RESEARCH PAPER

Reservoir rock typing of the Upper Cretaceous Wata Formation using core analysis data, Geisum field in the Gulf of Suez, Egypt

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Abstract

Reservoir rock typing of the Wata Formation is a crucial step in the exploration and development of hydrocarbon reservoirs. This study focuses on understanding porosity-permeability variations to delineate distinct reservoir rock types of the Wata Formation. The Wata Formation exhibits significant lithological variability, including sandstones, siltstones, shales, and carbonate rocks, making it challenging to assess reservoir properties. Several approaches were utilized for rock typing the Wata Formation in the Geisum field, using core data to classify different units based on the core porosity and core permeability relationship. The first approach depends on the flow zone indicator (FZI) and reservoir quality index (RQI); the second one employs the pore throat radius (R35 and/or R36) and the third approach is the discrete rock typing (DRT). The study analyzed data from 184 core samples obtained from two drilled wells in the Geisum field to identify the identical reservoir rock types for the Wata Formation. The relationship between porosity and permeability for each rock type showed a good correlation. Furthermore, the core permeability and predicted permeability from the various rock typing methods exhibited a strong correlation, with correlation coefficients (R^2) of 0.98, 0.84, and 0.97 for flow zone indicator, Winland R35, and DRT, respectively. It was concluded that the DRT method is the simplest and most efficient way to categorize the Wata Formation into different rock types. Notably, there was a very high correlation ($R^2 = 0.97$) between Kr36 and R35, which confirms that Kr36 can be used to distinguish the Wata Formation into different rock types based on pore aperture size. Three pore throat types were recognized, indicating that meso pores are the most prevalent for the Wata Formation in the study area.

Keywords: Geisum field, Gulf of Suez, Permeability prediction, Reservoir characterization, Rock typing, Wata Formation

1. Introduction

The Gulf of Suez in Egypt is one of the most mature basins for oil production. It spans 25 000 square kilometers and is situated between latitudes 27° 36′ N to 30° 06′ N and longitudes 32° 16′ to 34° 06′ E. The Gulf of Suez rift is divided into three dip provinces based on the regional structural setting and dip direction. The northern and southern provinces are characterized by normal faults dipping northeast and strata dipping southwest, while the central province has normal faults dipping southwest and strata dipping northeast.[1,2] More than 80 oil fields have been discovered in this basin and are producing from different reservoirs ranging in age from the Precambrian to Miocene.[3]

The Geisum field is an offshore oil field located in the southern part of the Gulf of Suez, approximately 40 km north of Hurghada, between latitudes 27° 45′ and 27° 34′ N, and longitudes 33° 42′ and 33° 00′ E (Fig. 1). The field was discovered by Mobil Exploration in 1981.[3]

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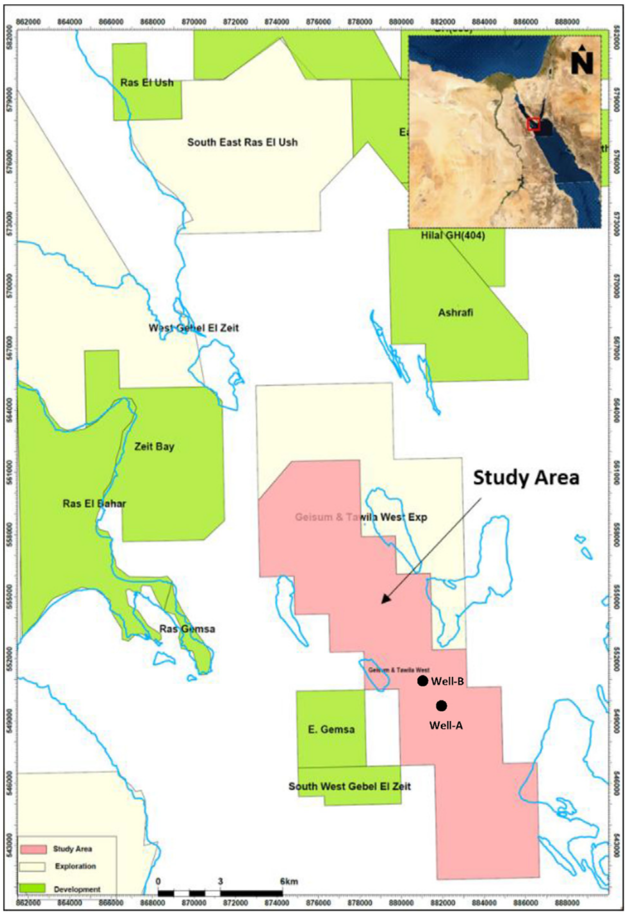

Fig. 1. The study area location map shows the distribution of the two studied wells.

