PaperID AU371

Author SUSHMA RAWAT , ONGC , India

Co-Authors S. Tiwari, PP Dash, PK Saha, B. Mandal

Deciphering the hydrocarbon proclivity of Mesozoic, Trap and Tertiary Plays through 3D Petroleum System(s) Modeling of Kutch-Saurashtra Basin

Authors : Sushma Rawat, S. Tiwari, PP Dash, PK Saha, B. Mandal KDMIPE, ONGC

Abstract

Kutch and Saurashtra Basins are poly cyclic basins situated in Western Continental part of India extending from onland to offshore areas with a geological rock record from Mesozoic to present. Exploration efforts have resulted in establishing presence of commercial hydrocarbons in Tertiary and Mesozoic sequences.

In view of sporadic success, 3D Petroleum System Modeling study was carried out to understand the dynamics of source, reservoir seal with generation, migration and entrapment of hydrocarbons in the basin.

Present PSM study established Jurassic and Cretaceous source sequence as main source layers. Paleocene and younger source rocks have not reached main oil window except L. Paleocene source rock in Kutch Low. Hydrocarbon maturity window falls approximately below 2500m. Jurassic source layers attain 50% transformation latest by E. Cretaceous and for Cretaceous source rock layers it ranges from 100Ma to 61Ma. L Paleocene source layers attain maturity only in the Kutch Low and all younger source rocks remain immature.

Based on the study, multiple hypothetical Petroleum Systems are established. 4 Mesozoic- Mesozoic / Paleogene / Neogene (.) and Tertiary petroleum systems are ascertained. Along with specific modelling for Deccan volcanic episode, a possible biogenic system in offshore was also envisaged from present modelling study.

1. INTRODUCTION

Kutch and Saurashtra are the poly-history basins extending from onland to adjoining offshore areas and witness geological rock record from Mesozoic through Tertiary, punctuated by number of unconformities, characteristically marked by thick Deccan Trap lava flow which erupted from Late Cretaceous to Early Paleocene. The Trap thickness generally increases from east to west - southwest in the range of 80m to >4000m. Hydrocarbon discoveries have been established both in Tertiary and in Mesozoic sequences, however, the success has been very limited, sporadic and small. The structures, A, B, C, D, E and F have confirmed hydrocarbon accumulation within Mid Miocene, Early Eocene, Paleocene, Cretaceous and Jurassic sections in Kutch- Saurashtra offshore. Even Deccan basalts have hydrocarbon accumulations. These discoveries have opened a new vista for hydrocarbon exploration in the Kutch shallow water area. Deep water exploration in the area has resulted in drilling of five deep water wells but without success so far.

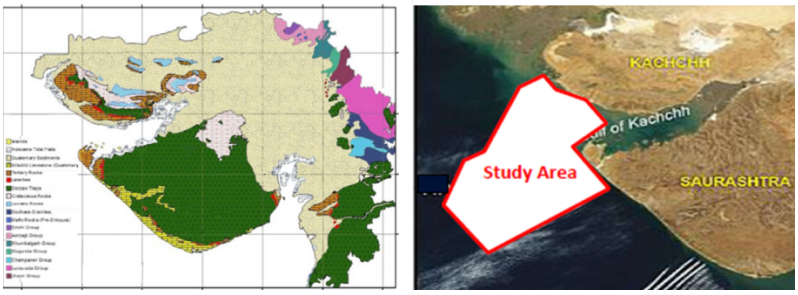

Fig.1: Map showing study area

The adjoining Indus Basin has witnessed major successes from both Mesozoics and Tertiaries. In view of the prolific hydrocarbon discoveries in the Indus Basin, this study was done to assess the hydrocarbon proclivity and also to firm up various elements of Petroleum System within the present day sedimentary and stratigraphic presence in the study area covering 62,500sq km.(Fig.1).

2. GRAVITY SIGNATURES

A prominent gravity high near the southern coastline of Kutch, whereas southern part of this gravity high protrudes in to Saurashtra mainland. In Kutch on land, thick Mesozoic rocks are exposed onland, providing calibration for GM studies and are modeled to laterally continue in the offshore, where it is again proven in drilled wells.

