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Reservoir Characteristics of Bajawan and Baba formations in Selected Wells of Bai Hassan Oil Field, Northern Iraq

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ABSTRACT

The study aims to analyze the petrophysical properties of the Bajawan and Baba formations in wells BH-80, BH-193, and BH-194 in the Bai Hassan oil field (northwest Kirkuk city) using available well logs. The results indicate that BH-193 has the lowest shale content, suggesting a cleaner depositional environment, whereas BH-194 has the highest shale content, potentially impacting reservoir quality in the Bajawan Formation. The transitional (Bajawan/Baba) formation appears relatively balanced in petrophysical properties, while the Baba Formation is more argillaceous, particularly in BH-193 and BH-194. Neutron, density, and sonic logs indicate that the Baba Formation exhibits the highest total porosity compared to Bajawan and the transitional formation, reflecting better storage capacity, with BH-194 recording the highest values and BH-193 the lowest, indicating weaker reservoir quality. Secondary porosity (SPI) is generally low, suggesting limited influence from dissolution or fracturing, except in the Baba Formation in BH-194, where higher values indicate greater secondary porosity development. Effective porosity (PHIE) is lower in the Bajawan Formation (%0.02 - %0.08) compared to the Baba Formation (%0.10 - %0.16), indicating better reservoir quality in the latter. Water saturation analysis from LLD, ILD, and MSFL resistivity logs shows that the Baba Formation has low water saturation (0.048-0.94), enhancing its hydrocarbon retention, whereas the Bajawan Formation has higher water saturation (0.155-0.804), which may reduce production efficiency.

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1. INTRODUCTION

The Bai Hassan oil field, discovered in the 1930s, is one of Iraq's major hydrocarbon resources and a crucial component of the Kirkuk oil field complex. It holds significant hydrocarbon reserves primarily within the Baba and Bajawan formations, which are part of the Oligocene-aged Kirkuk Group [1].

Geographically, Bai Hassan is located in northeastern Iraq within the Low Folded Zone, a subdivision of the Unstable Arabian Shelf, adjacent to the Zagros Fold Belt near Iraq's eastern border [2]. The carbonate stratigraphy of the Kirkuk oil field was first defined by [3] and later analyzed by several researchers, including [4, 5, 6, 7, 8].

The Oligocene depositional history of the Kirkuk Group includes nine formations, representing three main carbonate depositional environments: back-reef, reef, and fore-reef to basin facies [9,10].

The stratigraphic and lithological relationships between the Baba and Bajawan formations were analyzed through contact surfaces and rock characteristics, showing that their boundaries vary based on the lithology of adjacent formations. According to Buday, as cited in [11], the upper contact between Baba and Bajawan is conformable, while the boundary between

Bajawan and the overlying Jeribe Formation is unconformable, indicating a depositional hiatus or erosion before the deposition of Jeribe. Similarly, [4] confirmed that the Baba-Bajawan boundary is conformable in southern Kirkuk, while [12] suggested that the underlying Tarjil Formation also has a conformable contact with Baba.

Bai Hassan Oil Field is located in the northwest of the city of Kirkuk in northern Iraq, (Figure 1), this study aims to analyze the petrophysical properties of the Baba and Bajawan formations to gain a deeper understanding of their reservoir characteristics.

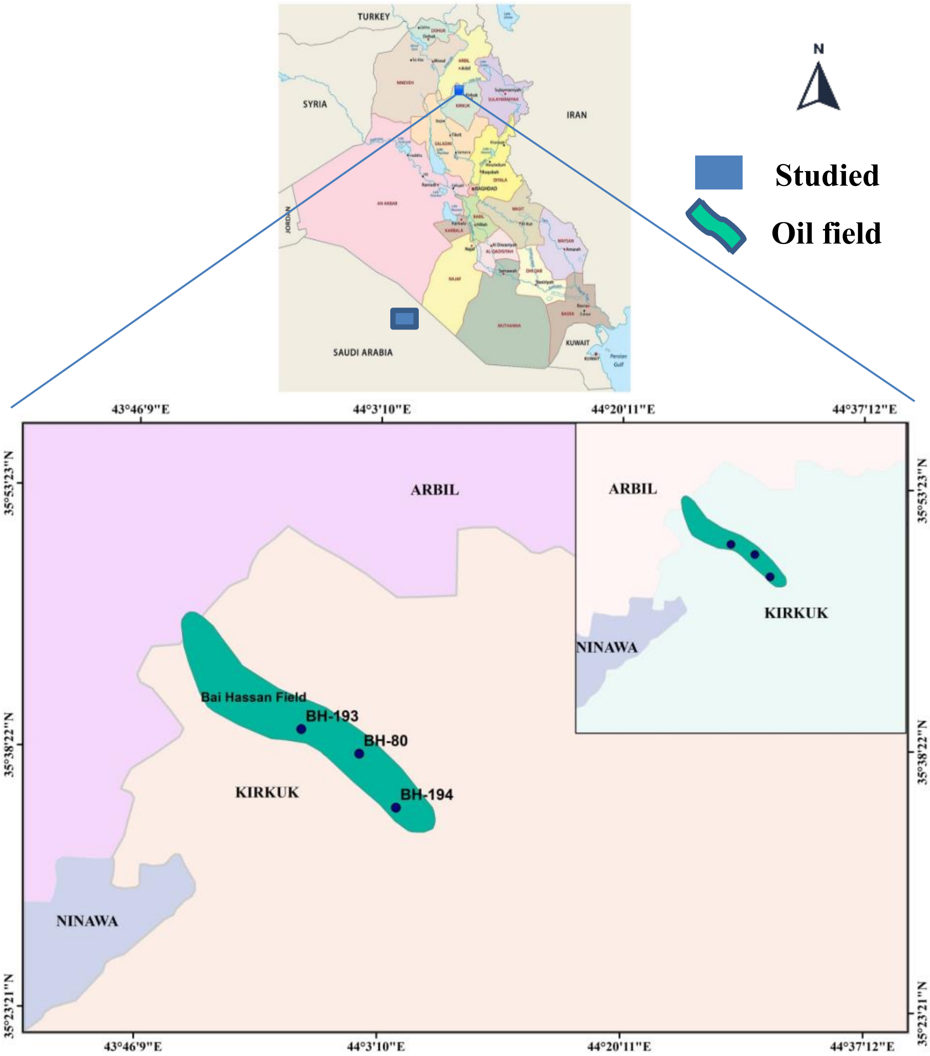


Figure1. location of studied area including selected wells.

2. METHOD

The data was obtained in LAS format from North Oil Company and then Interactive Petrophysics (IP)is used to evaluate reservoir quality. The analysis included identifying washout zones by comparing the wellbore diameter with the caliper log reading, and calculating the Gamma Ray Index (IGR) and Shale Volume (Vsh) using the appropriate equations. Lithology was determined through crossplot diagrams, and porosity was calculated from various porosity logs with the necessary corrections applied. Additionally, total, primary, secondary, and effective porosites were estimated according to the relevant equations, and water saturation and moveable oil were calculated using the electrical resistivity logs.

3. RESULTS AND DISCUSSION

3.1. Shale Volume Determination (Vsh):

Because shale is more radioactive than sand or carbonate, gamma ray logs can be used to calculate the volume of shale in porous reservoirs [13]. Calculation of the gamma ray index is the first step needed to determine the volume of shale from a gamma ray log,using the following formulas from [14]. The average shale volume calculated for the selected wells is presented in Table 1.

$$Vsh = 0.033 \times \left[2^{(2\times IGR)} - 1\right]$$

Where;

V_{sh} volume of shale

I_{GR} gamma ray index

Table 1: Shows the average values of the calculated the volume of shale in the selected wells.

