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# PETROPHYSICAL EVALUATION OF TOTAL ORGANIC CARBON CONTENT (TOC) IN AGBADA FORMATION, NIGER DELTA BASIN

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## ABSTRACT

**Total Organic Carbon (TOC) content which is crucial for source rock evaluation was analysed in the Agbada Formation based on density log method. Four organic-rich horizons delineated across six GABO wells in the Niger Delta showed average TOC values of 6.38wt% for horizon 1, 6.97wt% for horizon 2, 6.41wt% for horizon 3 and 5.67wt% for horizon 4. These values are above the standard minimum threshold value of source rock for hydrocarbon generation in the Niger Delta which is 0.5wt%. The values are also greater than 2wt%, and thus in rating, they are classified as excellent source rocks. The implication is that the organic-rich sediments (shale units) of the Agbada Formation are good source rocks and contribute to hydrocarbon generation in the Niger Delta basin.**

## INTRODUCTION

The Niger Delta which is made up of one petroleum system; the Tertiary Niger Delta (Akata-Agbada) Petroleum System has been extensively studied with publications from authors including Short and Stauble (1967), Ekweozor and Daukoru (1984), Tuttle et al. (1999), and Nwajide (2013). Others include Doust and Omatsola (1990), Reijers et al. (1997), Evamy et al. (1978), Hack et al. (2000), Nwachukwu (1986), and Whiteman (1982). It is composed of three main lithologic units; the basal marine Akata Formation of Palaeocene-Recent age with dominantly thick dark grey shale and some sand or silt in the upper part. It is the main hydrocarbon source rock in the Niger Delta. The paralic Agbada Formation of Eocene to Pleistocene age overlies the Akata Formation and is composed of alternating sandstone, siltstone and shale, and forms the main reservoir rock in the Niger Delta petroleum system with hydrocarbons being produced from sandstone and unconsolidated sands. The Benin Formation of Oligocene age is the topmost and most shallow part of the deltaic clastic wedge overlying the Agbada Formation. It is made up of continental deposits with over 70% of sands.

The Agbada Formation has intervals that contain organic carbon content sufficient to contribute to the generation of hydrocarbon in Niger Delta.

Oluwatoyin and Godfrey (2011) proposed that though the shales of the parallic Agbada Formation are source rocks in the Niger Delta, its hydrocarbon generation may not be in commercial quantity like the Akata Formation. This is because the Agbaga shales are immature in various part of the Delta, Nyantakyi et al. (2013).

It is generally accepted that good shaley source rocks of liquid hydrocarbon should normally have a minimum average Total Organic Content (TOC) of 1.0-2.0wt%. Good hydrocarbon source rocks must contain organic matter higher than 1% (wt% TOC), and these organic materials can only generate hydrocarbons, if the reach a level of thermal maturation high enough to generate and expel commercial quantities of oil and/or gas, Lashin and Mogren (2012). Ekweozor and Okoye (1980) stated TOC values range of 0.4-4.4wt% for the Niger Delta; Nwajide (2013) also stated that TOC of various samples of the Niger Delta rocks ranges from 50% for coals (with some recent analyses as high as 69.45wt%) to 0.1% and averages 1.68%.

TOC is one of the most important parameters for a resource play characterization, Verma and Marfurt (2014). The importance of TOC evaluation therefore cannot be overemphasized. For example, in the earliest stages of oil and gas exploration, one must be certain that sufficient source rock is present for the generation of hydrocarbons, Fertl and Chilingar (1988).

The feasibility of interpreting organic matter from wireline measurements stems from its physical properties, which differ considerably from those of the mineral components of its host rock: lower density, slower sonic velocity or higher sonic transit time, frequently higher uranium content, higher resistivity, and higher hydrogen and carbon concentrations. Consequently, the logs used for source rock evaluation most commonly include density, sonic, gamma ray, and resistivity, Herron (1991). Though with considerable limitations inherent in well log techniques for TOC evaluation, primarily due to the fact that several of these properties are quite similar to those of pore fluids, and therefore solid organic matter in source rocks is sometimes difficult to differentiate from either water- or hydrocarbon-filled porosity, well log techniques have been used extensively for TOC evaluation. For example, an integrated approach involving the use of the curve separation ΔlogR technique, which is credited to Passey et al., 1990, the optimal superposition coefficient ΔlogR technique, and the CARBOLOG technique respectively has been used by Sun et al. (2014) to calculate Total Organic Carbon (TOC) from well logs. Lashin and Mogren (2012), also used density log and a combination technique of resistivity and porosity logs (ΔlogR technique) to evaluate the TOC and source rock evaluation of the Lower Miocene rocks, in the October oil field, Gulf of Suez-Egypt. Verma and Marfurt (2014), also tried to compare the results of TOC estimation by Passey's estimation and multi-linear regression. The results showed that the multi-linear regression and Passey's method had the same trend in TOC curve but the absolute values were not the same.

