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Permeability Determination of The Mishrif Carbonate Reservoir in Buzurgan Oilfield Using the Integration Between Well Logs and Regression Analysis Technique

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ABSTRACT

The permeability is considered one of the most significant rock properties used in evaluating hydrocarbon reservoirs because this property controls the directional movement and flow rate of the reservoir's fluids. The permeability prediction of the carbonate reservoirs is a difficult task due to the heterogeneity of this type of reservoir rock. The study aims to determine the permeability of the Mishrif Formation, which represents the main carbonate reservoir in the Buzurgan oilfield using the integration between well log interpretation and regression analysis technique. Some well logs and core information of six wells in the Buzurgan oilfield have been used in this study, and the logging data for these wells are analyzed and interpreted using Techlog software and Exel Software. In addition, a 3D model of permeability is built using the Petrel Software. The results show that the Mishrif Formation is heterogeneous regarding the permeability, where it changes laterally and vertically. The average horizontal permeability of the Mishrif Formation ranges between (0.3-15 md), whereas the vertical permeability ranges between (0.4-16 md). The study reveals that MB21 and MC2 units represent the best reservoir of the Mishrif Formation, where these units are characterized by good permeability compared to the other stratigraphic units.

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تحديد نفاذية مكمن مشرف الكاربوناتي في حقل بزركان النفطي باستخدام التكامل بين مجسات الابار وتقنية تحليل الانحدار

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الملخص

تعتبر النفاذية واحدة من الخصائص الأكثر أهمية للصخور والتي تستخدم في تقييم المكامن النفطية لكونها تتحكم في مقدار واتجاه حركة سوائل المكمن. يعتبر تحديد مقدار وطبيعة النفاذية من المسائل الصعبة بسبب عدم تجانس صخور هذا النوع من المكامن. الهدف من هذه الدراسة هو تحديد نفاذية تكوين مشرف الذي يمثل المكمن الكربوناتي الرئيس في حقل بزركان النفطي باستخدام التكامل بين تفسير مجسات الآبار وتقنية تحليل الانحدار . تم استخدام ستة آبار في حقل بزركان النفطي في هذه الدراسة، حيث تم تحليل وتفسير بيانات المجسات لهذه الآبار باستخدام برنامج Techlog وبرنامج Exel. إضافة الى ذلك تم بناء موديل ثلاثي الابعاد للنفاذية باستخدام برنامج Petrel. أظهرت النتائج أن تكوين مشرف غير متجانس من حيث النفاذية، حيث تتغير النفاذية أفقياً وعمودياً. يتراوح متوسط النفاذية الأفقية لتكوين المشرف بين (0.3-15 ملي دارسي) بينما تتراوح النفاذية العمودية بين (0.4-16 ملي دارسي). وكشفت الدراسة أن وحدتي MB21 وMC2 تمثلان أفضل مكمن لتكوين مشرف، حيث تتميز هذه الوحدات بنفاذية جيدة مقارنة بالوحدات الطباقية الأخرى.

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Introduction

Permeability is regarded as one of the most important characteristics of petroleum reservoirs since it regulates the direction and fluid flow of the reservoir's fluid. In addition, this property is an essential factor in dynamic modeling. Therefore, it is necessary to determine accurately the values of permeability. In heterogeneous carbonate rocks, the prediction of permeability from well-log data is a complex and difficult problem. A variety of permeability prediction methods have been proposed based on empirical models or geological theories such as hydraulic flow units, Kozeny-Carmen equation, and the pore fractal model (Babak and Resnick, 2016; Babadagli and Al-Salmi, 2004; Abbaszadeh et al., 1996). There are numerous attempts to develop complex mathematical relationships between permeability, porosity, and other reservoir properties. These techniques have numerous restrictions and are only applicable to ideal rocks (Zhang et al., 2018). It is far more difficult to predict permeability for a true heterogeneous reservoir. These studies have enhanced our knowledge of the variables influencing permeability, but they haven't significantly increased the precision of permeability prediction (Shokir, 2006). Machine learning is widely used to characterize hydrocarbon reservoirs, including predicting permeability, porosity, lithology, and saturation (Wang et al., 2014; Shi et al., 2016; Zhang et al., 2018).

Machine learning is a multidisciplinary field With a broad range of study topics supporting its existence (Alzubi et al., 2018). Machine learning can characterize highly nonlinear relationships between permeability and porosity (Huang et al., 1996); (Babadagli and Al-Salmi, 2004). Many machine learning techniques such as multiple linear regression (MLR), support vector regression (SVR), fuzzy logic (FL), and artificial neural networks (ANN) have been used for years to improve the accuracy of permeability prediction (Mohaghegh et al., 1995), (Bagheripour, 2014); (Elkatatny et al., 2018).

This study aims to predict the permeability of the Mishrif Formation, which represents the main carbonate reservoir in the Buzurgan oilfield, using the integration between well logs interpretation and the regression analysis technique.