Formations	BH-80	BH-193	BH-194
Bajawan	0.057	0.026	0.161
Bajawan/Baba	0.064	0.050	0.065
Baba	0.048	0.122	0.124

The gamma ray log response illustrating the variation of shale content within the Bajawan and Baba formations is presented in Figures. 2, 3,4.

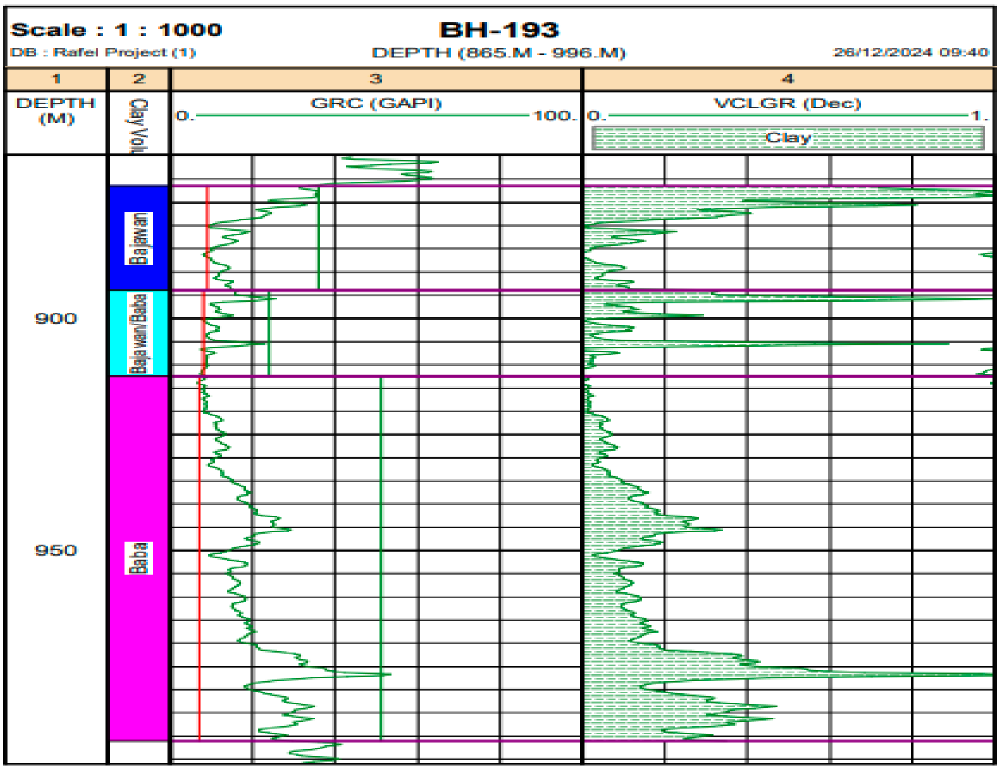
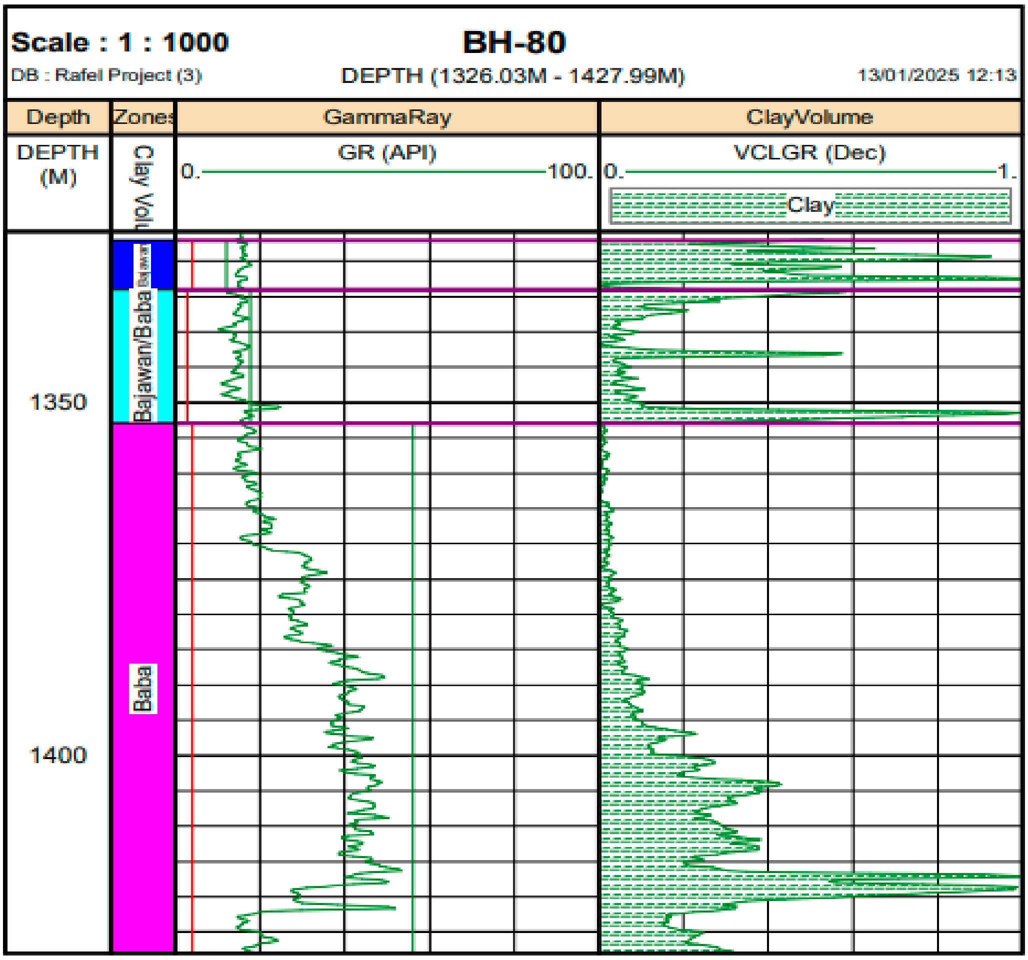
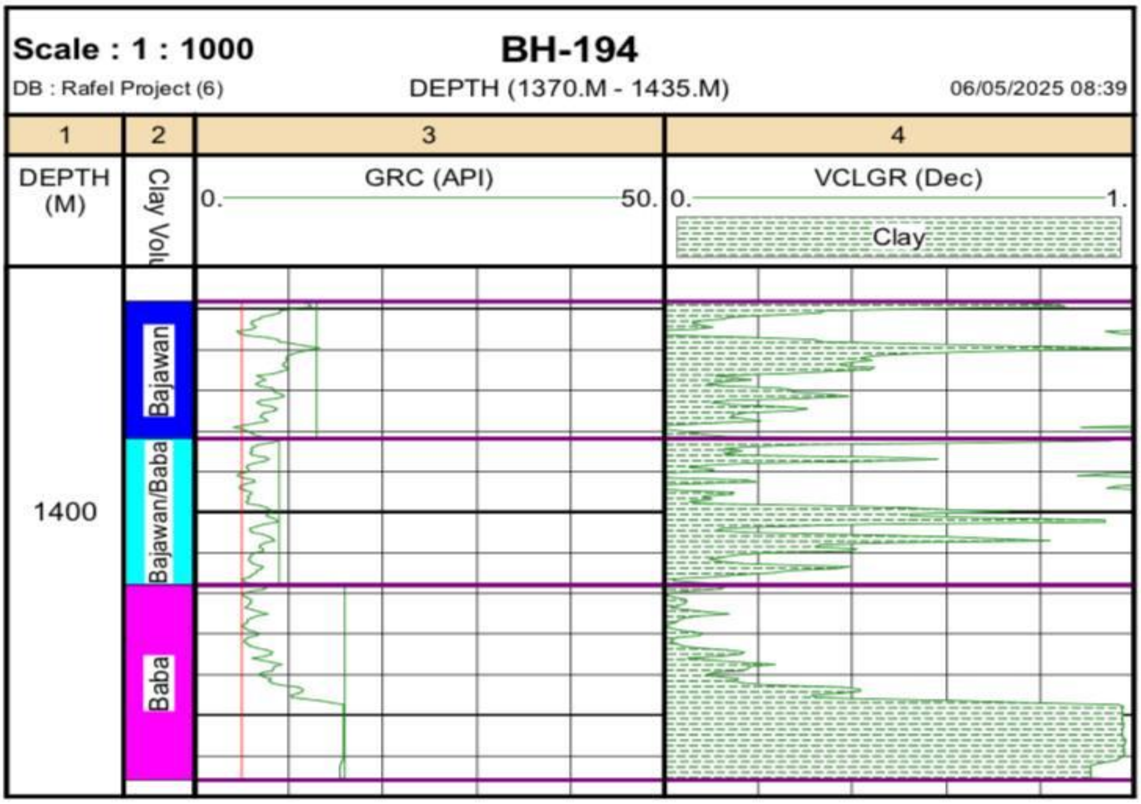


