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Using Statistical Regression to Determine Permeability in Un-Cored Well Sections

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Abstract— Permeability is the most essential parameter in reservoir characterization, reservoir management, and forecast the future performance of the reservoir. Permeability is directly measured from core routine analysis and well testing, these techniques are of highly costs; for that reason, a correlation is to be generated in order to estimate permeability in un-cored wells.

Cross plot shows that Mishrif reservoir consists mainly of limestone with an amount of sand and little shale. Plot of permeability versus porosity for well Amarah-5, show a (correlation coefficient) of (0.6767) by using best fit line.

The flow zone indicator method shows that Mishrif formation consists of eight units of flow (hydraulic units), and the obtained regression was with correlation coefficient between (0.872 - 0.994). By using Grace Program (Alternative Conditional Expectation) to generate a correlation, using normal logarthim of gamma ray, and neutron porosity as independent parameters, which gives correlation coefficient of 0.809. The flow zone indicator correlation is the best regression to estimate permeability; because the reservoir is divided into multiple units which reduce heterogeneity.

Keywords— permeability, porosity, well log, regression, FZI

1. Introduction

Determination of the values of permeability and the changes that occur within the productive layer is very important and a distinctive criterion in the development, improvement, description and evaluation of effective reservoirs. Permeability assessment in a complex and uniform reservoir is a complicated problem, because core samples and well testing information are frequently available for a limited number of wells.

This study aims to carry out a petrophysical evaluation of Mishrif formation in Amara oil field in southern Iraq, (Figure 1).Well logging and core analysis information are the basic data for this study.

First well (AM-1) was drilled in 1980 and then completed, Amara field located on the non-stable shelf at the Mesopotamian basin. Petroleum production under primary recovery started in the year 2000. The field currently has 6 wells.

Iraq south area is considered to be one of the wealthiest spots with petroleum in the world, with oil in reservoirs from geological ages ranging from Jurassic to Tertiary era. The studied reservoirs in oil field of Amarah are essentially of Cretaceous era.

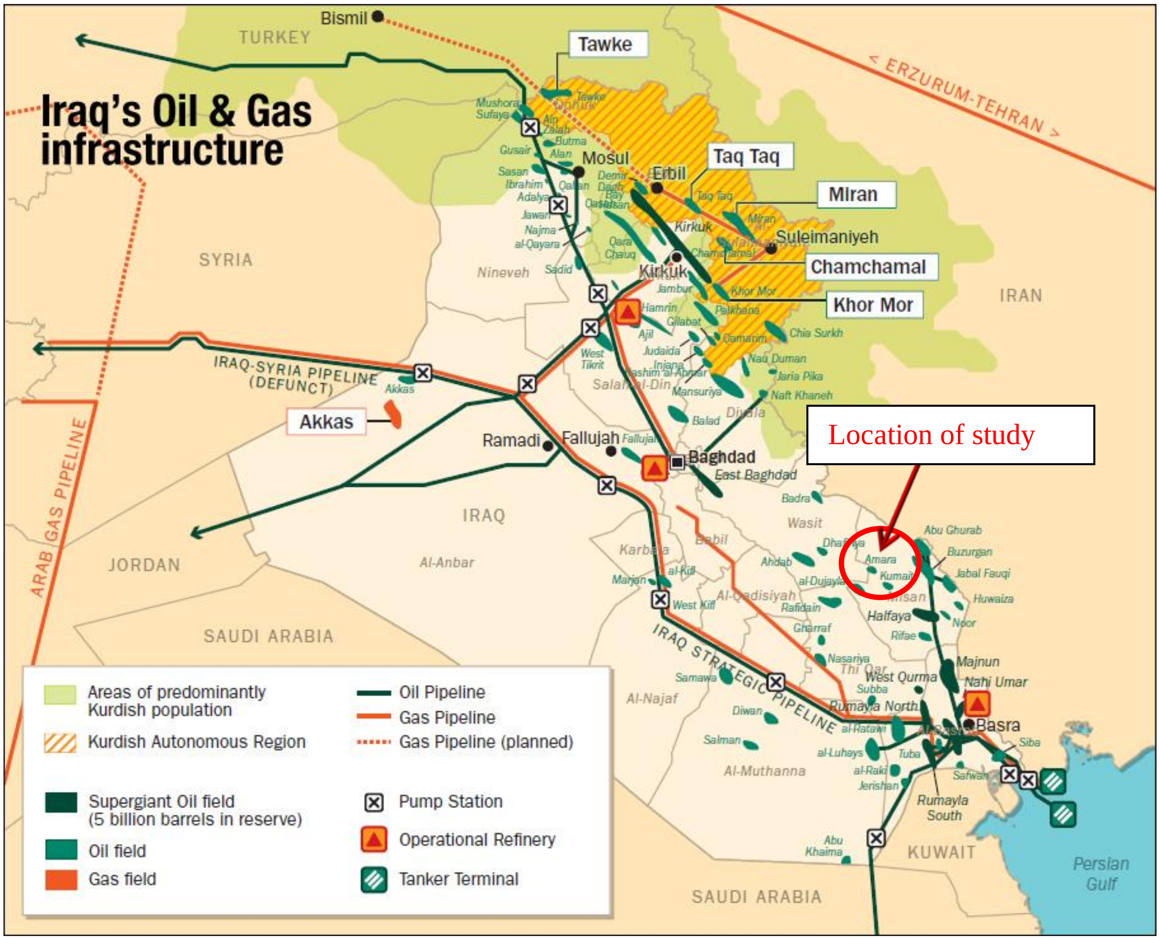

Figure 1. The red circle is area of interest, Amarah field Location, Iraq

2. Theory

The precise determination of permeability is a key parameter for the petroleum engineer because permeability controls the processes of well completion, producing plan, integrated management of reservoir, and affects field economic in its processes and development. Well log is one of the most common ways which is cheap and easy in determining the permeability to obtain more reliable and representative permeability value.

2.1 Determination of Flow Zone Indicator (FZI) and reservoir Quality Index (RQI)

In 1993 new method to estimate and recognize units of flow. The technique developed is focused on extracting characterization detail at the pore throat level scale. Further discussion regarding pore throat analysis is included in the reservoir characterization section. The pore geometry determines the hydraulic quality of the rock. Demonstrated a methodology by which reservoir pore throat are analyzed which results in the ability to identify flow units with similar hydraulic properties. The researchers developed this new methodology by modifying the Kozeny-Carmen equation. This equation expressed permeability in terms of porosity and specific area [1], [2], [3]. Three terms must be defined:

Flow Zone Indicator (FZI):

$$1 / ((Svgr)(K_z)^{0.5}) \qquad (1)$$

Reservoir Quality Index (um):

$$0.0314\ (K / \phi e)^{0.5} \qquad (2)$$

Porosity Normalization Index

$(\phi z) : \phi e / (1-\phi e)$ (3)

Where $Svgr$ is define as the unit grain volume of specific surface area, Kz is the Kozeny constant, which reflects grain shape, pore shape and tortuosity for the flow unit. The FZI value is considered to be constant within a flow unit.