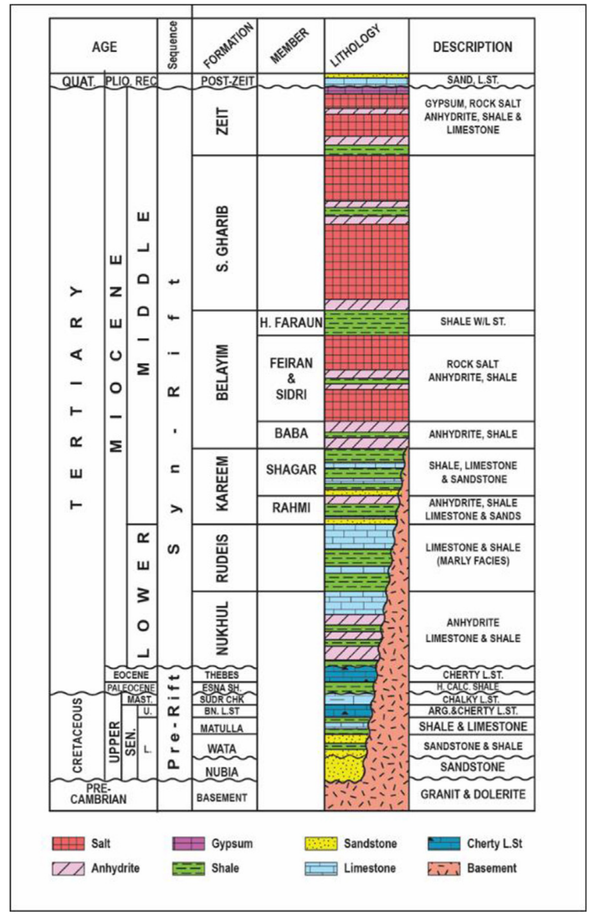

Fig. 2. The study area stratigraphic column, modified after EGPC, 1996.[3]

2. Geological setting

The oldest sedimentary units recorded in the Geisum field are the Lower Cretaceous (Nubia Facies), which is unconformably overlayed by fractured granitic basement and unconformably underlain by the Wata Formation. The Createaceous sandstone (Wata-Nubia) is a prolific producer of hydrocarbons in the Geisum field. The simplified stratigraphic section of the study area is depicted below (Fig. 2).[3]

The Geisum field falls within the structural province of the southern Gulf of Suez, with the main dip towards the southwest. The Geisum structure is a tilted fault block to the southwest, plunging gently northward and southward. The structures are dissected by numerous synthetic faults striking N-NE with a strike-slip component.[3]

3. Background

Several authors, such as[4,5] have focused on examining the Wata Formation in the Gulf of Suez regarding the distribution of microfacies, depositional framework, and petrophysical characteristics, as it is seen as a potentially productive reservoir rock in the region, showing lithological complexity in certain locations. The Wata Formation in the Geisum field is marked by a predominantly sandstone composition, interbedded with siltstone and laminated shale. The sandstones are predominantly quartzoses, with fine to very fine grain sizes, occasionally medium to coarse, and contain carbonaceous, micaceous, glauconitic, pyritic, and calcareous material (core report for the studied wells). The total sand thickness up to 200 feet on the flank and decreases up dip due to erosion. The average shale volume reaches to 30%, the porosity is around 17%, the average permeability is up to 500 mD and the average water saturation is 25% (according to the petrophysical evaluation and core data for the Wata Formation in Geisum field).

3.1. Rock typing approach

Reservoir rock typing is to categorize the reservoir properties according to their geological facies;

hence every rock type has similar geological and reservoir characteristics.[6] Rock type is a unit of rock that has a distinct set of diagenetic processes and depositional conditions, resulting in a distinct porosity-permeability relationship. Due to the estimation or prediction of permeability being one of the most challenging aspects for all reservoirs, several authors, including,[7–11] have studied the core porosity and permeability relationship in comparison to the conventional logs and have attempted to distinguish reservoirs into different facies. Several approaches have been employed for reservoir discrimination and prediction of the different flow units within a reservoir. Flow unit is the process of characterizing the reservoir into distinct units based on similar pore throat size distributions and comparable flow behavior, and it is the end result of diagenetic processes influence.[12,13]

The main objective of this study is to distinguish the Wata Formation into various rock types by applying different methods for rock typing based on the available core data.

4. Methodology

Several approaches for classifying the Wata Formation in the Geisum field have been chosen to investigate the reservoir properties by assessing the permeability and porosity relationships.

(a) Flow Zone Indicator (FZI) Method.
(b) Pore throat size R35 and R36 Methods.
(c) Discrete Rock Typing Method.

Routine core data is obtained from two wells, including four full-diameter cores of well-A in the Wata Formation with approximately 146 core samples of depth interval 4643–5109 feet, and one conventional core for well-B with 38 samples of depth interval 4788–5870 feet from the same formation resulting in a total of 184 core sample. The core data includes quantitative assessments of grain density, core permeability, and core porosity. These data are employed to identify the various rock types based on their porosity-permeability relationships. Porosity and permeability play a crucial role in determining fluid storage and flow characteristics in rocks and they have a significant impact on the reservoir performance. Therefore, these two factors are commonly referred to as 'reservoir quality'.[14]

The first indication that the reservoir has multiple rock types is the porosity-permeability relationship, which reveals a broad range of permeability values at a single porosity level. According to the core samples of the studied wells, the correlation coefficient (R^2) for the porosity-permeability relationship is 0.71, as shown in (Fig. 3), indicating several rock types within the Wata Formation.

