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Petro-physical Analysis of the Mushrif Formation Units in the Nasiriyah Field, Southern Iraq

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***Abstract*—Mushrif Formation is one of the major geological formations in southern Iraq because of its petro-physical characteristics and geographical extensions, which makes it an excellent oil reserve in that region. The present investigation identified the petro-physical characteristics of the Nasiriyah Oilfield's Mushrif Formation by interpreting the geophysical data of three wells (NS-1, NS-3, and NS-5).This study was carried out by the software (Techlog software 15.3). The study relied on quantitative and qualitative analyses of the borehole probe data. The lithology of Mushrif Formation was determined by knowing the response of the GR, Spontaneous potential, resistivity, neutron probe, and density, as well as from the analysis of the probe values from the cross plot, as most of the values for this analysis fell in the range of limestone rocks, some of them in the range of dolomite rocks, and a few of them in the range of sandstone.The petro-physical results of the current study showed that Mushrif Formation in the three wells has four distinct units, each of which has petro-physical properties that distinguish it from others. These units were labeled MB2, MB1, CR11, mA, and Mushrif. We used electrical probes, porosity probes, and GR probes to identify the upper (mA) and lower (mB) units. These two units are separated by barrier shales (CR11, Mushrif). mB1 and mB2 are the main reservoir units in the formation, characterized by their high hydrocarbon content and high proportions of mobile hydrocarbons compared to the remaining hydrocarbons. The mB1 unit is characterized by good petro-physical properties in terms of high porosity and low water saturation, which gives evidence of the presence of good quantities of crude oil in this range. It also showed that the MB1 unit in the Al Mushrif Formation has good characteristics, including high porosity (0.040) and permeability (6.683 mDa) with low water saturation values (0.180), making it suitable for oil accumulation.**

***Keywords*—Quantitative interpretation, Qualitative analysis, Petro-physical analysis, Mushrif Formation, Nasiriyah Oilfield.**

I. INTRODUCTION

The Oilfield under the study lies 38 kilometers northwest of Nasiriyah City in the southern Iraqi province of Thi-Qar. Three Cretaceous reservoirs—the Mushrif, Yamamah, and Nahr Omar Formations—had oil detected in five of the field's exploration oil wells [1]. The Mushrif Formation (Cenomanian-Early Turonian) is of significant geological importance in southern Iraq, due to its favorable petro-physical properties and extensive geographic distribution. Consequently, it represents a promising reservoir for hydrocarbons, following the Zubair Formation, which has the greatest economic potential. The stable shelf of the Arabian plate is where the Nasiriyah oilfield is located. Subsurface folds and domes are present, according to the findings of recent seismic measurements conducted in 1987 and 1988. The observed folding has a west-east and north-south direction, and its area is rather small (about 30 x 10 km). The anticlines remain uninfluenced by fracture, showing a 65-meter structural closure at the top surface of the Mushrif Formation, the field's principal reservoir formation. Situated within basement rocks that are 9–10 km deep, this structure has a moderate 1-2 degree inclination and dips NE–SW [2]. The Mesopotamian Basin zone's unstable platform is the site of the Nasiriyah Oilfield, which is described by [3], as an anticlinal fold measuring roughly 30 km in length and 10 km in width [4].

Mushrif Formation represents a heterogenous formation that was initially characterized as comprising organic detrital limestones with beds of algal, rudist, and coral-reef limestones, capped by limonitic freshwater limestones [5]. Oil-producing units and multiple zones can be found in the limestone reservoir of Mushrif Formation [6]. Based on organic materials deposited in anoxic marine environments, Mushrif crude oils in the Nasiriyah Oilfield can be categorized as a single category of oils that are non-biodegraded, marine, and non-waxy [7].

Cretaceous deposits in Iraq are about 3000 meters thick in the AP8 and AP9 Megasequence. The Cretaceous basin of Iraq includes three major cycles: late Tithonian-early Turonian; late Turonian-early Campanian; and late Campanian-Maastrichtian [8].

The research aims at a detailed study with two types of quantitative and qualitative analysis to evaluate the petro-physical properties of reservoir rocks in major and minor reservoir units within the Mushrif Formation, such as hydrocarbon-water saturation, porosity, permeability, and shale volume, as well as determining the formation's lithology.

II. LOCATION OF THE STUDY AREA

The Nasiriyah field is located in Thi Qar Governorate, approximately 38 kilometers northwest of Nasiriyah,

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between longitude (10° 60′ - 50° 57′) and latitude (34° 60′ - 34° 80′) as shown in “Fig.1”.

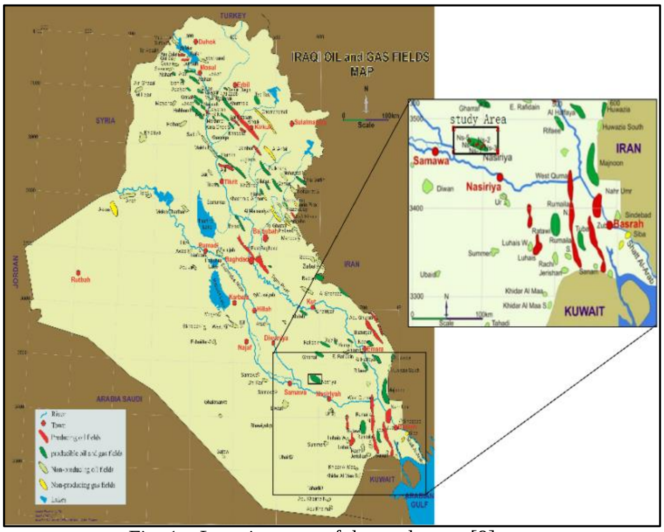

Fig. 1. Location map of the study area [9].

III. DATA BASE

The data set that is used in this study includes fourteen digital well logs (LAS files) such as GR, SP, DT, RHOB, NPHI, and Deep induction (ILD), and previous geological drilling reports including the coring description “Fig.2”.

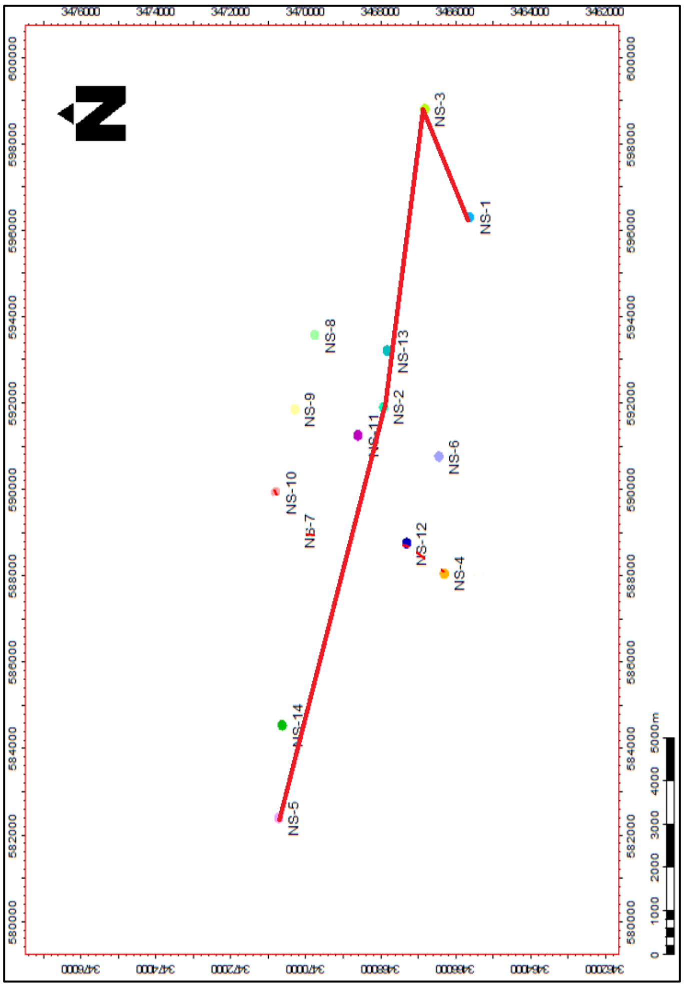

Fig. 2. Shows well locations in the studied area [10].

