Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org

Heterogeneity Modeling in a Carbonate Reservoir Using Geostatistical Simulation of Petrophysical Properties

Nuhad Al-Kanaani[1*], Mohammed Al Jawad[2] and Muwafaq Al-Shahwan[1]

[1] Department of Geology, College of Science, University of Basrah, Basrah, Iraq
[2] Department of Petroleum Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.
[*] Correspondence: alkanaaninuhar@gmail.com

Received:
29 February 2025
Accepted:
21 July 2025
Published:
31 October 2025

Abstract

The different types of rock and their properties in the Mishrif Formation, an important oil reservoir in the Ratawi oilfield in southern Iraq, influence how good the reservoir is and how much oil can be extracted. By employing geostatistical simulation techniques to describe the spatial distribution of facies and petrophysical characteristics, this study improves understanding of reservoir heterogeneity. To improve reservoir property estimates, a high-resolution 3D geostatistical reservoir model was developed to describe the petrophysical properties and microfacies of 15 wells. Based on an analysis of core data, the four primary microtypes that comprise the Mishrif Formation are packstone, wackestone, dolostone, and mudstone. Sequential Gaussian simulation was used to estimate permeability and porosity, and sequential indicator simulation was used to simulate microfacies. Variogram analysis gave rise to these geostatistical techniques. The Mishrif Formation's rudist-rich depositional environment was captured by constructing the 3D microfacies, permeability, and porosity models. By integrating core analysis with well log data, the finding provides important new information about diagenetic processes, depositional environments, and their effects on variations in porosity and permeability. This paper improves decision-making and optimization strategies for hydrocarbon production by strengthening reservoir management predictive models.

Keywords: Heterogeneity Modeling; Mishrif Reservoir; Geostatistical model; Petrophysical Properties

1. Introduction

The complex depositional and diagenetic histories of carbonate reservoirs, such as the Mishrif Formation, result in inherent heterogeneity that critically influences management strategies and reservoir characterization. An understanding of this heterogeneity is essential for accurate reservoir characterization and optimized hydrocarbon recovery. This study uses geostatistical techniques to simulate the spatial distribution of facies and petrophysical properties within the Mishrif Formation in the Ratawi oilfield.

The primary objectives include reservoir facies identification, petrophysical property quantification, and the creation of a detailed heterogeneity model to support reservoir development strategies. Petrophysical analyses were conducted on core samples and outcrop data obtained either from open boreholes or through laboratory measurements (Al-Kanaani, 2018; Hatif et al., 2020). Mohammed and Mahdi (2019) evaluated the petrophysical properties of the Mishrif Formation in the Tuba oilfield,

southern Iraq, using the Interactive Petrophysics (IP) software. It identified key reservoir units (MB1 and MB2) with high porosity and oil saturation, while other units (TM, MA, and CR2) have lower reservoir quality due to lithological variations. Additionally, these factors facilitate the application of evaluation methods to identify potential reservoir zones, classify the type of fluids that are contained in a reservoir, and measure the amount of oil resources (Al-Najm et al., 2018; Al-Dujaili et al., 2023).

The Mishrif Formation, which belongs to the Wasia Group, was deposited during the Late Cenomanian to Early Turonian cycle (Buday and Jassim, 2006). One of the most important problems in petroleum engineering is figuring out the optimal future reservoir performance that leads to more economically viable oil production. In order to accomplish that goal, a thorough reservoir geomodel was built, and flow modeling was done to assess fluid flow for the Mishrif Formation in Ratawi oilfield to capture reservoir heterogeneity.

Geological modeling describes reservoir geology, including lithological and structural characteristics and the spatial distribution of porosity, permeability, and water saturation, which dictate reservoir storage capacity and fluid behavior (Debski, 2010). Conceptually, a geological model is hierarchical, comprising sub-models such as structural, porosity, permeability, and water saturation models (Bai et al., 1994; Onovughe and Sofolabo, 2016; Mera et al., 2017). It encompasses a conceptual framework, mathematical representations, model parameters, and their realizations.

A geologic model is typically hierarchical, comprising various sub-models, including a structural model (which may or may not incorporate a fault model), a porosity model (Bai et al., 1994), a permeability model (Mera et al., 2017), and a water saturation model (Onovughe and Sofolabo, 2016). While there are diverse methods for characterizing models, a scientific model typically consists of several essential components: a conceptual model, a mathematical model, the model parameters, and realization of the model.

In many fields of application, 3D modeling serves as a crucial method for obtaining quantitative subsurface models, enabling the extraction of valuable information. Such 3D geologic information systems find utility in diverse areas like mineral potential mapping (An et al., 1994) and geo-hazard assessment (Culshaw, 2005). The information collected includes core analysis from 15 wells in the Mishrif reservoir as well as well logs (gamma ray, neutron porosity log, shale volume, and water saturation). Pixel-based sequential indicator simulation was used as the main geostatistical modeling method for the spatial distribution of microfacies inside each reservoir zone.

2. Geological Setting

The Mishrif Formation, deposited during the Late Cenomanian to Early Turonian (Fig. 1), consists primarily of carbonate rocks formed in shallow marine environments. The formation exhibits variations in depositional facies, ranging from platform carbonates to lagoonal and rudist-rich facies, influenced by tidal processes. These variations, combined with diagenetic alterations, create significant heterogeneities in reservoir quality. The Mishrif reservoir is crucial for hydrocarbon production in southern Iraq, including the Ratawi oilfield. The formation is part of the Wasia Group and primarily consists of limestone and dolomitic limestone, with bioclastic and oolitic limestone, marl, and shale interbeds (Al-Naqib, 1967; Al-Siddiki, 1978). The formation includes the Lower Mishrif Member, characterized by dense, mud-dominated wackestone and packstone formed in a low-energy outer ramp setting with low porosity and permeability, and the Upper Mishrif Member, composed of grain-dominated packstone and grainstone with rudist fragments, indicative of higher energy, shallow marine settings with higher porosity and permeability. The reservoir quality has been greatly impacted by diagenetic processes such as fracturing, dissolution, dolomitization, and cementation of calcite and dolomite (Al-Naqib, 1967; Al-Siddiki, 1978).

Hydrocarbon trapping mechanisms include structural traps like anticlinal structures and fault-related traps, as well as stratigraphic traps formed by lateral facies changes and pinch-outs within the carbonate platform (Al-Siddiki, 1978; Beydoon, 1993).

