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Research Article

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Comparative Analysis of Porosity Estimates in a Sandstone Reservoir: The Niger Delta as Case Study

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Abstract Sonic logs and density logs– derived porosities (ϕ_S and ϕ_D respectively)was estimated from two different reservoirs in a single well and comparatively analyzed in this study. The well log is taken from an oil field in the Niger Delta. The study is aimed at identifying a more statistically dependable method, relative to the methods described herewith, in estimating porosity values in the Niger Delta Basin. The well was logged for Transit times, bulk density of the formation and porosity from core analysis as a function of depth. Measures of normalized root mean square error (NRMSE), relative to porosities measured from core analysis at the reservoir intervals, and coefficient of variation were employed in determining which of the estimates were more reliable. For RESERVOIR I, the NRMSE for ϕ_S and ϕ_D were 17.96% and 18.68% respectively. For RESERVOIR II, the NRMSE for ϕ_S and ϕ_D were 17.35% and 19.29% respectively. Further analysis showed that the coefficient of variation for ϕ_S and ϕ_D in the first reservoir were 13.90% and 21.80% respectively, while they were 10.18% and 21.59%, respectively, in the second reservoir. Hence, the sonic log-derived porosities were considered to be a more reliable measure of porosity in the reservoirs of the Niger delta as it had a lower measure of NRMSE and coefficient of variation in the reservoirs of interest. The results obtained therefore, shows that sonic logging tool instead of density logging tool, gives a more reliable porosity value of a formation in the Niger Delta.

Keywords Porosity, Density logs, Sonic Logs, Core Analysis, Normalized root mean square error, Coefficient of variation

Introduction

Geophysically, well logging deals with continuously recording geophysical and petrophysical parameters down a well bore that may aid in describing reservoir characteristics like porosity, permeability, water saturation, lithology, *etc* [1-3]. According to Helle *et al* [4], as advances are made in describing these petrophysical parameters, enhancements are made in evaluating formation capabilities, reservoir characterization, identifying and quantifying hydrocarbon resources in the subsurface and evaluating fluid and rock properties [5]. Porosity is by definition, the pore volume per unit gross volume of a rock [6]. It gives a measure of the void spaces available in the rock [7, 8]. The process of obtaining core measurements are quite expensive (considering the process of obtaining the cores from individual wells to obtaining laboratory core measurements of the reservoir properties) relative to the process of obtaining the same measure of reservoir properties from well logs. Therefore, apart from estimates made from core measurements, how best can porosity be estimated from downhole wireline logs and other relevant data as they relate to the sandstone reservoir of the Niger Delta basin. It is however essential to note that porosities in sandstone reservoirs are commonly overestimated as have been revealed from comparing pre-drilling reservoir appraisals with post-drilling results [9].

Location and Geology of the Niger Delta

The Niger delta basin is situated on the continental margin of the Gulf of Guinea between latitude 3^o and 6^oN and longitude 5^o and 8^o E. The areal extent of the Niger delta is about $75000km^2$ with a clastic fill of about $12000m$ [10]. As described by Aigbedion and Aigbedion [11] and Ajaegwu *et al* [12], the Niger delta basin is divided into mainly three lithostratigraphic units; the Akata (Paleocene to Recent), Agbada (Eocene to Recent) and the Benin (Oligocene to Recent) Formations; which conforms with a lower pro-delta lithofacies, a middle delta front lithofacies and an upper delta top facies respectively.

According to Jubril and Amajor [13], the Niger Delta Province contains only one identified petroleum system referred to it as the Tertiary Niger Delta (Akata –Agbada) Petroleum System. The primary source rock is the Upper Akata Formation, the marine-shale facies of the delta, with possible contribution from interbedded marine shale of the lowermost Agbada Formation [14].

Methodology

To determine how best to predict porosities in the Niger Delta basin, log data, as well as data from core analysis, extracted at cored intervals from two reservoirs in a single well in the Niger Delta, supplied by Shell Petroleum Development Company (SPDC), was used in this research. The sets of data required for the completion of the research work are bulk density of clean fluid formation, transit time for the matrix fluid, matrix density, fluid density and porosity for core analysis. These well logs(specifically Sonic log and Density log) were used to compute porosity values. Determination of porosity values was achieved by digitizing the sonic and density logs. Sonic travel times and bulk densities were digitized at intervals defined by the core analysis for the two reservoirs in the well.

