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Bivariate Regression Analysis on Sonic Logs in the Niger Delta, Nigeria

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***Abstract**:*
Transit time curves are very useful in source rock studies. It indicates the presence of kerogen in the rock. In many wells the porosity log is either not available or transit-time is missing in the borehole section. A generalized equation could be obtained between total organic carbon (TOC) and transit time from sonic logs in nearby wells to generate transit-time curve for the targeted well. Equation is derived to calculate transit time from TOC for three wells, Pologbene-001, Umutu-002 and Ameshi-001. This was applied successfully on Well Abraka-001, 110km away. Results show that the calculated transit time is camparable to the values of transit time obtainable in other nearby wells.

Keywords: *Sonic, Regression, total organic carbon (TOC), Abraka-001, Transit-time*

1. Introduction

Total organic carbon (TOC) is very important consideration in source rock studies, conventional and unconventional, (Crain, 2013). The TOC is very difficult to obtain from the laboratory because of difficulties of sampling and costs of chemicals. Even though sonic logs are also scarce they could be obtained indirectly from rock eval pyrolys is data. The mass of hydrocarbons generated from a petroleum source rock can be calculated by using the following equations

HCG = (HG) (MOG) (1)
HCG = hydrocarbon generated by source rock unit
HG = hydrocarbons generated per gram of organic carbon
HG = HI Original – HI Present (2)
HI = hydrogen index
MOG = (TOC wt%) (FD)(VU) (3)
Where: MOG = mass of organic carbon
TOC = total organic carbon
FD = formation density
VU = volume of unit

1.1. Total Organic Carbon (TOC) and Source Rock

Organic carbon in the form of kerogen is the remnant of ancient life preserved in sedimentary rocks, after degradation by bacterial and chemical processes, and further modified by temperature, pressure, and time. The latter step, called thermal maturation, is a function of burial history (depth) and proximity to heat sources (Cain, 2013). Maturation provides the chemical reactions needed to give gas, oil, bitumen, pyrobitumen, and graphite (pure carbon) that are found while drilling wells for petroleum.Organic carbon is usually associated with shales or siltyshales, but may be present in relatively clean siltstone, sandstone, and carbonate rocks.A source rock is fine grained sediment rich in organic matter that could generate crude oil or natural gas after thermal alteration of kerogen in the Earth's crust.

The oil or gas could then migrate from the source rock to more porous and permeable sediments, where ultimately the oil or gas could accumulate to make a commercial oil or gas reservoir. If a source rock has not been exposed to temperatures of about 100 °C, it is termed a potential source rock. If generation and expulsion of oil or gas have occurred, it is termed an actual source rock. The terms immature and mature are commonly used to describe source rocks and also the current state of the kerogen contained in the rock.

1.2. Sonicor Acoustic Logs

The sonic log provides a formation's interval transit time, designated as Δt (delta-t, the reciprocal of the velocity). It is a measure of the formation's capacity to transmit sound waves. Geologically this capacity varies with lithology and rock texture, notably porosity (Telford, 2004).

Qualitatively, for the geologist, the sonic log is sensitive to subtle textural variations (of which porosity is only one) in both sands and shales. It can help to identify lithology and may help to indicate source rocks, normal compaction and overpressure and to some extent fractures. It is frequently used in correlation (Rider, 2002).

The conventional, general purpose sonic log tools measure the time it takes for a sound pulse to travel between a transmitter and a receiver, mounted a set distance away along the logging tool. The pulse measured is that of the compressional or 'p' wave and tool design enables the velocity of this wave that is, the formation to be measured. The compressional wave is simply fastest of 'first arrival', in which particles vibrates in the direction of the sense of movement. The compressional wave is followed by shear and Stoneley waves which, in the conventional tools, are ignored but in modern array acoustic tools, can be fully measured (Rider, 2002).