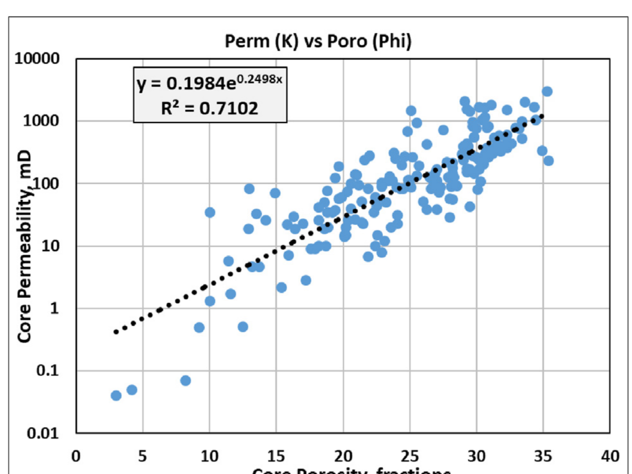

Fig. 3. Porosity-permeability relationships for the studied wells.

5. Results

5.1. Flow zone indicator (FZI) method

This rock typing method was developed by[15] as a useful tool for categorizing core data into hydraulic flow units and describing the permeability and reservoir properties. This method is widely applicable for reservoir discrimination and predicting permeability for intervals and wells that are not cored. The equation is applicable when permeability is in millidarcy and porosity is in fraction form.

$$\mathrm{FZI} = \mathrm{RQI}/\Phi z = \frac{0.0314\sqrt{\mathrm{K}/\Phi}}{\Phi/\left(1-\ \Phi\right)} \quad (1)$$

Where:

RQI (Reservoir Quality Index), µm.
Φz (Normalized Porosity Index), fractional.
K (Core Permeability), millidarcy.
Φ (Core Porosity), fractional.

Using equation (1), the (RQI) and (Φz) were calculated for each core plug sample. Plotting these parameters on a log-log scale helps to identify the reservoir flow units. Points on the same line indicate similar pore throats, while similar values of FZI will lie on a line, reflecting similar flow units (pore throats), as shown in (Fig. 4a). Eight distinct rock types have been classified within the Wata Formation (RRT1 to RRT8) as depicted in (Fig. 4b).

