin. The Nagapattinam sub-basin, which is located south of the Tranquebar sub-basin, has produced hydrocarbon from Kamalapuram Formation of Paleocene-Eocene age. The hydrocarbon bearing reservoir sands of this play in this sub-basin are mostly deposited in canyon fill set-up. Similar canyon fill set-up in Ariyalur-Pondicherry sub-basin is, however, non-hydrocarbon bearing. Recently, Kamalapuram Formation has been established as a structural play over Madanam High of Ariyalur-Pondicherry sub-basin. The current study involve preparation of play fairway map for Kamalapuram play in Ariyalur-Pondicherry and Tranquebar sub-basins of Cauvery basin covering an area of approximately 10500 sq. km.

Methodology

Play Fairway Analysis essentially begins with the preparation of a detailed Geological Model of the study area. In the study, the model comprise of eleven surfaces, viz., tops of Basement, Jurassic, Albian, Turonian, K/T boundary, Paleocene, Early Eocene, Eocene, Close to Oligocene top, a reflector close to Mid-Miocene top and present day surface. As the analysis required more precise understanding on the spatio-temporal distribution of facies, a 3D seismic facies model was generated based on well data and seismic attribute. The geological model (depth surfaces of key stratigraphic horizons / Faults / Facies) was utilized in Petroleum System Modeling. In this phase of workflow, well data and geo-chemical data was integrated. Source rock kinetics was carried out. Erosion maps and Paleo-water depths were integrated and Temperature and VRo data was calibrated. The TOC, Vitrinite Reflectance (VRo) and Transformation Ratio (TR) maps generated in the model was used for preparation of Chance of Success (COS) maps for the quality of source rock. Also, the Critical Moment of hydrocarbon migration from source to the available reservoir facies of Kamalapuram Formation along with the Migration Flux was derived from the model.

The third and final phase of the study was Play Fairway Analysis. In this phase, the individual maps corresponding to different elements of Petroleum System viz., Source, Reservoir and Seal, are first converted into their corresponding Common Risk Segment (CRS) maps by assigning a probability of success value to each element. The three Play Element CRS maps thus obtained were then combined using a second order multiplicative overlay to generate the Composite CRS (CCRS) map or Play Chance map of Kamalapuram Play. This paper focus mainly on the play chance mapping carried out for Kamalapuram Formation. The input required for the study was generated in the geological model and petroleum systems modeling. The Flow Chart used in this study is shown below (Fig 2):

