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PETROPHYSICAL COMPARISON USING WELL LOGS FOR THE UPPER PALEOGENE-EARLY NEOGENE SUCCESSION IN FAUQI AND ABU GHIRAB OIL FIELDS, SOUTH EASTERN IRAQ

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Abstract

The Oligocene-Miocene (the Upper Paleogene-Early Neogene succession), obtained in the Fauqi (FQ) and Abu Ghirab (AG) fields, is one of the most important hydrocarbon-bearing reservoirs, located in southeastern Iraq, notably within the Missan oil fields. In the Fauqi Oilfield, the Upper Paleogene-Early Neogene succession ranks as the second most productive, while in the Abu Ghirab Oilfield, it serves as the main source of oil production. This study aims to determine the main petrophysical properties (porosity, water saturation, and volume of shale) and compared them through the units of this succession (Jeribe-Euphrates, Upper part of Kirkuk group, Buzurgan Member, and Middle-Lower part of Kirkuk group) in four wells (FQ-x1and FQ-x2 in the Fauqi Oilfield) and (AG-y1and AG-y2 in the Abu Ghirab Oilfield) using Interactive Petrophysics software. The lithology of this succession is determined using the neutron-density logs, which is Jeribe-Euphrates (J-E) unit consist of dolomite and some limestone and anhydrite that damages the porosity in this unit and the ratio of dolomite is increasing toward FQ Field, on the other hand the thickness of this unit is decreasing in the same direction, while Upper Kirkuk (U.K.) unit is composed of limestone with some dolomite and sandstone. Buzurgan Member (B.M.), which separates the upper part of the Kirkuk unit from and Middle-Lower part of the Kirkuk unit, consists mainly of sandstone with a few carbonates. The Middle-Lower part of the Kirkuk group (M-L.K.) is composed of limestone, dolomite, and sandstone, as well as shale in abundance. In the FQ field, porosity increases toward the north-west, but in the AG field, it often increases toward the southeast. Because of the presence of anhydrite, which damages porosity, the (J-E) unit has very low porosity. It is improved downward in the B.M. and the U.K. with high quantities of shale. The J-E and U.K. units are considered the primary reservoir units because of their generally low water saturation, whereas the other formations are considered water-bearing zones. The results of this research show an important petrophysical difference between stratigraphic units in the Fauqi and Abu Ghirab Oilfields.

Keywords: Kirkuk group; Fauqi Oilfield; Abu Ghirab Oilfield; petrophysical properties.

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1. Introduction

The Paleogene-Early Neogene epoch is very interesting in Iraq and Iran because of the variety of its geological formations, many of which contain rocks with high hydrocarbon reservoir properties, making them commercially beneficial. The Later Paleogene-Early Neogene succession, situated in the Abu Ghirab and Fauqi Oilfields, and deposited during the Oligocene to Early Miocene period. Many researchers (Alrawi & Aldin, 1976; Fouad, 2012; Al-Baldawi, 2015; Al-Saad & Al-Shahwan, 2019; Al-Mamouri et al., 2022; and Al-Mishkil et al., 2023) are considering the Zagros Fold Belt as a potential reservoir for the Asmari group and were noticed that the clastic sedimentary deposits have an upward trend toward the Fauqi field, whereas the carbonate formations have a decline in the same directional vector; additionally, those reseachers determined that the geological formation is highly complex due to the presence of various depositional environments. These researchers examined the southern half of Iraq's Zagros fold belt. The approach, commonly known as reservoir assessment, attempts to detect, describe, and extract hydrocarbons from a reservoir. Well logging is critical to the hydrocarbon exploration and production sectors because it may provide such enormous quantities of data. These strategies can be used at any step of the hydrocarbon exploration and production process.

Reservoir characterisation is the methodical process of identifying the reservoir using geophysical, geological, and engineering datasets. Assessing petrophysical characteristics is an important aspect of reservoir characterisation. Petrophysical property variation is a result of a reservoir's geological history and may be described as the variations that occur when these characteristics pass through the reservoir. Variation is distinguished by heterogeneity. The petrophysical characteristics of oil-bearing rocks vary from pore to field level. As a result, petrophysical features are best understood by utilizing the scales of heterogeneity. This study aims to study the variation of the petrophysical properties in four wells at Abughirab and Fauqi oil fields, which will give a good vision of how to accurately manage the reservoir. Although various previous studies have focused on the Asmari group in the Fauqi and Abu Ghirab oilfields, the majority of them did not perform a direct comparison investigation of the petrophysical properties or stratigraphic changes between the two fields. As an example, Al-Baldawi (2020) examined the petrophysical properties of the Asmari Formation in the Abu Ghirab field, whereas Al-Saad & Al-Shahwan (2019) evaluated them in the Fauqi field. Other studies, such as those by Asad & Hamd-Allah (2022) and Abdul Aziz & Abdul Hussein (2021), focused on geological modeling or the connection between seismic and petrophysical characteristics rather than making a geographical comparison between fields. Therefore, the current study aims to perform a comprehensive and comparative petrophysical examination of the Later Paleogene-Early Neogene succession via both fields using four wells and Interactive Petrophysics software. This means measuring the amount of shale, porosity, and water saturation in major stratigraphic units and relating these properties to differences in lithology and thickness between fields.

2. Location of the study area

The Abu Ghirab and Fauqi fields are located in southern Iraq's Missan Governorate, close to the Iranian border (Figure 1). The Abu Ghirab Field is about 30 kilometers long and 5 kilometers wide, and it is located between the coordinates 3,575,000 and 3,600,000 in the north and 71,000 and 73,500 in the east (Al-Mamouri et al., 2022). The first well was drilled (AG-1) in 1971. Fauqi Oilfield is located about 50 km northeast of Amara city, about 350 kilometers to the southeast of Baghdad, and approximately 175 kilometers to the north of Basrah. It has an axial length of approximately 26 km and a width of around 6 km, located between northing coordinates 3,554,000 to 3,565,000 and easting coordinates 737,000 to 743,000. The first well (FQ-1) was drilled in 1974 (Aldalawy, 2012).

