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A New Approach for Enhanced Reservoir Characterization and Petrophysical Parameters Estimation in Northeast Sanan Field in Western Deserts of Egypt

Ramy A. AbuAlfadl[*], Mohamed I. Balaha[*], Attia M. Attia[*]

[*] Petroleum Engineering and Gas Technology Department, Faculty of Energy and Environmental Engineering, The British University in Egypt (BUE), Egypt

Corresponding author: attia.attia@bue.edu.eg

Abstract- The conventional hydrocarbon resources in the Egyptian western deserts are characterized with a high degree of heterogeneity. In turn, petrophysicists characterize such heterogeneous rocks with different flow units and rock types. Knowledge of the rock's petrophysical properties including permeability, porosity, pore throat radius, and lithology Index is essential for the development of reservoir characterization. It is well known that this knowledge is best gained from coring samples; however, coring for all wells is not economical. Subsequently, prediction of these parameters in uncored intervals is required with accurate estimation rates. Obviously, petrophysiscts applied several techniques for these purposes including the use of NMR methods however, such methods are not cost-effective nor time-saving. From these perspectives, this paper aims to develop a new approach through which heterogeneous rock intervals are divided into more homogeneous flow units depending on the lithology index and pore throat radius. Also, it aims to accurately determine the lithology index without the need to apply a Mercury Injection Capillary Pressure "MICP" test which eventually destroys the core properties and implies that the core sample is not applicable for any other purposes. Moreover, the study aims to provide an approach for calculating the most accurate value of the Flow Zone Indicator "FZI" without the need to use Nuclear Magnetic Resonance "NMR" methods which are very costly and time-consuming. In conclusion, for rock typing comparison purposes, other rock typing techniques were applied to the same data as Amaefule et al, Discrete Rock Typing "DRT", Winland R35, and Permeability Grouping techniques. Results showed that the developed technique "Litho-R35" could identify 11 rock types with a high regression coefficient R2. Besides, an equation was developed to estimate permeability with a very good regression coefficient (R2=0.9992) when compared with the core measured data. Additionally, the most accurate value of FZI was acquired without the use of NMR methods. Eventually, the developed technique serves for better rock typing practices and accurate estimation of varying petrophysical properties in uncored intervals.

Keywords- Petrophysical parameters, Reservoir characterization, Rock permeability, Rock typing

1. INTRODUCTION

Prediction of petrophysical rock properties in uncored intervals/wells is a common problematic step within petrophysicists engineering sectors. Reservoir characterization studies mostly require detailed knowledge of petrophysical properties at the drilled wells. However, most wells are not cored due to economic and time considerations. Therefore, an accurate estimation method of these petrophysical properties at the uncored intervals is significantly required for enhancing the reservoir description procedures (Desouky, 2005) .

Several investigators proposed traditional approaches for the prediction of permeability. These approaches were based on empirical correlations and constants. As proposed by the Kozeny-Carmen model (C., 1937; C Leverett & Aime, 1940; Kozeny, 1927), permeability could be estimated when considering porosity, specific surface area per unit grain volume "Sgr", pore shape factor "Kps" and tortuosity "τ" as shown in Eq. (1):

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$$k = \left(\frac{1}{K_{ps} * \tau^2 * Sv_{gr}^2}\right) * \frac{\varphi_e^3}{(1-\varphi_e)^2} \quad (1)$$

Many researchers attempted to use Eq. (1); however, the correlation concept was neither logical nor successful when applied because of the difficulty of computing the Kozeny constant (Kps*τ^2) and the lack of consideration of the Sgr (Chopra et al., 1987; Tiab & Donaldson, 2016; WJ Ebanks Jr, 1987).
Another approach proposed by (Amaefule et al., 1993), introduced the employment of the Hydraulic Flow Units "HFUs" concept in reservoir description. The term HFU was defined as an element representing a volume of the total reservoir rock at which both petrophysical and geological characteristics, affecting the fluid flow in the porous media, are consistent internally and predictably different from properties of other rock volumes.
However, this correlation did not consider many important petrophysical parameters as the Sgr, Kps, and τ. Instead, they were represented by the general parameter FZI as shown in **Eq. (2)**:

$$FZI = \frac{RQI}{\varphi_z} = \frac{0.0314\sqrt{\frac{k}{\varphi_e}}}{\frac{\varphi_e}{1-\varphi_e}} \quad (2)$$

Where,
K: Permeability, mD
φe: Effective Porosity, fraction
RQI: Reservoir Quality Index, mD
φz: Normalized Porosity, fraction

Nevertheless, the lack of consideration of these parameters limited the application of this technique for better reservoir description.

Winland proposed the theory of characterizing the reservoir and identifying HFUs based on Pore throat attributes. In later studies, many researchers dedicated the application of this theory as (Gunter et al., 1997). The basic concept of this technique was to calculate the Pore throat radius at 35% mercury saturation in a MICP test. This step was done through applying **Eq. (3)** as stated below:

$$\log(R35) = 0.732 + \{0.558 * \log[k]\} - \{0.864 * \log[100 * \varphi]\} \quad (3)$$

Where,
R35 is the pore throat radius at 35% mercury saturation in the MICP test.

The flow units were then classified into five ranges or rock types and were listed ascendingly as follows; nanoport, microport, mesoport, macroport, and megaport. However, the application of this technique did not show good results for reservoir description. The reason was that it considered only permeability and porosity when calculating the Pore throat attributes.

(Guo et al., 2007) analyzed (Amaefule et al., 1993) study and proposed the development of the FZI model into a discrete rock-type model. The following equation **Eq. (4)** shows the developed transformation:

$$DRT = ROUND[2 * LN(FZI) + 10.6] \quad (4)$$

Where,
DRT is the Discrete Rock Type
LN is the Natural Logarithm

The developed model aided the building of a 3D model that was utilized later in reservoir simulation applications. However, the same limitations of the Amaefule technique were still present as none of the pre-assumptions were substituted with reliable constituents. Moreover, a study by (Rezaee et al., 2007) proposed characterizing the reservoir into five rock types based on the core permeability values only. This technique was called the permeability grouping technique and was found to be applicable in conventional reservoirs. In later research, by (Mohamed

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Ahmed Fathy Omran & Attia Mahmoud Attia, 2018), the application of this technique was developed to consider unconventional reservoirs. Eventually, the resulting description showed nothing but scattering data points and never showed good regression coefficients.

(Attia & Shuaibu, 2015) conducted a study using tools like Discrete Rock Type (DRT), Flow Zone Indicator (FZI), and Winland R35 to recognize the rock types and the flow units by developing a reservoir characterization static model on four different wells. The intention of this study is identifying the reservoir barriers and the productive zones by alter the static model into a dynamic model to quantify the flow units of the reservoir using graphical methods like modified Lorenz plot (MLP), stratigraphic modified Lorenz plot (SMLP), stratigraphic flow profile (SFP). This approach is based on rock type, storage capacity, reservoir process speed, flow capacity, and physical structure.

(Shahat et al., 2021) proposed a new approach based on the Kozeny-Carman model that considered the formation True Resistivity (RT). This approach used well-log data for the purpose of petrophysical reservoir characterization. 1135 core samples with data from 21 logged wells were used for testing and validation in order to identify the effectiveness and reliability of the new approach. The RZI technique was applied to characterize the reservoir of an Algerian oil field into eight Electrical flow units with correlation coefficients of determination (R2) varying from 0.84 to 0.97. The new approach showed a high accuracy agreement on the number of distinct flow units compared with the Amaefule technique. Several empirical equations have been developed to calculate the permeability and the true formation resistivity for Uncored wells in addition to Sw and SWr for each rock type.

