An Unconventional Approach to Determine Source Rock Attributes by Integrating Wireline Logs with Geochemical Data in Eocene Sediments of KG Basin, India

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Source Rock, TOC, Vitrinite Reflectance and Level of Maturity, Vadaparru Shale

Abstract:

In the present study, source rock potential of Eocene sediments spanning over East Godavari sub-basin and Nizampatnam depression of prolific Krishna-Godavari basin has been analyzed. Vadaparru shale serves as the main source rock in the study area.

A total of 29 wells have been selected based on their spatial distribution. Standard geochemical (Rock Eval) analysis exist for 19 out of selected 29 wells. For the remaining wells, log based "Passey" method (Δ log R technique) has been used for TOC estimation. This approach can be applied in wells where source-rock samples do not exist for rock-eval analysis, but conventional logs, viz. gamma, density, resistivity, and sonic logs have been recorded. The proposed technique can, therefore, complement the already existing rock-eval analysis and extend the source-rock estimation in areas of sparse geochemical data. This technique also has the advantage of continuous evaluation along the wellbore, in contrast to discrete sample data. In the study, all necessary source rock attributes have been derived from well log data except Level of Maturity (LOM) which has been estimated based on regression equation generated by using lab generated Total Organic Carbon (TOC) data of known wells. The equation has then been used to find out TOC for the wells, where lab-based geochemical analysis has not been carried out. Vitrinite reflectance for the study area has been generated from Hood's Model

The study has revealed that average TOC of Eocene sediment is around 2.3%. TOC value is much higher in Godavari delta region compared to Krishna delta region. East Godavari sub-basin, exclusively around the Eocene Shelf edge near Narsapur region, exhibits a noteworthy potential of source rock. Analysis of Vitrinite Reflectance exhibits that this graben region along with Paleogene fault zone falls within Hydrocarbon window.

The Regression-based approach used in the study has demonstrated promising results in TOC estimation in comparison to lab-derived data. This indirect method has broadened the understanding of source attributes, in this part of KG basin which will aid in strategizing future exploration planning in other part of the basin.

Introduction:

The Krishna-Godavari petroliferous province is located along the East Coast of the Indian peninsula, situated between the Mahanadi basin to the north and the Cauvery basins to the south. This province is primarily characterized by a siliciclastic shelf margin. It covers an extensive area of 31,000. square kilometers on land and 199,000 square kilometers offshore. The sediment thickness in this region can exceed 7.0 kilometers. The basin consists of a diverse range of sediments, varying in age from the Early Permian to the Recent period. The onland part of the basin is largely covered by alluvium deposited by two major river systems, namely the Godavari

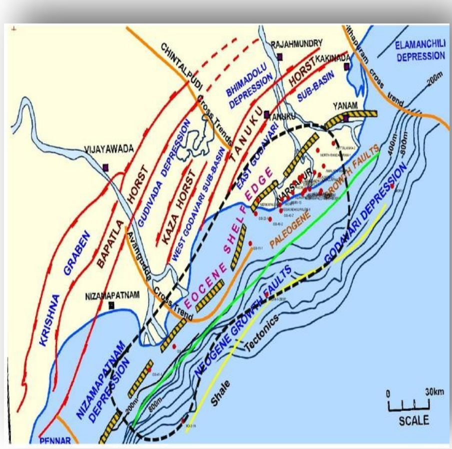

Figure 1: Study Area Marked by Black polygon in the tectonic map of KG basin. (after Rao and Mani 1993)

and Krishna rivers. Near the margin of the basin, several stratigraphic sequences are exposed, including the Lower Gondwana.

Our study area encompassed by Godavari and Krishna delta regions. Regional depositional trend of KG basin is NE-SW. Tanuku Horst (Figure-1) marks the boundary on the north and northeast sides and southern boundary is defined by the Godavari depression along with the Neogene growth fault area. To the west, study area is demarcated by the Nizamapattam depression and the Avangudda cross trend.

Vadaparru shale (Figure-4), an Eocene deposition, revealed as main source rock within the study area. This formation is dominated by claystone / shale with minor presence of sandstone and pyrite. This formation is characterized by resistivity log value 1-2 ohm-m and large value of GR (80-120 GAPI) and Neutron (45-50%) log. It underlies the Matsyapuri Sandstone Formation and, in some instances, occurs below the Bhimanapalli Limestone. The Razole Formation typically represents the base of the shale formation. Under the present study, detailed source potential of this Eocene deposit has been evaluated by combining geochemical and wireline log data of 29 wells, spread within Godavari and Krishna delta region.

