



**Evaluation of Cretaceous Sediments for Organic Richness and Level of Maturity using Petrophysical data**

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**Abstract**

A quantitative estimation of source rock parameters was attempted using experimental TOC data, porosity and resistivity log data acquired in the well sections of Periyapattinam, Perungulam, Ramanavalasai, Rajasingamangalam and Uchipuli in the Ramnad sub-basin. Cretaceous sedimentary succession was analyzed for organic richness and level of maturity using log R technique and crossplots for six exploratory wells in this sub-basin. The interpretation of results of both %TOC and LOM recognized that only Andimadam Formation consists of high values of TOC ranging from 4 to 6% and LOM from 8.6 to 12.0, indicating matured nature of organic source rocks in the Ramnad sub-basin. The study also found an excellent match between measured TOC and log TOC thereby suggesting that log TOC can be safely relied upon for estimating organic maturity in the Ramnad sub-basin. Increase in formation resistivity, decrease in formation density, increase of neutron porosity, increase in sonic transit time and increase in gamma ray activity were observed in many wells against the source rock rich Andimadam formation. All the log recorded parameters have responded to the matured source rock in the formation.

**Introduction**

Easy methods of finding oil and gas pools have substantially reduced and advanced exploration methods of oil and gas reserves from deeper sediments involving more complex geology have come into picture from the past decade. More advanced technologies both in the exploration and production domains have come into existence; one such technology is evaluation of sediments for

organic richness and level of organic maturity from porosity and resistivity logs.

The chief constituent of the organic matter (i.e. total organic carbon TOC) has been widely used to assess the potential of hydrocarbon resources in the sedimentary basins. Traditionally geochemical method is employed for determination of source rock parameters namely TOC, S<sub>1</sub>, S<sub>2</sub>, T<sub>max</sub> and VR<sub>o</sub>. This method is time consuming, cost intensive and can be measured at sampled intervals. This method is also error prone if sufficient care is not taken during sampling. An alternative to the geochemical method of determination of source rock parameters was developed by earlier petrophysicist. Among several reported methods available for estimation of TOC, four methods are popular and widely used: 1) directly by regression of core TOC with core bulk density; 2) logR technique; 3) based on the petrophysical response model; and 4) using an artificial neural network. The general conundrum of geoscientists in oil industry is to identify possible hydrocarbon resource plays. To accomplish this task, determining the potential organic shale sections is one of the primary exercises and again doing it inexpensively due to lack of readily available information for estimates. There are many methods available for quick estimation of TOC by interpretation of various electrical logs. One such method is log R developed by Passey et al which has been commonly used to determine total organic carbon richness (TOC) by cross-plotting sonic logs (DT) and log (natural logarithm) of resistivity data. This method allows organic richness to be assessed in a wide variety of lithologies and maturities using common well logs.

In water saturated, organic-lean rocks, the two curves parallel or overlies each other allow the shale calculation line to be determined. However, in either hydrocarbon reservoir rocks or organic-rich shale sections, a separation (log R) between the curves occurs. The separation in organic-rich intervals results from two effects: the porosity curve responds to the presence of low-density, low-velocity Kerogen, and the resistivity curve responds to the formation fluid. In mature source rocks the magnitude of the resistivity increases because of the presence of generated hydrocarbons. By cross-plotting multiple wells in a basin this technique can provide relative information for entire shale section of an area/basin. This method requires a simple cross-plot and log

## Source rock evaluation from Petrophysical data

calculation mathematics to provide a geoscientist sufficient data to easily and quickly determine potential organic shale sections. Across an area, these log cross-plots prop up the correlation and mapping of organic-rich shale sections and allow the geoscientist to quickly determine high prospective areas for further study.

The main objectives of this study are to qualitatively estimate total organic carbon (TOC), level of maturity (LOM) and (S<sub>2</sub>) source rock parameters for late Cretaceous successions in Periyapattinam, Perungulam, Ramanavalasai, Rajasingamangalam and Uchipuli fields in the Ramnad sub-basin (Swanson et al. 1960) by using log R technique of Passey et al. The results were verified with the lab determined parameters. The main advantage of this method was cost benefit, continuous measurement and quick delivery of results.