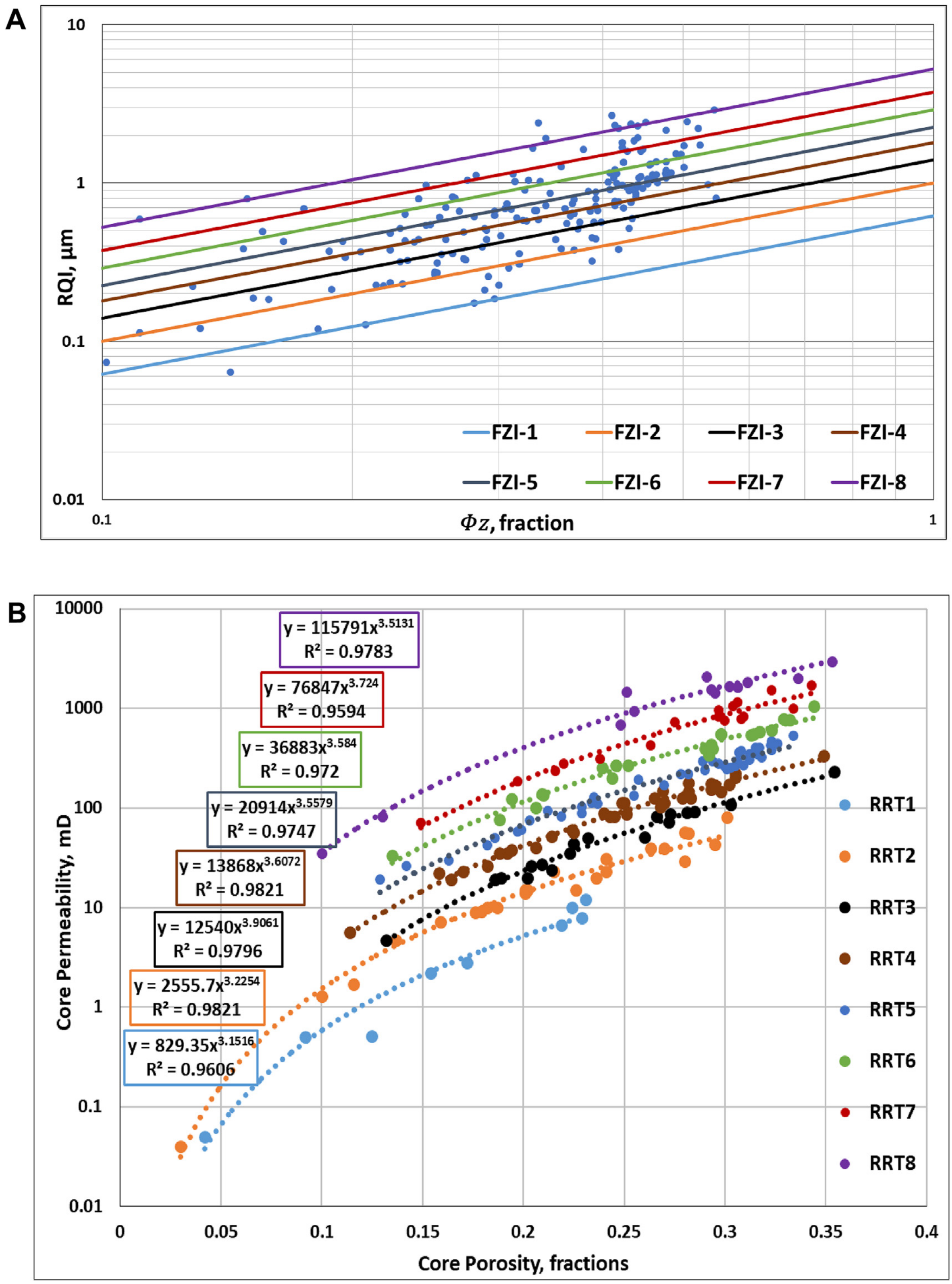

Fig. 4. A. RQI- Φz plot and flow zone indicator for Wata Formation. B. Porosity-permeability plot and flow zone indicator for Wata Formation.

Furthermore, a more accurate porosity-permeability relationship was generated for each group, resulting in correlation coefficients (R^2) up to 0.98, allowing for good estimation and prediction of permeability in un-core intervals.

5.2. Winland method (R35)

Winland developed a method for reservoir discrimination into different units based on the pore throat radius. The strongest correlation occurs when the pore throat size matches the 35% cumulative mercury saturation curve, known as R35. The R35 is determined using Equation (2), as presented by.[16]

$$\text{Log}\,(R35) = 0.732 + 0.588\log(K) - 0.864\log(\Phi) \quad (2)$$

Where:

R35 (pore throat radius when the mercury saturation is 35%), µm.

K (core permeability, millidarcy), Φ (core porosity, %)

To achieve the Winland model, all available core samples for the Wata Formation were used by plotting core permeability versus core porosity with Winland lines, then adjusting the pore throat radius until matching the plotted data and determining the ranges for every curve for every Winland line that represents a rock type or flow unit (Fig. 5a).