3. TECTONIC HISTORY :

Saurashtra and Kutch Basin are important geological regions in WCMI, with major geological and tectonic events of the region confined to Mesozoic and Cenozoic eras and are associated with

i. break-up of Africa from Indian block (Madagascar and Seychelles),
ii. break-up of Madagascar from India due to Marion hotspot activity, and
iii. break-up of Seychelles plateau from India followed by eruption of Deccan volcanics related to interaction of Reunion hotspot activity.
iv. Stress adjustments along the lineaments during Himalayan Orogeny

Thus, the study area has imprint of two hotspots – Marion and Reunion evolved through several stages of rifting–crustal thinning, magmatic under-plating and transient thermal effects.

Kutch-Saurashtra Basin opened up in response to southward propagation of N-S trending Indus rift due to separation of Africa from Greater India. This is supported by dominantly N-S to NNW-SSE trend as observed in time maps. Structure map at basement level shows development of number of longitudinal faults roughly trending N-S to NNW-SSE generating horst and graben features. Another set of transverse faults trending ENE- WSW has been mapped which affected earlier set of longitudinal faults. In general, Basement becomes shallower towards east. A major structural high trend near Saurashtra Arch has been observed. A prominent low trending N-S is observed near western offshore area.(Fig.2).

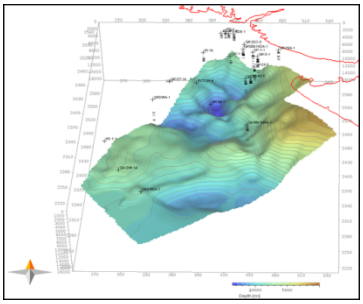

Fig.2. Depth Relief Surfaces (3D View)

4. GEOLOGICAL SETUP

Kutch-Saurashtra Basins lie north of commercially proven Mumbai Offshore. Onland part borders with commercially proven Cambay Basin on its eastern flanks and the deeper offshore Saurashtra borders with the Indus fan (to abyssal plain of Arabian Sea).

Kutch basin is an east-west oriented pericratonic embayment opening and deepening towards the Arabian Sea in the west, filled up with 1550 to 2500m of Mesozoic sediments along with 550m of Tertiary sediments in on land part and up to 4500m in offshore part as per well data. The sediment thickens from less than 500m in north to over 4500m in south and 200m in the east to over 1400m in deep sea towards western part of the basin indicating palaeo-slope towards SW.

Sedimentation in Kutch-Saurashtra Basin began during Jurassic with dominantly carbonate facies deposited in marginal marine to inner shelf under transgressive environment. Early Cretaceous is represented by clastic and carbonate alternations deposited in marginal marine to deltaic environment. Late Cretaceous sediments comprise of clastic facies deposited under fluvio-deltaic environment in the eastern part and marginal marine to paralic environment in the western part. Thick Mesozoic sediments are found to be present in central part and thin out on either side. Gravity data also suggests development of prominent low in the central part of the area.

Seismic mapping (Fig.3), as well as drilling of wells, have established presence of Jurassic sediments over the Saurashtra Arch area, while Cretaceous sediments are absent over the Arch. This observation coupled with lesser trap thickness over the Arch, are suggestive of late reactivation of Saurashtra Arch area during post Jurassic.

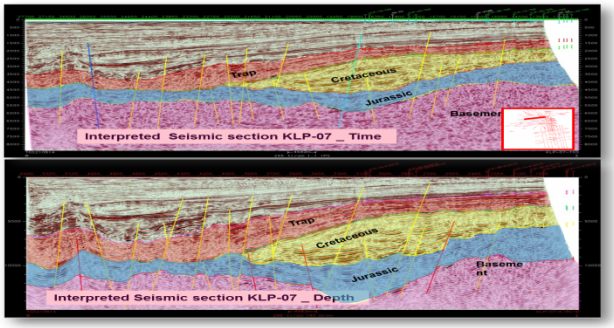

Fig.3. Interpreted Seismic Line KLP-07

After the Seychelles break-up, Tertiary sediments got deposited in a stable passive margin set up. Oligocene and younger sediments in offshore prograde basinwards. Deeper areas of shelf are dominated by argillaceous limestone / shale intercalations.

