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RESEARCH ARTICLE

CORRELATION ANALYSIS BETWEEN SONIC AND DENSITY LOGS FOR POROSITY DETERMINATION IN THE SOUTH-EASTERN PART OF THE NIGER DELTA BASIN OF NIGERIA

Horsfall, O. I., Omubo-Pepple[1], V. B. and Tamunobereton-ari, I.

Department of Physics, Rivers State University of Science and Technology, 500001, Port Harcourt, Nigeria

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ABSTRACT

This paper reports comparative analysis of porosity values computed from sonic and density logs obtained from the same wells. Two well logs (sonic and density) acquired from OML X were digitized and analyzed for porosity. Results obtained showed that velocity and bulk density increases with depth due to compaction of rocks and the porosity values obtained from the two oil wells decreases with depth. Porosity values obtained at various depth from both sonic and density logs were subjected to statistical analysis using standard deviation and coefficient of variation, which shows that, for well log A, the coefficient of variation for sonic log derived porosity and density log derived porosity were 30% and 50% respectively. Similarly, for well B, the coefficient of variation for sonic log derived porosity and density log derived porosity became 29% and 37% respectively. From the principle of statistical analysis the coefficient of variation with lower value is preferred hence the result shows that sonic log would be more reliable than density log in the computation and determination of formation rock porosity.

Key words: Porosity, rock matrix, standard deviation, coefficient of variation, sonic log, density log

INTRODUCTION

Geophysical well logging is the process of continuously recording of geophysical and petrophysical parameters such as porosity, permeability, lithology, water saturation etc (Avseth, Mukerji and Mavko 2005; Dewan 1983; Edward and Srivastava 1989; Telford *et al*., 1978). Advances in the study of these petrophysical parameters have lead to an enhanced formation evaluation capabilities, identification and quantification of hydrocarbon resources in the subsurface, evaluation of fluid and rock properties, reservoir characterization (Etu-Efeotor 1997; Murray *et al.*,1975; Prem 1997; Sheriff 1991). Porosity is one of these petrophysical parameters of study which is the amount of the fraction or the fraction of the total volume of rock (formation) occupied by pores or voids. It indicates how much fluid a rock can hold (Dewan 1983; Schlumber 2000; Tittman, Wahl 1965). Almost all oil and gas produced comes from the accumulations of the pore spaces of reservoir rocks. The quality and performance of the reservoir rocks depends on certain characteristics and properties; These properties include porosity (ϕ), permeability (k), grain size, grain shape, degree of compaction, amount of matrix, cement composition, type of fluid present and saturation of different units, of these porosity, permeability and saturation are the most prominent (Wyllie 1963).

METHODOLOGY

Data from two exploratory well logs A and B from multinational oil company operating within the Niger Delta was used for this research. Determination of porosity values was achieved by digitizing the sonic and density logs. Travel times and bulk densities were digitized every 10 meters interval to the bottom of the wells A and B. Porosity from sonic and density log can be computed for clean and consolidated formations with uniformly distributed small pores using the following equations.

Sonic log - Derived Porosity

The sonic tool measures the time it takes sound pulses to travel through the formation $(\Delta t_{\log})$. This time is referred to as the interval transit time, or slowness and it is the reciprocal of velocity of the sound wave. The interval transit time of a given formation is dependent on the Lithology elastic properties of the rock matrix, the property of the fluid in the rock, and porosity (Dewan 1983; Edward, Srivastava 1989; Keary, Brooks and Hill 2002; Moriss H. DeGroot 1975). Therefore a formation's matrix velocity must be known to derive sonic porosity either by chart or by using formula. The unit of $\Delta t_{\log}$ is usually in µs/ft or µs/m (microseconds per foot or/per metre) and the logs are normally recorded on track 3, on a linear scale. Integrated sonic logs can also be useful in interpreting seismic records, and can be very invaluable in the time to depth conversion of seismic data. Wyllie *et al*. (Avseth, Mukerji and Mavko 2005; Dewan 1983; Edward, Srivastava 1989; Prem 1997) proposed that the interval transit time (Δt) can be represented as the sum of the transit time in the matrix fraction (Δt_{ma}) and the transit time in the liquid fraction (Δt_f) thus

[1] ***Corresponding author*:** omubopepple@yahoo.com

$$\Delta t = (1-\phi_s)\Delta t_{ma} + \phi \Delta t_f \quad (1)$$

Re arranging eq. 1

$$\phi_s = \frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \quad (2)$$

In Eq. (2), ϕ_s = sonic-derived porosity; Δt =Acoustic transit time digitized from the sonic log in µs/ft Δt_f = Fluid transit time (189µS/ft); and Δt_{ma} = Transit time for the rock matrix (55.5µs/ft).

