# Burial history reconstruction and thermal maturity modeling of Proterozoic rocks of Bhima and Kaladgi basins

*Nishtha Agarwal*, S.Sundarraman, Simantini Pattanayak, Samrat Tiwari, Mayadhar Sahoo*
*(KDMIPE, ONGC, Dehradun) *agarwal_nishtha@ongc.co.in*

**Keywords**
1D Petroleum System Modelling (PSM), Bhima Basin, Kaladgi Basin, Burial history plot, Maturity, Transformation ratio

**Abstract**
The Bhima-Kaladgi Basin is a category III basin that isthe least explored for hydrocarbons because of the paucity of data leading to a poor understanding of tectonics, basin architecture, sedimentation history, and original depositional boundaries, which in turn limits the assessment of petroleum system elements and processes. The geologic record also provides minimal support, as much of the sediment column has been eroded in the geologic past. This study presents 1D Petroleum System(s) Modelling (PSM) to evaluate thermal maturity of sediments by integrating all available geochemical, geologic, and geophysical information by calibrating the model with available data sets.

**Introduction**
Bhima and Kaladgi are the two Proterozoic basins situated in the northern part of Dharwar craton in the Indian Peninsular Shield. These basins overlie the Archean granitic basement of Dharwar craton with a profound unconformity and have faulted contacts at many places. The north western and northern parts of Bhima and Kaladgi basins respectively remained concealed under the Deccan Trap of the Deccan Syneclise.
The east-west trending Kaladgi Basin is located in the northern part of the Archaean Dharwar Craton (Figure 1). The basin has an irregular elliptical outline with a great part concealed beneath the basaltic lava flows of Deccan Trap in the north and west. In the north, the outcrops occur as inliers within the Deccan Trap near Jamkhandi and the basin may extend further north beneath the Deccan Trap flows. Western Dharwar Craton consisting of an assemblage of Archean Peninsular Gneissic Complex, Hungund Schist Belt and Closepet Granite form the basement for Kaladgi sediments and are exposed towards north-east, east and south defining the basin boundary.
Bhima Basin is a Neoproterozoic, epicratonic, extensional basin, which formed as a result of gravity faulting (Figure 2). It is the smallest Proterozoic basin in India having an area of 5300 sq km over a stretch of 160 km in NE-SW direction covering parts of the states of Karnataka and Telangana. The basin is situated to the northwest of Cuddapah Basin and northeast of Kaladgi Basin.
Hydrocarbon exploration activity in Bhima-Kaladgi Basin has been initiated by the acquisition of 2D NSP seismic data. Geological setup and evolutionary history of the basin is very poorly understood. It is generally believed that these basins developed as interior sags. However, a first-order observation is that these may show significant structural differentiation with characteristic lithological assemblage of tuffs and pyroclastic matter indicating a rift origin.

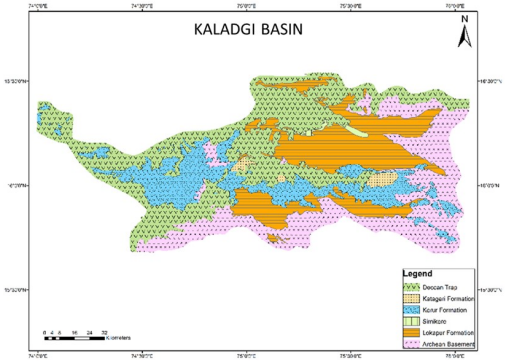

Figure 1: Geological Map of Kaladgi Basin (modified after Jayaprakash et al. 1987)

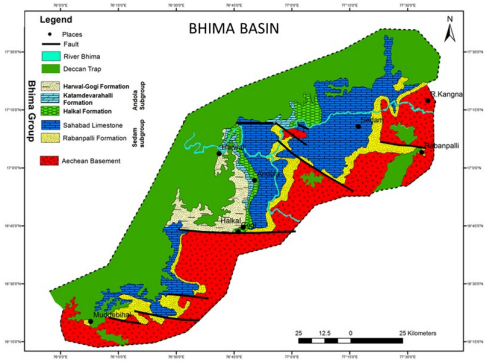

Figure 2: Geological Map of Bhima Basin (modified after Mishra et al. 1987)

