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Petrophysical interpretation of Euphrates Formation in Ajil Oil Field, Salah Al-Deen Governorate, Central Iraq

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Abstract

The study intends to well logs interpretation to determine the petrophysical parameters of Euphrates Formations in Ajeel Oil Field. The petrophysical properties have been determined from well logging, Euphrates Formation in terms of reservoirs units, consist of two Petrophysical properties. Total porosity, effect porosity and secondary porosity have been calculated from neutron, density, and sonic logs. secondary porosity is high and it's resulted from diagenesis processes in the formation. From RHOB-NPHI and N/M cross plot, Euphrates Formation composed mainly from Limestone and dolomite with nodules of anhydrite. Dhiban Formation composed mainly of anhydrite, so it's represented the cap rocks for Euphrates Reservoir were recognized based on the reading of GR, RHOB, NPHI, and DT logs. These rocks composed mainly from Anhydrite and anhydritic limestone. Hydrocarbone saturation include both gas and oil, where Ajeel oil field is production oil and gas.

Keywords: Ajeel oil field, Euphrates Formation, Perophysical Properties.

تفسير المجسات لتكوين الفرات في حقل عجيل النفطية، محافظة صلاح الدين، وسط العراق

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الخلاصة

تضمنت الدراسة تفسير الآبار لتحديد الخواص البتروفيزيائية لتكوين الفرات في حقل عجيل النفطية. الخواص البتروفيزيائية التي تم حسابها من مجسات الآبار ، بينت ان تكوين الفرات من وحدتين ممكنة. تم حساب المسامية الكلية ومسامية الفعالة والمسامية الثانوية من مجسات النيوترون والكثافة والمجس الصوتي. المسامية الثانوية عالية وهي ناتجة عن العمليات التحويرية في التكوين. من خلال مرئسمات RHOB-NPHI و N / M ، يتكون تكوين الفرات أساسا من الحجر الجيري والدولوميت مع عقد من الأنهدرايت. تكوين الذبان الانهدرايتي يمثل صخور الغطاء لتكوين الفرات والتي تم تمييزه من خلال مجس اشعة كما مجسات النيوترون والكثافة والمجس الصوتي. هذه الصخور تتكون بشكل رئيسي من الأنهدرايت والحجر الجيري الحاوي على الانهدرايت. يشمل التشبع الهيدروكربونات الغاز والنفط ، حيث ان حقل عجيل النفطية هو ينتج النفط والغاز .

Introduction:

Well logs interpretation is essential for understanding subsurface reservoir characterization [1]. Subsurface properties require physical measurements that made from well logging. The study depends on determining reservoir characterization from logs interpretation, such as lithology, primary and

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secondary porosity, type of fluids that filled porosities as well as their saturation, and stratigraphic boundary can be determined quantitatively from log response.

The Study Area

Ajeel field is located about 30 km to the North East of Tikrit city, North Iraq. The average elevation of the field area is 150-170 m above mean sea level. Four boreholes have been studied, [Figure-1]. Structurally, this field is part of many fields of structurally oriented NW-SE within northern part of adjacent to the low folded zone of the Zagros Fold Belt. Geographically within Salah Al-deen Governorate in the east of Tigris River between the cities of Tikrit and Beiji [2]

The Early-Mid Miocene Sequence can be divided into two second order sequences, each with shallow water carbonates passing up into evaporites. They are the Early Miocene and the Mid Miocene sequences. The formations previously included in the Early-Mid Miocene Sequence include the Asmari, Euphrates, Serikagni, Dhiban, Ghar, Jeribe and Lower Fars formations [3].

Lower Miocene limestones in Syria were referred to the Euphrates Formation by [4]. The formation is equivalent to the part of the Asmari Limestone of SE Iran. The Euphrates Formation passes laterally into continental clastics in Saudi Arabia, represented by the Hadrukh Formation [5].

Data and Methods

Reservoir characterization have been studied from 4 boreholes in Ajeel Oil Field (AJ-4, AJ-6, AJ-11, AJ-12). The well logging data were used from available records (LAS) are Gamma- Ray, Density, Neutron, Sonic, and Resistivity logs. The steps which are required before interpretation of well logging are involves first, processes of the digitization by Didger 3 program. Second, these data are loaded into the IP program and make the correction for well logging data, because well logging is indirect measurements that are influenced by the effects of environment (for example, mud circulation and mud properties). After corrections processes has been calculated the water saturation ratio and moveable hydrocarbons as well as the effective and secondary porosity, lithology and mineralogy for the three formations.

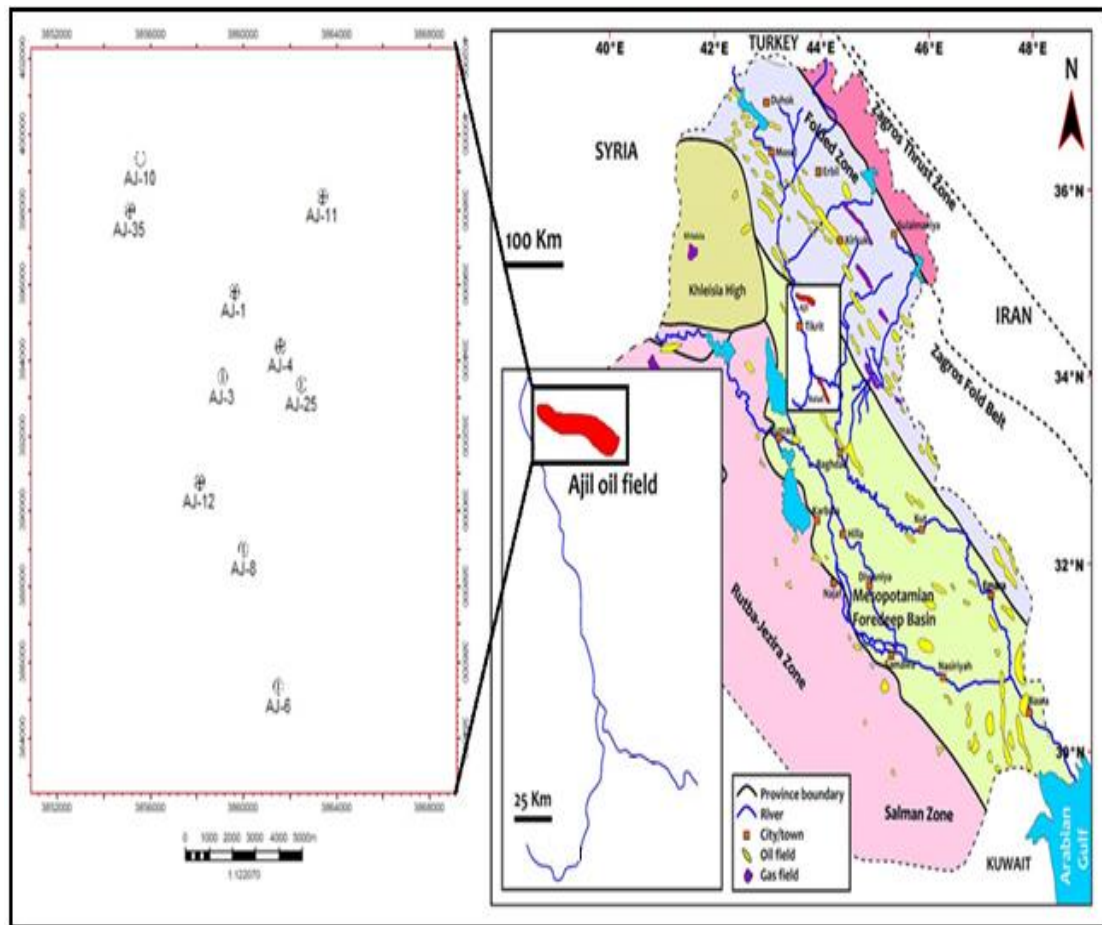


Figure 1- Location Map of the study area (Ajeel oil field) [2].

