GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 7, NO. 1 JANUARY 2001: 103 - 109
 ISSN 1118-0579

ORGANIC MATTER EVALUATION OF THE NKPORO SHALE, ANAMBRA BASIN, FROM WIRELINE LOGS

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(Received 8 September, 1999; Revision accepted 9 March. 2000)

ABSTRACT

A modified form of Schmoker's formation density log technique has been used in evaluating the total organic carbon content TOC of the continuous shale sections of the Nkporo Shale in three exploratory wells (Alade - 1, Anambra River - 1, and Anambra River - 3) in the Anambra Basin. Weight percent TOC was found to range from 0.2 - 4.9%; with an average of 2.8% in Alade - 1 well; 0.2 - 4.3%, with an average of 1.8% in the Anambra River - 1 well; and 0.2-5.3%, with an average of 3% in the Anambra River - 3 well. The average TOC values obtained in this study are similar to the average TOC values obtained from organic geochemical analysis of the Nkporo Shale in the Anambra Basin, the Afikpo Syncline, and the Calabar Flank.

Crossplots of the formation density and the gamma ray logs show a generally positive correlation between them; although a few intervals have high gamma ray values corresponding with low formation density. The positive correlation between the formation density and the gamma ray logs suggests a dominantly terrestrial source for the organic matter. Intervals with low formation density (high TOC) corresponding with high gamma ray values are interpreted as source beds with significant marine organic matter.

Keywords: *Organic carbon, wireline logs, source rocks, shale, basins.*

INTRODUCTION

A series of organic geochemical studies have been conducted both on outcrop and subsurface samples of shales in the southern Benue Trough and the Anambra Basin to assess their source rock characteristics. The Eze-Aku Formation (*Turonian*), the Awgu Shale (*Turonian-Coniacian*), and the Nkporo Shale (*Campano-Maastrichtian*) have received most of the attention (Agagu and Ekweozor, 1982; Petters and Ekweozor, 1982; 1982b; Unomah and Ekweozor, 1987, 1993; Akande and Viczian, 1996; Akaegbobi and Schmitt, 1998). The studies indicate that the sediments contain total organic carbon content (TOC) above the threshold value of 0.5 weight per cent for source rocks with the highest TOC values recorded from the Nkporo Shale.

Although organic geochemical analyses are very important in the identification and characterisation of source rocks, they are expensive, time consuming and are subject to the problems of sampling bias. Consequently researchers have developed new techniques involving the use of wireline logs, for the rapid assessment of the organic content of sedimentary rocks in frontier basins (Schmoker 1979, 1980; Schmoker and Hester, 1983; Meyer and Nederlof, 1984; Hester *et. al.*, 1990). Wireline logs are more readily available and the continuously recorded data eliminates the problem of limited samples and sampling bias. In this study the organic carbon content of the Nkporo Shale is estimated using a modified form of the formation density log technique formula, first developed by Schmoker (1979). The technique is hinged on the premise that, shales with a similar degree of compaction, are likely to have equal water saturation; therefore variations in density would be a function of the amount of organic matter present (Schmoker, 1979, Meyer and Nederlof, 1984).