Location and geological setting

The Buzurgan oilfield is located approximately 40 kilometers to the northeast of Amara City in the Iraqi south-eastern region, (Fig. 1). The oilfield was discovered in 1970, and the field's development stage began in 1976. The Buzurgan oilfield is located in the unstable platform – Mesopotamian Basin zone (Buday, 1980). The field's structure is an asymmetrical anticline that runs NW-SE for 40 kilometers and is 7 kilometers wide with two domes (north and south) separated by a saddle (Aldarraji and Almayahi, 2019). The Mishrif Formation is considered one of the major petroleum carbonate reservoirs in the Mesopotamian Basin, and about 30% of Iraqi confirmed oil reserves are found in this formation (Al-Sakini, 1992). According to Bellen et al., (1959), the Mishrif Formation is classified as an organic detrital limestone containing algal, rudist, and coral-reef limestone. Due to the existence of interconnecting vugs in a grain-dominated fabric, the rudist facies of the Mishrif Formation is regarded as one of the best hydrocarbon reservoirs in southern Mesopotamia (Mahdi et al., 2013). According to Reulet, (1970), the Mishrif Formation was subdivided into seven stratigraphic units: MA, MB11, MB12, MB21, MB22, MC1, and MC2. The main lithology of the MB21 unit, which represents the main oil-bearing reservoir in the Buzurgan oil field, is formed of bioclastic limestone (rudist and grainstone) and chalky limestone (Sang et al., 2017). In Buzurgan oilfield, Mohammed et al. (2021) referred that the MB21 unit is characterized by high effective porosity compared to the other units of the Mishrif Formation, while Sang et al. (2017) pointed out that the main oil-bearing zones MB21 and MC are characterized by moderate to high porosity and low to moderate permeability. The low value of permeability is attributed to the effect of the diagenesis and the low density of the fractures (Sang et al., 2017).

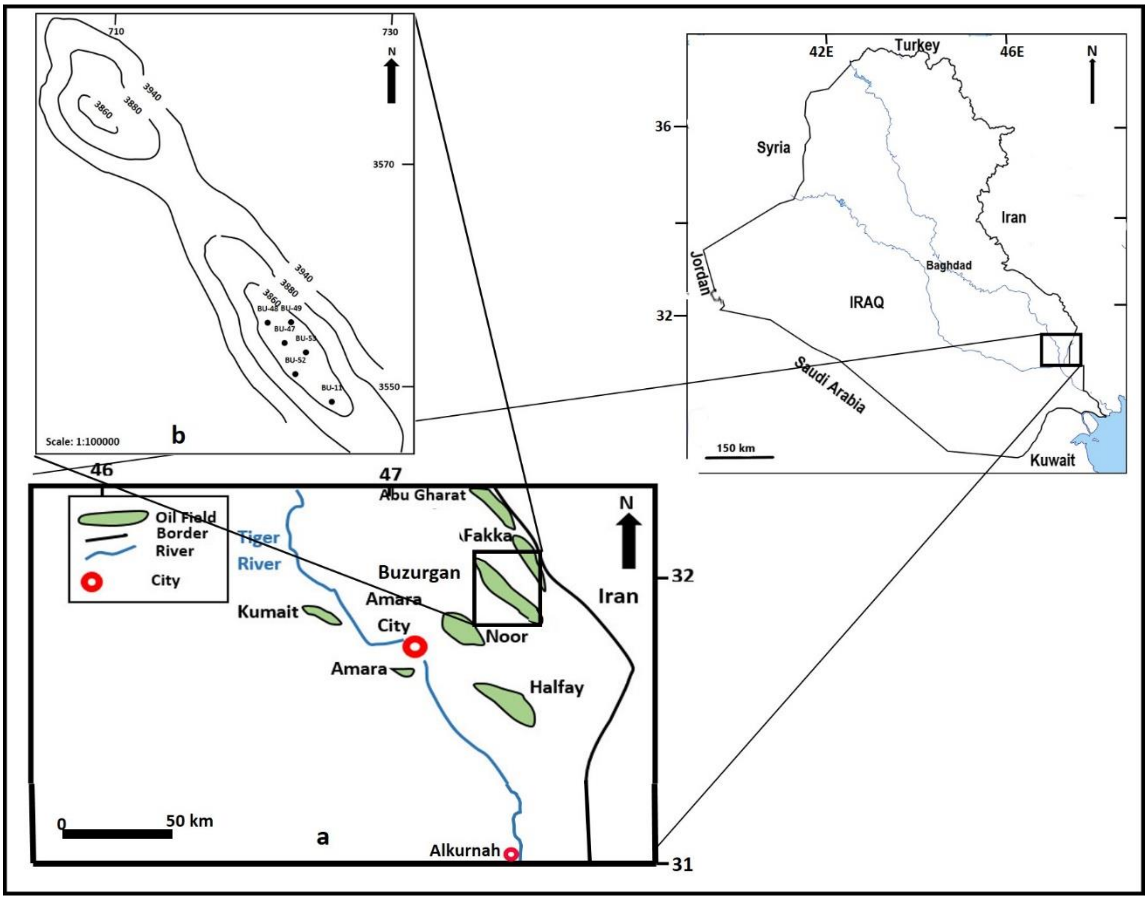

Fig. 1. Location map of the study area. (a) Location map of the Buzurgan oilfield, southern Iraq, (b) Structural map of the Mishrif Formation showing the location of study wells (modified from Mohammed et al. 2021).

Materials and Methods

The log data of the six wells (Bu-11, Bu-47, Bu-48, Bu-49, Bu-50, and Bu-53) in the Buzurgan oilfield has been used to determine the permeability of the Mishrif Formation (Fig. 1). The log data include neutron, density, and gamma-ray logs. The raw data were digitized using Didger software and then have been transformed into the Techlog 2015.3 software for analysis and interpretation. In addition, the core data (porosity and permeability) of the well (Buz-11) with depth interval (3800–3960m) have been used to calibrate and achieve accurate permeability values for the formation. Due to the lack of core measurement data that covers all patterns of permeability in the Mishrif Formation, it is difficult to use the artificial neural network method in this study. Therefore, the regression technique is applied to analyze and determine the permeability of the Mishrif Formation using Excel and Petrel softwares. The methodology used in this study is summarized in figure (2):

Firstly, the total porosity has been calculated from the density and neutron log using the following equation of Schlumberger (1974):

$$Ø_{Total} = Ø_D + Ø_N / 2 \qquad \text{------------------------} \ (1)$$

Where: $Ø_{Total}$ is the total porosity; $Ø_D$ is the density-derived porosity; $Ø_N$ is the neutron-derived porosity.

