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Clay content estimation and its impact on reservoir properties using well logging, Sijan Field, Syria

Abdelbaset M. Abudeif [1*], Ayoub Y. Alhussain [1], Mohammed A. Mohammed [1], Marwa M. Masoud [1]

[1] *Sohag University, Sohag, Egypt*
**Corresponding author: e-mail a.abudeif@science.sohag.edu.eg*

Abstract

Purpose. The purpose of this study is to investigate the clay content and petrophysical characteristics of the Rutbah Formation in the Sijan Field and their impact on production. This involves analyzing various borehole measurements to assess reser-voir quality and predict fluid flow behaviour. Additionally, the study aims to compare wells in the Sejan field to show the differences in petrophysical properties, especially hydrocarbon saturation in the Rutbah sand formation.

Methods. Methods include gamma-ray measurements to determine rock lithology and calculate shale volume. Permeability is analyzed using equations relating permeability and porosity. Porosity determination involves acoustic, neutron, and density porosity measurements. The Archie equation was used to calculate water and hydrocarbon saturations.

Findings. Gamma-ray measurements delineated the Rutbah Formation's upper and lower sections. The upper Rutbah exhibits higher gamma-ray anomalies and shale volumes compared to the lower Rutbah. Shale in the upper Rutbah leads to ineffective porosity, while the lower Rutbah, dominated by sandstone with minimal shale, shows higher permeability suitable for hydrocarbon production.

Originality. The study highlights the significance of well logging data as a cost-effective alternative to traditional methods for estimating clay content and assessing reservoir quality in real-time. It contributes to literature by investigating influence of clay content variations on reservoir properties, enhancing reservoir characterization and production forecasting.

Practical implications. The study provides insights for oil exploration and production strategies in the Rutbah Formation within the Euphrates Graben region. Understanding the distribution of clay minerals and their effects on reservoir properties can guide exploration and development efforts, optimizing hydrocarbon recovery.

Keywords: *Rutbah Formation, well logging, clay content, Euphrates Graben*

1. Introduction

Even though there are many different major energy sources available in the modern world, oil remains the most popular. This is because of the enormous oil reserves that have been found or are anticipated to be found in the future because of the development of contemporary technologies. It also stems from the fact that this fundamental material is less expensive to obtain and manufacture than alternative energy sources. Thus, it is crucial to concentrate on oil studies across all subject areas, particularly since oil has influenced and continues to influence global politics and the global economy [1].

One of the main pillars of the oil and gas industry in the modern era is well logging measurements. No successful investment in this field can operate without using these measurements to solve problems and steer erroneous decisions because they take advantage of the physical characteristics of rocks to provide highly accurate and excellent soundings of the specifications of the various layers.

Well logging measurements play a major role in evaluating oil fields in terms of production, storage, reserve estimation, and even improving production and yield. Therefore, the process of interpreting well data is a very important process in evaluating productive and storage wells and understanding the behaviour of the field [2].

Many authors focused on this region of Syria and studied the Euphrates Graben geological, structural, and geophysical nature [3]-[7]. This study focuses on the Rutbah Formation, which is a major oil reservoir in the area and dates to the Cretaceous period. It is regarded as one of the most significant formations in the geological section, having penetrated many local structures and containing commercial amounts of oil [8].

The borehole measurements were applied in the drilled wells to study the storage characteristics of the Rutbah Formation that contains hydrocarbons [9]. The majority of sand formations are characterized by petrophysical characteristics that qualify them to be excellent storage rocks. This storage capacity varies and depends on several factors, the most important of which are those factors that relate to the grains that make up the rock in terms of their volume, shape, and the way they are placed. In general, the sandy formations are not 100% pure, as they are mixed with shale proportions, as

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this ratio plays a strong negative role in affecting storage specifications, and this effect changes according to the proportion, type, and pattern of placement of shale [10].

Understanding the distribution of clay and its effects on reservoir properties is essential for successful reservoir characterization and production optimization. The accurate estimation of clay content in the Rutbah Formation is crucial for assessing reservoir quality and predicting fluid flow behaviour. Conventional methods for clay content estimation, such as laboratory analysis of core samples, are time-consuming, expensive, and often limited in spatial coverage. Well-logging data offers a cost-effective alternative for estimating clay content in real-time, but the interpretation of log responses in clay-bearing formations remains challenging. Additionally, the influence of clay content variations on reservoir properties needs to be systematically investigated to enhance reservoir characterization and production forecasting.

In this work, we will study the effect of shales on the storage characteristics and the productive capacity of sand formations. The method of borehole geophysical measurements depends on determining the specifications of formation by measuring some physical properties (radioactivity-density resistivity, etc.), which enables us to determine the storage properties of the studied formations. However, the cores taken at the study site will make our results more accurate and realistic, while the accuracy of the interpreter and his knowledge of the nature of the region play the main role in the accuracy and validity of the interpretation results. In general, clay has a significant impact on the reservoir properties of the layers, as it indirectly affects oil production. The biggest issue with clay rocks is their inability to pass hydrocarbon fluids, which means their permeability is low or nonexistent. Furthermore, the clay rocks are regarded as commercially worthless strata, regardless of the amount of hydrocarbons present. Definitely, lack of permeability in the reservoir leads to lack of production. It is crucial that the geophysicist and interpreter have the utmost interest in identifying the clay content and its distributions during any geophysical measurements. Since clay rocks have a high radioactivity, the best probes to identify these rocks are those that detect gamma-ray logs.

The findings of the gamma-ray measurements will thus take priority when identifying the clay bands that have an impact on production. The significance of this work comes from emphasizing how important well records are for determining and estimating a wide range of factors related to the characteristics of rock and the fluids it contains [11]. Apart from verifying the geology and petrophysical data of the Sijan field, there are several problems with the field's exploration.

This study aims to:

1) investigate the petrophysical characteristics of the Rutbah Formation in the Sijan Field and the impact on production through various borehole measurements;

2) compare the wells in the Sijan Field to demonstrate variations in thickness and petrophysical characteristics;

3) compute the oil reserves of the Rutbah sandy formation in the Sijan Field based on the data and information supplied by Al Furat Petroleum Company.

1.1. Geography of Syria

Syria is located in the northwestern part of the Middle East region (Fig. 1), and its lands are considered a semi-flat region, poor in important protrusions [12], with the exception of the Palmyra chain, which is located in the middle of the country.

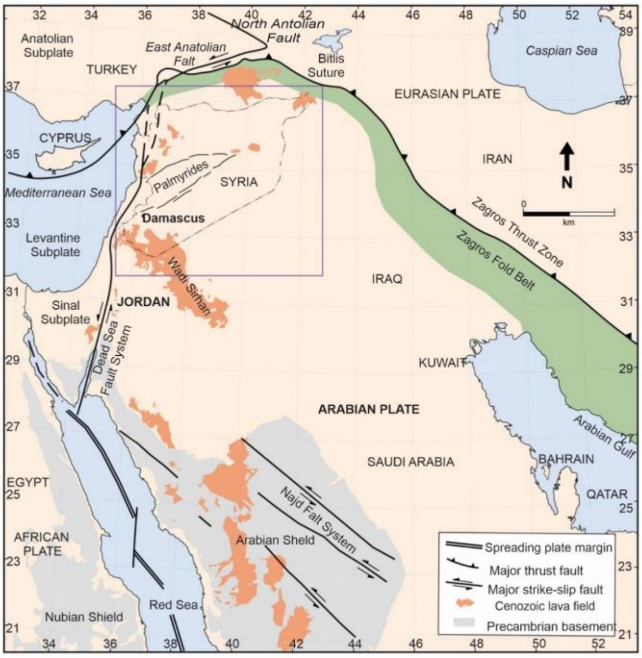

Figure 1. Map of Syria location in the Middle East

In the northwest, there is a mass of coastal mountains, which are classified by the pattern of eastern plains of the Mediterranean Sea. The desert stretches south of the Palmyrene chain, partially covered by modern basalts. As for the fourth part located to the north of the Palmyrene mountains, it is known as the plateau or promontory of Aleppo [13].