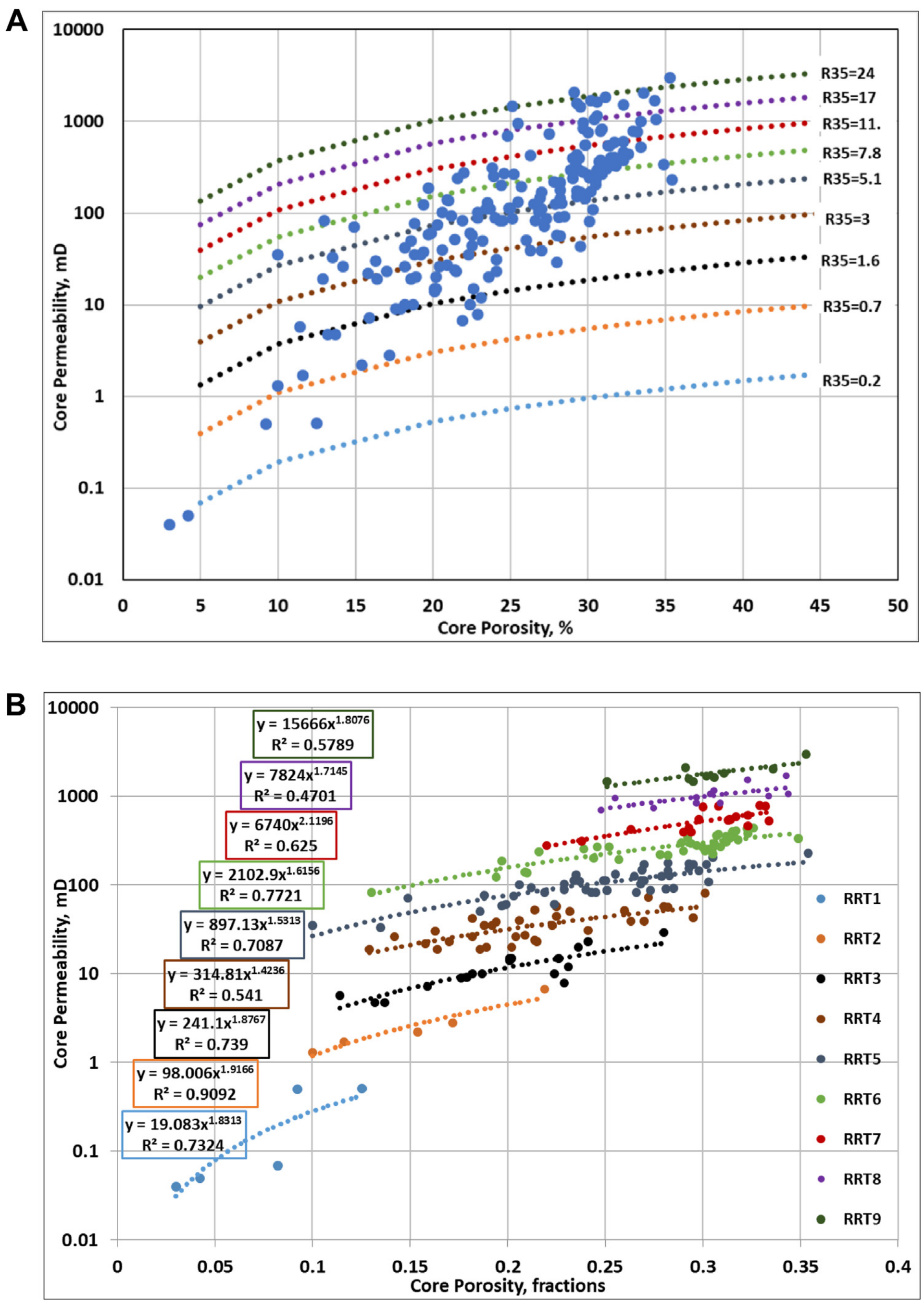

Fig. 5. A. Winland R35 pore throat size plot for Wata Formation. B. Porosity-Permeability plot and Winland R35 for Wata Formation.

According to the calculated pore throat radius, different rock types were recognized, and for every rock type the relation between porosity and permeability through Winland correlation was identified (Fig. 5b).

Based on the Winland R35 equation, the Wata Formation in the Geisum field was differentiated into nine different rock types. Each of these types exhibited similar pore throat size and a good correlation between porosity and permeability, with a correlation coefficient (R^2) of up to 0.90.

The R35 pore throat size was classified by[11] into five groups to describe the poor type. Mega port: R35 is above 100 μm. Macro port: R35 ranges from 10 to 100 μm. Meso port: R35 falls between 1 and 10 μm. Micro port: R35 ranges from 0.01 to 1 μm. Nano port: R35 is below 0.01 μm.

5.3. R36 method

A new approach (r36) was defined by[17] to differentiate the reservoir into different flow units and distinguish between nonproductive and productive wells based on the pore throat size. The pore aperture size which is below 0.5 μm is considered non-productive, while those greater than 0.5 μm or 5000 A° are productive. From the mercury injection test, one can determine the pore throat size corresponding to displacement pressure. The average peak points on log-log plots of mercury injection occur at a mercury saturation of 36%[18–20] while conducting the experiment on several core samples representing different reservoirs.

The r36 was determined using two different methods, one based on porosity data only (Ør36) and the other based on permeability data only (Kr36), and two reliable equations (Eqs. (3) and (4))[17] were proposed. One of the objectives of this work is to compare the r35 and r36 values across all the available core samples for the Wata Formation in the studied wells.

$$Ør36 = 466.82\ \exp.0.193Ø \quad (3)$$

$$Kr36 = 2277.5\ K\hat{}0.542 \quad (4)$$

Ør36 and Kr36 are in A° (Angstrom)

Ø (core porosity, %), K (core permeability, mD)

5.4. Winland (R35) vs. R36

The Equations (3) and (4) were used to calculate Ør36 and Kr36, and the relationship between R35 and r36 for porosity and permeability was obtained (Fig. 6a and b). The analysis revealed that the correlation between Ør36 and Winland R35 was not consistent enough ($R^2 = 0.56$), while an excellent correlation was found between Kr36 and Winland R35 ($R^2 = 0.97$). The Kr36 could be used as an alternative to the R35 to distinguish between productive and non-productive wells based on the pore aperture. It is necessary to note that Kr36 depends only on permeability, but R35 considers both porosity and permeability, so Kr36 may reduce the uncertainty related to human error by using only one measured variable.