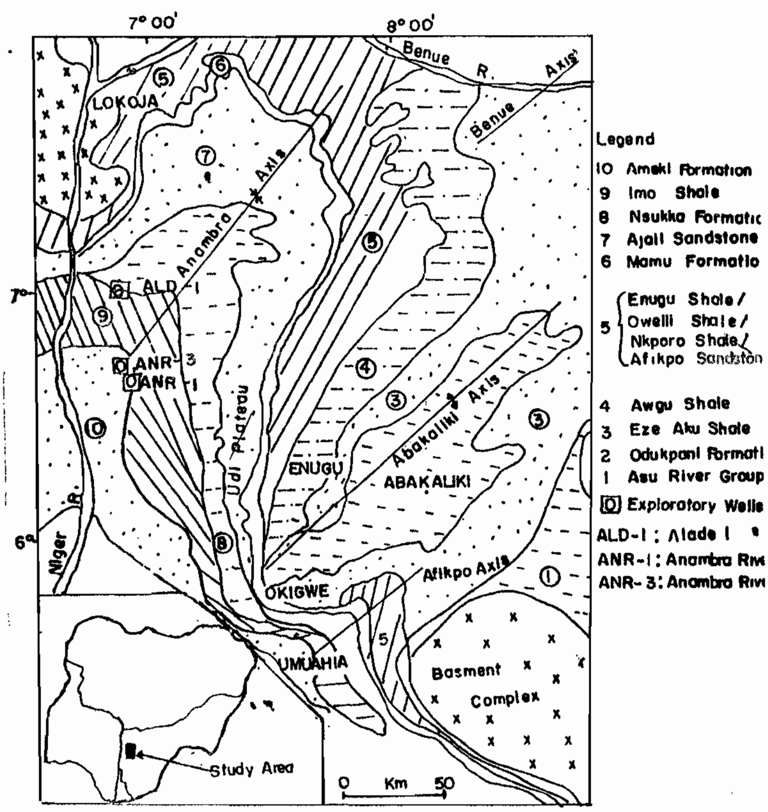

Fig. 1 Generalized Geologic Map of Southeastern Nigeria indicating location of Wells in this study. (Modified after Geological survey of Nigeria)

GEOLOGIC SETTING

The Anambra Basin is one of the onshore sedimentary basins in Southern Nigeria. It is located at the southern tip of the NE-SW trending Benue Trough

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(*aulacogen*), and bounded in the south by the Niger Delta. The Benin Hinge line, and the Abakaliki Anticlinorium bound it to the southwest and east respectively (Fig. 1). The basin is about 300km long and the width varies from about 40-160km. In pre-Santonian time (*Albian-Coniacian*) the Anambra Basin was a platform area bordering the Benue Trough in the southwest. But following the Santonian - Early Campanian tectonism, the Benue Trough was folded and uplifted to form the Benue Abakaliki fold belt (Murat, 1992; Hoque and Nwajide, 1985) and the Anambra platform was downwarped to form the Anambra Basin. A smaller structural depression, the Afikpo Syncline also developed on the southeast of the Abakaliki uplift.

The Campano - Maastrichtian Nkporo Shale is the oldest lithostratigraphic unit deposited in the Anambra Basin and the Afikpo Syncline. It oversteps outcrops of the Awgu Shale, Eze-Aku Shale and the Asu River Group (Petters, 1978; Whiteman, 1982). The formation consist mainly of blue or dark grey to black shales with occasional thin beds of sandy shale, and sandstone, although the formation becomes increasingly arenaceous in parts of the Anambra Basin where it passes into sandy lateral equivalents such as Otobi Sandstone in the north, and Owelli Sandstone in the south (Reyment, 1965; Whiteman, 1982; Agagu, *et al.* 1985). Deposition of the sediments occurred in a shallow marine environment during the late Campanian to Maastrichtian transgression (Reyment 1965). Overlying the Nkporo Shale is a Maastrichtian - Danian deltaic sequence made up of the Mamu Formation, the Ajali Sandstone, and the Nsukka Formation (Petters, 1978).

MATERIALS AND METHODS

Data for this study were obtained from three exploratory wells in the Anambra Basin namely: Alade - 1, Anambra River - 1, and Anambra River - 3, (Fig. 1). The data consist of formation density (ρ), Gamma ray (λ), and resistivity (Ω) logs.

The method of study is outlined below.