1.2. The Euphrates Graben

Sijan Field is located in the northeastern Euphrates Graben in eastern Syria. The eastern part of Euphrates Graben is in Iraqi territory, while its western part is in Syrian territory. And it is located above the structures of the slope of the Arabian surface (Fig. 2), with its fixed and mobile parts [14]. When the tectonic activity stopped with the beginning of the convergence between the Arabian and Anatolian plates, it resulted in the formation of this depression from the Middle to Late Cretaceous.

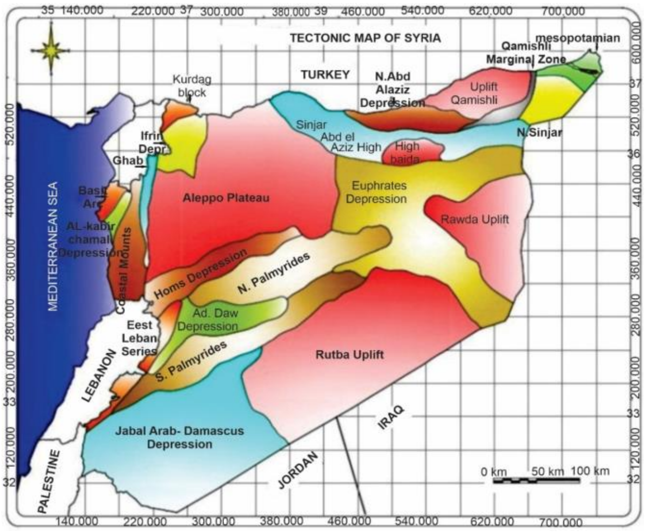

Figure 2. Location of the Euphrates Graben in relation to Syria

This Graben fills significant thicknesses of marine and continental Neogene sediments, and the results of deep drilling indicate the placement of the Cretaceous sediments overlying Carboniferous sediments. This Graben is bounded by the Rutbah uplift from the south, and the Aleppo uplift and the Palmyra chain from the west. In the north are the hills of Sinjar, Abd al-Aziz, and Twal al-Aba [6].

1.3. Structural and geological setting of the Sijan field

The Sijan field section is a series of 11 faulted dip closures with varying fluid levels (ranging from 2716 to 3090 mss), situated in the northeastern part of the Euphrates Graben in eastern Syria. It is roughly 20 km long, 5 km wide. An attempt has been made to integrate the structural model of the Sijan Field into the understanding of regional structural concepts. A very comprehensive analysis of the structural history and characteristics of the Euphrates graben can be found in "Structural analysis and kinematic framework of the Euphrates Graben, East Syria" [15].

Regional analysis of seismic semblance and attribute data over the central part of the Euphrates Graben indicates a strongly fragmented and multidirectional structural pattern with several well-defined and persistent trends. A characteristic of the Central Graben is a near-orthogonal pattern of fault trends defined by NW-SE and SW-NE trending lineaments. In addition, a subordinate set of laterally very persistent E-W alignments can be observed across the area [5]. Finally, a prominent deformation lineament, trending SSW-NNE, seems to be affecting the westernmost half of the Central Graben (Fig. 3). Figure 4 discusses the stratigraphic column of the eastern part of Syria, which includes the Rutbah Formation [16].

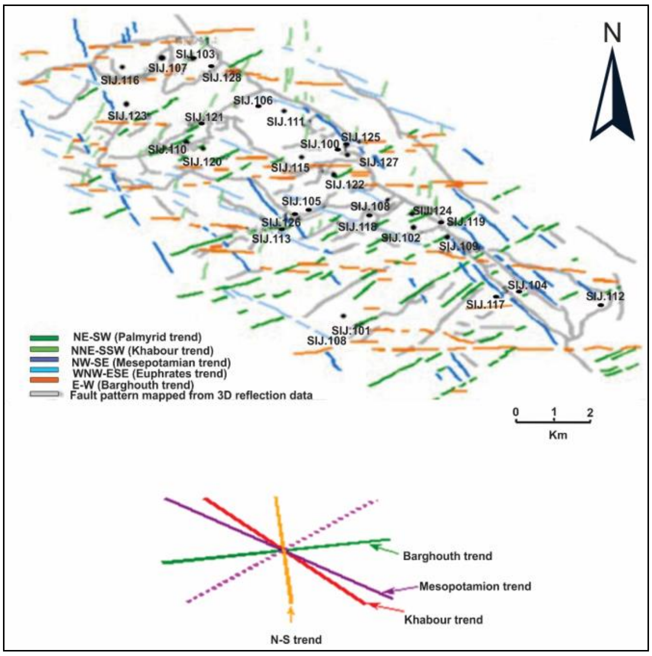

Figure 3. Structural situation in the Euphrates Graben [15]

1. Jeribe Formation. Jeribe Formation dates to the Miocene age, and its thickness is variable. It was found in all wells drilled in the Euphrates Lowland area. Generally, it consists mainly of limestone and dolomite with inclusions of anhydrite [17].

2. Shiranish Formation. This formation belongs to the Upper Cretaceous and consists of limestone in the upper section, while the Lower section consists of limestone with a greater percentage of clay [4].

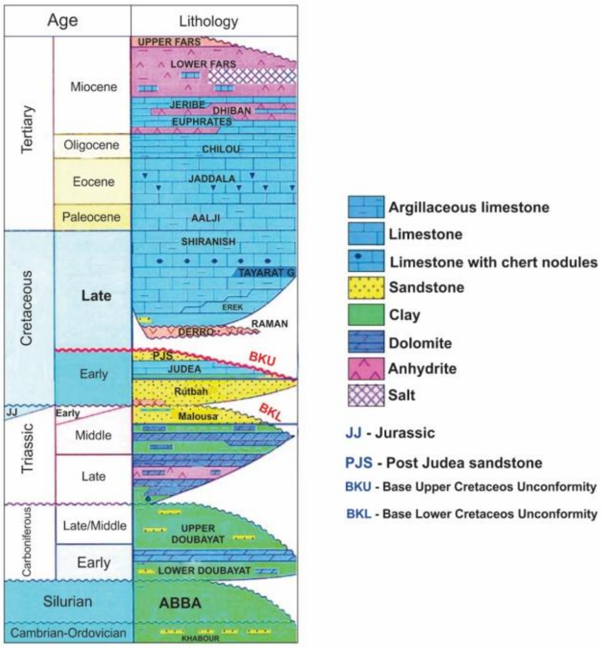

Figure 4. Stratigraphic column in the Euphrates Graben [16]

3. Derro Formation. This formation belongs to the Upper Cretaceous and consists of different lithologic facies, including clays and different types of volcanic deposits, and sometimes sands and anhydrite at the top of the formation [16].

4. Al-Judea Formation. This formation dates back to the Lower Cretaceous and is divided into two parts in the Euphrates Graben – the Upper Al-Judea Formation, which has a sandy rock and consists of sandstone and clay. Al-Judea Carbonate is composed of crystalline carbonates like limestone and dolomite [18].

