



Petroleum System and Play Types of Synrift Sequences, Ramand Subbasin, Cauvery Basin

K.Vasudevan*, L.V. Ramana, V.Nagasudha, A.Borthakur, S.K.Das,
Oil and Natural Gas Corporation Ltd, Cauvery Basin, Chennai, vasuk1@yahoo.com

Summary

- Ramnad sub basin, the southernmost onland tectonic block of Cauvery Basin, is a proven hydrocarbon province with five Gas fields producing from siliciclastic reservoirs of upper Cretaceous Nannilam and Bhuvanagiri formations.
- Exploratory drilling of 52 wells till date has established presence of commercial quantities of gas from debris flow sandstones of Senonian age with minor pools in deeper Turonian and shallower Paleocene sequences. The prospectivity of the deeper synrift fill has not been explored fully, as only a few wells have penetrated the deeper Lower Cretaceous / Upper Jurassic? stratigraphic succession.
- Basin scale analysis of high resolution 3D data and regional 2D data indicates that the deepest part of the rift graben contains approximately 4000m of Early Cretaceous and older sequences, including a probable pre rift sequence of Late Jurassic age, with a speculative synrift Petroleum System in operation in the deeper axial part of the basin. The synrift succession, envisaged to be initiated as an intracratonic lacustrine basin around 140ma, has the potential to possess rich source facies. The GME model invoked indicates that the synrift source facies would have reached the oil window top during Late Cretaceous time (around 70 ma). Formation of early inversion structures has been established to be as early as Turonian age. A conceptual model depicting the reservoir development close to Albian top points to the probability of presence of favourable reservoirs in the eastern rift shoulder margin. Gases of Cauvery Basin are thermogenically generated in the catagenetic stage of maturation from a source of mixed type II and III and are dominantly oil associated gases.
- The speculative synrift petroleum system postulated by the present study has all the components in favorable association indicating high *é*yet to find potentialí.
- Four major play types have been identified by detailed mapping of available geoscientific data. They are: Structural prospects within Albian in the eastern flexural margin High amplitude stratistuctural prospect corresponding to the early synrift lacustrine turbidite fan lobe of early Cretaceous age in the southwestern part of the graben Cenomanian structural play in the eastern flexural margin and Continuous type play of tight gas sands and Basin centered gas in the axial part of the graben.
- The present study has also brought out several prospects for hydrocarbon exploration which would help unlock the full potential of the early synrift petroleum system.



Introduction

Ramnad sub basin constitutes the southernmost onland tectonic unit of the polycyclic Cauvery Basin (Fig.1). It is one of the main producers of gaseous hydrocarbon with commercial quantities established in Upper Cretaceous sandy debris flow reservoirs within Nannilam and Bhuvanagiri formations. Five gas fields have been established with cumulative in place reserves to the tune of 21 MMm3 of OEG.

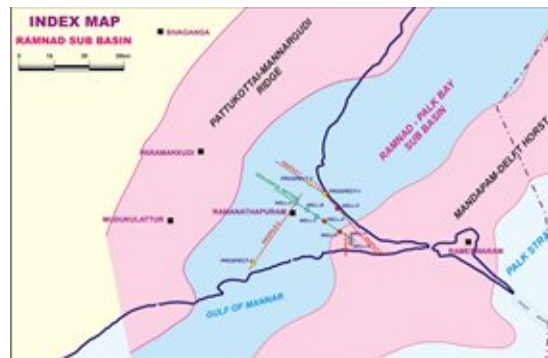


Fig.1 Index map of Ramnad Subbasin

Cretaceous reservoirs ranging in age from Santonian to Campanian (Nannilam Formation) constituted the primary exploratory target in the sub basin. Arenaceous reservoirs of Bhuvanagiri Formation of Coniacian to Turonian age is another exploratory target on structural culminations. In addition, gas discovery in Kamalapuram sand of Paleocene age in a recent well in Perungulam structure has opened up a new play in the Tertiary succession. However, the thick pile of synrift sequences corresponding to Andimadam Formation which constitutes nearly half of all the stratigraphic succession in the deeper part of the basin is yet to be explored systematically. A few wells have penetrated the top portion of Andimadam Formation with little exploratory success. The understanding of this succession is purely on geological concept and seismic mapping.

