

Tectono-depositional and Play fairway modelling of Paleocene-Early Eocene formations, Patan-Tharad - Sanchor Block North Cambay Basin, A thrust area for future exploration

Ambrish Kr.Tripathi*, Rekha, Manoj Kumar, Soumen Paul, Rajeev Tandon, Dhruvendra Singh

GEOPIC, ONGC, Dehradun

Email: *Tripathi_Ambrish@ongc.co.in

Keywords

Play fairway analysis, Petroleum system
Modeling, facies analysis, depositional modeling

Summary

Patan-Sanchor-Tharad region of Cambay Basin had eluded explorationists so far but recent commercial discovery in adjoining Barmer Basin has opened a new ray of hope to revisit this region. In this regard detailed gravity, structural modelling, depositional modeling, Petroleum system modeling and play fairway analysis of Paleocene-Early Eocene sequences have been done for prospectivity evaluation. Present study has brought out horst and graben geometry, accommodation centres, sediment dispersal pattern and depositional fabrics of the area during Paleocene-Early Eocene period. Potentiality of the hydrocarbon generation through transformation of kerogen to hydrocarbon, have been analyzed through 2D petroleum system modeling while reservoir facies potential have been inferred through seismic attribute analysis and lithofacies modelling. Based on integrated study a new depositional model and prospective areas have been delineated which will open a new door for exploration in this underexplored sectors of Cambay-Barmer basin sandwiched between two major hydrocarbon provinces, Cambay basin to the south and Barmer basin to the north. Although there are hydrocarbon discoveries in Patan block, but establishing commercial production is a big challenge because of very complex nature of tectonics and reservoir. In Tharad block, there is development of very good reservoir facies but the transformation ratio of the potential source rock is low, whereas Sanchor block is characterized by the presence of good source rock which has entered oil window with high transformation ratio. The Petroleum Systems Quick Look (PSQL) tool enabled rapid screening and evaluation of key exploration risk components (Source, reservoir, seal, trap and charge) in regional scale; whereas 2D petroleum system model allowed to understand them in detail. Combining with the detailed facies analysis and depositional modeling prospective areas are identified and prioritized for future exploration input.

Introduction

The petroleum systems and the tectono-stratigraphic development of the Patan-Tharad-Sanchor blocks of the Cambay-Barmer basin is poorly understood, though amenable geological condition prevailed in this block. Commercial hydrocarbon discoveries are mainly present to the south of Patan area in the Cambay basin and to the north of Sanchor area in the Barmer basin (Fig 1).

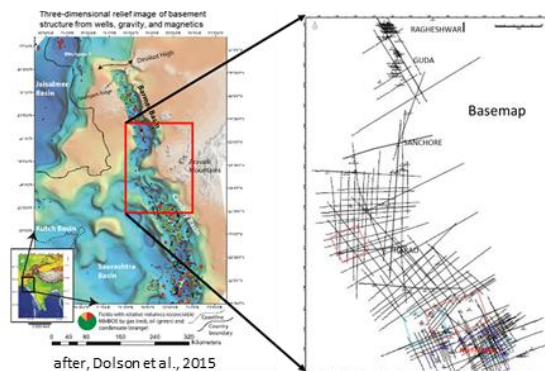


Fig 1: Basement relief image showing the Cambay-Barmer rift system, study area is shown in red polygon and the seismic layout map is on the right.

Current study focuses on detailed structural mapping of the seismic data, petroleum system modeling, depositional modeling and plays fairway analysis. The aim of this paper is to address the hydrocarbon potentiality of the Patan-Tharad-Sanchor area and discuss the tectono-stratigraphic evolution.

Geological setup and stratigraphy

Cambay Basin is a typical failed rift system extending from Gulf of Cambay in the south to the Barmer basin in the north, where it abuts against the Devikot high; formed in response to the separation of Greater India from Seychelles towards the end of Cretaceous. The N-S to NNW-SSE trending Cambay-Barmer rift system runs for about 615 Km and there is systematic decrease in the width of the rift from south to north. It is nearly 100 km near the Gulf of Cambay in the southern part, which progressively decreases towards the north in the Sanchor block to about 40km and to about 35 km further north in the Barmer basin. The maximum thickness of the sediments is more than 6km in the major depocentres. This block encompasses the pre-rift, synrift and post rift phases of sedimentation.