Density log - Derived Porosity

The density log records a formation's bulk density. This is essentially the overall density of a rock including solid matrix and the fluid enclosed in the pores. The log is scaled linearly in bulk density (g/cm^3) and includes a correction curve that indicates the degree of compensation applied to the bulk density data. Density logging is based on the physical phenomenon of gamma ray scattering as a function of the bulk density of an environment irradiated by a gamma ray source. The density log can be used quantitatively, to calculate porosity and indirectly to determine hydrocarbon density. It is also useful in calculation of acoustic impedance. Qualitatively, it is useful as a Lithology indicator, as well as identification of certain minerals, assessment of source rock organic matter content and identification of overpressure and fracture porosity. The formation bulk density is related to formation matrix density (ρ_{ma}) *and* formation fluid density (ρ_f) as:

$$\rho_b = (1-\phi)\rho_{ma} + \phi \rho_f \quad (3)$$

Re-arranging eq (3)

$$\phi_d = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (4)$$

where ϕ_d = density-derived porosity; ρ_{ma} = matrix density (2.648); ρ_b = bulk density (clean liquid filled formation); and ρ_f = fluid density (0.89). The porosity data obtained from density logs are considered to be total porosity.

RESULTS AND DISCUSSION

Numerical data obtained from the two wells are given by Tables 1 and 2 showing the depth, interval travel times, bulk densities, sonic-derived and density-derived porosities. Figures 1 to 6 showed trends of decreasing porosity with an increase in depth; attributed to the compactness of formation. Though, these trends are not linear with scattered point; these observations phenomena are perhaps due to changes in lithological characteristics at different depth points. Transit time also decreases with increasing depth; these are shown by Figures 2 and 5. Tables 3 – 6 show the results of the statistical analysis.

Table 1: Depth, Interval Transit time, bulk densities, sonic-derived and density-derived porosity relationship for well A.

Depth(m)	Δt (µs/ft)	ρ_b (g/cm^3)	ϕ_s (%)	ϕ_d (%)
2370	104	2.35	36	18
2380	105	2.38	37	16
2390	90	2.30	26	21
2400	95	2.17	30	29
2410	90	2.23	26	25
2420	100	2.18	33	28
2430	103	2.35	36	18
2440	100	2.30	33	21
2450	95	2.32	30	20
2460	105	2.30	37	21
2470	110	2.30	41	21
2480	90	2.35	26	18
2490	85	2.38	22	16
2500	100	2.40	33	15
2510	110	2.33	41	19
3170	102	2.46	35	12
3180	97	2.43	31	13
3190	78	2.33	17	19
3200	85	2.30	22	21
3210	83	2.25	20	23
3220	83	2.27	20	23
3230	84	2.25	21	24
3240	87	2.22	24	26
3250	83	2.55	20	7
3260	83	2.40	20	15
3270	84	2.42	21	14
3280	85	2.40	22	15
3290	87	2.56	24	5
3300	90	2.53	26	7
3310	82	2.37	20	17
3320	73	2.30	13	21
3330	80	2.55	18	7
3520	93	2.35	28	18
3530	80	2.31	18	20
3540	76	2.35	15	18
3550	80	2.40	18	15
3560	85	2.50	22	9
3570	72	2.40	12	15
3580	80	2.40	18	15
3590	82	2.43	20	13
3600	72	2.50	12	9
3610	82	2.59	20	4
3620	80	2.50	18	9
3630	87	2.42	24	14
3640	82	2.63	20	1
3650	82	2.55	20	6
3660	83	2.60	21	3
3670	92	2.53	27	7
3680	92	2.53	27	7
3690	80	2.40	18	15
3700	80	2.40	18	15
3710	80	2.53	18	7
3720	82	2.62	20	2
3730	80	2.60	20	3
3740	77	2.50	16	9
3750	72	2.37	12	17

Table 2: Depth, Interval Transit time, bulk densities, sonic-derived and density-derived porosity relationship for well B.

