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Enhancement of permeability estimation by high order polynomial regression for capillary pressure curve correlation with water saturation

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ABSTRACT

Suggesting a cost-effective and straightforward approach is indispensable for obtaining permeability estimates in carbonate reservoirs utilizing available well logs. In this study, several procedures were conducted to reach an optimum approach, primarily by constructing a correlation between capillary pressure and water saturation using core data plotted and utilized a good polynomial regression to obtain a better relationship, which leads to calculating the permeability. The second step is to use different theoretical models which Tixier introduces, Timur, Coats, and Dumanior, which resulted not good matching with the permeability from core analysis and modified Brown and Husseini correlation which used and gave better matching than others correlations by comparing the results with the calculated permeability depending on core data. The proposed approach in this study based on modified Husseini equation using the well logs data by applying Statistical regression techniques within capillary pressure prediction to enhance reservoir characterization can potentially advantage reservoir simulation efforts. Obtained results of permeability prediction based on capillary pressure correlation was examined for a certain well and compared with the measured permeability value of cores. There was a good matching between the predicted and measured permeability.

Keywords: First keyword, Second keyword, Third keyword, Fourth keyword, Fifth keyword

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1. Introduction

In reservoir development, the permeability of the rock is one of the most important factors to consider. The pore structure of the rock determines the permeability of rock. The pore structure, on the other hand, is highly complex and inhomogeneous. The investigation of the permeability of rocks has received the most significant amount of attention to date. For oil and gas reservoirs, traditional methods of determining permeability have relied on laboratory measurements of cores under in situ conditions, which is highly time-consuming and expensive [1]. Using borehole-geophysical logs, researchers believe they can accurately measure in situ permeability. The porosity of a reservoir can be determined by using the logging method [3], which is used to determine its permeability. Permeability, grain size distribution, porosity, pore size distribution, and the r of the pore size were all measured to understand better the relationship between these properties and permeability [1]. When two immiscible fluids come into contact, the pressure difference across the curved interface is known as capillary pressure (Pc). For oil/water systems in porous rock, Pc is generally defined as the difference in pressure between the oil phase (Po) and the water phase (Pw), which is [4] in this case.

$$Pc = Po - Pw \tag{1}$$

And expressed as a function of water saturation (SW) [3].
According to the American Petroleum Institute, core samples retrieved from petroleum-production wells are rarely subjected to laboratory tests to determine their permeability and capillary pressure. According to the American Petroleum Institute, core samples retrieved from petroleum-production wells are rarely subjected to

laboratory tests to determine their permeability and capillary pressure. Several small core samples are used to characterize large-scale multiphase flow petrophysical properties that affect hydrocarbon field production and recovery [4].

In most reservoirs, the immiscible oil, water, and gas phases can be found in the rock. Capillary forces are the manifestations of the forces that keep these fluids in equilibrium with one another and with the rock. During a flood, these forces may act in concert with frictional forces to prevent oil from flowing through the floodwater. Therefore, beneficial to gain a better understanding of capillary force nature. In the presence of two immiscible fluids, capillary pressure is produced due to the interfacial tension that exists at their interface [4].

Porous media were first depicted as a bundle of capillary tubes of varying diameters. An essential task in reservoir characterization is rock permeability prediction from well logs in un-cored wells. Only a few wells yield usable cores due to the prohibitive costs of coring and laboratory analysis. Because most wells are logged, it is a commonplace to use correlation equations derived from core samples to estimate permeability, available in the literature. Regression analysis is commonly used to estimate permeability from well logs. In carbonates, the relationship between porosity and permeability is typically linear, but it is much more erratic in sands. To use another metaphor, permeability prediction is essential in complex reservoirs such as carbonate reservoirs in complicated machines, which are difficult to understand and manipulate. Several different statistical regression techniques have previously been tested in previous studies to determine if permeability can be estimated more accurately using various good logs. A large amount of statistical evidence shows that regression analysis is effective [5].

