

Petrophysical study of the Rumaila Formation in Ratawi Oil Field, Southern Iraq

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ABSTRACT

The objective of this study was to evaluate the petrophysical characteristics of the Rumaila Formation in the Ratawi Oilfield by integrating reservoir and well-log data. Well-log interpretation was performed using IP 2018 software, version 4.5. Key petrophysical properties, including shale volume (0.067-0.62), effective porosity (0.06-0.239), and water saturation (0.48-0.69), were calculated and interpreted. Based on variations in these properties, the formation was subdivided into four main units (Ru-1-Ru-4), representing different reservoir-quality levels. Distinct differences were observed among the selected wells. In well RT-26, units Ru-4 and Ru-2 displayed average properties, whereas all units in well RT-24 exhibited fair-to-good parameters. All units in well RT-25 exhibited poor properties, indicating deterioration in reservoir quality within the central dome area. Computed petrophysical interpretation (CPI) revealed clear horizontal and vertical heterogeneity in the reservoir properties, with a gradual improvement from the northeast to the southwest. Matrix identification (MID) data and petrographic investigations further supported these results, confirming the dominance of calcite as the principal mineral and reinforcing the interpretation that the formation rocks are primarily composed of limestone. The study also employed a three-dimensional (3D) contour map, generated using Petrel software, to illustrate the structural and geographical extent of the reservoir. The findings contribute to establishing an accurate knowledge base for reservoir characterization, thereby supporting field-development strategies and production optimization in the Ratawi Oilfield.

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1 INTRODUCTION

The Middle Cretaceous Rumaila Formation, which comprises a thick carbonate sequence, is an important reservoir unit in the central Mesopotamian Basin [1]. The Mesopotamian Basin is one of the world's richest petroleum basins, and a considerable volume of oil within the basin is trapped in Cretaceous carbonate strata [2]. Rabanit (1952) originally characterized the Rumaila

Formation, and Smout (1956) subsequently named it. It is a Cenomanian member of the Wasia Group [3]. It represents a major reservoir unit in the southern, central, and northern parts of the Mesopotamian Basin, including the West Qurna, AD, and Hamrin fields, respectively [4]. The Rumaila Formation is widely distributed throughout the Mesopotamian Basin. Studies have revealed that the formation in selected wells from the central and southern parts of the basin consists of chalky and marly

limestone and is interpreted as representing deep-water, outer-shelf, or basinal carbonate deposits [5]. The Rumaila Formation consists mainly of limestone, dolomite, shale, and marl, reflecting the diversity of its associated sedimentary facies. These facies provide an important record of the depositional environment and geological evolution of the formation [6]. The Ratawi Field is located approximately 12 km west of the North Rumaila Field and 70 km northwest of Basrah. The study area is approximately 35 km long and 20 km wide, covering a surface area of approximately 700 km² [7]. Table 1 presents the geographical coordinates of the investigated wells. The Ratawi Field was initially identified through gravity surveys in the early 1940s and was subsequently investigated by the Basra Oil Company using seismic surveys in 1947 and 1948.

Table 1 UTM Coordinates of Wells

Well Name	Eastern	Northern
Rt-24	700100	3385450
Rt-25	699237	3382779
Rt-26	698500	3380512

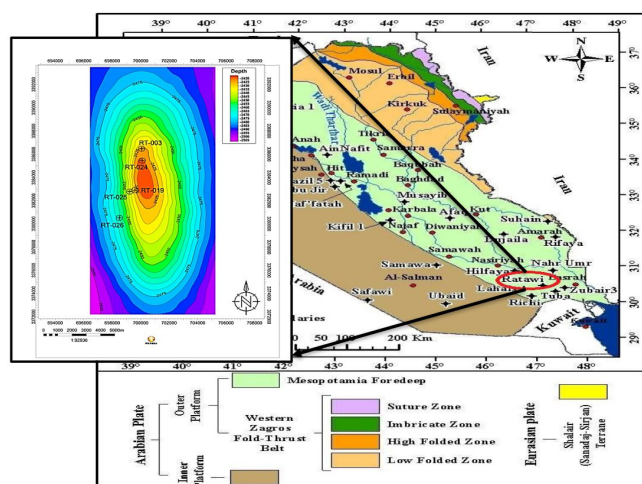


Fig. 1 Location map of the Ratawi Oil Field with a topographic map of the structure at the top of Rumaila Formation.

