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INTERPRETATION OF WELL LOG DATA OF THE JERIBE FORMATION TO PARAMETERS PETROPHYSICAL IN THE MANSURIYA GAS FIELD IN THE ZAGROS FOLD BELT BASIN, EAST IRAQ

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Abstract

The Mansuriya gas field, a most important hydrocarbon province in Middle Iraq, contains significant economic gas reserves, primarily in the Early Miocene Jeribe Formation. This study examines the reservoir petrophysical properties of the Jeribe Formation in wells Ms-1, Ms-2, and Ms-3 using a full well log analysis workflow. First, well logs (resistivity, gamma ray, neutron, and density) were digitized with Digger. Then, Techloge v.21 software was used to assess and quantify reservoir lithology, porosity, shale volume, and water, gas, and oil saturations. According to lithological interpretation based on density-neutron crossplots, the Jeribe Formation is primarily composed of dolomite and limestone, with localized anhydrite occurrences in gas-bearing intervals. The gamma-ray log analysis displays a low shale volume, indicating a mostly clean carbonate reservoir. The presence of radioactive minerals within the formation will probably account for the low gamma-ray response. The Jeribe Formation has been separated into seven distinct reservoir zones (J1 – J7). The average porosity values for Ms-1 and Ms-3 were 0.17, which is slightly higher than the 0.15 found for Ms-2. Water saturation values ranged from 0.18 to 0.29 in Ms-3. Shale volume estimates ranged between 0.09 and 0.14 for all wells. Permeability estimates ranged from 5.21 to 11.06 mD. Hydrocarbon saturation was still highest in Ms-2 (0.83), followed by Ms-1 (0.82), and lowest in Ms-3 (0.71). Particularly, the JB2 zone has been determined as a superior reservoir interval within the Jeribe Formation, with favorable effective porosity, low water saturation, high hydrocarbon saturation, and a sealing caprock provided by the JB1 anhydrite zone that lies above it.

Keywords: Mansuriya gas field; Jeribe Formation; Gas reserves; Petrophysical properties.

1. Introduction

The Zagros Foreland Basin is composed of the succession formed during the Zagros collision (Late Eocene – Holocene). Early Miocene units in Iraq include deepwater facies derived from

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the Serikagni formation (basinal) as well as shallow carbonate and evaporite facies to the Euphrates, Dhiban, and Jeribe Formations (Aqrawi et al., 2010). These facies are similar to the shallow water carbonate of Iran's Asmari Formation, which spans from the Oligocene to the Early Miocene (Al-Juboury et al., 2007), and is crucial as a carbonate reservoir in the Zagros Foreland Basin, including the Mansuriya Gas Field (Beydoun, 1998). The Jeribe Formation in the Middle Miocene sequence is mainly composed of dolomitic limestone and dolomite, reflecting shallow marine environments. It includes lagoonal, restricted, and open marine facies, indicating a carbonate platform setting (Al-Mamouri et al., 2022). The Formation is a significant hydrocarbon reservoir, with diagenetic processes such as (Al-Dabbas et al., 2013) enhancing its porosity and permeability.

The Mansuriya gas field in the Zagros Fold Belt is critical to Iraq's natural gas resource. The field is located in the northeastern zone of the Stable Shelf (Figure 2). The Early Miocene (Burdigalian) Jeribe Formation, deposited in the Mesopotamian Basin, has a semi-uniform thickness ranging from 60 to 65.5 meters (Table 1). The field currently has four wells, and all wells have been inspected (Figure 1).

The Mansuriya Gas Field, discovered in 1979, has proven gas reserves of 4.5 Tcf of natural gas, with an average production of 320 MMcf/d (Al-Mahdawi & Hussain, 2024). It is a lengthened anticlinal structure that runs from northwest to southeast, measuring 25 kilometers in length and 5 – 6 kilometers in width (Figure 1). The Jeribe Formation is considered the main reservoir, containing gas condensate fluid, and has a uniform thickness of approximately 60 m. The study uses wireline records to evaluate the petrophysical characteristics of the Jeribe Formation reservoir.

Table 1. Tops of the Jeribe Formation for the study wells.

Well	Tops(m)	Bottom(m)	E.L. (m)	G.L. (m)	Thickness (m)
Ms-1	1349	1415	83	76	66
Ms-2	1399	1460	88	81	61
Ms-3	1420	1482	90	83	62
Ms-4	1637	1697	136	129	60

