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Syn-rift architecture, depositional pattern and hydrocarbon prospectivity of syn-rift sediments in Tanjore sub-basin, Cauvery basin

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Summary

A few successes in Neduvasal-Vadatheru area have proved the hydrocarbon potential of syn-rift sediments in Tanjore sub-basin, Cauvery Basin but still a large area of the sub-basin necessitates exploration attention for syn-rift sediments. An attempt has been made to bring out a regional understanding of syn-rift architecture, depositional pattern by integrating available geo-scientific data and to analyze hydrocarbon prospectivity of syn-rift sediments in Tanjore sub-basin.

Within the synrift sediments, four syn-rift units have been identified representing distinct seismic facies. The seismic expression of these syn-rift units gives an idea about the linkage of their deposition with different stages of rift evolution. The lowermost unit have wedge shaped reflector packages and hummocky internal reflection configuration, representing early rift stage. The overlying unit comprising divergent reflection pattern with aggradations on footwall represents rift climax stage and the topmost two units with sub-parallel reflection configuration represent the late rift phase. The units deposited during rift climax stage have good source rock potential, whereas the units deposited in late rift stage possess favourable reservoir facies making a complete petroleum system within syn-rift sediments.

The core data indicates that the sandstones of syn-rift sequences were deposited dominantly by sandy debris flow during most part of the basin fill in shallow marine conditions with intermittent bottom current activity giving rise to reworking of earlier deposited sediments.

2D- Petroleum system modeling study along one seismo-geological cross section has brought out favorable hydrocarbon accumulation spots along the line.

Introduction

Cauvery Basin is a pericratonic rift basin, situated at the southeastern edge of the Indian landmass. Numerous down-to-basin extensional faulting took place in the Cauvery basin due to rifting and as a result of active subsidence along normal faults, trending parallel to the Pre-Cambrian Eastern Ghat-trend (NNE-SSW) given rise to horst-graben setting. Formation of grabens and horst blocks subdivided the Cauvery Basin into different sub-basins. Tanjore sub-basin is bounded on the north by Kumbakonam – Madanam ridge, on the west by Pre-Cambrian peninsular shield and on the south as well as east by Pattukottai- Mannargudi ridge, and partially continues to Tranquebar sub-basin in the North-East. Exploratory efforts are continuing since last five decades but only two wells in Neduvasal- Vadatheru area have established the hydrocarbon potential of syn-rift sediments.



Fig. 1 : Index Map



Four log markers have been identified in the syn-rift section on the basis of log characters and bio-stratigraphic control. Equivalent seismic markers could be traced and were mapped regionally along with Basement top. The four Cauvery Tanjore Syn-rift units bounded by these seismic markers were named as unit 1, unit 2, unit 3 & unit 4, from older to younger. These unit tops were dated with the available paleontological/ palynological informations. The top of unit 1, unit 2 & unit 4 have been assigned as Barremian (?), Aptian and Albian tops respectively, whereas unit 3 lie within Albian.

These identified units have distinct seismic facies. The seismic facies within the units indicate their depositional environment associated with the stage of rifting. Lower part of bottom most unit 1 was deposited during early rift stage. Rift climax stage prevailed during deposition of unit 2 and upper part of unit 1, whereas, unit 3 & 4 were deposited during late rift stage. It is observed that the potential and effective source are present in the unit 2, followed by unit 3 and better reservoir facies are developed in unit 3 & 4. The favorable reservoir facies are also expected in unit 1 in fans and channels deposited in early stage of rifting. Hence, the favorable Petroleum system exists within the synrift sediments.

The time structure map at Basement level indicates four isolated lows which merged to form two major lows at the end of rift, one extending from North-East to North-Central part and other in south. The Northern low is more prominent and wide spread. Southern low, which was earlier connected to western deepest low at basement level, got well differentiated as the rift progressed and becomes shallower and localized towards south-western margin. Moreover, Krishnapuram-Vadatheru-Orthanandu spur in the central part gradually becomes more prominent and widespread towards NW, bifurcating the two lows. The available core data indicates that the sediments were originally transported by fluvial drainage with considerable length of transportation and deposited in the shallow marine setup. The sedimentation was later dominated by sandy debris flow along with intermittent bottom current activity in shallow marine condition.

