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Estimation of Cutoff Values by Using Regression Lines Method in Mishrif Reservoir/ Missan oil Fields

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ABSTRACT

Net pay is one of the most important parameters used in determining initial oil in place of a reservoir. It can be delineated through the using of limiting values of the petrophysical properties of the reservoir. Those limiting values are named as the cutoff. This paper provides an insight into the application of regression line method in estimating porosity, clay volume and water saturation cutoff values in Mishrif reservoir/ Missan oil fields. The study included 29 wells distributed in seven oilfields of Halfaya, Buzurgan, Dujaila, Noor, Fauqi, Amara and Kumait.
This study is carried out by applying two types of linear regressions: Least square and Reduce Major Axis Regression.
The Mishrif formation was divided into three main units. They are MA, MB, and MC. The methods were applied to each unit of Mishrif formation individually and as one unit. The division of Mishrif formation into subunits led to a great improvement in the accuracy of the porosity-permeability correlations. The Results indicated that the regression lines method of defining cutoffs gives unrealistic values with the common assumption of permeability cutoff = 0.1 md.
Another assumption for permeability cutoff = 1 is made and it was chosen due to lithology and hydrocarbon type which are limestone and oil respectively. This assumption led to more realistic and higher porosity cutoff and smaller water saturation and clay volume cutoff values using the two types of regression lines.
Key Words: cutoff, porosity, permeability, clay volume, water saturation.

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احتساب قيم الحد القاطع للخواص البتروفيزيائية لمكمن المشرف/ حقول محافظة ميسان النفطية بطريقة خطوط الانحدار

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الخلاصة

يعتبر السمك الصافي للعطاء احد اهم العوامل التي يحسب من خلالها الاحتياطي النفطي لاي مكمن. ولغرض احتساب هذا السمك يتم استخدام قيم محددة للصفات البتروفيزيائية للمكمن تسمى بالحد القاطع. يوفر هذا البحث نظرة شاملة حول تطبيق طريقة خطوط الانحدار الاحصائية لاحتساب قيم الحدود القاطعة للمسامية والتشبع المائي وحجم الطين لمكمن المشرف في حقول محافظة ميسان النفطية. حيث شملت الدراسة تسع وعشرون بئرا موزعة على سبعة حقول نفطية هي: حلفاية، بزركان، دجيلة، نور، فكة، عمارة وكميت.
تم تطبيق نوعان من انواع خطوط الانحدار: Least square و Reduce Major Axis Regression. تم تقسيم مكمن المشرف الى ثلاث وحدات رئيسية هي : MA وMB و MC وايضا تم تطبيق الطريقة على مكمن المشرف باعتباره وحدة مكمنية واحدة. اظهرت النتائج زيادة دقة المضاهاات بين الصفات البتروفيزيائية المختلفة للوحدات المكمنية بصورة منفردة عنها عند اعتبار مكمن المشرف كوحدة واحدة.
بينت النتائج ايضا ان الفرضية الشائعة لقيمة الحد القاطع للنفاذية الذي يساوي 0.1 ملي دارسي بانه افتراض خاطيء لانه يعطي قيم حد قاطع غير واقعي للصفات البتروفيزيائية الاخرى. بينما الافتراض الذي يقضي بان قيمة الحد القاطع للنفاذية = 1 ملي دارسي (الذي حدد وفقا لنوع التكوين ونوع الهايدروكاربونات المتجمعة فيه، ولكون طبقة المشرف متكونة من الحجر الجيري ولاحتوائها على النفط) اعطى نتائج اكثر واقعية من الافتراض السابق.
الكلمات الرئيسية: الحد القاطع، المسامية، النفاذية، حجم الطين، التشبع المائي.

1. INTRODUCTION

Net pay can be defined as the portion of the reservoir that contains relatively good petrophysical properties and hydrocarbon accumulations that can be economically produced. It is considered as one of the most important parameters that used in the estimation of initial hydrocarbon in place, the analysis of fluid injection, well test interpretations, unitization procedure, and reservoir engineering studies. **Fig. 1** shows the steps of estimating Net Pay. The net-to-gross ratio NGR, which is the ratio of the net pay thickness to the gross (total) thickness of the reservoir is considered as a basic parameter in calculating hydrocarbon reserve.
Its determination regularly includes defining the onset values (cutoffs) of the reservoir properties needed. Those threshold values are designed to define these rocks volumes that have a small possibility to be productive. The cutoff values will differ depending on the intended process that needs to be taken, and therefore, should be fit for purpose, which means “the required use of the net pay often determines the method under which net pay is chosen. Since the method to choose net pay (and eventually NGR) relies on its usage, those uses determine also the method chosen for determining cut-off values, **Snyder, 1971.**
Net pay and NGR are needed for several reservoir characterization activities. A major use of net pay is to compute volumetric hydrocarbons in-place. Another use of net pay is to determine the total energy of the reservoir i.e. both moveable and non-moveable hydrocarbons are taken into consideration. Net pay for this purpose may be therefore much greater than that for volumetrics calculation, **George and Stiles, 1978.**

The third use of net pay is to evaluate the potential amount of hydrocarbon available for secondary recovery, meaning net pay with favorable relative permeability to the injected fluid, i.e. "floodable net pay", **Cobb and Marek, 1998**.
Net pay and NGR are crucial to quantify the hydrocarbon reserves and have a significant impact on the economic viability of hydrocarbon reservoir production, **Worthington and Cosentino, 2005**.