FZI define as:

$FZI = RQI / \phi z$ (4)

The derivation from Kozeny-Carmen equation yields the following logarithmic relationship:

$\text{Log } RQI = \log \phi z + \log FZI$ (5)

A log-log graph of data from a given flow unit or similar FZI value will be situated on a slope of straight line equal 1. The researchers further demonstrated that other flow units will fall on adjacent parallel lines. Each flow unit will have a separate FZI value. The FZI value or indicator will be for a given flow unit having similar pore throat characteristics [4].

Permeability normally is calculated by practical techniques like routine core analysis or well testing that are required cost and time; because of this using well log information to get petrophysical characteristics of oil formation like porosity and permeability is benefit. Petrophysical factors commonly have relation with logging records [5].

The profit of applying logging information to determine permeability was studied, which can supply a continuous profile of permeability for a specific well section. It has been explain that data correlation of statistical regression is very significant. We suggest a two procedure for evaluation of permeability which employs non-parametric regression in rely with multi-variate statistical analyzing [6].

The evaluate permeability of reservoir from calculated porosity using many techniques called linear regression, adjustment neuro-fuzzy inference system, and M5 decision trees. Performance of these methods used to model the relation of permeability and porosity for a complex formation. The technique efficiency was determined by root mean squared error (RMSE) and determination coefficient (R^2) [7].

2.2 Empirical models for Determining Permeability from Well Logs

In empirical modeling, the permeability is determined by calculating porosity and connate saturation of water for the core sample and improving mathematical models connecting irreducible water saturations and porosity for permeability prediction.

Application of the Kozeny equation for the estimation of unit grain volume of specific surface area (Sgv) was studied and the following relation was derived [8]:

$$Sgv = Spv\left(\frac{\phi e}{1-\phi e}\right) \quad (6)$$

Tixier gave the following expression to determine permeability use empirical correlation between water saturation and resistivity, pressure of capillary and water saturation, permeability and capillary pressure and created a method to determine permeability from gradient of resistivity as follow [9]:

$$K = C\left(a\frac{2.3}{\rho_w-\rho_0}\right)^2 \quad (7)$$

Where: $a = \frac{\Delta R}{\Delta D} \cdot \frac{1}{R_0}$

Dorfman et al. gave the following expression to determine permeability [10]:

$$K=10.0\frac{\varphi^{4.5}}{S_{wi}^{2}} \qquad (8)$$

According to equation of Kozeny and following, coefficients of correlation for some common water-wetting sandstone, considered the following permeability correlation [11]:

$$K=\frac{1}{2F}\left(\frac{\varphi}{1-\phi}\right)^{2}\frac{1}{s_{w_i}^{2}} \qquad (9)$$

Developed and improved empirical permeability correlation find to be rely on studies of logging and core information and the following formula presented [12].

$$\sqrt{k}=\frac{c}{w^{4}}\frac{\varphi^{2w}}{R_w/R_{tirr}} \qquad (10)$$

Where:

$C=23+456\rho_h-188\rho_h^2$

$w^2=3.75-\phi+\frac{(\log((Rw/Rtirr))^2}{2}$

It is obvious that permeability is of great important to be determined from core analysis, well test, or correlations, the core and well test are of great costs so they are not available for each well. Correlations are used instead but keep in mind the parameters of the empirical correlations should be estimated with high percent of accuracy. The empirical correlation should be modified for each oil field; the correlation should be modified for each field statistically.

2.3 Well Logging Interpretation

Petrophysics is rock properties study and their relation with fluids (gas, oil and water). Petro-physical properties involve: porosity; saturation of water, and volume of clay. Clay Volume Determination The following clay indicators have been used: Gamma Ray (GR); and Density Neutron. Porosity Determination porosity of rock is commonly estimated from records of one, or a relation of the following logging data: Neutron log and/or Density log, and sonic log Water Saturation Determination All water saturation determinations from resistivity logs in clean (non-shaly) formations with homogeneous intergranular porosity are based on Archie’s water saturation equation, or variations thereof,[13].

$$Sw^n=\frac{F\,Rw}{R\,t} \qquad (11)$$

F is usually obtained from the measured porosity of the formation using the following relationship:

$$F=\frac{a}{\emptyset^{m}} \qquad (12)$$

In this calculation Archie parameters are: a= 1, and m= 1.8 (fractured rocks).

2.4 Statistical Method for Permeability Determination

A nonlinear transformation of variable is generally used in practice problems of regression. Alternating conditional expectations (ACE) is one of these techniques to get those transformations that give the better fitting additive model.

ACE technique is used to get non-parametric correlation between permeability as dependent and porosity as independent variables. The porosity used for developing this correlation is core porosity. ACE technique was done by GRACE program. Program of GRACE creates a best correlation between multiple independent variables (x1, x2, x3 .....up to x30) and a dependent variable (y). This is achieved by transformations of non-parametric independent and dependent variables. Non-parametric utilize that no functional form is considered between variables, and the transformations are obtained merely rely on the set of data. The final correlation is obtained by graphing the sum of the transformed independent variables versus transformed dependent variable.

3. Materials and Methods

Well log interpretation and petro-physical properties are determined using interactive petro-physics software.

Porosity and permeability are measured in the core analysis laboratory (routine core analysis). Permeability is measured by passing a gas through the core. The porosity is measured by the saturation method. The data is arranged from porosity and permeability with depth in an excel file. Excel file is converted to a data file (.dat) by Surfer software.

The data file is entered into the ACE program, the independent and dependent parameters are specified in the program and then RUN the program and the results file is produced as an Excel file and it contains the correlations and other statistical parameters to indicate the accuracy of regression.

4. Results and Discussions

4.1 Log Interpretation

Figure 2 and figure 3 represent cross plots for Amarah oil field, which involve lithology determination (limestone) and secondary porosity detection. The interpretation also involves figure 4 which shows the computer-processed interpretation (CPI) of Amara field /Mishrif Formation for well AM- 5, which prove good hydrocarbon reserve.