Methodology:

The composition of hydrocarbons in a source rock is not fixed. It changes properties in rocks to the response to changing temperature and pressure conditions. The increasing temperature/pressure that accompanies with increasing depth of burial leads to thermal maturation of the hydrocarbon. In this process sediments are thermally cracked into smaller fragments and a trend is established where the lighter fractions increase as the density of oil decrease in sequence from oil, to lighter oil, to wet gas, and finally dry gas. The organic matter (OM) is the main component for identification of source rock. The amount of organic matter present in a source rock is expressed as TOC (Total Organic Carbon Content). The source rocks containing less than 0.5% TOC are considered as negligible potential source rock, TOC of 0.5-1.0% considered as marginal source rock and more than 1% considered substantial potential source rock (Rondeel, 2001).

Meyer and Nederlof (1984), assumed that Organic matter is originally deposited contemporaneously with the rock matrix grains and does not fill pore voids; perhaps with increased maturation, the kerogen is malleable enough to be squeezed into the pore space, but this should not significantly affect the pore volume in a shale unless the amount of organic matter is relatively high. organic-rich rocks are assumed to be composed of three components:

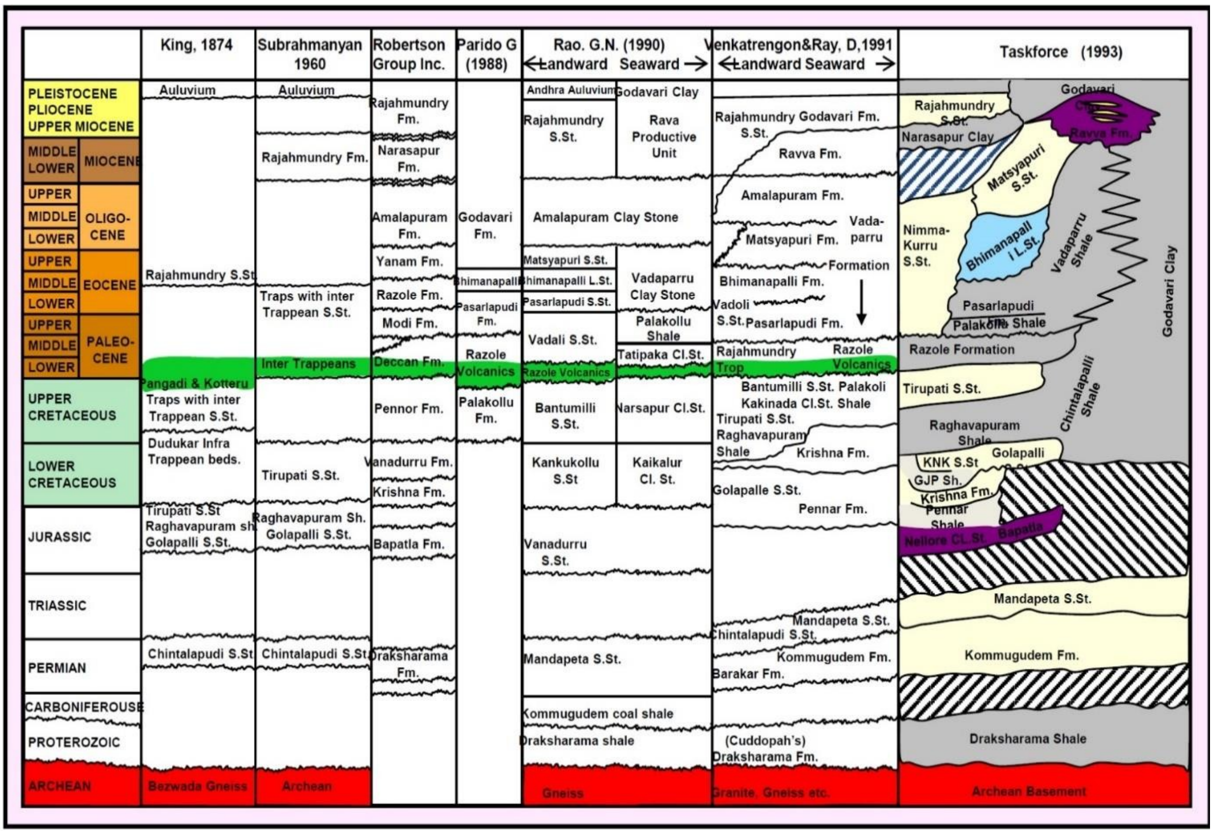

Figure 2: Stratigraphy of KG basin (after Rao G.N (1990), Pariod .G (1988))

