Estimate of Total Organic Carbon in petroleum source rocks of Recôncavo Basin using well logs

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Abstract

The $\Delta logR$ technique was developed and tested by EXXON/ESSO, beginning in 1979 and published by Passey et. al. in 1990. Using well logs, the technique allows to identify possible generating rocks and calculate the Total Organic Carbon (TOC) using a simple overlap of the resistivity profile (ILD, for example) with a porosity profile (neutron, sonic or density). Obeying a certain relation between the logarithmic scales of the resistivity profile and the decimal scales of the profiles of some of the porosity profiles. In this work, the sonic (Δt) and resistivity (Rild) profiles were used to characterize the Cexis Field generating rocks, located in the Recôncavo Basin. This method allows organic richness to be accurately assessed in a wide variety of lithologies and maturities using common well logs.

Introduction

When it is about well logs studies, it is very important to know in what rock model the research will be based. A rock can be represented by your solid part (matrix) and by your fluid part, that fills your pores (Figure 1A). In accord to Passeys technique, this rock is classified as non-source, because does not shows organic matter in your matrix.

It is called immature source rocks (Figure 1B) the rocks that has organic matter in the solid part, but does not occur pressure and temperature enough to increase the maturity and generate hydrocarbons, so, will have only water in their pores.

The mature generating rocks are the rocks that, besides shows organic matter in the solid part, shows hydrocarbons in their pores (Figure 1C). Is these rocks that we look to identify and calculate the TOC.

Some organic-rich rocks shows elevated values, that can reach $10wt.\%$ of TOC (Palciauskas, 1991). The generate rocks in this area are the shales from the Gomo Member of the Candeias Formation. The source rocks from Recôncavo basin have TOC values around $1wt.\%$.

For a better understanding of the answers from different logging tools in front of organic-rich rocks, it is necessary to know well the generating process.

Primary the organic matter is solid, and is a part of the sediment. After some time, the weight generated by the layers superposition of sedimentary rocks (increase in pressure and temperature), the organic matter will "cooking" partial and slowly, transforming into kerogen, organic matter insoluble in organic solvents, which becomes Gas and oil.

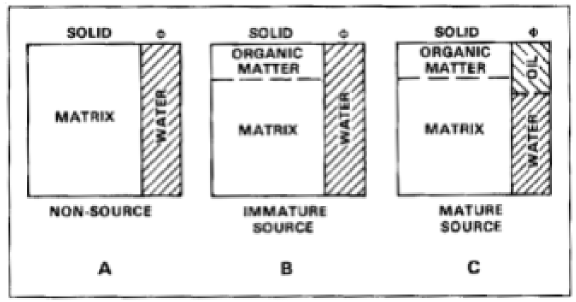

Figure 1: Schematic of solid and fluid components in source and non-source rocks (Passey, 1990)

To separate source rocks from possible source rocks must know the geophysic answers to organic-rich rocks and the changes during the maturation process. The potential generating rocks have different properties from the non-generating rocks. This properties include: (1) low density; (2) low velocity; (3) high rate of hydrogen; (4) high values of gamma-ray, because of the higher concentration of uranium (Swanson, 1966); and, for thermally mature rocks, (5) high resistivity values (because of the hydrocarbons that are stuck in the rock).

Method

Many techniques was desenvolved to establish a relation between the data in well logs and the presence of organic matter in the rock, or more specifically , the TOC. Fertl and Rieke (1980) and Schmoker (1981) proposed a correlation between the values of GR log and GR spectral log and the quantity of organic matter.

Dallenbach et al. (1983) proposed combine the GR log and transit-time log to obtain a parameter that directaly relates with the organic matter. Schmoker and Hester (1983) used density log to estimate the TOC.

Huang and Williamson (1996) applied neural networks to perform organic matter quantification, to do that, they used resistivity logs: the GR, and sonic log.

Mendelson and Toksöz (1985) used the multivariate regression to calculate the TOC, but it was not possible to calculate a generic expression. The results was good, but does not exist a global relation.

Passey et al. (1990), proposed a methodology denominated $\Delta logR$, wich is based in the answers of compressional transit-time log and deep resistivity log in front of an organic-rich rock.

The Passey's technique, the most practical to apply, uses an overlap of two curves, conveniently scaled, in way that when the rock does not present organic matter, the curves keep overlapping and come with together, responding to the porosity variations.

Thereby, the measures of hydrocarbons in generating rocks will separate the curves because of the different tool answers: the sonic log will grow, due to the presence of low velocity organic matter, and resistivity measurement will be higher due to the formations fluids (Stinco, 2001).