(Shahat et al., 2023) established a new approach to identify the flow zone indicators, rock types, tortuosity, permeability, and irreducible water saturation for uncored wells. The study used the electrical properties of the rock obtained from logging tools. The new approach established by modifying (Shahat et al., 2021). The Resistivity Zone Index (RZI) equation considers the tortuosity factor. The data from 21 logged wells was used to test the established approach's validity. Afterward, the validity of the proposed approach was compared to the Amaefule technique, which used 1135 core samples from the same reservoir. The R^2 values for the estimated flow zone indicators, tortuosity, permeability, and irreducible water saturation were 0.98, 0.98, 0.96, and 0.99, respectively.

In this study, 206 data points represented by a SCAL report were used to describe the Bahariya Northeast Sanan Field. The field is in the Western Deserts of Egypt and the geological description of the reservoir was approved to be a sandstone reservoir rock. The study discusses the derivation of a new correlation for petrophysical parameters prediction and flow unit identification. The derivation procedure of the new correlation considers many important parameters that were neglected by other reservoir rock typing techniques such as the lithology type and the pore-size distribution. In turn, these parameters contributed to the development of a new technique that combines the basic concepts of both (Amaefule et al., 1993) and Winland R35 techniques. Therefore, the new approach was named the "Litho-R35 Technique".

The objectives of this study are to identify the reservoir flow units by dividing the heterogenous formations into a more homogenous segment and to provide an approach for calculating the most accurate value of FZI without the need of applying NMR methods (Tiab & Donaldson, 2016). The study also aims to correlate permeability with other petrophysical parameters as to enhance reservoir rock characterization. In addition, it aims to predict the lithology index without the need of applying the MICP test which eventually destroys the core properties.

The following lines discuss the theory, methodology workflow, and results of the new approach. In addition, Tables 8 and 9 are provided to represent the results of each technique for simple comparison. Eventually, permeability estimated by the new approach is illustrated versus the core measured permeability and confirmed excellent regression coefficient (R^2=0.9992).

THEORY

New Approach "Litho-R35" Concept:

- **The Flow Zone Indicator Concept:**
  - From (Kozeny-Carmen 1937) Model, **Eq. (1)**

The Permeability was related to the specific surface area "Sv_{gr}^2" porosity "φe", pore shape factor "Kps" and tortuosity "τ".

  - From (Tiab et al., 1993) modification:

The effective zoning factor "KT" was introduced to compensate the Kps and τ multiplication.

$$k = \left(\frac{1}{K_T * Sv_{gr}^2}\right) * \frac{\varphi_e^3}{(1-\varphi_e)^2} \tag{5}$$

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Where,

K_T is equal $K_{ps} * \tau^2 = \left(\frac{1}{J_i}\right)^2$

Ji is the Lithology Index: J(Swn) at Swn=1

- From (Amaefule et al. 1993) model:

$$0.0314 * \sqrt{\frac{k}{\varphi_e}} = \frac{1}{S_{vgr} * \sqrt{K_T}} * \varphi_z \quad (6)$$

2. Methodology

Figure (1) shows a flow chart of the "Litho-R35" technique which describes the methodology utilized in a step-by-step procedure. It was illustrated according to the global flow chart standards.

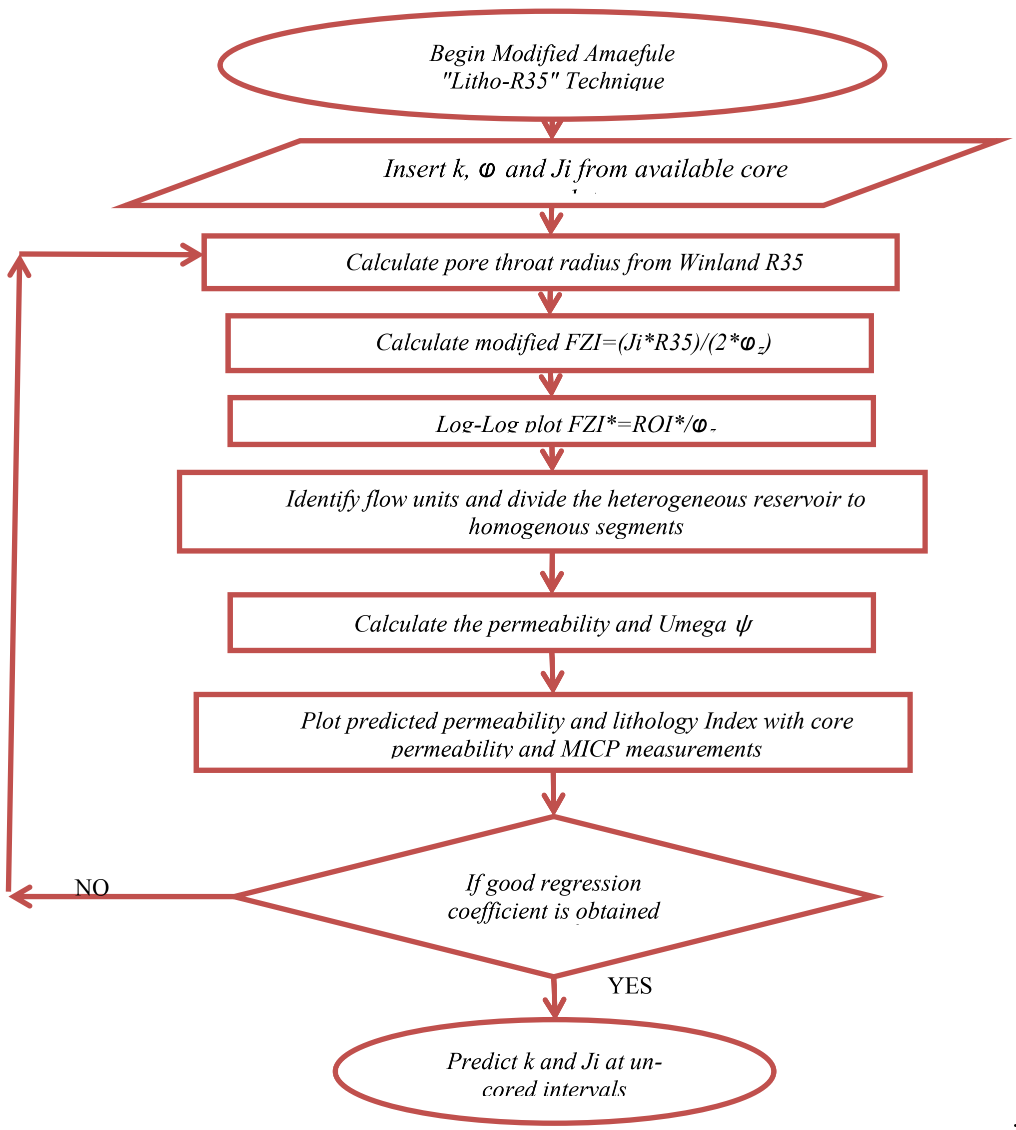

Figure 1: Litho-R35 Technique Workflow

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- **New approach derivation procedure:**

$$FZI = \frac{1}{S_{vgr} * \sqrt{K_T}} \quad (7)$$

Since,

$$S_{vp} = \frac{2}{R_{pth}} = \frac{2}{R_{pth}} \quad (8)$$

$$S_{vgr} = (\frac{\varphi}{1-\varphi} * S_{vp}) = (\varphi_z * S_{vp}) = (\varphi_z * \frac{2}{R_{pth}}) \quad (9)$$

$$K_T = \left(\frac{1}{J_i}\right)^2 \quad (10)$$

Combining Eq. (8-10) and substituting in Eq. (7), yielded the following equation:

$$FZI = \frac{J_i * R_{pth}}{2 * \varphi_z} \quad (11)$$

Where,
J_i is the lithology index
R_{pth} is the pore throat radius
φ_z is the normalized porosity

This equation is theoretically approaching the most accurate value of FZI (without the use of NMR methods), as stated by Tiab (2015) and written as:

$$FZI = \frac{J_i}{\rho_m * A_{NMR}} \quad (12)$$

Where,
J_i is the lithology index
ρ_m is the grain-matrix density, g/cm^3
A_{NMR} is the NMR surface area of dry material, m^2/g

- **Hydraulic flow units identification:**

Since Amaefule et al. related the FZI to the RQI and the Normalized Porosity as:

$$RQI = FZI * \varphi_z \quad (13)$$

Then, taking the logarithm of both sides yields the following,

$$\log(RQI) = \log(FZI) + \log(\varphi_z) \quad (14)$$

$$\log(RQI) = \log\left(\frac{J_i * R_{pth}}{2 * \varphi_z}\right) + \log(\varphi_z) \quad (15)$$

Eq (14) implies that when illustrating a log-log plot of RQI (y-axis) versus normalized porosity "φz" (x-axis), points referring to samples with relative values of FZI would lie on a straight line with unity slope (m=1). Other samples with different FZI values would lie on other parallel unit slope lines. This is due to relative Pore throat characteristics, which indicates that samples with relatively similar characteristics will create a single HFU.
Eventually, plotting the modified FZI versus Amaefule et al. FZI should yield a slope of unity. Then, permeability prediction will be accurately achieved as a function of the modified FZI.