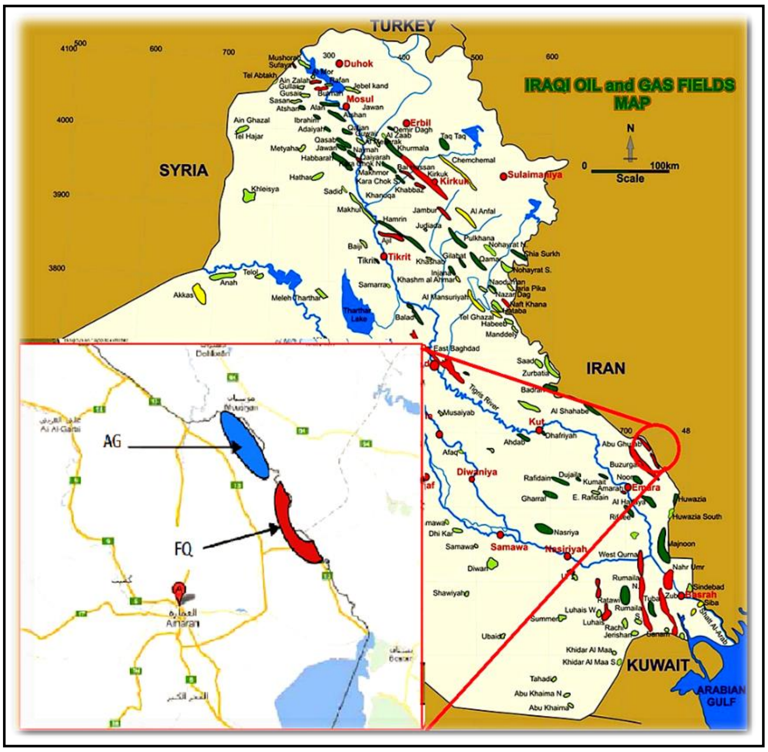

Figure 1. Location map of the study Oil field (modified from Al-Khafaji, 2015).

3. Tectonic and Structural Setting

The Abu Ghirab and Fauqi fields are situated within the Unstable Shelf, specifically in the Foothill Zone of the Hemrin–Makhul area, according to Iraq's longitudinal geological division, and lie within the Mesopotamian Block (Figure 2A), where it is bounded from the north by the Sirwan Fault and from the south by the Takhadid-Qurna Fault (Jassim & Goff, 2006). While it lies in suspended basins, the Foothill Zone of the Quasi platform of the Arabian plate. Abu Ghirab and Fauqi oilfields are located in the east anticlinal structural zone (Sang et al., 2017). Based on seismic survey data, the Abu Ghirab Field is composed of two asymmetrical anticlinal culminations separated by a structural saddle. The structure runs northwest-southeast. The southern culmination measures around 16.5 km in length and 5.5 km in width. The northern culmination expands into the Iranian territory, most likely continuing the Dehloran Field in Iran (Al-Saad & Al-Shahwan, 2019). The structure is a non-cylindrical anticline with numerous culminations in the southern and northern parts of the field, divided by depressions. Abu Ghirab structure is higher than Fauqi because the former is affected by the tectonic movements that occurred from east to west direction (Figure 2B; Alsinbili et al., 2013). Similarly, the seismic survey data for the Fauqi field revealed the presence of a 26-kilometer-long and 6-kilometer-wide geological structure. As in Abu Ghirab, the axis of the anticline is NW–SE, and the overall shape of the structure tends to take on the shape of an Enechelon fold (Figure 2B), which is formed by tension forces (Aldalawy, 2012).

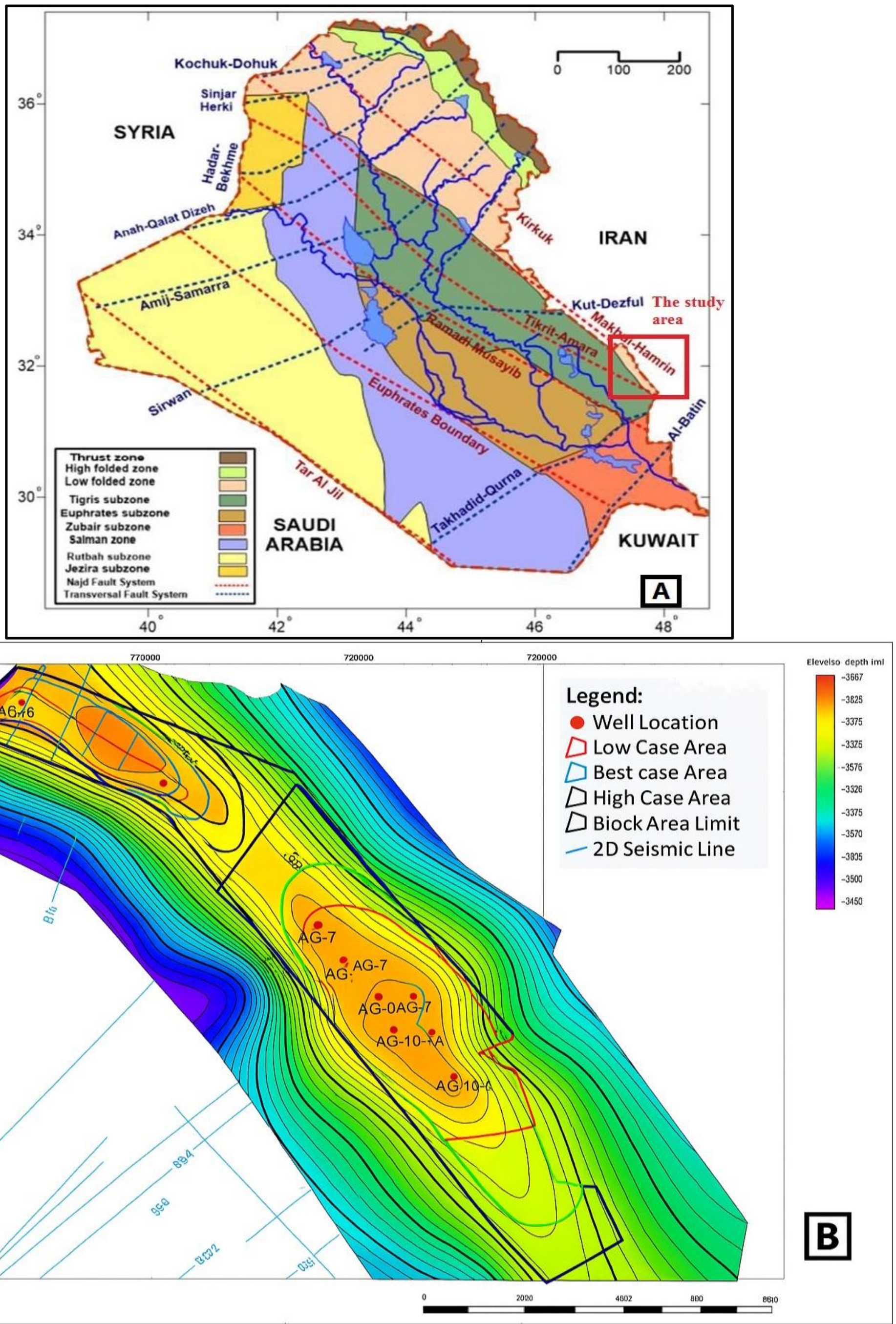

Figure 2. A) Tectonic location of Iraq showing the tectonic zone of the studied fields (Jassim & Goff, 2006). B) Structural map of studied Oilfields (CNOOC, 2012).