1. Density, gamma ray, and resistivity values were averaged over 20ft intervals in the Anambra River - 1 and the Alade - 1 wells which are calibrated in feet while they were averaged over 10m intervals in the Anambra River - 3 well, which is calibrated in metres.
2. The formation density if the sediment is barren of organic matter(ρB) was determined for each well by examining the formation density log and identifying the most dense shale intervals which are assumed to contain negligible amounts of organic matter.
3. The wt% totalorganic carbon (TOC) is determined quantitatively by using a modified form of Schmoker (1979) formula derived in this study (see appendix for details):

$$TOC(WT\%) = \frac{100(\rho B - \rho E)}{1.7\rho E} \quad = \text{(formula A)}$$

Where

ρB = density of shale when there is no organic matter

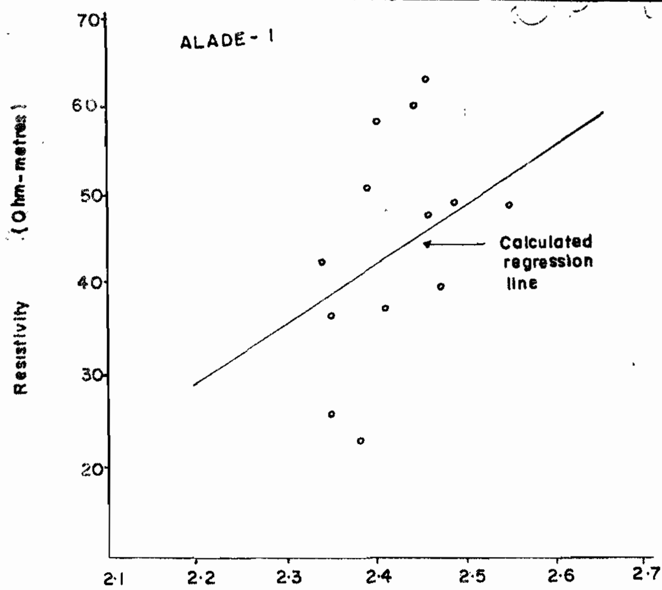

Fig. 2: Formation Density (Gm/cc)

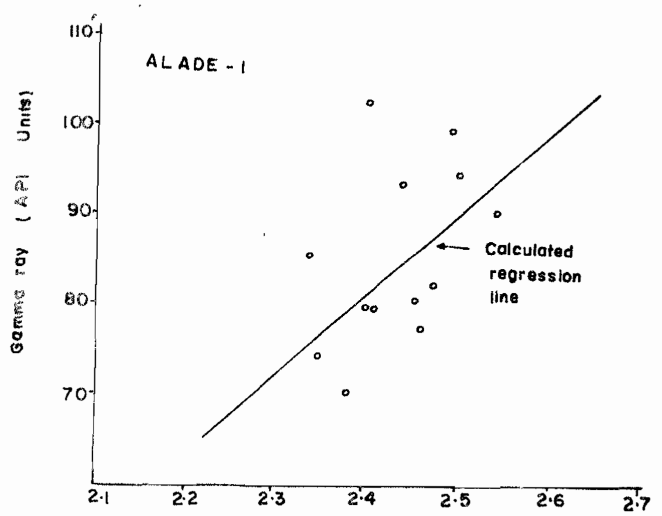

Fig. 3: Formation density (Gm/cc)

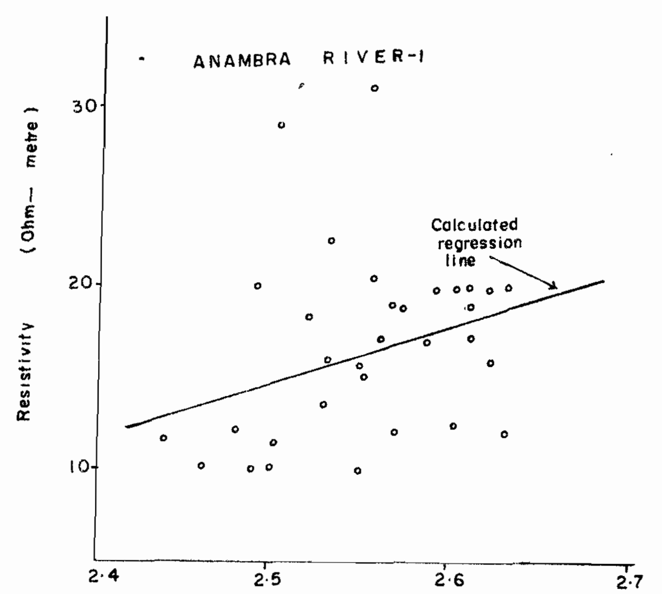

Fig. 4: Formation Density (Gm/cc)