The Rumaila Formation occurs within a moderately deep basin located north of the study area, with a typical thickness ranging from 100 to 120 m and gradually increasing toward the eastern and southern parts of the country [8]. The formation consists of mudstone facies deposited in a deep-water environment, which

gradually transition into shallower facies characterized by the predominance of clay-rich wackestone. In the southwestern part of the study area, the formation exceeds 100 m in thickness. This thickness is related to the presence of the Rumaila Basin within a well-developed continental-margin environment [9].

Petrographic examinations of four Cretaceous formations-the Maudud, Ahmadi, Rumaila, and Mishrif formations-revealed interbedded highly porous limestone and harder layers, reflecting contrasts in their sedimentary and reservoir characteristics. All formations contained water, whereas the hydrocarbon-bearing zones exhibited low acoustic impedance (AI). These characteristics were identified by examining acoustic-impedance cross-sections and Vp/Vs ratios [10].

Previous studies of the Ratawi Field showed that the Mishrif Formation is composed primarily of limestone, with a clay content of approximately 10%. Its petrophysical properties were evaluated using well logs and advanced analytical software to accurately determine its hydrocarbon potential [11]. A previous study [12] analyzed well-log data from the Rumaila Formation. The evaluation showed that the studied formation consists mainly of limestone, dolomite, shaly limestone, and marl. The Rumaila Formation was divided into two units (A and B), with generally similar reservoir characteristics. However, Unit B is thicker than Unit A, which may indicate a difference in reservoir potential.

Although numerous studies have examined various geological formations in the Ratawi Field, research specifically focusing on the Rumaila Formation remains limited. This research gap was the primary motivation for selecting the formation as the subject of the present study. Despite its significance, the Rumaila Formation has not been comprehensively investigated. Therefore, this study aims to provide an integrated petrophysical evaluation of the Rumaila Formation in the Ratawi Oilfield using data from three selected wells: RT-24, RT-25, and RT-26. Advanced interpretation methods involving gamma-ray, density, neutron, and deep and shallow resistivity logs were employed to evaluate the reservoir properties and identify stratigraphic intervals with comparatively good or poor reservoir quality. Well 8 was selected for this study because it contains an unproven unit within a strategically important area.

2 MATERIALS AND METHODS

Modern technologies and software were integrated to determine and analyze the petrophysical parameters of the Rumaila Formation reservoir in the Ratawi Oilfield and to develop a comprehensive understanding of reservoir performance and the distribution of its rock and reservoir properties. Open-hole log data from three vertical wells, RT-24, RT-25, and RT-26, were obtained and interpreted during the first stage of the study. The available data included basic geophysical well logs, namely gamma-ray (GR) logs for estimating shale volume (Vsh), bulk-density (RHOB) logs, neutron-porosity (NPHI) logs, and deep and shallow electrical-resistivity logs.

Petrophysical analysis was conducted using Interactive Petrophysics (IP 2018), version 4.5, an advanced well-log interpretation tool. The software enables comprehensive analysis, data-quality control, fluid-property calculations, and interactive interpretation of petrophysical parameters. The resulting interpretations can be modified and saved for further analysis. Gamma-ray logs were used to estimate Vsh by applying the Schlumberger (2013) equation, which is suitable for shaly rocks, particularly because the Rumaila Formation contains thin shale intervals. Density and neutron data were cross-plotted to determine the matrix composition and estimate total porosity because this method is reliable for characterizing common formation minerals, such as calcite, quartz, and dolomite.

The results indicated that secondary porosity had no significant effect on the porosity values, whereas the density and neutron logs showed good agreement in determining total porosity, thereby increasing confidence in the estimates. Secondary porosity was also calculated and graphically presented using the IP software interface. Computed petrophysical interpretation (CPI) profiles were constructed to illustrate reservoir heterogeneity among the different units and wells and to provide a comprehensive graphical representation of the petrophysical parameters. Based on this interpretation, the formation was divided into four main reservoir units: Ru-1, Ru-2, Ru-3, and Ru-4, as shown in Figures 9-11 in the Results section. This subdivision demonstrates variations in the properties among units and wells, thereby contributing to a more accurate understanding of reservoir behavior in both the vertical and horizontal directions.

To provide an additional geospatial dimension, a three-dimensional (3D) contour map of the study area was generated using Petrel software and included the locations of the three investigated wells. This map helped define

the structural and compositional extent of the reservoir, thereby supporting field-development strategies.