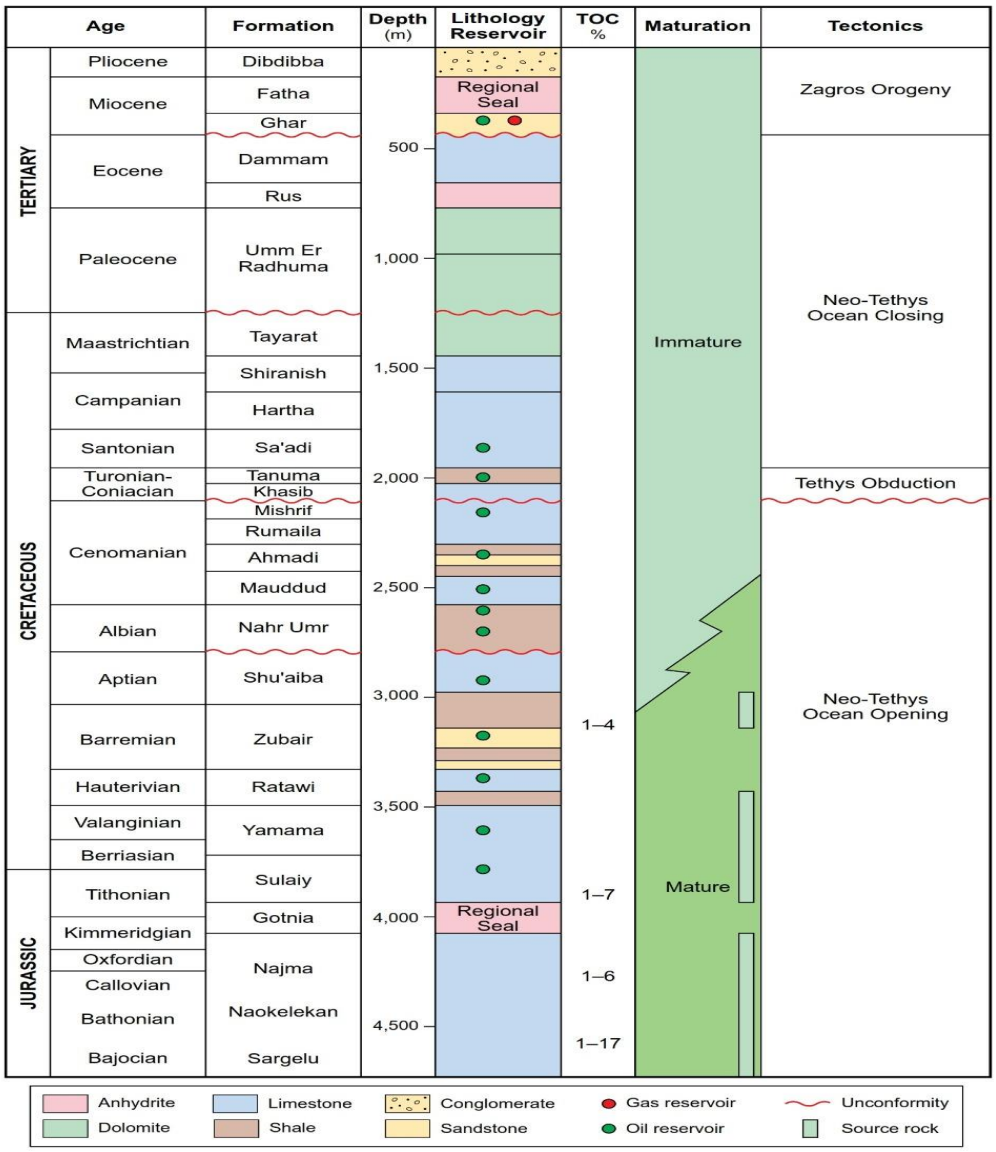


Fig.1. Stratigraphic column section in southern Iraq, Ratawi oilfield (after Al-Ameri et al., 2009

The Ratawi oilfield is located in a stable Mesopotamian zone, more specifically in the Zubair subzone (Fig. 2). It is bordered on the north and the south by the Takhadid-Qurna and Al-Batin transversal faults that belong to the Basra Block (Fig. 3). From the seismic surveys, it was defined that the structure is ovoid convex, extends north-south with approximately symmetrical flanks, and plunges with depth (Jassim and Goff, 2006). From the available geological and geophysical data, it can be inferred that there is structural influence due to salt (Hermoz Formation) dated back to the era of Infra-Cambrin, which has manifested itself on the Bouguer gravity maps as zones of negative anomalies belonging to Ratawi, Rumaila, and some parts of Zubair structures (Jassim and Goff, 2006).

The Mishrif Formation, which was deposited between the Late Cenomanian and Early Turonian periods, is distinguished by an unconformable contact with the overlying Khasib Formation and a conformable contact with the Rumaila Formation at its base (Jassim and Goff, 2006). It is mostly composed of limestone with sporadic shale intercalations and varied levels of oil impregnation (Sharland

et al., 2001). Because of salt tectonics, the formation has a structural tilt that first stretches southwestward before folding northeastward (Buday, 1980).