2D- Petroleum system modeling study along one seismo-geological cross section has brought out favorable hydrocarbon accumulation spots along the line.

Discussion

Log Analysis

Electrolog analysis and correlation of syn-rift sediments, encountered in 25 wells from the sub basin, has been carried out. Few log correlation profile are prepared in N-S & E-W direction to understand the sedimentation of synrift sediments. One regional stratigraphic correlation in N-S direction along the axial part of the basin is shown in fig 2.

The syn-rift top on the electrologs is characterised by typical higher gamma, higher resistivity and low Δt values with respect to younger sediments. This typical synrift top log marker is biostratigraphically calibrated as Albian from micropaleontological and palynological study.

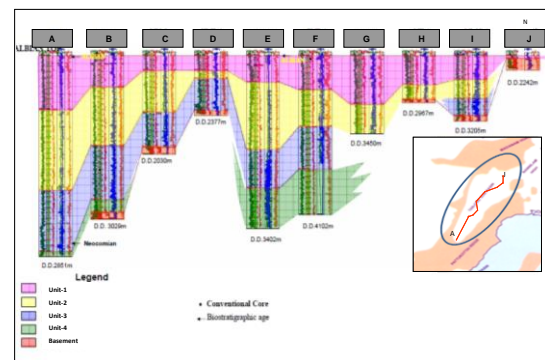


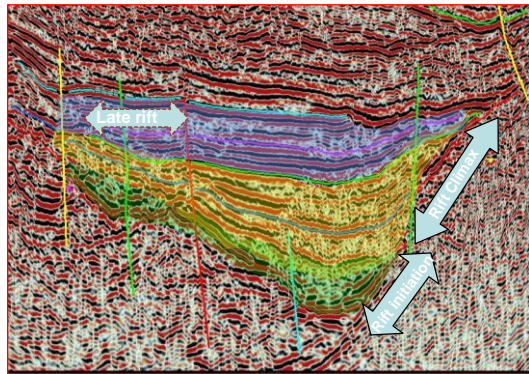
Fig. 2 : Log Correlation Profile in N-S Direction

The syn-rift sediments are further subdivided into four units, namely unit-1, 2, 3 & 4 from bottom to top. This subdivision is primarily developed from the wells in the central part of the sub basin which have encountered maximum thickness of syn-rift sediments. These four units are identified and correlated on the basis of gamma base line shift, distinct gamma trends and patterns. The top of these units on electrolog are also correlated on the seismic section through these wells, where they are characterized by regionally developed strong reflectors. The tops of these units are also age calibrated wherever biostratigraphic data availability permitted.

Seismic expression and its linkage to rift cycle



The seismic expression of different syn-rift units gives an idea about the distinct stages of rift evolution and associated depositional system (Fig. 3).



Late rift : Sub- parallel continuous reflectors

Rift Climax : Divergent reflection, aggradation

Rift Initiation : Wedge shaped reflector packages and hummocky internal seismic facies

Fig. 3: Rift cycle and related seismic expression

Rift basin stratigraphy commonly records an early stage of slow subsidence followed by abrupt increase in subsidence rate. The early stage of rift development are characterized by numerous small isolated fault bounding basins with displacement switching to major basin bounding fault during the rift climax. The phenomenon is well demonstrated in Tanjore sub-basin as four isolated lows bounded by smaller faults seen on Basement levels, finally switched to two major low having main displacement along the western margin fault (Fig. 4).

