Human Journals
Research Article
October 2022 Vol.:22, Issue:4

Characterization of the Paleogene Age Reservoir Formation of the Termit Basin, Using Petrophysical Parameters and Log Data: Case of the Agadem Block (East-Niger)

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Submitted: 25 September 2022
Accepted: 30 September 2022
Published: 30 October 2022

www.ijsrm.humanjournals.com

Keywords: Characterization, reservoir, petrophysics, logging data, Termit

ABSTRACT

The present study on the characterization of the Paleogene age reservoir formation of the Termit basin, has the general objective of characterizing in petroleum terms the reservoir units of the Sokor prospect of the Agadem block (Termit basin). The methodology implemented is based on the analysis of the petrophysical parameters of the SK-E1 well, such as the Porosity, the Permeability (K) and the Water saturation (S_w) as well as on the log data such as Resistivity (RD), Gamma Ray (GR) and Clay Volume (V_{sh})). The Paleogene reservoir formation (Sokor-1) of the SK-E1 well is mainly subdivided into three reservoir units separated by clay beds. This reservoir formation is the main exploration target for clayey intercalations of variable thickness. These reservoir units or levels are called E1, E2 and E3. The results obtained showed that among all the reservoir units, only the E1, E2 and E3 units are promising. These units have porosity values that can exceed 24,9 % and permeability values that can exceed 679,2 mD. The correlation of these two petrophysical parameters (porosity and permeability) showed that the reservoir units (E1, E2 and E3) present good values of porosity and permeability, this indicates that these units are the best reservoir units of the study prospect. The combined correlation of water saturation and resistivity as a function of depth makes it possible to deduce the nature of the fluids contained in the reservoir units, which can be either hydrocarbons or water. This indicates that reservoir units E1 and E2 have resistivity values varying from 10 Ohmm to 22,2 Ohmm respectively. According to this analysis, units E1 and E3 are the most saturated hydrocarbon reservoir units in the SK-E1 well of the Sokor prospect.

INTRODUCTION

The Termit Basin is a sub-basin belonging to the Eastern Niger Basin. It is one of the largest trenches belonging to the Cretaceous-Tertiary rift in West Africa and the Central Rift System (WCARS) [1-3]. It is one of the first basins rich in hydrocarbons [4]. The hydrocarbons currently discovered come from marine and continental source rocks of the Upper Cretaceous (thickness varying from 500 to 2000 m) and from marine and lacustrine sources of the Paleogene. Despite the exploitation of certain deposits and recent discoveries, the Termit basin, one of the largest troughs from the Cretaceous to the Tertiary still remains underexplored [5-7]. The reservoir formations of the Termit basin were set up in three periods: a period of rifting in the Upper Cretaceous, a period of thermal subsidence in the Lower Cretaceous and another period of rifting in the Paleogene. The target reservoir formation in this study is the Sokor-1 formation (Sokor alternations) of Paleogene age. This formation is subdivided into 3 reservoir units in the case of the Sk-E1 well.

The general objective of this study is to characterize in petroleum terms the formation of Sokor-1. The specific objectives are to; (1) determine the different reservoir levels of the Sokor-1 formation, (2) identify the nature of the fluid contained in these reservoir units. The methodology implemented is based on the analysis of petrophysical parameters such as Porosity, Permeability (K) and Water Saturation (S_w) as well as on log data such as Resistivity (RD), Gamma Ray (GR) and Clay Volume (V_{sh})). These parameters make it possible to assess the quality of the reservoirs as well as the nature of the fluids contained in the reservoir formation (Sokor-1).

REGIONAL GEOLOGICAL CONTEXT

The Termit Basin is an elongated intra-plate tectonic structure trending NW-SE and belongs to the West African Rifts Subsystem (WAS) itself belonging to the East African Rifts System. West and Center (WCARS) [6-7]. It is a Meso-Cenozoic Rift basin whose filling is of Cretaceous age lower than the Holocene-Pleistocene (Quaternary). The Termit basin is an intracontinental basin between Niger, Chad and Nigeria, it is one of the largest basins of eastern Niger lying astride between the Borno basin in Nigeria and the Doba-bongor basin in Chad [6-8]. It was developed during the opening of the Atlantic Ocean in the Cretaceous (Figure 1).