(1) the rock matrix, (2) the solid organic matter, and (3) the fluid(s) filling the pore space. Non-source rocks (Figure-3A) are composed primarily of only two components: the matrix and the fluid filling the pore space. In immature source rocks (Figure-3B), solid organic matter and rock matrix comprise the solid fraction, and formation water fills the pore space. As the source rock matures (Figure-3C), a portion of the solid organic matter is transformed to liquid (or gaseous) hydrocarbons which move into

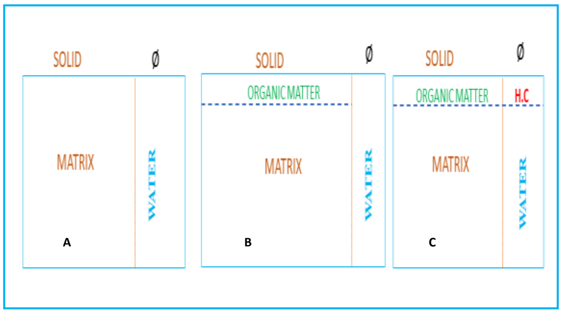

Figure 3: Schematic of solid and fluid components in source and non-source rocks (after Meyer and Nederlof (1984))

the pore space, displacing the formation water. By using the proposed model, (Figure -3) source rock has been identified based on the response of conventional logs (Resistivity, Sonic, Density and Gamma ray) besides incorporating mud log and core data.

In organic rich source rocks, the separation in organic-rich intervals is measured and called Δ log R parameter (Figure-4). This parameter is used to calculate TOC. Organic-rich intervals can be recognized by separation and non-parallelism of Resistivity and Sonic curves (Mayer, B.L, 1984, Passey, Q.R, 1990). It can be measured at each depth. The algebraic expression for the calculated Δ log R from the sonic and resistivity overlays is

Δ log R = log10(R/R baseline) +0.02*(Δt – Δt baseline) ……… (1)

Where Δ log R is the separation measured in logarithmic resistivity scale. R is the resistivity measured in ohm-m by the logging tool and Δt is slowness value measured by logging tool. R- baseline and Δt base line are the baseline values(figure-4) when the curves are base- lined in non-source, clay-rich rocks. Δ log R is linearly associated with the total organic carbon (TOC) content and is influenced by the maturity level (LOM). A derived empirical equation for estimating the TOC content in organic-rich rocks based on Δ log R is as follows

TOC = (Δ log R) x 10 ^ (2.297 – 0.1688 x LOM) .... (2) (Passey et.al -1990)

Here, TOC represents the total organic carbon content measured in weight percentage, and LOM denotes the measured level of maturity. In case of

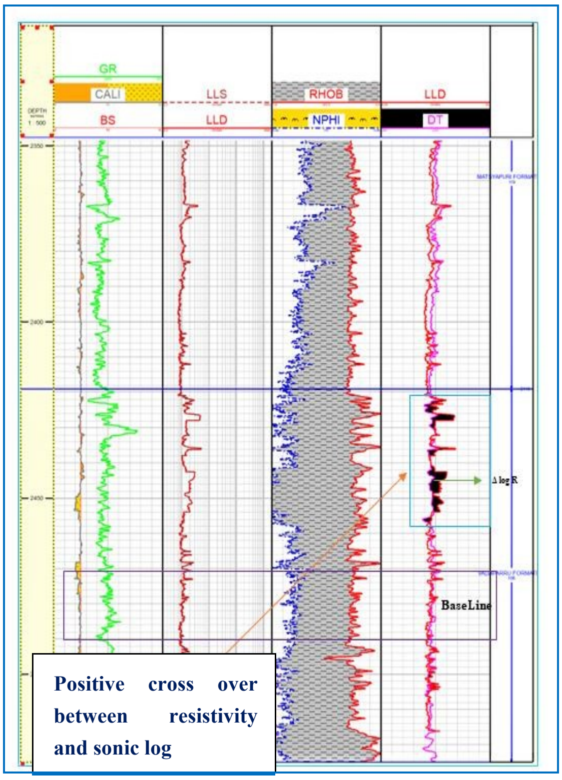

Figure 4: Composite plot for identification of source rock(Vadaparru Shale)

non-availability of geochemical data, LOM is calculated by generating burial history curve and Time -Temperature Index. Fortunately, we have information about TOC data for 19 wells in the study area. Among these 19 wells, a subset of 14 wells was selected for LOM calculation based on their spatial distribution. Then LOM is calculated using following formula