ρF = density of shale for the sample interval.

1.70 = a constant for shale with mineral matter density of 2.7gm/cc (Rider, 1991).

Table 1 Data and calculated TOC for Anambra River - 1

Sample No.	Depth (Ft)	ρ	γ	Ω	TOC
1	5940	2.55	77	15.00	2.0
2	5960	2.55	78	15.50	2.0
3	5980	2.53	72	22.50	2.5
4	6000	2.49	75	10.00	3.3
5	6020	2.46	75	10.00	4.3
6	6040	2.48	81	12.00	3.5
7	6060	2.50	82	11.60	3.0
8	6080	2.44	85	11.50	4.7
9	6100	2.53	88	13.50	2.5
10	6120	2.56	91	20.50	1.8
11	6140	2.57	92	19.00	1.5
12	6160	2.56	102	16.50	2.0
13	6180	2.49	101	20.00	3.3
14	6200	2.55	99	10.00	2.0
15	6220	2.57	92	12.00	1.5
16	6240	2.62	75	16.00	0.5
17	6260	2.58	78	17.00	1.3
18	6280	2.52	81	18.50	2.7
19	6300	2.62	88	20.00	0.5
20	6320	2.61	87	20.00	0.7
21	6340	2.61	90	19.00	0.7
22	6360	2.61	81	17.50	0.7
23	6380	2.60	87	20.00	0.9
24	6400	2.57	84	19.00	1.5
25	6420	2.57	80	19.00	1.5
26	6440	2.59	81	20.00	1.1
27	6460	2.63	96	20.00	0.1
28	6480	2.55	113	31.00	2.0
29	6500	2.53	98	16.00	2.6
30	6520	2.63	97	12.00	0.2
31	6540	2.63	94	20.00	0.2
32	6560	2.50	88	29.00	3.0
36	6640	2.60	81	12.50	0.9
37	6660	2.50	75	10.00	3.0
38	6680	2.54	78	10.00	2.10
Average		2.56	86.31	16.31	1.83

ρB 2.64

■ Source beds with significant marine organic.

Table 2 Data and Calculated TOC for Alade - 1

Sample No	Depth (Ft)	ρ	γ	Ω	TOC
1	2260	2.44	93	60	2.5
2	2280	2.47	82	40.00	1.8
3	2300	2.35	74	36.92	4.7
4	2320	2.38	70	23.00	3.9
5	2340	2.35	63	26.15	4.7
12	2480	2.41	79	37.69	3.0
13	2500	2.46	77	47.69	2.0
14	2520	2.40	79	58.46	3.3
17	2580	2.45	80	62.69	2.1
19	2620	2.39	102	50.76	3.5
21	2660	2.34	85	43.07	4.9
22	2680	2.50	94	44.62	1.1
25	2740	2.54	90	42.31	0.2
28	2800	2.49	99	49.23	1.3
Average		2.43	83.35	44.47	2.79

ρB = 2.55

■ Source beds with significant marine organic matter

The effect of pyrite is not accounted for in this formula because it occurs in traces in the Nkporo Shale. For formations in which pyrite occurs in significant amounts, the formula will be

$$TOC(WT\%) = \frac{100(\rho B - \rho E)}{1.38\rho E} \quad = \text{(formula B)}$$

Where 1.38 is a constant for shale with significant pyrite and mineral matrix density of 2.70gm/CC.

