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Lithology and minerals identification from well logs for Mishrif Formation in Ratawi oilfield

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Abstract

Lithology identification plays a crucial role in reservoir characteristics, as it directly influences petrophysical evaluations and informs decisions on permeable zone detection, hydrocarbon reserve estimation, and production optimization. This paper aims to identify lithology and minerals composition within the Mishrif Formation of the Ratawi Oilfield using well log data from five open hole logs of wells RT-2, RT-4, RT-5, RT-6, and RT-42. At this step, the logging lithology identification tasks often involve constructing a lithology identification model based on the assumption that the log data are interconnected. Lithology and minerals were identified using three empirical methods: Neutron-Density cross plots for lithology identification, M-N cross plots (also known as Litho-porosity cross plots) for mineral identification, and Matrix identification (MID) plots. Neutron-density cross plots show that the Mishrif formation consists of limestone with some data points tending to the dolomite line east of the field and to the sandstone line west of the field. The M-N and MID plots indicate that calcite is the major mineral for the Mishrif formation; however, quartz grows to the west of the area while dolomite increases to the east. These findings underscore the importance of integrating multiple well-log interpretation techniques to capture lithologic and mineralogical complexity, providing critical insights for reservoir management and targeted exploitation strategies in heterogeneous carbonate systems.

Keywords: Lithology; Minerals; Mishrif formation; Ratawi oilfield.

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1- Introduction

Lithology identification is an important and fundamental stage in geological research for applications such as reservoir characterization, drilling optimization, completion design optimization, reservoir potential identification, and petroleum development. For example, when rock type is defined, petroleum engineers can make much better decisions about how to develop a gas or oilfield. In addition, drilling techniques can be optimized for the specific rock by selecting the suitable drilling bits, and production engineers can predict how the reservoir will respond to production activities [1-4]. Therefore, accurate identification of lithology plays a role for several reasons [5, 6]. To begin with, it aids in comprehending the environment of deposition and revealing the processes and conditions that influenced the formation throughout Earth's history. This understanding holds importance in the realm of hydrocarbon reservoirs, where various rock types like sandstones and limestones can provide insights into specific depositional settings such as fluvial, marine, or coastal environments. By delving into the past of a region, we can enhance our ability to anticipate the distribution and characteristics of potential hydrocarbon reservoirs in that area [7]. Furthermore, it's crucial for estimating hydrocarbon reserves and evaluating the production potential of a reservoir alongside tuning drilling practices and studying geological formations in depth. Take rock classification as an example; it provides insights into porosity (the rock's ability to retain fluids such as oil or gas) and permeability (how easily fluids can move through the rock). These properties are essential for determining the potential for hydrocarbon production and for designing the most effective extraction strategies [8]. This information enables engineers to make informed decisions throughout the drilling and production operations.

Differentiating lithology can be achieved mainly through both direct and indirect methods [9]. The direct approach includes gathering drilling cuttings and cores from the formation while drilling and analyzing them to recognize the lithology [10]. However, this method is expensive, consuming and restricted by the accessibility of rock samples, making it impractical for oil and gas exploration [11]. Indirect techniques offer an approach to determining rock types without the need for physical samples like direct methods require of extracting samples from the rock itself. tricks like seismic surveys and well logging are used to gauge the properties of rocks buried

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deep underground. Through analyzing these characteristics and data collected from these methods, scientists and engineers can deduce the composition of the rock material. Gain valuable insights into its properties. Well logging stands out as a method for indirectly identifying different types of rocks [12]. Well logs are an effective way to assess reservoirs and play a key role in determining rock types present in the subsurface area due to their high resolution and smooth collection process [13]. Hence, they are a tool. In this regard, Gamma ray (GR), Density (RHOB), Neutron (NPHI), and Sonic (DT) logs are often utilized alongside well logs to identify lithology changes effectively. Cross-referencing logging data is a method used for identifying lithology [14].

Mishrif Formation is composed of limestones and shales deposited in the ramped platform, which was dominated by a shallow-water inner shelf [15]. Limestones are comprised of various bioclasts such as rudists, algae, mollusks, and foraminifera. The limestone fabric ranges from grainstone to pelagic lime mudstone. The thickness of the Mishrif Formation varies from 154 to 177m among Ratawi wells [5]. The interval of the Mishrif Formation consists of several upward coarsening, reflecting a regional regressive event [2].

Mishrif formation in the Ratawi oilfield has a unique problem due to its complicated lithology, so this complexity leads to challenges in optimizing the recovery factor as the different lithologies may respond differently to various production techniques [16]. In light of the complex lithology of the Mishrif Formation, the present study aims to identify accurately the lithology and minerals of the formation, which is essential for characterizing the reservoir and estimating hydrocarbon reserves accurately. Also, it is very important to detect perforation intervals to avoid non-permeable zones, which cause material losses. The behavior of fluid flow within the reservoir is influenced by lithology. Lithology and permeability are closely related; permeability defines the ease with which fluids can flow through rock, so lithology identification is useful to optimize production techniques and predict fluid flow patterns.

