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Spectral gamma-ray and conventional logs to evaluate hydrocarbon potentiality in Bahareya Formation, Hayat oil field, Northwestern Desert, Egypt

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Abstract: Different reservoir parameters (volume of shale, total and effective porosities, water saturation and hydrocarbon saturation) of Bahareya Formation were calculated in Hayat-1 well to determine the lithology of rocks and possibility of hydrocarbon accumulation. The volume of shale percentage along the well ranges from 10 to 40%. Meanwhile the depth ranging from 2020 to 2039 m are occupied by clay deposits, in which the values reach more than 75%. Different new applications using spectral gamma-ray logs, as thorium normalization and radiogenic heat production were applied to determine hydrocarbon accumulation zones and differentiate between source and reservoir rocks. The results of radioactive techniques agree well with the results of reservoir parameters, which were calculated from conventional logs, by a percentage ratio that reach more than 80%.

Key words: spectral gamma-ray, Bahareya formation, radiogenic heat production

1. Introduction

The Western Desert of Egypt, especially its northern part, is considered one of the promising areas where many oil fields are recorded. The reservoir rocks vary between clastic and limestone rocks. Besides, sediments bearing hydrocarbons differ in terms of sedimentation time, from Paleozoic sediments to Cenozoic sediments.

The Bahareya Formation, which was formed in the Mesozoic era, about 70 million years ago, and which consists of sandstone with intercalations of clay deposits (*Schlumberger, 1995*), is considered one of the important formations on which many geological and geophysical studies were carried out to determine its petrophysical properties and study the extent of its importance as source and reservoir rocks (*Abd-El Gawad et al., 2015*). This formation is also characterized by the presence of a complete exposed sec-

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tion in Jabal El-Dest area in Bahareya Oases in the Western Desert, which facilitated the conduct of many studies on this formation.

Conventional well logging has a fundamental role in evaluating the petrophysical properties of rocks, such as determining the percentage of shale volume in the rock, as well as both the percentage of water and hydrocarbon saturation. All these parameters have an effective role in determining the percentage of total and effective porosities in the rocks. This determines the extent of the pores, the ability of various fluids to pass through them, and the quality of the reservoir.

Recently, spectral gamma-ray logs were relied upon to define zones containing hydrocarbon materials, and heat generated by the radioactive decomposition of radioactive elements, which has a role in determining the extent of the maturity of hydrocarbon materials in the rocks. An equation has been derived by calculate the accurate values of the percentage of shale volume in the rock. Perhaps the most recent application is the use of spectral gamma ray logs to differentiate between reservoir rocks and source rocks (*Saunders et al., 1993*).

2. Geological setting

The Western Desert in Egypt represents nearly two-thirds of the Egypt's total surface area. Geographically, this area lies between the River Nile in the east and the Libyan Desert in the west. Subsurface studies have proven the existence of a group of sedimentary basins, the depths of which vary between shallow and deep (*Schlumberger, 1995*).

The stratigraphic column in the northern part of the Western Desert contains much of the sedimentary succession from Precambrian basement rocks to recent sediments. The sedimentary cover thickness in the NW Desert region ranges from 2990 to 10670 m. Marine transgression led to many severe deformations of the sedimentary rocks that make up most of basins in the Western Desert. These marine transgressions took place in three different periods, starting from middle of Paleozoic Era and during the end of this Era, while the third transgression was during the middle of the Mesozoic Era, (*Schlumberger, 1995*).

Hayat oil field is located at the confluence of the Matrouh and Shushan Basins in the Northwestern Desert of Egypt (Fig. 1). These two basins are filled with thick sediments of Lower Cretaceous and Jurassic. Hydrocarbon materials were seen through exploratory wells in this field in six zones in Alam Al-Bueib Formation, in addition to Bahareya Formation, (*El-Ayouty, 1990*).