5. PETROLEUM SYSTEMS AND HYDROCARBON BASE

The organic rich rift sediments in Kutch basin are Early Cretaceous sediments deposited in fluvial to shallow lacustrine settings having mainly terrestrial organic matter and these are possible source rocks. The dominant reservoir rocks are Early Cretaceous sands which are very thick in Kutch basin. The Paleocene sediments in the low between the D and I structures are mature and possible source rock for the D oils. The Paleocene sediments were deposited in a lagoonal setup and attained maturity in late Neogene.

From litho-stratigraphy point of view source rocks include the shales of the Bhuj and Jhuran Formation in Mesozoic section and Shales of Nakhatarana, Jakhau and Fulra Formation in Ceneozoic section. Reservoir rocks are present throughout most of the stratigraphic section in the Kutch-Saurashtra basin. Reservoir rocks include the sandstones and limestones of Late Jurassic to Late Cretaceous (Jhuran formation and Bhuj Formation) for Mesozoic section and sandstones and limestones of Late Paleocene to Middle Miocene (Nakhatarana Formation, Jakhau Formation Fulra Formation Godhra formation and Chhasra Formation) for Ceneozoic section. Traps are primarily anticlines and faulted anticlines with a few subtle stratigraphic traps. Seals include interbedded Paleocene, Eocene, Miocene shales and clays, and the thick clays of the Kandla Formation.

6. MODEL BUILDING

This study area is 62,500 sq. km. covering Shallow and Deep water areas of Kutch-Saurashtra offshore. Static model incorporating depth surfaces of key stratigraphic horizons and faults (Fig.4) and their corresponding facies model form the primary inputs for building a petroleum system model. Data obtained from wells drilled within the basin including information available in public domain has been integrated. Calibration data (VRo) is available for 12 wells.

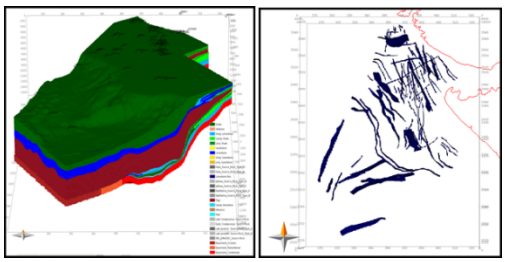

Fig.4. Static Model Geometry

7. SOURCE ROCK RICHNESS AND KEROGEN TYPE :

Based on the well data, total ten source sequences i.e. Middle Jurassic Middle, Late Jurassic lower, Late Jurassic upper, Early Cretaceous Lower, Early Cretaceous upper, Late Cretaceous lower, Late Cretaceous upper, Late Paleocene (Nakhatarana), Early Eocene (Jakhau) and Middle to Late Eocene (Fulra) applied in the model.

Mesozoic Source sequences:

a) Late Jurassic Source sequences: Jurassic sediments were deposited in shallow marine environment and are marginal source rocks. 10 to 25m mature source sequences (T_{max} 440°C) have been observed in well S and G, having average TOC 2% and HI 148 mgHC/gTOC. By using analogy with depth map (ratio slicing method), Late Jurassic source have been propagated pan basin where maximum source thickness assigned 210m.

b) Early to Late Cretaceous Source sequences: Mesozoic rocks studied in 16 exploratory wells in Kutch offshore. Cretaceous source sediments possess good organic matter richness in all the above wells (TOC ranges from 1.4-3.6% coupled with oil/gas prone OM (HI range: 151-179 mg Hc/g TOC). Onland Late Jurassic, Jhuran Formation exhibits oil/gas prone organic matter (Range of TOC: 0.78-2.09% with HI: 200-260 mg HC/g TOC) but not enough mature to generate oil/gas (VRo: 0.4 %). 10m sequence at 1230 and 1283m in well Banni-2 and at 1640and 1749m in well Nirona-1 exhibit gas generation potential. Dominance of marine input in Cretaceous sequence of G-C well is supported by high ratio of C29 hopane /C30 hopane biomarker along with Pr/Ph ratio 0.57-1.8. (Shukla M.K., 2004).