The generalized stratigraphy is given in (Table 1).

Structural Framework

Integrated structural map covering the entire area from Mehsana horst of the Cambay basin in the south to the Guda and Rageshwari area in the north (Barmer basin) was prepared to understand the major tectonic and structural elements present in the area which has influenced the evolution of the area. Deccan trap volcanics which covers

Tectono-depositional and Play fairway modelling of Patan -Tharad - Sanchor Block, Cambay Basin

the pre-rift topography is considered as technical basement in this basin above which syn-rift sedimentation took place. Time structure map of Trap top shows the NW-SE fault pattern is the dominant trend in the Patan-Tharad block, which turns to NE-SW in the Sanchor block. Whereas E-W trending faults creating the transfer zones and the accommodation zones (Fig 2). The eastern and western margin faults are clearly seen in some of the large seismic profiles covering the entire basin from west to east. Map clearly depicts the basement high on the both flanks, intrabasinal horsts, grabens, transfer/ accommodation zones of the basin. Tharad ridge is represented by a major transfer zone across which there is a shift in basinal axis and the northern margin of this ridge is marked by a reverse fault. There are two accommodation zones, one is to the south of Tharad low and another to the north of Patan low. North of the Sanchor depression (GR-A structure) there is another E-W trending ridge, which is possibly another transfer zone.

C PERIOD	SERIES	STAGE	BARMER BASIN	CAMBAY BASIN
C	PLEISTOCENE		UTTARLAI	ALLUVIUM
	PLIOCENE	PIACENZIAN	JAGADIA	JAMBUSAR + BROACH
		ZANCLEAN		
NEOGENE	MIOCENE	MESSINIAN	KAND	JAGADIA
		TORTONIAN		
		SERRAVALIAN		
		LANGHIAN		
	OLIGOCENE	BURDIGALIAN	TARPUR	BABGURI
		AQUITANIAN		TARKESHWAR
		CHATTIAN		
		RUPELIAN		
PALEOGENE	EOCENE	PRIABONIAN	KALOL	ANKLESVAR
		BARTONIAN		
		LUTETIAN		
		YPRESIAN		
	PALEOCENE	DHARVI DUNGAR	CAMBAY SHALE	
		THANETIAN		
		SELANDIAN		
		DANIAN		
	MAASTRICHTIAN	FATEHGARH	OLPAD	DECCAN TRAPS
		SHIV TEMPLE		

Table 1: Stratigraphy of Cambay and Barmer basin (modified after, Dolson et al., 2015).

In view of geological and tectonic similarities with Barmer Basin an integrated geological modelling has been carried out.

Facies analysis and depositional environment

Detailed facies analysis of 50 wells pertaining to Patan-Tharad-Sanchor area was carried out integrating core,

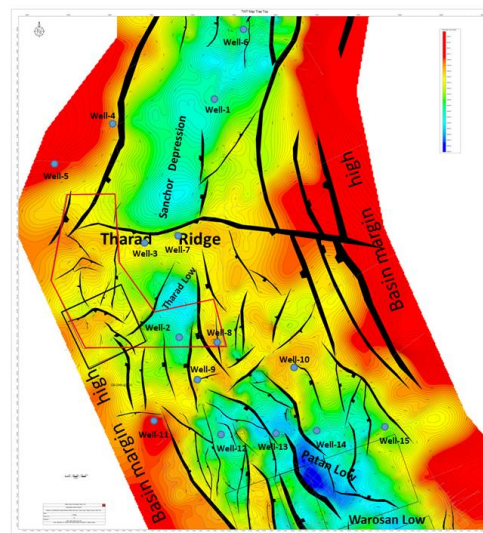


Fig 2: Time structure map showing tectonic set-up and horst - graben geometry with major lows highs, transfer and accommodation zones.

