# Evaluation of Petrophysical Properties Interpretations from Log Interpretation for Tertiary Reservoir /Ajeel Field

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**Abstract**

Tertiary Formation is divided into three main reservoir units. They are designated from top to bottom designated as Jeribe, Dhiban, and Euphrates. Jeribe unit is the main producing layer in the Tertiary Formation. Formation evaluation has been carried out for the Tertiary Formation of the Ajeel Field by analyzing various log and core data giving a full description of the properties in this Formation. Didger software package 3 was used to digitize the available log data, with the log interpretation by Interactive Petrophysics (IP V3.5) software which was used to correct the environmental parameters and produce the results of CPI. The logs studied were (caliper, deep resistivity, shallow resistivity, gamma ray, sonic porosity, neutron porosity and bulk density). Pickett method was used to determine of the Archie's parameters (the tortuosity factor (a), cementation exponent (m) and the saturation exponent (n)). Total porosity was also calculated using neutron-density porosity logs. The effective porosity was obtained from the total one after extracting the shale percentages from the formation. classical method were used to predicate permeability with the core permeability shows the method correlations. These correlations were used to estimate permeability in non-cored wells. According to these work, Tertiary Formation was divided into seven zones (Jeribe in to J1, J2, J3 and Dhiban in to D1, D2 and Euphrates in to E1, E2).

## 1. Introduction

Formation evaluation is the process of interpreting a combination of measurement taken inside a wellbore to detect and quantify hydrocarbons reserves in the rock adjacent to the well. Formation evaluation data can be gathered with wireline logging -while-drilling tools. Data are organized and interpreted by depth and represented on a graph called a log [1]. To define the physical properties of the reservoirs such as saturation, porosity, hydrocarbon movability, used wireline logs but the permeability is more difficult to obtain from logs but defined in other ways will be mentioned later [2]. The evaluation for petrophysical properties has an unequaled scope to observe the relationship between the saturation and porosity [3].

Formation evaluation is used in exploration, production and development for reservoir to determine whether a potential oil and/or gas field is commercially viable [4] and it consider an important for estimating oil reserves and plays a major role in the economics of oil [4].

### 1.1 Area of Study

Ajeel Field was discovered in 1977 with drilling of Aj-1 on the crest of a seismically mapped area. Ajeel oil field is located in the portions of Tikrit and Kirkuk provinces about 30 km North-East of Tikrit city, in Iraq. It mostly extend toward (North-East)-(South-West), and parallel to "Alnikhila" dome in "Hemreen" Oil Field, figure (1) shows the exactly location of Ajeel oil field in north of Iraq [5].

The drilling process started in 1977 for discovering the hydrocarbon accumulation. The Tertiary reservoir in this field is divided into two reservoirs, the Transition reservoir (an average depth 3175 ft RTKB) and the main reservoir (an average depth 3415 ft RTKB) [6].

Ajeel Field is situated on the flank of the Jabal Hamerin range of hills in plains of northern Iraq some 80km to the southeast Kirkuk and about 175km to NNW of Baghdad. The structure roughly (5X20km) in size, has a clear surface expression. The elevation of the field is some 250m above sea level [7].

In Ajeel field choice twelve wells to study, which penetrate Tertiary formation as illustrated figure (2). These wells are AJ-1, AJ-4, AJ-6, AJ-7, AJ-10, AJ-12, AJ-13, AJ-14, AJ-15, AJ-22, AJ-25, AJ-54.
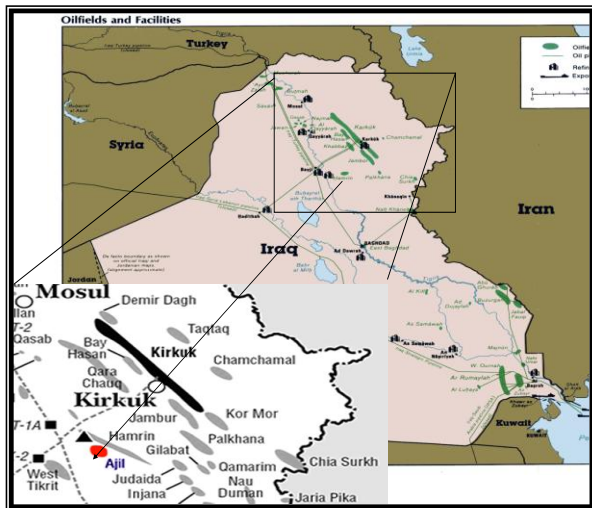


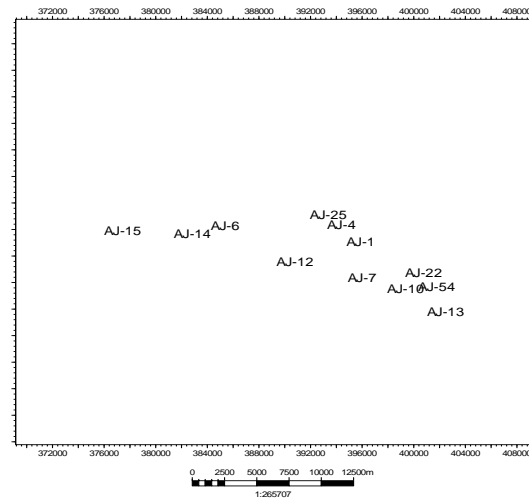Figure (1) Location of Ajeel Oilfield in North of Iraq [7]



Figure (2) Location Map of Ajeel Wells

## 1.2 Geological Characterization

The field is an asymmetrical WNW-ESE trending elongated anticline of 5x20km size, with gentle dips of 2-4° on west and east flanks, somewhat steeper dip of 7° on south flank, and very steeper dip of 20-25° on north flank. In spite of the fully good well converge; structural uncertainties still exist particularly on west flank due to poor seismic converge [6].

While no major faults have been renowned in the field, a number of minor faults (throws of up to 20m) explain the field which do not affect the continuity of the thick main reservoir accumulation but could well lead to block separation in thin transition beds layers. Figure (3) shows the Contour map and wells location of Ajeel oil field. The main reservoir consists of a 180m of thick sequence of dolomitised carbonates and minor anhydrites [8].

This separates into stratigraphic units which are from top to bottom: (the Jeribe, Dhiban, Euphrates and Serikagni (all of Miocene age)) lying unconformably on the basal anhydrite from Oligocene age. Overlying this main reservoir sequence is the transition beds set, which include a number of thin carbonate layers separated by continuous anhydrites accumulation in total thickness of some 120m of which thickest and probably best developed one is the 15m (T12-T115) layers [9].
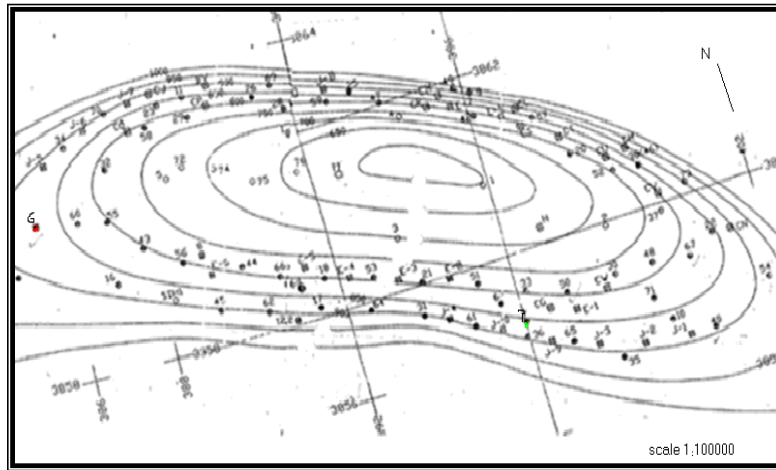
Figure (3) Contour Map and Wells Location of Ajeel Oilfield [6]

Dolomite is the main carbonate lithology in the main reservoir. In the Transition beds, carbonate is more evenly distributed as a mixture of limestone and dolomite. Jeribe which is the top most layer of main reservoir is a little muddy, dolomite carbonate unit with much anhydrite nodules. The underlying Dhiban unit is essentially the same as Jeribe but include a high concentration of anhydrite nodules, chiefly towards its base, which make it fundamentally a poor reservoir unit. Euphrates is again dolomitic but consist of less anhydrite, and has by far the best reservoir quality.