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- **Lithology Index Prediction without need for Mercury Injection Capillary Pressure test**

In this research, when plotting the modified FZI versus core FZI, an excellent regression coefficient of (R^2=0.9993) was obtained through the following correlation:

$$FZI_{Core} = 5.0113 * (Mod.FZI)^{0.9095} \quad (16)$$

Substituting the parameters representing the modified FZI Eq. (11) into Eq. (16), yielded the following equation:

$$FZI_{Core} = 5.0113 * \left(\frac{J_i * R_{35}}{2 * \varphi_Z}\right)^{0.9095} \quad (17)$$

Simplifying the multiplication of lithology index and Pore throat radius by one parameter that would be named Umega "$\oint$" as follows:

$$\oint = J_i * R_{35} \quad (18)$$

Hence,

$$\oint = \left(\frac{FZI_{core} \ * \varphi_Z^{0.9095}}{2.67}\right)^{1.1} \quad (19)$$

Therefore, by using **Eq. (19)**, the lithology index and Pore throat radius at any depth could be obtained as a function of FZI and porosity. By default, it will obviously compensate for the need of applying MICP tests.

- **Permeability Prediction:**

Permeability was correlated to the FZI by Amaefule et al (1993) as shown

$$\mathrm{k} = 1014 * (\mathrm{FZI})^2 * \frac{\varphi_e^3}{(1-\varphi_e)^2} \quad (20)$$

In this research, when plotting the modified FZI versus core FZI an excellent correlation coefficient of (R^2=0.9993) was obtained through the following correlation:

$$FZI_{Core} = 5.0113 * (Mod.FZI)^{0.9095} \quad (21)$$

Therefore, by algebraic substitutions in **Eq. (13)** as shown below, permeability could be correlated to the modified FZI stated below in **Eq. (20)**:

$$\mathrm{k} = 1014(5.0113 * (Mod.FZI)^{0.9095})^2 * \frac{\varphi_e^3}{(1-\varphi_e)^2} \quad (22)$$

$$\mathrm{k} = 25464.712 * (Mod.FZI)^{1.819} * \frac{\varphi_e^3}{(1-\varphi_e)^2} \quad (23)$$

Endorsing the constituents of modified FZI as in Eq. (11) yielded Eq. (24):

$$\mathrm{k} = 25464.712 * \left(\frac{J_i * R_{pth}}{2 * (\frac{\varphi}{1-\varphi})}\right)^{1.819} * \frac{\varphi_e^3}{(1-\varphi_e)^2} \quad (24)$$

Since R_{pth} could be estimated by Winland R35 technique then, the following can be obtained:

$$\mathrm{k} = 7217.14 * (J_i * R_{35})^{1.819} * \frac{\varphi_e^{1.181}}{(1-\varphi_e)^{0.181}} \quad (25)$$

Eventually, Eq. (25) served for accurate estimation of permeability in heterogeneous sandstone reservoirs with the knowledge of the Ji, R35, and porosity.

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3. Data Processing and Results

- **Application of the Permeability-Porosity Correlation Technique:**

Permeability prediction and reservoir rock typing are essential procedures for the enhanced description of a reservoir. The given data showed a high degree of heterogeneity and was described through K-φ correlation, which confirmed the existence of many different flow zones.

The illustration of porosity and permeability data showed scattering, and a high degree of heterogeneity (R^2 = 0.55) as shown in Figure (2). This implied that porosity alone was not enough to explain the variation of permeability in the intervals understudy.

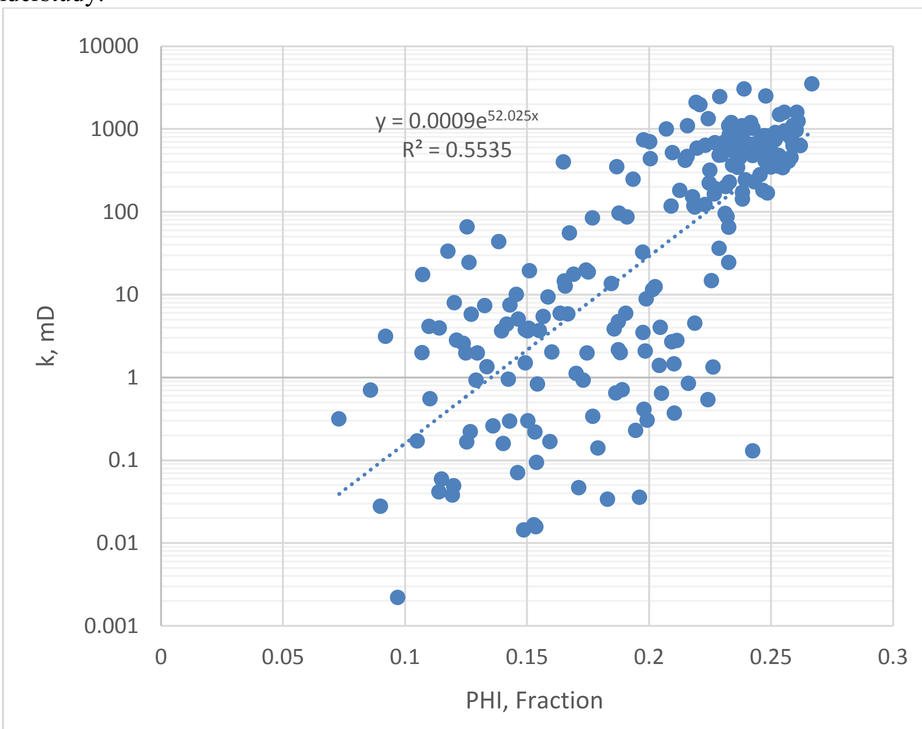

Figure 2: The Whole Data K-PHI Semi-Log Plot

- **Application of Rock Typing Techniques:**

In the following lines, reservoir rock typing techniques applied in this study are listed in descending order from the results accuracy perspective.

1. **Application of the developed approach "Litho-R35 Technique"**

The new approach derived a correlation to calculate the most accurate value of FZI which would allow reservoir engineers to dispense with the use of NMR methods. Subsequently, it proved to be a more economical and time-saving approach. The lithology Index obtained from the given MICP data is presented in Table 1. The average value (Ji=0.05) was taken due to the high degree of heterogeneity. This was confirmed by the point of view of Tiab (2016).

Table 1: Lithology Index from MICP-tested plug samples

Sample	Lithology Index, Ji	Average Ji
11	0.003	0.05
99	0.035	
131	0.03	
141	0.097	
170	0.083	

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As shown in the semi-log plot of K versus φ illustrated in Figure (3), the application of the new approach for rock typing technique yielded the highest accuracy in characterizing the reservoir into 11 different rock types implying better identification of flow units than Amaefule et al. technique and highest permeability prediction with regression coefficient (R^2 = 0.9992). Therefore, it is very applicable to be used for conventional sandstone reservoirs. The developed FZI values, their k-phi equations, and their regression coefficients R^2 are presented in Table 2.