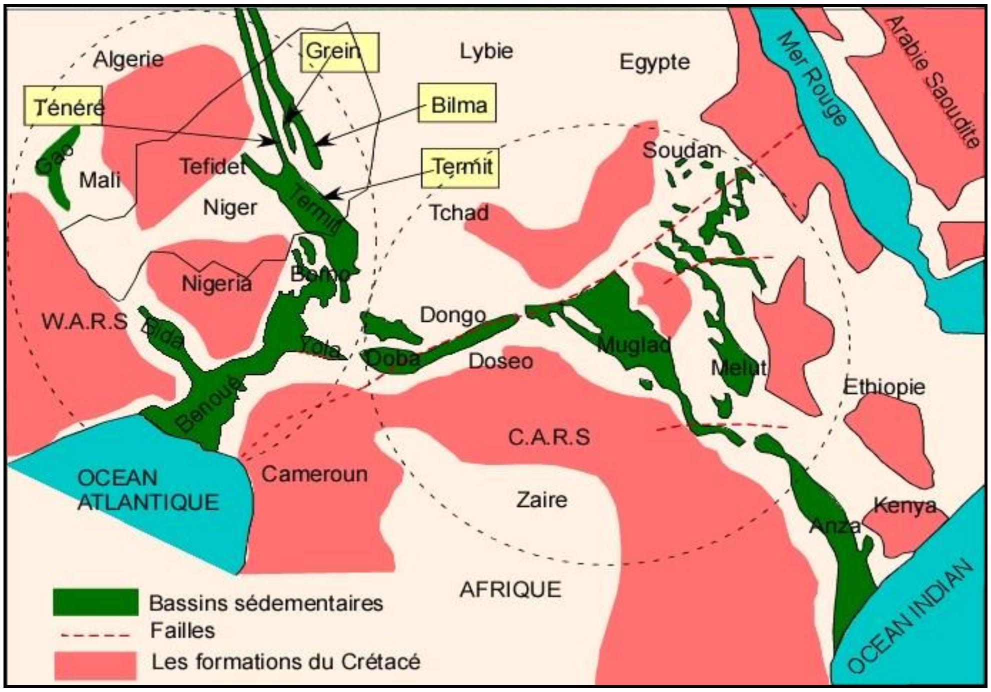

Figure 1: **Regional geological map showing the Termit basin in the WARS [6,7]**

LITHO-STRATIGRAPHIC ASPECT OF THE TERMIT BASIN

From its formation to the present day, the Termit Basin has experienced two deposition episodes: one (1) in the Upper Cretaceous accompanied by a marine transgression and the other (2) in the Paleogene [5.7-8]. The sedimentary series is made up of sandstone and marine and continental clays whose maximum thickness of deposit can exceed 12,000 m [3], [8]. According to the various data (seismic, drilling, paleontological and stratigraphic), the sequence of formations constituting the basin of Termit is composed from the base to the summit by:

• The Pan-African Basement which is composed of biotite gneiss, pegmatite, quartz, mica and phyllite and metamorphosed siltstones intercalated by limestone bed.

• Cretaceous formations

✓ The formation of the Lower Cretaceous K1, this is composed of continental deposits consisting of siliceous sandstone, Kaolinite and partially by quartzitic formations intercalated in places by thin clayey banks.

✓ The Upper Cretaceous K2 formation, this formation is composed by the Donga, Yogou and Madama formation. It constitutes the marine and fluvial deposits.

• The Paleogene formation which is mainly constituted by a layer of low velocity clay (Low Velocity Clays) and sandstone-clayey layers interstratified with thin layers of shale clay.

• The Neogene formation is formed mainly from fluvial deposits, consisting of sandstone-clayey in its lower part and massive intrastratified sandstone with a few thin layers of shale clay in its upper part.

• The recent formation of the Quaternary is composed of massive sandy beds of yellowish gray color and greenish gray to grayish clays.

All of its sedimentary formations rest on a Precambrian granitic and metamorphic basement reactivated during the Pan-African orogeny (Figure 2).

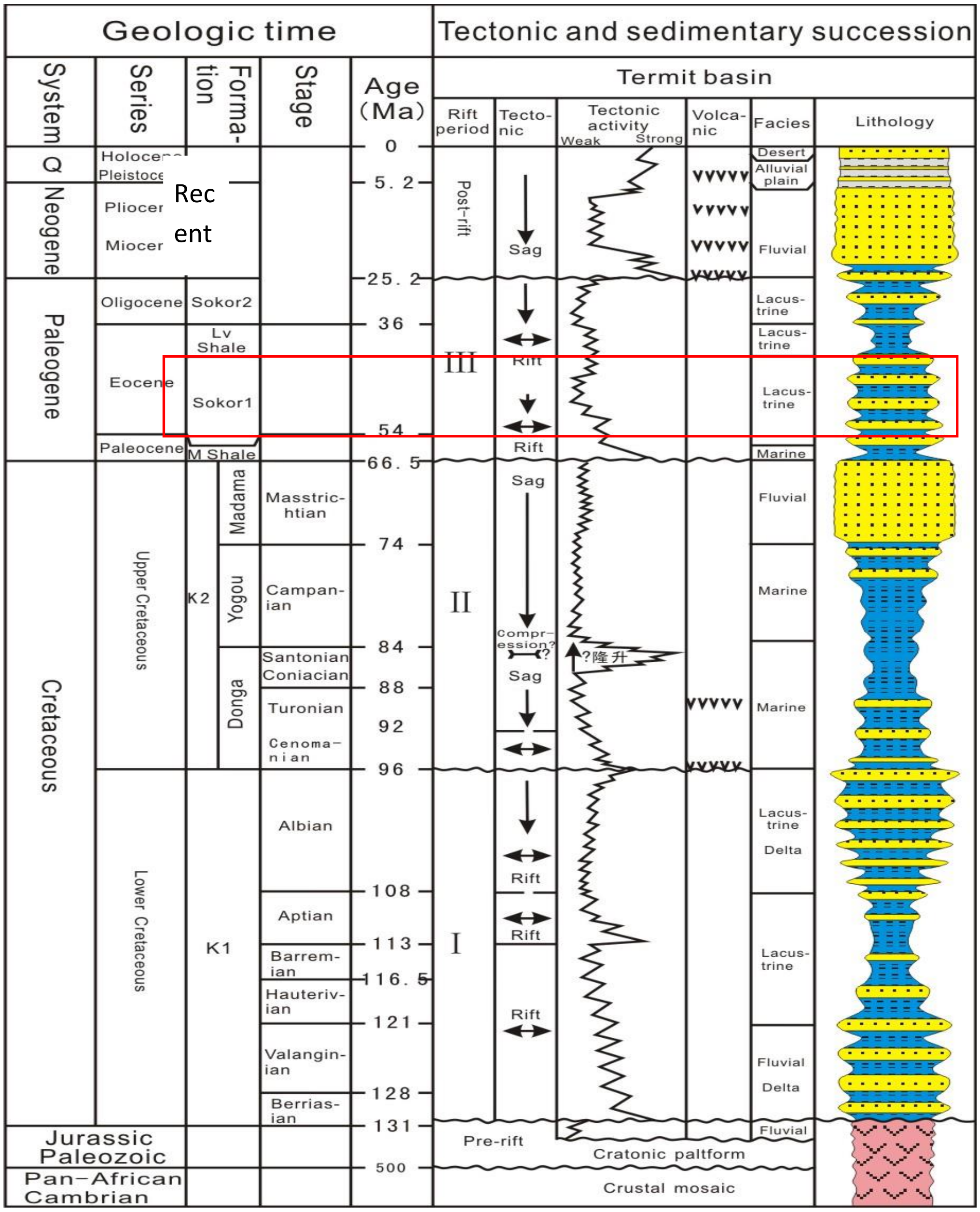

Figure 2: Litho-stratigraphic column of the Termit basin [7].

