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# A relook into Andimdam Play prospectivity in central and south western part of Ariyalur-Pondicherry sub basin of Cauvery Basin within the context of Play Fairway Analysis

## Abstract

Ariyalur-Pondicherry sub basin located in the northern part of Cauvery Basin has established hydrocarbon potential of various plays from Basement to Tertiary. Commercial production from fractured Basement play and Bhuvanagiri play of Turonian are already established. Exploration for Andimadam play has been mainly restricted to basinal part of the sub basin and only limited number of wells were drilled through. Hydrocarbon presence was indicted in the wells where the play has been encountered. However, commercial potential of Andimadam play is yet to be established in the sub-basin. Play Fairway Analysis was attempted to identify risk and rank areas based on play elements of hydrocarbon source potential, reservoir facies and probable cap rock. Accordingly, source rock properties, reservoir data, seal thickness and electro logs of drilled wells were integrated with 3D seismic data to generate facies map, CRS maps for source, reservoir and cap rocks. Composite CRS map was prepared to identify potential areas for Andimadam play in the sub basin. The result of the studies suggests that more prospective areas lie to the south western part as wells as to the unexplored areas south of wells # 8 and # 9. Though all the play elements are present in large area in the sub basin the quality of reservoir is a critical element for the play.

## Introduction

Ariyalur-Pondicherry sub basin (Fig.1) is the northern most sub basin of Cauvery basin where commercial successes are established from Bhuvanagiri play of Turonian and fractured Basement play along with encouraging results from Andimadam play of Albian & older and Nannilam play of Coniacian-Maastrichian age. However, the real potential of Andimadam play in the sub basin needs to be understood. The Play Fairway Analysis (PFA) is an attempt towards this objective by integrating the geological and geophysical data. in central and south western part of the sub basin.

## Regional Geological setting of Cauvery basin

The Cauvery basin is one among the major pericratonic rift basin along the east coast of India that have developed during the rift-drift events associated with the breakup of India from Gondwanaland. The Precambrian rocks of the Southern Granulite Terrain (SGT) and Eastern Ghat Mobile Belt (EGMB) limit the basin in the west. While the Chingleput high separates the Palar basin from Cauvery basin in the north, the Sri Lanka massif limits the basin in the south and towards east the basin extends into offshore and open to deep Bay of Bengal. The Basin covers an area of 1.5 lakh sq.km comprising onland (25,000 sq.km), shallow offshore areas (33,000 sq km) up to 200 m isobaths and about 95,000 sq km of deep-water offshore areas in the Cauvery Basin (Rangaraju et al. 1993; Bastia and Radhakrishna 2012). According to Prabhakar and Zutshi (1993), the basin is characterized by Jurassic–Early Cretaceous pattern of normal faults along NE–SW trending horsts and graben and these trends are in conformity with the Eastern Ghats trend.

The subsurface structure and the tectono-stratigraphic history of the Cauvery basin is well known from the previous geological and geophysical investigations (Sastri et al. 1973, 1981; Kumar 1983; Chandra et al. 1993; Prabhakar and Zutshi 1993; Rangaraju et al. 1993; Sahu 2008; Lal et al. 2009; Bastia and Radhakrishna; 2012). The basement is mainly composed of Archean metamorphic and igneous rocks comprising of granites, charnockites, quartzite, granitic gneiss and schists (Sastri et al. 1981; Sahu 2008).

Significant structural and tectonic elements observed in the Cauvery basin are: (i) Ariyalur–Pondicherry and (ii) Tanjavur–Tranquebar depressions separated by Kumbhakonam–Madanam ridge, (iii) Nagapattinam depression limited by Karaikal ridge on the north and Vedaranyam terrace in south, (iv) Palk Bay and Tanjavur depressions separated by Pattukotai-

Mannargudi ridge and (v) Mannar depression in Gulf of Mannar separated by Mandapam–Delft ridge from Palk Bay.