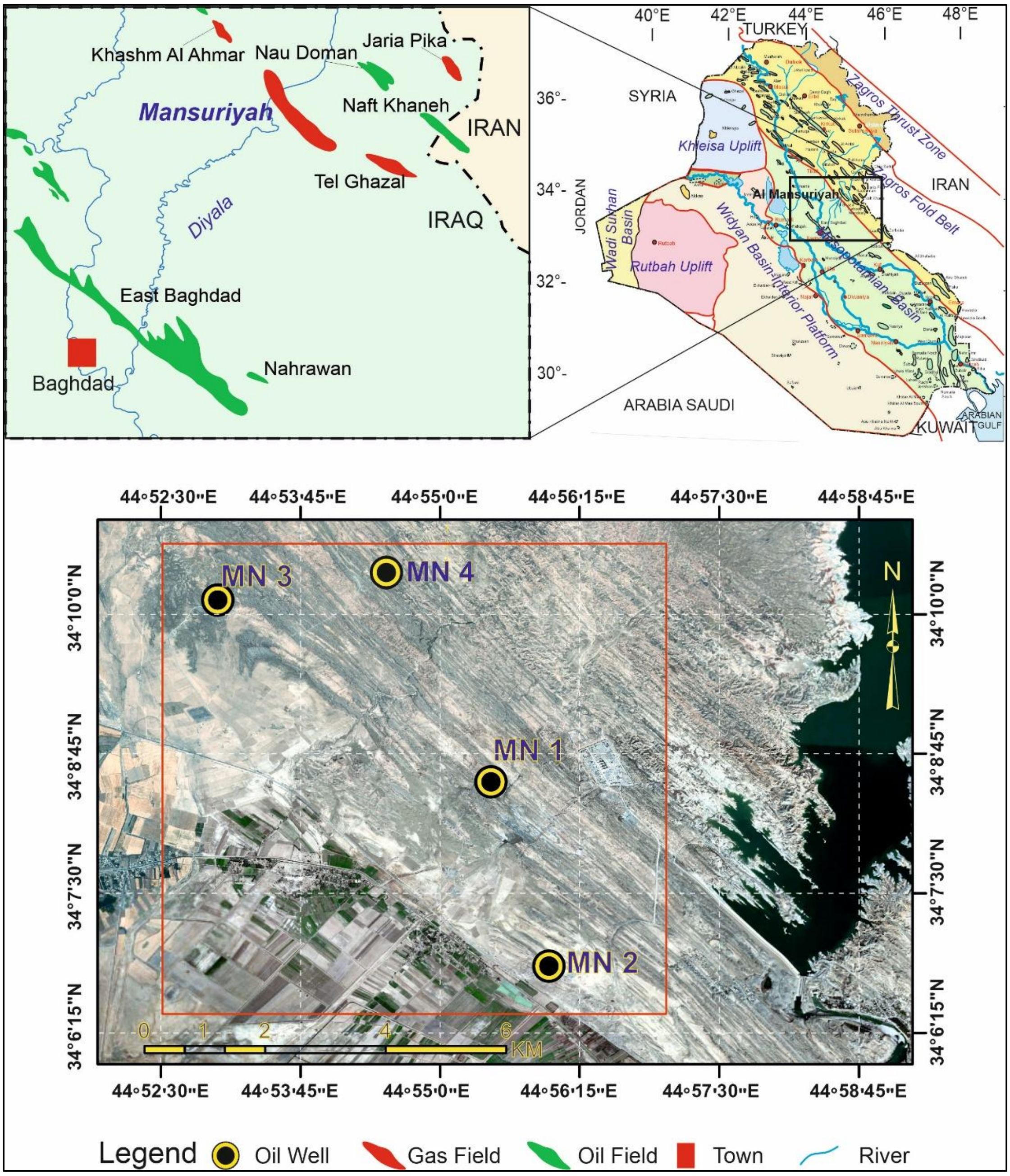

Figure 1. Upper: Location map of the studied gas field. Lower: Studied wells map, modified from (Al-Ameri & Al-Khafaji, 2014); Al-Mahdawi, 2023).

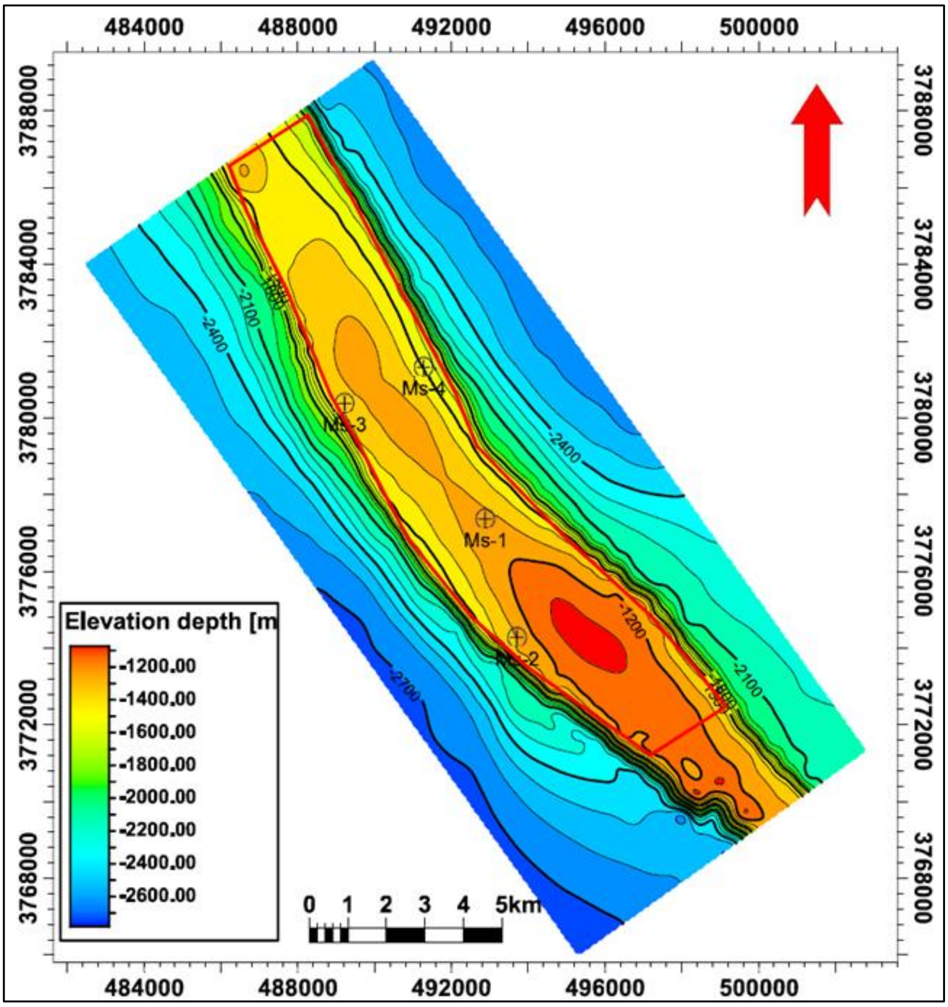

Figure 2. Structural contour map of the top of the Jeribe Formation in the Mansuriya gas field, central Iraq.

2. Geological Setting Stratigraphy

The Mesopotamian Basin, a narrow belt extending from northern Iraq to the Arabian Gulf, originated as an NW-trending foredeep during the Late Cretaceous when the Arabian Plate collided with the continental blocks of Eurasia. The basin is bordered to the east by the Zagros Mountains and to the west by the Mesozoic stable shelf (Aqrawi et al., 2010). The Zagros Orogeny, which primarily occurred in the late Miocene and Pliocene, resulted in the closure of the Neo-Tethys Ocean and the formation of a foredeep. Mesozoic-Cenozoic stratigraphic and lithostratigraphic unit sections suggest that the Mesopotamian Basin and Zagros fold belt are still experiencing tectonic activity. (Beydoun, 1998) The Zagros Basin, known for its complex stratigraphy and alternating sequences of carbonates and clastic sediments, is essential for oil exploration. Key reservoir units include Triassic to Cretaceous Carbonates, Tertiary sediments, and large anticlines, making it highly favorable for hydrocarbon trapping in giant oil fields.

