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A unique method for estimation of Total Organic Carbon (TOC) using logs

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Abstract

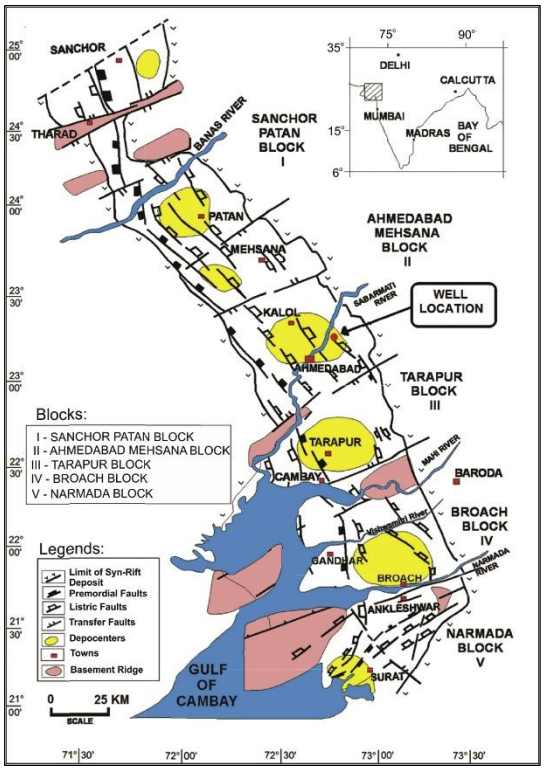
Total Organic Carbon (TOC) plays vital role in terms of Hydrocarbon Plays. It is well established fact that TOC richness along with other parameters such as maturity determine the Hydrocarbon generation potential of a source rock. Advancements in exploration technologies have led new gamut of exploration i.e. unconventional reservoirs. TOC quantification thus plays vital role in unconventional as well as petroleum play analysis. In this study attempt has been made to estimate TOC content of source rocks with excess radioactivity. A feasible Clay Indicator (I_{CL}) was established to determine clay content using Density & Neutron logs. The clay indicator was overlain on Gamma ray curve to delineate source rich rocks from non-source rocks. The study was carried out in a well of Ahmedabad block of Cambay Basin. Cambay basin has thick & widespread sequence of early Eocene transgressive facies called cambay shale which is also prime source rock for the area. The cambay shale holds good potential as play for shale gas. TOC distribution maps for derived from source rock analysis using such studies would certainly help in better understanding of conventional as well as unconventional play exploration. The study has imparted good results in TOC estimation as compared with lab derived data.

1. Introduction

Estimating the organic matter richness in source rocks is essential for studying the potential for generating oil and gas resources and is a necessary part of the exploration for oil and gas (Zhang et al., 1999). Total organic carbon (TOC) content is an indicator of organic matter richness (Zhang et al., 1999; Wang and Guo, 2000). It can be determined directly by geochemical analyses of source rock samples, including sidewall cores and formation cuttings. However, it is not practical to obtain samples from all intervals of all wells in any source rock play. The estimation of TOC from well logs has become increasingly important with the booming exploration and development of unconventional shale oil, shale gas, and tight oil resources worldwide, because TOC is one of the most significant parameters in formation evaluation for those resources, in addition to well-logging techniques that can help offset the discontinuity of core sample analysis.

A Source rock is an organic material rich rock that is capable of generating hydrocarbon when subjected to optimum temperature and pressure. The source rock potential is estimated based upon Total Organic Carbon content while quality is estimated using based upon Kerogen type & maturity. The lab derived TOC data is undoubtedly most precise and accurate however factors such as uncontaminated cuttings, time apart from economic factors are certain limitations to carry out lab studies for each & every well. Various methods of TOC estimation have been established which could broadly be classified into two categories viz, direct estimation based upon logs & secondly estimation based upon separation between logs. Delta Log R method based upon AC & Rt log curve overlay was proposed by Passey et al. (1990). While Jacobi et al. proposed method where in organic & inorganic grain densities were used to establish TOC. All the log based methods require calibration with sample for validation & accurate estimations. Fundamental behind Overlay methods lies ion the fact that source rocks have organic matter apart from the mineral components and thus this could delineate source & non source rocks. While core calibration methods has limitation in such differentiations. The log overlay category is better than core calibration when evaluating TOC Zhao et al. (2016).

2. **Geology of Study area:** The Cambay Basin is situated at Western Indian margin & it is narrow and elongated with a NNW-SSE trend, is a half-graben intracratonic rift, with sediments ranging in age from Late Cretaceous to Tertiary (Bhandari and Chowdhary, 1975).