TOC values obtained by using formula (B) are 20% higher than values obtained by using formula (A).

4. Formation density and gamma ray, and formation density and resistivity; were statistically analysed

Table 3 Data and Calculated TOC for Anambra River - 3

Sample No.	Depth (m)	ρ	λ	Ω	TOC
1	1810 ■	2.54	92	3.30	3.9
2	1820	2.59	83	5.40	2.7
3	1830	2.50	82	4.30	4.9
4	1840	2.52	83	3.60	4.4
5	1850	2.54	82	4.00	3.9
6	1860	2.53	77	3.60	4.3
7	1870	2.49	75	2.40	5.2
8	1880	2.52	72	2.35	4.4
9	1890	2.49	74	2.55	5.2
10	1900	2.48	77	2.70	5.3
11	1910	2.52	84	2.60	4.4
12	1920	2.53	89	2.55	4.3
15	1950	2.70	112	3.70	0.2
16	1960	2.64	104	3.70	1.5
17	1870	2.67	109	5.40	0.9
18	1980	2.70	109	4.20	0.2
20	2000	2.66	106	4.70	1.1
21	2010	2.66	103	6.30	1.1
22	2020	2.68	107	4.00	0.7
23	2030	2.62	98	6.30	2.0
24	2040	2.65	97	4.15	1.3
25	2050	2.64	95	5.00	1.5
26	2060	2.69	81	3.80	0.5
27	2070	2.62	90	2.65	2.0
28	2080	2.62	82	3.70	2.0
29	2090	2.55	87	3.00	3.5
30	2100	2.68	93	3.10	0.7
31	2110	2.57	87	2.85	3.0
32	2120	2.59	91	2.75	2.7
33	2130	2.59	93	3.40	2.7
34	2140	2.60	96	5.40	2.5
35	2150 ■	2.50	97	3.70	4.5
36	2160 ■	2.57	96	2.80	3.0
37	2170 ■	2.55	99	3.10	3.5
38	2180	2.52	82	2.65	4.4
39	2190	2.64	84	3.00	1.5
40	2200	2.64	87	3.20	2.1
41	2210	2.51	85	1.90	4.7
42	2220	2.55	89	2.00	3.5
43	2230	2.61	87	3.20	2.1
44	2240 ■	2.56	91	2.65	3.3
45	2250	2.58	91	2.85	2.8
46	2260	2.63	85	2.80	4.3
47	2270	2.60	86	2.35	2.5
48	2280	2.52	86	2.25	4.4
49	2290	2.55	88	2.20	3.5
50	2300	2.55	87	2.55	3.5
51	2310 ■	2.56	91	2.20	3.3
52	2320 ■	2.54	94	2.30	3.9
53	2330	2.60	88	2.20	2.5
54	2340	2.60	87	2.15	2.5
55	2350	2.59	87	2.30	2.7
56	2360 ■	2.56	90	2.20	3.3
57	2370	2.54	87	1.80	3.9
58	2380	2.58	85	1.9[illegible]	2.8
59	2390	2.55	85	2.25	3.5
60	2400	2.53	83	2.65	4.3
Average		2.58	89.72	3.20	2.97

ρB = 2.71

■ Source beds with significant marine organic matter

and plotted respectively to examine the relationship between these parameters and to understand the nature of the source rocks.

