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Petrophysical Evaluation of Mauddud Formation in Selected Wells from Ratawi Oil Field, Southern Iraq

Humam Q. Hameed*, Afrah H. Saleh
Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

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Abstract
The objective of this paper is determining the petrophysical properties of the Mauddud Formation (Albian-Early Turonian) in Ratawi Oil Field depending on the well logs data by using interactive petrophysical software IP (V4.5). We evaluated parameters of available logs that control the reservoir properties of the formation, including shale volume, effective porosity, and water saturation. Mauddud Formation is divided into five units, which are distinguished by various reservoir characteristics. These units are A, B, C, D, and E. Through analyzing results of the computer processed interpretation (CPI) of available wells, we observed that the main reservoir units are B and D, being distinguished by elevated values of effective porosity (10%-32%) and oil saturation (95%-30%) with low shale content (6%-30%). Whereas, units A, C, and E were characterized by low or non-reservoir properties, due to high water saturation and low values of effective porosity caused by increased volume shale.

Keywords: Ratawi Oil Field, Mauddud Formation, Petrophysical Properties, CPI.

تقييم تكوين مودود في ابار مختارة لحقل ارطاوي النفطي جنوب العراق

همام قصي حميد*، افراح حسن صالح
قسم علم الارض، كلية العلوم، جامعة بغداد، بغداد،العراق.

الخلاصة
الهدف من هذا الA, هو تحديد الخصائص البتروفيزيائية لتكوين مودود (Albian–Early Turonian) في حقل ارطاوي النفطي اعتمادًا على بيانات سجلات الآبار باستخدام برنامج بتروفيزيائي تفاعلي IP(V4–5) لتقييم معلمات السجلات المتاحة التي تتحكم بطبيعة الصفات المكمنية للتكوين مثل (حجم السجيل ، المسامية الفعالة ، وتشبع الماء). تم تقسيم التكوين الى خمس وحدات تميزت بخصائص مكمنية مختلفة. هذه الوحدات هي A , B , C , D و E. من خلال تحليل نتائج التفسير المعالّج بالحاسوب (CPI) للآبار المتوافرة ، لوحظ أن الوحدات المكمنية الرئيسة ضمن التكوين هي (B و D) لأنها تتميزبارتفاع المسامية الفعالة (10٪–32٪) والتشبع النفطي (95٪–30٪) مع انخفاض في محتوى السجيل (6٪–30٪). في حين أن وحدات A , C و E تميزت بأنخفاض او أنعدام الخصائص المكمنية نتيجة ارتفاع قيم التشبع المائي وانخفاض قيم المسامية الفعالة الناتجة عن المحتوى السجيلي العالي.

Introduction
The Mauddud Formation is considered as the most spread among the Lower Cretaceous formations in Iraq [1]. According to Owen and Nasr (1958), this formation consists of organic

*Email: humamqu835@gmail.com

limestone broken by occasional shale layers "green or bluish" [2]. This formation in Ratawi Oil Field belong to the southern provinces that represent a major oil-producing reservoir, due to good reservoir characteristics of reservoir rocks [3].

The target of this study is to interpret data collected from the available 4 well logs penetrating Mauddud formation in Ratawi oil field (Rt-19, Rt-24, Rt-25, and Rt-26) and identify the units with good reservoir characteristics from those with non-reservoir properties. Well log interpretation or petrophysical evaluation involves a series of calculations that are applied to evaluate several reservoir properties, such as porosity, water saturation, and volume shale, and control the reservoir quality. Various logs can be used to determine porosity and water saturation and to calculate reservoir compartmentalization [4].

Study Area

Ratawi Field situated within outer plat form within Arabian plate, in Mesopotamian zone at Zubair subzone (southern Iraq) [5], about 70 km northwest of the Basrah city and about 12 kilometers west of North Rumaila [6]. The geographic coordinates of its wells are listed in Table- 1. Ratawi field was recognized for the first time via the gravitational surveys in the beginning of 1940 and later surveyed during 1947 -1948 via utilizing seismic surveying approach by Basra Oil Company (Figure-1).

Table 1- The UTM coordinates of the studied wells in Ratawi oil field (Final geological reports from MOO.)

Well Name	Eastern	Northern
Rt-19	699587	3382903
Rt-24	700100	3385450
Rt-25	699237	3382779
Rt-26	698 500	3380512

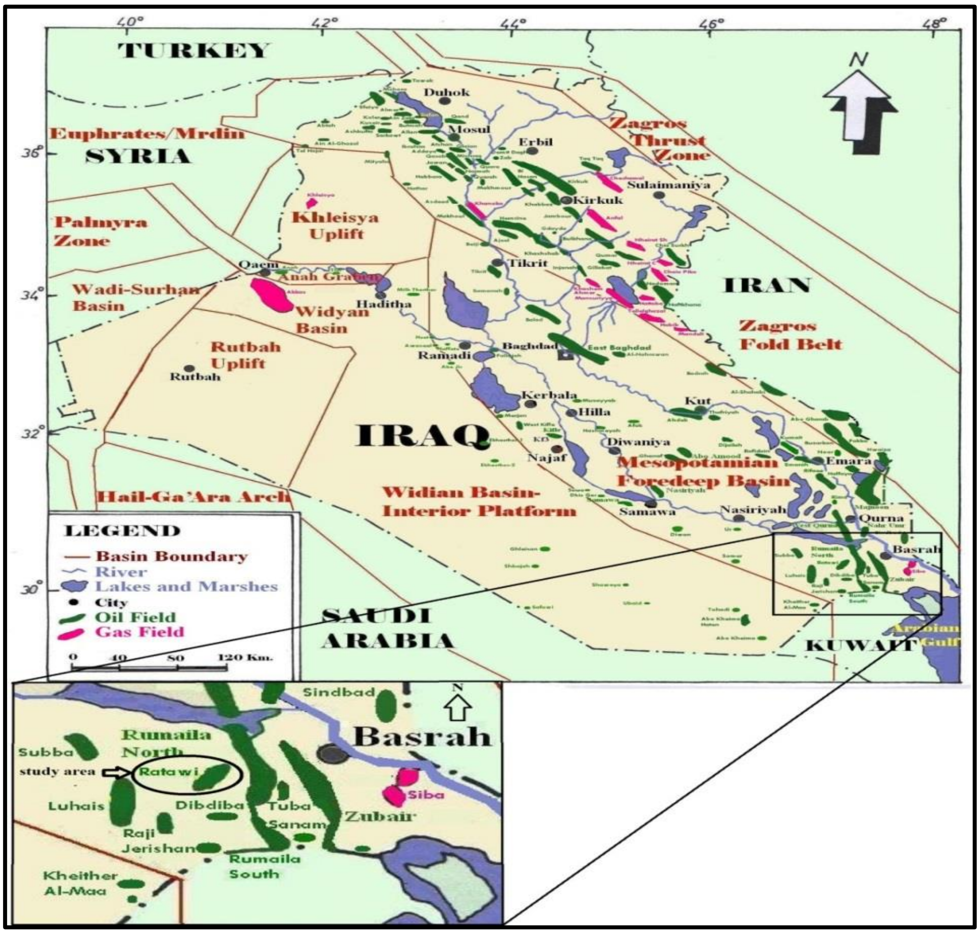


Figure 1- Map of the study area with a larger site in southern Iraq showing the locations of the study Area, modified from the map of Iraq[7].