2.1 Stratigraphic setting

The Rumaila Formation is one of the most widespread Cenomanian formations in southern and southwestern Iraq. The formation consists of fine-grained, marly, oligosteginal limestone interbedded with marl, grading downward into fine-grained chalky limestone. At the type locality, the lower contact of the Rumaila Formation with the Ahmadi Formation is conformable, whereas its upper contact is with the Mishrif Formation [13], as shown in Figure 2.

2.2 Determination of lithology and mineralogy

Lithology is a term used to describe the physical and mineralogical characteristics of rocks [14]. More accurate information on lithology, porosity, and other formation properties can be obtained by integrating conventional petrophysical cross-plots with well-log data [15].

2.3 Neutron–density cross-plots

Neutron–density cross-plots are commonly used to determine formation lithology and were among the earliest quantitative well-log interpretation tools. They are constructed by plotting neutron-porosity (NPHI) and bulk-density (RHOB) values on specialized charts. Lithological variations may also be evaluated by visually comparing the separation between the NPHI and RHOB curves [16]. Figures 3 and 4 show that most units of the Rumaila Formation plot along the limestone line.

2.4 Matrix identification plot

Matrix identification (MID) plots are used to identify formation lithology and represent an established quantitative interpretation method. They are constructed by plotting the relevant matrix-identification parameters on specialized charts [17].

$$\text{Rhoma} = \frac{\rho_b - \phi t a^* \rho_f}{1 - \phi t a} \quad (1)$$

$$\Delta t_{\text{maa}} = \frac{\Delta t \log - \phi t a^* \Delta t f}{1 - \phi t a} \quad (2)$$

where $\Delta t a$ represents the apparent total porosity; $\Delta t f$ is the interval transit time (185 μ s/ft in saline mud, 189 μ s/ft in fresh mud); and $\Delta t \log$ denotes the interval transit time recorded by the well log. ρ_b is the bulk density of the Formation (as measured in the log), ρ_f represents

the fluid density (1 g/cm^3 for fresh water and 1.1 g/cm^3 for saline mud), while Rhomaa indicates the bulk density of the rock matrix (g/cm^3). The MID intercept plot in Figures 3 and 4 indicates that most Rumaila Formation points fall within the calcite mineral range, confirming the dominance of this mineral in the Formation.

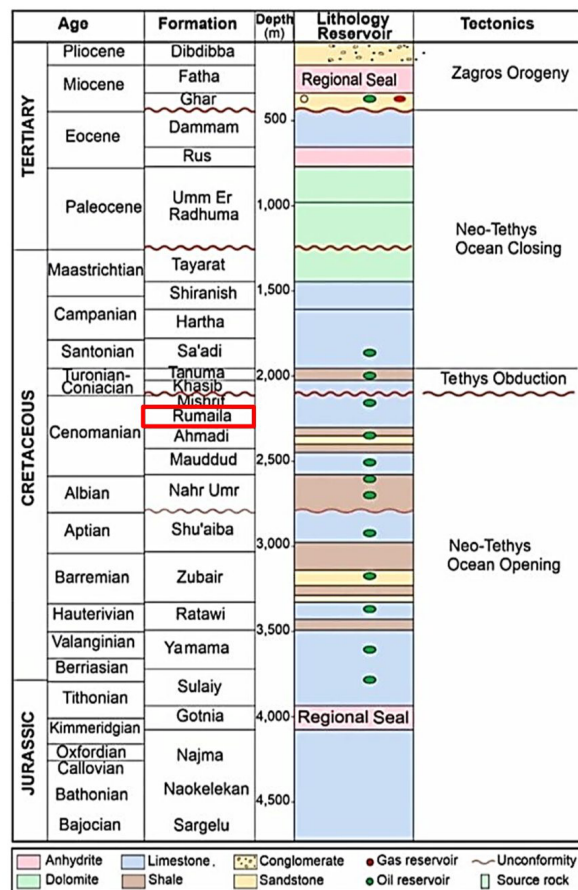


Fig. 2 Stratigraphic column In particular Rumaila Formation [17].