Figure 2. clay volume of Oligocene succession in BH-193



[Figure 3.](#) Clay volume of Oligocene succession in BH-80



[Figure 4.](#) clay volume of Oligocene succession in BH-194

3.2. Resistivity Correction:

According to [15], once the formation temperature is determined, the resistivity of various fluids (Rm, Rmf, or Rw) must be adjusted to the formation temperature using Arp's formula. The resistivity at formation temperature is manually calculated for all wells using this formula.

$$R_{TF} = \frac{R_{temp}(Temp + 21.0)}{(T_f + 21.0)}$$

Where:

R_{TF} : resistivity at formations temperature.

R_{Temp} : resistivity at a temperature other than the formation temperature.

$Temp$: temperature at which resistivity was measured (usually Celsius for depth in meters).

T_f : formation temperature (Celsius for depth in meters).

The drilling parameters for the selected boreholes in the Bajawan and Baba formations are summarized in Table 2.

Table 2. illustrate parameters of drilling boreholes for Bajawan and Baba Formation.

Well No.	**BH-80**	**BH-193**	**BH-194**	**RW=0.05 at 130 deg F**
Density mad	**1.09 gm/cc**	**1.9 gm/cc**	**1.06 gm/cc**	
RM	**0.84@80F**	**75**	**0.25**	
RMF	**0.713@78F**	**58**	**0.17**	
RMC	**0.5@81F**	**1**	**0.3**	
Max temp	**45C**	**37C**	**33C**	

3.3. Porosity Calculation:

3.3.1.Total Porosity (Total Porosity or N-D Porosity):

Total porosity is calculated by using the average readings from the density log and the neutron log, as shown in the equation below [16]:

$$PHI_{total} = NPHI + PHID$$

Where:

• PHI_total = Total porosity.
• NPHI = Porosity calculated from the neutron log.
• PHID = Porosity calculated from the density log.

The calculated total porosity values for the selected wells are presented in Table 3.

Table 3. The average value of (PHIT) for three wells.

Zone/Wells	**BH-80**	**BH-193**	**BH-194**
Bajawan	0.10	0.09	0.12
Bajawan/Baba	0.10	0.052	0.18
Baba	0.17	0.20	0.21

3.3.2. Secondary Porosity Index SPI:

Secondary porosity refers to the porosity that develops after deposition, such as the porosity created by fractures, voids, and channels within the rock formation due to diagenetic processes. It is calculated by subtracting the primary porosity (derived from the sonic log) from the total porosity, as shown in the following equation: The calculated secondary porosity values for the selected wells are presented in Table 4.

$$PHI_{sec} = PHI_{total} - PHIS$$

Where

• PHI_sec = Secondary porosity.
• PHIS = Primary porosity (derived from the sonic log).

Table 4. The average value of (SPI) for three wells.

Zone/Wells	**BH-80**	**BH-193**	**BH-194**
Bajawan	0.11	0.077	0.06
Bajawan/Baba	0.08	0.007	0.13
Baba	0.07	0.09	0.21

3.3.3. Effective Porosity (PHIE):

Effective porosity represents the ratio of the volume of interconnected pores within the rock to the total volume of the rock. It is calculated using the following equation:

$$PHIE = PHI_{total} \times (1 - V_{sh})$$

Where:

- PHIE = Effective porosity.
- PHI_{total} = Total porosity.
- V_{sh} = Shale volume fraction.

The calculated effective porosity values for the selected wells are presented in Table 5.

Table 5. The average value of (PHIE) for three wells

Zone/Wells	BH-80	BH-193	BH-194
Bajawan	**0.02**	**0.033**	**0.08**
Bajawan/Baba	**0.08**	**0.042**	**0.11**
Baba	**0.15**	**0.16**	**0.10**

The porosity log responses illustrate the variation within the Bajawan and Baba formations are presented in Figure 5, 6, 7.

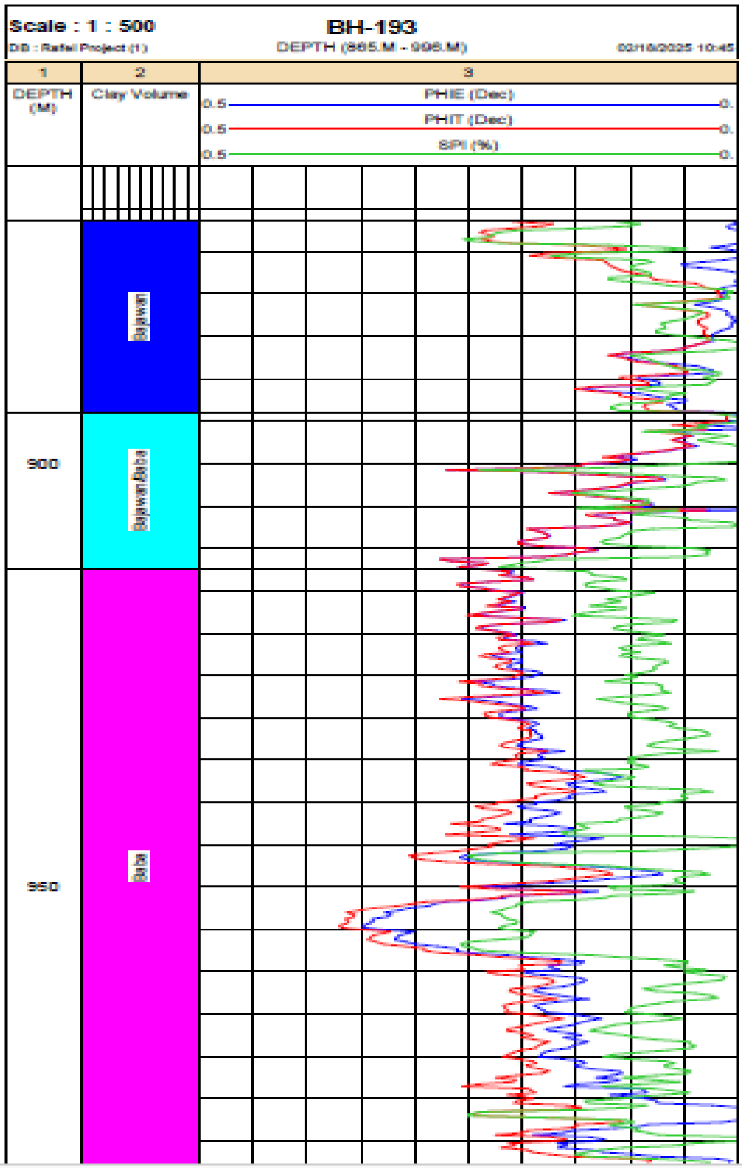


Figure 5. phi type of Oligocene succession in (BH-80)