5. The Rutbah Formation. It is divided into two parts: the Upper Rutbah, which belongs to the lower Cretaceous and consists of shale and small amount of sandstone. Lower Rutbah is of Lower Cretaceous and consists mainly of sandstone and a small amount of clay deposits [4].

6. Malousa Formation. This formation belongs to the Upper Triassic and consists of sandstones in addition to clay deposits [16].

2. Methods

The available data was collected from three sources:

1. Well logging geophysical measurements, such as: Long Spacing Sonic Sonde LSS, Compensated Neutron Log CNL, The Gamma Ray Tool, Litho-density tool LDT, Deep Induction log ILD, Medium induction log ILM [19].

2. Rock core measurements: the significance of these practical data is in their ability to calculate mathematical constants like permeability, which in turn helps determine the investability of the rocky areas [20].

3. Available data on the field: geological information about the study area, maps of the seismic composition, well drilling reports and geological reports for drilled wells, well tests, core samples, and the data gathered from different well measurements.

Data was collected for ten wells that penetrated the Rutbah Formation in the area under study. The following methods are used to analyze the wells and determine the petrophysical characteristics of each well:

– method of gamma-ray measurements is used to determine the lithology of rocks, distinguish between sand layers and shale zones, and then calculate the volume of shale present in these zones;

– the second method is to determine the permeability using basic information and the equation between permeability and porosity;

– a method for determining total and effective porosity from acoustic, neutron, and density porosity measurements;

– the Archie equation to calculate the water saturation and deduce the hydrocarbon saturation.

3. Results and discussion

3.1. Determine formation boundaries

To determine the lithology of the Rutbah Formation, several measurements were used, the most important of which is gamma-ray radiometric measurements.

3.1.1. Gamma-ray probe

The Rutbah Formation was divided into two parts, the Upper Rutbah and the Lower Rutbah. As for the Upper Rutbah, it showed high gamma-ray anomalies, extending from depths 2882 to 2927 m. While the Lower Rutbah begins from a depth of 2927 m and reaches a depth of 3030 m, where the Lower Rutbah shows significantly and continuously low gamma-ray anomalies with some minor distortions. This indicates a decrease in the amount of shale in this region in varying proportions, and its absence sometimes in thin layers. Here the gamma-ray anomaly again reaches a depth of 3030 m, that is, the Malusa Formation, which is not considered a hydrocarbon storage formation in the studied wells.

To determine the amount of clay distributed in the two parts of the Rutbah Formation, gamma-ray radiometric measurements are used (Fig. 5).

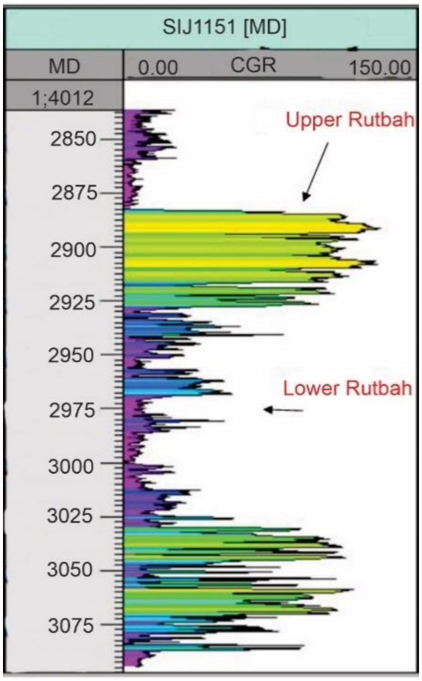

Figure 5. Gamma ray values are increasing in the Upper Rutbah and decreasing in the Lower Rutbah up to the Malousa Formation

3.1.2. Porosity sondes

3.1.2.1. Neutron log

The neutron line took on fluctuating values against most of the layers from the beginning of the measurement on the earth surface to a depth of 2883 m, where the values rose significantly, thus indicating high porosity. Then they returned to a relatively low decline at a depth of 2927.88 m, indicating the presence of less porosity in those layers to a depth of 3029.66 m (Fig. 6).

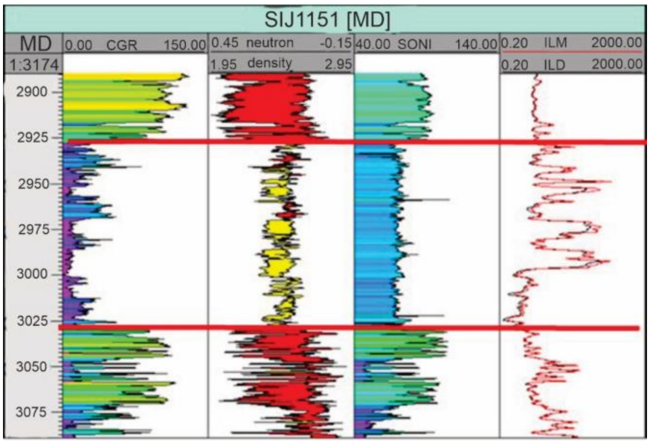

Figure 6. The Rutbah Formation lower boundaries based on porosity and resistivity measurements

3.1.2.2. Density log

From a depth of 2927.88 m, the density line indicates decreasing in rock density to a depth of 3029.66 m. This indicates the presence of sand layers that may have been deposited in this range (Fig. 6).

3.1.2.3. Sonic log

Sonic recordings are considered porous recordings, so they do not play a major role in determining the formation lithology, but they may be a useful addition to other recordings that can be used to determine the formation lithology. Thus, determine the upper and lower limits of the studied formation. These recordings show low sound travel times in the Lower Rutbah Formation, starting from depth of 2927.88 m to a depth of 3029.66 m.

3.1.3. Deep resistivity

When we notice an increase in the depth resistivity values, it is either an oil storage formation or an impermeable formation. All of the above measurements show a noticeable change in the recording, starting from a depth of 2927.88 m to a depth of 3029.66 m, which indicates that the selected formation is the stored formation, and the matter will be clearer after determining the lithology of the formation. So, the borders of the lineup are shown in Figure 6.

3.2. Determination of the lithology

Create illustrative charts and histograms. The purpose of this phase is to gather information that will help with the appropriate assessment of the reservoir properties as well as preliminary data on the penetrated formations [21]. We can depict the density, neutron, and radiation measurement values along a particular axis, in accordance with Schlumberger's well interpretation diagrams, rather than choosing axes at random, to provide the distribution of measurement values along lines, each of which denotes a distinct lithology type.

Specific depths are also specified to represent the measured values (Fig. 7).

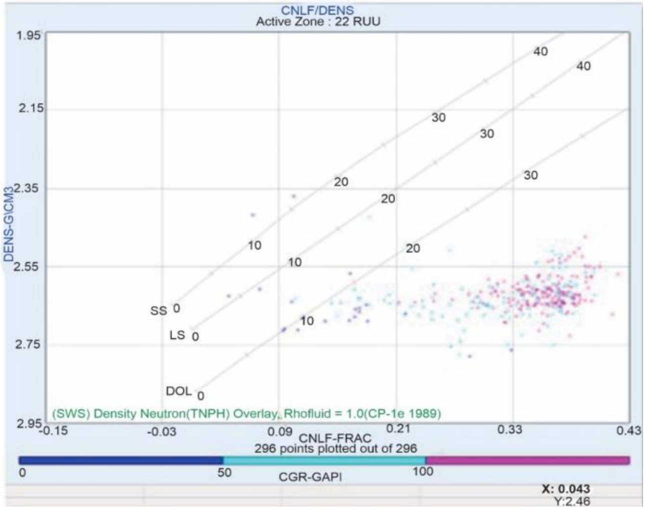

Figure 7. Cross plot for the Upper Rutbah Formation

The histogram (Fig. 8) shows the repetition of gamma-ray values in the Upper Rutbah Formation. As can be seen from this chart, the frequency of high gamma-ray values between 120 and 150 API is high, and values between 60 and 120 were less frequent. In contrast, very low gamma-ray values are almost non-existent, especially values from zero to 30 API.