IV. MUSHRIF FORMATION

Mushrif Formation is distinguished by high heterogeneity. Mushrif Formation represents a highly complex sequence, initially described as a complex of detrital limestone containing, occasionally, algal, rudist, and coral-reef limestone, capped by limonitic freshwater limestone [11]. The principal layers of Mushrif reservoir are characterized by the presence of bioclastic and poloidal facies, which are indicative of shoal and shelf margin facies [12]. This Formation is divided into several members (mA, CR11, mB1, mB2, and Mushrif) with a total thickness of approximately 168 meters. The main oil horizon is the lower part of the formation (mB1). Conducted a geochemical analysis of Mushrif Formation of the Nasiriyah Oilfield, which revealed that the Mushrif source rocks are the carbonate sediments of the Jurassic-Surely Formation “Fig. 3.”.

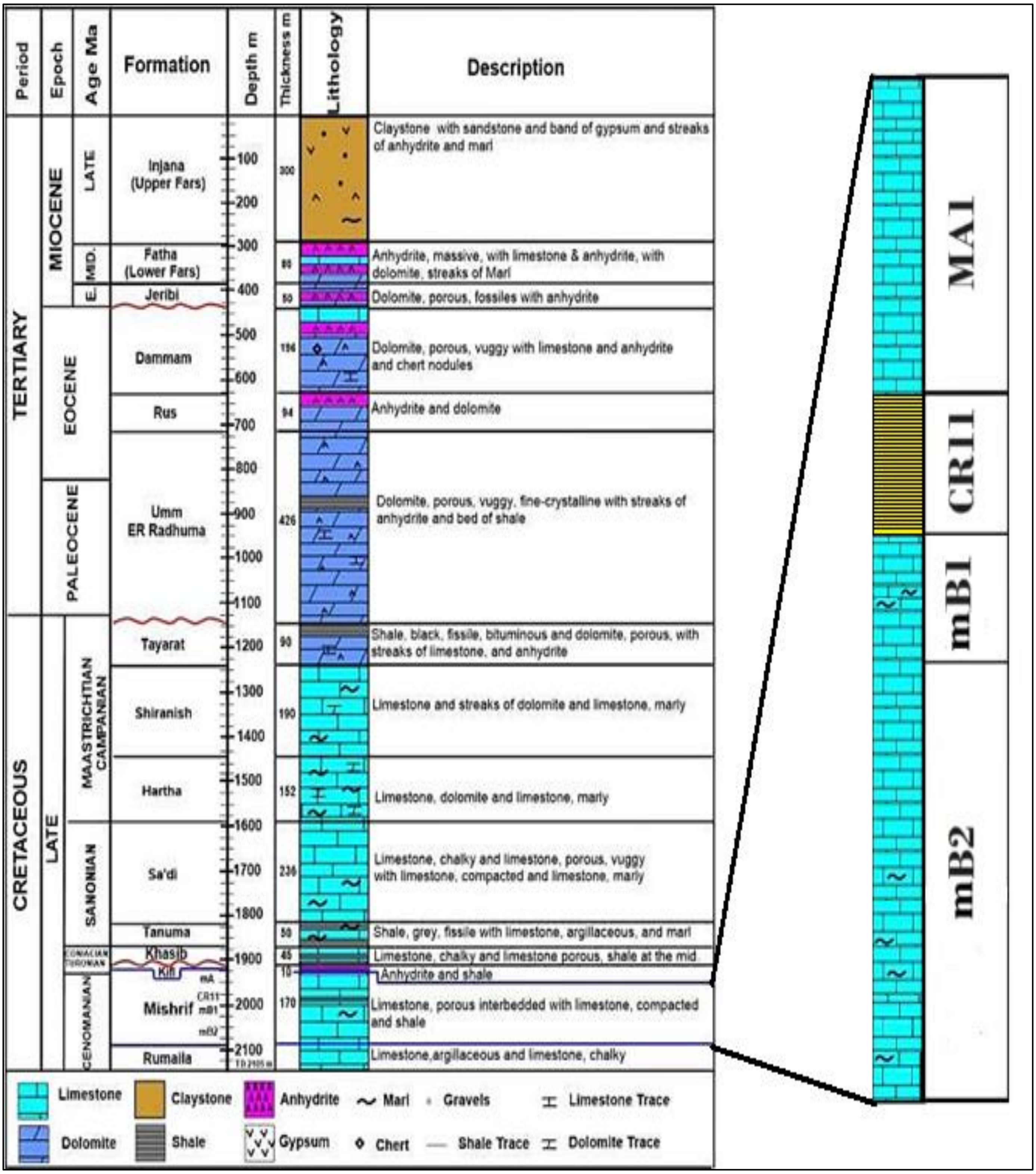

Fig. 3. The blue color delineates the boundaries of the study's focus, which is the Mushrif Formation, a generic stratigraphic column of the Nasiriyah Oilfield compiled from various Thi-Qar Oil Company papers, modified after [13].

V. METHODOLOGY

Methods involved gathering preliminary data from the wells in the research area's final reports and the identification of the wells housing the needed study-related logs and their associated data (NS-1, NS-2, and NS-5). Mushrif Formation has been divided into several units based on the difference in physical properties using the Techlog software (15.3). Data is interpreted quantitatively (represented by Neutron log, density log, resistance log, SP log, resistivity log, GR log, total and effective porosity logs) and qualitatively (The statistical analysis of the study wells was conducted evaluating petro-physical properties by drawing a histogram of (Sw-Sh, k, and Ø) to represent hydrocarbon-water saturation, permeability, and porosity, respectively, in addition to identifying the lithology of the Formation rocks.

A. Shale volume (Vsh) Calculation:

Neutron and density logs were utilized to determine the porosity of Mushrif Formation. The density log was computed using the following formula [14]:

$$I_{GR} = \frac{GRlog - GRmin}{GRmax - GRmin} \quad (1)$$

Where: GRmin = minimal gamma (clean sand or carbonate), GRmax = maximum gamma-ray (shale), IGR = gamma-ray index, GRlog = gamma-ray reading by log (API). For older rock, the shale volume was calculated using the following method [14]:

$$Vsh = 0.33 * (2^{(2* \mathrm{IGR})} - 1) \quad (2)$$

B. Porosity Determination:

Porosity is a measure of a reservoir rock's capacity to hold hydrocarbons, hence determining its value is the most important characteristic [15]:

$$ØD = \frac{(\rho ma - \rho b)}{(\rho ma - \rho f)} \quad (3)$$

Where: ØD = porosity by density log, p ma = dry rock density (g/cm3) for the limestone formation in this study = 2.71g/cm3, p f = fluid density (g/cm3), and p b = bulk density as recorded by log [15].

The shale effect is subtracted from the porosity calculation using the following equation [16]when the shale volume exceeds 10%:

$$ØDcor. = ØD - (Vsh \times Ø\, D_{sh}) \quad (4)$$

The Neutron read is already in porosity units. If the shale volume is more than 10%, the following equation is used [16]:

$$Ø\, NCor = ØN - (Vsh * ØN_{sh}) \quad (5)$$

Where: Dsh = Density porosity for shale, ØNsh = Neutron porosity for shale, Vsh = bulk density of shale.