Methodology

A structural counter map was constructed by using Peteral software 2009. IP software 2018 (V 4.5) was used to carry out the environmental corrections (hole-size, mud cake and invasion effects) that conform to the Schlumberger requirements for the application of required equations. Well log interpretation and petrophysical analysis of Mauddud Formation were carried out using IP 2018 (V 4.5).

Structure and Geologic Setting

The results of seismic surveys' interpretation indicated that the Ratawi Field structure is an ovoid convexity that extends toward North-South with almost symmetrical flanks, while its plunge increases with depth [8]. Five wells were selected in this study that are distributed along the anticline structure of the Ratawi Oil Field, as illustrated in Figure- 2. The lower contact of Mauddud Formation with Nahr Umr Formation might be produced from stratigraphic discontinuity developed during flooding of clastic dominated shelf, leading to deposition of shallow-water carbonates. The upper contact of this formation with Ahmadi Formation suggests that clastics predominated on the shelf again [3].

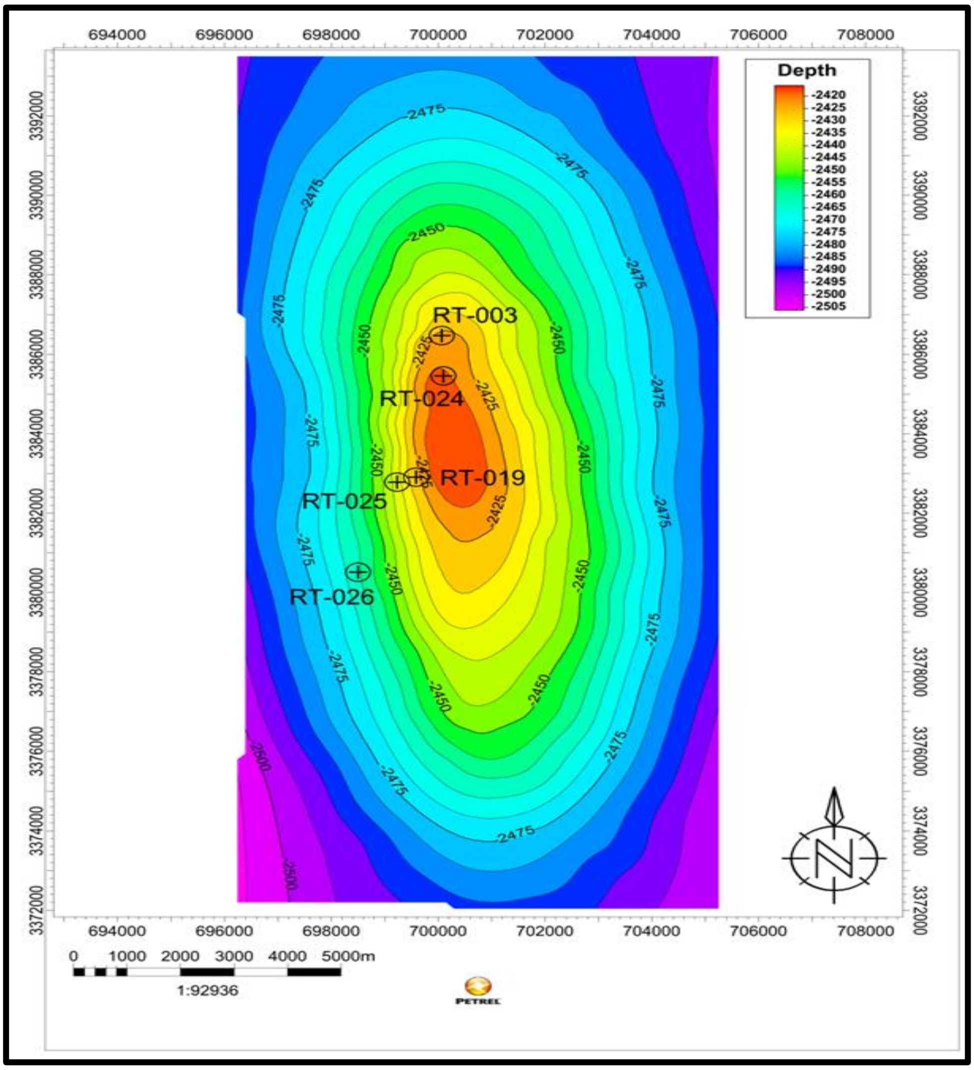


Figure 2- Structural map of top of Mauddud Formation in Ratawi Oil Field.

Environmental Correction

Before interpreting well logs, various environmental corrections, such as shale effect, borehole conditions, depth of invasion, etc., were applied to create measurements according to borehole and sub-surface conditions. These corrections were made on gamma-ray, density, neutron, and resistivity logs). Figure- 3 illustrates that the difference between the original and corrected readings was slight