Ariyalur-Pondicherry depression is the northern most sub-basin of Cauvery Basin and is separated by Kumbakonam-Madanam ridge from the adjacent Tanjore-Tranquebar sub basins. This sub-basin, an asymmetric rift graben trending NE-SW, is flanked by outcropping Achaean granitic gneisses in the West & Northwest, Kumbakonam-Madanam ridge in the South/ Southeast and East and extending towards Northeast to the present day offshore up to 200m isobath into Bay of Bengal.

A series of longitudinal normal faults trending NE-SW, almost parallel to Pre-Cambrian Eastern Ghat trend formed during the rifting of Gondwana-land, are the main extensional faults through which active subsidence has occurred is associated with syn-rift phase of basin formation has been responsible for the horst-graben setting of Cauvery Basin. Another set of younger reactivated orthogonal fault system is trending NW-SE dissecting the pre-existing fault. This fault system played major role in sediment deposition and hydrocarbon accumulation and migration.

The Pre-Cambrian Basement is overlain by Andimadam Formation (Fig.2) of Late Jurassic to Early Cretaceous period considered as synrift sequence is having more than 1500m thickness. Syn-rift sediments were deposited mainly as independent alluvial fans from adjacent highs, in lacustrine and shallow marine conditions. Sattapadi shale of Cenomanian marine transgression forms the main regional seal for hydrocarbon accumulation of Andimadam play is also rich in source rock along with the source rock of Valanginian-Albian age. Stratigraphic succession of Ariyalur-Pondicherry sub-basin is shown in figure below.

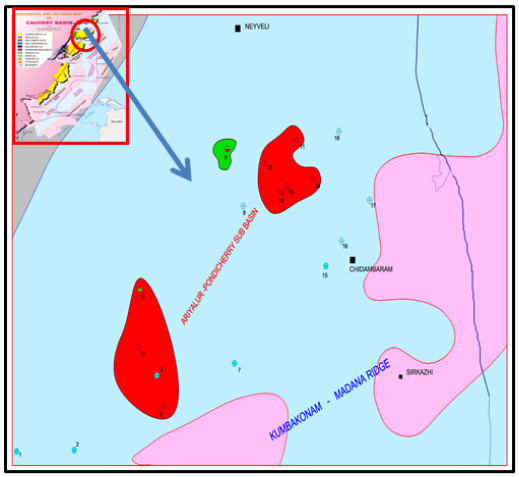


Fig-1: Location map of A-P sub-basin

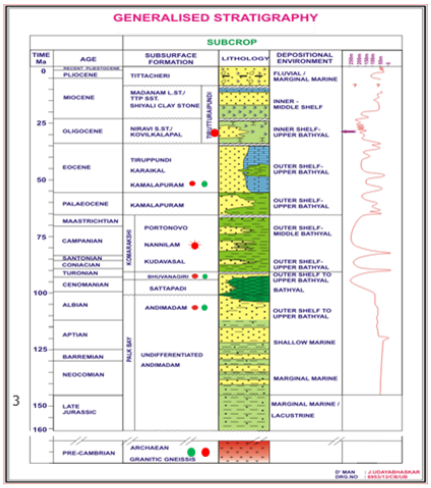


Fig-2: General stratigraphy of A-P sub-basin

Andimadam Formation is highly arkosic in composition, massive with sub angular floating granules, dish structures and interbedded with highly carbonaceous shale. Based on the core studies this formation is subdivided into three new members viz. Lower, Middle and Upper; deposited in proximal fan delta, mid to distal fan delta and proximal to mid fan delta conditions respectively on slope (as no shelf development) in shallow marine environment. The sediment supply was dominantly from point source and drainage was axial. (Dilip Bharktya et. al, March 2011)

## Present study

Present study is carried out in 3D seismic covered central and south western part of A-P sub-basin along with source rock and petrophysical data of 18 wells spread over the area which have drilled through Andimadam play though entire section is not penetrated in all the wells. In most of the wells this play has been tested either conventionally or by DST method. The testing results were not very encouraging from commercial point of view due to poor petro-physical properties of the reservoir. However, the results show Andimadam is a potential play in the area. To identify exploration risk and rank the area based on the play elements like source potential, reservoir facies and seal presence to provide an effective petroleum play, the study was attempted. The results of Play Fairway Analysis provide the foundation for an exploration campaign of the play in the area.