The Serikagni involve muddy carbonate sequence. The Basal anhydrite contains of a single layer of massive anhydrite with a thickness of 2-8m extending over huge areas, hence it can provide a bar to vertical flow.

The bottom- most "Favreina" unit (informal name) has deep water carbonate facies of poor reservoir quality in the lower part, but has best shallow-water dolomites towards the top.

The carbonates offer a complex sequence of events including calcite and anhydrite cementation, leaching, dolomitisation, compaction, and pressure solution. The main porosity kind is mouldic/ vuggy kind formed by filtrate. Heavy compaction effects combined with facies. Controlled matrix properties were responsible for the strict character of sediments on the steep northern flank. The distinguished quantitative reservoir properties as applicable to the several reservoir units of interest in the field (thickness, porosity and permeability) are indicated in table (1-1).

The transition beds are much less sure than in the main reservoir. For the western part of the field which for the thin transition bed layers could be unattached by faulting from the east [6].

Table (1-1) Quantitative Reservoir Properties [6]

| Formation | Thickness m | Porosity % | Permeability md |
|-----------|-------------|------------|-----------------|
| $T_5$ | 2-5 | 20 | 7 |
| $T_6$ | 5-8 | 26 | 22 |
| $T_9$ | 1-3 | 18 | 5 |
| $T_{10}$ | 1-3 | 23 | 11 |
| $T_{11}$ | 2-6 | 21 | 5 |
| $T_{12-15}$ | 12-19 | 23 | 12 |
| $T_{16}$ | 1-4 | 18 | 13 |
| $T_{18}$ | 2-7 | 15 | 3 |
| $T_{19-20}$ | 4-7 | 18 | 5 |
| Jeribe | 23-32 | 24 | 17 |
| Dhiban | 27-32 | 18 | 8 |
| Euphrates | 75-85 | 24 | 36 |

**1.3 Aims of Study**

1.  Well log interpretation and the evaluating for petrophysical properties of the reservoir units of Ajeel field using logs data and core analysis.

2. To define the several properties of the reservoir such as porosity, permeability, hydrocarbon saturation, shale volume, lithology, and bulk volume of water using available logs.

## 2. Materials and Methods

### 2.1 Software and data

The used material in this study include:

1-Digger package 3 was used to digitize the available log data,

2- Interactive Petrophysics (IP V3.5) software, which was used to correct the environmental parameters and produce the results of CPI.

3-Las file for 12 well (AJ-1, AJ-4, AJ-6, AJ-7, AJ-10, AJ-12, AJ-13, AJ-14, AJ-15, AJ-22, AJ-25, AJ-54).

### 2.2 Environmental Corrections of Well Logs

Environmental corrections were used Schlumberger charts 2005, which are provided to (IP) program as the environmental correction model. Borehole environment affects well logs reading such as borehole size, temperature, pressure, shale effect, invasion effect and other environmental factors affect the well logging tool responses. Environmental corrections are applied to correct the logging measurements to the standard conditions [8].Table (3-2) shows the common log environmental corrections.

Table (3-2) Summary of Common Log Environmental Corrections [8]

| Measurement | Effects |
|---|---|
| **Gamma ray** | Mud resistivity, hole size, and tool  position |
| **Spherically focused** | Mud resistivity, hole size, and tool position |
| **Induction** | Mud resistivity, hole size, and tool position |
| **Neutron logs** | Hole size, temperature, pressure, borehole, and formation salinity; mud weight, mud type, mud cake thickness, and tool position |
| **Density logs** | Hole size, formation density and mud weight |

It has been noted that the difference between the original logs readings and the corrected logs readings was too small except only in bad hole condition were the hole was more caved or washout. Schlumberger Environmental Corrections presented in (IP) software are used for correcting the studied well logs formation. Table (3-3) shows the corrected logs:

Table (3-3) Corrected Logs

| NO | Input logs | Corrected logs |
|---|---|---|
| 1 | GR | GRC |
| 2 | RHOB | RHOBC |
| 3 | NPHI | NPHIC |
| 4 | RT | RTC |
| 5 | MSFL | MSFLC |

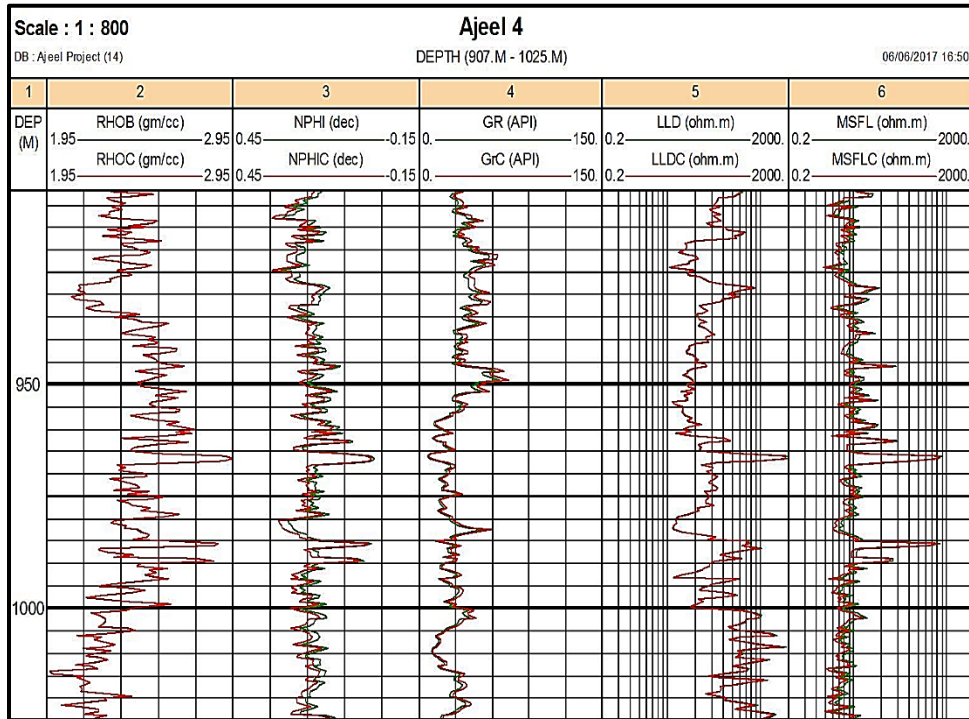Figures (3-3) & (3-4) show corrected well AJ-4 & AJ-6, respectively.