The Jeribe Formation, originally identified by Bellen et al. (2005), is a type locality in the Sinjar anticline believed to have formed during the Early Miocene. It was later included in the Middle Miocene Sequence and is characterized by an unconformity surface with the Serikagni formation. The depositional environment of the formation is a reef (Bellen et al., 1959). The formation consists of marly limestones that have been partially dolomitized and anhydrite with blue marl streaks. Al-Mansuriya fields have two asymmetrical wings and a distinct pattern due to the orogeny movement, which peaked during the Miocene/Pliocene era with the formation of the Zagros Mountains. The formation can be found in wells dug in the Ain Zalah region and northeast of the type section in northwestern Iraq. The formation may resemble the Middle Asmari and Upper Asmari in their uppermost portions in Iran (Rajabi & Ghafor, 2024). The Jeribe formation comprises four distinct depocenters in two significant basins along an NW – SE trend (James & Wynd, 1965).

The Jeribe Formation, with its type locality in the Sinjar anticline, is believed to date back to the Early Miocene and was later included in the Middle Miocene Sequence. It is characterized by an unconformity surface with the Serikagni Formation. The formation is present in wells drilled in the Ain Zalah region to the northeast of the type section in northwestern Iraq (Al-Juboury et al., 2007). The Formation comprises four distinct depocenters in two significant basins along an NW-SE trend. The Jeribe Formation was deposited relatively regularly during the Early Miocene (Burdigalian) epoch and has a total thickness of 65 meters. The Dhiban Formation is conformable with the lower contact of Jeribe in the Mansuriya gas field, while the Upper contact is unconformable with the Fatha Formation (James et al., 1965; Figure 3).

3. Methodology

This study aims to establish accurate petrophysical characteristics for the Jeribe Formation in the Mansuriya gas field in Central Iraq. The technique includes wireline log data provided by the Midland Oil Company in Baghdad. In addition to the Mansuriya structure, four wells, Ms-1, Ms-2, Ms-3, and Ms-4, were selected to investigate the Middle Miocene reservoir features and estimate hydrocarbon potential.

3.1. Data collection

Data collection and analysis for the Jeribe reservoir of Mansuriya Gas Field included core data, well tops, well logs, seismic interpretation reports, final well reports, and final geological reports. The study utilized data from four wells, with the well-log analysis incorporating conventional, gamma ray, dual induction resistivity, micro resistivity, neutron, density, and acoustic logs. Reservoir properties were determined using Techlog software, which included lithology, flow zones, well tops, porosity, and fluid saturation.

3.2. Data Processing and Interpretation

Data processing and Interpretation is the next essential step following data collection, and the following software was employed in this step, with each software performing a specific job in processing and interpreting the collected data: Didger V.5 was used to digitize the logs. Then the data was submitted to Techlog V.21 to measure the petrophysical properties such as the porosity, effective porosity, and fluid saturation, and determine the lithology.

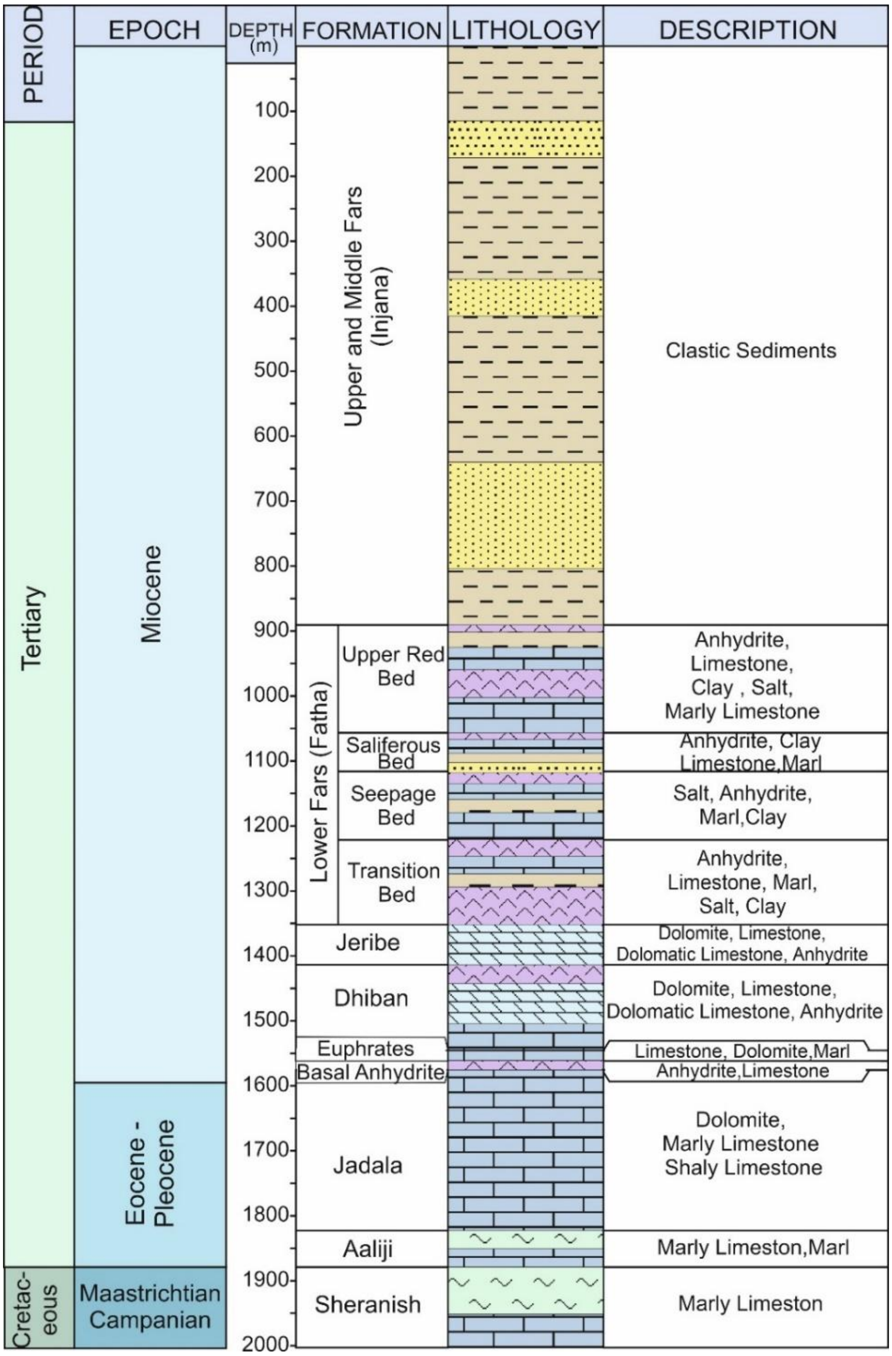

Figure 3. Stratigraphic succession of Ms-2 in the Mansuriya Gas Field, drawn based on data from (Mahmood & Shakir, 2024).