Depth(m)	Δt (µs/ft)	ρ_b (g/cm^3)	ϕ_s (%)	ϕ_d (%)
2620	108	2.50	39	9
2630	108	2.35	39	18
2640	93	2.45	28	12
2650	93	2.45	28	12
2660	90	2.35	26	18
2670	83	2.28	21	22

2680	86	2.52	23	8
2690	84	2.32	21	20
2700	82	2.29	20	22
2710	85	2.25	22	24
2720	83	2.20	21	27
3140	85	2.25	22	24
3150	83	2.50	21	9
3160	90	2.37	26	17
3170	100	2.35	33	18
3180	82	2.38	20	16
3190	95	2.35	30	18
3200	87	2.45	24	12
3210	128	1.98	54	41
3220	147	2.20	67	27
3230	100	2.15	33	30
3240	90	2.40	26	15
3250	98	2.33	32	19
3260	105	2.35	37	18
3270	88	2.45	24	12
3280	85	2.40	22	15
3290	100	2.45	33	12
3300	108	2.35	39	18
3310	114	2.30	44	21
3320	110	2.32	41	20
3330	105	2.33	37	19
3340	105	2.40	37	15
3350	103	2.23	36	25
3360	98	2.35	32	18
3370	105	2.29	37	22
3380	108	2.34	39	19
3390	110	2.23	41	25
3400	67	2.53	7	7
3410	84	2.37	21	17
3420	103	2.55	36	6
3430	80	2.39	18	16
3440	80	2.52	18	8
3450	105	2.45	37	12
3460	93	2.33	28	19
3470	100	2.50	33	9
3480	100	2.37	33	17
3490	100	2.42	33	14
3500	103	2.42	36	14

