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Petrophysical Evaluation and Reservoir Characterization of the Lower Jurassic Mus Formation Using Wireline Logs: A case study from the Harir Oil Field, Kurdistan Region, Iraq

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Abstract

The Lower Jurassic Mus Formation is a significant hydrocarbon reservoir in northern Iraq. The interpretations of the petrophysical property using wireline logs play an important role in the reservoir characterization, providing key insights into lithology, shale volume, porosity, permeability, flow zone indicator, as well as water and hydrocarbon saturations. In this study, Petrophysical techniques were applied to evaluate the Mus Formation in the Harir oil field, Kurdistan region of Iraq. The analysis was wireline log data from Well JSK-1, using a suite of logs that consisted of Gamma Ray, Caliper, Density, Neutron, and Resistivity Logs to evaluate the petrophysical properties of the Mus Formation. The Mus Formation was determined from the subsurface with a total thickness of about 40m. The main lithologies include limestone, dolomitic limestone, dolomite, and minor sandstone fragments with minimal shale content. The average porosity within the pay zone was 10%, with a permeability of 400mD. The water and hydrocarbon saturation in the pay zone was 70 % and 30% respectively. The total thickness of the reservoir rock was 40m, with a pay zone thickness of 2.1m. The findings indicate that the upper part of the Mus Formation shows a good reservoir quality, as evidenced by the presence of the pay zone and resistivity value of the formation. These results suggest that the Mus Formation contains an active hydrocarbon-bearing interval and the potential to contribute to the future hydrocarbon exploration and production in different oil fields of northern Iraq.

Keywords: Reservoir Characterization, Petrophysical Properties, Mus Formation, Hariri Oil Filed, Northern Iraq.

1. Introduction

Carbonate reservoirs contain approximately 60% of global oil and 40% gas (Montaron, 2008; Yang et al., 2018). However, their characterization is often challenging due to complex diagenesis, heterogeneity, and variation in petrophysical properties (Agar and Humpsion, 2014; Chander et al., 2015). Carbonate reservoirs of the Middle East contain a significant portion of the oil and gas reserves (Harriosn and Jing, 2001). Iraq has huge oil and gas reserves, estimated to be the second portion after Saudi Arabia (Kumins, 2007). Part of these reserves are located in the reservoirs of the Kurdistan Region of Iraq, which is approximately 15 billion barrels (Mackertich and Samarrai, 2015). The majority of source rocks of the Mus Formation are underlain by the Butmah Formation and Triassic source rocks (Zangana et al., 2022)

The growing commercial concentration in recent oil locations in the Middle Jurassic Mus Formation has required information about the petrophysical properties that control reservoir performance distributions, which are characteristics of this carbonate formation. Due to the interest in intervals of the Mus Formation in oil production that have been subjected to petrophysical studies (Abdula, R.A., 2016; and Mohialdeen, I.M., 2018). Understanding the uncertainties of the petrophysical properties is important for reservoir performance (Bera and Belhaj, 2016). It is not allowable to study the reservoir characteristics without knowing the petrophysical properties. In carbonate reservoirs, petrophysical properties play an important role in the quality of the reservoir (Jennings and Lucia, 2003).

Well logging method is extensively utilized in carbonate reservoirs to estimate petrophysical properties and hydrocarbon saturations (Aswad et al., 2024). These estimations are used to determine the reservoir properties and connectivity, volume of hydrocarbon, and development in the oilfields (Stadtműller and Jarzyna, 2023). The variety of pore throats that formed due to the diagenetic process makes a reservoir challenge in carbonate rocks (Riazi, 2018). Petrophysical properties include porosity and permeability, mineralogy and shale volume, which are critical for assessment of the reservoir properties and performance

of the carbonate reservoirs (Taib and Donaldson, 2004; Aswad, 2020). There are many techniques to evaluate the relationship between porosity and permeability to identify the reservoir properties (Lucia, 1999)

Their lack of investigations has been studied the petrophysical properties of the Mus Formation. Mohialdeen (2018) studied the hydrocarbon generation potential and palynofacies analysis of the Mus Formation in Miran oil field based on the source rock samples. Abdullah (2016) studied the geochemical assessment of the Mus Formation at Hawler oil field at well Zab-1, and the samples showed poor source rock.

Mus Formation was first described by Dunnington (1953), in Well Butmah-2. Mus Formation in that Well comprises 50 m of limestone. According to Aqrawi et al. (2010), lithological of Mus consists mainly of limestone, dolomitic limestone, and marly limestone. The Mus Formation age is considered at late Jurassic to late Liassic (Jassim et al., 2006). Upper and lower contacts of the Mus Formation are conformable with the Alan and Adaiyah formations, respectively (Jassim and Buday, 2006). The Depositional environment of the Mus Formation is considered a Lagoon marine environment (Alsharhan and Narin, 2003).

The study aims to bridge an existing knowledge gap by offering a comprehensive analysis of the petrophysical properties of the Mus Formation. It focuses on petrophysical properties and reservoir characteristics of a representative oil well located in the Kurdistan Region of Iraq. The primary research question is to thoroughly assess the petrophysical characteristics of the Mus Formation within a productive oil field in Northern Iraq. The findings are expected to provide valuable insights into the distribution of the hydrocarbon in the reservoir zones. This study is particularly significant as it delivers an in-depth investigation into all key aspects of the Mus Formation, enhancing the understanding of accurate lithology, total and effective porosity, permeability, flow zone indicator, water and hydrocarbon saturations, movable and residual hydrocarbon saturations, and reservoir pay zones. In this study using available wireline logs of the Mus Formation have been selected for this study to characterize the petrophysical properties of the JSK-1 Well of the Harir oil field (Fig. 1).