In the use of the density technique, a significant decrease in bulk density occurs in the presence of organics which have a low density, relative to that of their host minerals, Herron (1991).

The study is aimed at investigating the hydrocarbon potential source rocks of Agbada Formation, using well log suites from six GABO wells in the Niger Delta.

The density log technique which involves the use of density log was employed to investigate total organic carbon (TOC) content.

This objective was achieved by correlating shale horizons across wells (Fig. 10), mapping these organic-rich horizons using the gamma ray log, and also reading off density values from density logs.

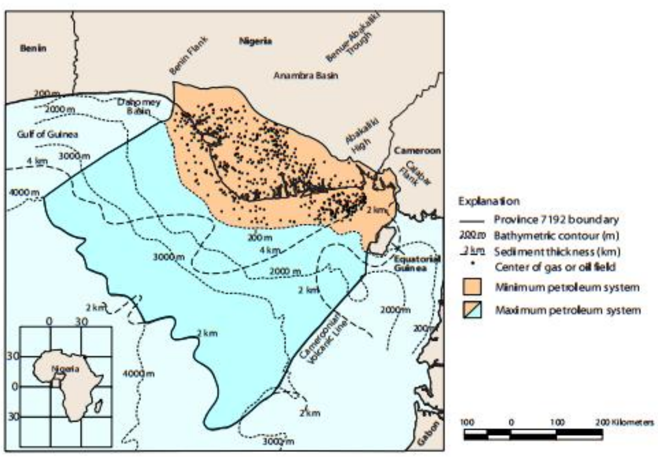


**Figure 1. General outline of the Niger Delta petroleum province (adopted from Tuttle et al, 1999)**

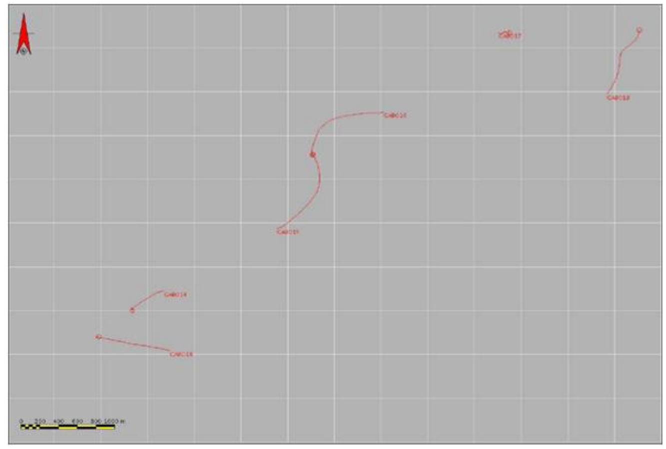

**Figure 2. Base map of the study area showing well control points**

## METHODOLOGY

**Selection of horizons**

Four organic-rich horizons (shale formations) from six wells were delineated from gamma ray logs and designated as horizons HI, HII, HIII and HIV respectively, being mapped at depths ranges within the Agbada Formation, and choosing horizons with distinct thicknesses.

Gamma-ray and density values were carefully estimated from these horizons. The six logs are from GABO wells 14, 15, 16, 17, 18 and 19 respectively from a Niger Delta field. Fig. 2 is a base map of the study area showing the distribution of these wells showing a trend in the NE-SW direction of the field.