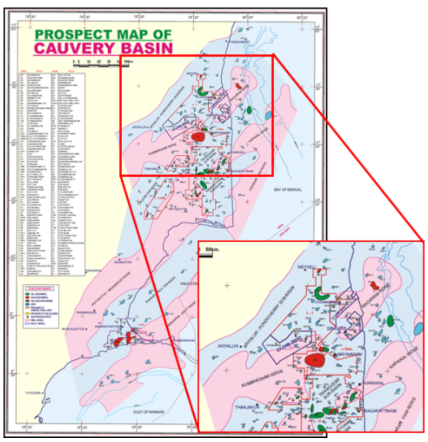


Fig 1: Map showing Study Area

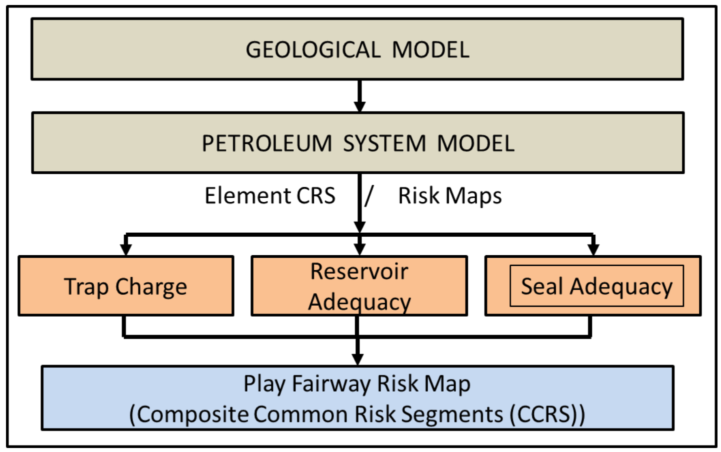


Fig 2: Flow Chart for Play Fairway Risk Map

Play Chance Mapping

Before elaborating on the techniques of Play Chance Mapping, an idea on the geological model is necessary. The Geological model which comprises of eleven surfaces of the static model starting from Basement top to present day surface, was sub-divided proportionately into a 175 layer model. This model has a grid size of 500m x 500m and minimum vertical resolution of 9.2 m. The model contained 10.2 million cells. Lithology curve of around 130 key wells were used along with seismic RMS attribute volume, which was used as secondary attribute for constraining the facies. Sequential Indicator Simulation (SIS) method was utilized to create the facies model with RMS attribute as secondary property. The Geological model which comprise of the surfaces, faults and facies was used in Petroleum System Modeling.

In the study area, appreciable sand thickness is observed in Lower Kamalapuram Formation along the axis of canyon eroded on Cretaceous top surface. Wells which were falling away from canyons have very less thickness of sand. As regards the provenance of these sands, it is envisaged that the coarser sediments were brought from western basement massif and deposited along the canyon in unstable tectonic environment. The Upper Kamalapuram Formation, on the other hand, is deposited as prograding sequence as observed in seismic transects.

Source rocks of Albian and older age play a vital role in charging the reservoirs of Kamalapuram Formation. The intervening shale layers within the Formation act as a seal, apart from the presence of an overlying regional seal i.e., the Karaikal Shale of Eocene age.

In the present study, different properties of the key play elements such as the presence, maturity and Transformation Ratio of source, charging, critical moment, reservoir presence, reservoir effective porosity, seal presence and seal thickness are each converted into Chance of Success (COS) maps. They are converted through a suite of geological property-to-chance transform methods. Chance of success values is assigned for a particular element based on logical assumptions, ranging from 0 to 1, with 0 representing least probability and 1 representing highest probability). Such as, for a TOC value of 1, chance of success assigned is 70%, whereas for TOC value of 0.20, chance of success assumed is 10%. All individual play element chance maps are then combined into a CRS map for trap charge, reservoir adequacy and seal adequacy. The Trap Charge CRS map includes not only the COS maps of source elements but also the probability of hydrocarbon migration. Finally, all these CRS maps are combined to generate a "Composite Common Risk Segment (CCRS) map" (Fig 3). The Trap Charge CRS map constitutes Source rock presence, Source rock quality, Migration pathways and Critical moment. The Reservoir Adequacy CRS map is a combination of reservoir presence and reservoir quality. Reservoir presence is determined from the seismic facies volume and the effective porosity derived from Petroleum System Model is utilized for reservoir quality. The Seal Adequacy COS map is prepared by combining both the seal presence and gross thickness of seal above the reservoir.

