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Porosity- Depth Estimation in Clastic Rocks from Sonic Logs in Chad Basin, Nigeria

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ABSTRACT

Determination of porosity of Sand Formation in Chard basin Nigeria was carried out in order to assess its hydrocarbon potential. Five well logs from the study area were used. The gamma ray log and sonic log were employed to determine lithologies and their respective porosities. The lithologies delineated were sand and shale beds. Estimation of shale volume for each delineated lithology was calculated using the gamma ray index (IGR). Porosity estimation was carried out on each well using delineated transit time by employing transit time matrix. The range of porosities within the study area as delineated from the available wells is 0.2-61.3%. This could be due to less overburden pressure within the formation. An exponential model was obtained for the depth-porosity model with regression coefficient ranging between 0.5313 and 0.9105. The variation of porosity in each well showed that porosity decreased with depth. The estimated porosity values indicate that the Chad basin has potential for hydrocarbon exploitation.

INTRODUCTION

The Nigerian sector of the Chad Basin has been an area of interest in terms of hydrocarbon exploration mainly by the Nigerian National Petroleum Corporation (NNPC). Several authors have thus highlighted the factors that have motivated the commencement of oil exploration activities in the basin. These include Ajayi and Ajakaiye (1983), Cratchely et al. (1984), Avbovbo et al. (1986), Nwankwo (2007) and Nwaezeapu et al. (1992), Nwaezeapu and Bako (1982) and Obaje et al. (2003). The increasing interest in exploring the Bornu Basin was sparked off by the discovery of oil and gas in the neighborhood and the diversification of Nigeria’s exploration programs to increase oil reserves base. Ilozobhie et al. (2009) reported that since 1984 a total of 23 wells have been drilled by Frontier Exploration Services (FES) under the Nigeria Petroleum Investment Management Services (NAPIMS) with little or no commercial hydrocarbon presence detected. The study was carried out using wireline logs from six wells. The study, however, revealed that hydrocarbon generative indices present make the study area a hydrocarbon province.

The search for hydrocarbon fluid begins with geological activities followed by geophysical activities. The geological activities include surface mapping and aerial survey. The information obtained from the geological activities is then used for geophysical activities which involve the determination of subsurface properties of rock formation.

A number of authors have published works based on several geophysical methods which support the view that the Chad Basin is petroliferous. Nwankwo et. al. (2012) evaluated the petroleum potentials and prospects in the Chad Basin from heat flow and gravity data and concluded that the basin is petroliferous.

llozobhie et. al. (2009) used well log to evaluate sand-shaliness in Bornu Basin. In their study, log intervals representing permeable sand units were demarcated from the available five well logs for the study. The individual sand beds varied in thickness from one another, separated from each other by shale beds. Using appropriate petrophysical formula such as Gamma index, minimum and maximum gamma values at chosen stratigraphic intervals, sand-shaliness of the basin was evaluated.

A good log is a downhole record made during or after drilling a well. The records are used to determine subsurface properties such as porosity, permeability and water saturation. These provide the essential information that enhances the interpretation of the subsurface geology of the area penetrated and facilitates geological correlation across different areas of interest.

The aim of this study is to utilize sonic log data to determine the porosity of the Sand Formations in the Chad basin for assessment of its hydrocarbon potential.

LOCATION OF STUDY AREA

Detailed account of the location and origin of Chad Basin has been given by Nwankwo et al. (2011). According to the authors, the basin lies within a vast area of Central and West Africa at an elevation of between 200 m and 500 m above sea level. It is centered on Lake Chad and forms the largest drainage inland basin in Africa, occupying an area of about 2,500,000 km^2 and extending over parts of the Republic of Niger, Chad, Sudan and the northern part of Cameroon and Nigeria (Fig. 1). It lies between latitudes 10^oN and 14^oN and longitudes 12^0E and 16^0E.

Oteze and Fayose (1988) explained that the Nigerian sector of the Chad basin covers about 152,000km^2 of territory in Bornu, Bauchi, Plateau and Kano States and contributes only 6.5% of the entire basin.

GEOLOGY OF CHAD BASIN

Chad Basin contains about 4.65 km of marine and continental sediments made up of the Bima Sandstone, Gongila Formation, Fika Shale, Kern Kern and Chad Formations (Table 1). Crystalline basement rocks, mainly of granitic and gneissic compositions rim the basin with some mica schist, basalts, minor basic and acidic intrusions (particularly of Tertiary age) occur commonly within parts of the basin.

Table 1 summary of the stratigraphic units in the Chad Basins (Modified from Nwankwo et al., 2010).