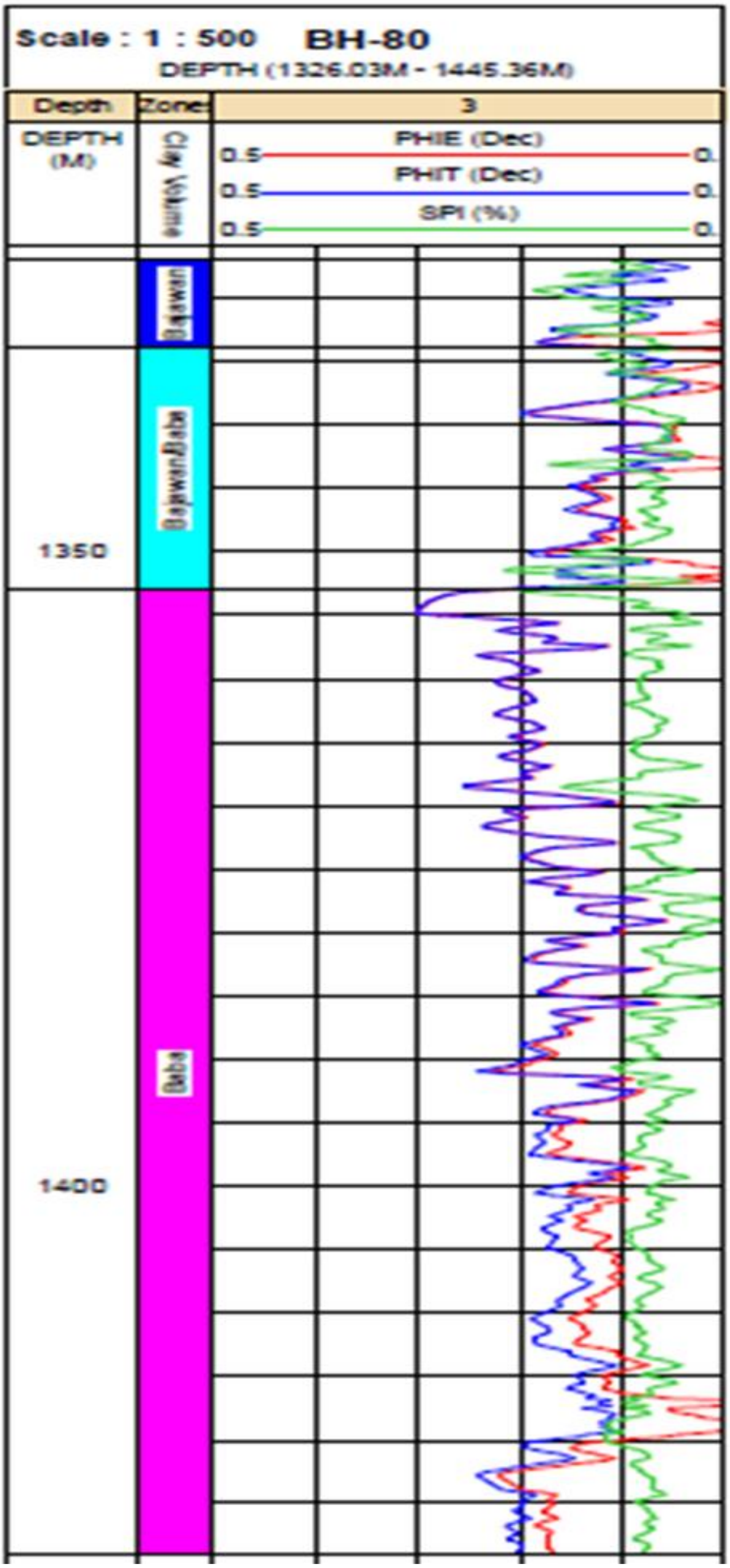


Figure 6. phi type of Oligocene succession in (BH-193)

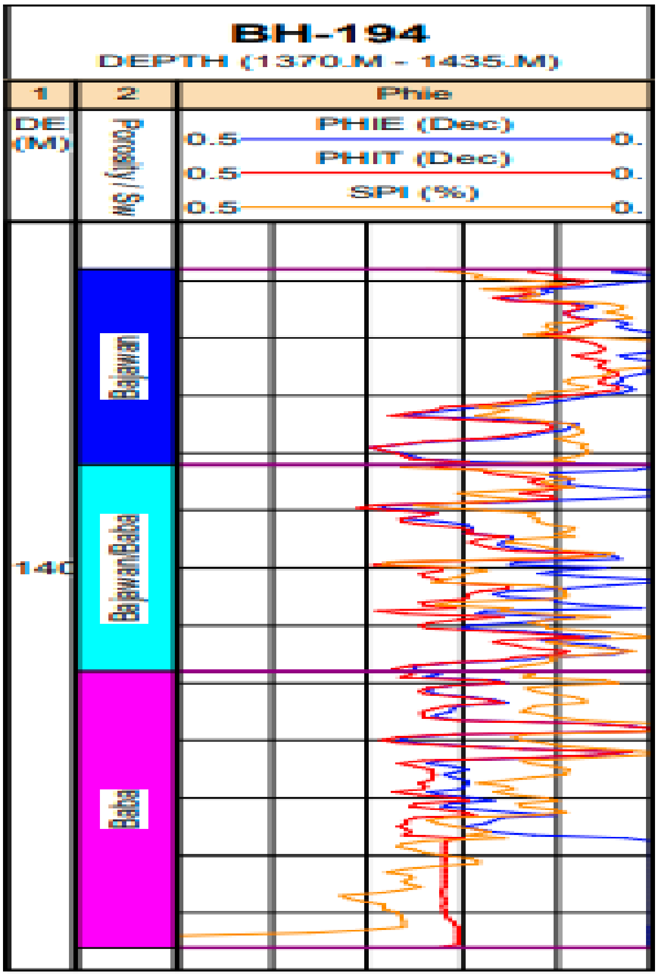


Figure 7. phi types of Oligocene succession in BH-194

3.3.4. Bulk Volume of Water (BVW):

The product of a formation's water saturation (Sw) and its porosity (φ) is the bulk volume of water (BVW) [13].

$$BVW = Sw * \varphi$$

where:
BVW = bulk volume water of uninvaded zone.
Sw = water saturation of uninvaded zone (Archie equation)
φ = porosity
On the other, hand the bulk volume of water can be computed in the flushed zone using the following formula [17,18].

$$BVXO = Sxo * \varphi$$

where:
BVXO = bulk volume water of flushed zone.
Sxo= water saturation in the flushed zone.
Table 6. show the BVW of the studied formations.

Table 6. the average value of (SW) for three wells

Saturation water	SW		
Zone/well	BH-80	BH-193	BH-194
Bajawan	**0.155**	0.173	**0.804**
Bajawan/Baba	**0.128**	**0.078**	**0.717**
Baba	**0.048**	**0.063**	**0.943**

3.3.5. Analysis and Interpretation of Crossplots:

Crossplot diagrams are used in various important areas, including determining the lithology of the formation, the percentage of shale content, the type of porosity, the degree of water saturation in the formation, and the effect of fluid presence on the porosity of the formation.

Below are some of the key types of crossplots that have been analyzed and interpreted from wells (BH-80, BH-193) only, due to insufficient data for well (BH-194).

D-N Cross Plot for Lithology Identification:

All data points are located between the boundaries of limestone and dolomite for wells BH-193 and BH-80, accompanied by the presence of shale, with a minor proportion of sand (Figures 8 and 9). The plot indicates that the porosity is moderate to good, which can be attributed to diagenetic processes.