## Petroleum System Elements

**Source Rock characteristics**

In Ariyallur-Pondicherry sub-basin, which is the main source kitchen for Bhuvanagiri, Pandanallur and Madanam areas, within Andimadam sequence, effective source rocks have been identified in well # 7 in the depth interval 3750- 4220m and in well # 15 from 4620 to 4720m. Well # 6 drilled towards the south western part of the sub-basin, shale in the interval 3380-3385 contains fair to excellent quantity of organic matter (TOC= 2.67%, S2=2.02 and HI=76) which is considered as the kitchen for hydrocarbon presence in Andimadam area as well as Pandanallur Basement. Well # 5 shows the sediments in the interval 3845m to 3850m have very good organic matter richness. In well # 4, oil & gas prone source rock is present in Andimadam Formation in the interval 3580-4525m (TOC=0.25-2.73%, S2=0.30-3.93, HI=44-232).

**Reservoir Characteristics**

Andimadam Formation is highly arkosic in composition, massive with sub angular floating granules, dish structures and interbedded with highly carbonaceous source rock rich shales which are mature enough to generate oil and gas hydrocarbons. The sandstone is predominantly light grey and dirty white with occasional medium grey, fine to coarse, occasionally very coarse grained and floating sub angular to angular granules at places, moderately hard and compact, angular to sub-rounded grains are ill sorted and arkosic in composition. The interbedded shale is predominantly dark grey, moderately hard and compact, well fissile, richly carbonaceous and associated with free sulphur. Abundant organic debris and coaly matter is present. Green colored chloritic micaceous shale is observed in places.

Most of the wells in the study area like well #4, #5 and #6 shows presence of gas while drilling Andimadam play. Towards the northern part well #11 on testing flowed gas @ 860m3/d with thin film of oil. Gas presence was reported from wells #18, #16 and #8 while oil and gas were observed in wells #7 and #15. In well #14 oil shows were observed towards top part of the play but on testing flowed little gas with formation water. Though hydrocarbon is established in the area, production testing results of these wells suggests that poor petro-physical properties of the reservoir might be the causative for the less productivity of the play.

**Entrapment characteristics**

A series of longitudinal faults trending NE-SW are the main extensional faults associated with the syn-rift phase of basin formation and another orthogonal fault system is trending NW-SE dissecting the older played a major role in hydrocarbon migration and accumulation

The wide spread transgressive Sattapadi shale is acting as regional cap rock for the play. From drilled wells it is understood that intervening shales within Andimadam Formation would also serve as cap rocks. Faults having connection to deeper source sequences would act as conduit for migration of hydrocarbons. Seismic analysis suggests that in addition to structural entrapment strati-structural closures are also been evidenced.

## Play Fairway Analysis of Andimadam Formation

Play fairway analysis of Andimadam Formation has been carried out by assimilating 3D seismic data of the study area with drilled wells data like reservoir thickness, Cap rock thickness and laboratory studies. Different source rock parameters viz., Tmax, TOC, S2, HI etc. has been considered for preparing source rock potential map of the area. To ascertain the reservoir thickness of Andimadam Formation sand/ shale ratio of the same has been calculated. Shale thickness above Andimadam Formation is considered for cap rock map preparation. Since the Andimadam sediments are deposited during the rift phase it is presumed that most of the major Basement faults are extending to Andimadam and will act as conduit for migration of hydrocarbon.

Different electrolog correlation profiles are analysesd in dip and strike directions from marginal side to basinal part to know the presence of major petroleum system elements like source rock, reservoir rock and cap rock and their distribution across the sub–basin. From the correlation it is evidenced that towards the basinal part of A-P sub-basin, Andimadam Formation is deteriorating its reservoir characteristics. Presence of effective seal rock is evidenced from electro log correlation as well as seismic data.

**Time and Depth Maps**

3D seismic volume of the study area was analysed and calibrated with drilled wells. Basement and Albian tops were correlated and maps generated. Time and depth relief and structure maps (Fig.3) close to top of Basement shows the gradual deepening towards north-east with an intra basinal high around Bhuvanagiri area.