Geology of the area in brief:

Ramnad sub-basin and its continuation in Palk Bay-Gulf of Mannar area are limited in the northwest by Pattukottai - Mannargudi ridge and in the southeast by Mandapam-Delft ridge. The sub basin holds sediments over 6000 m in thickness, ranging in age from Upper Jurassic?/ Lower Cretaceous to Recent (Fig.2). The synrift sedimentary column comprises mainly shale and sandstone in the Andimadam Formation. Drift phase sedimentation representing the upper Cretaceous Bhuvanagiri, Kudavasal Shale, Nannilam and Porto Novo formations is

predominantly sand shale alternations with minor limestone development. The passive margin sequences were deposited on the easterly tilted shelf slope regime with well defined coast line. The siliciclastic sequences are interspersed with major limestone succession corresponding to Eocene and Miocene periods.

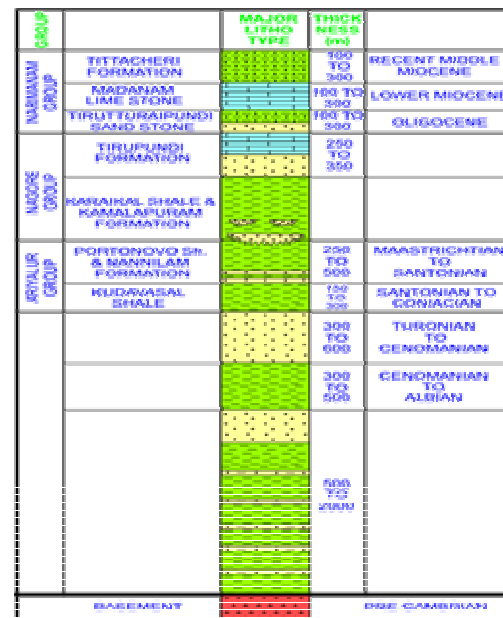


Figure 2: Generalised Stratigraphy of Ramnad Basin

Nannilam and Bhuvanagiri reservoirs had been deposited in this area through mass transport mechanisms, viz., debris flow and high density turbidity currents. Kamalapuram reservoirs occur as submarine channel fill or slope fan/ basin floor fan overlying the Cretaceous unconformity. The k/t unconformity topography had acted as depositional substratum for the distribution of Lower Kamalapuram reservoirs.

The present study has brought out the presence of thick pririft sequences in the Ramnad and adjacent Palk Bay area. Considering the position of the Cauvery Basin in the plate tectonic reconstruction model, the initiation of synrift graben in the southern most part of the Indian craton is envisaged to have begun as early as 160 Ma(Oxfordian). Early synrift sedimentation was initiated in intracratonic sag phase in lacustrine environment favorable for rich source facies development. As the separation from Antarctica progressed, a transition from lacustrine to brackish water through later inlets from the marginal sea would have resulted in gradual increase in sea level. The thick alternation of sand shale sequences encountered in the Albian and older sections of the wells point to the development of intimate succession of source and reservoirs. Regional marine



transgression marking the end of rift phase occurred in Cenomanian time inundating the rift grabens. Regional development of Sattapadi Shale of Cenomanian age marks this episode.

Description of envisaged petroleum system

Source rock:

Pre Albian and Albian shale within Andimadam Formation is considered to be the main source rock. Ramnad low aligned in NNE-SSW direction is the major depocentre for source facies

Very few wells in the western and eastern flanks have been drilled deep into Andimadam Formation. Thin streaks of effective source rocks encountered within Pre Albian and Albian sequence in wells have indicated proclivity to predominantly oil associated gas.