4. Stratigraphic Setting

The Oligocene epoch was defined by the development of tectonic movements that controlled the progress and retreat of the sea, resulting in a rapid environmental overlap and a diversity of horizontal and vertical facies that formed the present stratigraphic position (Jassim & Goff, 2006). Oligocene-aged rocks may be found in the Low Folded Zone and central Iraq in nine formations, the majority of which are limestone related to back reef, reef, and fore reef sequences. These formations often have limited surface exposure and underground expansions. The Palani, Tarjil, Shurau, and Sheikh Alas formations are from the Early Oligocene period, while the Bajwan and Baba formations are from the Middle Oligocene. This geologic period includes the Anah, Azkand, and Ibrahim formations (Late Oligocene) (Sissakian, 2013). The Later Paleogene-Early Neogene succession includes sedimentary layers from the Late Eocene to the Early Miocene. The formation is dated to the Early Miocene-Oligocene and is separated into the Jeribe-Euphrates Formation (Early to Middle Miocene) and the Kirkuk Group (Oligocene). (Al-Saad and Al-Shahwan, 2019). In Iraq, the Late Paleogene-Early Neogene succession sits on top of the Jadala, Pila Sp, and Avanah formations. In Iran, the Asmari Group covers the Pabdeh and Shahbazan formations, and in the Zagros basin, it is covered by Fatha/ Gascharan (Figure 3).

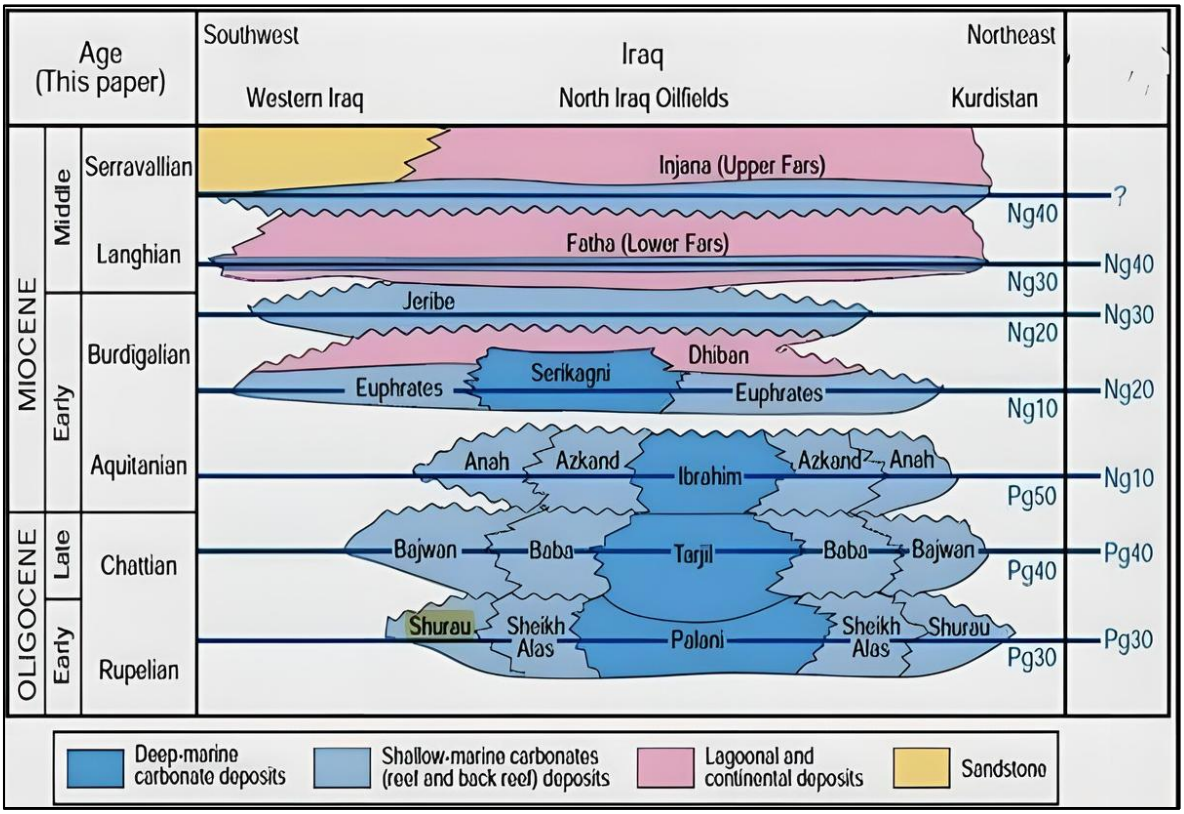

Figure 3. Chronostratigraphic column of the Oligocene to the Early Miocene showing the Formations of the Later Paleogene-Early Neogene succession (Palani, Tarjil, Shurau, Sheikh Alas, Ibrahim, Baba, Anah, Azkand, and Bajwan formations) (modified by Al-Banna (2008), from Van Bellen et al. (1959).

5. Methodology

The study involves obtaining data from two wells in the Fauqi Oilfield (FQ-x1 and FQ-x2) and two wells at Abu Ghirab Oilfield (AG-y1 and AG-y2), including open-hole logs such as Gamma Ray (GR), Density, Caliper, Neutron, Sonic, and Resistivity logs, and the objective of

A- Qualitative interpretation to identify formation boundaries and measure the thickness of units and lithological assessment using Neutron – Density crossplot.

B- The process includes quantitatively analyzing and interpreting well logs to determine the principal petrophysical parameters such as porosity (φ), water saturation (Sw), and shale volume (vsh) using Interactive Petrophysics software (IP) version 4.6. The petrophysical characteristics were calculated using conventional equations inferred from Asquith & Krygowski (2004)by the following research approaches (Figure 4), which were used to attain the study's objectives.