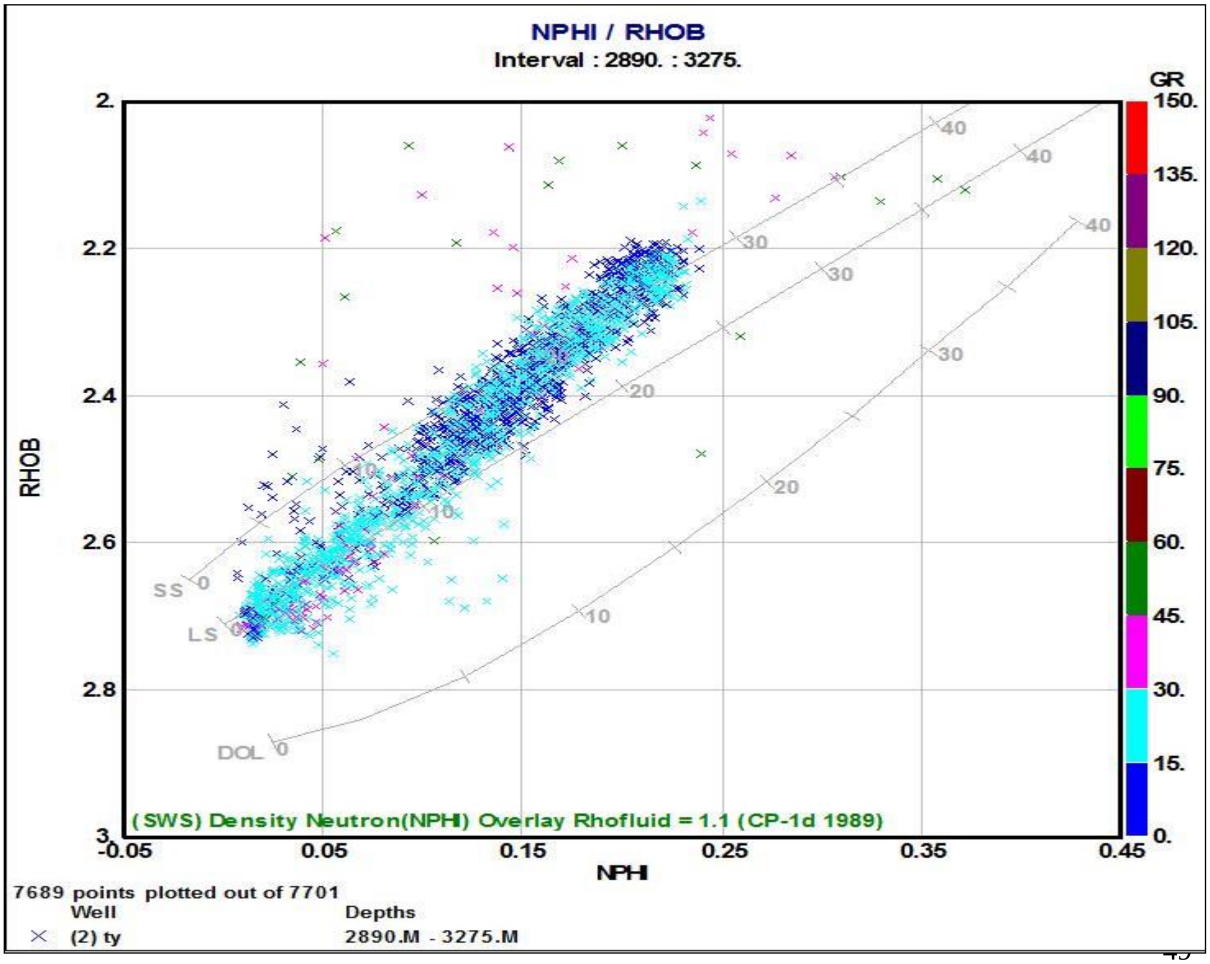

Figure 2. Cross-plot of ΦN and ΦD for well AM- 5, Mishrif formation

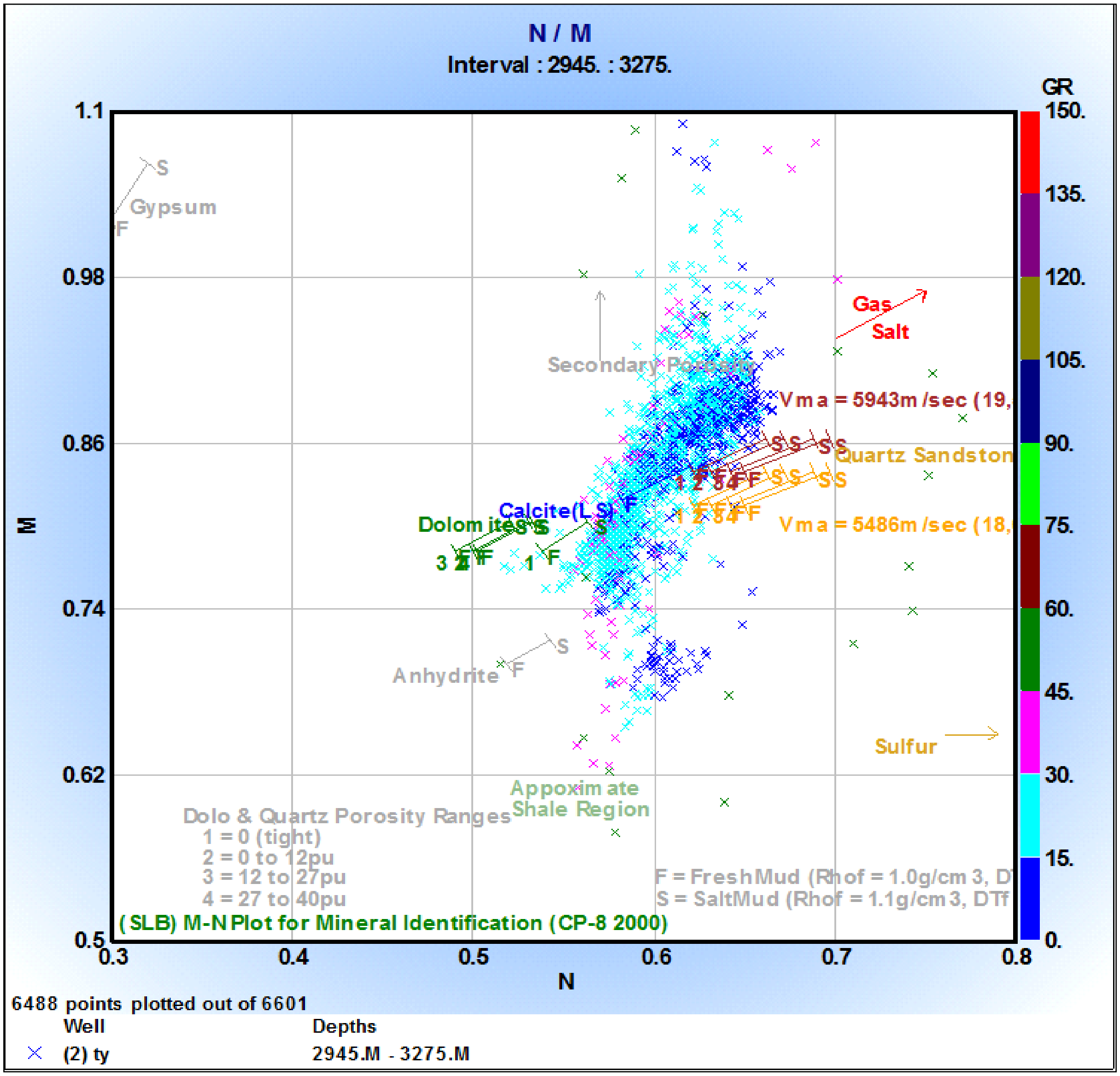

Figure 3. Cross-plot of M-N for well AM- 5, Mishrif formation

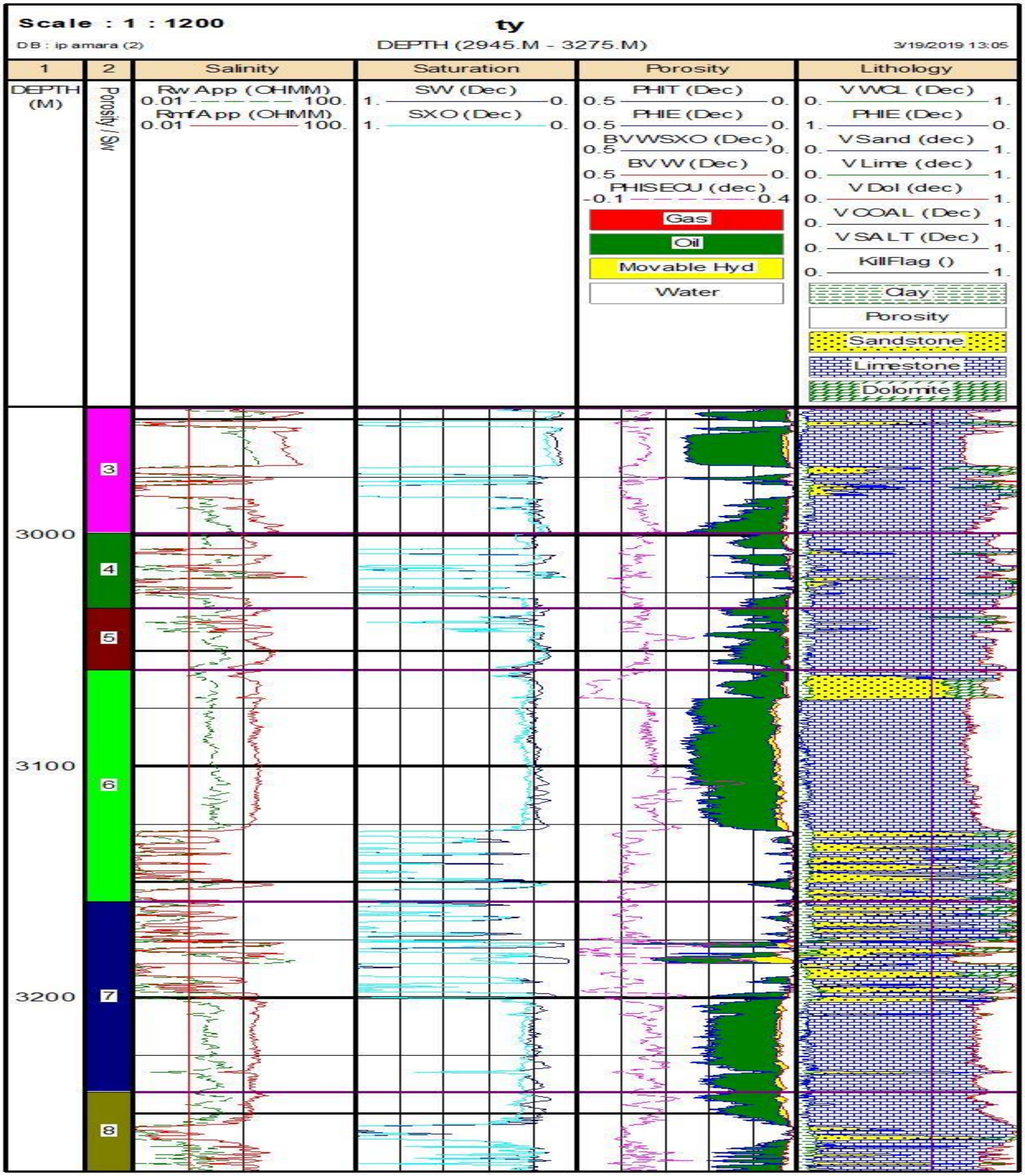

Figure 4. CPI for AM- 5, Mishrif formation

4.2 Identification of Hydraulic Flow Unit (HFU) by Flow Zone Indicator (FZI) and Reservoir Quality Index (RQI)

Figure 5 below shows a plot of porosity versus permeability for a core information of Mishrif Formation units for well AM- 5 in Amara Oil Field. These points indicate that relationships between porosity and permeability are not clear. Therefore permeability prediction needs more parameters in order to get accurate permeability results. The value of (R^2) in the figure 5 below is of a minimum value of (R^2) 0.6767. This low value indicate to high complexity. The raise in permeability does not necessarily result in raise in porosity, and vice versa.