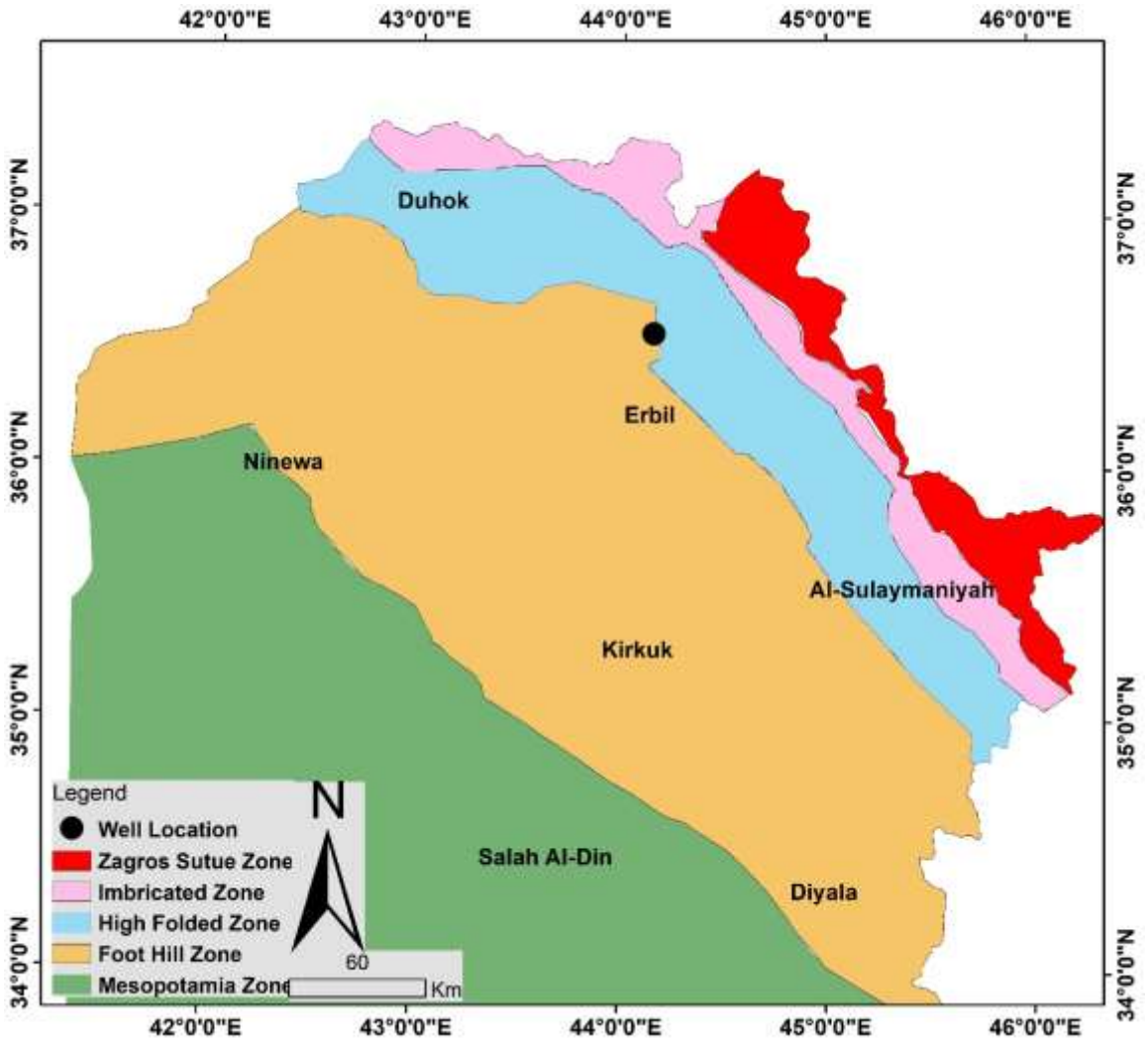


Fig. 1: Location of the studied Well and tectonic map of the area after (Fouad, 2010)

2. Location and Geological Setting

Tectonically, the Kurdistan Region is an active region caused by its location, which is close to the border of the Arabian plate (Jassim and Goff, 2006). It is located to the NE of the Arabian Peninsula, and the Hercynian Orogeny was the major tectonic activity that impacted the Arabian Plate (Haq and Al-Qahtani, 2005). The studied area is located at the Harir oil field Jisk-1 well in Northern Iraq. Jisk -1 Well is positioned 40 km to the northeast of Erbil, and the coordinates of the drilled Well are E:440 9' 17.318" and N:360 32' 47.667". The Harir oil field was found in 2010 by the Ministry of Natural Resources of Kurdistan (NMR). The area lies on the Safin Anticline, which is a directional trend of axis that is NW-SE belonging to the Zagros Fold Belt (ZFB) (Omer, 2011). ZFB formed during Eocene time, caused by the collision between Eurasian and Neo-Tethyan plates (Khoshnaw et al., 2019). ZFB is associated with many hydrocarbon productions and oil and gas reserves (Zebari and Burberry, 2015). Mus formation belongs to ZFB, is a main target of many international oil companies, and oil fields include of Atrush, Ain Al Safra, Benenan, Bijel, Bina Bawi, Demir Dagh, Harir, Shaikhan, and Sarta.

3. Methodology

As figure out in Table (1), wireline logging data from JSK-1 wells that represented the Mus Formation in the Harir Oil Field was obtained through a joint venture between NMR and Marason International Company. The dataset includes a full set of conventional wireline logs (Gamma Ray log, Neutron Log, Density Log, Caliper Log, and Resistivity Logs). The work started with checking all the data from the LAS file. Then, plotting the diagrams and curves has mostly relied on the Schlumberger Company's use of Techlog 64version 2015.3 software and ArcGIS version 10.8.

Table. 1. Detailed of the drilled Well location and studied field

Field	Formation	Well	Interval (m)		Thickness (m)	Coordination
Harir	Mus	JSK-1	Top	Bottom	40	E:44 9 17.318 424353.426
			1930	1970		N:36 32 47.667 4044906.529

3.1. Lithology: It is a main step to be identified for working with any reservoirs. It determined from N-D cross plots (Asquith and Krygowski, 2004)

3.2. Shale volume

Shale volume determination via the Larionov method.

IGr = {GRlog-GRmin}/{GRmax-GRmin} and used Larionov all abbreviations in Table (2).

3.3. Porosity: - Porosity refers to the proportion of the bulk volume to the pore volume, according to Aswad et al., (2023).

3.3.1. Total and Effective porosity: The total porosity for the current study was estimated from porosity N - D cross plots. Total porosity from N-D cross plots calculated by.

$$\phi_D = \frac{\rho_{ma}-\rho_b}{\rho_{ma}-\rho_f} \quad , \quad \phi_T = \frac{\phi_N + \phi_D}{2}, \quad \phi_{E\ =\phi_T} \times (1\text{-Vsh}),$$

3.4. Permeability: Permeability can be estimated via the following equation in wireline logs. Permeability from Wyllie - Rose K = {100 Ø 2.25/ Swi}2 which represents the ability of rock to pass through fluids.