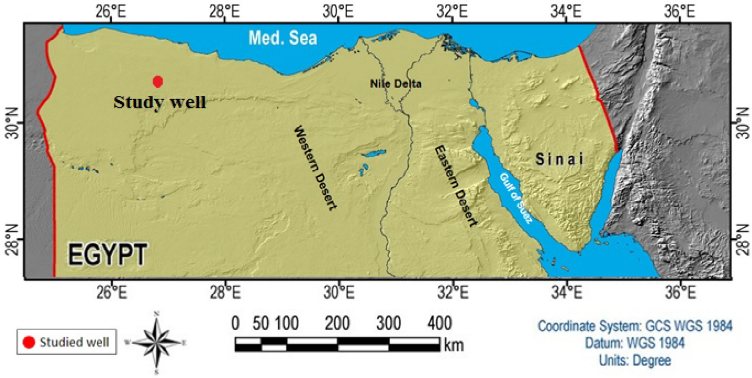

Fig. 1. Location map of the studied Hayat-1x well (Hayat oil field, Northwestern Desert, Egypt).

Closure structures (three- and four-way fault blocks) were formed, which acted as traps for hydrocarbon materials in these basins. These blocks were formed in the direction of the Syrian Arc structural trend (*Teama and Nabawy, 2016; Shehata et al., 2020, 2021; Nabawy et al., 2022*).

Abu-Shady et al. (2010) stated that, shale and mixed medium to coarse-sandstone grains are the main components of Bahareya Formation, with some carbonate traces (Fig. 2). Depending on the integration of seismic achievements and the calculated petrophysical parameters of both Bahareya (Lower and Upper) Members, some zones of Bahareya Formation are shown to be promising for oil production (*El-Dally et al., 2023*).

The organic content of Bahareya Formation varies from poor to very rich content and the potential source is well generated with Kerogen type II/III. Reduction conditions led to the contribution of terrestrial organic matter with essential marine organic matter, as is evident from the isoprenoids data (*Abd-El Gawad et al., 2015*).

3. Methodology

Evaluating the reservoir parameters as volume of shale, total porosity, effective porosity, water saturation and hydrocarbon saturation were calculated

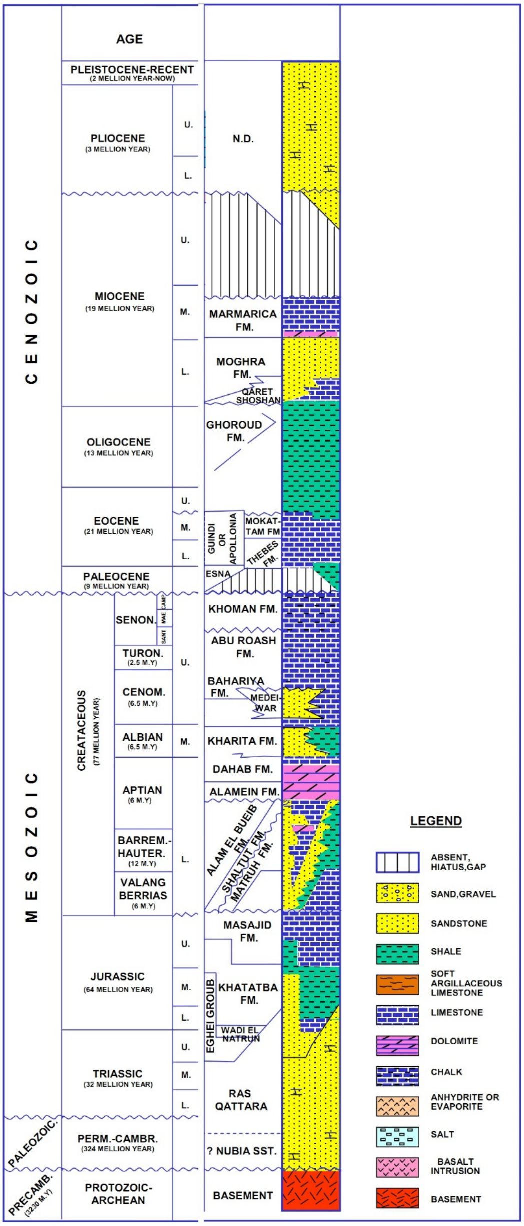

Fig. 2. Stratigraphic column of the NW Desert, Egypt (*Schlumberger, 1995*).

depending on the conventional logs: GR, deep resistivity, neutron and density logs.

