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Estimation of Source Rock Organic-Richness from Gamma Ray (Gr) Log; Eocene Section, Parts of the Western Niger Delta, Nigeria

B. A. Olisa. B. D. Ako and J. S. Ojo
Corresponding Author: B. A. Olisa.

Abstract: *A study was conducted to estimate source-rock organic richness from well logs. Source-rocks are measured by the amount of organic matter (TOC) present in sediments. The laboratory methods are limited by sample collections and movements from the field to the laboratory. As a result of difficulties in core and side wall sampling, many of the boreholes are without TOC data. Crossplots of TOC against GR leads to a relationship that enables TOC to be calculated from GR data. The GR log obtained from Shell Petroleum and Development Company (SPDC) in parts of western Niger Delta is in-situ and continuous along the borehole. Five wells available for the analysis are Pologbene-001, Okwefe-001, Abraka-001, Umutu-002 and Ameshi-001. The wells intervals chosen were controlled by the availability of rock-eval TOC results for the ages. The rock-eval data was first crossplotted against GR. The second step was keeping matrix and fluid(s) components of the source rock constant by averaging the stratigraphic positions of the TOC and GR in each well and rearrangements of the stratigraphic positions according to depth. The third step was extraction of TOC and GR according to the established hypothesis and crossplot of the filtered data against each other. Four of the five wells (Pologbene-001, Okwefe-001, Umutu-002 and Ameshi-001) were used for the derivation of the equation. The graph of the filtered data shows a straight line passing through all the points with correlation coefficient R^2 equal to 0.9488. The fifth well (Abraka-001), was used to test the results. The equation of the line was then used to calculate TOC for Eocene Section for Abraka-001.It is evident that the GR-derive TOC values correspond to rock-eval TOC at corresponding depths. It is thus concluded that TOC can be obtained from GR log.*

Key words: *Estimation, Wells, Sources, Log Analysis*

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I. Introduction

The Niger Delta is one of the sedimentary basins in Nigeria. It is located on the Gulf of Guinea, between longitudes 5^0 E to 8^0 E and latitudes 3^0 N to 7^0 N (Figures 1 and 2). To assess source rock of an area, total organic carbon (TOC) must be known (Passey et al. 1990). The traditional means of assessing TOC (organic matter -kerogen) present in sediments is through the laboratory methods- pyrolysis, elemental analysis and visual kerogen inspection. The results of the analysis might not be representative of the insitu conditions of the sediments because analysis depends on samples collection. The short comings of the laboratory methods include movement of samples from the field to the laboratory, cost implications (core recovery) and lack of continuous sampling of well sections.

The general purpose of gamma ray log analysis to determine the TOC is to provide method for continuous analysis of shale sections without the use of rock samples.

Previous works had related organic matter with GR qualitatively (Meyer and Nederlof, 1984) and quantitatively (Schmoker, 1981). Schmoker (1981), proposed (equation 1) to determine organic matter from GR.

$$Ø_0 = (\lambda_B - \lambda)/1.378A \quad (1)$$

where, $Ø_0$ is the organic-matter content of the shale (fractional volume), λ the gamma-ray intensity (API units), λ_B is the gamma-ray intensity if no organic matter is present (API units), and A the slope of the cross-plot of gamma ray intensity and formation density (API units/(g/cm3).

To determine organic content of the source rock from equation 1, major limitations such as the dependence of GR values on conditions of presence or absence of organic matter and formation density and the slope of a graph have to be addressed. GR value of λ_B considered matrix and fluid(s) contents in the equation.

Jia et al. (2012) and Prasad et al. (2005) predicted that gamma ray and TOC are linearly related whilst source rock (Passey et al.1990) consists of matrix, organic matter and fluid(s).

The aim of this research is to remove and derive an equation (for Eocene section) between gamma ray (GR) and TOC values in the form of

$$y = mx + c \quad (2$$

y = variable on the y-axis = GR values
x = variable on the x-axis = TOC (rock-eval values)
m = constant (matrix and fluid contents of source rock).
c = intercept on the y-axis.
The objectives are to use only gamma ray to determine TOC, validate the equation derived on an independent well and to compare the calculated TOC with the laboratory measured TOC for the same intervals.

Geology of the area

The Niger Delta Tertiary sediments contain Paleogene (Eocene) and Neogene (Oligocene to Recent) sediments deposited in high energy constructive deltaic environments and differentiated into continental Benin, paralic Agbada, and pro-delta Akata facies (Figure 3). These formations are diachronous in the Niger Delta (Short and Stauble, 1967).

The type locality of Akata Formation is at Akata-1 well, Lat. 4^0 41'50.5''N; Long. $7^0$46'58.6''E. The interval is 7,180 -11,121 feet (2188-3389m). The Akata Formation is lowermost. It is characterized by a uniform shale development. The shale in general is dark gray, in some places sandy or silty, and contains, especially in the upper part of the Formation, plant remains and some mica.