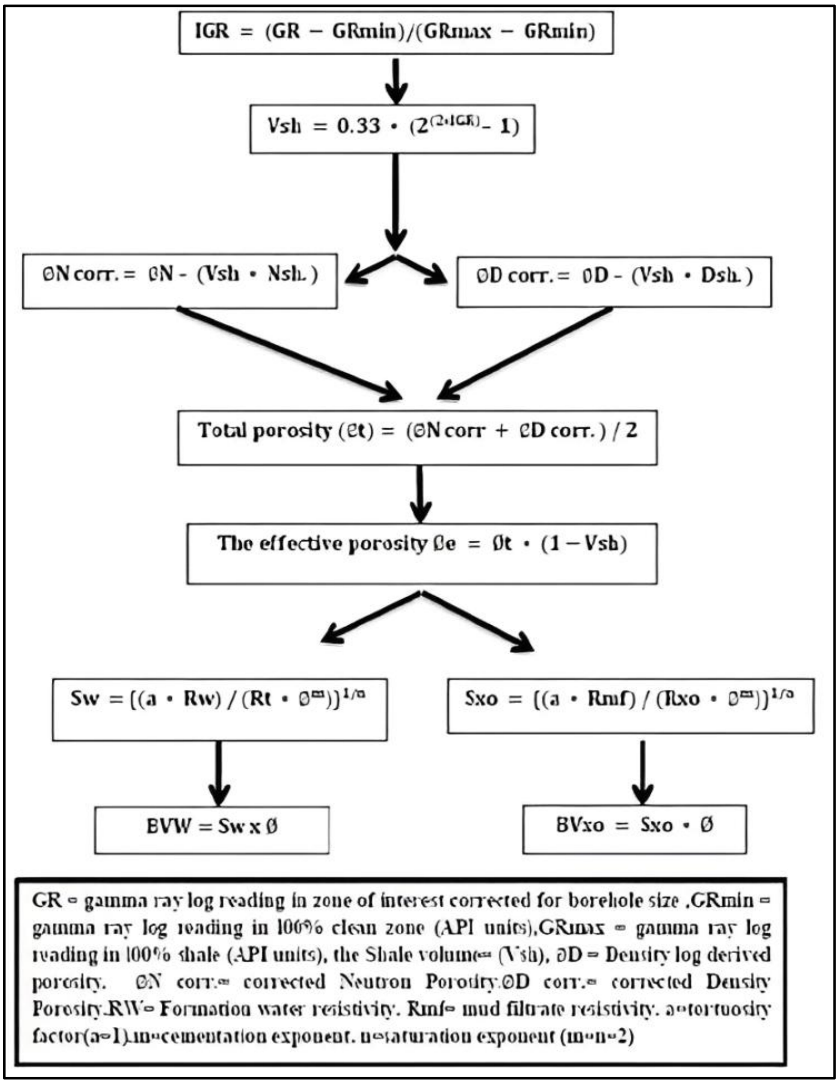

Figure 4: Diagram shows steps and parameters of quantitative interpretation of well logs (Al-Baldawi, 2020).

6. Results and Discussions

6.1. Lithological properties of the Asmari units

The Later Paleogene-Early Neogene succession was divided into four lithological units, which are from bottom to top: the Middle-lower part of the Kirkuk group, the Buzurgan member, the Upper part of the Kirkuk group, and the Jeribe-Euphrates formation (Figure 5). Each unit consists of different lithologies and has different petrophysical properties as well as variation in environmental systems due to continual sea-level variations. The cross-plot of porosity logs—specifically neutron and density logs—is an effective tool to understand the lithology of this succession, as log responses vary based on the formation's mineral composition and fluid content. This approach determines lithology by graphing the neutron porosity recorded by the neutron log on the horizontal axis and the bulk density (RHOB) recorded by the density log on the vertical axis (Bowen, 2003; Schlumberger, 2009; Figures 6 – 9). The lithological units of the Asmari group, as mentioned previously, are classified into:

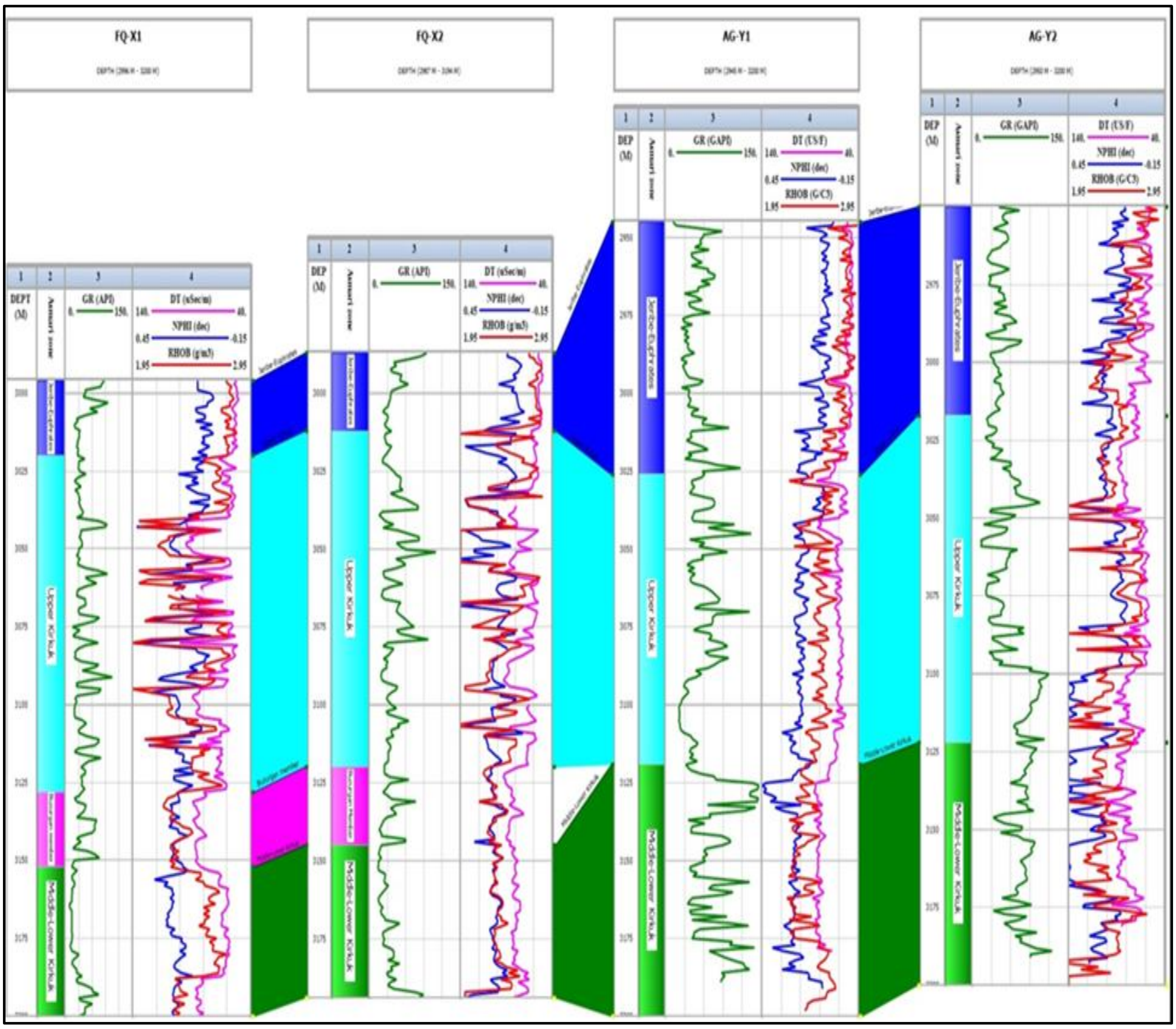

Figure 5. The horizontal correlation section shows reservoir units across the studied wells.

