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Petrophysical Analysis of E5 sand group of Sokor Formation, Termit Basin, Niger

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Abstract. The main objective of well logging is to estimate the petrophysical properties of reservoirs which includes porosity and hydrocarbon saturation for hydrocarbon exploration and production purposes. This paper portrays the result of a wireline log study on the E5 sand group of Sokor Formation of the Paleogene in Termit Basin. The objectives of this research are to differentiate the log characteristics of the sediment in the Sokor Formation and provide a preliminary result of the porosity, permeability and hydrocarbon saturation of the study area. A total number of 3 wells were fully evaluated for this research. A compilation of wirelines data sets availability which includes calliper log, gamma ray log (GR), neutron log (NPHI), density log (RHOB) and resistivity logs (RD and RS) were carefully analysed during this study. Petrophysical analysis reveals that the E5 sand group of Sokor Formation has a very high porosity of up to 28.7% and high hydrocarbon saturation up to 88.7%. The suggests future work should include the integration of well log analysis with core analysis.

1. Introduction

The Termit Basin is located in the Western African Rift System (WARS) of Western Central African Rift System (WCARS). It is bounded by the Tenere and Tefidet basin in the north and Bornu basin in the south[1]. It has a total length of approximately 300km and covers an area of approximately 2.7×10^4 km². It is composed of several formations known as Donga, Yogou, and Madama (Upper Cretaceous), Sokor-1 (Paleocene-Eocene) and Sokor-2(Oligocene). Existing petroleum system in Termit Basin are present in the Upper Cretaceous and Paleogene specifically the Yogou–Sokor-1 and Sokor-1–Sokor-2 systems with most of the hydrocarbon discoveries were found in Sokor-1 Formation[2].

Previous studies have shown that Sokor Formation has excellent reservoir properties suitable for hydrocarbon accumulation. However, quantitative log analysis for E5 sand group of Sokor Formation to determine its porosity and water saturation has not been fully evaluated. This paper shows the result of the petrophysical analysis of 3 sets of well logs data (A1, A2 and A3) from the Termit Basin area in Western Central African Rift System (WCARS). The aim of the petrophysical analysis is to analyse the log responses and to convert them into petrophysical properties such as porosity, permeability and oil saturation [3]. In this analysis, qualitative interpretation was done by the optimizing the calliper log, gamma ray log (GR), neutron log (NPHI), density log (RHOB) and resistivity logs (RD and RS) to determine the lithology of the rock Formation and distinguishing between reservoir and non-reservoir zones. Quantitative interpretation was conducted to estimate the values of petrophysical properties of the zones of interest (reservoir) such as porosity and hydrocarbon saturation. The petrophysical analysis is aimed to provide a more realistic representation of the petrophysical properties of Sokor Formation which can support the formation evaluation for exploration purposes in the future.



2. Geological Setting and Background

Niger is located in West Africa between the latitude of 12° N and the Tropic of Cancer line. It covers an area of $1.27 \times 10^6 \text{ km}^2$. It is bounded by Algeria and Libya to the north, Mali and Burkina Faso to the west, Benin and Nigeria to the south and Chad to the east[4]. Termit basin is one of Mesozoic-Cenozoic rift basins and the largest basin in the West Africa Rift System (WARS) of the Western Central African Rift System (WCARS). Termit Basin is enclosed by Tefidet and Tenere basins on the northwest, and Borau basin at southeast[1]. It has a total length of approximately 300km long measured from north to south. The width of the narrowest area of the Termit Basin which is located at the north end, is about 60km, while the widest area is about 110km across located at the south area of the Termit Basin [5]. It covers an area of approximately $2.7 \times 10^4 \text{ km}^2$ and trends NW – SE[2]. The general vertical profile of Termit Basin consists of the Precambrian basement which are made of igneous and metamorphic rock. The basement created a unique trend of faults that act as the trend direction for the Cretaceous-Tertiary rifts in Termit Basin. It is overlain by the Lower Cretaceous, Upper Cretaceous, Paleogene, Neogene and Recent sediments deposited in sedimentary basins[6]. Several kilometers of Lower Cretaceous clastic sediments, primarily lacustrine shale and sandstone, were deposited during rifting. During late Lower Cretaceous, active rifting caused a thermal subsidence to occur. This allowed the progradation of spreading fluvial, deltaic and, shallow marine facies[5].