The Agbada Formation overlies the Akata Formation. It is characterized by the alternation of sandstone and sand bodies with shale layers. The sequence penetrated in Agbada-2 well is at interval of 5760-9500 feet (1755-2895m) below derrick floor and the type locality is at (Lat. $4^0$55' 39.94''N; Long. 7^0'50.92''E). It can be divided into two units: an upper one in which sandstone-shale alternations are abundant and shale intercalations relatively thin; and a lower unit in which the shale units become more prominent and in some places are thicker than the intercalated sandstone of sand bodies. The sandstone percentage ranges from 75 in the upper unit to 50 in the lower unit.

Elele-1 well is the type locality of Benin Formation. The top of the section is at the surface, and the base at a depth of 4,600 feet (1402m), and it is represented as the top of the highest shale bearing a marine fauna. On the log a more pronounce break appears at 3,700 feet (1127m) but this was found to have only local significance. The sequence penetrated is predominantly (more than 90 %) sandy with few shale intercalation with the shale more abundant toward the base. The sand and sandstone are coarse-grained, commonly very angular and pebbly to very fine-grained. In general they appear to be very poorly sorted. The gamma log reading is generally low.

Previous Work

Bustin (1988), in a detailed source-rock study on side-wall core and cuttings from the Agbada-Akata transition or uppermost Akata Formations, concluded that there are no rich source rocks in the delta. With respect to oil potential, Bustin claims that the poor source-rock quality has been more than compensated for by their great volume, excellent migration drainage. The oil potential is further enhanced by permeable interbedded sandstone and rapid hydrocarbon generation resulting from high sedimentation rates. The total organic-carbon (TOC) content of sandstone, siltstone, and shales in his study is essentially the same (average of 1.4 to 1.6%TOC). The content, however, seems to vary with age of the strata- a trend of decreasing content with decreasing age (average 2.2% in the late Eocene compared to 0.9% in Pliocene strata). Bustin's Eocene TOC average compares well with the averages of 2.5% and 2.3% obtained for Agbada-Akata shales in two wells. Nwachukwu and Chukwura (1986) report values as high as 5.2% in paralic shales (Agbada Formation) from the western part of the delta.

II. Materials and Methodology

Five regionally spread wells {Pologbene-001 (total depth 9496 ft (2894 m), Okwefe-001 (total depth 11835 ft (3607 m), Umutu-002 (total depth 11257 ft (3431 m), Abraka-001 (total depth 12772 ft (3893 m) and Ameshi-001 (total depth 13799 ft (4206 m)} were available for this analysis (Figures 2 Table 1). The laboratory data (TOC) was fundamental to this analysis. All the wells had GR logs and rock eval TOC data calibrated with biostratigraphic palynological data, obtained from sidewall samples provided by Shell Petroleum and Development Company (SPDC).

The wells and GR logs actively involved in the formulation of the equation are shown in Figure 4. Abraka-001 is the well used for validation of the equation (Figure 5).

Three steps were followed to determine the TOC. The first step was the cross-plot of laboratory TOC (rock-eval pyrolysis) against GR at the same depth range. This process was required to know the variation of raw organic matter (in association with the matrix and fluid(s) content) against GR (Figure 6A-E).

Second step was the removal of lithological and mineralogical effects. This step was divided into two sub-steps.

(A) Re-arrangements of TOC and GR values for each well to the nearest hundredths and then averaged (Tables 2A-C).
(B) The averaged TOC and gamma ray values were then combined (Table 3) for all the wells.

Step 3 was the application of the hypotheses of Jia et al. 2012 and Prasad et al. 2005, that TOC is directly related to GR. Table 3 shows the data sorted according to increasing TOC and GR from the shallowest to the deepest. Table 4 is the filtered (sorted) data cross-plotted as TOC (wt %) against GR (API) (Figure 7).

III. Results and Discussions

Figure 6 shows that crossplot of laboratory TOC against GR unfiltered values. The correlation is very poor for all the wells, as shown by the correlation coefficient values for

I. Pologbene-001 (Figure 6A), correlation coefficient R^2 is 0.037 = 3.7% (very poor).
The equation of the line is:
1. $Y = -3.699x + 86.46$ (3)

II. Okwefe-001 (Figure 6B), correlation coefficient R^2 is0.002 = 0.2% (very poor).
The equation of the line is:
1. $Y = 0.075X + 80.30$ (4)

III. Abraka-001 (Figure 6C), correlation coefficient R^2 is 0.0112 = 1.12% (very poor).
The equation of the line is:
1. $Y = -2.866X + 43.62$ (5)

IV. Umutu-002 (Figure 6D), correlation coefficient is 0.2837 (28.23%) (Poor).
The equation of the line is:
1. $Y = 31.935X – 45.467$ (6)

V. Ameshi-001 (Figure 6E), correlation coefficient is 0.022 = 2.2% (poor).
The equation of the line is:
$Y = -13.60X + 69.85$ (7)

This poor correlation is as a result of the composition of the matrix and the fluid(s) effects masking the direct relationships between the TOC and the gamma ray.

