Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 12 Volume 25 December 2019

Chemical, Petroleum and Environmental Engineering

Comparative Permeability Estimation Method and Identification of Rock Types using Cluster Analysis from Well Logs and Core Analysis Data in Tertiary Carbonate Reservoir-Khabaz Oil Field

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ABSTRACT

Characterization of the heterogonous reservoir is complex representation and evaluation of petrophysical properties and application of the relationships between porosity-permeability within the framework of hydraulic flow units is used to estimate permeability in un-cored wells. Techniques of flow unit or hydraulic flow unit (HFU) divided the reservoir into zones laterally and vertically which can be managed and control fluid flow within flow unit and considerably is entirely different with other flow units through reservoir. Each flow unit can be distinguished by applying the relationships of flow zone indicator (FZI) method. Supporting the relationship between porosity and permeability by using flow zone indictor is carried out for evaluating the reservoir quality and identification of flow unit used in reservoir zonation. In this study, flow zone indicator has been used to identify five layers belonging to Tertiary reservoirs.

Consequently, the porosity-permeability cross plot has been done depending on FZI values as groups and for each group denoted to reservoir rock types.

On the other hand, extending rock type identification in un-cored wells should apply a cluster analysis approach by using well logs data. Reservoir zonation has been achieved by cluster analysis approach and for each group known as cluster which variation and different with others. Five clusters generated in this study and permeability estimated depend on these groups in un-cored wells by using well log data that gives good results compared with different empirical methods.

Keywords: (Flow Zone Indicator) FZI, Cluster Analysis, Permeability.

مقارنه طرق تخمين النفاذية وتشخيص نوعيات الصخور اعتمادا على التحليل الاحصائي العنقودي باستخدام بيانات مجسات الابار وتحاليل اللباب للمكمن الثلاثي في حقل خباز النفطي

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الخلاصه

خصائص صخور المكامن غير المتجانسة يكون تمثيلها معقدا ,وتقييم الخصائص البتروفيزيائية وتطبيقات العلاقات بين المسامية والنفاذية ضمن هيكل او نموذج وحدات الجريان الهيدروليكي تستخدم لتخمين النفاذية في الابار ذات المقاطع الغير ماخذوذ اللباب فيها

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2019.12.04

Article received: 27/12/2018
Article accepted: 2/2/2019
Article published: 1/12/2019

تقنية وحدات السريات تعرف على انها مقاطع عموديا وجانبيا يمكن مقارنتها وتمثيلها كخرائط خلال المكمن والتي تتحكم بالجريان والتي تختلف بين الصخور. كل وحدة سريان يمكن تمييزهما باستخدام طريقة مؤشر وحدات السريان.لذا تقسيم المكمن الى طبقات من خلال مؤشرا وحدات السريان وتشخيص تلك الوحدات يمكن من خلالها تقييم نوعية المكمن باستخدام علاقات المسامية مع النفاذية. في هذه الدراسة المكمن الثلاثي تم تقسيمه الى خمس وحدات سريان هيدروليكية بالاعتماد على طريقة مؤشر وحدة السريان الموزعة خلال المقطع. لكي يتم تحديد نوعية الصخور المكمنية , بيانات علاقات المسامية والنفاذية لكل طبقة بالاعتماد على تسقيط مؤشر وحدات السريان. المرحلة الثانية في هذه الدراسة, طريقة تحليل التجميع الاحصائية استخدمت كي نقوم بتقسيم المكمن الى نوعيات صخارية للمناطق الغير ماخوذ فيها لباب باستخدام بيانات مجسات الابار. الهدف من طريقة تحليل التجميعي الاحصائية هو تصنيف البيانات الى تجمعات, كل مجموعة تختلف في خصائصها عن المجموعة الاخرى. في هذه الدراسة تم تشخيص خمس تجمعات والتي من خلالها تم تحديد النفاذية باستخدام علاقاتها مع وحدات السريان الهيدروليكية باستخدام مجسات الابار والتي اعطت توافقا جيد مع تلك المحسوبة من بيانات اللباب عندما تم مقارنتها مع الطرق التجريبية مباشر من مجسات الابار.

الكلمات الرئيسية: مؤشر وحدات السريان, تحليل الاحصائي التجميعي, النفاذية

1. INTRODUCTION

Permeability is considered as the crucial parameter in reservoir studies that is used in the development and description of reservoir. Core samples analysis, well tests, and well logs are different sources of permeability data and because lower cost and continuous profile through well using well log data to estimate the permeability. The porosity and water saturation are used to estimate permeability from logging data and established correlations, **Taslimi et al., 2008**. The concept of Hydraulic Flow Units (HFU) is more sophisticated approach to determine permeability and recognize the rock type through the reservoir by using well log and core data that used identical pore throat during groups and clusters. Developing and deriving cluster analysis by using Interactive petrophysics v 3.05 is a suitable method to identify the hydraulic flow units. Moreover, many well log data are used in models of cluster analysis to generate the best variety of clusters and groups that will denote different reservoir rock types. Hence, the importance of using cluster analysis to extend the flow unit determination to the un-cored intervals in the wells. Therefore, porosity-permeability relationship is derived depends on FZI from core data can establish different groups and extended to un-cored wells by using well logging. On the other hand, permeability estimation can be developed from this relationship to enhance method compared with other empirical approaches that are used to determine permeability from well logging.