Borehole Environment

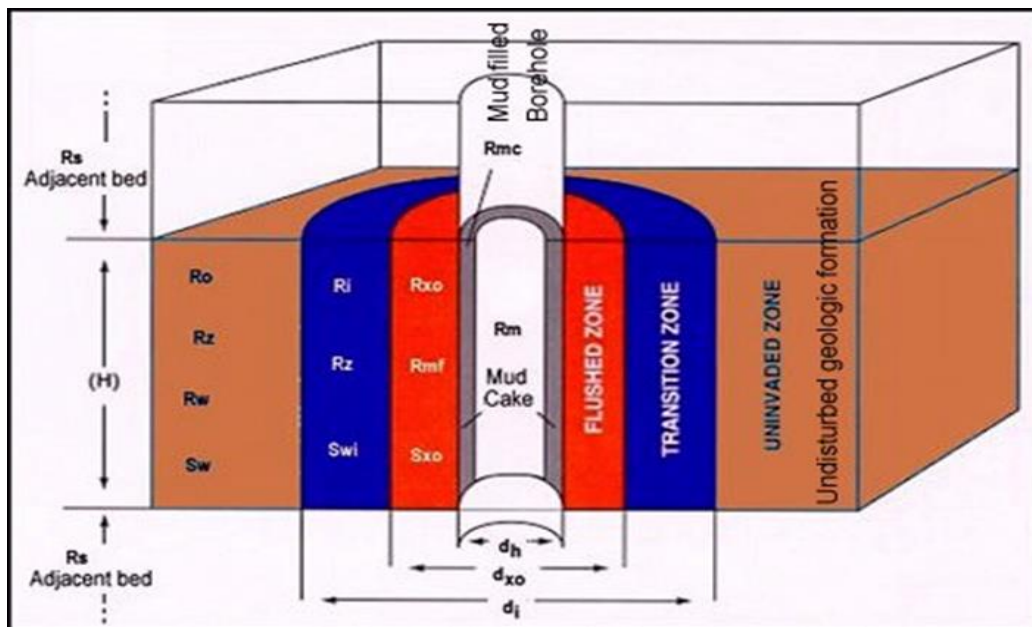
During drilling the well, the hydrostatic pressure of the mud column is usually greater than the pore pressure of the formations. This prevents the well from “blowing out”. The resultant differential pressure between the mud column and formation forces mud filtrate into the permeable formation, and the solid particles of the mud are deposited on the borehole wall where they form a mudcake [Figure-2]. Mudcake usually has a very low permeability (of the order of 10^{-2} - 10^{-4} md) and, once developed, considerably reduces the rate of further mud filtrate invasion to very close to the borehole and most of the original formation water and some of the hydrocarbons may be flushed away by the filtrate. This zone is referred to as the flushed zone [6].

Environmental Corrections

The environmental corrections are very important to be match between the actual condition in borehole and the calibration of the test pit tool. All corrections should be applied on all wireline logs (Gamma ray, Density, Neutron and Resistivity logs) according to the Schlumberger's environmental correction. In this study, Interactive Petrophysics software has been used to apply these corrections.

Corrections of Resistivity logs

The resistivity log measures apparent resistivity. It's represent a resistivity of isotropic, homogeneous medium. If the measurement conditions will be known, the apparent resistivity represents a true resistivity. Before using these log in reservoir interpretation should be correction the types of resistivity logs such as LLD to LLDC, LLS to LLSC, MSFL to MSFLC [Figure-3]. These correction has been done by use IP software based on SLB charts.



Modified from http://www.tuckercanada.com/logbook/general/borehole_environment.htm January 2005

Resistivity	Water Saturation
R_s = SHOULDER OR ADJACENT BED RESISTIVITY	S_{xo} = FLUSHED ZONE WATER SATURATION
R_m = MUD RESISTIVITY	S_{wi} = TRANSITION ZONE WATER SATURATION
R_{mc} = MUD CAKE RESISTIVITY	S_w = UNINVADED ZONE WATER SATURATION
R_{xo} = FLUSHED ZONE RESISTIVITY	
R_{mf} = MUD FILTRATE RESISTIVITY	
R_i = TRANSITION ZONE RESISTIVITY	
R_z = FLUID RESISTIVITY OF TRANSITION ZONE	
R_o = UNINVADED ZONE RESISTIVITY	
R_t = UNINVADED ZONE RESISTIVITY	
R_w = FORMATION WATER RESISTIVITY	
Thickness	Diameter
h_{mc} = MUDCAKE THICKNESS	d_h = BOREHOLE DIAMETER
H = ZONE THICKNESS	d_{xo} = FLUSHED ZONE DIAMETER
	d_i = DIAMETER OF INVASION

Figure 2- Borehole environment and symbols used in log interpretation. [7].

Corrections of Density and Neutron logs

In order to get accuracy results, density and neutron logs must be corrected for the shaliness, Figure- 4. showed the RHOBC and NPHIC. Corrections were made according to the following formula relationships and depending on Schlumberger's environmental correction:

For density porosity log according to the [8]
 $\text{ØD Correction} = \text{Ød} - (\text{Vsh} \times \text{ØDsh})$ (1)

For neutron porosity log according to [9]
 $\text{ØN correction} = \text{ØN} - (\text{Vsh} \times \text{ØNsh})$ (2)

Where,

Vsh: represents the shale volume.