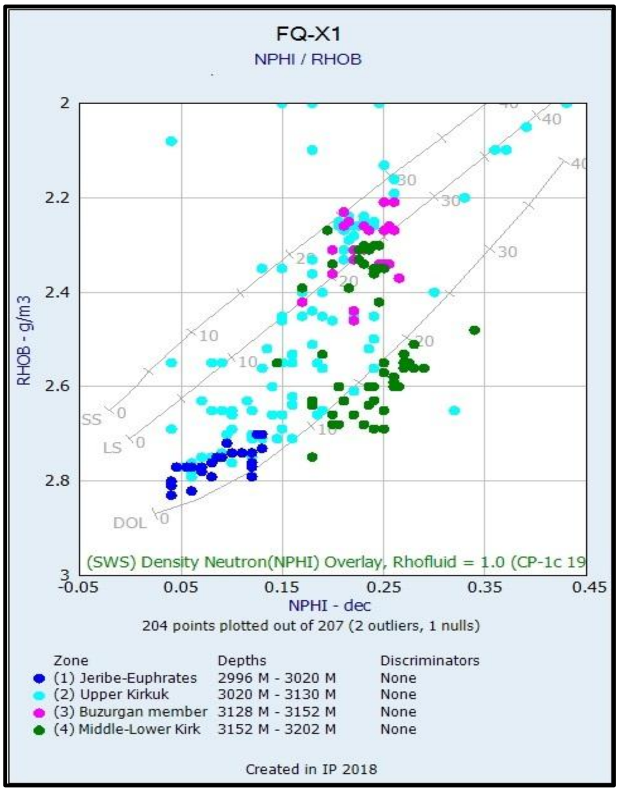

Figure 6. The neutron versus density cross plot to detect the common lithology in well FQ-x1.

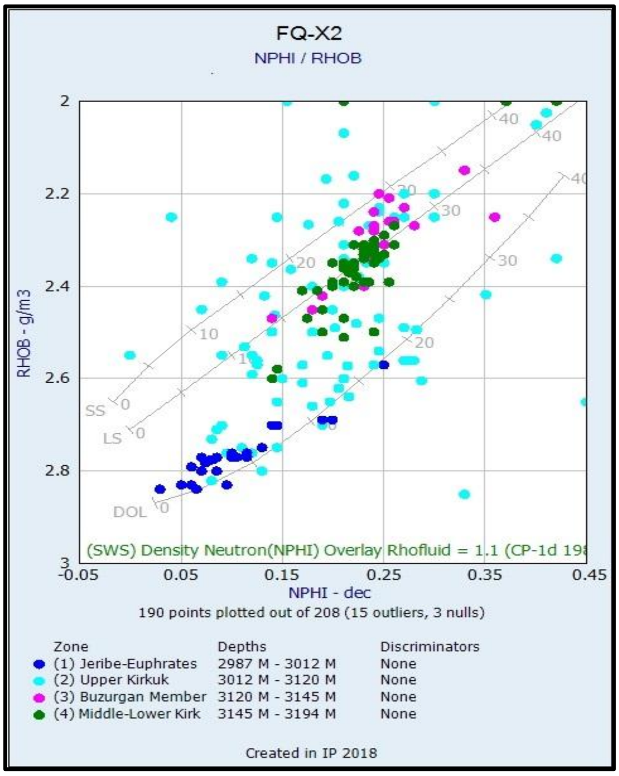

Figure 7. The neutron versus density cross plot to detect the common lithology in well FQx2.

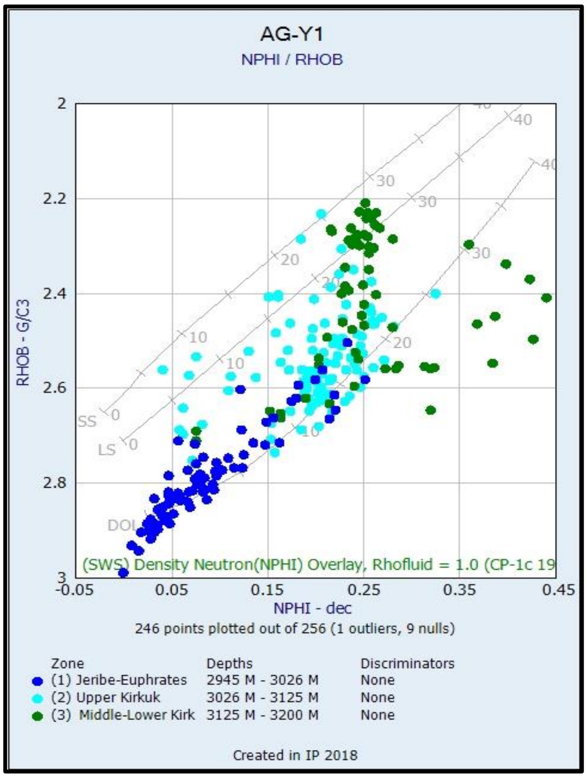

Figure 8. The neutron versus density cross plot to detect the common lithology in well AG-y1.

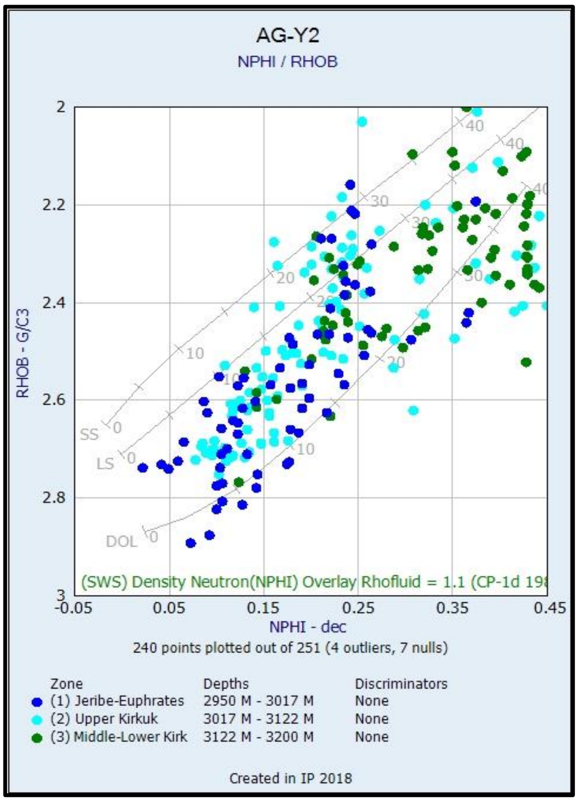

Figure 9. The neutron versus density cross plot to detect the common in well AG-y2.