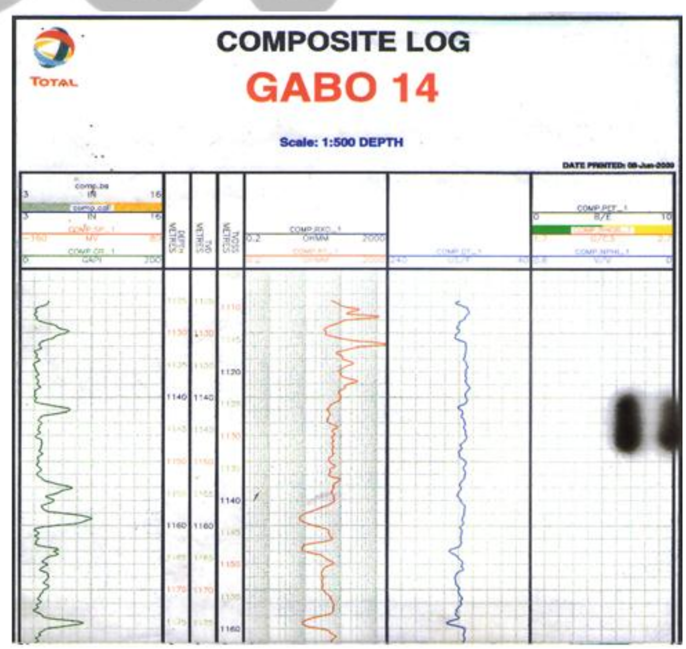


**Figure 3. A typical wireline log of GABO well 14**

## Parameters for evaluation

The parameters of interest are total organic carbon (TOC) and density. TOC is a crucial parameter for evaluating source rocks, and it depends on the quantity of organic matter present in a rock formation. It is expressed in weight percentage (wt %). The presence of organic matter in a rock formation lowers the density of that formation (Asquith and Gibson, 1983; Rider, 1986; Schlumberger, 1972), therefore comparatively; sands will be denser than organic-rich shale. Density has an inverse relationship with TOC, and it is expressed in (g/c3 also g/cc).

## Density determination

Density of the horizons (HI, HII, HIII and HIV) of GABO wells 14 to 19 were estimated from density logs (Fig. 3 shows a typical wire-line log of GABO well 14) by reading off and recording the average density log values at selected depth intervals across each horizon. Density log readings are affected by the amount of organic matter in a formation. The horizons with higher density log readings have low amount of organic matter and vice-versa.

## Determination of Total Organic Carbon (TOC)

TOC is rated as POOR (< 0.5%), FAIR (0.5% - 1.0%), GOOD (1.0% - 2.0%) or EXCELLENT (> 2.0%).
TOC was estimated for each horizon across the wells using the expression shown below:

$TOC = A/\Delta b - B$

Where A = 154.497 and,
B= 57.261 are constants.
$\Delta b$ is the density log reading;
Total organic matter (TOM) is also calculated from the expression below:

$TOM = TOC \times 1.72$

## RESULTS

The estimated total organic carbon content (TOC) and density reading of the four organic-rich horizons from the 6 wells are shown in table 1 – 6.

**GABO WELL 14**

| | | Depth Range (m) | Thickness (m) | G.R (API) | Density log (G/C$_3$) | TOC (wt %) | TOM (wt %) |
|---|---|---|---|---|---|---|---|
| TABLE 1 | Horizon I $H_I$ | 2244.00-2288.00 | 44.00 | 9943 | 2.45 | 5.80 | 9.97 |
| | Horizon II $H_{II}$ | 2361.00-2410.00 | 49.00 | 104.34 | 2.41 | 6.85 | 11.77 |
| | Horizon III $H_{III}$ | 2426.00-2484.00 | 58.00 | 101.21 | 2.39 | 7.38 | 12.70 |
| | Horizon IV $H_{IV}$ | 2490.00-2625.00 | 135.00 | 100.05 | 2.44 | 6.06 | 10.41 |
| TABLE 2 | **GABO WELL 15** | | | | | | |
| | Horizon I $H_I$ | 2233.32-2281.66 | 48.34 | 112.97 | 2.46 | 5.54 | 9.53 |
| | Horizon II $H_{II}$ | 2350.00-2401.66 | 51.66 | 119.6 | 2.38 | 7.65 | 13.16 |
| | Horizon III $H_{III}$ | 2421.66-2378.34 | 56.68 | 119.24 | 2.43 | 6.32 | 10.87 |
| | Horizon IV $H_{IV}$ | 2503.34-2635.00 | 131.66 | 118.14 | 2.45 | 5.80 | 9.97 |
| TABLE 3 | **GABO WELL 16** | | | | | | |
| | Horizon I $H_I$ | 2217.51-2270.00 | 52.49 | 101.64 | 2.47 | 5.29 | 9.10 |
| | Horizon II $H_{II}$ | 2333.70-2384.67 | 50.97 | 107.95 | 2.39 | 7.38 | 12.70 |
| | Horizon III $H_{III}$ | 2401.69-2469.16 | 67.49 | 103.96 | 2.43 | 6.32 | 10.87 |
| | Horizon IV $H_{IV}$ | 2491.34-2637.51 | 146.17 | 103.9 | 2.47 | 5.29 | 9.10 |