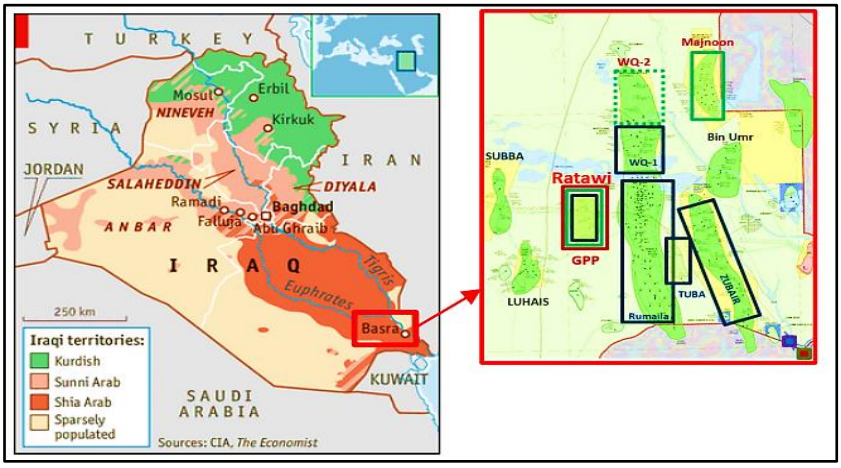


Fig.2. Location map of Ratawi oilfield

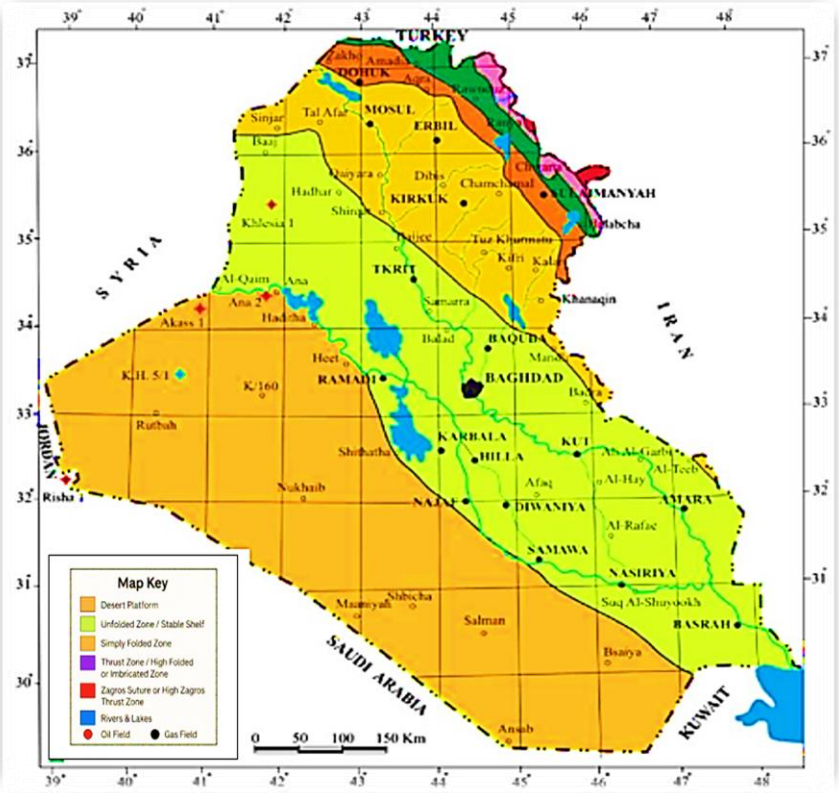


Fig. 3: Tectonic map of Iraq (Fouad, 2015)

3. Materials and Methodology

The study used geostatistical simulation methods and different data sources to understand the variations in the carbonate reservoir, including its rock types, features, and porosity patterns. These reservoir variables were identified by using well logs (Gamma ray, resistivity, density, and neutron logs) for wells RT-02, RT-04, RT-05, RT-06, RT-07, RT-017, RT-019, RT-029, RT-036, RT-041, RT-042,

RT-043, RT-051, RT-052, and RT-053, and laboratory measurements of porosity, permeability, and microfacies (Fig. 4). The microfacies were used to ascertain data for core analysis. The geostatistical simulation, based on the well log and core data, modeled the facies distribution using sequential indicator simulation (SIS). Sequential Gaussian simulation (SGS) was used to simulate petrophysical characteristics, including porosity and permeability, within each facies. The variogram parameters for the simulation were defined based on the results of a variogram analysis that evaluated the spatial continuity of facies and characteristics.

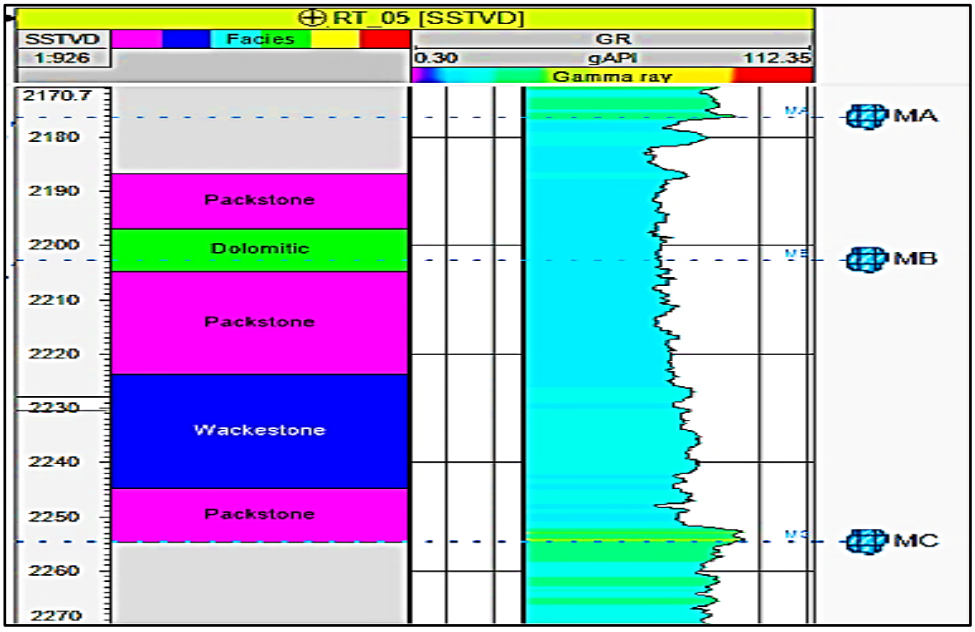


Fig. 4. Lithofacies and gamma ray log interpretation of well RT-05

4. Results and Discussion

The distribution of the Mishrif Formation's facies in the Ratawi Field has a direct impact on permeability and porosity and affects the reservoir characteristics. The packstone facies is known for its fine-grained texture and well-cemented. It is typically linked to higher porosity and permeability, which improves the reservoir's capacity to produce and store oil. The porosity and permeability of the wackestone facies, characterized by finer particles and a less cemented structure, constrain the reservoir's production capacity. To predict possible high-production zones inside the reservoir, it is essential to comprehend this facies distribution. This information can be included in reservoir modeling to increase the precision of production projections, which helps choose the best well placements and create more effective injection and production plans for upcoming operations.

4.1. Spatial Facies Modeling

The Mishrif Formation in the Ratawi oilfield is mostly composed of rudist-rich packstone, dolomite, mudstones, and lagoonal wackestone. Thin section and core analysis were used to classify lithofacies. From lithology and fossils, depositional environments were deduced; packstone suggested shallow marine environments, whereas wackestone suggested lagoonal conditions. The geostatistical simulation identified regions of substantial reservoir potential associated with grainstone facies. The spatial facies model accurately depicts the stratigraphic reservoir characteristics when all hydraulic components are incorporated.