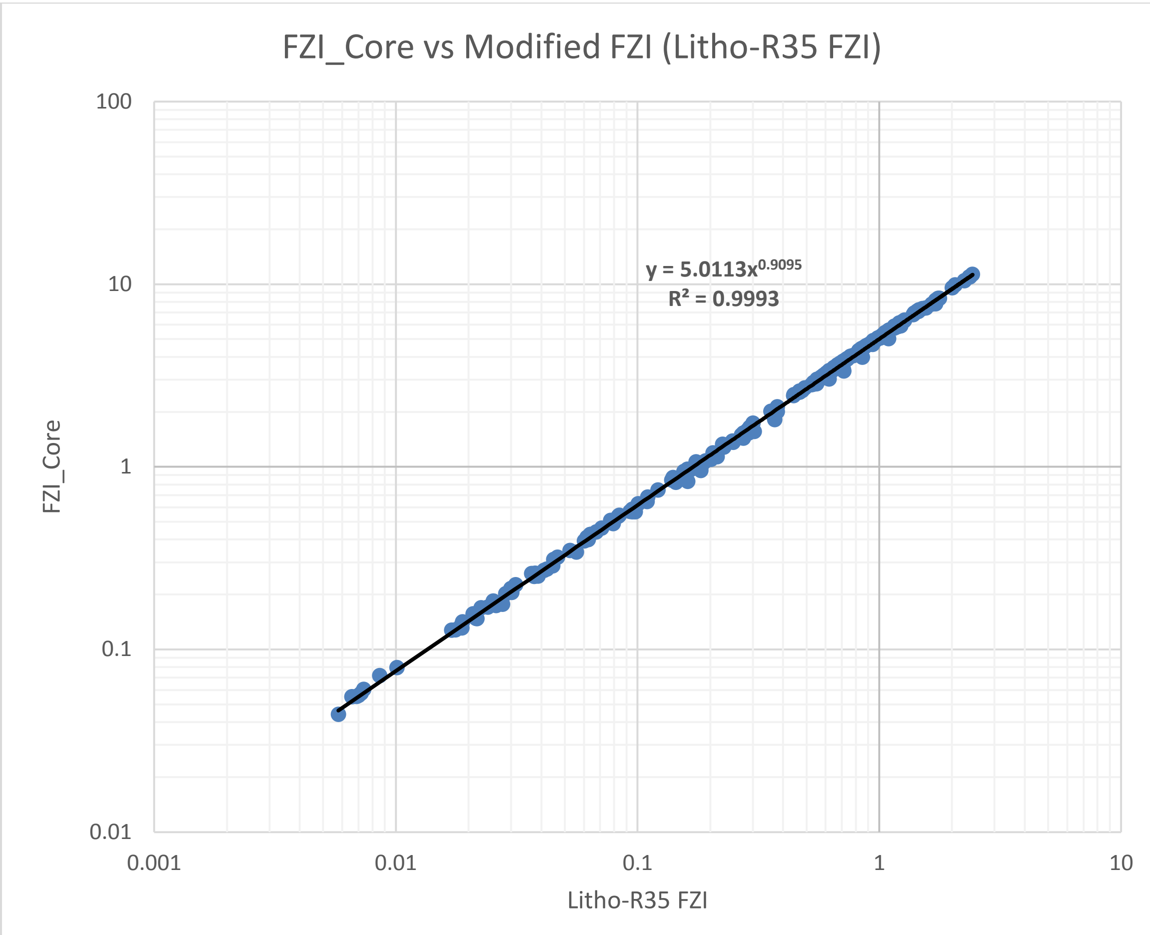

Figure 3: Core FZI vs Modified Litho-R35 FZI

Table 2: Litho-R35 rock typing method results

#	Litho-R35, FZI	Equation	R^2
1	0.01	$K = 61.055 * \varphi^{4.3694}$	$R^2 = 0.9586$
2	0.02	$K = 117.13 * \varphi^{3.7324}$	$R^2 = 0.9544$
3	0.03	$K = 247.72 * \varphi^{3.7946}$	$R^2 = 0.9877$
4	0.04	$K = 351.07 * \varphi^{3.6469}$	$R^2 = 0.9611$
5	0.1	$K = 1179.8 * \varphi^{3.5655}$	$R^2 = 0.6463$
6	0.2	$K = 5699.8 * \varphi^{3.6913}$	$R^2 = 0.9305$
7	0.3	$K = 13426 * \varphi^{3.7301}$	$R^2 = 0.9923$
8	0.4	$K = 32351 * \varphi^{3.9024}$	$R^2 = 0.9912$
9	0.5	$K = 12673 * \varphi^{3.0307}$	$R^2 = 0.8765$
10	1	$K = 230012 * \varphi^{4.2456}$	$R^2 = 0.7142$
11	2	$K = 4E+06 * \varphi^{5.1498}$	$R^2 = 0.8786$

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The plot illustrated of the developed FZI versus Core FZI in Figure (4), shows that the FZI values were not the same. However, high regression coefficient was found by the regression trendline. This implies that at any depth, an accurate value of FZI is achievable by applying the trendline equation.

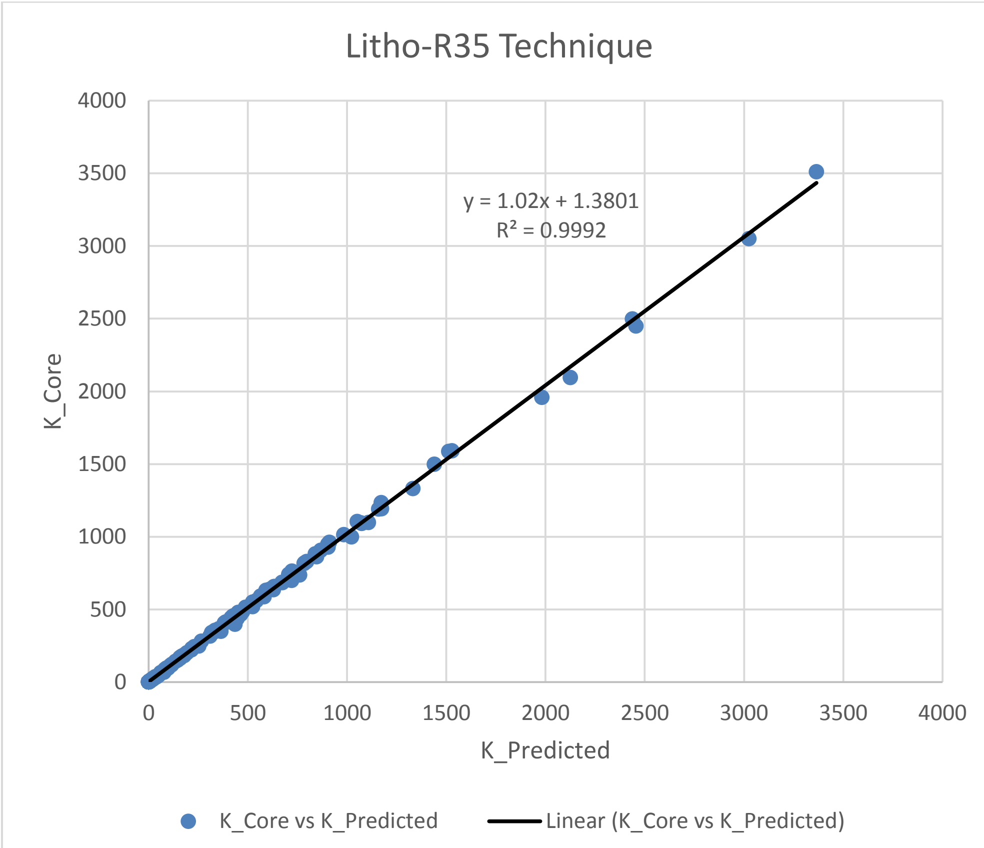

Figure 4: Core Permeability vs Predicted Permeability for "Litho-R35" Method

The prediction of permeability through the "Litho-R35" technique was achieved using Eq. (25) where the pore throat radius was calculated using the Winland R35 technique. Also, according to the MICP data the lithology index was substituted with (Ji=0.05). The results were illustrated in Figure (5) and showed a very g Therefore, it proved to be applicable for conventional sandstone reservoirs characterizing aspects good regression coefficient.