RESULTS

Averaged log values (ρ, λ, Ω) and computed wt% organic carbon from the formation density logs are shown in Tables 1, 2, and 3 for wells Alade - 1, Anambra River - 1, and, Anambra River - 3, respectively. A total of 176.8m (520ft) of section was sampled in the Alade - 1 well; TOC values ranged from 0.2 - 4.9 wt% with an average of 2.8wt%. From Anambra River-1

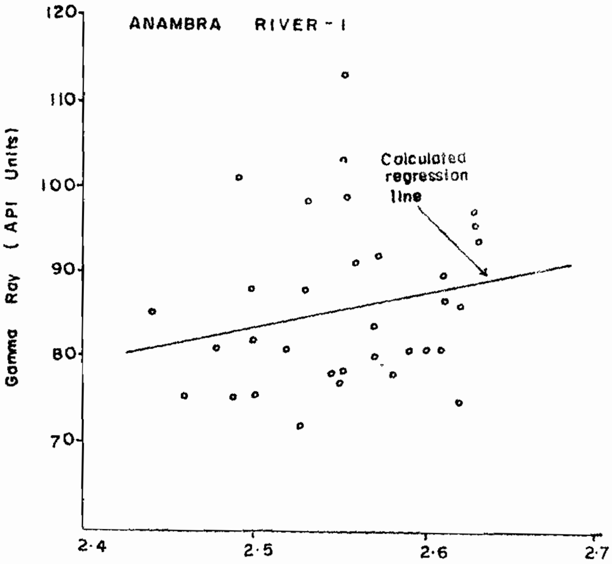

Fig. 5 : Formation density (Gm/cc)

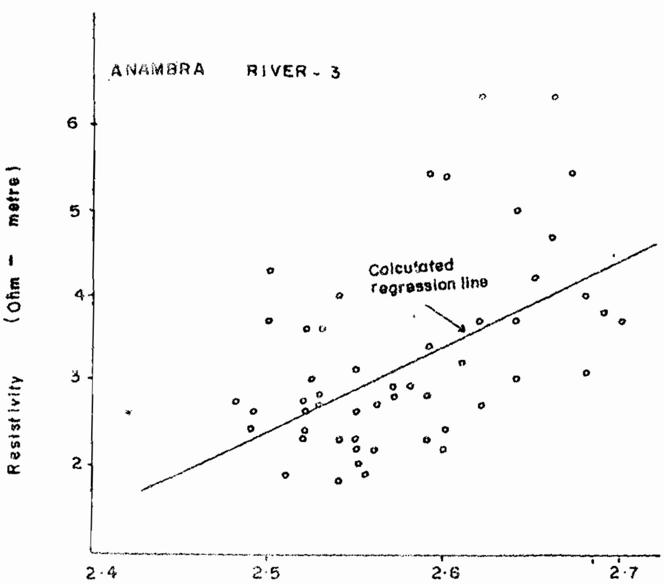

Fig. 6: Formation Density (Gm/cc)

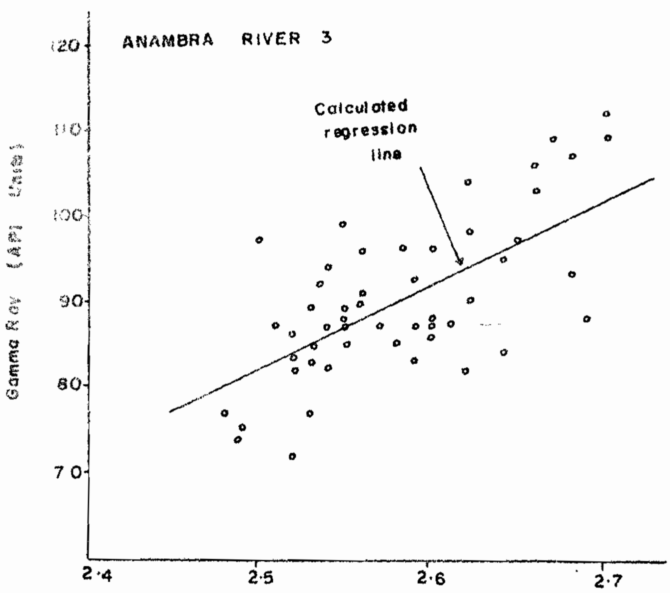

Fig. 7: Formation density (Gm/cc)

well, 228.6m (750ft) of section was sampled, TOC values ranged from 0.2-4.3 wt% with an average of 1.8wt%. The total section sampled in Anambra River-3 well is 600m; TOC values ranged from 0.2 - 5.3wt% with an average of 3.0wt% (Tables 4 and 5).