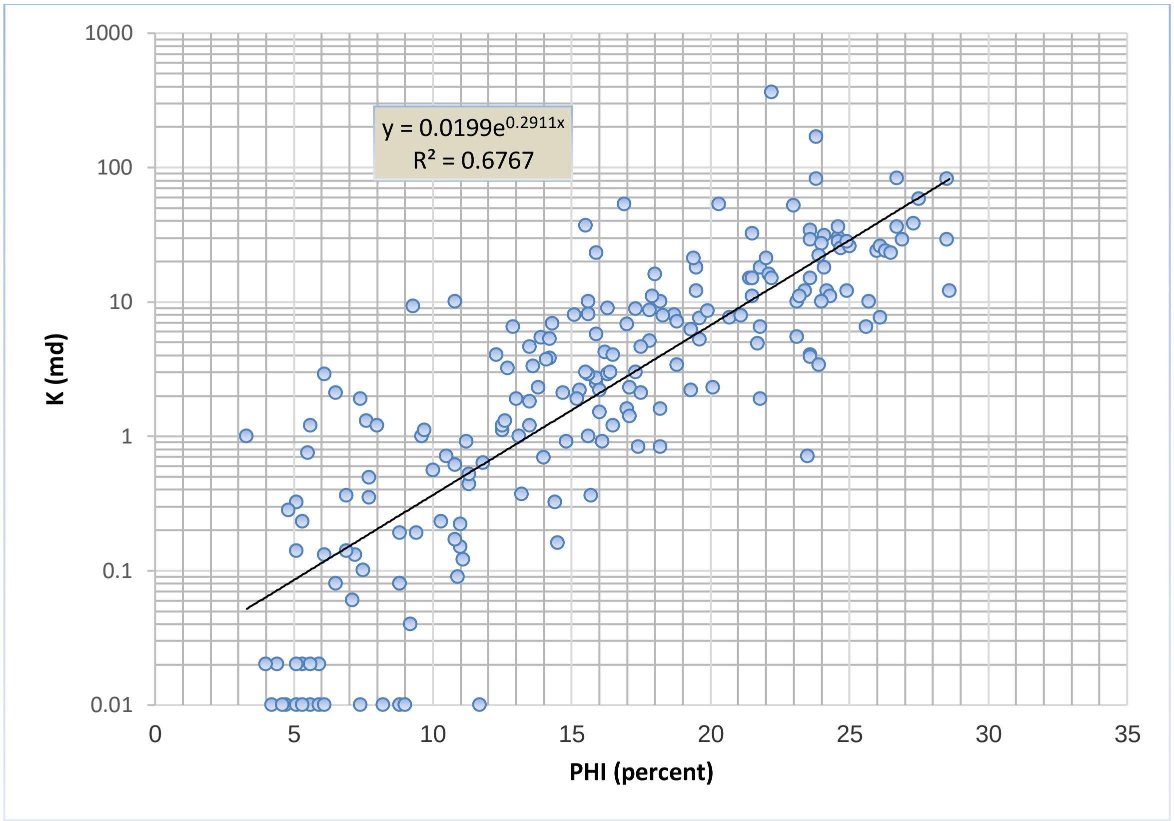

Figure 5. Permeability – Porosity relationship for Mishrif formation well AM- 5

A plot of the logarithm of the normalized porosity (ϕz) versus the logarithm of the reservoir quality index (RQI) for different magnitudes of the Flow Zone Indicator (FZI) (Figure 6). All the data points that fall on the similar (FZI) straight line could be account to have same pore throat characteristics, (figure 6) shows the existences of eight different hydraulic subunits within interval of the cored of Mishrif formation. These subunits are identified by a certain mean value of FZI.

4.3 Statistical method

The following figure 7 to figure 9 shows ACE technique results by Grace software for Amara oil field. ACE technique is used to get non-parametric correlation between permeability as dependent and porosity as independent variables. The porosity used for developing this correlation is core porosity. ACE technique was done by GRACE program. The results of GRACE program for Mishrif reservoir (figure 10) show predicted and measured permeability profiles for this method. Tables 1 show ACE, FZI, LSM models and correlation coefficients for each method. By comparing the core permeability and predicted permeability it

was noticed that ACE technique gives more accurate results than multiple regression method. 75% of available data used to generate ACE model and 25% of remain data used to test the validity of the model.
In the previous method the relationship was generated by ACE algorithm between permeability as dependent variable and core porosity as independent variable. Now in this method the model is generated by replacing the porosity with group of logs. Six well logs have been chosen as independent variables which are; neutron log (NPHI), bulk density (RHOB), dual lateral log (LLD), micro spherically focused log (MSFL), sonic transit time (DT), and gamma ray log (GR). Using these well logs as independent variables will help to get more accurate statistical correlation.

Now model validation made by applied the equations on the rest 25% of the data that kept checking the accuracy of the model, and plot of predicted and measured permeability profiles versus depth.

Generally, ACE technique gives more accurate results than multiple regression method. Using ACE with set of well logs as independent variables, more accurate results are obtained. This is obvious from the higher correlation coefficients [14], [15], [16].

In ACE (Alternative Conditional Expectation) program, Mishrif formation data of well#1 in Amara oil field were used. Grace program was used in order to obtain correlations and correlation coefficient of (140) data points of AM- 5 as shown above. The correlation coefficient equals to (R^2= 0.882), the correlation which was obtained from Grace Program of (140) data. The remaining (60) data of AM- 5 as shown below, which has correlation coefficient (R^2= 0.995) to make-sure that the work is safe track and to raise the precision of the correlations, (figure 10) shows the permeability versus depth.
Another regression was generated using permeability with group log data (ln GR, ln NPHI versus ln K core) the correlation coefficient is (R^2= 0.809). Table 1 summarized all generated regressions.