MATERIAL AND METHODS

The data used in this study come from the Sokor-E1 well of the Sokor prospect of the Agadem block of the Termit basin. These data include petrophysical parameter data which mainly consist of Porosity (Φ), Permeability (K) and Water Saturation (S_w) as well as log data such as Resistivity (RD), Gamma Ray (GR) and the volume of clay (V_{sh}).

RESULTS AND DISCUSSIONS

The Table below summarizes the results of the petrophysical parameters and log data used in this study. These results come from the SK-E1 well of the Sokor prospect in the Termit basin.

Table 1: Results of the petrophysical parameters and logs of the reservoir units of the Sokor-E1 well of the Sokor prospect. (Thick: Thickness; RD: Resistivity; POR: Porosity; PERM: Permeability; SW: Water saturation; VSH: Volume of Clay).

Formation	***Prof TOIT***	***Prof MUR***	***Epais***	***POR***	***S_W***	***V_{Sh}***	***RD***	***PERM***
	(m)	(m)	(m)	(%)	(%)	(%)	(Ohmm)	(mD)
E1	1678,2	1679,5	1.3	18,5	65,9	58,0	6.9	596,3
	1682,8	1683,3	0,5	22.8	67.2	37.2	4.3	724,5
	1688	1689	1	23,0	55,2	14,3	6,4	679,2
	1692,2	1694,3	2,1	18,7	49,4	22,3	8,9	457,8
	1695,9	1696,9	1,1	20,3	50,6	44,5	7,8	501,5
	1701,3	1703,6	2,2	23,8	47,4	16,0	8,3	523,7
	1706,6	1707,6	1,0	15,7	52,5	41,9	8,2	279,3
	1717,1	1717,9	0,8	20.7	51	38	7,2	440,9
	1726,6	1728,9	2,3	20,7	48,1	12,4	8,3	452,7
	1733	1737,1	4,1	24,3	33,8	15,3	15,5	731,7
	1738,5	1741,6	3,1	24,9	30	12,1	15,8	617
E2	1763	1763,7	0,7	16,5	72,7	28,2	9,1	550,2
	1765,4	1768,1	2,7	21,8	31,6	13,4	33,8	515,5
	1769,6	1770,1	0,5	21,8	61,8	42	8,5	786,5
	1789,4	1792,5	3,1	24,7	62,4	11,7	12,4	414,3
	1794,4	1798,9	4,6	20,4	61,5	7,2	22,2	449,7
E3	1857,2	1860,6	3,4	20,7	77	22,4	10	487,9
	1866	1870,3	4,3	23,5	62	11,5	12,4	759,17
	2100,6	2104,4	3,9	21,7	65,4	12,3	17,7	524,49
	2121,5	2126,7	5,2	21,7	66,7	6,1	22,9	516,27

Variation of porosity according to depth

The curve in Figure 3 shows the variation in porosity as a function of depth in the different reservoir units of the SK-E1 well.

Unit E1: In this unit, the middle and the base are marked by the highest porosity values of 23.8% (1703.6 m) and 24.9% (1741.6 m), respectively. The summit is marked by the lowest values 18.5% (1679.5 m). Overall, the unit indicates good to excellent porosities.

Unit E2: The highest porosity values are observed at the base and in the middle of the unit with respective proportions of 20.4% (1798.9 m) and 21.8% (1770. 1m). The lower values are observed at the summit with a proportion of 16.5% (1763.7 m). Good to very good porosities (>20%) are observed at the base and in the middle. The top is marked by a medium to good porosity (<20%).

Unit E3: The highest values of porosity are observed at the top and at the base of the unit respectively 20.7% (1860.6 m) and 21.7% (2126.7 m). The middle is marked with the highest values 23.5% (1870.3m). The unit presents good to very good porosities (>20%) from the base to the top.

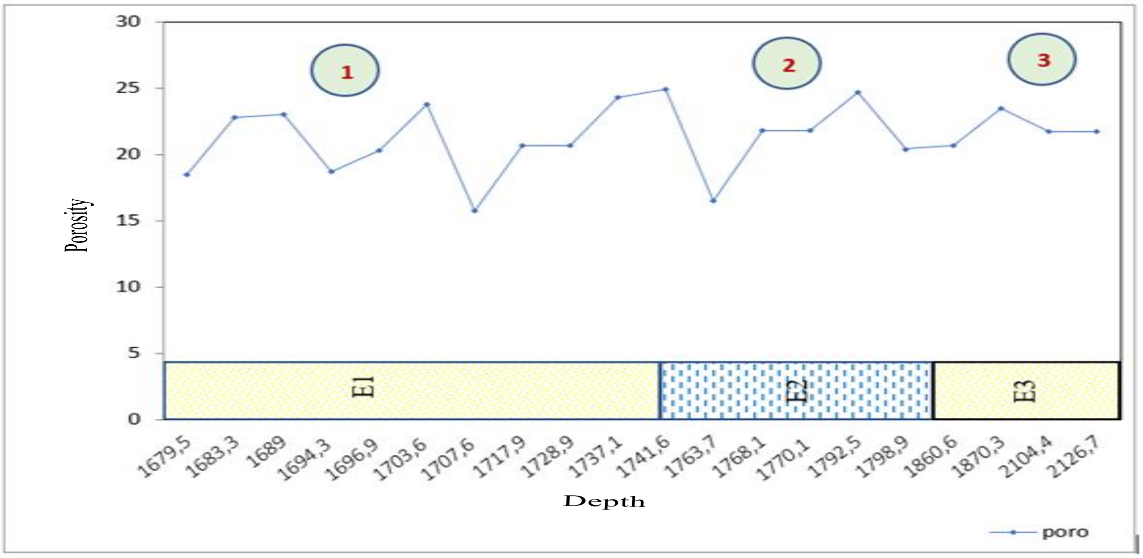

Figure 3: Variation in porosity as a function of depth within the reservoir units of the SK-E1 well.