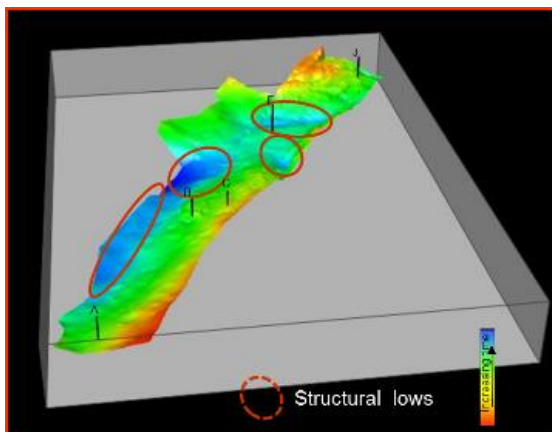


Fig 4 : 3D view at Basement top

The stratigraphy of many continental rift basin shows a vertical transition from an early fluvial , shallow lake or

shallow marine succession to a deep lake or deep marine succession. Prosser (1993) termed these two stages in rift-basin development the “rift initiation” when the rate of fault displacement is relatively low and sedimentation keep pace with subsidence, and the “rift climax” when the rate of fault displacement increases markedly and sedimentation cannot keep pace with subsidence.

During early rift stage, the reflection geometry show an overall wedge shaped geometry. The hummocky discontinuous reflectors suggest a channelized system lying in a longitudinal position. Prograding reflector geometry in the very lowest fill, implying sedimentation was able to infill the space created through subsidence (Fig. 5). The similar pattern is seen in the lower part of unit 1, which demonstrates the early rift stage during deposition.

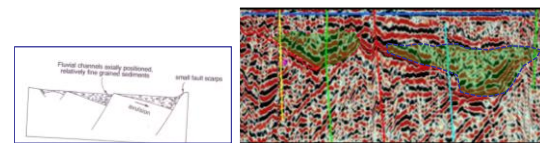


Fig.5 : Early Rift Stage

During rift climax stage, the maximum rate of displacement on fault causes sedimentation outpaced by subsidence. On seismic section, the rift climax system is characterized by an increased amount of aggradations, together with the development of divergent forms related to continue tilting of the hanging wall during deposition (Fig. 6). The seismic facies indicate that the rift climax started during later part of deposition of-unit 1. The upper part of unit 1 is deposited during early rift climax stage.

The onset of mid-rift climax systems tract is associated with the point at which transgression of the hanging wall slope occurs. At this point there will be fundamental change in sediment transport direction: from gravity driven downslope to along-slope current driven trends. The late rift climax systems is taken to consist of the depositional system that predominate in a totally submerged environment. This will be seen as a blanket of sediment of relatively uniform thickness draping the asymmetric basin topography. The late rift climax system is characterized on seismic section as a draping reflector that can be traced across the basin onto the adjacent footwall and hanging wall crests. The unit 2 have been deposited in mid rift and late rift climax stage as represented by seismic character (Fig. 6).

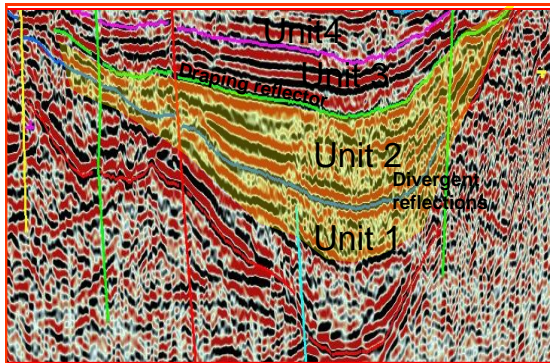


Fig 6: Rift Climax & Late Rift Stage

During the late synrift phase the tilting of the hanging wall and differential subsidence across the fault plane ceases and the rate of regional subsidence will decrease. The sediment supply out paced the rate of tectonic/fault controlled subsidence, resulting into the deposition of well sorted coarser clastics which would act as good reservoir. Seismic expression would be the more continuous and parallel reflectors than the earlier sequences (Fig. 6). The unit 3 and unit 4 have been deposited in the late syn-rift phase and expected to have better reservoir characteristics. The time structure map at the basement level indicate four isolated lows which were later merged to form two major lows as the rift progressed. (Fig. 4&7)