Formation	**Lithology**	**Depositional Environment**	**Age**
Chad Formation	Sandy Strata interlayered by argillaceous sediments	Fluvial, and mixed Environment	Pleistocene to Pliocene
Keri-Keri Formation	Grit, sandstone and clayey grit	Fluvial, lacustrine	Paleocene
Filka shale	Mixed limestone/ shale sequence	Center lacustrine and Marine	Senonian
Gongilia Formation	Sequence of sandstones, clays, shales and limestone layers.	Marginal to center lacustrine and marine	Turonian
Bima Sandstone	Largely composed of coarse fedspaththic and cross-bedded sandstones.	Continental	Cenomanian
Basement Complex			Pre-Cenomanian

Fig. 1: Location Map showing Chad Basin outline.

MATERIALS AND METHODS

The datasets used for this study are gamma ray and sonic logs obtained from five wells Ziye, Tuma, Murshe, Krumuta and Kanadi. The gamma ray log shows different lithologies (shale and sand beds) while the sonic log was used to determine the interval transit time for an acoustic wave to reach the formation beds. Details of well log interpretation techniques can be read in Rider (1990), Schlumberger (1989) and Schlumberger (1991).

Determination of Shale and Sands from Gamma Ray Log.

The formation beds of interest are shale and sand. They were delineated with the aid of gamma ray log. Each bed ranged from 0-150API (American Petroleum Institute), having a cutoff line at 75API. Also, quick look interpretation was employed. The signature of gamma ray log towards the right shows Shale Formation while that of Gamma Ray (GR) towards the left shows Sand Formation. The formation beds were delineated at depths of their various formations. The thickness of each bed was read and recorded from the log. Within the thickness of each formation, certain depths were chosen and the readings of both sand and shale Formations were determined with respect to their various depth in meters. Shale volumes were evaluated with equation 1.

$$\%V_{sh} = 1.7 - [3.38 - (IGR + 0.7)^2]^{1/2} \times \frac{100}{1} \qquad 1$$

Where,

$$IGR = \frac{(GR_{log} - GR_{sand})}{(GR_{shale} - GR_{sand})} \qquad 2$$

GR_{log}, is the gamma ray (GR) values in API units. The sand (GR_{sand}) and shale (GR_{shale}) baselines are the minimum and maximum values respectively in the gamma ray log. $\%V_{sh}$ is percentage volume of shale.

Determination of Transit Time and Porosity

For porosity of sand and shale formations to be determined, the corresponding transit time Δt for each delineated lithology at any depth for each well was read and recorded from the sonic log.

The percentage porosity for each well was calculated using equation 3

$$\%\Phi = \left(\frac{\Delta t_{log} - \Delta t_{max}}{\Delta t_{fl} - \Delta t_{max}}\right) \times \frac{100}{1} \qquad 3$$

Where, Φ = Formation porosity

Δt_{max} = Transit time matrix = 62.5$\mu s/f$t

Δt_{log} = Transit time of the log

Δt_{fl} = Transit time of fluid = 189$\mu s/f$t

RESULTS

The computed values of the porosity and volume of shale in the delineated sand bodies of Krumta and Kanadi wells are shown in Tables 2 and 3 respectively. The thicknesses of the sand bodies are also shown in the tables. The computed volume of shales in the sand bodies ranges from 0.3 to 20.35% for Krumta well and 7.27 to 21.06% for the Kanadi well. The computed shale volume for the sand bodies in the other wells also within the range of 0.3 to 22.0 %. The shale volume in the sand bodies is good for any reservoir in the area.

Table 2: Petrophysical properties of Krumta well sand bodies

S/n	Depth Range	Depth (m)	Thickness (m)	GR (API)	Δt (µs/f)	%Φ	IGR	Vsh (%)
1	1399-1414	1400	15	21	68	9.4	0.01	0.33
		1406		22.5	64	6.4	0.02	0.84
		1410		30	64	6.4	0.08	3.52
2	1444-1518	1450	74	36	57	1.1	0.13	5.85
		1460		36	58	1.9	0.13	5.85
		1470		31	61	4.1	0.09	3.89
		1480		30	58	1.9	0.08	3.52
3	1702-1707	1704	5	66	110	40.8	0.37	20.35
4	1722-1732	1724	10	60	103	35.6	0.32	17.04
		1728		60	124	51.3	0.32	17.04
5	1991.5-1997.5	1993	6	60	83	20.6	0.32	17.04
6	2122-2133.5	2123	11.5	50	82	19.9	0.24	12.00
7	2136-2142	2138	6	45	88	24.3	0.20	9.69
8	2759-2764	2760	5	36	80	18.4	0.13	5.85
		2763		36	56	0.4	0.13	5.85
9	2913-2923	2915	10	30	60	3.4	0.08	3.52
		2921		30	60	3.4	0.08	3.52