6.1.1. Jeribe / Euphrates Formation (Unit A)

This unit is the topmost stratigraphic unit of the Early Miocene age. It is underlain by the Upper Kirkuk Formation and overlained by the Middle Miocene Fatha Formation (Lower Fars), which is distinguished by its composition of salt and anhydrite. This unit shows a more or less constant thickness throughout AG-wells, the same thing for FQ-wells, but the thicknesses in the former are greater than in the latter. The neutron–density cross plot showed that all the points were located within the areas of the dolomite and, to a lesser extent, the limestone, with some inclusions of anhydrite and shale.

6.1.2. Upper part of Kirkuk Group (Unit B)

This unit is the second member of this succession (Oligocene), which is overlain by dolomite from the early Miocene Jeribe/Euphrates unit and underlain by shale and siltstone from the Oligocene Buzurgan Member. The thickness of this formation changes from one well to another depending on its position in the structural fold, or the depositional basin, and the degree of settlement. Unit B, corresponding to the Upper Kirkuk, is primarily composed of dolomite, limestone, and shale. It developed on a mixed to restricted platform and serves as a significant reservoir due to its large oil reserves.

6.1.3. Buzurgan member (Unit C)

This unit of the Upper Paleogene-Early Neogene succession (Oligocene) is limited above by the Upper Kirkuk unit and below by the middle to lower Kirkuk unit (also Oligocene), which is distinguished by reduced formation density and higher neutron and acoustic log readings. The Buzargan unit lithology is predominantly sandstone, siltstone, and shale, which was deposited in a transitional environment (Mixed Platform), and it also contains limestone (especially in the AG field). This unit appears in FQ-x1 and FQ-x2 wells but disappears in wells AG-y1 and AG-y2.

6.1.4. Middle - Lower part of Kirkuk Group (Unit D)

The final unit is the Middle-Lower Kirkuk (Oligocene), which is underlain by the Jaddala Formation (Mid-Late Eocene) at the bottom and overlain by the Buzurgan member (Oligocene) at the top. It was noted from the neutron-density crossplot that all the points were located within dolomite, sandstone, and limestone. This unit, in general, is composed of limestone light, gray, highly argillaceous interbedded with shale, marl, with intercalations of dolomite, which increases in the upper part of this unit towards the Fauqi field.

6.2. Petrophysical properties

The lithological composition and variations in well log responses at units, as shown by notable changes in gamma-ray, resistivity, and porosity logs, define the petrophysical and reservoir characteristics of the Upper Paleogene-Early Neogene succession, as interpreted from the examined wells. Table 1 shows the average values of the main petrophysical properties in each unit for the studied wells. The variation of petrophysical properties will be shown vertically through single wells using computer processing interpretation (CPI) as illustrated in Figures 10, 11, 12, and 13. Starting with the thicknesses of units, it is clear that the thickness of the Jeribe/Euphrates Formation is decreasing toward SE from AG to FQ fields, while Upper Kirkuk shows stability in its thickness. Buzurgan member appears in a number of wells in the AG field and does not appear on other wells, such as the studied wells AG-y1 and AG-y2, but appears in all wells of the Fauqi field. Finally, from the wells that penetrated Middle-Lower Kirkuk. It is clear that this formation has a thickness higher than the others, especially in the FQ field. The porosity distribution is illustrated in the CPI figures. At the beginning of the Jeribe/Euphrates unit, it is evident that recorded porosity in this unit is generally poor in the AG field based on Leverson's (1972) porosity classification. However, the lower section of well AG-y2 stands out, showing a porosity of approximately 0.31. Effective porosity is improved toward the FQ field, especially in well FQ-x2, as shown by CPI figures. Porosity distribution through the Upper Kirkuk unit is improved toward the FQ field direction, which has good to very good porosities in that sector, but is decreasing toward AG wells, except for the upper part of well AG-y2. The porosity in the Buzurgan member in both FQ wells is homogeneous and has good values higher than 0.11. The porosity in Middle - Lower Kirkuk. unit in AG field is subjected to changing values along this unit which has a good porosity, while the top of the culmination have bad porosity, this may be ascribed to the influence of existence of shale where it leads to decrease porosity, but some places their porosity is increased due to the effect of dolomitization and presence of sand stone. In the FQ field, the porosity is high in most parts of the field except in the lower parts of wells, which is also ascribed to the effect of the diagenesis process, as clearly shown in the secondary porosity index (SPI) curves in well FQ-x2.

Table 1. Mean petrophysical properties of the units in the studied wells.

WELLS	UNITS	Thickness (m)	Vsh (dec.m)	PHIE	SW
FQ-x1	J-E unit	25	0.157	0.077	0.368
	U.K unit	111	0.121	0.189	0.338
	B.M	25	0.102	0.241	0.593
	M-L.K unit	51	0.047	0.223	0.585
FQ-x2	J-E unit	26	0.142	0.071	0.566
	U.K unit	109	0.113	0.234	0.363
	B.M	26	0.081	0.279	0.492
	M-L.K unit	50	0.100	0.235	0.757
AG-y1	J-E unit	82	0.066	0.036	0.835
	U.K unit	100	0.096	0.124	0.664
	M-L.K unit	76	0.195	0.113	0.998
AG-y2	J-E unit	68	0.080	0.111	0.457
	U.K unit	106	0.122	0.120	0.744
	M-L.K unit	70	0.267	0.146	0.769

Water saturation in general is low in the Jeribe/ Euphrates unit and Upper Kirkuk unit, so it is regarded as the main reservoir unit, while the other units are not oil-bearing zones. The sw values in the Buzurgan member in the FQ field are generally high, except in some places in the upper and middle parts of well FQ-x1, which are characterized by low values. The Middle-Lower Kirkuk unit is characterized by a water-bearing zone due to high values of water saturation except for well FQ-x1.