Crossplots of density and gamma ray, and density and resistivity indicate a generally positive correlation between density and the two other parameters (Figs. 2, 3, 4, 5, 6 and 7), Coefficient of correlation values range from very low in Anambra River - 1 to moderate in Alade - 1 and good in Anambra River - 3 for density and gamma ray. The coefficient of correlation ranges from very low in Anambra River - 1, to low in Alade - 1 and moderate in Anambra River - 3 for density and resistivity. A few intervals in each well deviate from the general trend obtained from crossplots. These intervals have higher than average gamma ray and resistivity values corresponding to low formation density, and higher than average TOC values.

DISCUSSION AND CONCLUSION

The average TOC values obtained in this study, which range from 1.8 - 3.0wt% for the three wells is well above the minimum TOC of 0.5wt% required for source rocks (Dow, 1978). The values are also similar to the results obtained from various organic geochemical analyses in the Anambra Basin, Afikpo Syncline, and the Calabar Flank (Agagu and Ekweozor, 1982; Unomah and Ekweozor, 1993; Akaegbobi and Schmitt, 1998; Table 4). Nwachukwu and Chukwura (1986) in their study of the organic matter of the Agbada Formation also applied the formation density technique, in addition to organic geochemical analysis and obtained TOC values that agreed to plus or minus 20% of organic geochemical results in the Abiteye - 13 well, in the Western Niger Delta.

The generally positive correlation between formation density and gamma ray, and between formation density and resistivity, indicates that there is no significant resistivity or gamma ray anomaly due to the organic carbon content of the shales. The observed resistivity and gamma values were thus a function of shale density. Furthermore the positive correlation between formation density and the gamma ray logs may be indicative of a dominantly terrestrial source for the organic matter. Marine sourced organic matter is usually enriched in uranium because of the absorption of uranium ion by marine plankton (Meyer and Nederloff, 1984; Rider, 1991). Consequently source rocks with significant marine organic matter have higher gamma ray values corresponding with the low density of the source rocks. The organic matter in the Nkporo Shale is therefore concluded to be dominantly terrestrial. The intervals in the three wells with high gamma ray values, corresponding to low density and high TOC values are interpreted as source beds or condensed sections with significant marine organic matter representing periods of marine flooding and sediment starvation in the basin (Emery and Myers, 1996). Organic geochemical analyses by previous workers indicate that the Nkporo Shale organic matter is dominantly terrestrial in the Anambra basin, and the Afikpo syncline with the latter containing a higher

Table 4 Log derived TOC values for the three wells studied

WELL	AVERAGE TOC WT%	TOC RANGE	Range of Average TOC for the three wells.
Alade - 1	2.8	0.2 4.9	
Anambra River 1	1.8	0.2 4.3	1.8 3.0
Anambra River 3	3.0	0.2 5.3	

Table 5 TOC values obtained from organic geochemical analysis for Nkporo Shale compared with log derived average value

AUTHOR/BASIN	ANAMBRA BASIN	AFIKPO SYNCLINE	CALABAR FLANK
Unomah and Ekweozor (1993)	0.7 2.5	1.4 2.0	1.3 2.9
Agagu and Ekweozor (1982)	2.0		
Akaegbobi and Schmitt (1998)	1.6 - 3.76		
Elf Report	1 3.0		
This Report	1.8 - 3.0		