2.5 Petrophysical parameters

2.5.1 Shale volume estimation (Vsh)

The amount of shale present significantly affects the interpretation of formation porosity and water saturation, both of which influence the estimated hydrocarbon saturation [18]. The gamma-ray log was used to estimate the shale volume in the Mauddud Formation. The clean-formation baseline was defined using the minimum gamma-ray value, whereas the shale baseline was defined using the maximum value. The shale content can substantially affect the reservoir's storage capacity [19].

The gamma ray index (IGR) was computed using the following formula to determine the amount of shale.

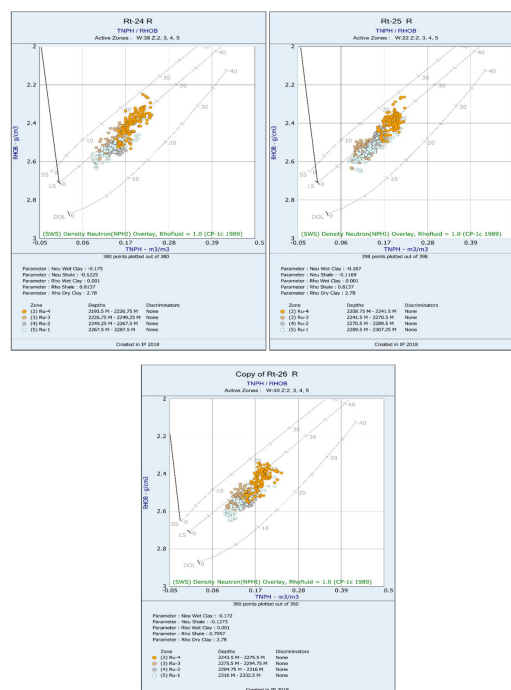


Fig. 3 Neutron-Density Cross plot of Rumaila Formation in wells (Rt-24) , (Rt-25) and (Rt-26).

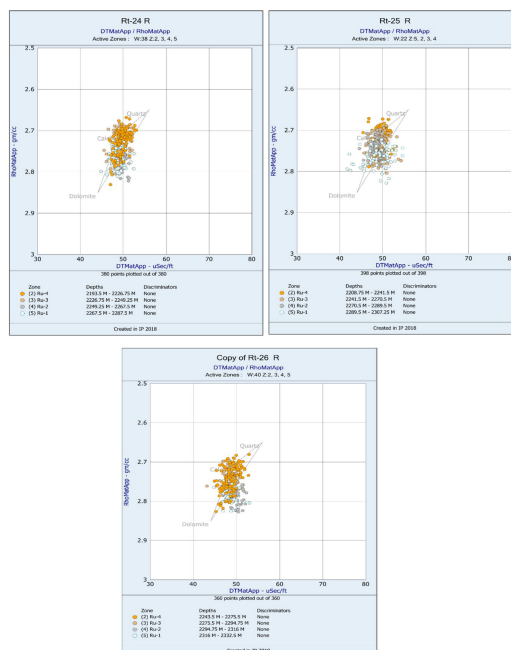


Fig. 4 MID , cross plot for Rumaila Formation from wells (Rt-24), (Rt-25) and (Rt-26).

$$\text{IGR} = (\text{GRlog} - \text{GRmin}) / (\text{GRmax} - \text{GRmin}) \quad (3)$$

Where, IGR = gamma ray index, GRlog = gamma ray reading by log(API), GRmin = minimum gamma (clean sand or carbonate), GRmax = maximum gamma ray (shale).

$$V_{sh} = 0.33 * (2^{2*IGR} - 1) \quad (4)$$

Where: Vsh = volume shale, IGR = index of gamma ray.

Figure 5 displays the amount of shale in the Rumaila Formation in the (Rt-24) (Rt-25) and (Rt-26) wells.