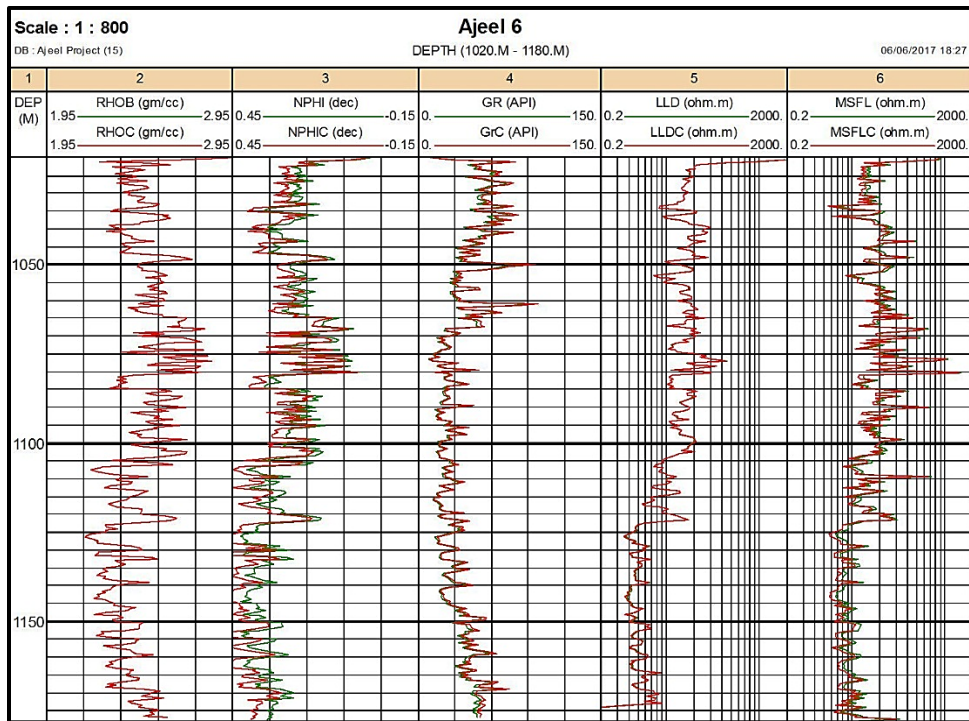Figure (3-3) Environmental Corrections for the Well AJ-4



Figure (3-4) Environmental Corrections for the Well AJ-6

## 3 Results and Discussion

Petrophysical Properties Interpretations is the study of rock properties and their interactions with fluids (gases, liquid hydrocarbons and aqueous solutions) [10, 11].The petrophysical properties that are discussed in this text include:

- Shale volume
- Porosity
- Water saturation

### 3.1 Shale Volume

Shale [12] is composed by the consolidation of fine grained material formed by mud, clay and silt. Shale is mainly porous and not permeable contains hydrocarbons formed good cap rocks and do not form reservoir. The presence of shale in a reservoir can cause wrong values for water saturation and porosity derived from logs and cause for all porosity tools (Density, Neutron and Sonic) will record too high porosity and will cause resistivity log to record too low resistivity. Methods of calculating volume of shale:

- GR
- Density- Neutron

### 3.1.1 Clay Volume Determination from GR

The GR log is a measurement of the natural radioactivity of formation. In sedimentary formations, the log reflects the shale content of formation because the radioactive elements refer to concentrate in shale and clays. The clean formations usually have a very low level of radioactivity, unless a radioactive contaminant such as granite wash or volcanic ash is present or formation waters contain dissolved radioactive salts [11]. At first, the well logs were digitized by using Didger software and then digitized data uploaded to IP software. Then determine the volume of shale from gamma ray log, calculate gamma ray index ($I_{GR}$) by using the following equation [13, 14]:

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad \text{--------------- (3-9)}$$

After $I_{GR}$ is calculated, then, $V_{sh}$ is calculated from the following equation. For consolidated and older rocks [15]:

$$V_{sh} = 0.33[2^{(2 * I_{GR})} - 1.0] \quad \text{--------------- (3-10)}$$

### 3.1.2 Neutron–Density Plots

The neutron–density cross plot is more necessary for many log interpretation procedures. Neutron and density measurements are affected by lithology, porosity, hydrocarbon density.

Volume of clay from the cross plot between Density and Neutron logs in a very shaly formation defined by reference to the gamma ray, first, clay point is identified and clean limestone point also identified, density for clean limestone is usually taken 2.71.

Note the $\phi_D$ and $\phi_N$ crossplot can be used with good accuracy in oil bearing formation, the present of gas or light oil will cause the point to shift in the northwesterly direction. In such cases $V_{sh}$ should be evaluated from GR or SP to evaluate the amount of shift [13]. Neutron-density cross plot, is used for detecting the lithology. The cross plots for wells show that most of points fall on the dolomite and some point fall on limestone. This indicates that Tertiary formation consists mainly from a combination matrix of limestone and dolomite. Figure (3-5) shows the cross plot of $\phi_N$ and $\phi_D$ with clean and clay line for well Aj-6.
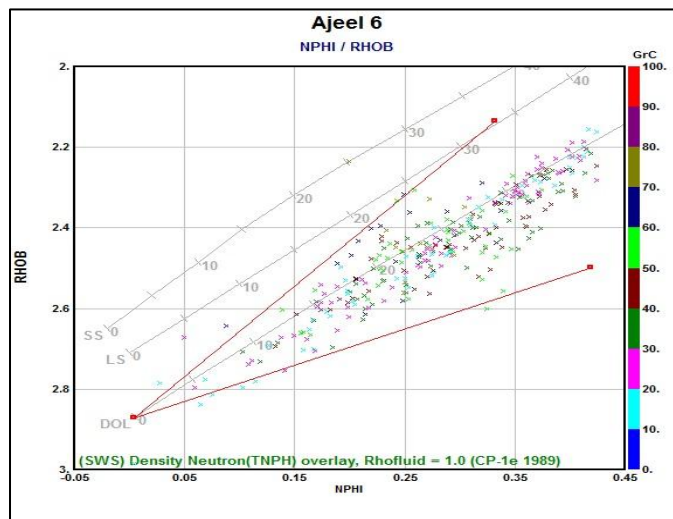


Figure (3-5) Neutron –Density Cross Plot for Well AJ-6

**3.2 Porosity Determination**

The measurement of porosity is important to the petroleum engineer since the porosity determines the storage capacity of the reservoir for oil. Porosity is determined from the measurements from one, or a combination of the following logs density log, neutron log and sonic log. Interactive Petrophysics Program (IP) $v3.5$ is used to calculate the porosity using density and neutron log [16, 17].

The neutron –density logs provide the good combination for detecting gas zones, porosity and volume of shale. Density –neutron crossplots was used to determine porosity, before using crossplot neutron porosity and density porosity must be corrected for shale content, and both porosities must be suitable porosity scale (sandstone, limestone, and dolomite).