LOM=13.6078-5.924*LOG10(TOC/Δ log R) ---- ……… (3) (B. LeCompete-2009)

LOM is influenced by various factors such as burial history, pressure, temperature, and others. Due to this dependence on multiple factors, the LOM cannot be determined solely from well log data. Though it can be inferred indirectly from open hole logs. For example, gamma ray logs can help in identifying the presence of organic-rich shales, which are potential source rocks. The gamma ray response can vary with increasing maturity, as the organic content changes (Guidry, F., Luffel, D., Olszewski, A., 1990). Additionally, resistivity logs can help in differentiate between hydrocarbon-bearing and non-hydrocarbon-bearing formations, which can be indicative of the maturity and hydrocarbon potential of the source rock. However, for our studied wells correlation coefficient between resistivity and LOM is around 30-40%. Nearly similar kind of results were obtained for the density

and neutron log as well. Subsequently, an endeavor was made to establish a correlation between calculated LOM values and the average Δ log R

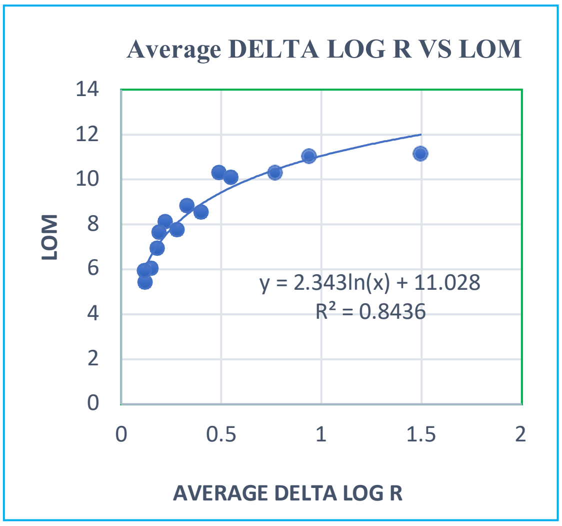

Figure 5: LOM and Average Delta Log R Plot

value within the zone of interest (Figure-5). It reveals that a strong correlation (R^2=.94) exists between these two parameters in the logarithmic scale Based on the regression analysis, the following relationship (Eq-4) is established between LOM and the average Δ log R

LOM = 2.34 * ln (average Δ log R over the zone of interest) + 11.028................ (4)

The generated level of maturity (LOM), calculated by using Eq-4, is utilized to determine vitrinite reflectance (%Ro) (Figure-6). Vitrinite reflectance (%Ro) is a commonly used parameter in resource play evaluation, indicating the potential of source rocks to generate oil, gas, or condensate. The maturity of source rock is categorized into different oil windows based on their %Ro values and they are following:

- Vitrinite reflectance values below 0.8% indicate immature source rocks.
- Oil zone ranges from 0.8% to 1.0%.
- Condensate/mixed zone encompasses values between 1.0% and 1.4%.
- Reflectance values above 1.4% indicate the dry gas window

These oil windows provide insight into the probable hydrocarbon output. However, it is important to note that mixed production can occur, and there may be local variations in the relationship between vitrinite, maturity, and hydrocarbon generation. According to Hood's data, the conversion from LOM to %Ro is as follows.

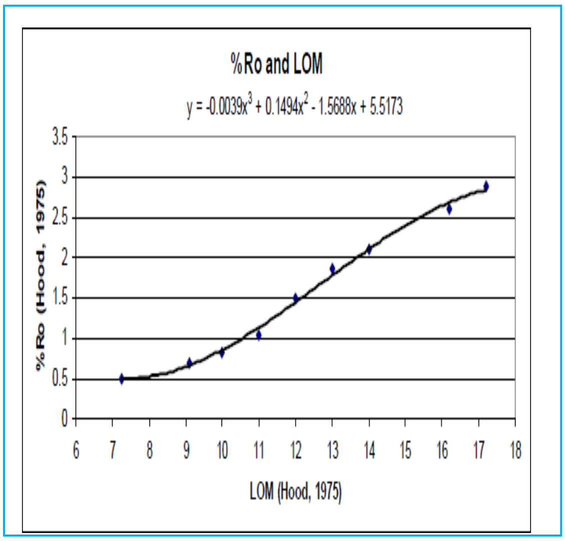

Figure 6: % R and LOM correlation chart (Hood)