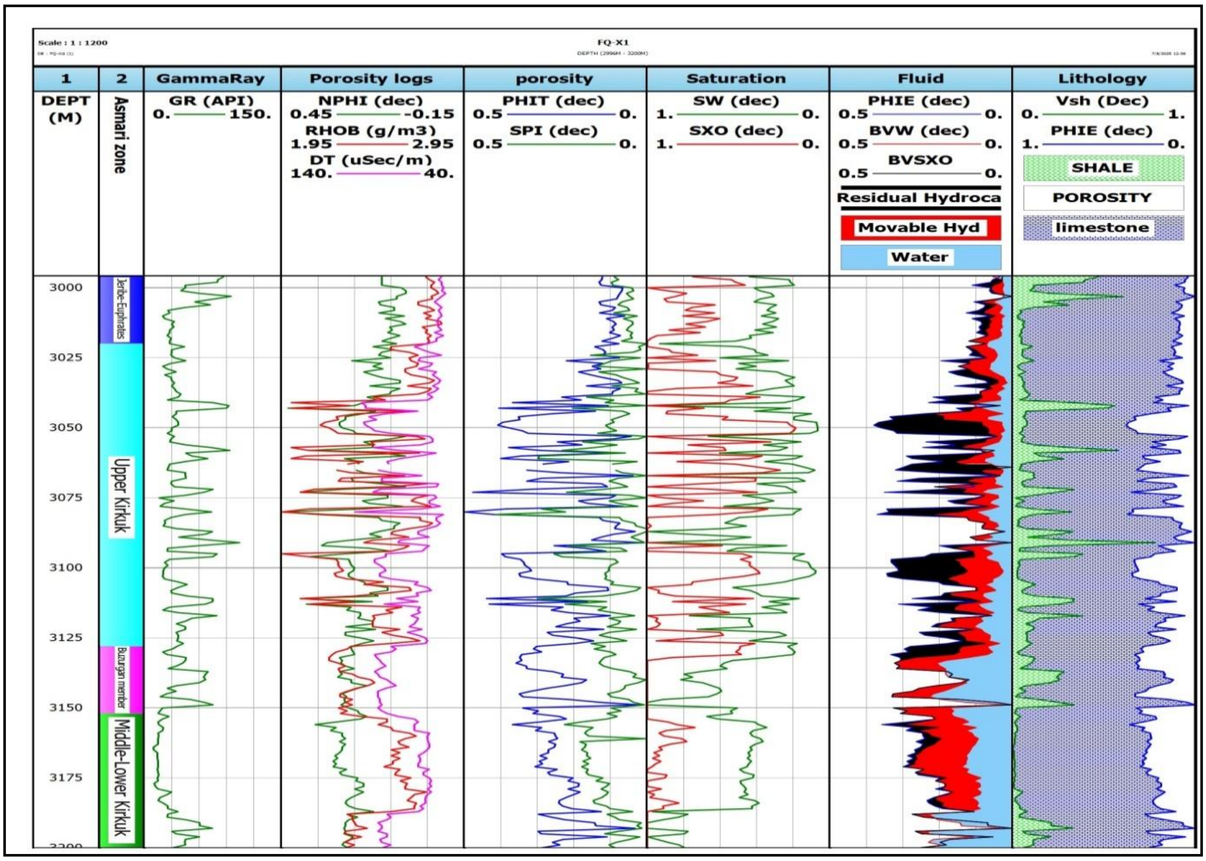

Figure 10. Computerized processing interpretation (CPI) of well FQ-x1

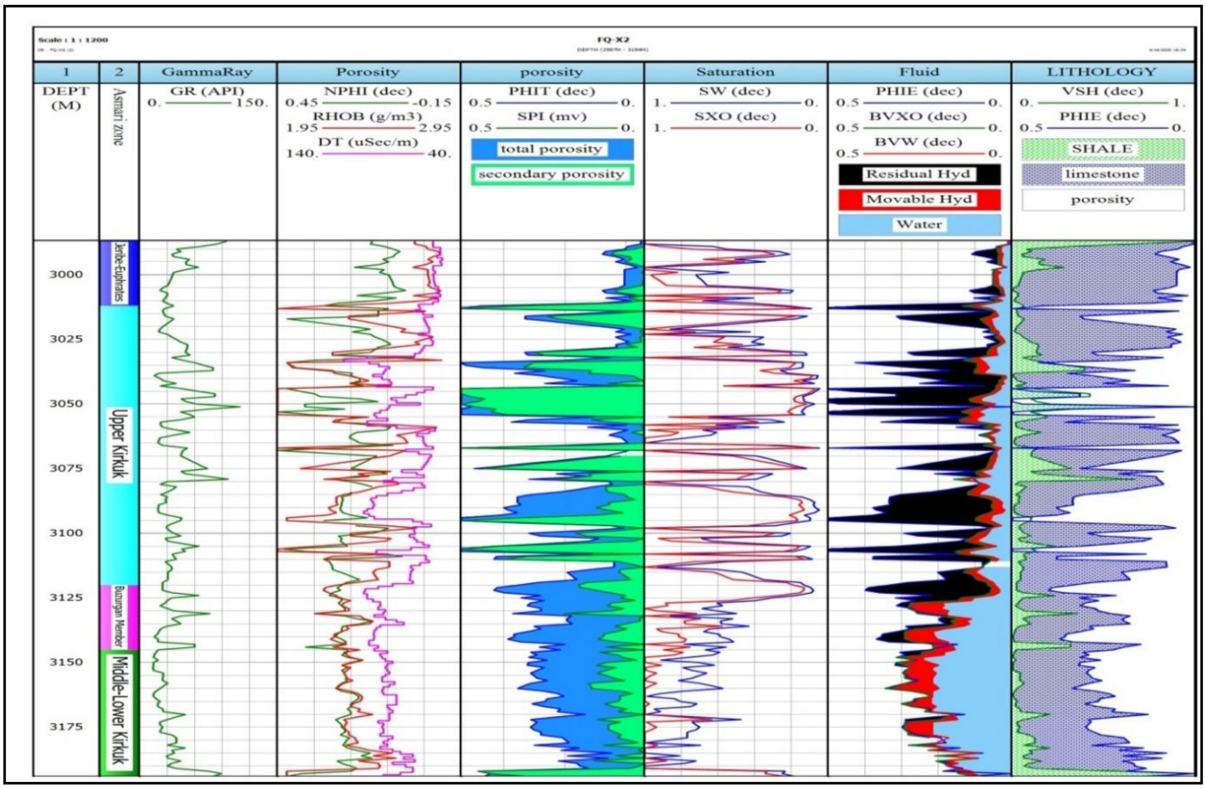

Figure 11. Computerized processing interpretation (CPI) of well FQ-x2.

