Formation evaluation for Mishrif Formation in Selected Wells from Noor Oilfield

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Abstract
This study aims at making formation evaluation for Mishrif Formation in three wells within Noor Oilfield which are: No-1, No-2 and No-5. The study includes calculations of shale volume and porosity, water saturation using Archie method, measuring the bulk volume of water (BVW) and using Buckle plot, as well as measuring the movable and residual hydrocarbons. These calculations were carried out using Interactive Petrophysics (IP) version 3.5 software as well as using Petrel 2009 software for structural map construction and correlation purposes. It was found that the Mishrif Formation in Noor Oilfield is not at irreducible water saturation, though it is of good reservoir characteristics and hydrocarbon production especially at the upper part of the formation.

Keywords: Porosity, water saturation, movable hydrocarbon, residual hydrocarbon.

تقييم تكوين المشرف في آبار مختارة من حقل نور النفطي

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الخلاصة:
يهدف البحث الى اجراء عملية تقييم لتكوين المشرف في حقل نور النفطي. تتضمن الدراسة ثلاثة آبار هي: No-1، No-2 و No-5. تشتمل هذه الدراسة على حساب كل من حجم السجيل و المسامية، التشبع المائي باستخدام طريقة آرجي (Archie method) وحساب حجم الماء الكلي (BVW) في التكوين والاستعانة بمخطط Buckle، بالاضافة الى حساب كمية الهيدروكاربونات القابلة وغير القابلة للحركة.
هذه الحسابات تمت باستخدام برنامج (Interactive Petrophysics (IP) version 3.5) بالاضافة الى الاستعانة ببرنامج (Petrel 2009) لغرض انشاء الخارطة التركيبية للحقل ولعمل المظاهاة بين الابار. وتم التوصل الى ان تكوين المشرف في حقل نور ذو انتاجية جيدة للهايدروكاربونات وخصوصاً في أعلى التكوين.

1. Introduction

The concept of formation evaluation is very important to estimate the amount of the fluids in the formation as well as the type of these fluids and whether there is an economical benefit in drilling wells down to this formation or not.

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Mishrif Formation is considered one of the main productive reservoirs in southern Iraq. It reflects a continuous deposition on a shallow carbonate platform developed during the Upper Cenomanian-Early Turonian period [1]. The Mishrif Formation represents a heterogeneous formation originally described as organic detrital limestones, with beds of algal, rudist, and coral-reef limestones, capped by limonitic fresh water limestones ([2] in [3]).

As the Noor oil field is one of the fields that have been recently developed and because there is not enough studies regarding Mishrif Formation within this oil field, this study aims to evaluate Mishrif Formation in three selected wells, No-1, 2 and 5, within Noor oil field, so that it could be an addition to the other previous studies concerning this formation.

Mishrif Formation in Noor oilfield is divided into sixteen zones according to the subdivisions made by the Ministry of oil, eight of which are reservoir zones. From top of the formation these eight zones are: MA, MB11, MB12, MB21, MB22, MC1, MC2 and MC3. These reservoir zones are separated from each other by barriers, which are of less or no porosity.

In order to evaluate Mishrif Formation, volume of shale (Vsh) and different types of porosities (Total porosity, effective porosity & primary and secondary porosity) must be calculated. Eventually, these will be utilized in the calculations of water saturation (Sw) of the formation which helps in finding out where the good and poor reservoir characteristics occur within the formation.

2. Study Area

Noor Oilfield is located in the south east of Iraq, about 15 km north east of Amara city, Missan Governorate figure-1. The field is NW- SE trending anticline, and is about 18.9 km long and 5.9 Km wide. The thickness of Mishrif Formation in studied wells ranges between 380.2 m-385.9 m table-1. Eight boreholes have been drilled in Noor Oilfield and three of them have been studied (No.1, No.2 and No.5).

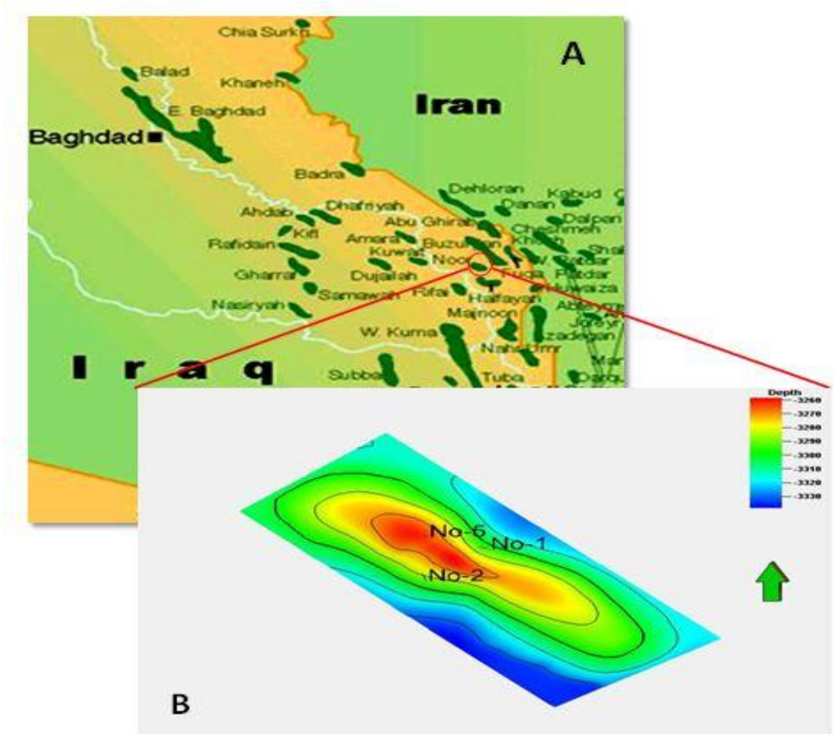

Figure 1- A: Location of study area. **B:** Structural contour map for Top of Mishrif in Noor oilfield showing the location of the studied wells (made using Petrel 2009).