3.5. Flow zone indicator: this is to understanding the flow behavior and reservoir quality to enhance the production volume (Porras and Campos, 2001).

$$FZI = \frac{RQI}{QZ} \qquad QZ = \frac{\phi e}{1-\phi e} \qquad RQI = 0.0314\frac{k}{\phi e}$$

3.6. Water saturation estimation relies on the lithology of the formation

Archie equation: It is used to asses water saturation in reservoirs where the shale content is less than 15%. This equation is suitable for the Mus Formation due to free shale zones Han et al., (2021).

$$Sw = [(\frac{a}{\phi^m})(\frac{Rw}{Rt})]^{1/n}, \qquad F = \frac{a}{\emptyset m}$$

3.6.1. Hydrocarbon saturation is crucial for oil companies to evaluate hydrocarbon in the reservoirs (Aswad et al, 2024). After the water saturation is identified, the hydrocarbon saturation is extracted from unity. Shc = 1 – Sw

3.6.2. Movable hydrocarbon saturation Movable hydrocarbon saturation includes the volume of oil that can be estimated in the reservoir. MHS = {Sxo- Sw}* ØE

3.6.3. Residual Hydrocarbon Saturation (RHS): RHS can be calculated flushed zone saturation.

RHS= (1-Sxo)

Table (2): Terminology and symbols utilized in the methodology and equations

Symb/Abbr	Description	Symb/Abbr	Description
IGR	Index Gamma Ray	Rw	Formation water resistivity
GRlog	Gamma-ray log value in zone of interest, API unit	ρ_b	Bulk density
GRmax	Gamma-ray log value in shaly bed, API	ρ_f	Fluid density
GRcln	Gamma-ray value in clean zone, API	K	Permeability
Vsh	Volume of shale	Swi	Irreducible water saturation
Δt	Travel transit time from log curve	Rw	Formation water resistivity
$\Delta Tmat$	Travel transit time in the matrix	ρ_b	Bulk density
ΔT f	Travel transit time in fluids	ρ_f	Fluid density
ϕd	Density porosity	K	Permeability
ϕs	Sonic porosity	Sw	Water saturation
ϕn	Neutron porosity	Rt	True resistivity
ϕt	Total porosity	Rsh	Shale resistivity
ϕe	Effective porosity	MHS	Movable hydrocarbon saturation
SwA	Water saturation by Archie equation	Sxo	Flushed zone saturation
Shc	Hydrocarbon saturation	m	Cementation exponent = 2
a	Tortuosity factor = 1	n	Saturation exponent = 2
FZI	Flow Zone Indicator	RQI	Rock Quality Index
QZ	Normalized Porosity Index		

4. Results

This part provides the results that obtained from the cross plots of lithology, shale volume, porosity, permeability, flow zone indicator, water and hydrocarbon saturation, movable and residue hydrocarbon saturations and net reservoir of the Mus Formation in the JSK-1 Well at Harir oil field in the northern Iraq. The impacts on the fluid volume and reservoir behavior will be discussed.

4.1. Lithology

Lithology of the Mus Formation identified through Neutron -Density cross plots. Neutron and Density provides extensive information about which used to identify the lithology of the subsurface drilled wells. Three lithologies were defined based on the values of density and neutron cross plots. The data points are mainly clustered between the limestone and dolomite trend lines, with limited extension toward the sandstone line. This indicates that the dominant lithology is carbonate, primarily: limestone, dolomitic limestone and minor dolomite. The Mus Formation in this interval is a carbonate-dominated reservoir with negligible shale and sandstone influence. The sandstone that related to the clay fragments. The previous studied identified the shale within the Mus Formation based on the cutting samples. Limestone was the dominant lithology of the Mus Formation in this study and compared to the previous study Fig.2. The RHOB (density) and neutron porosity (PHIT_ND / PHIE_ND) curves generally track each other with minimal separation. This behavior is characteristic of Limestone and dolomitic limestone with Limited gas influence (no strong crossover). The Mus Formation is composed mainly of carbonates (limestone–dolomite system). The absence of strong neutron–density crossover suggests no significant gas zones and dominantly liquid-filled pores (oil/water).

4.2. Shale volume

Mus Formation is a carbonate formation that contains free shale intervals. Shale volume identified by Gamma Ray index and used Stieber Miocene to assess the values of shale in all zones (Larionov, 1969). There are many zones identified through wireline logs. However, all zones are containing shale less than 10% (Fig.2). The (GR) log shows consistently low values throughout the interval (~1928–1970 m). The Vshale track indicates very low shale content, with only minor increases in a few thin intervals. The formation is clean and shale-poor, confirming a carbonate-dominated lithology. Minor shale streaks are thin and discontinuous, having limited impact on reservoir quality. This indicate the Mus Formation is clean formation during lower Miocene period and the shale volume at pay zones is zero.