All previous studies depended on core analysis and seismic data for lithology identification of the Mishrif formation, but this study identifies lithology and minerals by using well-logging data for selected wells in the Ratawi oilfield.

Ratawi oilfield is a promising hydrocarbon-bearing structure with several reservoirs, and it lies northwest of Basrah city and west of the Northern Rumaila Field [16]. Geophysical interpretation has indicated the presence of a salt structure beneath the Ratawi field, and the field's formation and development are influenced by tectonic movement and salt structure activity [16].

The Ratawi oilfield is located 70 km west of Basra city and has an elongated dome structure of approximately 20 km×10 km approximately. The Ratawi field is situated to the west of the Rumaila field, close to the route of the Strategic Pipeline and 12 km south of Hor Al-Hammar, near the coordinates (E 705.4-696.36) and (N 3394.183-3373.8), see Fig. 1 [17]. Five wells from the Ratawi oilfield were chosen to identify the lithology and minerals of the Mishrif formation due to their consistent distribution across the formation as shown in (Fig. 2).

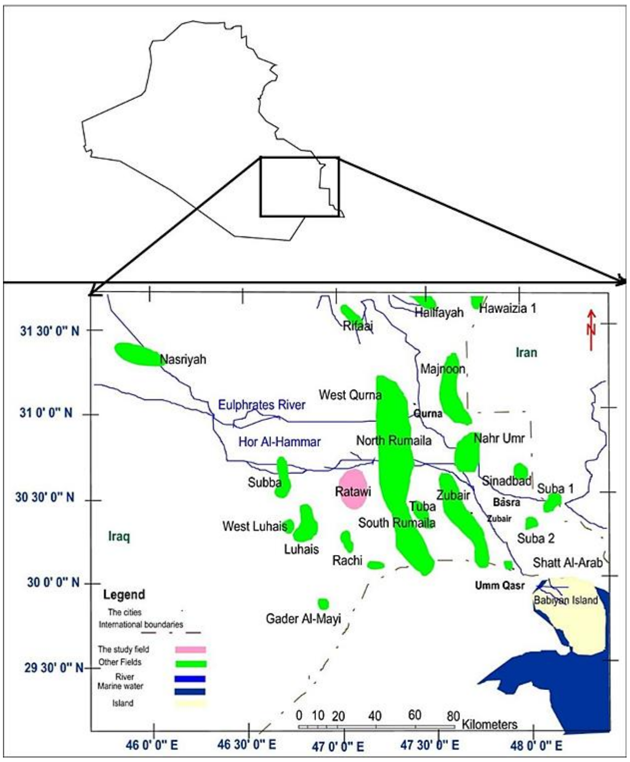

Fig. 1. Location Map of Ratawi Oilfield [17]

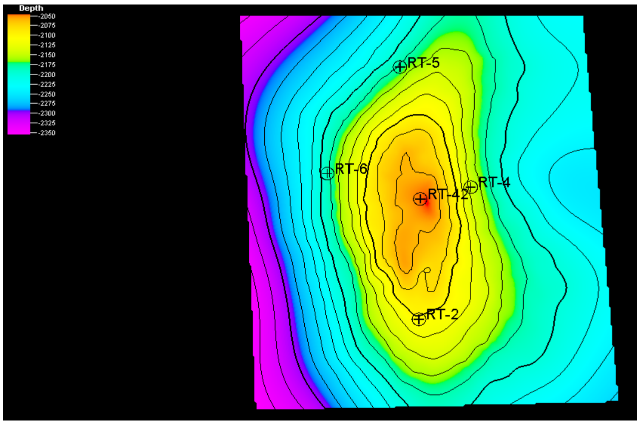

Fig. 2. Geographical Map of the Ratawi Field with Location of Wells

2- Methodology

This study utilized well log data from five wells (RT-2, RT-4, RT-5, RT-6, and RT-42) in the Ratawi oilfield to identify the lithology and mineralogy of the Mishrif formation. The data included gamma ray, density, sonic, and neutron logs acquired during open hole logging. Interactive Petrophysical software was used to analyze and visualize the well-log data.

Lithology and Mineral Identification Techniques:

2.1. Neutron-density cross plot for lithology identification

Schlumberger Educational Services has discussed a method known as the neutron density cross plot for identifying lithology, which is widely utilized for this purpose [18-20]. The neutron log and density log, when used together, play a role in categorizing lithology and assessing clay content as well as gas content and shaliness in a rock type. This cross plot displays lithology lines that indicate limestone, dolomite and sandstone formations suited for liquid-filled boreholes, with water or water-based drilling mud [21].