Sonic log-derived porosity

The sonic log is classified as a porosity log, and relates the porosity of a formation to the interval transit time of a compressional sound wave which is travelling along the axis of the borehole through the formation [15]. The interval travel time is dependent on both porosity and lithology. For this work, porosity will be defined from sonic log based on Wyllie-time average equation [16] which is generally expressed as;

$$\Phi_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}} \qquad \textbf{Eqn. 1}$$

Where

$\Phi_s = Sonic\ derived\ porosity$

$\Delta t_{log} = Sonic\ travel\ time\ from\ \log(in\ \mu s/m)$

$\Delta t_{ma} = Sonictraveltimeinthematrix\ (55\ \mu s/ft\ or\ 180.45\ \mu s/m\ for\ typical\ sandstone\ reservoir)$

$\Delta t_{fl} = Sonictraveltimeintheformationfluid\ (215 \mu s/ft\ or\ 705.38\ \mu s/m, assuming\ \ the\ entire\ formation\ is\ hydrocarbon\ bearing)$

Density log-derived porosity

Generally, the density tool estimates the electron density of a formation which, for most earth materials of interest in hydrocarbon exploration, is related to formation bulk density through a constant [17] and the formation density can be linked to the porosity of the formation [15]. In other words, the bulk-density (ρ_b) is dependent on the matrix density, the density of fluids in the pore and the porosity in the formation. Hence, the porosity of the formation, as estimated from a density log, is expressed as [18];

$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \qquad \textbf{Eqn. 2}$$

Where

$\Phi_D = density\ derived\ porosity$

$\rho_{ma} = matrix\ density\ (2.65gcm^{-3}, Density\ of\ sandstone)$

$\rho_b = Formation\ bulk\ density\ from\ well\ log\ (in\ gcm^{-3})$

$\rho_{fl} = Fluid\ density\ (0.75gcm^{-3}, Density\ of\ oil\ contained\ in\ drilling\ mud)$

Combination of Density and Sonic derived porosity

The average of the density and sonic derived porosities will then be compared to the porosity extracted from core data to see if this helps in providing a better estimate of the formation porosity.

Error analysis and Criteria for Model Fit

There are several measures in place to evaluate the deviation between modelled and observed data. However, the normalised root mean square error (NRMSE) will be adopted in this work to evaluate the fit of the estimated models to the data from core analysis. According to Janssen and Heuberger [19], the root mean square error, RMSE, can be mathematically defined as:

Eqn. 3

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}}$$

Where P_i is the i^{th} predicted data, O_i is the i^{th} observed data and *N* is the number of data points. Furthermore, the normalised root mean squared error (NMRSE) is defined as:

Eqn. 4

$$NRMSE = \frac{RMSE}{\bar{O}}$$

Where $\bar{O}$ is the average of the observed data.This measure has values between zero (for a model that perfectly fits the observed data) and infinity (for a model that is random compared to the observed data), i.e. the smaller the *NRMSE* measure, the better the model. If expressed in percentage, as can be sometimes done, *NRMSE* can be seen as the time averaged percentage deviation of the model from the observed data [20].

To further emphasize the measure of reliability of the porosity estimation method, statistical data analysis will be carried out, with the aid of the software ***GraphPad Prism 7,*** defining the coefficient of variation for set of porosities at the two reservoir intervals. The smaller the coefficient of variation, the better and more reliable the estimation method [21].

Results and Discussions

Results

Table 1: Depth, Interval Transit Time, Sonic-Derived Porosity, Bulk Densities, Density-Derived Porosity, Core-Derived Porosity and Square of Residuals Relationship for RESERVOIR I.

Depth (ft)	**Transit Time ($\mu s/ft$)**	**Sonic log-derived Porosity, Φ_S (%)**	**Bulk Density, (g/cm^3)**	**Density log-derived Porosity, Φ_D (%)**	**Core-Derived Porosity, Φ_C(%)**	**Square of Residuals**	
						$(\Phi_S - \Phi_C)^2$	$(\Phi_D - \Phi_C)^2$
7874	85.6	19.13	2.33	16.68	21.40	5.18	22.24
7875	86.29	19.56	2.23	22.16	26.20	44.14	16.34
7881	90.5	22.19	2.19	24.42	24.80	6.83	0.14
7882	90.71	22.32	2.19	24.16	27.80	30.04	13.26
7888	90.1	21.94	2.29	19.11	26.00	16.50	47.54
7890	92.3	23.31	2.19	24.42	31.10	60.65	44.61
7891	92.94	23.71	2.17	25.26	31.20	56.06	35.25
7898	83.35	17.72	2.27	20.16	25.80	65.31	31.83
7905	83.21	17.63	2.30	18.68	24.10	41.84	29.33
7906	86	19.38	2.27	20.26	27.00	58.14	45.39
7907	86.6	19.75	2.25	20.95	26.10	40.32	26.55
7908	88.1	20.69	2.25	20.84	24.30	13.05	11.96
7910	86.39	19.62	2.31	18.11	27.30	59.00	84.54
7917	83.55	17.84	2.30	18.63	23.50	31.99	23.70
7921	84.79	18.62	2.32	17.32	19.90	1.64	6.68
7922	84.5	18.44	2.37	14.89	22.10	13.41	51.92
7924	86.1	19.44	2.52	6.63	16.30	9.84	93.48
7925	86.35	19.59	2.47	9.37	15.70	15.16	40.09
7926	86	19.38	2.45	10.47	17.90	2.18	55.15
7927	84.75	18.59	2.50	7.68	15.90	7.26	67.50
7930	79.85	15.53	2.37	14.63	22.80	52.83	66.72
7932	79.6	15.38	2.36	15.11	21.40	36.30	39.62