Condensates of Ramnad are paraffinic in nature and might have been generated from mixed marine Type II/III organic matter deposited in sub-oxic to peat swamp environment

Generation and Migration

TTI calculations of well A show that the Sattapadi Shale and lower part of the Bhuvanagiri Formation entered oil window. Recent study by ONGC, (Chaudhury, A., et al., 2007) has indicated the possibility of synrift source facies entering the Oil window stage as early as 70ma.

All gases of Cauvery Basin are thermogenically generated in the catagenetic stage of maturation from a source of mixed type II and III and are dominantly oil associated gases suggesting generation of gases during peak generation time (critical moment) and not during gas window stage.

Considering the colossal thickness of rift sequences and the synrift subsidence history of the basin, the source facies at the deeper part of the basin could have reached expulsion phase in the upper Cretaceous time itself as has been brought out by the regional studies.

The specific gravity of gases of are dominantly between 0.61 ñ 0.7. Since, all the gases are oil associated gases of thermogenic origin, this lighter nature of the gases indicates long distances of migration / phase segregation (Mangotra, et al, 2004).

Structure Formation

The regional tectonic fabric of the basin exhibits an older NNE-SSW fault set intercepted by a younger EW fault set. The established pools at upper Cretaceous reservoir levels are all located along or at the intersection of these two trends. At least two episodes of inversion have been postulated in this basin, one coeval to the Turonian hot spot activity and another beginning at the Cretaceous / Tertiary boundary. The effect of the inversion is to form passive hanging wall anticlines and fault closures along the pre-existing fault blocks which got rotated.

The regional dip parallel geological section depicts the various tectonic blocks and components of synrift petroleum system (Fig.3). It can be observed that the established gas fields are located in the eastern most tectonic block along the rift shoulder margin of the basin.

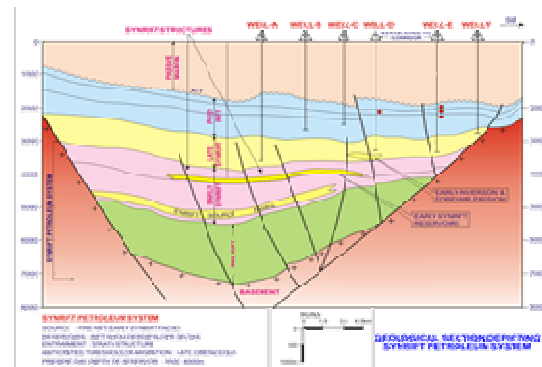


Fig.3 : NW-SE geological section depicting Synrift Petroleum system.

Reservoir Development & Quality

Andimadam sequence is predominantly sandy in the western graben bounding fault side and predominantly shaly in the eastern rift shoulder margin side. In general the sand shale ratio of the Andimadam succession in the wells located on the eastern flexural margin ranges from 20 to 25%. Thickness of the individual sand streaks varies from 1 to 6 m with porosity in the range of 8-10%. Deposition of some limestone is noticed in wells F & G drilled in the eastern margin. Marginal increasing trend in porosity (8-14%) is noticed towards further east.

The development of good quality reservoirs is the single major risk in the exploration for deeper synrift plays. However, considering the critical moment as early as 70ma the Andimadam reservoirs would not have suffered diagenetic effects. The hypothetical model invoked to depict the development of reservoir sequences in a rising sea level cycle along the flexural margin indicates that the landward migrating coarser clastic deposited at the top of the prerift sequences would have been ideal reservoir window for the synrift charging (Fig. 4).

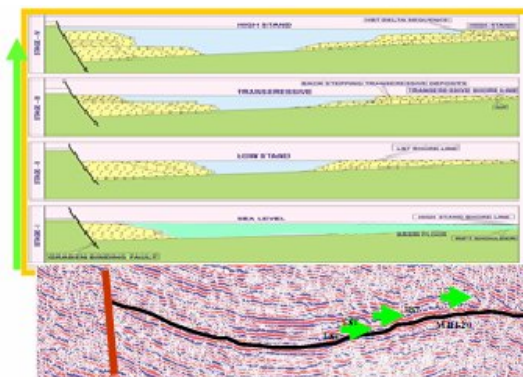


Fig.4: Cartoon depiction of reservoir development on flexural margin of rift basin.