2. METHODOLOGY

Regression line method is known widely in identifying net pay by the use of porosity (not just the porosity but any alternate parameter such as water saturation Sw, clay volume Vsh or resistivity of the formation Rt). This method includes the using of semi-logarithmic porosity vs. permeability cross-plots and least-squares regression line to achieve the porosity cut-off, **Cosentino, 1997.**
Fig. 2 Shows the Procedure for defining a consistent set of petrophysical cut-offs: permeability, porosity, water saturation, shale volume cut-off.

2.1 General Considerations Concerning Linear Regression:

The overall problem of linear regression is to generate a predictor of a quantity Y (e.g. log permeability) from the known value of a variable X (e.g. porosity). The variable being investigated is the dependent or regressed variable designated Y; individual observations of the dependent variable are indicated as yi. The other variable is the predictor or regressor variable and is denoted X, with individual observations, xi. The fitted line will cross the Y-axis at a point b0 (the intercept) and will have a slope b1, **Rawlings, 1998**.
The expected relationship between Y and X is linear. The regression line equation is as follows:

$$\overline{Yi} = b_0 + b_1.xi \tag{1}$$

Where:
$\overline{Yi}$ is the estimated value of yi for any value of xi.
Considering that only the variable Y is assumed to be measured with error gives specific coefficients b's referring to the Y-on-X line. In contrary, in the case that only the variable X is assumed to be with errors, it gives distinct coefficients b's that correspond to the X-on-Y line.

- *Y-on-X regression line:*
  This method depends on least-squares regression in finding b's in Eq. (1) and by minimizing squared differences summation between the predicted responses and the observed variable, yi, as expressed by Eq. (2).

$$\sum_{i=1}^{n}(\bar{y}i - yi)2 = min \tag{2}$$

Where:
n is the number of points.
The technique justification is calculated using differential calculus, **Jensen, et al., 2003**. The coefficients b0 and b1 can be defined as follow, **Davis, 2002.**

$$b1 = \frac{\sum_{i=1}^{n} xi.yi - \frac{\sum_{i=1}^{n} xi \sum_{i=1}^{n} yi)}{n}}{\sum_{i=1}^{n} xi^2 - \frac{\left(\sum_{i=1}^{n} xi\right)^2}{n}} \qquad (3)$$

$$b_0 = \frac{\sum_{i=1}^{n} yi}{n} - b_1 \frac{\sum_{i=1}^{n} xi}{n} = \overline{Y} - b_1\overline{X} \qquad (4)$$

1. *The reduced major axis line*

The second method is where both variables Y and X are assumed that they having errors. Estimation of both b0 and b1 is minimizing the summation of the area of the triangle formed by the fitted line observations. The deviations in both the X and Y directions product is minimized. It results in what named the reduced major axis, or commonly referred to it as the “RMA line”. Which is more appropriate in comparison with standard regression lines when X (the independent variable) has been measured with significant error. In that case, slope estimation will be biased, **Davis, 2002.**

The reduced major axis is expressed as an ordinary linear equation, such as Eq. (3). The coefficients can be estimated as follows:

$$b_1 = \frac{\sigma_Y}{\sigma_X} = \sqrt{\frac{\sum_{i=1}^{n} xi^2 - \frac{b1\sum_{i=1}^{n} xi}{n}}{\sum_{i=1}^{n} yi^2 - \frac{(\sum_{i=1}^{n} yi)^\wedge 2}{n}}} \qquad (5)$$

$$b_0 = \overline{Y} - b1\,\overline{X} \qquad (6)$$

Due to fit purpose philosophy, $Ø_{cYONX}$ which is the porosity cutoff value that is resulted from least squares regression line is preferred in delineating NP, While $Ø_{cRMA}$ which is the porosity cutoff value that is resulted from RMA regression line is preferred in evaluating net to gross.

3. LOG INTERPRETATION

The well logs are influenced by some of the downhole conditions so they should be corrected through environment correction software, that condition is salinity, drilling mud, filter cake, and borehole size, **Goldberg, 1997.**

All available well logs that include Spontaneous potential, gamma ray, density porosity, neutron porosity, and resistivity log were digitized using Didger V4 software. Environmental corrections of well logs were done using Interactive Petrophysics software V3.5 and Schlumberger charts were chosen to correct the logs.

The maximum error (the maximum difference between environmentally corrected and uncorrected well logs) was computed for all wells.

Clay volume was calculated using two different logs: Corrected Gamma Ray (GR) and Spontaneous potential log (SP).

The volume of shale content that computed in Mishrif formation, is generally less than 20% of the bulk volume.
Using true resistivity values obtained from deep resistivity log (uninvaded zone resistivity Rt) and effective porosity (Øe), water saturation values were determined using Archie's equation considering the values of saturation exponent (n) = 2, cementation factor (m) = 1.8 and tortuosity factor = 1 which was taken from core analysis of Halfaya field, **Yonggui, 2013**.

4. SUBUNITS DIVISION

The Mishrif formation was divided into three main units: MA, MB, and MC. Some wells have a lithological column which shows the depth of each Mishrif subunit.
In some wells, that column is missing. So a division of Mishrif formation is needed to be made, which are Dujaila-1 and Dujaila-2.
By using Interactive Petrophysics V3.5 Software, the discretization was made due to the change in petrophysical properties range with a depth of well logs data into three main units that are mentioned above.