1.3. The Sonic Log and Source Rock

Sonic logs show the difference in compaction between organic-lean sediments and source rocks. Sonic logs therefore can be used to determine source rocks quantitatively: a relative decrease in sonic transit time and an increase in resistivity indicate an organic rich layer in non-permeable sediments. Where density logs are affected by rugosity of the borehole wall or presence of pyrite, sonic logs may prove more reliable than density logs. Therefore, it is always useful to make both sonic/resistivity and density/resistivity cross-plots for source rock identification. Because the interval transit time is affected by the water/organic matter ratio, mineral composition, clay content, and grain-to-grain pressure, sonic logs cannot be used alone to estimate the organic content of source rocks. They can be used if correlated with density logs, Meyer and Nederlof, (1984).

1.4. Source Rocks of the Niger Delta

Samples from several wells have been analyzed for their source-rock properties, and were found to be consistently poor. Although samples from a wide variety of depositional environments (ranging from fully marine shales, through marine/paralicshales) were analyzed, not only was the organic content low, but it was of humic and mixed types which are purported to be precursors for gas and light oil, respectively (Evamy et al., 1978).

It has been assumed that the most effective source rocks are the marine shales and the shale interbedded with the paralic sandstones, particularly in the lower part of the paralic sequence where the shales are at least volumetrically more important. Where the 'kitchen' lies well below the top of the continuous shales, any oil generated is considered to have only remote chance of finding its way into the overlying reservoirs, as the faults at depth within the shales are not considered to provide effective migration paths. It is of importance, therefore, to know the facies at and directly above the 'kitchen'.

1.5. Organic Matter in the Niger Delta

Organic matter in Tertiary Niger Delta is mainly a mixtures of types II and III kerogen as defined by pyrolysis, has a high pristine/phytane ratio (> 1%), and are related to the age of the strata and depositional environments (Bustin, 1988). The most significant variation is the decline in mean total organic carbon (TOC) content from late Eocene (2.2% TOC) to Pliocene strata (0.90 TOC) and an associated general decline in pyrolysis-defined hydrogen index (HI) and pristine/phytane ratio. The decrease in TOC and HI in younger strata reflects increase dilution of a nearly constant supply of terrestrial organic matter with the generally higher sedimentation rates of younger strata.

The low pristine/phytane ratio of younger strata may reflect less-oxidizing depositional conditions. The variation in organic matter with depositional depth zones (defined by foramineral assemblages) is significant, although less important than variation due to age. The highest TOC and HI values occur in non-marine swamp, marsh, and floodplain deposits, reflecting proximity to the organic source. Beach, barrier and offshore bar facies have lower TOC and HI values due to selective winnowing of organic matter and greater oxidation.

Bustin (1988), in a study on source-rock on side-wall core and cuttings from Agbada-Akata transition or uppermost Akata Formation, gave TOC contents of sandstone, siltstone, and shale as essentially the same (average of 1.4 to 1.6% TOC).

1.6. Oil and Gas Kitchen

The depth to the top of the present-day oil 'kitchen' and its position in relation to the continuous shales are well known in the Niger Delta. The difference between the eastern and western parts of the delta is striking. Over a large part of the area west of the Niger and Nun Rivers, the top of the oil 'kitchen' lies well above the continuous shales, within the paralic and paralic to marine sequence, Bustin (1988). This pattern results from the paralic sequence being generally thinner over the eastern part of the delta. Of greater significance than the position of oil 'kitchen' today is its position at various times in the past. A reconstruction was made to show the depth to the oil 'kitchen' and its relation to the marine shales at the end of deposition of selected pollen subzone.

1.7. Problem Definition

Currently, the method used to estimate the TOC is the traditional method (laboratory) in the Niger Delta. The difficulties of this method are requirements that involve the use of core or sidewall samples and that samples are collected at discreet points in the borehole.

Bivariate regression to determine the TOC is attempted because it does not require the use of samples.

1.8. Aim and Objectives

1.8.1. Research Aim and Objectives

The aim of this research is to use sonic logs to estimate organic richness (TOC) using bivariate regression.

The objectives are to:

- Source TOC data of the Niger Delta from literature
- Use hypothesis to investigate sonic relationship to TOC
- Use petrel software in the analysis
- Calculate TOC from sonic log
- Validate results

1.9. Materials

The materials used for this research comprise of wells and their location (Figure 1), well intervals, sonic logs for the wells, rockeval pyrolysis data (TOC) and biostratigraphical data, Oil Mining License (OML) and base map**.** The well log data were loaded into petrel 2009 interpretation software for data interpretation.