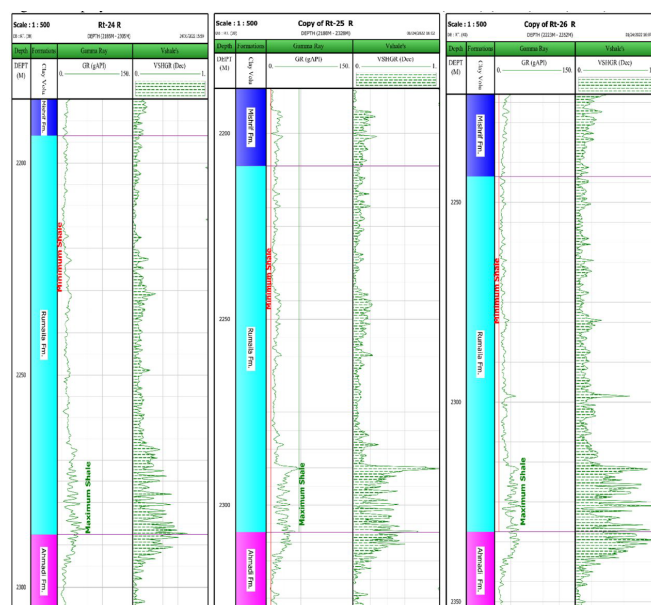


Fig. 5 Clay Volume (VCLGR) calculation by GR log in Wells (Rt-24), (Rt-25) and (Rt-26).

2.5.2 Effective porosity (ϕ_e)

Effective porosity is defined as the ratio of the volume of interconnected pores to the total volume of the reservoir rock [20]. The highest effective-porosity values were recorded in well RT-24 and were classified as very good according to Levorsen's (1972) effective-porosity classification. The effective porosity of the Rumaila Formation in the Ratawi Oilfield is strongly controlled by diagenetic processes.

In Ru-1, dissolution and early dolomitization were the dominant processes, producing secondary vuggy and moldic porosity and resulting in high effective porosity and good reservoir quality. In Ru-2, mechanical

compaction and partial calcite cementation reduced the original intergranular porosity, although minor dissolution locally enhanced pore connectivity, resulting in moderate porosity. Ru-3 was mainly affected by intense compaction, late calcite and anhydrite cementation, and late dolomitization, resulting in poor reservoir quality and low intercrystalline porosity. In Ru-4, extensive dolomitization followed by localized dissolution generated intercrystalline and fracture porosity. However, this porosity was partially reduced by late-stage cementation, resulting in variable porosity values.

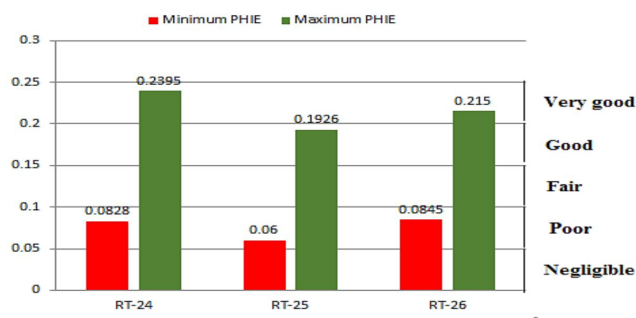


Fig. 6 Effective porosity in wells. According to the Leverson classification in Wells (Rt-24), (Rt-25), (Rt-26).

2.5.3 Secondary porosity

In general, the secondary porosity index (SPI) was lower than the total porosity. However, elevated SPI values were observed in units Ru-1 and Ru-3, particularly in wells RT-25 and RT-26. These elevated values may indicate the influence of diagenetic processes on the porosity of the Rumaila Formation, as shown in Figure 7.

2.6 Computer processed interpretations (CPI)

Computer-processed interpretation (CPI) refers to the computer-assisted analysis and integration of geological data, including seismic data, well logs, and spatial data, using specialized algorithms and software. CPI can assist geologists in identifying mineral deposits, modeling reservoirs, and interpreting subsurface features. It also enables the extraction of petrophysical parameters in digital form, including shale volume, porosity, water saturation, and other properties, as presented in Tables 2–4. Table 5 compares the average petrophysical parameters of the four reservoir units across all investigated wells. This technology accelerates data analysis, improves interpretation accuracy, and supports resource exploration and development. The CPI profiles of the selected wells are presented in Figures 8–10.

