



P 191

Understanding of Petroleum Systems of Gondwana and Paleogene Sediments in Bengal Basin, India: A two (2D) dimensional basin modeling study

D.K. Phaye*, D.K. Srivastava, M.V.Nambiar, A.K. Sinha, V. Prabhakar, S. Das #

Summary

In past 50 years of exploration and by drilling of nearly 40 wells in the Bengal Basin of India, no commercial accumulations have been observed so far. An understanding of petroleum system of Bengal Basin is very essential to know whether it is incomplete or the basin lacks potential generating centers. Basin and Petroleum System Modeling (BPSM) through numerical simulation is fast emerging as powerful and effective tool to analyze key elements of petroleum system including charge modeling. In this paper, we present results of the BPSM study attempted to bring out a systematic evaluation of petroleum systems using PetroMod software. 1D modeling carried out on selected well locations to know heat flow trends, maturity and temperature profiles and 2D modeling attempted along three regional seismic transects passing through drilled wells incorporating all the available geological and geochemical information. The drilled well data confirms the existence of organic richness & source rock potential within the Lower Gondwana sequence, Cretaceous and Tertiary sequences. HI values in the potential source rock sections are consistently less than 150mgHC/gTOC signifying type-III kerogen. However, few wells have HI values in the range of 200-300mgHC/gTOC indicating minor contribution of type-II kerogen.

Numbers of scenarios were simulated for all the three 2D models. Modeling results indicate that within the Gondwana sequence, critical moment is at the time of Rajmahal magmatic event i.e ~115Ma and indication of additional late charge along the hinge zone due to late Tertiary burial. In Paleogene sequence, an active Eocene-Oligocene petroleum system is observed but due to low source potential & maturity the overall amount of hydrocarbon available for migration is very low.

Reservoirs, which are in direct contact to the Eocene source rock, are potentially charged as no or short distance migration is required. The eastern Mio-Pliocene depocenters show significantly higher source rock maturity but the timing is unfavourable to charge the ~16 Ma and younger structures to the west of hinge zone. In the offshore part (along the modeled profile), hydrocarbon expelled from the deeper sources but could not reach in to the shallower traps resulting very high percentage of saturation.

Keywords: Petroleum Systems, Bengal Basin

Introduction

Bengal Basin lies between latitude 25°-20°30' and longitude 87°30'-90°30'. Towards south, the basin extends to offshore region of Bay of Bengal. It occupies an area of about 90,700 sq. km. Hydrocarbon generation in the basin is confirmed, as localized accumulations and few oil/gas shows have been observed by drilling. However, no commercial success observed so far. This paper presents the output of the Basin and Petroleum System Modeling (BPSM) study (Fig.1) The general objective of the study was to establish the characteristics of the petroleum system as the Gondwana and Tertiary sequences host potential

petroleum systems in the Bengal Basin. However, the main objectives were defined as follows:

- Assess effects of volcanism in the basin and study Heat Flow characteristics which might have played a major role in maturation.
- Assess expected kitchen/generative centers in the basin center and study the timing of charging.

Acquire additional understanding of petroleum migration including possible migration paths and the role of faults and seals.



Figure 1: Map showing location of regional transects.

Tectonics and Geology

Bengal basin, a polycyclic basin, has evolved through two distinct tectonic episodes. It initiated as an intracratonic rifted basin within Gondwana land during Late Paleozoic/Mid Mesozoic time and received the continental Gondwana sediments. This phase of basin development ended with wide spread volcanism during Early Cretaceous times of continental flood basalts (Rajmahal Trap) covering the Gondwana sediments almost as a veneer. The second phase of basin formation took place when Indian Craton separated out completely from the Gondwana land and kept on moving northwards. During this journey of the Indian plate, the pericratonic part on the eastern margin (along with Gondwana sediments) of the traps, continuously subsided eastward and received colossal volume of sediments from Late Mesozoic through Tertiary to Recent times in a passive margin set-up (Roybarman A., 1983). The generalized stratigraphy of Bengal Basin is given in Fig.2

Model Building

Input data includes static geological model, depositional history, lithofacies and source rock characteristics. These data were obtained from the well completion reports of the wells along which 1D modeling carried out, which were used to quickly define thermal boundary conditions for 2D Modeling.