To obtain porosity from the sonic log, a modified Wiley equation is used [16]:

$$\phi_S = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \quad (6)$$

When the volume of shale exceeds 10%, the following formula is utilized:

$$Ø_{Scor.} = Ø_S - (Vsh \times Ø_S\text{-}sh) \quad (7)$$

Where S-sh is the porosity of shale determined by the sonic log, Δtlog = interval transit time in the formation, Δtfl = interval transit time in the fluid of the formation, and ØS = sonic-derived porosity.

Mushrif Formation overall porosity was calculated using a combination of Neutron-Density logs. To calculate the total porosity from neutron and density data, Schlumberger proposed the following equation in 1974 [17]:

$$ØT = \frac{\Phi Ncor + \Phi Dcor}{2} \quad (8)$$

The effective porosity (e) can be determined by the following equation [17]:

$$Øe = Øt \times (1 - Vsh) \quad (9)$$

Finally, the secondary porosity is calculated using the following [17] formula

$$SPI = (Øt - Ø_{Scor}) \quad (10)$$

$$K = 10000\, Ø_e^{\,4.5} / S_{wi}^{\,2} \quad (11)$$

Where: k= permeability, Swi = irreducible water saturation, Øe = effective porosity.

C. Hydrocarbon-Water Saturation Estimation:

In the well-log analysis, the water saturation (SW) value plays a crucial role in identifying the hydrocarbon movement from movable oil saturation. The following formulas were used to determine the water saturation of the research area's wells [19].

$$S_W = (\mathrm{FR_w}/\mathrm{R_t})^{1/n} \quad (12)$$

$$S_{XO} = (FR_{mf}/R_{xo})^{1/n} \quad (13)$$

Where n is the saturation exponent, which for carbonate rocks has a value of 2, and SW is the water saturation of the uninvaded zone (%), Sxo is the water saturation of the flushed zone (%) Formation Factor (F), Formation Water Resistivity (Rw), True Resistivity of Formation (Rt), Mud Filterate Resistivity (Rmf), and Flushed Zone Resistance (Rxo) are all expressed in terms of millimeters.

D. Weight and Movement of Hydrocarbons Calculation:

A thorough assessment of the oil-range productivity requires computations beyond just determining the water saturation (Sw). These computations include:

- Using the following formulas, determine the total water volume in the drilling mud's flushed and uninvaded zones [20]

$$BVW = Sw\emptyset \tag{14}$$

$$BVxo = Sxo\emptyset \tag{15}$$

Where: BVW= Total water volume of the uninvaded zone and BVXO= Total water volume of the flushed area.

- The volume of all hydrocarbons in the equation, both mobile and immobile [20]:

$$BVO = Sh * \emptyset \tag{16}$$

Where: BVO=Total volume of hydrocarbons.

- Equation's oil saturation of the moveable hydrocarbons [21]:

$$MOS = Sxo - Sw \tag{17}$$

Where: MOS = movable oil saturation

- Equation for calculating the saturation of non-movable oil waste [21]:

$$ROS = 1 - Sxo \tag{18}$$

Where: ROS=Saturation of oil reducible.

VI. Quantitatively interpretation

Accurate analysis of well data allows for mapping the distribution of reservoir properties and facilitates the prediction of areas with high production potential. The use of advanced techniques in analyzing petro-physical data has had a significant impact on clarifying the relationships between petro-physical properties and the factors influencing them, which enhances the effectiveness of field evaluation and development processes.

A. Interpretation of Mushrif Formation Log-View in well NS-1

Depth (1950 m to 2003 m), approximately this thickness is a medium-porosity limestone rock that does not contain oil as it is saturated with water. From (2003 m to 2012 m), it is a shale rock in which the GR is high, therefore the shale volume is high, and the total porosity is high, but the effective porosity is zero, so it acts as a cover rock for the reservoir.(2012m to 2062m), this thickness is characterized by the presence of hydrocarbons, as evidenced by the high reading resistivity probe, high porosity but low water saturation, with some barriers interspersed in the reservoir where water saturation is high and porosity is low. From a depth (of 2062m to the end of the log) of the reservoir is a period of high water saturation and medium porosity “Fig. 4”.

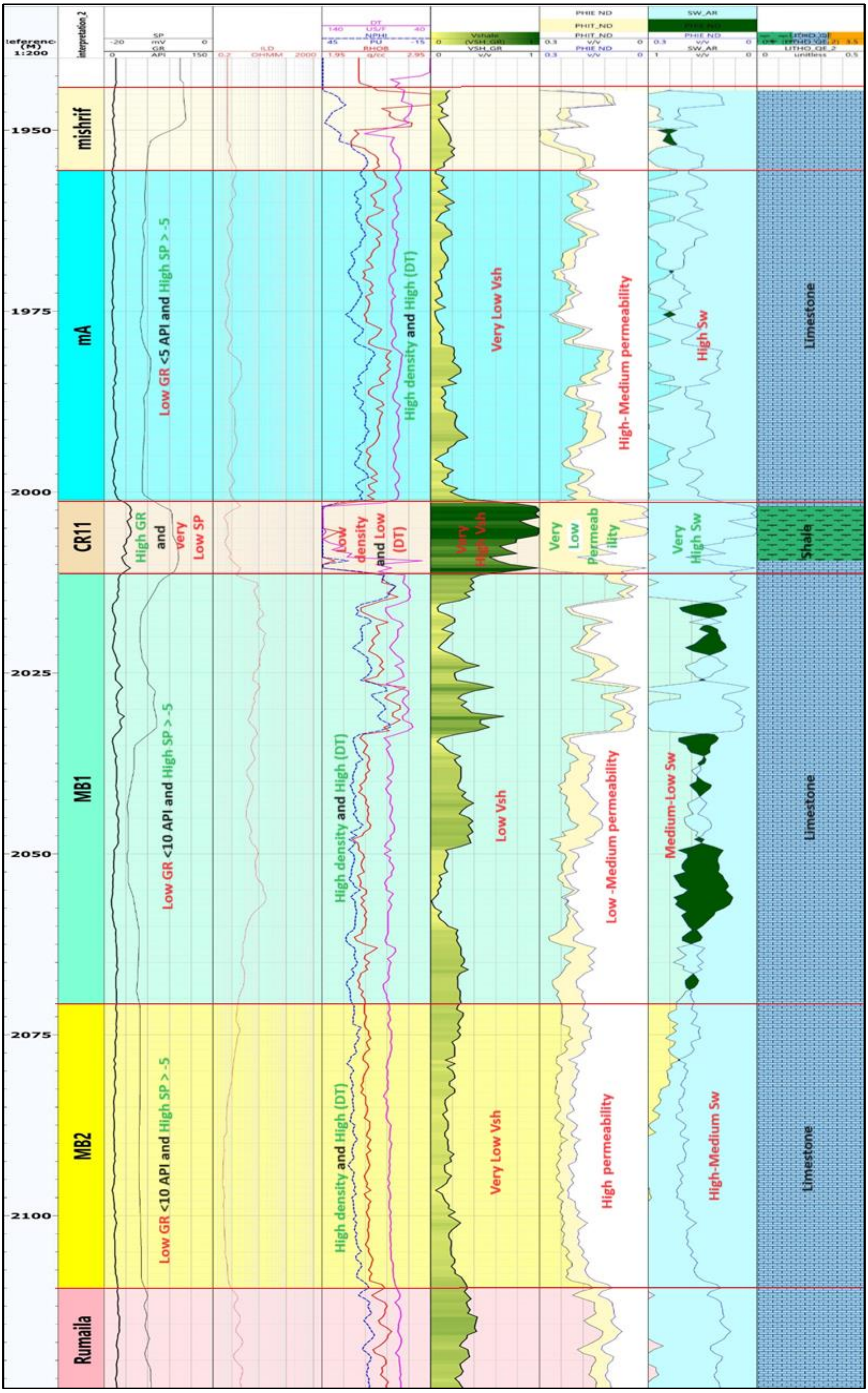

Fig. 4. Quantitative interpretation of the Mushrif Formation in the well (NS-1)