7933	80.55	15.97	2.33	16.74	20.50	20.53	14.16
7935	80.1	15.69	2.45	10.74	18.20	6.31	55.70
7936	80.1	15.69	2.46	10.21	14.70	0.98	20.16
7939	79.55	15.34	2.37	14.84	22.80	55.60	63.33
7940	80.7	16.06	2.39	13.63	18.90	8.05	27.76
7942	80.49	15.93	2.54	5.68	20.90	24.69	231.52
7947	77.76	14.23	2.38	14.37	24.30	101.51	98.64
7948	77.71	14.19	2.39	13.84	15.30	1.22	2.13
7950	77.2	13.88	2.35	16.00	22.30	70.98	39.69
7953	79.25	15.16	2.33	16.79	19.70	20.65	8.47
7954	80.1	15.69	2.37	14.84	22.70	49.18	61.75
7955	79.25	15.16	2.35	15.63	21.10	35.33	29.90
7957	78.35	14.59	2.35	15.79	22.10	56.34	39.82
7958	79.7	15.44	2.31	18.05	22.30	47.09	18.04
7961	80.91	16.19	2.32	17.32	20.80	21.22	12.14
7965	84.8	18.63	2.37	14.79	20.60	3.90	33.76
7966	85.89	19.31	2.32	17.63	23.30	15.95	32.13
7969	82.3	17.06	2.34	16.32	23.60	42.74	53.06
7971	81.85	16.78	2.36	15.26	21.80	25.19	42.73
7972	81	16.25	2.32	17.53	20.50	18.06	8.84
7976	77.75	14.22	2.33	16.95	23.40	84.30	41.64
7980	79.2	15.13	2.31	18.05	17.70	6.63	0.12
7981	77.26	13.91	2.33	16.95	22.00	65.41	25.53
7982	77.1	13.81	2.35	15.63	21.20	54.58	31.01
7983	78	14.38	2.32	17.37	17.20	7.98	0.03
7989	80.2	15.75	2.31	18.05	21.80	36.60	14.04
7991	78.11	14.44	2.34	16.58	21.00	42.98	19.55
7995	81.7	16.69	2.35	15.74	20.50	14.54	22.69
7996	81	16.25	2.42	12.21	21.50	27.56	86.29
7998	80.65	16.03	2.51	7.32	9.80	38.83	6.17
7999	81	16.25	2.44	10.95	12.70	12.60	3.07
8000	81.25	16.41	2.34	16.47	14.60	3.26	3.51
8001	80.35	15.84	2.31	17.89	22.20	40.40	18.54
8002	79.85	15.53	2.28	19.63	21.90	40.56	5.15
8004	77.9	14.31	2.31	18.16	23.70	88.13	30.71
8005	78.3	14.56	2.31	17.79	16.50	3.75	1.66
8008	77.45	14.03	2.34	16.16	20.50	41.84	18.85
8010	78.8	14.88	2.34	16.47	20.60	32.78	17.03
8012	78.8	14.88	2.32	17.58	21.30	41.28	13.85
8016	83.94	18.09	2.26	20.58	22.40	18.60	3.32
8018	77.35	13.97	2.36	15.32	19.00	25.31	13.57
8023	76.9	13.69	2.37	14.58	19.70	36.15	26.23
8025	79.55	15.34	2.32	17.37	20.60	27.63	10.44
8026	79.25	15.16	2.31	17.79	21.20	36.53	11.63
8028	79	15.00	2.36	15.53	19.20	17.64	13.50
8030	79.95	15.59	2.36	15.11	9.10	42.17	36.06
8031	80.34	15.84	2.34	16.26	20.80	24.63	20.58
8032	78.9	14.94	2.34	16.32	21.20	39.22	23.86
8034	79	15.00	2.39	13.74	14.30	0.49	0.32
8039	82.05	16.91	2.40	13.16	18.20	1.67	25.42
8041	81.2	16.38	2.33	17.05	20.40	16.20	11.20
8042	80.85	16.16	2.31	18.11	22.40	38.98	18.44
8044	78.5	14.69	2.34	16.11	17.60	8.48	2.23
8046	78.35	14.59	2.33	17.00	20.60	36.08	12.96
8047	79.2	15.13	2.35	15.89	20.60	29.98	22.14
8049	81.5	16.56	2.31	17.89	20.90	18.81	9.03
8052	78.7	14.81	2.33	17.05	20.80	35.85	14.04
8054	80.7	16.06	2.29	18.84	20.50	19.69	2.75

