JJEES

JJEES (2025) 16 (3): 284-288
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Evaluation of Petrophysical Properties and Oil Content of Hartha Formation in Qayyarah Oil Field, Northern Iraq

Bashar A. Al-Juraisy [1*] and Maan H. Abdullah Al-Majid [2]

[1] *Department of Geology - College of Science, University of Mosul, Mosul-Iraq*
[2] *Department of Petroleum Reservoir Engineering- College of Petroleum and Mining Engineering, University of Mosul, Mosul-Iraq*

Received on February 13, 2025, Accepted on March 3, 2025

Abstract

Among the many oil fields in Iraq, the Qayyarah oil field is considered one of the most important fields in producing heavy oil. Oil is produced in this field from more than one formation, and the Hartha Formation is considered one of the important formations produced in this field, as well as in many producing fields in Iraq because of its good reservoir properties.

In the current study, data from three wells (A-1, A-2, and A-3) were used and analyzed to identify some petrophysical properties and oil content of the rocks of the Hartha Formation.

Analysis and interpretation were made using the Didger program to convert analoque data into digital data and the IP3.5 program to analyze and interpret digital data.

The study results showed that the rocks of the Hartha Formation have relatively good porosity. Also, with regard to the oil content, most parts of the formation contain a relatively good percentage of oil, and the formation can also be divided based on the oil content into three regions (A, B, and C). The first zone (A) contains the largest percentages of oil saturation, while the third zone (C) does not contain oil.

Keywords: *Petrophysical, Properties; Oil, Content, Hartha, Qayyarah*

1. Introduction

Qayyarah oil field can be considered one of the important oil fields in northern Iraq. Its dimensions are about 16 kilometers long and 5-kilometer wide, and structurally, it is an asymmetrical anticline. According to some publications, its field's oil reserves are estimated is about 800 million barrels of crude oil (API gravity 15°). One of most important reservoir formations in this oil field is Hartha Formation (Upper Campanian-Lower Maastrichtian) which consists mainly of limestone (detrital & glauconitic), and it's dolomitized in some places with layers of shale and chalk (Jassim and Goff, 2006).

The importance of the Hartha formation lies in the fact that it is one of the reservoirs and produces oil in many oil fields in Iraq; therefore has aroused the interest of many researchers like (Homadi and Al-Zaidy, 2020; Al-Badrani et al.,2021; Al-Hadidy et al., 2022; Abed and Al-Jaberi, 2023; Albarzanji and Alhamdani, 2024).

Geophysical well logs are one of the most widely used scientific tools in subsurface investigation, especially in the mining and oil industry. It is usually used the open (non-cased) wells for determination of the petrophysical and reservoir properties (Serra,1988; Al-Juraisy, and Al-Majid, 2021; Al-Majid, 2021; Abuseda and Sayed, 2022; Al-Mawla et al., 2023; Umoren et al., 2023) in addition to determining the formation lithology and shale distribution.

The aim of the current study is to evaluate some petrophysical characteristics, the most important one being the oil content in the Hartha Formation. Through this, the quantities of oil reserves and the economic feasibility of extraction can be estimated.

2. Site Description:

The study area (Qayyarah oil field) is situated on the western side of the Tigris River, approximately 55 km southwest of Mosul city. It is located within a low folded zone according to the tectonic division of Iraq (Dunnington, 2005). One of the region's most important general features is the presence of linear structures in a northwest-southeast direction, such as the Najma, Jewan, and Qayyarah anticline (Figure 1).

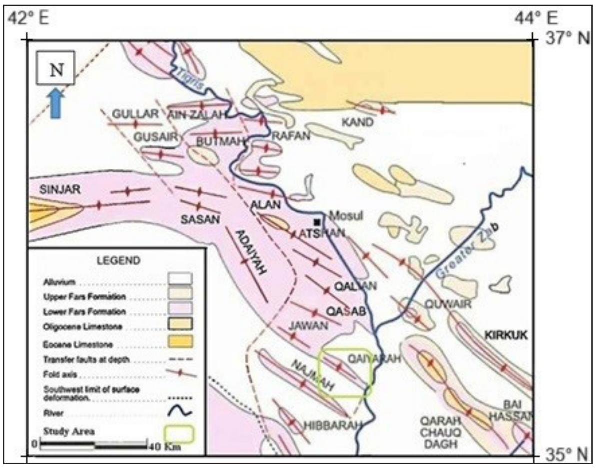

Figure 1. Geological map of the study area (modified from Aqrawi et al., 2010)