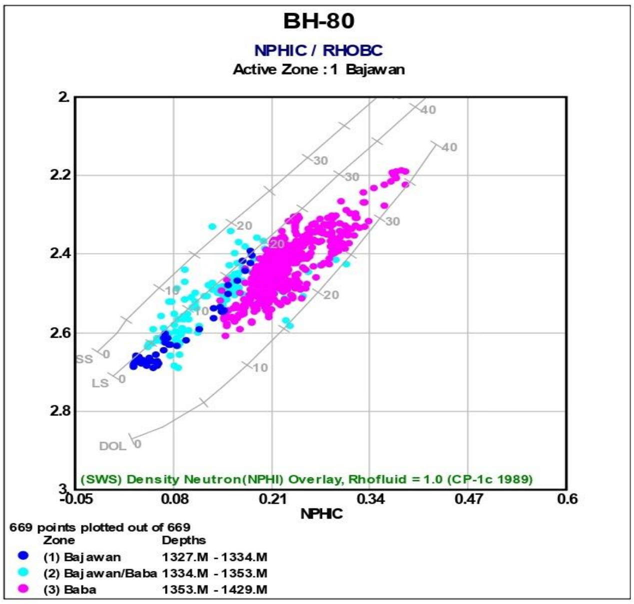


Figure 8. Lithology determination (D-N Crossplot) for BH-80.

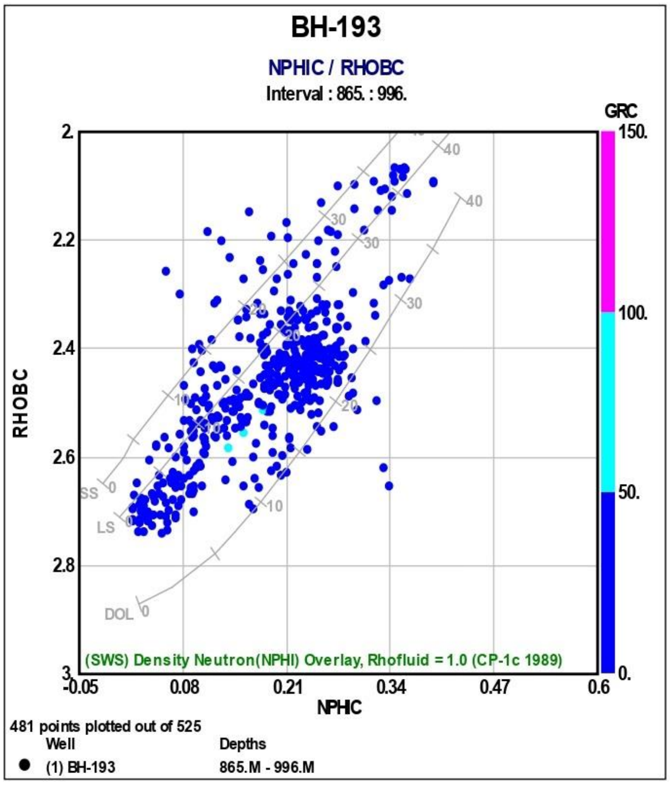


Figure 9. Lithology determination (D-N Crossplot) for (BH-193)

3.3.6. M_N Cross Plot for Mineralogy Identification:

In well BH-193, the points of the Bajawan Formation are concentrated between calcite and dolomite. As for the contact zone (Bajawan/Baba), the points are scattered between calcite and dolomite, which is attributed to the dolomitization process.

For the Baba Formation, the points are concentrated between calcite and dolomite, with a small percentage within the quartz boundary. This is attributed to the presence of silicate components within the carbonate formation, indicating a mixed deposition of carbonate and silicate minerals as shown in Figures (10 and 11). In well BH-80, all points for the two formations are concentrated between calcite and dolomite, with a small percentage of quartz. This suggests a good porosity characteristic resulting from diagenetic processes.

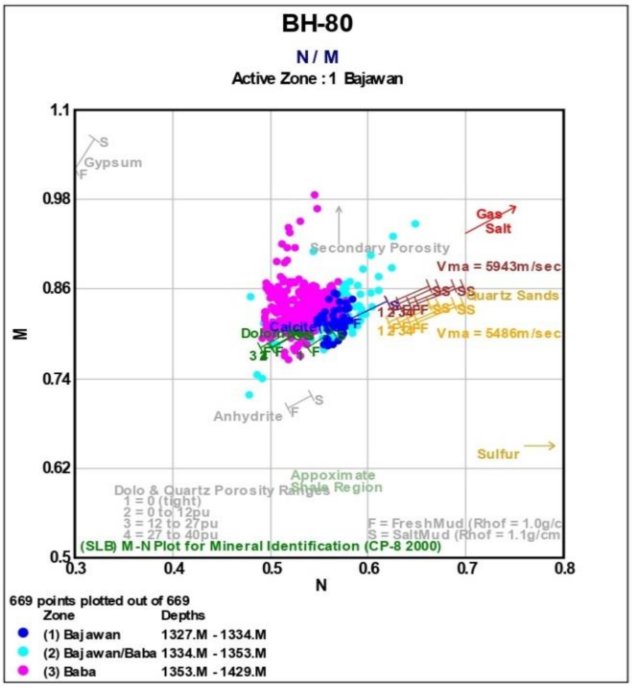


Figure 10. M-N Cross plot for mineralogy identification (BH-80)

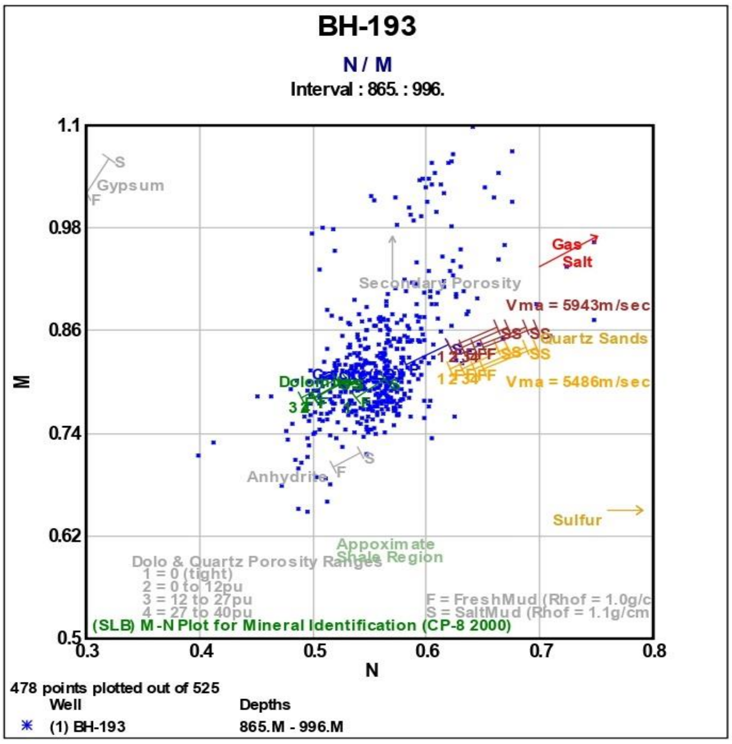


Figure 11. M-N Cross plot for mineralogy identification (BH-193)

3.3.7. Matrix Identification (MID) Cross Plot:

In well BH-80, all data points concentrated within the Bajawan Formation are lying within the boundaries of calcite. The contact zone (Bajawan/ Baba formations) transitions from the calcite boundary to a lower percentage of dolomite, largely influenced by diagenetic processes. As for the Baba Formation, it is primarily concentrated between calcite and dolomite, supporting the occurrence of the dolomitization process (Figure 12). In well BH-193, all points fall between calcite and dolomite, with a very small percentage of points lying within the sand boundary. This is attributed to the presence of moderate to good porosity in (Figure 13).