4. Results and Discussion

The open well logs were analyzed to conduct qualitative interpretation by examining the behavior of the curves used in this study. By observing the GR-log in wells, we were able to identify that radioactive elements are usually found in higher concentrations in muds and shales, while they are less concentrated in clean formations (Schlumberger, 1989). This is due to the GR-log's ability to measure the shale content of the Formation. The Jeribe Formation is known to be a clean formation in the area under investigation. The Jeribe formation, on the other hand, is gas-filled and lacks water, leading it to be previously considered as a single zone.

It is possible to verify the type of fluid that fills the pores using a neutron log. When pores are filled with gas instead of oil or water, neutron porosity will be lowered. This occurs because there is a lower concentration of hydrogen in the gas compared to oil or water, resulting in a decrease in neutron porosity. This phenomenon is called the gas effect. Neutron logs are also utilized to determine the lithology of the Jeribe Formation, which consists of limestone with dolomitic limestone interbedded at specific depths. This determination is made in conjunction with density logs; if the density is low and the neutron is high, then the rock is limestone. Conversely, if the neutron-density logs show a positive separation, then the rock is dolomite. Resistivity logs are a function of the rock fluid and are used to identify porous areas (G. B. Asquith & Krygowski, 2004).

4.1. Shale volume determination from G.R. log

The gamma-ray log measures the amount of naturally occurring radioactivity in the formation. In siliciclastic environments, it is useful to distinguish between sand and shale (Darling, 2005). Rocks with low radiation levels, such as sandstone and limestone, are considered clean rocks since the gamma-ray (G.R.) log (Figure 4; Asquith and Krygowski, 2004) can be used to identify them. To calculate Vsh values, the gamma-ray log (G.R. Log) must be utilized, and the gamma-ray index (IGR) needs to be determined using Schlumberger's approach (Schlumberger, 1972)

$$GR = (GRlog - GRmin)/(GRmax - GRmin) \tag{1}$$

The GR log in Jeribe carbonate rocks showed lower gamma responses than spectrally corrected gamma ray GRC curves, indicating a "clean" Jeribe Formation regarding shale content. The G.R. log reveals that in wells Ms-2 and Ms-3, there is no shale or maybe a tiny amount. Wells Ms-1 had somewhat higher amounts of shale content, as shown in Figure 4.

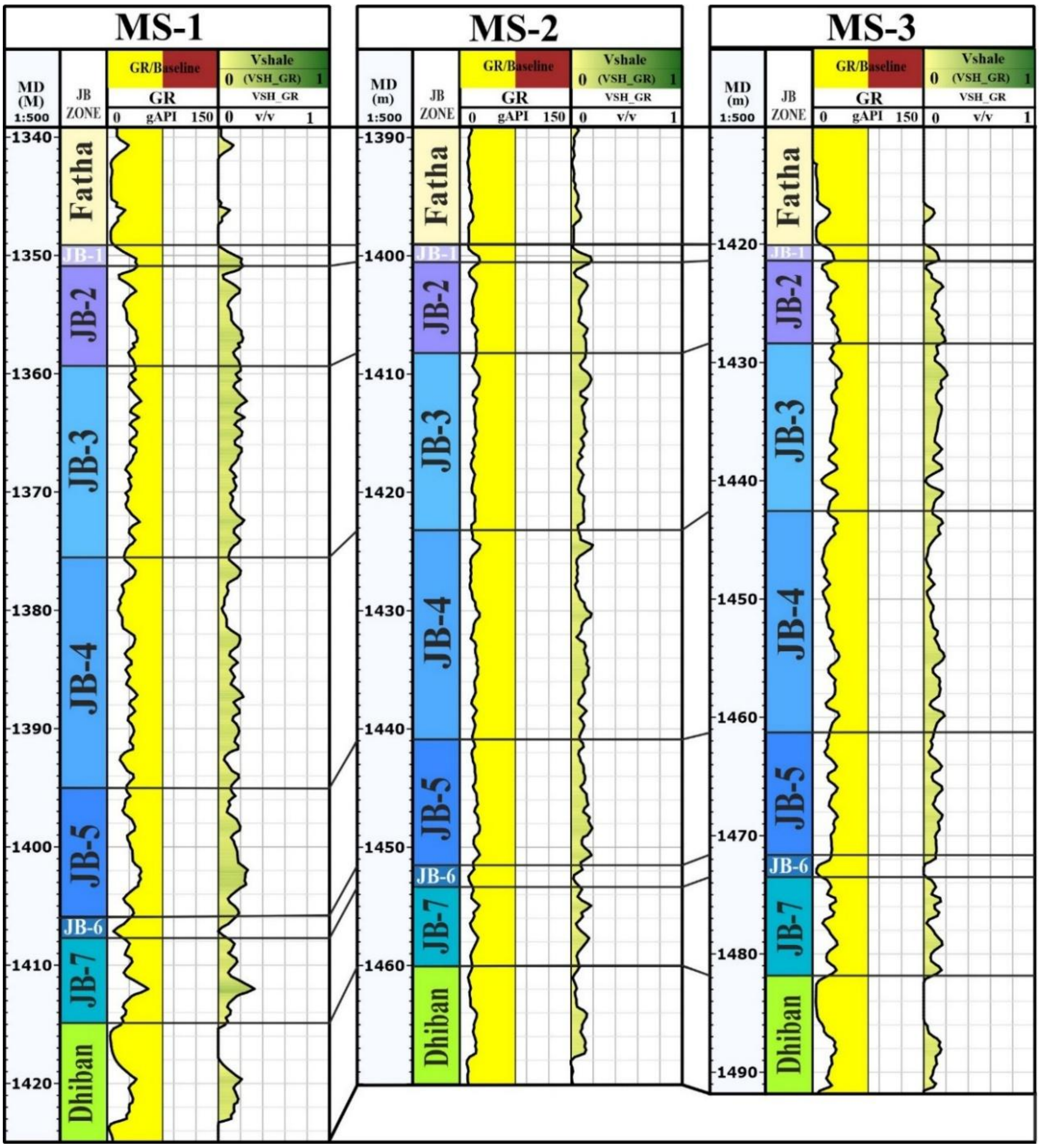

Figure 4. Shale volume determination from the G.R. log of the Jeribe Formation in wells Ms-1, Ms-2, and Ms-3.

