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APPRAISAL OF HYDROCARBON POTENTIAL IN WESTERN GHANA OILFIELD (TANO BASIN)

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Abstract

The petrophysical analysis was applied to composite well logs data on some selected exploratory wells 1S-1X, 1S-3AS and 1S-4AX all in the Western Tano Basin in Ghana. For each well geophysical data such resistivity log, formation density log, compensated neutron log and gamma ray log was available for evaluation of the potential of the basin via Archie and Wylie Rose models among others. The potential of the basin was evaluated relative to important Petrophysical parameters as porosity, permeability, water saturation, the volume of shale and pay zone depth. The derived parameters give mean values of oil bearing zone in all wells on porosity range from 24.34% to 25.48%, and permeability range from 81.13mD to 115.42mD. The mean values for the gas bearing zones range from 14.89% to 19.33% for porosity and 0.18mD to 1.23mD for permeability. The mean values of water saturation for wells 1S-1X, 1S-3AX and 1S-4AX stand at 41.7%, 56.8% and 40.4% respectively suggesting good hydrocarbon saturation potential.

From the preceding, it stands out that the oil bearing zone is more porous and much permeable than the gas bearing zones. The hydrocarbon bearing zones for the three wells 1S-1X, 1S-3AX and 1S-4AX were found to be 18m, 33m, and 44m respectively. The Tano basin estimate of hydrocarbon bearing zone appears to be low hence its hydrocarbon is not sufficient enough.

Keywords: Water saturation; Tano Basin; Porosity; Permeability; Hydrocarbon Potential, Volume of shale.

1. Introduction

The Western Ghana Oil basin (Tano Basin) has witnessed numerous hydrocarbon exploration and investigation over the last century. Extensive gas and oil investigation continued with some oil discovery in 1978 (1S-1X). Similar findings have been reported in prospective wells with results tested about 1500 BOPD [1]. Due to the complexities in hydrocarbon exploration major discovery has been reported in recent years, 2007. The potential of hydrocarbon in the Western Ghana basin enclave has been of development interest. This work aims at estimating the Petrophysical parameters and analysis to judge the hydrocarbon potential in the basin from geophysical data from wells 1S-1X, 1S-3AX and 1S-4AX.

Hydrocarbon reserves potential is a key function in formation estimation and by large extent reserves capacity evaluation. It equally offers a lead variable in reservoir formation development and modeling. Key among the Petrophysical parameters includes water saturation, porosity, and permeability. Water saturation determination has always preceded the estimation of hydrocarbon potential. Accurate determination of hydrocarbon saturation, therefore, hinges on reliable water saturation predictions. Water saturation has been historically and reliably determined from standard well logs through accurate models. Historically the Archie's model [2] has been widely used in literature for the determination of water saturation. Archie's model has been found to be reliable with some limitations in that it applies to clean sands or none shale sands [3]. However, absolutely clean sand or none shale reservoir rocks hardly exit. The

Archie's model is a function of rock porosity, tortuosity factor, cementation exponent and saturation exponent. These factors are dynamic and therefore dependent on the geologic location of the area. The potential of the basin would, therefore, depend on water saturation, porosity and permeability trends of the basin.

The study uses accurate determinations of the Petrophysical properties which are essential to assess the economic viability of these reservoir wells in the Western Ghana oilfield.

2. Theory

As mentioned earlier, cementation factor, *m,* saturation exponent, *n,* and tortuosity factor, *a,* are key variables in the Archie's model. A conservative value of 2 has been assumed for cementation factor. For saturation exponent, it is reported in the literature to be between 2 (strongly water-wet rocks) and 25 (strongly oil-wet rocks) [4]. A value of unity is usually assumed for tortuosity, *a.* It is certain that wrong assumption of these variables affects the reliability of the saturation estimates. Archie's model [2] was initiated based on two experimental connections where resistivity index *(RI)* and formation factor (*F).* The resistivity index and formation factor are expressed as in Equation 1 and 2

$$RI = \frac{R_t}{R_o} = \frac{1}{S_W^n} \tag{1}$$

$$F = \frac{R_o}{R_W} = \frac{a}{\emptyset^m} \tag{2}$$

where *Rt* is the true resistivity of the rock saturated with both formation water and hydrocarbons; *R o* is the resistivity of a 100% water (brine)-saturated sandstone; S_w water saturation in fraction and *n* is the saturation exponent, R_w is the water (brine) resistivity; and *m* is the cementation factor, *a* is a tortuosity factor, ∅ rock porosity in a fraction.