# Burial history reconstruction and thermal maturity modeling of Bhima and Kaladgi basins

## Stratigraphy

Kaladgi Basin spread over an area of 8800 sq. km. Some part of the northern and western extension of the basin is concealed under the Deccan Traps. Where the traps are removed by weathering and erosion; the rocks of Kaladgi are exposed as inliers (Raha and Sastry, 1982) (Figure 3). The entire sedimentary succession of the basin is represented by Kaladgi Supergroup. Stratigraphically, the Kaladgi Supergroup is divided into older Bagalkot Group (Mesoproterozoic) and younger Badami Group (Neoproterozoic) separated by an angular unconformity. The lithology includes mainly conglomerate, quartzarenites, argillites, limestones and dolomites.

Bhima basin covers an area of 5300 sq. km. The basin is made up of Neoproterozoic limestone and shale with thin but fairly continuous arenite and conglomerate bed at the base exposing the unconformity contact at several places along the southern margin (Figure 4).

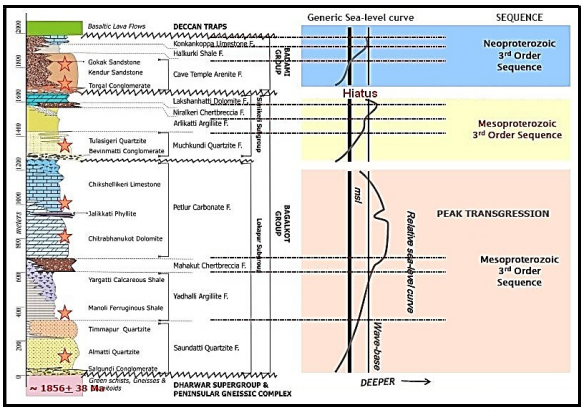


Figure 3: Generalized Stratigraphy of Kaladgi Basin (Pillai, 2008)

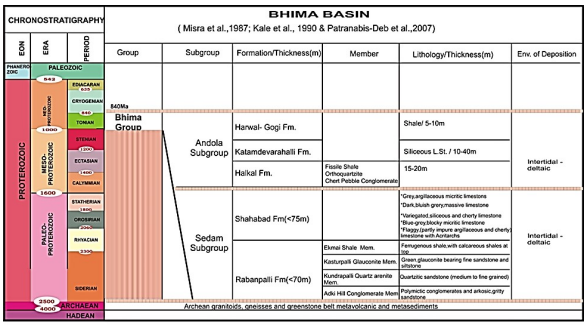


Figure 4: Generalized Stratigraphy of Bhima Basin (Mishra et. al., 1987; Kale et.al., 1990 & Patranabis-Deb et. al., 2007)

## Input data

Geological data: Geological mapping was conducted over the entire Bhima-Kaladgi Basin by various workers (Figures 1 & 2).

Geophysical data: From the gravity modeling study, it is inferred that the maximum sedimentary thickness is around 4500 and 230 m in Kaladgi and Bhima basin respectively (Unpublished ONGC report, Geophysics group, KDMIPE) (Figure 5).