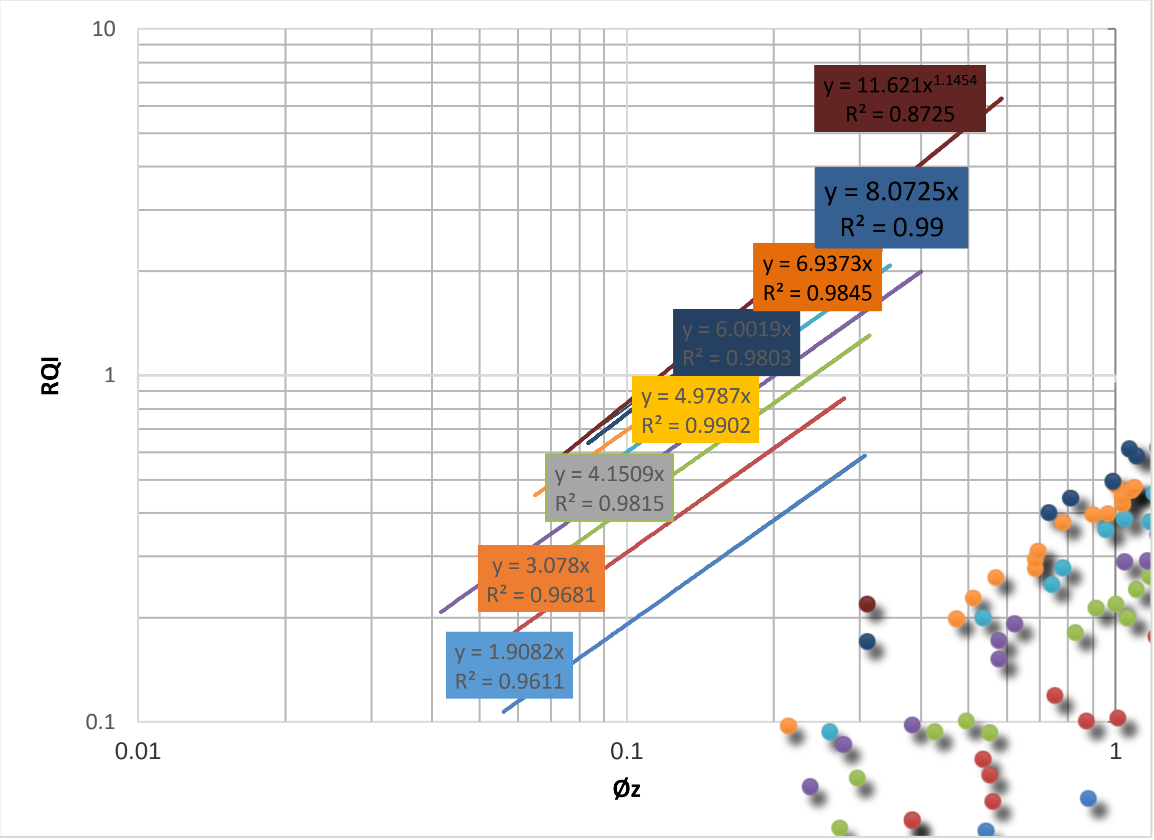

Figure 6. RQI vs ϕz for well AM-5 in Amara field Mishrif Formation

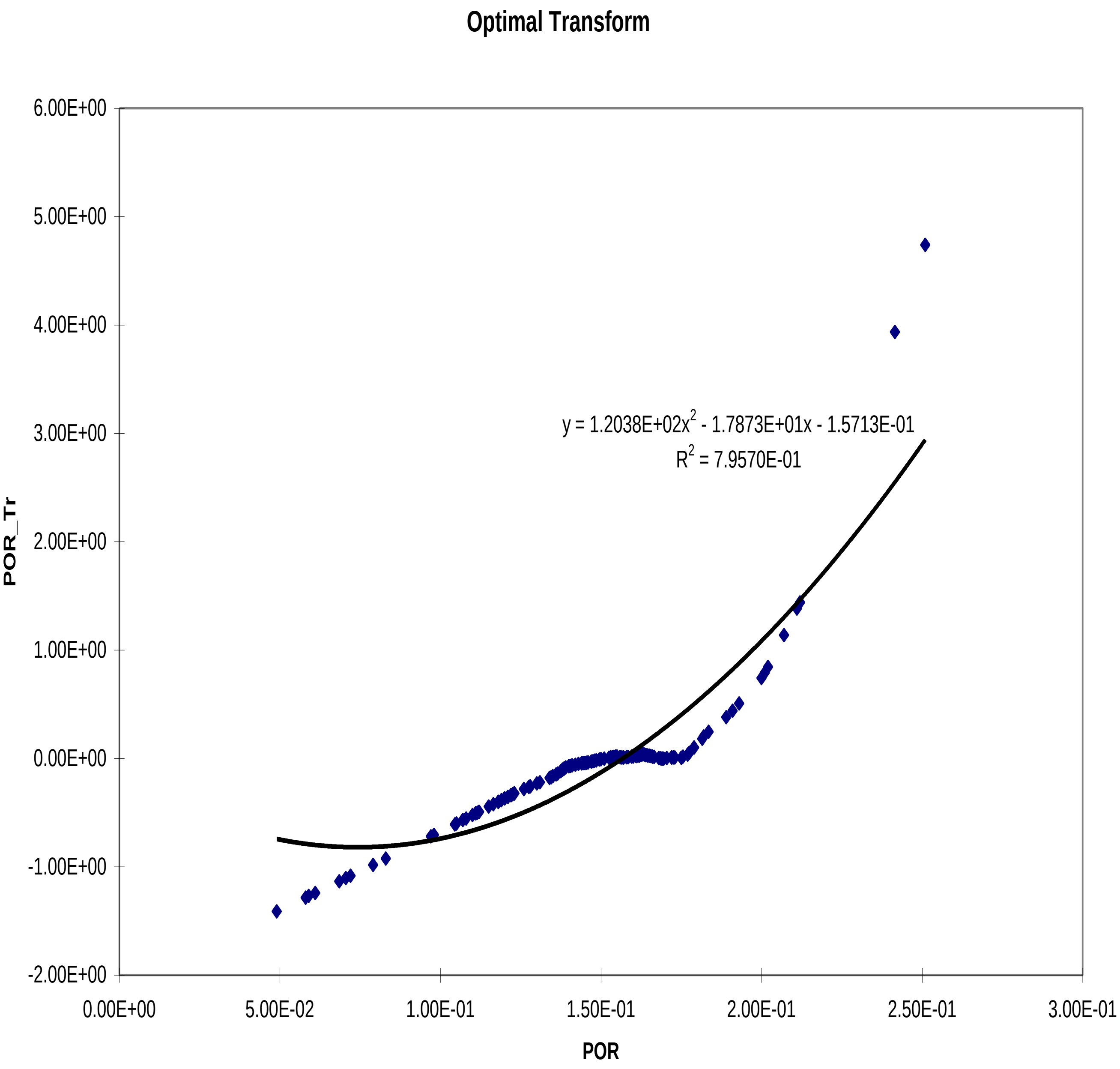

Figure 7. Optimal Transform of porosity

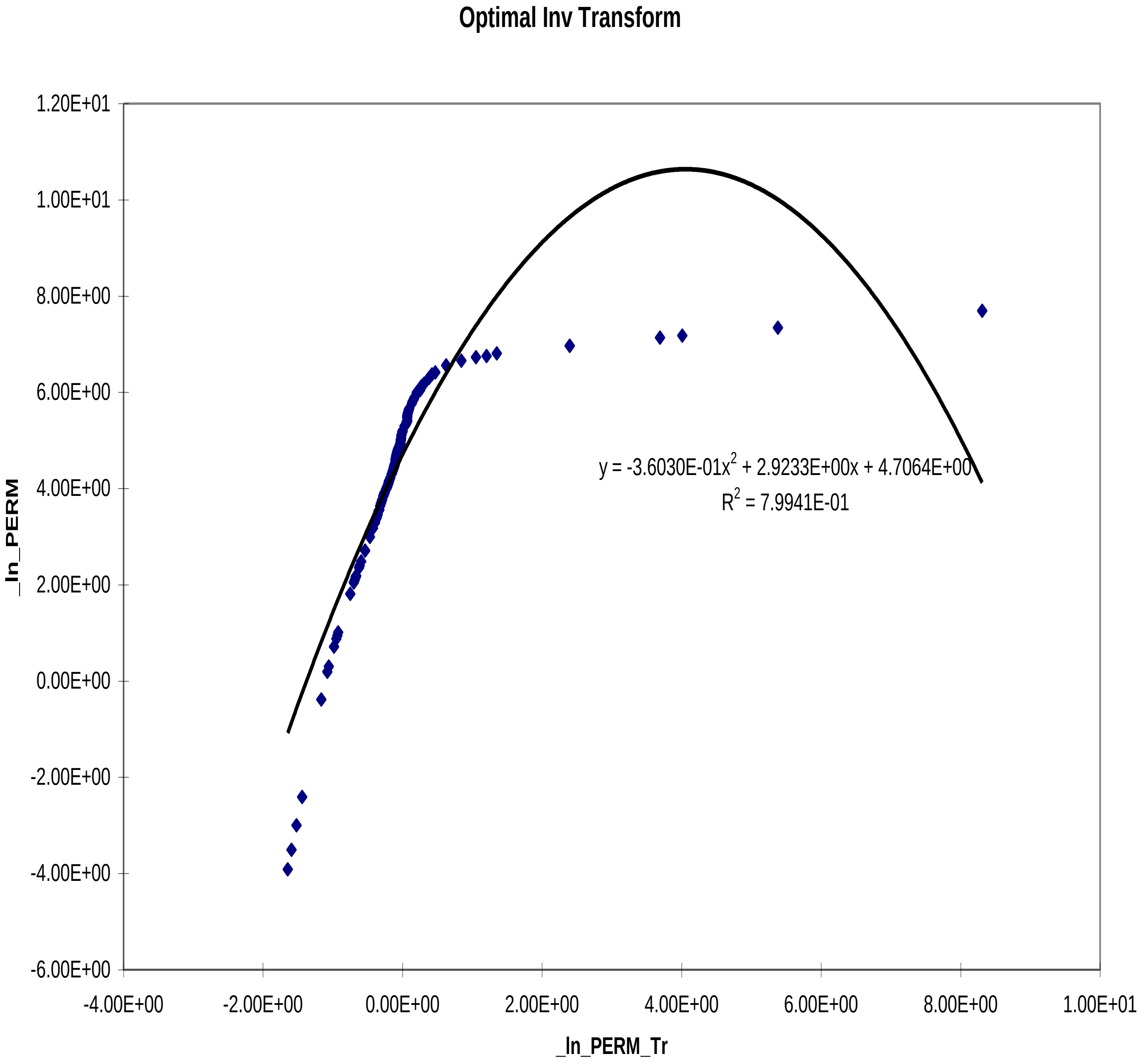

Figure 8. Optimal Transform normal logarithm of permeability

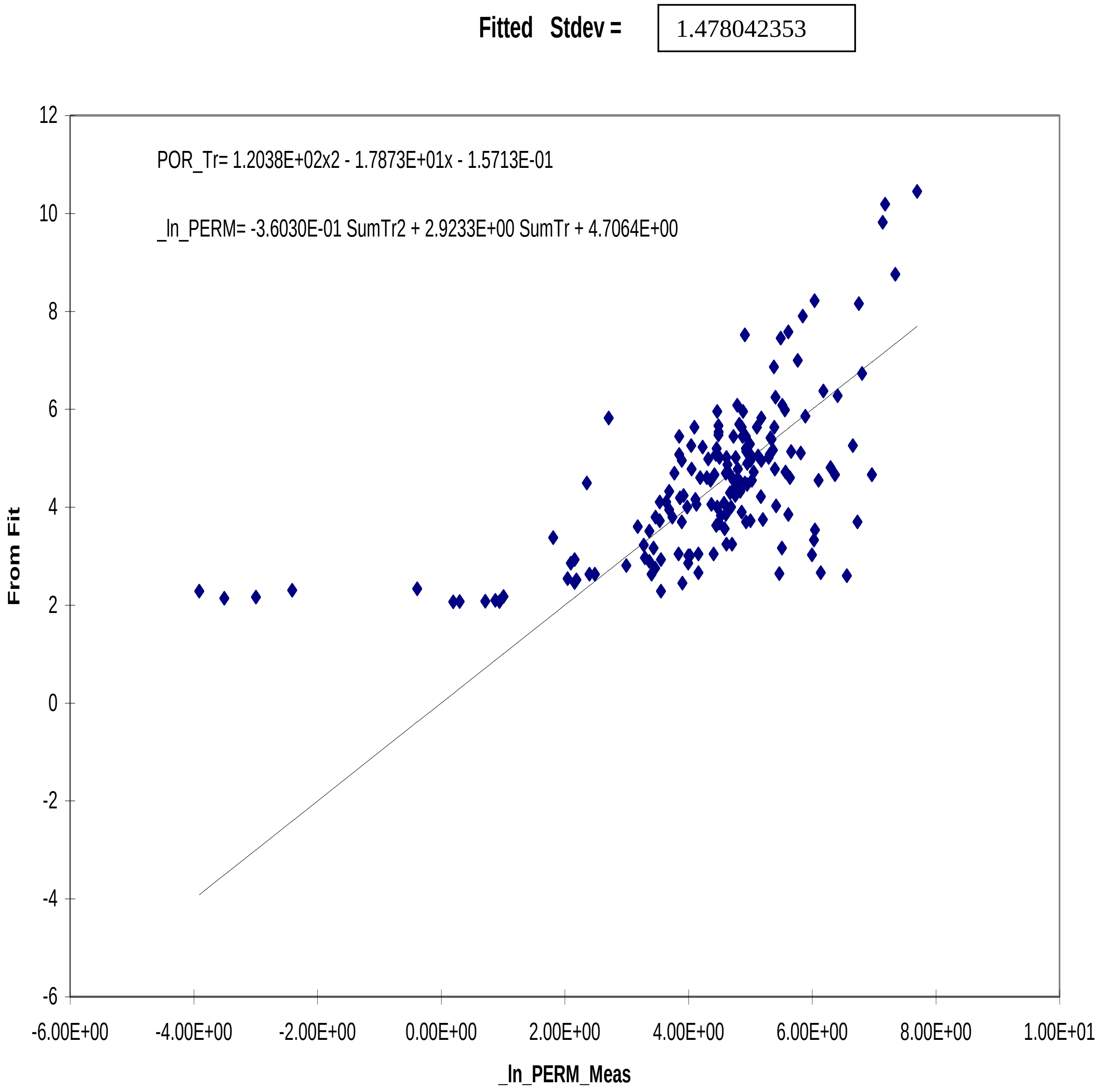

Figure 9. Fitted standard deviation for measured permeability

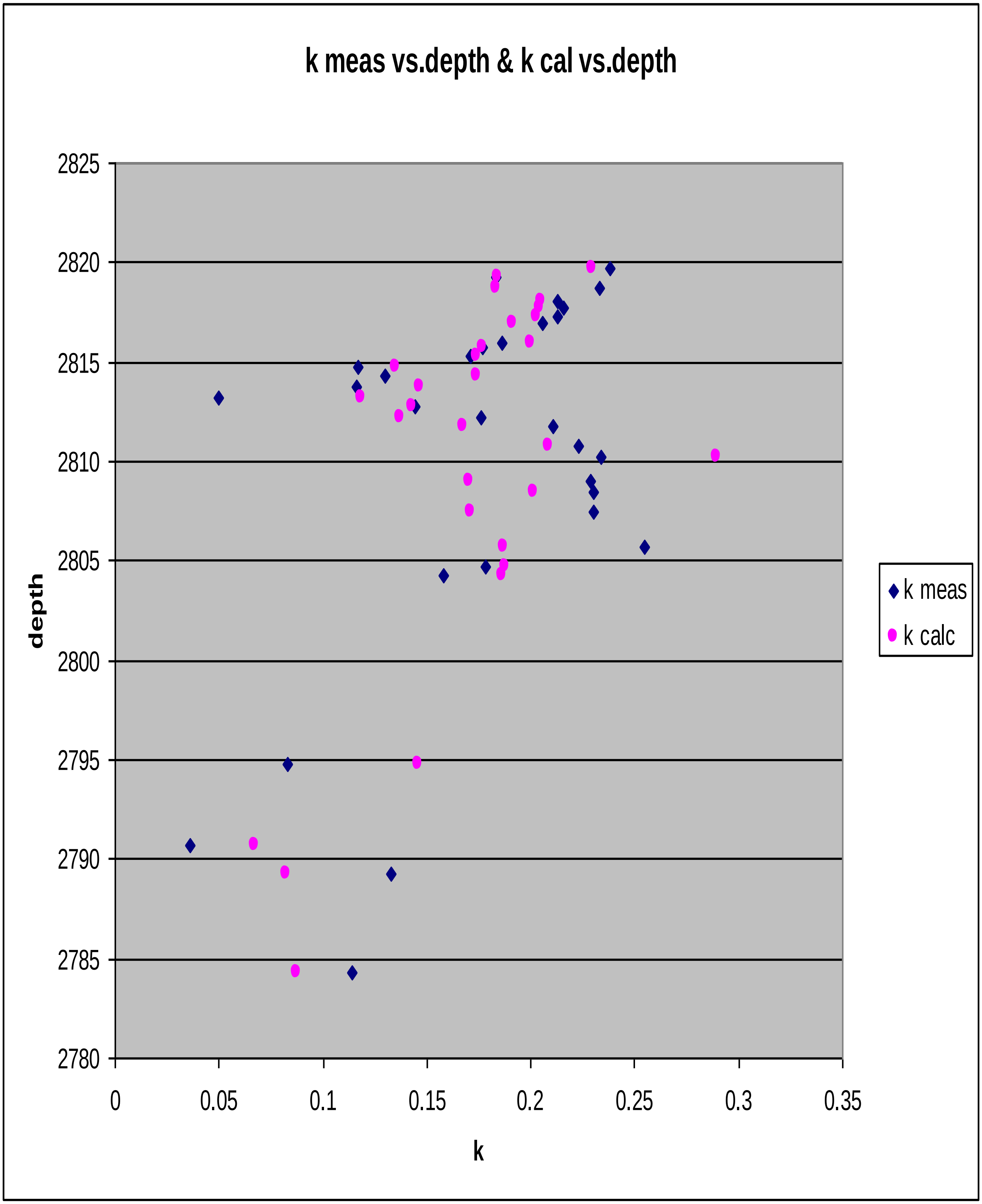

Figure 10. K core vs. depth, and K calculated vs. depth AM-5, Mishrif formation

Table 1. Produced regressions

Parameter used	regression	Correlation Coefficient, (R^2)	Standard deviation, (SD)
Less square method	$K=0.0199e^{0.2911x}$	0.6767	
Permeability and porosity (ACE techniques)	$K=1.2038*10^{2*}x^2-1.7873*10^1*x-1.5713*10^{-1}$	0.882	1.478042353
Permeability and group of logs (ACE techniques)	$K=-2.1345*10^{-5}*X^2 1.016*10^2 X+4.8082*10^{-1}$	0.809	0.296
FZI method			
FZI-1	$K(MA1)=1.6133Ø^{0.8887}$	0.9786	