5. FIELD APPLICATION

Water saturation values were obtained from well logs by using Archie's equation. Clay volume values were obtained from Gamma Ray log. Core porosity and permeability were used in this method.
Two types of regression lines were used: linear (least square) and reduce major axis. The first type of regression is used to find net pay values, while the second is preferred in the estimation of the net to gross ratio, **Jensen and Menke, 2006.**
Two assumptions of permeability cutoff value were made:

- Because of the carbonate lithology and oil existence, a value of k cutoff equals 1md is assumed, **Bouffin, 2007**.
- Due to the field experience, a value of k cutoff equals 0.1md is assumed for Mishrif reservoir in Missan region to find porosity cutoff using k vs. Ø cross plot.

After concluding the porosity cutoff values from k vs. Ø cross plot by using the previously mentioned assumption of permeability cutoff, the clay volume and water saturation cutoff values were obtained using the previously concluded porosity cutoff values.
Fig.3 through **13** show the cross-plot of the present method **Fig. 3** through **6** shows the cross-plots of core porosity vs. permeability, **Fig. 7** through **9** illustrate core porosity vs. water saturation cross-plot and **Fig. 10** through **13** illustrate core porosity vs. clay volume cross-plot of units MA, MB, MC and Mishrif formation as one unit respectively.

6. RESULTS AND DISCUSSION

The results that were concluded during this study are:

1. Making unit discretization of Mishrif formation as three units they are: MA, MB, and MC led to an increase in the coefficient R^2 of the core porosity and permeability to values higher than that of considering Mishrif formation as one unit by 17%. That can be noticed by comparing the R^2 of **Fig. 3, 4** and **5** for MA, MB, and MC units respectively with **Fig. 6** for Mishrif formation as a whole.

2. Using the regression line method, the results of assuming kc =1md gives values of porosity cutoff that are high and water saturation and clay volume are small in comparison to the other assumption. While assuming Kc = 0.1md gives the lowest values of porosity and the highest clay volume and water saturation cutoff values in comparison to the other assumption. The results of the porosity cutoff of this assumption are unrealistic so they were neglected. The unreasonable results of this method are caused by the high possibility of error in the assumption of the permeability cutoff.

The results of this method are shown in **Table 1** and **2**, the first is of linear regression and the other is to reducing major axis regression.

7. CONCLUSIONS

1. The discretization of Mishrif formation into units leads to increase the accuracy of the correlations of the petrophysical properties, therefore, the estimated cutoff values become more realistic
2. The results indicated that the regression line method (lease square and RMA) gives unrealistic results of cutoffs values with the commonly used assumption of Kc = 0.1md while the second assumption of K = 1md gives higher and more reasonable porosity and smaller clay volume and water saturation cutoff values.

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NOMENCLATURE

a, n, and m= Archie's Parameters, dimensionless
GR= gamma ray log, grapi
Kc = permeability cut-off, md
Rmf = resistivity of mud, ohm.m
Rt = resistivity of the uninvaded zone, ohm.m
Sw = water saturation, a fraction
Vcl = clay volume, fraction

GREEK SYMBOLS

$Ø_e$= effective porosity
ØCY-On-X= porosity cut off that estimate from least square regression line method, a fraction
ØRMA= porosity cutoff that is estimated from reducing major axis regression line method, a fraction.