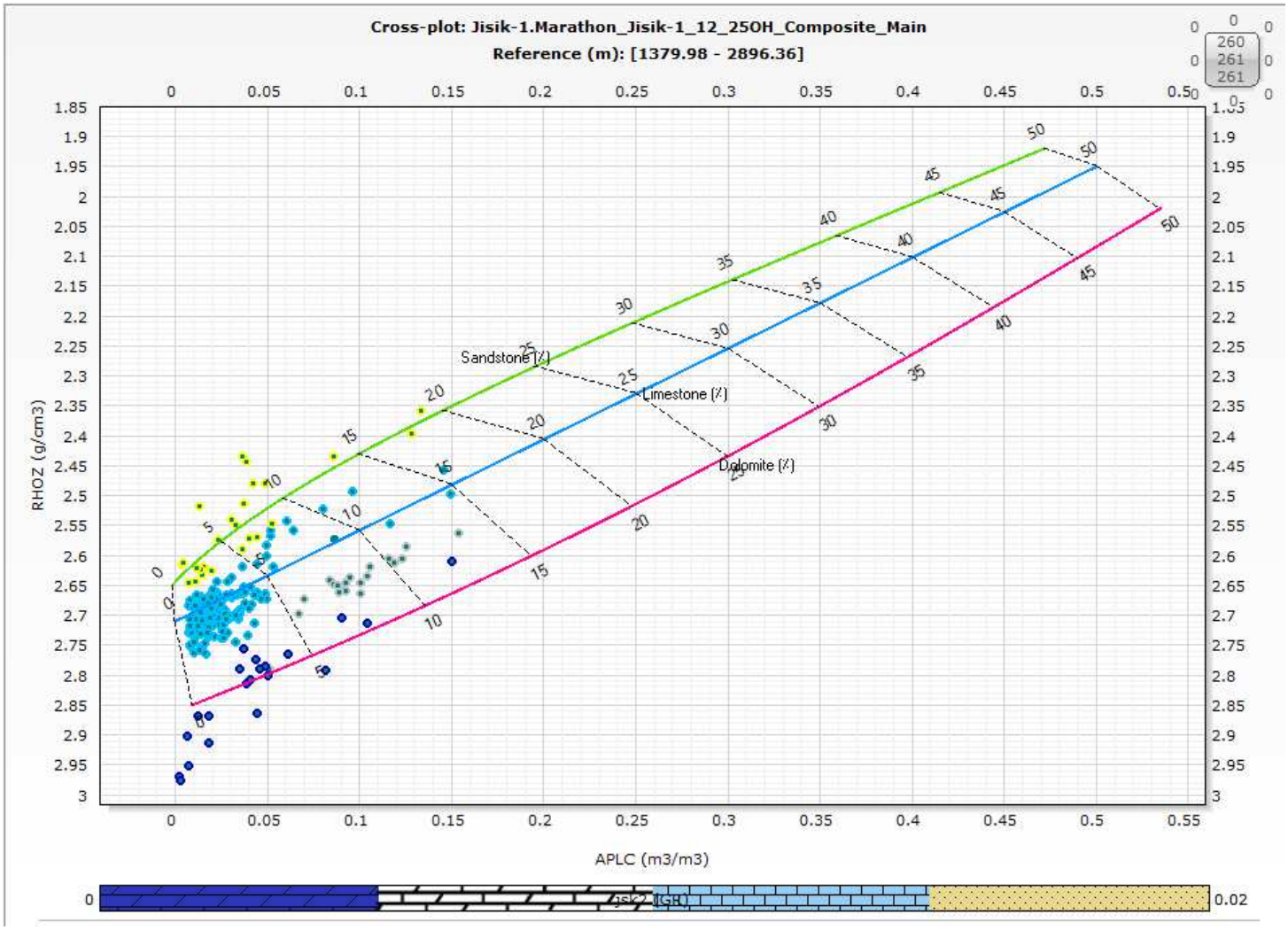


Fig.2. Cross-plots of the neutron and density parameters are utilized to determine the lithology of the Mus Formation. The legend at the bottom of the figure indicates the lithological classifications from left to right: dark blue represents dolomite, white indicates dolomitic limestone, light blue corresponds to limestone, and yellow denotes sandstone. These lithologies are the primary types identified through wireline log analysis.

4.3. Porosity

Porosity is a primary reservoir parameter that impact on the volume of hydrocarbon 38. Total porosity was calculated from equation three. Total porosity was calculated form density and neutron logs which was the average porosity obtained from the logs. The total porosity is varying across the depths and lithology of the Mus Formation. The total and effective porosity (PHIT_ND, PHIE_ND) range approximately from ~3% to 12%, with most values clustering around 5–10%. Slightly higher porosity zones are observed in the upper part of the formation (~1930–1940 m). The reservoir shows low to moderate porosity, typical of tight carbonate reservoirs. The maximum total porosity was 16%. Effective porosity was calculated from the total porosity and combined with shale volume. Effective porosity represents the connected pores and shale volume taken from the log calculations of the effective porosity and then compared with total porosity which shows the connected pores of the Mus Formation. the active zones of the Mus Formation can be determined by the effective porosity. The Mus Formation effective porosity is closely to the total porosity due to clean zones of the mud Formation. the average effective porosity 15% and 3% in limestone and dolomite zones respectively Fig.3.

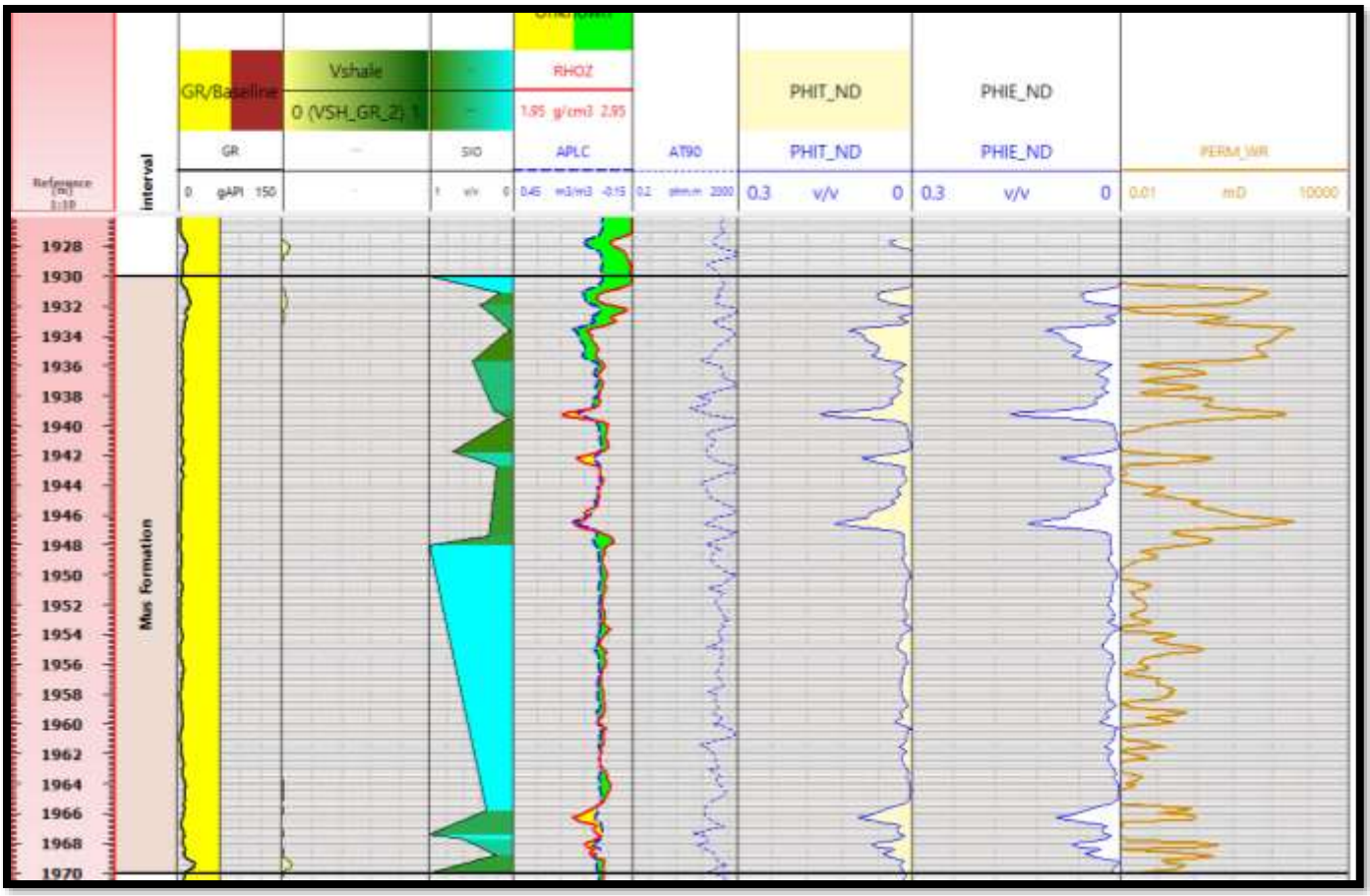


Fig. 3: Cross-plots of depth, zonation, gamma ray (GR), shale volume, neutron-density total porosity (PHIT_ND), effective porosity (PHIE_ND), and permeability (PERM) are presented with a focus on evaluating total and effective porosity as well as permeability. The caption further clarifies that the figure illustrates the variations in total and effective porosity and permeability with depth in the Jeribe Formation, based on wireline log data.