Methodology, described above, has been complied through the following chart:

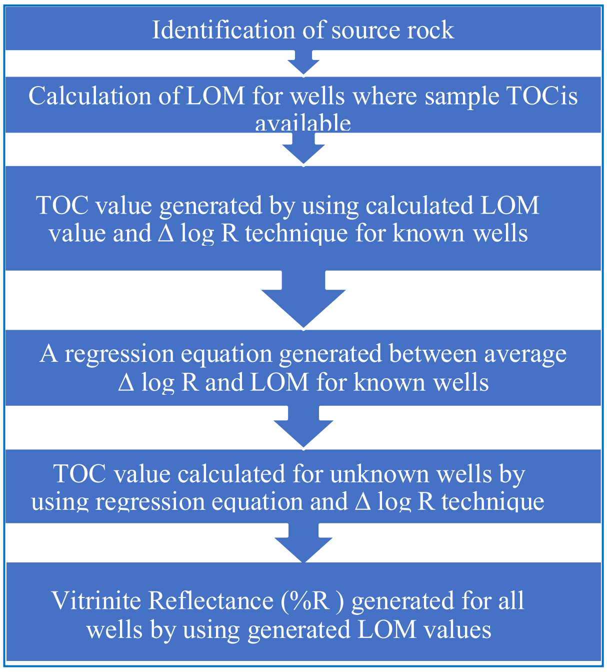

Figure 7: Flow chart for generation of log-based TOC and %R

Result and Discussion:

The calculated total organic carbon (TOC) values, derived by applying Equations 1 to 4, have been compiled and presented in Table 1. Additionally, Table 1 includes the results obtained from the geochemical analysis also

Well Name	Sample TOC (%) (A)	Log Derived TOC (%) (B)	Error (%) =(A-B)
ADAVIAPLEM-XX	2.91	3.25	-0.340
PASARLAPUDI-ZZ	3.71	3.33	0.380
AMALAPURAM-YY	4.31	3.77	0.540
SITARAMAPURAM-Z	1.68	1.02	0.660
MORI-XX	3.96	3.22	0.740

Table 1: Comparison of TOC data between known wells

The analysis of Table1 reveals a notable similarity between the log derived total organic carbon (TOC) values and the TOC values obtained from samples. This promising outcome prompted us to compute the TOC values for 05 unknown wells. TOC data derived from log data has been presented in table 2 for reference and "TOC" log curve for well MORI-XX has shown in Figure-8.

Well Name	Log Derived TOC (%)	LOM
KESANAPALLI-XX	2.33	11.69
PASARLAPUDI-ZZ	3.68	10.14
AMALAPURAM-YY	2.64	8.24
KW-XX	3.03	10.34
MORI-XX	3.33	8.96

Table 2: Well Log derived Total Organic Carbon (TOC) Value for Wells devoid of geochemical Data

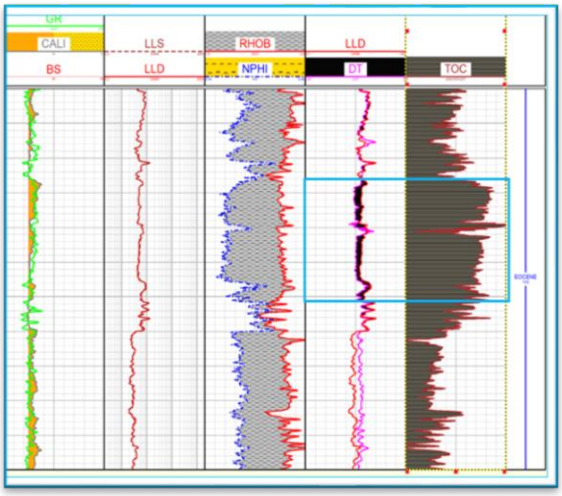

Figure 8: Log Derived TOC data for well Mori-xx. Zone marked by blue square has a maximum TOC value of 3.3%