### Conceptual Model of Organic-Rich Rocks

Source rocks are commonly shales and lime-mudstones that contain significant amount of organic matter. Non source rocks also contain organic matter but the amount is generally not significant (i.e., less than 1 wt. %). The usual method for assessing the richness and maturity of source rocks is through a variety of laboratory analyses. This paper discusses the effect that organic matter has on the response of common well logging tools and proposes an easily implemented curve overlay method that is calibrated for organic richness and maturity.

For the purpose of this work, organic rich rocks are assumed to be composed of three components (Fig. 1): (1) the rock matrix, (2) the solid organic matter, and (3) the fluid(s) filling the pore space. Non-source rocks are composed primarily of only two components: the matrix and the fluid filling the pore space (Fig. 1A). In immature source rocks, solid organic matter and rock matrix comprise the solid fraction and formation water fills the pore space (Fig. 1B). As the source rock matures a portion of the solid organic matter is transformed to liquid (or gaseous) hydrocarbons which move into the pore space, displacing the formation water (Fig. 1C). The effects of these physical transformations on the porosity and resistivity log responses are the subject of this work.

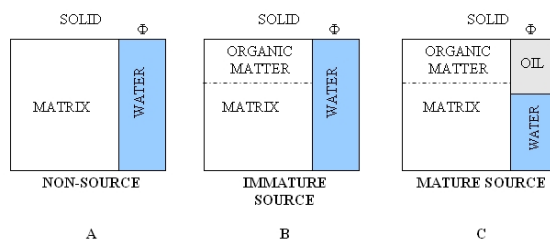


Fig. 1. Schematic of solid and fluid components in source and non-source rocks (after Passey et al., 1990).

### Data Source and Methods

A complete set of log data utilized in this work was obtained from the National Oil Company (ONGC). Interactive Petrophysics software (version IP 4.1) was used to generate logR (separation between resistivity and sonic log when overlain) and determine total organic carbon richness (TOC). TOC present in the source rock effects the response of several types of logs, especially increasing trend both in sonic travel time and formation resistivity. In organic lean rocks the log scales are adjusted so that the sonic and resistivity curves are overlain on each other. In organic rich rocks, due to the presence of Kerogen sonic log reads higher travel time and resistivity log reads higher resistivity because Kerogen is more resistive compared to formation water which is present in the pores of the formation. Rock-Eval pyrolysis was used to determine the type and maturity of the organic matter and to detect petroleum potential in sediments. A separate track has been generated to compare TOC derived from logs and experimentally derived TOC data.

The algebraic expressions for the calculated logR from the Sonic Vs Resistivity, Neutron Vs Resistivity and Density Vs Resistivity overlays are given as follows:

$$\log R \text{ Sonic} = \log_{10} (R / R\text{-baseline}) + 0.02 (Dt - Dt\text{-baseline})$$

$$\log R \text{ Neutron} = \log_{10} (R / R\text{-baseline}) + 4.0 (N - N\text{-baseline})$$

$$\log R \text{ Density} = \log_{10} (R / R\text{-baseline}) - 2.5 (b - b\text{-baseline})$$

The logR separation is linearly related to the TOC content and is a function of maturity. The empirical equation for calculating TOC content in organic rich rocks from logR is:

$TOC = (\log R) \times 10 (2.297 - 0.1688 \times LOM)$ , where TOC is the total organic carbon content (wt %) and LOM is the measured level of maturity. LOM is obtained from the vitrinite reflectance (V<sub>ro</sub>) or thermal alteration index by using the maturation indicators.

Using Fig. 2 the logR separation can be transformed directly to TOC if the maturity can be determined or estimated. In practice, LOM is obtained from a variety of sample analysis (e.g. vitrinite reflectance, thermal alteration index, or T<sub>max</sub>), or from estimates of burial and thermal history. In this study, Passey et

## Source rock evaluation from Petrophysical data

al. (1990) was adopted for plotting  $\log R$  vs TOC (Fig. 2) and to determine LOM (level of organic maturity) type and calculation of  $S_2$  (mg HC/g Rock) (Fig. 3).