Determination of water saturation

The determination of water saturation (S_w) is very critical to the evaluation of accurate water and hydrocarbon saturation. Rearranging Eq. 1and substituting into Eq. 2 gives

$$S_w = \left(\frac{1}{RI}\right)^{\frac{1}{n}} = \left(\frac{F\times R_W}{R_t}\right)^{\frac{1}{n}} \tag{3}$$

$$S_w = \sqrt[n]{\frac{a\times R_W}{\emptyset^m \times R_t}} \tag{4}$$

Water saturation S_w as shown in Eq. 4, therefore, depends on the variables as explained above with R_t, R_w, and ∅ obtainable from standard well logs. ∅ can be determined from conventional or nuclear magnetic resonance well logs [5]. Deep lateral resistivity (RLLD) or deep induction resistivity (RILD) logs are equally usable for determination of R_t and R_w [6].

Schlumberger well services [7] provides empirical charts available for validation of the well logs data. The other parameters in Eq. 4 that is *a, m* and *n* can be obtained through laboratory experiments on the reservoir rock samples as well as the fluids from the formation or well under consideration. However, due to the difficult nature of having representative samples within the zones combined with its time constraints, it is proposed to use log-derived resistivity and porosity cross-plots with well log data availability [8]. For sandstone formation as the case of the study area the formation resistivity factor is estimated with a = 0.61 and m = 2.

Determination of Irreducible Water Saturation

The phase of hydrocarbon saturation largely depends on the available permeability type and the irreducible water saturation (S_{wi}). A cross plot of porosity (∅) and water saturation (Sw) from log data is established and finding the best hyperbola to the data. Once the product of (∅ × Sw) has been determined, the irreducible water saturation is found by entering effective porosity on the appropriate charts [7]. For clean sandstone reservoir, the recommended parameter for the product (Ø × Sw) lies within 0.08 to 0.12 [9].

Permeability Estimation from the Wylie-Rose Method

Permeability is determined based on the general expression of [10]. Their proposed model have empirical relationships in which permeability can be estimated from porosity and irreducible water saturation derived from well logs. From their model, permeability is expressed as in Equation 5 and 6.

$$K = \left(\frac{79\times\emptyset^3}{Swi}\right)^2 for\ gas \quad (5)$$

$$K = \left(\frac{250\times\emptyset^3}{Swi}\right)^2 for\ oil \quad (6)$$

where K is absolute permeability and ∅ is the true porosity, and Swi is irreducible water saturation.

Porosity calculations

Porosity is an additional measure of the quality of porous media. This is measured experimentally from density tools or density logs and neutron logs. The density porosity is derived as a function [2] formation bulk density and bulk matrix density as Equ. 7.

$$\emptyset_D = \frac{2.71-\rho_b}{2.71-\rho_f} \quad (7)$$

where: ρ_b: is the bulk density of matrix, and it is usually between 2.65gm/cc and 2.87gm/cc depending on the rock type, while ρ_f: is the fluid density which varies between 1gm/cc and 1.1gm/cc for fresh water mud and salt water mud respectively.

Neutron logs indicate the level of hydrogen amounts in clean formations (i.e., shale-free), where the pores are filled with water or oil. Therefore hydrogen is concentrated in the fluid-filled pores, energy loss can be related to the formation porosity (ΦN) [11]. Hence, an average of density and neutron porosity is derived.

3. Study area

In this study, three wells namely 1S-1X, 1S-3AS, and 1S-4AX were studied, tables 1a to 1c. The studied wells are located in the Western Basin (Tano Basin), a sub-basin of Cape Three Point. It forms part of the larger Ivory Coast Basin in the Gulf of Guinea of West Africa. Geographically, the area lies 4°46′ north of latitude and about 3° west of longitude, east-west onshore-offshore structural basin [12]. It is precisely 35km offshore of Ghana and occupies about 3000km^2 Figure 1.