The microfacies model aids in understanding depositional settings and capturing heterogeneity levels for integration into the reservoir flow model (Walker, 1992; Mikes; Geel, 2006). Additionally, it

serves as a manual for predicting reservoir properties by controlling fluid flow heterogeneities and features (Walker, 1992). The most used geostatistical modeling method for reservoir simulation is sequential indicator simulation (SIS), which uses the indicator variogram to depict the geographical distribution of facies. The spatial facies distribution in the Mishrif Formation's Ratawi Field shows that packstone facies have higher porosity and permeability, leading to better reservoir quality and production, while wackestone facies have lower porosity and permeability, resulting in less production. This feature makes it easier to find areas with a lot of development potential.

4.2. Spatial Petrophysical Modeling

The permeability and porosity of reservoir facies control are observed in the spatial distributions, with grainstone showing the greatest values because of its intricate pore geometry. Lagoonal facies include micrite, which reduces their permeability while maintaining a moderate porosity. The results of the simulation, which closely match the core data, confirm the approach. SGS, or conditional sequential Gaussian simulation, is the most used geostatistical approach for generating stochastic random fields of continuous variables, including permeability and porosity. By honoring data distribution, variograms, and spatial trends, SGS effectively captures reservoir heterogeneity. The geometry and continuity of reservoir characteristics, which have a direct impact on flow behavior, are better understood through methods like to the variogram. The generation of multiple equiprobable stochastic images guarantees a realistic representation of reservoir properties (Deutsch and Journel, 1998) (Fig.5).

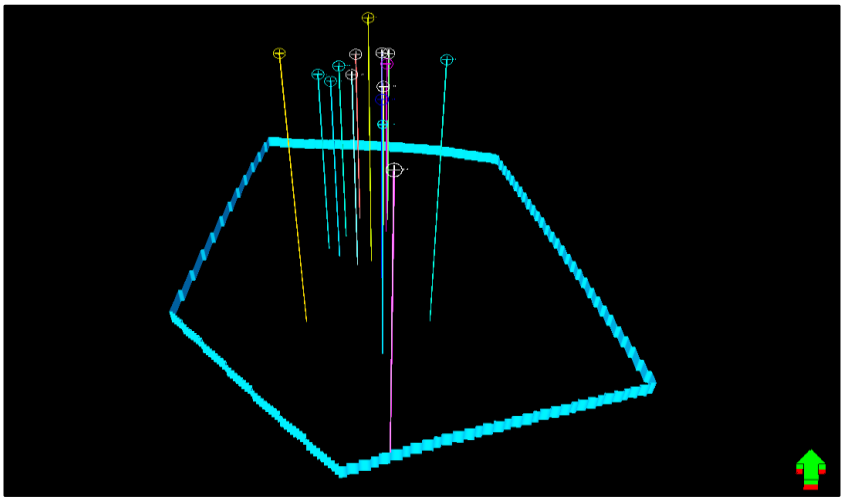


Fig. 5. Well locations used for petrophysical analysis in the Ratawi oilfield, Mishrif Formation

Fig. 3 shows the spatial distribution of wells in the Ratawi oilfield, where petrophysical data, including lithology, permeability, and porosity, have been gathered. It aids in determining well spacing, comprehending well data coverage, and finding any data gaps that can affect reservoir characterization. This step is essential for confirming the representativeness and correctness of the petrophysical data to ensure it is suitable for further modeling and analysis. Developing the 3D property model begins with building the structural model using horizon modeling and grid structure. To account for the reservoir in all future geology and reservoir models, the grid structure includes setting up the grid system. The orthogonal corner gridding had 145 grids in the I direction and 204 grids in the J direction, with each grid's chosen dimensions measuring 150 by 150 m.

There were 1,094,460 grids in total across all the layers. The major reservoir's three zones have been separated into 37 layers with a thickness of roughly 3.835 m each for the purpose of representing a more accurate geological framework in horizon modeling. The Ratawi oilfield/Mishrif Formation's horizon modeling and structural gridded surface are depicted in Figs. 5 and 6. 3D geostatistical

microfacies modeling was accomplished using the Sequential Indicator Simulation method, which consists of four main steps: upscaling well log data, creating and fitting an indicator variogram, generating a random seed number, and analyzing the frequency distribution of the upscaled data points.

Fig. 6 uses horizon modeling tools to depict the structural framework of the Mishrif Formation. It highlights depth changes and structural trends while defining the reservoir's top and base surfaces. Horizon modeling is crucial for comprehending the formation's geometrical structure, spotting structural highs and lows, and locating possible hydrocarbon traps that could affect reservoir productivity.