2.2. M-N cross plot for minerals identification

The Litho-Porosity (M-N) Cross-Plot is commonly used in geology to improve the precision of determining rock characteristics to conduct tri-porosity calculations using well log data [22-24]. It assists in identifying rock properties by offering a clear indication of clay content and effectively distinguishing between shale and sand layers. Every type of rock mineral is represented as a point on the plot of parameters M and N. By plotting well-logging data on the M-N grid, a continuous map of the formation's rock properties can be created [25]. This method allows for the creation of a map showcasing the rock properties of the formation continuously, which helps in the precise estimation of porosity in intricate rocks and provides vital lithology information for comprehensive stratigraphic evaluations. One of the uses of the M-N cross plot is to identify secondary porosity. This results in a rise in the M value from a decrease in density while maintaining an N value as Δt remains unaffected by secondary porosity [26]. The calculations for M and N are determined using the equations provided [25].

$$M = \frac{\Delta t_f - \Delta t}{\rho_b - \rho_f} * 0.01 \quad (1)$$

$$N = \frac{\emptyset_{Nf} - \emptyset_N}{\rho_b - \rho_f} \quad (2)$$

2.3. The matrix identification (MID) plot

This plot was developed to address the limitations of the M-N plot. The features of the M and N are replaced by the apparent density of the matrix (ρ_{ma}) and the apparent t sound travel time (Δt_{ma}) [27]. In contrast to the M-N cross plot, this approach offers advantages [28]:

- It is unaffected by the mud filtrate's saltiness.
- Each matrix point is distinct.
- Δt_{ma} and ρ_{ma} have a direct physical meaning.

The following formulae are used to compute the MID plot parameters [27]:

$$\rho_{ma} = \frac{\rho_b - (\rho_f \cdot \emptyset_{ta})}{1 - \emptyset_{ta}} \quad (3)$$

$$\Delta t_{ma} = \frac{\Delta t - (\emptyset_{ta} \cdot \Delta t_f)}{1 - \emptyset_{ta}} \quad (4)$$

The development of this plot greatly influences the analysis of subsurface formations in geophysics and reservoir engineering by offering improved precision and dependability in gathering data for understanding subsurface formations.

3- Results and discussion

Identifying lithology plays a key role in characterizing and modeling reservoirs, and it depends on data from cuttings and cores. The oil and gas sector uses lithology well logs to provide insights for geological modeling of underground formations. These logs record the physical traits of rock formations encountered while drilling, including their density, porosity, and mineral makeup. This data has an impact on evaluating the well's potential output and deciding on the right methods to extract hydrocarbons. Common types of lithology well logs include gamma ray logs and porosity logs that help geoscientists and engineers interpret the lithology of the formations and make informed decisions about well completion and production strategies.

Well logging data, which are available in almost all wells, even horizontal wells, were used for lithology detection. In this regard, porosity logs including neutron, sonic and density were employed for the generation of some important empirical charts for lithology identification and minerals identification in the Mishrif Formation in the Ratawi oilfield. For this purpose, neutron-density cross-plot along with MID pot and MN plot were generated based on well logging data from five wells.

Neutron-density cross plots for studied wells indicate that data points are concentrated on the limestone line so that the limestone makes up most of the lithology for the Mishrif formation, as shown in Fig. 3 to Fig. 7. On the other hand, we can notice some data points tend to the dolomite line in the MB1 and MB2 zones for the wells RT-5, RT-2and RT-4, which may result from the dolomization processes formed through the replacement of calcium ions in calcite by magnesium ions in seawater, this finding is accurate because it is identical with depositional analysis of Mishrif formation [29]. The concentration of sandstone increases in the west direction in well RT-6, which reduces the reservoir quality and increases sand production.

The Neutron-Density cross plot for RT-2 in the Mishrif Formation at the Ratawi Oil Field, as shown in Fig. 3, is a valuable tool for identifying lithology and evaluating porosity. The plot shows an inverse relationship between neutron porosity and density, with higher porosity corresponding to lower density. This relationship aids in identifying rock varieties in the formation. The data points grouped around iso-porosity lines reveal differences in rock characteristics; the colors probably denote lithologies, like limestone, dolomite, shale and sandstone.

The Mishrif Formation mainly consists of limestones with notable dolomite and shale layers dispersed throughout it. We can distinguish limestone and dolomite by their moderate to high porosity and density values; however, shale stands out with its lower density and porosity levels. Understanding these lithologies is key to gauging the reservoirs' ability to store oil and gas effectively and for guiding drilling and production strategies. As a result, the Neutron Density cross plot is essential for studying and assessing the Mishrif Formation, as it helps visualize the rock types and their characteristics effectively. Identifying high-porosity limestone and dolomite suggests a reservoir quality whereas shale layers play a crucial role as flow barriers impacting fluid movement within the formation.