The following equations are used to correct $\phi_D$ and $\phi_N$ for shale content [17]:

$$\phi_N = \phi_N - [(\frac{\phi_{N\,clay}}{0.45}) * 0.3 * Vcl\,] \text{------------- (3-11)}$$

$$\phi_D = \phi_D - [(\frac{\phi_{D\,clay}}{0.45}) * 0.13 * Vcl\,] \text{------------ (3-12)}$$

Then porosity determined by using the following equation [13]:

$$\phi = \sqrt{\frac{\phi_N^2 + \phi_D^2}{2}} \quad \text{------------ (3-13)}$$

The effective porosity (ratio of the volume of interconnected pore to the total volume of reservoir rock) determined by the following equation:

$\phi_e = \phi_T * (1.0 - Vcl)$ ------------- (3-14)

$\phi_e$: effective porosity

$\phi_T$: total porosity

$V_{cl}$ : clay volume

Secondary porosity is porosity formed within a reservoir after the process of deposition, vuggy or fracture secondary porosity can be calculated by secondary porosity index (SPI).

$$SPI = \phi t - \phi sonic \text{------------- (3-15)}$$

**3.3 Water Saturation Determination**

Water saturation determinations from resistivity logs in clean (nonshaly) formations with homogeneous intergranular porosity are based on Archie's water saturation equation. The equation [18] (2-1) used to calculate Sw. F is taken from the measured porosity of the formation from equation (2-2). The water saturation in the flushed zone (*Sxo*) a similar expression exists:

$$Sxo^n = \frac{F\,Rmf}{Rxo} \text{----------------- (3-16)}$$

Where

Rmf is the mud filtrate resistivity

Rxo is the flushed zone resistivity

n is the saturation exponent

Sxo and Sw can be used to compute the amount of moveable hydrocarbon [8]:

Moveable hydrocarbon $= \phi sxo - \phi sw$ ----------- (3-17)

**3.4 Determination of Water Formation Resistivity**

A careful value of formation water resistivity (Rw) is primary to complete interpretation process. Formation water is the water uncontaminated by drilling mud and called interstitial water or connate water. The resistivity of formation water (Rw) is necessary parameter required for calculating hydrocarbon and water saturation. Three methods are used to determine Rw [19].

**3.4.1 Formation Water Resistivity from the SP**

The good values of Rw can be easily being found from the SP curve recorded in clean no shally formation. Equation can be written in resistivity terms as**:**

$$SSP = -K \log \frac{Rmfe}{Rwe} \quad \text{---------------- (3-18)}$$

Rwe is the equivalent formation water resistivity and Rmfe is the equivalent mud filtrate resistivity. Knowing the formation temperature, the static SP value recorded can be transformed into the resistivity ratio Rmfe/Rwe when the resistivity (Rmf) of sample of mud filtrate measured, the equivalent formation water resistivity, Rwe is easily

calculated. By using Interactive Petrophysic program depending on SP log, but we don't have SP log readings so we did not use this method.

### 3.4.2 Formation Water Resistivity from Ratio Method

Ratio method is based on the a direct comparison between the readings of the micro resistivity tool which read Rxo and deep resistivity tool reading Rt and it is derived from Archie formula. Such in the following equations:
Where the porosity is eliminated in the virgin zone we can write:

$$Rt = F * \frac{Rw}{Sw^2} \text{---------------- (3-19)}$$

In the invaded zone

$$Rxo = F * \frac{Rmf}{Sxo^2} \text{---------------- (3-20)}$$

In the water zone, where:

$$Sw = Sxo = 1 \text{---------------- (3-21)}$$

Substituting equations (3.19) and (3.20) in equation (3.21) give us:

$$\frac{Rxo}{Rt} = \frac{Rmf}{Rw} \text{---------------- (3-22)}$$

In practice

$$Rw = \frac{Rdeep}{Rshallow} * Rmf \text{---------------- (3-23)}$$

The results can be seen in table (3-4).

Table (3-4) The Values of Water Formation Resistivity from Ratio Method

| Rw from Ratio method | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Formation** | **AJ-1** | **AJ-4** | **AJ-6** | **AJ-10** | **AJ-12** | **AJ-13** | **AJ-14** | **AJ-15** |
| **Jeribe** | 0.0596 | 0.065 | 0.043 | 0.068 | 0.054 | 0.058 | 0.066 | 0.045 |
| **Dhiban** | 0.0634 | 0.044 | 0.065 | 0.049 | 0.058 | 0.006 | 0.055 | 0.051 |
| **Euphrates** | 0.066 | 0.059 | 0.07 | 0.063 | 0.061 | 0.059 | 0.064 | 0.062 |

### 3.4.3 Formation Water Resistivity from Water Analysis

Rw can be estimated from analysis of water sample it can be determined when the chemical analysis of the formation water is available. This method converted concentration of ions into equivalent Nacl concentration. The concentration of a solution of pure Nacl has the same resistivity of (Rw) at a given temperature because the major component of dissolved material in generality of formation waters is sodium chloride, the NaCl concentration is the weighted sum of the individual ion concentration, once the equivalent Nacl concentration is gained, the Rw can be obtained by using the equations [20] (3-24) and (3-25). Table (3-5) represents Rw values for all the studied wells.

$$Rw@_{75} = 0.0123 + \frac{3647.5}{\{NaCl\,(ppm)\}^{0.955}} \text{---------------- (3-24)}$$

$$Rwfm = Rw75 * \frac{81.77}{ft+6.77} \text{---------------- (3-25)}$$

Where,
Rw75: Formation water resistivity @ 75°F
Rw: Formation water resistivity @ formation temperature, °F.
CSP: Nacl concentration in ppm
Ppm: part per million
Ft: formation temperature

The results show in table (3-5).

Table (3-5) The Values of Water Formation Resistivity from Water Analysis

| | AJ-14 | | AJ-15 | | AJ-22 | | AJ-54 | |
|---|---|---|---|---|---|---|---|---|
| **Layer** | **Con.ppm** | **RW** | **Con.ppm** | **RW** | **Con.ppm** | **RW** | **Con.ppm** | **RW** |
| **Jeribe** | 163824 | 0.0505 | 71521 | 0.09 | | | 107155 | 0.069 |
| **Dhiban** | | | | | 99460 | 0.073 | | |
| **Euphrates** | 112895 | 0.066 | 110990 | 0.067 | 107073 | 0.069 | | |

**3.5 Determination of Archie's Parameters (a, m and n) from Well Logs Using Pickett's Method**

Archie's equation (2-16) is applied to determine water saturation. The analysis for Archie's parameters (a, m & n) have the higher influence on water saturation calculations than the resistivity [7]. Rearrangement of equation (2-16) and by using logarithms, gives a straight line equation as given below:

$$Sw^n = \frac{a.Rw}{\phi^m Rt} \text{----------------- (2-16)}$$

$$\log Rt = -m \log \phi + \log(a\,Rw) - n \log Sw \text{----------------- (3-26)}$$

In the water bearing zone, in a 100% water bearing formation $(Rt = Ro)$ the equation (3-26) becomes;

$$\log Rt = -m \log \phi + \log(a\,Rw) \text{---------------- (3-27)}$$

Equation (3-27) this cross plot involves plotting $\phi$ versus resistivity deep (Rt) on log – log graph paper and the straight line on log –log plot with a slope = m and intercept equal to (a.Rw) at ($\phi$=1) where Rw is known previously. For 100 % water bearing formation equation (3-26) becomes;

$$a\,Rw = \phi^m Rt \text{---------------- (3-28)}$$

Equation (2-16) can be rewritten for irreducible water levels;

$$Swi^n = \frac{a.Rw}{\phi^m Rtirr} \text{---------------- (3-29)}$$

Archie's parameters a, m, and n had been calculated by drawing the best straight line in the water zone on cross plot between $\phi$ versus Rt by IP program. At begging, we used all wells together then, calculated the value of Rw = 0.06 and determine Archie's parameters as m=2, n=2 and a=1 show in figure (3-7).