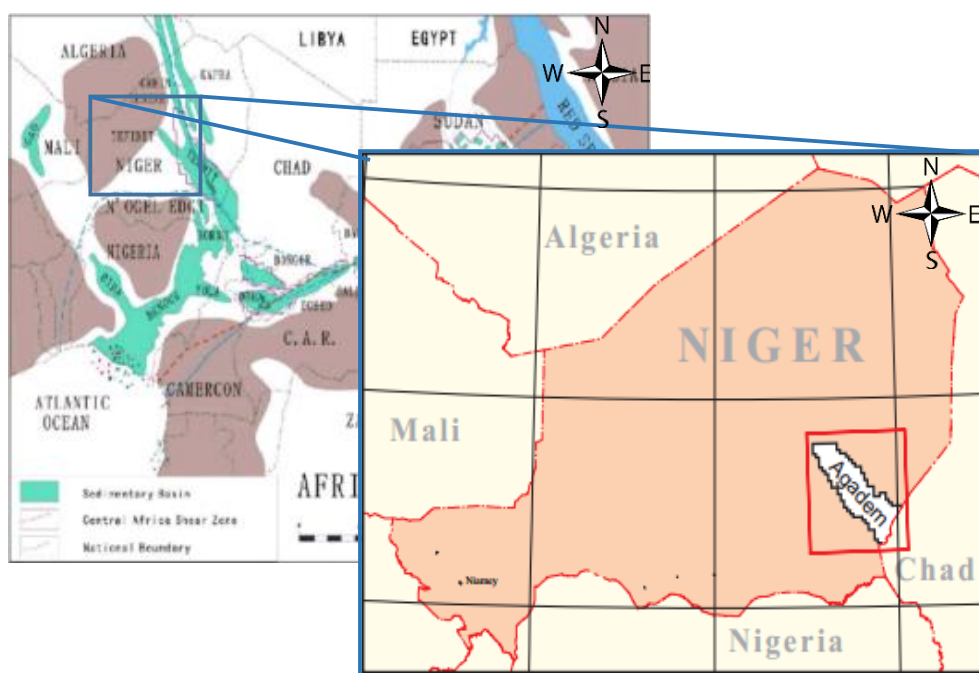


Figure 1. Regional Map of Termit Basin and Agadem Block (Modified from Liu, 2015 and Pan, 2013)

3. Petroleum System

3.1. Source Rock

The hydrocarbon source beds of the Termit Basin are located within the Upper Cretaceous mudstones which is in Donga and Yogou Formation while Paleogene mudstones which are located in the Sokor-1 and Sokor-2 Formation[7]. The Donga Formation varies of grey to dark marine shale, a poor to fair quality source rock, which is dominated by the Type II and III kerogen[1]. The TOC value for the Donga Formation mudstones varies from 0.42% to 1.47%, averaging 0.89%, and S2 yields range from 0.29 to 2.8 mg HC/g rock, averaging 1.1 mg HC/g rock. The Yogou Formation can be separated into two members known as the upper and lower members separated by a conformable boundary. The upper member consists of by interbedded light to medium grey sandstones and light to dark grey mudstones, while the lower member consists of thick dark grey to black mudstones. The TOC within the Yogou Formation varies from 0.36% to 23.32%, with an average of 2.6%. The Rock-Eval pyrolysis, S2 within the Yogou Formation varies from 0.15 to 70.15 mg HC/g rock, which has an average of 5.59 mg HC/g rock. The maximum temperature Tmax vs Hydrocogen index HI analysis reveals that the organic matter of the upper member of the Yogou Formation contains Type I, II, II-III and III kerogen while the lower member is dominated by Type II-III and III material[2]. Gray to dark gray lacustrine shale of Sokor Formation composed of organic shale, that was deposited during the of the second rift cycle. It is a good to excellent source rock which has a high HI values reaching 800 mg HC/g. The TOC content ranges from 0.2% to 23.7% with kerogen Type I and II.

3.2. Reservoir

The reservoirs rock for the Termit Basin are found in the Sokor-1 and Yogou Formations. The reservoir within Sokor-1 and Yogou Formations are sandstones of the fluvial, deltaic and lacustrine depositional environments. The thickness of sandstone in, Sokor-1 Formation varies from less than 1m-50 m, (2% of the sandstone is above 40m), which represent composite bodies of stacked channels. It composed high quality quartz sandstones, have porosity varying from 16% to 36% with mean of 20%-28%, and permeability from 250 md to 1 Darcy. The thickness of sandstones in Yogou Formation varies from less than 1 m- 25 m. The average porosity and permeability varies from 20% to 25% and 100 to 250 mD, respectively[1].