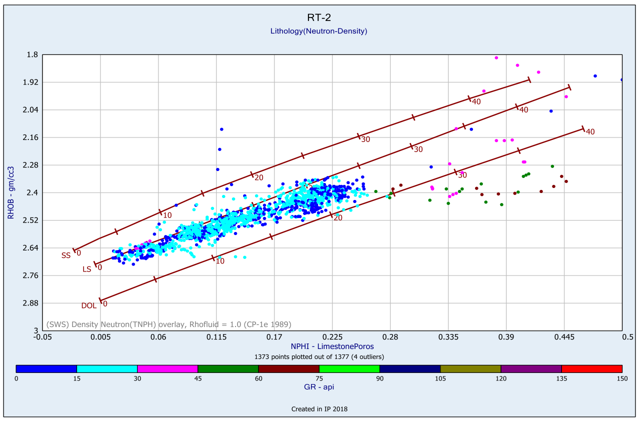

Fig. 3. Neutron-Density Cross Plot for Logs in Well RT-2

The plot of the Neutron-Density cross plot for Well RT-4 in the Mishrif Formation, as represented in Fig. 4, provides some crucial lithological information. This plot depicts a negative correlation between neutron porosity and density, allowing the points to navigate within the iso-porosity islands. The limestone has moderate to high values of porosity accompanied by moderate to high density. Dolomite, on the other side, shows low values of porosity and high density. Shale, which has low density and porosity, is prevalent at the upper left. The rocks of the Mishrif Formation are predominantly carbonates and consist of limestone and dolomite, which are essential for the reservoir quality. The data points' distinct clustering illustrates the noticeable lithological changes, which are very vital in reservoir characterization and management. High-porosity limestone and dolomites are indicators of good reservoir quality, and sandstone units consist of shale layers that inhibit fluid movements, hence defining the reservoir and the strategies to be employed. This analysis assists in exploring and developing the Ratawi Oil Field.

Fig. 5 shows the Neutron-Density cross plot for Well RT-5 in the Mishrif Formation, revealing an inverse relationship between neutron porosity (NPHI) and density (RHOB), with data points indicating different lithologies. Limestone is identified by moderate to high porosity and moderate density values, clustered around the middle of the plot, while dolomite shows lower porosity and higher density values, found towards the lower right. Shale, characterized by lower density and porosity, clusters towards the upper left. The Mishrif Formation at Well RT-5 is predominantly composed of carbonate rocks, including limestone and dolomite, which are essential for reservoir quality. The distinct clustering of data points along iso-porosity lines indicates clear lithological variations, crucial for effective reservoir characterization and management. High-porosity limestone and dolomite suggest good reservoir quality, while shale layers act as barriers, influencing fluid flow and reservoir strategies.

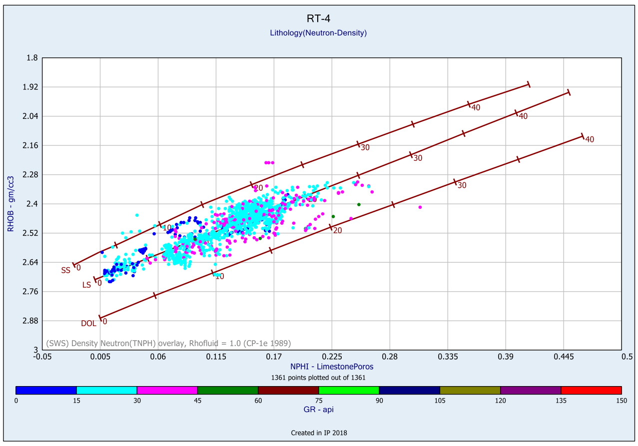

Fig. 4. Neutron-Density Cross Plot for Logs in Well RT-4

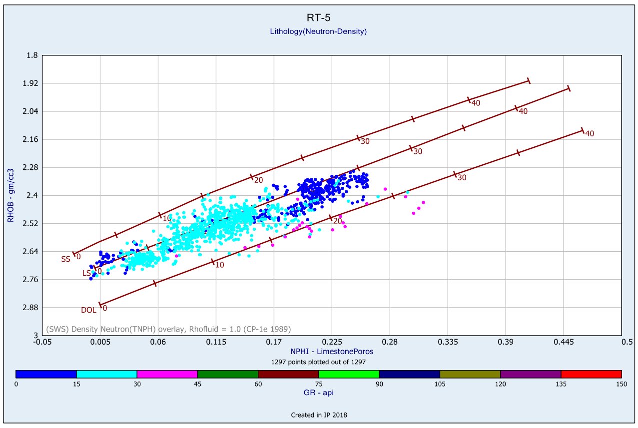

Fig. 5. Neutron-Density Cross Plot for Logs in Well RT-5

The graph in Fig. 6 for Well RT. 6 in the Mishrif Formation displays a connection between neutron porosity (NPHI) and density (RHOB) with different rock types being showcased by the plotted points on the chart. Limestone points are depicted in blue. Demonstrate moderate to high porosity and density values as they cluster at the center of the plot. On the other hand, dolomite points in green show lower porosity and higher density as they are situated towards the bottom right corner. Shale areas are highlighted in red. Show lower density and porosity values mainly positioned towards the upper left side of the graph; meanwhile, transitional zones of limestone/dolomite represented by purple dots exhibit a mix of properties. The Mishrif Formation at Well RT–06 comprises mostly carbonate rocks like limestone and dolomite that play a role in maintaining reservoir quality. The noticeable grouping of data points along iso porosity lines indicates lithological differences that are essential for proper reservoir analysis and planning. Porous limestone and dolomite suggest favorable reservoir quality, while shale layers serve as obstacles that impact the flow of fluids and decisions regarding reservoir management strategies. This assessment aligns with findings from Wells RT—2 to RT-5, which validate the lithological traits throughout the formation.