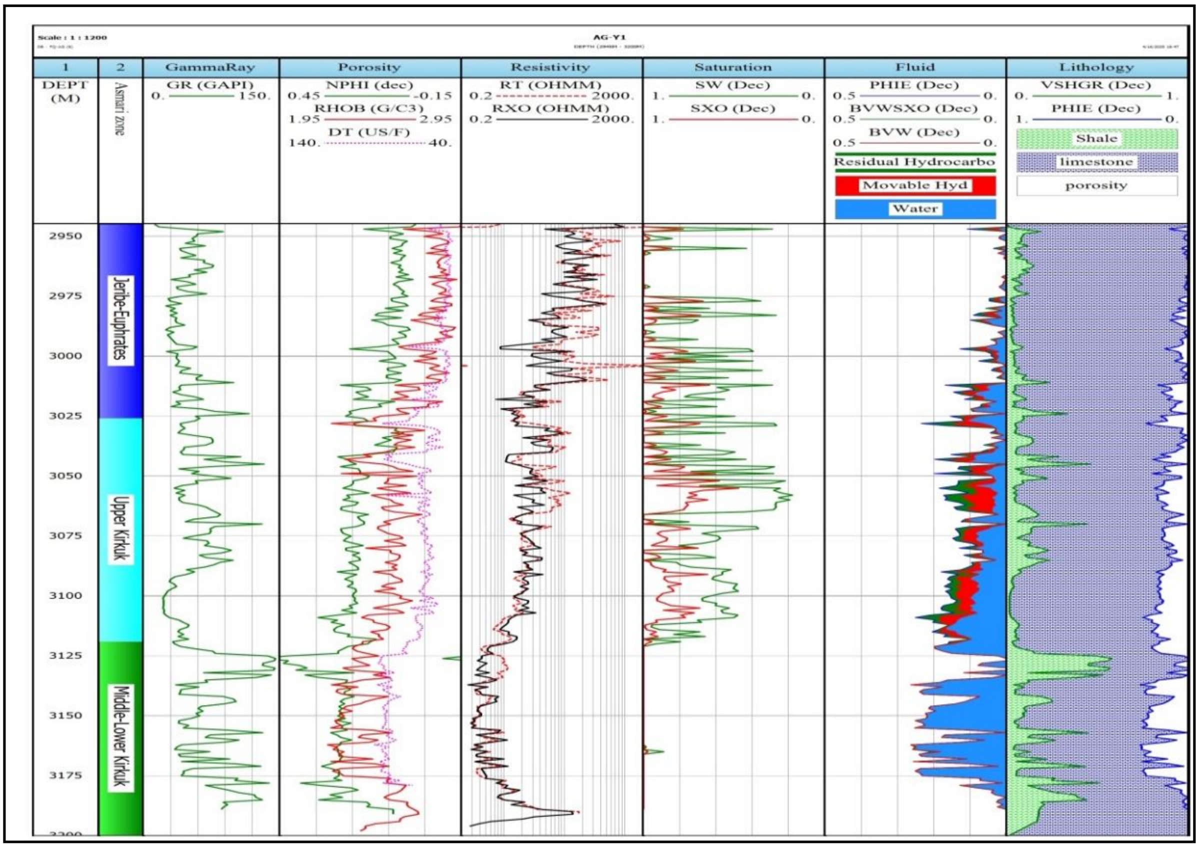

Figure 12. Computerized processing interpretation (CPI) of well AG-y1.

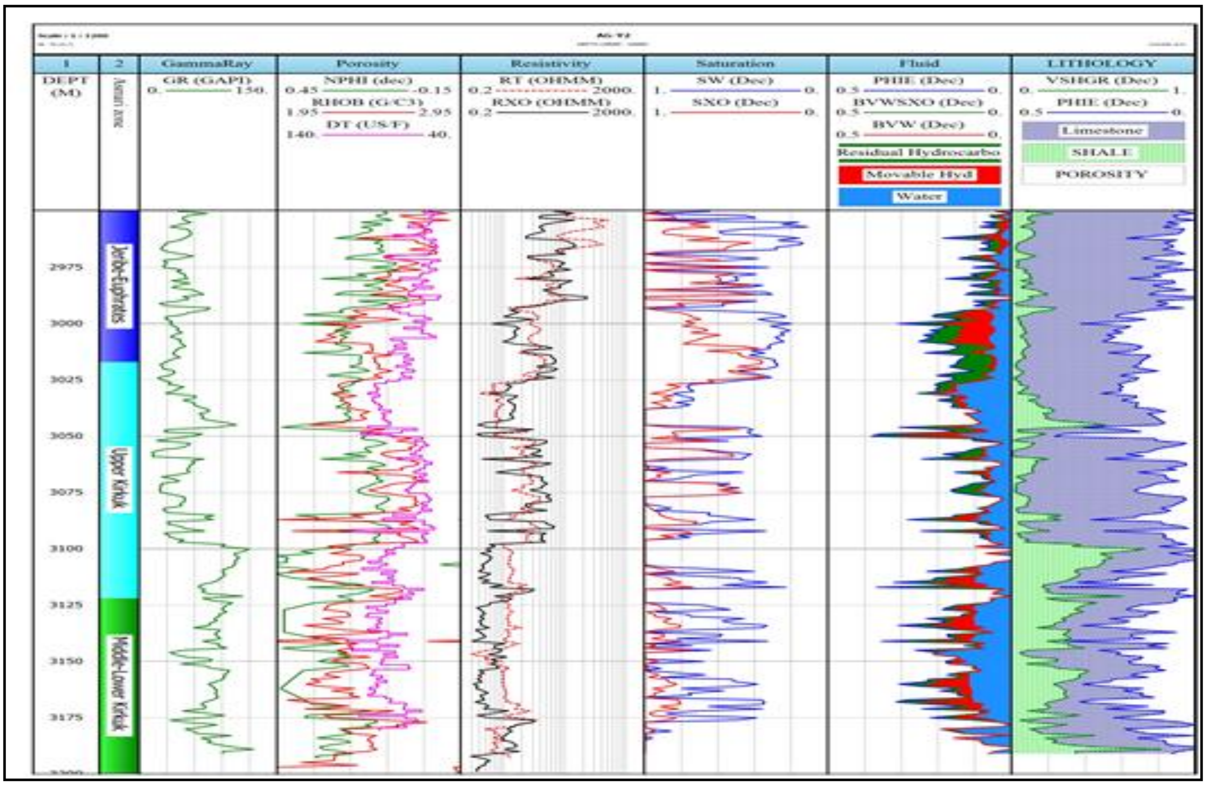

Figure 13. Computerized processing interpretation (CPI) of well AG-y2.

7. CONCLUSIONS

According to the well logs interpretations as shown in CPI figures, the Upper Paleogene-Early Neogene succession exhibits rapid and broad variations in its geological and petrophysical character on various scales. These variances are mostly due to the presence of various depositional settings, as well as the subsequent tectonic and diagenetic processes. The Upper Paleogene-Early Neogene succession is divided into four units according to the log behavior and lithology: these stratigraphic units include Jeribe / Euphrates (Unit A), upper Kirkuk (Unit B), Buzurgan member (Unit C), and Middle-Lower Kirkuk (Unit D). The Jeribe /Euphrates unit mainly consists of dolomite, limestone, and shale, with occasional anhydrite layers. Unit B, representing the Upper Kirkuk, is predominantly composed of dolomite, sandstone, limestone, and shale, developed in a mixed to restricted platform setting. This unit is particularly important as a reservoir because of its high hydrocarbon saturation. The Buzurgan member's lithology is predominantly sandstone, siltstone, and shale, which was deposited in a transitional environment (Mixed Platform). Unit Middle-Lower Kirkuk's lithology mainly consists of sandstone, accompanied by limestone and shale. This unit is represented by high water saturation. In general, porosity is rising in the south-east of the Abu Ghirab field, while it is increasing in the north-west of FQ. J-E has very low porosity due to the presence of anhydrite, which damages the porosity. It is improved downward in unit B. and unit C. Water saturation in general is low in unit A and unit B., so it is regarded as the main reservoir units.

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