Table 1- Mishrif Formation thickness in Noor studied wells.

Well Name	Top (m)	Bottom (m)	Thickness (m)
No-1	3308	3691.5	383.5
No-2	3299	3679.2	380.2
No-5	3282	3667.9	385.9

3. Shale volume determination (Vsh)

Calculation of gamma ray index is the first step needed to determine the volume of shale from a gamma ray log [4]:

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Where:

I_{GR} = gamma ray index.
GR_{log} = gamma ray reading of formation.
GR_{min} = minimum gamma ray (clean sand or carbonate).
GR_{max} = maximum gamma ray (shale).

As Mishrif Formation is considered an old rock, therefore, the volume of shale (V_{sh}) formula used in this study is the Larionov (1969) for old rocks [4]:

$$V_{sh} = 0.33 \times \left(2^{2.I_{GR}} - 1\right)$$

It was found that the volume of shale in Mishrif Formation is low figure-2.

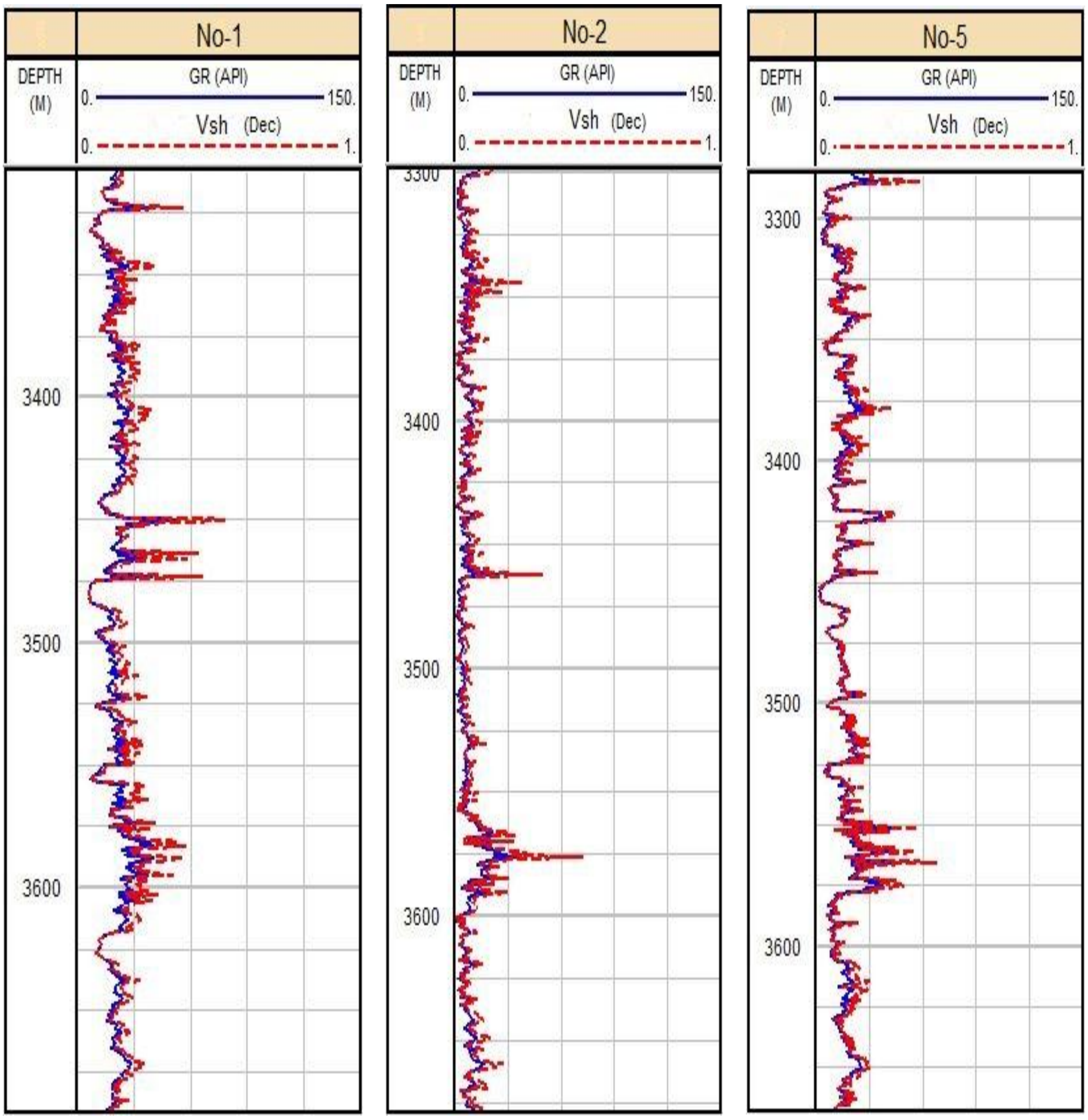

Figure 2- Gamma ray (GR) and volume of shale (Vsh) in the studied wells No-1, 2 &5.

4. Determination of Porosity

Porosity is the second parameter needed to be measured in order to evaluate Mishrif Formation Figure-3. The porosity that is calculated in this study is of three types:

A. Total Porosity

For the purpose of formation evaluation, the neutron log is used in combination with the density log for porosity and lithology determination [5]. The following formula is used for calculating the combination porosity [6]:

$$\phi_{N.D} = \sqrt{\frac{\phi_n^2 - \phi_d^2}{2}}$$

Where ϕ_n and ϕ_d are neutron and density porosities. It has been suggested that the square root equation is preferable as a means of suppressing the effect of any residual gas in the flushed zone.

This combination can be named the total porosity ϕ_t [4]. Total porosity is defined as the ratio of volume of all the pores to the bulk volume of a material, regardless of water or not all of the pores are connected [7].