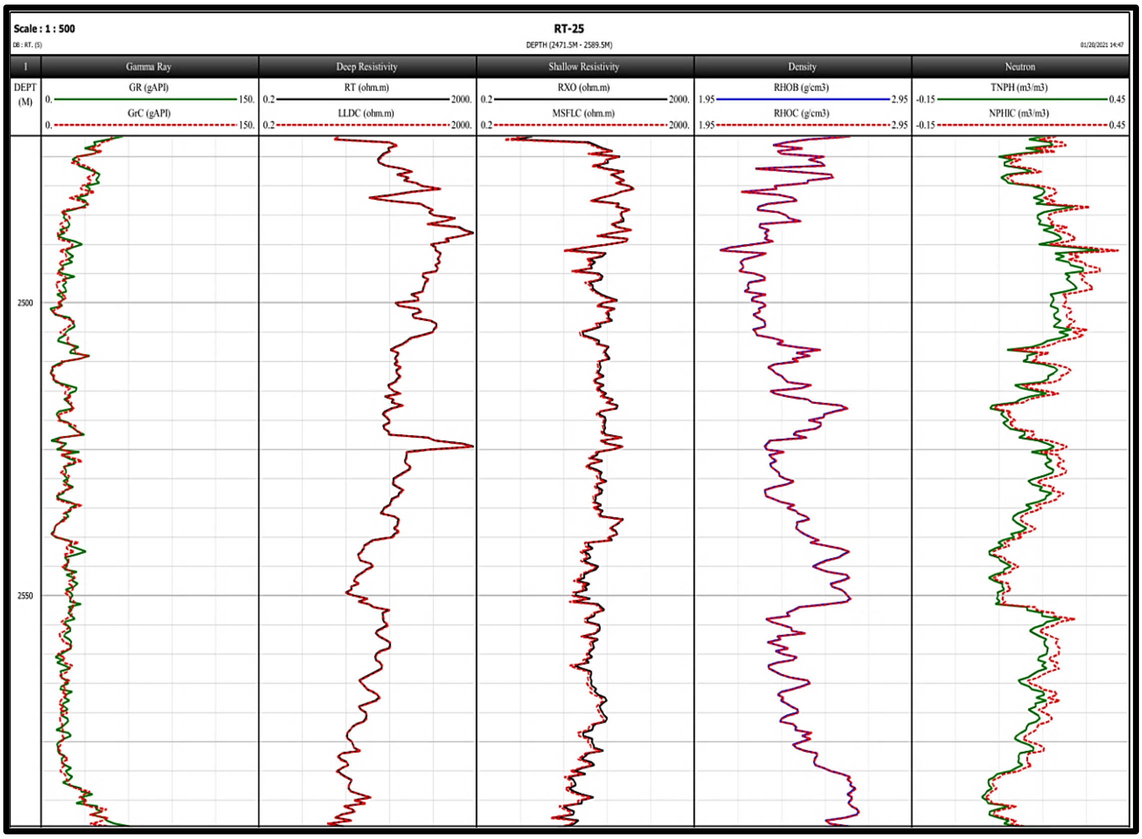


Figure 3-Environmental correction for selected logs of Rt-25.

Determination of Lithology and Mineralogy

Lithology is a term used to describe the primary mineralogy of rocks [9]. By using standard petrophysical cross plots between combination of well logs, more accurate indications for lithology, porosity and other information are determined [10].

1- Neutron (NPHI) - Density (RHOB) cross plots

These plots are among the oldest quantitative interpretation tools and the main method for determining formation lithology. They are achieved by comparing between (NPHI) readings and (RHOB) readings according to the visual separation of the curves or plotting the two values on special graphs [11].

Figure- 4(a) illustrates that the majority points of Mauddud formation units are located on the limestone line, but some points of units A and B scattered toward sand stone line, while some points of C and E units scattered toward dolomite line.

2- Matrix Identification (MID) Plot

By using this method, data on the type of lithology, gas, and secondary porosity can also be obtained. To use this method, three requirements must be provided. These include data of total porosity (øt), apparent grain density (Rhomaa), and apparent matrix transit time (Δtmaa), which can be obtained with the following equations [12]:

$$Rhomaa = \frac{\rho b - \emptyset ta * \rho f}{1 - \emptyset ta} \quad (1)$$

$$\Delta tmaa = \frac{\Delta t\ log - \emptyset ta * \Delta tf}{1 - \emptyset ta} \quad (2)$$

where Rhomaa = apparent density of matrix (gm/ Cm3); Δtmaa = apparent transit time in rock matrix (µsec/ft); φta = apparent total porosity; Δtf = interval transit time (in salt water mud = 185 µsec/ft; in fresh water mud = 189 µsec/ft); Δt log = interval transit time (the log reading); *Pb* = formation bulk density (the log reading); *Pf* = fluid density (1 g/ cm^3 for fresh water and 1.1 g/ cm^3 for salt mud).

Figure- 4(b) illustrates the MID cross plot, which show almost all points of Mauddud formation units are located on calcite minerals (dominant) and some points of units A and B scattered toward the quartz area while some points of C and E units scattered toward dolomite area.

M-N cross plot

By using this method, mineralogy of the formation can be detected. The method requires the provision of porosity logs (neutron, density and sonic logs) because M-N values depend on matrix porosity, which can be obtained with the following equations [9]:

$$M = \frac{\Delta\text{tf} - \Delta\text{t log}}{\rho b - \rho f} \times 0.01 \quad (3)$$

$$N = \frac{\emptyset\text{NF} - \emptyset\text{N}}{\rho\text{b} - \rho f} \quad (4)$$

where $\emptyset_{Nf}$ = neutron porosity for fluid =1; $\emptyset_{N}$ = neutron porosity.

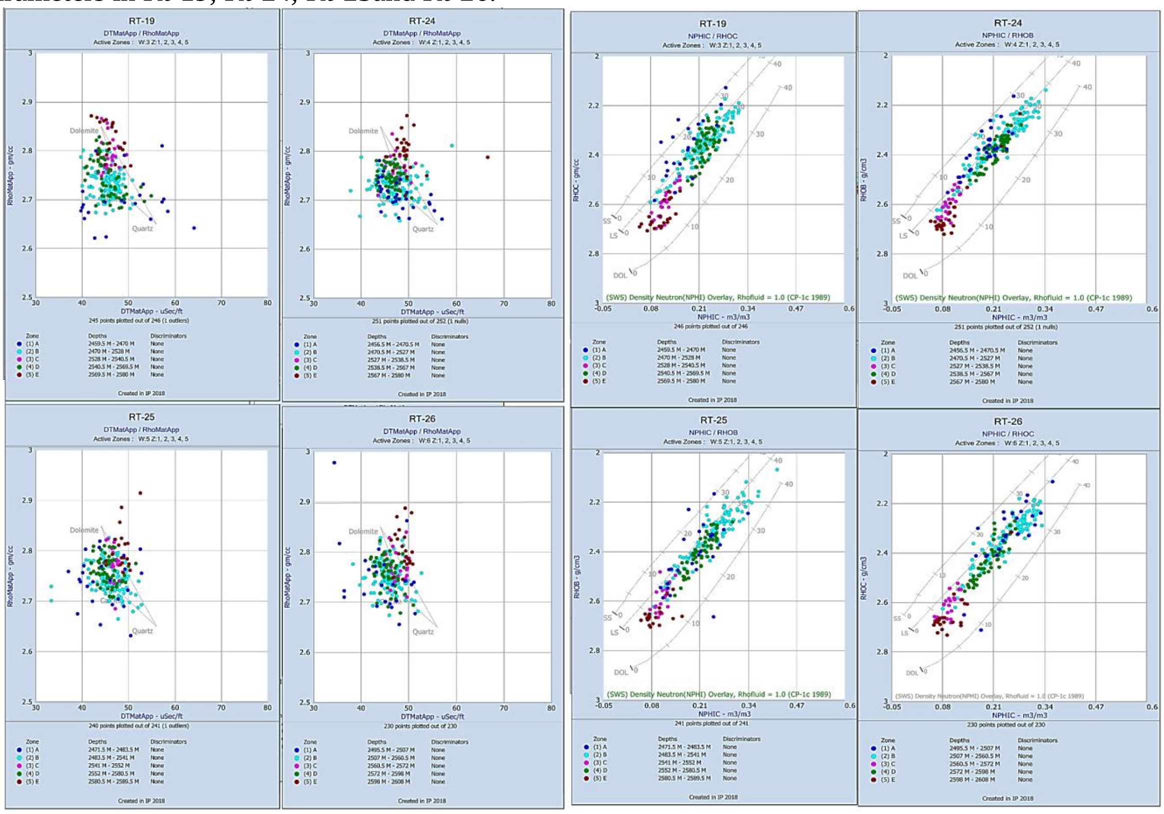
Figures- 5(a) illustrates that almost all points of Mauddud formation units are located on calcite mineral (dominant) and some points of units A and B scattered toward the secondary porosity area while some points of C and E units scattered toward dolomite area.