* Corresponding author e-mail: basharaziz@uomosul.edu.iq

The varying thickness of Hartha Formation in the Qayyarah field was attributed by some researchers to ground movements in the Late Cretaceous, which affected the study area, represented by many complex faults and narrow grabens (Ditmar et al., 1971; Murrise, 1980).

Petrographically Hartha Formation in the study area consists of organic, clastic, and dolomitized limestone. It is affected by several types of diagenetic processes, the most important of which are dolomitization, compaction, cementation, silicification, and neomorphism. Several porosity types, including interparticle, vuggy, moldic, fractures, and channel, have been found in the formation rocks, as shown in the figure (Younis et al., 2015).

According to wells information in the study area, the thickness of the formation varies between 61-187 m. This variation in thickness may be due to various depositional basin shapes (Jassim and Buday 2006). Figure 2 shows the petrographic section of the Hartha Formation in one of the study wells (A-1).

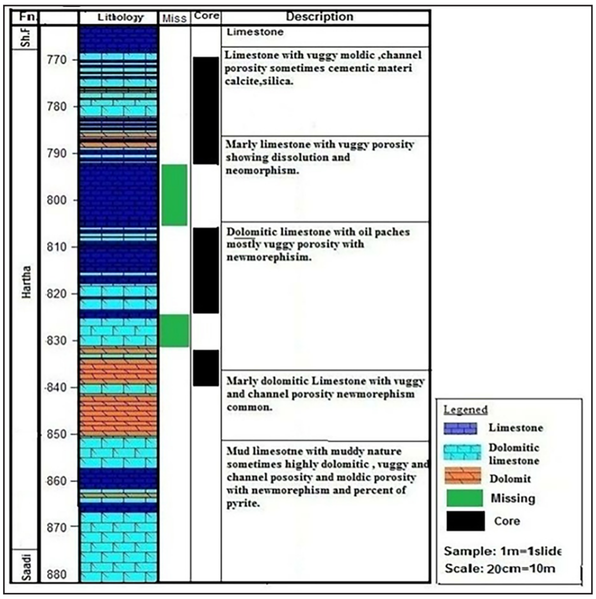

Figure 2. Petrographic section of well A-1 (Younis et al., 2015)

3. Materials and methods

This study used analogue data for three wells from the Qayyarah oil field (A-1, A-2, and A-3) after converting them to the digital format using the Didger software and IP3.5 software to analyze and represent the data. These data were are: Caliper (Cal.), Gamma-ray (GR), Density (RHOB), Neutron (NPHI), Sonic (DT), and three types of Resistivity logs (LLD, LLS, and MSFL).

The work can be summarized in five main stages:

Evaluate the shale percentage using the non-linear gamma ray Larionov equations for tertiary age (Eq.1)

$$Vsh = 0.083 * \left[2^{(3.7\times IGR)} - 1\right] \tag{1}$$

Where: IGR represent gamma ray coefficient = $\frac{\text{GRlog}-\text{GRmin}}{\text{GRmax}-\text{GRmin}}$

GRlog, GRmax, and Grmin represent gamma log value, maximum, and minimum reading of gamma log respectively

Determine the formation's lithology and mineralogy using NPHI/Density and N/M cross-plots, whereas:

$$\text{N} = \frac{(\text{NPHIf} - \text{NPHIlog})}{(\rho\text{b} - \rho\text{f})} \tag{2}$$

$$\text{M} = \frac{(\Delta\text{tf}-\Delta\text{tlog})}{(\rho\text{b} - \rho\text{f})} * 0.01 \tag{3}$$

NPHIf: Neutron porosity for drilling fluid =1; NPHIlog Neutron porosity reading; ρb: Density log reading; ρf: Density of the drilling fluid (1 g/cm3 of fresh water); Δtf: The time difference of the sound wave traveling through the drilling fluid =189 m.sec./ft for fresh clay (it's used) ; Δtlog: Sonic log reading.