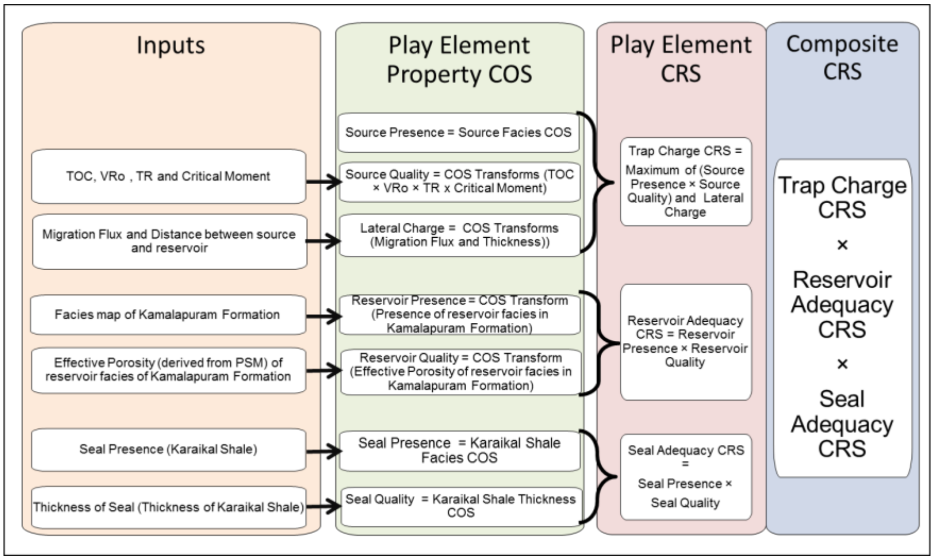


Fig 3: Flow Chart for Composite CRS (CCRS) map used in the study

Trap Charge CRS map

Petroleum System Modeling indicates that the reservoirs of Kamalapuram Formation are charged from Albian and older source sequence. As this sequence is an effective source rock with very good organic matter richness (TOC values ranges from 1.17% to 4.08%), identified on the basis of geochemical data of drilled wells both at the basin center and also towards the periphery, the COS for presence of source is taken as 1. TOC, Maturity, Transformation Ratio and Critical Moment are considered in calculating the source rock quality. The COS Transform values used in the preparation of COS map for TOC, VRo and TR is shown in Table 1:

COS Transform					
TOC Transform		VRo Transform		TR Transform	
TOC	COS	VRo	COS	TR	COS
0.20	0.10	0.05	0.00	5.00	0.10
0.50	0.30	0.80	0.50	20.00	0.20
1.00	0.70	1.00	0.75	30.00	0.60
2.00	1.00	1.50	1.00	50.00	1.00

Table 1: COS Transform values for TOC, VRo and TR

An average of COS values for TOC, VRo and TR in three sub-layers representing upper, middle and lower part of the source sequence is mapped for the respective COS maps of Source Quality (Fig 4a and Fig. 4b). Also the Critical Moment for these source layers are considered while calculating the CRS map of Trap Charge. As deposition of Karaikal Shale which act as a regional cap rock took place during Eocene age (approx. 55 Ma to 33 Ma), areas of source rock having critical moment between 55 Ma and 33 Ma is assigned a probability value of 1. In case of Lateral Charge, two variables viz., the migration flux and the thickness of sediments between the reservoir and effective kitchen are used. From Petroleum System Modeling, it is observed that the frequency of migration flux is relatively high towards the basin margin around Mandanam-Kumbakonam and Karaikal highs. Polygons representing high, moderate and poor migration flux are drawn and COS values assigned accordingly. The presence of faults that transcends the Cretaceous top upto Kamalapuram reservoir levels are also considered while creating these polygons. The second variable used in calculating the Lateral Charge is the thickness between the reservoir and effective kitchen. It is assumed that thicker the Upper Cretaceous sediments, migration of hydrocarbon from Lower Cretaceous and Late Jurassic source sediments to the target plays shall be more hindered. COS map for this variable is prepared considering COS values of 0.75 where the intervening sediment thickness is less than or equal to 300m and 0.15 where it is equal to or more than 3500m. Maximum value of the COS of source rock presence, quality and lateral charge results in the Composite Risk segment (CRS) map of Trap Charge (Fig 5a).

Reservoir Adequacy CRS map

The CRS map for reservoir adequacy is prepared by combining the COS maps of reservoir presence and quality. In the facies model, the Kamalapuram Formation is sub-divided into 64 sub-layers. Reservoir presence is determined from the spatio-temporal distribution of sandy and silty facies within six sub-layers. Sandstone and siltstone facies in these sub-layers are considered as having a probability of 80% in regards to reservoir presence (COS of 0.80) (Fig 4c).Similarly, the reservoir quality of these sub-layers is taken from the effective porosity derived from the Petroleum System Model. Reservoir quality represented by effective porosity derived from Petroleum System Model and having a value of more than 20% porosity is assigned a COS value of 1. Combining the COS maps of reservoir presence and quality, the CRS map of reservoir adequacy for Kamalapuram Formation is derived (Fig 5b).