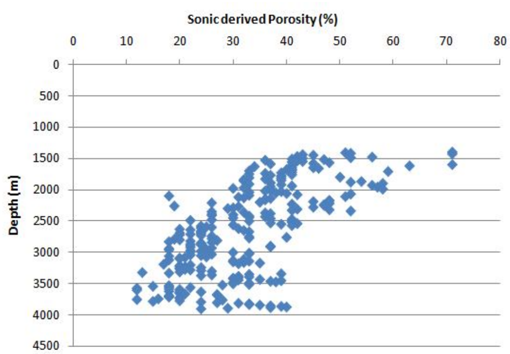

Figure 1: Depth Vs Sonic-Porosity for Well A

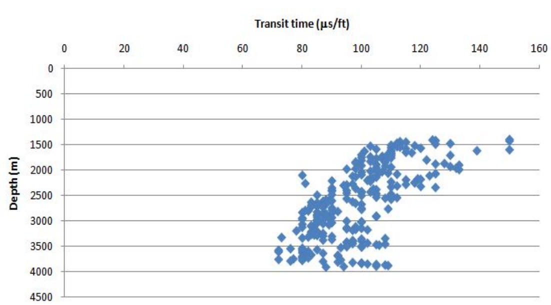

Figure 2: Depth Vs Transit Time for Well A

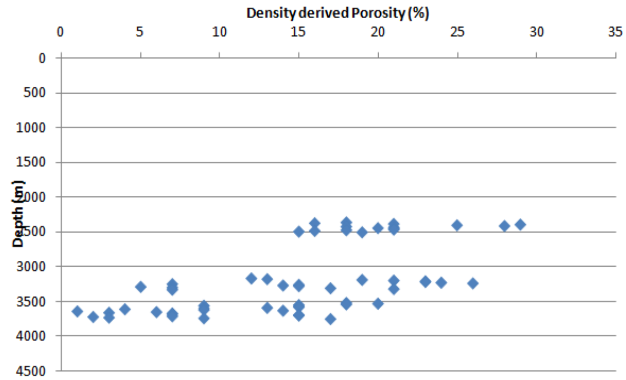

Figure 3: Depth Vs Density Porosity for well A

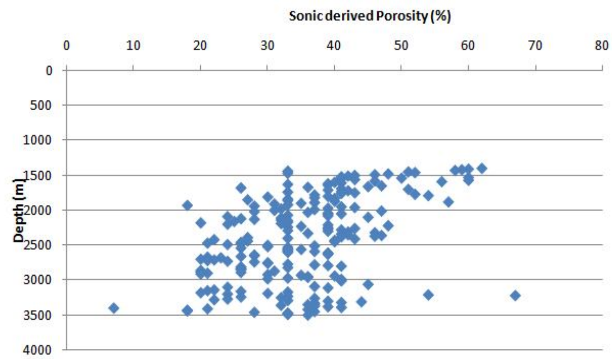

Figure 4: Depth Vs Porosity for well B

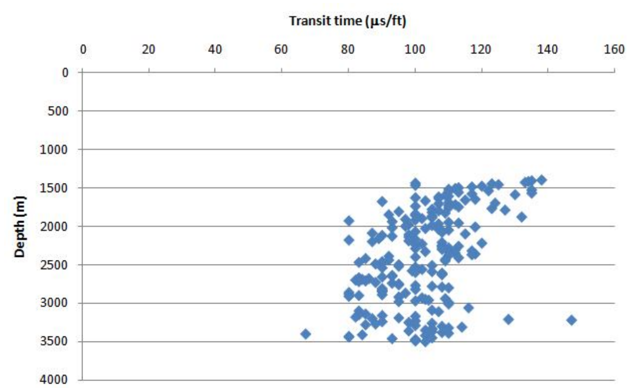

Figure 5: Depth Vs Transit Time for well B

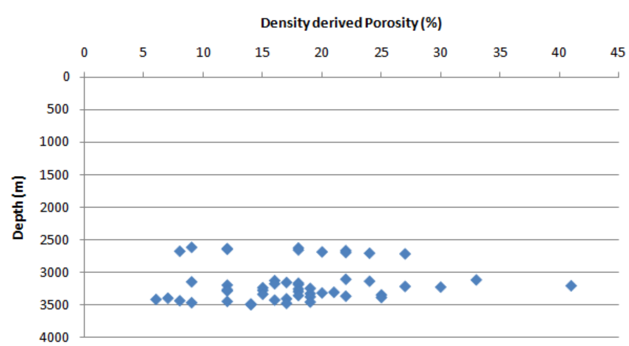

Fig.6: Depth Vs Density Porosity for well B

Table 3: Statistical table showing the calculation of standard deviation for Sonic- derived-porosity for Well A

Class Interval	Frequency	ϕ_s (%)	$F\phi_s$	$\bar{\phi}_s$ (%)	$(\phi_s - \bar{\phi}_s)$ %	$(\phi_s - \bar{\phi}_s)^2$ %	$F(\phi_s - \bar{\phi}_s)^2$ %
10 – 14	3	12	36	24.3	-12.3	151.29	453.87
15 - 19	11	17	187	24.3	-7.3	53.29	586.19
20 - 24	21	22	462	24.3	-2.3	5.29	110.09
25 – 29	7	27	189	24.3	2.7	7.29	51.09
30 – 34	6	32	192	24.3	7.7	59.29	355.03
35 – 39	5	37	185	24.3	12.7	161.29	806.45
40 – 44	2	42	84	24.3	17.7	313.59	629.58
	$\sum F=55$	$\sum F\phi_s=1335$					$\sum F(\phi_s - \bar{\phi}_s)^2 = 2989.95$

From [10, 11] we calculate: $\phi_s = \frac{\sum \phi_s}{\sum F} = \frac{1335}{55} = 24.3$ $\delta_s = \sqrt{\sum \frac{F(\phi_s - \bar{\phi}_s)^2}{N}} = \sqrt{\sum \frac{2989.95}{55}} = 7.37$

Also, from [12], we obtain $(CV)_s = \frac{\delta_s}{\phi_s} x100\% = \frac{7.34}{24.3} x100\% = 30\%$

Where ϕ_s is the mean computed porosity for sonic log, δ_s is the standard deviation for sonic log and CV is the coefficient of variation.

Table 4: Statistical table showing the calculation of standard deviation for density derived-porosity for Well A

Class Interval	Frequency	ϕ_d (%)	$F\phi_d$	$\bar{\phi}_d$ %	$(\phi_d - \bar{\phi}_d)$ %	$(\phi_d - \bar{\phi}_d)^2$ %	$F(\phi_d - \bar{\phi}_d)^2$ %
1 – 4	5	2.5	12.5	14.5	-12.27	150.55	752.75
5 - 9	12	7	84	14.5	-7.77	60.39	724.44
10 - 14	5	12	60	14.5	-2.27	7.69	38.35
15 – 19	18	17	306	14.5	2.23	4.97	89.46
20 – 24	11	22	242	14.5	7.23	52.27	574.97
25 – 29	4	24	108	14.5	12.23	149.57	598.28
	$\sum F=55$	$\sum F\phi_d=812.5$					$\sum F(\phi_d - \bar{\phi}_d)^2 = 2778.25$

$$\phi_d = \frac{\sum F\phi_d}{\sum F} = \frac{812.5}{55} = 14.77 \qquad \delta_d = \sqrt{\sum \frac{F(\phi_d - \delta_d)^2}{N}} = \sqrt{\sum \frac{2778.25}{55}} = 7.10$$

$$(CV)_d = \frac{\delta_d}{\phi_d} x100\% = \frac{7.10}{14.77} x100\% = 48\%$$

Thus $(CV)_s \angle (CV)_d$

Where $\bar{\phi}_d$ = Mean computed porosity for density, δ_d = Computed standard deviation for density and CV = Coefficient of variation