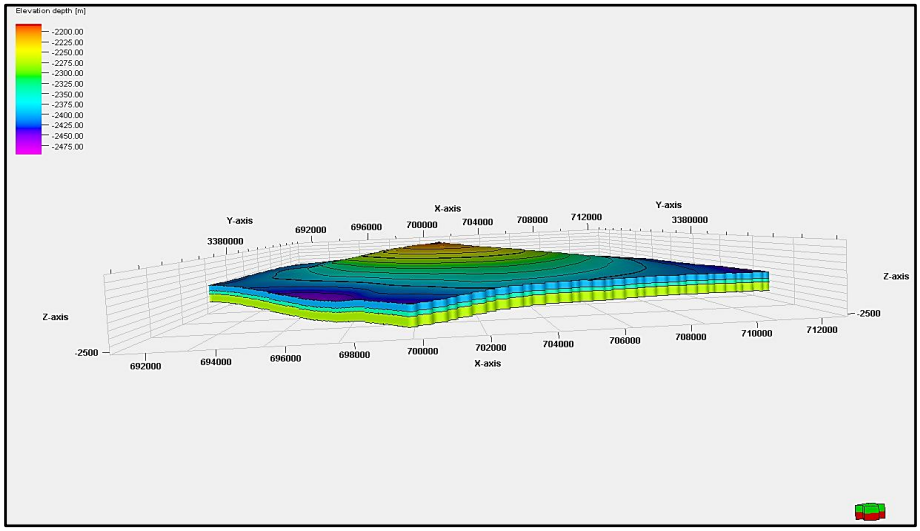


Fig.6**.** Horizon modeling for the Ratawi oilfield, Mishrif Formation

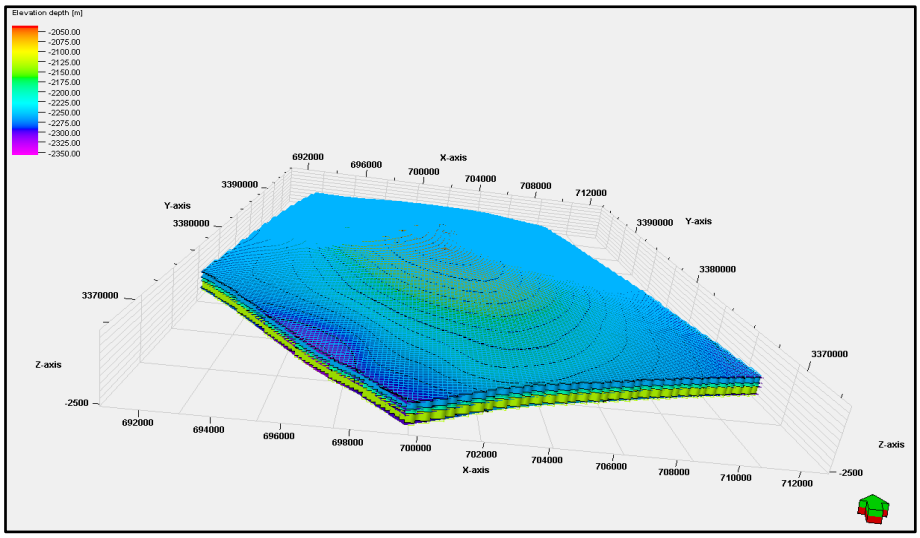


Fig.7. The gridded structural model of the Mishrif Formation zones, Ratawi oilfield

Fig. 7 displays the gridded structural model of the several Mishrif Formation zones. The gridding method improves the reservoir's spatial representation, ensuring a precise structural underpinning for simulation research. This image facilitates reservoir compartmentalization analysis and offers insights into the interconnectedness of several reservoir zones, both of which are critical for production planning, by displaying the structural changes. Since the empirical indicator variogram was created, better variogram models have taken its place to measure the usual covariance parameters (sill, nugget, and range) used in spatial distribution methods. The spherical modeling was found to be the most effective

in fitting all indication variograms for all microfacies in all directions. Table 1 displays the indicator variogram parameters for the microfacies modeling based on the three microfacies.

For sequential indicator simulation, the range, nugget, and sill are crucial factors from the indicator variogram. A nugget is a small-scale variability, such as measurement mistakes; range is the distance at which the correlation between data points becomes zero, and sill is the maximum dissimilarity between the collected data. Compared to indicator kriging, which is less flexible and more deterministic when it comes to handling data distribution and smoothing, these factors aid in the creation of 3D facies models, which provide a more accurate portrayal of geographical variability.

Table 1. Indicator variogram parameters of the microfacies for the studied formation

Microfacies	Anisotropy Range			Variogram Parameters			Variogram Type
	Major	**Minor**	**Vertical**	**Sill**	**Azimuth**	**Nugget**	
Packstone	10875	10422	94.6	1.0	0	0.01	Spherical
Wackestone	9203	8530	94.6	1.0	0	0.01	Spherical
Dolomite	12500	11006	94.6	1.0	0	0.01	Spherical
Mudstone	8700	7809	94.6	1.0	0	0.01	Spherical

For sequential indicator simulation, the range, nugget, and sill are crucial factors from the indicator variogram. A nugget is a small-scale variability, such as measurement mistakes; range is the distance at which the correlation between data points becomes zero, and sill is the maximum dissimilarity between the collected data. Compared to indicator kriging, which is less flexible and more deterministic when it comes to handling data distribution and smoothing, these factors aid in the creation of 3D facies models, which provide a more accurate portrayal of geographical variability.

A three-dimensional geostatistical simulation of the distribution of microfacies in the Mishrif Formation is shown in Fig. 8. It predicts the rock types in unsampled areas by combining geological trends and borehole data. Because it directly affects porosity, permeability, and fluid flow behavior, the microfacies model is essential to reservoir characterization. Different depositional environments, from low-energy mud-dominated lagoons to high-energy shoal grainstone, are reflected in the spatial distribution of microfacies. The distribution of reservoir quality is governed by these facies' heterogeneities, which have an impact on flow routes and hydrocarbon storage. Planning well trajectories, determining the best drilling targets, and improving reservoir management techniques to optimize hydrocarbon recovery all depend on accurate microfacies distribution.

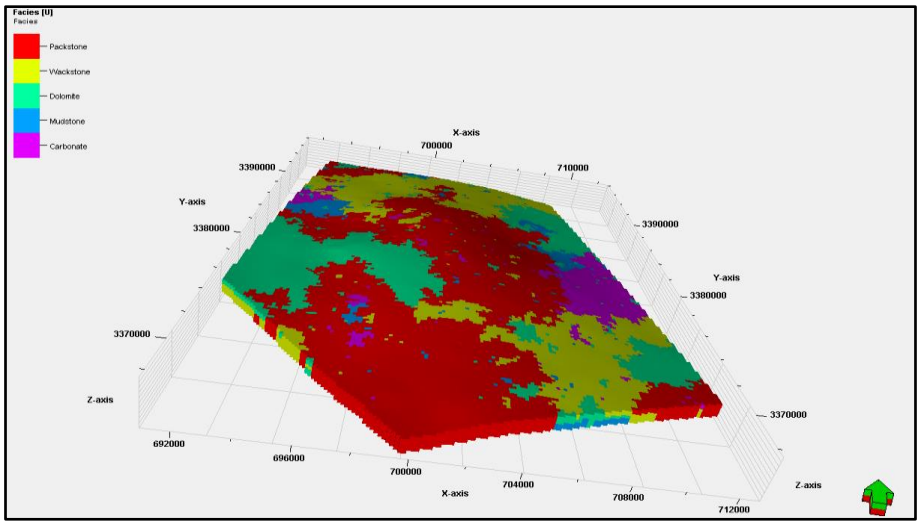


Fig. 8. 3D geostatistical microfacies simulation of the Mishrif Formation in the Ratawi oilfield

A statistical study of the distinct microfacies types obtained from the geostatistical microfacies simulation is shown in Fig. 8. By revealing the frequency and proportions of different microfacies, the histogram helps to clarify the microfacies and how they affect reservoir heterogeneity. The most used stochastic simulation algorithm for petrophysical modeling that captures reservoir variability is Sequential Gaussian Simulation (SGS).