ØN: represents neutron porosity in shale formation

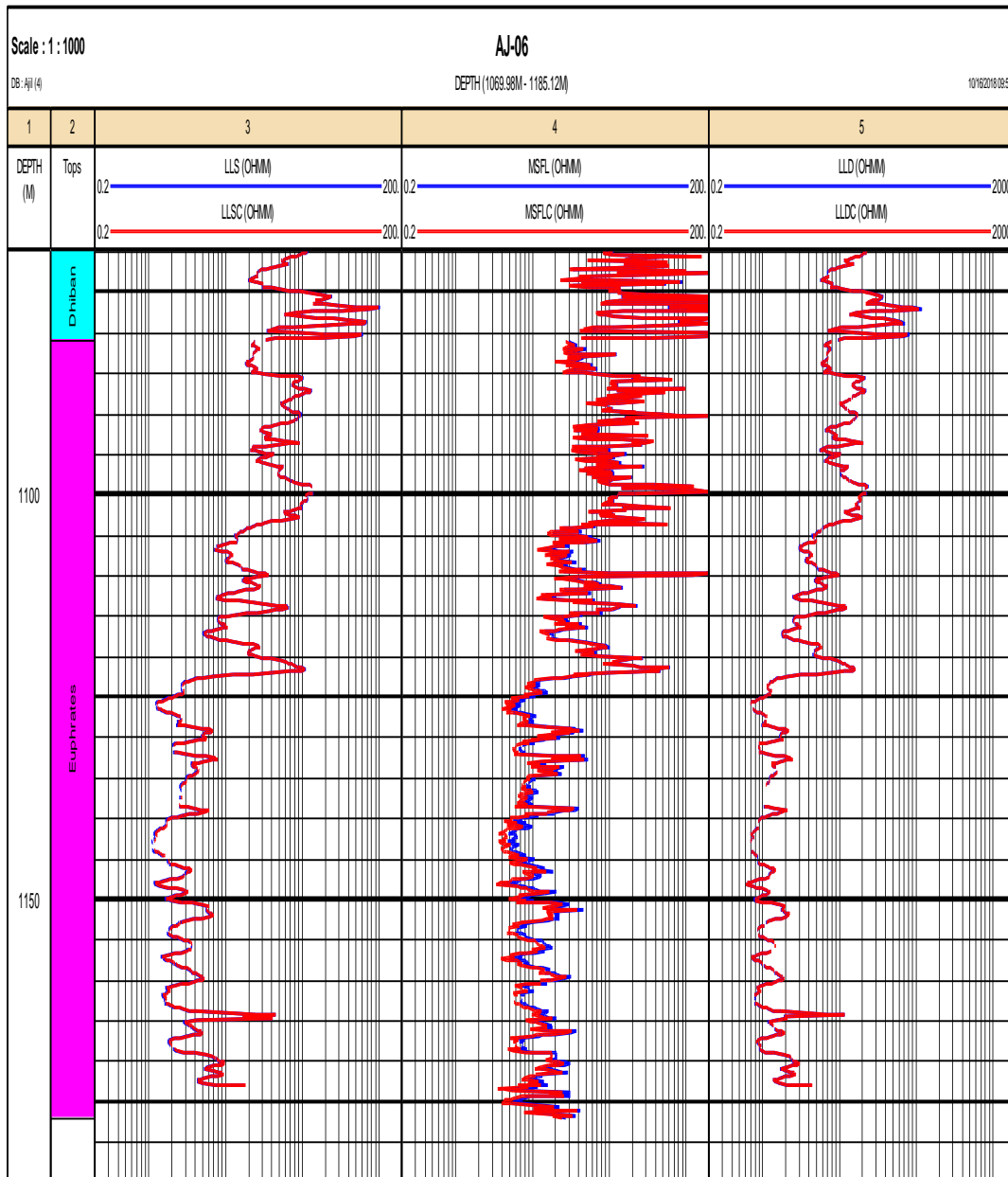


Figure 3- Resistivity logs correction in AJ-6 well.

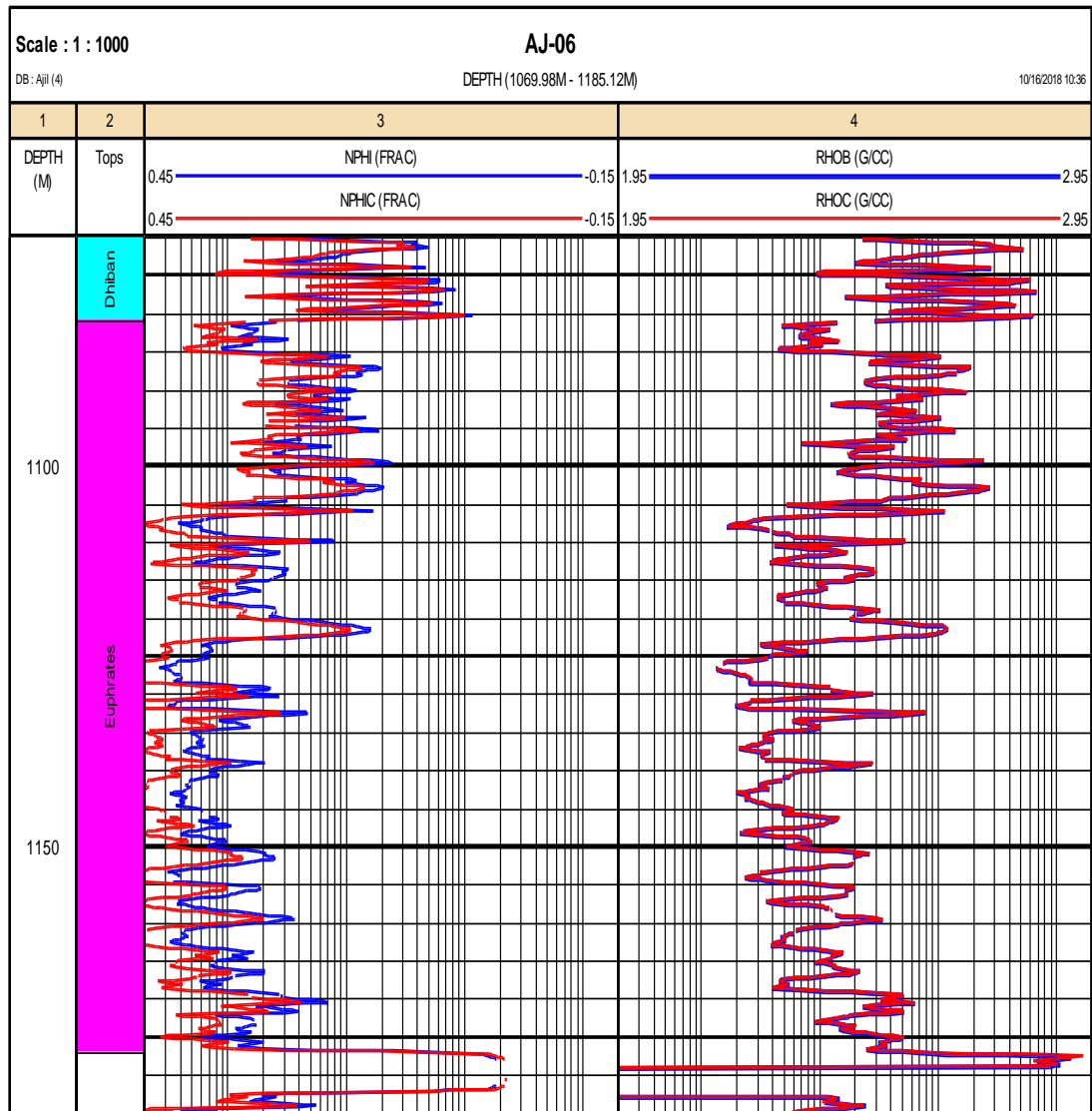


Figure 4- Showing NPHI, NPHIC and RHOB, RHOC in AJ-6 well.

Petrophysical Parameters

1-Determination of clay volume (Vsh)

The presence of shale in a reservoir can cause erroneous values for water saturation and porosity derived from logs. Whenever shale present in formation, the sonic and neutron tools will record too high. But the density tool will not record too high if the density of shale is equal to or greater than the reservoir matrix density. Also, the presence of shale in a formation will cause the resistivity log to record too low resistivity [10]. Before clay volume calculation should be make the correction for GR log to get more accuracy, so has been done the GR correction before calculate volume of shale. [Figure-5].

In order to calculate volume of shale for consolidated rocks, the following formula is used [11]:

$$I_{GR} = (GR_{log} - GR_{min}) / (GR_{max} - GR_{min}) \dots \dots \dots (3)$$

Where GR_{log} is the gamma ray reading from log

GR_{max} is the maximum reading from log

GR_{min} is the minimum reading of gamma ray from log.