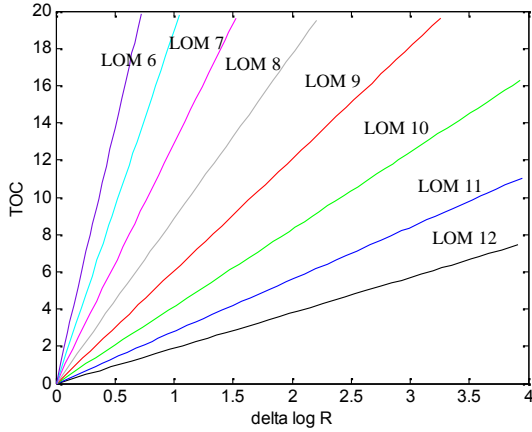


Fig. 2. Level of organic maturity (LOM) derived by cross plotting  $\log R$  vs. TOC (wt %)

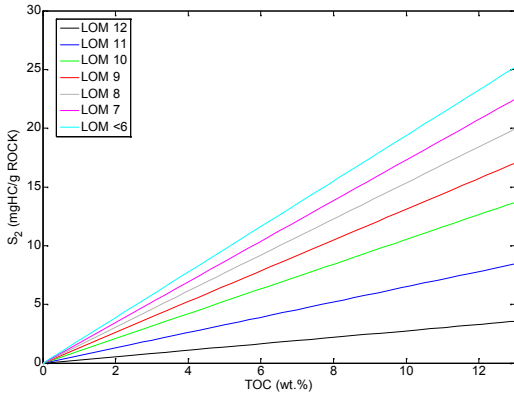


Fig. 3. Determination of  $S_2$  (mg HC/g Rock) from the plot of TOC(wt%) and LOM

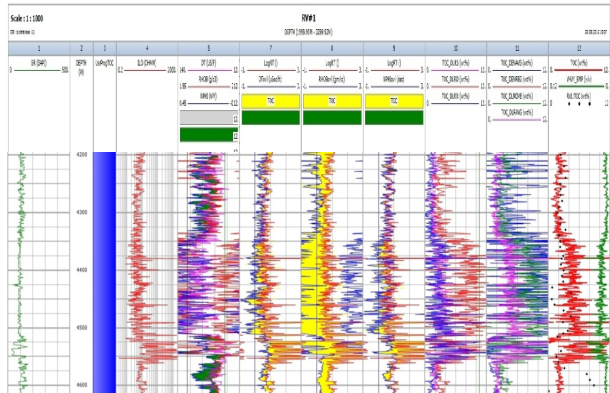
The interactive petrophysics software includes the TOC module that computes the wt% (weight percentage) of organic contents from density relationships and/or  $\log R$  (Delta log resistivity) methods. 14 different density relationships are used to predict TOC and are combined through averaging to produce the final TOC. Alternatively  $\log R$  can be used with Sonic, Density and Neutron logs with an average or weighted average to produce the final TOC. The density and Neutron porosity equations in

Phi/Sw module have been modified to include the wt% and volumes of TOC (Kerogen) to allow the correct determination of porosity and hydrocarbon volume in the pore space. A TOC (wt%) Equation and Kerogen Mineral have been added to the Mineral Solver to include the results from the TOC module into the model.

### Results

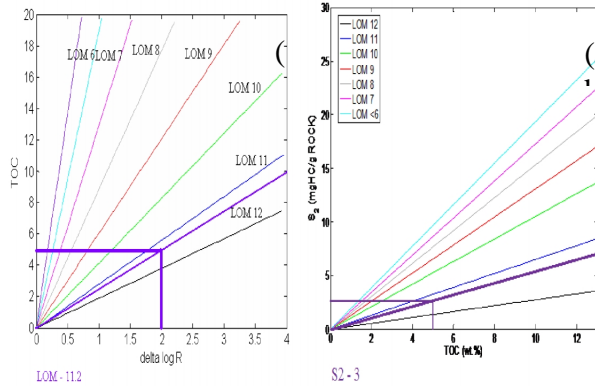
The present study mainly focused on eight exploratory wells drilled into cretaceous succession (Andimadam, Sattappadi, Bhuvanagiri formations in stratigraphic order) in the Ramnad sub-basin for evaluating its source potential by determining TOC, LOM and  $S_2$  values. TOC log is generated by overlaying porosity and resistivity logs. This log consists of 12 tracks namely gamma ray log track (green), depth track (black), resistivity track (red), porosity logs track (density (orange), neutron (violet) and sonic (pink)), resistivity and porosity overlay track and TOC track (red).  $\log R$  is obtained from the separation between resistivity (red) and porosity logs (density, neutron and sonic), preferably sonic log (blue) since it is not affected by bad hole conditions.