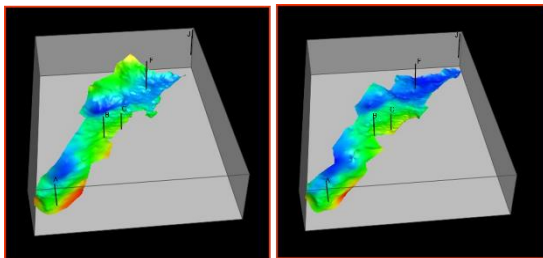


Fig. 7 : 3D View at top of Unit 1 & Unit 2

The northern low becomes more prominent and wide spread at the end of rift as seen on time structure maps. Southern low, which was earlier connected to western deepest low at basement level, got well differentiated at the top of unit 2 & unit 3. At the end of rifting, it becomes shallower and localized towards western margin. As the rifting progressed, Krishnapuram-Vadatheru-Orthanandu spur become gradually more widespread towards NW.

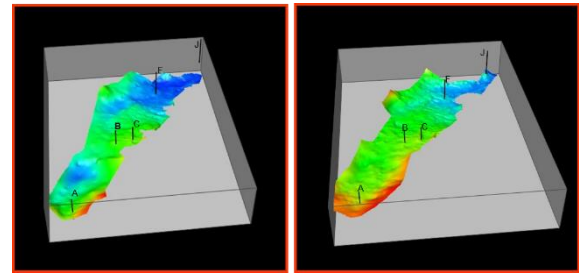


Fig. 7A : 3D View at top of Unit 3 & Unit 4

Core Data Analysis

The core data indicates that the sandstones of syn rift sequences were deposited dominantly by sandy debris flow during most part of the basin fill in shallow marine conditions with intermittent bottom current activity giving rise to reworking of earlier deposited sediments (Fig. 8).

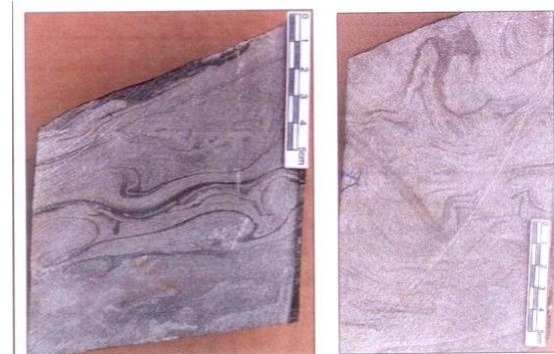


Fig. 8 : Core segments from unit 1 showing slump folds

The sandstones are mainly feldspathic /or quartz wacke with moderate primary porosity in younger synrift units i.e unit 3 & 4. Reservoir characteristics are influenced by mechanical compaction, filling of pores by clay minerals and early calcite cementation resulting in porosity reduction, mainly in older units. At places secondary porosities are developed due to dissolution of calcite and feldspar grains and dolomitization of calcite cement.

Sand Thickness & Attribute Maps

Sand thickness maps of different syn-rift units are prepared from the well data of limited wells which penetrated in the syn rift deposits. The sand thickness in each unit was determined by using the gamma and neutron-density electro-logs. The unit 3 & 4 show comparatively good sand thickness and a very good correlation are seen with the

attribute maps of the similar units. Higher sand thicknesses are observed in unit 3 in northern part which are represented by high amplitudes in AAA maps (Fig. 9).

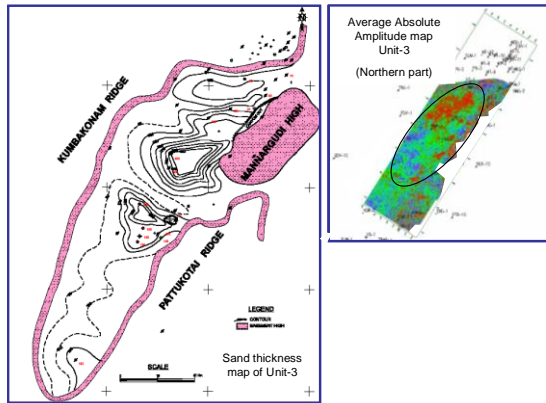


Fig. 9 : Sand thickness & AAA map (Part) of Unit 3

Petroleum System Analysis:

Source

It is already proven that Andimadam Fm, which is mainly comprised of syn rift sediments, is the source rock for the commercial oil and gas occurrences in the Cauvery basin. Source rock study for different wells in Tanjore sub basin has been carried out in detail which indicated that good quality of organic matter (up to 6.7% TOC) is present in shales of Syn rift/Andimadam Formation. Three distinct types of organic facies are identified within the source sediments as given below:

- a) Type III with minor type II organic matter (Gas + sub. Oil prone), in early phase of maturation.
- b) Type III organic matter (Gas prone) in early mid phase of maturation.
- c) Type II and Type III organic matter (oil prone in peak stage of maturation).

The distribution pattern of effective source rock in the sub basin suggests that better source rock potential exists in the wells which are in the central part of the sub basin lying in the depocentres identified in this study.

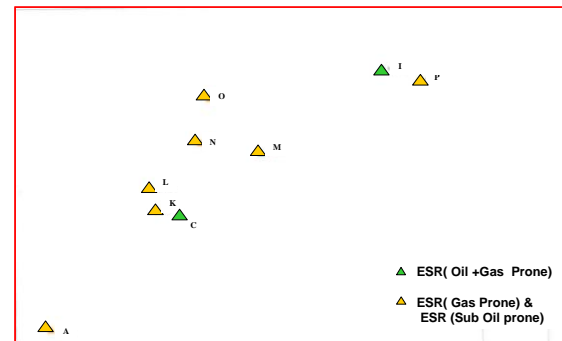


Fig. 10 : Distribution of Effective Source rock

An analysis of the source rock distribution within the syn rift units is also attempted. It is observed that the potential source rocks and effective source is present in the unit 2, and followed by lower part of unit 3. Unit 2 has the best source rock potential as it was deposited during rift climax stage.

As far as migration is concerned the short distance migration is envisaged in the sub basin.

Reservoir

The integrated analysis of well data and seismic data has brought the presence of abundant reservoir facies

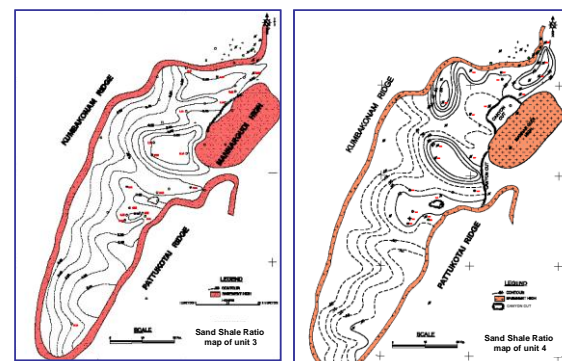


Fig. 11 : Sand/Shale Ratio Maps of Unit 3 & 4

(sandstone) in the syn-rift sediment interbedded with source rock facies (shales). The sand/Shale ratio maps show better reservoir facies development in the unit-3 & 4. The better reservoir facies are also expected in unit-1 in fan wedges, channels etc as it was deposited in early stage of rifting.

Entrapment

Structural culmination and fault closure in the syn rift sequences are prospective entrapments. Still more important entrapment can be provided by stratigraphic traps formed by the wedge outs and pinch out of the syn-rift reservoir strata. The wedge out phenomenon is observed at the basin margins and more characteristically at the intrabasinal paleohighs at the accommodation zones. Few such paleo highs and accommodation zones are identified in the northern part of the sub basin.

2D- Petroleum system modeling

2D- Petroleum system modeling study along one seismo-geological cross section has been carried out to model paleo-history reconstruction and to assess hydrocarbon generation and migration to evaluate the possible hydrocarbon prospectivity in Tanjore sub-basin of Cauvery Basin.

The modeled section (Fig.12) covers the entire geological domain and passes through three drilled wells The lateral extent of the line is approx. 68.5 Km .