**GABO WELL 17**

| | | Depth Range (m) | Thickness (m) | G.R (API) | Density log (G/C$_3$) | TOC (wt %) | TOM (wt %) |
|---|---|---|---|---|---|---|---|
| TABLE 4 | Horizon I $H_I$ | 202333-2041.67 | 18.34 | 107.4 | 2.35 | 8.48 | 14.59 |
| | Horizon II $H_{II}$ | 2180.84-2235.00 | 54.16 | 107.71 | 2.46 | 5.54 | 9.53 |
| | Horizon III $H_{III}$ | 2296.67-2355.00 | 58.33 | 112.4 | 2.44 | 6.06 | 10.42 |
| | Horizon IV $H_{IV}$ | 2403.33-2452.51 | 49.18 | 111.48 | 2.47 | 5.29 | 9.10 |
| TABLE 5 | **GABO WELL 18** | | | | | | |
| | Horizon I $H_I$ | 2260.00-2291.66 | 31.66 | 125.93 | 2.46 | 5.54 | 9.53 |
| | Horizon II $H_{II}$ | 2306.66-2323.50 | 16.84 | 116.05 | 2.32 | 9.33 | 16.05 |
| | Horizon III $H_{III}$ | 2366.66-2415.00 | 48.34 | 124.56 | 2.45 | 5.80 | 9.97 |
| | Horizon IV $H_{IV}$ | 2426.66-2478.34 | 51.68 | 118.41 | 2.46 | 5.54 | 9.53 |
| TABLE 6 | **GABO WELL 19** | | | | | | |
| | Horizon I $H_I$ | 2008.33-2033.34 | 25.01 | 114.1 | 2.38 | 7.65 | 13.16 |
| | Horizon II $H_{II}$ | 2163.33-2215.00 | 51.67 | 113.03 | 2.48 | 5.04 | 8.66 |
| | Horizon III $H_{III}$ | 2230.00-2250.00 | 20.00 | 113.63 | 2.42 | 6.58 | 11.32 |
| | Horizon IV $H_{IV}$ | 2281.67-2418.33 | 136.66 | 117.31 | 2.44 | 6.06 | 10.42 |

**Table 7: Density, TOC and TOM data for horizon I**

| Horizon I | Density (g/c$^3$) | TOC (wt %) | TOM (wt %) |
|---|---|---|---|
| GABO 14 | 2.45 | 5.80 | 9.97 |
| GABO 15 | 2.46 | 5.54 | 9.53 |
| GABO 16 | 2.47 | 5.29 | 9.10 |
| GABO 17 | 2.35 | 8.48 | 14.59 |
| GABO 18 | 2.46 | 5.54 | 9.53 |
| GABO 19 | 2.38 | 7.65 | 13.16 |
| AVERAGE | 2.43 | 6.38 | 10.98 |

**Table 8: Density, TOC and TOM data for horizon II**

| Horizon II | Density (g/c$^3$) | TOC (wt %) | TOM (wt %) |
|---|---|---|---|
| GABO 14 | 2.41 | 6.85 | 11.77 |
| GABO 15 | 2.38 | 7.65 | 13.16 |
| GABO 16 | 2.39 | 7.38 | 12.70 |
| GABO 17 | 2.46 | 5.54 | 9.53 |
| GABO 18 | 2.32 | 9.33 | 16.05 |
| GABO 19 | 2.48 | 5.04 | 8.66 |
| AVERAGE | 2.41 | 6.97 | 11.98 |

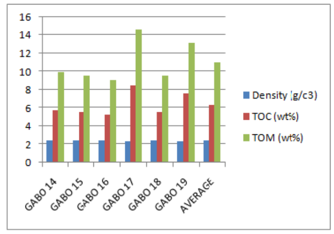


**Fig. 4: Bar chart showing the relationship between density, TOC and TOM for horizon I**

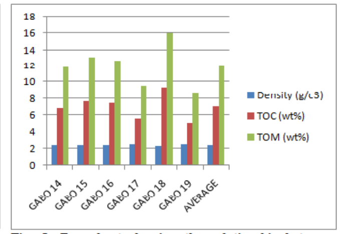


**Fig. 5: Bar chart showing the relationship between density, TOC and TOM for horizon II**

**Table 9: Density, TOC and TOM data for horizon III**

| Horizon III | Density (g/c$^3$) | TOC (wt %) | TOM (wt %) |
|---|---|---|---|
| GABO 14 | 2.39 | 7.38 | 12.70 |
| GABO 15 | 2.43 | 6.32 | 10.87 |
| GABO 16 | 2.43 | 6.32 | 10.87 |
| GABO 17 | 2.44 | 6.06 | 10.42 |
| GABO 18 | 2.45 | 5.80 | 9.97 |
| GABO 19 | 2.42 | 6.58 | 11.32 |
| AVERAGE | 2.43 | 6.41 | 11.02 |