In well PE#AX, TOC log was generated by overlaying porosity and resistivity logs (Fig.4). The log reveals that the Andimadam Formation (4400 – 4600m) contains excellent TOC (4 – 6%) both from well logs and lab measurements. There is a relative increase of resistivity and porosity against Andimadam Formation compared to overlying Sattappadi Formation.  $\log R$  is  $\sim 2$  in the Andimadam Formation whereas in the Sattappadi Formation it is less than or equal to 1. Figure 5a shows the level of organic maturity (LOM) derived by cross plotting  $\log R$  vs. TOC (wt %), and  $S_2$  (Fig. 5b) from a cross plot of TOC and LOM. Both TOC and calculated  $S_2$  values are in good agreement with the measured data from core/cutting samples throughout the study interval. The fine grained sediments within this sequence have good hydrocarbon generating potential ( $S_2 = 3$  mg HC/g rock) preferably gas as LOM = 11.2.



## Source rock evaluation from Petrophysical data

Fig. 4. TOC log generated from the wireline logs using Interactive Petrophysics software for well PE#AX. (C1-gamma ray, C2-depth, C4-deep resistivity, C5-porosity logs, C7- logR- t, C8- logR-rhob,C9- logR-nphi,C10-TOC derived from various porosity logs,C12- TOC derived from well logs and lab).



log R and determination of  $S_2$ (mg HC/g Rock) from the plot of TOC(wt%) and LOM of Andimadam formation for the well PE#AX.

In well UP#CX, TOC log was generated for the depth interval from 2000 to 3000m which includes Nannilam, Kudavasal, Bhuvanagiri, Sattapadi and Andimadam formations (Figs. 6 and 7). It is seen that against the Andimadam formation the increase in resistivity and increase in porosity in all the three porosity logs is evident due the increase in the presence of Kerogen compared to the overlying formations. In Bhuvanagiri formation, logR and TOC are present in the range of 0 to 0.5 and 2 to 3 (wt%) which indicates fair to good concentration of organic matter.  $S_2$  and level of organic maturity (LOM) indicate 4.9 and 7.5 respectively (Figs. 8a and b). In spite of sufficient organic matter richness, there is no hydrocarbon generation potentials since the quality of organic matter is poor. In Andimadam formation, logR and TOC are present in the range of 1 and 3 (wt%) which indicates good concentration of organic matter.  $S_2$  and level of organic maturity (LOM) indicate 2 and 11 respectively (Figs. 9a and b). The organic matter within this sequence cannot generate hydrocarbons because of low value of  $S_2$ . The lithology of Bhuvanagiri and Nannilam formations (depth interval 2650-2675m) is predominantly sandstone, and shows considerable variance between log and lab measured TOC values.

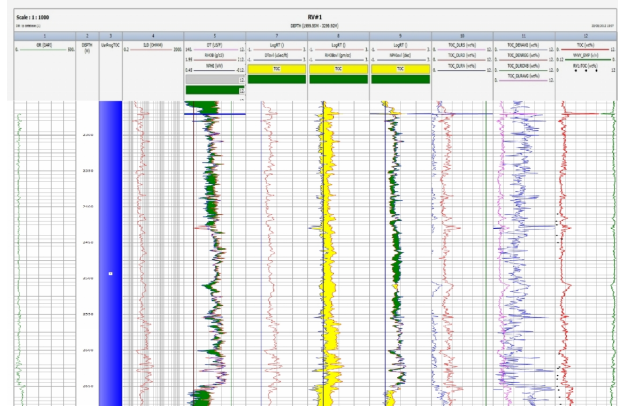


Fig. 6. TOC log generated from the wireline logs using Interactive Petrophysics software for well UP#CX (Bhuvanagiri). (C1-gamma ray, C2-depth, C4-deep resistivity, C5-porosity logs, C7- logR- t, C8- logR-rhob,C9- logR-nphi,C10-TOC derived from various porosity logs,C12- TOC derived from well logs and lab).