2. THEORETICAL BACKGROUND

Many methods had been applied to estimate permeability as empirical models depending on porosity and irreducible water saturation from well logging in addition to porosity-permeability. Many investigators conducted different studies and attempt to enhance methods derived from the permeability into a model with general applicability have done an excellent amount of work. However, they concluded from studies that there are many variables related to determining the permeability, **Balan et al., 1995**. Specific surface area per unit grain volume (S_{gv}) is one of the most important concerns with their models relating permeability and can be determined directly from well logs however instead from core analysis. Therefore, derived permeability from well logging was based on specific surface area per unit grain volume (S_{gv}) to irreducible water saturation.

The relationship between irreducible water saturation and rock texture relating to specific surface area per unit grain volume was the main reason for trying to attach permeability. It is standard that in rocks of comparable texture, i.e., from a similar reservoir, there's often a definite relationship between irreducible saturation and permeability. However, if the rock texture changes the permeability for a similar irreducible saturation, it might disagree by many orders of magnitude, **Xue et al., 1996**.

2.1 Empirical Models for Determining Permeability from Well Logs

Tixier (1949) introduced and derived the formula with new parameters:

$$k = 62.5 \frac{\varphi^6}{S_{Wi}^2} \quad (1)$$

k = permeability, md.
φ_e = effective porosity, fraction.

Timur (1968) conducted the study depending on 155 sandstone samples from three completely different oil fields from North America and applied a reduced major axis (RMA) method which supported the best correlation coefficient to the data obtained by laboratory measurements:

$$k = 0.136 \frac{\varphi^{4.4}}{S_{Wi}^2} \quad (2)$$

Coates and Denoo (1974) introduced the formula used to determine permeability from well logging:

$$k^{1\backslash 2} = 100 \frac{\varphi^2 (1 - \mathrm{Sw_i})}{\mathrm{S_{wi}}} \quad (3)$$

But, **Lacentre et al., 2008,** which was cited in Schlumberger SLIP/A, (1989) had done a different modification for the formula which was more simple:

$$k = 10.0 \frac{\varphi^{4.5}}{S_{Wi}^2} \quad (4)$$

Additionally, the formula as mentioned previously cannot apply in water-bearing zone when S_w = 100% and in the intervals with zero porosity gives zero permeability.

2.2 Permeability from Flow Zone Indicator (FZI)

Many researchers used Flow Zone Indicator (FZI) to enhance porosity-permeability from core data to generate groups related to rock type through reservoir. Permeability predictions in un-cored intervals of wells should be taking continuous responses from well logging. Therefore, to apply FZI technique in derived permeability firstly generate relationship between porosity and permeability based on FZI from core data and then extending these relationships to uncored wells using log well logging data. **Amaefule et al., 1993** introduced a new concept of hydraulic unitization to identifying hydraulic flow unit through reservoir and estimating permeability based on this concept in uncored intervals in wells. This study calculated the flow zone indicator (FZI) from core data and showed that magnitudes and distribution of flow units manage and control fluid flow, sweep and recovery efficiencies in reservoir. The following equation was used to determine permeability; every flow unit has a mean FZI value (**Amaefule et.al, 1993)**:

$$k = 1014\ \mathrm{FZI}^2 \frac{\varphi_e^3}{(1-\varphi_e)^2} \quad (5)$$

where:
k is permeability in md, φ_e is effective porosity in fraction, and, FZI=Flow Zone Index in (μm).

3 RESULTS AND DISCUSSIONS

3.1 Relationship of Porosity to Permeability for Core Plugs Data

Porosity-permeability relationship from core data was used to identification of degree in reservoir heterogeneous, especially in carbonate reservoir. Permeability Correlation based on rock type could be a basic procedure that can be applied during core data. However, because of high heterogeneous of pore and pore geometry which lead to results, it is not satisfactory in these correlations. In general, classical methods to determine permeability is done by using a relationship of log permeability with porosity which is linear:

$$\log k=436.67\varphi-43.98 \qquad (6)$$

From the classical approach with the correlation of determination R^2 =0.19 which is very low indicating that the relationship between porosity and permeability is nonlinear and it is concluded that for any given rock type, the different porosity/permeability relationships are proof of the existence of various hydraulic units, as shown in **Fig. 1.**

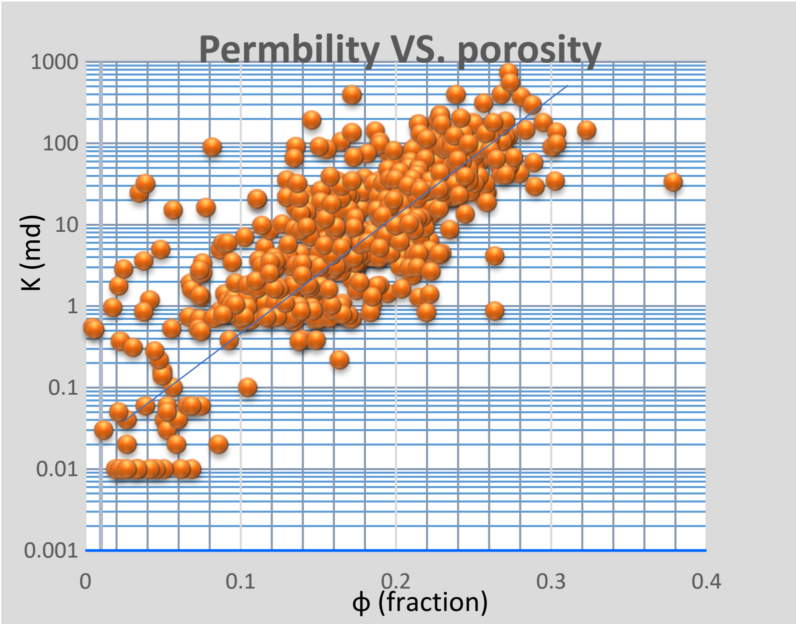

Figure 1. Permeability-Porosity relationship.