Then use all well alone and determine (a, m, n) in table (3-6). The figures (3-8) & (3-9) represent Pickett's plot for the wells AJ-1 & AJ-4, respectively.

Table (3-6) Archie's Parameters

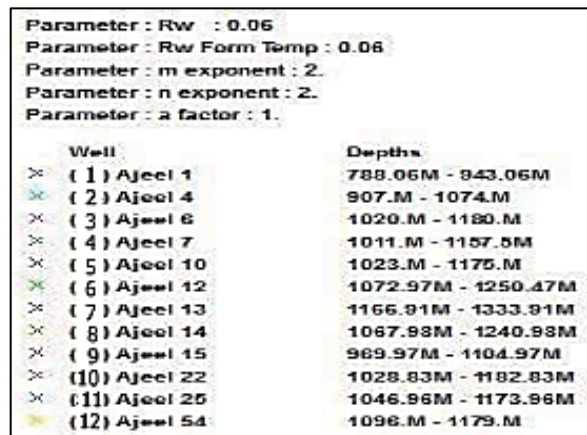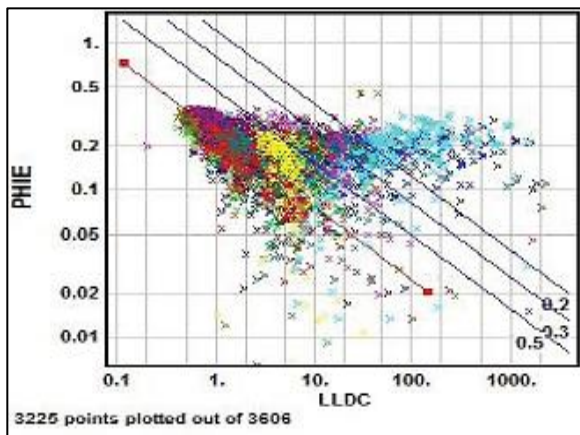| Well No. | a | m | n |
|----------|-----|------|------|
| 1 | 1.4 | 2 | 2 |
| 4 | 1 | 2 | 2 |
| 6 | 1.2 | 2 | 1.5 |
| 7 | 1.4 | 1.7 | 1.4 |
| 10 | 1.1 | 1.8 | 2 |
| 12 | 1 | 1.7 | 1.5 |
| 13 | 1.2 | 1.5 | 1.4 |
| 14 | 1.1 | 1.7 | 1.5 |
| 15 | 1 | 1.8 | 1.72 |
| 22 | 1 | 2 | 2 |
| 25 | 1 | 1.72 | 1.9 |
| 54 | 1.3 | 1.77 | 1.76 |



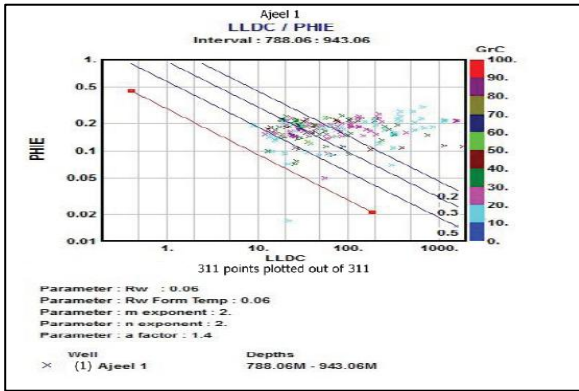Figure (3-7) Values of Archie's Parameters by Picket's Plot for Ajeel Field
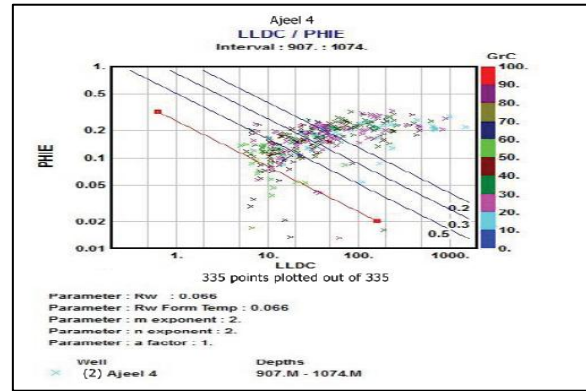
Figure (3-8) Pickett's Plot for AJ-1



Figure (3-9) Pickett's Plot for AJ-4

## 3.6 Fluid and Formation Analysis

Depending on the matrix density of the carbonate rocks, a Limestone/ Dolomite model was used as a first step in the IP program. The formation evaluation after log curves conditioning process was done as follows:

- Determination of lithology
- Calculation of clay volume
- Calculation of porosity
- Calculation of water saturation
- Permeability modeling

### 3.6.1 Water and Hydrocarbon Saturations Determination

Porosity and fluid saturation are among the most important reservoir properties used in the reserve estimation of oil and gas. Because of the heterogeneity of most reservoirs regarded the continuous recording of these properties vs. depth is necessary for accurate evaluations [21].

Fluid saturation is estimated from resistivity measurement by the Archie equation (2-16) to calculate the water saturation in uninvaded zone.

$$Sw^n = \frac{a.Rw}{\phi^m Rt} \text{----------------- (2-16)}$$

This is the saturation needed to determine the original hydrocarbon in place, **Darwin and Julian,** 2008 [8]. It is to be noted that, when Eq. (2-16) is used with micro-resistivity logs it gives the value of the water saturation in the flushed zone, which is composed of mud filtrate resistivity Rmf expressed by equation (3-34).

$$Sxo = \left(\frac{a.Rmf}{\phi^m Rxo}\right)^{1/n} \text{----------------- (3-30)}$$

In equation (3-30) can be used to estimate the movable hydrocarbon saturation and the residual oil saturation, depending on coefficients (a, m and n) these parameters have a large influence on calculation of water saturation. The residual oil saturation Sor, and the movable hydrocarbon Shr, is calculated from the following equations.

$$Sor = \phi * (1 - Sxo) \text{----------------- (3-31)}$$
$$Shr = \phi * (Sxo - Sw) \text{----------------- (3-32)}$$

Determination of flushed zone water saturation has its advantage where the ratio Sw/Sxo is an indicator of oil movability. When Sw/Sxo=1, then no moved hydrocarbon. If Sw/Sxo is 0.7 or less, that means that there is an indication of movable hydrocarbon existence [11]. The results of fluid analysis are shown in figures (3-10) & (3-11) for AJ-1 & AJ-4 and the plots for the other wells are shown in appendix (A).

### 3.6.2 Formation Analysis (Bulk Volume Analysis)

The bulk volume of water can be identified as a unit volume of porous media occupied by water. The bulk volume of hydrocarbon is the amount of hydrocarbon in the pore volume. The computer processed interpretation (CPI) is a set of logs for the results of porosity, saturation, fluid & matrix analysis tracks and other parameters of interpretation.