4.4. Permeability

Permeability was directly related to the fluid flow through porous rocks that directly related to the pore throat and pore connectivity. The permeability of the Mus Formation is varying from zone interval to interval. The

limestone lithology represents high permeability compared to dolomite and others. The highest permeability of the Mus Formation is at depth 1934 which is limestone. The maximum permeability is approximately 400mD. The other interval recorded low permeability due to disconnected of pore throat (Fig. 3). The permeability curve shows strong variability, ranging from Very low values (<1 mD) to several hundred mD in localized intervals. Higher permeability zones are mainly concentrated in Upper intervals (~1930–1940 m). Reservoir permeability is highly heterogeneous. High permeability streaks likely result from Fracturing and Secondary porosity (vugs, dissolution). These zones represent the main productive intervals (pay zone ~2.1 m).

4.5. Flow zone indicators

Flow zone indicator is used for to identify the fluid flow and generate permeability. FZI is associated with intervals of limestone and represent high FZI. This indicator that the reservoir pay zone located in the limestone interval. The upper part of the Mus Formation contains high value of the FZI. This indicate that the active hydrocarbon zone should be at upper part of the Formation (Fig. 4). Based on log responses, the formation can be divided into three zones which are Upper Zone (~1928–1940 m). characterized by Lower GR (clean carbonate), slightly higher porosity, increased permeability and moderate resistivity. Middle Zone (~1940–1960 m) is characterized by very low shale content, Low porosity and reduced permeability. Lower Zone (~1960–1970 m) is characterized by slight increase in heterogeneity and minor improvement in porosity/permeability

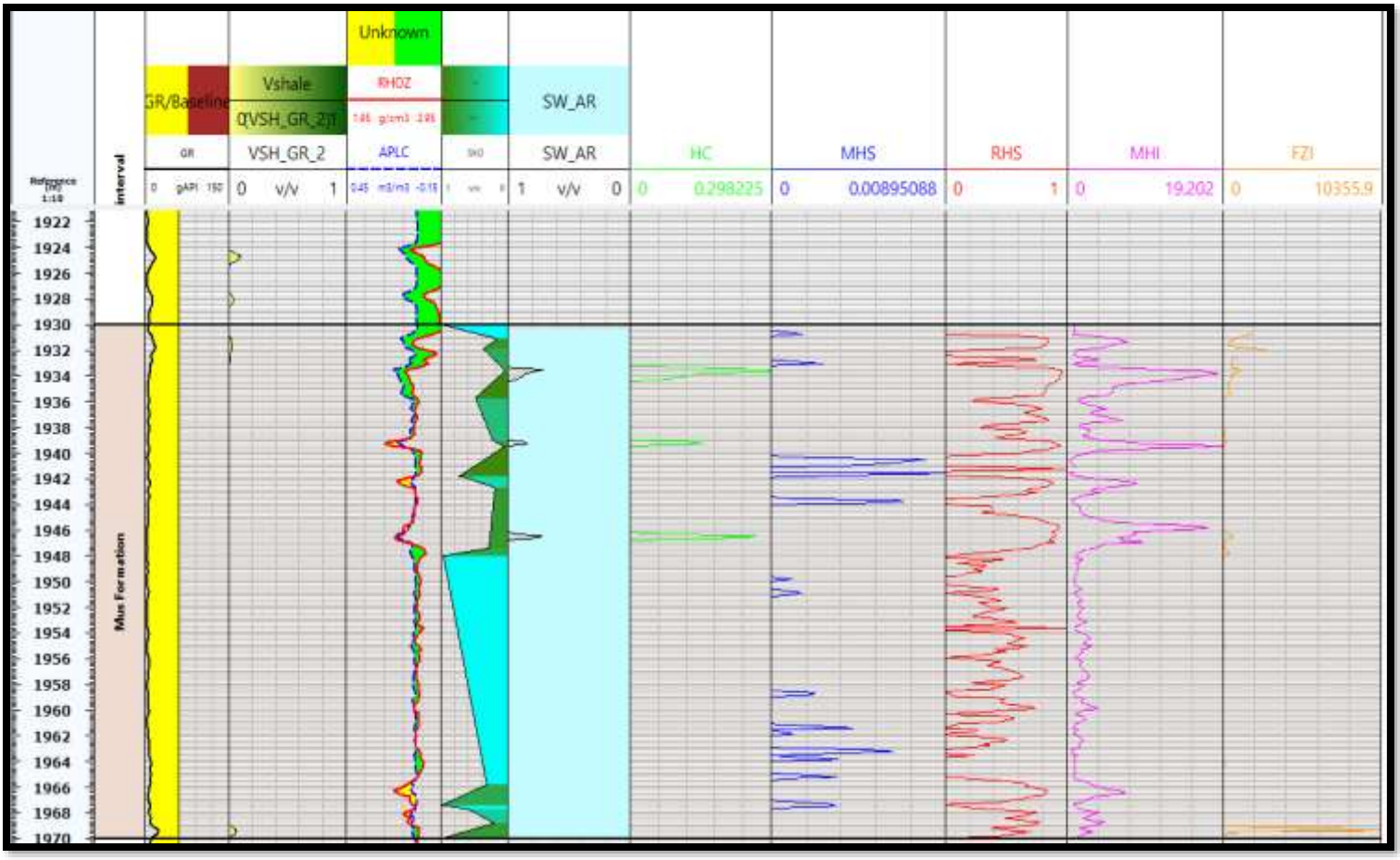


Fig. 4: Cross-plots of depth, zonation, gamma ray (GR), neutron-density (N-D) relationships, water and hydrocarbon saturation, as well as movable and residual hydrocarbon saturation, and flow zone indicator (FZI) are presented. Water saturation (Sw) values were calculated using Archie's equation

4.6. Water and hydrocarbon saturation

Saturation is a play role in the fluid flow in the reservoir. The average water saturation in the pay zones of the Mus Formation is about 70%. The average hydrocarbon saturation in the pay zones of the Mus Formation is about 30%. Both movable and residual hydrocarbon saturation are present in the reservoirs of the Mus Formation. The upper part of the Mus Formation indicates low movable while middle of the Mus Formation indicates high value of the movable hydrocarbon saturation (Fig. 4). The water saturation (SW_AR) track shows Predominantly high-water saturation (approaching 1.0) in most intervals and localized reductions in Sw in specific depths (notably ~1930–1945 m). The HC track (green curve) indicates generally low hydrocarbon saturation and noticeable increases in the upper interval (~1930–1945 m).

4.7. Net pay

Rock, reservoir and pay zones of the Mus Formation provides different petrophysical properties and reservoir characterization. The gross thickness of the Mus Formation is 40m, the reservoir thickness is 40m, whereas the pay zone is 2.1m. the low thickness of the pay zone related to the contributions of the reservoir parameters which indicate low value. The Formation contains medium porosity and permeability at the pay zone. The fundamental parameters of the newt to gross are illustrated in the Table.3. the limestone lithology is a main reservoir pay zone in the Mus Formation (Fig. 5).