3- Determination of Archie's Parameters

The pickett plot is considered as one of the important methods to determine water saturation. It can determine cementation factor (m), water resistivity (Rw) and matrix parameters for density and sonic logs (Rhoma & ΔTma) [13].

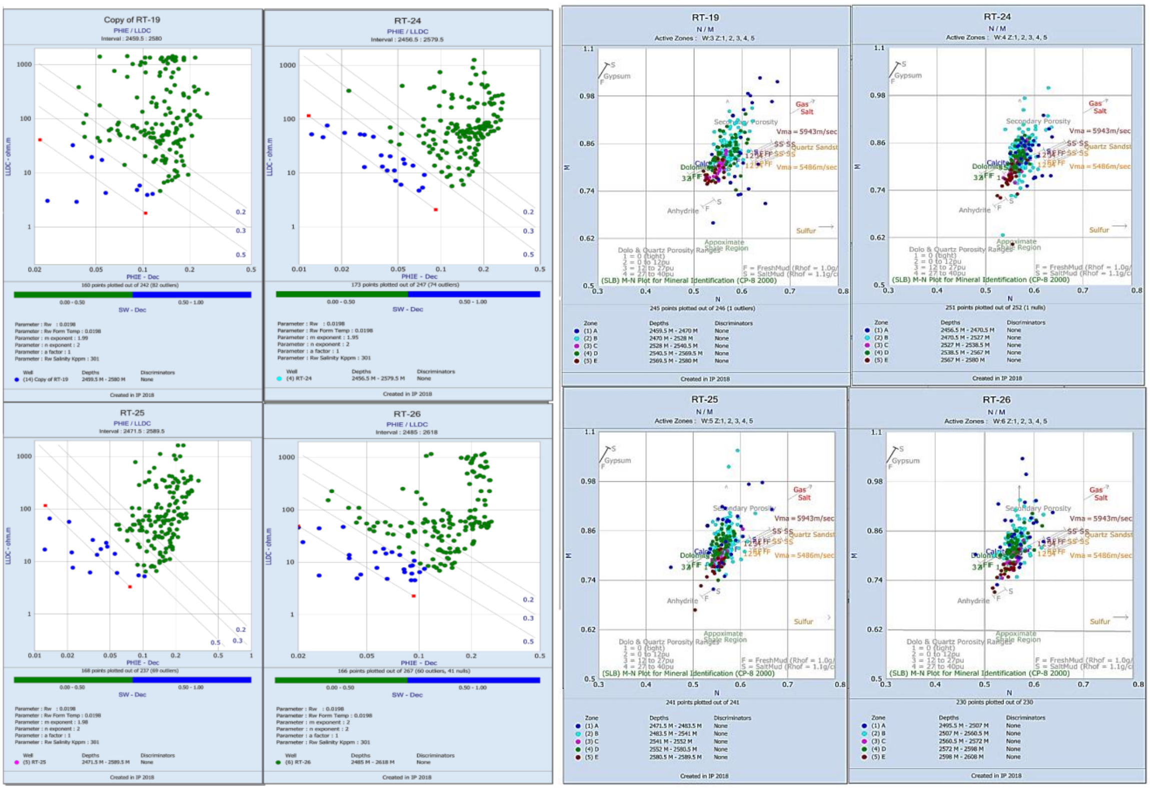
In this study, we relied on this technique to determine Archie's Parameters (m, n, and a) primarily by setting (Rt) on x axis and (PHIE) on y axis, using the Interactive Petrophysics software (V 4.5).

Figure-5(b) illustrates the results of applying the Pickett plot method that determined Archie's Parameters in Rt-19, Rt-24, Rt-25and Rt-26.



(a) (b)

Figure 4- (a) N-D cross plots and (b) MID cross plots for wells Rt-19, 24, 25 and 26



(a) (b)

Figure 5- (a) M-N cross plots and (b) Pickett plots for wells Rt-19, 24, 25 and 26.

Petrophysical parameters

Shale Volume Estimation (Vsh)

The Gamma ray log was used to calculate the shale volume within Mauddud Formation, where the maximum reading through this log is taken as a shale point and the minimum reading as a clean point. The content of shale is directly proportional to reservoir capacity [14].

To calculate shale volume, we first determined the gamma ray index (I_{GR}) by using the following equation [15]:

$$I_{GR} = (GRlog - GRmin) / (GRmax - GRmin) \quad (5)$$

where GRlog = gamma ray reading of formation; GRmin = minimum gamma ray reading (clean sand or carbonate); GRmax = maximum gamma ray reading (shale).

Then, according to the age of this formation, the following equation was used to determine shale volume of old rocks [16]:

$$Vsh = 0.33 * (2^{2*IGR} - 1) \quad (6)$$

Figure- 6 illustrates shale volume of Mauddud Formation in Rt-24 and Rt-25 wells. We observe a clear increase of the shale volume in the lower and upper parts of this formation, whereas a decreased value was recorded inside it.