3.3. Seal

The mudstones within the Sokor-2 represent the regional seal of the Termit Basin that are deposited during the second rifting cycles because it is composed of thick of lacustrine mudstones. The average thickness of the seal can reach up to 100m and 500m in the proximal and central basin, respectively. Intra-Formational mudstone and shale that formed within Sokor-1 and Yogou Formations act as local seal rock for individual reservoirs both at top and lateral seals against which reservoir sands are juxtaposed due to faulting. Hydrocarbon is mainly found in structural traps, which were dominated with footwall blocks and horsts, controlled by faults formed during rifting cycle[1].

3.4. Trap

The WCARS hydrocarbon traps are mostly made up of fault blocks[8]. The hydrocarbon stored within the reservoir rock of Termit basin are mainly founded by structural traps. The structural trap is dominated by the footwall blocks and horsts, which are affected by the faults that are formed during the rifting process [3].

4. Objective

To investigate the petrophysical properties of E5 sand group of Sokor Formation.

5. Methodology

The methodology of this research uses both qualitative and quantitative interpretation. Qualitative interpretation is done by identifying the zones of interest which is clean sandstone within the formation. The separation between the clean sandstone and shale is determined by using the gamma ray, density, neutron and resistivity logs. The clean sandstone with hydrocarbon has a characteristics of low GR response, low density response, mid-high neutron log response, high resistivity response, and wide separation between the shallow and deep resistivity response.

The initial step in quantitative interpretation is estimating the shale volume. The shale volume is determined to estimate the fraction of clay in the rock formation for the calculation of effective porosity. The shale volume is calculated using the gamma ray response. The equation for the shale volume V_{sh} using GR response is:

$$V_{sh} = \frac{GR_{log} - GR_{sand}}{GR_{shale} - GR_{sand}} \quad (1)$$

Neutron porosity obtained from the neutron log is known as the total neutron porosity Φ_{TN} . In order to estimate the neutron effective porosity Φ_{EN} , the shale-bound water must be removed from the neutron total porosity. Total density porosity Φ_{TD} can also be calculated using the density logs via equation (2). In order to estimate the density effective porosity Φ_{ED} , the shale-bound water must be removed from the total density porosity. The equation for the correction of effective density porosity from the total density porosity is given in equation (3):

$$\Phi_{TD} = \frac{\rho_{matrix} - \rho_{log}}{\rho_{matrix} - \rho_{fluid}} \quad (2)$$

$$\Phi_{ED} = \Phi_{TD} - (V_{sh}\Phi_{sh}) \quad (3)$$

Since the analysis of the wells shows the presence of oil, the effective porosity, Φ_E for both density and neutron logs is calculated using the equation:

$$\Phi_E = \frac{\Phi_{ED} + \Phi_{EN}}{2} \quad (4)$$

Water saturation, S_w , is calculated using the Archie's equation. Archie's equation is the equation that is derived from the resistivity and porosity of sedimentary rock to estimate water saturation. The Archie's equation is given as

$$S_w = \left(\frac{aR_w}{(\Phi^m)R_t} \right)^{\frac{1}{n}} \quad (5)$$

S_w	= Water Saturation	m	= cementation exponent
a	= tortuosity constant	n	= saturation exponent
R_w	= resistivity of Formation water	R_t	= resistivity of true Formation

Hydrocarbon saturation, S_{hc} , is computed using the equation:

$$S_{hc} = 1 - S_w \quad (6)$$

6. Results and Discussion

6.1. Qualitative Interpretation

Lithology identification is conducted to describe the mineralogy of the formation, thus distinguishing between sandstone (reservoir) and shale (non-reservoir). Gamma ray logs play an important role to determine lithology as it measures the concentration of the clay content in the Formation. Low response of GR logs indicates the presence of sandstone, while high response of GR log indicates the presence of shale.

Determination of formation permeability was done using calliper logs and resistivity logs. Calliper logs records the size of the borehole diameter relative to the bit size. The presence of mudcake represents the presence of sandstone due to the porosity and permeability of the sandstone that act as a filter that allows the mud filtrate to enter the formation, leaving the mud at the borehole wall, hence, reducing its diameter. Separation between deep and shallow resistivity logs represents the permeability of the formation. Wide separation of the deep and shallow resistivity logs represents a permeable formation. Three zones of sandstone intervals were identified to have a good potential hydrocarbon reserves.