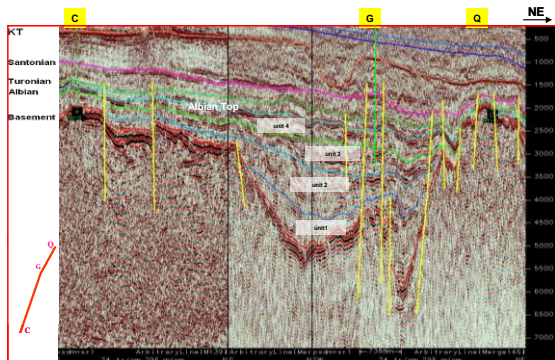


Fig 12 : 2D Modeled Section

The synrift units were further divided into different layers on the basis of source/reservoir facies. (Fig.12A).

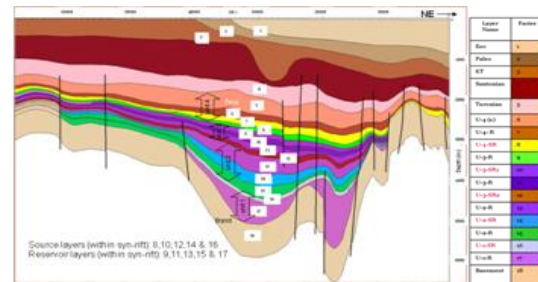


Fig. 12A : Facies Distribution along modeled section

The details of the modeled layers and their petroleum system element has been shown in Table 1.

Table 1

Age	Layers	Name of Layer given in model	Petroleum System Element	Facies No.
Eocene	Eocene Top	Eocene		1
Paleocene	Paleocene Top	Paleocene		2
KT	KT	KT		3
Late Cretaceous	Santonian	Santonian	Seal	4
	Turonian	Turonian	Seal	5
Early Cretaceous	CTSR-unit 4	Unit4	Seal	6
		Unit4-reservoir-1	Reservoir	7
		Unit4-SR	Source Rock (type III)	8
	CTSR-unit 3	Unit-3-reservoir	Reservoir	9
		Unit3-SR1	Source Rock (type III)	10
		Unit3-reservoir	Reservoir	11
		Unit3-SR2	Source Rock (type III)	12
	CTSR-unit 2	Unit2-reservoir	Reservoir	13
		Unit2-SR	Source Rock (type III)	14
		Unit2-reservoir	Reservoir	15
CTSR-unit 1	Unit1-SR	Source Rock (type III)	16	
	Unit1-reservoir	Reservoir	17	
Pre-Cambrian	Basement	Basement		18

2D modeling along above seismo-geological section in the study area indicates the possibility of following two accumulations (Fig. 12 C).

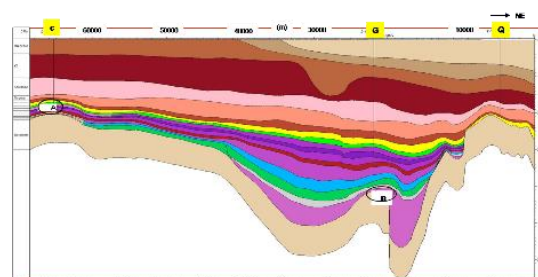


Fig. 12B : Modeled Hydrocarbon Accumulations

- On the top of unit 3 layer near well C (oil and gas)
- In unit-1 layer at the deeper basinal part of the section (mainly gas)



The results from source rock tracking indicate that the hydrocarbon accumulation on the top of unit 3 layer near well C is mainly contributed from unit 3- SR2 (type II) source rock with very minor contribution from unit3 – SR-1(type III) source rock. In the other hydrocarbon accumulation in unit1 layer at the deeper basinal part of the section, the accumulated gases are mainly contributed by deepest unit1-SR source rock with a minor contribution from unit2-SR and unit3SR-1 source rocks.