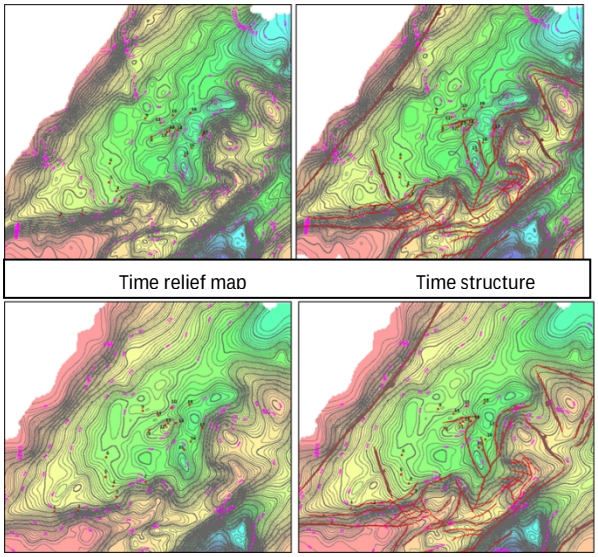


Fig.3: Time and Depth maps of Basement

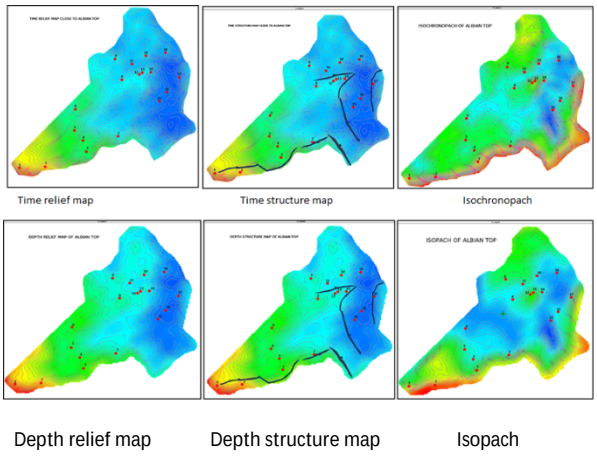


Fig4.Time and Depth maps of Albian

Time and depth relief maps (Fig.4) close to top of Albian which corresponds to Andimadam Formation top shows gradual deepening of the Formation to the basinal part with localised highs around well #6, 8, 9 and Bhuvanagiri areas. Time and Depth structure maps (Fig.4) clearly shows the presence of major faults in the area. Isochronopach (Fig.4) and Isopach (Fig.4) maps were prepared for Albian shows that huge thickness of Andimadam Formation is available in the sub-basin with thickness more than 1500m along the corridor from well # 15 to 18 and to east-north east of well # 6. This isochronopach has been used as base map for extrapolating various parameters throughout the study area and thus to prepare CRS maps.

## CRS MAPS

### Source Rock CRS

Source rock data of wells in and around the study area have been analysed for different parameters like TOC, T max, S2 and HI. Individual maps for TOC, Tmax, S2 and HI were prepared and final composite CRS map for source rock has also been made. TOC, which shows the organic matter richness in the area, values are ranging in between 3-7% in A-P sub-basin. For preparation of map maximum TOC value in Andimadam play has been considered along with the isochronopach map of Andimadam Formation covered by 3D seismic data as base map for extrapolating into other parts of the study area. The TOC map shows presence of better TOC around well #16 (8.12%) and well # 3 (4.92%) which is segmented as low, moderate and high risk areas based on values >4%, 2-4% and <2% respectively.

Tmax map is constructed for its distribution in the area explains that the maximum value is observed in well #17 (468°C) followed by well #16 (466°C). The map has been prioritised as low, moderate and high risk segment as temperature value >435°C, 430-435°C and <430°C respectively. From the map it is clear that maximum temperature is present around well #17 and well-6. Better Tmax of more than 455°C is observed around well #9, 13 and well #4 and the map further brings out that rest of the sub-basin also have Tmax value more than 445°C which shows that the sediments are thermally matured.