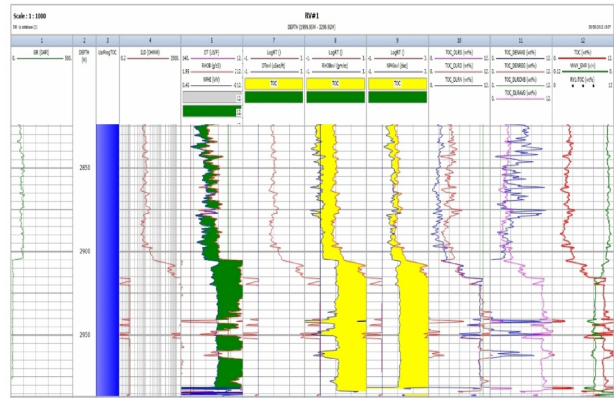
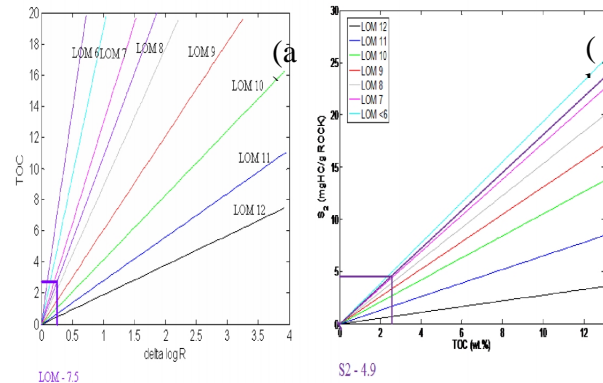


Fig. 7. TOC log generated from the wireline logs using Interactive Petrophysics software for well UP#CX (Andimadam). (C1-gamma ray, C2-depth, C4-deep resistivity, C5-porosity logs, C7- logR- t, C8- logR-rhob,C9- logR-nphi,C10-TOC derived from various porosity logs,C12- TOC derived from well logs and lab)



## Source rock evaluation from Petrophysical data

Fig. 8a and b. LOM derived from the crossplot of TOC and log R and determination of  $S_2$ (mg HC/g Rock) from the plot of TOC(wt%) and LOM of Bhuvanagiri formation for the well UP#CX.

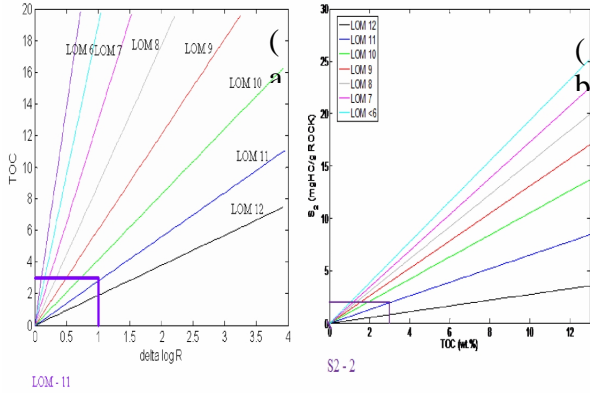


Fig. 9a and b. LOM derived from the crossplot of TOC and log R and determination of  $S_2$ (mg HC/g Rock) from the plot of TOC(wt%) and LOM of Andimadam formation for the well UP#CX.

In the well RV#FX, TOC log was generated from 2000 to 3050m which covers the entire Cretaceous section (Fig. 10). There is a sharp increase in the resistivity from 2 to 10 ohmm against the Andimadam formation compared to the overlying formation. However, porosity has not appreciably increased against the Andimadam formation probably due to over maturation of the source rock. The upper Cretaceous formations contain TOC from 1%, log R 0 to 1,  $S_2$  (0) and LOM (12) which indicates fair concentration of organic matter but no hydrocarbon generation potential (Figs. 11a and b). Andimadam Formation in the depth interval from 2876- 3000m shows log R (1.5), TOC (2),  $S_2$  (0) and LOM (12.5) which indicates good concentration of organic matter and the entire organic matter is converted to hydrocarbons (Figs. 12a and b). Lab measured TOC coincide with log derived values from 2850-2720m; lab values are slightly lower from 2780-2700m; lab values are less than half of log values in the interval from 2950-2875m and coincide closely from 3000-2950m depth interval with log derived values.