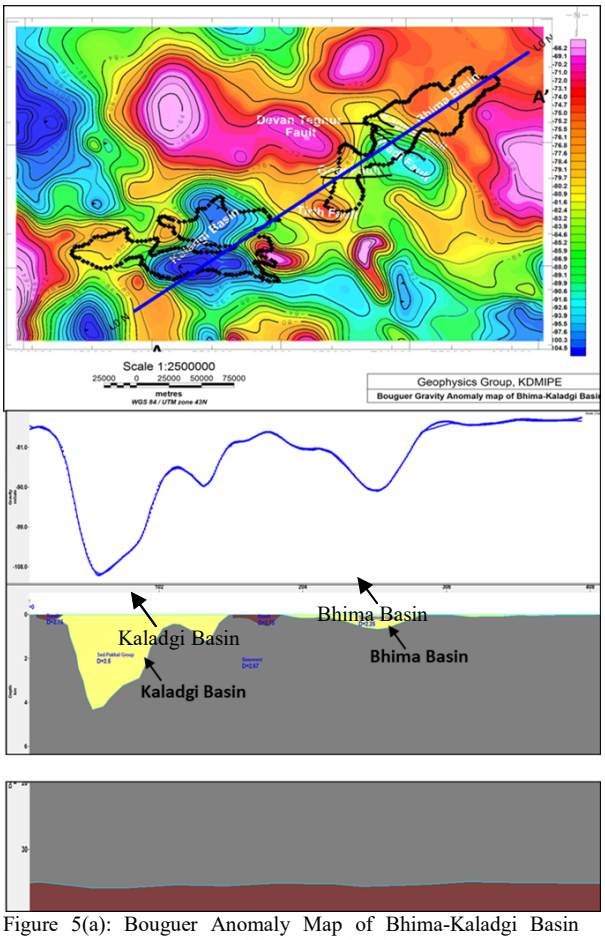


Figure 5(a): Bouguer Anomaly Map of Bhima-Kaladgi Basin showing AA' gravity modeling profile (b): Gravity Modeling along Profile A-A'

Calibration data in Bhima basin: Estimation of peak temperature by study of carbonaceous matter in brecciated limestone, (Patnaik, et. al., 2016). Carbonaceous matter is identified in outcrop samples of brecciated limestone in Kanchankayi area. Bitumen reflectance measurements have been carried

**Burial history reconstruction and thermal maturity modeling of Bhima and Kaladgi basins**

out on highly polished thin section under reflected light which indicates its bituminous rank. The bitumen reflectance of the samples was subsequently converted to estimate temperature peak of hydrothermal environment using Schoenherr et al. (2007) and Barker and Pawlewicz (1994). Bitumen reflectance varies from 0.50% to 0.91% (Table1). Bitumen reflectance converted to Vitrinite Reflectance of the carbonaceous matter was found to be in the range of 0.70 to 1.09% and temperature peak value for hydrothermal activity was estimated to be 108.23ºC to 164.34 ºC. The temperature range is corroborated by fluid inclusion studies carried out on the secondary calcite samples from the same area (Patnaik, 2014).

Calibration data used for Kaladgi Basin : Illite crystallinity index or Kubler's Index. The illite crystallinity (IC) index is a commonly used parameter for describing low-grade metamorphism of pelitic rocks. On the basis of IC index, these zones are classified as diagenetic, anchizone and epizone.
The grade of metamorphism and thermal maturity of the Mesoproterozoic Bagalkot Group in the Kaladgi basin of southwestern India has been determined using the illite crystallinity (IC) index. IC index was determined from the argillite samples of four stratigraphic levels (Mukherjee, M.K. et. al, 2019) viz., Ramdurg Formation (basal unit), Yargatti Formation (intermediate lower unit), Yadahalli Formation (intermediate upper unit) and Hoskatti formation (upper unit). IC index (Kubler equivalent) values range between 0.54◦Δ2θ and 0.24◦Δ2θ (in a set of 37 samples) and indicate a deep diagenetic to high anchizone metamorphic grade within a temperature range of ~180 to 300◦C (Figure 6). Considering an average Mesoproterozoic geothermal gradient of 35◦C/km based on drilled well datasets of Vindhyan Basin a thermal model calibration was achieved for the same.

**1D Petroleum System Modelling**

The main purpose of 1D Petroleum System Modelling is to reconstruct the burial history of the basin. The model shows the thermal maturation of source rocks over time, transformation ratio of hydrocarbon generation, onset of oil generation and timing of peak generation. 1D Petroleum System Modelling has been attempted using PetroMod software in the Kaladgi and Bhima basins at a location in the deepest part of the basin. The Kaladgi basin has a sedimentary column of about 4500 m and the Bhima basin has only 230 m of sedimentary column.

**1D Petroleum System Modelling of Kaladgi and Bhima Basin**

The age of each formation has been assigned to build the Petroleum system model for determining the timing of the processes that generate, move and trap hydrocarbon. Kaladgi basin has Mesoproterozoic and Neoproterozoic sediments (Figure 6) above basement and Bhima basin has Neoproterozoic to Precambrian-Cambrian boundary sediments above basement (Figure 7) (Shukla, et.al. 2020).