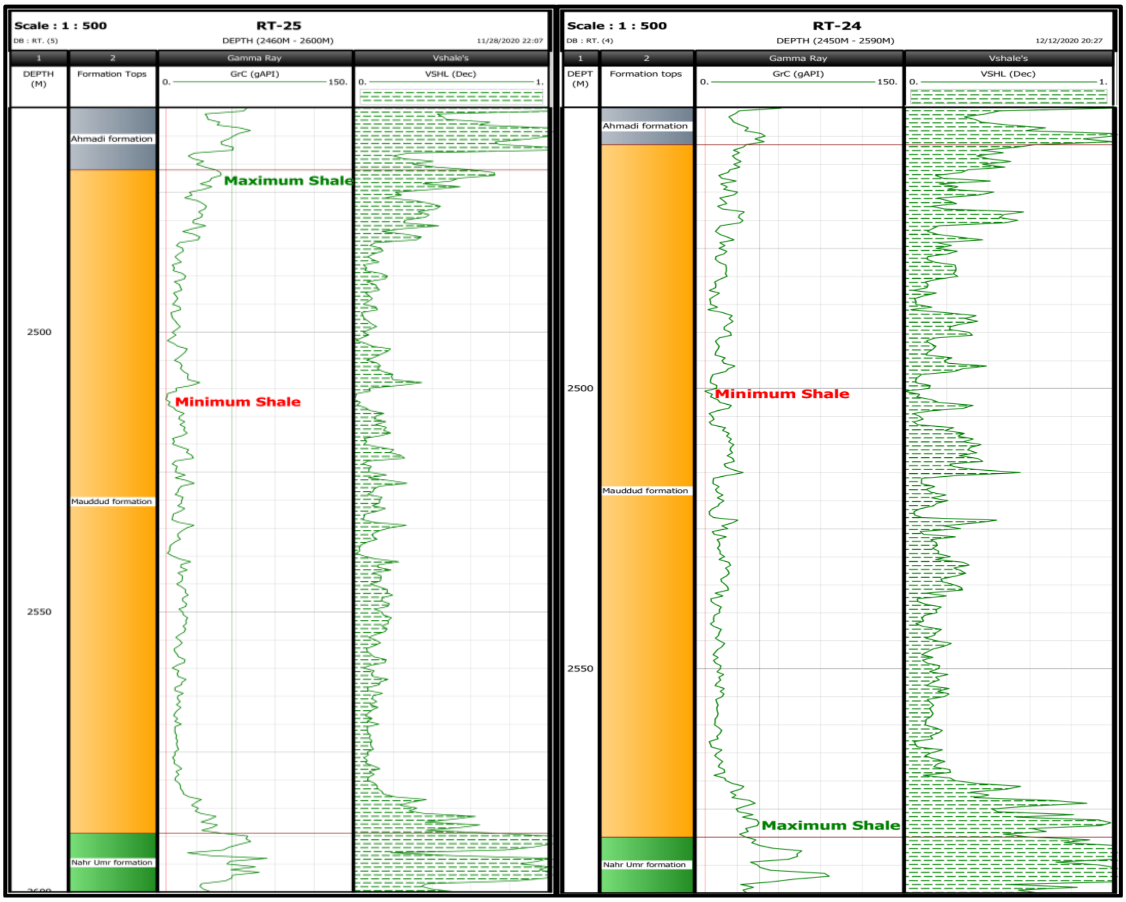


Figure 6- Shale volume (VSHL) results calculated by GR log in wells Rt-24 and Rt-25.

Determination of Porosity (Ø)

Total porosity (Φt): Total porosity represents the volume ratio of all pores to the bulk volume of a material, without recognizing if the pores are interconnected or not [17]. This porosity value can be calculated through neutron and density logs by the following equation [15]:

$$\Phi t = \frac{\Phi N + \Phi D}{2} \qquad (7)$$

where Φt = total porosity (Neutron-Density log); ΦN = neutron porosity; ΦD = density porosity.

Effective porosity (Φe): Effective porosity represents the volume ratio of interconnected pores to the bulk volume for a reservoir rock [17]. This porosity value can be calculated by the following equation [12]:

$$\Phi e = \Phi t \times (1 - VSh) \qquad (8)$$

Primary porosity: Primary porosity represents the pores associated with original depositional texture of the sediment, i.e. the pore space in between the detrital grains and within the depositional matrix [18].

Secondary porosity (SP): Secondary porosity represents the pores that result from geological processes that affect sediments after sedimentation [19]. This porosity can be calculated by the following equation [12] :

$$SPI = (\Phi t - \Phi s) \qquad (9)$$

where SPI = secondary porosity index; Φs = porosity from sonic log.

Figure-7 illustrates the relation between total porosity (PHIT) and SPI in Rt-24 and Rt-25 wells. We noted that PHIT value is in general higher than that of SPI, with the increases in some regions referring to effects of digenesis processes in Mauddud Formation, like dolomatization and dissolution. Also, the best reading of the effective porosity was observed at units B and D, which ranged between 10%-32%.

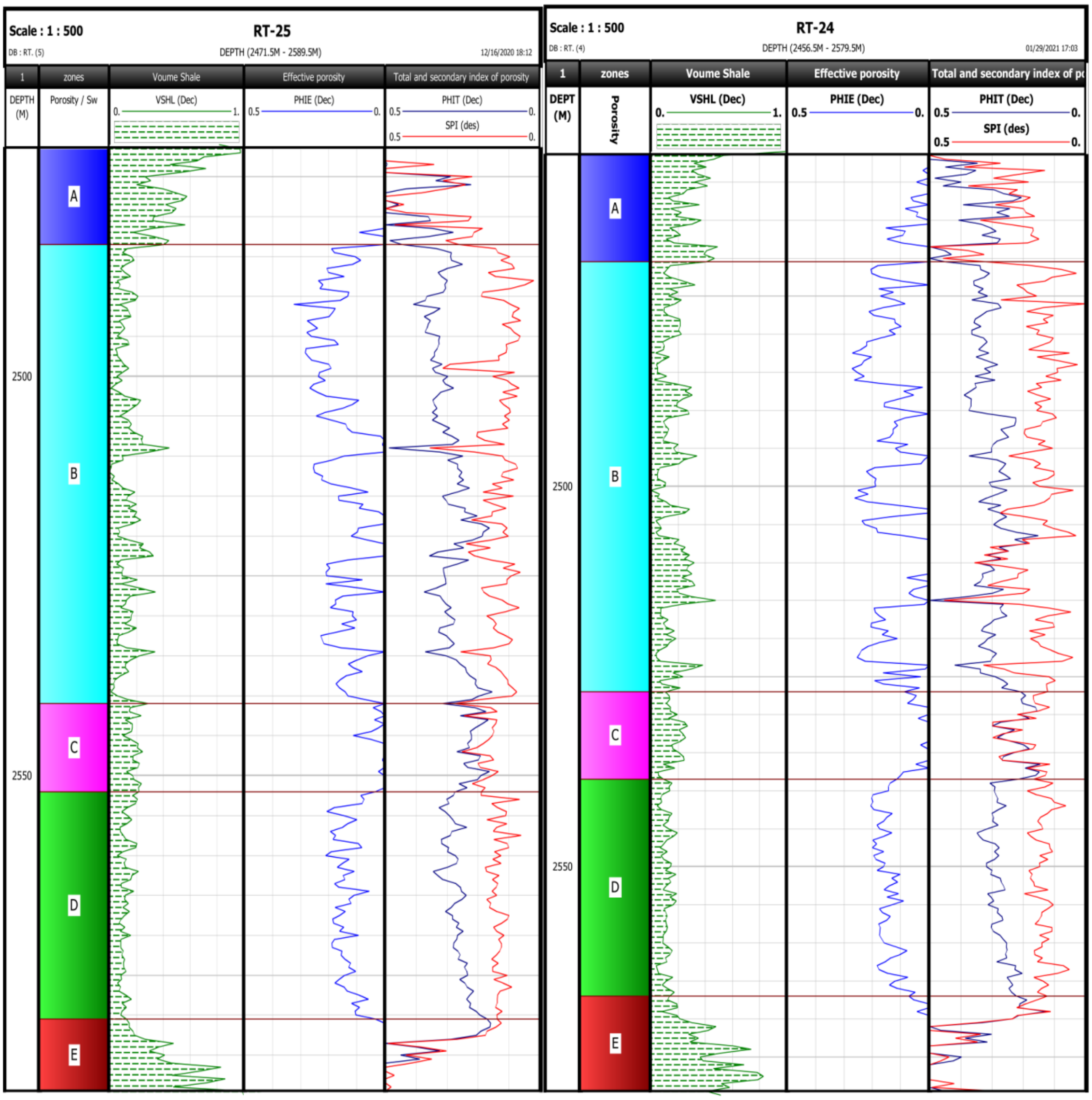


Figure 7-Effective Porosity (PHIE) and the relation between the total porosity (PHIT) and secondary porosity (SPI), with the effects of GR log in wells Rt-24 and Rt-25.