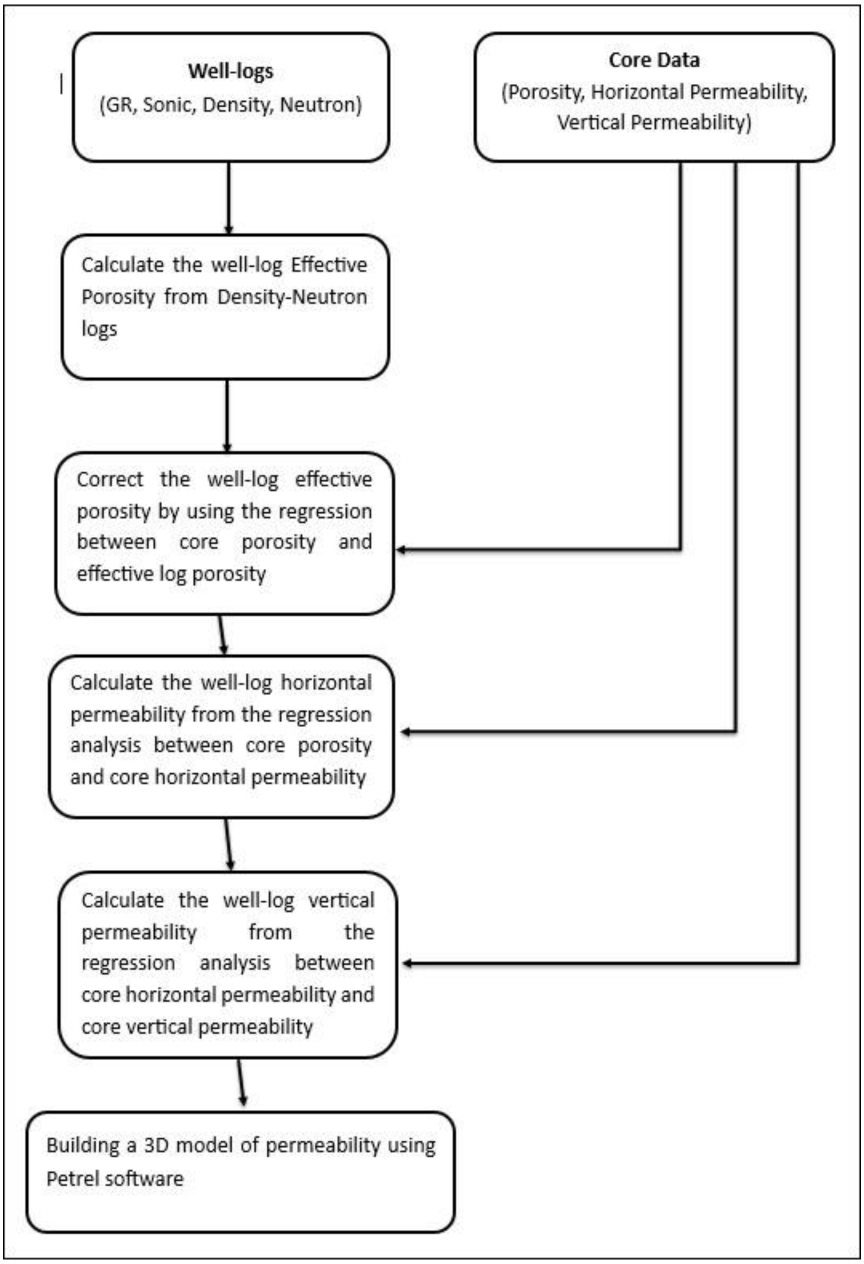

Fig. 2. Methodology flow chart that has been used in this study.

Then, the effective porosity has been estimated using the following equation of Schlumberger (1972):

$$\text{Ø}_{Eff} = \text{Ø}_{Total}\,(1 - V_{sh}) \text{ -------------------------- } (2)$$

Where: Ø_{Eff} is the effective porosity; Ø_{Total} is the total porosity; V_{sh} is the shale volume.

After that, the log-effective porosity is corrected using the regression between core-porosity and log-effective porosity. Then, the log-horizontal porosity is estimated from the regression analysis between core- porosity and core-horizontal permeability. Due to the lack of core samples, the core-porosity and core-permeability data are obtained from the Misan oil company.

The log-vertical permeability is predicted from the regression analysis between core-horizontal permeability and core-vertical permeability. Finally, a 3D model of permeability is constructed using Petrel software.

Results

Permeability is a directional property in X, Y, and Z directions, so the horizontal permeability refers to X and Y directions, and the vertical permeability refers to the Z direction. To determine the horizontal permeability (X), the core-measured porosity values are plotted against core-measured permeability on a linear logarithmic scale to define the relationship between porosity and permeability (Fig. 3). The R-squared value of the correlation is 0.759, which represents a good relationship between the porosity and permeability of the Mishrif Formation. The horizontal core-permeability is calculated from core-porosity by using the following equation:

$$\text{Log}(K_h) = 0.1415*\text{PHIC} - 1.3924 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

K_h: Horizontal core-permeability (md).

PHIC: Core-porosity (%).