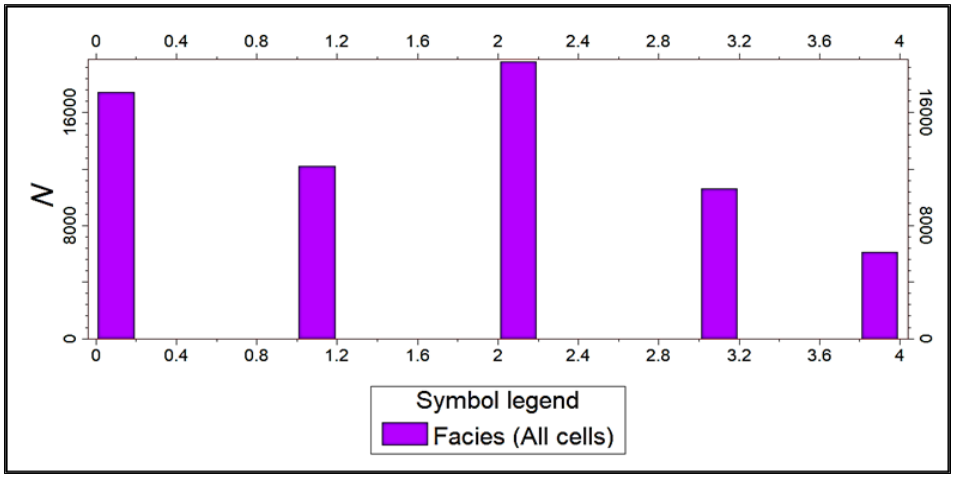


Fig. 9. Histogram of discrete microfacies simulation of the Mishrif Formation in the Ratawi oilfield

SGS honors trends, variograms, parameter distributions, and all the data. Upscaling the data is necessary before doing any spatial modeling. Based on the property-related histogram, the arithmetic mean has been utilized for porosity upscaling, whereas the harmonic mean has been employed for permeability upscaling. Before applying the SGS, the variogram for the petrophysical properties of all four facies should be constructed and modeled. The sequential Gaussian simulation for spatial modeling follows the standard values for range, sill, and nugget, along with the seed number, after fitting the variogram. The variograms have conditioned the four microfacies (packstone, wackestone, dolomite, and mudstone) produced by the sequential indicator simulation. Each type of facies necessitates the creation of a distinct variogram, as the spatial distribution of the parameters varies depending on that type. Tables 2 and 3 display the variogram parameters for permeability and porosity, respectively, based on the four types of microfacies.

Table 2. Permeability variogram parameters of reservoir zones for the studied formation.

Zones	Anisotropy Range			Variogram Parameters			Variogram
	Major	**Minor**	**Vertical**	**Sill**	**Azimuth**	**Nugget**	**Type**
MA-MB	11000	10875	46.1	1.0	0	0.01	Spherical
MB-MC	10000	9000	54.6	1.0	0	0.01	Spherical
MC-MD	7500	6800	50	1.0	0	0.01	Spherical

Table 3. Porosity variogram parameters of reservoir zones for the studied formation

Zones	Anisotropy Range			Variogram Parameters			Variogram
	Major	**Minor**	**Vertical**	**Sill**	**Azimuth**	**Nugget**	**Type**
MA-MB	10875	9000	94.8	1.0	0	0.02	Spherical
MB-MC	7000	6506	57.5	1.0	0	0.01	Spherical
MC-MD	6000	5540	80	1.0	0	0.04	Spherical

Figs. 10 and 11 show the 3D geostatistical models of permeability and porosity, respectively, distributed according to the microfacies. Grainstone facies, mainly located in the upper and middle parts (zones MA-MB and MB-MC), are characterized by high permeability and porosity due to better pore

connectivity, while lagoonal micrite and muddy facies dominate the lower parts (MC-MD), exhibiting lower values. Figs. 9 and 11 display the histograms of permeability and porosity, reflecting the heterogeneity linked to the facies distribution. Grainstone contributes to higher property values, whereas micrite-rich facies correspond to lower ranges. This facies arrangement significantly influences fluid flow, with grainstone acting as the main reservoir facies and mudstone as baffles to flow.

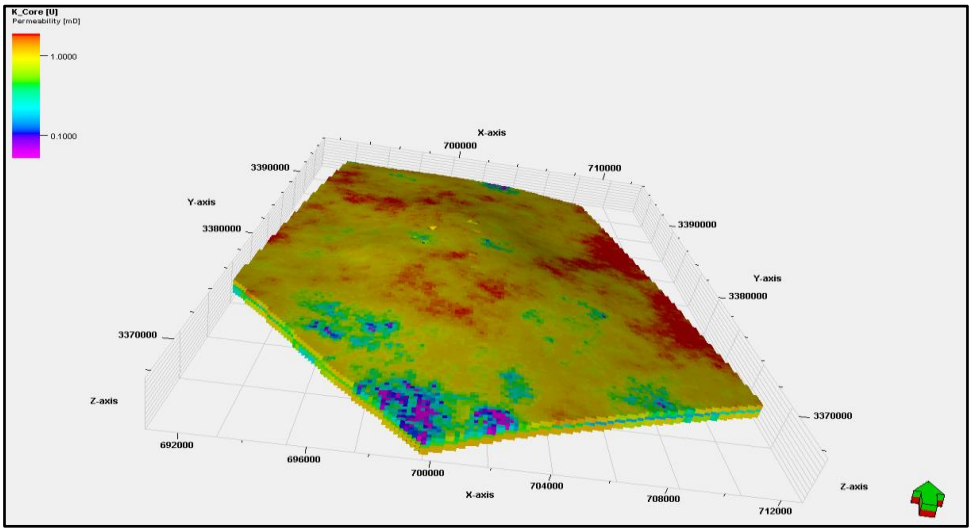


Fig.10. Microfacies distribution of the Mishrif Formation based on 3D geostatistical permeability simulation

According to the 3D permeability model, grain-dominated microfacies are found in the eastern and southeast regions of the field, which are mostly home to high-permeability zones. Conversely, permeability is reduced towards the southwest direction, likely associated with mud-dominated facies. This distribution pattern highlights the facies control over reservoir quality throughout the Mishrif Formation.