1.10. Wells, Location and Intervals

Three wells and their locations were selected from Shell Petroleum Development Company (SPDC) Data base, based primarily on availability of rock-eval pyrolysis, sonic data and geological ages (Table 1, Figure 1).

2. Methodology

2.1. Bivariate Regression

The method of analysis of total Organic Carbon (TOC) is bivariate regression analysis on well logs. Bivariate regression analysis is a method whereby a variable, TOC is cross-plotted against another variable, transit time to facilitate comparison of the predicted data to the actual data, Meldelson, (1985).

The analysis commenced with a review of necessary literature on previous works on wells (Figure 1) and Total Organic Carbon, the Niger Delta, facies and source rocks. Then laboratory TOC data gathering was undertaken. After this, availability of geophysical logs was sought at Shell Petroleum and Development Company (SPDC) data base. Available data were loaded into Petrel 2009 software. Well suitability was checked for well logs analysis.

Lithologic analyses were first carried out to separate sands from shales. Then, regression analyses were then performed on the logs to find relationships between the sonic and TOC. TOC was determined from the relationships for each of the wells and each of the logs. Interpretations were done and results were presented.

Total organic carbon (TOC) calculation by bivariate regression depends on geological ages and depositional environments. There are three sections classified according to the depositional environments of Akata, Agbada and Benin Formations of the Niger Delta and age (Figure 2).

Estimation of TOC depends on the availability of rock-eval samples and well logs (Table 1) to classify the deposits and estimate the TOC. With the aid of model curve (Passey et al. 1990) as a guide, the rock-eval data were reorganized. The log characteristics of organic-rich rocks depend mainly on log responses to organic matter and rock matrix. The organic rich rocks with high organic matter contents have the following characteristics (Jia et al. 2012, Prasad et al.2009).

2.2. Estimation of TOC from Sonic Log

The organic matter is the light weight medium that is not conducive to acoustic wave transmission. The acoustic travel time is greater than that of the rock matrix. The organic rich rock has a high acoustic log value (Jia et al., 2012). To estimate TOC from well log, three steps are used. These steps were cross-plot of rockeval and sonic data, removal of the masking effects of lithology and mineralogy and cross-plot of filtered TOC and sonic data.

Sonic logs were available in three wells. These wells are Pologbene-001, Umutu-001 and Ameshi-001, (Table 1).

Laboratory (TOC) data was plotted against sonic log data at Pologbene-001 (Appendix A). Results show that the correlation is very poor (Figure 3).

The equation of the line is:

$$Y = -2.003x + 111.25 \quad (4)$$

where Y is transit-time and X is TOC

R^2 is 0.026 (2.6%). Correlation is very poor.

Coefficient of X is negative 2.003

For Umutu-002 (Appendix B), results show that the correlation is very poor (Figure 4).

The equation of the line is:

$$Y = 0.4189x + 86.757 \quad (5)$$

where Y is transit-time and X is TOC

R^2 is 0.2049 (20%). Correlation is poor.

For Ameshi-001 (Appendix C), results show that the correlation is very poor (Figure5).

The equation of the line is:

$$Y = 1.3919X + 105.31 \quad (6)$$

$R^2 = 0.0086$ (poor correlation)

Table 2 shows that there is no relationship between the rockeval data and sonic log probably due to lithological and mineralogic effects.

The data between TOC and sonic in Table 2A, 2B and 2C had to be re-arranged to agree with the stated hypothesis of Jia et al,(2012), Meyer and Nederl of, (1984), for best combination.

To remove the mineralogical effects, the hypothesis relating organic matter with sonic log response was used. Organic matter is directly related to transit-time (Jia et al., 2002, Meyer and Nederl of 1984). TOC data and transit time data were rearranged to conform to the hypothesis. Firstly, TOC and sonic log data for each well was organized in hundreds. The data points were recorded according to sample depth (Table 3). The final extraction of data was produced in Table 4 to conform to the hypothesis relating TOC with transit-time. The hypothesis states that: the higher the TOC, the higher is the transit-time.