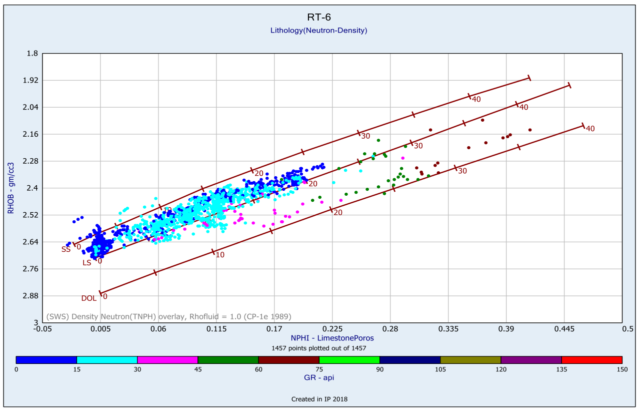

Fig. 6. Neutron-Density Cross Plot for Logs in Well RT-6

The Neutron-Density cross plot for Well RT-42 in the Mishrif Formation, as illustrated in Fig. 7, demonstrates an inverse relationship between neutron porosity (NPHI) and bulk density (RHOB), with data points highlighting diverse lithologies. Limestone is marked by blue dots with moderate to high porosity and density values clustering together at the center, while dolomite is indicated by green dots with lower porosity and higher density located towards the bottom right corner. Shale, which appears in red, known for having lower density and porosity values that tend to group together towards the upper left side of the chart at Well RT-42 from the Mishrif Formation, predominantly consists of carbonate rocks like limestone and dolomite that are critical for maintaining reservoir quality. The noticeable clustering of data points along iso-porosity lines highlights lithological differences that are important for properly characterizing and managing reservoirs. High-porosity limestone and dolomite suggest reservoir quality, whereas shale layers serve as barriers affecting fluid flow and overall reservoir strategies. The findings align with the data collected from Wells RT-1 to RT-5 and support the presence of consistent lithological features throughout the formation.

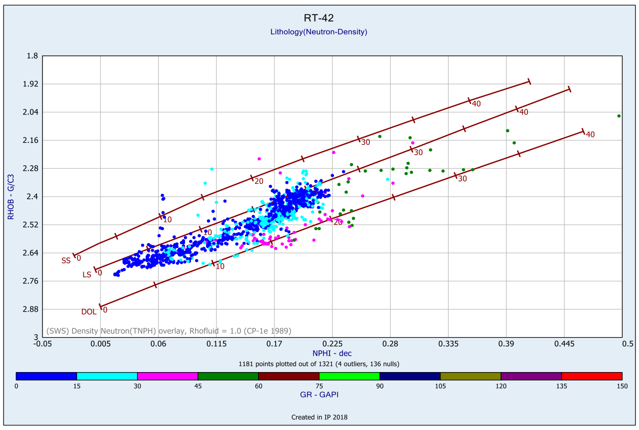

Fig. 7. Neutron-Density Cross Plot for Logs in Well RT-42

The analysis of M-N plots (Fig. 8 to Fig. 12) for the Mishrif Formation in the Ratawi Oil Field provides insights into its lithological composition and reservoir characteristics. These plots suggest that the formation consists mainly of carbonate rocks like dolomite and limestone with notable lithological variations such as anhydrite, gypsum, and sulfur interspersed within. Areas with high porosity indicate potential for good reservoir quality, while layers of anhydrite and gypsum could impede fluid movement. The heterogeneity of the formation is evident through the types of rocks present and how they are spread out in the area. By studying data from wells RT-2 to RT-42, as shown in Fig. 8 to Fig. 12, we can see clear features of different rock types like dolomite and limestone separated by sulfur content, along with how siltstone and sandstone impact the properties of the reservoir. These discoveries stress the need for examination and incorporation of more geological information to improve simulation models for reservoirs and strategically place wells to boost oil recovery. In addition, the M-N plots of the studied wells indicate that calcite is the main mineral in the Mishrif Reservoir, as shown in Fig. 8 to Fig. 12. Scatter data points are observed towards the secondary porosity at wells RT-2 and RT-4, which can enhance reservoir fluid flow, this finding is accurate because it is identical with previous studies [30, 31]. Some data points shift towards quartz in the western well (RT-6), as shown in Fig. 11, which suggests a westward increase in sandstone content within the Mishrif formation.