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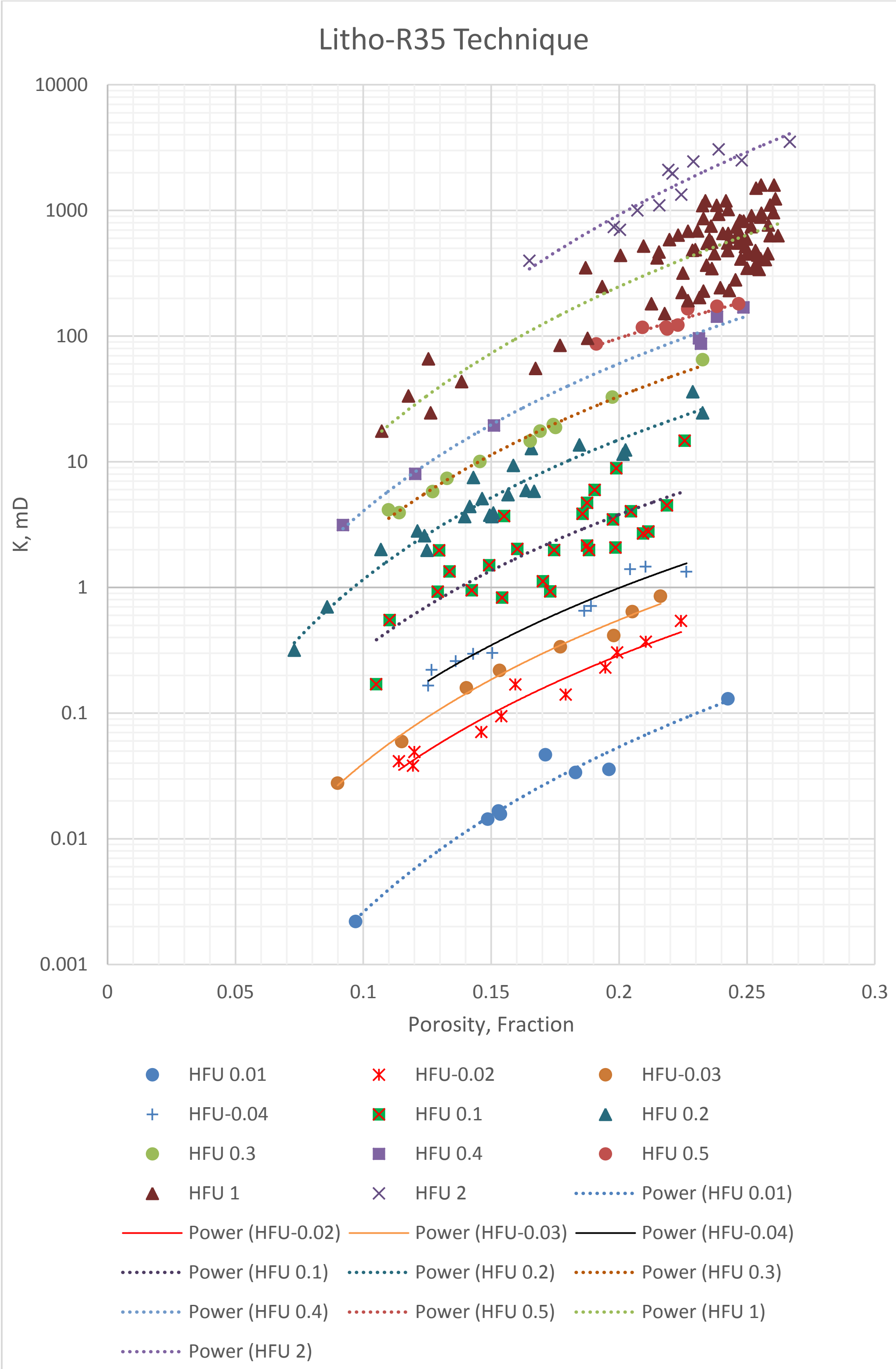

Figure 5: Semi-log plot of permeability vs porosity for Litho-R35 method

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2. Application of Amaefule et al Technique

The semi-log plot of K versus φ was illustrated as shown in Figure (6) and 14 hydraulic flow units were identified. Amaefule FZI values, their k-phi equations, and their regression coefficients R^2 are listed in Table 3. The prediction of permeability using the Amaefule et al. technique gave very good results when compared with the core-measured permeability as illustrated in Figure (7).

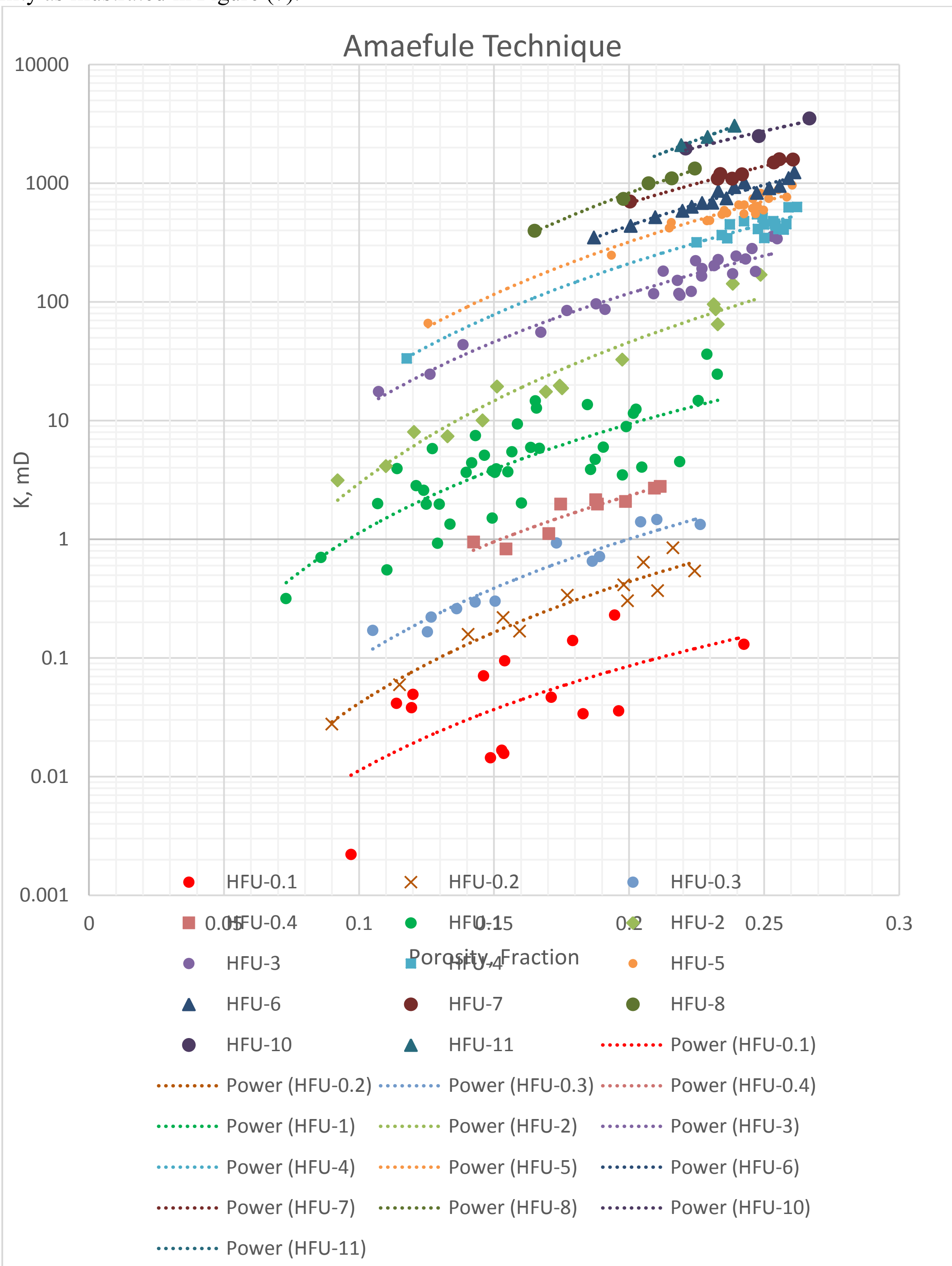

Figure 6: Amaefule et al. rock typing method K vs PHI

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Table 3: Amaefule et al. rock typing method results