The final step in the analysis is the cross-plot of the filtered TOC wt % and Transit-time in µsec/ft (Table 4).
A plot of TOC in the horizontal axis and Transit-time in the vertical axis is shown Figure 6.
The equation of the line is:

$$Y = 22.557X + 28.522 \quad (7)$$

Y = Sonic (Transit-time)
X = TOC
R^2 = 0.9632 (96.32 % very good).
Coefficient of X is 22.557

3. Validation of Result

Abraka-001 has rock-eval data but no sonic log. Equation 7 was used to calculate the sonic data for the Eocene section (Table 5).

Appendix A and B show the rock eval and sonic data for Pologbene-001 and Umutu-002 wells. The sections presented are the Eocene sections which correlate well with the sonic calculated using equation 7 at Abraka-001 (Table 5).

4. Conclusion

Transit time for Abraka-001 has been calculated from derived equation:

$$Y = 22.557X + 28.522$$

With correlation coefficient of 96.3%. The result is comparable with other sonic data obtain in Eocene section in the Niger Delta.

5. References

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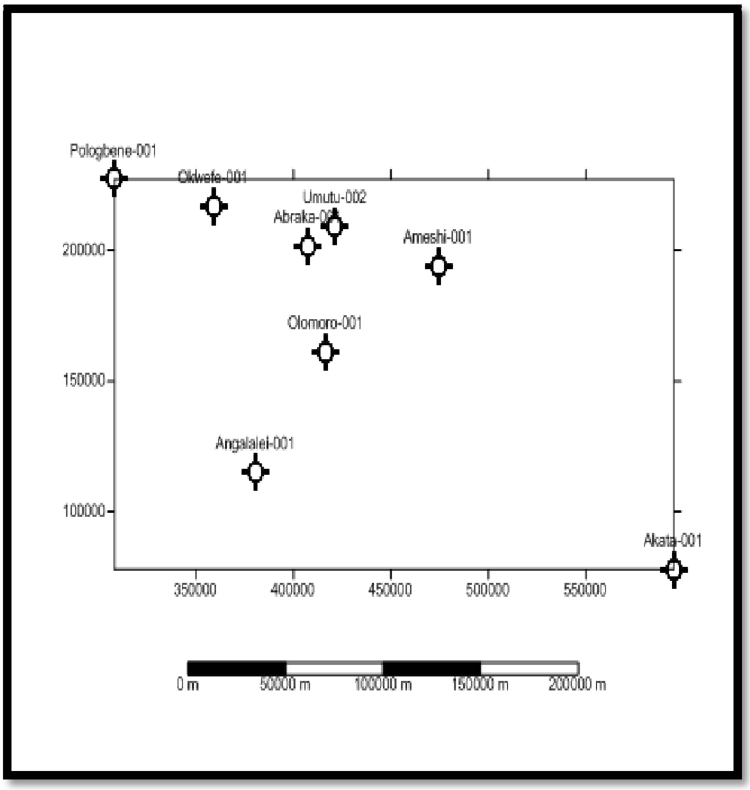

Figure 1: Location of the Wells in the Project Area

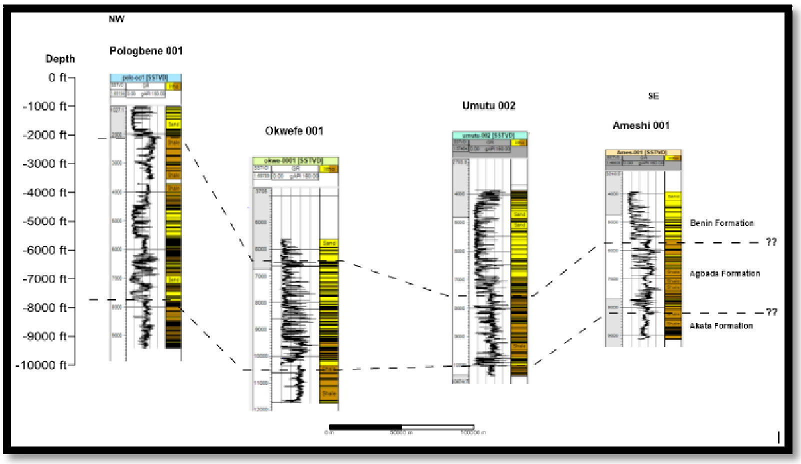

Figure 2: Northwest-Southeast Correlations of Formation.