Evaluate Total porosity (PHIT) and Effective porosity (PHIE) (which represents the most important porosity in oil extraction) from Neutron, Density, and Sonic log according to the following equations:

$$\text{PHIT} = \frac{\text{PHIN} + \text{PHID}}{2} \tag{4}$$

$$\text{PHIE} = \text{PHIT} * (1 - \text{Vsh}) \tag{5}$$

Finally, evaluate the total oil saturation (So) and water saturation (Sw) in Hartha Formation rocks whereas:

$$Sw = \left(\frac{aRw}{Rt * PHI^m}\right)^{1/n} \tag{6}$$

$$Sw = \left(\frac{Ro}{Rt}\right)^{1/n} \tag{7}$$

$$So = 1 - Sw \tag{8}$$

4. Results

4.1 Shale percentage evaluation

By calculating the percentage of shale, we can notice that the formation in the study area contains a relatively small percentage of shale, with a close average percentage in the three wells, as shown in Table 1.

Table 1. Shale ratios in the three studied wells

Well	Shale percentage (%.)		
	Minimum	Maximum	Average
A-1	1.2	97.8*	14.3
A-2	0.2	38.5	15.2
A-3	1.1	31.1	13

**In very limited places*

4.2 Lithology and Mineralogy Determination

According to the results of the neutron porosity/Density cross-plots (Figure 3), it is clear that the lithology of the Hartha Formation in the area consists mainly of limestone with a percentage of dolomitic limestone. The percentage of dolomitic limestone increases at well A-1, where a percentage of points are located below the limestone line towards the dolomite (Figure 3a).

On the other hand, to estimate the mineralogy of formation rocks, M-N plots (Boddy and Smith, 2009) were used,

M-N plots (Figure 4) showed that the main component of the formation rocks in the area is calcite (the main component of limestone rocks) and that some points trend towards the dolomite mineral. These points increase in number at well A-1, which supports the results of the previous cross-plots (Figure 4a).