The hydrocarbon generation potential measured by S2 in mg HC/g of rock is good in well #9 (7.49) and #12 (8.18). Towards south and south western part of the sub-basin around well #7 (4.66), well #3 (5.83) and well #4 (4.51) areas the generation potential is fair.

HI values which indicates hydrocarbon preservation potential of the sediments is 261 mg HC/g of TOC in well # 4 shows good preservation potential around Andimadam area. In addition to this other area are in and around well #9 (223mg HC/g of TOC), well #15 (200mg HC/g of TOC) and well #7 (190mg HC/g of TOC). The map has been divided as high potential area where the HI value is >50mg HC/g of TOC as source rock starts to generate gas and moderate and high risk area is marked where the value is less than 50mg HC/g of TOC.

Individual maps for TOC, Tmax, S2 and HI were prepared on the basis of isochronopach map of Andimadam Formation are divided in to three areas on the basis of their values and marked as high, moderate and low promising areas. After prioritising the area all the four maps were overlaid each other and another set of composite maps with high, moderate and low promising areas were prepared. By overlaying these three maps final source rock CRS (Fig.5) map for Andimadam Formation was prepared. Source rock CRS shows that the high potential area lies towards north east and east of well #6, southern part of Andimadam area and around well #3. Moderately potential source rock exists in more than 70% of the study area especially around well #9, Andimadam and around well #15.

**Reservoir Rock CRS**

Andimadam play top has been marked in all the wells of the study area which was drilled through/ into Andimadam Formation. Gross thickness of sand and shale were calculated separately and sand/shale ratio has been worked out. Map of sand/shale ratio (Fig.6) was prepared using isochronopach of Andimadam Formation as base map. Since only two wells were drilled in to Basement in A-P sub-basin it is very difficult to ascertain the sand maxima area in the sub-basin. But from the map prepared it is envisaged that most of the area is covered by sand / shale ratio >1 and more reservoir facies is available around Andimadam area from well # 8 to 9 and areas to the north of well #7. The CRS has been segmented as low risk area where sand/shale ratio is >1, as moderate where ratio is 0.5-1 and as high risk area where the value is <0.5%.

**Cap Rock CRS**

For preparing Cap rock CRS (Fig.7) shale thickness above Andimadam Formation was calculated in all wells of the study area. The CRS map segmented as area with Shale cap of >50m is considered as high, that of 25-50m as moderate and < 25m as low priority areas. Shale cap of more than 100m is available in almost all wells except few wells in Bhuvanagiri area around well #12 and #7. It shows that there is no potential risk persists for seal.

## Andimadam Play CCRS Map

Based on the source rock, Reservoir rock and Cap rock CRS maps three individual risk maps for Andimadam play was prepared. The maximum potential or low risk area map was demarcated by considering the low risk area of source rock, reservoir rock having sand/ shale ratio more than one and cap rock having more than 50m shale. After overlapping all the three maps and wherever all the parameters with above criterion are present has been considered as most promising areas for Andimadam prospect exploration. Accordingly, the moderate risk map was also prepared by considering the moderate risk source rock area, reservoir facies having sand / shale ratio 0.5-1 and shale cap of 25-50m thickness. Area with presence of all these three factors has been marked as moderate potential/ moderate risk area for the prospect identification. Low potential or high risk map was prepared by taking the low potential area of source rock presence, reservoir facies with <0.5% sand/shale ratio and cap rock with <25m shale thickness and their presence in particular area has been considered as low potential area.

Composite CRS map (Fig.8) for Andimadam Formation was prepared by transferring the three risk areas in to a single map. From this composite CRS map area around well #.4, towards NE of well # 6 and to north of well # 7 are most promising segment with low risk for exploration of Andimadam play. Moderate risk areas are area between well # 8 and #9, Bhuvanagiri area, to the north, west and south of well #15 and south and SW of Andimadam area. Rest of the mapped area is considered as high risk segment for Andimadam play exploration. It is worth mention that the scanty data of source rock has played major role in deciding the risk segment. Therefore, it is suggested that the moderate risk segment can also be considered as potential for exploration in the study area.