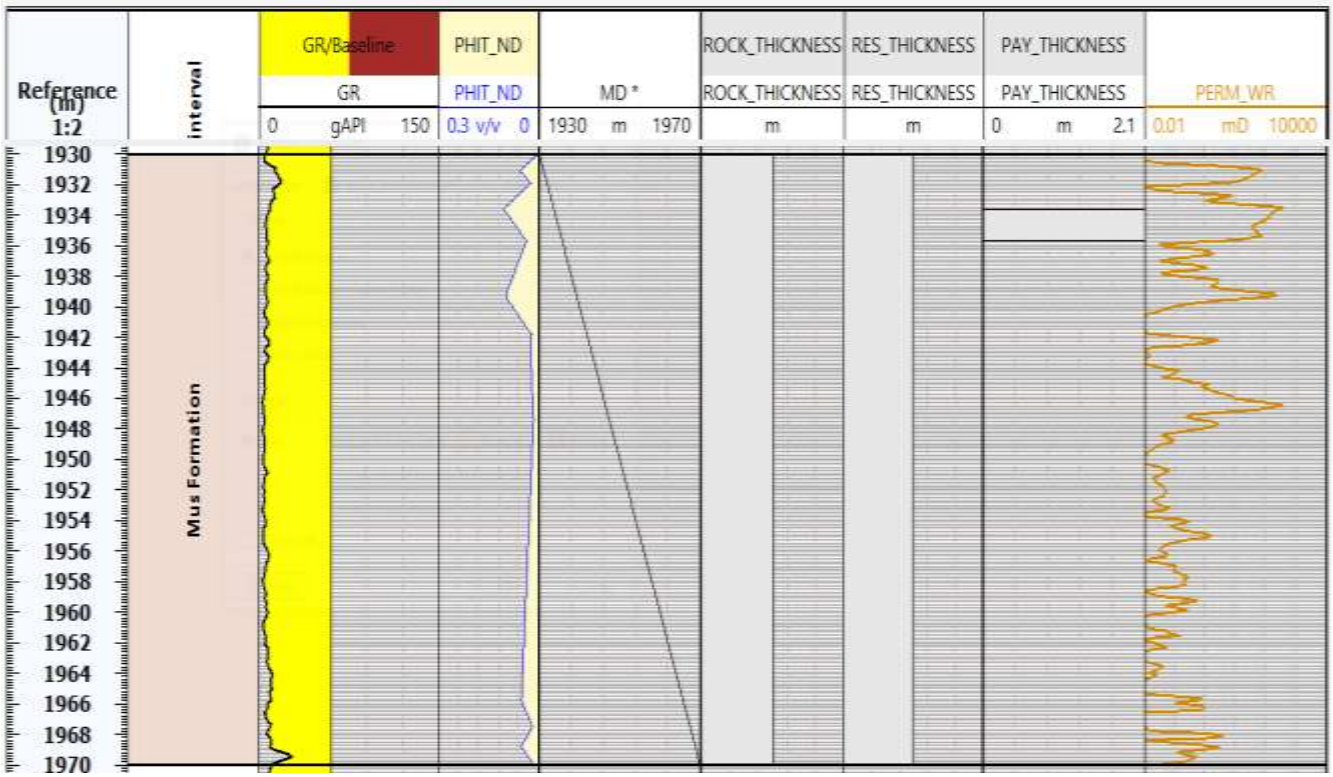


Fig. 5: The figure illustrates the distribution of total rock thickness, reservoir thickness, and pay thickness, with a specific emphasis on the main reservoir and pay intervals within the dolomite lithology. These thicknesses are then compared to zones of high permeability within the pay zone

Table. 3: A comprehensive explanation of all parameters applied in assessing the petrophysical properties of the formation.

Flag names	Top (m)	Bottom (m)	Gross	Net	Net to Gross	AV. Shale %	AV. Porosity %	AV. W Saturation %	AV. Hc Saturation %	AV. Permeability mD
Rock	130	170	40	40	1.030	0.002	0.030	0.90	0.10	23.8
Reservoir	130	170	40	40	1.030	0.002	0.030	0.90	0.10	23.8
Pay	130	170	40	2.1	0.052	0.00	0.104	0.70	0.30	405.42

5. Discussion

The Mus Formation, situated within the structurally active Zagros Fold Belt, represents a key carbonate reservoir in the Kurdistan region. This formation has been influenced by complex tectonic events, including the collision between the Eurasian and Arabian plate tectonics, which has a significant accommodation space deposited with thick intervals of the Jurassic Formations (Zebari et al., 2020). The petrophysical analysis of Well JSK-1 provides insights into the reservoir quality and heterogeneity of the Mus Formation. The density–neutron cross-plot demonstrates that the Mus Formation in Well JSK-1 is predominantly composed of limestone and dolomitic carbonates with low to moderate porosity. While the overall reservoir quality is moderate to poor, localized zones of enhanced porosity—likely associated with dolomitization and secondary porosity—indicate the presence of productive intervals. These findings support the interpretation of an active hydrocarbon-bearing system with limited but significant reservoir potential. (Abdulla, 2016). (Mohiaden, 2018). The presence of sandstone is likely attributed to detrital or reworked clastic components mixed with the carbonate matrix. (Fig.2 and 6). The well log analysis confirms that the Mus Formation in Well JSK-1 is a clean carbonate reservoir with low shale content and heterogeneous petrophysical properties. Although the overall porosity is relatively low, localized intervals in the upper part of the formation exhibit enhanced porosity and permeability, forming a thin but significant pay zone. The reservoir is predominantly liquid-bearing, with limited gas influence, and its quality is primarily controlled by diagenetic processes and secondary porosity development. These findings support the presence of economically viable hydrocarbon zones despite the generally tight nature of the formation. The Mus Formation exhibits low shale content, low to moderate porosity and highly variable permeability Reservoir quality is of the Mus Formation generally is moderate but locally good in thin intervals due to diagenesis control, fracturing and lithological heterogeneity.

The N-D cross plots provide extensive lithology, and also, the cross plot provides information about the neutron porosity. Shale volume is identified based on the Gamma ray and Larionov method, which indicates free of shale in all intervals. The clean nature of the formation, as confirmed by very low Gamma Ray values and the absence of significant shale, enhances the reliability of porosity and saturation estimates. The Mus Formation is a clean carbonate formation based on shale and fragments of anhydrite. So, shale volume in the Mus Formation is negligible, with most intervals showing less than 10% and a complete absence of shale in the pay zone. The porosity of the Mus Formation is low to medium. Fig. 7 shows the relationship between total porosity from all lithologies with permeability. The maximum total porosity is located in the sandstone lithology, which is 15% while the limestone lithology provides 13%. The low value of lithology due to fragments and the diagenetic process of the carbonate rocks. Fig.8. illustrate the relationship between permeability and effective porosity. The average effective porosity is 10% which is in the limestone lithology. The limestone provides better porosity due to dissolution and diagenetic processes (Hussein et al., 2022).