4.2. Calculation of porosity

According to Lucia (2007), determining the porosity of a reservoir rock is essential because it serves as an indicator of its capacity to hold hydrocarbons. There are numerous methods available for calculating porosity, including analyzing supporting data or using investigative data.

4.2.1. Neutron log porosity

The amount of hydrogen in a deposit is measured using neutron logs, sometimes referred to as porosity logs. The neutron log (NPHI) determines the liquid fluid porosity in clean formations (those without Shale) when the porosity is filled with either water or oil (Asquith & Krygowski, 2004). Delineating porous formations and assessing their porosity are the main uses for neutron logs. The amount of hydrogen in the Formation has the biggest impact on them (Schlumberger, 1972.)The neutron log was maintained in API units. In dirty reservoirs, the neutron log will always yield a higher apparent porosity measurement than there is because shale always contains some bound water. The hydrogen content of hydrocarbon gas is lower than that of water and oil, which are almost equal. Thus, the neutron log might obtain a porosity reading in gas reservoirs (Selley, 1998)

4.2.2. Density log porosity

The unit of measurement for density is grams per cubic centimeter, or g/cm3, and is represented by the Greek letter ρ. The density log uses two different density values: the bulk density (b or RHOB) and the matrix density (ρma). The bulk density is the combined density of the solid and liquid components of the entire formation, as determined by the measurements taken with the logging equipment. The matrix density is the density of the robust framework of rock. Porosity can be computed from the bulk density of clean liquid-filled formations when the matrix density (ρma) and the liquid-filled density (ρf) are known (Asquith and Krygowski, 2004). Wiley's equation also states that porosity can be computed using one of the porosity logs, such as density (Wyllie et al., 1958)

$$\boldsymbol{\emptyset_D = \frac{(\rho_{ma} - p_b)}{(\rho_{ma} - \rho_f)}} \quad (2)$$

$\emptyset_D$: porosity measured from the Density log
ρ_{ma}: Density of dry rock (g/cm^3)
p_b : density of fluid (g/cm^3)
ρ_f : The total density of a formation is taken from the log values and measured in units(g/cm3).

Carbonate rocks have a higher total porosity than effective porosity due to the presence of shale, with more shale resulting in a more significant difference. The Jeribe Formation in the Mansuriya gas field contains little or no shale, so the total porosity is equal to the effective porosity.

The presence of anhydrite layers in the formation, such as at depths of 1349 m and 1409 m in the Mn-2 well, led to very low porosity, which allowed them to act as cap layers for the other reservoir zone of the Jeribe Formation (Figure 5).

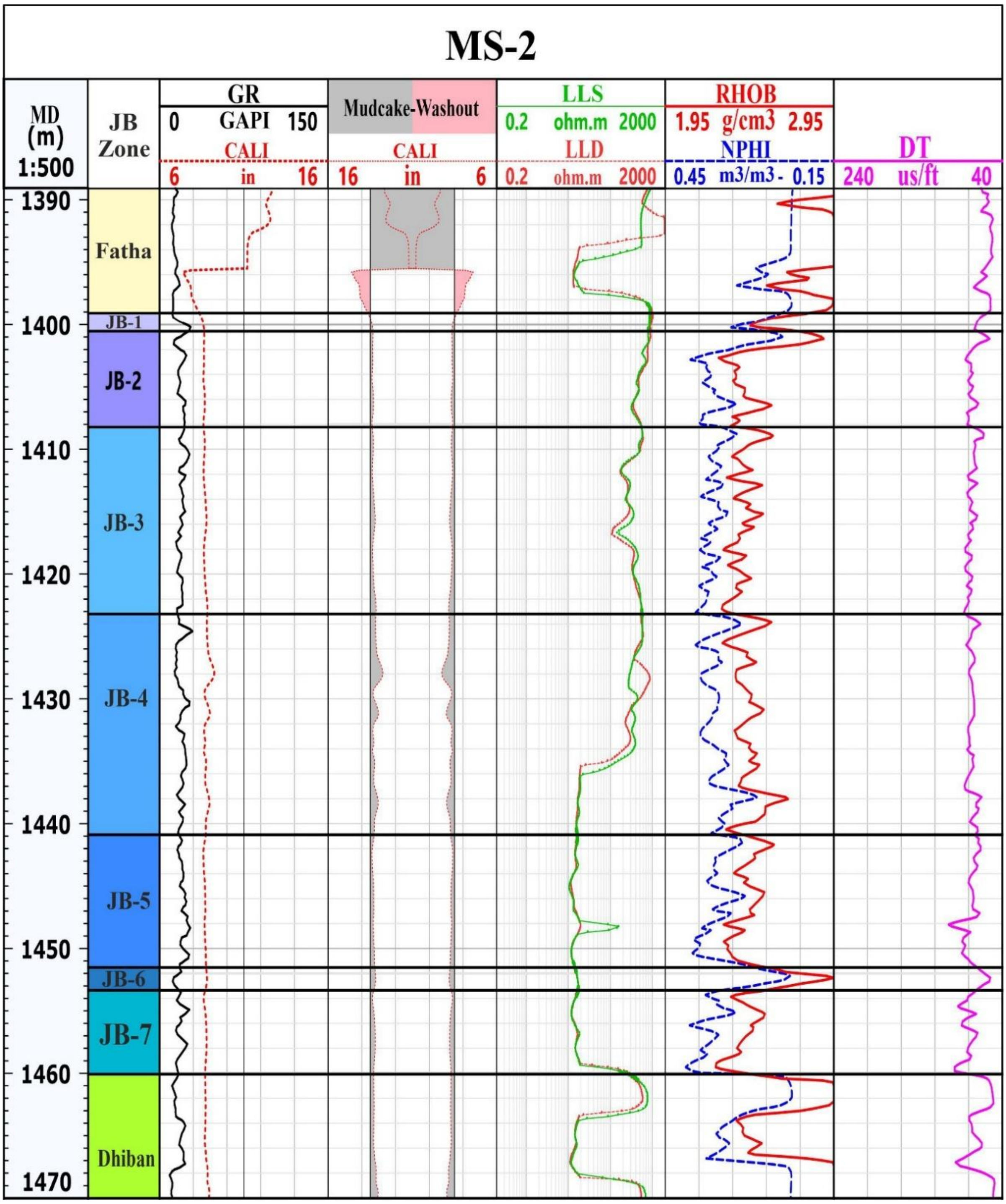

Figure 5. Example for qualitative Interpretation of the Jeribe Formation in the well Ms-2.