ABBREVIATION

NP= net pay
NGR= net to gross ratio
RMA= reduce major axis

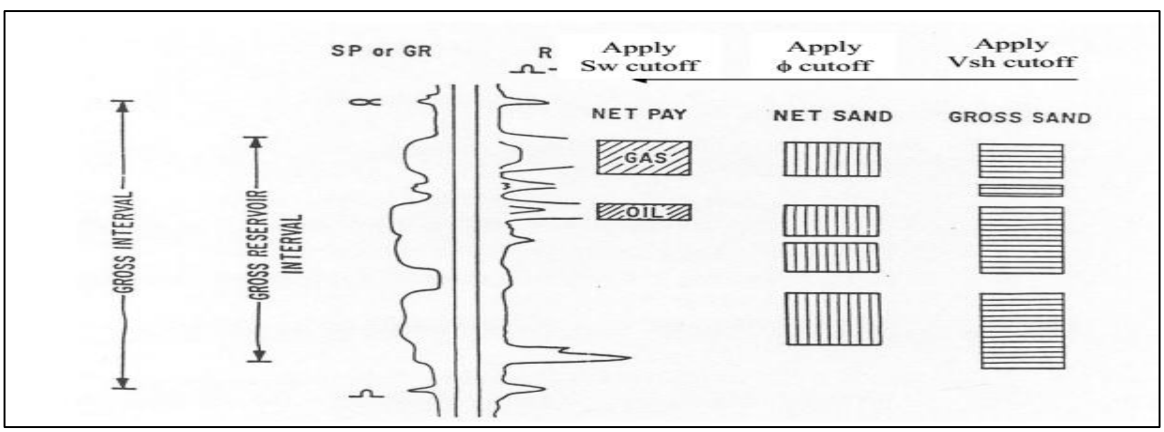

Figure 1. Definition of reservoir intervals, **Cosentino, 1997.**

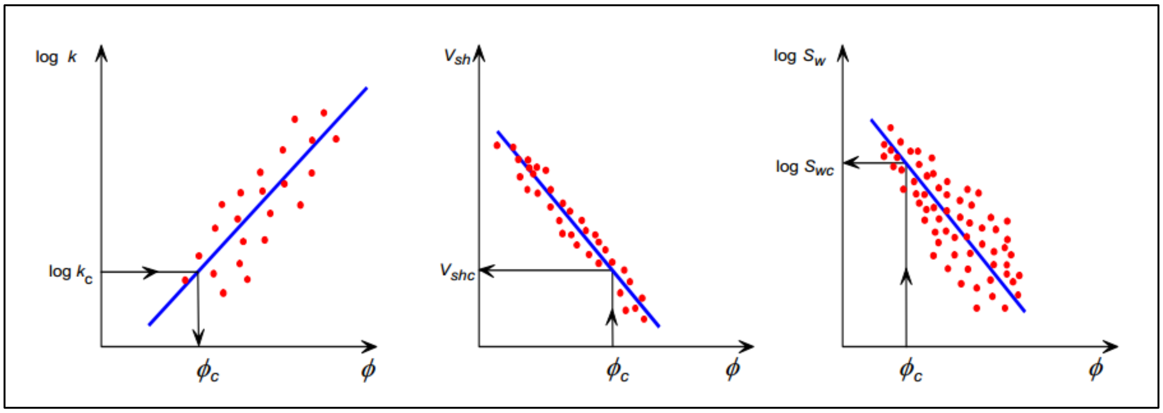

Figure 2. Cutoff procedure of regression line method, **Davis, 2002.**

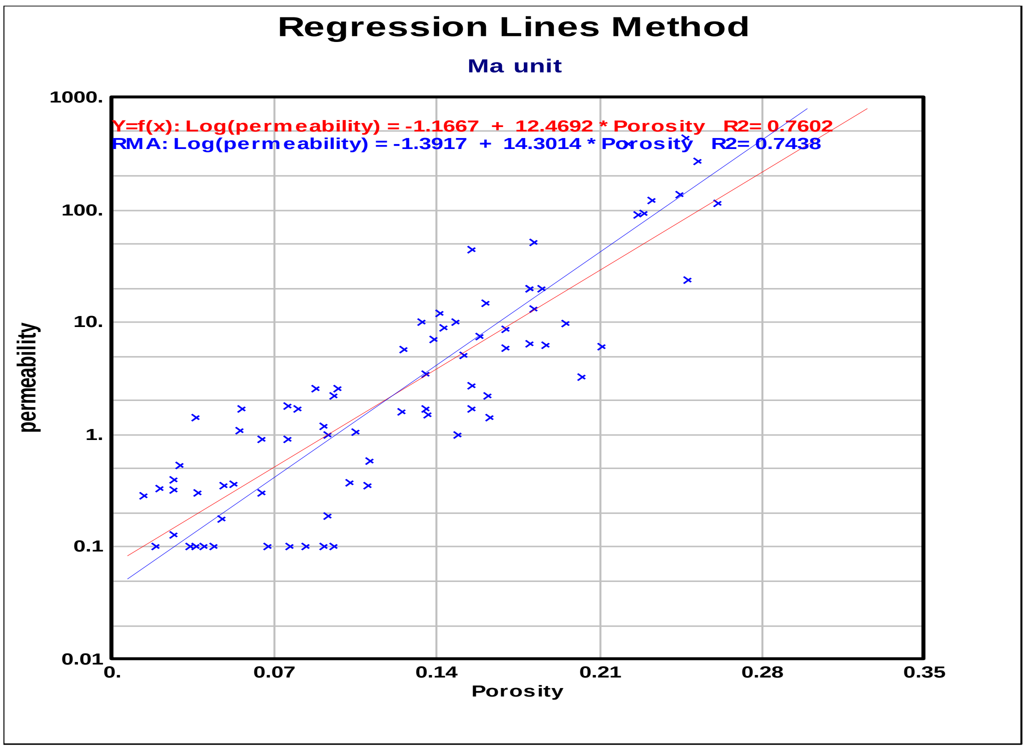

Figure 3. Log core permeability vs. core porosity cross plot for Ma unit.

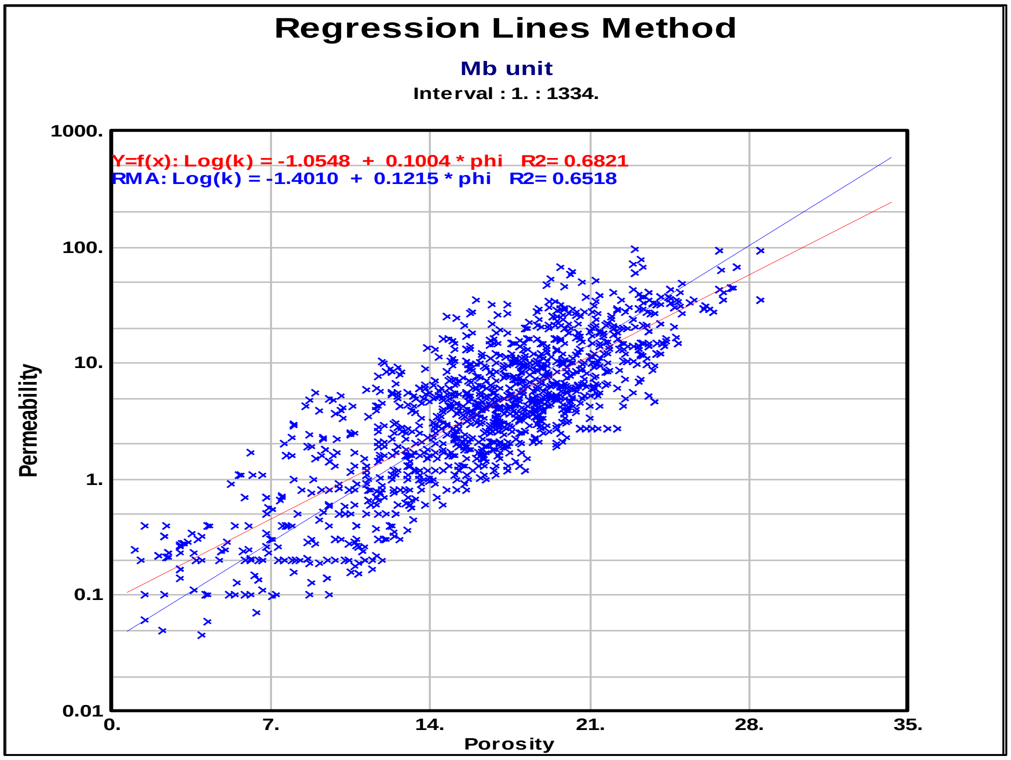

Figure 4. Log core permeability vs. core porosity cross plot for Mb unit.