While the permeability logs for sandstones are frequently correlated with porosity, the porosity permeability relationship for carbonates is much more complex and erratic. Accordingly, the ability to predict permeability is critical for the characterization and understanding of complex reservoirs, such as those formed by carbonates. Several different statistical regression techniques have previously been tested in previous studies to determine if permeability can be estimated more accurately using various well logs. It has been demonstrated in several instances that using statistical regression for data correlation is very helpful when it comes to predicting complex reservoirs. Using all of the possible well logs to predict permeability does not yield accurate results because the chance of spurious correlation increases with the number of logs used. Using all of the possible well logs to predict permeability does not produce accurate results because the chance of spurious correlation increases with the number of logs used. Using all of the possible well logs to predict permeability does not yield accurate results because the chance of spurious correlation increases with the number of logs used.

2. Theoretical background

2.1. Porosity and permeability

The ratio of the total volume of the material to the total volume of the pores is further accompanied by the knowledge that the material is divisible into two groups: pores and non-pores. A concept relating to the porosity of something is called effective porosity or absolute porosity. The effective porosity is defined as the ratio of the interconnected pore volume to the total volume [1][2].:

$$\phi = \frac{V_P}{V_B} \tag{2}$$

The most valuable property of reservoir rock is its effective porosity, which can determine permeability. the permeability of a porous medium is a property of the medium and can be quantified by measuring the amount of fluid that can flow through the medium as a result of the medium's permeability

Also known as conductivity, permeability is a way to estimate the fluid conductivity of a material. The permeability is equal to the reciprocal resistance offered to fluid flow by the porous medium [1].

Since The fluid is passed throw interconnected pores therefore as connected increase the permeability well be increasing the permeability and the porosity, as shown in figure (1)

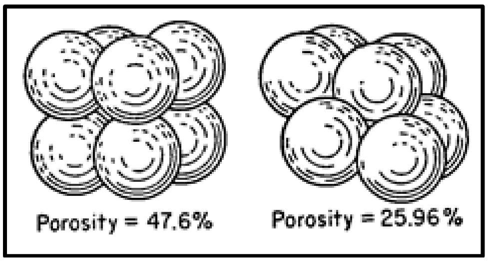

Figure 1. Effect of particle shape on porosity measurements

2.2. Capillary pressure and water saturation

Capillary pressure is defined as the difference in pressure between two immiscible fluids that exist across their interface. Assuming that the system's wettability is well-understood, capillary pressure will always be positive if defined as the difference between the pressures in the non-wetting and wetting phases [4][6].

$$\mathrm{P_C = P_{nw} - P_w} \tag{3}$$

For example, consider the following for an oil-water system (water wet):

$$\mathrm{P_C = P_o - P_w} \tag{4}$$

Interfacial tension, also known as capillary pressure, results from the opposing forces of intermolecular forces at the interface separating two immiscible fluids. When the attractive forces on molecules at the surface are not equal, a barrier forms at the interface, which causes the interfacial tension. The capillary pressure can also be determined using a capillaries method or a capillary tube, depending on the situation. Water and oil are mixed in this method based on the hydrostatic pressure of the two phases. According to figure (2), the oil/water interfaces will rise or fall in the tube until the capillary forces balance gravitational forces [4] and oil/water interfaces are balanced.

2.3. Interfacial tension and radius of pores relationship

Because the interface is in equilibrium, any segment of the interface can have its force balanced. The interfacial forces are eliminated by treating the interface that is not in direct contact with the solid as a free body. As shown in figure (3), a force balance would result in [8], which is as follows: The product of (internal pressure minus external pressure) * cross-sectional area equals the product of (internal pressure minus external pressure).