In this study, because the formation regards as an old rock, the equation in [12] and [13] were used.

$$Vsh = 0.33 (2^{2 * I_{GR}} - 1.0) \dots \dots \dots (4)$$

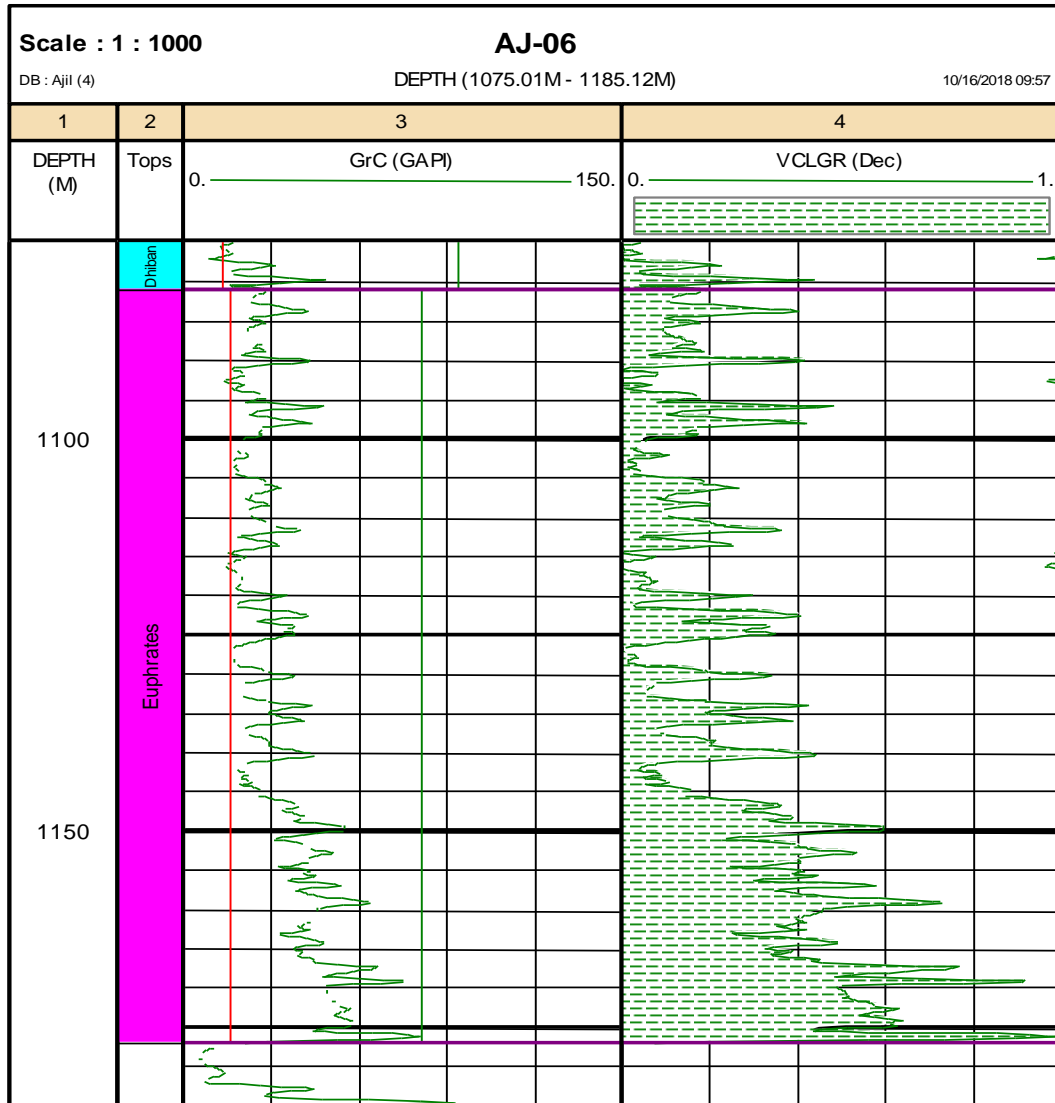


Figure 5- Vsh calculation from GRC log in AJ-6 well.

2- Determination of Porosity (ϕ)

Porosity can be defined as the percentage of voids to the total volume of rock. It is measured as a percent and expressed as the symbol (ϕ).

Porosity (ϕ) = Volume of pores /total volume of rock $\times 100\%$ (5)

Porosity can be calculated from the combination of neutron-density logs. Density log represent as a porosity log that measures the electron density of the formation [14].

Total porosity

Total porosity is defined as the ratio of the volume of all the pores to the bulk volume of a material, regardless of whether or not all of the pores are interconnected [15].

[16] proposed an equation to compute the total porosity from neutron and density logs that may be expressed as.

$\phi_t = (\phi_N + \phi_D / 2)$ (6)

Effective porosity

Effective porosity is the ratio of the volume of interconnected pores to the total volume of reservoir rock [17]. It is also defined as the total porosity minus the clay- bound water and water held as porosity within the clays [18]. Effective of porosity can be

calculated from the following formula:

$\phi_{eff} = \phi_{total} \times (1 - v_{sh})$ [19] (7)

Primary and secondary Porosity

The primary porosity is the amount of pores present in the sediments at time of deposition. It is usually a function of the amount of space between rock-forming grains [7]. The sonic porosity represents the primary (intergranular) porosity [10]. Secondary porosity (vuggy, moldic, channels and fracture) are the result of geological processes (diagenesis) after the deposition of sediments [20].

Sonic log was used to determine primary porosity according to the following formula [21]

$$\text{ØS} = (\Delta\log - \Delta t_{ma}) / \Delta t_{fl} - \Delta t_{ma} \dots\dots\dots (8)$$

Where:

Øs=porosity derived from sonic log

Δt_{ma}=interval transit time in the matrix.

Δlog=interval transit time in the fluid in the formation.

Δt_{fl}= interval transit time in the fluid.

Presence of hydrocarbon lead to the increase in Δt, therefore, [22] suggested the following formula in order to denied hydrocarbon effect. Secondary porosity was computed by the difference between total porosity and the primary porosity was derived from Sonic log.

$$\text{Ø} = \text{ØS} \times 0.7 \dots\dots\dots \text{gas} \dots\dots\dots (9)$$

$$\text{S} \times 0.9 \dots\dots\dots \text{oil } \text{Ø} = \text{Ø}$$

There is another step to avoid shale effect from sonic log:

$$\text{ØS correction} = \text{ØS} - (V_{sh} - \text{ØSch}) \dots\dots\dots (10)$$

Finally, the index of secondary porosity (SPI) can be calculated according to the following

Formula [8]

$$\text{SPI} = (\text{Øt} - \text{ØS correction}) \dots\dots\dots (11)$$

[Figure-6]. show the log response of PHI-DEN. from density log curve, PHI-NEU. From Neutron log curve, PHI-SON from sonic log curve, total, and effective porosity in Euphrates Formation

3- Water and Hydrocarbon Saturation

In a formation containing oil, or gas, both of which are electrical insulators, the resistivity is a function of Formation Factor (F), water resistivity (R_w), and water saturation (S_w). Water saturation is the fraction of pore volume occupied by formation water [23]. [24] determined experimentally that the water saturation in the following formula:

$$S_w = (F R_w / R_t)^{1/n} \dots\dots\dots (12)$$

S_w = Water saturation of uninvaded zone

F= Formation factor

R_w= Resistivity of water ohm-m³/m

R_t= Resistivity of the uninvaded zone ohm-m³/m

n= usually taken as 2 in limestone

The water saturation could be calculated for the invaded zone in the following formula:

$$S_{xo} = (F R_{mf} / R_{xo})^{1/n} \dots\dots\dots (13)$$

S_{xo}= Water saturation of the uninvaded zone

F= Formation factor

R_{mf}= Resistivity of mud infiltrate ohm-m³/m

R_{xo}= Resistivity of invaded zone ohm-m³/m

n= usually taken as 2 in limestone

R_t is obtained from the deep resistivity log, and R_{xo} is obtained from the microspherically focused resistivity log formation factor is the constant of proportionality of resistivity of clean formation with the resistivity of the brine with which is fully saturated. Archie proposed the formula [23]:

$$F = a / \phi^m \dots\dots\dots (14)$$

Where m is the cementation factor, it is equal to 2 in carbonate. And (a) is constant and equal to 1 in compacted formation.