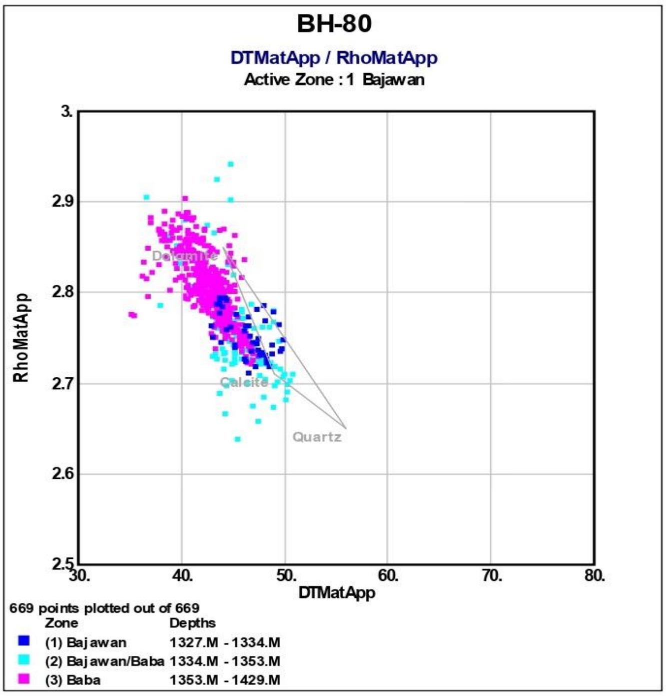


Figure 12. Matrix crossplot Oligocene succession in (BH-80)

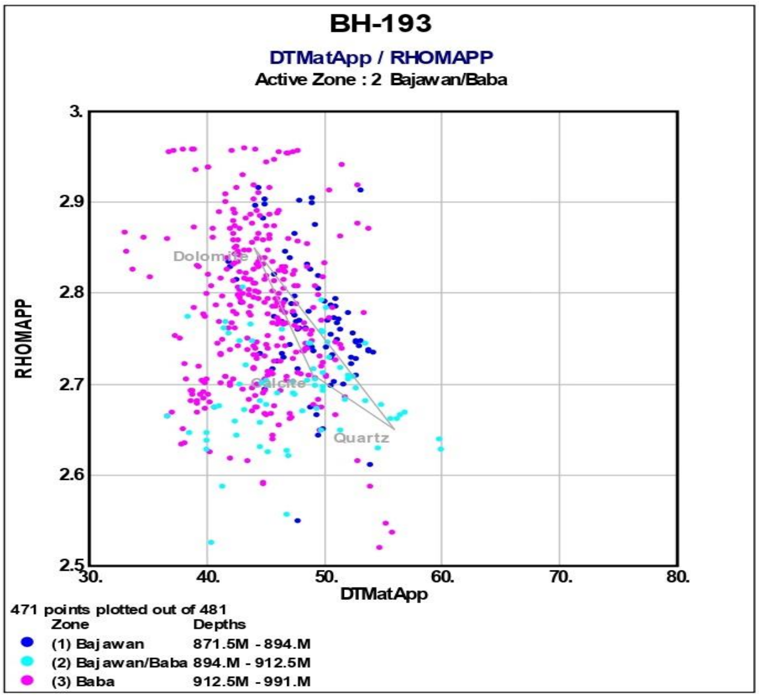


Figure 13. Matrix crossplot Oligocene succession in (BH-193)

3.4. Zones Evaluation:

3.4.1. Bajawan Formation:

The (Fig. 14, 15 and 16) show the results of wells BH-193, BH-80, and BH-194 in the Bajawan Formation were analyzed using Computer Processed Interpretation (CPI) through the IP program.

- The borehole environment is clean according to the caliper log in three well.
- Low clay content, but it increases in the upper part of the formation in well BH-193.
- Total porosity is low (0.09% - 0.12%), indicating poor reservoir quality.
- Effective porosity ranges between (0.033% - 0.08%), confirming weak fluid storage capacity in three well.
- Presence of secondary porosity due to dissolution processes.
- Water saturation is high in well BH-194 (0.804%) compared to the other wells.
- The net-to-gross (N/G) ratio is relatively low, with the highest value in well BH-194 (0.527), indicating limited productivity potential.

3.4.2. Baba/Bajawan Formation:

The (Figures 14, 15 and 16) show The results of wells BH-193, BH-80, and BH-194 in the Bajawan/Baba Formation were analyzed using Computer Processed Interpretation (CPI) through the IP program.

- The borehole environment is clean in all wells, with a weak clay effect (0.057% - 0.0654%).
- Total porosity is low but varies between wells, with the highest value in well BH-194 (0.18%).
- Effective porosity ranges from (0.04% - 0.11%), indicating moderate to poor fluid storage and flow capacity in three well.
- Secondary porosity is noticeable in well BH-80 (0.08%) and well BH-194 (0.13%), indicating diagenetic alterations in the rock.
- The formation contains hydrocarbon-rich layers, with oil presence in high-porosity depths, especially in well BH-193.
- The net-to-gross (N/G) ratio is highest in well BH-194 (0.90), reflecting its high productivity potential.

3.4.3. Baba Formation:

The (Figures 14, 15 and 16) show The results of wells BH-193, BH-80, and BH-194 in the Baba Formation were analyzed using Computer Processed Interpretation (CPI) through the IP program.

- Partial borehole wall collapse is observed in well BH-193, while the borehole environment is clean in the other wells.
- Clay content varies and increases in the lower sections of the formation in all well.
- Total porosity is relatively good, reaching 0.21% in well BH-194, indicating better reservoir quality.
- Effective porosity ranges between (0.16% - 0.10%), indicating relatively good fluid storage and transmission capacity in all well.
- Secondary porosity significantly influences all wells, enhancing storage and permeability.
- Water saturation is low in wells BH-80 and BH-193 (0.06% - 0.04%) but high in well BH-194 (0.94%).
- The formation contains good amounts of movable oil, enhancing production potential, especially in well BH-193.
- The net-to-gross (N/G) ratio is high in well BH-193 (0.83%), indicating a significant proportion of productive layers.