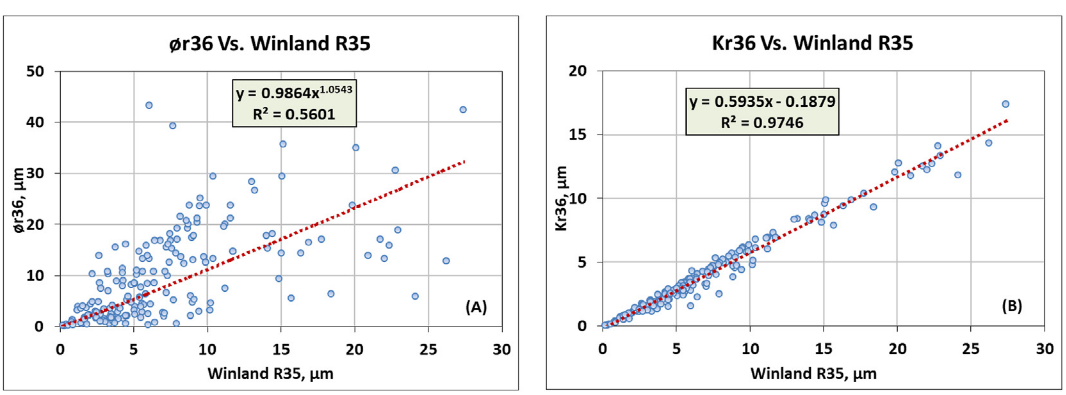

Fig. 6. R36 vs. R35, (A) Ør36 and (B) Kr36.

5.5. Discrete rock typing method (DRT)

The discrete rock typing (DRT) method classifies the reservoir into different hydraulic units by analyzing the porosity-permeability relationship. To achieve this method, the FZI values were calculated, and then these values were transformed into discrete values using equation (5).[21]

$$DRT = Round\,(2*\ln(FZI) + 10.6) \quad (5)$$

Based on this method, all FZI data have been converted to five discrete values. All core data points which have similar DRT values will be clustered together since the same DRT values represent similar reservoir properties. According to the DRT method, five rock types or hydraulic units have been identified within the Wata Formation (Fig. 7).

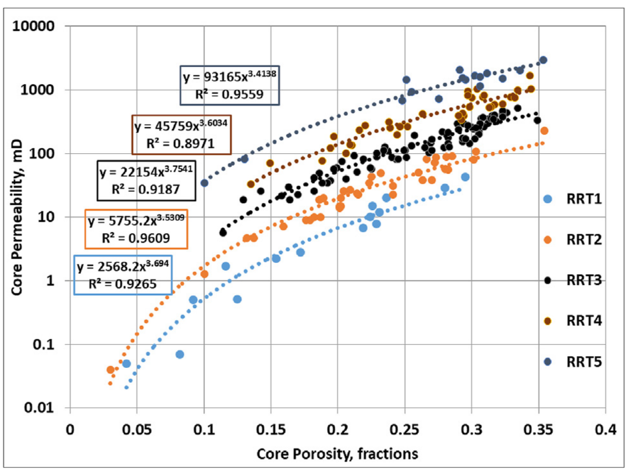

Fig. 7. Porosity-permeability plot and discrete rock typing method for Wata Formation.

6. Discussion

The main objective of this study was to assess the petrophysical behavior of core samples from the Wata Formation by utilizing various rock typing techniques, including flow zone indicator, Winland R35, El Sayed (R36), and discrete rock typing. Eight different rock types (RRT1-RRT8) were identified by using FZI and it was observed that RRT5 is the dominant one (Table 1). Using the Winland R35 rock typing method, the Wata Formation was differentiated into nine rock types or flow units, and three pore throat types were recognized (Table 2).

The Kr36 and R35 were plotted vertically along the Wata Formation for the two studied wells (Fig. 8a and b). These plots displayed a series of hydraulic flow units (FU) that corresponded to different pore aperture sizes, indicating that meso pores are the most prevalent for the Wata Formation in the study area.

Using the DRT method, the Wata Formation was categorized into only five different rock types.

Cross-plots for porosity (Ø) vs. permeability (K) based on each RRT's estimated by the FZI, Winland R35, and DRT methods revealed that (Ø) vs. (K) show a very high correlation coefficient (R^2) for all rock types identified by using the FZI, where R^2 ranges from 0.95 to 0.98. Similarly, for the DRT method, R^2 shows good correlation and ranges from 0.89 to 0.96. However, for the Winland R35 method, the correlation coefficient was the minimum among these methods, with R^2 ranging from 0.47 to 0.9. Table 3 summarizes the results of the three methods.

Table 1. A summary of the identified rock types for the Wata Formation based on FZI method.

Rock type	Porosity (%)	Permeability (mD)	Normalized porosity	RQI	FZI	Samples no.
RRT1	4.2–23.1	0.05–12	0.04–0.3	0.034–0.22	0.44–0.78	9
RRT2	3–30.1	0.04–81	0.03–0.43	0.036–0.51	0.82–1.19	24
RRT3	13.2–35.4	4.7–230	0.15–0.54	0.18–0.80	1.22–1.53	18
RRT4	11.4–34.9	5.7–336	0.13–0.53	0.22–0.97	1.63–2.01	36
RRT5	12.9–33.4	19–527	0.14–0.50	0.38–1.24	2.06–2.57	44
RRT6	13.5–34.3	33–1050	0.15–0.52	0.49–1.73	2.6–3.30	23
RRT7	14.9–34.3	71–1690	0.17–0.52	0.68–2.20	3.41–4.49	17
RRT8	10–35.3	35–2980	0.11–0.54	0.58–2.88	4.81–7.13	13

Table 2. A summary of the identified rock types for the Wata Formation based on Winland R35 method.