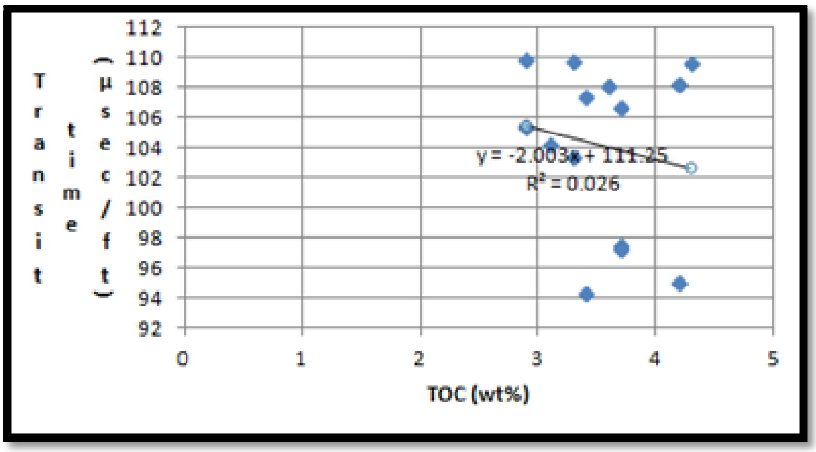

Figure 3: Cross-Plot of Transit-Time against Laboratory (TOC) In Pologbene-001

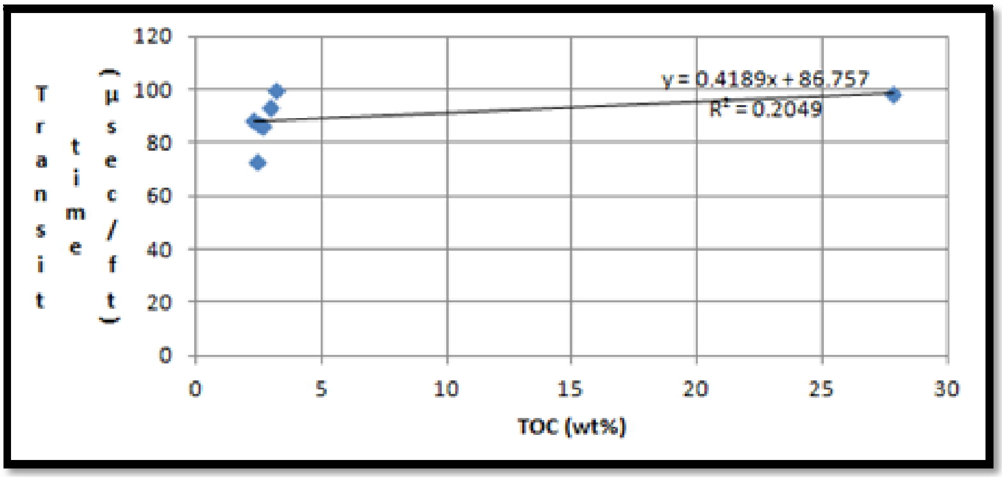

Figure 4: Cross-Plot of Transit-Time against Laboratory (TOC) in Umutu-001

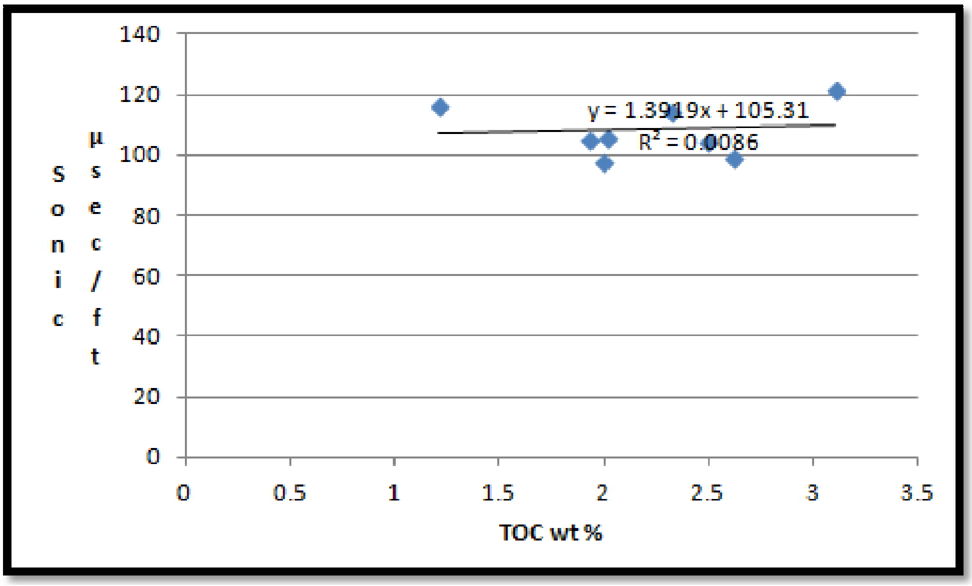

Figure 5: Cross-Plot of Transit-Time against Laboratory (TOC) in Ameshi-001

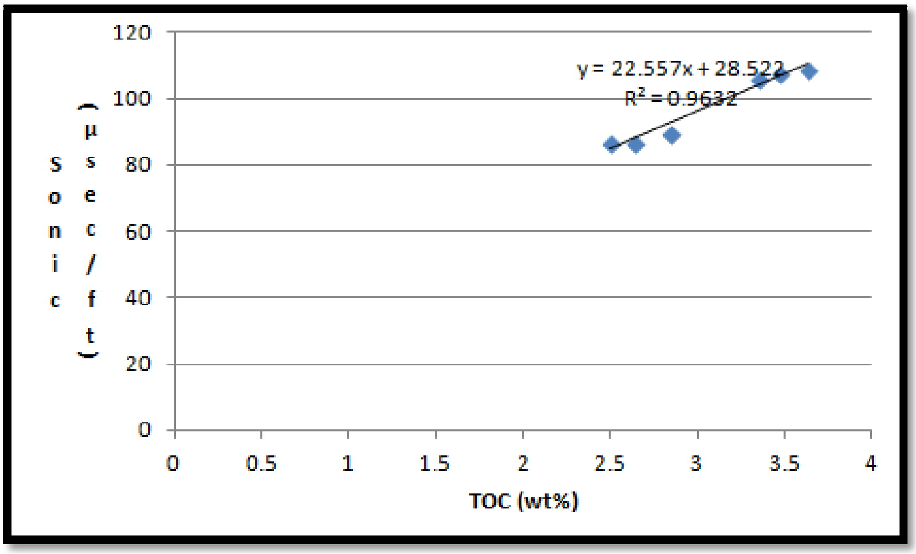

Figure 6: Cross-Plot of TOC against Sonic after Filtering Effects

Well	Dept. range (ft)	Sonic µsec/ft	TOC wt%
Pologbene-001	8930-9330	+	+
Umutu-002	6465-7590	+	+
Okwefe-001	7450-9790	+	ND
Abraka-001	9645-10575	+	ND
Ameshi-001	7237-9191	+	+

Table 1: Materials Used for the Analysis

Pologbene-001		
Depth (ft)	TOC (wt %)	Sonic (µsec/ft)
8900	3.35	106.22
9000	3.75	96
9100	3.47	107.9
9200	3.63	108.8
9300	3.35	105.48

Table 2A: Re-Arranged TOC and Sonic Data at Pologbene-001

Umutu-002		
Depth (ft)	TOC (wt%)	Sonic (µsec/ft)
7400	2.64	86.95
7500	2.84	89.88
7600	2.74	101.77
7700	3.85	96.97
7800	2.85	104.53
7900	2.56	94.5

