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Methodology to Obtain an Accurate TOC Output from Spectroscopy Logs in Oil Base Mud Systems

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Introduction

The Litho Scanner* pulsed-neutron spectroscopy tool combines the advantages of inelastic and capture gamma-ray spectroscopy, thus enabling the stand-alone evaluation of Total Organic Carbon (TOC). Use of oil-based mud presents a new challenge in which the carbon in the borehole must be accurately resolved from the organic carbon of the reservoir to get an accurate formation TOC value. A previous publication demonstrated the accuracy of TOC in wells with both water and oil based mud systems. In these cases, the boreholes were in good condition and a constant borehole carbon correction produced good results. However, the borehole carbon signal is sensitive to variations in borehole size, borehole shape, and other environmental effects which must be taken into account to get an accurate TOC.

Monte Carlo modeling is a valuable technique for understanding the measurement sensitivity to elements in the borehole over a wide range of environmental conditions. It is possible to derive a borehole correction purely from modeling, but unfortunately an accurate mud composition is rarely available in practice. A better solution is to combine modeling information with in-situ empirical data in order to customize an accurate borehole correction for each well. The method is fully automated in software to provide a robust and repeatable correction. The most pressing application is to correct the TOC measurement when hydrocarbons are present in the borehole, but the method is theoretically applicable to any mineral element in the borehole as well.
Multiple examples of field data illustrate the variable impact of borehole carbon on raw TOC measurements and the efficacy of the new automatic borehole correction in producing accurate TOC.

Measurement Summary

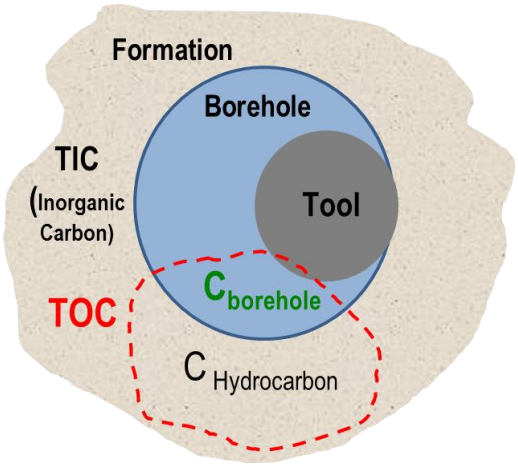

Figure 1 – Components of Spectroscopy total carbon measurement.

The total carbon measured by elemental spectroscopy tools is a combination of the carbon associated with the rock mineralogy, the formation organic carbon, and the organic carbon present in the borehole as illustrated in Figure 1. Calculation of TOC starts with combining the inelastic and capture elemental yields in a closure model (INCP) to determine elemental concentrations in the dry rock. These elements are combined to provide a dry weight mineralogy which enables calculation of the total inorganic carbon (TIC) in the formation by

$$TIC = 0.12\ Wt_{Calcite} + 0.13\ Wt_{Dolomite} + 0.104\ Wt_{Siderite}$$

where the coefficients in the equation represent the weight fraction of carbon for each mineral. Formation TOC is then calculated from

$$TOC = \text{Total Carbon} - TIC - \text{Borehole Carbon Offset}$$

where borehole carbon offset is a constant value determined in a formation known to have zero TOC.

*Mark of Schlumberger

Borehole Corrections

With water based mud systems, the carbon content in the borehole fluid is usually minimal and a constant carbon offset works well for the determination of TOC. When oil based mud systems are used, the carbon content in the mud is significant, and the total organic carbon signal is sensitive to borehole size, borehole shape, and other environmental effects. The example in Figure 2 shows the correlation between borehole size and TOC calculated with a constant carbon offset in a well drilled with an oil base mud system. It is clear that the borehole carbon effect on calculated TOC is significant and must be accounted for.

Monte Carlo modeling is a valuable technique for understanding the measurement sensitivity to elements in the borehole over a wide range of environmental conditions. The modeling results in Figure 3 show that there is not a simple linear relationship between the borehole carbon offset and the borehole size or the oil/water ratio in the mud system.

In practice, an accurate downhole mud composition is not available, thus making it extremely difficult to implement a pure modeling-derived borehole correction. We can use the Litho Scanner carbon measurement in conjunction with borehole caliper data to determine the carbon offset at a fixed hole size, and also to empirically determine the carbon offset sensitivity to borehole size in each well as illustrated by the constant offset points plotted in Figure 4. These values are used to normalize the results from modeling, thereby customizing the correction function for the mud system at hand. The final carbon correction is a function of borehole size at each depth in the wellbore. The use of modeling additionally allows for the possibility of secondary corrections based on tool standoff and formation properties, but these are not yet fully explored. The borehole correction methodology is self-calibrating for systematic caliper offsets or calibration errors. However, it is very important that that the caliper data adequately define the borehole area, and X-Y caliper data is necessary in areas prone to elliptical-shaped boreholes or enlargement on a single axis of the hole. The methodology to optimize the correction parameters takes into account the statistical uncertainty of the carbon measurement and assumes that an interval of zero TOC exists within the logged interval. Log analyst interaction is minimized, as the data fitting is fully automated in software to provide a robust and repeatable correction in both oil based and water based mud systems.