The hydrocarbon generation has taken place in basinal part where unit3-SR-2 (type II), unit3-SR-1 (type III), unit2-SR and unit1–SR (type III) source facies are mature and attained critical moment at 83.5 Ma, 69.2 Ma, 80 Ma and 89 Ma respectively(Table 2). The expelled hydrocarbons have migrated up-dip and reservoirized in structures.

Table 2

Sl. No	Source Rock	Critical Moment (Ma)	Present day conversion (%)
1	Unit4-SR	66	57
2	Unit3-SR1	69.2	67
3	Unit3-SR2	83.5	95
4	Unit2-SR	80	82
5	Unit1-SR	89	82

The modeling results are only indicative and suggest that source rocks are mature and generated and expelled hydrocarbons. However, any hydrocarbon accumulation requires the availability of suitable traps for entrapment at the time of hydrocarbon expulsion and migration.

Prospective areas

The study has established that a favourable petroleum system exists within the synrift sediments in Tanjore sub-basin. Two wells have already been producing from syn-rift section in Naduvasal-Vadatheru area. Their success need to be expanded to other part of sub-basin. Some prospective areas have been identified in the northern & southern part of the sub-basin.

Towards north, the accommodation zone in Satanur area forms a prospective zone and structural features are also seen close to that. In the southern part of sub-basin fault closure and wedge outs against basement high have also been identified which may be prospective.

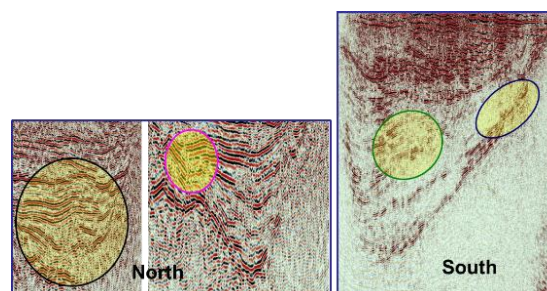


Fig. 13 : Prospective areas

Conclusions

A few successes have proved the hydrocarbon potential of syn-rift sediments in Tanjore sub-basin, Cauvery Basin but the success is confined to Neduvasal-Vadatheru area only and large area of the sub-basin still necessitates exploration attention for synrift sediments. An attempt has been made to bring out a regional understanding of synrift architecture by integrating available geo-scientific data and to analyze hydrocarbon prospectivity of synrift sediments.

Four log markers were identified in the syn-rift section on the basis of log characters and bio-stratigraphic control. Equivalent seismic markers could be traced and were mapped regionally along with Basement top. The four Cauvery Tanjore Syn-rift units bounded by these seismic markers, were named as unit 1, unit 2, unit 3 & unit 4, from older to younger. These unit tops were dated with the available paleontological/ palynological informations. The top of unit 1, unit 2 & unit 4 have been assigned as Barremian (?), Aptian and Albian tops respectively, whereas unit 3 lie within Albian.

These identified units have distinct seismic facies, which express their depositional environment associated with the stage of rifting. Lower part of bottom most unit1 was deposited during early rift stage. Rift climax stage prevailed during deposition of unit 2 and upper part of unit 1, whereas, unit 3 & 4 were deposited during late rift stage. The available core data indicates that the sediments were originally transported by fluvial drainage with considerable length of transportation and deposited in the shallow marine setup. The sedimentation was later dominated by sandy debris flow along with intermittent bottom current activity in shallow marine condition. The reservoir characteristics of unit 3 & 4 is having moderate



to good primary porosity and is mainly composed of arenite to feldspathic/ quartz wacke.

It is observed that the potential and effective source are present mainly in the unit 2 and better reservoir facies are developed in unit 3 & 4. The favorable reservoir facies are also expected in unit 1 in fans and channels deposited in early stage of rifting. 2D- Petroleum system modeling study along one seismo-geological cross section has brought out favorable hydrocarbon accumulation spots along the line.

The study indicates that a complete petroleum system exist within syn-rift sediments which have been established by few success. The success need to be expanded to other parts of sub-basin, which are lesser explored. The identified prospective areas may be targeted.

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"Views expressed in the paper are solely of the authors and does not necessarily reflects the views of ONGC"

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