The R_{mf} is known for bottom hole temperature and it should be corrected for formation temperature. The temperature gradient is required in order to calculate formation temperature:

$$G = (BHT - ST) / TD \dots\dots\dots (15)$$

Where:

G is temperature gradient

BHT is bottom hole temperature

ST is surface temperature

TD is total depth.

Now formation temperature could be calculated:

$$FT = G * Fd + ST \dots\dots\dots (16)$$

Where FT is formation temp., and Fd is formation depth. The R_{mf} could be corrected for the formation temp. Using the following equation:

$$R_{mf \text{ formation}} = R_{mf \text{ temp}} * (BHT. + 6077) / (FT + 6.77) \dots\dots\dots (17)$$

Where $R_{mf \text{ temp}}$ is the resistivity of R_{mf} at known temp., which is the BHT.

The R_w could be calculated in more than one way. This study calculates the R_w from the SP log based on the following equations [23].

$$R_w @ 75^\circ F = (77 * R_{we} + 5) / (146 - 377 * R_{we}) \dots\dots\dots (18)$$

Where R_{we} is the equivalent water resistivity and it could be calculated using:

$$R_{we} = R_{mfe} / (10 - SSP/K) \dots\dots\dots (5.14)$$

Where:

$$K = 60 + (0.133 * ST) \dots\dots\dots (19)$$

SSP is the static SP curve and it could be calculated by knowing the deference between the maximum negative deflection and the opposite positive deflection (shale base line) for thick permeable bed [23].

R_{mfe} is the equivalent resistivity of mud infiltrate, and it can be calculated by computing the R_{mf} at 75°F then:

$$R_{mfe} = R_{mf} * 0.85 \dots\dots\dots (20)$$

After calculating R_w at 75°F it is then converted to the formation temperature.

After calculating S_w , the saturation of hydrocarbon could be calculated using:

$$S_h = 1 - S_w \dots\dots\dots (21)$$

Where:

S_h is the hydrocarbon saturation.

However, the shale volume also affects resistivity logs, hence affecting the water saturation derived from logs. [22] in [23] suggests that for shale to significantly affect log-derived water saturations, shale content must be greater than 10 to 15%. The V_{sh} at some intervals actually is greater than 10%. In order to remove the effect of shale when calculating saturation, the following equation is used:

$$S_w = (0.4 * R_w / \phi^2) * [-(V_{sh} / R_{sh}) + [(V_{sh} / R_{sh})^2 + (5\phi^2 / R_t * R_w)]^{0.5}] \dots\dots (22)$$

Where:

R_{sh} is the resistivity of shale.

Water and hydrocarbon saturation are calculated and corrected for shale for Euphrates Formations at Ajeel oil field.

The hydrocarbon-water zones occur in all studied wells. However, water saturation can be high as observed in some intervals (Figures 9 and 10). Therefore, calculation of irreducible water saturation (S_{irr}) is required, which is obtained by computing bulk volume water (BVW) and porosity [10].

$$BVW = S_w * \Phi \dots\dots\dots (23)$$

Where:

BVW=bulk volume water

S_w =water saturation

Φ =porosity

If values of BVW are constant or very close to constant, they represent homogeneous zones with irreducible water saturation. The water at such zones will be non- moveable because it is held on grains by capillary pressure. Therefore, hydrocarbon produced from that zone should be water-free [25] in [23].

Figures-[9, 10] show the values of S_h and S_w in AJ-4 and AJ-6 wells.

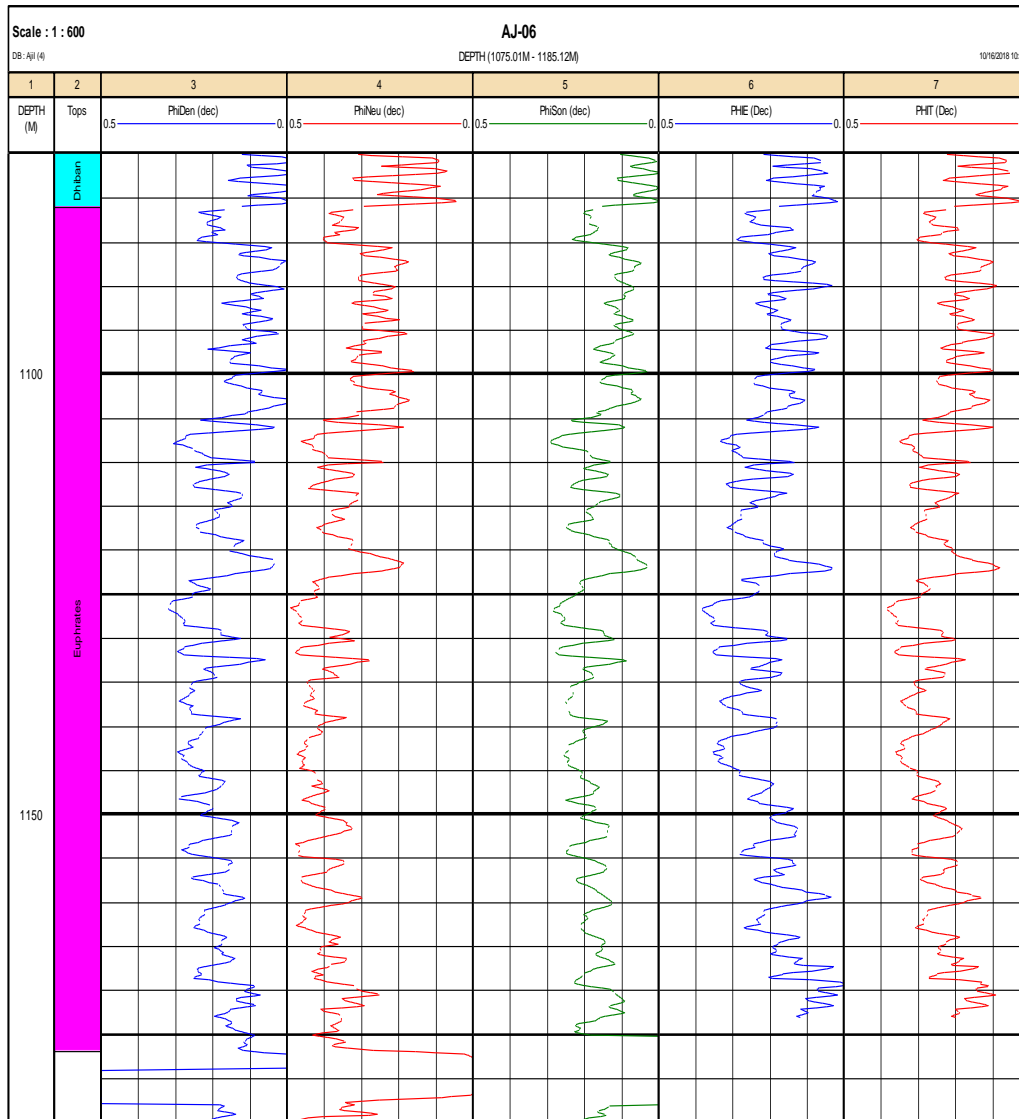


Figure 6- logs showing porosity type in AJ-6 well.