Table 3: Petrophysical properties of Kanadi well sand bodies

S/n	Depth Range	Depth (m)	Thickness (m)	GR (API)	Δt (μs/f)	%Φ	IGR	Vsh (%)
1	578-583	582	5	63	60	3.4	0.36	19.79
2	756-760	757	4	48	132	57.3	0.23	11.21
3	861-863	861.5	2	65	120	48.3	0.38	21.06
		862.5		63	120	48.3	0.36	19.79
4	869-871	870	2	60	122	49.8	0.33	17.94
5	1011-1012.5	1012	1.5	40	62	4.9	0.16	7.27
6	1376-1378	1377.4	2	60	95	29.6	0.33	17.94
7	1442.5-1445	1443	2.5	45	65	7.1	0.20	9.69
8	1551-1554	1552	3	50	95	29.6	0.24	12.26
9	2290-2297	2293	7	45	58	1.9	0.20	9.69
		2295		40	63	5.6	0.16	7.27
10	2312-2314	2313	2	51	70	10.9	0.25	12.80
11	2316-2319	2317	3	55	64	6.4	0.29	15.01
12	2615-2618	2616	3	50	57	1.1	0.24	12.26

Porosity Depth Model

The computed porosity for the sand bodies in the five wells was plotted against the corresponding depths of the sand bodies in Figures 2 to 6. The range of porosities within the study area as delineated from the available wells is 0.2-61.percent.