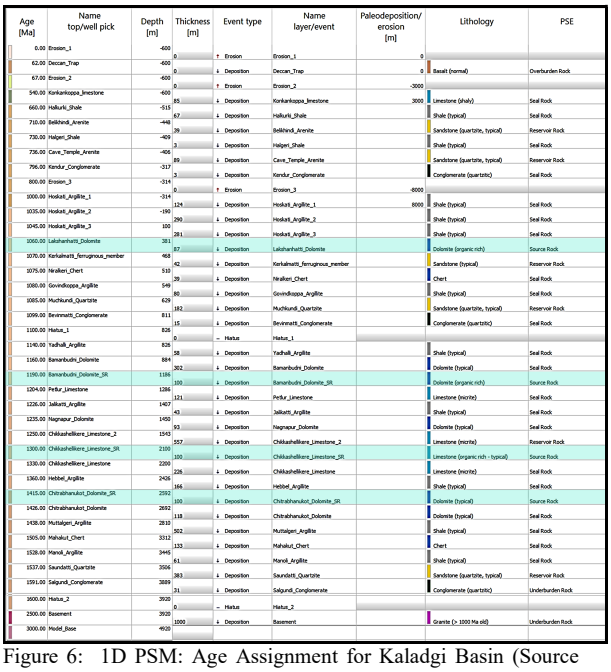

Figure 6: 1D PSM: Age Assignment for Kaladgi Basin (Source rocks demarcated with blue)

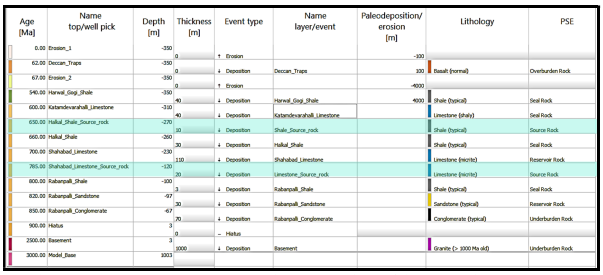

Figure 7: 1D PSM: Age Assignment for Bhima Basin(Source rocks demarcated in blue)

# Burial history reconstruction and thermal maturity modeling of Bhima and Kaladgi basins

## Source rock characteristics

Speculative source sequences have been assigned in both the 1D model. Source sequences have been assigned lacustrine or marine source rock kinetics to understand the timing of hydrocarbon generation.
Three default source kinetics available on PetroMod platform have been used in both the 1D models, two marine source kinetics and one lacustrine.

- Burnham (1989) TII kinetics has been used for modeling source rocks having a maximum activation energy at 51 kcl/mol (Figure 8).
- Pepper&Corvi(1995) TII-S(A) kinetics has been used for limestone source rock having a maximum activation energy at 49 kcl/mol (Figure 10).
- Behar_et_al(1997) TI(GRS) kinetic has been used for shale source rock having a maximum activation energy at 54 kcl/mol (Figure 9).

Source rocks envisaged for Kaladgi basin have been assigned in the following formations:

1. Chitrabhanukot Dolomite
2. Chikkashelikere Limestone
3. Bamanbudni Dolomite
4. Lakshanahatti Dolomite

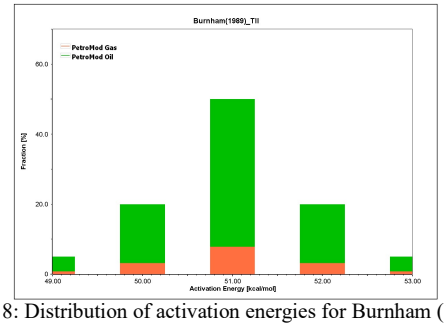


Figure 8: Distribution of activation energies for Burnham (1989) _ TII source kinetics

Source rocks envisaged for Bhima basin have been assigned in the following formations :