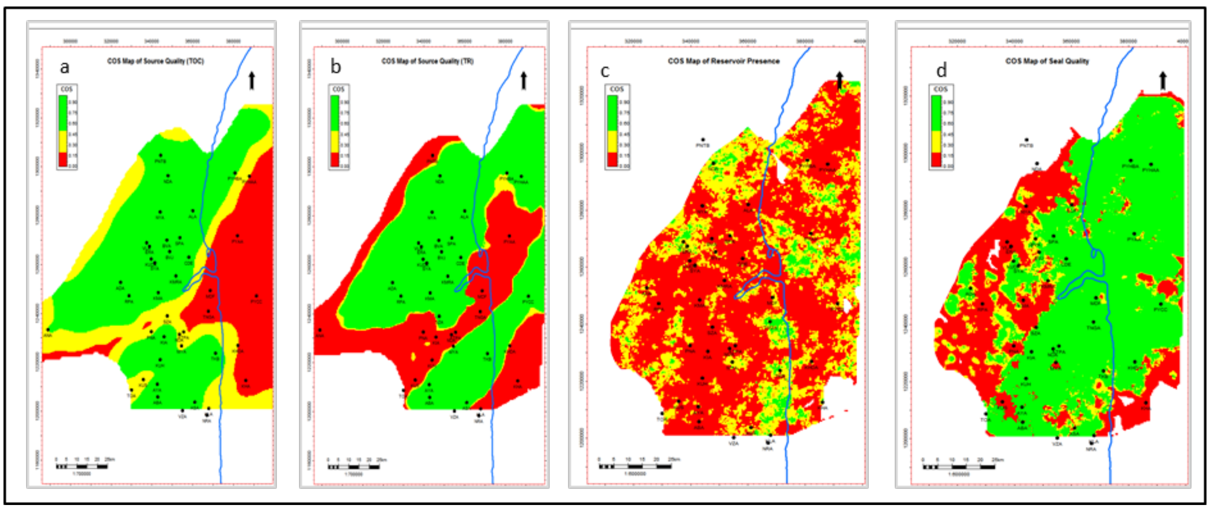


Fig 4: COS maps of (a) TOC of Source, (b) TR of Source, (c) Reservoir Presence (d) Seal Quality

Seal Adequacy CRS map

The Karaikal Shale overlying the Kamalapuram Formation of Paleocene to Early Eocene age acts as a regional seal. Moreover, intervening shaly layers within the Kamalapuram reservoir sands also act as a top seal. For preparation of CRS map of seal adequacy, presence and thickness of shale above Kamalapuram Formation is used. In the facies model, Karaikal Shale sequence of Eocene to Early Eocene age is divided into 10 sub-layers. Shaly facies of three sub-layers within the sequence were averaged to create the COS map of seal presence above Kamalapuram Formation. Also the gross shale thickness within the sequence is considered for preparation of seal quality (Fig 4d). Thickness of less than 10m is assigned a COS of 0.1 and a thickness of more than 30m is assigned a COS of 0.9. The CRS map of seal adequacy for Kamalapuram Play (Fig 5c) was thus prepared combining the COS maps of seal presence and seal quality.