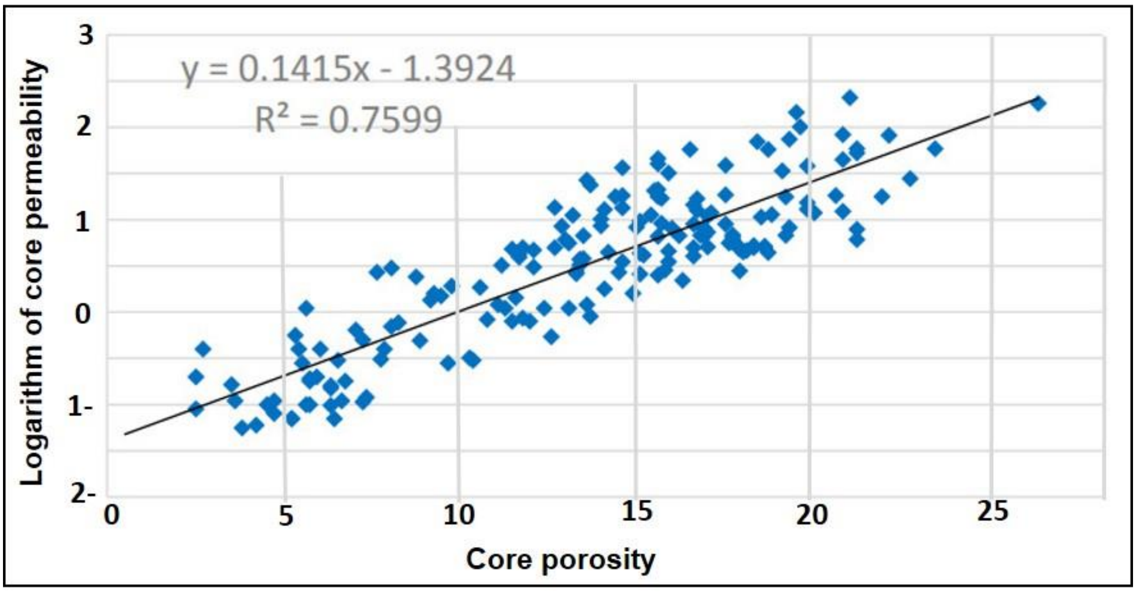

Fig. 3. The relationship between total core-derived porosity and core-derived permeability.

In order to determine the final horizontal permeability in all studied wells, the core-porosity has been replaced by the final effective porosity in equation (1), and using the regression technique in Techlog software. The horizontal permeability of the Mishrif Formation in all studied wells are illustrated in figure (4). The average horizontal permeability values of the stratigraphic units of Mishrif Formation are illustrated in Table (1). The results show that the horizontal permeability of the Mishrif Formation changes laterally and vertically, and it ranges between (0.2-15 md) (Table 1). The MB21 and MC1 units represent the best reservoir units of Mishrif Formation due to these units are characterized by good horizontal permeability, 15 md and 9.5 md respectively (Fig. 4 and Table 1).

The core-measured vertical permeability values are plotted against core-measured horizontal permeability on a logarithmic-logarithmic scale to obtain the relationship between the vertical and horizontal permeability (Fig. 5). The R-squared value of the correlation is 0.70, which represents a good correlation between vertical permeability and horizontal permeability.

The vertical core-permeability is calculated from the horizontal core-permeability by using the following equation:

$$K_v = 1.4584*(K_h)^{0.8457} \text{ ……………………. (2)}$$

Where:

K_v: Vertical core-permeability (md).

K_h: Horizontal core-permeability (md).

The Mishrif Formation's vertical log-permeability is derived by replacing the horizontal core-permeability with the final horizontal log-permeability in equation (2) (Fig. 6). The results show that there is a difference in the vertical permeability among the stratigraphic units of the Mishrif Formation (Fig. 6). In general, the average value of the vertical permeability of Mishrif Formation ranges between (0.4-16 md). The MB21 and MC2 units are characterized by good vertical permeability, where the average vertical permeability values of these units are 16 md and 11 md respectively.