Table 5: Statistical table showing the calculation of standard deviation for Sonic- derived-porosity for Well B

Class Interval	Frequency	ϕ_s (%)	$F\phi_s$	$\bar{\phi}_s$ (%)	$(\phi_s - \bar{\phi}_s)$ %	$(\phi_s - \bar{\phi}_s)^2$ %	$F(\phi_s - \bar{\phi}_s)^2$ %
5 – 9	1	7	7	30.25	-23.25	540.56	540.50
10 – 14	0	12	0	30.25	-18.25	330.06	0.0000
15 - 19	0	17	0	30.25	-13.25	175.56	0.000
20 - 24	18	22	396	30.25	8.25	68.06	1225.08
25 – 29	11	27	297	30.25	3.25	10.56	112.75
30 – 34	12	32	384	30.25	1.75	3.06	36.72
35 – 39	12	37	444	30.25	6.75	45.56	546.72
40 – 44	4	42	168	30.25	11.75	138.06	552.24
45 – 49	0	47	000	30.25	16.75	280.56	0.000
50 – 54	1	52	52	30.25	21.75	437.06	473.00
55 - 59	0	57	000	30.25	26.75	715.56	0.000
60 – 64	0	62	000	30.25	31.75	1008.06	0.000
65 - 69	1	67	67	30.25	36.75	1350.56	1350.56
	$\sum F=60$	$\sum F\phi_s=1815$					$\sum F(\phi_s - \bar{\phi}_s)^2 = 4800.97$

$$\phi_s = \frac{\sum \phi_s}{\sum F} = \frac{1815}{60} = 30.25 \qquad \delta_s = \sqrt{\sum \frac{(\phi_d - \bar{\phi}_d)^2}{N}} = \sqrt{\sum \frac{4800.97}{60}} = 8.95$$

$$(CV)_s = \frac{\delta_s}{\phi_s} x100\% = \frac{8.95}{30.25} x100\% = 29\%$$

Table 6: Statistical table showing the calculation of standard deviation for density derived-porosity for Well B

Class Interval	Frequency	ϕ_d (%)	$F\phi_d$	$\bar{\phi}_d$ (%)	$(\phi_d - \bar{\phi}_d)$(%)	$(\phi_d - \bar{\phi}_d)^2$ (%)	$F\ (\phi_d - \bar{\phi}_d)^2$ (%)
5 - 9	5	7	35	18.9	-11.9	141.61	708.05
10 - 14	8	12	96	18.9	-6.9	47.61	380.88
15 – 19	25	17	425	18.9	-1.9	3.61	90.25
20 – 24	10	22	220	18.9	3.1	9.61	96.10
25 – 29	7	27	189	18.9	8.1	65.61	459.27
30 - 34	4	32	128	18.9	13.1	171.61	689.44
35 – 39	0	37	0	18.9	18.1	327.61	0.000
40 - 44	1	40	42	18.9	23.1	533.61	533.61
	$\sum F = 60$	$\sum F\phi_d$ =1135					$\sum F(\phi_d - \bar{\phi}_d)^2$ = 2954.60

$$\phi_d(\%) = \frac{\sum F\phi_d}{\sum F} = \frac{1135}{60} = 18.90$$

$$\delta_d = \sqrt{\sum \frac{(\phi_d - \bar{\phi}_d)^2}{N}} = \sqrt{\sum \frac{2954.60}{60}} = 7.02$$

$$(CV)_d = \frac{\delta_d}{\phi_d} x100\% = \frac{7.02}{18.90} x100\% = 37\%$$

Thus $(CV)_s \angle (CV)_d$

Conclusions

Porosity generally decreases with depth irrespective of different tools used in the measurement – Sonic log or Density log. Porosity was observed as a function of depth and lithology as porosity of rocks decreases with depth and also varies significantly in different lithologies. Porosity of rocks decreases with increase in bulk density. However, from the principle of statistical analysis the coefficient of variation for sonic log derived porosity is lower than that of density log derived porosity, implying that Sonic Log is more reliable than density log in porosity estimation.

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