8055	81.3	16.44	2.31	18.11	22.50	36.75	19.31
8056	80.7	16.06	2.31	17.79	23.60	56.81	33.76
8057	80.1	15.69	2.31	18.00	22.00	39.85	16.00
8059	79.25	15.16	2.32	17.21	20.10	24.44	8.35
8062	77.25	13.91	2.35	15.79	18.30	19.31	6.30
8063	78.2	14.50	2.31	17.95	21.40	47.61	11.92
8065	79.75	15.47	2.33	16.79	20.20	22.38	11.63
					RMSE	5.57	5.35
					NRMSE	***0.1796***	***0.1868***

Table 2: Depth, Interval Transit Time, Sonic-Derived Porosity, Bulk Densities, Density-Derived Porosity, Core-Derived Porosity and Square of Residuals Relationship for RESERVOIR II.

Depth (ft)	**Transit Time** ($\mu s/ft$)	**Sonic log-derived Porosity,** Φ_S (%)	**Bulk Density,** (g/cm^3)	**Density log-derived Porosity,** Φ_D (%)	**Core Porosity,** Φ_C (%)	**Square of Residuals**	
						$(\Phi_S - \Phi_C)^2$	$(\Phi_D - \Phi_C)^2$
8338	86.3	19.56	2.51	7.26	16.10	11.99	78.09
8340	85.6	19.13	2.27	19.95	23.50	19.14	12.62
8341	84.35	18.34	2.27	20.26	24.10	33.13	14.72
8342	83.09	17.56	2.31	18.16	17.60	0.00	0.31
8343	83.1	17.56	2.40	13.16	24.00	41.44	117.55
8347	84.15	18.22	2.30	18.42	23.90	32.28	30.02
8348	83.36	17.73	2.31	17.79	22.40	21.86	21.26
8349	86	19.38	2.26	20.32	13.60	33.35	45.10
8350	84.55	18.47	2.25	21.16	24.90	41.36	14.00
8359	83.75	17.97	2.25	20.84	25.70	59.77	23.60
8360	83.55	17.84	2.26	20.37	22.80	24.56	5.91
8361	85.8	19.25	2.25	20.95	24.00	22.56	9.32
8364	91.9	23.06	2.11	28.47	28.80	32.92	0.11
8366	83.95	18.09	2.24	21.37	29.10	121.14	59.78
8370	84.5	18.44	2.30	18.63	21.90	11.99	10.68
8371	84.81	18.63	2.28	19.58	22.90	18.22	11.03
8372	87.71	20.44	2.29	18.89	23.90	11.95	25.05
8373	91.56	22.85	2.19	24.05	23.50	0.42	0.31
8377	84.3	18.31	2.35	15.79	19.60	1.66	14.52
8383	82.6	17.25	2.25	20.84	24.10	46.92	10.61
8384	81.4	16.50	2.34	16.47	23.90	54.76	55.15
8385	81.8	16.75	2.33	16.63	13.60	9.92	9.19
8386	82.5	17.19	2.33	17.11	22.50	28.22	29.10
8387	83.5	17.81	2.30	18.26	21.00	10.16	7.49
8389	80.65	16.03	2.35	15.68	24.00	63.50	69.15
8393	82.01	16.88	2.23	22.05	24.40	56.53	5.51
8394	85.3	18.94	2.21	23.26	22.10	10.00	1.35
8395	84.1	18.19	2.34	16.58	23.30	26.14	45.17
8396	83.05	17.53	2.29	18.84	20.60	9.42	3.09
8397	81.85	16.78	2.27	20.00	21.80	25.19	3.24
8398	81.55	16.59	2.30	18.21	24.20	57.86	35.87
8399	81.1	16.31	2.37	14.84	21.80	30.11	48.41
8400	82	16.88	2.33	16.63	16.30	0.33	0.11
8402	81.45	16.53	2.31	17.74	20.50	15.75	7.64
8403	81.7	16.69	2.29	19.05	14.30	5.70	22.59
8404	81.15	16.34	2.31	17.95	21.50	26.59	12.62
8406	80	15.63	2.34	16.53	18.80	10.08	5.17
8407	80.7	16.06	2.31	18.16	22.80	45.39	21.55
8412	84.75	18.59	2.32	17.42	23.20	21.22	33.40
8414	82.9	17.44	2.33	16.84	20.30	8.19	11.96
8419	83.21	17.63	2.46	10.16	19.70	4.28	91.05
8421	84.9	18.69	2.46	10.16	16.40	5.23	38.96