4- Determination of lithology and Mineralogy

The lithology and mineralogy of the studied formations has been determined by using two cross plots

Neutron-density lithology cross plot

These logs combination are used to identify lithology. The horizontal axis represents the neutron log; while the vertical axis represents density log [9]. The neutron–density cross plot is one of the oldest quantitative interpretation tools it was the principal method for determining the formation lithology [26]. The gamma ray log measures the natural radiation of a formation and primarily functions as a lithology log. It helps differentiate shales (high radioactivity) from sands, carbonates, and anhydrites (low radioactivity). The neutron log is a porosity device that is used to measure the amount of hydrogen in a formation, which is assumed to be related to porosity. The density log is a porosity device that measures electron density, and from that, formation bulk density. When these three logs are used together, lithologies can be determined [13]. These logs shown in [Figure-7]

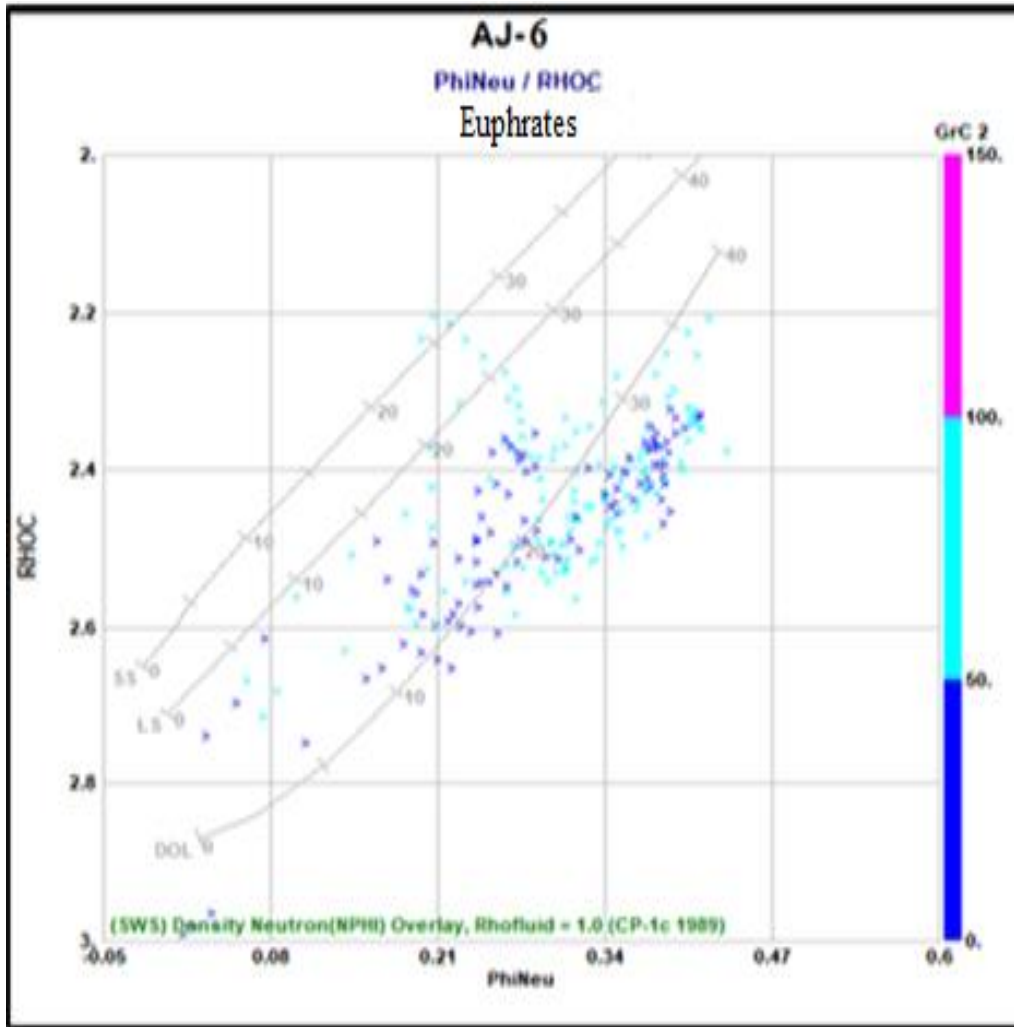


Figure-7 Neutron- density lithology plot for the Euphrates Formation in well AJ-6

M-N cross plot

This cross plot is used to identify mineral mixtures from sonic density and neutron log to provide the Lithology-dependent quantities, M and N, [22]. M and N are defined as: The two formula used in this method take the readings from the three porosity log and remove the effect of porosity, thereby leaving only the lithological effect.

$$M = (\Delta t_{fl} - \Delta t / \rho_b - \rho_{fl}) \times 0.01 \quad \dots\dots (16)$$

$$N = \phi N_{ft} - \phi N / \rho_b - P_f \quad 1 \dots\dots (17)$$

Where:

- Δt =interval transit time in the formation
- Δt_{fl} =interval transit time in the fluid of the formation
- ρ_b =formation bulk density
- ρ_{fl} =fluid density
- ϕN =neutron porosity
- ϕN_{ft} =neutron porosity of the fluid of the formation (usually =1.0)

Figure-8 have been showed M-N cross plot of the studied formations consist of limestone, dolomitic limestone, and anhydritic limestone in Euphrates Formation represented by mainly calcite and dolomite are the main minerals.