B. Interpretation of Mushrif Formation Log-View in well NS-3

This interval consists of Limestone rocks from depths (1950 m to 1998 m), with medium porosity and no hydrocarbons as they are saturated with water. Depth (1998 m to 2005 m) are shale rocks in which the GR is high; therefore, the shale volume is high and the total porosity is high, but the effective porosity is zero, so it acts as a cover rock for the reservoir. And depth (2005 m to 2073 m), this Intervale is characterized by the presence of hydrocarbons, as evidenced by the resistivity probe with a high reading and high porosity but low water saturation, with some barriers interspersed in the reservoir where water saturation is high and porosity is low. From 2075 m depth to the end of the reservoir of the log is a period of high-water saturation and medium porosity., as shown in "Fig. 5".

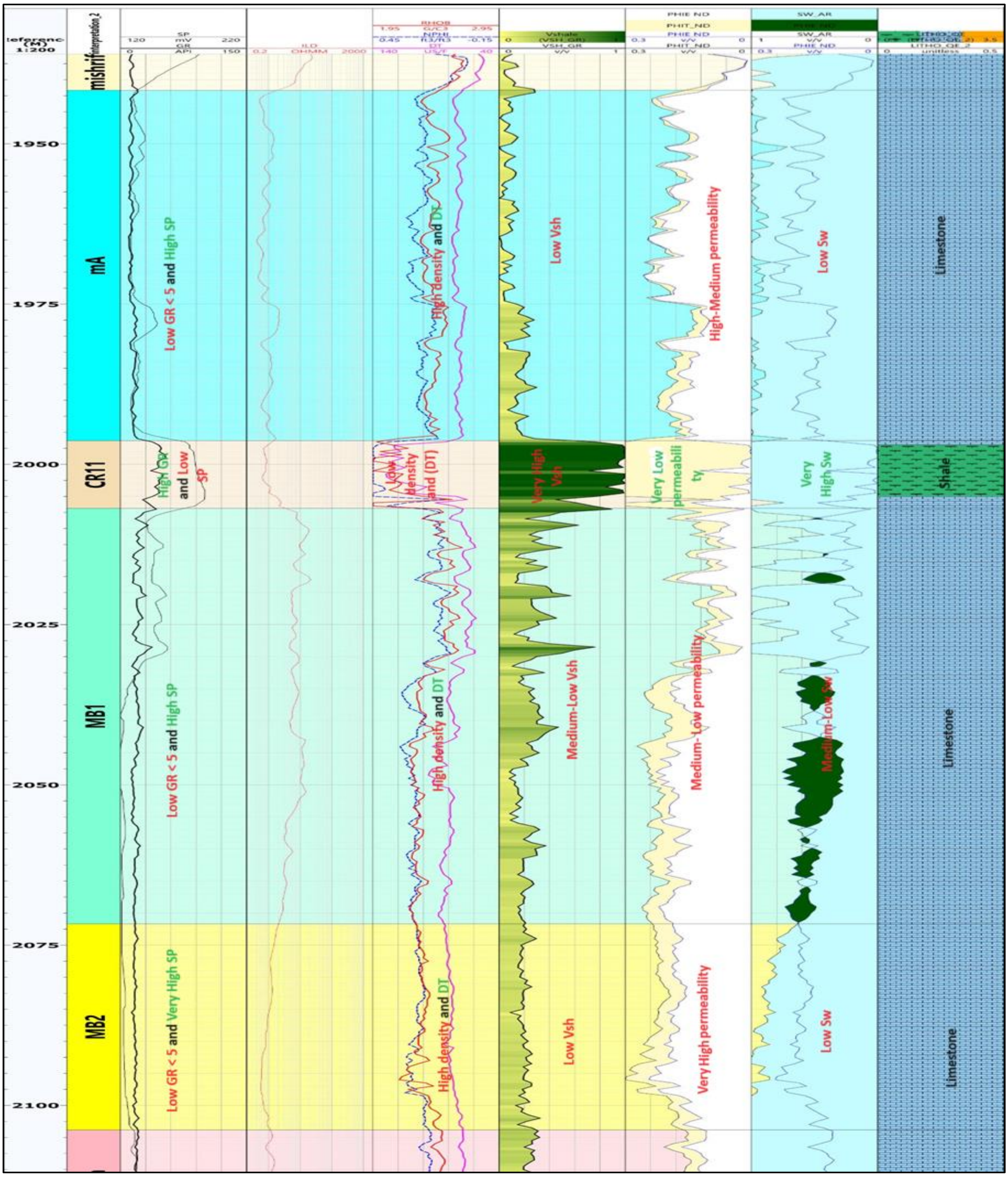

Fig. 5. Quantitative interpretation of the Mushrif Formation in the well (NS-3).

C. Interpretation of Mushrif Formation Log-View in well NS-5

This medium-porosity interval does not contain oil as it is saturated with water at depth (1925 m to 1978 m) and is limestone. From depth (1980 m to 2000 m), it is a shale rock in which the GR is high, therefore the shale volume is high, and the total porosity is high, but the effective porosity is zero, so it acts as a cover rock for the reservoir. From depth (2003 m to 2065 m), this period is characterized by the presence of hydrocarbons, as evidenced by the high reading resistivity probe, high porosity, but low water saturation, with some barriers interspersed in the reservoir where water saturation is high and porosity is low. From depth m2067 to the end of the reservoir of the log is a period of high-water saturation and medium porosity, as shown in “Fig. 6”.