Thus:

$$\mathrm{P_{nw}}\,(\pi r^2) = \sigma\cos\theta(2\pi r) + \mathrm{P_w}(\pi r^2) \tag{5}$$

Therefore:

$$(\mathrm{P_{nw} - P_w})\pi r^2 = \sigma\cos\theta(2\pi r) \tag{6}$$

And since by definition
$\mathrm{P_C = P_{nw} - P_w}$
and

$$P_c = \frac{2\sigma\cos\theta}{r} \tag{7}$$

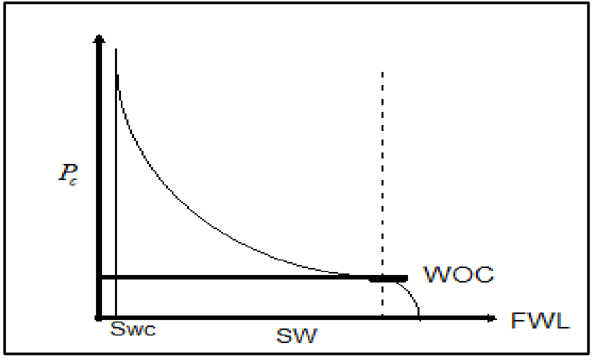

Figure 2. Capillary pressure and water saturation curves

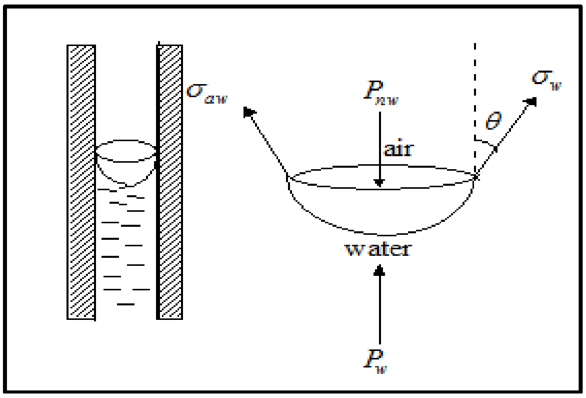

Figure 3. Wetting and non-wetting phase interface

3. Results and discussions

One of the Iraqi oil fields as a case study has been applied using its well logging and core data on our suggested approach. However, many values were utilized for capillary pressure in two zones and well logging interpretation values for porosity and water saturation. There are two zones with petrophysical properties from well logging and core analysis as shown in figure (4), which was conducted in this study.