It is situated between the Saurashtra Craton in the west, Aravalli to the north-east, and Deccan craton in the southeast. with well-established petroleum systems. The basin is subdivided into 5 sub tectonic blocks namely Sanchor-Patan, Ahmedabad-Mehsana, Tarapur, Broach & Narmada-Tapti blocks. Biswas (1982, 1987), Biswas et al. (1994) Raju (1969). In the Cambay basin, oil/gas reservoirs and potential source rocks occur mainly in the Paleocene–middle Eocene sequences of the Olpad, Cambay Shale, and Kalol formations (Figure 2) (Yalcin et al., 1988; Banerjee and Rao, 1993). Late Eocene Cambay Shale is wide spread across the basin and is considered to the kitchen/ source rock for the Tertiary Petroleum system of the region. The study area is located in Sanand field of Ahmedabad block.

Figure 1: Cambay Basin with tectonic elements (modified after Raju et el)

3. Sample Data:

Data selection & Quality analysis: Wireline data for the Well: A from Ahmedabad area of Cambay basin was chosen. For the study purpose Cambay Shale data was chosen as it is proven to be a good source rocks based upon various geochemical analysis carried out in the area. The Neutron-Density log quality data is dependent upon the well bore rugosity which is decipher using caliper logs. Thus for the sake of getting reliable & consistent data a predefined cut off of 10% was applied on caliper log wherein data with over gauging of more than 10% was discarded. Further Geological formation wise data in congruence to nearby wells was matched for quality purpose. Total Organic Carbon (TOC) data was obtained from lab data & used as reference plot for comparing with log derived TOC.

3.1 Methodology:

The source rock are generally Shale, Lime Mud or Marl that contains significant quantity of organic matter (>2%). Zhang et al., 1999). Rock Minerals - Clay & Non Clay minerals, Kerogen & Fluids occupying pore spaces in a nutshell form a source rock. While Non source rock lacks Kerogen in composition. It is prudent to call absence of Kerogen determines whether the rock is source rock or not. Thus understanding Kerogen & its physical properties is crucial factor. Various geochemical analysis have provided insights about the physical & chemical properties of Kerogen. Kerogen has low density, Low velocity & high radioactivity & resistivity. Gamma Ray activity is high in reducing environments such transgressive deep environment litho-facies such as shale. Freshwater & lacustrine depositional environments lack radioactivity. The abundance of oxygen in freshwater inhibits deposition of Uraniurm Ions thus radioactivity is less or negligible. This paper focuses upon

the source rock which exhibit high gamma ray activity. Thus high Gamma ray content can be contributed to Clay minerals & Kerogen rather than non-clay minerals with low GR values. Thus a parameter to mark out clay mineral contribution would help in estimate TOC. Based upon that logic a clay indicator plot was developed for overlay method.

Table 1. Source rock ideal log signatures

Log	Characteristic response in Source rock	Possible reasons
Gamma Ray	High GR values or activity as compared non-source rock with comparable mineral composition	Presence of Organic matter having high Uranium content
Resistivity	Increase in resistivity	OM have low conductivity
Acoustic	Increase in transit time	Slowness of OM
Bulk Density	Low density	OM has density low density values (1.15 to 1.65 gm/cc)
Neutron	Increase in neutron values	OM increases apparent neutron porosity

References: Fertl and Chilingar (1988), Passey et al. (1990), Lewis et al. (2004) Waters et al.

The Gamma Ray activity in source rock is dominantly contributed by clay minerals and Kerogen rather than non-clay minerals. Thus a parameter indicating clay mineral content with respect to total gamma ray count would help in to estimate TOC from the both responses.

3.2 Developing Clay Indicator (I_{CL})

Neutron log (CNL) & Density log together called as porosity logs are interdependent. It was also found that the apparent neutron porosity of shale is greater than the apparent density porosity. Herein, the apparent porosity means that calcite was assumed as the matrix because the CNL log response is typically calibrated in limestone. The apparent neutron porosity and density porosity are given by equations 1 and 2, respectively:

$$\Phi_{Na} = \Phi_N/100 \qquad [1]$$

$$\Phi_{Da} = (\rho_b - \rho_{ma}) / (\rho_f - \rho_{ma}) \qquad [2]$$

Where
ΦNa = apparent neutron porosity of the limestone calibration in volume/volume.
ΦN = CNL log value in porosity units
ΦDa = Apparent density porosity of the limestone calibration in volume/ volume ρ_b is the DEN log value in grams per cubic centimeter
ρ_{ma} = Density value of limestone, 2.71 g/cm3
ρ_f = Fluid density value, 1.0 g/cm3

The difference between the apparent neutron and density porosities is defined as the clay indicator (Icl), which functions similarly to GR logs in nonsource rocks and should also work in source rocks. The clay indicator is described as

$$I_{cl} = \Phi_{Na} - \Phi_{Da} \qquad [3]$$

The difference between the apparent CNL and DEN porosities for Kerogen should be similar to that of the non-clay minerals if the clay indicator works in source rocks.