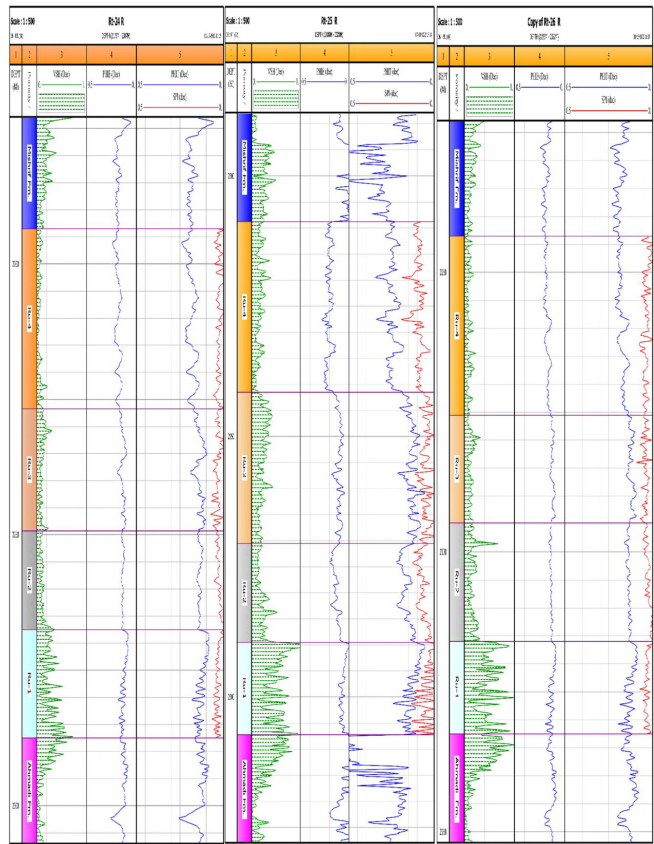


Fig. 7 GR log, effective porosity (PHIE), the correlation between total porosity (PHIT) and secondary porosity (SPI), for (Rt-24) ,(Rt-25) and (Rt-26) Wells.

Table 2 Despicable properties reservoir Rumaila in well RT-24.

UNIT	PHE (%)	VSH (%)	SW (%)	SXO (%)	BVW (%)	BVWSXO (%)	THICK (m)
RU-1	0.1	0.28	0.55	0.78	0.065	0.11	19
RU-2	0.14	0.15	0.52	0.89	0.075	0.12	19
RU-3	0.13	0.12	0.49	0.72	0.067	0.125	22
RU-4	0.18	0.07	0.48	0.70	0.09	0.13	33.5

Table 3 Despicable properties reservoir Rumaila in well RT-25.

UNIT	PHE (%)	VSH (%)	SW (%)	SXO (%)	BVW (%)	BVWSXO (%)	THICK (m)
RU-1	0.07	0.16	0.55	0.86	0.06	0.09	16.5
RU-2	0.11	0.095	0.69	0.87	0.07	0.11	19.5
RU-3	0.10	0.11	0.63	0.81	0.05	0.09	30
RU-4	0.15	0.067	0.68	0.78	0.09	0.14	32

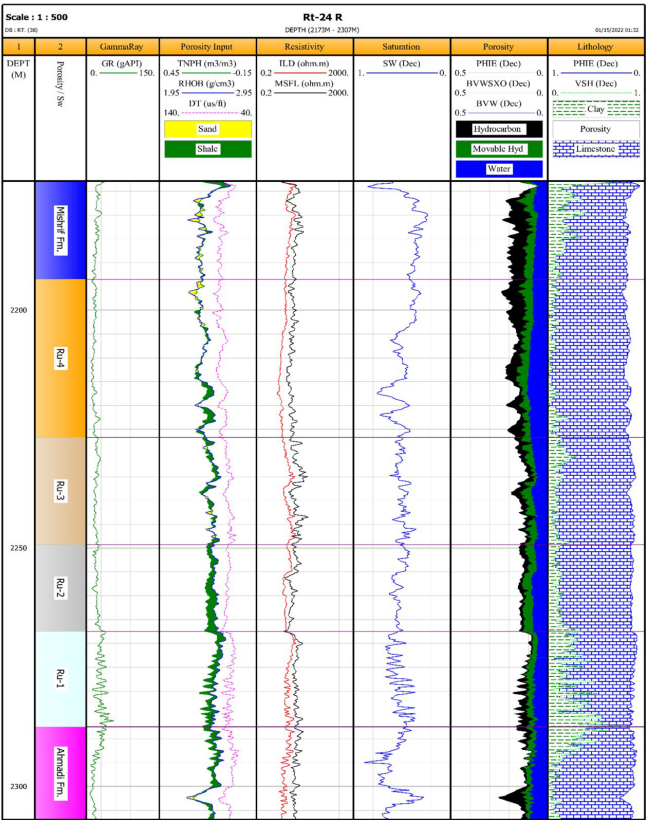


Fig. 8 Shown CPI of Rumaila Formation in well (Rt-24) .

Table 4 Despicable properties reservoir Rumaila in well RT-26.