B. Effective Porosity

Effective porosity is the total porosity less than pore space occupied by shale or clay [8]. The term “effective porosity” or “connected” pore space is commonly used to denote porosity that is most available for fluid flow [9]. It is also defined as the total porosity minus the clay- bound water and water held as porosity within the clays [10]. The V_{sh} can be used to calculate the effective porosity (ϕ_{eff}) of the formation:

$$\phi_{eff} = \phi_{total} * (1 - V_{sh})$$

C. Primary and secondary Porosity

Primary porosity is the amount of pore space presents in the sediment at the time of deposition, or formed during sedimentation. It is a function of the amount of space between rock-forming grains[11].

The development of vugs and fractures as found in carbonate reservoir rocks is termed Secondary Porosity and it is a function of the depositional history and diagensis of the rocks [7].

Primary porosity is that which is present within carbonate particles at the time of their formation, and between particles at the time of deposition. Secondary porosity may develop at any time in the history of the sediments or rocks, in the eogenetic to telogenetic environments [12].

In carbonates, secondary porosity is usually more important than primary porosity. The major sources of secondary porosity are fracturing, solution and chemical replacement [13].

When sonic porosities are compared with neutron and density porosities, the total porosity can be subdivided between "primary porosity" (interparticle porosity) recorded by the sonic log and "secondary porosity" (vugs and/or fractures) computed as the difference between the sonic porosity and the neutron and/or density porosity [6].

The secondary porosity index is the difference between the neutron-density porosity and the sonic porosity [14] as illustrated in the following formula:

$$SPI = (\phi_{n.d} - \phi_s)$$

Where:

SPI = Secondary porosity index. $\phi_{n.d}$ = density and neutron porosities combination.

ϕ_s = sonic - derived porosity.

In this study, secondary porosity of Mishrif formation is generally less than the primary porosity.

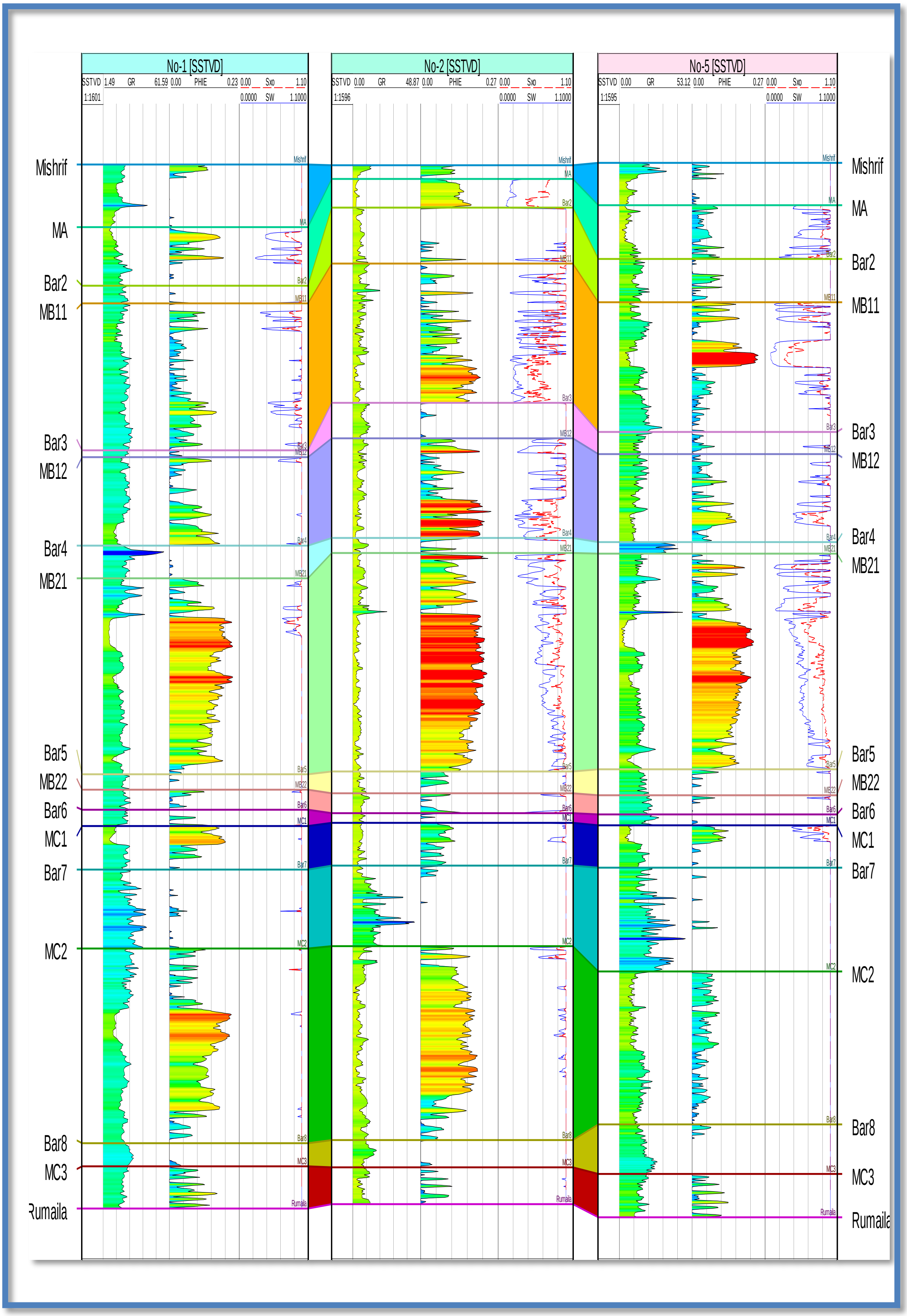

Figure 3- Correlation between the three studied wells within their main reservoir units, including their Gamma ray log (Gr), Porosity (PHIE) and their water saturation (Sw).