The method permit that the sonic log may be replaced by neutron or density logs, comparing them to resistivity log, however, sonic log showed better results. This occurs perhaps because sonic log is less influenced by the borehole conditions than density and neutron logs.

The scale that relates compressional transit-time with formation resistivity is that every $50\mu sec/ft$ in the sonic log corresponds to one logarithmic cycle in the resistivity log.

Then, must be defined a baseline. the curves needs to overlap each other when it is measured a non-source rock with fine granulation (for example, a water filled shale), so as the curves will diverge when there is organic matter. Therefore, to overlap the curves you must identify a non-source shale.

After establish the baseline values, the identification of the zones rich in hydrocarbons turn simple, and it is given from the separation of the curves. Although, it is not only on generating rocks that the curves separation occur.

It is observed cases where the unwanted separation of the curves occur. The separation in hydrocarbons reservoir rocks, for example, can be easily identify through GR log, and exclude for calculation.

The two effects that causes the wanted separation are: (1) the sonic log responds to low density and low velocity of organic matter; and (2) resistivity log responds to the presence of hydrocarbon that fills the pores of the rock. This separation is calculated and it is called $\Delta logR$.

The algebraic expression to calculate the $\Delta logR$ by using the sonic log and the resistivity log is:

$$\Delta logR = \log_{10}(R/R_{baseline}) + 0.02(\Delta t - \Delta t_{baseline}) \quad (1)$$

where

- $\Delta logR$ is the separation between the curves measured in logarithm cycles;
- R is the resistivity measured by the tool (in ohm.m) ;
- Δt is the compressional transit-time measured in $\mu sec/ft$;
- $R_{baseline}$ and $\Delta t_{baseline}$ are the values of the resistivity and sonic in the overlap;
- the 0.02 constant is based on the relation between the logarithm cycle of resistivity for each $50\mu sec/ft$.

There is a linear relation between the curves separation and the total organic carbon, in function of the maturity (LOM). The empiric equation to calculate the TOC in organic-rich rocks from the values of $\Delta logR$ is:

$$TOC = (\Delta logR)10^{(2.297-(0.16889(LOM))} \quad (2)$$

where

- TOC is the Total Organic Carbon (in percent);
- LOM is the Level of Organic Metamorphism, represents the maturity and may vary from 5 to 12 .

The theoretical concepts used from which the equations were originated are detailed in the Passey et al. (1990). Posteriorly, Henderson (1999) produced one variant of the technique to extend it use to reservoir rocks.

The equations that calculates the $\Delta logR$ separation using the neutron log are:

$$\Delta logR_{Neu} = \log_{10}(R/R_{baseline}) + 4.0(\phi N - \phi N_{baseline}) \quad (3)$$

and for the density log are:

$$\Delta logR_{Den} = \log_{10}(R/R_{baseline}) - 2.50(\rho_b - \rho_{baseline}) \quad (4)$$

where

- $\Delta logR_{Neu}$ is the separation between the resistivity and neutron logs;
- $\Delta logR_{Den}$ is the separation between the resistivity and density logs.

Normally the results obtained with the combination sonic/resistivity are superior compared to the combination neutron/resistivity and density/resistivity.

Some other factors that may provoke the separation of the curves are shown in Figure 2. A few care must be taken to minimize the interpretive errors due to the eventual separation of the curves, such as:

(1) Bad conditions of borehole may cause separation between the curves, that are verify through the caliper, which permit to eliminate this rocks of the calculations.(2) Cycle skipping occur in sonic log and may cause an unwanted separation of the curves. This can be identified and inconsiderate in the calculation of the TOC.(3) Uncompacted sediments also characterize an unwanted separation of the curves. In this cases, the values of Δt exceed $150\mu sec/ft$ ($500\mu s/m$), such values should be, thus, inconsiderate. (4) Rocks with very low porosity may cause a big unwanted separation of the curves, in this cases must be verified the low values of Δt (generally $50\mu sec/ft$), and high values resistivity. The same occur in (5) igneous rocks (intrusive or extrusive).

The technique may not be efficient in thin layers (less than $0.5m$), however, in the majority of the cases, there is no interest in layers with this order of magnitude.