Porosity ratio varies across the formation, influenced by lithology and diagenetic alterations. Limestone zones show the highest total porosity up to 16%, while dolomite zones tend to have lower values around 3–6% due to recrystallization and cementation processes. The average effective porosity was found to be around 10%, particularly concentrated in the upper intervals of the formation. These values reflect well-connected pore networks in the clean carbonate zones. Permeability demonstrates a direct relationship with lithology

and effective porosity. The highest permeability (approximately 400 mD) occurs in limestone intervals, especially near the top of the formation. In contrast, dolomitic and deeper zones exhibit reduced permeability, possibly due to diagenetic compaction and poor pore connectivity. This variation indicates a vertically heterogeneous reservoir with more productive intervals in the upper Mus Formation. (Fig. 8). The flow zone indicator values further validate the high-quality reservoir potential of the upper intervals. These zones exhibit well-developed pore systems capable of facilitating fluid movement, which are critical for hydrocarbon production planning. The lower FZI values in dolomitic intervals correspond with lower porosity and permeability values, suggesting limited reservoir potential in those sections.

Fluid saturation indicates that water saturation dominates most intervals, with an average of 70% in the pay zone. Hydrocarbon saturation, calculated at 30%, is economically significant and confirms the presence of movable hydrocarbons. The movable hydrocarbon saturation varies vertically, with peak values in the middle part of the formation, while the residual hydrocarbon saturation is higher in the flushed zones. These saturation profiles support the identification of zones with the highest production potential. The reservoir is largely water-wet and water-bearing. Sw zones indicate potential hydrocarbon-bearing intervals. However, hydrocarbon presence is limited but concentrated in thin zones and confirms the presence of a thin pay zone (~2.1 m).

Despite the net pay interval being relatively thin, 2.1 m out of a total 40 m gross thickness, its petrophysical properties (high porosity, permeability, and hydrocarbon saturation) are favorable for hydrocarbon recovery. The limestone-dominated intervals are the most productive, underpinned by favorable FZI, MHS, and saturation profiles. This reflects that even thin intervals can contribute significantly to production if petrophysical characteristics are favorable. In summary, the petrophysical evaluation highlights that the upper part of the Mus Formation, composed primarily of clean limestone, holds the best reservoir potential due to its superior porosity, permeability, and hydrocarbon saturation. The reservoir behavior is controlled by lithological heterogeneity and pore structure evolution, making detailed petrophysical analysis essential for future exploration and production planning in the region.

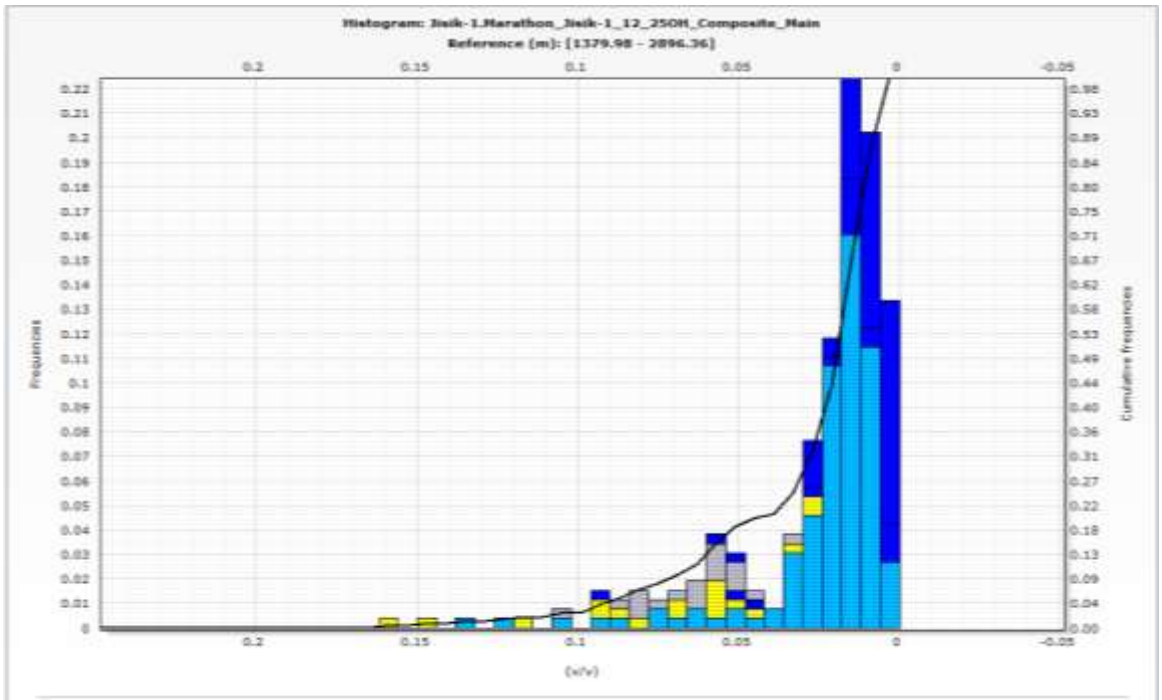


Fig. 6: The histogram illustrates the lithological distribution of the Mus Formation, highlighting limestone as the dominant lithology.