Fluid content of the sandstone is determined using the density logs (RHOB) and neutron logs (NPHI). The characteristics of the cross over between the two logs response were used to determine the fluid content. All the log responses from the sandstone zone generate a lower density and middle-high neutron porosity which is associated with the presence of liquid content. Hydrocarbon content is determined by the deep resistivity logs (RD). Indication of the RD which is middle-high (exceeds 20ohm-m) represents hydrocarbon is reserve within the reservoir interval. Figure 3 shows the well log responses of well A2 in Sokor-1 Formation. Three zones of low GR response are labelled as X1, X2 and X3 are identified which indicates the presence of sandstone formation. Figure 2 shows the well response of well A2. All three wells are then correlated to assess the homogeneity distribution of the sandstone interval. Figure 3 shows the well correlation for wells A1, A2 and A3.

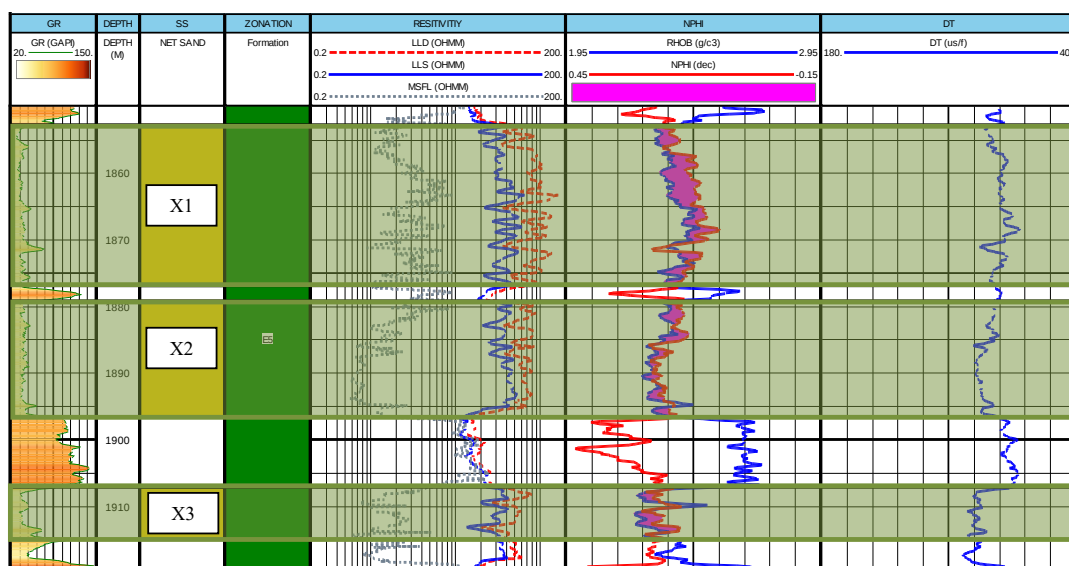


Figure 2. Well log response of well A2 in E5 sand area, area shaded in green indicates the presence of oil.