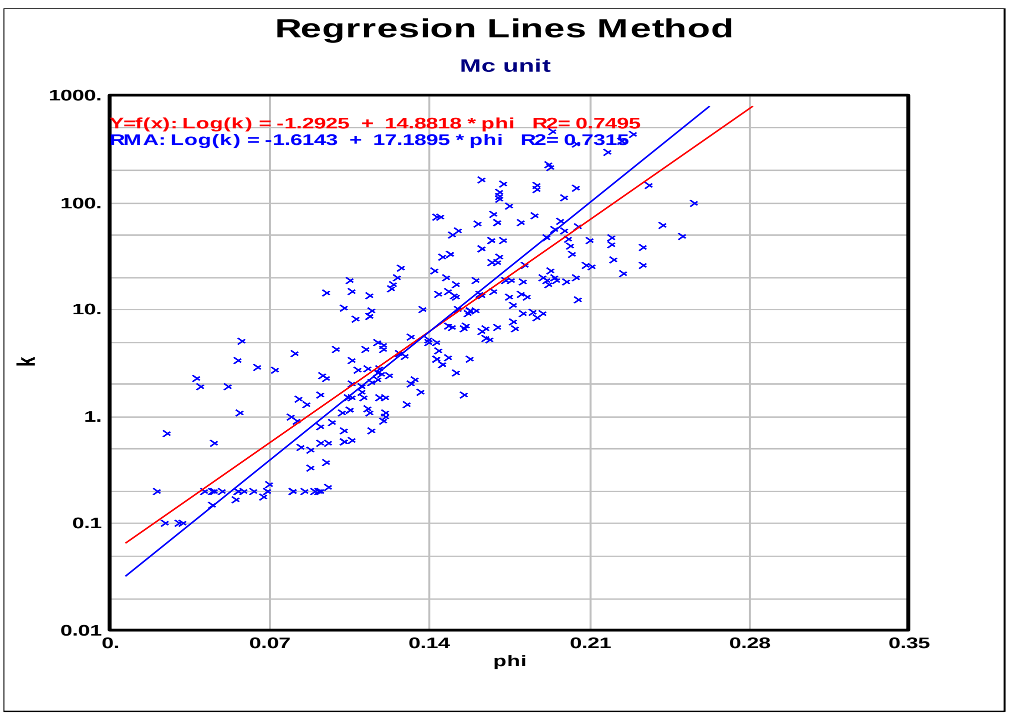

Figure 5. Log core permeability vs. core porosity cross plot for Mc unit.

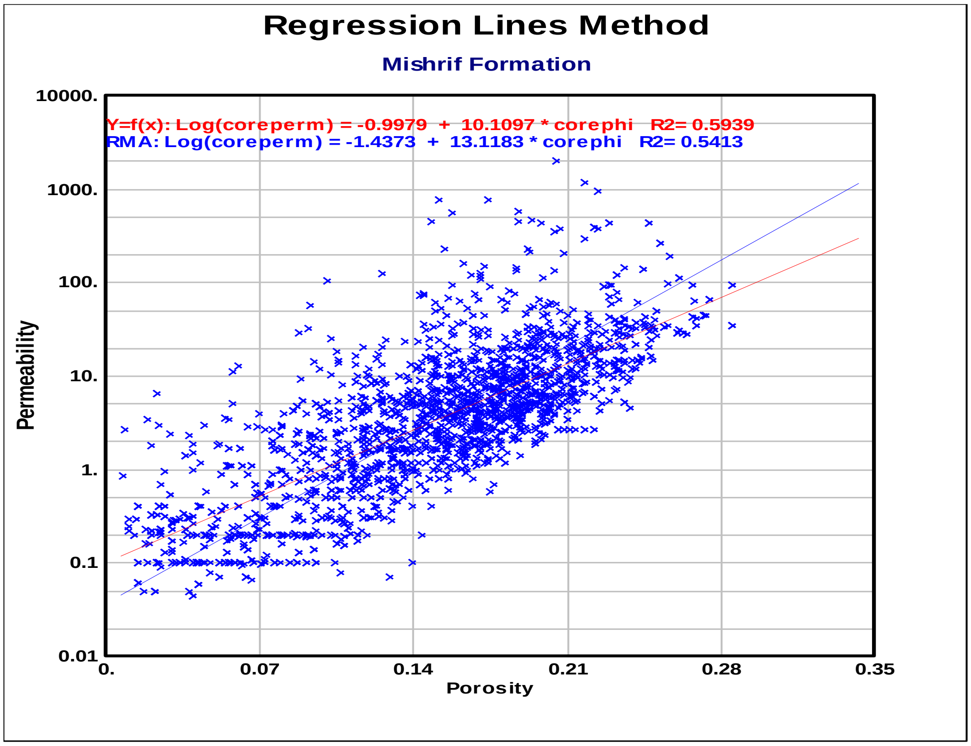

Figure 6. Log core permeability vs. core porosity Cross Plot for Mishrif Formation.