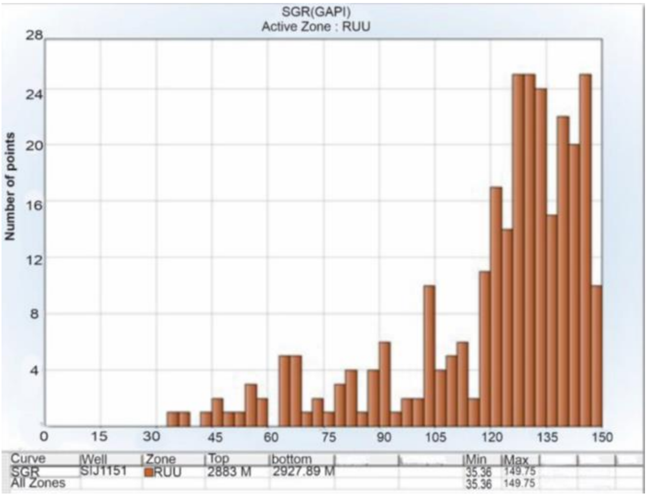

Figure 8. Histogram shows the repetition of gamma-ray values in the Upper Rutbah Formation

Figure 9 indicates that the predominant lithology between depths of 2927 and 3030 m is composed of carbonate rocks such sandstone, limestone, and dolomite. Due to the colours that indicate radioactivity, we can also distinguish clay from other rocks. For example, the blue colour indicates measurements with radiation less than 50% API (American Petroleum Institute), which represents a non-clay group. There is a fairly small group of clay rocks of phosphorescent colour, while pink colour indicates high gamma-ray values. This corresponds to the distribution of radioactivity values on the gamma axis at the bottom of this figure. Also, density measurements, *Y*-axis and neutron measurements, *X*-axis, taken together give us preliminary indications of the lithological description of the penetrating formations.

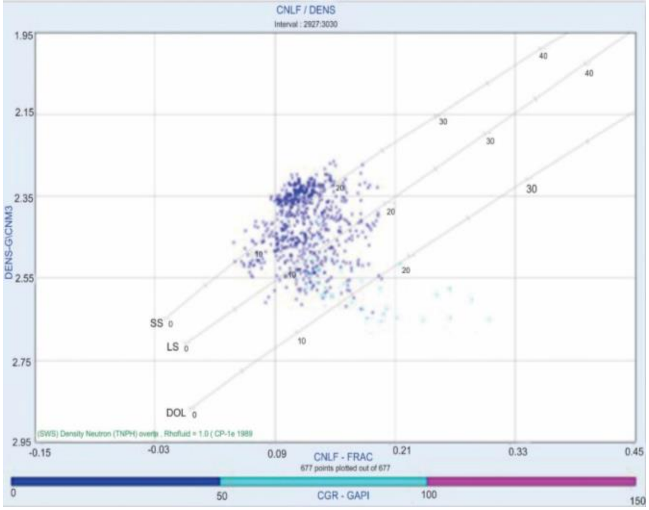

Figure 9. Cross plot for the Lower Rutbah Formation

The histogram (Fig. 10) shows a recurrence of gamma-ray values in the Lower Rutbah Formation. As chart shows, there is a high recurrence of low gamma-ray values of less than 50 API. While very high gamma-ray values are almost non-existent, especially those exceeding 90 API.

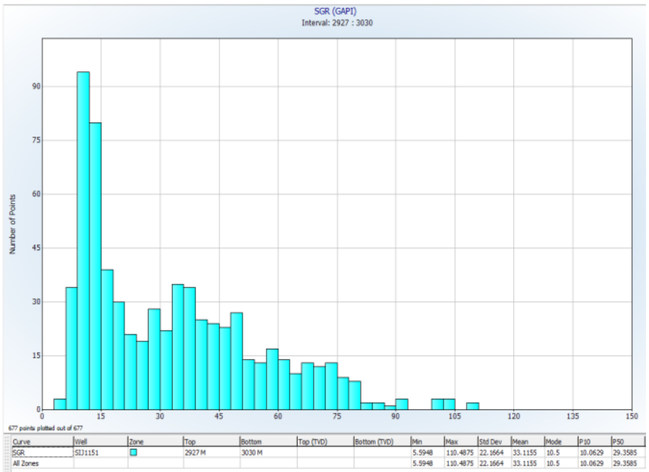

Figure 10. Histogram shows the repetition of gamma-ray values in the Lower Rutbah Formation.

3.3. Calculate the shale volume

After setting the reserve formation limits, the shale volume in each range was calculated by Equation (1). It was determined whether it was an investable range, that is, the percentage of shale was less than 50% [22]:

$$V_{sh} = I_{GR} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}}, \quad (1)$$

where:

I_{GR} – the gamma-ray index;

$GR_{\log}$ – the gamma-ray readings of formation;

$GR_{\min}$ – the minimum gamma-ray value;

$GR_{\max}$ – the maximum gamma-ray value.

3.3.1. Calculate the shale volume in the Upper Rutbah Formation

The shale volume in this formation is calculated by using minimum and maximum gamma-ray values, and the gamma-ray value measured at a specific point at the depth at which the shale is located (Table 1).

Table 1. Maximum and minimum gamma-ray values in the Upper Rutbah Formation, in addition to gamma-ray measurements at a specific measuring point

Depth, m	GR_{min}	GR_{max}	GR 2900 m
2882 to 2927	26.64	130.06	110

The minimum and maximum gamma-ray values were measured in the Upper Rutbah Formation. Next, Equation (1) was applied to calculate the shale volume at a depth point of 2900 m by taking a specific value for gamma rays at that location (Table 1).

It can be seen that there is a strong correlation between increased shale volume and high gamma-ray levels after performing the above computation for each measurement point (Fig. 11). Using Equation (1), V_{sh} = 0.80%.

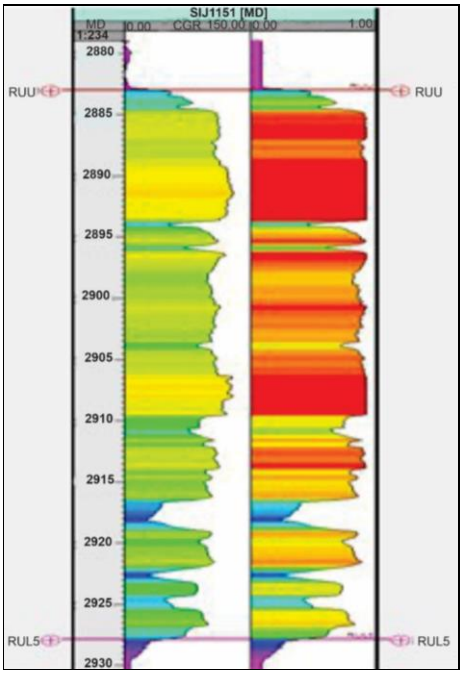

Figure 11. Shale volume versus the Upper Rutbah Formation using gamma-ray measurements

The histogram in Figure 12 indicates that shale volume estimates were high in the Upper Rutbah Formation, which is almost identical to the gamma-ray readings. High shale volume values (from 62 to 90%) were frequent, but values from 26 to 60% were less frequent, and low shale values (from 0 to 20%) were not found at all.