Synrift play description

Four major plays have been envisaged in the synrift petroleum system and prospects to test the plays identified. A brief description of the plays is given below:

1. Structural prospects within Albian in the eastern flexural margin (Fig.5). These are the early inversion structures formed during Turonian time prior to the peak generation phase of synrift source and hence are favorable locales for early charging. The four way structural closures are located adjacent to the proven hydrocarbon corridor and along the path of migration. Possibility of early generation and migration would have ensures charging of liquid hydrocarbon in these prospects.

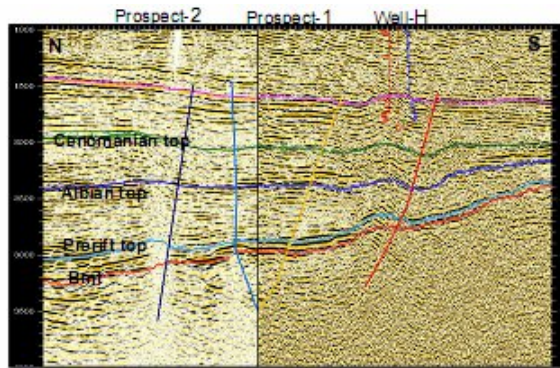


Fig.5. Regional dip parallel 2D seismic section (Profile 1) indicating Synrift structural prospects

2. **High amplitude stratistuctural prospect** in the early synrift lacustrine turbidite fan lobe of early Cretaceous age ranging from Valanginian (140ma) to Aptian(120ma) in the southwestern part of the graben. The depositional model depicts a lacustrine turbidite system (Katz,B.J.et al, 1990) depositing lobate sand body on the faulted lake floor depositional surface, through a SW-NE feeder channel. Ramnad subbasin developed as intra cratonic sag and there was no inlet of sea in to the graben possible at this time. Probably, an intracratonic lake developed which was fed from SW by the early drainage developed on the foot wall dip slope. Sediment gravity flows would have been initiated through slope failure of shallow lacustrine sands deposited on the foot wall block or as dense turbid river flow during floods. The turbid flow through the feeder channel spread on the lake floor topography which was dissected by faults. The individual sand lobes were deposited in the resultant blocks. This is evidenced by the dissected nature of the sand lobe. The composite turbidite sand lobe consists of at least three distinct units representing three flow episodes.

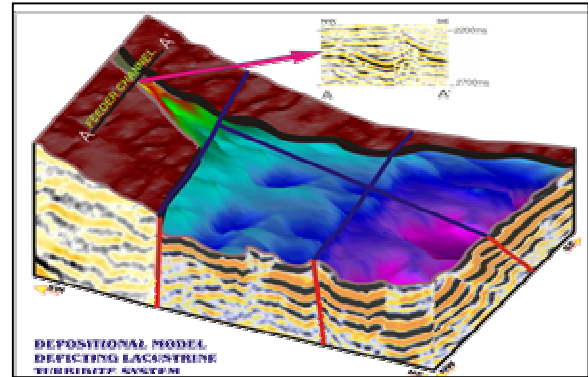


Fig.6 Cartoon depiction of the lacustrine turbidite fan lobe system.

3. **Cenomanian structural play** in the eastern flexural margin. Wells F & G have indicated presence of liquid hydrocarbon from the calcareous sand stone reservoirs of Cenomanian age (Fig.7). This play appears prospective in the eastern most part of the onland Ramnad subbasin along the rising flank of the Delft Ridge. The reservoir quality is expected to improve as this corridor is close to the provenance from rift shoulder. Also the objective window is structurally much shallower as compared to the prospects in the west. This play assumes significance as this is the only lead that has yielded liquid hydrocarbon in the entire Ramnad Subbasin. Discovery of oil from this play will significantly enhance the potential of the basin