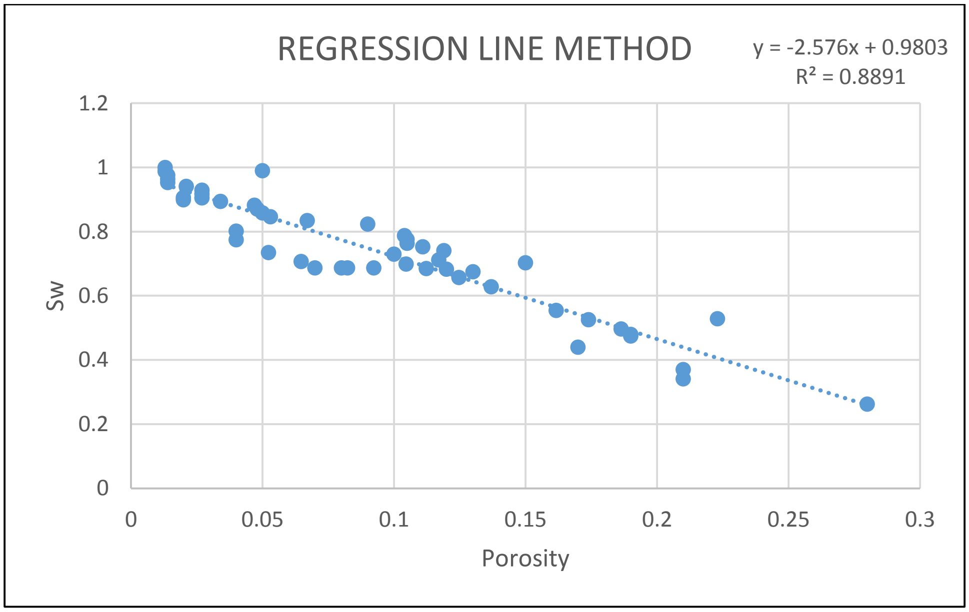

Figure 7. Water saturation vs. core porosity cross plot for Ma unit.

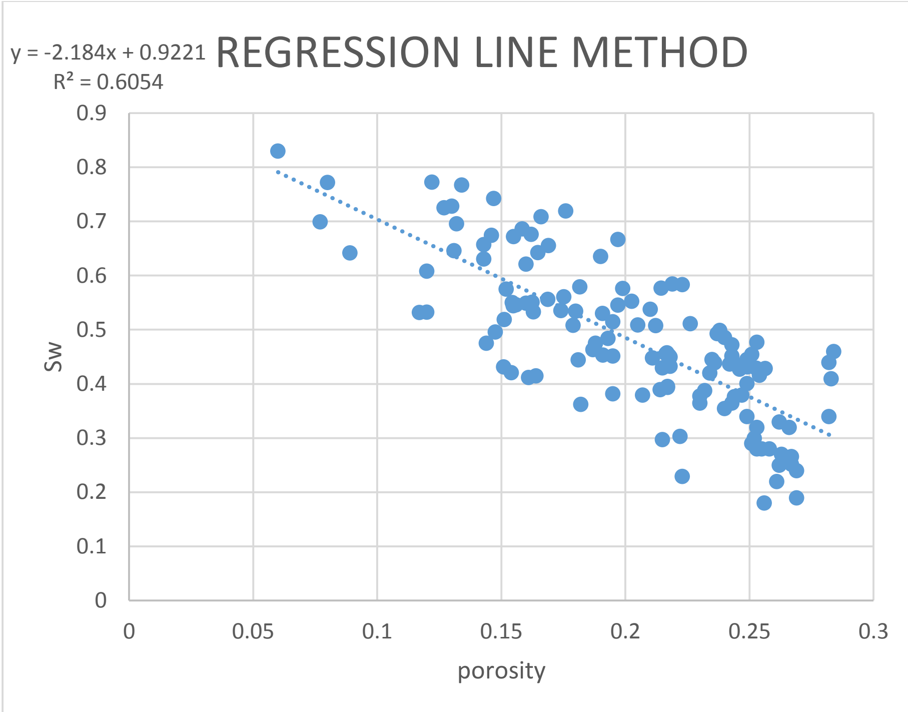

Figure 8. Water saturation vs. core porosity cross plot for Mb unit.