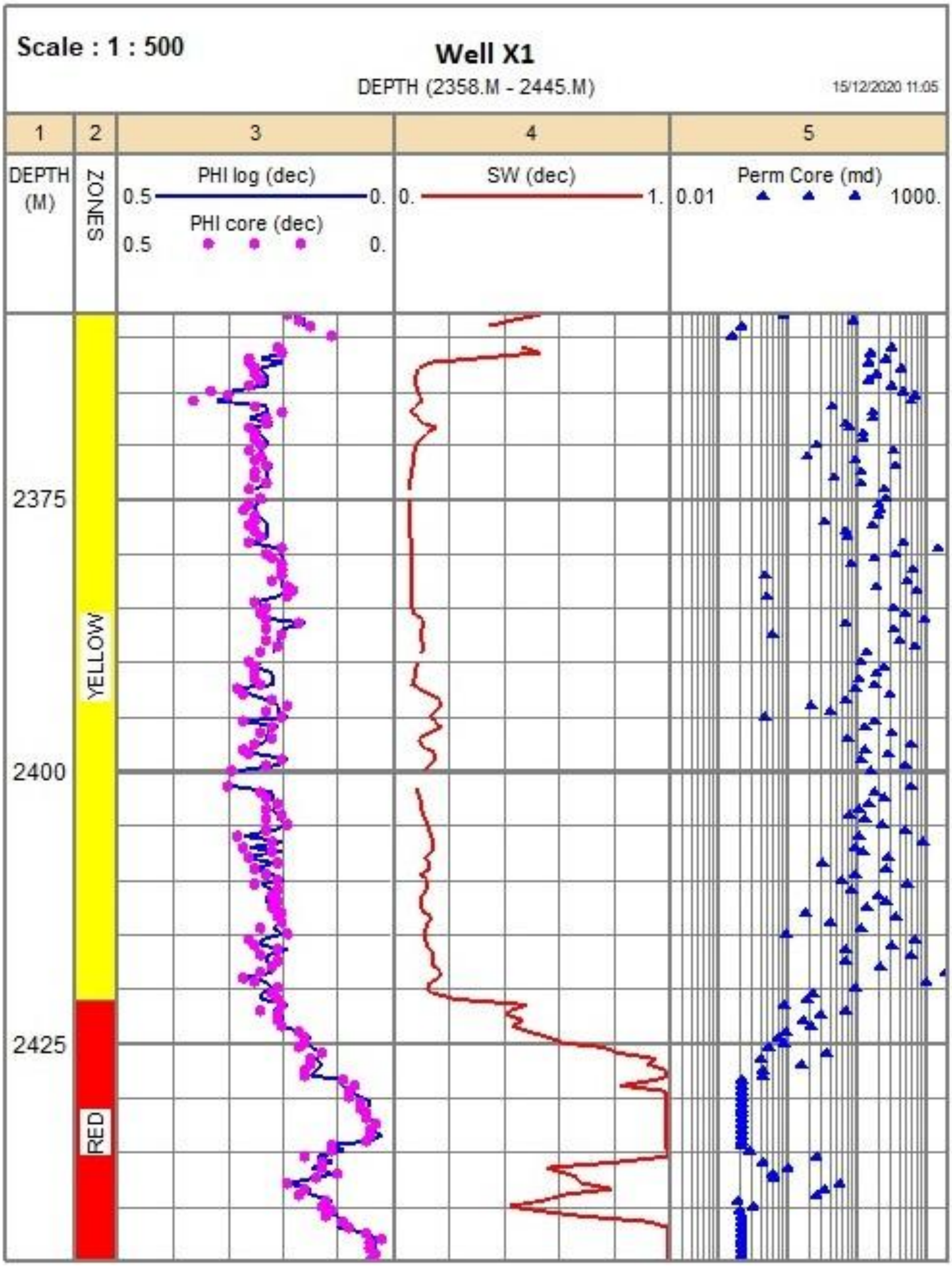

Figure 4. Two zones with petrophysical properties from well logging and core analysis

Firstly, a correlation between capillary pressure and water saturation has been applied to get a good polynomial equation greater than the third order for better fitting with the curve as shown in Figure 5.

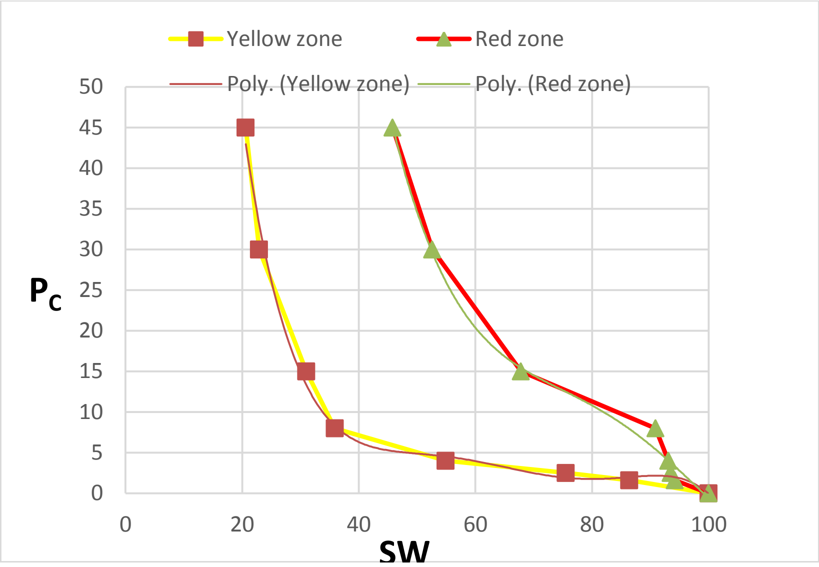

Figure 5. Correlation between capillary pressure and water saturation

From the Figure 5 fifth and fourth-order polynomial regression applied to calculate capillary pressure from water saturation trend in the yellow zone and red zone respectively.

$$P_C = -3E\text{-}07Sw^5 + 9E\text{-}05Sw^4 - 0.0119Sw^3 + 0.7605Sw^2 - 23.875Sw + 300.59 \qquad \text{for Yellow Zone} \tag{8}$$

$$P_C = 1E\text{-}05Sw^4 - 0.0041Sw^3 + 0.528Sw^2 - 29.841Sw + 649.52 \qquad \text{for Red Zone} \tag{9}$$

A correlation between porosity and water saturation for two zones is conducted to obtain capillary pressure from well logging and give an acceptance relationship, as shown in Figure 6.