4.3. Lithology

4.3.1. Neutron-density cross plot for lithology identification

Sandstone, limestone, or dolomite formations filled with either gas or water can be identified using neutron-density cross-plots. However, the accuracy of density-neutron cross-plot analysis may be compromised in heterogeneous formations like dolomitic cemented sandstone.

The density of red dots representing Neutrons was used to identify the best match for the set of points in multi-crossing plots from multiple wells (Figure 6). The majority of red dots were located in well 1, following the dolomite and limestone curves. In well 2, there were hardly any points along the sandstone curve, with most points aligning more closely with the dolomite and limestone curves. Well 3 had more points along the sandstone curve compared to wells 1 and 2, indicating that sandstone, limestone, and dolomite are the primary lithological constituents of the Mansouriya formation.

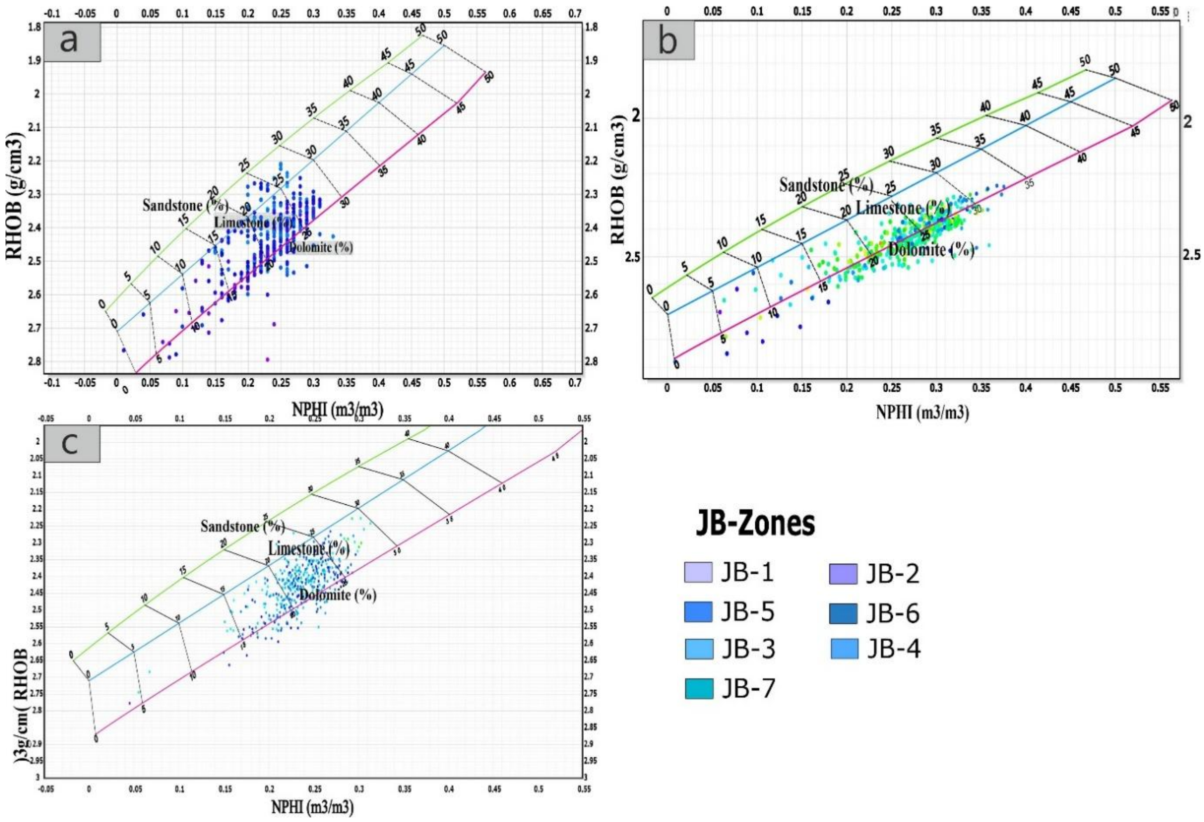

Figure 6. Shows the cross plot of Neutron porosity and Density porosity for the well (a) Ms-1, (b) Ms-2, and (c) Ms-3.

4.3.2. M-N Cross-Plot for mineral identifications

The M-N cross plot was utilized in well-log analysis to identify minerals in formations with intricate lithology (Asquith & Krygowski, 2004). (M-N) A cross plot can be employed for lithology determination, gas detection, clay minerals classification, and more. Each mineral possesses a distinct set of (M, N) values, and this concept applies to binary and ternary minerals models. The values of (M and N) are calculated using the following (Schlumberger, 2009):

$$M = \frac{\Delta t_f - \Delta t}{\rho b - \rho f} * 1 \tag{3}$$

$$N = \frac{\emptyset N_f - \emptyset N}{\rho b - \rho f} \tag{4}$$

Where:

Δt_f : $185 \frac{\mu sec}{ft}$ $for\ a\ salt\ mud$ (210 $oil\ base\ mud$)

$\rho f = \frac{1.1g}{cm^3} for\ salt\ mud\ but\ for\ oil\ base\ mud\ 0.8$

The multi M – N cross plot for the Jeribe Formation in all wells shows that the data is centered on the dolomite area with extension toward the secondary porosity area, from this we can determine that most of the Jeribe Formation consists of dolomite (represented by dolomite area) with some limestone and anhydrite (represented by calcite region and anhydrite region (Figure 7).