Table 1a. WELL 1S - 1X raw petrophysical data

ZONES	Depth / Meters	GR API	Msfl	Rllm shallow	Rlld Deep	Density g/cc	CNL ØN
1	1838 - 1841	30	10	20	40	2.45	6
5	1850 - 1853	42	4	7	7	2.325	23
8	1856 - 1857	45	3.5	9	9	2.275	22.5
9	1857 - 1859	45	2.2	7	7	2.275	22.5
10	1859 - 1861	40	6	9.8	9.8	2.25	25.5
11	1861 - 1864	35	7	10	20	2.40	12
12	1864 - 1867	45	3	8	8	2.275	24
13	1867 - 1868	45	10	17	17	2.425	13.5

Table 1b. WELL 1S - 3AX raw petrophysical data

ZONE	Depth Meters	GR API	Msfl	Rllm shallow	Rlld Deep	FDC (ØD)	CNL (ØN)
2	2034 - 2035	30	3	3	9.5	2.4	32
8	2042 - 2043	50	2	2	8	2.45	33
22	2158 - 2164	30	1.5	4	5	2.31	36.8
38	2223 - 2225	22	10	90	90	2.45	36
67	2360 - 2363	30	1.5	5	7	2.38	30
69	2364 - 2365	30	2.5	6	8	2.35	15
71	2366 - 2367	30	1.5	5	7	2.35	21

72	2367 - 2370	30	2	5	7.5	2.35	21
73	2370 - 2371	30	2	4.5	7.5	2.35	21
74	2371 - 2373	30	10	6	8	2.33	22.5
75	2373 - 2375	30	2	4	4.2	2.33	22.5
76	2375 - 2377	30	6	5	5	2.33	21
77	2377 - 2393	65	0.9	0.95	0.95	2.39	28
78	2393 - 2396	72	2	0.96	0.96	2.42	31

Table 1c. WELL 1S - 4AX raw petrophysical data

Zone	Depth Meters	GR API	Msfl	Rllm shallow	Rlld Deep	CNL (ØN)	FDC (ØD)
7	1856 - 1859	67.5	3	3	3	30	2.4
8	1859 - 1862	67.5	3	4	4	28.5	2.43
9	1862 - 1864	45	4	9	9	24	2.38
10	1864 - 1865	37	60	30	40	21	2.45
11	1865 - 1867	37	5	10	15	25.5	2.32
12	1867 - 1868	37	40	20	30	18	2.4
13	1868 - 1870	37	5	9.7	10	18	2.4
14	1870 - 1871	37	60	20	30	18	2.4
15	1871 - 1878	45	5	9.5	9.7	24	2.35
16	1878 - 1879	37.5	5	20	30	21	2.38
17	1879 - 1881	37.5	40	30	30	18	2.4
18	1881 - 1885	45	3	7	8	27	2.34
19	1885 - 1887	45	9.5	9	9	27	2.4
20	1887 - 1889	45	4	7	7	28	2.35