The formation analysis results for the wells are given in Figures (3-10) & (3-11) for AJ-1 & AJ-4, in the bulk volume analysis track. These figures, which represent Computer Processed Interpretation (CPI), depict as the followings:

1. Porosity analysis track, which is divided in to effective porosity (φe), water filled porosity in the invaded zone (*Bvwxo* = φe.Sxo), and water filled porosity in the uninvaded zone (*Bvw*= φe.Sw). The area between (φe.Sxo) and (φe.Sw) represents the movable hydrocarbon, but the area between (φe) and (*Bvw*) represents the total hydrocarbon.

2. Bulk volume analysis is divided into effective porosity (φe), percentage of shale (Vsh), and percentage of non-shale matrix (Dolomite). The percentage of shale or the volume of clay (Vcl) was mainly determined by using the gamma ray data such as equation (3-1).In addition, and depending on the lithology of carbonate reservoir, the neutron density porosity model was used for the porosity calculation, while the sonic porosity model was used for the bad hole interval.
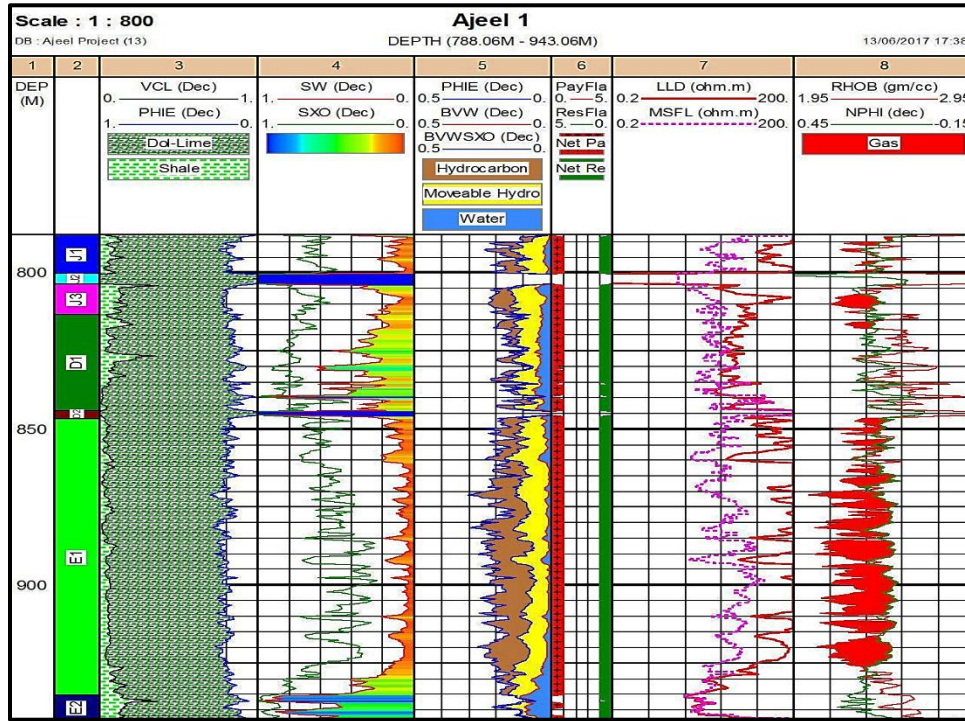


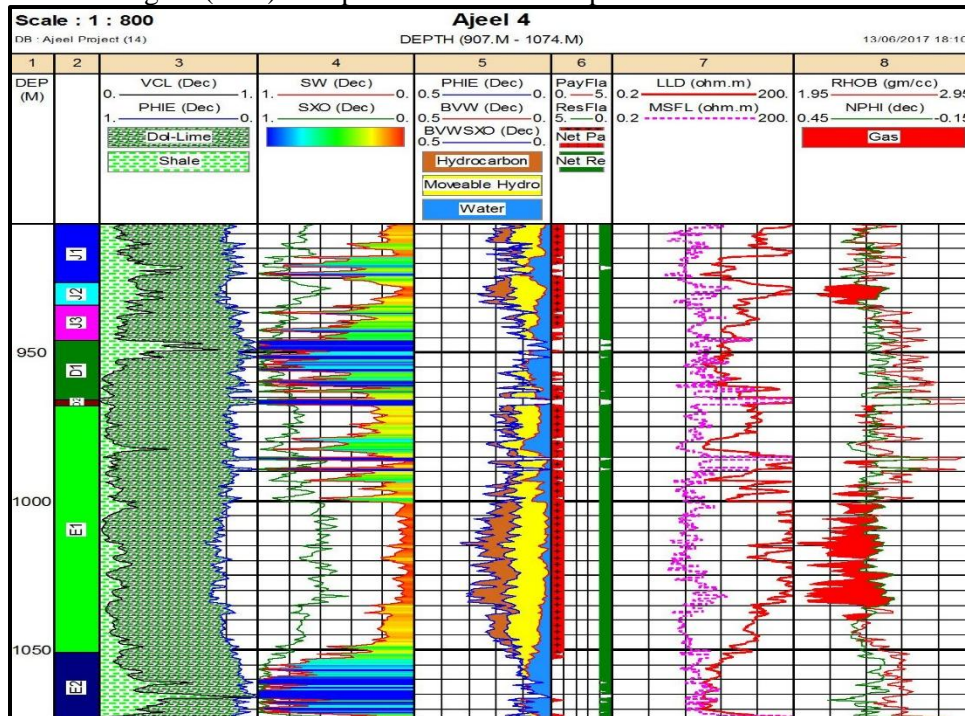Figure (3-10) Computer Processed Interpretation for Well AJ-1



Figure (3-11) Computer Processed Interpretation for Well AJ-4

**3.7 Determination of Petrophysical Parameters Cut-Off**

Cutoffs (in petroleum engineering) are limiting points at which the processing of flowing of fluid is stopped. Every layer has cutoffs for (petro physical properties= porosity, permeability and saturation) the benefit of cutoff is to eliminate those rock volumes that don't contribute significantly to the reservoir evaluation product. The principle use of cutoffs is to delineate net pay, which can be described as the summation of those depth intervals through which hydrocarbons are producible [22].

Cut-off parameters are expressed in four forms namely porosity($\varphi$), shale volume (Vsh), permeability (k), and water saturation (Sw), it is used to determine net to gross from IP software to be used in petrel program to calculate oil in place.

The properties of the production zone must be:-

1. Porosity > cut-off porosity.
2. Permeability > cut-off permeability.
3. Water saturation < cut-off water saturation.

A suitable shale volume cut-off (Vsh) should be used to distinguish the reservoir rock from shales. The rationale behind using this value is that, when the shaliness of a formation exceeds a certain limit, the effective porosity of the formation will be reduced to zero. This shale porosity does not contribute to storage of formation fluids such as hydrocarbons. The actual value of shale volume cut-off was estimated for this reservoir as 50 %. Porosity cutoff is simply defined as least porosity of rock that the fluid can move through it, also it is critical value for a required permeability which is commonly obtained from a porosity-permeability plot.

The porosity cutoff is selected to provide enough absolute permeability to ensure economic production and use it to estimate Hydrocarbon in place.

Porosity-permeability relationship variation with rock type (pore type) and grain size, that plays an important role in influencing on the porosity-Permeability. The porosity-permeability relationship is the important tool for defining porosity cut-off.

Porosity cut-off values are established through assuming permeability cut-off, when the value of porosity cutoff for the Reservoir is small, the reservoir regarded well because it has more layers have fluid can be out and no negligible more amount of this layer.