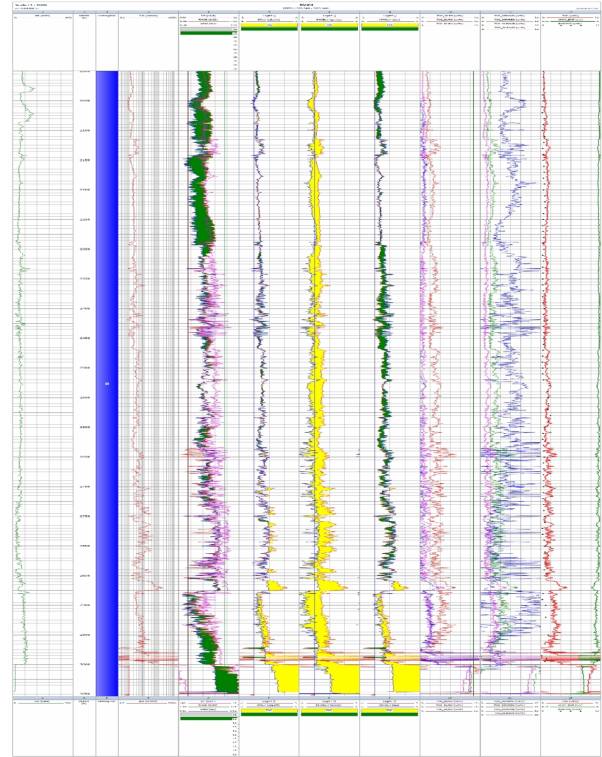


Fig. 10. TOC log generated from the wireline logs using Interactive Petrophysics software for well RV#FX. (C1-gamma ray, C2-depth, C4-deep resistivity, C5-porosity logs, C7- logR- t, C8- logRt-rhob, C9- logRt-nphi, C10-TOC derived from various porosity logs, C12- TOC derived from well logs and lab).

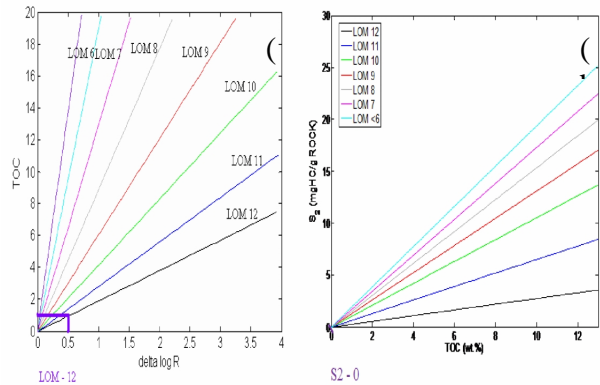


Fig. 11a and b. LOM derived from the crossplot of TOC and log R and determination of  $S_2$ (mg HC/g Rock) from the

## Source rock evaluation from Petrophysical data

plot of TOC(wt%) and LOM of upper Cretaceous formation for the well RV#FX.

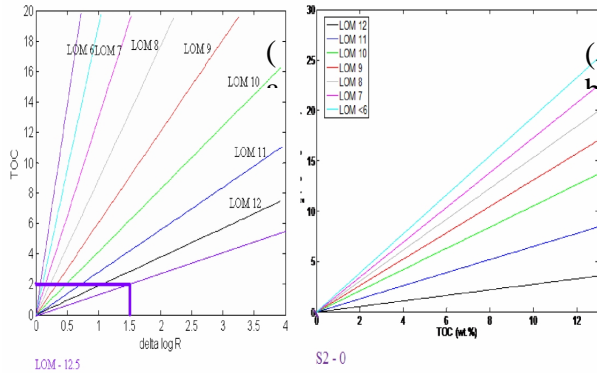


Fig. 12a and b. LOM derived from the crossplot of TOC and  $\log R$  and determination of  $S_2$ (mg HC/g Rock) from the plot of TOC(wt%) and LOM of Andimadam formation for the well RV#FX.