1. Halkal Shale
2. Shahabad Limestone

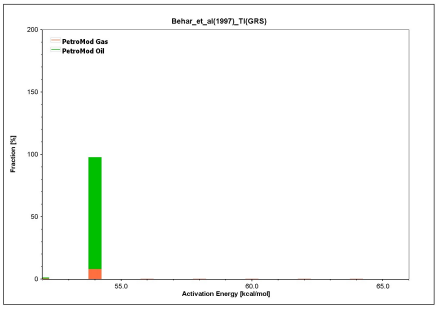


Figure 9: Distribution of activation energies for Behar_et_al(1997)_TI(GRS) source kinetics

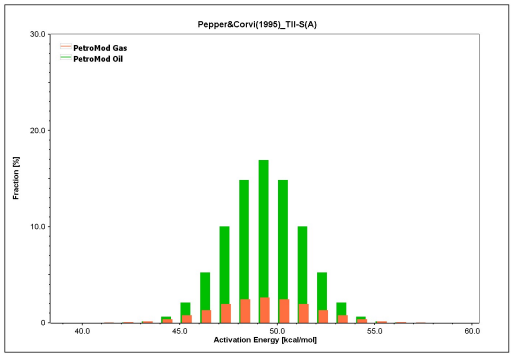


Figure 10: Distribution of activation energies for Pepper&Corvi(1995)_TII-S(A) source kinetics

## Boundary conditions

The boundary conditions applied are (Figure 11 & 12):

- Sediment water interface temperature (SWIT)
- Paleo Water Depth (PWD)
- Heat Flow (HF)


Figure 11: Modeled boundary conditions for Kaladgi Basin

# Burial history reconstruction and thermal maturity modeling of Bhima and Kaladgi basins

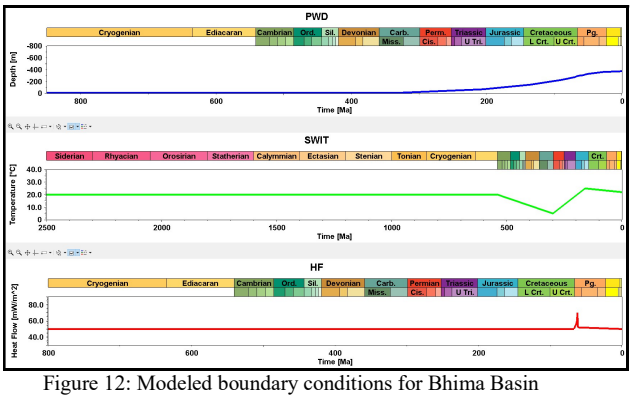


Figure 12: Modeled boundary conditions for Bhima Basin

## Burial history plot

Burial history chart is shown in Figure 13 & 14.

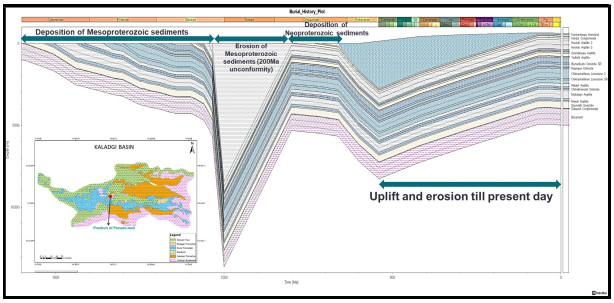


Figure 13: Burial history plot for Kaladgi Basin

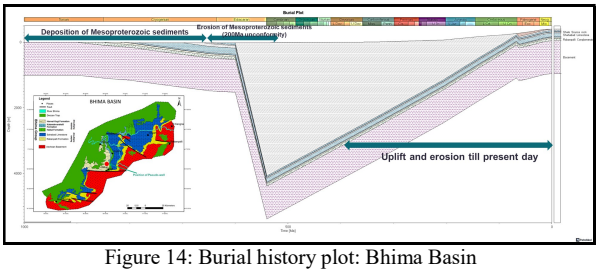


Figure 14: Burial history plot: Bhima Basin

## Temperature Calibration

The temperature of precipitation of the carbonaceous matter is estimated to be in the range of 108ºC-164ºC (Patnaik, et. al., 2016). To calibrate our data, a total erosion of 4000 m is envisaged on top of Harwal Gogi Shales in this basin. Figure 15 shows the temperate overlay plot and maximum temperature reached in outcrop samples of Bhima basin.