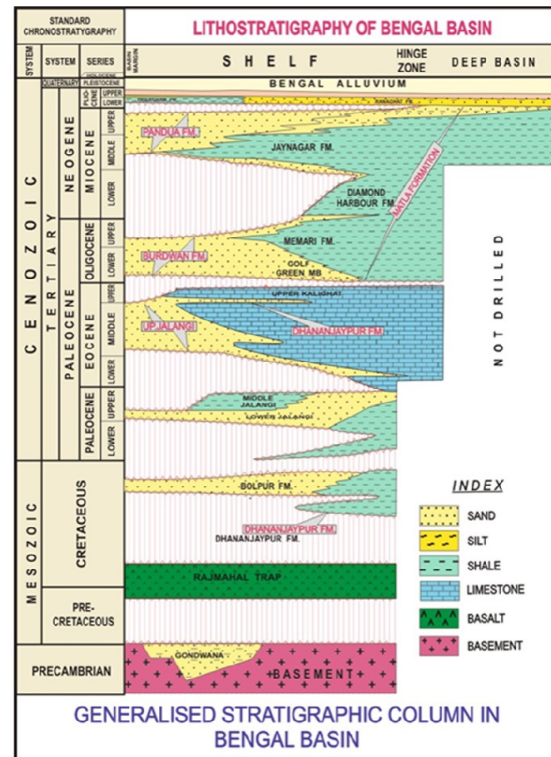


Figure 2: Generalized Stratigraphic of the Bengal Basin

The source rock parameters and other calibration data were taken from the Lab reports and well logs.

A total of three NW-SE seismic lines passing through drilled wells were selected for the study. Two of them (WB-A and WB- B) are located in the northern part of the basin. One of them line-SB-C is located in the offshore part of the basin (Fig.1).

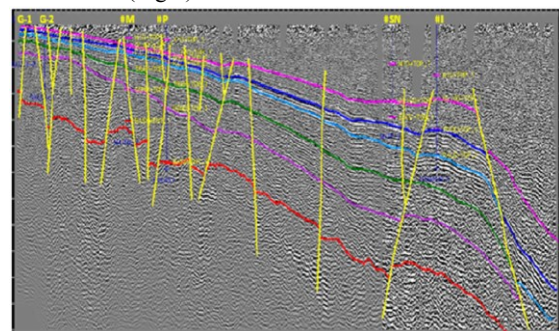


Figure 3: Interpreted seismic line WB-B with geometries.

In order to test the deeper part of the basin (east of the Hinge zone), we have slightly extended the modeled section from the original seismic line (Fig.3). In Fig.4, a vertical black line marks the limit of the seismic line and with that the lateral limit of seismic control.

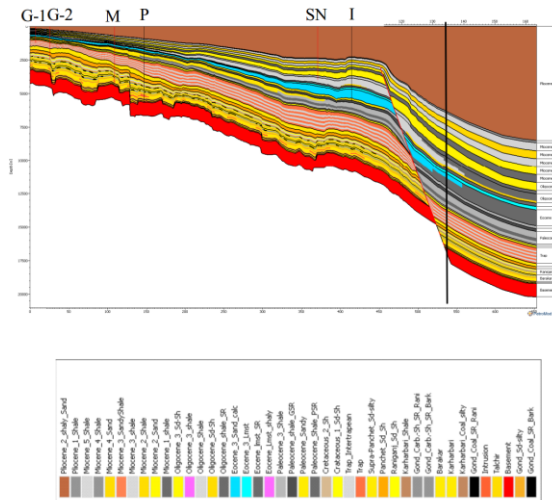


Figure 4: Model Geometry with facies distribution along WB-B

Source rock properties

Source rock parameters are given in Table 1. For Paleocene SR a TOC and HI trend based on drilled well data was assigned. (A detailed source rock study of Bengal Basin is reported in Sinha et. al., 2010)