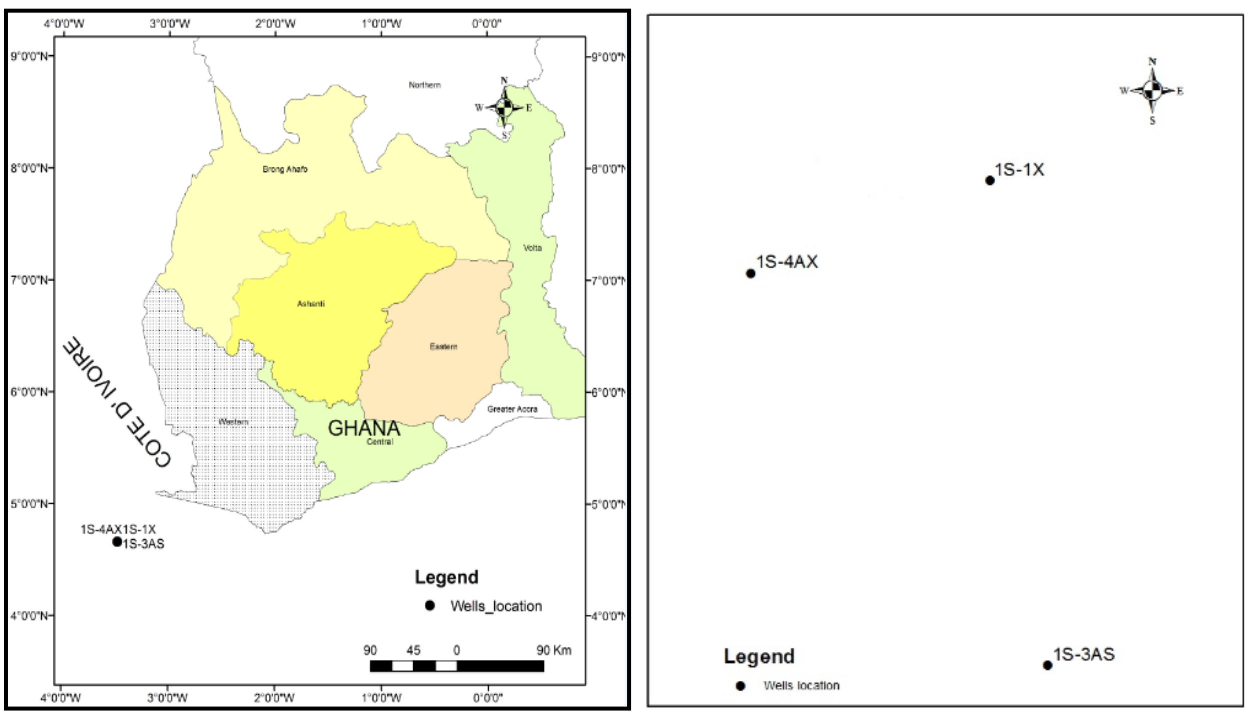

Figure 1. Location of studied wells

4. Results and discussions

4.1. Analysis of results of Well 1S-1X

Table 2a details the characterized oil and gas hydrocarbon zones. The well shows a pay zone depth of about 18m. The evaluated petrophysical values of the oil zones read much higher values than the gas zones. Discriminating the petrophysical properties in oil and gas zones shows that the former zone is more previous and penetrable. This translate to average porosity, permeability and water saturation values of 25.48%, 115.42mD and 41.17% which are in favour of the oil zone and that of the gas zone as 14.89%, 0.19mD, and 41.6% respectively. The well reveals over 50% of the hydrocarbon concentration.

Table 2a. WELL 1S - 1X Reservoir Hydrocarbon Potential

Vsh, GR	Ø	Sw	Sxo	Sw/Sxo	Swi	K/mD	Hydrocarbon Predicted
0.09	12.42	0.382	0.976	0.391	0.760	0.04	Gas
0.35	23.73	0.478	0.808	0.591	0.425	61.84	Oil
0.41	25.19	0.397	0.814	0.488	0.400	99.80	Oil
0.41	25.19	0.450	1.026	0.439	0.400	99.80	Oil
0.30	27.42	0.350	0.571	0.612	0.372	191.78	Oil
0.20	16.30	0.412	0.889	0.463	0.640	0.29	Gas
0.41	25.87	0.410	0.856	0.479	0.389	123.89	Oil
0.41	15.96	0.456	0.760	0.600	0.660	0.24	Gas

4.2. Analysis of results of Well 1S-3AX

A total of 13 hydrocarbon zones well delineated from this well Table 2b. The zones are predominantly oil bearing zones with average porosity, permeability and water saturation values of 24.47%, 92.03mD and 56.8% respectively. The hydrocarbon bearing zone detected reveals a pay zone depth of 44m with hydrocarbon saturation of about 43%.