Table 2B: Re-Arranged TOC and Sonic Data at Umutu-002

Ameshi-001		
Depth (ft)	TOC (wt %)	Sonic (µsec/ft)
7400	2.64	86.95
7500	2.84	89.88
7600	2.74	101.77
7700	3.85	96.97
7800	2.85	104.53
7900	2.56	94.5

Table 2C: Re-Arranged TOC and Sonic Data at Ameshi-001

Data Combination: Pologbene-001, Umutu-002 and Ameshi-001			
Depth	Depth (ft)	TOC (wt%)	Sonic (µsec/ft)
Umutu-002	7300	2.5	87.1
Ameshi-001	7300	1.21	116.88
Umutu-002	7400	2.64	86.95
Umutu-002	7500	2.84	89.88
Umutu-002	7700	3.85	96.97
Umutu-002	7800	2.85	104.53
Umutu-002	7900	2.56	94.5
Ameshi-001	8200	2.61	99.62
Ameshi-001	8600	2.49	104.82
Ameshi-001	8700	3.1	121.64
Pologbene-001.	8900	3.35	106.22
Pologbene-001.	9000	3.75	96
Pologbene-001.	9100	3.47	107.9
Pologbene-001.	9200	3.63	108.8
Pologbene-001.	9300	3.35	105.48

Table 3: Combination of Data from All the Wells

Data Combination: Pologbene-001, Umutu-002 and Ameshi-001		
Depth (ft)	TOC (wt%)	Sonic (µsec/ft)
7300	2.5	87.1
7400	2.64	86.95
7500	2.84	89.88
8900	3.35	106.22
9100	3.47	107.9
9200	3.63	108.8

Table 4: Combination of Data from All the Wells

Abraka-001			
Depth(ft)	Pz	TOC	CAL. SONIC
9645	P480	1.09	53.10913
9675	P480	1.43	60.77851
9705	P480	1.37	59.42509
10230	P480	2.1	75.8917
10261	P480	2.16	77.24512
10290	P480	3.62	110.1783
10320	P480	1.55	63.48535
10350	P480	1.4	60.1018
10380	P480	1.37	59.42509
10425	P480	2.38	82.20766
10470	P480	1.74	67.77118
10500	P480	1.2	55.5904
10530	P480	1.23	56.26711
10575	P480	1.04	51.98128
10920	P470	2.26	79.50082
10950	P470	1.36	59.19952
10990	P470	1.88	70.92916
11010	P470	2.05	74.76385

Table 5: Calculation of Transit Time in Abraka-001

Appendix A

Pologbene-001			
Depth(ft)	Pzone	TOCWt %	Sonicµsec/ft
8930	F5700	3.1	104.26
8960	F5700	3.6	108.18
9000	F5700	3.7	97.57
9030	F5700	4.2	95.09
9050	F5700	3.7	97.41
9090	F5700	3.4	94.46
9110	F5700	4.2	108.34
9150	F5700	3.3	109.83
9180	F5700	2.9	105.42
9200	F5700	3.7	106.71
9240	F5700	2.9	109.99
9260	F5700	4.3	109.68
9300	F5700	3.4	107.50

Appendix B

Umutu-002			
Depth (ft)	Pzone	TOC Wt %	Sonic µsec/ft
6465	P470	27.80	11.75
7365	P470	2.5	24.63
7410	P470	3.17	11.16
7440	P470	2.41	18.72
7450	P470	2.33	20.3
7560	P470	2.69	15.41
7590	P470	2.99	13.11

Appendix C

Ameshi-001			
Depth (ft)	Pzone	TOC Wt %	Sonic µsec/ft
7237	F5700	2.0	106.28
7376	F5700	1.21	116.88
7596	F5700	1.99	97.94
8276	F5700	2.61	99.62
8674	F5700	2.49	104.82
8744	F5700	3.1	121.64
9142	F5700	2.32	114.52
9191	F5700	1.92	105.31