SR Facies	Lithology	TO C	Kinetic	HI
Oligocene_shale_SR	Shale (typical)	1.2	Purnea-1_Bengal_Olig	175
Eocene_lmst_SR	Limestone (organic rich - typical)	1.5	Purnea-1_Bengal_Eoc	100
Paleocene_shale_GSR	Shale (typical)	Map	Purnea-1_Bengal_GSR	Map
Paleocene_Shale_PSR	Shale (organic rich, typical)	2	Purnea-1_Bengal_PSR	200
Gond_Carb.-Sh_SR_Rani	Shale (typical)	2	Purnea-1_Bengal_Sh_Rani	120
Gond_Carb.-Sh_SR_Bark	Shale (typical)	2	Purnea-1_Bengal_Sh_Bark	120
Gond_Coal_SR_Rani	COALSilt	10	Permian_Coal_Rani	150
Gond_Coal_SR_Bark	COALSilt	10	Permian_Coal_Bark	150

Table 1: Source rock properties

Two different kinetics were used for the source rocks. One for the Gondwana source rocks and one for all Paleogene source rocks (Fig. 5 and 6).

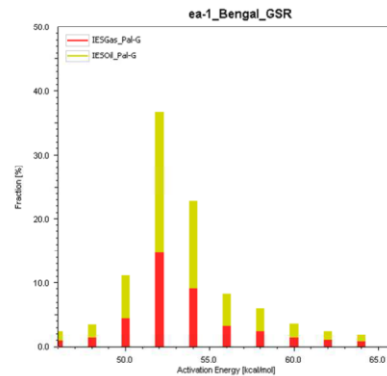


Figure 5: Paleogene SR kinetic.

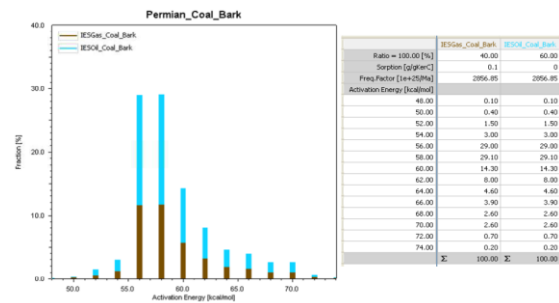


Figure 6: Gondwana SR kinetic.

Boundary Conditions

Paleo water depth (PWD)

Paleobathymetry data were used in the reconstruction of the subsidence that occurred within the basin. Paleobathymetry values used in the modeling were obtained from the available published Lab reports and published literature (Fig.7).

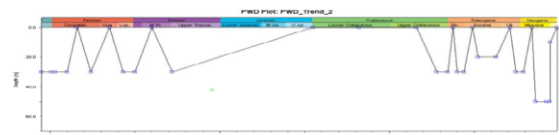


Figure 7: Paleo water depth trend assigned to the models.

Sediment Water Interface Temperature (SWIT)

Surface temperature evolution was modeled in accordance with global mean surface temperature as defined

by Wygrala (1989). Average surface temperature of $\sim 27^{\circ}\text{C}$ was observed during onset of the rift, which was decreased to $\sim 21^{\circ}\text{C}$ during Late Palaeocene to Miocene period. These temperatures are adjusted to PWD in order to estimate the SWIT (Fig.8)

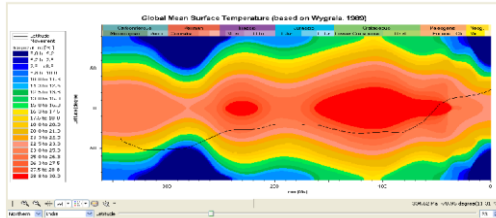


Figure 8: SWIT automatic tool setting as assigned to the models.