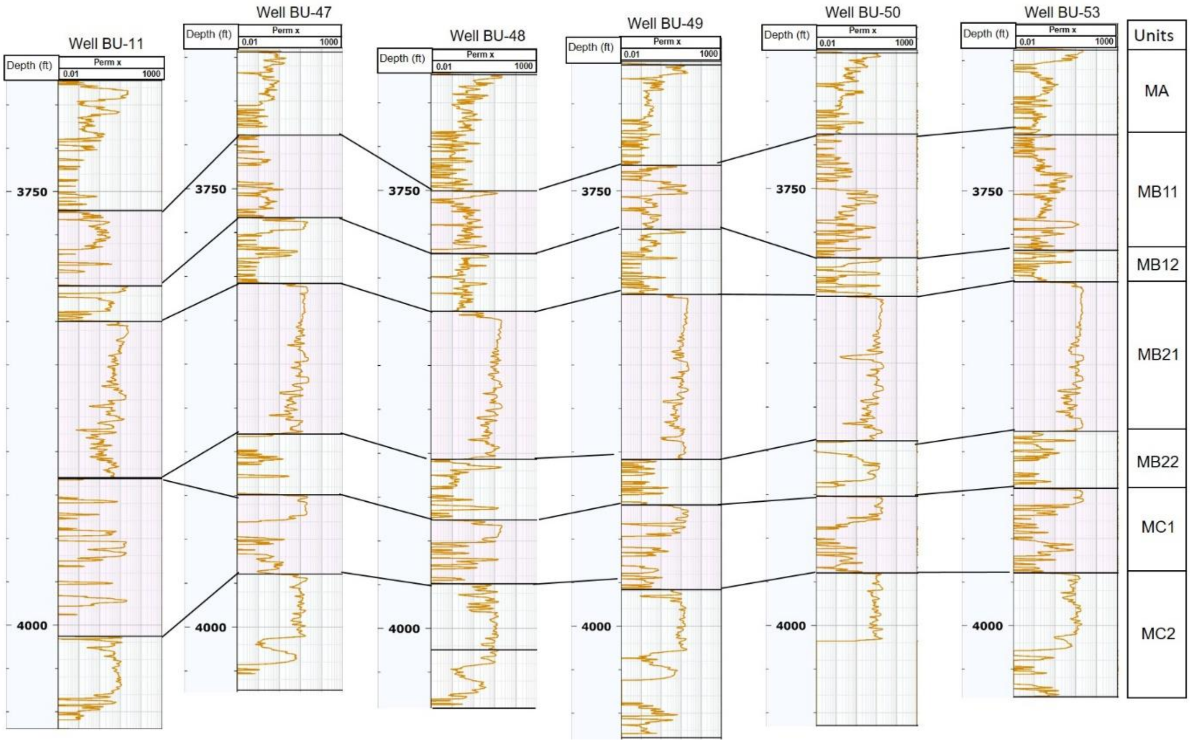

Fig. 4. The horizontal log-permeability of the stratigraphic units of Mishrif Formation in the studied wells.

Table 1: The average values of the horizontal and vertical permeability of the Mishrif Formation, Buzurgan oilfield.

Stratigraphic Units	Horizontal Permeability (md)	Vertical Permeability (md)
MA	0.40	0.45
MB11	0.30	0.50
MB12	3.5	4.0
MB21	15.0	16.0
MB22	0.20	0.40
MC1	0.35	0.60
MC2	9.5	11.0

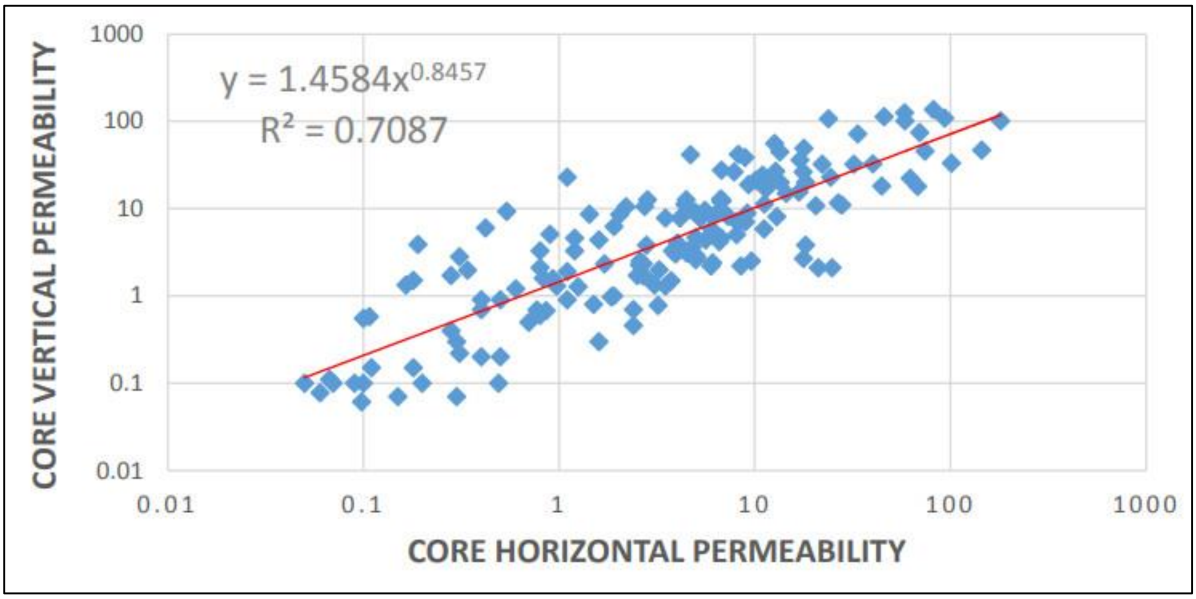

Fig. 5. The relationship between core horizontal permeability and core vertical permeability.

To define the lateral and vertical variations in the permeability of the Mishrif Formation in the Buzurgan oil field, a 3D modeling of the permeability has been constructed using Petrel software. The permeability modeling of the Mishrif Formation is constructed on the basis of dividing the formation into four zones, and using different algorithms (Table 2). This division is established through the creation of five contour maps, which represent the tops of the stratigraphic units (MA, MB2, MC1, MC2), and the base of the MC2 unit. The structural contour map of the top of Mishrif Formation has been used in building the permeability model, and the results of the permeability modeling are illustrated in figures (7, 8, 9, and 10).