8422	85.15	18.84	2.36	15.37	18.80	0.00	11.78
8423	83.65	17.91	2.39	13.63	20.60	7.26	48.56
8427	82.7	17.31	2.27	20.11	23.30	35.85	10.21
8431	81.4	16.50	2.26	20.47	26.10	92.16	31.66
8432	81.8	16.75	2.32	17.58	21.60	23.52	16.17
8433	82.4	17.13	2.30	18.21	22.70	31.08	20.16
8436	81.35	16.47	2.32	17.26	20.30	14.68	9.22
8437	81.21	16.38	2.39	13.53	16.30	0.01	7.69
8438	83.7	17.94	2.44	11.26	18.30	0.13	49.52
8439	83	17.50	2.32	17.58	15.30	4.84	5.19
8442	79.7	15.44	2.40	13.00	20.70	27.69	59.29
8445	81.85	16.78	2.35	15.58	18.40	2.62	7.96
8446	82.29	17.06	2.39	13.58	17.80	0.55	17.82
8447	81.3	16.44	2.49	8.53	19.80	11.31	127.10
8449	83.3	17.69	2.33	16.74	19.50	3.29	7.64
8454	82.4	17.13	2.23	22.00	25.80	75.26	14.44
8455	82.89	17.43	2.26	20.58	24.30	47.18	13.85
8456	80.55	15.97	2.34	16.21	18.30	5.43	4.37
8457	79.61	15.38	2.35	15.95	22.50	50.68	42.94
8458	82.6	17.25	2.34	16.32	20.70	11.90	19.22
8461	82.05	16.91	2.33	16.84	20.00	9.57	9.97
8463	81	16.25	2.33	16.84	22.80	42.90	35.50
8464	80.25	15.78	2.29	19.00	23.50	59.58	20.25
8465	79.61	15.38	2.30	18.37	23.10	59.58	22.39
8467	80.85	16.16	2.35	16.05	22.40	38.98	40.29
8468	81.55	16.59	2.37	14.79	15.00	2.54	0.04
8470	78.71	14.82	2.45	10.68	23.00	66.93	151.68
8472	81.8	16.75	2.29	18.79	17.80	1.10	0.98
8473	81.25	16.41	2.29	19.00	22.70	39.61	13.69
8475	81.5	16.56	2.29	19.16	20.00	11.82	0.71
8479	82.85	17.41	2.30	18.53	16.50	0.82	4.11
8480	81.9	16.81	2.29	18.95	23.50	44.72	20.73
8481	81.2	16.38	2.34	16.26	20.90	20.48	21.50
8482	81.3	16.44	2.33	16.84	20.50	16.50	13.38
8487	80.3	15.81	2.33	16.89	15.70	0.01	1.43
8488	79.36	15.23	2.34	16.32	22.90	58.91	43.35
8489	81.7	16.69	2.30	18.21	22.30	31.50	16.72
8490	82.45	17.16	2.31	17.68	17.30	0.02	0.15
8491	80.65	16.03	2.30	18.58	24.10	65.10	30.48
8499	80.35	15.84	2.50	7.68	9.40	41.52	2.94
8500	80	15.63	2.48	8.79	16.00	0.14	51.99
8502	78.85	14.91	2.42	12.00	19.40	20.19	54.76
8508	81	16.25	2.29	19.21	21.90	31.92	7.23
8512	78.9	14.94	2.30	18.26	22.60	58.71	18.81
8515	80.4	15.88	2.40	13.37	22.30	41.28	79.77
8517	83.4	17.75	2.26	20.37	24.70	48.30	18.76
8522	80.9	16.19	2.30	18.53	24.40	67.45	34.50
8524	84.55	18.47	2.23	22.00	26.10	58.24	16.81
8527	90.9	22.44	2.21	23.16	30.10	58.71	48.19
8528	88.7	21.06	2.20	23.79	29.90	78.10	37.34
8535	81.05	16.28	2.30	18.32	24.40	65.91	37.02
8538	83.7	17.94	2.33	16.95	24.10	37.98	51.16
8542	94.6	24.75	2.18	24.63	30.10	28.62	29.90
8543	88.54	20.96	2.21	23.00	31.10	102.77	65.61
8544	85.9	19.31	2.31	17.84	16.80	6.31	1.09
8549	87.7	20.44	2.24	21.63	28.40	63.40	45.81
8550	86.39	19.62	2.21	23.37	26.10	42.01	7.46
8552	81.06	16.29	2.31	17.89	26.50	104.30	74.05