5. Water Saturation Determination (Archie's Method)

Water saturation is the percentage of pore volume in a rock which is occupied by formation water. Water saturation is measured in percent and has the symbol S_w [15]

$$\textbf{Water Saturation } (S_w) = \frac{\text{formation water occupying pores}}{\text{total pore space in the rock}}$$

Water saturation represents an important log interpretation concept because you can determine the hydrocarbon saturation of a reservoir by subtracting water saturation from the value one (where 1.0 = 100% water saturation) [15]. Water saturation is calculated from resistivity, induction, and porosity logs using the Archie equation [9].

Water Saturation for reservoir's uninvaded zone figure-4 is calculated by the Archie formula [15].

$$S_w = \left[\frac{a}{\emptyset^m} \times \frac{R_w}{R_t}\right]^{1/n}$$

Where:
Sw: water saturation of the uninvaded zone (Archie method).
Rw: resistivity of formation water at formation temperature.
R_t: true resistivity of formation.
Ø: Porosity.
a: tortuosity factor.
m: cementation exponent.
n: saturation exponent which varies from 1.8 to 2.5 but is normally equal to 2.0.

Water saturation of formations flushed zone (S_{xo}) figure-4 is also based on Archie equation, but two variables are changed [15].

$$S_{xo} = \left[\frac{a}{\emptyset^m} \times \frac{R_{mf}}{R_{xo}}\right]^{1/n}$$

Where:
S_{xo}: water saturation of the flushed zone.
R_{mf}: resistivity of the mud filtrate at formation temperature.
R_{xo}: Sallow resistivity.
Ø: Porosity.
a: tortuosity factor.
m: cementation exponent.
n: saturation exponent which varies from 1.8 to 2.5 but is normally equal to 2.0.

The water saturation of uninvaded zone (Sw) and water saturation of the invaded zone (Sxo) are calculated by using previously mentioned parameters figure-3.

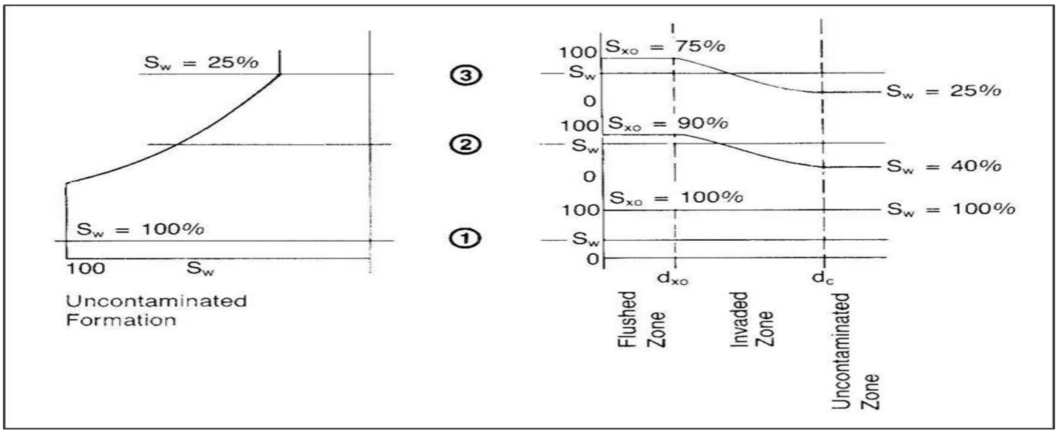

Figure 4-Variations of water saturation with distance from the borehole [11].

6. Bulk Volume of Water (BVW)

The product of a formation's water saturation (Sw) and its porosity (φ) is the bulk volume of water (*BVW*) [4].

$$\boldsymbol{BVW = S_w \times \emptyset}$$

On other hand the bulk volume of water can be computed in the flushed zone using the following formula [16 in 17].

$$\boldsymbol{BVXO = S_{xo} \times \emptyset}$$

Where:
BVW: bulk volume of water of uninvaded zone
BVXO: bulk volume of water of flushed zone
Sw: water saturation of uninvaded zone
Sxo: water saturation in the flushed zone
Ø: porosity

If values for bulk volume water, calculated at several depths in a formation, are constant or very close to constant, they indicate that the zone is homogenous and at irreducible water saturation. Water calculated in the uninvaded zone (S_w) will not move because it is held on grains by capillary pressure. Therefore, hydrocarbon production from a zone at irreducible water saturation should be water-free. A formation not at irreducible water saturation (S_{wirr}) exhibits wide variations in bulk volume water values [18 in 4].

Because production of water in a well can affect a prospect's economics, it is important to know the bulk volume water and whether the formation is at irreducible water saturation (S_{wirr}) [4]. The best method to be use is Buckle plot. The Buckles plot is a graph of porosity (φ) versus *(Sw*). Points of equal *BVW* form hyperbolic curves across this plot. If *BVW* is plotted using data from a formation at irreducible water saturation, the points fall along a single hyperbolic curve figure-5-a. If the data come from reservoirs with higher percentages of produced water, the points are more scattered figures-5-b and figure-5-c) [4].