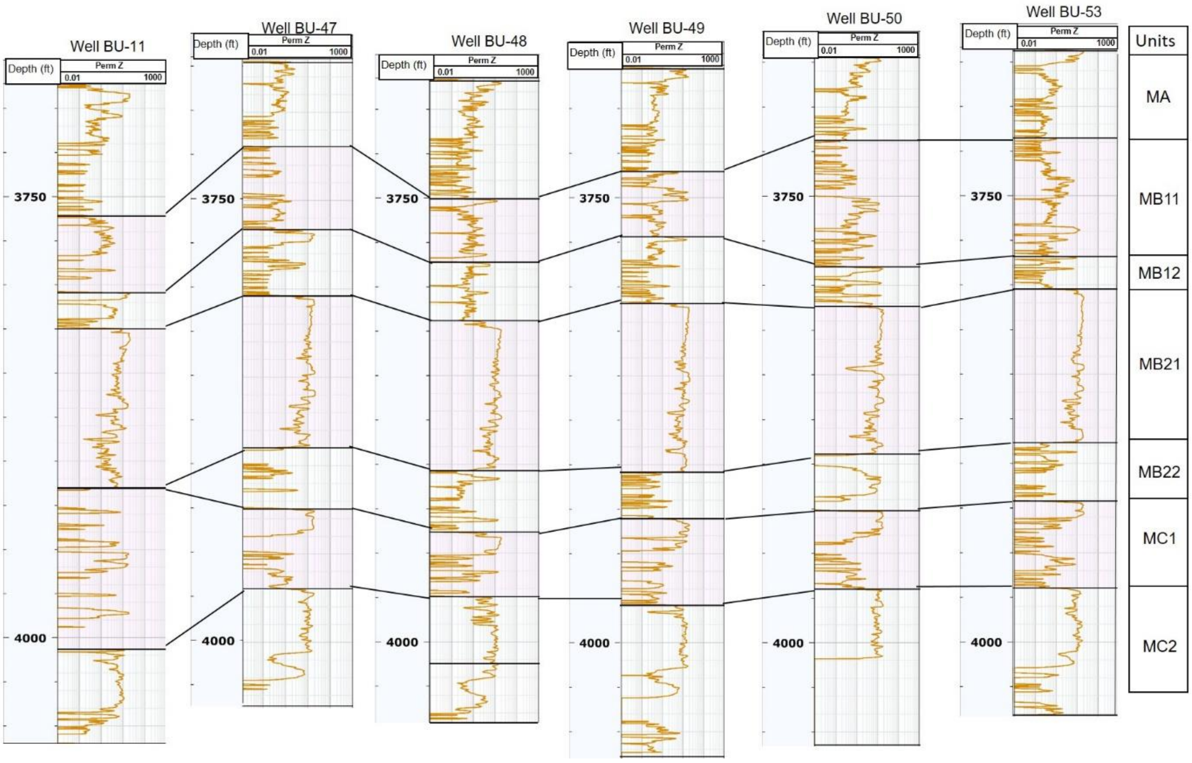

Fig. 6. The vertical log-permeability of the stratigraphic units of Mishrif Formation in the studied wells.

Table 2: The zones and algorithms that have been used in the permeability modeling.

Zones	Algorithms
MA-MB1	Sequential Gaussian Simulation (SGS).
MB2	Sequential Gaussian Simulation (SGS) with porosity Collected Co-Kriging.
MC1	Sequential Gaussian Simulation (SGS) with porosity Collected Co-Kriging.
MC2	Sequential Gaussian Simulation (SGS) with porosity Collected Co-Kriging.

Discussion

Based on the integration between porosity data calculated from well logs and regression analysis technique, the permeability of the Mishrif Formation has been predicted in the un-cored wells. The results show that the Mishrif Formation is a heterogeneous formation in term of permeability, where the permeability of the formation changes vertically and lateraly. This variation in the permeability may be attributed to the lithology, where the Mishrif Formation is characterized by an organic detrital limestone and coral-reef limestone. In addition, the development of secondary porosity in the Mishrif Formation has an influence on the permeability, where there is an increase in permeability for the stratigraphic units that are characterized by high secondary porosity (Fig. 11). In general, the permeability of the Mishrif Formation ranges from low to moderate values, and the MB21 and MC1 units have good permeability compared to the other stratigraphic units of the formation (Fig. 11). This can be attributed to the influence of diagenesis, where the reservoir quality is mainly affected by differential dissolution and differential cementation (Al-Qayim, 2010).

Conclusion

The study's findings reveal that the Mishrif Formation has non-homogeneous permeability, with lateral and vertical variance in the values of the horizontal and vertical permeability of the Mishrif Formation's stratigraphic units. The horizontal permeability ranges from (0.2-15 md), whereas the vertical permeability ranges from (0.4-16 md). The study shows that the MB21 and MC2 units of the Mishrif Formation are the best reservoirs with good permeability (15md and 9.5md for horizontal permeability) and (16md and 11md for vertical permeability) respectively.

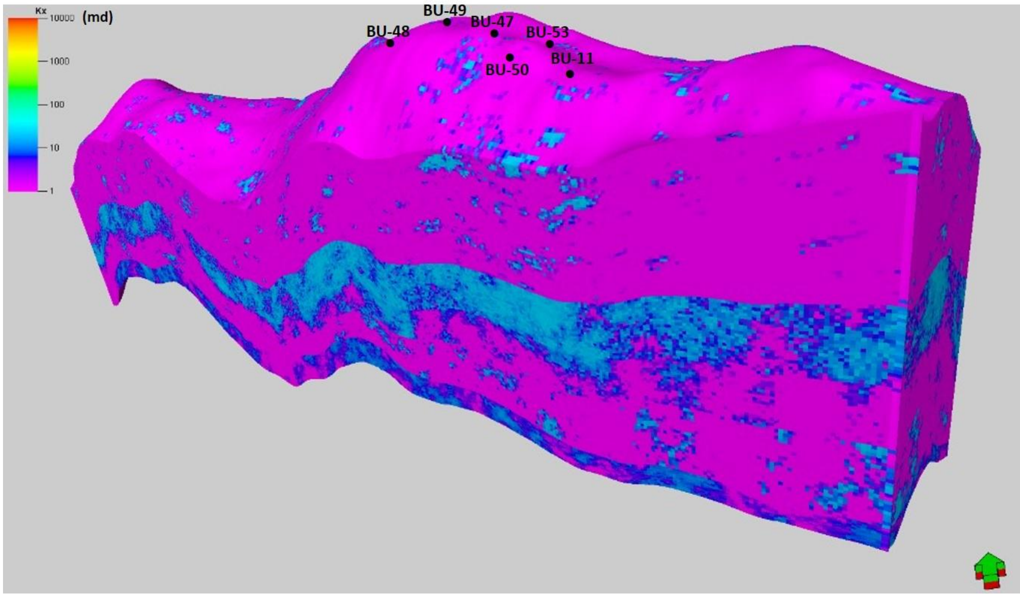

Fig. 7. A 3D horizontal permeability model of the Mishrif Formation, showing the locations of the studied wells.