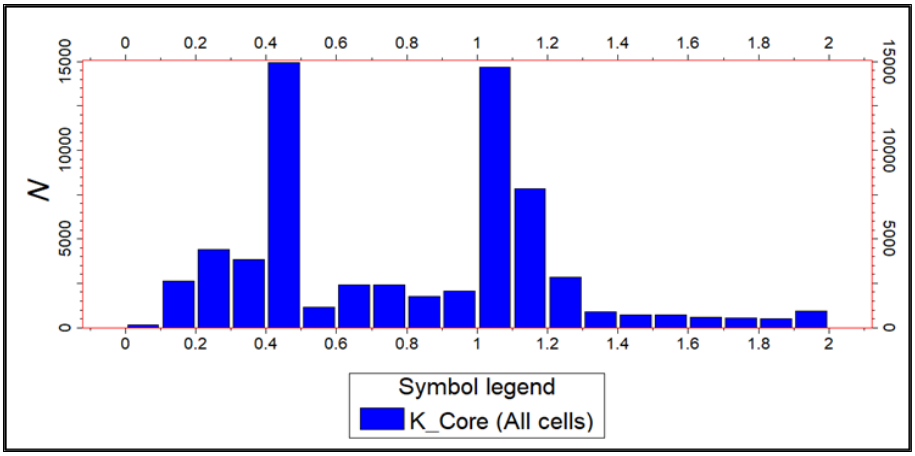


Fig.11. Histogram of the permeability simulation of microfacies distributions of the Mishrif Formation in the Ratawi oilfield

The geostatistical simulation's permeability values are statistically depicted in Fig. 12, which shows a bimodal distribution with two noticeable peaks at 0.45 and 1.0. This distribution illustrates the complexity of the reservoir, with mud-dominated facies found in the field's southwestern and peripheral regions predominantly linked to lower permeability values (~0.45). Grain-dominated facies, on the other hand, are found in the eastern to southeastern regions of the field and are associated with greater

permeability values (~1.0). Furthermore, the prolonged tail towards higher permeability values (up to 2.0) suggests that there are isolated, extremely high permeability zones that may be connected to reefal or channelized deposits. It is essential to comprehend this distribution to improve overall reservoir management, optimize gas injection and waterflooding activities, and create efficient production strategies.

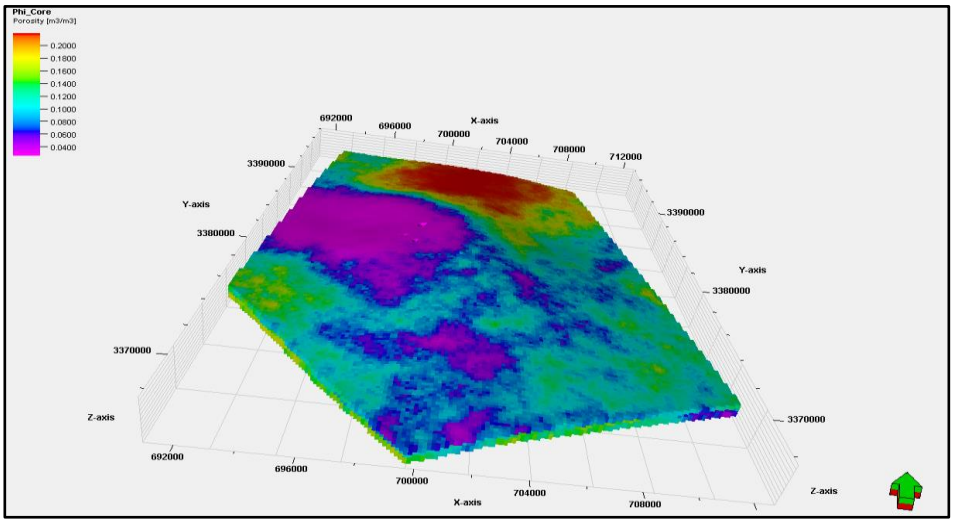


Fig.12. Microfacies distribution of the Mishrif Formation in the Ratawi oilfield based on 3D geostatistical porosity simulation

The three-dimensional porosity distribution throughout the Mishrif Formation, produced by geostatistical simulation, is shown in Fig. 13. The porosity model aids in the evaluation of fluid flow behavior, hydrocarbon storage capacity, and reservoir quality. This simulation increases the accuracy of hydrocarbon volume prediction by introducing microfacies controls, which give a more accurate depiction of reservoir heterogeneity.

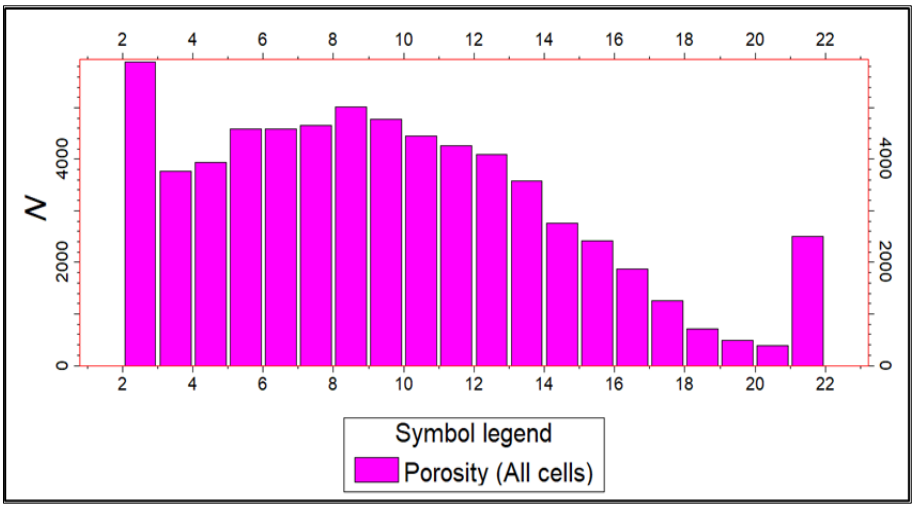


Fig. 13. Porosity simulation histogram based on the distribution of microfacies for the Mishrif Formation in the Ratawi oilfield

The statistical distribution of porosity values derived from the geostatistical simulation is shown in Fig. 11. It assists in identifying variations in reservoir quality, computing the ranges of porosity that are currently in use, and assessing potential sweet spots for hydrocarbon accumulation. Knowledge of

porosity distribution is essential for reservoir characterization, reserve estimation, and production optimization.