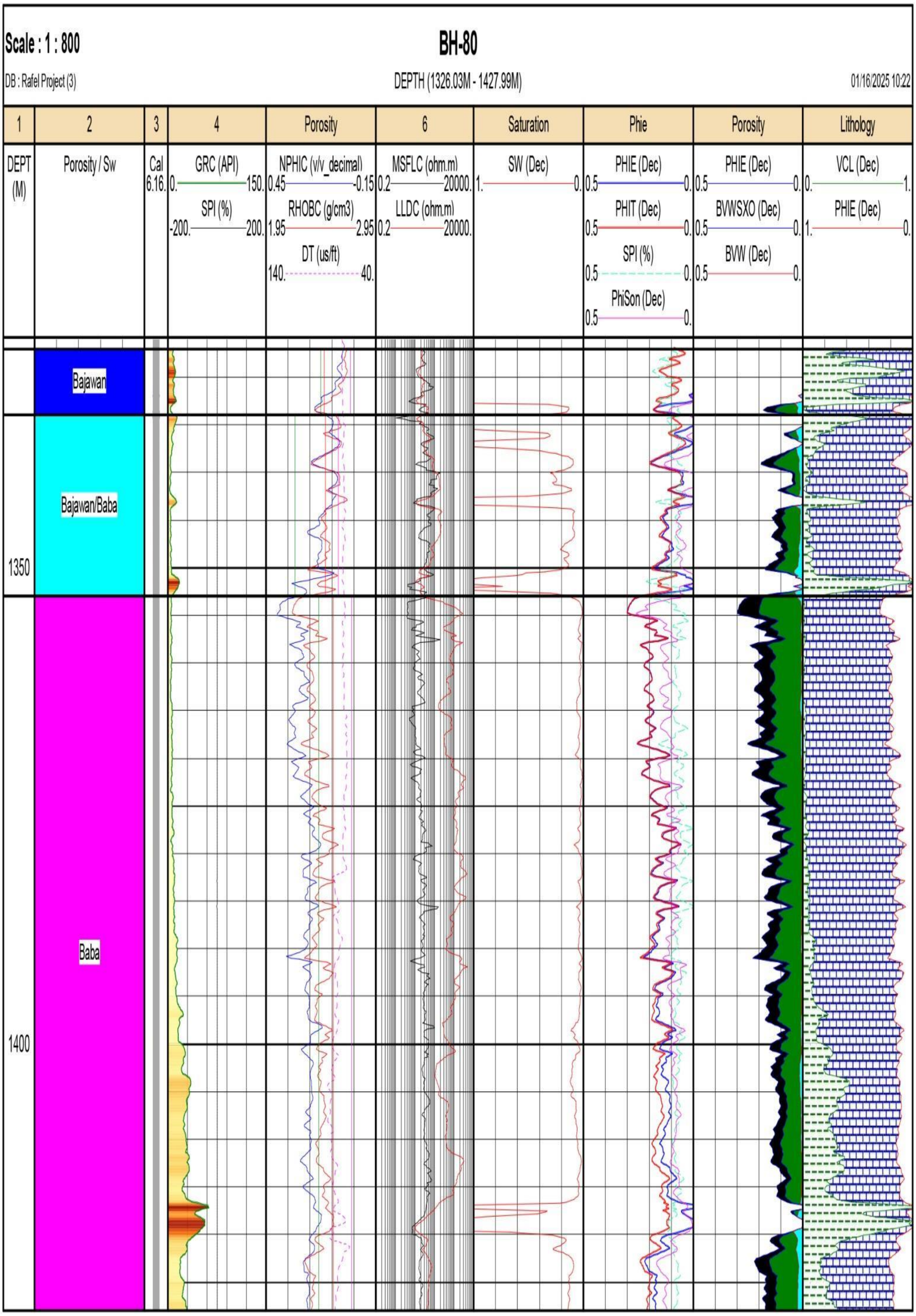


Figure 14. (IP clustering analysis of the Bajawan and Baba Formation in the well (BH-80).

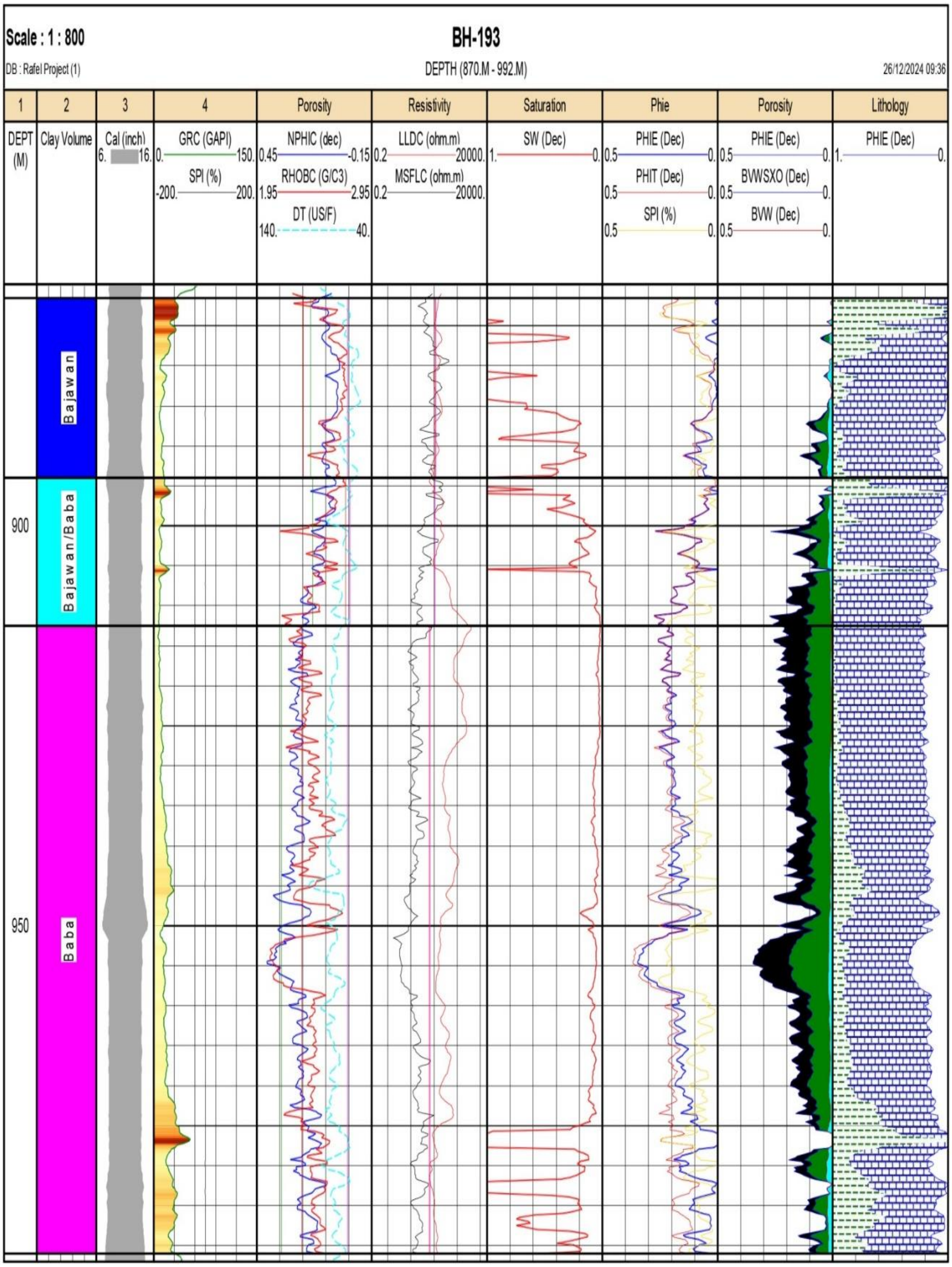
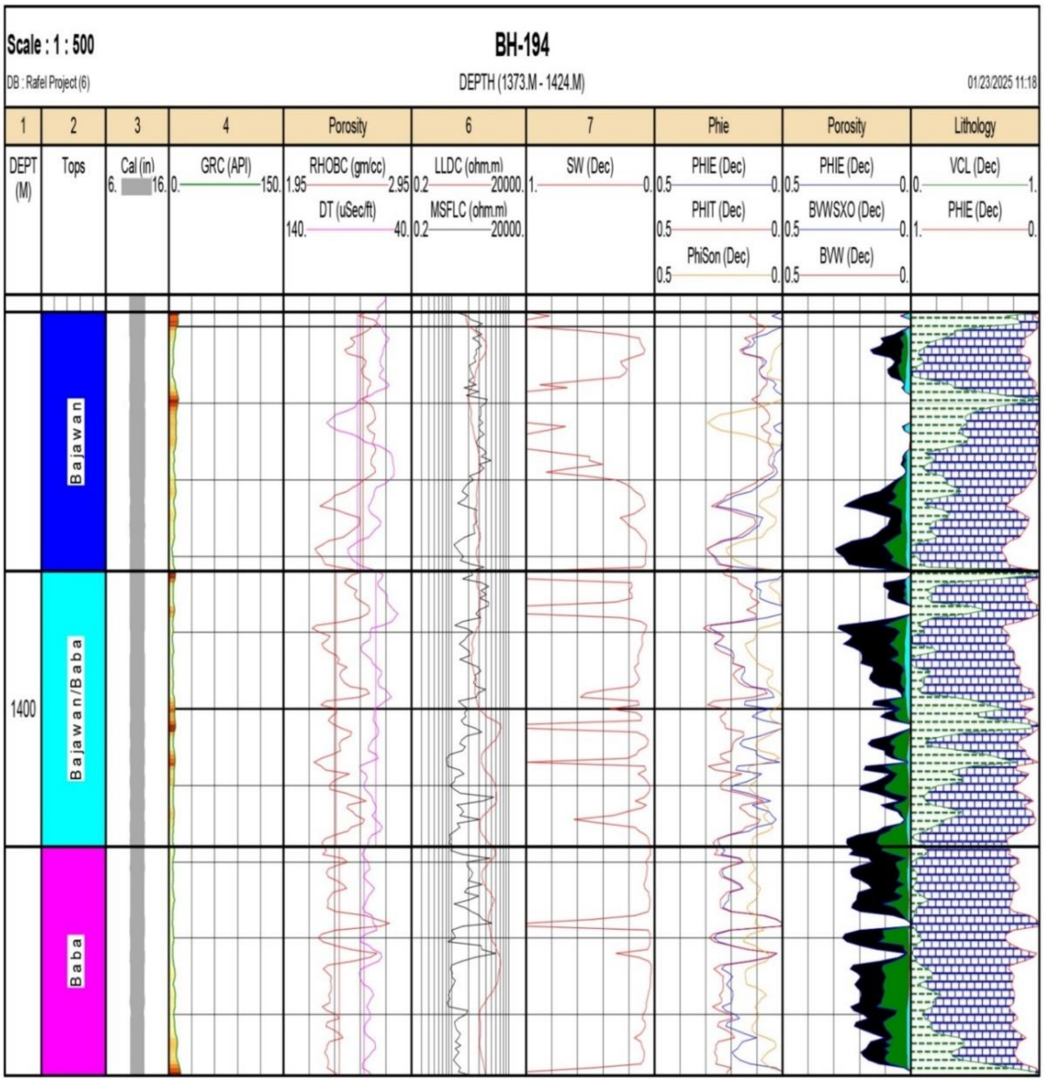