Composite CRS (CCRS) map

The CCRS map of Kamalapuram play (Fig 6) indicates good probability of hydrocarbon occurrence over Madanam high (Area A in Fig 6), which has already been established by the wells MDF and TNGA. Similar probability is also seen in area north of Tirukaddiyur around well TKB (Area B in Fig 6). It is worth mentioning that the well TKB has indicated fluorescence and presence of gas from Kamalapuram

Formation during drilling, though not interesting from commercial hydrocarbon point of view. Another zone showing good probability of hydrocarbon occurrence is the area around Mayiladuthurai in Tranquebar sub-basin. High probability of hydrocarbon occurrence is seen along the north-western flanks of Karaikal high (Area E in Fig 6). Similar probability is also seen north of the well ALA in isolated patches along the coastline. The north-western edge of Ariyalur-Pondicherry sub-basin, between PONA and PNTB (Area C in Fig 6) show moderate to high probability of hydrocarbon occurrence. The PYA structure, in offshore area (Area D in Fig 6), also indicates better probability for hydrocarbon occurrence within Paleocene to Early Eocene sediments as seen in the CCRS map.

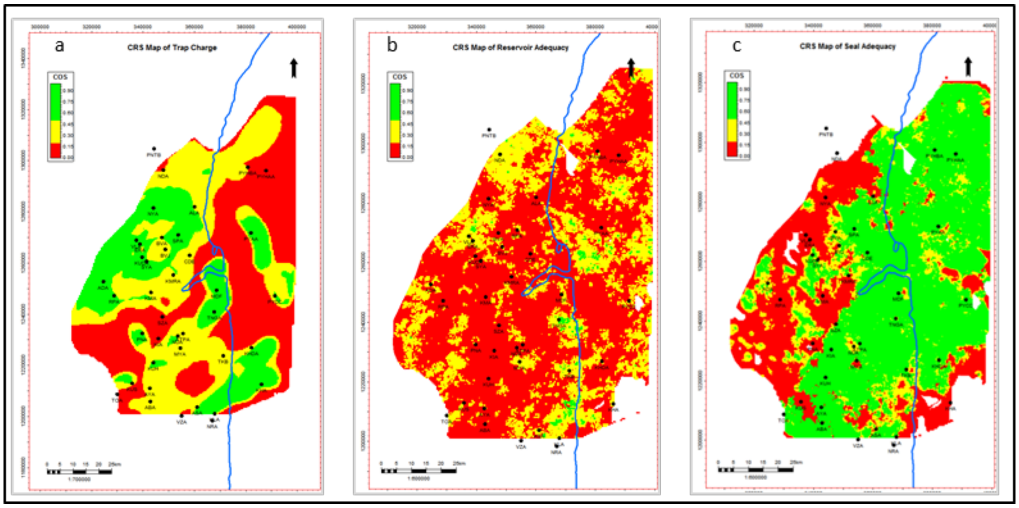
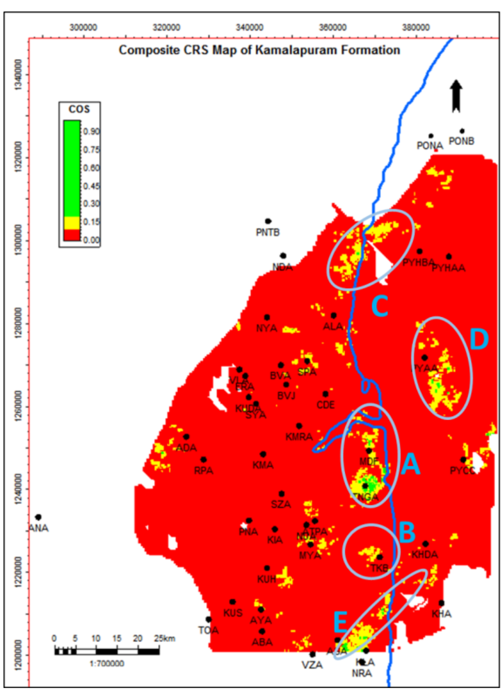


Fig 5: CRS map of (a) Trap Charge, (b) Reservoir Adequacy and (c) Seal Adequacy

Based on the CCRS map derived for Kamalapuram Play, the Play Fairway map for the same is prepared (Fig 7). This map highlights the sweet spots or high probability areas of hydrocarbon occurrence overlaid upon the source pod and reservoir presence. The Madanam and Thirunagari areas have better probability of hydrocarbon accumulation. Similarly, the eastern part of PYA structure and the north-western flanks of Karaikal High are interesting from Play Fairway point of view. In the north-western edge of Ariyalur-Pondicherry sub-basin, the area between PONA and PNTB deserve attention as can be seen in the Play Fairway Map.