Variation of permeability as a function of depth

The curve in Figure 4 shows the variation in permeability as a function of depth within the reservoir units of the SK-E1 well.

Unit E1: In this unit, the middle and the base are marked by the highest permeability values of 523.7 mD (1703.6 m) and 617 mD (1741.6 m) respectively. The summit is marked by the lowest values 501.5 mD (1679.5 m). Overall, the unit indicates good to very good permeabilities ((>100 mD).

Unit E2: The lowest values of permeability are revealed at the base and at the top of the unit of 449.7 mD (1798.9 m) and 550.2 (1763.7 m) respectively. The higher values are revealed in the middle 786.5 mD (1770.1 m). Overall, the unit indicates good to very good permeabilities ((>100 mD).

Unit E3: The highest permeability values are revealed at the top and base of the unit of 487.9 mD (1860.6 m) and 516.27 mD (2126.7 m) respectively. The middle is marked the highest values 759.17 mD (1870.3m). Overall, the unit indicates good to very good permeabilities (>100 mD).

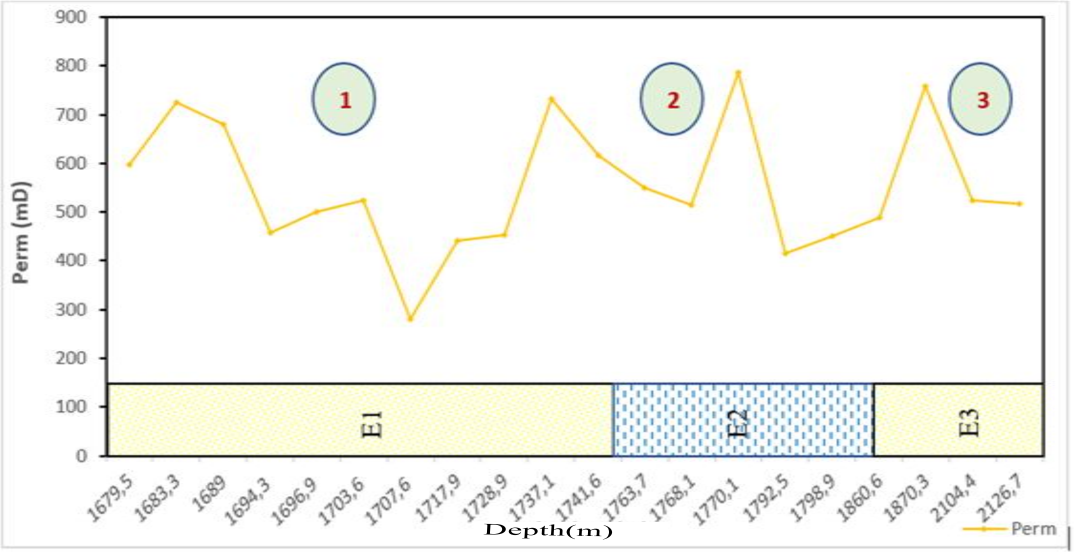

Figure 4: Variation in permeability as a function of depth within the reservoir units of the SK-E1 well.

III.3. Variation of clay volume according to depth

Figure 5 shows the variation in clay volume (V_{sh}) as a function of depth within the reservoir units of the Sokor-E1 well.

Unit E1: In this unit, the summit and the middle are marked by the highest proportions of clay volume of 58% (1679.5 m) and 44.5% (1696.9 m), respectively. The base is marked by the lowest values 12.1% (1741.6 m). In this unit, the volume of clay slightly affects the quality of the reservoir, this is explained by the fact that the clay minerals do not fill the intergranular pores of the formation as illustrated by the microphotographs of the blades.

Unit E2: The highest values of clay volumes are observed at the top and in the middle with respective proportions of 28.2% (1763.7 m) and 42% (1770.1 m). The lowest clay volume values are observed at the base with a proportion of 7.2% (1798.9 m). This is explained by the fact that the clay minerals obstruct the intergranular spaces and also note very thick clayey interbeds observed in the middle. This is illustrated by the petrographic analyzes of the microphotographs of the thin sections.

Unit E3: The highest permeability values are observed at the top and in the middle of the unit with respective proportions of 22.4% (1860.6 m) and 11.5% (1870.3 m). The base is marked with the lowest proportions 6.1% (2126.7 m). Unit E1 has low proportions of clay volume, this is explained by the low presence of clay minerals between the intergranular spaces.

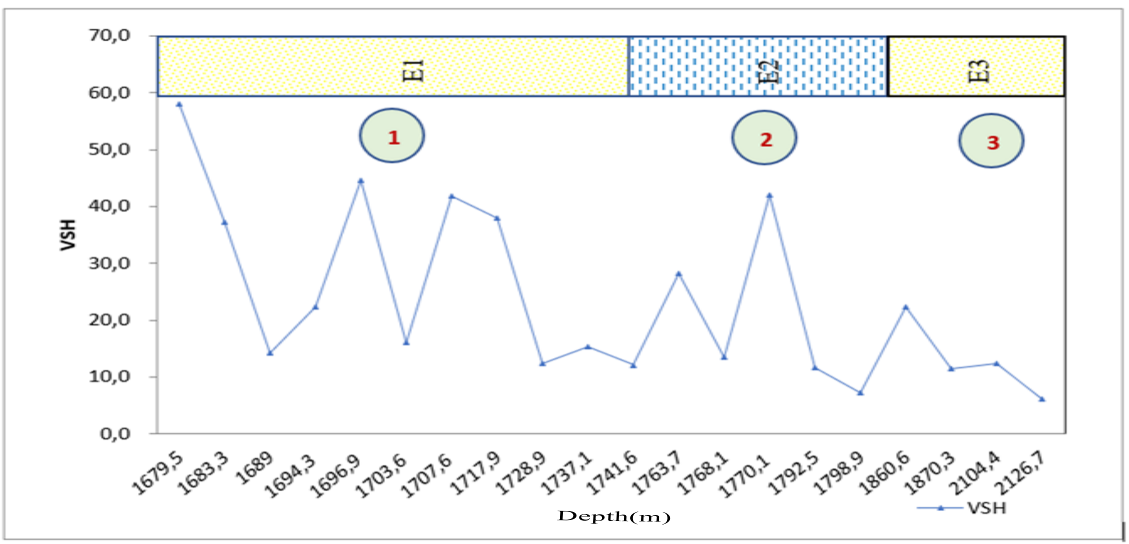

Figure 5: Variation in clay volume as a function of depth within the reservoir units of the Sokor-E1 well.