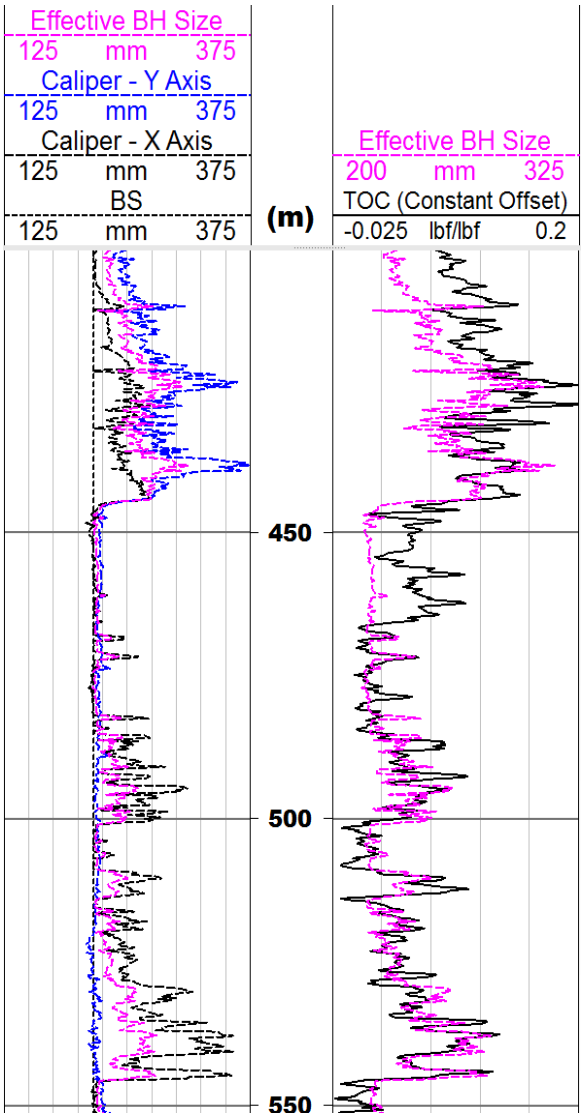

Figure 2 - Comparison of borehole size to TOC calculated with constant borehole carbon offset.

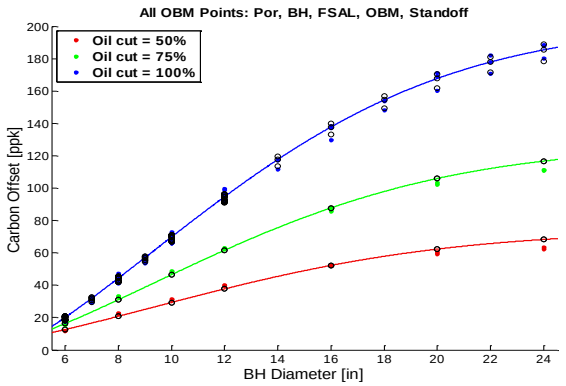

Figure 3 - Modeling results for carbon offset correction as a function of borehole size and OBM water/oil ratio.

Figure 5 shows the result of borehole corrections on TOC. The grey shading in the right track highlights the borehole corrected TOC results, and the yellow shading between this fully corrected and the constant-corrected TOC shows the magnitude of the borehole carbon correction due to varying hole size.

In the crossplot of Figure 6, the borehole corrected TOC points are plotted in a grey color. Note that the minimum TOC values after borehole correction no longer correlate to the borehole enlargement.

Conclusions

While a constant carbon correction to TOC works well in most water based mud systems, the carbon measurement and resulting TOC output from spectroscopy tools shows significant sensitivity to hole size in wells drilled with OBM mud systems. A new borehole correction technique has been developed that combines modeling with empirical data from the well in question to apply a level-by-level borehole carbon correction that is optimized for its borehole properties and the mud properties. The method is fully automated in software to provide a robust and repeatable correction with minimal need for log analyst intervention.

This technique has shown excellent results in both OBM and WBM mud systems in all of the wells evaluated to date. The ability to provide a TOC output from Litho Scanner that is corrected for borehole organic carbon provides a measurement that can be used quantitatively for formation evaluation in wells drilled with either water based or oil based mud systems.