cuttings and well log data along with the sedimentological and biostratigraphic data with the aim to demarcate the potential source-reservoir-seal facies and infer the depositional environment. Integration of seismic data provided the necessary insight into the basin architecture (rift shoulders, horsts, grabens, transfer and accommodation zones) and major depositional elements. On the basis of seismic stratal pattern, number of unconformity bounded units are identified. 2D facies models along number of E-W profiles were prepared assimilating the lithological information with the seismic stratal pattern which reveal the major depositional elements present in the section (Fig 3). These 2D facies models are the inputs for the 3D depositional model building. In the 3D model building, basin/basement configuration and surface geology apart from the climatic forcing have been taken into account since they have profound influence on the sediment type, drainage development and sediment dispersal pattern in intra-cratonic rift system. The major steps involved in this are

1. Lithological interpretation integrating core cutting and well log data
2. Integration of biostratigraphic data
3. Interpretation of key 2D seismic lines within a sequence stratigraphic perspective
4. Construction of 2D facies model integrating well log and seismic data
5. Reconstruction of basement configuration from the structural map
6. Identification of major depocentres from the isopach maps

Tectono-depositional and Play fairway modelling of Patan -Tharad - Sanchor Block, Cambay Basin

7. 3D depositional model building integrating well data, 2D facies models and surface geology and gravity-magnetic data

Depositional model is conceptualized integrating all the available surface and subsurface data, therefore it honors all the basement faults, well data and surface geology. The salient features of this model is that the Tharad ridge acted as a transverse basement high during the Paleocene time and therefore the marine influence is restricted to the south of this ridge (source rock is developed in Olpad and Older Cambay Shale Formation). The depositional slope of the basin is to the south, however across the Tharad ridge there is a reversal in the dip towards the north where a lacustrine system developed (Barmer Hill Formation having rich lacustrine source rock). Broad alluvial fan/fan delta complex model laterally associated with lacustrine/marine basin has been brought out for the Olpad- Cambay Shale succession.

One major transfer zones and two accommodation zones are present in the modelled area, which are at a high angle (almost at the right angle) to the basin forming normal faults. Along the transfer/accommodation zones, fault overlaps between the basin bounding en echelon faults where the footwall zone of one fault passes into the hanging wall of an adjacent fault forming an oblique monoclonal down bend, which are sites of major drainage entry into the basin. Transfer zone corresponding to the Tharad ridge acted as a major point of sediment entry both from the eastern side and western side forming sand rich lobes as encountered in Well-3 and Well-7. There is another major sand entry point NE of Well-10, sand lobes corresponding to this system is encountered in the well Well-9 and Well-8. Distribution of these good quality sandstone is governed by the inter-basinal horsts, grabens and transverse faults. Intra-basinal horsts acted as the local source areas which filled the adjacent lows. 2D Facies model shows alluvial fans from the footwall and cones from the hanging wall blocks, which are present all along the basin margin and intrabasinal horsts (Fig 3). Rapid facies variation is seen along the strike and dip direction.

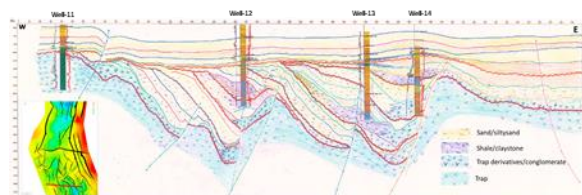


Fig 3: 2D facies model along an E-W profile, built through integration of seismic, well log, core and cutting data.