Units E1 and E3 have low volume proportions of clay; this indicates that these units contain few clay minerals which obstruct the intergranular pores.

Unit E2 has a somewhat high proportion of clay volume, indicating that intergranular spaces are generally filled with clay minerals [19-20].

III.4. Variation of water saturation as a function of depth within the reservoir units of the SK-E1 well

The graph of **Figure 6**, shows the variation in water saturation (S_W) as a function of depth within the reservoir units of the SK-E1 well.

Unit E1: according to this analysis, the top and the middle of the unit are marked by respective water saturation values of 65.9% (1679.5 m) and 47.4% (1703.6 m) the highest. The base is marked by the lowest water saturation values around 30% (1741.6 m). Overall, unit E1 is less saturated with water [16].

Unit E2: The highest values of water saturation are observed at the top and in the middle of the unit with respective proportions of 72.7% (1763.7 m) and 61.8% (1770 .1m). The lower values are observed at the base of the unit approximately 61.5% (1798.9 m). Overall, unit E2 is saturated with water.

Unit E3: The highest values of water saturation are observed at the top and at the base of the unit respectively of 77% (1860.6 m) and 66.7% (2126.7 m). The middle is marked by the lowest values 62% (1870.3m). The unit is less saturated in the middle and a little saturated at the ends.

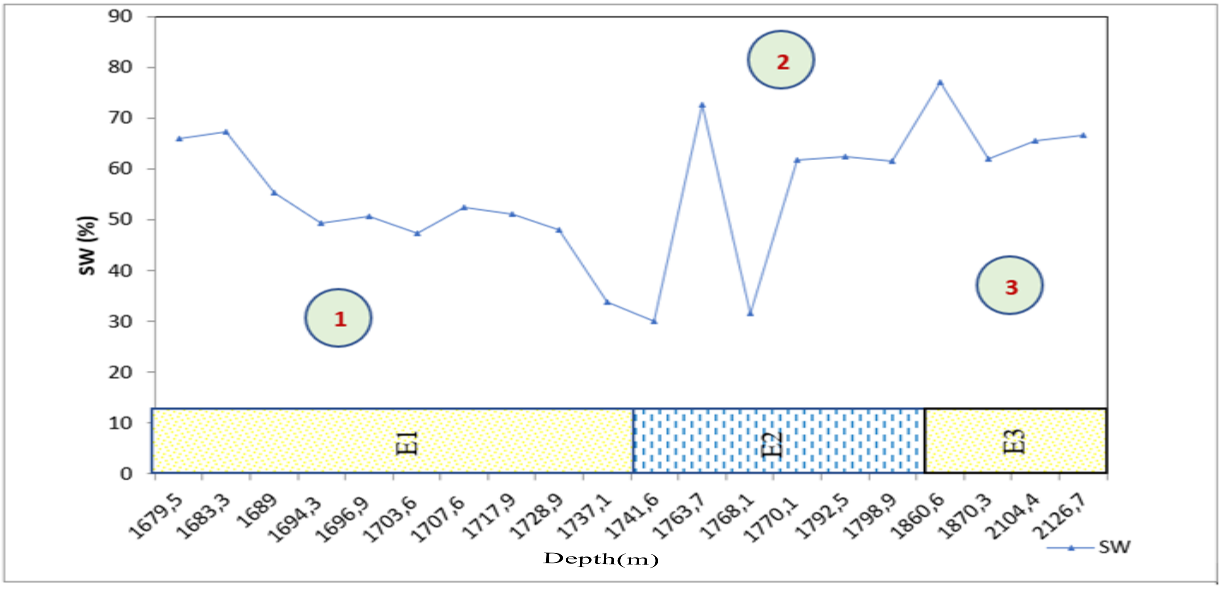

Figure 6: Variation of water saturation (SW) as a function of depth within the reservoir units of well SK-E1.

III.5. Combined correlation between porosity (Φ) and permeability (K) as a function of depth within the reservoir units of the SK-E1 well

Unit E1: In this unit, porosity and permeability vary in the same direction with the highest respective values of 23.8% (1703.6 m) and 24.9% (1741.6 m) and 523.7 mD (1703.6 m) and 617 mD (1741.6 m) in the middle and the base. The top of the unit is marked by the lowest respective values of 18.5% (1679.5 m) for porosity and 501.5 mD (1679.5 m) for permeability. Overall, the unit indicates good to excellent porosities (>25%) and good to very good permeabilities (>100 mD). According to these values, the E1 unit has good reservoir qualities, allowing it to contain and allow fluids to circulate freely [12-13] [16].

Unit E2: In this unit, porosity and permeability vary in the same direction with the highest values respectively of 20.4% (1798.9 m) and 21.8% (1770.1 m) at the summit and 449.7 mD (1798.9 m) and 550.2 mD (1763.7 m) at the base. The middle of this unit presents the peak of the two values respectively of 16.5% (1763.7 m) for porosity and 786.5 mD (1770.1 m) for permeability. Good to very good porosities (>20%) are observed at the base and in the middle. The summit is marked by average to good porosity (<20%) and good to very good permeability (>100 mD).