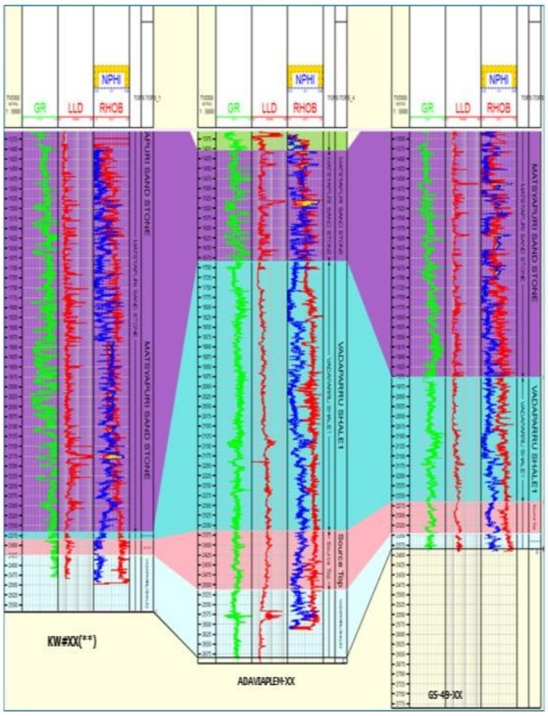

Figure 9: Correlation of Vadaparru shale (Blue and light blue color) between wells where sample data were available and well where sample data was unavailable (Marked by **). Source Top is marked by Magenta color

Eocene top in our study area, in line with "Eocene Shelf edge", dips towards S-W direction (Figure-10). "Eocene shelf edge" in Godavari delta region exhibits a significant source rock potential. However Potential of source rock diminishes considerably as we move beyond the Avangudda cross trend towards the Krishna graben (Figure-11). Additionally, source rock potential has been identified in the Paleogene Growth fault area (Figure-11).

The analysis of vitrinite reflectance values (Figure 12) reveals a compelling insight. It is evident that, exclusively wells situated within graben area of East Godavari sub basin, near Narsapur region, fall within Hydrocarbon window of .8 to1.2 (Figure-12). Similarly, in Krishna delta region, well near to the

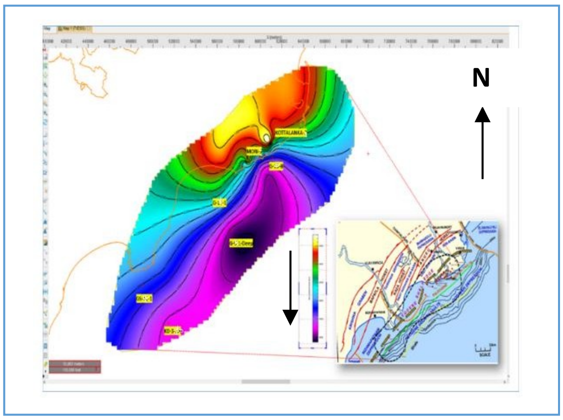

Figure 10: Variation of Eocene Top within Study area

Paleoogene growth fault region is only falling within optimal Hydrocarbon window zone.

Upon simultaneous plotting of all parameters (TOC,%R and LOM), it becomes evident that in shallowerpart of Krishna Delta region (Figure-13), the primary obstacle to hydrocarbon generation is not maturity, but rather significantly lower amount of total organic carbon (TOC) compared to the Godavari Delta region.