Water and Hydrocarbon Saturation

Water saturation (Sw) is the amount of the formation's water that exist in rock pores, whilst the hydrocarbon saturation (Shr) value is equal to 1 - water saturation [13, 14]. The values of water saturation for uninvaded zones (Sw) and invaded zones (Sxo) were calculated by using the following equations [20]:

$$Sw = \{(a * Rw) / (Rt * \_m)\}1/n \quad (10)$$

$$Sxo = \{(a * Rmf) / (Rxo * \_m)\}1/n \quad (11)$$

where Rw = resistivity of water formation determined by laboratory analysis of Cross and Pickett plots; a = tortuosity factor; m = cementation factor; n = saturation exponent.

Then, the hydrocarbon saturation was calculated by the following equation:

$$S_h = 1 - Sw \quad (12)$$

We calculated the residual hydrocarbon saturation by the following equation introduced by Asquith, Krygowski, and Gibson [13]:

$$S_{hr} = 1\text{-}Sxo \quad (13)$$

Then, the moveable hydrocarbon saturation was calculated by the following equation:

$$S_{hm} = Sxo\text{-}Sw \quad (14)$$

where S_{hr} = residual hydrocarbon saturation; S_{hm} = movable hydrocarbon saturation; Sxo = water saturation in the invaded zone; Sw = water saturation in the uninvaded zone.

Bulk Volume Analysis

Bulk volume of water for the uninvaded zone (BVW) and the invaded zone (BVXO) is the result of their water saturation (Sw) and porosity. They can be calculated by applying the following equations [9]:

$$BVw = Sw * Ø \quad (15)$$

$$BVxo = Sxo * Ø \quad (16)$$

While, the bulk volume of hydrocarbons can be calculated by the following equation :

$$Bvo = Sh * \Phi \quad (17)$$

where Bvo = bulk volume of hydrocarbon; Sh = hydrocarbon saturation; Φ = porosity.

Reservoir Evaluation of Mauddud Formation

Mauddud Formation in Ratawi Oil Field was divided into five reservoir zones or units, according to the analysis of petrophysical properties. Two of these units are important reservoir units with high oil content, while the others are considered as non-reservoir units (Figures- 8, 9, 10, and 11)

The reservoir properties of Mauddud units are illustrated in the following description from top to bottom:

First unit (A)

This unit represents the uppermost part of Mauddud Formation. The porosity is very low and considered negligible, with a mean value of about 1%. Water saturation ranged 0.10-1 with a mean value of 0.91. Hence, the A-unit is considered as the cap rock for Mauddud reservoir (Table- 2).

Second Unit (B)

This unit represents an important reservoir unit in Mauddud Formation because it contains the main content of oil reserves. The porosity showed a range of 0.01-0.26 and water saturation range was about 0.01-1, with a mean value of 0.25 (Table- 2).

Third Unit (C)

The porosity in this unit is very low and considered negligible, with a mean of about 1%, whereas water saturation ranged 0.18-1 with a mean of 0.94. Hence, the C-unit is a non-reservoir unit in Mauddud Formation (Table- 2).

Forth Unit (D)

This unit represents the second important reservoir unit in Mauddud Formation after unit (B). The Porosity ranged 0.05-0.21 and water saturation ranged 0.07-1, with a mean of 0.30.

Fifth Unit (E)

This unit represents the lower unit, i.e. located at the bottom of Mauddud Formation, with porosity range of 0.01-0.1 and water saturation range of 0.47-1, with a mean of 0.98. Hence, the E-unit is a non-reservoir unit in Mauddud Formation.

Table 2- The classification of porosity according to [21] .

Type of porosity	**%**
Negligible	0-5
Poor	5-10
Fair	10-15
Good	15-20
Very good	20-25