Table 2 shows that there is no relationship between depth and TOC or GR in each of the wells. Also, there is no relationship between TOC and the GR.

In Table 3, the Eocene data is shallowest at Umutu-002 and Ameshi-001 at a depth of 7365 ft (2245 m) and 7376 ft (2248 m) respectively. The corresponding values of TOC in the wells are 2.5 and 1.2 wt %. The gamma ray values for the wells are the same (26.1 API). The deepest Eocene data for the TOC and GR is at Okwefe-001 at a depth of 11000 ft (3353 m). TOC and gamma ray are 4 wt % and 84 API respectively. When correlated against depth, there is no relationship between the TOC and GR.

In Table 4, the masking effects between TOC and GR had been removed using the hypotheses (TOC increases as the GR increases). TOC is increasing with depth as well as GR. Figure 7 is the result of a plot of filtered TOC against GR in Table 4.

The equation of the line is:

$$y = 29.649x - 31.732 \quad (R^2 = 0.9488) \qquad (8)$$

This equation was tested on a separate well (Abraka-001) (Table 5) to compare the GR-derived TOC with rock-eval TOC. Laboratory TOC and calculated TOC correlate at the following sampling points: 10261 ft (3128 m), 10425 ft (3178 m), 10470 ft (3191 m), 10920 ft (3328 m), 10990 ft (3350 m), and 11010 ft (3356 m) (indicated in green color).

Only six sampling points correlate at Abraka-001 due to the fact that only four well were used as input in the equation.

IV. Conclusion

We have used only gamma ray log to derive an equation to estimate total organic carbon (TOC) for Eocene section in the Niger Delta. The use of the equation has not been tested in other basins due to lack of data. An equation is derived to estimate Total organic carbon (TOC) from gamma ray log on a regional basis. The equation when tested for validation in Abraka-001 Eocene section, the calculated TOC correlates with six sidewall sample rock-eval TOC, out of eighteen. The remaining samples did not correlate. This is due to the use of only four wells to derive the equation.

Given Eocene sections in the Niger Delta, the equation is proposed to determine TOC and then applied for exploration purposes. There is a need to improve on the result as more wells, Eocene rock-eval data and GR logs are available.

Acknowledgements

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Table1. Available wells, Interval analyzed GR and Rock-eval values.

Name	Interval analyzed (ft)	Pzones	Gamma ray (GR) (API)	Rock-eval TOC (wt %)
Pologbene-001	8930-9330	P470/480	51.3-86.5	3-4
Umutu-002	6465-8040	P470/480	23-105	2-28
Okwefe-001	7450-10620	P470/480	0.88-115	1-77
Abraka-001	9640-11040	P470/480	27-89	1-4
Ameshi-001	7237-9191	P470/480	43.6-108.5	1-3

Table 2A . Re-arrangements to the nearest hundredths in Pologbene-001

Depth (ft)	Depth (m)	Pzone	TOC(wt%) av.	GR (API) av.
8900	2713	P480-P470	3.35	72
9000	2743	P480-P470	3.75	79
9100	2774	P480-P470	3.47	79
9200	2804	P480-P470	3.63	69
9300	2835	P480-P470	3.35	62

Table 2B. Re-arrangements to the nearest hundredths in Umutu-002

Depth (ft)	Depth (m)	Pzone	TOC (wt%) av.	GR (API) av.
7400	2256	p480	2.64	50.4
7500	2286	p480	2.84	28.9
7600	2316	p480	2.74	89
7700	2347	p480	3.85	83
7800	2377	p480	2.85	78.9
7900	2408	p480	2.56	88.4

Table 2C. Re-arrangements to the nearest hundredths in Okwefe-001

Ameshi-001				
Depth (ft)	Depth (m)	Pzone	TOC (wt%) av.	GR(API) av.
7200	2195	p480	2.01	18.88
7300	2225	p480	1.21	26.14
7500	2286	p480	1.99	163.91
7600	2316	p480	2.61	44.67
7700	2347	p480	2.49	21.19
8200	2499	p480	3.1	15.4
9100	2774	p480	2.32	13.59
9200	2804	p480	1.92	15

Table3. Combination of TOC and GR in all wells

Well	Depth(ft)	Depth(m)	TOC wt %	GR API
Umutu-002	7365	2245	2.5	26.1
Ameshi-001	7376	2248	1.21	26.14
Umutu-002	7400	2259	2.64	50.4
Umutu-002	7500	2286	2.84	31.9