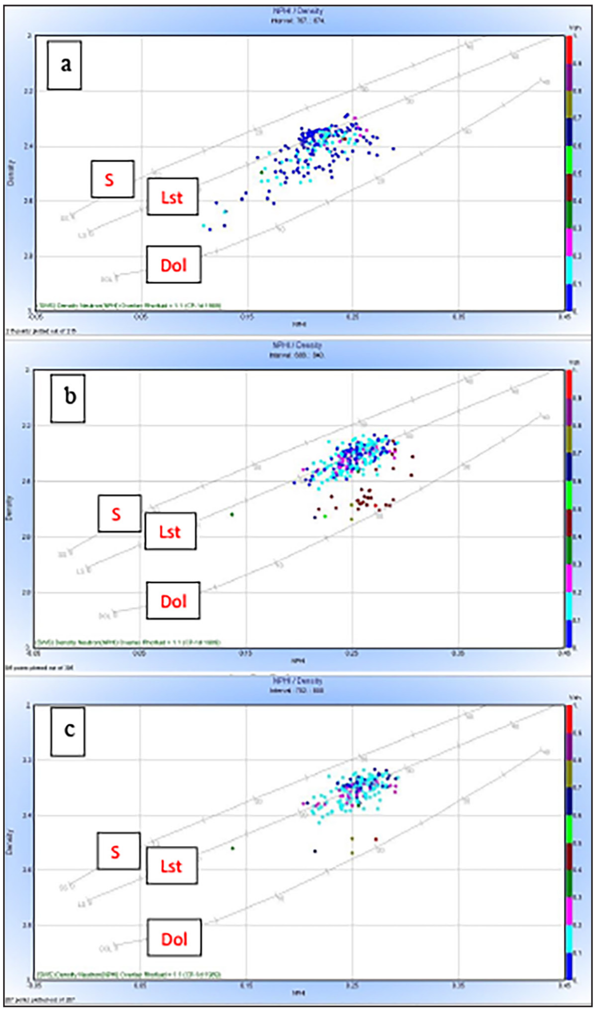

Figure 3. porosity/Density cross-plots for studied wells a: A-1, b: A-2, c: A-3

4.3 Evaluation of porosity types

Two main types of porosity were estimated from porosity logs data (Neutron" PHIN", Density" PHID, and Sonic" PHIS") after making corrections to the shale percentage (PHINc, PHIDc, and PHISc). These two main types are 1-Total porosity (PHIT) and 2-Effective porosity" PHIE") as shown in the figures 4, 5, and 6. From these figures, it can be seen that a large match between the total and effective porosity in most parts of the formation and for the three wells is due to the relatively low percentage of shale in the formation rocks. It is also some porosity details shown in the Table 2:

Table 2. The total and effective porosity values for the three wells.

Well	Depth of Hartha Formation (m.)	Porosity (%)					
		Total			Effective		
		Min.	Max.	Average	Min.	Max.	Average
A-1	767-874	8.2	24.1	19.3	0.1*	23.2	17.8
A-2	688-840	6.7*	24	19.6	7.2*	22.5	17.2
A-3	704-790	12.2	27.3	24.2	5.6*	25.4	21.3