#	FZI	Equation	R^2
1	0.1	$K = 9.5977 *\varphi^{2.9324}$	$R^2 = 0.3844$
2	0.2	$K = 104.27 *\varphi^{3.4008}$	$R^2 = 0.9376$
3	0.3	$K = 210.18 *\varphi^{3.3191}$	$R^2 = 0.9183$
4	0.4	$K = 352.91 *\varphi^{3.1179}$	$R^2 = 0.8639$
5	1	$K = 1269.6 *\varphi^{3.0514}$	$R^2 = 0.6297$
6	2	$K = 26359 *\varphi^{3.9497}$	$R^2 = 0.9431$
7	3	$K = 22856 *\varphi^{3.2717}$	$R^2 = 0.9315$
8	4	$K = 53498 *\varphi^{3.4408}$	$R^2 = 0.9464$
9	5	$K = 95591 *\varphi^{3.5399}$	$R^2 = 0.9568$
10	6	$K = 130398 *\varphi^{3.5375}$	$R^2 = 0.9406$
11	7	$K = 120683 *\varphi^{3.2173}$	$R^2 = 0.9635$
12	8	$K = 451419 * \varphi^{3.915}$	$R^2 = 0.9892$
13	10	$K = 177780 *\varphi^{3.0056}$	$R^2 = 0.9502$
14	11	$K = 2E+06 *\varphi^{4.3729}$	$R^2 = 0.9893$

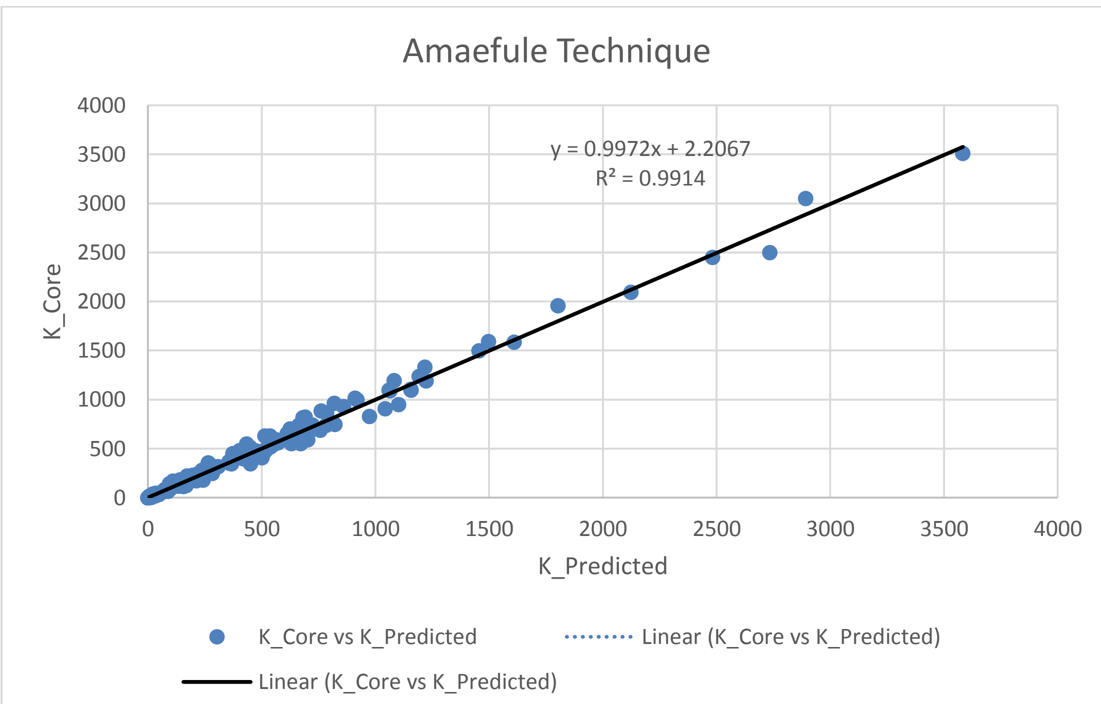

Figure 7: Core Permeability vs Predicted Permeability for Amaefule et al. Method

3. Application of DRT Technique

The semi-log plot of K versus φ was illustrated as shown in Figure (8) and 10 discrete rock types were identified. DRT values and their k-phi equations are presented in Table 4. However, most of the regression coefficients R^2 were low which lists this technique after the Amaefule technique.

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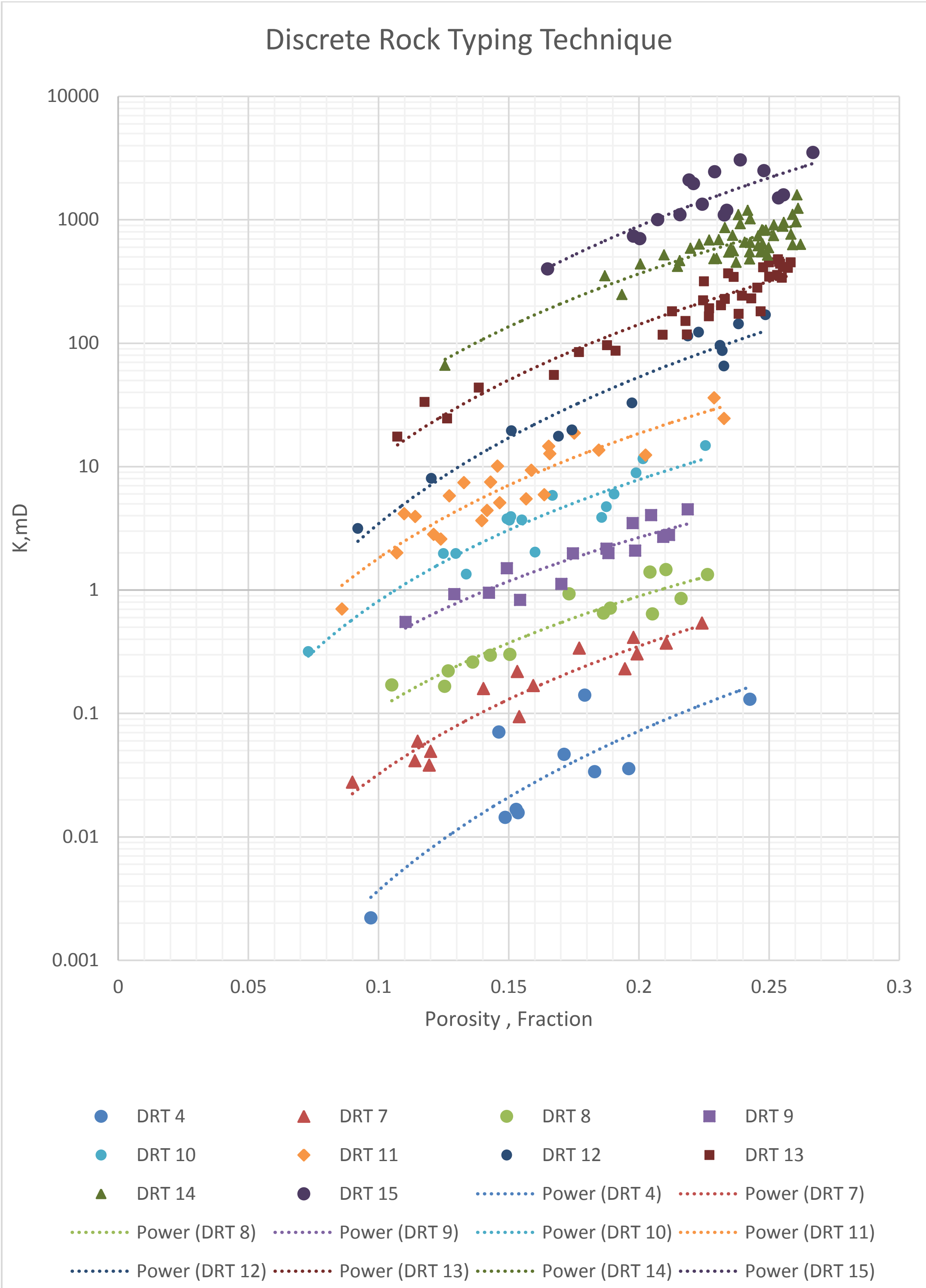