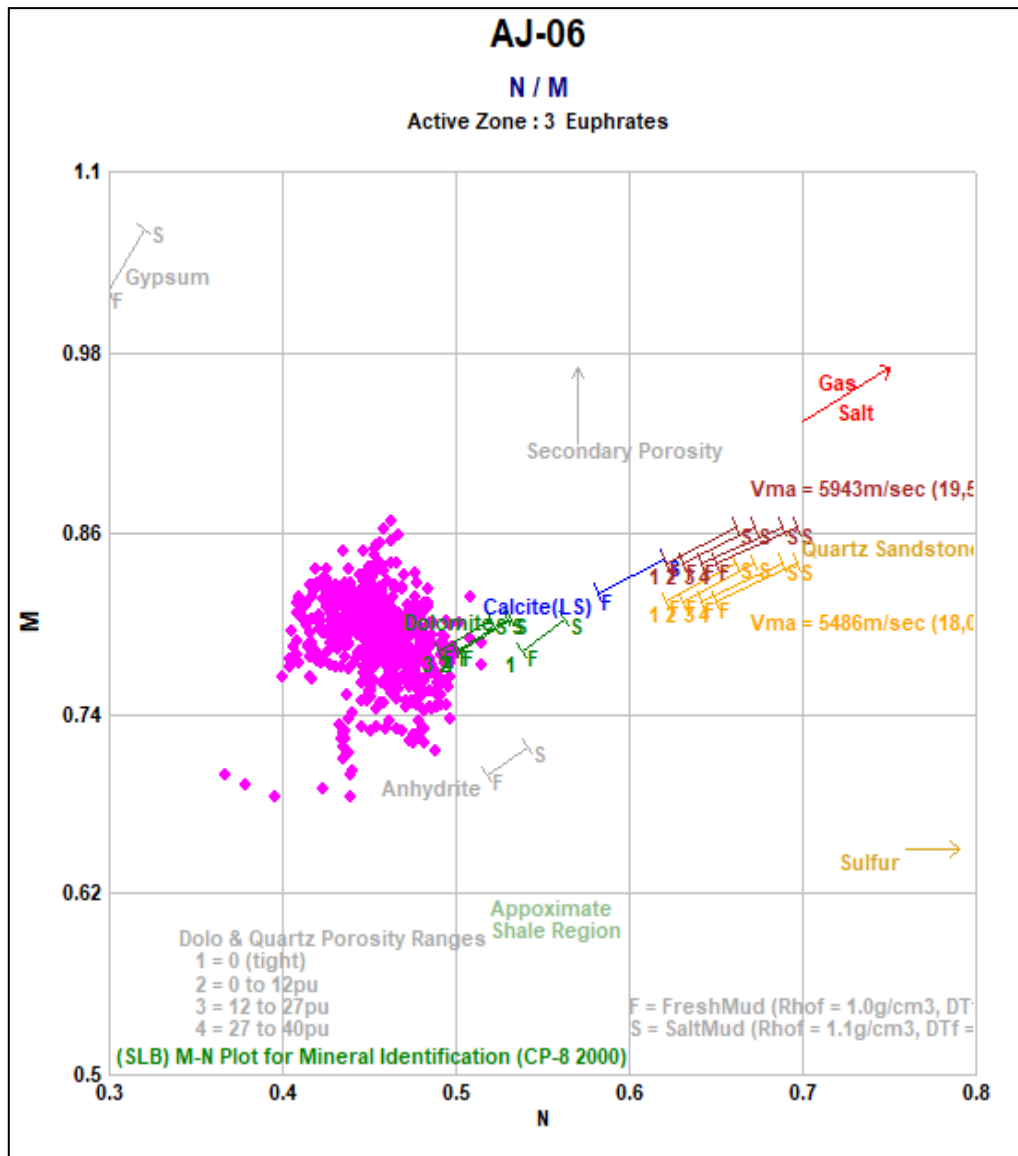


Figure 8- N/M lithology plot for the Euphrates Formation in well AJ-6.

Computer processes interpretation

The results from the computer processes interpretation (CPI) of Euphrates Formation that are deduced using Interactive Petro physics (IP) software.

The porosity in the Euphrates Formation is good due to diagenetic processes such as dolomitization and dissolution. These processes have important effect on the formation and give it a good reservoir property, because the important factor of reservoir properties is presence porosity and this character is very common in Euphrates Formation and from studied thin section has been showed how the diagenesis processes especially the constructive processes for porosity, so in more intervals in Euphrates Formation has shown high values of porosity and bearing for hydrocarbons. Figures-(9, 10).

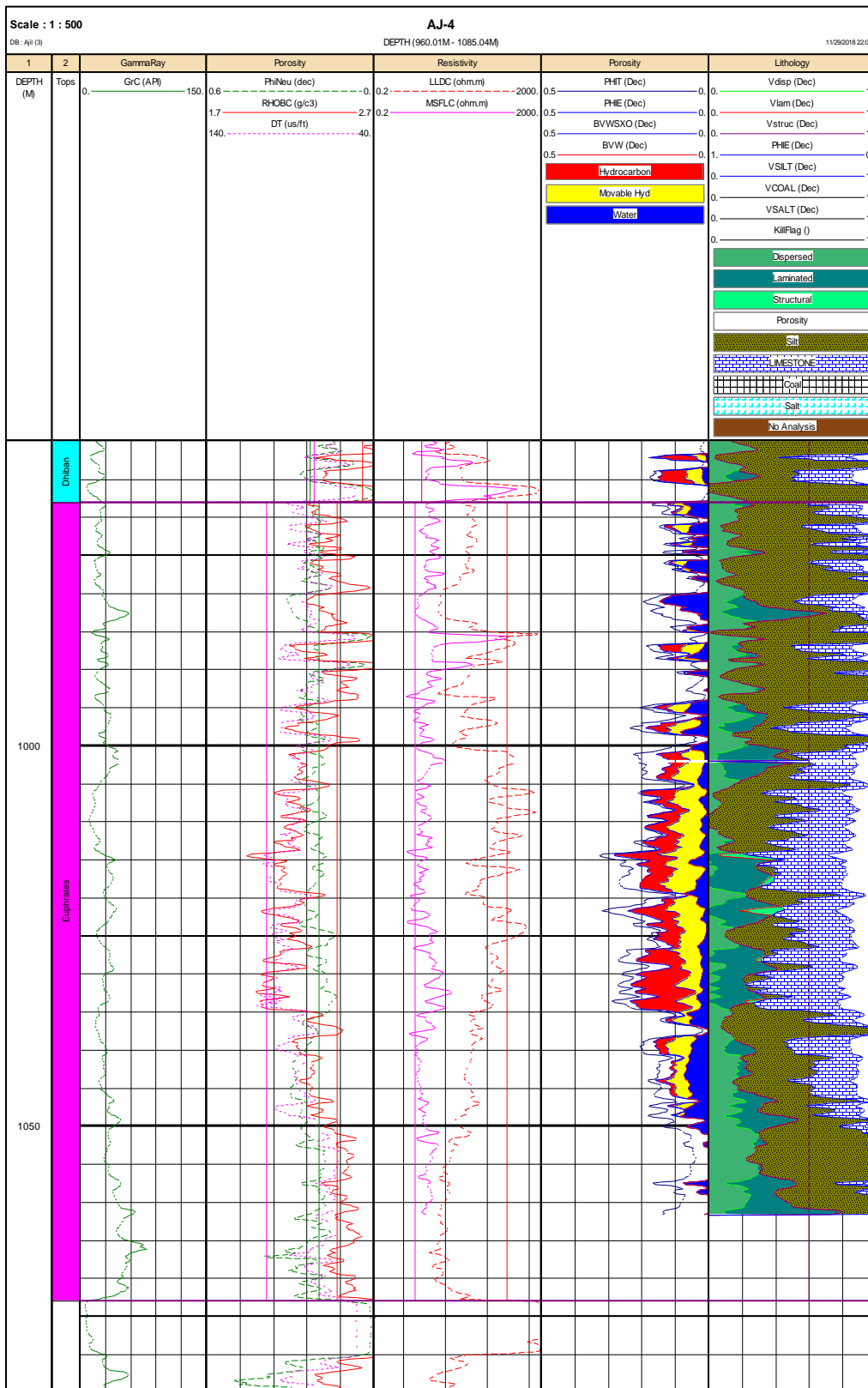


Figure 9- CPI of AJ-4 well.