Umutu-002	7700	2347	3.85	83.3
Umutu-002	7800	2377	2.85	78.9
Umutu-002	7900	2408	2.56	93.9
Ameshi-001	8276	2523	2.61	44.67
Ameshi-001	8674	2644	2.49	21.19
Ameshi-001	8744	2665	3.1	15.4
Pologbene-001.	8900	2713	3.35	72
Pologbene-001.	9000	2743	3.75	79
Pologbene-001..	9100	2774	3.47	79
Pologbene-001.	9200	2804	3.63	69
Pologbene-001.	9300	2835	3.35	62
Okwefe-001	11000	3353	4	84

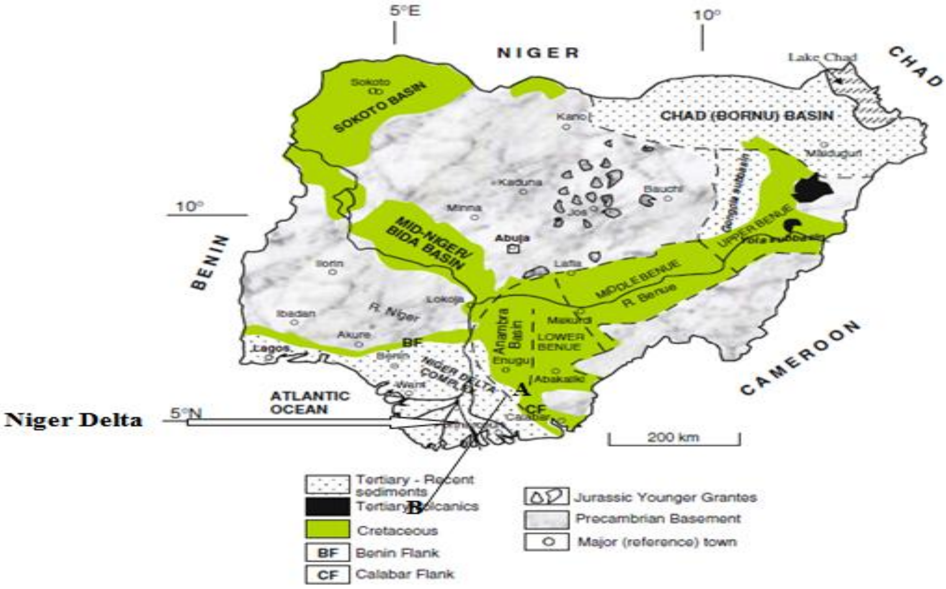
Table 4. Final re-arrangement of TOC and GR according to hypothesis

Depth (ft).	Depth (m).	TOC (wt %)	GR (API)
7365	2245	1.9	26
7500	2286	2	31.9
8565	2611	2.55	32.9
8900	2713	3.35	72
9050	2758	3.61	79
11000	3353	4	84

Table 5. Validation of equation in Abraka-001

Abraka-001					
Depth (ft)	Depth (m)	Pz	Lab. (TOC) (wt %)	GR (API)	Calc. TOC (wt%)
9645	2940	P480	1.09	64.5	3.245708
9675	2949	P480	1.43	88.5	4.055179
9705	2958	P480	1.37	30	2.082094
10230	3118	P480	2.1	55.9	2.955648
10261	3128	P480	2.16	33.6	2.203514
10290	3136	P480	3.62	31.3	2.12594
10320	3146	P480	1.55	59.3	3.070323
10350	3155	P480	1.4	35.8	2.277716
10380	3164	P480	1.37	24.6	1.899963
10425	3178	P480	2.38	35.8	2.277716
10470	3191	P480	1.74	28.9	2.044993
10500	3200	P480	1.2	26.3	1.9573
10530	3210	P480	1.23	29.5	2.06523
10575	3223	P480	1.04	26.3	1.9573
10920	3328	P470	2.26	33.2	2.190023
10950	3338	P470	1.36	27.2	1.987656
10990	3350	P470	1.88	31.1	2.119195
11010	3356	P470	2.05	33.9	2.213633

Figure1. Sedimentary Basins of Nigeria and Location of the Niger Delta (After Obaje et al. 2006)