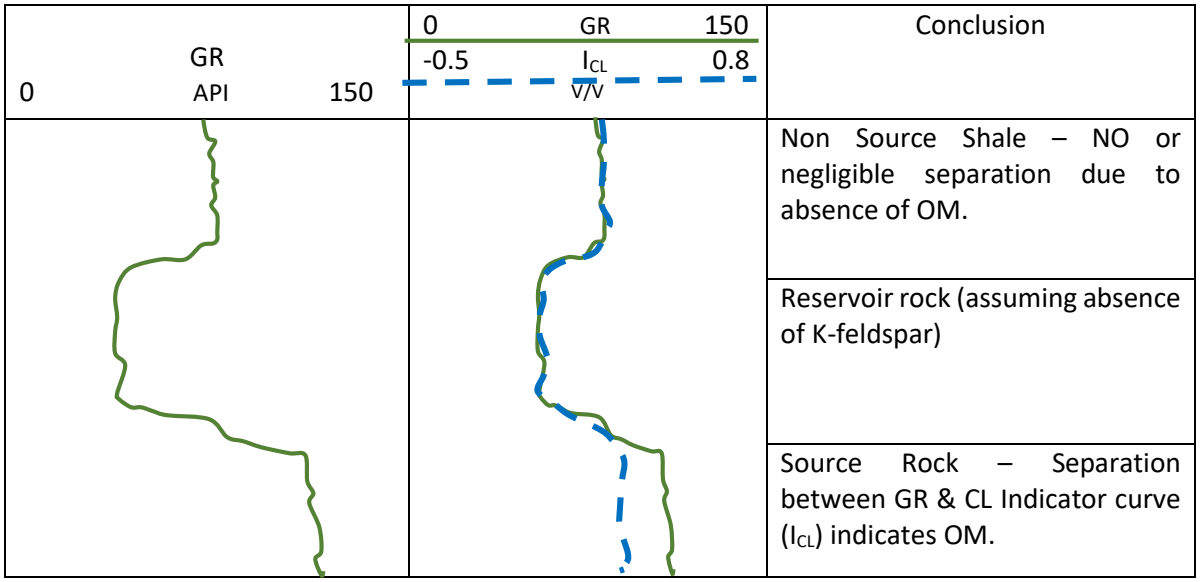


Figure 2: Conceptual model to illustrate Clay indicator functioning. Clay indicator (Icl) is plotted as overlay with Gamma ray log. In the source rock both the curves separate with each other while non-source rock both the plots should overlie.

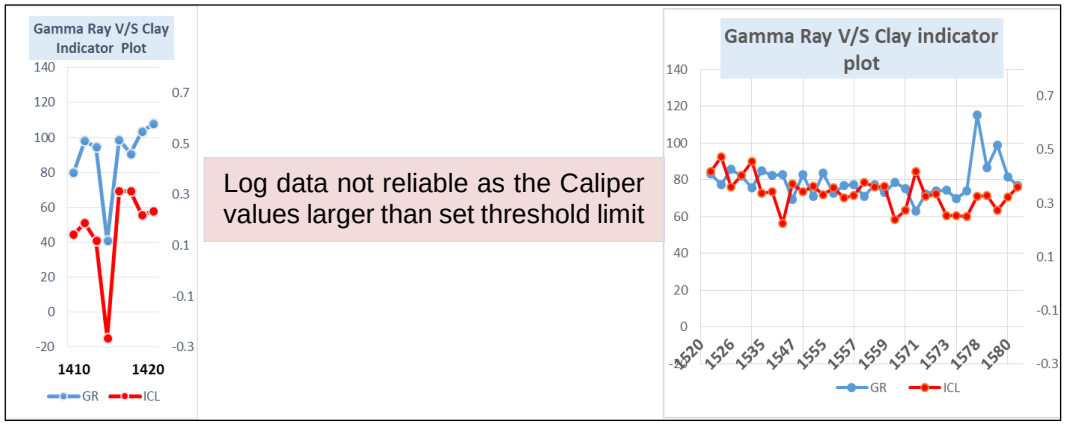


Figure 3: Gamma ray v/s Clay indicator plot overlay plotted against depth for the Well:A from Sanand field of Cambay Basin. Separation between the two curves indicates Organic Matter. White patch in the plot indicates bad borehole conditions wherein log data was discarded due to caliper log readings were above threshold limit i.e. Above 9.4 inches.