3.2 Permeability Estimation from Well Logs

Historically, irreducible water saturation and porosity from well logging based on Archie's equation have been used to estimate permeability by empirical correlations.

Tixier (1949), Timur (1968), Coates and Dumanoir (1974) introduced good correlations used to determine permeability with different coefficients that can determine it by regression methods. Interactive Petrophysics program v 3.4 was applied in this study to estimate permeability from well logging based on the following formula:

$$K=a \times \frac{\varphi^b}{swi^c} \qquad (7)$$

where;

a,b,c: constants depending on the used correlation.

The constant for calculation permeability in Interactive Petrophysics (IP V 3.4) are: Timur : a = 8581 b = 4.4, and c = 2; Morris Biggs Oil: a = 62500 b = 6, and c = 2; Morris Biggs Gas: a = 6241 b = 6, and c = 2; and Schlumberger: a = 10000 b = 4.5, and c = 2. These equations are applicable solely over zones that are at irreducible water saturation, i.e., hydrocarbon zones on top of the transition zone.

The permeability for KZ-16 calculated by using (IP v 3.4) program using the three on top of mentioned methods (Timur, Morris Biggs oil, and Schlumberger) as shown in **Fig. 2**. The same results of calculated permeability by Timur and Schlumberger method was obtained, whereas a bit distinction comparing with Morris Biggs Oil methodology. The calculated permeability by using Interactive Petrophysics v3.4 program was planned with the core permeability. There's poor relationship between them; therefore, the calculated permeability by log interpretation was not adopted in this study.

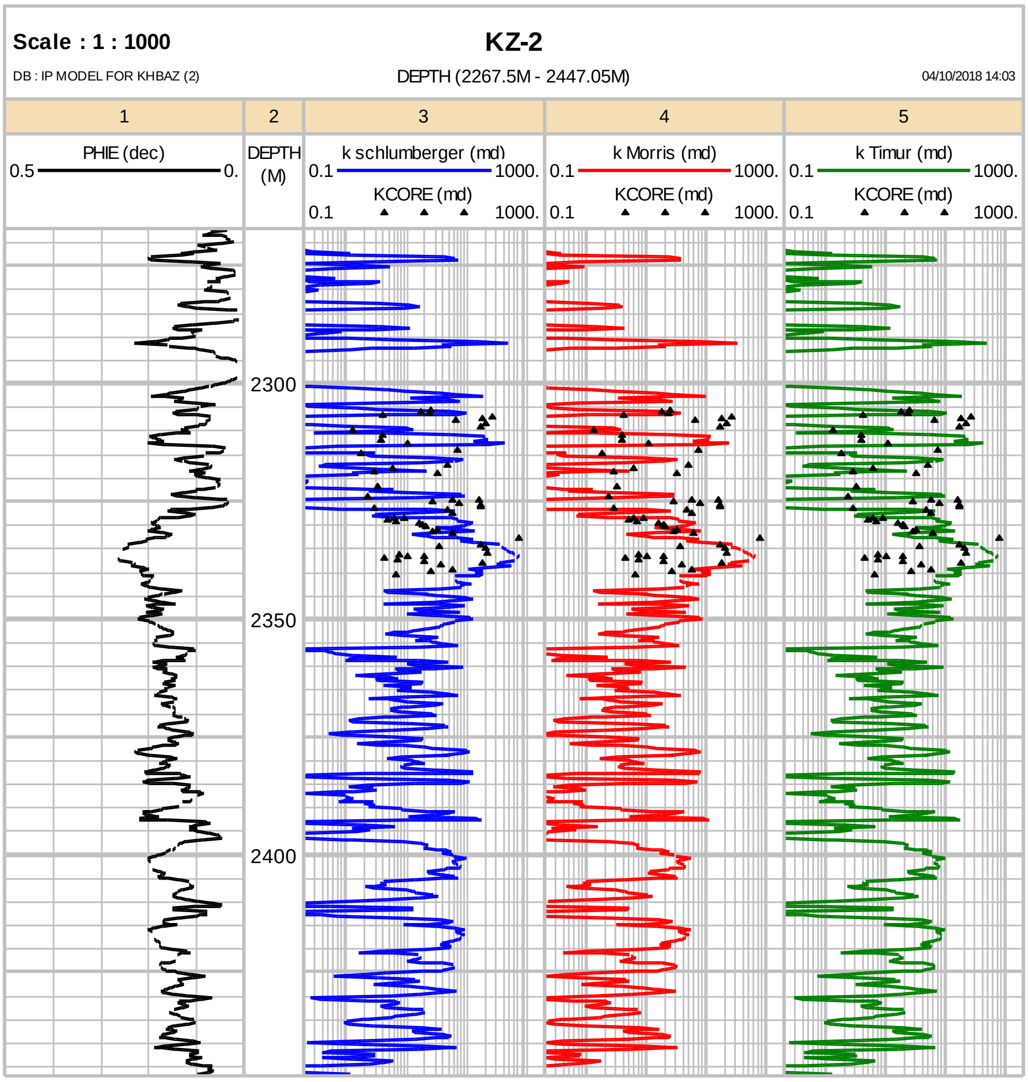

Figure 2. Permeability estimation from well log for KZ-2.