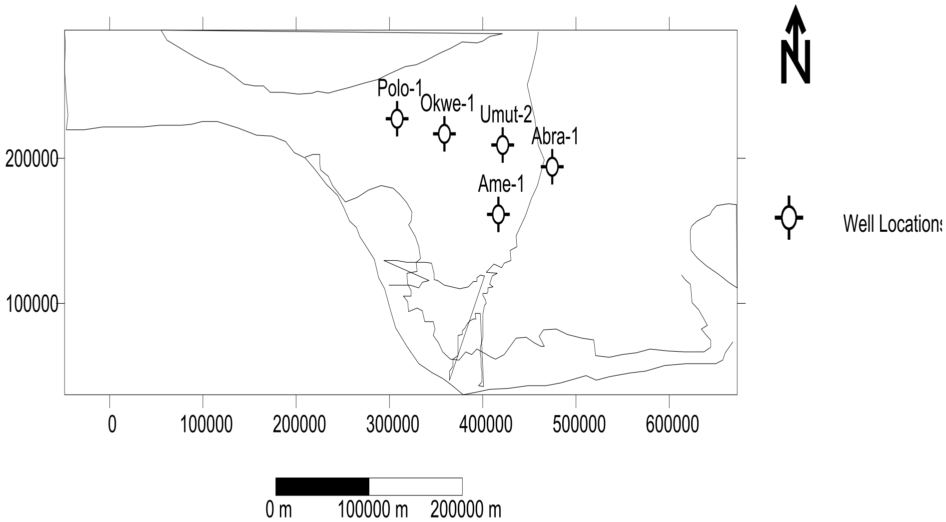


Figure2. Wells Location in the Study area

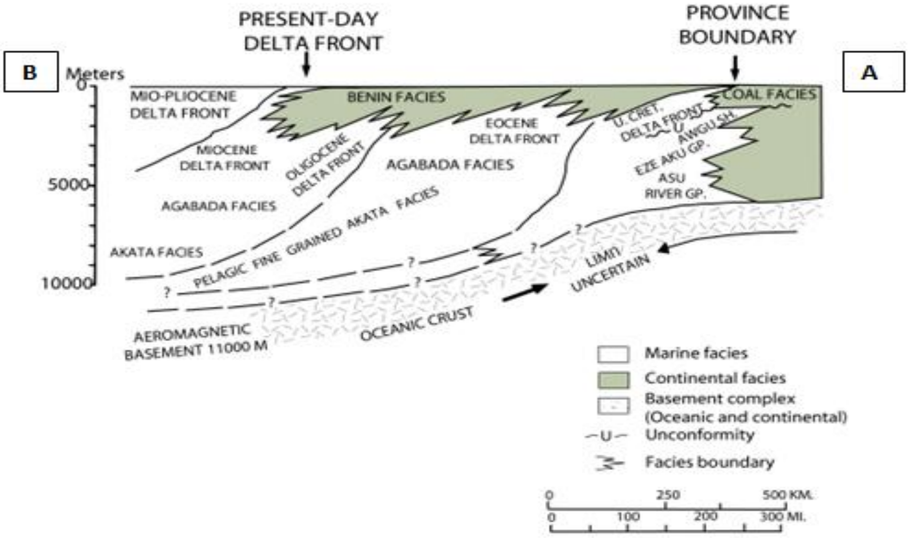


Figure3. Schematic section of Niger Delta of Figure 1 (U. S. Geological Survey Open File Report 99-50H)

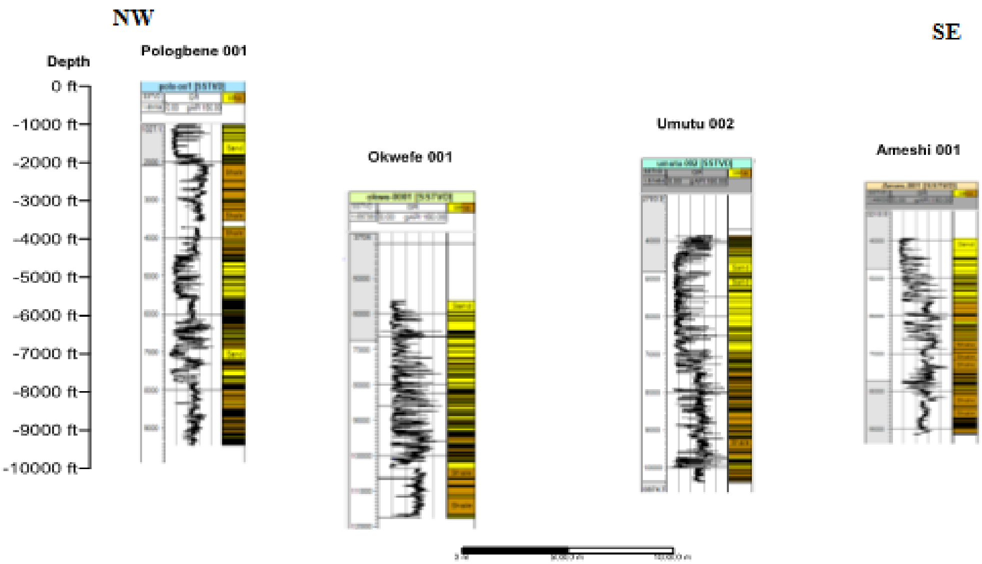


Figure 4. Wells and GR logs used to derive equation and proposed formation boundary.