Table 2b. WELL 1S - 3AX Reservoir Hydrocarbon Potential

Vsh, GR	Ø	Sw	Sxo	Sw/Sxo	Swi	K/mD	Hydrocarbon Predicted
0.18	26.57	0.366	0.833	0.440	0.45	108.47	Oil
0.57	26.09	0.407	1.039	0.391	0.46	93.18	Oil
0.18	31.62	0.424	0.990	0.429	0.38	432.33	Oil
0.02	28.00	0.113	0.433	0.261	0.43	163.05	Oil
0.18	25.87	0.438	1.210	0.362	0.463	87.49	Oil
0.18	19.33	0.549	1.254	0.437	0.625	0.83	Gas
0.18	21.95	0.517	1.426	0.362	0.54	23.96	Oil
0.18	21.95	0.499	1.235	0.404	0.54	23.96	Oil
0.18	21.95	0.499	1.235	0.404	0.54	23.96	Oil
0.18	23.33	0.455	0.520	0.875	0.516	37.83	Oil
0.18	23.33	0.628	1.162	0.540	0.516	37.83	Oil
0.18	22.62	0.593	0.692	0.857	0.532	29.56	Oil
0.86	24.46	1.258	1.652	0.762	0.484	57.17	Oil
1.00	25.50	1.201	1.063	1.129	0.47	77.71	Oil

4.3. Analysis of results of Well 1S-4AX

A total of 14 hydrocarbon bearing zones is detected in this well Table 2c. The zones predicted both oil and gas in equal measure with a total pay zone depth of 33m. However, the oil zones show more porous and permeable than the gas zones. This translate to average porosity, permeability, and water saturation values of 24.34%, 81.13mD and 47% which are in favour of the oil zone and that of the gas zone as 19.22%, 1.23mD, and 31.4% respectively. Additionally, the well reveals well of over 50% hydrocarbon saturation.

Table 2c. WELL 1S - 4AX Reservoir Hydrocarbon Potential

Vsh, GR	Ø	Sw	Sxo	Sw/Sxo	Swi	K/mD	Hydrocarbon Predicted
0.70	25.37	0.683	0.873	0.782	0.39	109.60	Oil
0.70	23.75	0.632	0.932	0.678	0.425	62.13	Oil
0.21	22.53	0.444	0.851	0.522	0.45	40.34	Oil
0.04	18.89	0.251	0.262	0.958	0.528	1.02	Gas
0.04	25.13	0.308	0.682	0.452	0.401	97.98	Oil
0.04	18.86	0.290	0.321	0.903	0.528	1.01	Gas
0.04	18.86	0.503	0.909	0.553	0.528	1.01	Gas
0.04	18.86	0.290	0.262	1.107	0.528	1.01	Gas
0.21	23.44	0.411	0.732	0.562	0.43	56.00	Oil
0.05	20.98	0.261	0.817	0.319	0.48	2.31	Gas
0.05	18.86	0.290	0.321	0.903	0.528	1.01	Gas
0.21	25.31	0.419	0.875	0.479	0.392	106.84	Oil
0.21	23.63	0.423	0.527	0.804	0.42	61.62	Oil
0.21	25.56	0.444	0.750	0.591	0.39	114.54	Oil

4.4. Porosity, Water saturation, Volume of shale versus Depth

Figures 2 to 4 show how the comparison of porosity, water saturation and volume of shale with the depth of burial for well 1S-1X, 1S-3AS and 1S-4AS.

A comparison of porosity water saturation and volume of shale values from the Tano Basin Sandstone indicate a predictable relationship with depth is owing to diagenetic changes in the pore structure. This predictive relationship is useful for evaluating the geological separation capacity. The relationship between burial depth with porosity, water saturation, and volume is useful for prediction of the petrophysical character. Understanding the relationship between Petrophysical parameters and depth also provides information that can be used in numerical models. The fundamental relationship of decreasing porosity and volume of shale with depth generally holds true on a well 1S-3AX and 1S-4AX except water saturation. However, in well 1S-1X a reversal in the porosity and volume of ash with depth relationship is observed.