Unit E3: In this unit, permeability and porosity vary in the same direction with respective values of 487.9 mD (1860.6 m) and 20.7% (1860.6 m) at the top and 516.27 mD (2126.7 m) and 21.7% (2126.7 m) at the base. The middle is marked by the highest values 759.17 mD (1870.3m) for permeability and 23.5% (1870.3m) for porosity. Unit E3 has good permeability (>100 mD) and porosity (>20%) values. These good values make it possible to appreciate the quality of the E3 tank unit. According to these values, the E3 unit has good reservoir qualities, allowing it to contain and allow fluids to circulate freely.

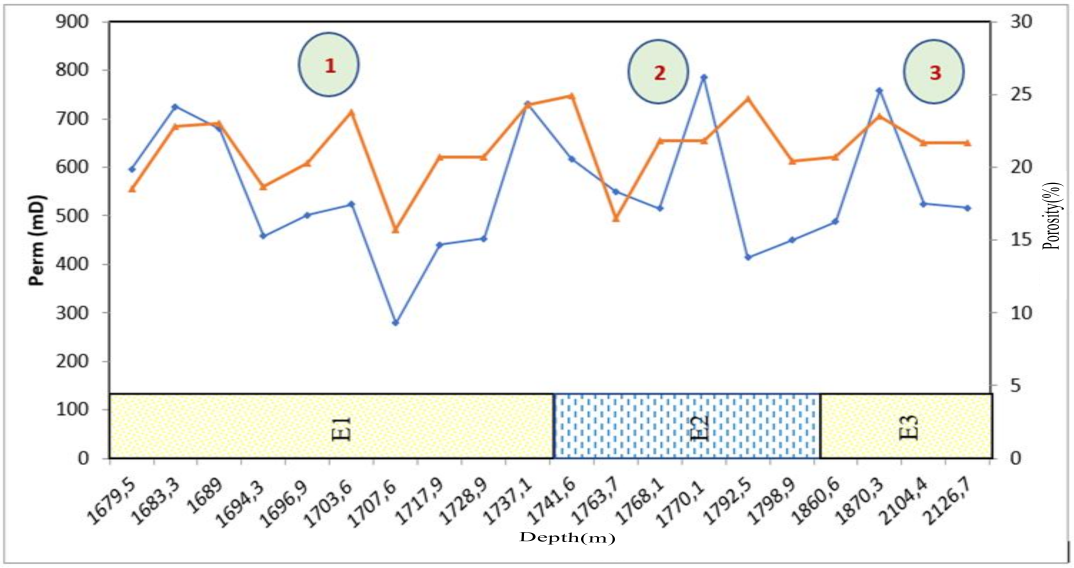

Figure 7: Combined correlation between porosity and permeability as a function of depth within the reservoir units of the SK-E1 well.

The relationship between permeability and porosity (Figure 8), shows a distribution of its parameters into three groups (A, B and C). Group A indicates lower values, group B high values and group C the highest values. This group distribution of its two petrophysical parameters is linked to the grain size (medium, coarse to very coarse grains) constituting the reservoir formation [9] [16].

According to the graph below (Figure 8), the relationship between permeability and porosity gives approximately a straight line. Within sandstone reservoir units, there is a good correlation between these two parameters [14] [16] [18].

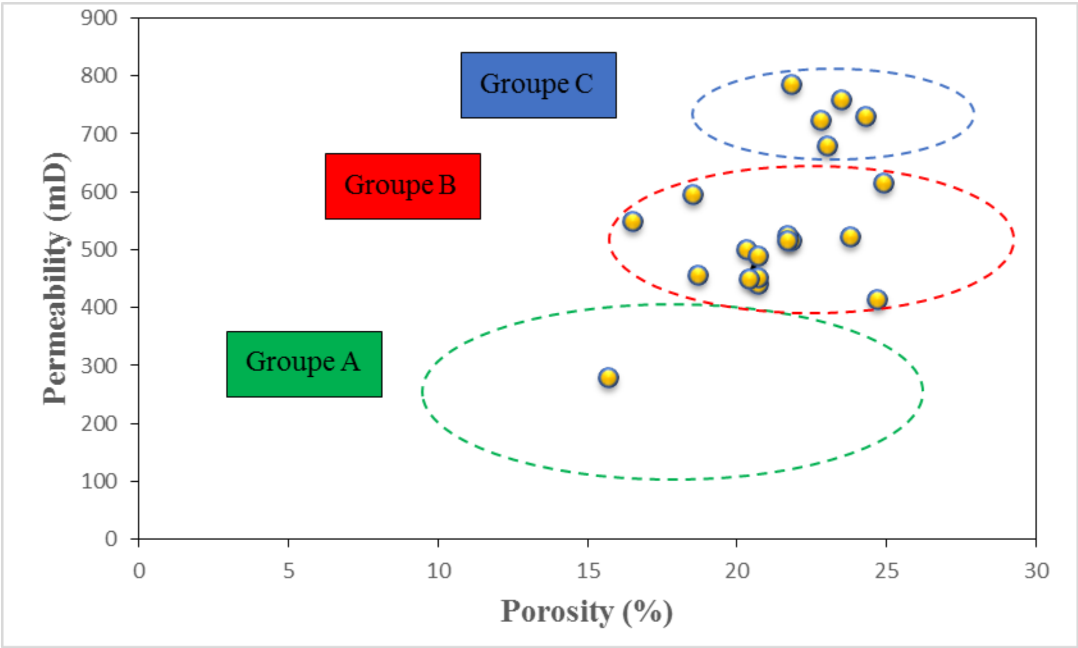

Figure 8: Relationship between permeability and porosity within the reservoir units of the SK-E1 well.

III.6. Combined relationship between water saturation and resistivity as a function of depth within the reservoir units of the SK-E1 well

The curves of Figure 9, shows the correlation between water saturation and resistivity as a function of depth. This correlation makes it possible to deduce the nature of the fluids contained in the reservoir units, which can be either hydrocarbons or water. Resistivity (RD) is the key parameter for determining the nature of the fluids in place. Low to very low resistivity, the fluid contained in the tank is water. High to very high resistivity the contained fluids are hydrocarbons [12] [19].