Figures (3-12)&(3-13)&(3-14) show a cross plot of porosity vs. permeability measured by using core data of Ajeel Oil Field for three units Jeribe, Euphrate, Dhiban.

Permeability cutoff means Pores with Permeability less than cutoff value, will not allow fluids to flow, the permeability values equal to 0.1 md as the commonly used value depending on reservoir fluid.

Water Saturation cutoff from final well report equal to 60 % shown in equation below:

$$\text{Sw cutoff} = 1 - \text{Sor} \text{------------------- (3-33)}$$

Sor: The oil saturation level above which the oil starts to moveable.

Notice from these figures below the porosity cut-off for Jeribe, Dhiban and Euphrates formation are 4.5, 5 and 6 respectively. From porosity cut-off considered the most productive unit is Jeribe because it has less value of porosity cut-off (4.5).
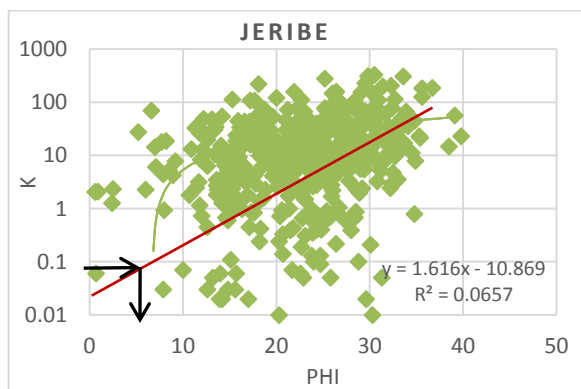


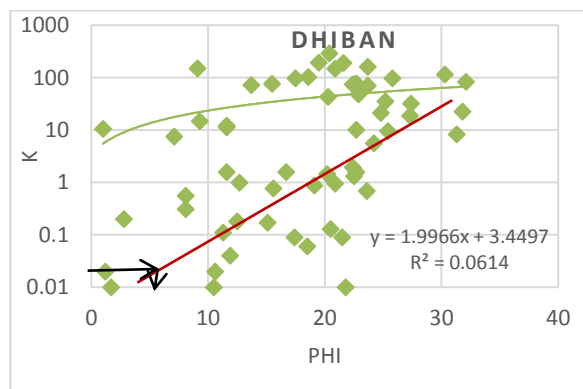Figure (3-12) Porosity Cut-off for Jeribe Formation

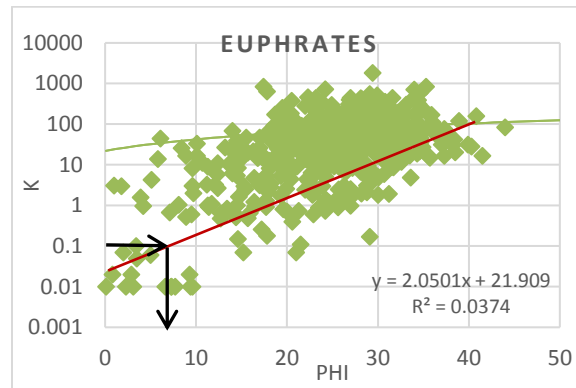Figure (3-13) Porosity Cut-off for Dhiban Formation

Figure (3-14) Porosity Cut-off for Euphrates Formation

## 3.8 Permeability Prediction

Permeability (K) is the property of a rock, considered a channel for fluid flow, measured by Darcies or milliDaries [23] and controlled by the size of the connecting passage between pores. Permeability is measured parallel to the bedding planes of the reservoir rock called horizontal permeability and it considered the chief path of the fluid to flow into the well. But, the vertical permeability is less than horizontal permeability, due to the arrangement and packing of the rock grains during deposition [24] and measured across the bedding planes.

Permeability is determined from core analysis but most wells are not cored and permeability is estimated in uncored sections by porosity versus permeability relationships.

Permeability is measured in the laboratory by encasing a sample of known length and diameter in an air-tight sleeve [25] in a horizontal position. The liquid of known viscosity is injected into a sample of known length and diameter. The samples are either lengths of whole core 6 in or 1 in plugs drilled from the cores. The pressure drop across the sample and the flow rate are calculated and permeability is measured by using the Darcy equation. This method is called the Klinkenberg effect, and it is very important in low-permeability rocks [26].

## 3.9 Methods to Determine Permeability

The well logs provide detection, not evaluation, of the permeability for a zone. Some well logs and their results such as porosity logs can be used to estimate permeability by experimental correlation of log response to core permeability data and the Porosity is used larger than resistivity to evaluate the permeability. The evaluation of K from well log is very difficult because correlation between porosity and permeability may be not very accurate because the K is a measure of dynamic properties of the formation but the logs make static measurements.

Permeability of a reservoir near a well bore depends on fluid flow (invasion), buildup of mud cake, and spread between reservoir fluids and mud filtrate that's mean permeability varies with time and space [27].

The correlation coefficient ($R^2$), which ranges from (0) to (1), can used as a criterion to compare between the k-estimated and k-core values.If the value of ($R^2$) equal to (1) it is considered a perfect correlation in the sample and no difference between the k –estimated and the k–core values. If the value of ($R^2$) equal to (0) it is considered very bad and this equation is not helpful to predict permeability values.

## 3.9.1 Classical Method

The results of core analysis in the laboratory can be used to calculate the permeability in uncored intervals where coring is usually available in a given wells with short intervals shown in equation (3-34):

$$\log (k) = a\,\phi + b \text{-------------------- (3-34)}$$

The available core data are taken from the first nine wells (core plugs for wells AJ-1, AJ-4, AJ-6, AJ-10, AJ-13, AJ-14, AJ-22, AJ-25, and AJ-54).

The porosity are plotted with logarithm of air permeability for each unit such as in figures (3-15), (3-16), and (3-17) for Jeribe, Dhiban and Euphrates respectively. The equation for each unit is then applied to detect the permeability in uncored intervals by using this way. Table (3-7) represents the equations for each unit**.** The increase in porosity is followed by an increase in permeability, but the amount of increase in porosity is not directly proportional to permeability, due to non-connected pores that do not contribute to permeability.

Table (3-7) Results of the Classical Method

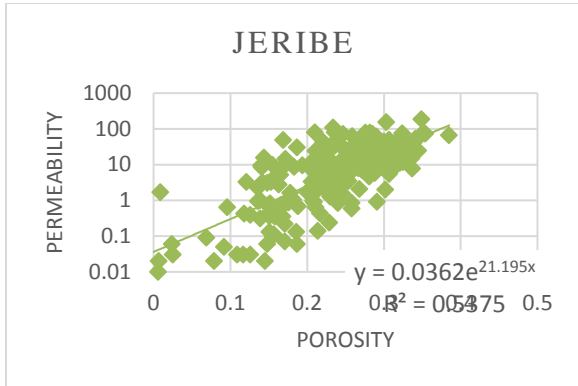| The unit | Permeability Formula | R² |
|----------|---------------------|-----|
| Jeribe | $K=0.0362\ e^{21.195\phi}$ | 0.5375 |
| Dhiban | $K=0.0204e^{31.181\phi}$ | 0.6932 |
| Euphrates | $K=0.0097e^{27.537\phi}$ | 0.6219 |