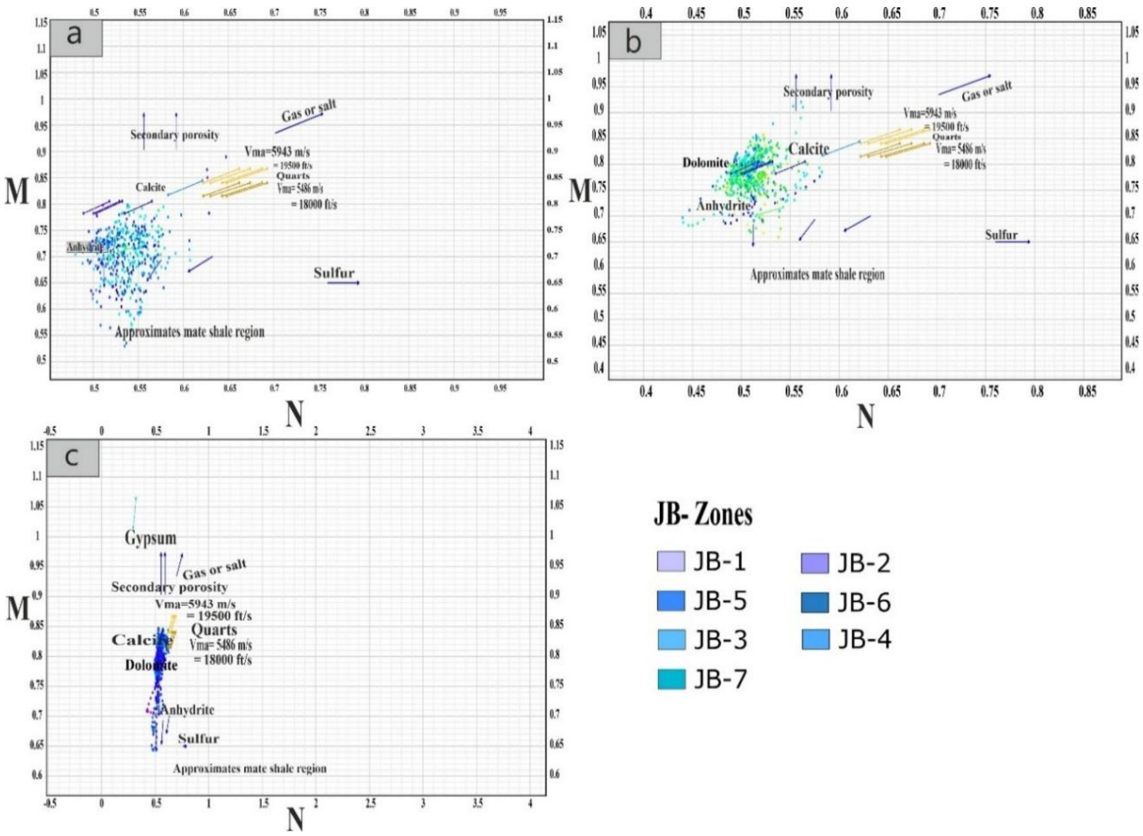

Figure 7. The M-N cross plot for the studied wells (a) Ms-1, (b) Ms-2, (c)Ms-3.

4.4. Fluid and Formation Analysis

Saturation assessment is crucial for evaluating reservoirs because it indicates the presence of water or hydrocarbons within the formation. The Archie Formula (developed in 1942): calculates the percentage of pore volume occupied by formation water, also known as water saturation :

$$Sw = (F.R_w/Rt)^{1/n} \qquad (5)$$

Where:
Sw: water saturation of the uninvaded zone.
F: formation Factor from ($F = a/\emptyset^m$), a = tortuosity factor = 1, m = cementation formation = (1.69 – 2.08)
Rw: resistivity of water formation equals 0.047 ohm.
Rt: true resistivity is taken from deep resistivity
n: saturation exponent (assumed 2 from the final report)

The formation factor is calculated from observed porosity, which includes total, net, average, and water saturation values. The water saturation value of the productive pay zone is less than 60%, indicating that the effective porosity is greater than 12%, as shown by the relationship among total and average porosity values, see Figure 8.

The hydrocarbon saturation (Sh) represents the residual pore volume unfilled with water. It is obtained by using the Schlumberger formula (1987)

$$Sh = (1 - Sw) \qquad (6)$$

4.5. Evaluation of the Jeribe Formation

Limestone sporadically scattered throughout the Formation serves as the primary reservoir in the Mansuriya gas field and enhances the petrophysical characteristics of the Formation. Because the entire Formation is gas-bearing and lacks a water zone, it was determined practically and by examining the behavior of the logs in Fig.8 that the Jeribe Formation was separated into 7 zones, based on changes in petrophysical properties, well log behavior, and lithology. The distribution of petrophysical characteristics in the investigated wells in the Mansuriya gas field is depicted in Figure 8 and Table 2, explaining how the amount of Shale, total and effective porosity, and water saturation were calculated.

Several factors influence the gas quality and quantity of each reservoir zone. Higher porosity leads to lower water saturation, resulting in increased production. In the Mansuriya gas field, Ms-1 is approximately 66 meters thick, Ms-2 is around 60.5 meters thick, Ms-3 is about 61.5 meters thick, and Ms-4 is roughly 60 meters thick. These zones are primarily composed of limestone with a small amount of shale

4.5.1. JB1 Zone

The thickness of this zone is t approximately (0.91 – 1.6) meters. This section of the formation lies between the rocks of the Fatha formation above and the JB2 zone below, and it acts as a cap rock.

4.5.2. JB2 Zone

The thickness of this zone is t approximately (5.7 – 8.2) meters in the wells of the Mansuriya field; this part of the Formation is determined between the zone (JB-1) that is located above it and the zone (JB-3) that borders it from the bottom This zone is regarded as one of the most exceptional reservoir zones within the Jeribe Formation, owing to its outstanding effective porosity, optimal water and hydrocarbon saturation levels, and the presence of the overlying JB1 zone (anhydrite), which enhances its sealing capacity.

4.5.3. JB3 Zone

The thickness of this zone is t approximately 14.2 – 16 meters in the wells of Mansuriya field, a jibe formation, and this part of the Formation is determined between the zone (JB-2) that is located above it and the zone (JB-4) that borders it from the bottom.

4.5.4. JB4 Zone

The thickness of this zone is approximately 17.6 – 19.4 meters in the wells of the Mansuriya field at the Jeribe Formation, and this part of the Formation is determined between the zone (JB-3) that is located above it and the zone (JB-5) that borders it from the bottom.