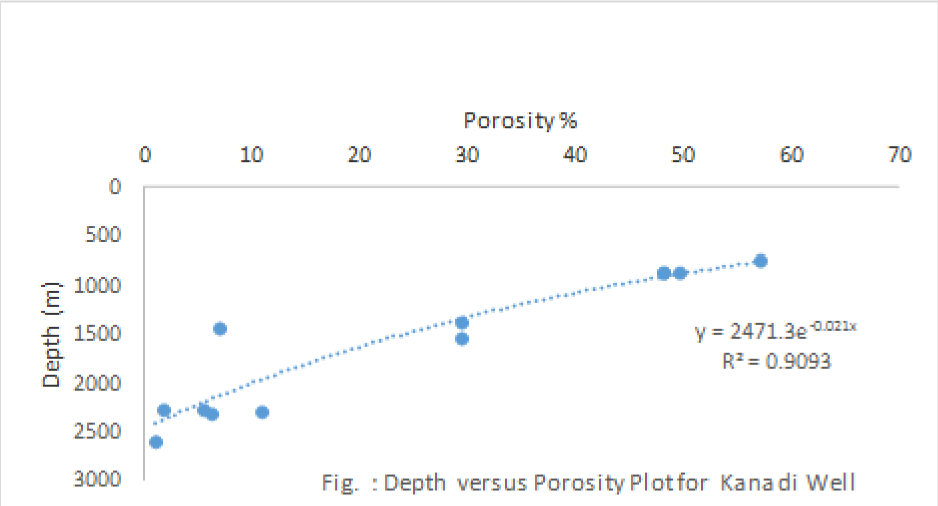

Fig. 2: Depth versus Porosity Plot for Kanadi Well sand bodies

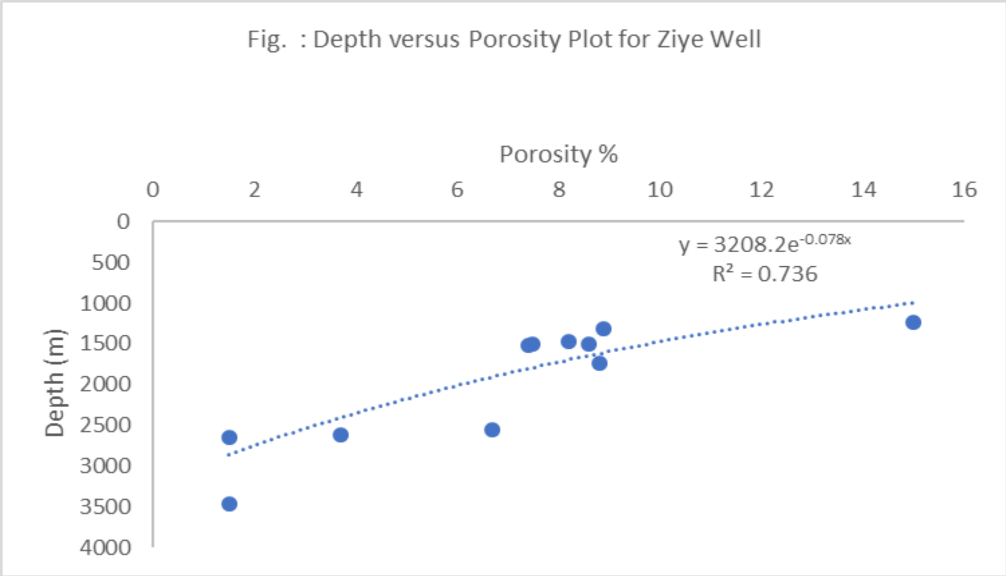

Fig. 3: Depth versus Porosity Plot for Ziye Well sand bodies

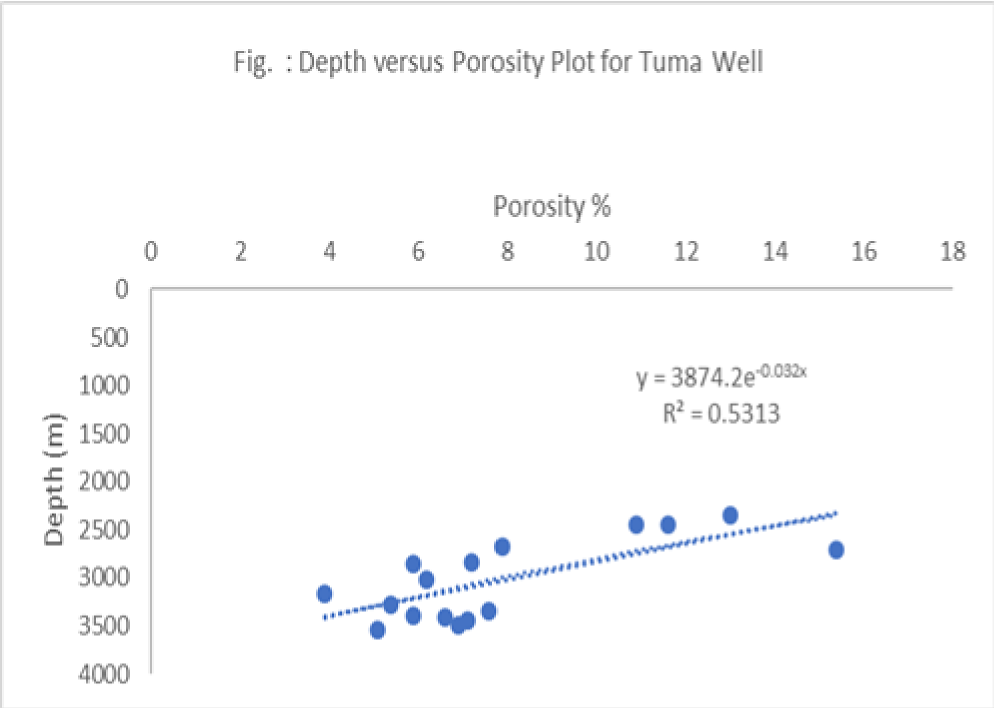

Fig. 4: Depth versus Porosity Plot for Tuma Well sand bodies

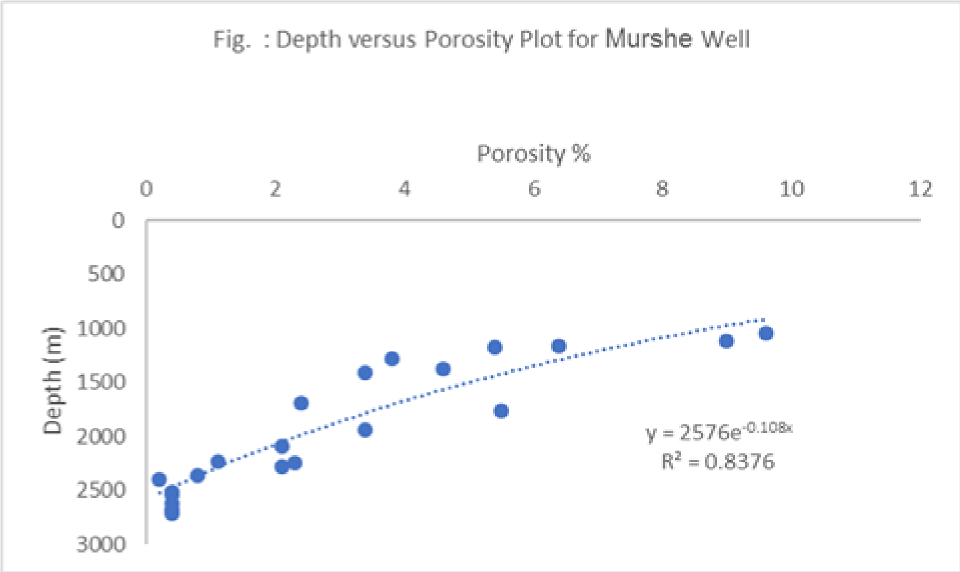

Fig. 5: Depth versus Porosity Plot for Murshe Well sand bodies

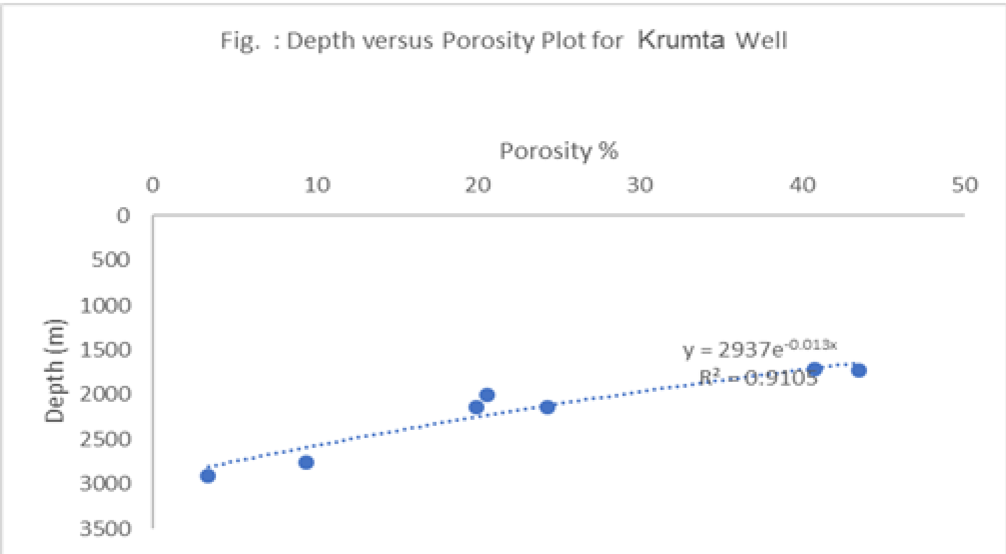

Fig. 6: Depth versus Porosity Plot for Krumta Well sand bodies

The porosity-depth model for the five wells show that exponential relationship is the best fit for the porosity and depth in the study area. The model equations and the regression coefficients are:

$$Y = 2471.3e^{-0.021x} \quad (4)$$

$R^2 = 0.9093$

$$Y = 3208.2e^{-0.078x} \quad (5)$$

$R^2 = 0.736$

$$Y = 3874.2e^{-0.032x} \quad (6)$$

$R^2 = 0.5313$

$$Y = 2576e^{-0.108x} \quad (7)$$

$R^2 = 0.8376$

$$Y = 2937e^{-0.013x} \quad (8)$$

$R^2 = 0.9105$

Where,

Y = depth (m)

X = Porosity (%)

Conventionally, porosity changes in clastic sediments is a function of depth and tend to decrease as the depth of burial of these sediments increases. This is mainly influenced by overburden pressure. The conventional trend of decrease in porosity with increasing depth was observed in the porosity versus depth plots. As sediments are deposited, they become more and more compacted. Pore fluids are continually expelled from the sediments and this reduces the porosity. If a normal compaction trend is followed (i.e. if there are continuous deposition and compaction), the porosity reduction with depth will be systematic. The porosity-depth cross-plots in sand in the five wells show a good exponential trend with regression coefficient ranging between 0.5313 and 0.9105. The high regression coefficient values show that the modeled equation can be used for porosity determination in the study area with confidence.

CONCLUSION

The range of porosities computed from the sonic logs within the study area as delineated from the available wells is 0.2-61.3%. This could be due to less overburden pressure within the formation. The porosity decreases with depth. The porosity of 0-5% is negligible, 5-10% is poor, 15-20% is good and 20-30% is very good while porosity of greater than 30% is excellent. The estimated porosity values indicate that the Chad basin has potential for hydrocarbon exploitation.

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