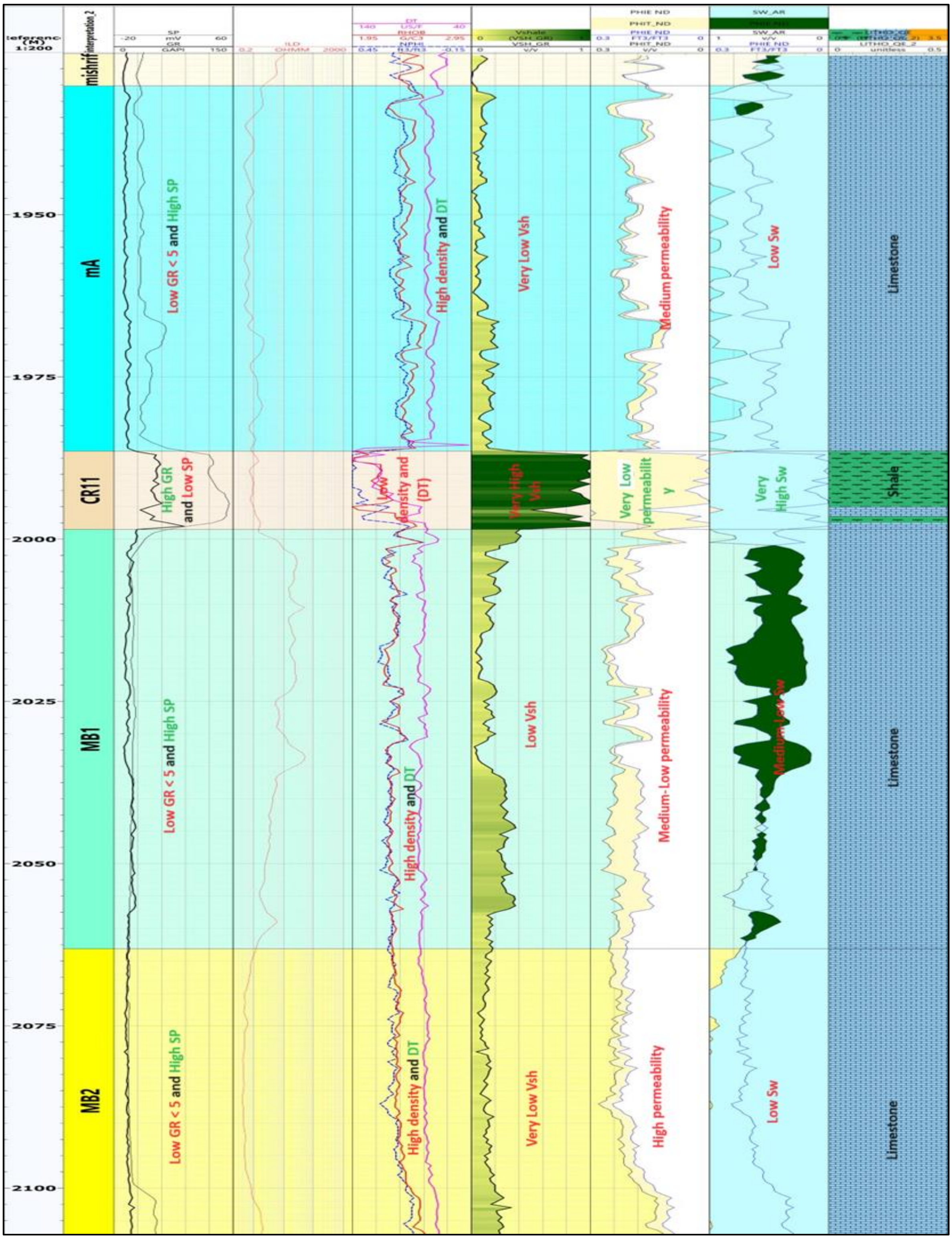

Fig. 6. Quantitative interpretation of the Mushrif Formation in the well (NS-5).

D. Permeability analysis

The plot shows the value of the permeability property of the studied wells in the formation units (Mushrif, CR11, mA, mB1, and mB2), which range from (very high, high, and very low), respectively, showing the rock changes of the formation units, where the unit (mB1) is the best range containing very high permeability “Fig. 7”.

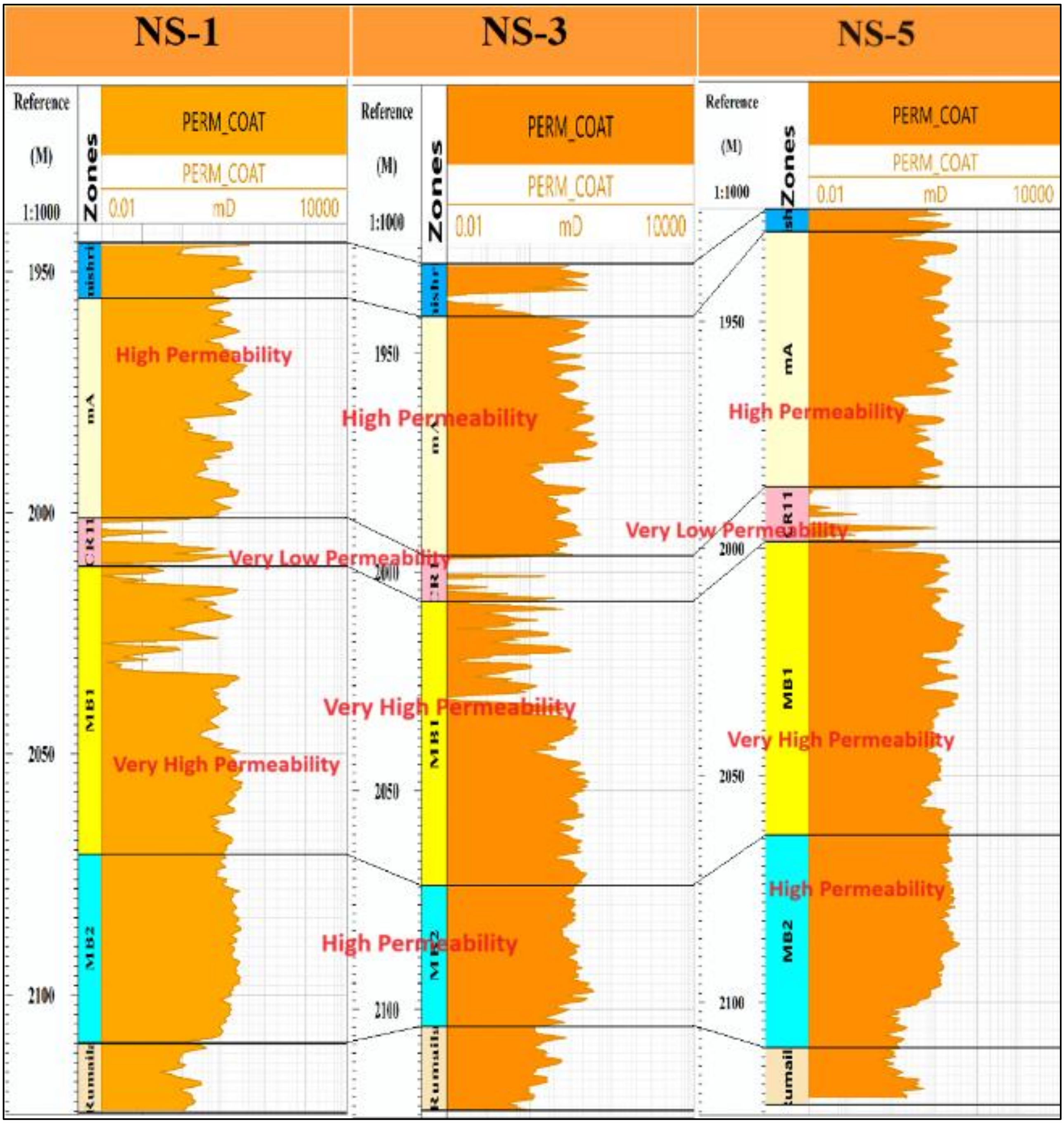

Fig. 7. Permeability curves for units (Mushrif) in the studied wells (NS-1,3,5).

E. Saturation analysis (water - hydrocarbons)

The saturation characteristic of the formation zone ranges from a very high hydrocarbon saturation and a very low water saturation in the mB2 range to the lowest hydrocarbon saturation and a very high value in the CRII range with an oscillating value of water and hydrocarbon saturation in two ranges (mA and mB2). “Fig. 8”.