Figure 15. (IP) clustering analysis of the Bajawan and Baba Formation in the well (BH-193).



[Figure 16.](#) (IP) clustering analysis of the Bajawan and Baba Formation in the well(BH-194).

4. CONCLUSION

The Bajawan and Baba formations, as well as the transition zone between them,were studied in wells BH-80, BH-193, BH-194 within the Kirkuk oil field using the IP software for data analysis, and the following results were obtained:

The shale volume was calculated using the gamma-ray log, in addition to calculating porosity types using porosity logs. The interpretation results showed the followings:

1. Shale Volume: in the BH-193m the Bajawan Formation recorded the lowest shale volume value (0.026%), making it the most suitable for production, while in the BH-194 recorded the highest value (0.161%), which may affect reservoir quality. The Bajawan/Baba transition zone had moderate values (0.050 - 0.065%), whereas Baba Formation had higher values (up to 0.124%).

2. Lithology: Crossplot interpretations showed that the dominant rock type in both formations is porous dolomitic limestone.

3. Total and Primary Porosity: In Bajawan formation value of total porosity ranged from (0.09% - 0.12%), in Bajawan/Baba (0.05% - 0.18%), and in Baba Formation between (0.17% - 0.21%). The primary porosity ranged between (0.005% - 0.10%) in all wells.

4. Secondary Porosity: The values varied, ranging between (0.06% - 0.11%) in Bajawan Formation, between (0.007% - 0.13%) in Bajawan/Baba, and the highest value (0.21%) was recorded in BH-194 within the Baba Formation.

5. Effective Porosity: The Baba Formation recorded the highest effective porosity value between (0.15 - 0.16%), making it the best for fluid storage and transmission, while in Bajawan Formation recorded the lowest

value between (0.02 - 0.08%). The Bajawan/Baba transition zone showed moderate porosity values between (0.042 - 0.11%).

6. Water Saturation: BH-80 and BH-193 had low water saturation value, indicating good oil potential:

•In Bajawan Formation between (%0.155 -% 0.173), in Bajawan/Baba between (%0.128 - %0.078), in Baba Formation between (%0.048 -% 0.063)

• BH-194 recorded high-water saturation, making it less productive:

•In Bajawan Formation (%0.804), Bajawan/Baba (%0.717) , and Baba Formation (%0.943)

The most favorable formation for oil production is Baba Formation in well BH-80 and BH-193 due to the low water saturation, which is less than %0.07.

Ethical Clearance

This study did not involve human participants, animals, or any identifiable personal data. Therefore, ethical approval was not required.

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REFERENCES

[1] I. M. Ghafor and P. Rajabi, “Stratigraphy, Microfacies, Paleoenvironments and Paleoecology of Asmari Formation (Oligocene - Miocene), Zagros Basin, Western Iran”, Iraqi Geol. Jour, Vol. 57. 2024, DOI : https://doi.org/10.46717/igj.57.2C.15ms-2024-9-23

[2] S. F.A. Fouad, “Structural Tectonic Map of Iraq”, Iraqi Bul. of Geol. and Min., Vol.11, No.1, pp. 1- 7, 2015.

[3] F. R.S. Henson, “Cretaceous and Tertiary reef formations and associated sediments in Middle east‖”, Amer. Asso. of Petr. Geol. Bull., Vol. 34, pp. 215- 238, 1950.

[4] K. M. Al-Naqib, “Geology of the southern area of Kirkuk Liwa, Iraq”, 2nd Arab Petroleum Congress, Berirut Vol. 2, pp. 45–81, 1960.

[5] R. C. V. Bellen, “The stratigraphy of the Main Limestone of the Kirkuk, Bai Hassan and Qara Chauq Dagh structures in Northern Iraq”, JournnaI of the Institute of Petroleum, Vol. 42, pp. 233-263, 1956.

[6] H. V. Dunnington, “Generation, migration, accumulation, and dissipation of oil in northern Iraq, Middle East”, 1958.

[7] Q. A. Muhammad, “Biostratigraphy of Kirkuk Group in Kirkuk and Bai-Hassan areas” MSc. Thesis, Dept. of Geol, Uni. of Baghdad, Baghdad-Iraq, 1983.

[8] A. H. Majid and J. Veizer, “Deposition and chemical diagenesis of Tertiary carbonates, Kirkuk oil field, Iraq”, Amer. Asso. of Petr. Geol. Bull., Vol. 70, No. 7, pp. 898-913, 1986.

[9] R. C. V. Bellen, H. Dunnington, R. Wetzel and D. Morton, “Lexique Stratigraphique, Interntional. Asie, Iraq”, p. 333. 1959.

[10] M. E. El-Eissa, “The two sub depositional cycle of the Early Miocene in Kirkuk oil field area, north Iraq”, Jour. of Geol. Soci., Vol. 25, pp. 41–58, 1992.

[11] S. Z. Jassim, and J. C. Goff, “Geology of Iraq”, Published by Dolin, Prague and Moravian Museum, Brno, p. 341, 2006.

[12] S. O. A. Kharajiany, “Sedimentary facies of Oligocene rock units in Ashdagh mountain-Sangaw District-Kurdistan Region”, MSc. Thesis (unpublished), Univ. of Sulai. Sulaimani, p. 106, 2008.

[13] G. Asquith, and C. Gibson, “Basic well logs analysis for geologists: methods in Exploration series”, Amer. Asso. of Petr. Geol. Bull., p. 216, 1982.

[14] Dresser Atlas, “Log Interpretation Charts”, Houston, Dresser Industries, Inc., p. 107, 1979.

[15] G. B. Asquith, and D. Krygowski, “Basic Well Log Analysis”, 2nd Edition: Amer. Asso. of Petr. Geol. Bull., Methods in Exploration Series 16., p. 244, 2004.

[16] Schlumberger, “Cased Hole Log Interpretation Principles/Applications”, Houston, Schlumberger Wireline and Testing, p. 198, 1998.

[17] Schlumberger, “Log interpretation charts”, Schlumberger, p. 106, 1984.

[18] W. K. Hamdan, “Petrel software modeling of Mishrif Formation in Buzergan field”, M.Sc. Thesis, Departmentof Geology, university of Baghdad, 90p.