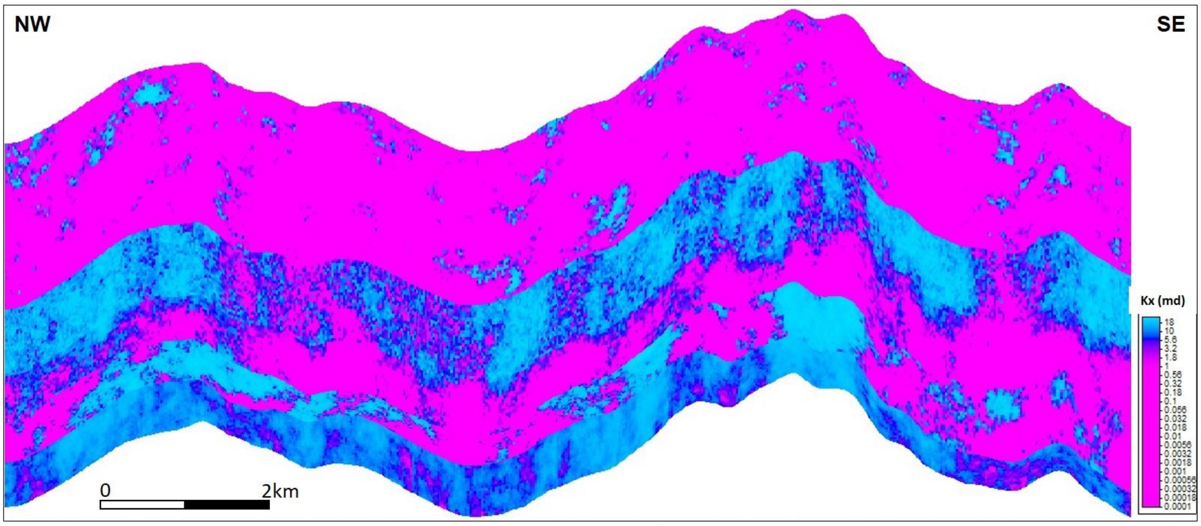

Fig. 8. NW-SE cross-section of the horizontal permeability of the Mishrif Formation, Buzurgan Oilfield.

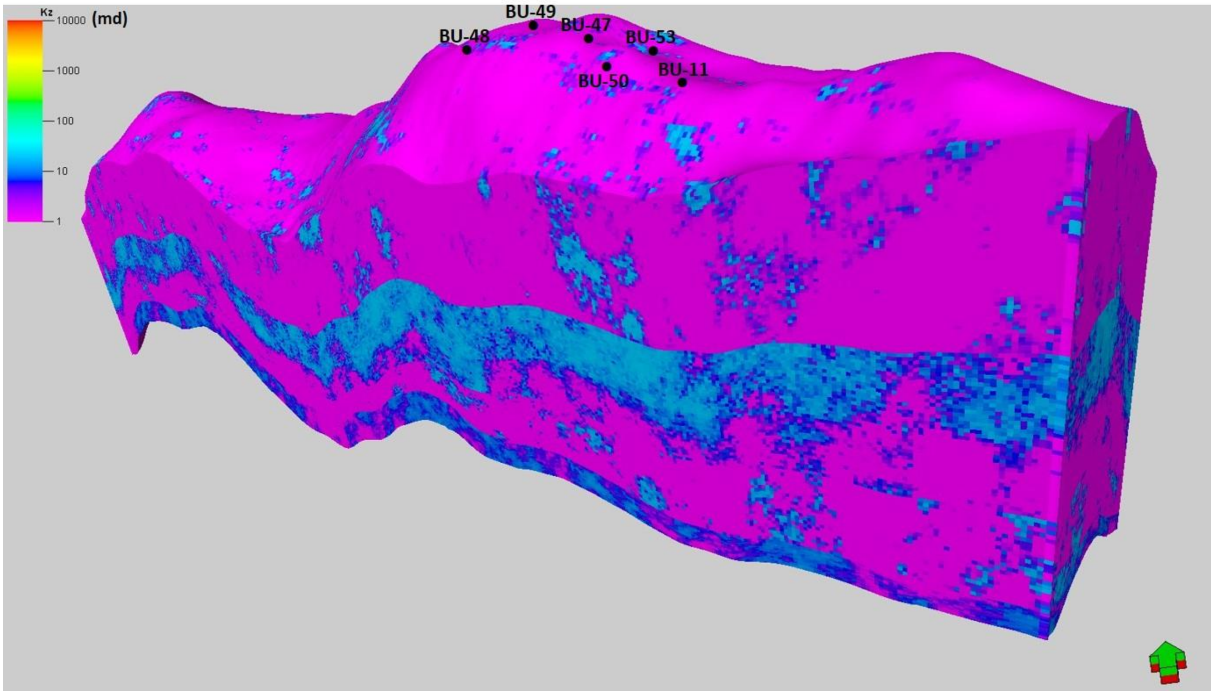

Fig. 9. A 3D vertical permeability model of the Mishrif Formation, showing the locations of the studied wells.