Mini basins formed by the half grabens acted as localised sinks which accommodated most the sediments supplied from the intrabasinal horsts as well as sediment entered through external drainage systems. Because of this there is very less possibility of longitudinal drainage during this

stage of sedimentation. Composition of the sediment is the function of the country rock/provenance; in our study area well data indicate that the base of the Tertiary sediments is the trap volcanics, which supplies trap wash on weathering and erosion. Granitic rocks are exposed to the east and NE of Tharad ridge and same is inferred from GM data for the western and NW side of this ridge which had supplied sugary feldspathic sandstone into the basin. In the Pantan and Tharad depression source rock is developed in Olpad and Older Cambay Shale formations which is considered to be of marine origin, where as in the Sanchor depression during the same time organic rich lacustrine shale was deposited as Barmer Hill Formation.

PETROLEUM SYSTEM AND ENTRAPMENT MODELLING

a) Source rock potential of the areas

In the Sanchor block, the subsurface data obtained from drilled Well-1 showed that the Barmer Hill and the Dharvi-Dungar formation act as a source rock. Owing to its deposition in lacustrine setting (deep lacustrine basin) the shales of Barmer Hill Formation consist of Type-I Kerogen with high HI and low OI. On the other hand Dharvi-Dungar Formation, which is comparable to Tharad Formation of Cambay basin consists of lignitic Type-II kerogen and Type-III kerogen, which are mostly immature in the Sanchor area.

Geochemical Studies conducted on the samples from parametric well-1, indicate that the organic carbon percentage ranges from 1.84 to 2.76 %. Vitrinite reflectance data suggests that the sediments below 1900 m are matured. The Tmax values for Dharvi-Dungar/ Tharad equivalent formation range between 435°C and 441°C. Ro for Lower Tharad level is 0.64 and for the Upper Tharad levels it is around 0.45. This suggests that the sedimentary section is fairly close to the oil maturation window. In the Tharad low, south of Tharad ridge parametric Well-2 has given the indication of the presence of source rock within the Paleocene section, the average organic content of the potential source rock is 0.98%. The HI value of 45 suggests presence of type-III kerogen with a moderate quality organic matter capable of generating gas.

Similarly Patan depression is characterized by the presence of good quality source rock within the Older Cambay shale interval, and this source interval is buried deep enough to enter the gas generation window.

b) Reservoir

In the study area, early rift sandstones and conglomerates of the Olpad Formation which were deposited in alluvial, fluvial and lacustrine settings can form reasonably good reservoirs. Further in the sandstone-coal-shale succession within the Tharad Formation and equivalent stratigraphic intervals in the Sanchor depression has proven reservoir properties.

Tectono-depositional and Play fairway modelling of Patan -Tharad - Sanchor Block, Cambay Basin

c) Entrapment Mechanism

Entrapment is expected to be structural in nature, however there are number of features which has stratigraphic components also. Structures formed due to fault block rotation are most common of all. There are number of fault closers which shows reverse sense of displacement and strikes orthogonal to the basin trend, these structures are result of the strike slip movement along these zones.

d) Envisaged Petroleum system

Owing to excellent source rock potential and maturity levels reached upto catagenetic stage, Barmer Hill Formation has been considered as source rock in the Sanchor low. It is envisaged that hydrocarbon generated in Sanchor low may charge the reservoir sands within the Fatehgarh and Dharvi-Dungar formations. Shale within these formations as well as (Tarapur/Wav Formation) of Late Eocene-Oligocene age can act as a regional seal. To the south of the Tharad ridge in the Tharad and Patan depression the main source rock contributing hydrocarbon is the Older Cambay Shale, this source rich formation thins out towards the north gradually from Warosan low to Patan low and gets less important in Tharad low, the potential reservoirs are within the Olpad Formation and overlying Tharad Formation. In the Patan low, Olpad level sandstone/siltstones are charged; whereas in the Tharad low major reservoir facies has developed within the Late Paleocene-Early Eocene interval. Shale within the Olpad Formation and Tarapur Shale can act as cap. So, two petroleum systems Older Cambay Shale-Olpad and Older Cambay Shale-Tharad are envisaged.

Petroleum system modelling

Results

To understand the different components of petroleum system, 2D petroleum system modeling was done along E-W sections which captures the basin geometry and passes through key wells having source rock and maturity data for better control and calibration of the model (Fig 4).