8553	81.55	16.59	2.32	17.47	20.10	12.29	6.90
8554	81.9	16.81	2.32	17.47	21.70	23.89	17.86
8555	81.1	16.31	2.30	18.26	21.90	31.22	13.23
8557	80.9	16.19	2.30	18.37	24.80	74.18	41.37
8563	80.2	15.75	2.32	17.37	21.80	36.60	19.64
8564	80.4	15.88	2.29	18.79	22.50	43.89	13.77
8565	79.9	15.56	2.31	17.84	21.80	38.91	15.66
8569	83.8	18.00	2.31	18.11	17.70	0.09	0.16
8570	85.95	19.34	2.28	19.53	23.50	17.27	15.79
8571	87.36	20.23	2.24	21.84	22.60	5.64	0.57
8572	88.1	20.69	2.21	23.11	24.10	11.65	0.99
8575	83.1	17.56	2.27	20.00	29.40	140.13	88.36
8576	81.9	16.81	2.25	21.00	26.40	91.92	29.16
8577	80.7	16.06	2.28	19.68	26.10	100.75	41.16
8578	81.35	16.47	2.27	20.16	23.70	52.29	12.55
8582	87	20.00	2.21	23.11	23.90	15.21	0.63
8587	82	16.88	2.26	20.47	25.10	67.65	21.40
8591	78.06	14.41	2.34	16.58	24.10	93.85	56.57
8592	78.15	14.47	2.36	15.11	24.20	94.70	82.71
8597	86.84	19.90	2.28	19.53	20.90	1.00	1.89
8598	84.4	18.38	2.31	17.79	25.00	43.89	51.99
8599	82.1	16.94	2.29	19.00	23.90	48.48	24.01
8600	82.35	17.09	2.36	15.42	24.10	49.09	75.32
8602	81.45	16.53	2.25	20.84	23.10	43.15	5.10
8605	82.55	17.22	2.30	18.37	23.30	36.98	24.32
8612	79.1	15.06	2.31	17.95	21.30	38.91	11.24
8613	79.05	15.03	2.31	17.74	21.60	43.15	14.92
8616	80.35	15.84	2.28	19.42	22.10	39.14	7.18
8619	80.95	16.22	2.31	18.16	19.80	12.83	2.70
8623	78.9	14.94	2.32	17.53	18.30	11.31	0.60
8625	79.75	15.47	2.34	16.53	18.30	8.02	3.15
8630	80.85	16.16	2.34	16.58	18.60	5.97	4.08
8631	80	15.63	2.42	12.00	21.10	29.98	82.81
8632	79.75	15.47	2.47	9.26	12.80	7.12	12.51
8634	81	16.25	2.54	5.58	14.40	3.42	77.81
8637	85.64	19.15	2.58	3.63	11.30	61.62	58.80
					RMSE	5.76	5.18
					NRMSE	***0.1735***	***0.1929***

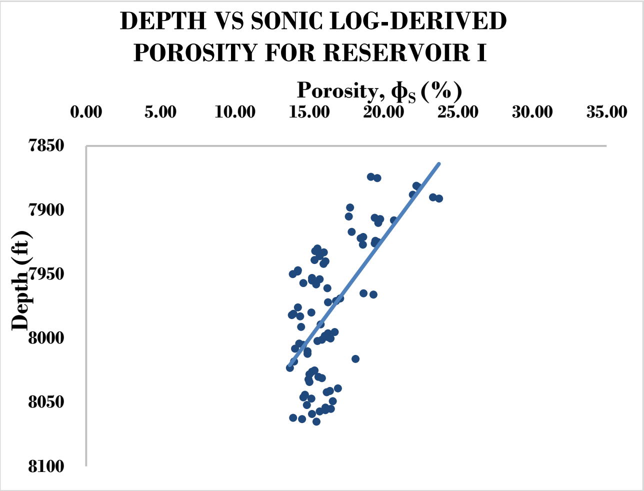

Figure 1: Relationship between Depth and Sonic log-derived Porosity for RESERVOIR I

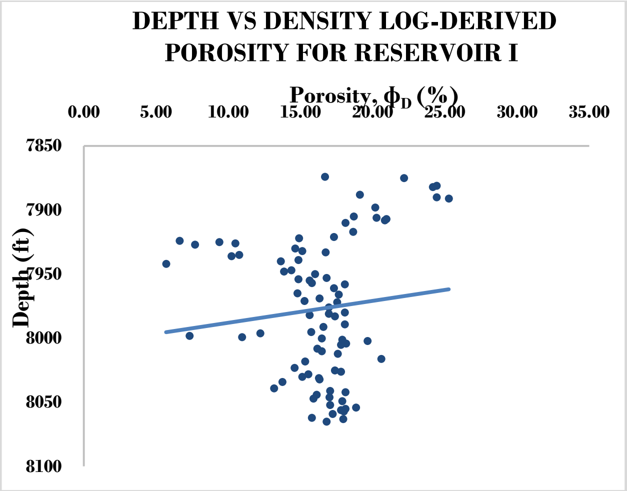

Figure 2: Relationship between Depth and Density log-derived Porosity for RESERVOIR I