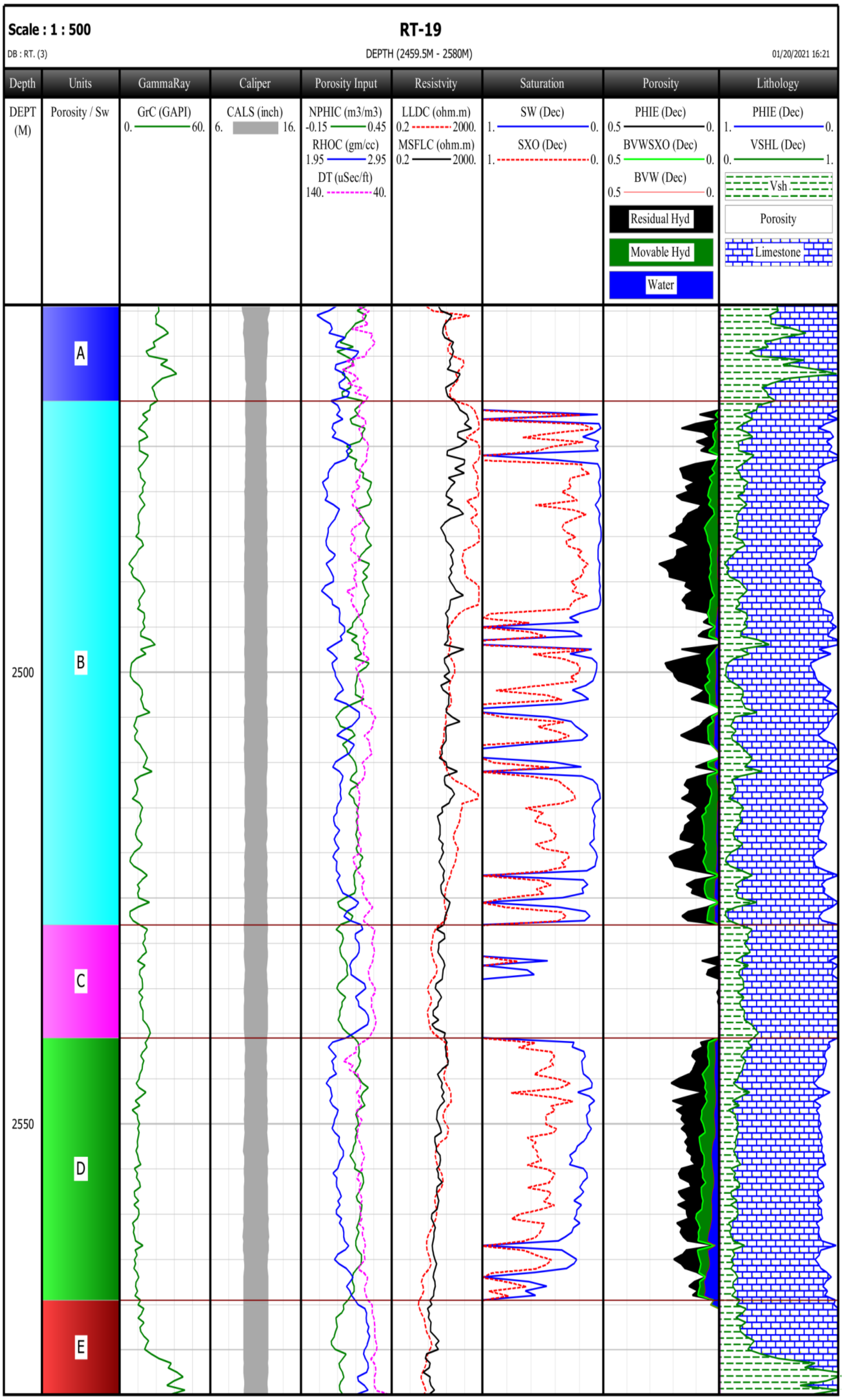


Figure 8- Computer Processed Interpretation of Mauddud Formation at well Rt-19.

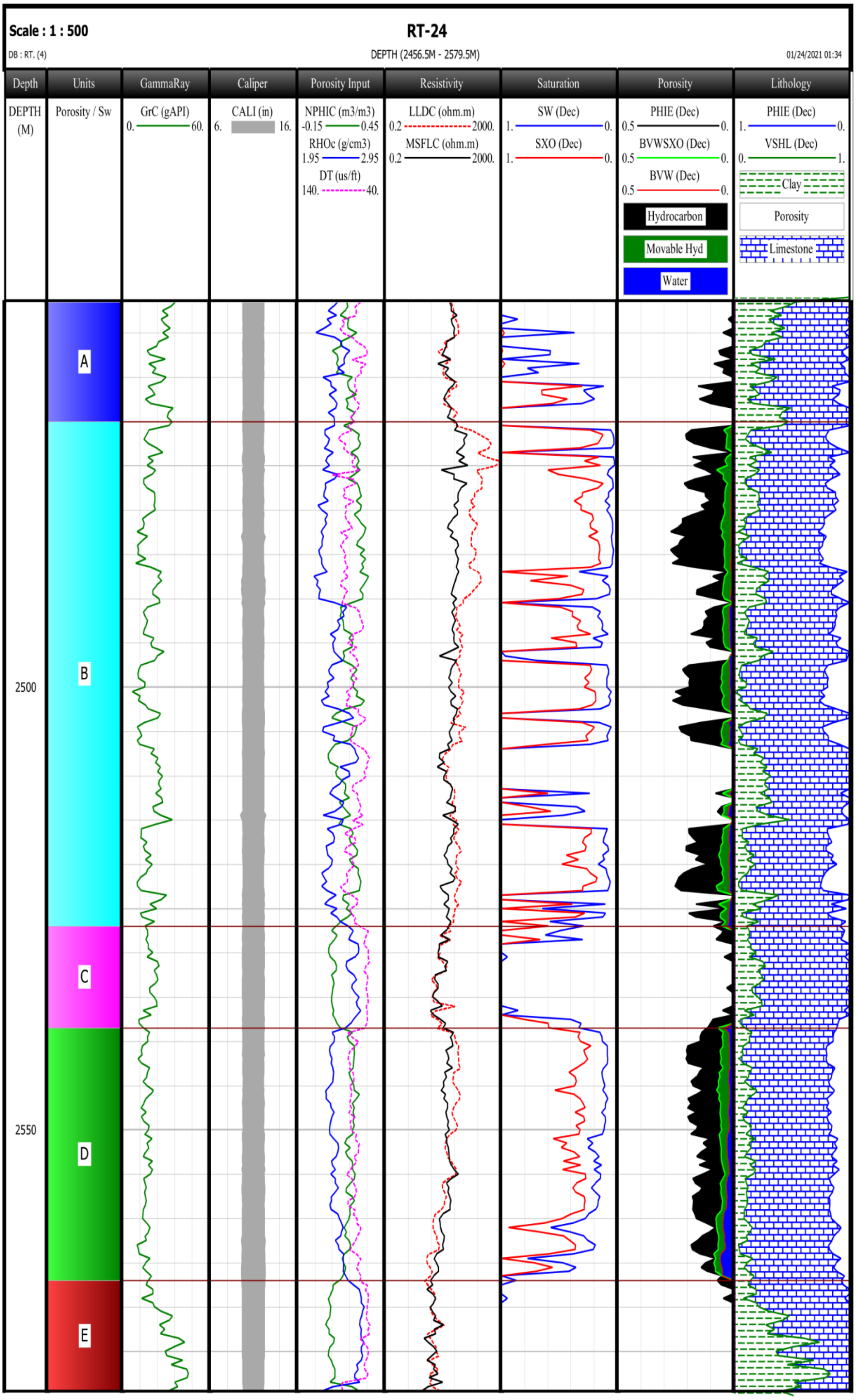


Figure 9- Computer Processed Interpretation of Mauddud Formation at well Rt-24.