3.3 Flow Zone Indicator Method

The Flow Zone indicator (FZI) methodology for classifying core data into Hydraulic Units with specific FZI provides correct correlations between permeability and porosity if FZI of the reservoir rock is considered. FZI is estimated from core data within the cored wells, and it's sometimes applied to un-cored wells through correlations with log attributes, **Amaefule et al., 1993**. The final approach is given influent equations:

$$RQI=0.0314\sqrt{\frac{K}{\varphi}} \quad (8)$$

$$\Phi z=\left(\frac{\varphi}{1-\varphi}\right) \quad (9)$$

$$FZI=\left(\frac{RQI}{\varphi z}\right) \quad (10)$$

By taking the logarithm of both sides of Eq. (10), the final approach can be written as follows:

$$\log RQI = \log \varphi z + \log FZI \quad (11)$$

Fig.3 shows that plot of RQI vs. Φz lies on parallel lines based on previously mentioned equations. The intercept of the line at Φz = 1 is that the specific flow zone is indicator of every cluster. Different FZI values of core samples can show on completely different lines. Points that lie on every line got same pore throat description and, therefore, same flow unit. **Fig.4** shows that four rock type or cluster is determined from core data in tertiary reservoir in Khabaz field. According to specific values of FZI permeability–porosity correlation generated for every cluster by simple analysis of core permeability-porosity data as shown in **Fig.5.** The generated permeability correlations application in un-cored well depends on FZI values that are predicted from log data by statistical analysis. The generated permeability formulas are tabulated in **Table. 1** and applied in cored well.

To apply FZI through uncored wells and using equation within **Table.1,** cluster analysis methodology has been carried out to determine the flow unit from well logs. Different well logs data from 21 wells in Tertiary reservoir/Khabaz field have been used to generate clusters through uncored intervals by using Interactive petrophysics program 3.5. Well logs data include sonic (DT), bulk density (RHOB), water saturation in flushed zone (Sxo), water saturation (Sw), and effective porosity (PHIE), and shale volume (Vcl) logs were used as input file for cluster analysis model. Fifteen clusters have been chosen assuming to cover all data variation. Assuming initial guess mean value for every cluster and seed input value by taking K-mean statistical technique for given clusters, then by many trials to minimize number of squares deference at intervals cluster between data points and cluster mean value, **Andrew et al., 2012**.

Cluster Randomness Plot was used to identifying different clusters based on variety of rock types, **Schlumberger, 2008**.

The randomness plot has been applied in Tertiary reservoir that refers to four groups based on rocks types by identifying the number heights peaks as shown within the **Fig. 6.** The hierarchal technique has been conducted to show rock type in different groups can differentiate between them based on different colors in tree- diagram

Cluster analysis technique showed that the quality of four rocks types based on k-mean values of petrophysical properties and tabulated within **Table 2.** According to k-mean values and analysis for every cluster which denote to four rock types as:-

1- Group has Very good quality rock type.
2- Group has Good quality rock type.
3- Group has Moderate quality rock type.
4- Group has Bad quality rock type.

Fig. 7 shows the final graphical representation of cluster analysis for selected wells. The identified rocks types and permeability estimation in un-cored well in tertiary reservoir planned in contours type for wells Kz-4 and KZ-2 as shown in **Figs 8** and **9**.

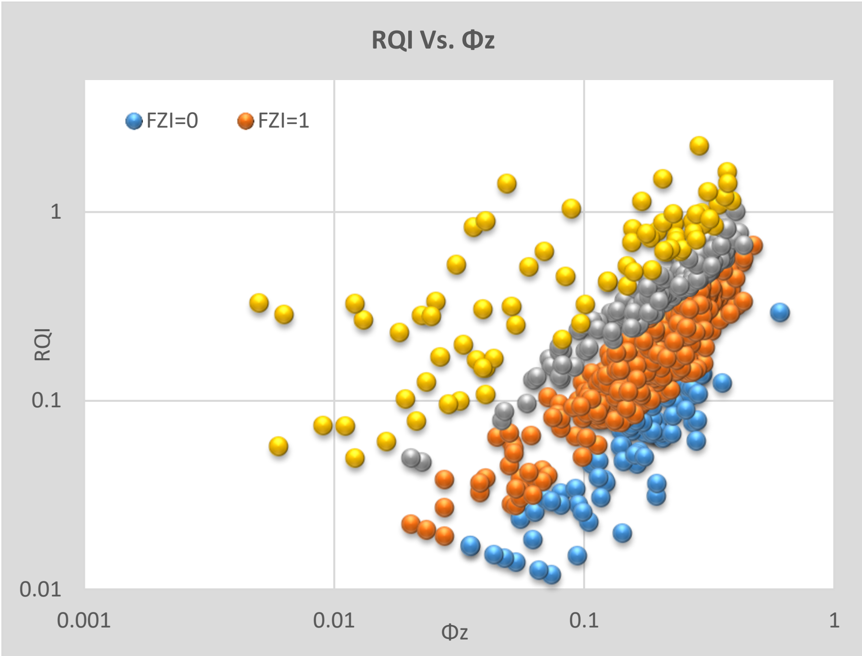

Figure 3. RQI vs. Φz for the Tertiary Reservoir in Khabaz filed.