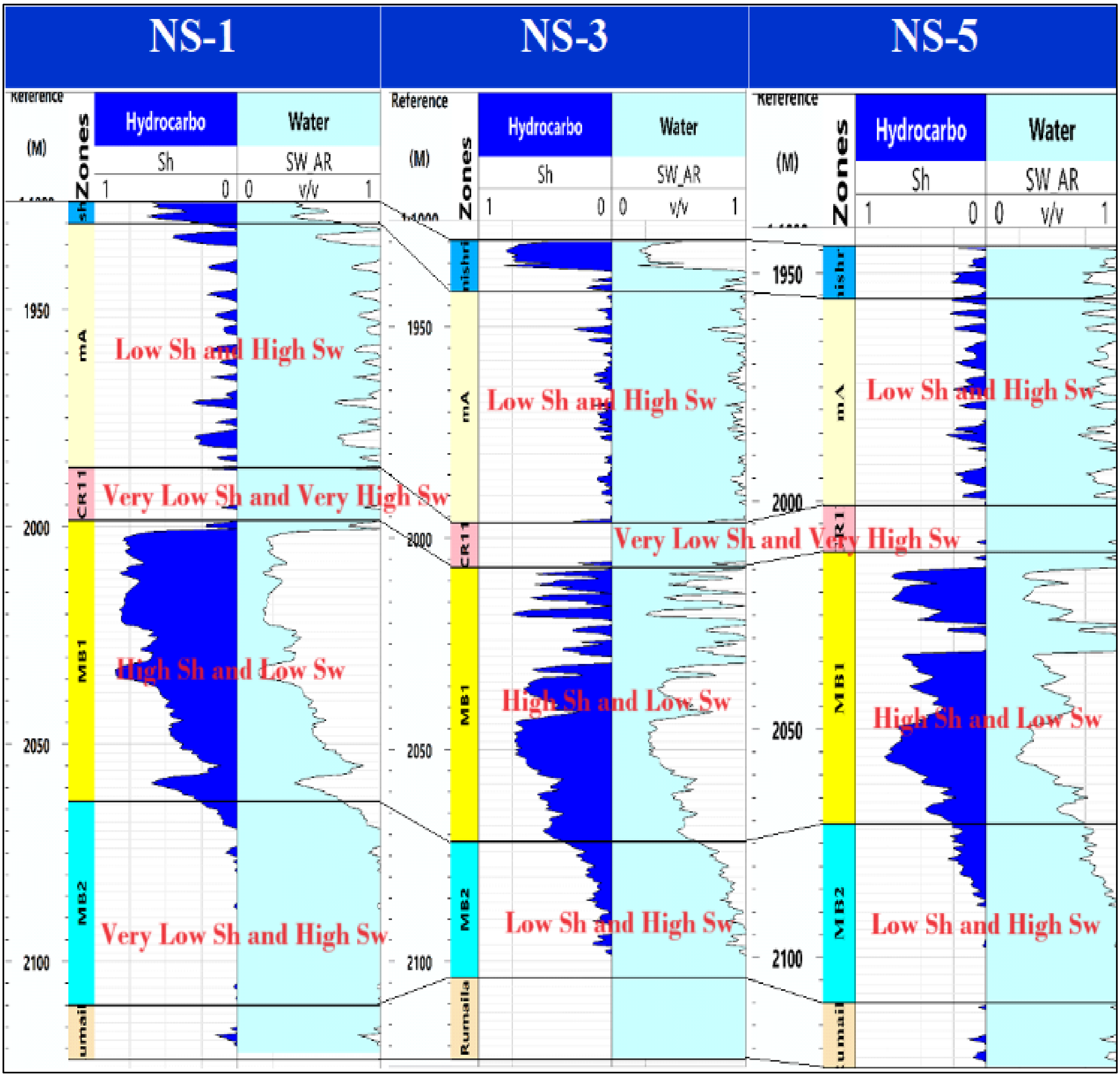

Fig. 8. Water and hydrocarbon saturation curves for units (Mushrif) in the studied wells (NS-1,3,5)

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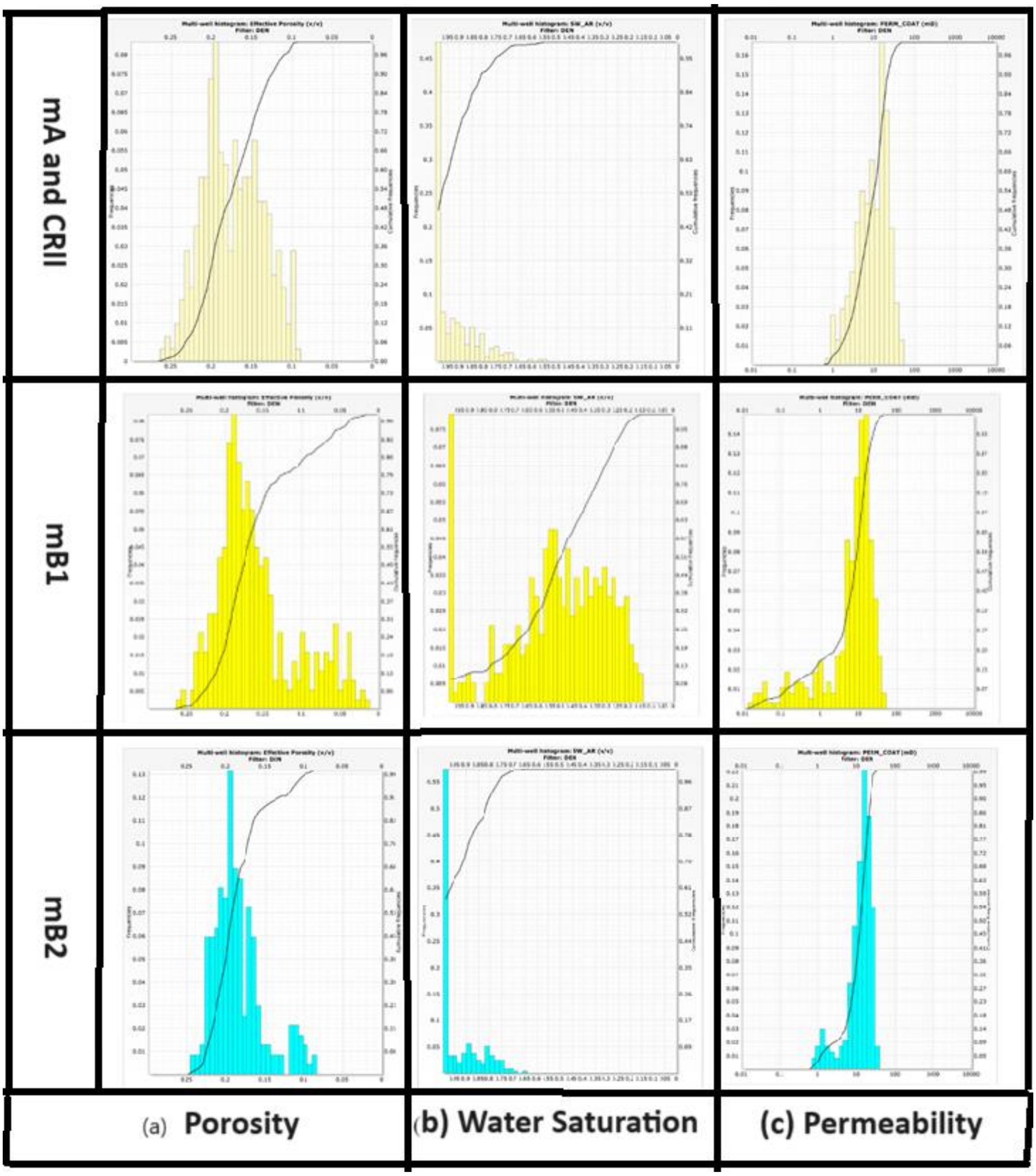

Fig. 9. Petro-physical cumulative curve of the unit (mA,mB, and CRll) for the studied wells.

VII. Qualitatively interpretation

To evaluate the petro-physical properties in two different ways, a statistical analysis of the study wells was carried out by plotting a histogram and identifying the lithology of relationships between the GR, NPHI, and RHOB logs for each well of the study wells to identify the best well in terms of shale content and porosity.

A. Descriptive – Statistics

Through the statistical histogram charts, the Mushrif Formation contains five petro-physically variable units, namely (Mushrif, CR11, mA, mB1, and mB2). Each unit has special characteristics that differ from the others. It was found that the value of the porosity, water saturation, and permeability of forming units is in "Fig. 9".