## Conclusions

Based on the studies carried out it is suggested that more prospective areas lie around Andimadam area as wells as the unexplored areas south of well #8 and also around #9. The composite risk map for Andimadam play shows that a lot of area with good potential of the play exists in unexplored areas like the area in between Bhuvanagiri and Andimadam.

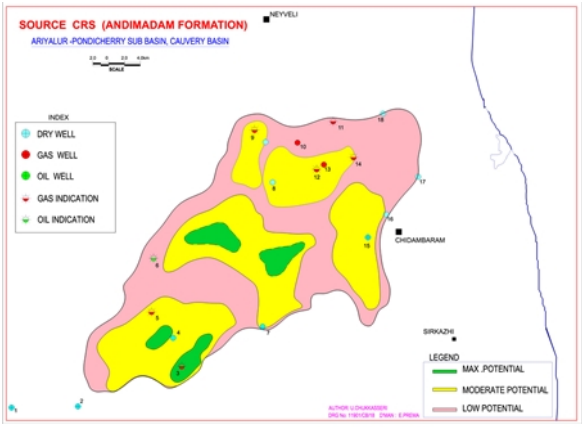


Fig.5: Source CRS map

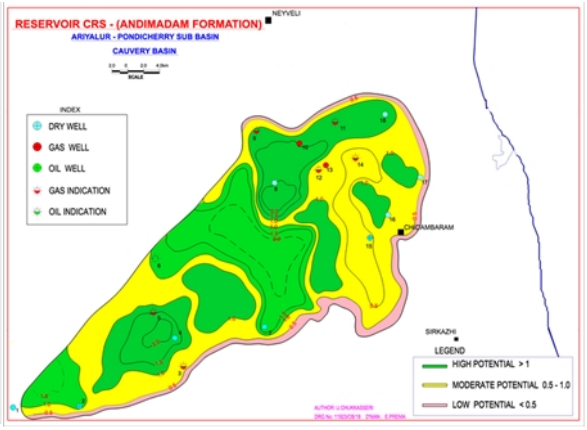


Fig.6: Reservoir CRS map

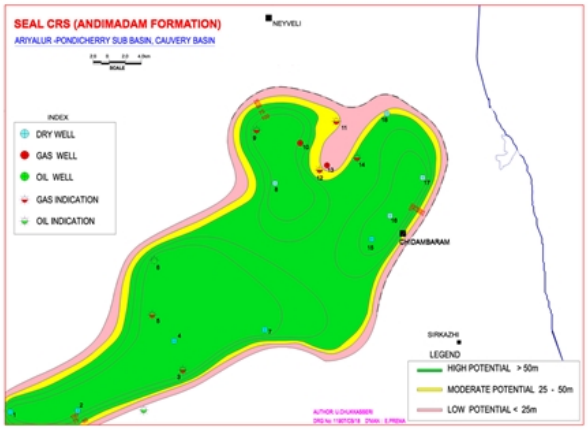


Fig.7: Seal CRS map

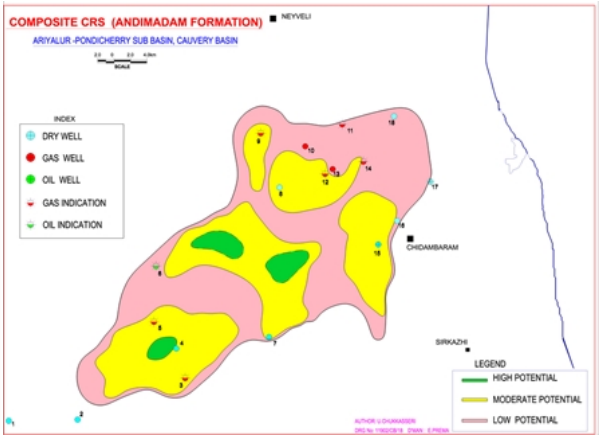


Fig.8: Composite CRS of Andimadam Formation

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