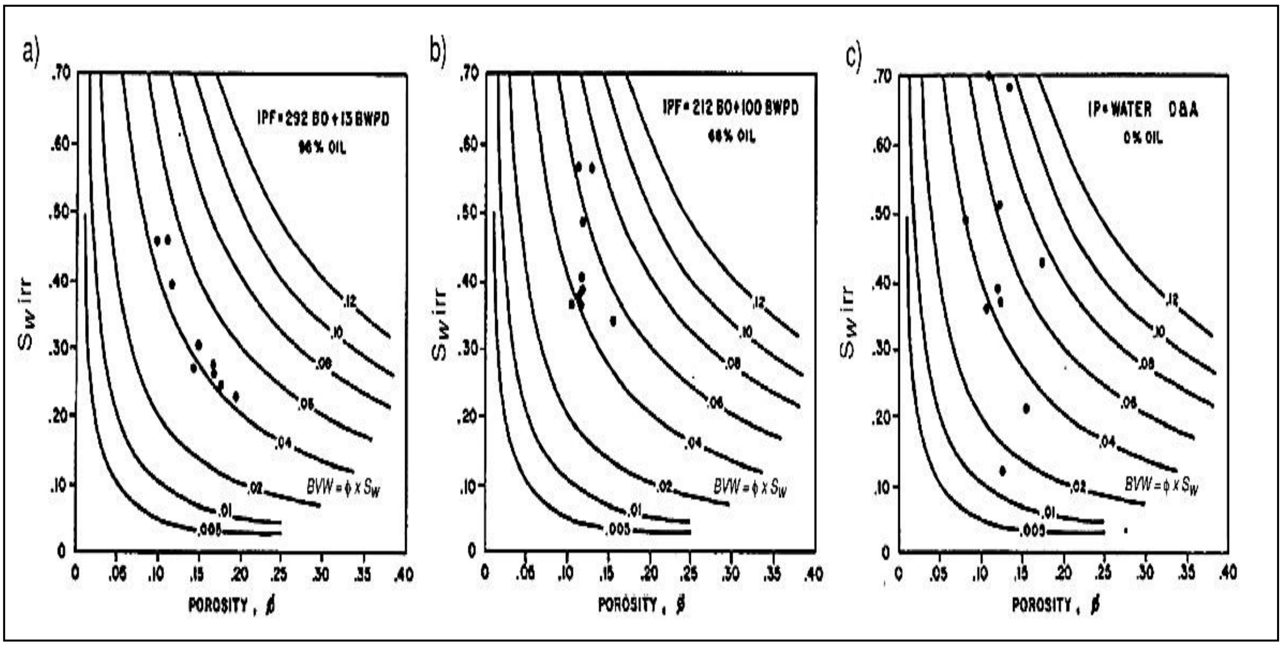

Figure 5-Buckle's plots (porosity vs. water saturation) [2].

Figure-6 to figure-8 illustrate the Buckle plots for Mishrif Formation in wells No-1, 2 & 5 respectively. Regarding the well No-1, it is clear that the points are scattered among many hyperbolic curves. This proves that the formation is not at irreducible water saturation. The points are also distributed to the right side of the two figures and they refer to rather higher porosities and high water saturation values, which prove that the well is of weak oil production and more water is produced. As concerns the Wells No-2 and No-5, the formation is also not at irreducible water saturation; though most of the points are nearly close to the right side of the figure. Many of these points record porosity and water saturation values that make the formation in this well of high oil production.

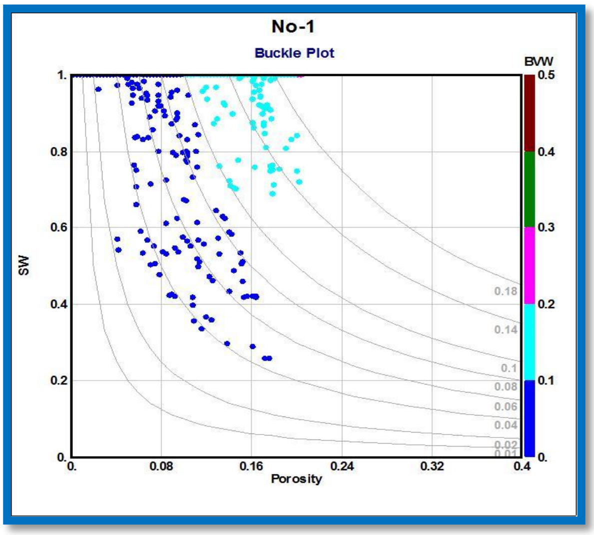

Figure 6- Buckles plots for well No-1.

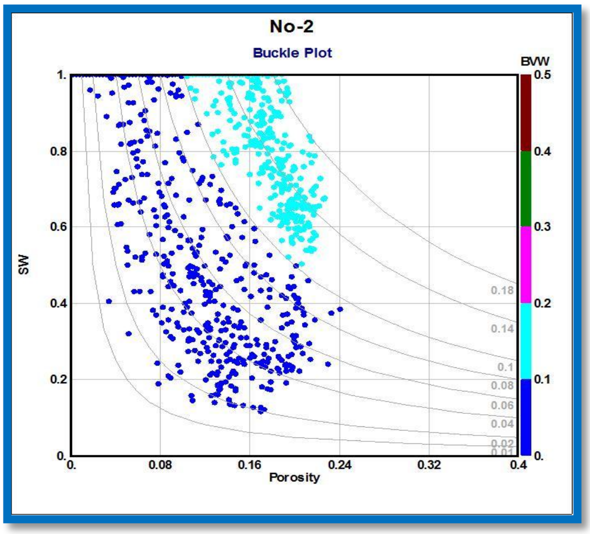

Figure 7- Buckles plots for well No-2.

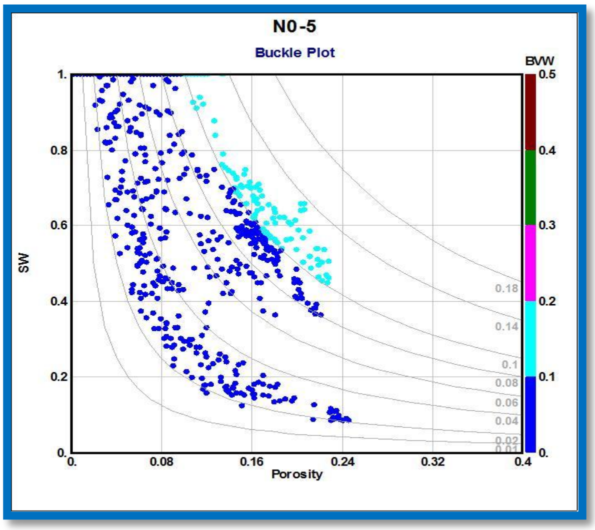

Figure 8- Buckles plots for well No-5

7. Movable and Residual Hydrocarbons

The residual oil saturation corresponds to oil that cannot be moved without resorting to special recovery techniques [19]. The residual hydrocarbon saturation is equal to [20]:

$$S_{hr} = 1 - S_{xo}$$

Where:
S_{hr}: The residual hydrocarbon saturation, fraction.
S_{xo}: water saturation in the flushed zone.
The equation gives the saturation of unmoved or residual hydrocarbons in the invaded zone [20].