FZI-2	$K(MB11)=2.98\ Ø^{0.9909}$	0.9739	
FZI-3	$K(MB12)=4.4337\ Ø^{1.04}$	0.985	
FZI-4	$K(MB13)=4.9397\ Ø^{0.9906}$	0.9937	
FZI-5	$K(MB2)=6.0019\ Ø$	0.9803	
FZI-6	$K(MC1)=6.9664\ Ø^{1.0037}$	0.9901	
FZI-7	$K(MC2)=8.0725\ Ø$	0.9927	
FZI-8	$K(MC3)=11.621\ Ø^{1.1454}$	0.8725	

5. Conclusion

In the preceding work, permeability estimation for the hydrocarbon units comprising the Mishrif reservoir formation in the Amarah field was carried out. The work is based on core analyses information and well logging for two wells, which are considered to represent this study. The permeability correlations of each of the hydrocarbon units were obtained. From the present study, the following are some conclusions:

1. The study consists of well log analysis and permeability estimation by rigid empirical equations and correlations generation using statistical methods for Amara Oil Field.

2. The Matrix identification (MID) and the M-N cross-plots indicated that all the crossed sections consist mainly of limestone with some dolomite and little shale.

3. By applying FZI method, eight hydraulic units are noticed alternate in Mishrif Formation.

4. Prediction of reservoir permeability for Mishrif Formation using FZI method always greatly enhances the prediction of permeability.

5. Traditional regression in estimating permeability, improve the overall permeability statistical model.
6. Eight different units are identified in the Mishrif Formation, depending on well logs interpretation, Flow Zone Indicator approach, porosity-permeability cross plots, and Gracter's cross plots.

7. Permeability porosity relation from less square method (R^2= 0.676), permeability correlation with porosity from ACE (R^2= 0.88) with groups of logs (0.94), and from FZI (R^2= 0.872- 0.994). FZI give superiority than other methods because it is take in consideration reservoir heterogeneity.

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