### Discussion

Wireline logs are useful to identify source rocks and serve as an indicator for the source rock potential provided that the source rocks have a minimum thickness and sufficiently rich in organic matter. Wireline methods for estimating organic matter content have the advantage of economy, readily available sources of data and the continuous sampling of a vertically heterogeneous shale section. However, the lab measured geochemical analysis generally offer specific advantage in making direct measurement of organic content but the extent and nature of geochemical sampling provide the greatest limitation to quantitative appraisal of organic content. Cutting samples are usually collected over an interval of about 10 m. They represent an average assessment of organic content for the studied intervals in this study. However, the results of wireline logging technique have adequately highlighted the limitations inherent in quantitative determination. Therefore, the correlation between the results from lab derived geochemical analysis and log technique is important to prove the successfulness of wireline technique in evaluating the organic richness in any study. These limitations will be arisen from the absence of absolute values definable for log reading of organic matter. Accordingly, the well logging methods that involve direct calibration with core/cutting data are only reliable within a localized area or a subbasin.

The interpretation results of both %TOC and LOM and lithofacies allow to recognize different organic facies in the present study. The stratigraphically oldest Andimadam Formation consists of predominantly alternations of minor sand and major shale alternations as characterized by high gamma and high resistivity. Also, %TOC derived and measured show high values ranging from 4 to 6% and LOM from 8.6 to 12.0. There is also excellent match between mTOC (measured TOC) and dTOC (derived TOC) in the Andimadam Formation of all the study wells. The high %TOC and LOM (>9) indicates matured nature of organic source rocks in the Andimadam Formation in the Ramnad sub-basin.

The overlying Sattapadi and Bhuvanagiri formations are dominantly shale facies with minor sandy facies occurring in upper part of Bhuvanagiri Formation. However, the mTOC and dTOC show low values ranging from 0-1%, while LOM ranges from 1-3. The very low values of LOM suggest immature nature of moderately rich organic source rocks occurring in the Bhuvanagiri and Sattapadi formations. While Nannilam Formation consists of reservoir sandy facies in its upper part, it contains very poor TOC and LOM values indicating no source potential of organic facies in this formation.

The measured TOC values from core/sidewall core and ditch cuttings and log derived TOC following were compared for all the study well sections in the Ramnad subbasin. For all the seven exploratory wells, we found fairly good correlation between log-derived TOC values with measured TOC values from side wall cores, conventional cores or cutting samples. However, in wells RV#FX and RS#GX, we found mismatch between the two values at certain depth intervals. The sediment samples are predominantly cuttings and thus often subject to downhole contamination, thereby giving spurious measured TOC values. Therefore, this mismatch can be attributed to the nature of samples.

However, in most cases, the match is very good and this has enabled to apply the  $\log R$  technique in wells for which no samples are available. Also, the ability to perform the  $\log R$  technique at a well site using properly-scaled sonic and resistivity curves further provides an advantage for identifying organic rich intervals to be sampled with a side wall coring tool. Therefore, this study further proposes that log-derived TOC can be relied upon for evaluating

## Source rock evaluation from Petrophysical data

organic source potential in the Ramand sub-basin, wherever measured data is not available or unreliable due to sample contamination.

### Summary and Conclusion

Geochemical parameters viz., TOC, S<sub>2</sub> and LOM were derived from wireline log data using the principle of log R (developed by Passey et al., 1990) for eight exploratory wells of Ramnad sub-basin of Cauvery basin. The results were validated with lab derived parameters. The concentration of TOC, S<sub>2</sub> and LOM for different litho units of Cretaceous sediments enabled us to derive the following conclusions:

- log R technique is useful to evaluate %TOC and organic maturity for 8 exploratory wells.
- log R separation shows direct relation with %TOC, while comparison of mTOC (measured TOC) and dTOC (derived TOC) found closely matching for most depth intervals in all well sections.
- However, mismatch found for few depth intervals in wells RV-FX and RS-GX can be attributed to sample contamination due to uphole cavings.
- The good match found between mTOC and dTOC in most depth intervals in all 8 well sections suggests that dTOC can be safely relied upon for estimating %TOC and LOM in the Ramnad sub-basin.
- Log derived TOC (dTOC) has advantage over mTOC as it can be derived at the well site and can be used readily for planning side wall core especially in source rich intervals, if side wall core pertains to evaluate source potential generally done in shale gas exploration.
- mTOC is cost intensive as it involves collection of samples, packing them, transporting them to the central location and making elaborate measurements which is time consuming.
- The input log data for dTOC method is any how recorded in all the drilled wells. There

is no additional cost implication for data acquisition.

- Once the method is established it can be used quickly and reliably for large well sections in the entire sub-basin.

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