Comparison of S_w and S_{xo} in a hydrocarbon zone is considered to give movable hydrocarbons. It is equal to the fraction of movable hydrocarbons in the formation [20].

$$S_{hm} = S_{xo} - S_w$$

Where:

S_{hm}: movable hydrocarbon saturation, fraction.

The percentage volume in terms of the reservoir is given by multiplying the term by the porosity, Ø, i.e. % volume of reservoir with movable hydrocarbons = (S_{xo} – S_w) × Ø [20].

The bulk volume of water as well as the movable and residual hydrocarbon has also measured using IP. Since the water saturation values measured from IP were depended, these were also dependent on the results obtained from it.

In the figure-9 to figure-11 which represent Computer Processed Interpretation (CPI), the porosity track is divided into effective porosity ($Ø_e$), water filled porosity in the invaded zone (BVWSXO), and water filled porosity in the uninvaded zone (BVW); and depict the following:

-The area between (Effective porosity) and (BVWSXO) represents the residual hydrocarbon.

-The area between (BVWSXO) and (BVW) represents the movable hydrocarbon.

-The area between (Effective porosity) and (BVW) represents total hydrocarbon.

8. Evaluation of Mishrif reservoir Zones

In order to evaluate reservoir characteristics of Mishrif Formation, the bulk volume of water and hydrocarbon (both movable and residual) will be discussed with changes in thickness, gamma ray values and porosity (effective porosity) for each reservoir zone in all wells. The porosity track in figure-9 to figure-11 illustrates this evaluation.

MA Reservoir Zone

This is the uppermost reservoir zone of Mishrif Formation in Noor oil field. It is considered one of the productive reservoir zones within Noor oil field. Its average thickness is about 15.18 meters. This zone in well No-1 is characterized by good effective porosity and contains good amount movable hydrocarbon. Nevertheless, the zone in this well contains considerable amount of water with the presence of some residual hydrocarbon. In No-2 the zone shows good reservoir characteristics of relatively high porosity and significant amount of movable hydrocarbon with low water saturation; but it also occupies considerable amount of residual hydrocarbons. In No-5, MA zone has relatively low effective porosity and almost is filled with water and the hydrocarbon appears to be very small or negligible.

MB11 Reservoir Zone

This zone is one of the large and main productive reservoir zones of Mishrif Formation in Noor field. The average thickness of this zone is about 52.41 m. It is characterized by very low gamma ray values. The zone in wells No-1 shows weak oil production. The porosity of this reservoir zone in this well is mostly occupied by water. In well No-2, the thick MB11 reservoir zone is characterized by high effective porosity especially within its lower part. The bulk volume of hydrocarbon (both movable and residual) occupies the largest fraction rather than water. The zone shows good movable hydrocarbon. In well No-5, the MB11 is characterized generally by high porosity in its upper and middle parts though the lower part porosity declines and filled with water.

MB12 Reservoir Zone

The average thickness of this zone is about 32.23 m. It is represented by low values of gamma ray and high porosity. MB12 in well No-1 is of high effective porosity but it is water productive because the pores are filled by water. In well No-2 is a good oil productive zone. It is characterized by high effective porosity and despite the presence of considerable volume of water and residual hydrocarbon; there is a good volume of movable hydrocarbon. In well No- 5 the porosity is mostly occupied by water and there is only small fraction of movable hydrocarbon.

MB21 Reservoir Zone

This zone is the thickest reservoir zone. It records an average thickness of 77.78 m. It is characterized by low gamma ray. MB21 in No-1 is highly porous but the water occupies almost all the pores. In wells No-2 and No-5 they represent high porous zones. Large fraction of the porosity is filled with water. Also there is notable presence of irreducible hydrocarbon.

MB22 Reservoir Zone

As all reservoir zones of Mishrif Formation, this zone records low gamma ray; and unlike the MB21 reservoir zone, it is the thinnest reservoir unit in all wells. MB22 reservoir zone is characterized by no or weak reservoir characteristics. The zone has low porosity and only contains water in wells No-1, 2. In wells No-5, MB22 zone is of negligible porosity.

MC1 Reservoir Zone

The average thickness of this zone is approximately 16 meters. The low gamma ray and good porosity values characterize this zone. The zone in general contains only water except in well No-5 in which there are small fraction of movable hydrocarbon.

MC2 and MC3 Reservoir Zones

These two zones are characterized by low gamma ray and good porosity. The average thickness of MC2 zone is 63.93 meters while MC3 reservoir zone is about 17.4 meters thick. These two porous zones in all the three studied wells contain only water.

From previous discussion, it can be seen that in general the Mishrif Formation shows good reservoir characteristics at the upper parts of the formation. There are good amounts of hydrocarbons, although some of these hydrocarbons are residual but the amount of movable hydrocarbons are good especially in wells No-2 and No-5.

It is also obvious that Mishrif Formation has only water productions in its lower part where the reservoir characteristics becomes bad and the hydrocarbon production is weak ore absent.