References

Radtke, R. J., Lorente, M., Adolph, B., Berheide, M., Fricke, S., Grau, J., Herron, S., Horkowitz, J., Jorion, B., Madio, D., May, D., Miles, J., Perkins, L., Philip, O., Roscoe, B., Rose, D., and Stoller, C., 2012, *A New Capture and Inelastic Spectroscopy Tool Takes Geochemical Logging to the Next Level*: Transactions of the SPWLA 53th Annual Logging Symposium, Cartagena, Colombia, June 16-20.

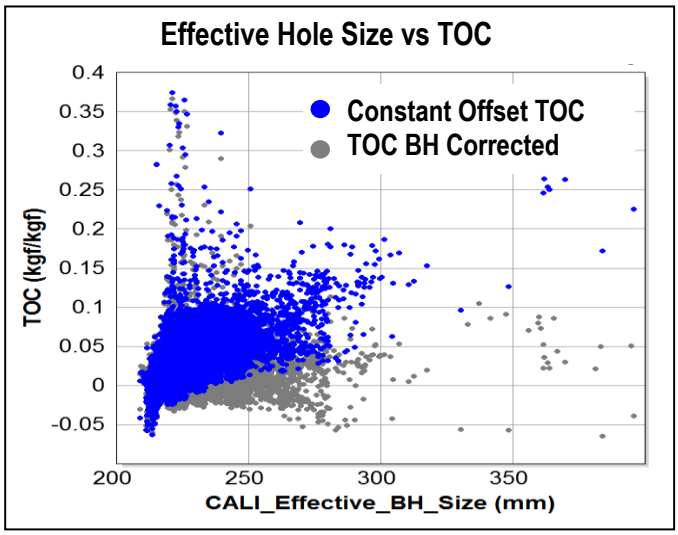

Figure 4 - Cross plot of TOC versus Hole Size for constant offset and borehole carbon corrected outputs.

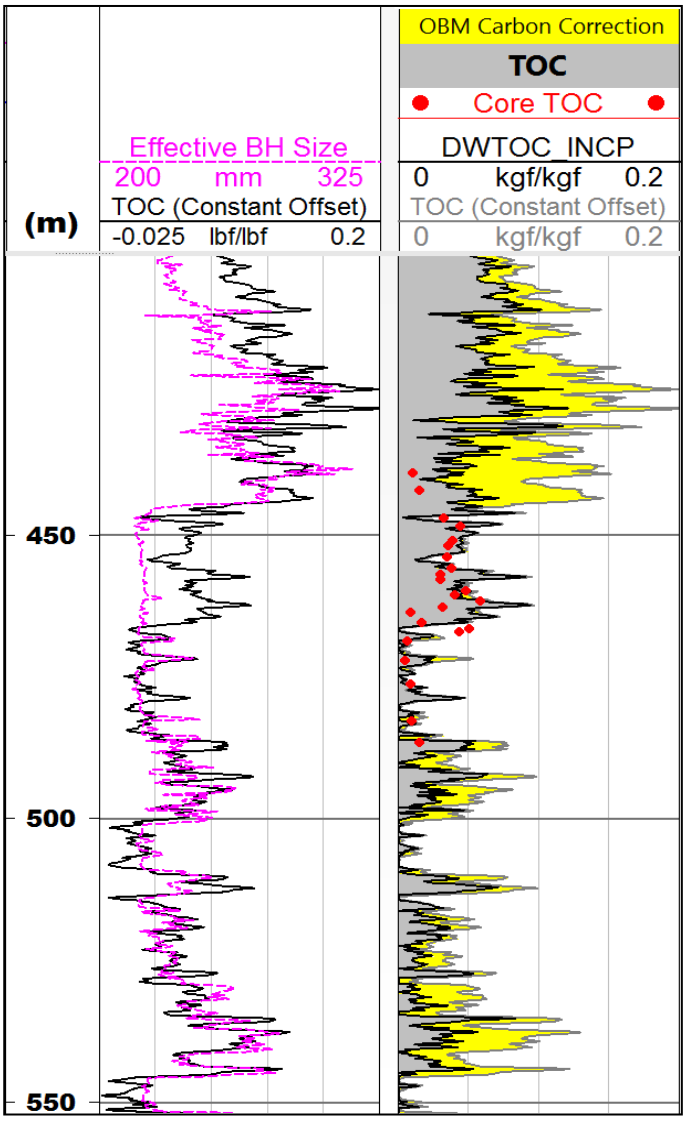

Figure 5 - Comparison of constant offset TOC, corrected TOC, and TOC from core analysis an OBM well with borehole enlargement.