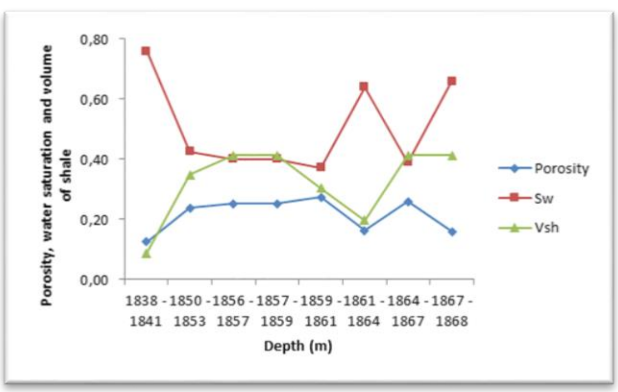

Figure 2. Depth plot of Petrophysical properties of well 1S-1X

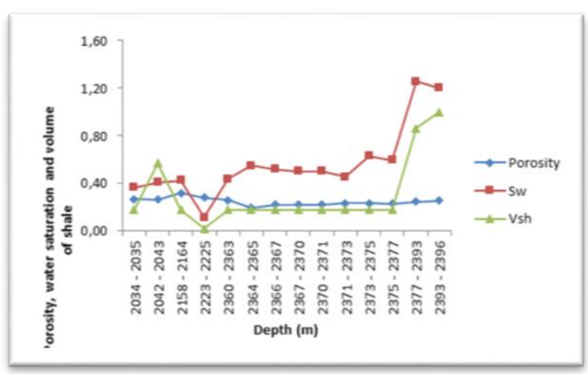

Figure 3. Depth plot of Petrophysical properties of well 1S-3AX

4.5. Porosity-Permeability

Permeability and porosity are largely affected by the size of grains and sorting [13]. Many studies have shown that permeability is a function of porosity. As predictable in figure 5, permeability increases with grain size increases and sorting. This shows that as porosity increases there is a direct effect on permeability. The cross plots of permeability and porosity for the three wells 1S- 1X, 1S-3AX and 1S-4AX share similar characteristics regarding trend. Porosity ranges from 12.42% to 27.42% and permeability ranges from 0.04mD to 432mD.

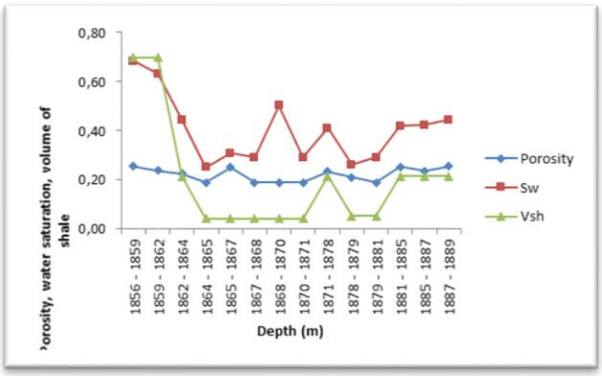

Figure 4. Depth plot of Petrophysical properties of well 1S-4AX

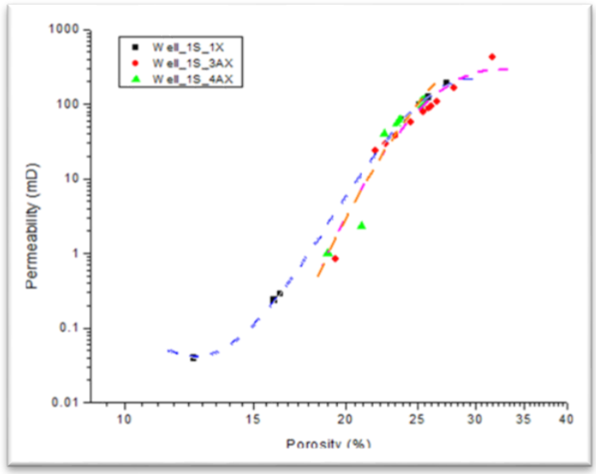

Figure 5. Permeability versus porosity plots

5. Conclusions

Petrophysical analyses were carried on available well log data from the three exploratory wells in the Western Tano Basin in Ghana. The Petrophysical variable derived from the log analyses includes permeability, porosity, water saturation and volume of shale. These Petrophysical parameters were handy to characterize the reservoir and then determine the potential of the basin. From the unified estimation of the Petrophysical parameters from the three wells and the supporting discernment it is safe to suggest that the Tano Basin has some potential for oil and gas. This is confirmed by the observation of oil and gas in all three wells at different bearing zones which range between 1838m and 2396m. The permeability and porosity evaluations confirm the porous and more permeable nature of oil bearing zones than gas bearing zones in literature. The tighter the reservoir, the more inclined it is to be gas bearing. Hydrocarbon pay zones were found to be between 18m and 44m.

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