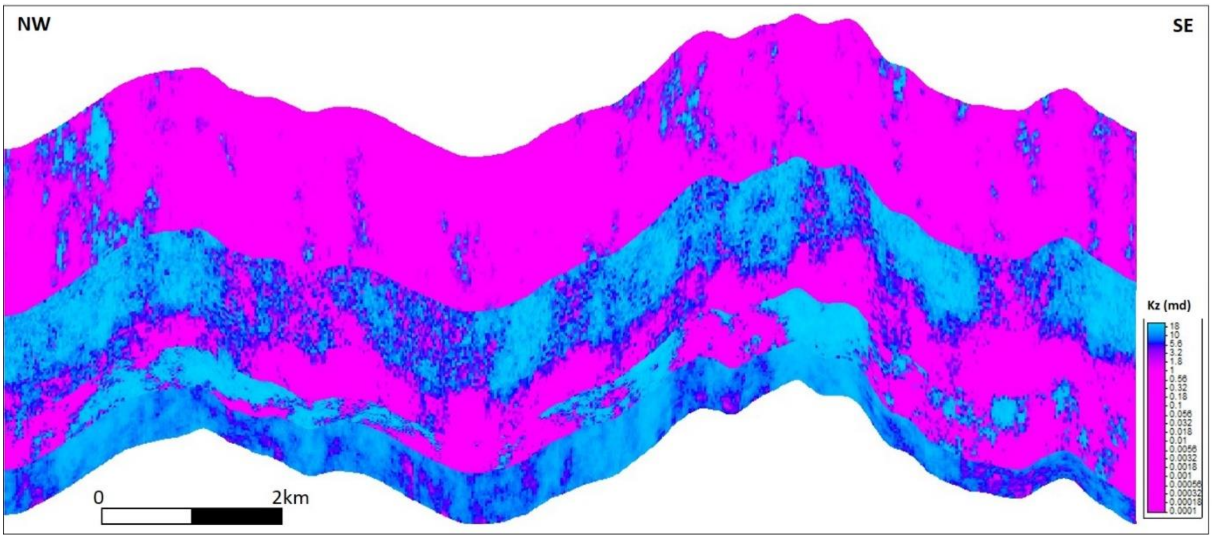

Fig. 10. NW-SE cross-section of the vertical permeability of the Mishrif Formation, Buzurgan Oilfield.

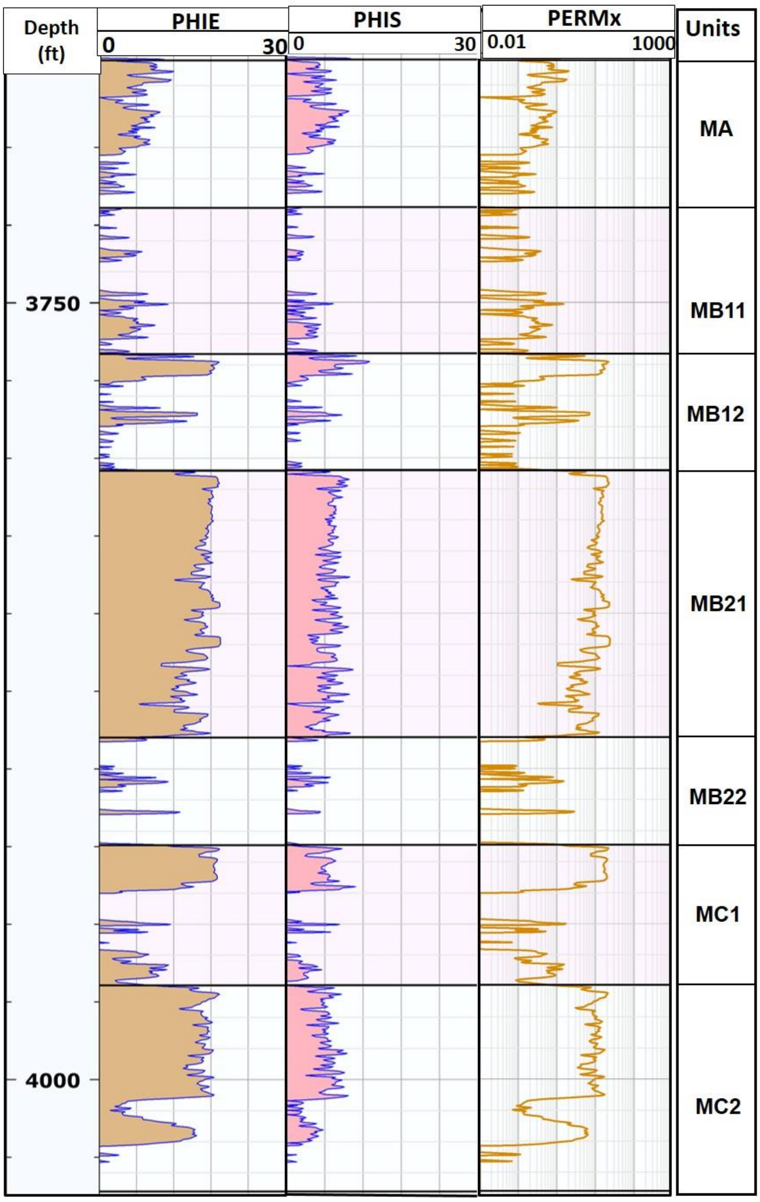

Fig. 11. The comparison between the effective porosity (PHIE), secondary porosity (PHIS), and horizontal permeability (PERMx) in the well BU-47.

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