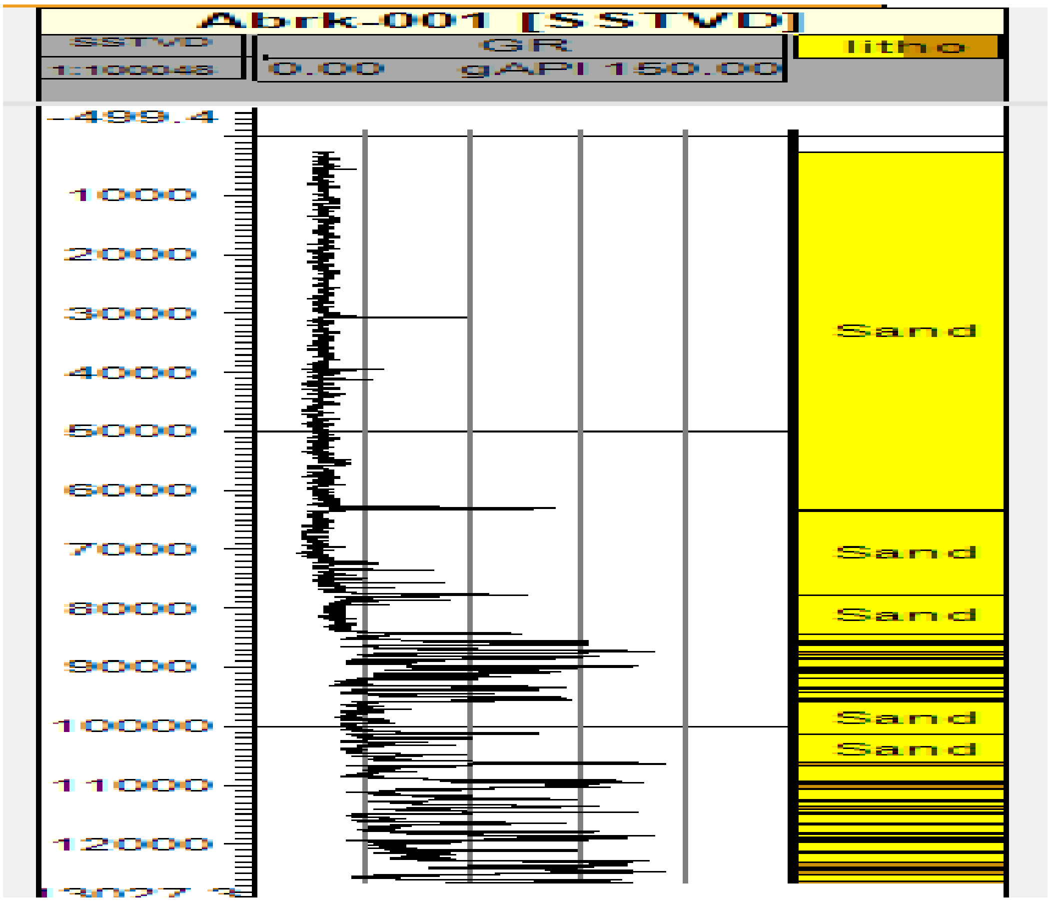


Figure5. Abraka-001: Well used for validation of Equation

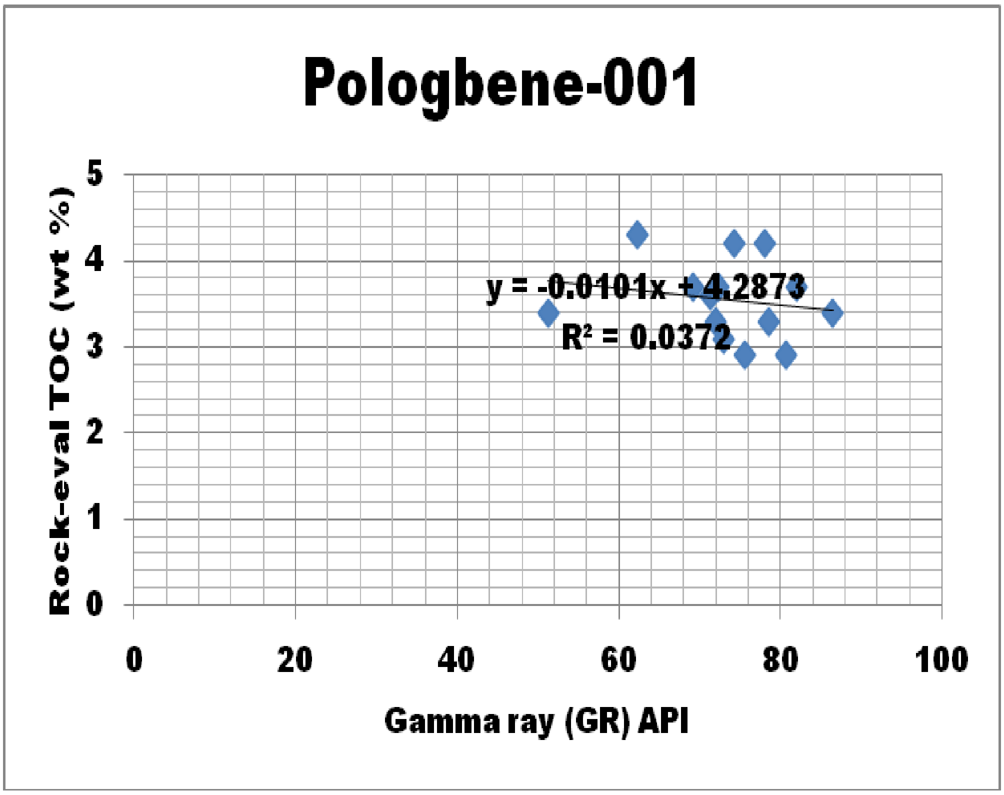


Figure6A. Plot of GR against laboratory rock-eval TOC at Pologbene-001

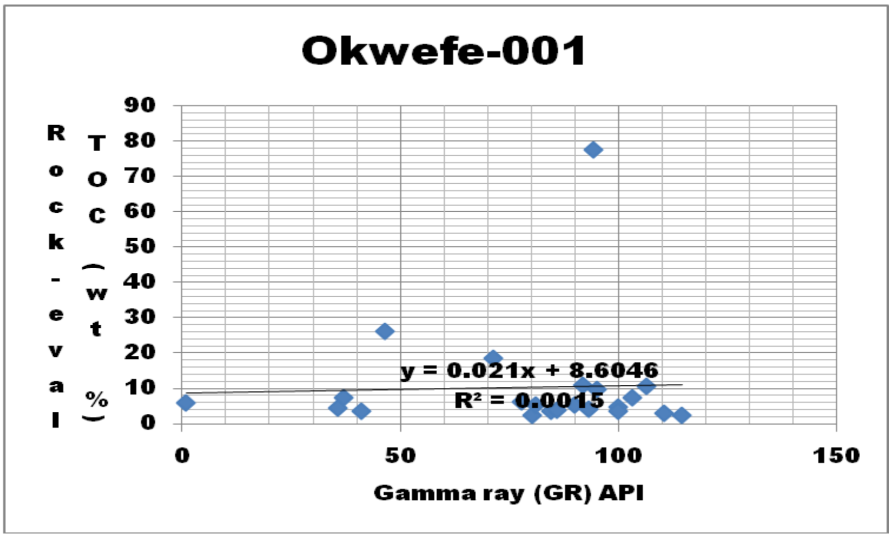