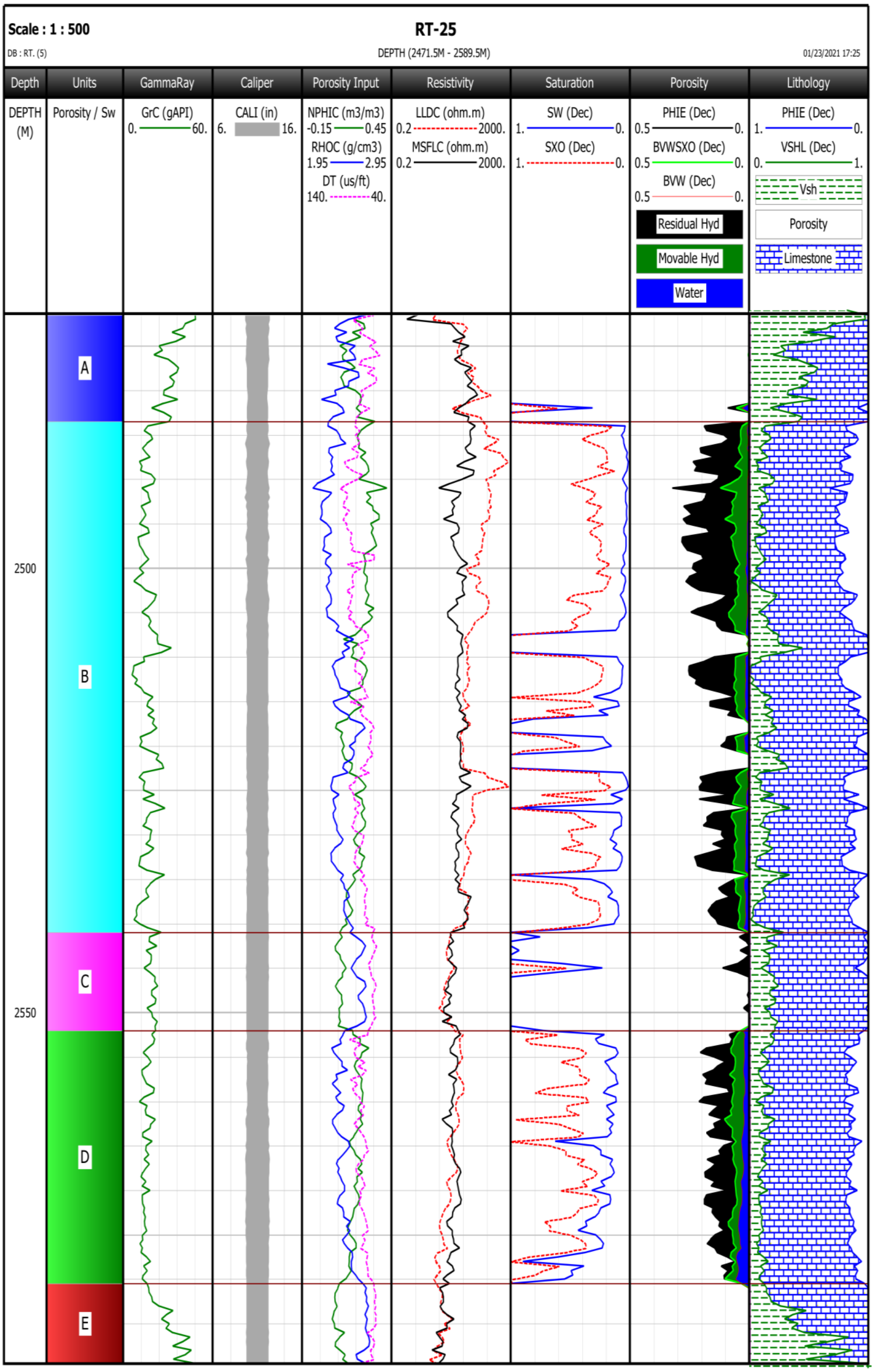


Figure 10- Computer Processed Interpretation of Mauddud Formation at well Rt-25.

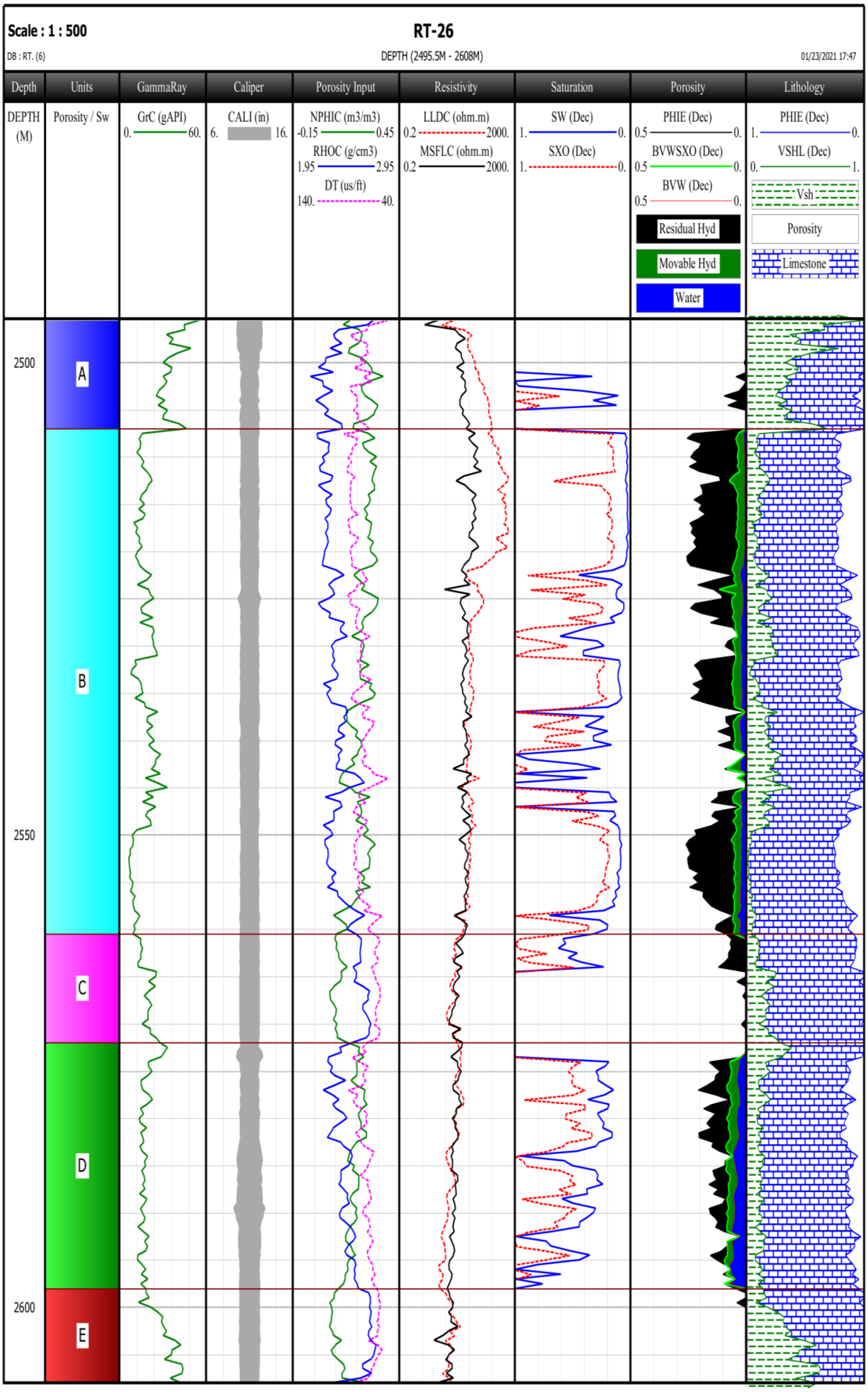


Figure 11- Computer Processed Interpretation of Mauddud Formation at well Rt-26.

Conclusions

The lithology and mineralogy cross plot show that the lithology of Mauddud Formation containing mainly of limestone with less amount of dolomite in lower part and little of sandstone in upper part. As for minerals, it is composed of calcite. The computer processes interpretation (CPI) of (4) boreholes of Ratawi Field have been deduced using IP software. The computer processed interpretation showed that the Mauddud Formation consists mainly of 5 reservoir units are; A, B, C, D and E .The most important reservoir units are B and D due to their log response that are characterized by low GR log and water saturation with high porosity values as derived from sonic, density and neutron logs indicating that mean good reservoir properties. While, other units represent barriers or non-reservoir properties.

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