Rock type	Porosity (%)	Permeability (mD)	R35 (μm)	Samples no.	Pore type
RRT1	3–12.5	0.04–0.51	0.18–0.52	5	Micro port
RRT2	10–21.9	1.3–6.7	0.80–1.14	5	Micro port
RRT3	11.4–28	4.7–29	1.21–2.19	18	Meso port
RRT4	12.9–30.1	19–81	2.33–3.96	33	Meso port
RRT5	10–35.4	33–230	4.08–6.42	46	Meso port
RRT6	13–34.9	83–439	6.80–9.51	38	Meso port
RRT7	22–33.4	277–779	9.74–14.09	18	Macro port
RRT8	24.8–34.4	689–1690	14.42–20.11	12	Macro port
RRT9	25.1–35.3	1448–2980	20.92–27.38	9	Macro port

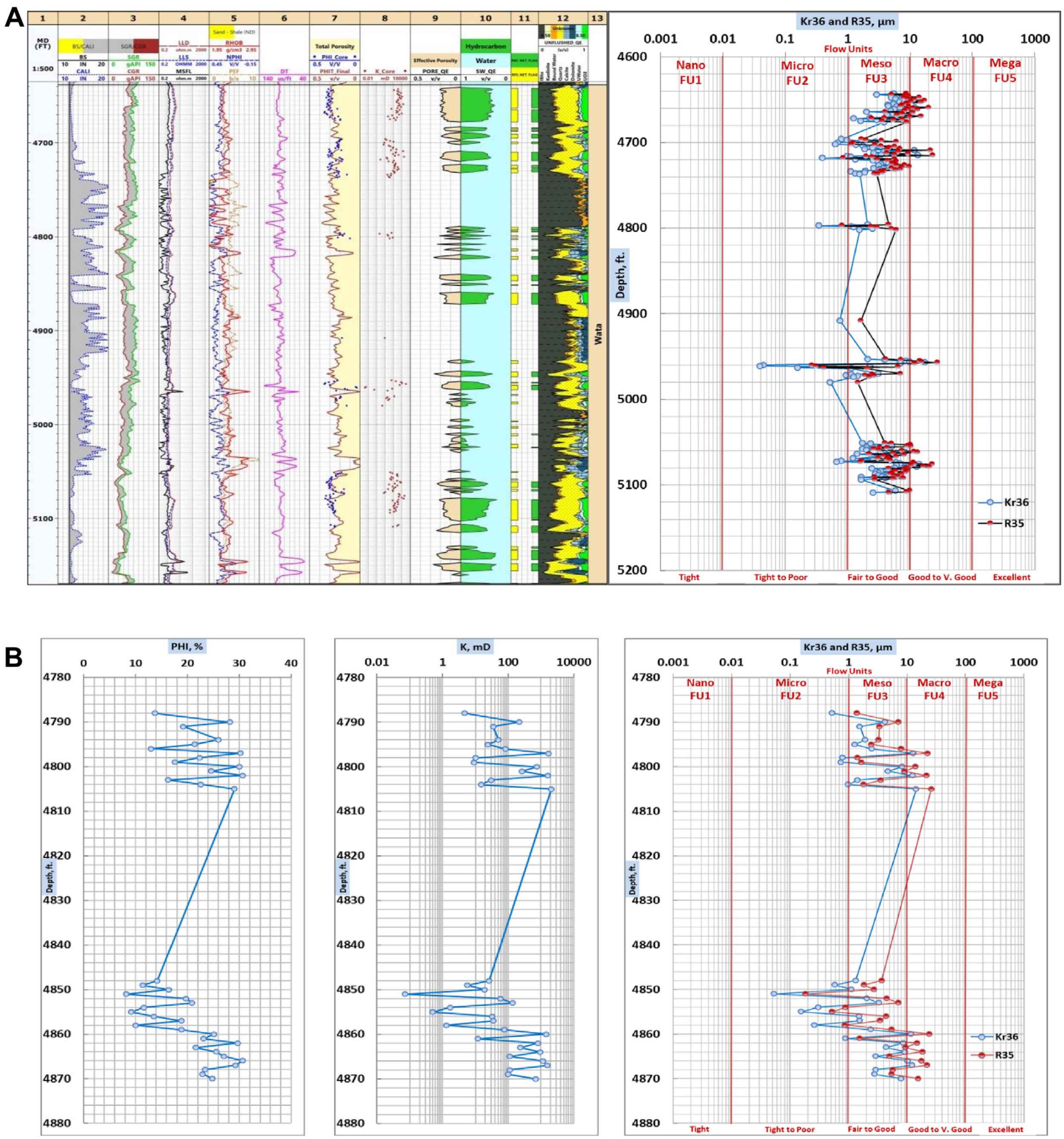

Fig. 8. A. Petrophysical Analysis and Kr36 with R35 along Wata Formation for Well-A. B. Vertical profile of Porosity (PHI), Permeability (K) and Kr36 with R35 along Wata Formation for Well-B.