Figure6B. Plot of GR against laboratory rock-eval TOC at Okwefe-001

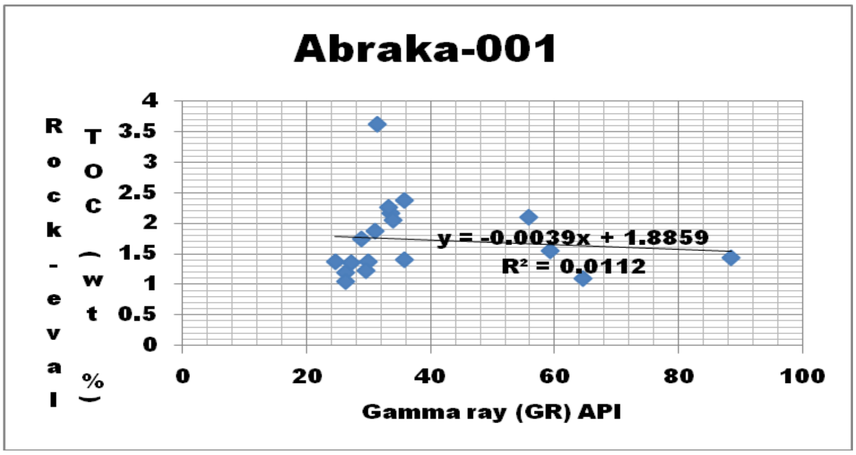


Figure 6C. Plot of GR against laboratory rock-eval TOC at Abraka-001

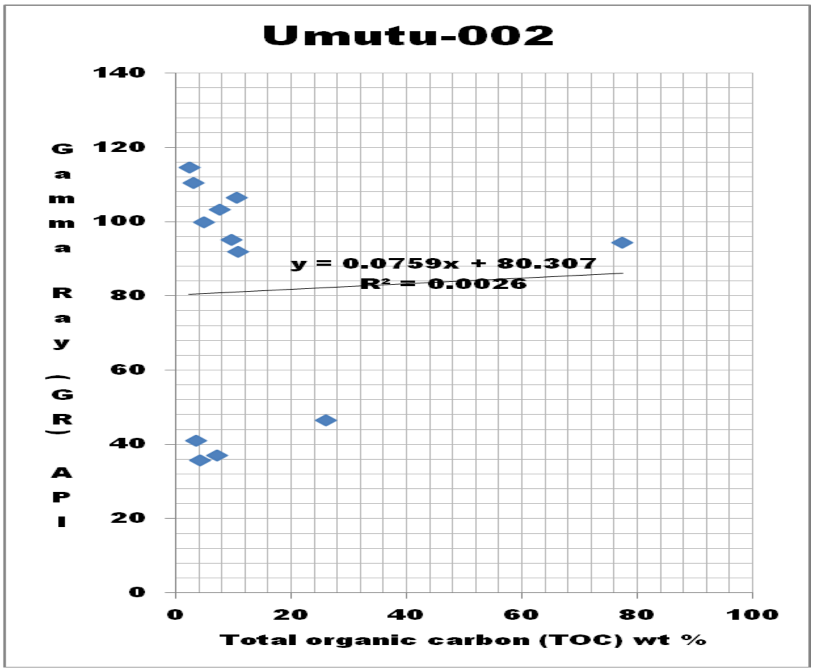


Figure 6D. Plot of GR against laboratory rock-eval TOC at Umutu-002