The Mushrif and CR11 units are low porosity and permeability units that form the cap rock, and the mA unit is characterized by high porosity and permeability, while the mB unit was divided into mB1, which has good porosity and permeability characteristics with high hydrocarbon saturation, and mB2, which is considered the best and largest unit of the reservoir and consists mainly of limestone with high porosity and good permeability, as shown in "Table. 1".

B. Neutron-Density cross plot for lithology identification

Neutron (NPHL- Log)-Density cross-plots help to determine the lithology of pure lithologies such as sandstone, limestone, or dolomite, which are oil- or water-filled formations. If the formation is heterogeneous, such as dolomitic cemented sandstone, then the density-neutron cross-plot analysis can be misleading. Neutron-density multi-crossing plots for many wells, showing the best match for the set of points “Fig. 10,11,12”. most of which lie on the limestone curve in units of formation in wells (NS-1, NS-3, and NS-5), which are the main components of the lithology of the Mushrif Formation. A few points are distributed on the dolomite and sandstone curves in the Nasiriyah oilfield.

Table. 1. A statistical summary of the units of Mushrif Formation in the studied wells.

Unit	property	No. of points	Min. value	Max. value	Average	St.dv.	C.V
mA	PHIE (v/v)	312	0.092	0.259	0.030	0.036	0.001
	Sw_AR (v/v)	312	0.549	1	0.072	0.090	0.008
	K (md)	312	0.745	46.798	7.287	9.054	81.987
MB1	PHIE (v/v)	379	0.017	0.259	0.040	0.052	0.002
	Sw_AR (v/v)	379	0.147	1	0.180	0.225	0.050
	K (md)	379	0.0008	46.798	6.683	8.643	74.713
MB2	PHIE (v/v)	235	0.089	0.245	0.024	0.032	0.001
	Sw_AR (v/v)	235	0.652	1	0.074	0.087	0.007
	K (md)	235	0.652	37.471	6.061	7.569	57.299