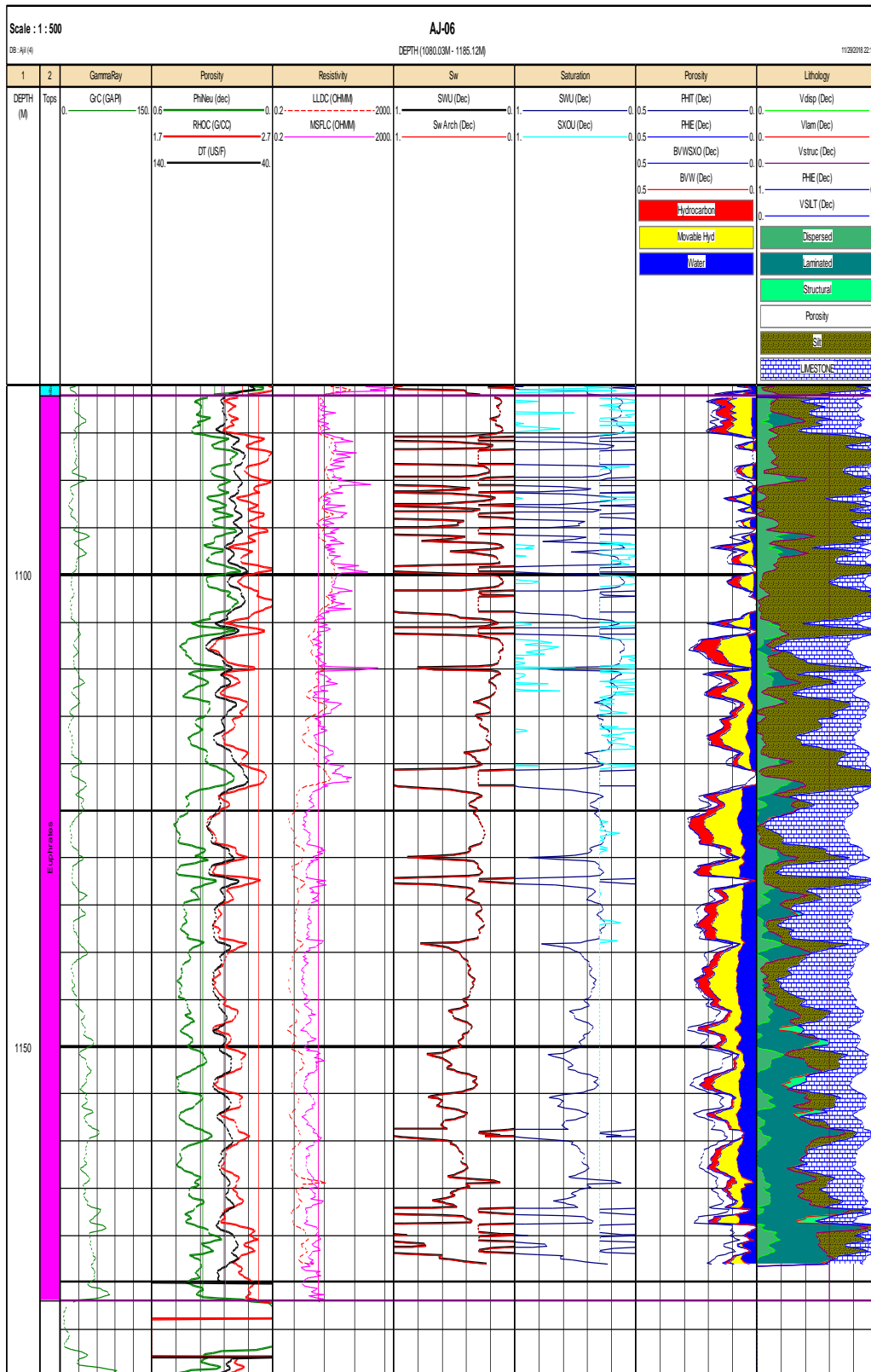


Figure 10- CPI for AJ-6 well.

Discussion and Results

1- Total porosity, effective porosity and secondary porosity have been calculated from neutron, density, and sonic logs. secondary porosity is high; it's indicates by effect of diagenesis processes in the formation.

- 2- Primary porosity is poor to fair in the reservoir according to the classification of porosity [27]
- 3- The results from the computer processes interpretation (CPI) of the studied formation that are deduced using Interactive Petro physics (IP) software. The secondary porosity in the Euphrates Formation is good due to diagenetic processes such as dolomitization and dissolution. In more intervals in Euphrates Formation has shown high values of porosity and bearing for hydrocarbons, Figure-11 show the porosity types which are diagnosed within Euphrates formation.
- 4- Hydrocarbone saturation include both gas and oil, where Ajeel oil field is production oil and gas. Hydrocarbon saturation vs. water saturation shows that Hydrocarbon saturation in the reservoir is varying from poor to moderately comparison with water saturation.
- 5- From RHOB-NPHI cross plot, Euphrates Formation composed mainly from Limestone and dolomite with minor of anhydrite.
- 6- From M-N cross plots shows the mineralogy of the Euphrates Formation composed mainly form calcite and dolomite.
- 7- Dhiban Formation represents cap rock for Euphrates Formation because the lithology type of rock that is possessed this Formation. The anhydrite rocks nature is non permeable, so will keep the hydrocarbon and prevent it from escape from reservoir formation. Dhiban Formation composed of large quantity of Anhydrite and anhydritic limestone, which are recognized based on the reading of GR, RHOB, NPHI, and DT logs.

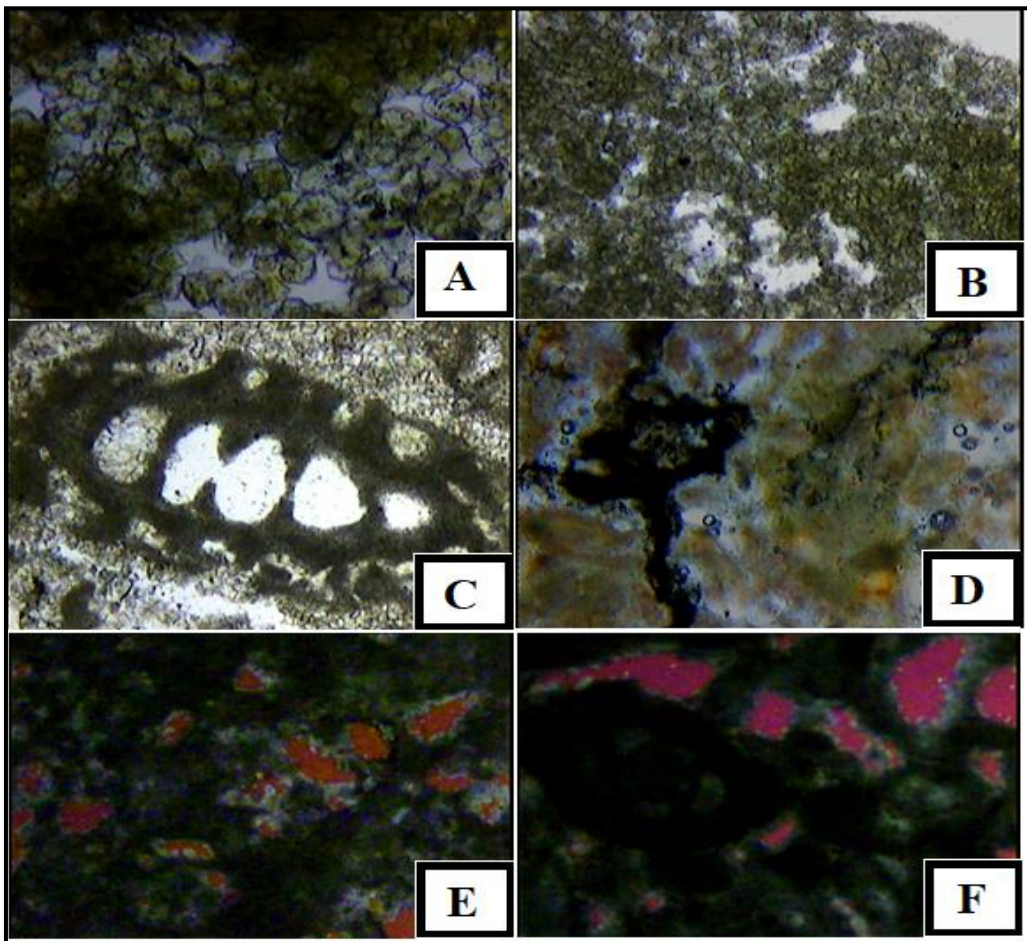


Figure 11- Porosity types which are diagnosed within Euphrates Formation: A and B Intercrystal porosity within dolomite crystals, C Moldic porosity, D Channel porosity, E and F Vuggy porosity.

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