Basal Heat Flow

The basal HF trend was interpreted with two peaks. One during Gondwana deposition (rifting) and one during the Rajmahal trap magmatic event. Fig.9 also shows that the basal HF is interpreted to basically the same during the Paleogene.

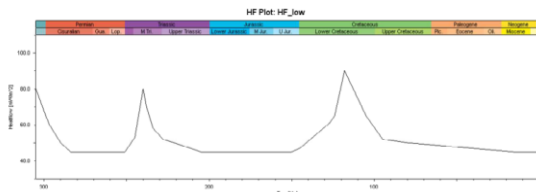


Figure 9: HF trend assigned to the models.

Calibration and results

Pressure

At the S#1 well location strong overpressures were encountered within the Miocene and the Eocene section. The model along SB-C section has been therefore calibrated to the available pressure data (Fig.10).

Temperature / Maturity

Temperature and Vitrinite reflectance calibration for WB -B model is shown in Fig.11 and 12 respectively.

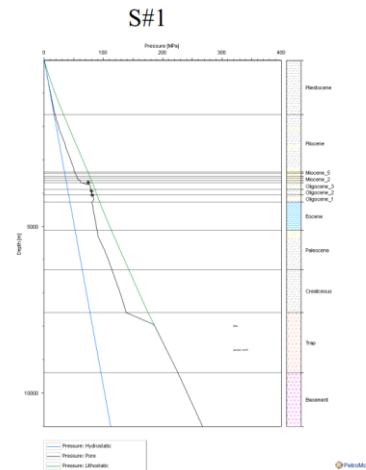


Figure 10: Pressure calibration at the S#1 well location.

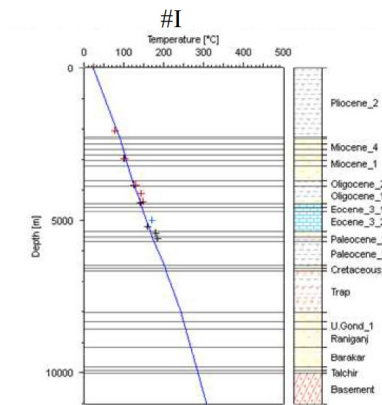


Figure 11: Temperature calibration at I well location

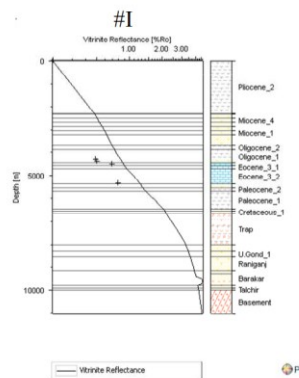


Figure 12: Vitrinite reflectance calibration along model WB-B at I well

Modeling Results and Discussion

Maturity: The Gondwana sequence is at present day mostly over mature, even within the shallow area. This is mainly due to the effect of the magmatic intrusions at ~118Ma. As shown in Fig.13, the Gondwana sequence was mostly matured or already at 85Ma.

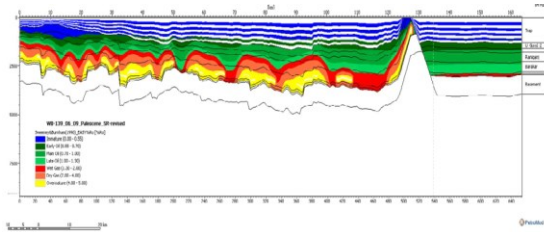


Figure 13: At 85 Ma Sweeney&Burnham VRo% in standard maturity ranges for model WB-B.

Transformation Ratio (TR):

Time Vs TR% can be analyzed in Fig.14 for Gondwana and Paleocene source rocks.