Figure 8: DRT rock typing method K vs PHI

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Table 4: DRT rock typing method results

#	DRT	Equation	R^2
1	4	$K = 71.397* \varphi^{4.2862}$	$R^2 = 0.692$
2	7	$K = 89.547* \varphi^{3.4432}$	$R^2 = 0.9098$
3	8	$K = 117.14* \varphi^{3.0312}$	$R^2 = 0.8795$
4	9	$K = 257.86* \varphi^{2.8402}$	$R^2 = 0.8431$
5	10	$K = 1506* \varphi^{3.2665}$	$R^2 = 0.8911$
6	11	$K = 4101.5* \varphi^{3.354}$	$R^2 = 0.8385$
7	12	$K = 30666* \varphi^{3.949}$	$R^2 = 0.9274$
8	13	$K = 46877* \varphi^{3.604}$	$R^2 = 0.9024$
9	14	$K = 90937* \varphi^{3.4287}$	$R^2 = 0.7255$
10	15	$K = 602034* \varphi^{4.0497}$	$R^2 = 0.6744$

4. Application of Winland R35 Technique

Winland R35 technique could only identify the micro-port, meso-port, and mega-port ranges of the Pore throat radius as shown in Tables 5 and 6. In the semi-log plot of K versus φ illustrated in Figure (9) a high degree of data scattering was found, which confirmed that rock typing upon knowledge of permeability and porosity was not sufficient.

Table 5: Winland rock typing method results

#	R35	Range	Equation	R^2
1	0.1-0.5	Micro-port	$K = 1E+13* \varphi^{16.561}$	$R^2 = 0.89$
2	0.5-2	Meso-port	$K = 1E+11* \varphi^{13.538}$	$R^2 = 0.63$
3	>10	Mega-port	$K = 44027* \varphi^{2.5662}$	$R^2 = 0.135$

Table 6: Winland rock typing method Pore throats as percent of the reservoir

R35	**<0.1**	**0.1-0.5**	**0.5-2**	**2-10**	**>10**
Range	Nano-port	Micro-port	Meso-port	Macro-port	Mega-port
Percentage of Reservoir	0%	23.6%	32.4%	0%	44%

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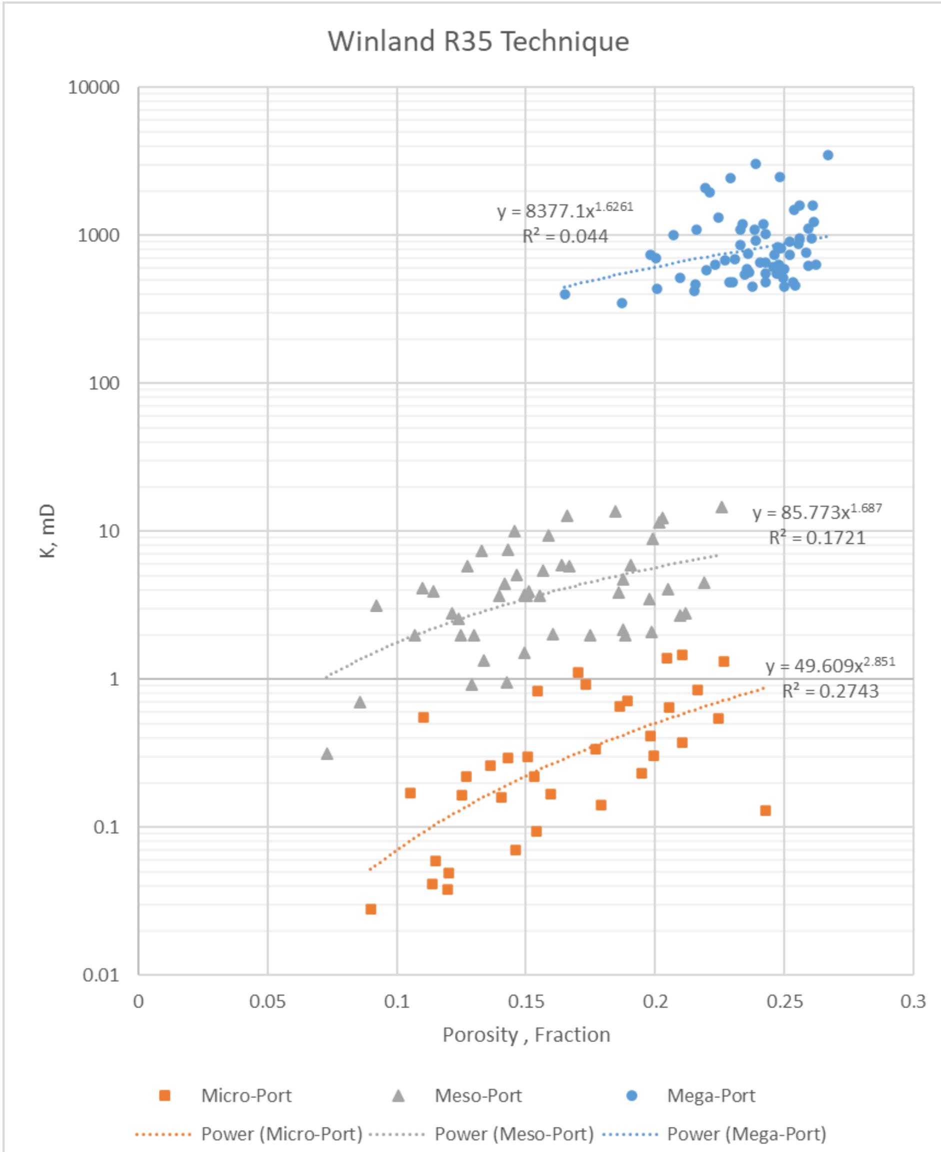

Figure 9: Winland rock typing method K vs PHI

5. Application of K-Grouping Technique

This technique presented obvious results of data scattering and consequently low R^2 values were presented as shown in Figure 10 and Tables 7-9.