Table 3. Outlines the findings of the three different rock typing method of the Wata Formation.

Rock type	FZI		Winland R35		DRT	
	Φ-K relation	R^2	Φ-K relation	R^2	Φ-K relation	R^2
RRT1	$y = 829.35x^{3.1516}$	0.96	$y = 19.083x^{1.8313}$	0.73	$y = 2568.2x^{3.694}$	0.92
RRT2	$y = 2555.7x^{3.2254}$	0.98	$y = 98.006x^{1.9166}$	0.9	$y = 5755.2x^{3.5309}$	0.96
RRT3	$y = 12540x^{3.9061}$	0.97	$y = 241.1x^{1.8767}$	0.73	$y = 22154x^{3.7541}$	0.91
RRT4	$y = 13868x^{3.6072}$	0.98	$y = 314.81x^{1.4236}$	0.54	$y = 45759x^{3.6034}$	0.89
RRT5	$y = 20914x^{3.5579}$	0.97	$y = 897.13x^{1.5313}$	0.7	$y = 93165x^{3.4138}$	0.95
RRT6	$y = 36883x^{3.584}$	0.97	$y = 2102.9x^{1.6156}$	0.77		
RRT7	$y = 76847x^{3.724}$	0.95	$y = 6740x^{2.1196}$	0.62		
RRT8	$y = 115791x^{3.5131}$	0.97	$y = 7824x^{1.7145}$	0.47		
RRT9			$y = 15666x^{1.8076}$	0.57		

x, Φ (Porosity, fractional); y, K (Permeability, mD).

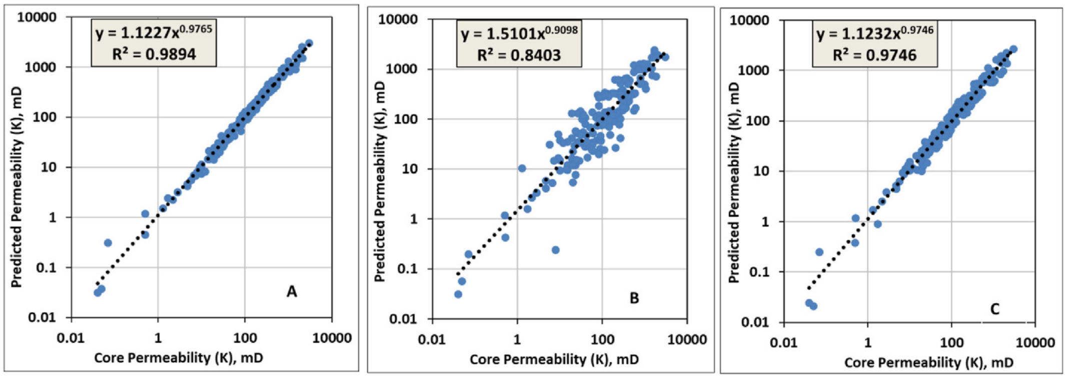

Fig. 9. Core Permeability versus Predicted Permeability using, flow zone indicator (A), Winland R35 (B) and discrete rock typing (C).

Finally, comparing the predicted permeability using all the proposed equations for the FZI, Winland R35 and DRT methods against the actual core permeability, a strong correlation between the two was obtained. The R^2 between the predicted and actual core permeability was found to be 0.98, 0.97 and 0.84 for FZI, DRT and Winland, respectively (Fig. 9).

6.1. Conclusions

The Wata Formation in the Geisum field is a significant pre-Miocene reservoir, so it was essential to study this reservoir petrophysically through the available core samples to distinguish the Wata Formation into various rock types based on their porosity-permeability relationship.

Various rock typing methods were applied, including FZI, Winland R35, R36, and DRT. An accurate porosity-permeability relationship was proposed for each rock type, with the highest correlation coefficient ($R^2 = 0.98$) achieved using the FZI. When utilizing Winland R35, it was observed that the R^2 ranged from 0.47 to 0.90, although nine distinct rock types were identified.

Additionally, the correlation between core permeability and predicted permeability reached its highest ($R^2 = 0.98$) when applying the FZI method and 0.84 with Winland R35 and 0.97 with DRT method, which concluded that the DRT method is the most straightforward and effective approach to classify the Wata Formation into distinct rock types, with a correlation factor R^2 of 97% between measured and predicted permeability and only five rock types were identified. Furthermore, the new approach R36 showed a very good correlation between Kr36 and R35. Therefore, it is valuable to use Kr36 in distinguishing reservoirs into different flow units according to the pore aperture size.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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