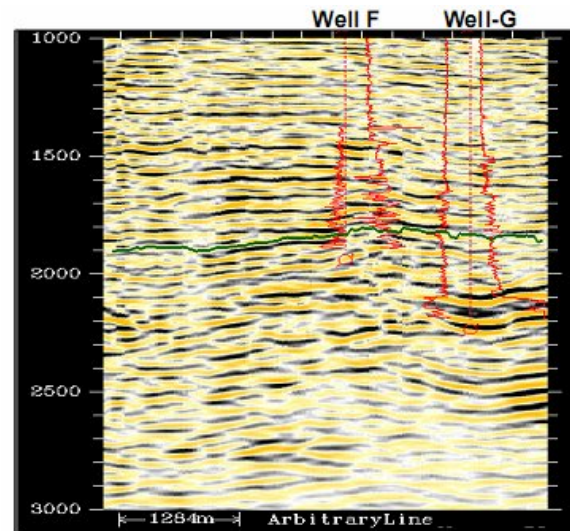


Fig.7: 3D arbitrary line depicting Cenomanian structural play in the eastern flexural margin



4. Continuous type play of tight gas sands and Basin centered gas in the axial part of the graben. These are the envisaged frontier plays in the axial part of the graben wherein the rift fill and older prerift sediments together attain great thickness of 4 to 4.5 Km. Intimate association of rich lacustrine source and reservoir rocks within the early synrift sequences would have given rise to continuous type plays and basin centered gas. Although the hydrocarbon potential of these plays are envisaged to be quite good, they would pose both exploration and exploitation challenges owing to their depth of occurrence around 5Km.

Conclusions

The present study has brought out the presence of a Total Petroleum System within the synrift sequences of Ramnad subbasin, Cauvery Basin.

Early synrift lacustrine source facies are envisaged to be rich in TOC and capable of generating both liquid and gaseous hydrocarbons. The peak generation is estimated to be around 70ma.

Reservoirs within Albian and older sequences are in general observed to have poor porosity and constitute the single major exploration risk. However, if the charging had preceded the post rift burial as has been envisaged in the present study, then these reservoirs would not have suffered diagenetic destruction of porosity and hence would have preserved good reservoir properties.

The early inversion structures were formed in Turonian time prior to peak generation time and the prospects located along the migration fairway constitute good exploration targets.

Early synrift lacustrine turbidite system presents a very attractive exploration play and is capable of hosting significant volume of liquid hydrocarbons.

Along the eastern flexural margin the Cenomanian structural play is also interesting as it occurs at considerably shallow depth as compare to the other play types.

The Continuous type play and basin centered gas play may assume considerable significance in the future particularly with their potential to host huge quantities of gas.

The present study has brought out that the hitherto under explored synrift sequences of Ramnad subbasin present a variety of play types with significant yet to find potential. Concerted efforts by drilling and induction of modern production techniques are needed to convert these resources into commercial hydrocarbon fields.

References

1. Chaudhury.A., Murthy.K.S., Ramana.L.V., Rao.M.V, Dobriyal.J.P, Chidambaram.L., Neeraja.P. and Saha.G.C., 2007, Sequence stratigraphic framework, Cauvery basin, Unpublished report
2. Katz.B.J., 1990, Lacustrine basin exploration-Case studies and modern analogs, AAPG Memoir 50.
3. Mangotra.S.R., Prabhakar.V., Sarkar.J. and Rana.B.S., 2004, Geochemistry of oil / condensates and migration trends in Cauvery Basin, ONGC unpublished report
4. Vasudevan.K., Sylvester.J.M., Murthy.J.V.V.S.N., Rangachary.V., Ananthanarayanan.P.N., 1998, Exploration for stratigraphic and subtle traps in Cauvery basin, Lessons learnt and future perspective, ONGC Bulletin, Vol.35, No.2

Acknowledgements

We are thankful to ONGC for the kind permission to publish the work. We are indebted to Shri.J.S.Sekhon, GM, Basin Manager, Cauvery, ONGC for the support and encouragement. Our sincere thanks are due to Dr. D.V.R.Murthy, GM (GP), ONGC, for critically reviewing the work and suggesting improvements.