3.3.2. Calculate the shale volume in the Lower Rutbah Formation

Gamma-ray values exhibit an obvious decrease in the Lower Rutbah Formation, except for a few scattered anomalies. Also, the maximum and minimum gamma-ray measurement values were determined in the Lower Rutbah Formation.

The shale volume at a specific depth point was then determined by Equation (1). After determining the shale volume at each measuring location in the Lower Rutbah Formation, it can be seen that low gamma-ray levels correlate with a decrease in shale volume (Fig. 13). Use the law to the Rutbah range at a specified depth of 2971.038 m. The Lower Rutbah begins at a depth of 2927 m and reaches a depth of 3030 m (Table 2). Using Equation (1), V_{sh} = 0.24%. Then apply this equation to all members of the formation (Fig. 13).

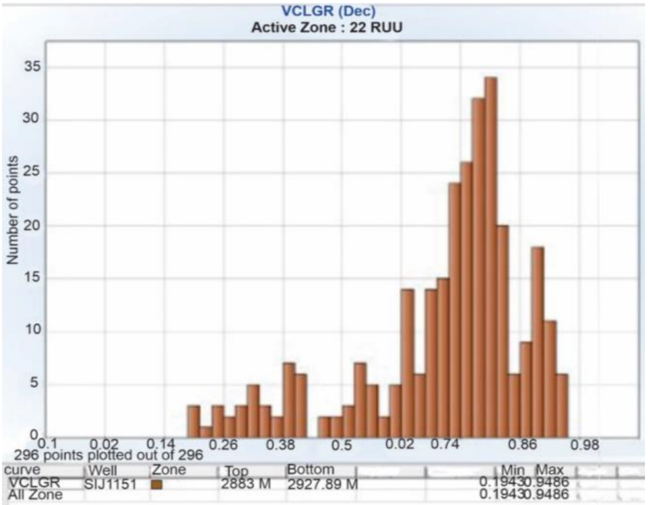

Figure 12. Histogram shows the repetition of gamma-ray volume values in the Upper Rutbah Formation.

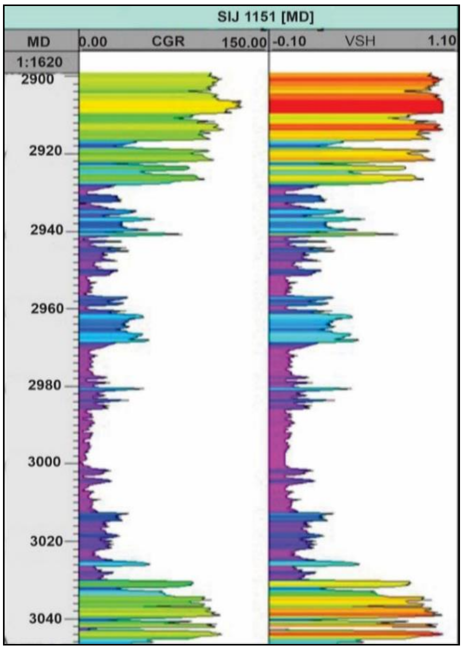

Figure 13. Shale volume versus the Lower Rutbah Formation using gamma-ray measurements

Table 2. Maximum and minimum gamma-ray values in the Lower Rutbah Formation, in addition to gamma-ray measurements at a specific measuring point

Depth, m	GR_{min}	GR_{max}	GR 2971 m
2927 to 3030	5.12	142.61	38.2

Moreover, the histogram in Figure 14 indicates that shale volume estimates were low in the Lower Rutbah Formation, almost equivalent to the gamma-ray readings. There is a high frequency of low shale values, from 10 to 20%, while values ranging from 20 to 50% are less frequent, while high shale values of more than 60% are infrequent.

3.4. The effect of shale on porosity in the Upper and Lower Rutbah Formations

3.4.1. Porosity in the Upper Rutbah Formation

According to Equation (2) and using the information in Table 3, the density- derived porosity in the Upper Rutbah Formation is calculated [22]:

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}, \quad (2)$$

where:

ϕ_D – the density-derived porosity;

ρ_{ma} – the matrix density [23];

ρ_b – the formation bulk density;

ρ_{fl} – the fluid density.

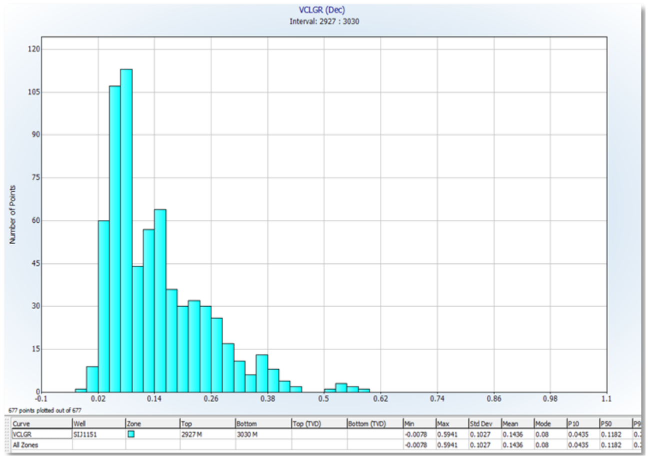

Figure 14. Histogram shows the repetition of gamma-ray volume values in the Lower Rutbah

Table 3. Density values in rock structure and layer fluids, in addition to neutron density

Depth, m	ρ_{ma}	ρ_b (2900 m)	ρ_f	ϕ_N (3000 m)
2882 to 2927	2.78	2.61	1	0.34

According to Equation (2), ϕ_D = 0.09%. Average porosity (density and neutrality):

$$\phi_{N-D} = \frac{\phi_N + \phi_D}{2}. \quad (3)$$

Using Equation (3) to the data from Table 3: ϕ_{N-D} = 0.12%.

The porosity of the Upper Rutbah Formation decreases markedly, particularly in the dense porosity, due to a significant lamellar shale deposit. This leads to a significant increase in rock density, resulting in a minimum density of porosity (Fig. 15).

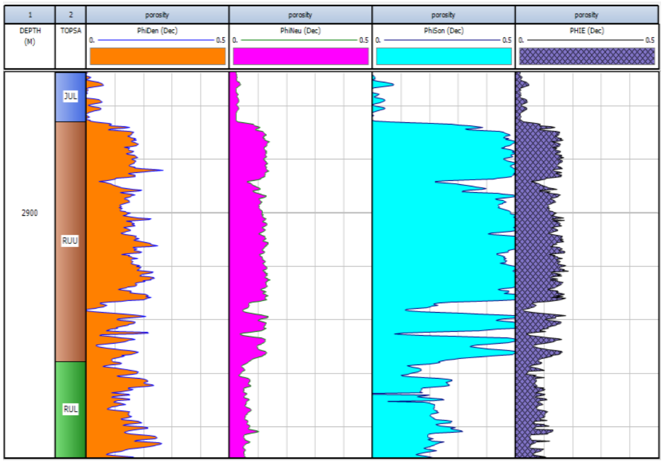

Figure 15. The different porosity (density, neutron, average porosity) in the Upper Rutbah Formation

3.4.2. Porosity in the Lower Rutbah Formation

The following results are obtained by applying Equation (2) to the Lower Rutbah bands using the data in Table 4. Using Equation (2) to the data in Table 4, ϕ_D = 0.23% (3000 m). Using Equation (3) to the data in Table 4, ϕ_{N-D} = 0.18%.