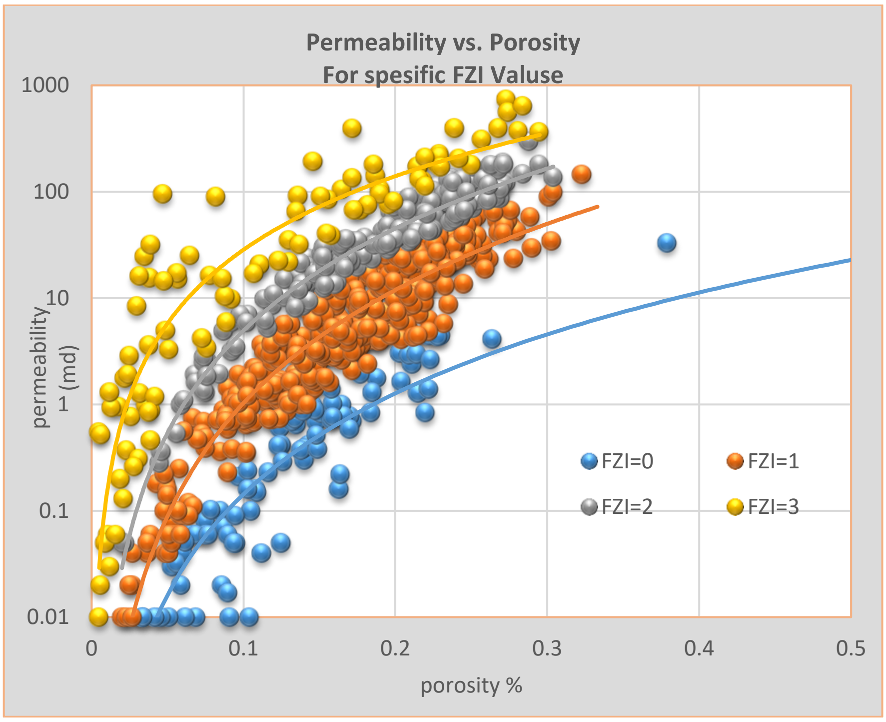

Figure 4. Perm-porosity with FZI values for Tertiary Reservoir in Khabaz filed.

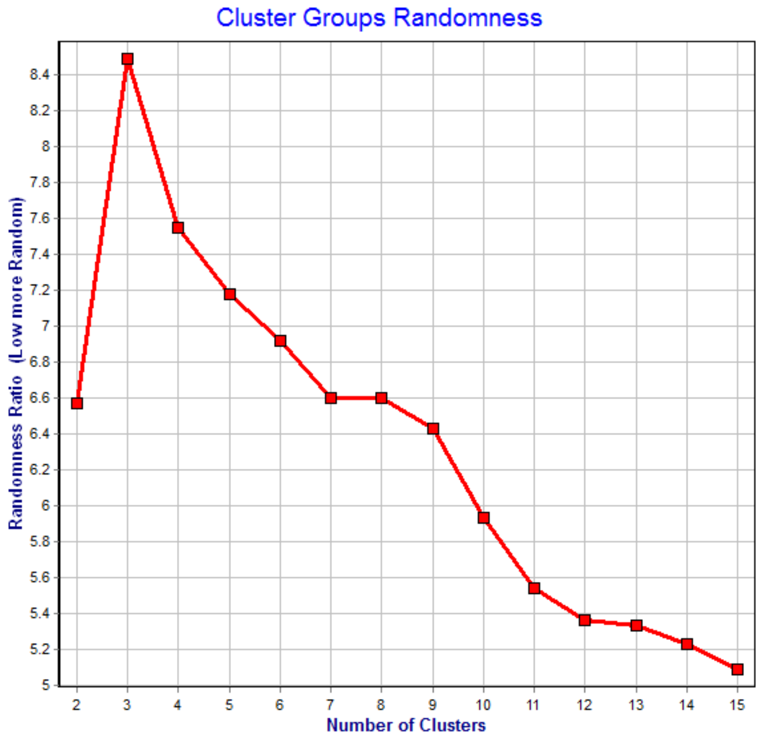

Figure 5. Cluster group randomness for tertiary reservoir.