UNIT	PHE (%)	VSH (%)	SW (%)	SXO (%)	BVW (%)	BVWSXO (%)	THICK (m)
RU-1	0.09	0.62	0.50	0.83	0.08	0.11	31.5
RU-2	0.12	0.30	0.54	0.92	0.09	0.12	19.5
RU-3	0.11	0.22	0.52	0.84	0.08	0.10	21
RU-4	0.17	0.17	0.59	0.91	0.11	0.14	19.5

Table 5 Average Petrophysical Parameters of Rumaila Reservoir Units (RU-1 to RU-4) Across All Wells.

Unit	Average VSH	Average PHE	Average SW	Average BVW
RU-1	0.35	0.08	0.53	0.06
RU-2	0.18	0.12	0.58	0.07
RU-3	0.15	0.11	0.54	0.06
RU-4	0.10	0.16	0.58	0.09

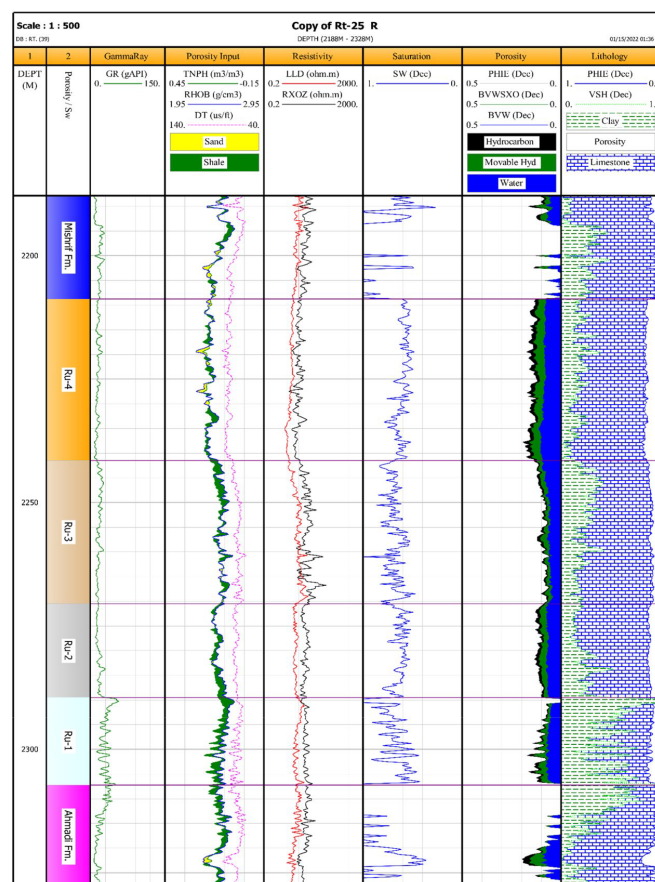


Fig. 9 Shown CPI of Rumaila Formation in well (Rt-25).

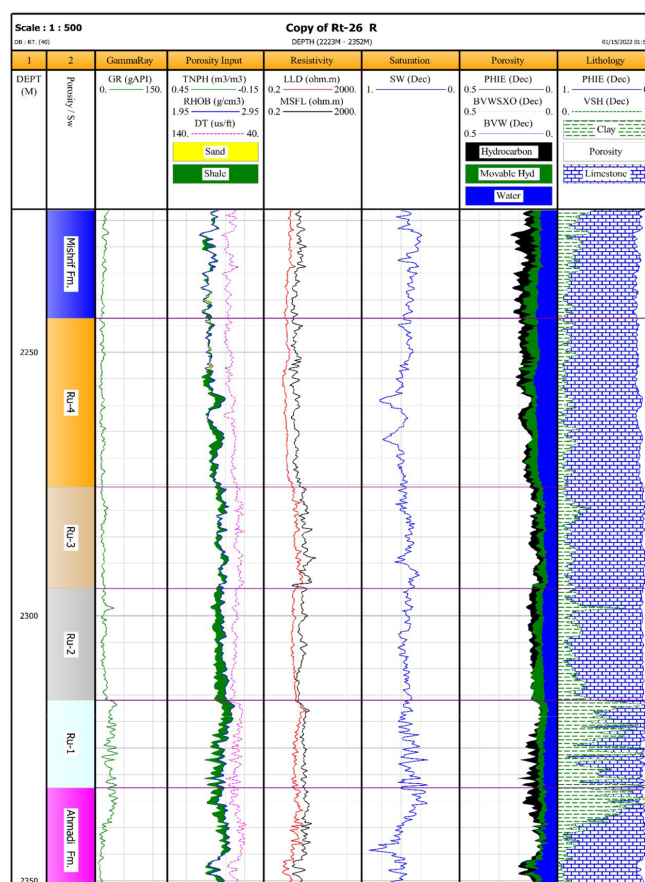


Fig. 10 Shown CPI of Rumaila Formation in well (Rt-26).