Table 4. Density values in the rock texture and layer fluids, in addition to the neutron density

Depth, m	ρ_{ma}	ρ_b (2900 m)	ρ_f	ϕ_N (3000 m)
2927 to 3030	2.65	2.61	1.16	0.14

Figure 16 shows the different porosity (density, neutron, average porosity) in the Lower Rutbah Formation.

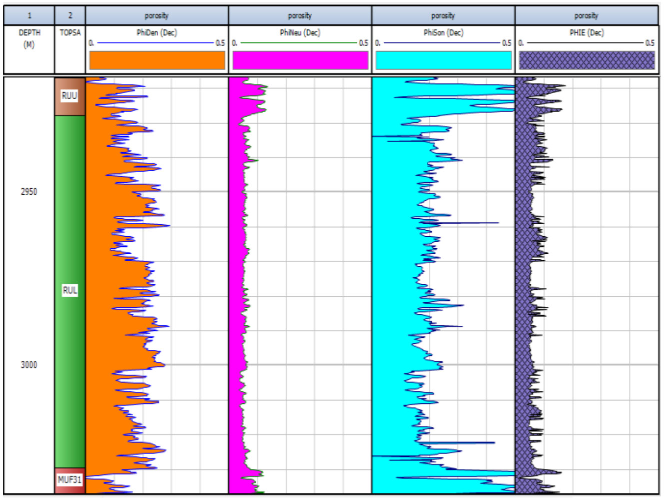

Figure 16. The different porosity (density, neutron, average porosity) in the Lower Rutbah Formation

3.5. The effect of shale on permeability in the Upper and Lower Rutbah Formations

3.5.1. Permeability in the Upper Rutbah Formation

Given the shale's non-interconnected pores, which contribute to its overall low permeability (Fig. 17), it is evident that the permeability in the Upper Rutbah is similarly low or non-existent. Consequently, there is absolutely no need to determine the saturation in this zone, because permeability is non-existent.

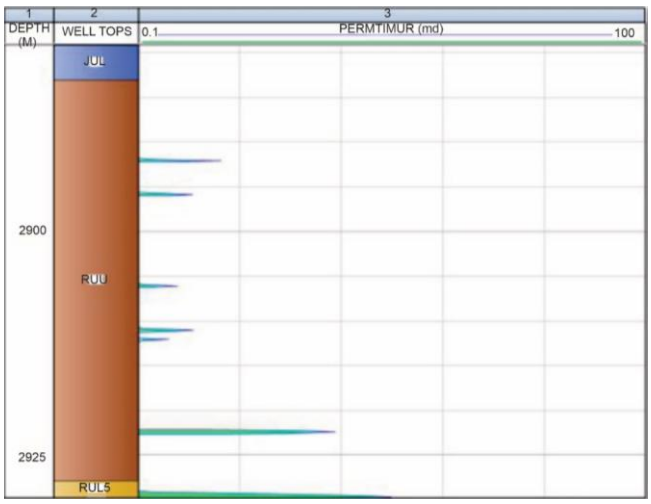

Figure 17. The permeability curve in the Upper Rutbah Formation

3.5.2. Permeability in the Lower Rutbah Formation

As for the Lower Rutbah Formation, which consists mostly of sand, ignoring the very narrow shale ranges, we were able, to use core data taken from the same well to determine the parameters required to calculate this permeability (Table 5).

It was found that the Lower Rutbah Formation is characterized by high permeability (Fig. 18).

Figure 19 explains the direct equation between porosity and permeability in sandy areas.

Table 5. Permeability (K) values in the Lower Rutbah Formation versus depth

No	Well	Zone	Depth, m	Permeability (*K*), mD	Log *K*	No	Well	Zone	Depth, m	Permeability (*K*), mD	Log *K*
1	SIJ1151	RUL	2935.00	4.0	0.60206	46	SIJ1151	RUL	2985.15	352.0	2.54654
2	SIJ1151	RUL	2936.20	1.8	0.25527	47	SIJ1151	RUL	2986.12	1180.0	3.07188
3	SIJ1151	RUL	2937.75	1.8	0.25527	48	SIJ1151	RUL	2987.20	699.0	2.84448
4	SIJ1151	RUL	2938.00	1.8	0.25527	49	SIJ1151	RUL	2988.10	5160.0	3.71265
5	SIJ1151	RUL	2940.00	9.9	0.99564	50	SIJ1151	RUL	2989.30	1380.0	3.13988
6	SIJ1151	RUL	2941.20	4990.0	3.69810	51	SIJ1151	RUL	2990.50	442.0	2.64542
7	SIJ1151	RUL	2942.10	1910.0	3.28103	52	SIJ1151	RUL	2991.10	1650.0	3.21748
8	SIJ1151	RUL	2943.30	377.0	2.57634	53	SIJ1151	RUL	2992.00	1880.0	3.27416
9	SIJ1151	RUL	2944.20	2.2	0.34242	54	SIJ1151	RUL	2993.20	1900.0	3.27875
10	SIJ1151	RUL	2945.10	4.3	0.63347	55	SIJ1151	RUL	2994.10	2420.0	3.38382
11	SIJ1151	RUL	2946.00	16.0	1.20412	56	SIJ1151	RUL	2995.00	2020.0	3.30535
12	SIJ1151	RUL	2947.20	551.0	2.74115	57	SIJ1151	RUL	2996.20	935.0	2.97081
13	SIJ1151	RUL	2948.10	208.0	2.31806	58	SIJ1151	RUL	2997.10	2230.0	3.34830
14	SIJ1151	RUL	2949.00	2270.0	3.35603	59	SIJ1151	RUL	2998.05	2550.0	3.40654
15	SIJ1151	RUL	2950.20	2.7	0.43136	60	SIJ1151	RUL	2999.20	3710.0	3.56937
16	SIJ1151	RUL	2951.40	1690.0	3.22789	61	SIJ1151	RUL	3000.10	7870.0	3.89597
17	SIJ1151	RUL	2952.00	2370.0	3.37475	62	SIJ1151	RUL	3001.00	29.0	1.46240
18	SIJ1151	RUL	2953.20	3220.0	3.50786	63	SIJ1151	RUL	3002.00	1.8	0.25527
19	SIJ1151	RUL	2955.00	1810.0	3.25768	64	SIJ1151	RUL	3003.10	24.0	1.38021
20	SIJ1151	RUL	2956.20	116.0	2.06446	65	SIJ1151	RUL	3004.30	1.5	0.17609
21	SIJ1151	RUL	2957.40	2.7	0.43136	66	SIJ1151	RUL	3005.20	587.0	2.76864
22	SIJ1151	RUL	2958.60	5.2	0.71600	67	SIJ1151	RUL	3006.10	3940.0	3.59550
23	SIJ1151	RUL	2959.20	1300.0	3.11394	68	SIJ1151	RUL	3007.00	32.0	1.50515
24	SIJ1151	RUL	2962.20	3.6	0.55630	69	SIJ1151	RUL	3008.20	5310.0	3.72509
25	SIJ1151	RUL	2964.00	16.0	1.20412	70	SIJ1151	RUL	3009.10	393.0	2.59439
26	SIJ1151	RUL	2965.20	1.2	0.07918	71	SIJ1151	RUL	3010.10	1570.0	3.19590
27	SIJ1151	RUL	2967.88	1.4	0.14613	72	SIJ1151	RUL	3011.20	52.0	1.71600
28	SIJ1151	RUL	2968.25	4.8	0.68124	73	SIJ1151	RUL	3012.10	3.3	0.51851
29	SIJ1151	RUL	2969.10	2.3	0.36173	74	SIJ1151	RUL	3013.00	1.1	0.04139
30	SIJ1151	RUL	2970.00	2560.0	3.40824	75	SIJ1151	RUL	3013.60	17.0	1.23045
31	SIJ1151	RUL	2971.07	705.0	2.84819	76	SIJ1151	RUL	3014.20	1.5	0.17609
32	SIJ1151	RUL	2971.30	257.0	2.40993	77	SIJ1151	RUL	3015.10	11.0	1.04139
33	SIJ1151	RUL	2972.20	3380.0	3.52892	78	SIJ1151	RUL	3016.00	3.8	0.57978
34	SIJ1151	RUL	2973.10	3810.0	3.58092	79	SIJ1151	RUL	3017.20	14.0	1.14613
35	SIJ1151	RUL	2974.00	990.0	2.99564	80	SIJ1151	RUL	3018.10	12.0	1.07918
36	SIJ1151	RUL	2975.20	7850.0	3.89487	81	SIJ1151	RUL	3019.10	2.8	0.44716
37	SIJ1151	RUL	2976.10	5220.0	3.71767	82	SIJ1151	RUL	3020.20	12.0	1.07918
38	SIJ1151	RUL	2977.30	586.0	2.76790	83	SIJ1151	RUL	3021.40	628.0	2.79796
39	SIJ1151	RUL	2978.20	1450.0	3.16137	84	SIJ1151	RUL	3022.04	1190.0	3.07555
40	SIJ1151	RUL	2979.25	1330.0	3.12385	85	SIJ1151	RUL	3023.20	122.0	2.08636
41	SIJ1151	RUL	2980.23	1.1	0.04139	86	SIJ1151	RUL	3024.10	1770.0	3.24797
42	SIJ1151	RUL	2981.23	326.0	2.51322	87	SIJ1151	RUL	3025.00	1.6	0.20412
43	SIJ1151	RUL	2982.19	46.0	1.66276	88	SIJ1151	RUL	3026.20	664.0	2.82217
44	SIJ1151	RUL	2983.00	5.0	0.69897	89	SIJ1151	RUL	3027.10	227.0	2.35603
45	SIJ1151	RUL	2984.15	25.0	1.39794						