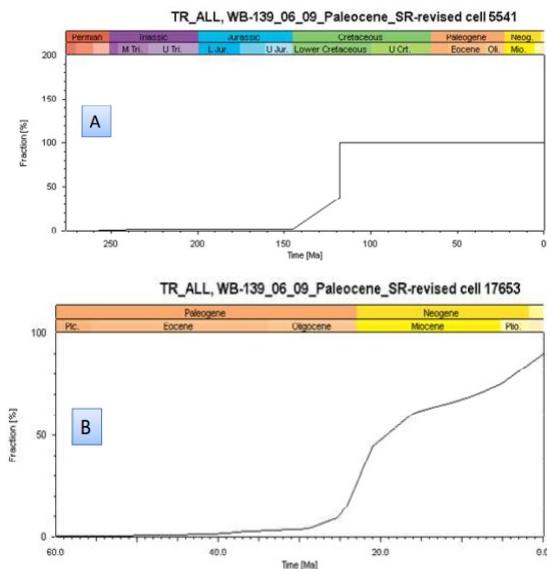


Figure 14: Transformation ratios through time A: Gondwana SR and B: Paleocene SR

Generation and Expulsion Timing

In the Gondwana sequence, we observe that most of the hydrocarbons were expelled during the Rajmahal igneous event. Only in the deepest part of the basin, later additional expulsion occurred, but those areas are at very deeper present day. (Fig.15)

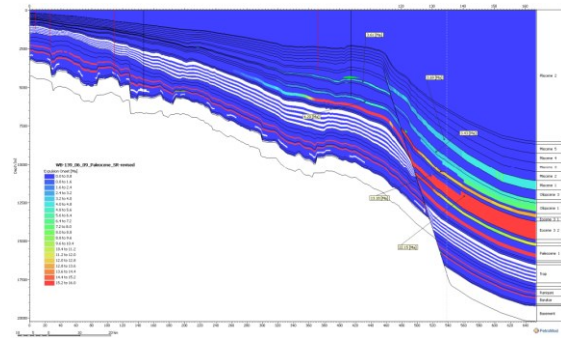


Figure 15: Onset of expulsion along model WB-B. Note that only the I structure is charged

Effect of Volcanism in the basin: Temperature, Maturity, Transformation and Generation

In the Bengal Basin, the Gondwana sequences were tested and Fig.16 clearly shows that without intrusions also the shallow part of the section has reached maximum transformation at the time of the Rajmahal igneous event. Only the deepest part of the model shows additional transformation at later stage.

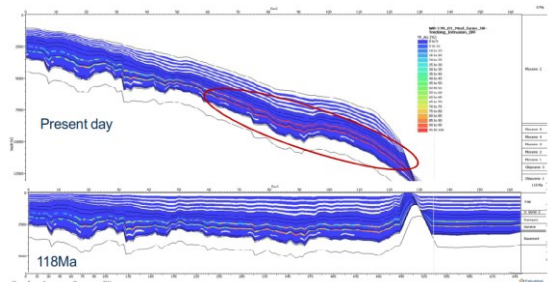


Figure 16: Source rock transformation ratios within the Gondwana sequence along model WB-B, both at Present day and at 118Ma.

For the WB-B section, the expulsion masses show a clear distinction between the Gondwana and the Paleogene source rocks. Fig.17 shows a comparison between the timing of expulsion between Gondwana and Eocene source rocks. The Gondwana sequence has expelled most of its potential during or just after the Rajmahal igneous event, while the Eocene matured and expelled hydrocarbons not before the Miocene. In this deeper part of the Basin (east of the Hinge Zone) is also included in the output data.