In the reservoir unit E1: In this unit, the water saturation (Sw) and the resistivity (RD) vary in the opposite direction with the respective values 65.9% (1679.5 m) and 6.9 Ohmm (1679 .5 m) at the top and respective values of 47.4% (1703.6 m) and 8.3 Ohmm (1703.6 m) in the middle. The peak of the resistive is observed at the base of the 15.8 Ohmm unit (1741.6 m) with a water saturation percentage of 30% (1741.6 m). The low values of saturation and the high values of resistivity indicate that unit E1 is less saturated with water and is reforming a large amount of hydrocarbons from the base to the center [12] [14].

In the reservoir unit E2: In this unit, the water saturation (SW) and the resistivity (RD) vary in the opposite direction with the respective values of 72.7% (1763.7 m) and 9.1 Ohmm (2052.4 m) at the top and the respective values 61.5% (1798.9 m) and 22.2 Ohmm (1798.9 m) at the base. The middle of the unit is marked by resistivity values 33.8 Ohmm (1768.1 m) and water saturation values 31.6% (1768.1 m). The fluctuation of water saturation (S_W) and resistivity (RD) (high or low), indicates that the unit contains both hydrocarbons and water.

In the reservoir unit E3: In this unit, the water saturation (S_W) and the resistivity (RD) vary in the opposite direction with the respective values 77% (1860.6 m) and 10 Ohmm (1860.6 m) at the top and the respective values of 62% (1870.3 m) and 12.4 Ohmm (1870.3 m) in the middle. The peak of the resistive is observed at the base of the 22.9 Ohmm unit (2126.7 m) with a water saturation percentage of 66.7% (2126.7 m). Unit E3 is less saturated with water and contains a large amount of hydrocarbons.

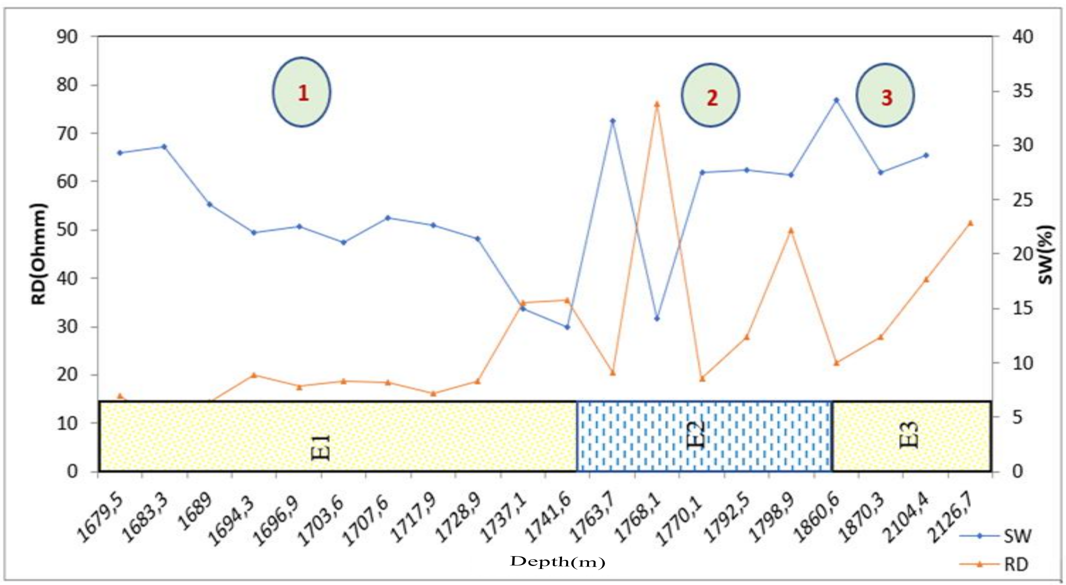

Figure 9: Combined correlation between water saturation and resistivity as a function of depth within the reservoir units of the SK-E1 well.

III.7. Correlation between water saturation (SW), porosity (Φ), permeability (K) and resistivity (RD) as a function of depth

The graph of Figure 10, indicates the combined correlation between water saturation (SW), porosity (Φ), permeability (K) and resistivity (RD) of the Sokor-E1 well reservoir units as a function of the depth. The combined correlation of the various petrophysical parameters and the log data made it possible to better define the potential levels of hydrocarbons and the levels saturated with water [16-17].

Unit E1: This unit E1 presents good values of porosity and permeability as a whole (from the base to the top), high values of water saturation at the top and in the middle (low values at the base), high resistivity values in the middle and at the base (low values at the top). Based on these values, unit E1 is somewhat saturated with water at the top and contains significant amounts of hydrocarbons [16].

Unit E2: E2 presents good values of porosity and permeability as a whole (from the base to the top), high values of water saturation at the top and in the middle (low values at the base), high values of resistivity in the middle and at the base (low values at the top. According to these values, unit E2 is less saturated with water at the top and contains hydrocarbons in the middle and at the base.

Unit E3: In this unit, the porosity and the permeability present good values as a whole (from the base to the top), the water saturation is very low (at the extremities and in the middle) on the other hand high values of the resistivity (from the base to the top) [18] [20].

Based on these values, unit E3 is characterized as a good reservoir unit and contains a significant amount of hydrocarbons (as a whole). The characterization of the different reservoir units containing hydrocarbons and water was established from the cross-correlation of the different log curves (Figure 11). Indeed, at reservoir units E1 and E3, there is a low water saturation, a high resistivity: which makes it possible to characterize these units as units that contain a large quantity of hydrocarbons (Figure 11). At reservoir units E2, it can be seen that water saturation and resistivity fluctuate; which makes it possible to characterize this unit likely to contain both hydrocarbons and water (Figure 11) [16.18-19].