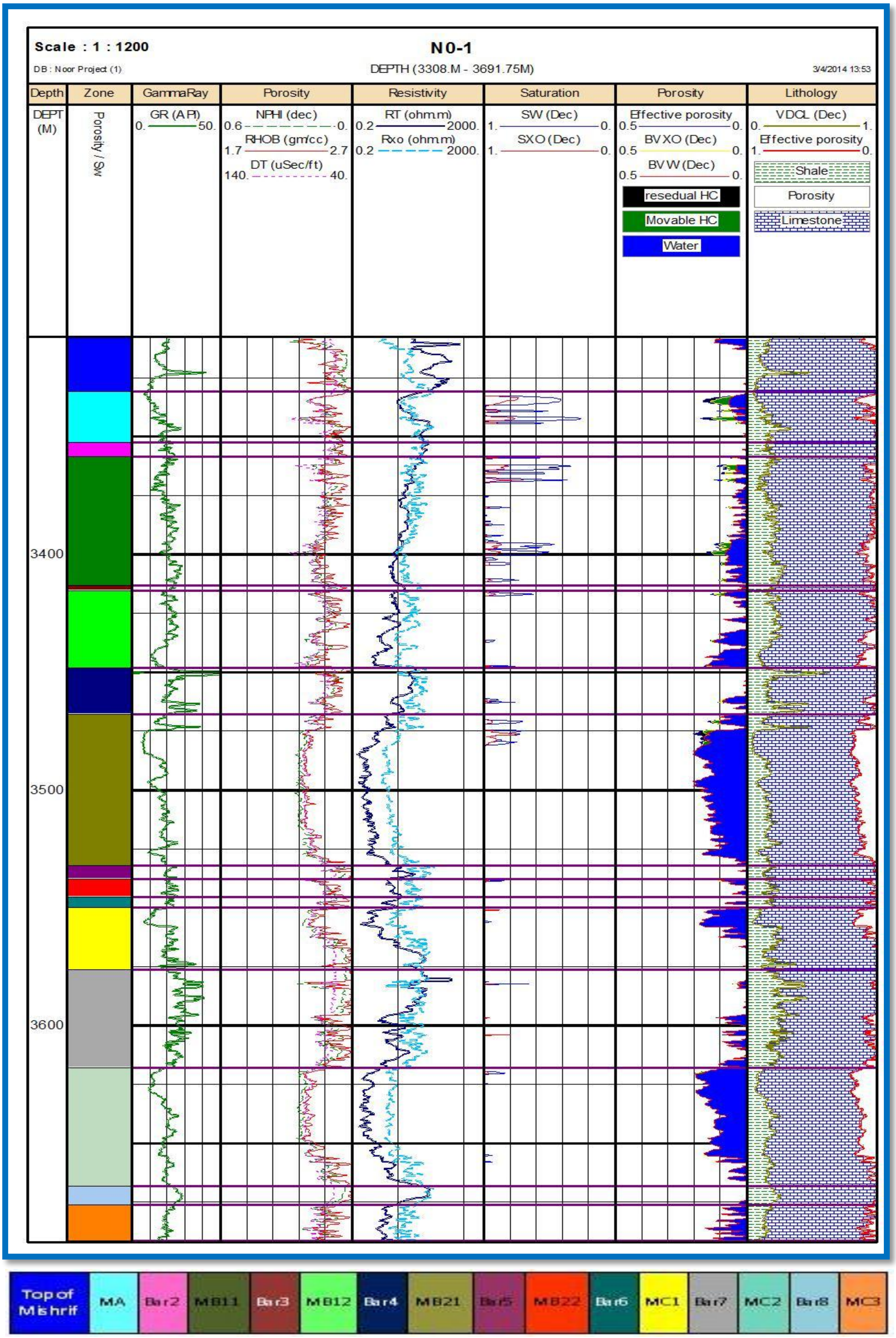

Figure 9- Computer Processed Interpretation (CPI) of well No-1.