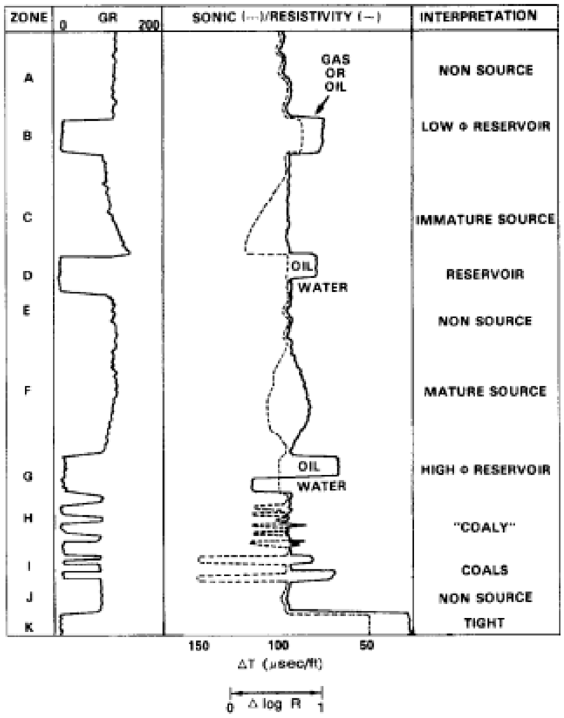

Figure 2: Interpretation guide for possible separations between sonic and resistivity logs (Passey, 1990)

relation between the TOC (measure in laboratory) and the separation $\Delta logR$. The regression can be done with assistance from the graphic below:

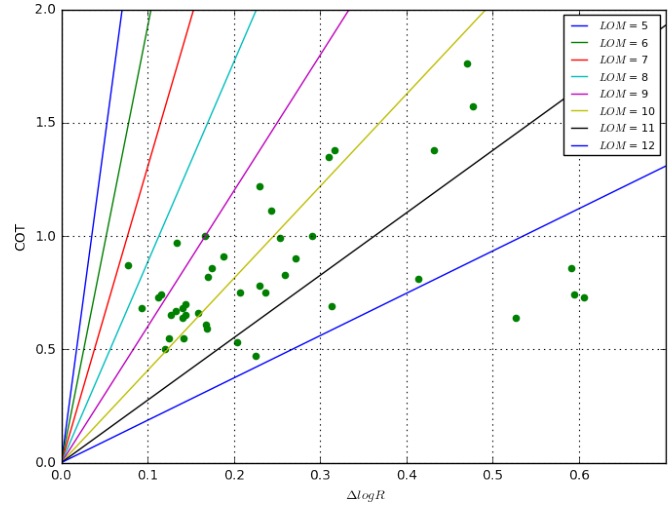

Figure 3: Graphic used to estimate the LOM for the borehole. The different color lines represent the maturity levels varying from $LOM = 5$ to $LOM = 12$. The green dots were used to found the LOM of the borehole (10.6)

Results

In Candeias Field, the Gomo Member, besides been the generator, is the producer of the hydrocarbons through the fractured shales. This zone is denominated the third zone of production from the Candeias Formation and is characterized by an unconventional reservatory, in other words, does not presents petrophysical characteristics capable of guarantee that the accumulated hydrocarbon will be produced by simple process of recuperation. The oil producing zone by fractured shales was discovered in 1958 when it was produced on average $610m^3$ of petroleum per day (Oliveira, 2012).

To calibrating the method it was used geochemical data from the borehole 3-CX-0025-BA, what includes the Gomo Member from Candeias Formation. Based on well log data associated to geochemical information, it was possible to establish basic parameters to calculate the TOC through the separation of the curves: $R_{baseline} = 2.6\ ohm.m$, $\Delta t_{baseline} = 85\ \mu sec/ft$ and $LOM = 10.6$.

After been defined the values of the baseline, the identity of generation zones occur where the curve separation is bigger. The separations are proportional to the TOC, under a factor that depends on the level of organic metamorphism (LOM).

The LOM calculation was realized with contribution of the graphic represented in Figure 3. The values of resistivity and compressional transit-time of the baseline was chosen in an interval of non-generating shale, 1660 to 1760 meters.

To determinate the LOM, it is necessary establish a linear

The figure 4 shows the borehole 3-CX-0025-BA, and in addition to the gamma-ray log and sonic and resistivity overlay curves, shows the apparent correlation between the calculated TOC through Passeys technique, represented by the blue curve, and the geochemical laboratory data, represented by the black points.

It is also noticed that the separations between the sonic log and the resistivity log are not accented, probably due to the low values of TOC, in addition to great roughness of the shales, that can be measured by the caliper e noted by the behavior in sonic log.

Even so, it was possible to stipulate values of TOC for every well interval of the borehole, by using the separations.