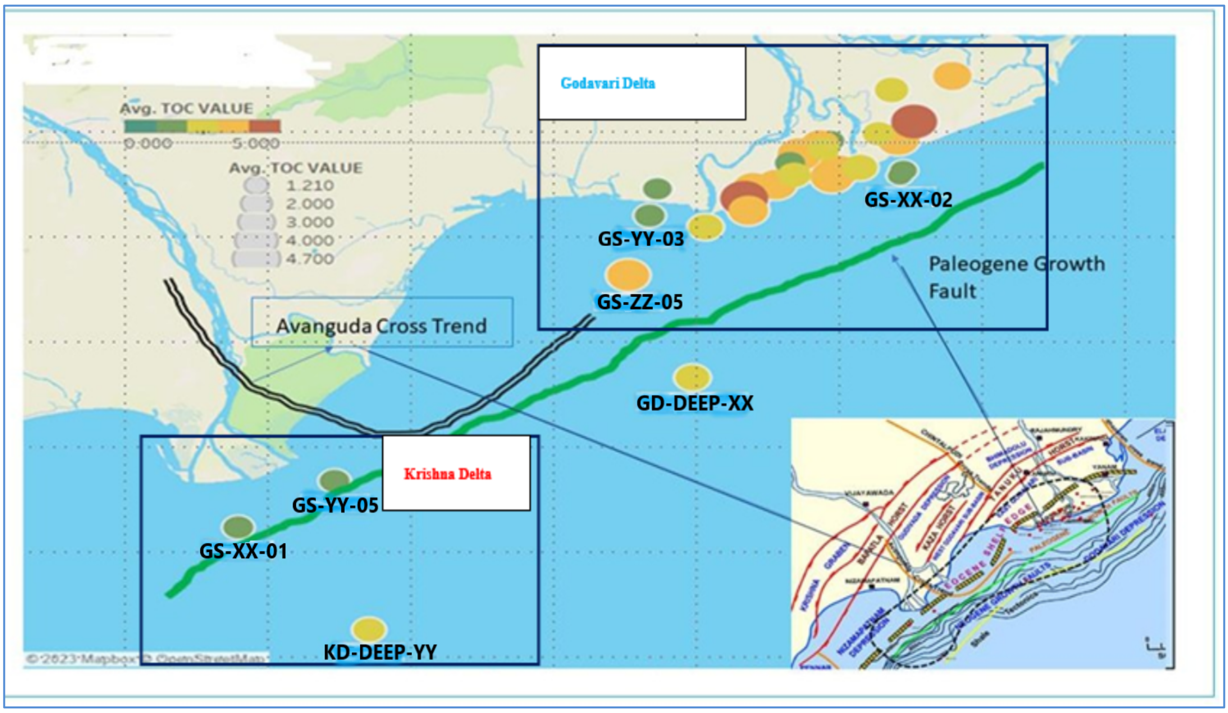

Figure 11: Distribution of TOC in Study area. TOC value in Godavari delta is relatively higher than Krishna delta

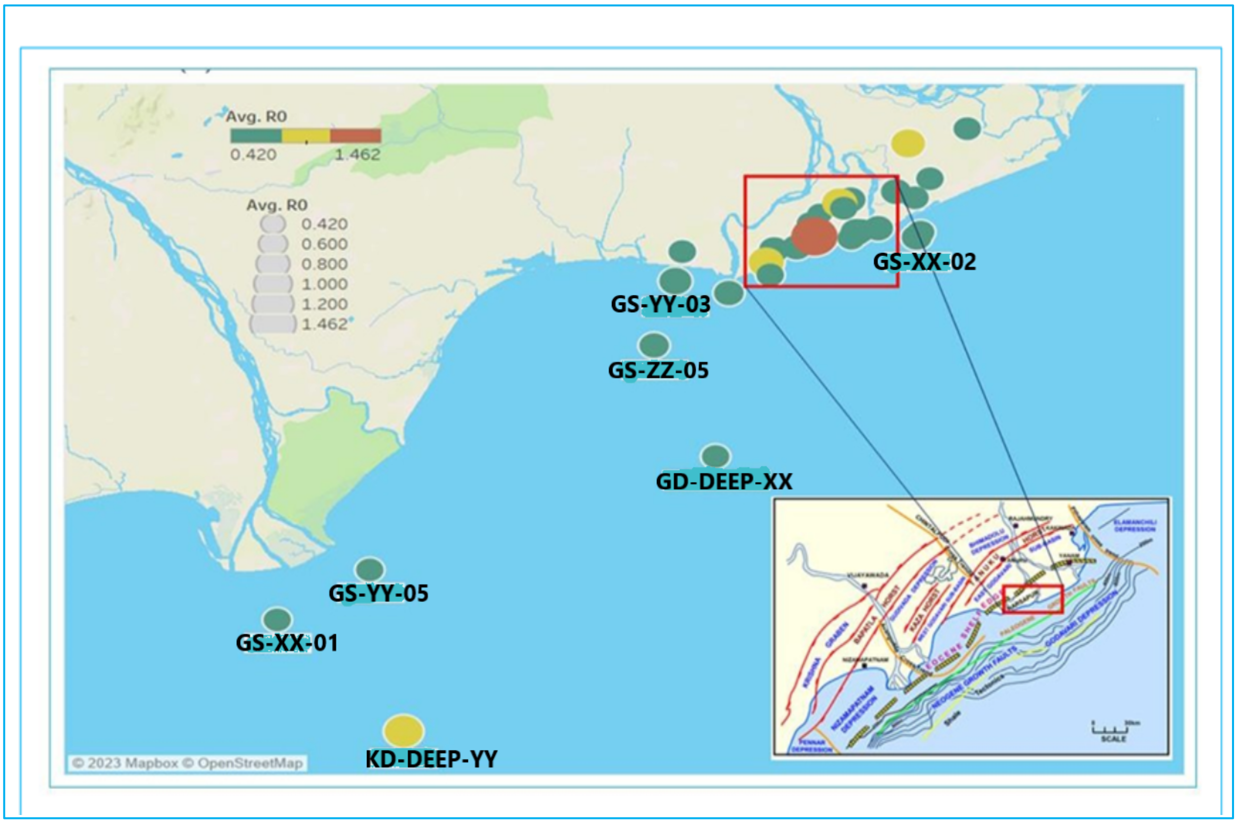

Figure 12: Distribution of % R within study area. Region which falls under optimal Hydrocarbon window in East Godavari sub- basin is marked by Red square box