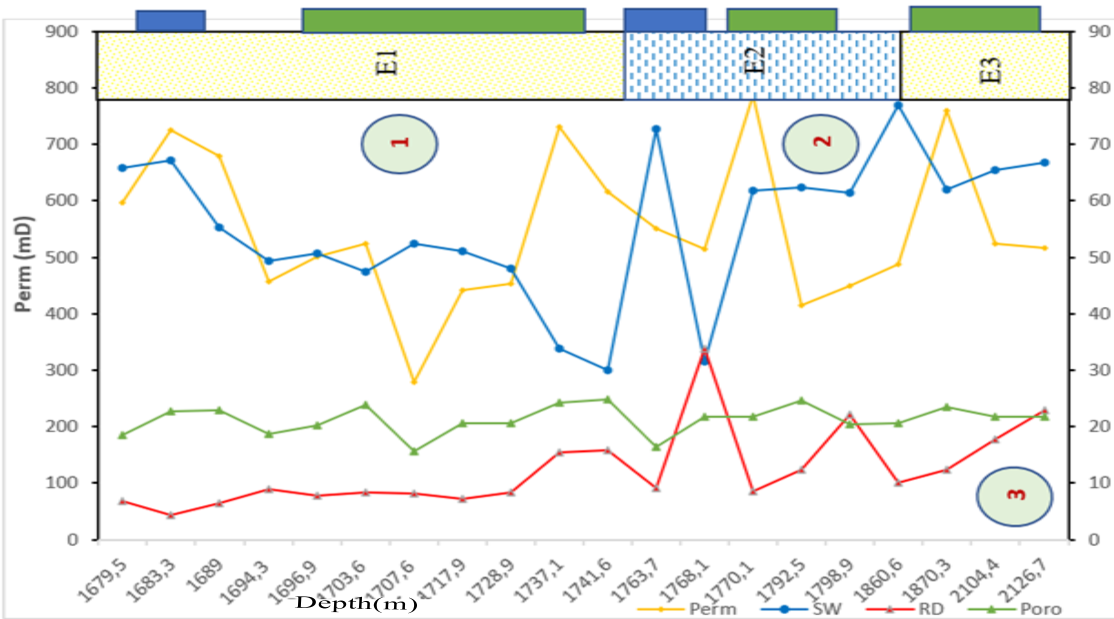

Figure 10: Combined correlation between porosity (Φ), water saturation (S_W), permeability (K) and resistivity Depth (RD) as a function of depth within the reservoir units of the SK-E1 well

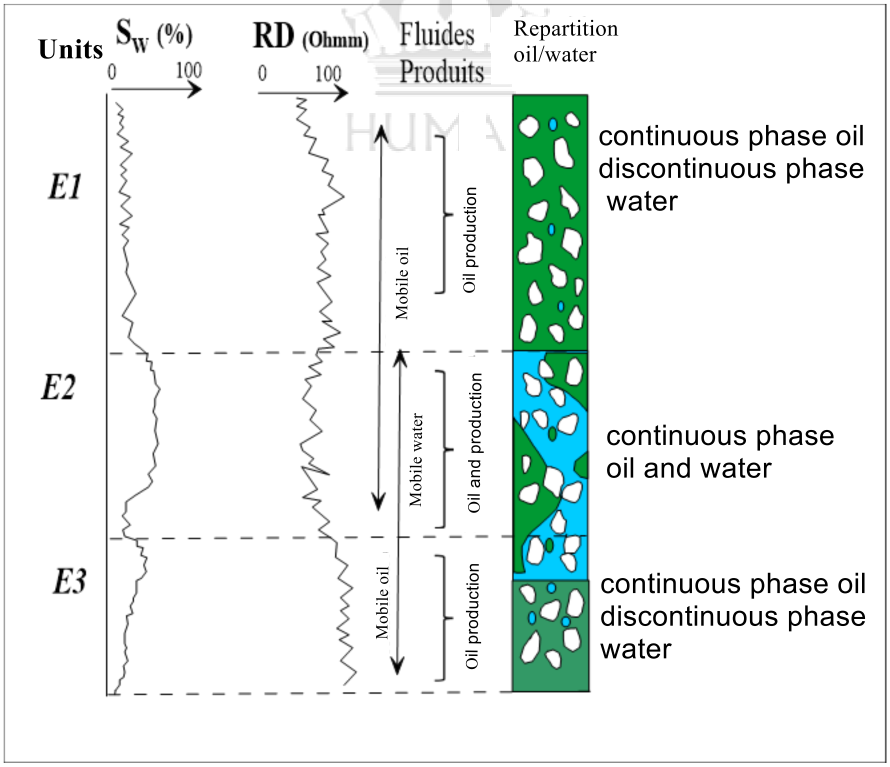

Figure 11: Distribution of the different fluids (Oils and/or Water) contained in the reservoir units within the SK-E1 well.

CONCLUSION

The petrophysical and logging analyzes of the Sokor-1 reservoir formation of the wells of the study prospects made it possible to understand the different types of fluids contained in the reservoir units as well as the degree of clay content that impacts them. The results obtained showed that among all the reservoir units, only the E1, E2 and E3 units are promising. These units have porosity values that can exceed 24.9% and permeability values that can exceed 679.2 mD. The correlation of these two petrophysical parameters (porosity and permeability) showed that the E1 reservoir unit has more good values of porosity and permeability, this indicates that this unit is the best reservoir unit of the study prospects.

The combined correlation of permeability with porosity and water saturation allowed the identification of reservoir units saturated with water. It emerges from this analysis that the reservoir units E2 and E3 are in places saturated with water with a water saturation value that can reach 100 %. The combined correlation between porosity (Φ), permeability (K), water saturation (S_W), and resistivity (RD) as a function of depth indicates that the quantity and distribution of hydrocarbons are closely related to both. parameters (S_W and RD) in combination. Indeed, a high-water saturation (S_W) with a low resistivity (RD) indicates low quantities of hydrocarbons so the unit is saturated with water. The combined correlation of water saturation and resistivity as a function of depth makes it possible to deduce the nature of the fluids contained in the reservoir units, which can be either hydrocarbons or water. This indicates that reservoir units E1 and E2 have resistivity values varying from 10 Ohmm to 22.2 Ohmm respectively. According to this analysis, unit E2 is more saturated with hydrocarbons in the Sokor prospect.

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