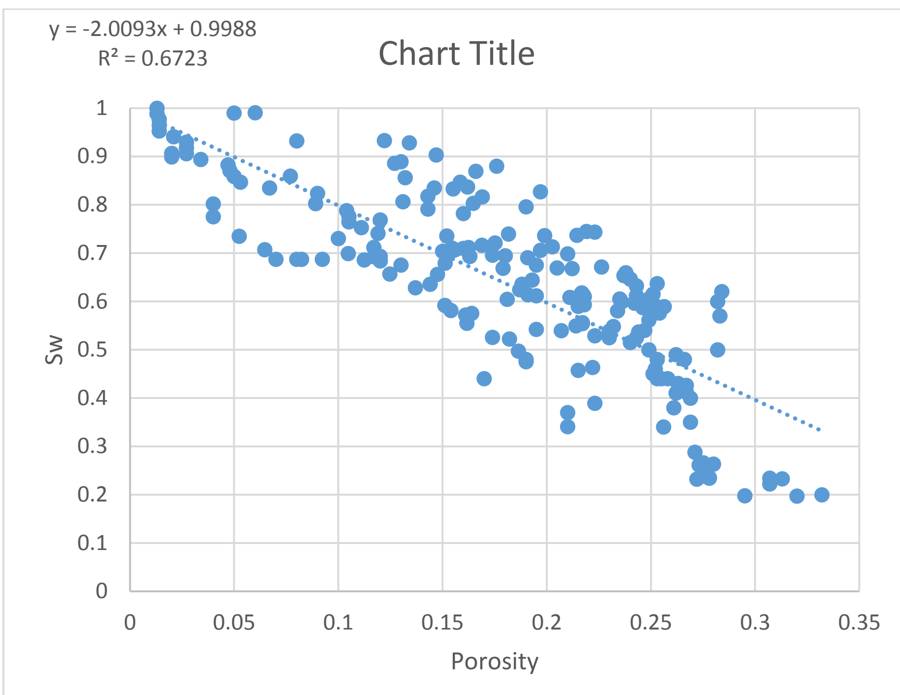

Figure 9. Water saturation vs. core porosity cross plot for Mishrif formation.

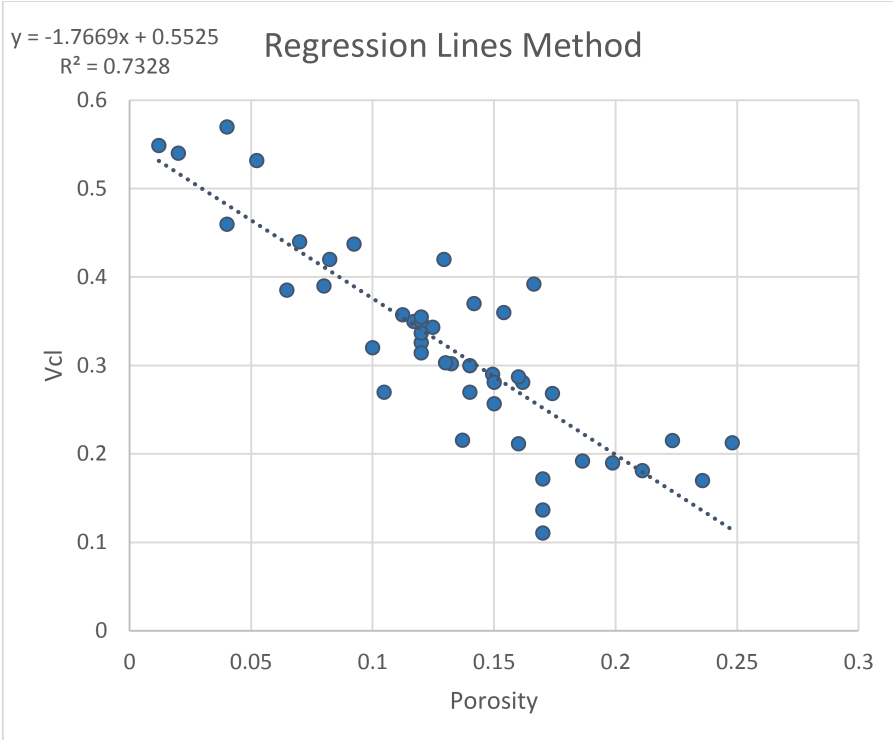

Figure 10. Clay volume vs. core porosity cross plot for Ma unit.

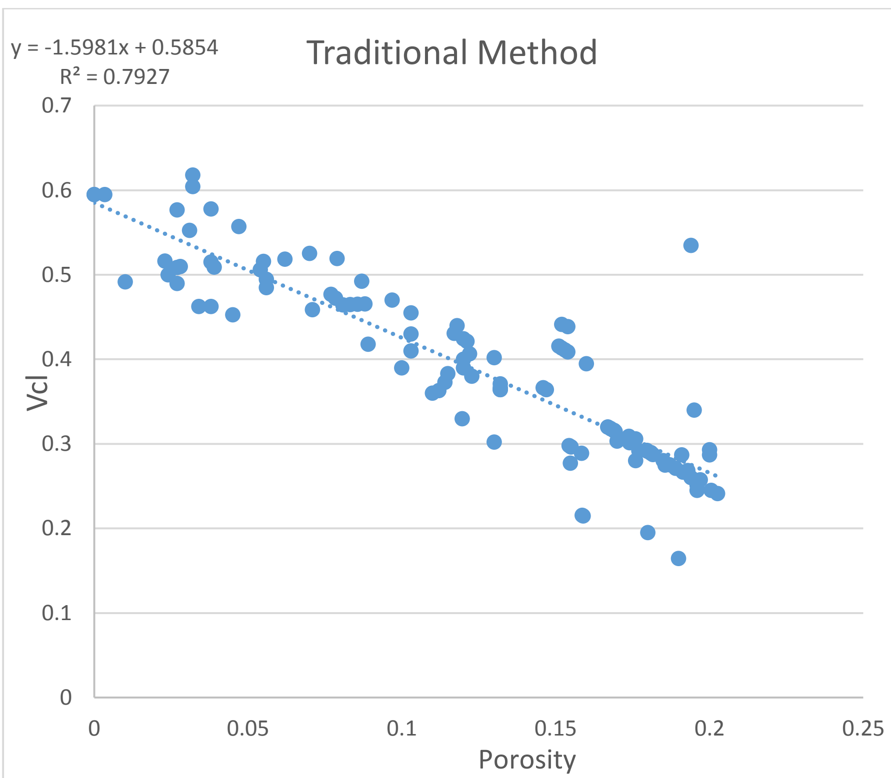

Figure 11. Clay volume vs. core porosity cross plot for Mb unit.