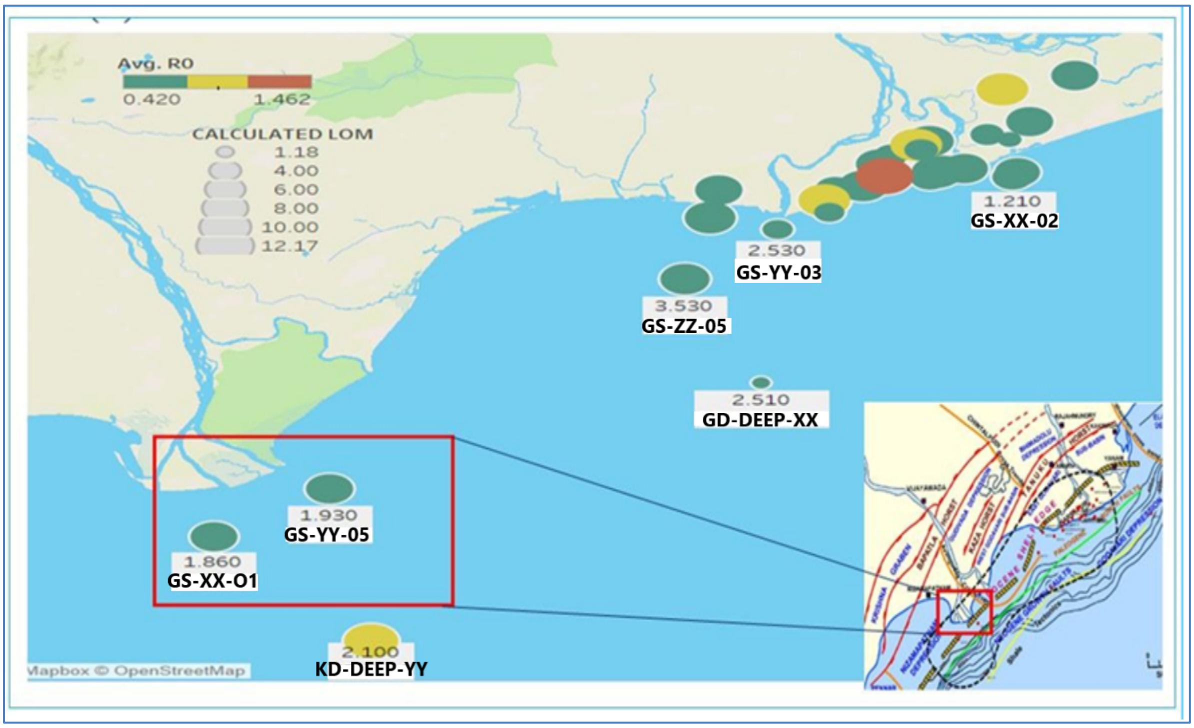

Figure 13: Distribution of Geochemical attributes in study area. Shallow offshore of Krishna delta is Marked by Red square Box

Conclusion:

This regression-based approach, used in the study has demonstrated promising results in estimation of source rock attributes in Eocene sediment of KG basin. Overall, the study reveals that:

- Predicted TOC value in study area is around 2-2.5%
- The estimated TOC values were compared with measured sample values, and average estimated error from sampled data were found to be less than 0.5 %, (Table -1). It provides confidence for implementing this approach on a regional scale.
- Appropriate condition, in terms of % R and TOC, for generation of hydrocarbon from source rock prevails in 'East Godavari' graben area and Paleogene growth fault region (Figure-11,12). Maturity of organic content is the significant challenge for other regions of Godavari delta.
- The shallower portion of the Krishna delta zone does not encounter maturity-related concerns (as shown in Figure-13). Rather, it displays lower total organic carbon (TOC) values compared to the Godavari delta region, although these values are still sufficient for hydrocarbon generation.

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