**Table 10: Density, TOC and TOM data for horizon IV**

| Horizon IV | Density (g/c$^3$) | TOC (wt %) | TOM (wt %) |
|---|---|---|---|
| GABO 14 | 2.44 | 6.06 | 10.42 |
| GABO 15 | 2.45 | 5.80 | 9.97 |
| GABO 16 | 2.47 | 5.29 | 9.10 |
| GABO 17 | 2.47 | 5.29 | 9.10 |
| GABO 18 | 2.46 | 5.54 | 9.53 |
| GABO 19 | 2.44 | 6.06 | 10.42 |
| AVERAGE | 2.46 | 5.67 | 9.76 |

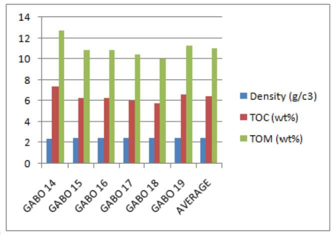


**Fig. 6: Bar chart showing the relationship between density, TOC and TOM for horizon III**

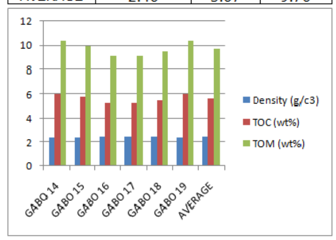


**Fig. 7: Bar chart showing the relationship between density, TOC and TOM for horizon IV**

**Table 11: Average density, TOC and TOM data for the four horizons**

| Horizon | Average Density (g/c$^3$) | Average TOC (wt %) | Average TOM (wt %) |
|---|---|---|---|
| HI | 2.43 | 6.38 | 10.98 |
| HII | 2.41 | 6.97 | 11.98 |
| HIII | 2.43 | 6.41 | 11.03 |
| HIV | 2.46 | 5.98 | 7.71 |

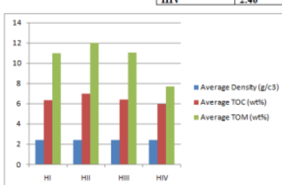


Fig. 8: histogram of average density, TOC and TOM for the four horizons

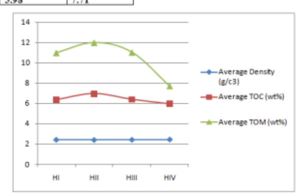


Fig. 9: a graph showing relationship of average density, TOC and TOM for the four horizons

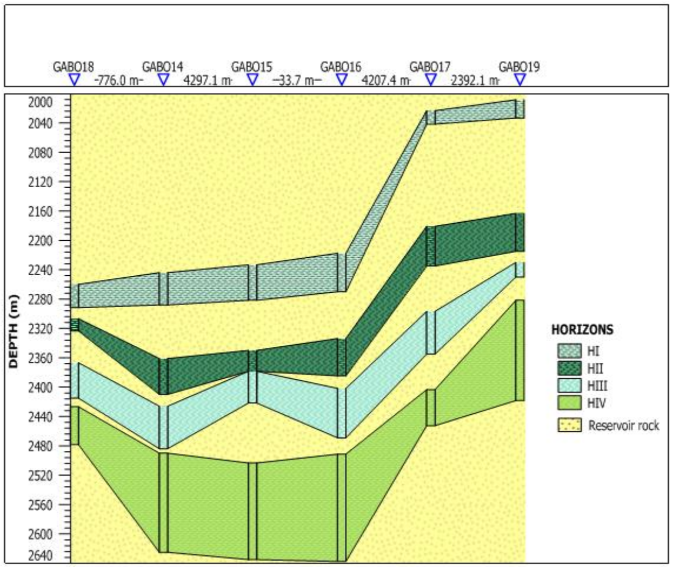


**Figure 10. Fence-diagram showing the four horizons**

Tables 1-6 show details of results for four shale horizons from GABO wells 14 to 19 obtained from the evaluation of the log data for depth range, thicknesses, gamma ray reading and density, and from the empirical applications used to calculate TOC and TOM respectively for the delineated horizons. Also tables 7 to 10 show results and their averages for density, TOC and TOM respectively. Figures 4 to 7 show corresponding complementary plots of histograms for the four horizons, showing the relationship between these parameters. Table 11 presents the averages of density, TOC and TOM for the four horizons, while figures 8 and 9 are plots of histogram and graph respectively of the averages of these parameters showing their relationship.