This profile bisects the area from west to east encompassing multiple horst and grabens. Initial model geometry was prepared based on the stratal pattern of the seismic section (Fig 4).

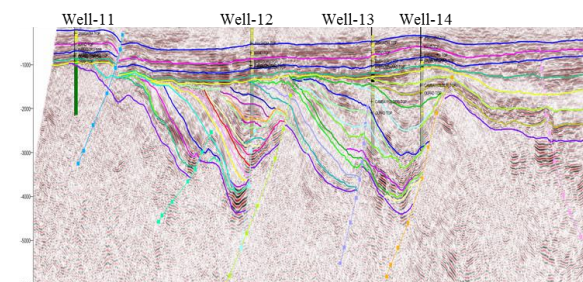


Fig 4: Interpreted E-W seismic profile passing through drilled wells 11, 12, 13 and 14.

Subsequently different facies was assigned to individual layers based on the drilled wells falling on the profile as shown in (Fig 5).

The results of the 2D maturity model as well as the maturity and transformation ratio of source rock layers is presented in the following section.

2D maturity model indicates that the sediment below 2200 m fall in oil maturity window. Also the sediments in

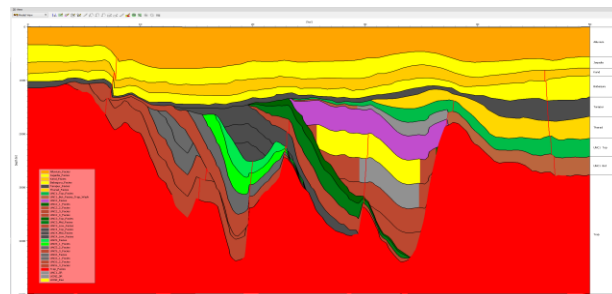


Fig 5: 2D petroleum system model with facies assignment for source, reservoir, seal, underburden and overburden.

deepest portion of the graben with burial depth greater than 3500 m reach gas window (Fig 6).

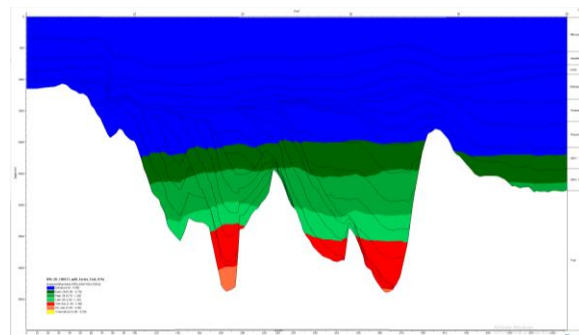


Fig 6: 2D petroleum system model with maturity overlay.

Play fairway modelling

A quick look petroleum system workflow was carried out in Petrel to understand the different element of petroleum system. The Petroleum Systems Quick Look tool (PSQL) enable rapid screening and evaluation of key exploration risk components (trap, reservoir, charge and seal).

TOC and HI data was considered for 9 wells for generating source rock maturation map. The TOC and HI maps were generated using the isopach trend between Olpad and Trap top. Reservoir facies map was generated using RMS amplitude attribute as trend. Since the most of the area is covered with 2D seismic dataset. The attribute generated for individual 2D line was krigged using the data analysis and keeping it consistent with regional trend (Fig 8)

Tectono-depositional and Play fairway modelling of Patan -Tharad - Sanchor Block, Cambay Basin

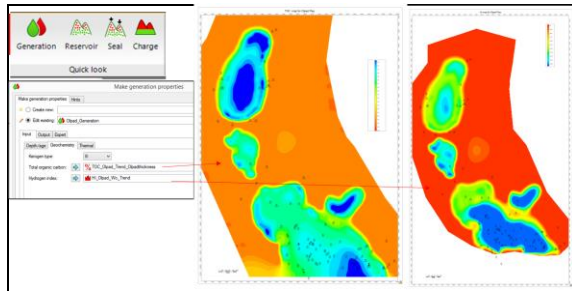


Fig 7: Geochemical input map of (a) TOC and (b) HI for the Paleocene source rock (Olpad/OCS /Barmer Hill).