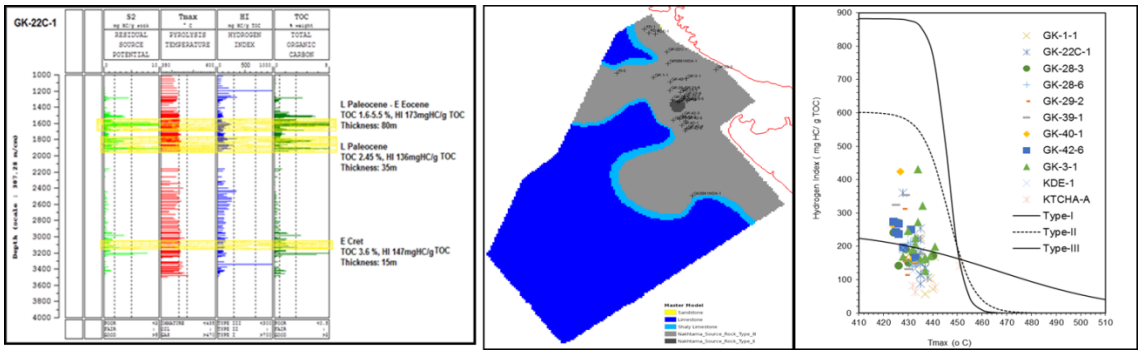

Fig.5. Source Rock Richness and Kerogen Type

c) Tertiary Source sequences: In general, studies indicate that TOC % and HI values in shallow offshore is better (range, TOC: 3-9% and HI: 97-260 mg HC /g TOC) than deep waters. Further, it is also observed that Tertiary sequences in spite of possessing good organic matter richness and oil/gas prone organic matter are not in oil window zone in the drilled locations. It may attain adequate thermal maturity in the basinal lows and thus can act as effective source rocks. 10 to 170 m thick organic rich source layers mainly have generated dominantly from type III organic matter with a contribution of type. Geochemical characterization of EOM from sediments of K-A well reveals the presence of migratory and in-situ generated hydrocarbons. (Shukla M.K., 2004).

8. THERMAL MODELING

8.1 Boundary Conditions : Boundary conditions need to be defined for the heat, pressure and fluid flow analysis through the entire simulated geologic history. The usual boundary condition data for the heat flow analysis are temperature maps on sediment-water interface (SWIT) and the basal heat flow maps for the respective events.

8.2 Sediment-Water-Interface-Temperature and Paleo-Water-Depth : This is the upper boundary condition for the modeling process, defining the surface temperatures through geological time. Settings for Kutch-Saurashtra basin: Plate: India (Northern Hemisphere) - Present day latitude 21° North

Paleo Water Depth (PWD) data were prepared through analyzing biostratigraphic data and lithological composition.

8.3 Basal Heat Flow : The goal of heat flow analysis is paleo-temperature calculation, a prerequisite for determining geochemical reaction rates. The heat flow trends first need to be calibrated and then assigned to

the model. The lower boundary condition is the basal heat flow (HF). Combination of **'**Heat Flow Calibration**'** tool of 'PetroMod' and traditional 1D extractions were used to arrive at the calibrated heat flow in the basin. Maturity calibration data i.e. VRo & Bottom Hole Temperature (BHT) data is available for 12 and 23 wells respectively. Heat Flow was in the range of ~60-70mW/m2 observed during Deccan Trap volcanics in the model. There is a gradual decrease in Heat Flow through time during passive margin setup.