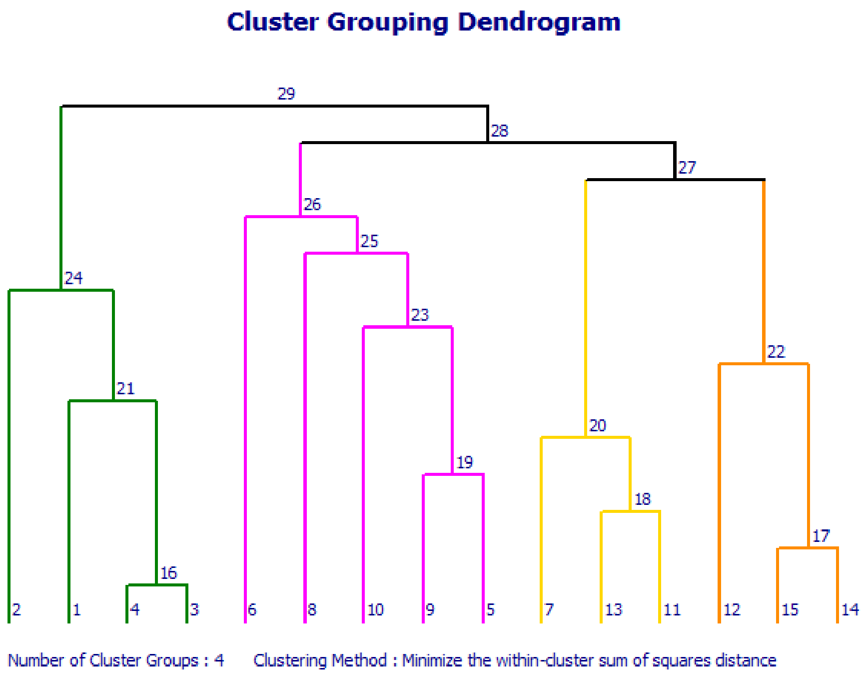

Figure 6. Cluster grouping tree diagram for Tertiary reservoir.

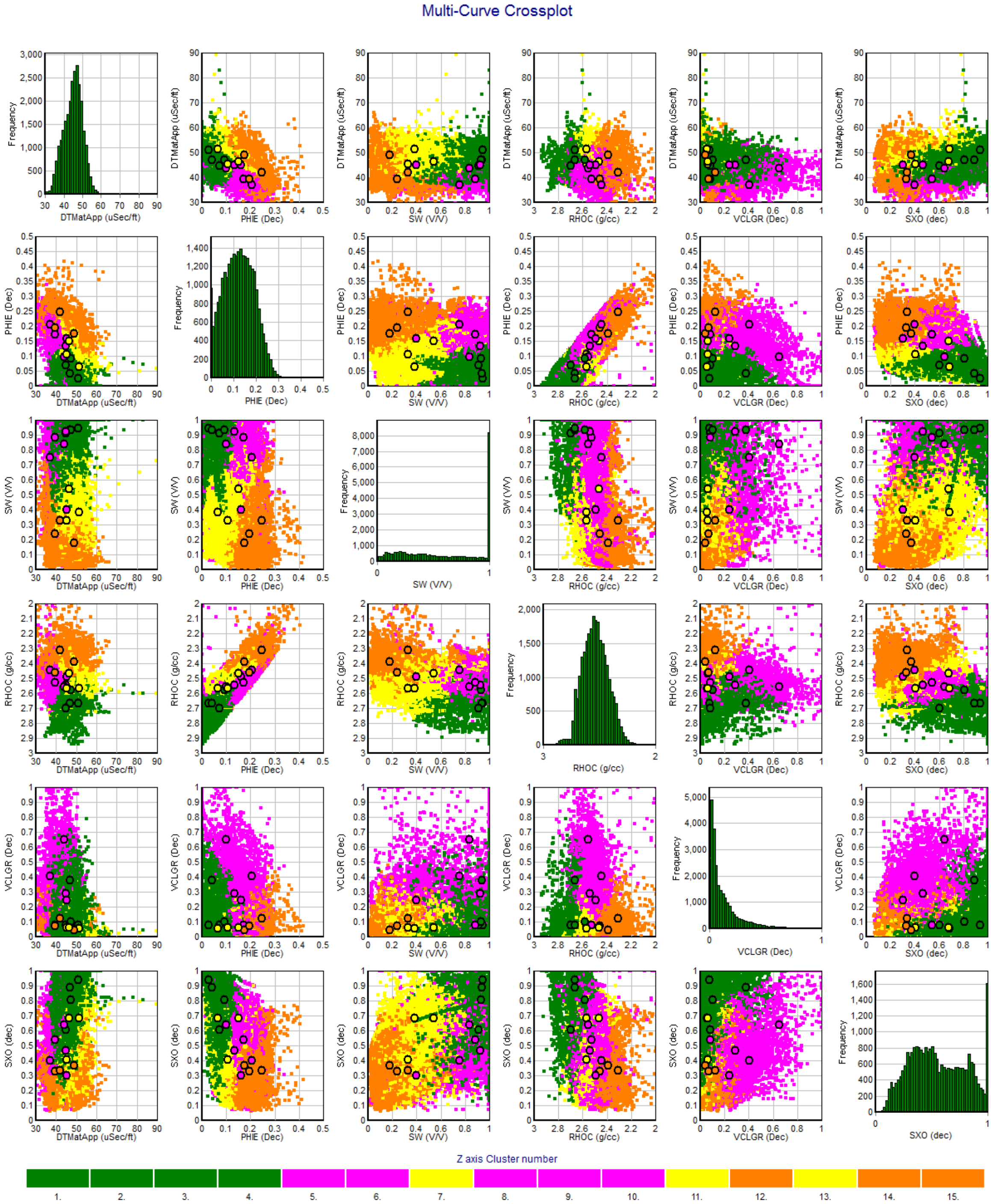

Figure 7. Graphical of cluster analysis in Tertiary reservoir.