5. Conclusions

The geostatistical simulation of the facies and petrophysical properties in the Mishrif Formation provides a comprehensive understanding of the reservoir heterogeneity in the Ratawi oilfield. The eastern and southeastern regions of the field are predominantly occupied by grain-dominated packstone microfacies, which are mostly linked to high-porosity and high-permeability zones. Mud-dominated wackestone and mudstone microfacies, on the other hand, are primarily found in the southern and peripheral regions and have much lower porosity and permeability values. A high degree of agreement was seen between the microfacies distributions and the 3D petrophysical property models in the permeability and porosity histograms.

The usefulness of sequential Gaussian simulation and sequential indicator simulation for accurately simulating the distribution of petrophysical properties and microfacies in the reservoir is confirmed by this consistency. Overall, the complex heterogeneity of the Mishrif Formation is effectively captured by this geostatistical approach, offering insightful information for improving reservoir development plans, especially when it comes to identifying the most productive zones and handling heterogeneity-related difficulties.

Acknowledgments

The authors are grateful to Basrah Oil Company for providing the data that was essential for this study. Their cooperation and assistance were crucial for the successful completion of this study.

References

Al-Ameri, T.A., Al-Khafaji, A.J., John Zumberge, J, 2009. Petroleum system analysis of the Mishrif reservoir in the Ratawi, Zubair, North and South Rumaila oil fields, southern Iraq. GeoArabia, 14 (4), 91–108. https://doi.org/10.2113/geoarabia140491

Al-Dujaili, A.N., Shabani, M., Al-Jawad, M.S., 2023. Lithofacies, deposition, and clinoforms characterization using detailed core data, nuclear magnetic resonance logs, and modular formation dynamics tests for Mishrif Formation intervals in West Qurna/1 Oil Field, Iraq. Society of Petroleum Engineers Reservoir Evaluation & Engineering, 1–13.

Al-Kanaani, N.A., 2018. Petrophysical properties of Euphrates, Bajwan, Jribe, and Dihban formations at Iraqi Gas Reservoir, in the North of Iraq. Journal of Physics: Conference Series, 1818(1), 012117. https://doi.org/10.1088/1742-6596/1818/1/012117

Al-Naqib, K.M., 1967. Geology of the Arabian Peninsula, Southwestern Iraq. U.S. Geological Survey Professional Paper, 560-G, 54. https://doi.org/10.3133/pp560G

Al-Najm, F.M., Handhal, A.M., Al-Kanaani, N.A., 2018. Three-dimensional geological-reservoir model of the Mishrif Formation in the Halfaya Field. Thi-Qar University Journal for Engineering Sciences, 9(2), 40–52.

Al-Siddiki, A.A., 1978. Subsurface geology of southeastern Iraq. 10th Arab Petroleum Congress, Tripoli, Libya, Paper No. 141 (B.2), 47.

An, P., Moon, W.M., Bonham-Carter, G.F., 1994. Uncertainty management in integration of exploration data using the belief function. Nonrenewable Resources, 3(1), 60–71. https://doi.org/10.1007/BF02261716.

Bai, M., Ma, Q., Roegiers, J., 1994. Nonlinear dual-porosity model. Applied Mathematical Modelling, 18(11), 602–610. https://doi.org/10.1016/0307-904X(94)90318-2.

Beydoon, Z.R., 1993. Arabian Plate Hydrocarbon Geology and Potential: A Plate Tectonic Approach. American Association of Petroleum Geologists.

Buday, T., 1980. The Regional Geology of Iraq: Stratigraphy and Paleogeography. Vol. 1. Ministry of Oil and Minerals, State Organization for Minerals, Baghdad, Iraq.

Culshaw, M.G., 2005. From concept towards reality: Developing the attributed 3D geologic model of the shallow subsurface. Quarterly Journal of Engineering Geology and Hydrogeology, 38, 231–284. https://doi.org/10.1144/1470-9236/04-072.

Debski, W., 2010. Probabilistic Inverse Theory. In: Dmowska, R. (ed.), Advances in Geophysics. Elsevier.pp. 1-102.

Deutsch, C.V., Journel, A.G., 1998. GSLIB: Geostatistical Software Library and User's Guide (2nd ed.). Oxford University Press.

Fouad, S.F., 2015. Tectonic Map of Iraq, Scale 1:1000,000. 3rd Edition. Iraqi Bulletin of Geology and Mining, 11 (1), 1-7.

Hatif, M.M., Al-Shahwan, M.F., Al-Yaseri, A.A., 2020. Comparative organic geochemical study of Cretaceous reservoirs of Zubair Oil Field, Southern Iraq. Iraqi Geological Journal, 53(2D), 128–147. https://doi.org/10.46717/igj.53.2D.9MS-2020.10-31

Jassim, S.Z., Goff, J.C., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno.

Mera, J.P., Chiamulera, M.E., Mantelli, M.B., 2017. Permeability model of sintered porous media: Analysis and experiments. Heat and Mass Transfer, 53(11), 3277–3285. https://doi.org/10.1007/s00231-017-2028-1.

Mikes, D., Geel, C. R., 2006. Standard facies models to incorporate all heterogeneity levels in a reservoir model. Marine and Petroleum Geology, 23, 943–959. https://doi.org/10.1016/j.marpetgeo.2005.06.007.

Mohammed, M.J., Mahdi, T.A., 2019. Petrophysical characterizations of Mishrif Formation in selected wells of Tuba Oil Field, Southern Iraq. Iraqi Journal of Science, 60(3), 516–527. Onovughe, E., Sofolabo, A., 2016. Saturation modelling: Using the Maxman-Smits model/equation in saturation determination in dispersed shaly sands. JMEST, 3(6), 4985–4992.

Sharland, P.R., Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., Horbury, A.D., Simmons, M.D., 2001. Arabian Plate Sequence Stratigraphy. GeoArabia Special Publication 2, Gulf PetroLink, Bahrain.

Walker, R.G., 1992. Facies, facies models and modern stratigraphic concepts. Geological Association of Canada.