9. MATURITY

9.1 Calibration Data : VRo Calibration data exists for 12 wells in the basin. Wide spread Bottom Hole Temperature data (BHT) of 23 wells covering the basin has been considered for the calibration and good calibration is achieved for most of the available wells.

Maturity overlay shows that hydrocarbon generation window falls below 2500m approximately. The maturities of different source rock layers were calculated in PetroMod based on the Easy-Ro% vitrinite reflectance kinetics by Sweeny & Burnham (1990). Rock maturity overlay for Middle Jurassic source rock shows a maturity, ranging from main oil to over mature window in areas north of Saurashtra Arch whereas in areas south of Arch, it ranges from immature to over mature window. Late Cretaceous upper source rock appears to be completely transformed with very high tranformation ratios (>95%) in most areas north of Saurashtra Arch as well as in south of it.

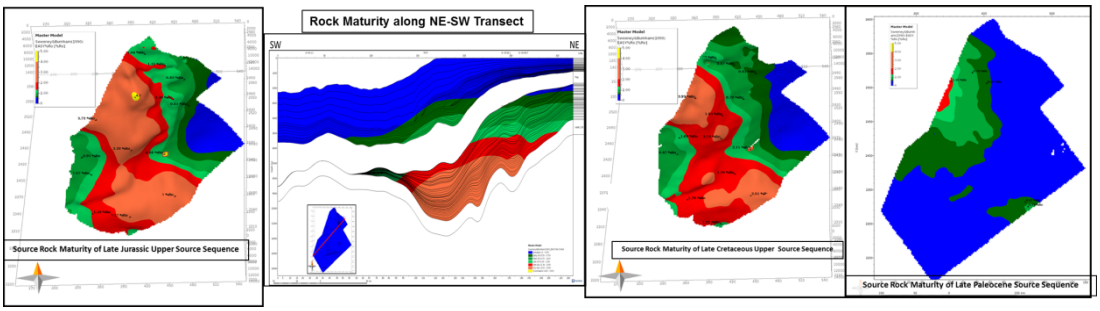

Fig.6. Source Rock Maturity of Mid Jurassic, Cretaceous and Paleocene sequences

Late Paleocene source rock appears to be transformed with tranformation ratios upto 80% in Low area south west of KI wells and upto 40% around well GK-B north of Saurashtra Arch whereas rest of the area is immature so will not have transformation ratios. Hence, the Late Paleocene source rock is not very significant in terms of hydrocarbon generation volumes in entire basin except low area present south west of KI wells.

9.2 Generation and Expulsion

Onset of generation and expulsion of hydrocarbons from a source rock depends on quality of organic matter, source rock kinetics, heat flow, sedimentary thickness and evolution of the basin. Critical Moment is the time which best depicts the generation–migration–accumulation of hydrocarbons in a petroleum system. Generally, Critical Moment is taken as 50% of transformation of the organic matter. At this time it is assumed that source rock has expelled sufficient quantity to have effective migration and accumulation.

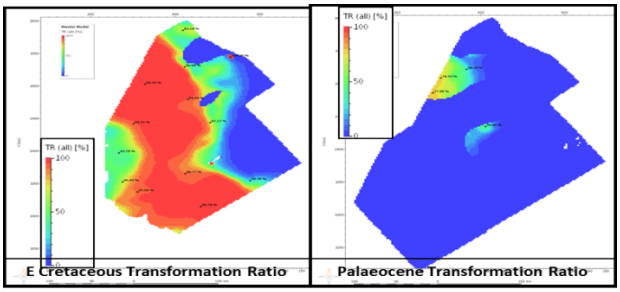

Fig.7. Transformation Ratio of Cretaceous and Paleocene source rock layers

Middle to late Eocene source rocks are yet to attain Critical Moment in the entire basin as the source rocks are relatively immature and show or no transformation at all (Fig.5.64).