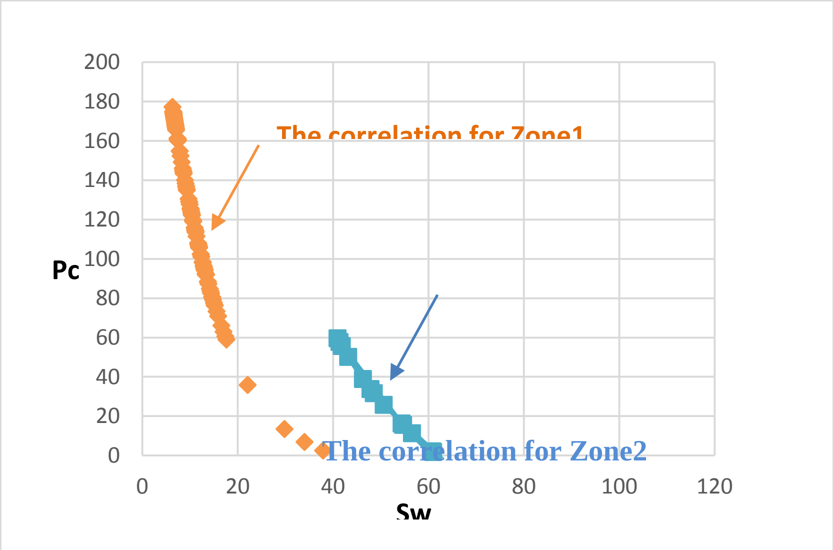

Figure 6. Correlation between capillary pressure vs. water saturation from well log

A study was introduced for one Iraqi oil field to estimate a good acceptance correlation between permeability and other petrophysical properties depend on capillary pressure data. The equation is modified by Brown and Husseini (1977) [9] and fitted to data to find the best method for estimation of formation permeability from well logs, included capillary pressure (Pc), water saturation (Sw), and porosity (φ) where:

$$k = 57\frac{\varphi^{0.86}}{P_c^{0.89}S_w^{1.26}} \tag{10}$$

In addition to a different empirical model is based on the correlation between permeability, porosity, and irreducible water saturation in this study to calculate permeability from well log as shown in Figure 7.