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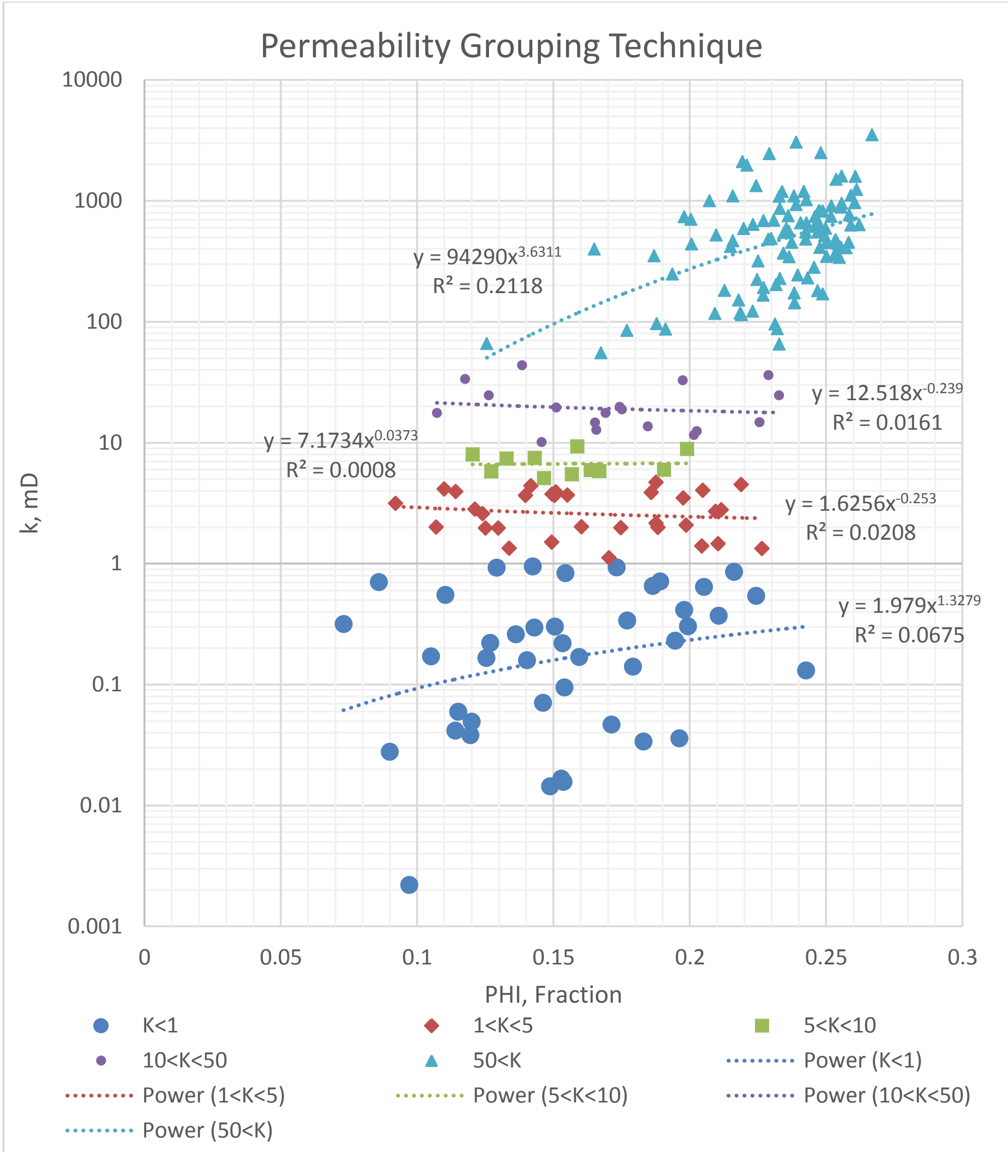

Figure 10: k-Grouping rock typing method k vs PHI

Table 7: k-Grouping rock typing method results

K Classes, mD	Equation	R^2
<1	$K = 1.979 * \varphi^{1.3279}$	$R^2 = 0.0675$
1-5	$K = 1.6256 * \varphi^{-0.253}$	$R^2 = 0.0208$
5-10	$K = 7.1734 * \varphi^{0.0373}$	$R^2 = 0.0008$
10-50	$K = 12.518 * \varphi^{-0.239}$	$R^2 = 0.0161$
>50	$K = 94290 * \varphi^{3.6311}$	$R^2 = 0.2118$

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Table 8: Comparison table showing R2 values from each method

#	Amaefule et al. FZI	R^2	Litho-R35, FZI	R^2
1	0.1	$R^2 = 0.3844$	0.01	$R^2 = 0.9586$
2	0.2	$R^2 = 0.9376$	0.02	$R^2 = 0.9544$
3	0.3	$R^2 = 0.9183$	0.03	$R^2 = 0.9877$
4	0.4	$R^2 = 0.8639$	0.04	$R^2 = 0.9611$
5	1	$R^2 = 0.6297$	0.1	$R^2 = 0.6463$
6	2	$R^2 = 0.9431$	0.2	$R^2 = 0.9305$
7	3	$R^2 = 0.9315$	0.3	$R^2 = 0.9923$
8	4	$R^2 = 0.9464$	0.4	$R^2 = 0.9912$
9	5	$R^2 = 0.9568$	0.5	$R^2 = 0.8765$
10	6	$R^2 = 0.9406$	1	$R^2 = 0.7142$
11	7	$R^2 = 0.9635$	2	$R^2 = 0.8786$
12	8	$R^2 = 0.9892$		
13	10	$R^2 = 0.9502$		
14	11	$R^2 = 0.9893$		

Table 9: Comparison table showing R2 values from each method

#	DRT	R^2	K Classes, mD	R^2	Winland R35	R^2
1	4	$R^2 = 0.692$	<1	$R^2 = 0.9355$	0.1-0.5	$R^2 = 0.89$
2	7	$R^2 = 0.9098$	1-5	$R^2 = 0.4418$	0.5-2	$R^2 = 0.63$
3	8	$R^2 = 0.8795$	5-10	$R^2 = 0.2771$	>10	$R^2 = 0.135$
4	9	$R^2 = 0.8431$	10-50	$R^2 = 0.6036$		
5	10	$R^2 = 0.8911$	>50	$R^2 = 0.0785$		
6	11	$R^2 = 0.8385$				
7	12	$R^2 = 0.9274$				
8	13	$R^2 = 0.9024$				
9	14	$R^2 = 0.7255$				
10	15	$R^2 = 0.6744$				

4. CONCLUSION

- The given data showed a high degree of heterogeneity and was described through K-φ correlation, which confirmed the existence of many different flow zones. The new reservoir rock typing technique in this study aimed to characterize the Bahariya Northeast Sanan field which is located in the Western Deserts of Egypt.
- The new approach for the rock typing technique yielded the best results in characterizing the reservoir into 11 different rock types. Therefore, it proved to be highly effective in characterizing flow units and predicting permeability in conventional sandstone reservoirs.
- Permeability predicted using the "Litho-R35" technique showed the best results with an excellent regression coefficient (R^2=0.9992).
- Meanwhile, advanced developments of this technique, using the algebraic simplification of Umega, should certify an opportunity for accurate estimation of the actual fluid flow path (tortuosity) and practically prove that the use of NMR methods is not necessary anymore for estimating the most accurate value of FZI, lithology index, specific surface areas, and many other rock properties.
- Eventually, Tables 8 and 9 were illustrated to simplify the comparison perspectives, showing the flow units identified by each applied technique and their regression coefficients R^2.

APPENDIX

APPENDIX A: COMMON ABBREVIATIONS

RQI: Reservoir Quality Index
HFU: Hydraulic Flow Unit
FZI: Flow Zone Indicator

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NMR: Nuclear Magnetic Resonance
MICP: Mercury Injection Capillary Pressure Test
R35: Pore throat radius at 35% mercury saturation in MICP test
φz: Normalized porosity
Svgr: Specific surface area per unit grain volume
Svp: Specific area per unit pore volume
Kps: Shape factor
Rpth: Pore Throat Radius
KT: Effective Zoning Factor;(KT=K) ps*τ)

APPENDIX B: GREEK ALPHABET

ρ_m: grain-matrix density, g/cm^3

J_i: Lithology index

A_{NMR}: NMR surface area of dry material, m^2/g

τ: Tortuosity factor

∲: Umega multiplication parameter = J_i*R35

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