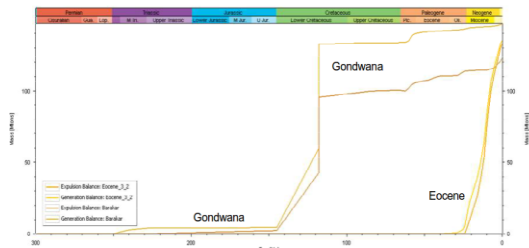


Figure 17: Comparison of the generation/expulsion curves of Gondwana sequence and Eocene source rock through time

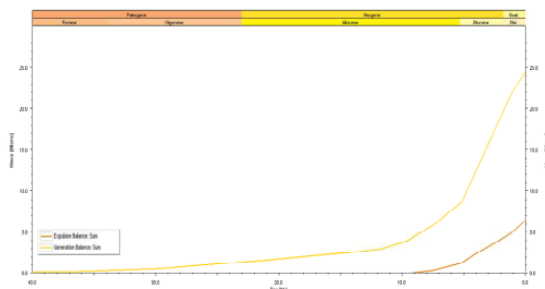


Figure 18: Generated and expelled masses from the WB-A model through modeled geological time.

If we analyze only at the area west of the Hinge Zone, (Fig.18 and 19) we observe the generation and expulsion history of all modeled source rocks along model WB-A. In this model the expulsion started earliest at 10Ma, while generation started some 20 million years earlier. This section does not cover much area to the east of the Hinge Zone. That is why we can use this section to best depicts the timing of expulsion towards west of the Hinge Zone.

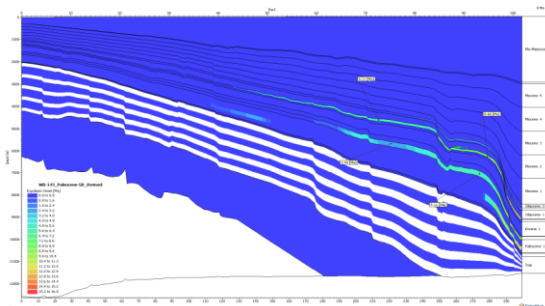


Figure 19: Onset of expulsion along model WB-A.

Petroleum Migration

Migration and Play Concept

In the Bengal Basin wells in the shelf area of the Basin have shown good reservoir sands that appear to

shale out towards the Hinge Zone. The Eocene carbonates are known to have very poor reservoir quality. No reef facies has been encountered. Overall, structural traps are rare and are generally concentrated along the Hinge Zone.

In the well #1, an oil-bearing sand body was encountered. However, I#2 drilled close by did not penetrate the sand. This indicates that those Oligocene sands are very localized within a shaly section. Charge for the I sands is likely to have occurred from the Eocene source rock just below (Fig.20). Which could be extended to other areas along the Hinge Zone?

Based on the drilling results, up-dip migration from the deeper buried sources near the Hinge Zone towards the West is an unlikely scenario.

Migration Results

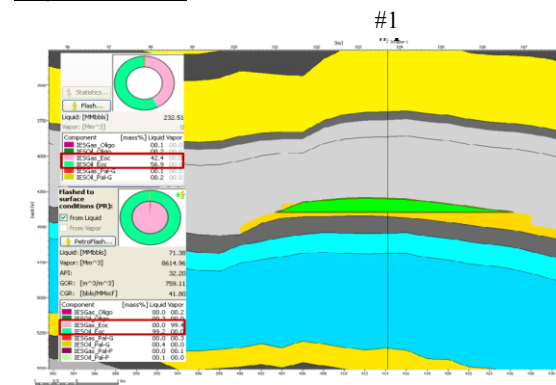


Figure 20: Close-up view of the I structure and accumulation along model WB-B

Along the offshore Model SB-C (Fig.21), we have not observed accumulations. This is due to the fact that all expelled hydrocarbons remain within the source itself and within the shaly sequences directly above.