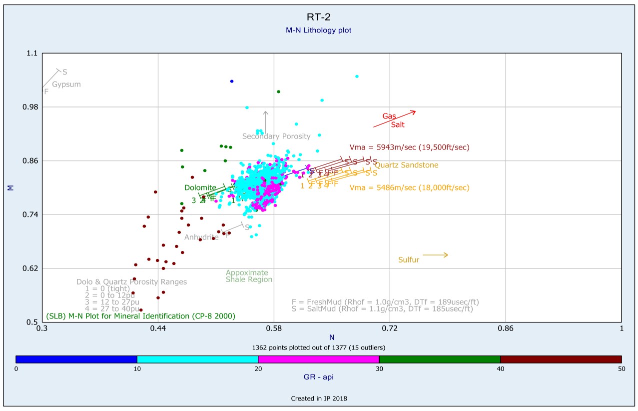

Fig. 8. M-N Plot for Logs in Well RT-2

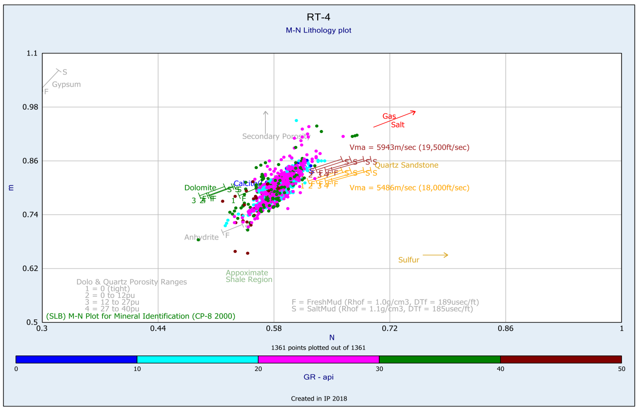

Fig. 9. M-N Plot for Logs in Well RT-4

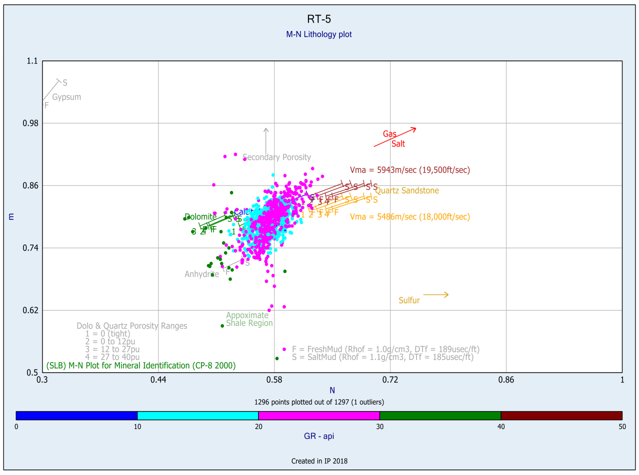

Fig. 10. M-N Plot for Logs in Well RT-5

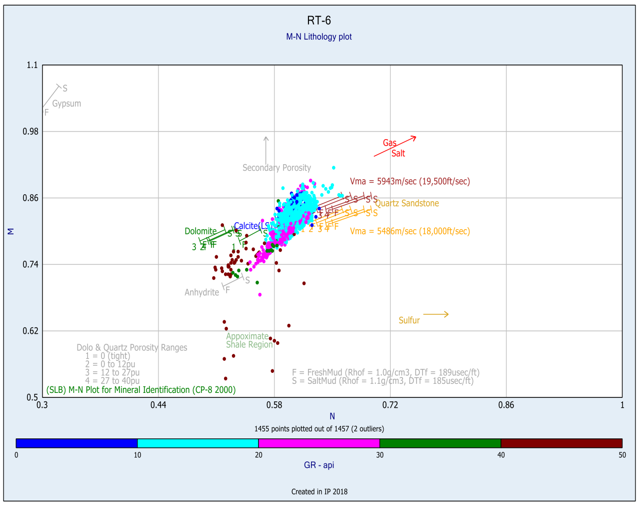

Fig. 11. M-N Plot for Logs in Well RT-6

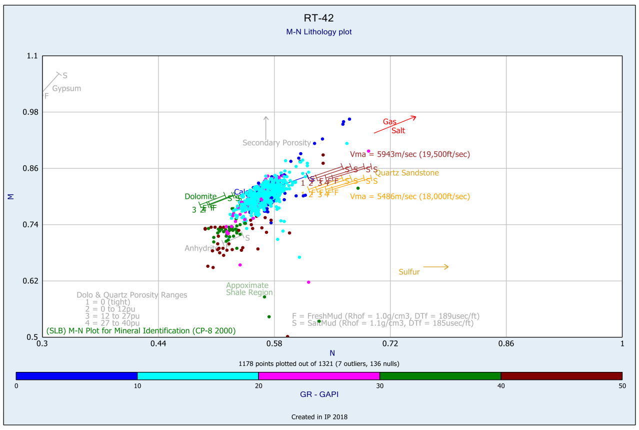

Fig. 12. M-N Plot for Logs in Well RT-42

The analysis of MID plots for Wells RT-2, RT-4, RT-5, RT-6, and RT-42 in the Mishrif Formation at the Ratawi Oil Field, as illustrated in Fig. 13 to Fig. 17, reveals significant lithological insights. These plots indicate distinct clusters of data points corresponding to dolomite, limestone, quartz, and anhydrite. High-porosity zones associated with dolomite-rich intervals suggest favorable reservoir conditions. The presence of sulfur, siltstone, and sandstone in Well RT-2 (Fig. 13) indicates additional heterogeneity, while Wells RT-4 (Fig. 14) and RT-5 (Fig. 15) show similar lithological trends with dominant dolomite and quartz compositions. Well RT-6 (Fig. 16) exhibits a more diverse lithology, including dolomite, limestone, and quartz, highlighting distinct relationships between gamma-ray and neutron log readings. The MID plot for Well RT-42 (Fig. 17) shows the presence of anhydrite, which can act as a barrier to fluid flow, affecting reservoir heterogeneity. These findings underscore the importance of integrating MID plot analysis with other geological data to refine reservoir simulation models and optimize well placement for enhanced hydrocarbon recovery.