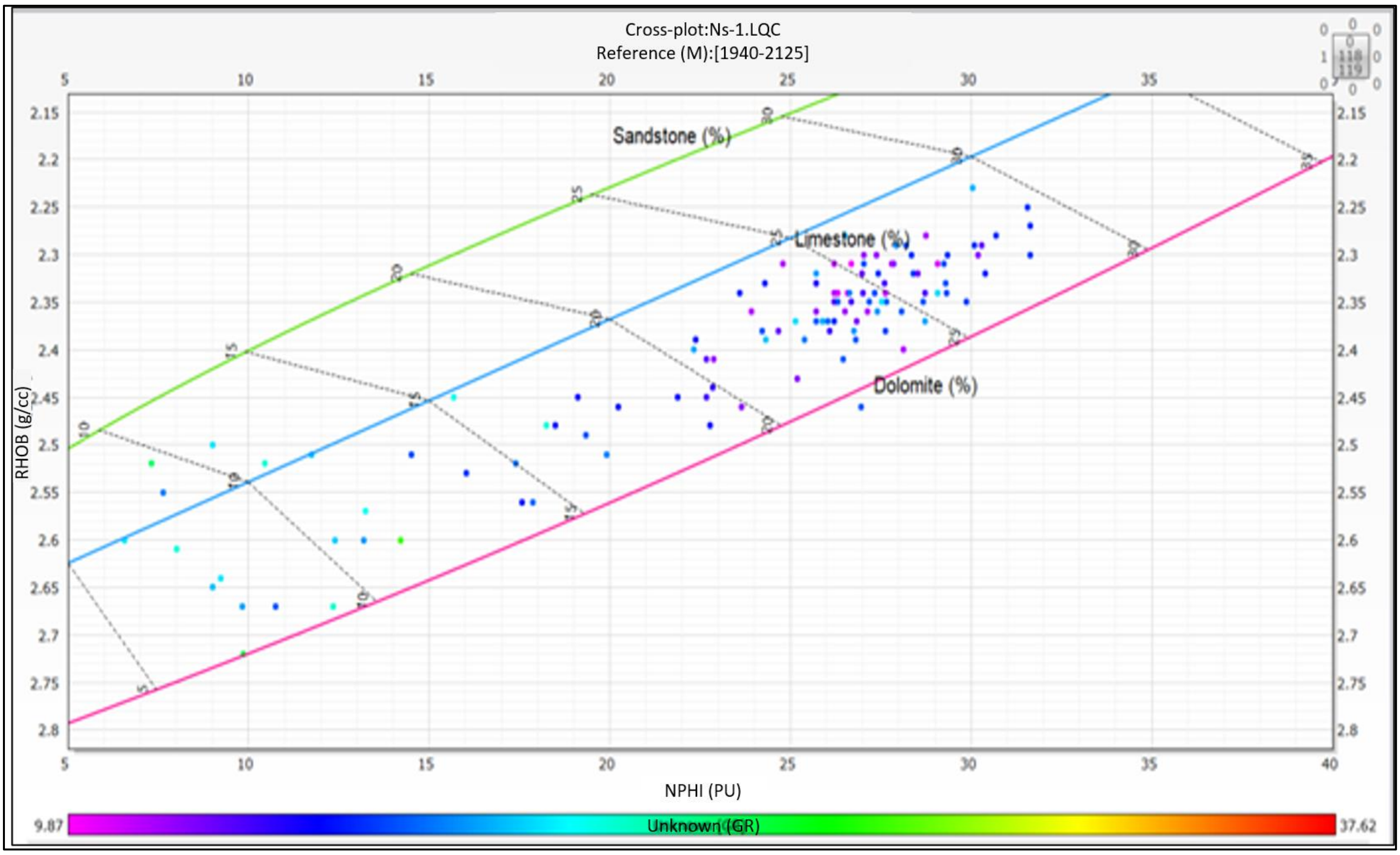

Fig. 10. Cross plot of Neutron porosity and Density porosity for the well NS-1

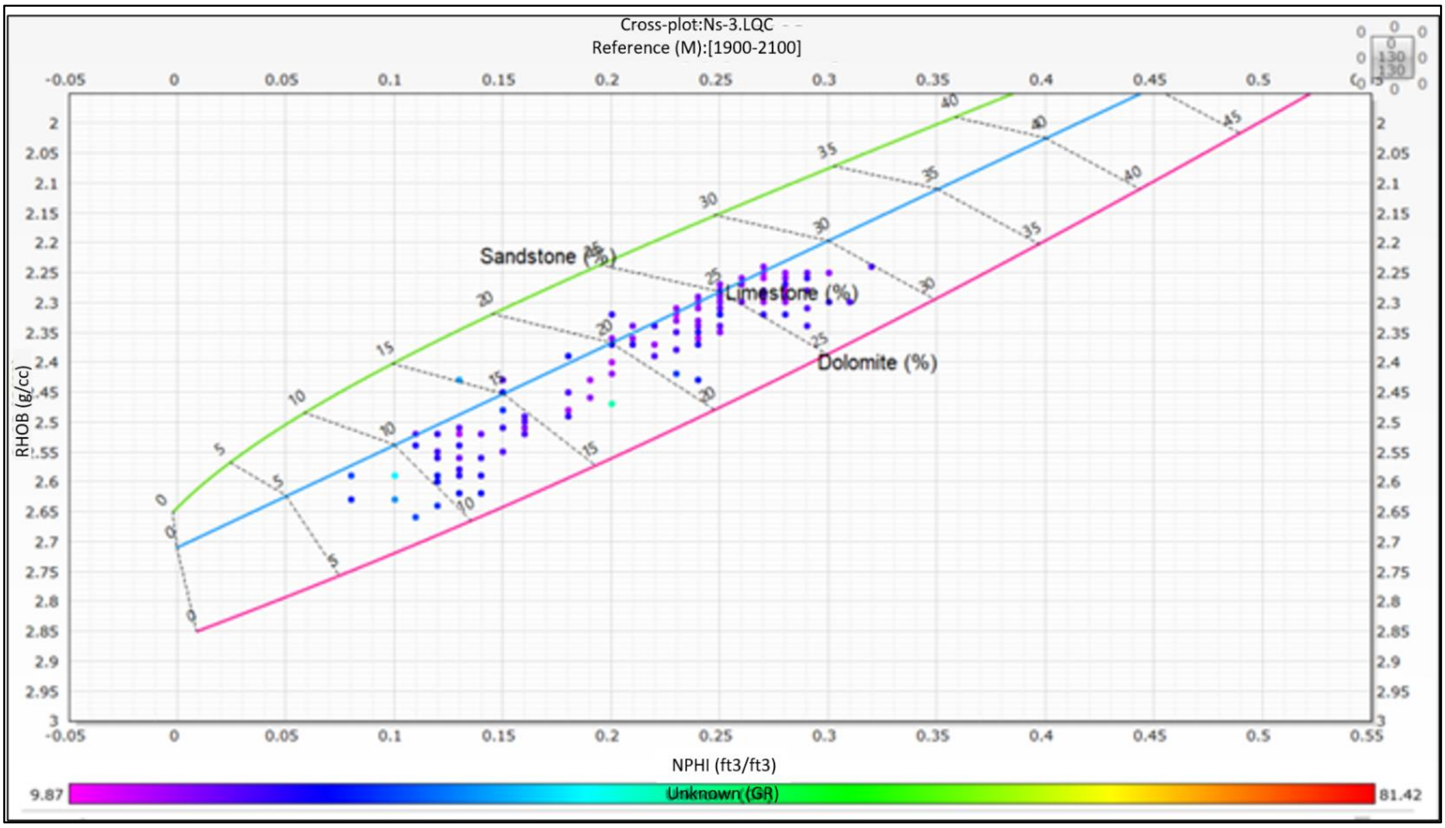

Fig. 11. Cross plot of Neutron porosity and Density porosity for the well NS-3

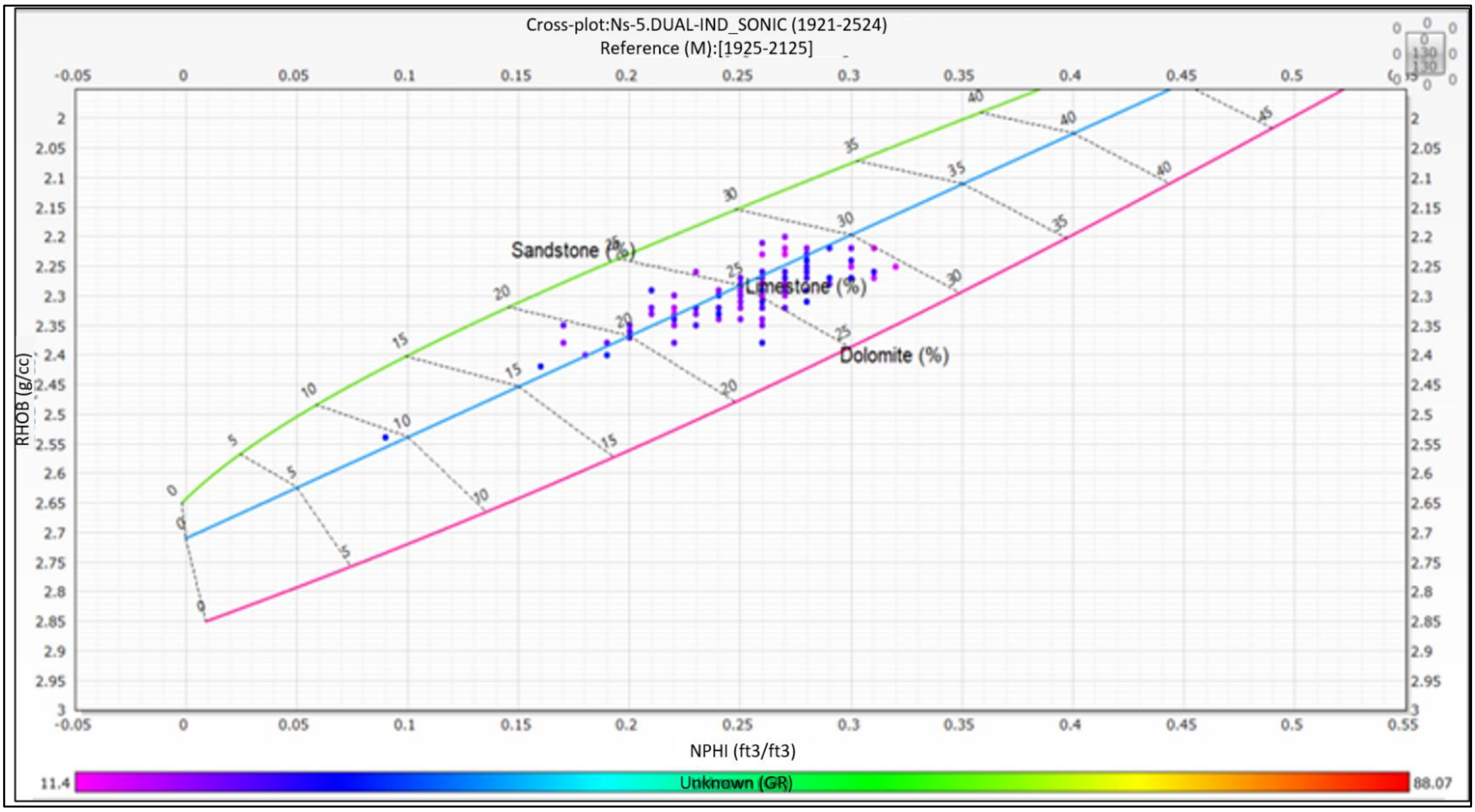

Fig. 12. Cross plot of Neutron porosity and Density porosity for the well NS-5.

VIII. CONCLUSION

After conducting the study and analyzing the data from the NS-1, NS-3, and NS-5 oil wells and studying the results of the quantitative and qualitative evaluation, and based on the differences in petro-physical properties, Mushrif formation in the Nasiriyah Oilfield was divided into four units (mA, CRII, mB1, and mB2).

From analyze the direct and indirect results of the wells, it was found that unit (CR11) represents the main barrier (Cape Rock) in the formation with very low porosity and permeability with a high GR value, and from this, it is composed of shale rocks with a high percentage and very low hydrocarbon content.

Units mA and mB2 have relatively high effective porosity, good permeability, very high water content with low hydrocarbon content, low GR value, and high Vsh and Sp values. They are composed of limestone rocks of a very high value. Units (mB1, mB2) are the main oil-bearing units in the Mushrif formation and are characterized by the presence of hydrocarbons due to their relatively high effective porosity, good permeability, very low water content with very high hydrocarbon content, very low GR value and very high Vsh and Sp values. It is composed of limestone rocks of very high value.

It is worth noting that the mean statistical values of porosity (0.040), water saturation (0.180), and permeability (6.683 mDa) in Unit mB1 of the Mushrif Formation have a high quality of reservoir properties.

Neutron-density multi-crossing plots for many wells, most of which lie on the limestone curve in units of formation in wells (NS-1, NS-3, and NS-5), which are the main components of the lithology of the Mushrif Formation. A few points are distributed on the dolomite and sandstone curves in the Nasiriyah oilfield.

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CONFLICT OF INTEREST

Authors declare that they have no conflict of interest.

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