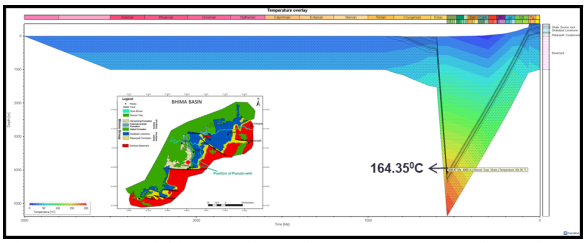


Figure 15: Burial history plot with Temperature overlay: Bhima Basin

## Maturity

Illite Crystallinity data suggests an exhumation of ~7.5-8km of Mesoproterozoic sediments in Kaladgi basin. A total erosion of 8000 m is envisaged on top of Hoskatti Argillite and 3000m at the top of Konankoppa Limestone in this basin. Source rocks of Kaladgi basin are in overmature window. Maturity overlay is shown in figure 16.

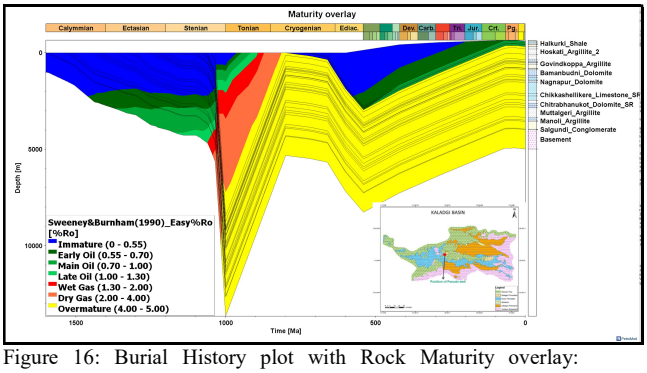


Figure 16: Burial History plot with Rock Maturity overlay: Kaladgi Basin

Source rocks of Bhima basin are in wet gas window. Maturity overlay is shown in figure 17.

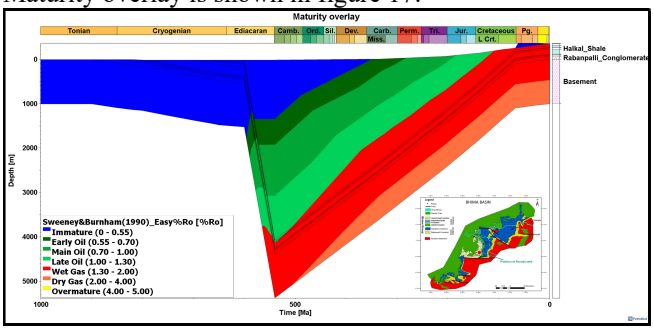


Figure 17: Burial History plot with Rock Maturity overlay: Bhima Basin

# Burial history reconstruction and thermal maturity modeling of Bhima and Kaladgi basins

## Transformation ratio

Transformation ratio of all the source rocks in Kaladgi Basin is >90%. TR overlay is shown in figure 18. Transformation of all the source rock layers took place before 1100 Ma (Figure 19).