Conclusions

This method has simple application and give accurate values of Total Organic Carbon through common well logs. The residual error in this well was $\pm 0,388$.

Even for low TOC values the method was efficient in the estimate. Thus, we can apply the technique developed by Passey in old wells, using just the common well logs, without the need of further measures

The $\Delta logR$ separation can occur without organic-rich source rocks, but these intervals can be easily recognized and excluded.

Acknowledgements

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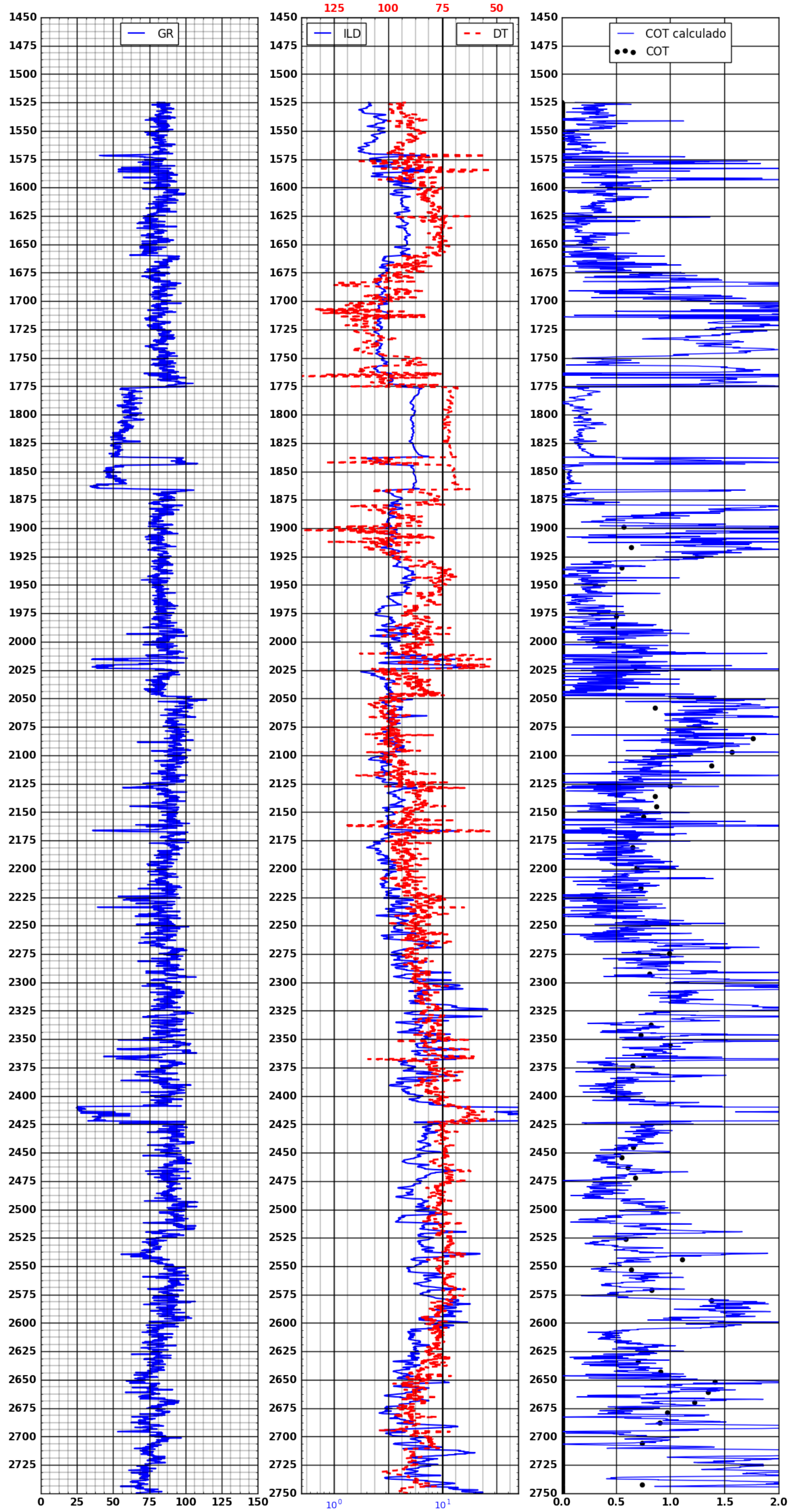

Figure 4: 3-CX-0025-BA well. Gamma-ray log on the left. ILD (blue line) and DT (red line) registers in the middle. And on the right, the calculated TOC values are the blue curve, and the black points are the TOC values of laboratory geochemistry data.

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