3.6. Effect of shale on water saturation in the Upper and Lower Rutbah Formations

3.6.1. Water saturations in the Lower Rutbah Formation

The fluids present in the rocky voids fill all or most of the pores, so that this fluid consists of a mixture of water and oil in varying proportions. To calculate these saturations, the Archie Equation (4) is used, taking into account that water is a medium that conducts electrical current, unlike oil, which is considered an insulating medium [22]:

$$S_w^n = \frac{a}{\phi^m} \cdot \frac{R_w}{R_t}, \quad (4)$$

where:

S_w – the water saturation;
R_w – formation water resistivity, equal to 0.0434 Ω;
R_t – true formation water resistivity, equal to 0.31Ω;
ϕ – the effective porosity;
a – the tortuosity factor (often taken to be 1);
m – the cementation factor (varies around 2);
n – the saturation exponent (generally 2).

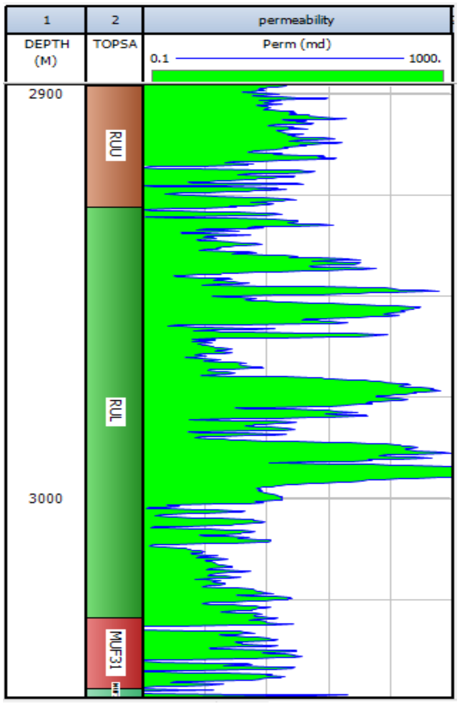

Figure 18. The permeability in the Lower Rutbah Formation

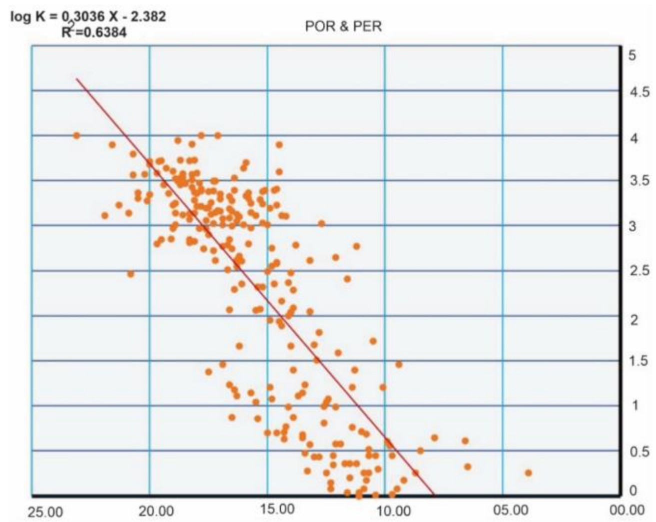

Figure 19. The equation between porosity and permeability in the Lower Rutbah Formation

Water saturation is obtained after the lower Rutbah layers (Fig. 20) are subjected to the Archie Equation (4).

3.6.2. Water saturation in the Upper Rutbah Formation

Since the Upper Rutbah Formation consists mainly of shale and cannot be invested in oil, there is no need to calculate the saturation value for it. Consequently, it makes no sense to use the Archie equation to determine the water saturation values there. At the same time, it is illogical to use the Archie equation to calculate water saturation in the Upper Rutbah Formation, as the parameters used in the Archie equation are taken for the oil-producing sectors and are not suitable for the non-productive shale sector.

3.7. Oil saturation

The determination of hydrocarbon saturation follows the determination of water saturation [22], and this can be achieved by using Equation (5).

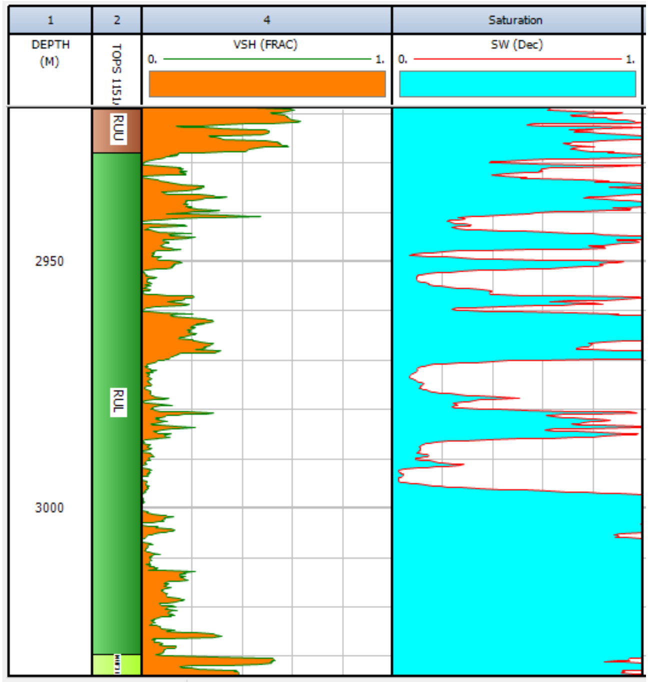

Figure 20. Water saturation in the Lower Rutbah Formation

$$S_{hc} = 1 - S_w , \qquad (5)$$

where:

S_{hc} – the hydrocarbon saturation;

S_w – water saturation.