Fig. 3 to Fig. 17 indicate that the most dominant lithology in the Mishrif formation is limestone, and the dominant mineral is calcite with a small percentage of secondary porosity.

Using the empirical cross-plots generated in this study aids in better reservoir characterization and modeling along the Ratawi oilfield. All methods indicate calcite ($CaCO_3$) as the dominant mineral in the Mishrif reservoir. Dolomite and shale are accessory minerals seen in the Mishrif Formation. Clay is intercalated in the upper interval, and argillaceous facies are possible, mainly in the lower zone of the Mishrif. The sand (quartz) concentration increases westward, while dolomite increases towards the east of the field.

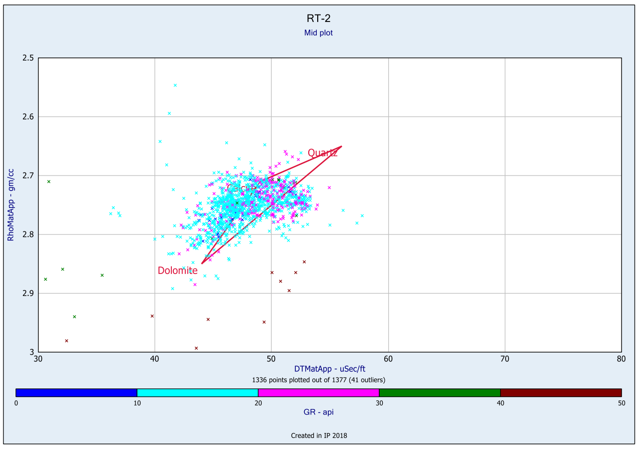

Fig. 13. MID Plot for Well RT-2

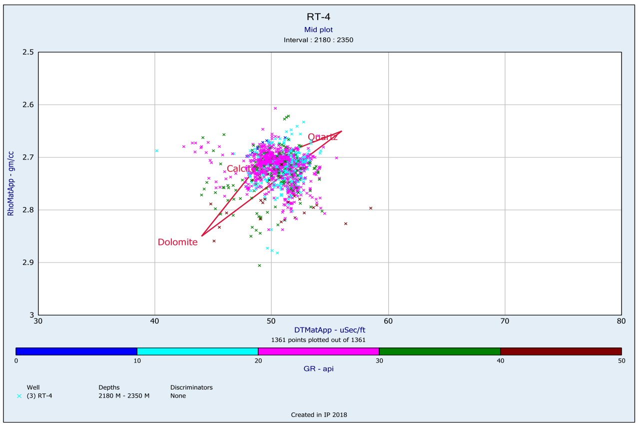

Fig. 14. MID Plot for Well RT-4

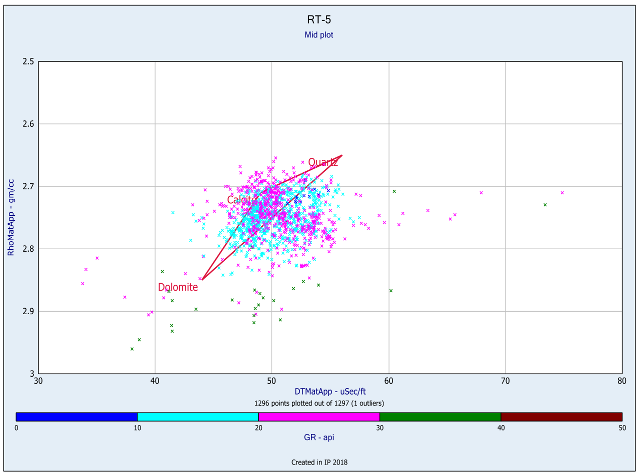

Fig. 15. MID Plot for Well RT-5

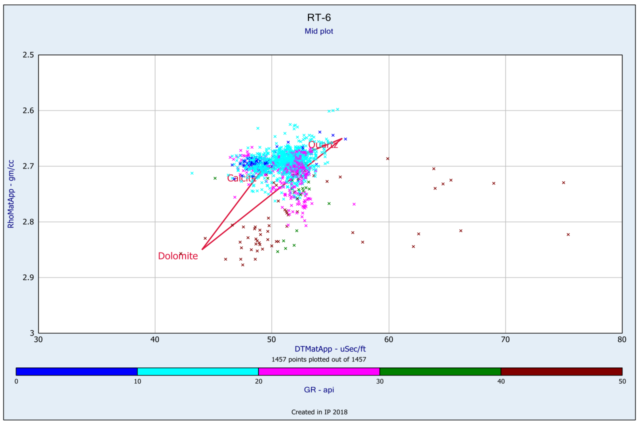

Fig. 16. MID Plot for Well RT-6

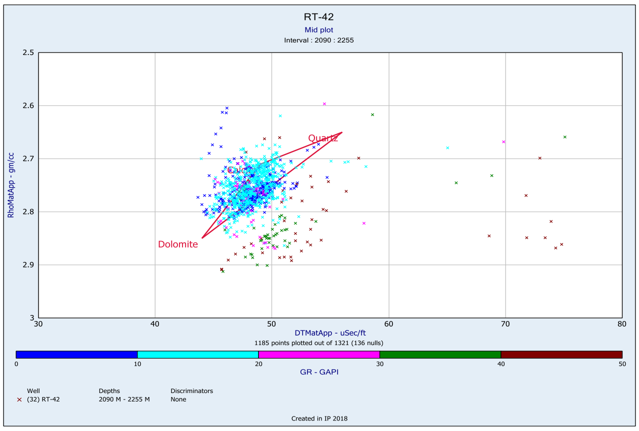

Fig. 17. MID Plot for Well RT-42

The integrated analysis of lithology in the Mishrif Formation at the Ratawi Oil Field, combining Neutron-Density cross plots (Fig. 3 - Fig. 7), M-N plots (Fig. 8 - Fig. 12), and MID plots (Fig. 13 - Fig. 17), provides a comprehensive understanding of the formation's lithological composition. Both M-N and Neutron-Density cross plots effectively identify different lithologies, including limestone, dolomite, and shale, and highlight high-porosity zones associated with limestone and dolomite, indicative of good reservoir quality. The presence of multiple lithologies and their spatial distribution underscore the formation's heterogeneity, with anhydrite and gypsum layers likely acting as barriers to fluid flow. The MID plots further confirm lithological variations, particularly between dolomite, limestone, quartz, and anhydrite, and reinforce the association of high porosity with dolomite-rich intervals. The presence of sulfur, siltstone, and sandstone in certain wells highlights additional heterogeneity. Overall, this integrated analysis offers a robust understanding of the Mishrif Formation's lithology, emphasizing the importance of high-porosity carbonate rocks for reservoir quality and the impact of anhydrite and gypsum layers on fluid flow.

4- Conclusions