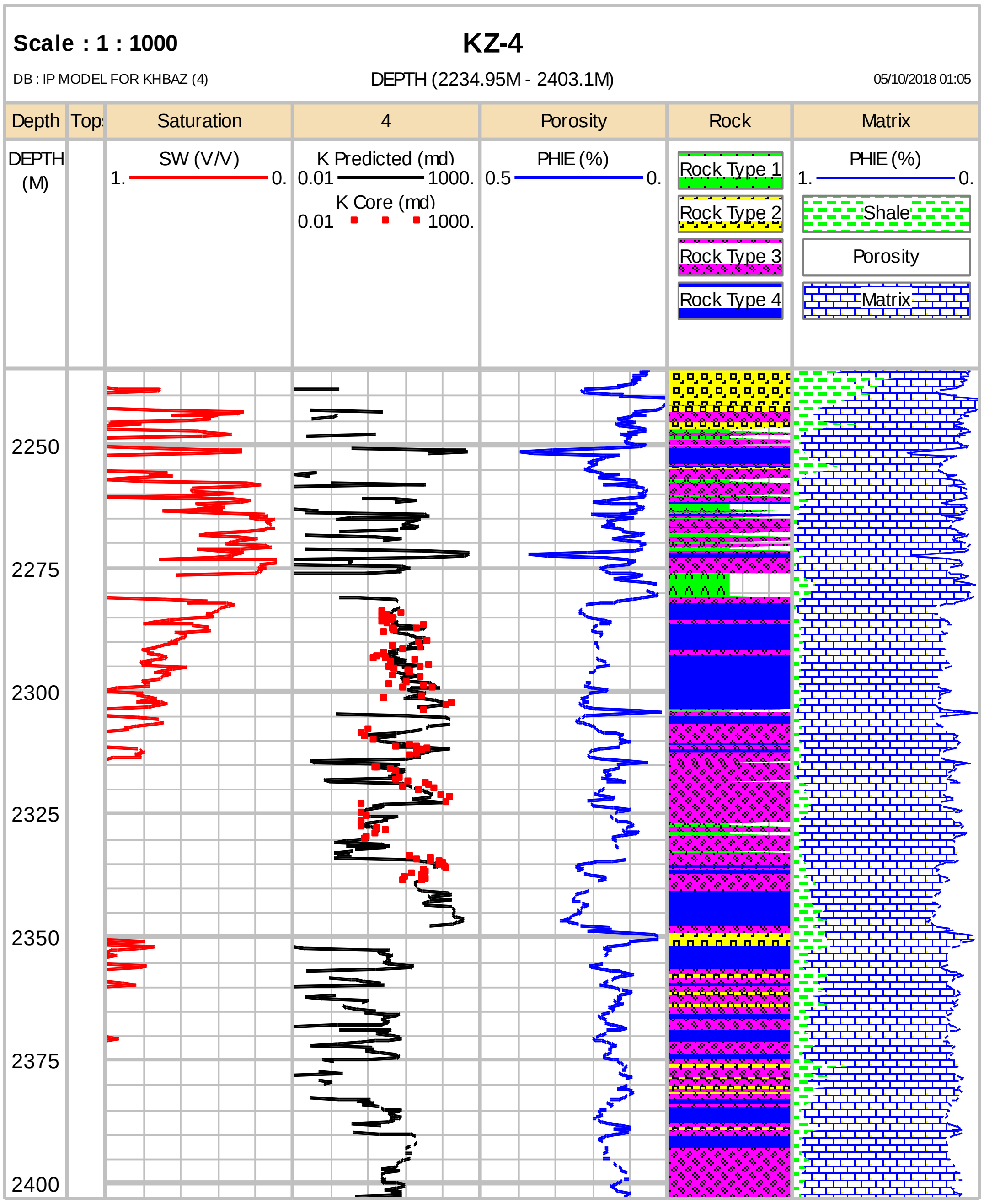

Figure 8. Rock type and permeability estimation by cluster analysis for KZ-4.