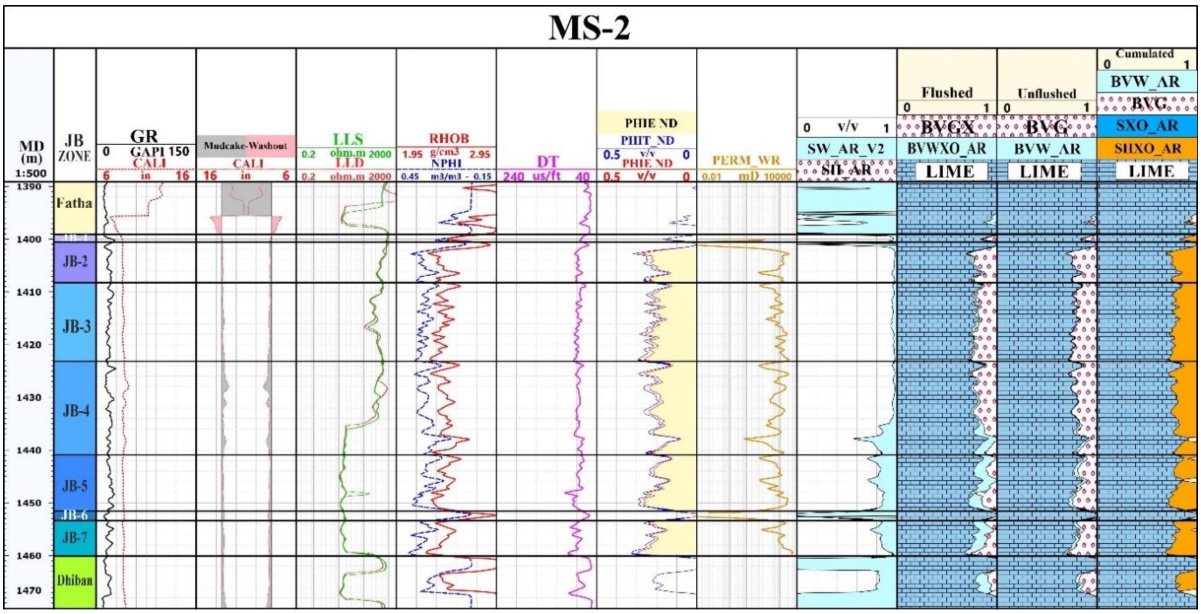

Figure 8. Computer-processed Interpretation (CPI) for well Ms-2, showing many petrophysical parameters of the Jeribe Formation.

Table 2. The average petrophysical properties of the Jeribe reservoir in the study well.

WELL NO.	ZONES	PERM	VSH	PHIE	PHIT	SW	SH_AR
Ms-1	JB-1	1.37	0.16	0.09	0.13	0.05	0.95
	JB-2	11.75	0.15	0.14	0.19	0.09	0.91
	JB-3	17.05	0.16	0.16	0.21	0.11	0.89
	JB-4	14.14	0.14	0.15	0.2	0.16	0.84
	JB-5	13.6	0.16	0.15	0.2	0.24	0.76
	JB-6	0.43	0.06	0.06	0.08	0.44	0.56
	JB-7	19.11	0.13	0.17	0.21	0.18	0.81
Ms-2	JB-1	0.83	0.09	0.07	0.1	0.053	0.947
	JB-2	9.08	0.11	0.18	0.19	0.03	0.97
	JB-3	7.9	0.11	0.18	0.19	0.04	0.96
	JB-4	5.39	0.11	0.16	0.17	0.05	0.95
	JB-5	6.89	0.12	0.17	0.18	0.19	0.81
	JB-6	0.01	0.05	0.05	0.05	0.79	0.31
	JB-7	10.88	0.09	0.19	0.2	0.16	0.84
Ms-3	JB-1	0.65	0.12	0.09	0.12	0.08	0.92
	JB-2	5.02	0.12	0.16	0.19	0.07	0.93
	JB-3	7.78	0.13	0.18	0.22	0.1	0.90
	JB-4	6.62	0.09	0.15	0.19	0.16	0.84
	JB-5	6.91	0.11	0.17	0.2	0.35	0.65
	JB-6	0.03	0.12	0	0.03	0.91	0.09
	JB-7	9.5	0.1	0.17	0.21	0.31	0.69

4.5.5. JB5 Zone

The thickness of this zone is approximately 9.3 – 10.7 meters in the wells of Mansuriya field, at Jeribe Formation, and this part of the Formation is determined between the zone (JB-4) that is located above it and the zone (JB-6) that borders it from the bottom. These zones (JB4 and JB5) are considered reservoirs composed of dolomite, where the positive separation happened for NPHI and RHOP.

4.5.6. JB6 Zone

The thickness of this zone is t approximately 1.6 – 1.9 meters in the wells of the Mansuriya gas field, a Jeribe Formation, and this part of the Formation is determined between the zone (JB-5) that is located above it and the zone (JB-7) that borders it from the bottom.

4.5.7. JB7 Zone

The thickness of this zone is t approximately 6.4 – 8.3 meters in the wells of the Mansuriya field, a Jeribe Formation, and this part of the Formation is determined between the zone (JB-6) that is located above it and the Formation of Dhiban that borders from the bottom, and this zone is the last in the Formation of the Jeribe.

5. Conclusions

In the current research, the Techloge ve. 21 program and available logs, such as (gamma radiation log, density log, neutron log, acoustic log, and resistivity logs), were used for this formation, which was divided into seven zones. The results indicate that JB1 is Cap Rock, and JB2 and JB3 are limestone rock reservoirs. However, in JB4 and JB5, a positive separation was observed in the density-neutron logs, indicating the presence of a reservoir of dolomite rocks in JB6. This zone served as a Cap Rock. The gamma-ray log indicated that the volume of the shale in the Jeribe formation was low, and the formation may be clean or have a low shale content. Except for zone JB7, there is a slight increase in the gamma-ray log, indicating that this zone is contaminated with mud. This small reading is likely due to the presence of radioactive materials in the formation rocks or the element Uranium. Since the Jeribe formation is regarded as having a low shale content or being clean, the total porosity is approximately equal to the effective porosity. These parameters Petrophysical characteristics of the Jeribe formation, used to calculate and study the volume of shale, porosity, water saturations, permeability, and percentage of hydrocarbons.

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