**In very limited places*

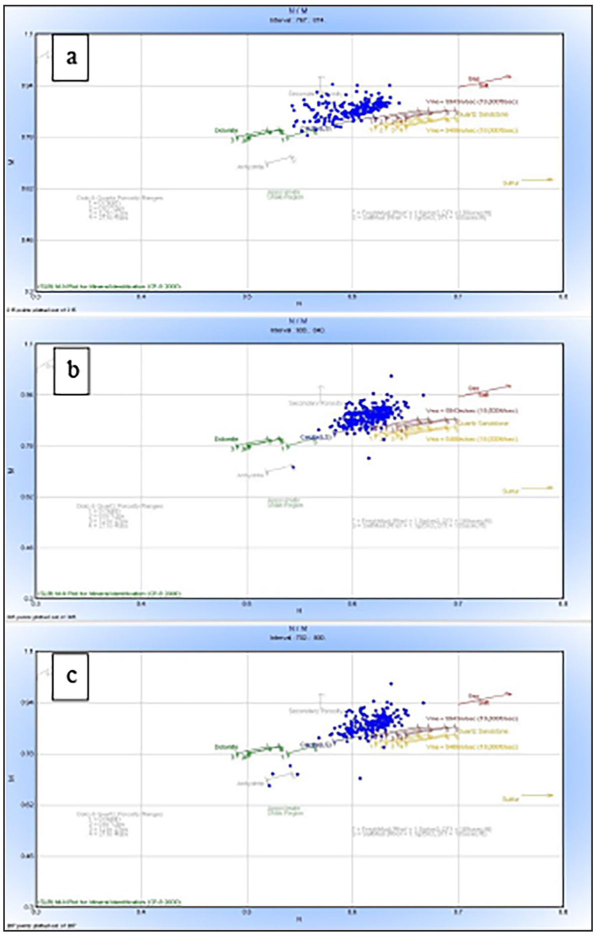

Figure 4. N/M cross-plots for studied wells a: A-1, b: A-2, c: A-3

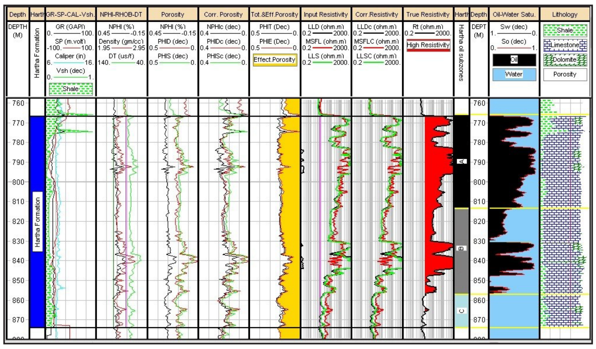

Figure 5. Interpretation results of A-1 well log data

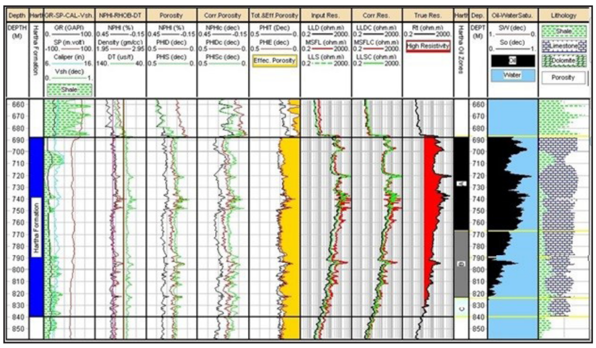

Figure 6. Interpretation results of A-2 well log data

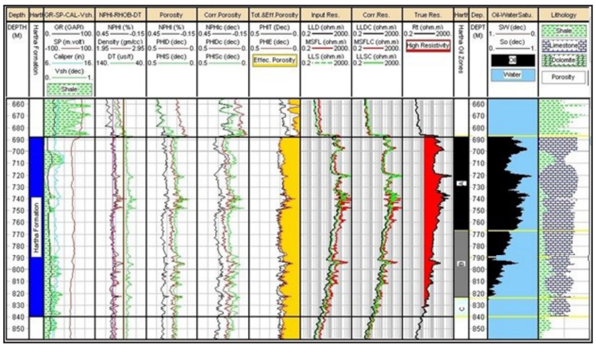

Figure 7. Interpretation results of A-3 well log data

From Figures 5 and 6, we can notice that the Hartha Formation can be divided into three zones in each well based on the oil saturation: The first(A) contains a high percentage of saturation, the second(B) contains a lower percentage of oil saturation. At the same time, the third zone(C) is almost devoid of oil content and contains only water. Table 3 shows some characteristics of the three zones along with the percentage of oil saturation for the three zones in the study wells.

Table 3. Average porosity and oil saturation of wells zones

Well	Depth of Hartha Formation (m.)	Zone	Depth of zone (m.)	Average value 0f porosity (%)		Average oil saturation from the total solution (%)
				Total porosity	Effective porosity	
A-1	767-874	A	767-812.5	20.3	18.5	69.3
		B	812.5-856.5	17.9	16.8	35.9
		C	856.5-874	18.5	17.2	0.0
A-2	688-840	A	688-767.3	19.1	17.4	57.1
		B	767.3-823.2	19.9	17.1	26.9
		C	823.2-840	20.4	16.5	0.0
A-3	704-767	A	704-741.8	24.3	21.3	27.2
		B	741.8-771.1	23.6	20.6	1.0
		C	771.1-790	22.6	18.8	0.0

5. Discussion

The position of the solutions contained in the rocks follows the gravitational differential, as water occupies the lower part of the rock formations due to its high density compared to oil, which is usually located above the water, and this was clearly observed through the results of interpreting the borehole data (Figures 5, 6, and 7).

By observing the interpretation of the results of the well data, it is clear that the three wells vary between the wells, as well as the value of one well. It may be related to the subsurface structural situation, like the effect of subsurface faults or the variance of the number of internal fractures. The distribution of oil over the three zones within each well may be related to the gravitational differential of the oil. It also depended on the effective porosity values for each area, and this indicates that effective porosity has an important role in oil content. It can be clearly observed from the values of effective porosity and saturation percentage in table 3, where the oil saturation percentage increases in each well with increasing effective porosity.

6. Conclusion

From the results of the current study, the following can be concluded:

- The average total porosity of the Hartha Formation ranged between 19.3-24.2 for the three wells, while the average effective porosity ranged between 17.2-21.3.
- Oil saturation varies from each well to another in the Qayyarah field, where its average from zero to approximately 69.3%.
- The Haritha formation in the Qayyarah field was divided into three zones depending on the percentage of its saturation with oil (A, B, C), the highest of which is in the upper zone (A). In contrast, the lower zone does not contain oil.
- The percentage of oil saturation inside each well depended on the percentage of effective porosity inside the well, as the percentage of oil saturation increases with the increase in effective porosity, considering the gravitational differentiation of solutions inside the rocks.

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