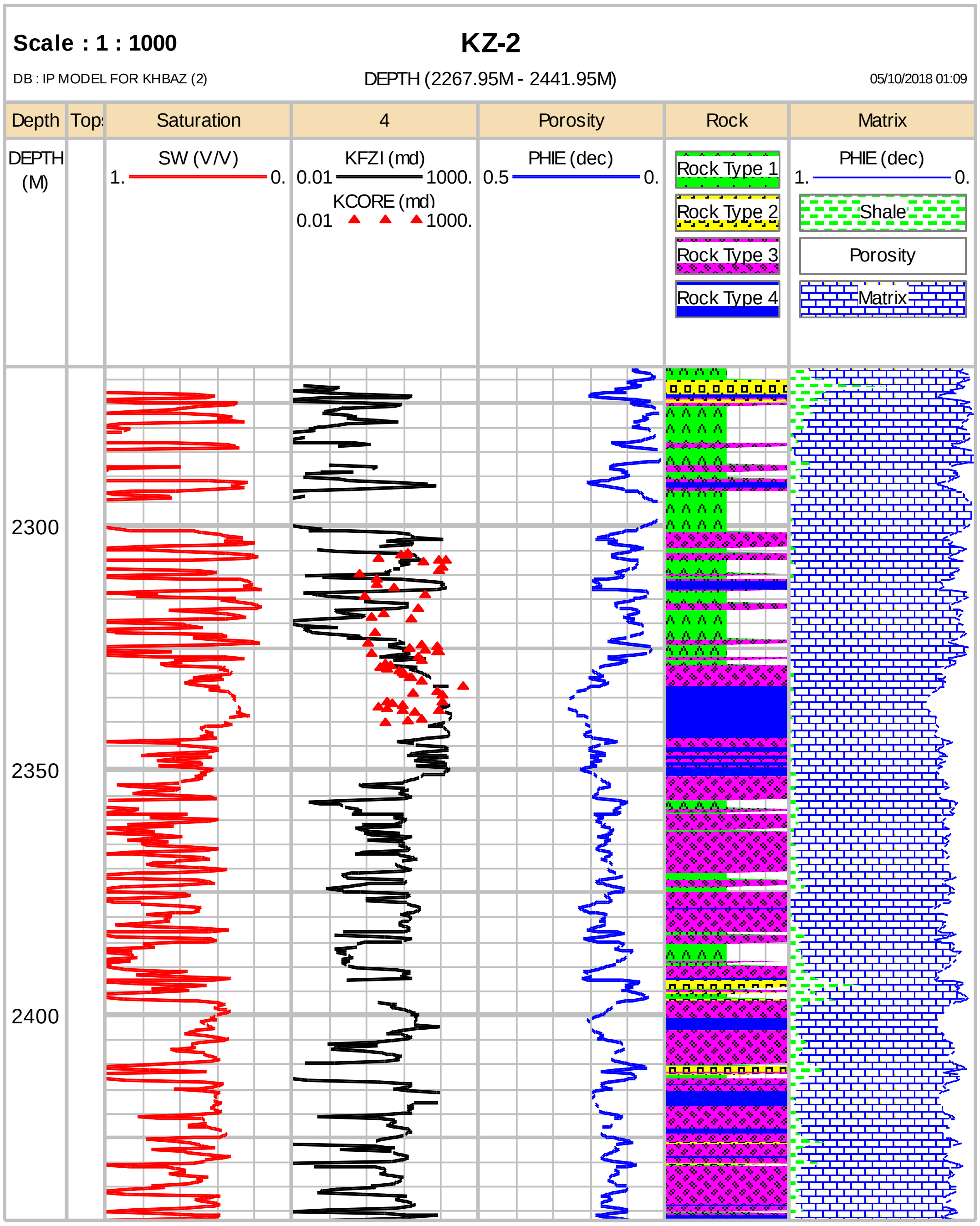

Figure 9. Rock type and permeability estimation by cluster analysis for KZ-2.

Table 1. Permeability formulas from FZI values.

FZI	Formula	R^2
FZI=0	$k = 201.65\varphi^{3.1481}$	0.8422
FZI=1	$k = 3497.1\varphi^{3.5306}$	0.8903
FZI=2	$k = 7714.1\varphi^{3.1939}$	0.9581
FZI=3	$k = 5652.1\varphi^{2.2982}$	0.8433

Table 2. K- mean cluster results.

clusters			DTMatApp		PHIE		SW		RHOC		VCL	SXO		
cluster	group	Points	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
1	1	2586	51.04	2.61	0.026	0.020	0.942	0.124	2.66	0.049	0.076	0.060	0.937	0.0773
2	1	762	46.926	3.55	0.042	0.030	0.93	0.154	2.66	0.07	0.377	0.108	0.891	0.114
3	1	1755	44.615	3.39	0.070	0.024	0.912	0.155	2.69	0.065	0.079	0.054	0.604	0.162
4	1	2198	47.109	2.54	0.091	0.024	0.934	0.104	2.57	0.049	0.101	0.059	0.805	0.0910
5	2	1964	44.842	2.61	0.13	0.030	0.922	0.132	2.54	0.066	0.286	0.092	0.464	0.12
6	2	679	43.779	3.65	0.098	0.045	0.837	0.251	2.55	0.091	0.65	0.138	0.640	0.205
7	3	2110	51.276	3.08	0.065	0.027	0.386	0.170	2.56	0.051	0.057	0.052	0.681	0.146
8	2	581	36.996	3.69	0.206	0.038	0.752	0.272	2.44	0.089	0.40	0.128	0.400	0.155
9	2	1436	45.1	2.58	0.15	0.032	0.397	0.172	2.48	0.055	0.242	0.087	0.300	0.11
10	2	2293	39.36	2.66	0.172	0.033	0.885	0.146	2.52	0.063	0.08	0.053	0.540	0.156
11	3	2290	45.203	2.9	0.105	0.024	0.327	0.155	2.56	0.054	0.062	0.049	0.405	0.139
12	4	2334	48.986	3.19	0.175	0.030	0.175	0.099	2.38	0.061	0.042	0.037	0.368	0.138
13	3	1730	46.292	2.33	0.149	0.028	0.538	0.190	2.46	0.048	0.06	0.043	0.680	0.10
14	4	2377	39.262	2.46	0.194	0.029	0.23	0.160	2.46	0.051	0.07	0.055	0.329	0.125
15	4	1353	42.073	3.66	0.248	0.033	0.326	0.258	2.31	0.089	0.120	0.070	0.334	0.15

4. CONCLUSIONS

1. Enhancement of porosity permeability relationship is based on dividing the data into groups, and each group denotes to a hydraulic flow unit.
2. Five distinct hydraulic units are based on the FZI approach within the cored interval in Tertiary Reservoir.
3. Cluster analysis technique has been achieved in Tertiary reservoir to determine an optimal number of clusters that should be used in identifying rock types in uncored intervals.
4. Permeability estimation has been applied based on hydraulic flow unit (HFU) by Cluster Analysis in uncored intervals using well log data.
5. Validation of permeability determination is achieved compared with different empirical methods which gave good, acceptable match (show reliable correspondence) with measured permeability from core.

NOMENCLATURE

k = permeability, md.

φ_e = effective porosity, fraction.

FZI=Flow Zone Index, (μm).

S_{wi} = irreducible water saturation, fraction.

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