3.7.1. Hydrocarbon saturation in the Upper Rutbah Formation

Since the hydrocarbon saturation in this sector was not calculated, it will only be done for the Lower Rutbah Formation. This is because the water saturation in the Upper Rutbah Formation was not calculated.

3.7.2. Hydrocarbon saturation in the Lower Rutbah Formation

After applying Equation (4) to the water saturation values in the Lower Rutbah Formation, the hydrocarbons saturation is obtained (Fig. 21).

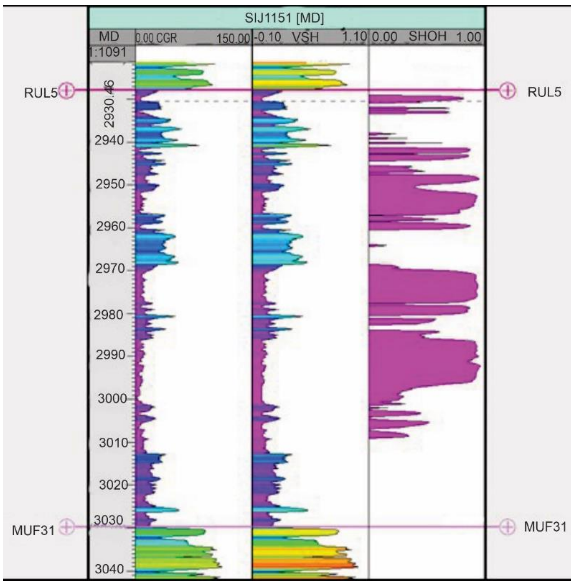

Figure 21. Oil saturation in the Lower Rutbah Formation

3.7.3. Prospects of future research

The following recommendations were provided after completion of this research:

– conducting a 3D seismic study, especially in the southern region of the Sijan field, which helps to better identify the locations of oil zones and define the boundaries of reservoirs more accurately compared to 2D data;

– drilling more wells in the vicinity of the well SIJ.129 after analyzing the 3D seismic data, especially in the southern and southwestern parts of the field;

– improving the understanding of the petrophysical properties of Rutbah Formation in the Sijan field by using data collected from different wells to identify the most productive areas and guide future drilling operations to reduce risks and increase return on investment.

While conducting scientific research at nearby sites such as Omar, Ghawari, and Al-Yimken, no comparable work has been done at the Sijan field. In order to accurately distinguish between the clay content and its distribution within the field, as well as to determine its detrimental effects on the storage properties, the current work is unique in its study of the Sijan field and relies on detailed petrophysical measurements, including density, resistivity, sonic, and gamma-ray logging. However, other studies in the nearby of the Euphrates Graben regions have focused on assessing the overall characteristics of rocks, as well as the geological, structural, and tectonic conditions, without going into the specifics of storage. This suggests that, compared to related studies, this research adds a new and comprehensive dimension to the examination of oil reservoir parameters and validates its usefulness as a cutting-edge resource for reservoir analysis and exploratory decision-making.

4. Conclusions

This research focuses on investigating the shale content and its effects on reservoir properties such as porosity and permeability in the Rutbah Formation within the northeastern part of the Euphrates Graben, Syria, based on well logging data analysis. Here are the most key findings: well logging techniques, particularly gamma-ray measurements, enabled the delineation of the Upper and Lower Rutbah Formations based on distinct anomalies. The Upper Rutbah Formation exhibits higher gamma-ray anomalies compared to the Lower Rutbah. The Upper Rutbah shows higher shale volumes compared to the Lower Rutbah, indicating variations in clay content within the formation. Analysis of porosity, including density and neutron logs, reveals differences in effective porosity between the Upper and Lower Rutbah Formations.

The presence of shale in the Upper Rutbah exhibits ineffective porosity compared to the Lower Rutbah with effective porosity. Permeability calculations indicate low permeability in the Upper Rutbah due to the presence of shale, rendering it non-investable for hydrocarbon production. In contrast, the Lower Rutbah, dominated by sandstone with minimal shale content, exhibits higher permeability, making it suitable for hydrocarbon production. The study highlights the importance of clay content assessment in reservoir estimate, as it significantly influences reservoir properties such as porosity and permeability, ultimately affecting hydrocarbon production potential. Understanding the distribution of clay minerals and their effects on reservoir properties provides valuable insights for oil exploration and production strategies in the Rutbah Formation within the Euphrates Graben region. The findings can guide future exploration and development efforts in similar geological settings, optimizing hydrocarbon recovery processes.

Author contributions

Conceptualization: AMA, MAM; Investigation: AMA, AYA, MAM; Methodology: AMA, AYA, MAM, MMM; Resources: AYA; Software: AYA, MMM; Supervision: AMA, MAM, MMM; Writing – original draft: AYA, MMM; Writing – review & editing: AMA, AYA, MMM. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Оцінка вмісту глини та її впливу на властивості пласта за даними каротажу свердловин, родовище Сейян, Сирія

А.М. Абудейф, А.Й. Альхусейн, М.А. Мохамед, М.М. Масуд

Мета. Вивчення вмісту глини та петрофізичних характеристик Рутбахської формації на Сейянському родовищі та їх впливу на видобуток на основі аналізу різних свердловинних вимірювань для оцінки якості пласта і прогнозування поведінки потоку рідини. Дослідження також має на меті порівняти свердловини на родовищі Сейян, щоб показати відмінності в петрофізичних властивостях, особливо в насиченості вуглеводнями піщаної формації Рутбах.

Методика досліджень включає вимірювання гамма-випромінюванням для визначення літології порід та підрахунку об'єму сланцю. Проникність аналізується за допомогою рівнянь, що стосуються проникності та пористості. Визначення пористості включає акустичне, нейтронне та густинне вимірювання пористості. Рівняння Арчі було використано для розрахунку водо- та вуглеводневої насиченості.

Результати. За допомогою вимірювання гамма-випромінювання було окреслено верхню та нижню частини формації Рутбах. Виявлено, що верхня частина Рутбах демонструє більш високі гамма-аномалії та об'єми сланцю порівняно з нижньою частиною Рутбах. Виявлено, що сланець у верхній частині Рутбах призводить до неефективної пористості, тоді як нижня частина Рутбах, де переважають пісковики з мінімальною кількістю сланців, демонструє вищу проникність, придатну для видобутку вуглеводнів.

Наукова новизна. Дослідження підкреслює важливість даних каротажу свердловин як економічно ефективної альтернативи традиційним методам оцінки вмісту глини та оцінки якості пласта в режимі реального часу, що робить відповідний внесок для розширення знань, досліджуючи вплив варіацій вмісту глини на властивості пласта і покращуючи його характеристику та прогнозування видобутку.

Практична значимість. Дослідження дає уявлення про стратегії розвідки та видобутку нафти у формації Рутбах в Євфрат-Грабенському регіоні. Розуміння розподілу глинистих мінералів та їхнього впливу на властивості пластів може спрямовувати зусилля з розвідки та розробки, оптимізуючи видобуток вуглеводнів.

Ключові слова: *формація Рутбах, каротаж свердловин, вміст глини, Євфрат-Грабен*

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