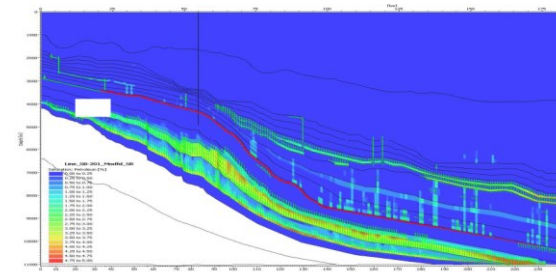


Figure 21: Present day hydrocarbon saturations along model SB-C, migration vectors is also shown



There are two reasons for the retention of hydrocarbons at saturations. First we have modeled that most of the deeper part of the section is very high in shale content. That means that any migration of hydrocarbons will be very slow. The expulsion from the Eocene and younger sources has occurred relatively late in time, thus not sufficient time was available to migrate hydrocarbons to reservoirs at shallower levels. Additionally, the overall expelled masses are quite low.

Sensitivities of organic content on total potential

In the Basin, we defined the upper Paleocene SR as a good source in the shallow part of the basin, while as a very lean source in the deeper part of the Basin. We have tested a good upper Paleocene source rock throughout the entire section length of WB-B. In this scenario we assigned 4% TOC across the entire layer.

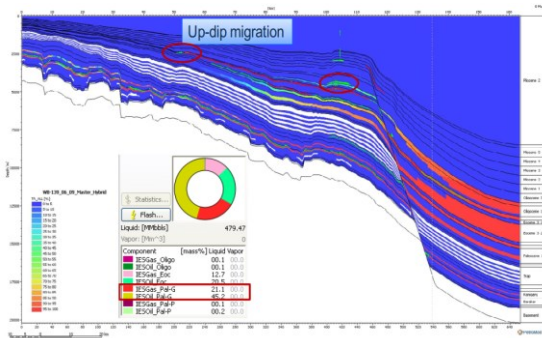


Figure 22: Migration results at present day applying 4% TOC to the upper Paleocene source rock.

The migration results as shown in Fig.22 are inconsistent with many observations made along the section. First we observe that the accumulated masses at the I structure are significantly higher than in the master scenario. This is due to the additional charge from the Paleocene source rock in this rich scenario. The analysis done so far on the well# I oil indicates that it was derived from the Eocene source rock. Therefore an additional charge from a Paleocene source is not very likely.

Secondly, a rich Paleocene source leads to substantial up-dip migration into shallower structural traps. This modeling result is also contradicting the drilling results. None of the drilled wells up-dip from well #I has ever encountered any oils shows. Therefore a rich source that has expelled significant masses of hydrocarbons for up-dip migration is very unlikely.

Conclusions

Existence of two potential Petroleum systems within Gondwana and Paleogene sequence is possible in the Bengal Basin.

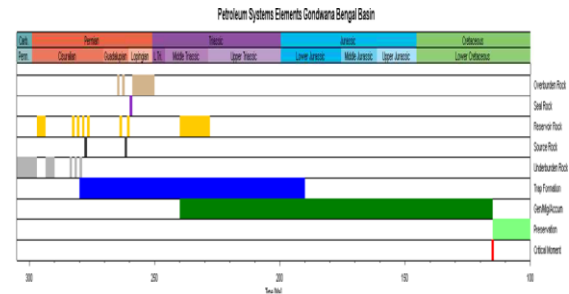


Figure 23: Petroleum Systems Elements Chart for the Paleogene sequence in the Bengal Basin.

In the Gondwana sequence we observe the critical moment to be at the time of the Rajmahal magmatic event (with or without intrusives). However, the deeper part of the Gondwana (in the vicinity of the Hinge Zone), later burial may have delivered an additional charge not shown in Fig.23.

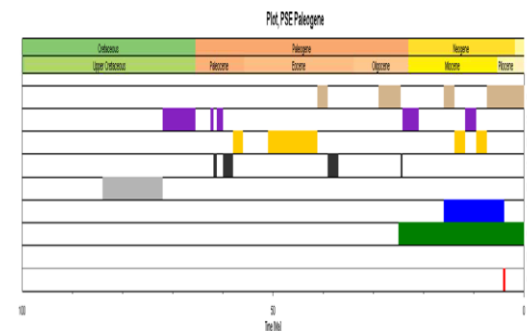


Figure 24: Petroleum Systems Elements Chart for the Paleogene sequence in the Bengal Basin.