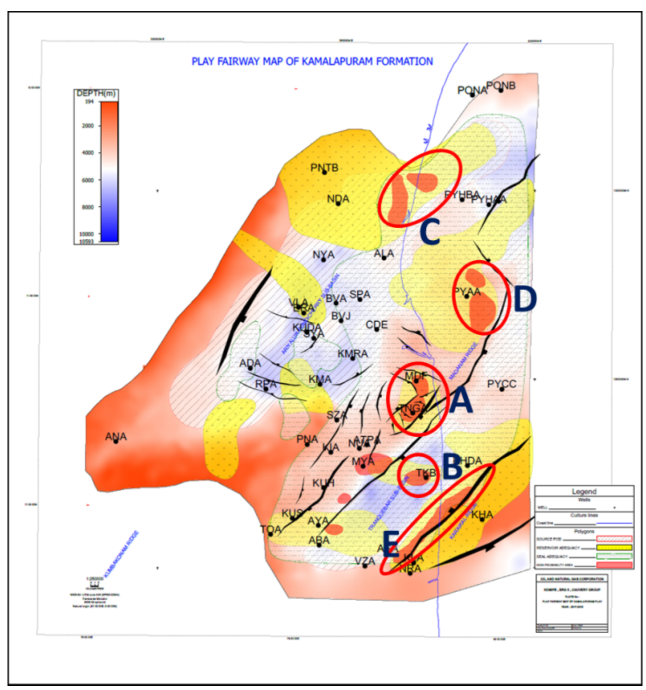


Fig 6: Composite CRS map of Kamalapuram Formation

Fig7: Play Fairway map of Kamalapuram Formation

Implication on Hydrocarbon Exploration

Taking cue from the hydrocarbon bearing fields within the canyon set-up of Nagapattinam sub-basin, several wells were drilled in similar set-up of Ariyalur-Pondicherry sub-basins. But all turned out to be dry. Though there was no dearth of reservoir facies in these wells within Kamalapuram Formation, the lack of charging due to presence of thick shaly section between the source pod and reservoir facies hindered hydrocarbon migration. Also the quality of regional seal becomes poor towards the western part of the basin. Exploring for hydrocarbon within Kamalapuram Formation in Ariyalur-Pondicherry sub-basin, barring the region close to Pondicherry and along Madanam-Kumbakonam high, may be risky. The most promising area for hydrocarbon exploration of Kamalapuram Play in the study area is over the Kumbakonam-Madanam-Portonovo high. The rising flanks on either side of Tranquebar sub-basin, most importantly towards the Karaikal high, looks interesting.

Conclusion

The Play Fairway map of Kamalapuram play indicates high probability of exploration success over Madanam high. It is worth mentioning that the Madanam and Thirunagari fields over Madanam high, where high probability areas is seen (Zone A in Fig. 6), has proved hydrocarbon accumulation within Kamalapuram Formation. Apart from that, area around Tirukaddiyur (TKB, Zone B in Fig. 6) and the north-western flanks of Karaikal high (Zone E in Fig. 6) also indicate good probabaility of hydrocarbon occurrence. Similarly, the PYA structure (Zone D in Fig. 6) indicates favourable locales for hydrocarbon exploration. In the western edge of Ariyalur-Pondicherry sub-basin, the area between PONA and PNTB (Zone C in Fig. 6) deserve attention as can be seen in the Play Fairway Map.

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