3 RESULTS AND DISCUSSION

A detailed petrophysical analysis of the Rumaila Formation was performed by interpreting geophysical well logs and evaluating fundamental properties, including effective porosity (PHIE), shale volume (VSH), water saturation (SW), bulk volume water (BVW), and bulk volume water in the flushed zone (BVWSXO). Based on vertical variations in these properties, the reservoir was divided into four main units, Ru-1, Ru-2, Ru-3, and Ru-4, and their characteristics were compared across wells RT-24, RT-25, and RT-26.

Unit Ru-1 exhibited relatively low effective porosity across all wells, ranging from 0.07 to 0.10 . Shale volume increased substantially, particularly in well RT-26, where VSH reached 0.62 . The saturation curves indicated SW values of approximately 0.50 – 0.55, with a considerable proportion of water

saturation in the flushed zone (SXO). The BVW values were also low, ranging from 0.06 to 0.08 , suggesting that this unit has limited hydrocarbon-storage potential compared with the other units.

Unit Ru-2 exhibited increased effective porosity, ranging from 0.11 to 0.14 , and a relative decrease in shale volume. This decrease was most apparent in well RT-25, where VSH was 0.095, indicating a comparatively cleaner reservoir interval. However, SW increased slightly, reaching 0.69 in RT-25, whereas BVW showed a minor decrease relative to Ru-1. These findings imply that the reservoir is cleaner in this unit but still contains a relatively high proportion of bound or free water.

Unit Ru-3 exhibited favorable petrophysical properties. Moderate effective porosity, ranging from 0.10 to 0.13 , and low shale volume, ranging from 0.11 to 0.22 , were recorded across the three wells.

Water saturation was also comparatively low, ranging from 0.49 to 0.63, whereas BVW ranged from 0.05 to 0.08. These characteristics may indicate favorable hydrocarbon potential, particularly in intervals with higher porosity and lower water saturation.

Unit Ru-4 exhibited favorable effective porosity, ranging from 0.15 to 0.18, and low shale volume (<0.17). Water saturation remained relatively high, ranging from 0.48 to 0.68. Nevertheless, BVW values in the underlying unsaturated and partially saturated intervals were higher than those in the overlying unit, suggesting partial pore occupancy by potentially mobile hydrocarbons. Ru-4 was also the thickest of the four units, making it a potential target for further evaluation and development.

The three wells showed generally consistent distributions of porosity and water saturation among the reservoir units. Minor differences may be attributed to lateral facies variations or diagenetic overprinting. Well RT-26 exhibited a higher shale volume than the other wells, particularly in Ru-1, which may adversely affect production at this location. Ru-4 appears to be the most prospective unit for further investigation and development because of its relatively high effective porosity and greater thickness.

4 CONCLUSION

Calcite was the predominant mineral in the limestone composing the Rumaila Formation. Based on shale volume, water saturation, effective porosity, and well-log responses, the formation was subdivided into four units. In well RT-26, only Ru-2 and Ru-4 exhibited moderate reservoir characteristics, whereas all units in RT-24 showed moderate-to-good petrophysical properties. In contrast, all units in RT-25 exhibited poor reservoir properties.

Ru-4 represents the most promising unit for further development because of its relatively high effective porosity and greater thickness. However, its locally high water saturation indicates that detailed zonal evaluation is required before making field-development decisions. The computer-processed interpretation (CPI) demonstrated horizontal and vertical heterogeneity in the reservoir properties.

Well RT-24, located in the northeastern part of the study area, exhibited good reservoir properties, whereas RT-26, located to the southwest, showed moderate properties. The central dome around RT-25 was characterized by poor reservoir properties.

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Data availability

N/A

DECLARATIONS

Conflict of interest

The authors declare no competing interests

Consent to publish

N/A

Ethical approval

N/A

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