For the Paleogene sequence the critical moment was interpreted to be at 4Ma (Fig.24). At 4Ma the Eocene source rock has reached about 50% transformation ratio along the Hinge Zone. The potential deeper sources (mainly Paleocene) and also the Eocene to the east of the Hinge Zone may have expelled hydrocarbons as early as 25Ma. However the I structure was interpreted to have formed after 16Ma.

Kitchen areas

In the Basin, the kitchen area for the Gondwana sequence is difficult to define. But if restricting it to a late charge,



the kitchen area would be in those areas where the Gondwana sequence was buried to deeper depth during the Tertiary.

For the Paleogene sequence the kitchen area is very much confined around the Hinge Zone. East of the Hinge another kitchen could be defined, although the timing of generation/expulsion from the deep kitchen east of the Hinge Zone may not be right for charging structures west of the Hinge Zone fault.

Effect of Volcanism

Modeling has shown that intrusives in the Gondwana sequence within the Bengal Basin would have a significant influence on the expelled masses at the time of the Rajmahal magmatic event. No additional late charge would be possible during additional Tertiary burial.

Hydrocarbon Migration and Accumulation

The migration results in the Bengal Basin show:

- Oligocene sands in contact or very near to mature Eocene sources can be charged with Eocene oils (I-play)
- Generally small masses are available for migration and long distance migration is very unlikely
- In the offshore, expelled hydrocarbons from deeper sources may not have reached to shallower traps. Any sheet-like sands would allow up-dip migration (if quantities are great enough).
- In the Bengal Basin we could show that the only area that has some hydrocarbon potential will be located along the Hinge Zone. Structure I has already shown that the Eocene-Oligocene Petroleum system is working. Because of poor source rocks, low expelled masses and potentially very limited Oligocene reservoir sands we do not expect very large accumulations along the Hinge Zone.
- Any exploration along the Hinge Zone should focus on the mapping of the top Eocene to identify kitchen areas and mapping of Oligocene sands as their presence is essential to trap any Eocene oils.

Acknowledgement

The authors are grateful to Dr. D. K. Dasgupta, HOI KDMIPE for his constant guidance. Authors also

express their sincere thanks to Smt. Shipra S. Bhagwani, GGM-Head, BRG for guidance. Authors express their sincere gratitude to Shri C. Mahapatra, GGM (Geology) for his constant guidance, supervision, valuable suggestions and encouragement at different stages. The authors acknowledge the ONGC management for giving the permission to publish this work. The views expressed here are solely those of the authors and not necessarily of the organization where they are working

References

- Behar, and PG Hatcher, 1997, Experimental determination of the reaction kinetics and product ... eds., *Advances in Petroleum* Burnham, A. K., 1989. A simple model of petroleum formation and cracking. Lawrence Liverpool Lab. Report. UCID 21665, March, 1989
- Hantschel, T., and A.I. Kauerauf, 2009, *Fundamentals of Basin and Petroleum Systems Modeling*: Springer Verlag Berlin, 476 p.
- Roybarman, A. 1983. Geology and hydrocarbon prospects of west Bengal, , *Petroleum Asia Journal*, p.51-56.
- Sinha A.K. et al., 2010: *Geochemical Analysis and Thermal Modeling of Bengal Basin for Understanding Petroleum System and GME Cycle of the Basin* (Unpublished KDMIPE report)
- Well completion reports of drilled wells in Bengal onland and offshore areas, Unpublished ONGC Report
- Wygrala B. P., 1989. Integrated study of an oil field in the southern Po basin, northern Italy. *Berichtekern for schungsanlagejulich* 2313:p.217