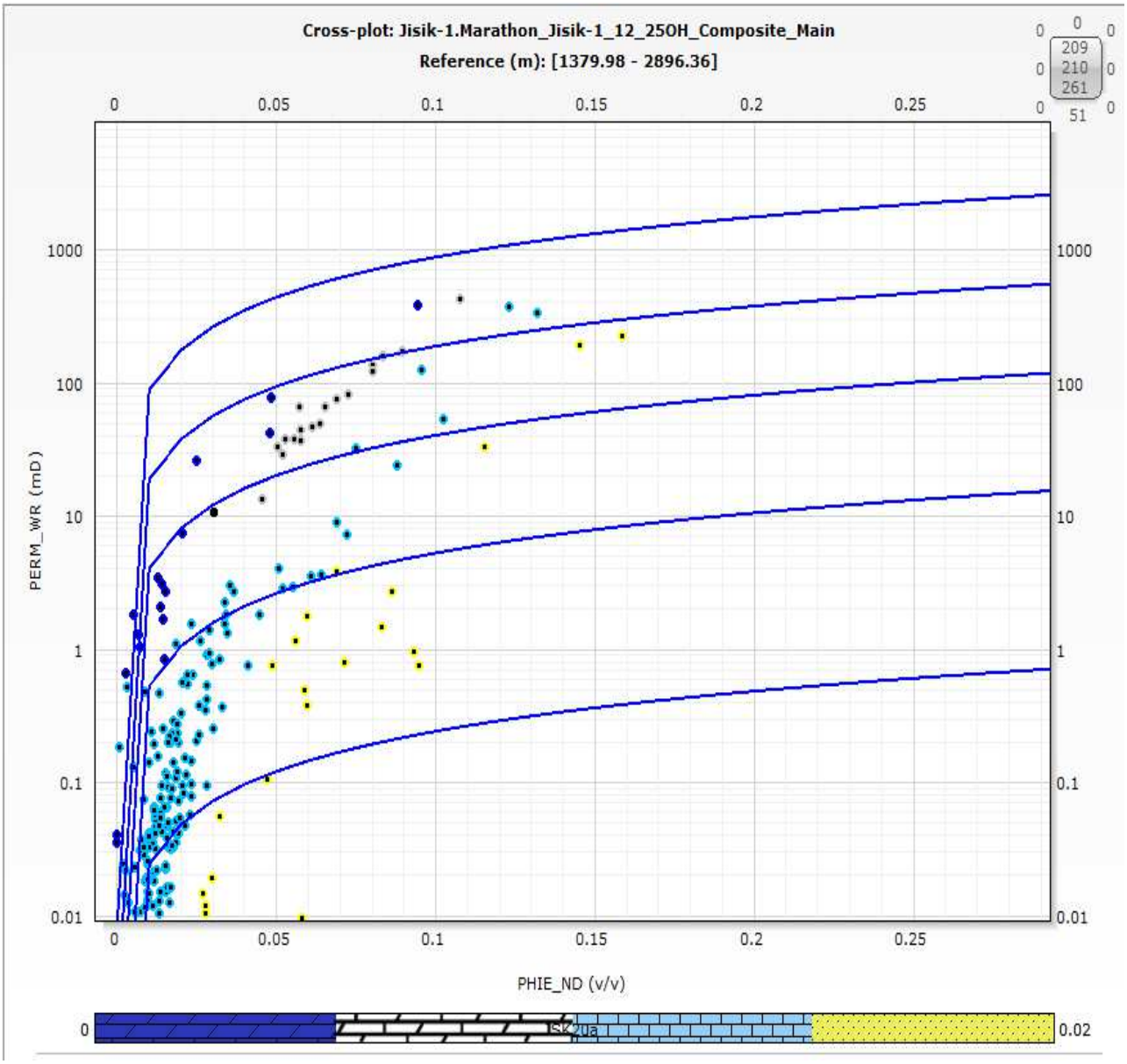


Fig.7: the figure shows the relationship between total porosity and permeability, along with the lithological distribution of the Mus Formation, highlighting the dominant rock types

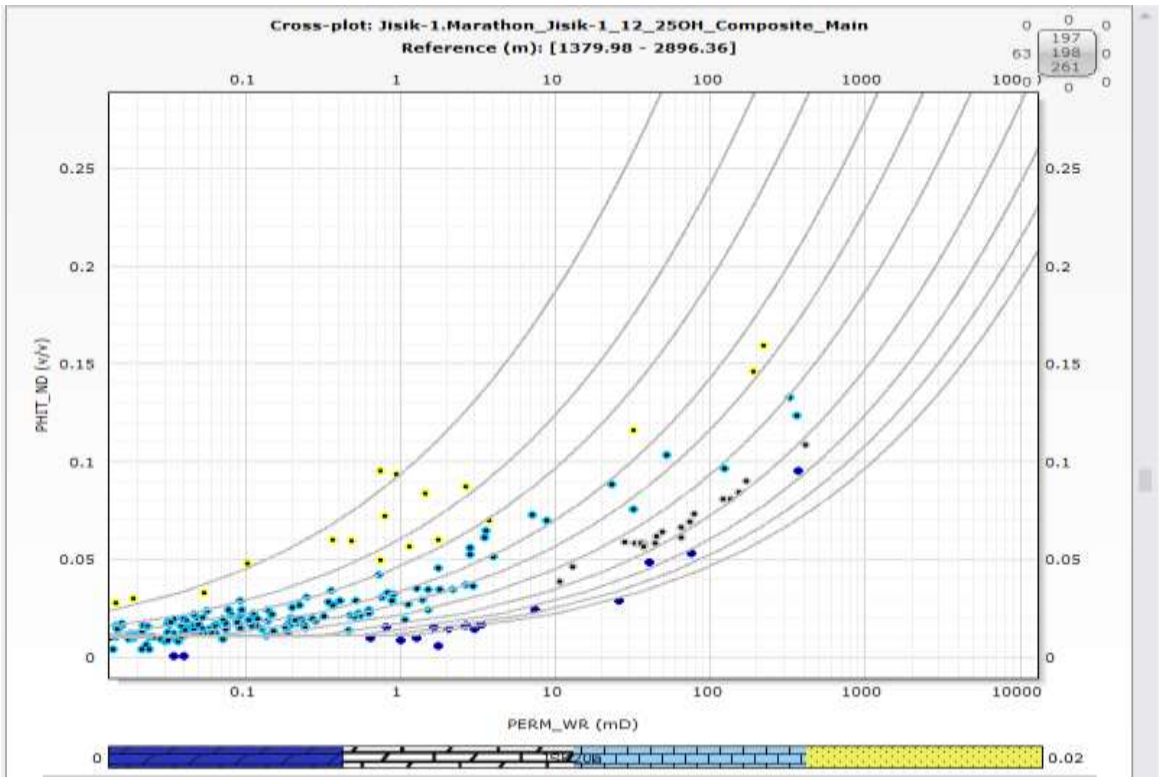


Fig.8: the figure shows the relationship between effective porosity and permeability, along with the lithological distribution of the Mus Formation, highlighting the dominant rock types

Conclusions

This study presents a comprehensive analysis of the petrophysical properties of the Lower Jurassic Mus Formation in Well JSK-1, Harir oil field. Offering key insights into its reservoir characteristics.

- The Mus Formation is a clean carbonate unit with a gross thickness of 40 m and a pay zone of 2.1 m.
- Limestone is the dominant lithology in the productive interval, exhibiting high porosity of about 10% and permeability of approximately 400 mD.
- The advanced petrophysical analysis confirms that the Mus Formation in Well JSK-1 is **a** heterogeneous carbonate reservoir with predominantly high-water saturation and limited hydrocarbon accumulation.
- The integration of Sw, HC, MHI, and FZI highlights the presence of distinct hydraulic flow units, with the upper interval (~1930–1945 m) representing the main productive zone.

Despite generally poor to moderate reservoir quality**,** localized enhancements in pore structure and permeability create economically significant pay intervals. These findings emphasize the importance of detailed petrophysical characterization in identifying productive zones within tight carbonate reservoirs. The study's novel contribution lies in its comprehensive petrophysical approach, integrating wireline log interpretation with reservoir modeling metrics, making it valuable for future field development strategies.

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