Table 6 Statistical Analysis Summary

Well	Interval Sampled and Thickness	No. of Samples (N)	Cross-Plotted Parameters	Covariance	Coefficient of Correlation	Regression line	Remarks
Alade 1	2260 2840ft (580ft) (176.8m)	14	γ vs ρ	0.33	0.51	γ = 90.56ρ-136.51	Moderate Correlation
		14	Ω vs ρ	0.23	0.34	Ω = 64.17ρ-111.46	Low Correlation
Anambra River 1	5940-6700ft (750ft) (228.6m)	35	γ vs ρ	0.09	0.20	γ = 36.15ρ-6.23	Very Low Correlation
		35	Ω vs ρ	0.07	0.29	Ω = 28.46ρ-56.12	Very Low Correlation
Anambra River-3	1810 2410m (600m)	57	γ vs ρ	0.35	0.69	γ = 102.66ρ-176.12	Good Correlation
		57	Ω vs ρ	0.03	0.51%	Ω = 9.52ρ-21.36	Moderate Correlation

proportion of marine derived organic matter (Agagu and Ekweozor, 1982; Unomah and Ekweozor,1987; Akaegbobi and Schmitt, 1998).

Although source rock analysis from wireline logs is a promising area of research, the techniques are still being developed. Integrated studies involving both wireline and geochemical data will be needed to fully assess the applicability of the techniques to the Anambra basin, and other frontier basins in Nigeria. This paper is therefore an attempt to stimulate interest in this vital area of research.

ACKNOWLEDGEMENT

We are grateful to ELF Nigeria Limited for supplying the data used in this study.

APPENDIX

Formula for Converting Volume Percent (Vol %) Organic Carbon into Weight Percent (Wt %) Organic Carbon

If we take a cube of sediment with side T and volume V_S, then: $V_S = T^3$ 1

If volume percent (vol %) organic carbon in the cube is V_{PC}, then volume of organic carbon (V_C)

$$= \frac{T^3}{100} V_{PC} \quad \ldots\ldots\ldots\ldots \quad 2$$

Mass of organic carbon in the cube (M_C) = $V_C \rho C$ 3

where ρC = density of organic matter (approximattely 1.0)

Mass of sediment (M_S) = $T^3 \rho F$ 4

where ρF = formation density

Weight percent total organic carbon (wt% TOC) =

$$\frac{100 M_C}{M_S} \quad \ldots\ldots\ldots\ldots \quad 5$$

Substituting for V_C in equation (3), $M_C = \frac{T^3 \rho C V_{PC}}{100}$ 6

Substituting for M _ and M_C in equation 5;

$$\text{wt\% TOC} = \frac{V_{PC}\rho C}{\rho F} \qquad = \frac{V_{PC}}{\rho F} \quad \ldots\ldots \quad 7$$

According to Schmoker (1979) the fractional volume (θ_o) of organic matter is related to the formation density thus:

$$\theta_o = \frac{\rho B - \rho F}{1.38} \quad \ldots\ldots\ldots\ldots \quad 8$$

where θ_o = fractional volume of organic matter

ρB = density of the formation when there no organic matter; this is taken to the most dense shale interval.

ρF = formation density

1.38 = constant for shale with mineral matr density of 2.7gm/cc. The formula tak into account the effect of pyrite formation density. When the effect pyrite is negligible it becomes

$$\theta_o = \frac{\rho B - \rho F}{1.70} \quad \ldots\ldots\ldots\ldots$$

Volume percent organic matter

$$(V_{PC}) = 100\theta_o = 100 \frac{(\rho B - \rho F)}{1.70} \quad \ldots\ldots\ldots\ldots\ldots 10$$

Therefore substituting for V_{PC} in equation 7;

$$\text{TOC (wt\%)} = 100 \frac{(\rho B - \rho F)}{1.70\rho F} \quad \ldots\ldots \text{ 11 a (formula A)}$$

This is the formula used in estimating the weight percent organic carbon content of the Nkporo Shale in this study.

For formation in which pyrité occurs in significant amount the appropriate formula is:

$$\text{TOC (wt\%)} = 100 \frac{(\rho B - \rho F)}{1.38\rho F} \quad \text{11 b (formula B)}$$

TOC values obtained by using formula B are twenty percent higher than values obtained using formula A.

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