## DISCUSSION

From tables 1- 6, there is a clear evidence of the relationship between density, TOC and TOM. The relationship is an inverse one, that is, the lower the density, the higher the TOC and TOM and vice versa.

Horizon 1 (HI) has density range from 2.35g/cc (GABO17) to 2.47g/cc (GABO16) and an average value of 2.43g/cc. The TOC is least in GABO16 with a value of 5.29wt% and highest in GABO17, with a value of 8.48wt% and an average value of 6.38wt%. Average TOM is 10.98wt% with least value of 9.10wt% (GABO16) and highest value of 14.59wt% (GABO17). Horizon 2 (HII) has density range from 2.32g/cc (GABO18) to 2.48g/cc (GABO19) and an average value of 2.41g/cc. The average TOC value for this horizon is 6.97wt%, with least value of 5.04wt% (GABO19) and highest value of 9.33wt% in GABO18. Average value of TOM is 11.98wt% and least value is 8.66wt% in GABO 19 and highest in GABO18 with a value of 16.05wt%.

Horizon 3 (HIII) has density range from 2.39g/cc in GABO14 to 2.45g/cc in GABO18 and an average value of 2.43g/cc. The TOC is least in GABO18 with a value of 5.80wt% and highest in GABO14, with a value of 7.38wt% and an average value of 6.41wt%. Average TOM is 11.02wt% with least value of 9.97wt% in GABO18 and highest value of 12.70wt% in GABO14.

Horizon 4 (HIV) has an average density of 2.46g/cc with least value of 2.44g/cc in GABO14 and 19 respectively, and highest value of 2.47g/cc in GABO16 and 17 respectively. The TOC is least in GABO16 and 17, with a value of 5.29wt%, while the highest value of 6.06wt% is seen in GABO14 and 19 respectively. The average value of TOC here is 5.67wt%. Corresponding average value for TOM in this horizon is 9.76wt%, with least value of 9.10wt% observed in GABO16 and 17, and highest value of 10.42wt% observed in GABO14 and 19.

Table 11 is data for average density; TOC and TOM for the four horizons. Apart from horizon 1, there is a marked increase in density with depth with a corresponding decrease in TOC and TOM respectively. This relationship is also seen in the corresponding bar chart plot in figure 8 and the graph in figure 9. The curves for average TOC and TOM plots decrease with increasing depth and density.

The average densities of the four shale horizons correlated across the 6 GABO wells through the Agbada Formation in the Niger Delta range from 2.41g/cc in horizon 2 to 2.46g/cc in horizon4 (these fall within the shale density range of 2.4-2.8g/cc). Average TOC for the four horizons range from 5.98wt% in horizon 4 to 6.97wt% in horizon 2. Also the TOM range from 7.71wt% in horizon 4 to 11.98wt% in horizon 2.

## SUMMARY



Results from the four horizons (HI, HII, HIII and HIV) show average TOC values which are greater than the standard minimum threshold value (0.5%) for hydrocarbon generation earlier estimated for the Niger Delta. Table 12 clearly shows that all four horizons have excellent rating values (i.e. >2wt%) for hydrocarbon generation revealing that the Agbada shale units are potential source rocks contributing to the generation of hydrocarbons in the Niger Delta.

Table 12: Average TOC values and rating for the four horizons

| HORIZON | AVERAGE TOC wt% | AVERAGE TOM wt% | RATING |
|---|---|---|---|
| HI | 6.38 | 10.98 | EXCELLENT |
| HII | 6.97 | 11.98 | EXCELLENT |
| HIII | 6.41 | 11.02 | EXCELLENT |
| HIV | 5.67 | 9.76 | EXCELLENT |

## CONCLUSION

From the forgoing results, it is clear that the shale units of the Agbada Formation are good source rocks for hydrocarbon generation in the Niger Delta. This view agrees with that of Oluwatoyin and Godfrey (2011) that used a geochemical method to estimate TOC in Agbada Formation, and concluded that these shale units of the parallic Formation are source rocks in the Niger Delta, though the hydrocarbon generated may not be in commercial quantity like the Akata formation.

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