10. Accumulation and Origin of Charge in Different Reservoirs

Charge modeling was carried out for the layer split model in which the facies input was taken from the maps prepared on the basis of drilled well data and paleogepgraphic analysis of the basin.
The models have shown huge loss of hydrocarbon (mainly as top loss) and distribution of accumulation is not convincing as per the pattern of known fields in the basin. An optimized scenario was attempted by increasing the seal capacity. This results in coherency with the pattern of known accumulations or major fields in the basin. Most of the hydrocarbon has migrated through faults apart from vertical migration through pores due to permeability threshold. (Fig.8)

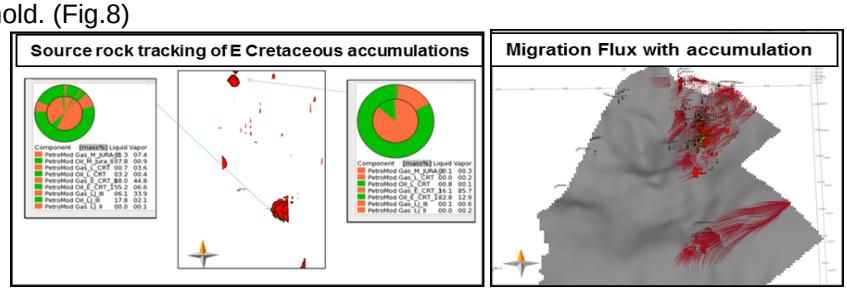

Fig. 8. Hydrocarbon Migration Flux and accumulations

Although most of the structures were available for Mesozoics during critical moment, but migration vectors overlays depict top and side flow losses of hydrocarbon.

Majority of known fields/accumulations are observed in the modeling output. Based on the Source Rock tracking multiple Petroleum systems can be ascertained:

1. Middle Jurassic - Late Jurassic/ Early Cretaceous/Late Cretaceous/Paleogene /Neogene(.),
2. Late Jurassic - Late Jurassic / Early Cretaceous / Late Cretaceous / Paleogene / Neogene (.),
3. Early Cretaceous - Early Cretaceous/Late Cretaceous/Paleogene / Neogene (.)
4. Late Cretaceous - Late Cretaceous /Paleogene / Neogene (.)
5. Late Paleocene - Early Eocene (.)
6. Early Eocene - Early to late Eocene/ Middle Miocene (.)
7. Middle to Late Eocene – Middle Miocene (.)
8. Biogenic system within Neogene sequences

11. UNCERTAINTIES IN INPUT PARAMETERS

Numerical models, including basin and petroleum system models, provide scenarios for what might have happened given various constraints on the input data. The impact of uncertain data can be studied by multiple simulation runs with varying model parameters.

12. SUMMARY

- Source layers from Middle to L Jurassic and Cretaceous sequence are main source layers in Kutch-Saurashtra Basin based on various geochemical studies and established through present PSM study.
- Tertiaries, i.e., Paleocene and younger source rocks are barely reaching the main oil window in the north of Saurashtra Arch and transformation ratios are very low except for Paleocene source rock in KI Low, hence these source rocks would not be contributing much.
- Main hydrocarbon generation maturity window falls approximately below 2500m and varies.
- Modeling also indicates a possibility of biogenic system within Neogene sequences.

Exploration in Deepwater areas remains ‘High Risk’, as maturity modelling demonstrates that if Tertiary source rock is present with optimal quality, it is largely immature and may be localized. Deccan basalt imparts differing interpretation and model scenarios. Mesozoic Petroleum Systems need to be addressed with a detailed paleo- geographic analysis at a higher resolution.

Acknowledgements

We express thanks to Dr. Hari Lal, ED, HOI-KDMIPE for his encouragement and support. We also express our thanks to Dr. A. Siawal GM, (Geol), Head(s) - BRG for his guidance. We sincerely acknowledge the support provided by Shri U.C Pradhan, GM (Geol) during the course of study.

References :

- Magoon, L .B and Dow W. G, (1994): The Petroleum System from source to trap, AAPG Memoir, 60, Tulsa, American Association of Petroleum Geologists, p249-260
- Integrated geological modeling of Kutch-Saurashtra Basin including Petroleum System(s) Modeling, 2016, KDMIPE Unpublished report.