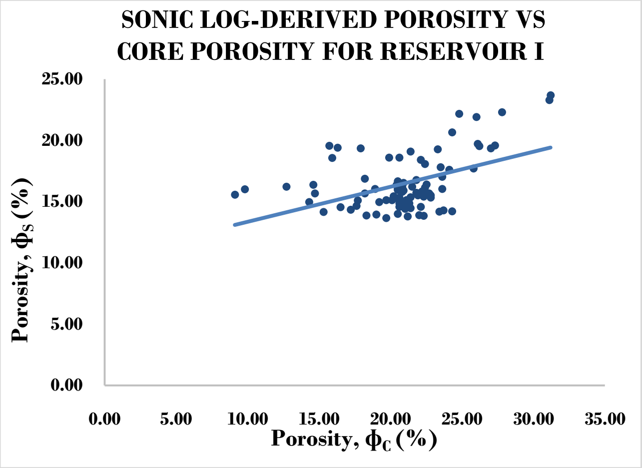

Figure 2: Relationship between Core-derived porosity and Sonic log-derived Porosity for RESERVOIR I

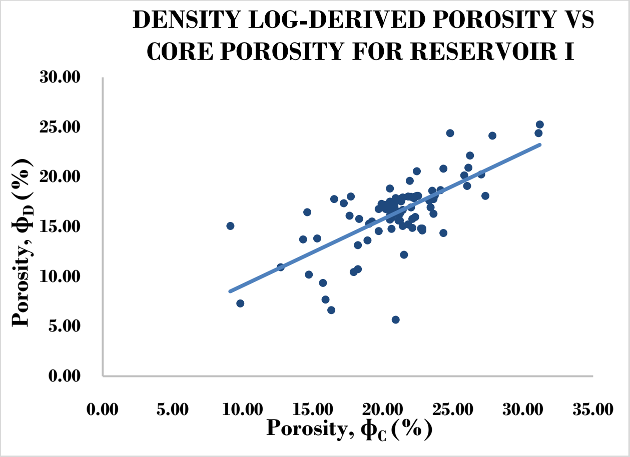

Figure 3: Relationship between Core-derived porosity and Density log-derived Porosity for RESERVOIR I

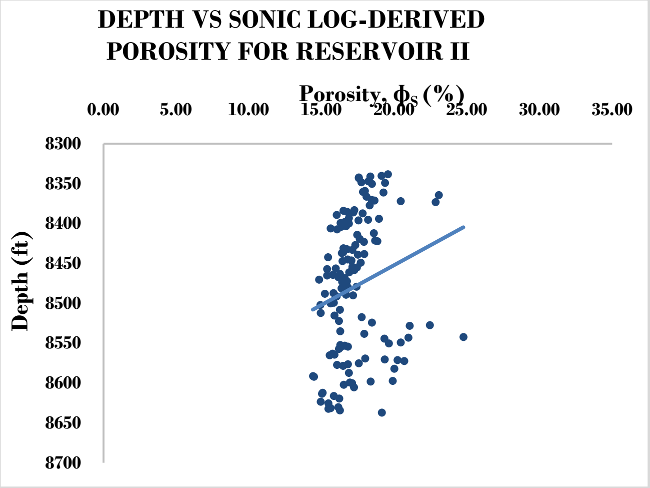

Figure 4: Relationship between Depth and Sonic log-derived Porosity for RESERVOIR II

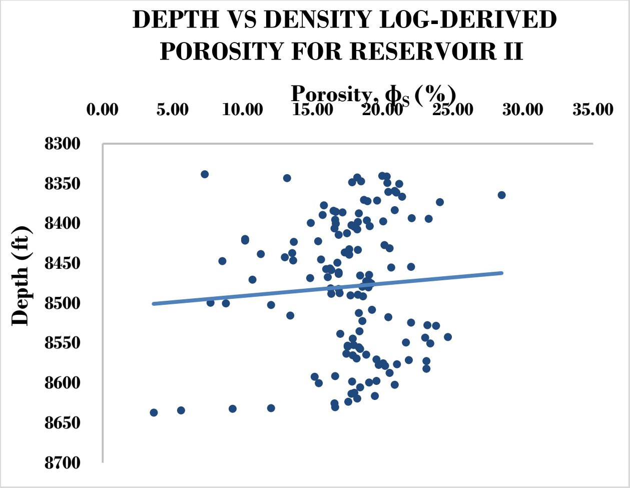

Figure 5: Relationship between Depth and Density log-derived Porosity for RESERVOIR II

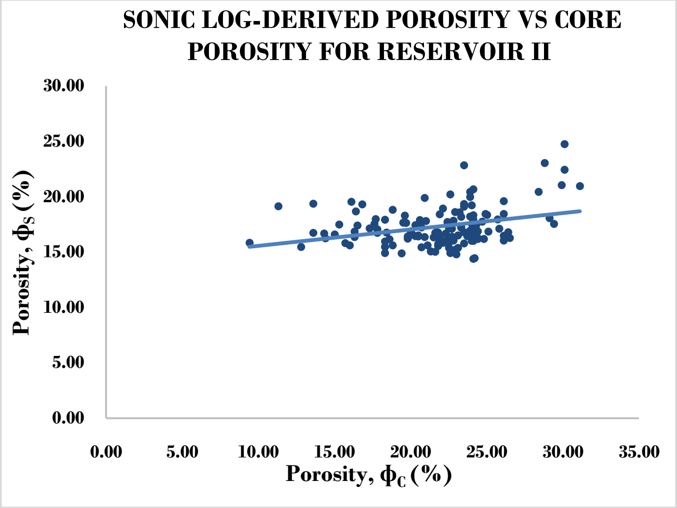

Figure 7: Relationship between Core-derived porosity and Sonic log-derived Porosity for RESERVOIR II