All the inputs were used for charge model, TOC, HI, heat flow, porosity (calculated by depth-porosity conversion for reservoir), capillary pressure for seal and overburden pressure.

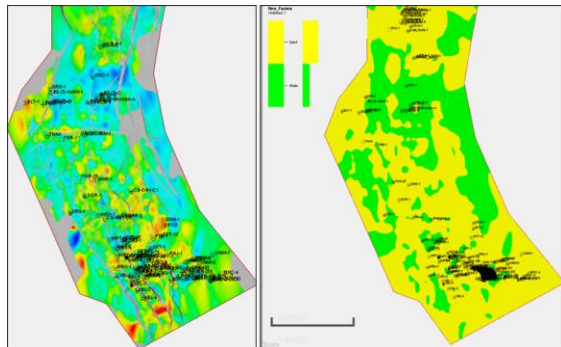


Fig 8: Reservoir input map of (a) RMS amplitude map and (b) facies map.

With the available dataset maturity and transformation ratio maps were prepared which shows spatial maturity and transformation variation for the Paleocene source rocks. Maturity map indicate that the Patan area has reached upto the gas generation window, whereas Tharad and Sanchor lows are within the late Oil window. In terms of transformation ration of the source rock, Tharad low is showing relatively low transformation ratio as compared to Patan and Sanchor lows (Fig 9).

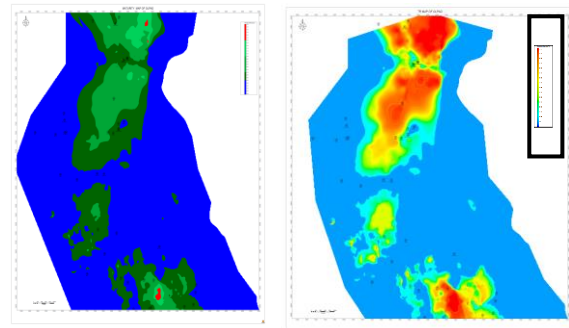


Figure 9: (a) Maturity and (b) Transformation ratio map.

All the inputs were used to generate critical risk segment (CRS) maps for source, reservoir, seal and charge. Composite critical risk segment (CCRS) map was generated integrating all the CRS maps for the study area. Since none of the well was reported to be dry due to seal failure seal was given lowest risk.

As shown in the generated CCRS map (Fig 10), the main risk remains generation and migration of hydrocarbon from source rock to reservoir. Reservoir heterogeneity can be an issue however on the basis of 2D seismic dataset it is difficult to comment on reservoir quality in the study area.

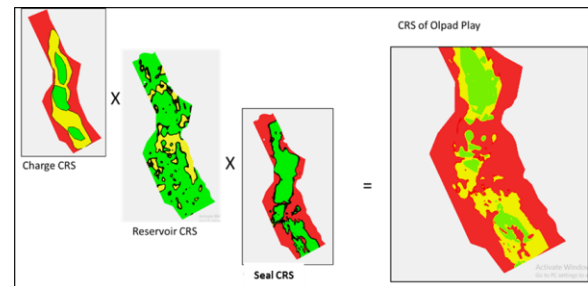


Fig 10: Play chance map of Olpad Play.

North (Sanchor area) and South (South patan) are shown low risk. Sanchor region appears interesting in terms presence of working petroleum system. However, this is based on certain assumption as available dataset is limited. Data indicates that both the Sanchor and Patan area have generated hydrocarbons, but the Tharad low has poor transformation ratio. The main risk in the Patan area is the reservoir, in the Tharad area, charge is the main risk. Sanchor area is virtually unexplored and awaits exploratory input.

Finally, composite maturity and transformation ratio maps were prepared for the entire Cambay-Barmer basin integrating the previous studies with the current study. This gave a holistic understanding of Petroleum system of Barmer and Cambay Basin.