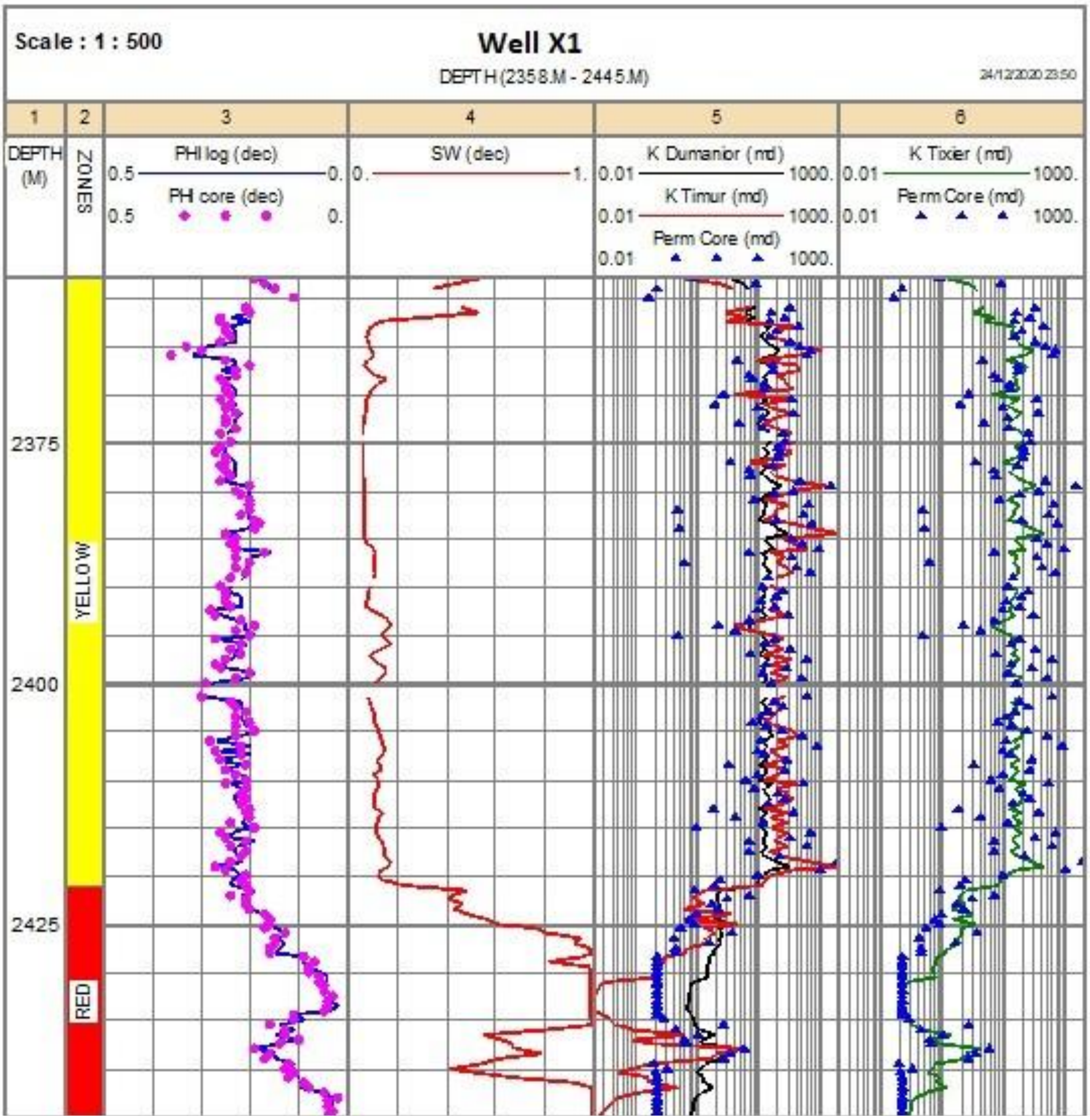

Figure 7. Results of permeability prediction from empirical methods

It is noticed the results of the permeability from Tixier [10], Timur [11], and Coates & Dumanoir [12] are not good matchings and significant-high values compared with permeability from core data.

The estimation of permeability in this study depends on the correlation of capillary pressure from experimental data as core samples. This regression is used to calculate capillary pressure from well logging based on water saturation and porosity values. However, an excellent modified equation by Husseini et al. applied by Statistical techniques using water saturation Sw, capillary pressure Pc, and porosity(φ) as independent variables, and permeability as the dependent variable, nonlinear estimation using regression analysis was employed to find the optimum equation for permeability prediction for the carbonate formation for well of the case study [13],[14].

$$k = 2341 \frac{\varphi^{2.31}}{P_c^{0.27} S_w^{0.64}} \tag{11}$$

The modified of the following relationship that is used to predict the permeability in a carbonate reservoir in this study:

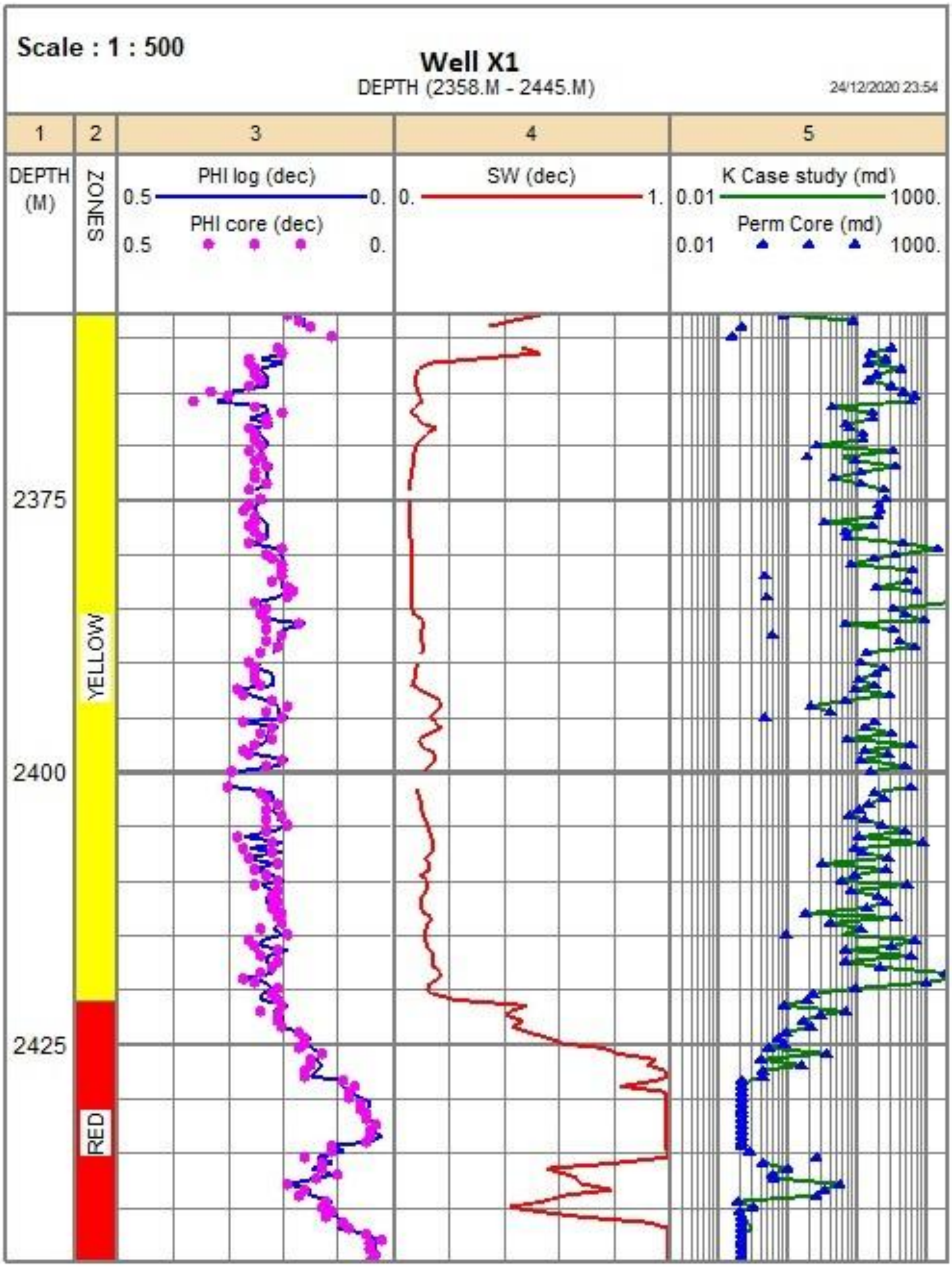

Figure 8. Results of permeability from capillary pressure correlation

Figure 8 shows the profile between calculated permeability from modified Eq. (11) for this study, and that give good results and good matching compared with other studies depend on permeability from core data.

4. Conclusion

- A good correlation has been obtained for capillary pressure calculation from well log by using polynomial regression
- The most sophisticated method in this study is to predict permeability from the capillary pressure curve resulting in closer predictions to core permeabilities and allowed better characterization of the reservoir.

- All previously discussed empirical methods were applied to log data for heterogeneous formation. According to the data, the last technique outperforms the others.

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