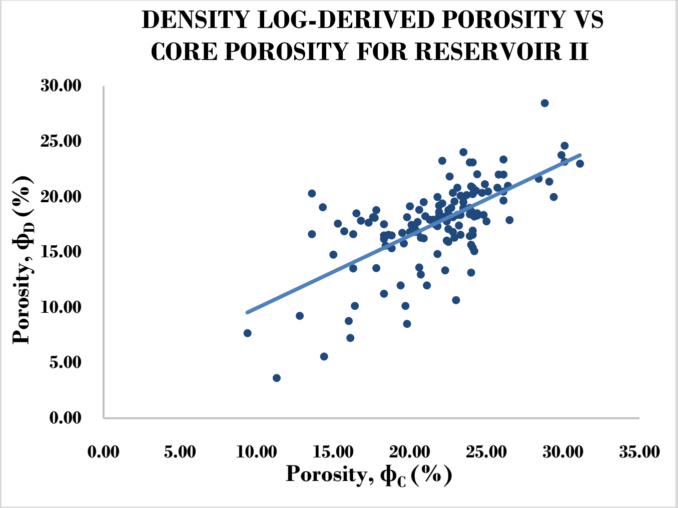

Figure 8: Relationship between Core-derived porosity and Density log-derived Porosity for RESERVOIR II

Table 3: Results of statistical analysis for RESERVOIR I (Done with GraphPad Prism 7)

	Sonic log-derived Porosity, Φ_S	**Density log-derived Porosity, Φ_D**
Minimum	13.69	5.680
Maximum	23.71	25.26
Mean	16.50	16.40
Std. Deviation	2.293	3.576
Std. Error of Mean	0.2458	0.3834
Coefficient of variation	***13.90%***	***21.80%***

Table 4: Results of statistical analysis for RESERVOIR II (Done with GraphPad Prism 7)

	Sonic log-derived Porosity, Φ_S	**Density log-derived Porosity, Φ_D**
Minimum	14.41	3.630
Maximum	24.75	28.47
Mean	17.30	17.62
Std. Deviation	1.761	3.805
Std. Error of Mean	0.1510	0.3262
Coefficient of variation	***10.18%***	***21.59%***

Discussion

Numerical data obtained from the two reservoirs (I and II) of interest are shown in Tables 1 and 2. There is a general decrease in porosity, as described from sonic and density logs, with depth, as seen in Figures1, 2, 5 and 6. This could be as a result of the compactness of formation leading to changes in lithological characteristics at varying depths.

Also contained in Tables 1 and 2 are the normalized root mean square errors (NRMSE) for both methods of porosity estimation in both reservoirs. For RESERVOIR I, The NRMSE was 17.96% for sonic log-derive porosity values and 18.68% for density log-derived porosity values. For RESERVOIR II, The NRMSE was 17.35% for sonic log-derive porosity values and 19.29% for density log-derived porosity values. This result shows that porosities estimated from sonic logs provide better estimates of porosity.

For further emphasis, *Tables 3* and *4* shows the results obtained for the statistical analysis. Evidently, the sonic log-derived porosities provide better estimates of porosities relative to the density log-derived porosities as it has a lower coefficient of variation (13.90% and 21.80% for sonic and density logs-derived porosity respectively in RESERVOIR I and 10.18% and 21.59% for sonic and density logs-derived porosity respectively in RESERVOIR II) in both reservoirs.

Though Helle *et al* [4] suggested that no single log measurement sufficiently provides reliable values of porosity, the results from this study shows that the porosities described from the sonic log seem to provide a better estimate of porosities in the Niger Delta as had been shown earlier by Horsfall *et al* [22].

Conclusions

This study was aimed at comparing and determining the most reliable way to estimate porosity from sonic log and density log in a sandstone reservoir, with the Niger Delta formation as case study. To do this, the normalized room mean square error (NRMSE) and coefficient of variation was calculated for both methods of porosity estimation from two reservoirs in a single well from the Niger Delta. One thing of note in the results obtained is that, irrespective of the method employed in porosity estimation, there is a decrease of porosity with depth. From the results of this study, it was evident that sonic log-derived porosities, relative to density log-derived porosities, provide a better estimate of the in-situ porosity in the Niger Delta.

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