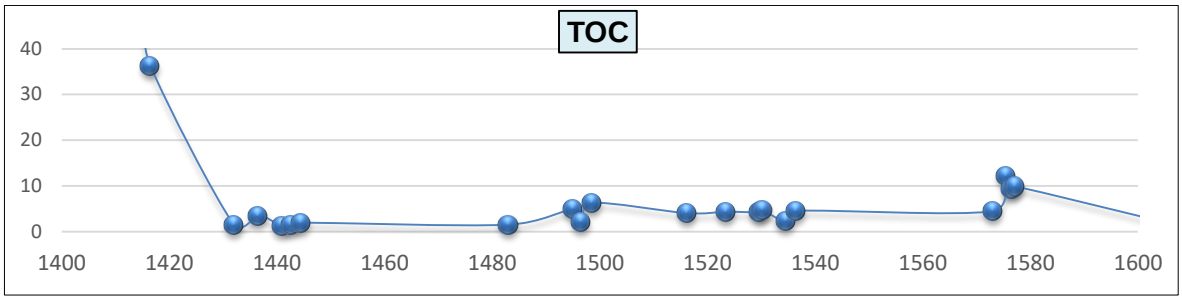


Figure 4: Actual TOC as derived from cutting samples plotted against depth on Y-axis. Data courtesy: RGL Vadodara, ONGC.

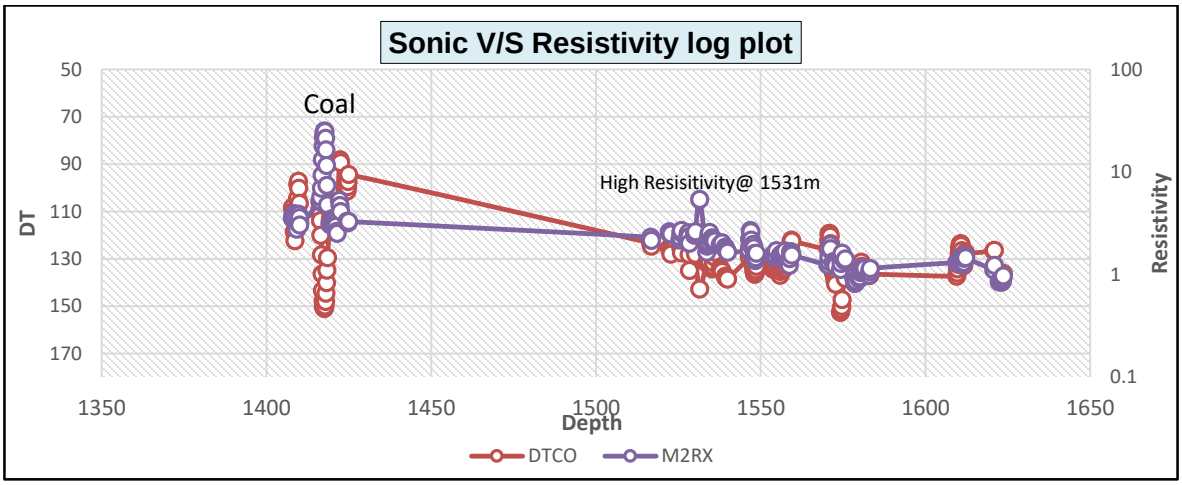


Figure 5: DT V/S Rt plot as proposed by Passey et al. 1990. Around 1420 sharp separation is seen between the two logs indicating coal which is also verified from well lithology. As discussed earlier in DeltaLogR method high resistivity is observed. At depth 1531m separation is seen between the data however lab TOC value is relatively less.

Discussion

The overlay methods for estimating TOC from well logs are better than direct core calibrations. DeltalogR method proposed by Passey et al (1990) uses Acoustic & Rt logs & it delineates source rocks & non-source rocks to much extent. However the method adopted in this study paper based upon overlay method proposed by zhang et al. 2016 avoids the failures of DeltalogR method. Various Overlay methods have their own merits and demerits, DeltalogR method of passey The DeltalogR method fails to cover abnormal Resistivity values in the overlay plots. While Jacobi method which is based upon the principle of overlying inorganic & organic grain densities based upon NMR logs have provided good estimates however NMR log availability is a constraint. The method is applicable for source rocks with good radioactivity & negligible or no K-feldspar content. The GR response values of clay minerals are higher than those of nonclay minerals, except for K-feldspar.

Conclusions

Various Geochemical analysis of source rocks have provided insights about the radioactivity in source rocks is mainly contributed by Clay minerals & Kerogen. A method to to delineate clay mineral contribution in Gamma Ray activity would lead into determining Kerogen content of the source rock. K-Feldspar contribution should be negligible or none as K-feldspars have exhibited high radioactivity

& could be present as non-clay minerals. Thus while adopting this methodology prior geochemical data must be known or would be required prior to using this method.A practical clay indicator has been established to reflect clay content using DEN and CNL logs. The clay indicator is effective in nonsource rocks. In addition, its effectiveness in source rocks the Clay Indicator (Icl) overlay method has imparted well results in TOC estimation as compared to actual lab data from the well of Cambay Basin.

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