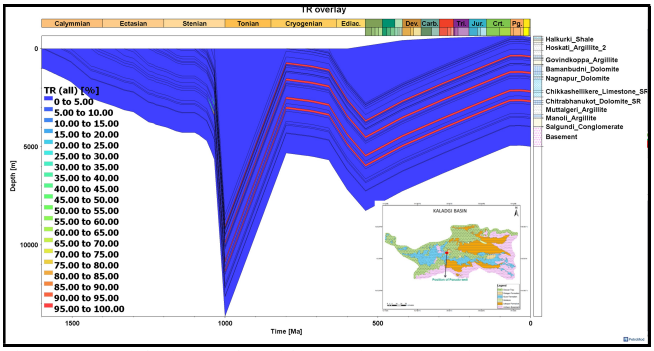


Figure 18: Burial History plot with Transformation ratio overlay: Kaladgi Basin

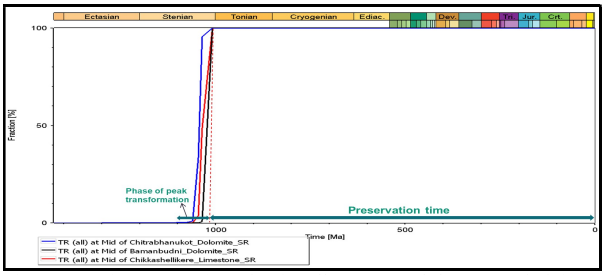


Figure 19: Time extraction plot for all source rock layers: Kaladgi Basin

Transformation ratio of all the source rocks in Bhima Basin is >90%. TR overlay is shown in figure 20.

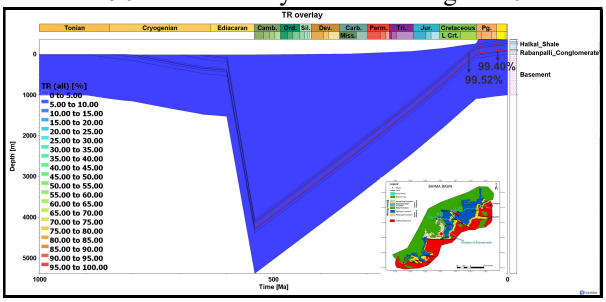


Figure 20: Burial History plot with Transformation ratio overlay: Bhima Basin

Transformation of all the source rock layers took place before 540Ma (Figure 21). The expelled hydrocarbon will have long preservation time of 540 Ma.

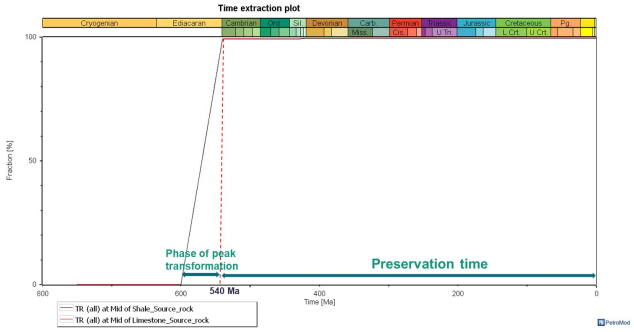


Figure 21: Time extraction plot for all source rock layers: Bhima Basin

## Petroleum system event chart

The speculative petroleum system event chart is shown in Figure 22 & 23.

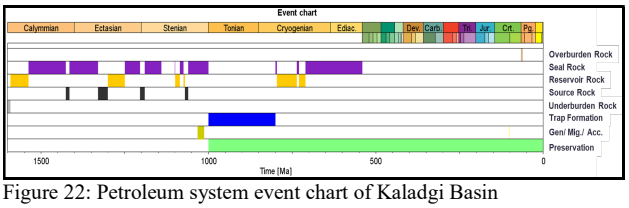


Figure 22: Petroleum system event chart of Kaladgi Basin

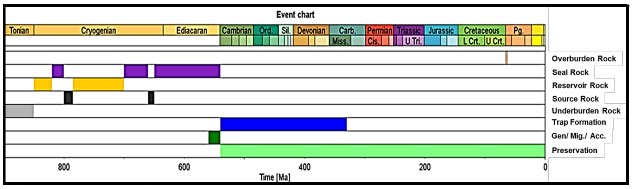


Figure 23: Petroleum system event chart of Bhima Basin

## Conclusions

- In most of the exposed outcrops low-grade metamorphism is prevalent in the Kaladgi group of rocks. Temperatures and pressures which are required for low grade metamorphism are much higher than the highest possible temperatures at which hydrocarbon generation takes place. Modeled 1D PSM results justify the observations in geological outcrops.
- In the Kaladgi basin, based on Illite Crystallinity or Kubler Index data a total erosion of 8000m is modeled on top of Hoskatti Argillite and 3000 m at the top of Konankoppa Limestone in this basin. The resultant rock maturity shows that the Mesoproterozoic rocks are overmature.
- In the Bhima Basin, a total erosion of 4000m is modeled on top of Haral Gogi shales based on

peak temperature of precipitation of the carbonaceous matter in brecciated limestones. The resultant rock maturity shows that the rocks are in wet gas window.