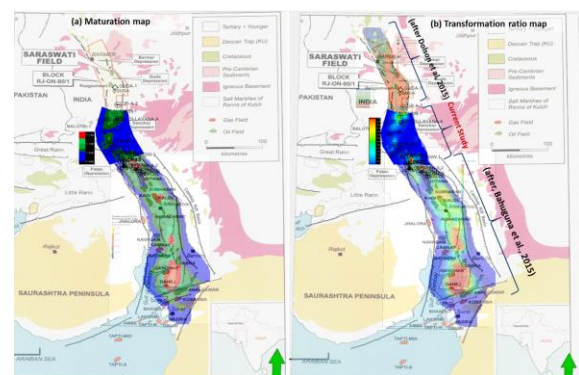


Fig 11: Composite (a) Maturity and (b) transformation ratio map of Barmer and Cambay Basin.

Tectono-depositional and Play fairway modelling of Patan -Tharad - Sanchor Block, Cambay Basin

Current study is in conformance to the earlier studies. Transformation ratio map of the Barmer basin also shows very high TR towards the southern part of the Barmer basin i.e. Sanchor block. Similarly in the Patan block TR is high and the maturity map shows that the Paleocene source rocks has entered the gas window.

Conclusions

1. In view of geological and tectonic similarities with Barmer Basin an integrated structural framework has been evolved. Tharad ridge separates Cambay Basin from Barmer Basin. There is change in the trend of the basin forming faults from NW-SE to NE-SW. Major depocentres are separated by transfer/accommodation zones.
2. Seismic interpretation in a sequence stratigraphic framework established the presence of multiple unconformities formed due to fault block rotation. Earliest graben formation in this area was towards the west, with successively younger grabens to the east.
3. Well data indicate that the base of the Tertiary sediments varies from granitic basement, Mesozoic sediments and trap volcanics. Granitic rocks are exposed to the east and NW of Tharad ridge which had supplied feldspathic sandstone into the basin having very good reservoir quality in the Tharad block. Whereas Deccan volcanics has supplied trap wash.
4. Broad alluvial fan/fan delta complex model laterally associated with lacustrine/marine basin has been brought out for the Paleocene- Early Eocene succession of the area.
5. Petroleum system modeling has led to identification of three generation centres, Sanchor, Patan and Tharad lows. Maturity map indicate that Sanchor and Tharad lows are falling in the early to main oil window and Patan low has entered the gas window. TR map indicate that that the TR is high in Patan and Sanchor area and low in Tharad area.
6. RMS amplitude map supplemented with lithofacies maps was given as the input for play fairway analysis.
7. Play chance map indicate that the risk varies from one segment of the study area to other, in the Patan area the main risk is reservoir, in the Tharad area charge is the main risk. Sanchor area seems to be favourable and having high chance of success.

8. The present work is based on the integration of scanty available data with poor to moderate data quality. In the view of the results discussed above, this area warrants dedicated exploration efforts as any exploratory success in this area may open up a huge area for future exploration.

Acknowledgements

The authors sincerely acknowledge the ONGC authority for permitting to present the data and the findings of the study.

The author is indebted to Shri Ashutosh Bhardwaj ED-HOI, ONGC, Shri Anil Sood, former ED-HOI GEOPIC, ONGC and Dr. Harilal, GGM (Geophy), Head INTEG, GEOPIC for their guidance and valuable suggestions during the course of study. Authors also acknowledge the constructive suggestions of Basin Team, WON, made during the course of study.

References

Bahuguna et al., 2015, Integrated Geological Modeling of Western Onland Basin (Cambay Basin) including Petroleum System(s) Modeling. Unpublished report, ONGC Project No: IP.14I.BNBDB.IJ01.

J. Dolson, Stuart D. Burley, V. R. Sunder, V. Kothari, B. Naidu, N. P. Whiteley, P. Farrimond, A. Taylor, N. Direen, and B. Ananthakrishnan 2015, The discovery of the Barmer Basin, Rajasthan, India, and its petroleum geology. AAPG Bull, v. 99, no. 3, pp. 433–465.