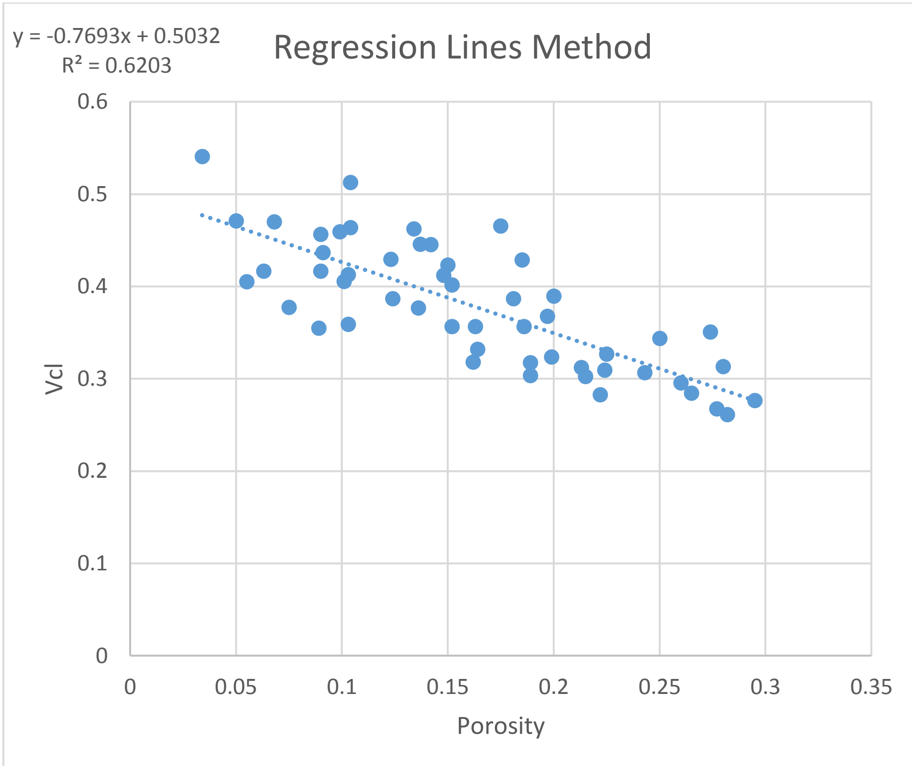

Figure 12. Clay volume vs. core porosity cross plot for Mc unit.

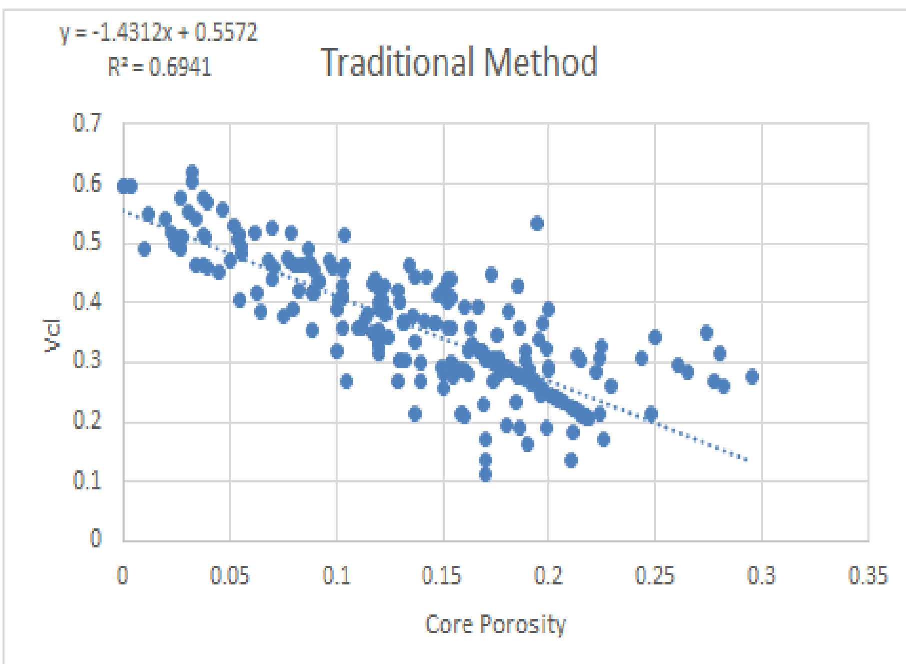

Figure 13. Clay volume vs. core porosity cross plot for the Mishrif formation

Table 1. Porosity cutoff values by using Linear (least square) regression line method.

Unit	Kc=1			Kc=0.1		
	$Ø_{CYONX}$	Vclc ,	Swc	$Ø_{CYONX}$	Vclc ,	Swc
Ma	9.4	38.6	73.8	1.34	52.9	95
Mb	10.15	42.3	70	0.77	57.3	75.4
Mc	8.2	44	--	1.14	49.5	--
Mishrif formation	9.9	41.5	80	0.92	54.4	81.4

Table 2. Porosity cutoff values by using RMA regression line method.

Unit	Kc=1			Kc=0.1		
	$Ø_{CRMA}$	Vclc ,	Swc	$Ø_{CRMA}$	Vclc ,	Swc
Ma	9.7	38.11	73	2.74	50.4	91
Mb	11.13	41	69	3.3	53.2	85
Mc	9.7	43	--	2.79	48	--
Mishrif formation	11.1	40	77.6	3.32	51	93.2