The current study focused on the application of petrophysical data as indirect tools for lithology identification in the Mishrif Formation, Ratawi oilfield. Mishrif Formation is one of the most important formations in Iraq, both economically and geologically, which was deposited during the Upper Cretaceous period (Cenomanian – Early Turonian) and is regarded as the principal carbonate reservoirs in central and southern Iraq. Petrophysical cross-plots including neutron-density, MID and M-N plots show that the Upper Cretaceous Mishrif formation is mainly composed of limestone (calcite) dominant lithology. Dolomite is included as a minor accessory mineral and can be negligible in most intervals. Clay is intercalated in the upper interval, and argillaceous facies are possible, mainly in the lower zone of the Mishrif. The sand (quartz) concentration is increasing westward in the field, but the concentration of dolomite is rising eastward.

Nomenclature

Δt_f Transit Time of the Fluid, µsec/ft.
Δt Transit Time (from log), µsec/ft.
ρ_b Formation Bulk Density (from log), gm/cc.
ρ_f Fluid Density, gm/cc.
ϕ_{Nf} Neutron porosity of the fluid (usually 1.0).
ϕ_N Neutron porosity.
ϕ_{ta} The apparent total porosity, fraction.
ρ_{ma} The apparent matrix density, g/cc.
Δt_{ma} The apparent transit time, µsec/ft,

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تحديد الليثولوجيا والمعادن من مجسات الابار لتكوين المشرف في حقل رطاوي النفطي

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الخلاصة

يهدف هذا البحث إلى التعرف على ليثولوجيا والمعادن من بيانات سجلات الآبار لتكوين المشرف في حقل رطاوي النفطي باستخدام سجلات الجس للآبار RT-2، RT-4، RT-5، RT-6، وRT-42. يعد تحديد ليثولوجيا أمرًا ضروريًا للأنشطة التحليلية الجيولوجية مثل توصيف الخزان والتنقيب عن النفط. في هذه الخطوة، غالبًا ما تتضمن مهام تحديد ليثولوجبا بناء نموذج تعريف للصخور بناءً على افتراض أن بيانات السجل مترابطة. وقد تم تحديد ليثولوجيا تكوين المشرف باستخدام مخططات سجل الكثافة مع سجل النيوترون، والتي اوضحت أن تكوين المشرف يتكون من الحجر الجيري مع بعض نقاط البيانات التي تميل إلى خط الدولومايت في شرق الحقل وأخرى تميل الى خط الحجر الرملي في غرب الحقل. تم استخدام مخططات M-N وMID لتحديد المعادن، والتي أظهرت أن الكالسيت هو المعدن الرئيسي في تكوين المشرف ولكن يزداد معدن الكوارتز غربي الحقل ويزداد معدن الدولومايت في الاتجاه الشرقي.

الكلمات الدالة: حقل رطاوي النفطي، مكمن المشرف، معادن، ليثولوجيا.