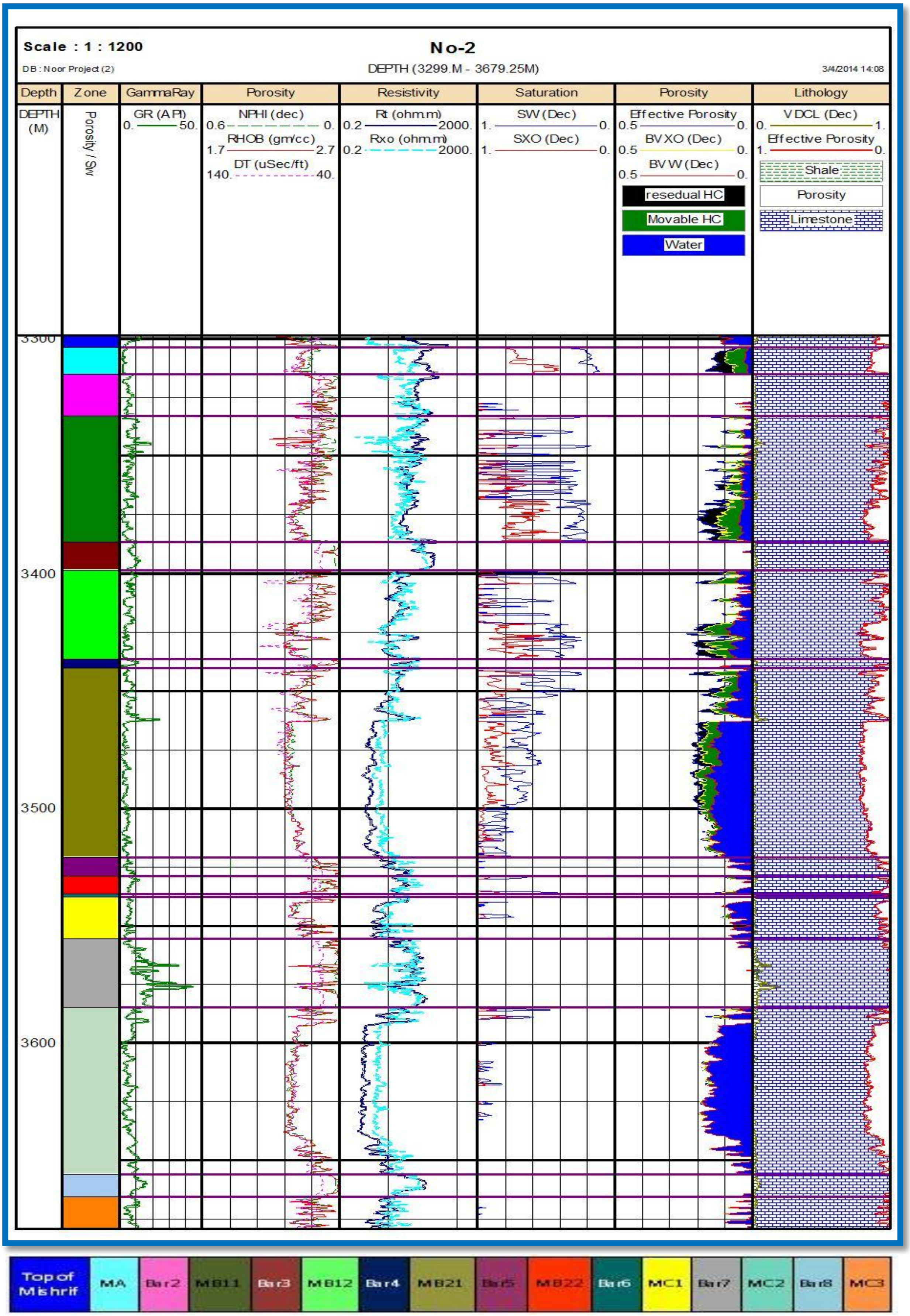

Figure 10- Computer Processed Interpretation (CPI) of well No-2.

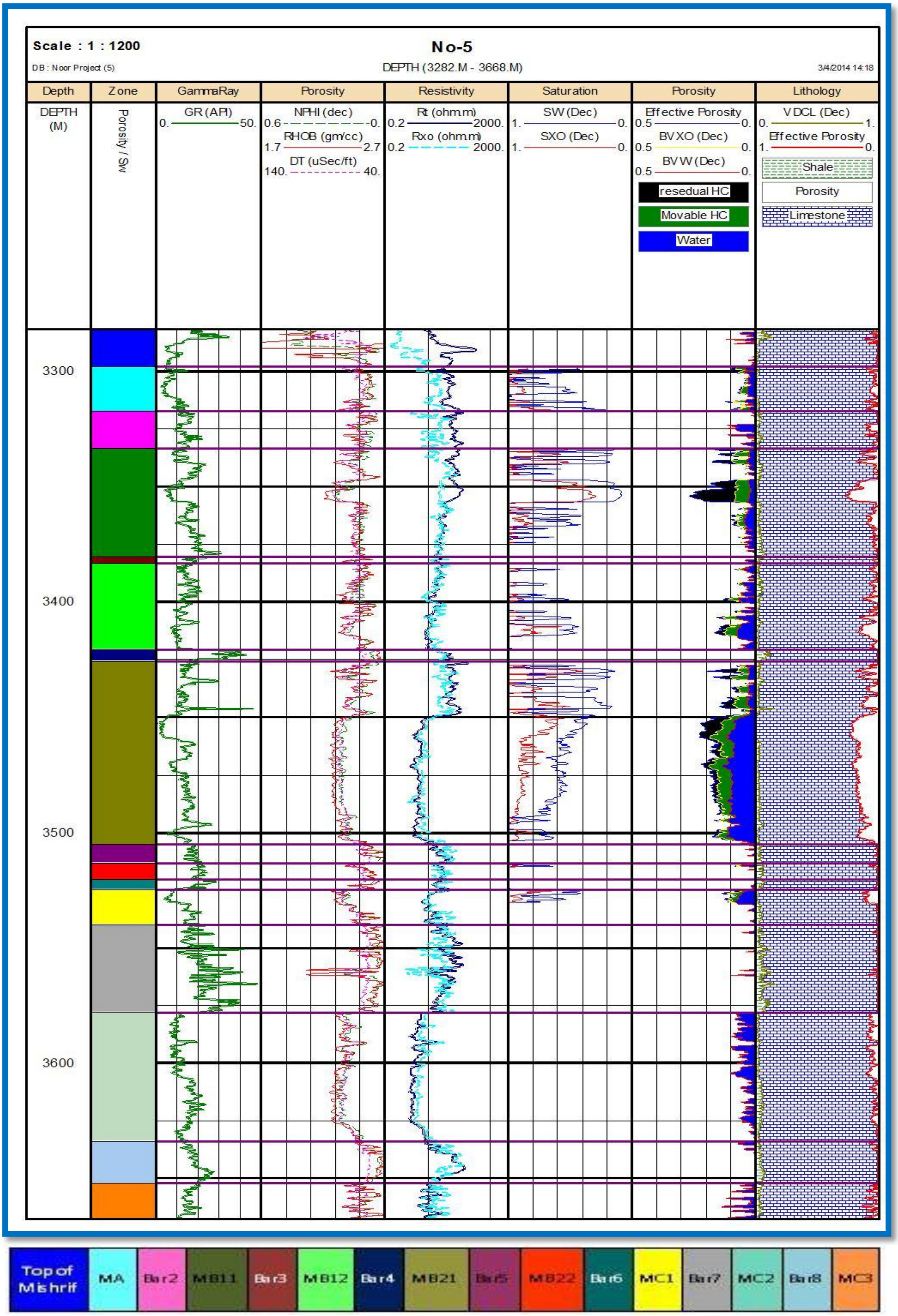

Figure 11- Computer Processed Interpretation (CPI) of well No-5.

9. Conclusion

The formation evaluation shows that the Mishrif Formation has good reservoir characteristics. It effectively reveals the percentage and the type of porosity, the value of water saturation of the formation (both in invaded and uninvaded zones) as well as the amount bulk volume of the water in the formation and the amount and the distribution of movable and residual hydrocarbons as well. Buckle Plot that has been used in this analysis, shows that Mishrif Formation is not at irreducible water saturation and that although there is a considerable amount of oil production, water is also relatively produced. Therefore Mishrif Formation in Noor oilfield has good reservoir characteristics and hydrocarbon production especially at its upper part, in reservoir zones MA, MB11 and MB12, and these characteristics become weak and hydrocarbons production decreases gradually towards its lower part of the formation.

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