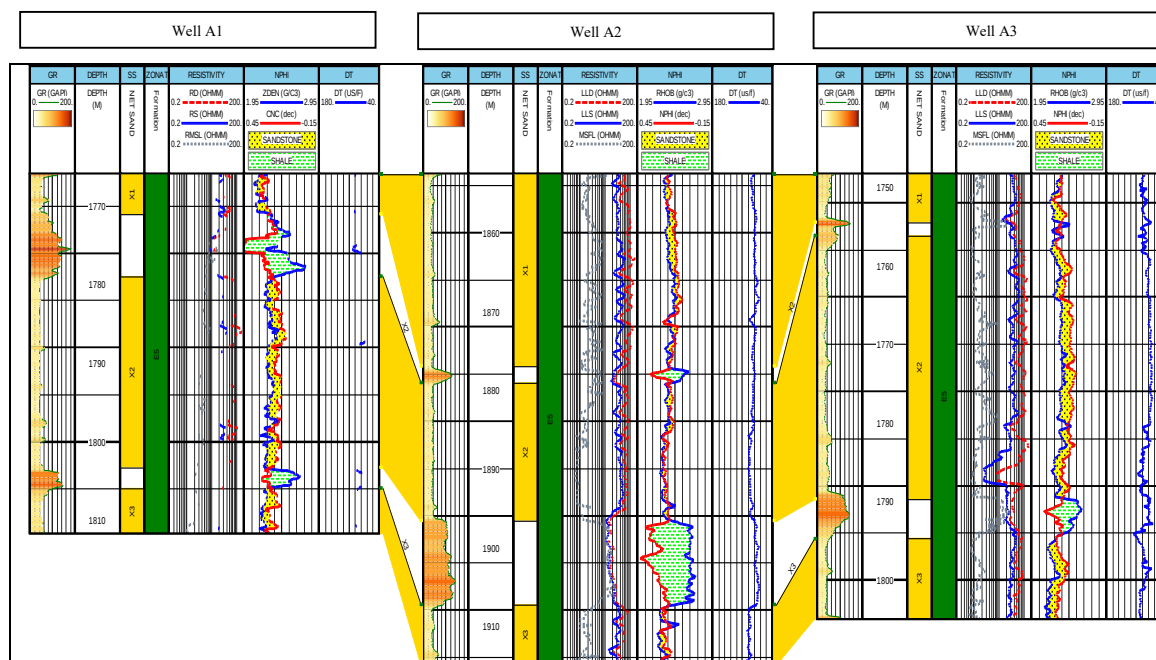


Figure 3. Well Correlation for wells A1, A2 and A3

Table 1, Table 2 and Table 3 represent the summary of results obtained from the qualitative interpretation for E5 member in Sokor-1 Formation of Well A1, A2 and A3 respectively.

Table 1. Results of qualitative interpretation for E5 sand group in Sokor-1 Formation of Well A1

No	Depth Interval(m)	Thickness(m)	Lithology	Shows	Zone
1	1766-1771	5	Sandstone	Oil	X1
2	1779-1803	24	Sandstone	Oil	X2
3	1806-1829	23	Sandstone	Oil	X3

Table 2. Results of qualitative interpretation for E5 sand group in Sokor-1 Formation of Well A2

No	Depth Interval(m)	Thickness(m)	Lithology	Shows	Zone
1	1853-1877	24	Sandstone	Oil	X1
2	1879-1897	18	Sandstone	Oil	X2
3	1907-1915	12	Sandstone	Oil	X3

Table 3. Results of qualitative interpretation for E5 sand group in Sokor-1 Formation of Well A3

No	Depth Interval(m)	Thickness(m)	Lithology	Shows	Zone
1	1749-1755	6	Sandstone	Oil	X1
2	1763-1790	27	Sandstone	Oil	X2
3	1795-1805	10	Sandstone	Oil	X3

6.2. Quantitative Interpretation

Quantitative petrophysical analysis was conducted to determine the petrophysical properties of the formation. Petrophysical properties are calculated using the equation that mentioned earlier in this paper. Quantitative petrophysical analysis was conducted at the zones of interest that was determined using the qualitative interpretation. Table 4 summarizes the results from the petrophysical analysis from all three wells in the area. The petrophysical properties are represented by the values of porosity, Φ , water saturation, S_w , and hydrocarbon saturation, S_{hc} .

Table 4. Results of petrophysical analysis for E5 sand group in Sokor-1 Formation for all wells

No	Well	Zone	Φ (%)	S_w (%)	S_{hc} (%)
1	A1	X1	28.7	30.1	69.9
2		X2	22.5	30.1	69.9
3		X3	25.6	34.3	65.7
4	A2	X1	16.8	32.7	67.3
5		X2	20.2	27.5	72.5
6		X3	22.1	29.5	70.5
7	A3	X1	23.2	35.7	64.3
8		X2	19.8	34.6	65.4
9		X3	26.7	27.0	73

6.3. Discussion

Based on the petrophysical analysis conducted on all wells A1, A2, and A3 shows that sand body E5 in Sokor-1 Formation has an excellent vertically distribution of high thickness of sandstone, up to 27m, because they were deposited in a fluvial environment. Low gamma ray, mudcake, wide separation of deep and shallow resistivity, crossover of low density and middle high neutron, and high resistivity response from the well logs show the favourable characteristics for accumulation of oil. The bodies of sandstone were correlated in 3 wells within the study area labelled as X1, X2 and X3 using beds marker. The porosity of all the interpreted zone has a range between 16.8 to 28.7%. The hydrocarbon saturation show has a range from 64.3% to 88.7%. This result shows that the sand group has the ideal petrophysical properties to allow hydrocarbon accumulation.

7. Conclusion

The objective in petrophysical analysis of E5 sand group for Sokor Formation in Termit Basin, was accomplished. The results show that the Sokor Formation contains adequate properties with high porosity average of 22.51% and up to 28.7% and high hydrocarbon saturation up 88.7%. A more realistic result can be obtained from petrophysical-core integration to validate the parameters calculated, which can be conduct in the future. A wider area within the Termit Basin for petrophysical analysis can also be conducted in the future to obtain a more accurate result. As a conclusion, the methodology and results obtained from this study can be used to improve the petrophysical properties of E5 sand group of Sokor Formation for exploration purposes in the future.

8. Acknowledgment

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