- Transformation ratio indicates complete transformation of all source sequences by the end of Mesoproterozoic for Kaladgi basin and by the end of Neoproterozoics for Bhima basin.
- Analogous with Vindhyan Basin where hydrocarbon gas discoveries have been made within Proterozoic sequences, with similar rock maturity window, possibility of a petroleum system is not ruled out. Although, given the fact that the entire Kaladgi and Bhima basin have undergone massive uplift through geological past, extremely long preservation time of possibly generated hydrocarbons will be required.
- Geochemical studies of adsorbed gas in soil do indicate presence of gaseous hydrocarbons and thus likelihood of a potential petroleum system cannot be ruled out completely.

## Acknowledgements

The authors express their sincere gratitude to Smt. Sushma Rawat, Director (Exploration) for her kind permission to publish this paper. The authors are thankful to Shri Nandan K Verma, GGM-HOI KDMIPE, for his support in permitting the publication of this paper. Views expressed in the paper are of the authors and not necessarily of the organization they represent.

## References

Barker, C., Pawlewicz, M., 1994. Calculation of vitrinite reflectance from thermal histories and peak temperatures. A comparison of methods. In: Mukhopadhyay, P.K., Dow, W.G. (Eds.), Vitrinite reûectance as a maturity parameter: applications and limitations. ACS Symposium series v. 570, pp. 216–229.

Bouger Anamoly Map and Gravity Modeling. Unpublished ONGC reports, Geophysics Group, KDMIPE, Dehradun.

Jayaprakash, A.V., Sundaram, V., Hans, K. and Mishra, R.N., 1987. Geology of Kaladgi-Badami Basin, Karnataka. In: Purana Basins of Peninsular India. Mem. Geol. Soc. India, no.6, pp.201-225.

Jacob, H., 1989. Classiûcation, structure, genesis and practical importance of natural solid oil bitumen ("migrabitumen"). International Journal of Coal Geology v. 11, pp.65–79.

Mishra, R.N., Jayaprakash, A.V., Hans, S.K. & Sundaram, V., 1987. Bhima Group of Upper Proterozoic- A stratigraphic puzzle. Mem. Geol. Soc. Ind. No.6, pp.227-237.

Mukherjee, M.K., Modak, M. and Ghosh, J., 2019. Illite crystallinity index from the Mesoproterozoic sedimentary cover of the Kaladgi basin, southwestern India: Implications on crustal depths of subsidence and deformation. J. Earth Syst. Sci. 128:101

Patnaik Sikta, 2014. R&D Annual Report 2014. Unpublished Internal Report, Atomic Minerals Directorate for Exploration and Research, Hyderabad.

Patnaik, S. Chakrabarti, K., Pradhan, A.K. and Bhattacharya, D., 2016. Petrographic characteristics of carbonaceous matter in brecciated limestone at Kanchankayi area, Yadgir district, Karnataka: genetic implications for uranium mineralization. Atomic Minerals Directorate for Exploration and Research, Hyderabad.

Pillai, S.P. and Kale, V.S., 2008. Interplay of tectonism and eustacy. International Association for Gondwana Research

Raha, P.K. and Sastry, M.V.A., 1982. Stromatolites and Precambrian stratigraphy in India. Precambrian Res., v.18, pp.293-318.

Schoenherr, J., Littke, R., Urai, J.L., Kukla, P.A., Rawahi, Z., 2007. Polyphase thermal evolution in the Infra-Cambrian Ara Group (South Oman Salt Basin) as deduced by maturity of solid reservoir bitumen. Organic Geochemistry v. 38, pp. 1293 – 1318.

Shukla, Y. and Sharma, M., 2020. Ediacaran Discs from the Bhima Group, Karnataka, South India. Journal Geological Society of India, Vol.95, May 2020, pp.483-490