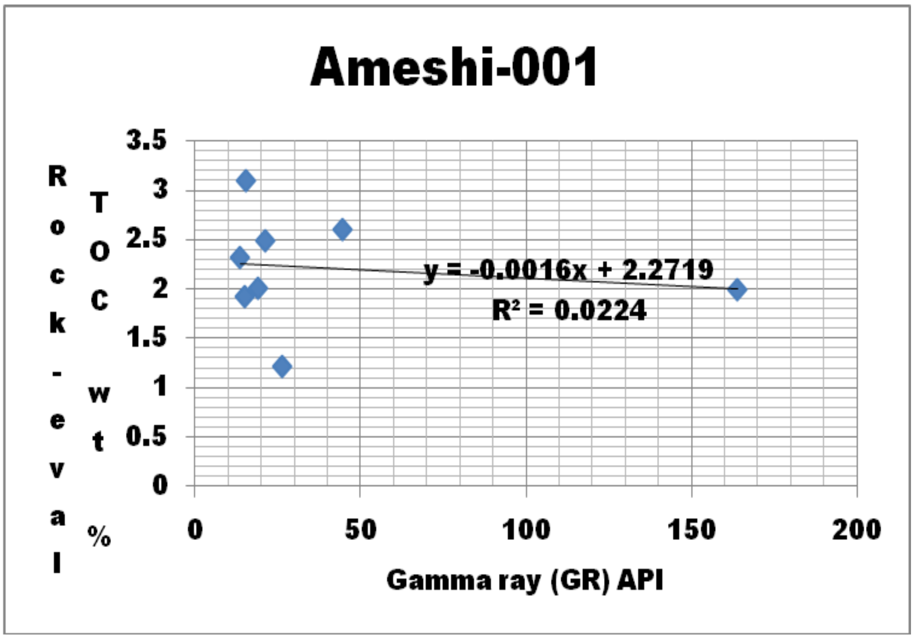


Figure6E. Plot of GR against laboratory rock-eval TOC at Ameshi-001

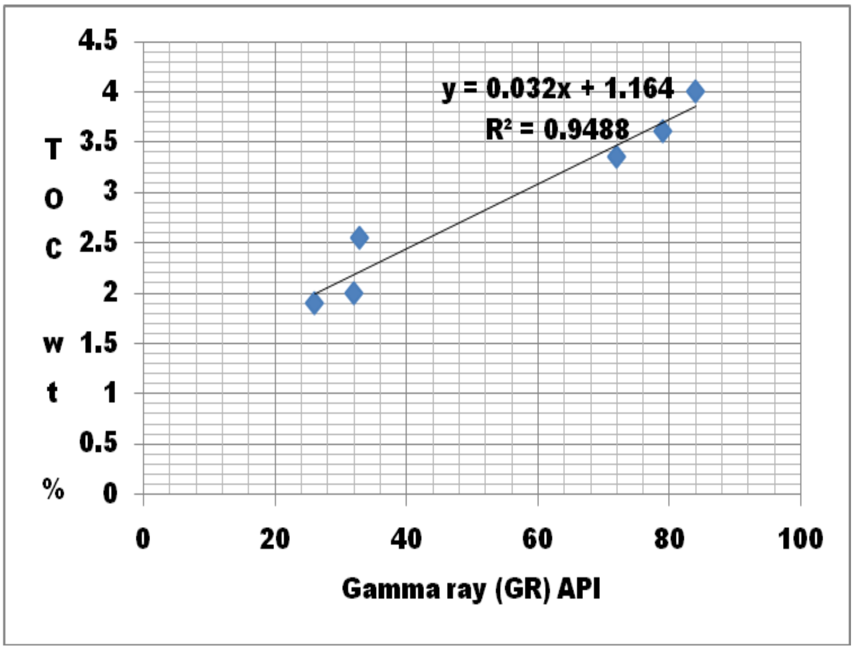


Figure7. Cross-plot of GR against TOC after filtering effects of Wells

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