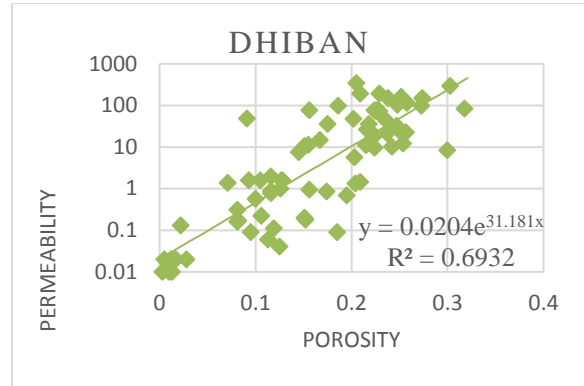Figure (3-15) Permeability vs Porosity of Unit Jeribe



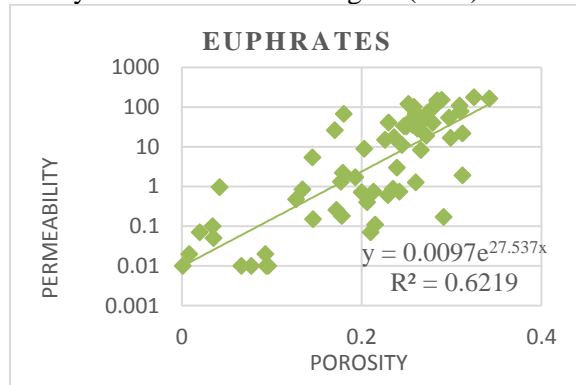Figure (3-16) Permeability vs Porosity of Unit Dhiban



Figure (3-17) Permeability vs Porosity of Unit Euphrates

The values of permeability for carbonate reservoirs usually vary greatly. Determination of permeability is the most important in the development of effective reservoir description. The evaluation of permeability in Tertiary formation for Ajeel field was determined by three ways, classical, neural and flow zone indicator method [28]. Results of permeability predictions show in figures (3-22) & (3-23) for AJ-1 & AJ-4,
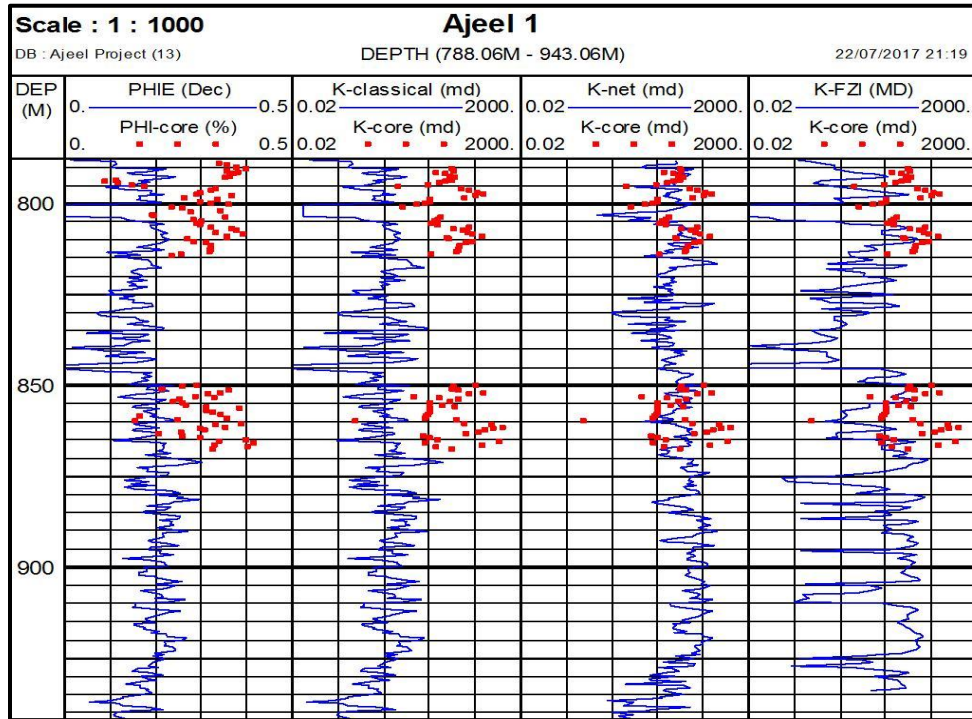
Figure (3-22) Results of Permeabilities Prediction vs. Permeability of    Core for AJ-1
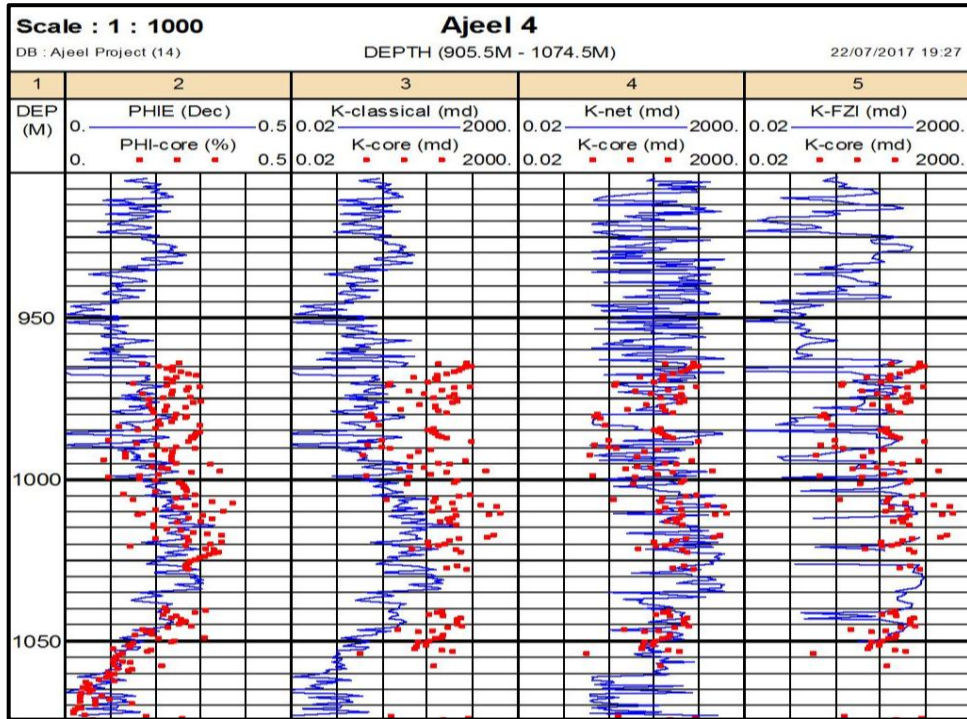


Figure (3-23) Results of Permeabilities Prediction vs. Permeability of Core for AJ-4

## 4. Conclusions

1. By using the neutron-density cross plot for wells, the lithology of the studied formation was identified Most of the data points fall on the dolomite and some point fall on limestone. This indicates that Tertiary Formation consists mainly from a combination matrix of limestone and dolomite.

2. Archie's parameters (a, m and n) values where estimated from Pickett's plot, the tortuosity factor (a) ranges between (1) to (1.4), saturation exponent (n) from (1.4) to (2) and cementation exponent (m) from (1.5) to (2).

This method gives accurate values as it deals with log data, while other methods are considered as highly uncertain due to little data availability.

3. Shale volume, Porosity, permeability, water saturation, have been determined.

**Acknowledgements**

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