Volume of shale (Vsh) which is considered as the main reservoir parameter was calculated using the equation derived by *Dresser Atlas (1979)*, who states that, the Gamma-ray Index (GRI) can be calculated as:

$$\mathrm{I_{GR}} = \frac{\mathrm{GR_{log}} - \mathrm{GR_{min}}}{\mathrm{GR_{max}} - \mathrm{GR_{min}}}\,,$$

where: $\mathrm{I_{GR}}$ is Gamma-ray Index, $\mathrm{GR_{log}}$ is gamma-ray reading value, $\mathrm{GR_{min}}$ is minimal gamma-ray value, $\mathrm{GR_{max}}$ is maximal gamma-ray value.

Radiogenic heat production (RHP) values were calculated depending on the concentration values of the different radioactive elements (K, eU and eTh) and rock density values using the *Rybach (1988)* equation:

$$\mathrm{A}(\mu\mathrm{W/m^3}) = 10^{-3} \times \rho\,[(95.2 \times \mathrm{eU}) + (25.6 \times \mathrm{eTh}) + (34.8 \times \mathrm{K})]\,,$$

where: A is the radiogenic heat production (μW/m^3), ρ is the rock density (g/cc).

According to *Nabih and Al Alfy (2021)*, the RHP values can be used to differentiate between source and reservoir rocks.

Saunders et al. (1993) derived an equation to determine the hydrocarbon accumulation zones depending on the distribution of radioactive elements in the rocks. They stated that eU and K values were normalized to eTh values and if the resulted (DRAD) values are positive, then they indicate a hydrocarbon accumulation zone. They called this technique: thorium normalization. The thorium normalization equations can be illustrated as:

$$\mathrm{Ki} = \frac{\mathrm{mean\,Ks}}{\mathrm{mean\,eThs}} \times \mathrm{eThs}\,,$$

$$\mathrm{eUi} = \frac{\mathrm{mean\,eUs}}{\mathrm{mean\,eThs}} \times \mathrm{eThs}\,,$$

where: Ki is the ideal potassium value, eUi is the ideal equivalent uranium value, Ks is the reading potassium value, eUs is the reading equivalent uranium value, Ths is the reading equivalent thorium value.

Deviation of the real values from the calculated ones for each reading were obtained using the following two equations:

$$\mathrm{KD\%} = \frac{\mathrm{Ks} - \mathrm{Ki}}{\mathrm{Ks}}\,,$$

$$\mathrm{eUD\%} = \frac{\mathrm{eUs} - \mathrm{eUi}}{\mathrm{eUs}}\,,$$

where: KD% and eUD% are the relative deviations expressed as a fraction of the reading value.

KD% and eUD% variations can be combined as a single positive number, DRAD, which is the difference between both of them:

$$\mathrm{DRAD} = \mathrm{eUD\%} - \mathrm{KD\%}\,.$$

The application of Thorium normalization on ground or aerial spectral gamma-ray data was used. There have been many attempts to apply this method to well logging. To confirm the possibility of identifying hydrocarbon accumulation zones in subsurface rocks in wells and to compare these zones with those identified from conventional well logs by calculating reservoir properties, we refer to (*Al-Alfy et al., 2013; Skupio and de Alemar Barberes, 2017; El-Khadragy et al., 2018* and others).

Total organic carbon (TOC) percentage was calculated from an empirical equation derived by (*Schmoker, 1989*), depending on density log values, where the density range of organic carbon is 1.2 − 1.4 g/cc and the density of clay minerals is 2.7 g/cc. The equation can be used as:

$$\mathrm{TOC} = (157/\rho\mathrm{b}) - 58.3\,,$$

where: ρb is bulk density.

Log-Wizard software was used to calculate the different reservoir parameters from well logging data. The results and lithology were collected and drawn by well Cad program.

4. Results and discussion

Traditional methods for calculating the petrophysical properties of rocks rely on using conventional well log data, such as: total gamma-ray, resistivity, density and neutron logs. Figure 3 shows the properties that were calculated for the rocks using Log Wizard program. These properties are represented in the calculations of volume of shale, total porosity, effective porosity, water saturation, and hydrocarbon saturation percentages. The

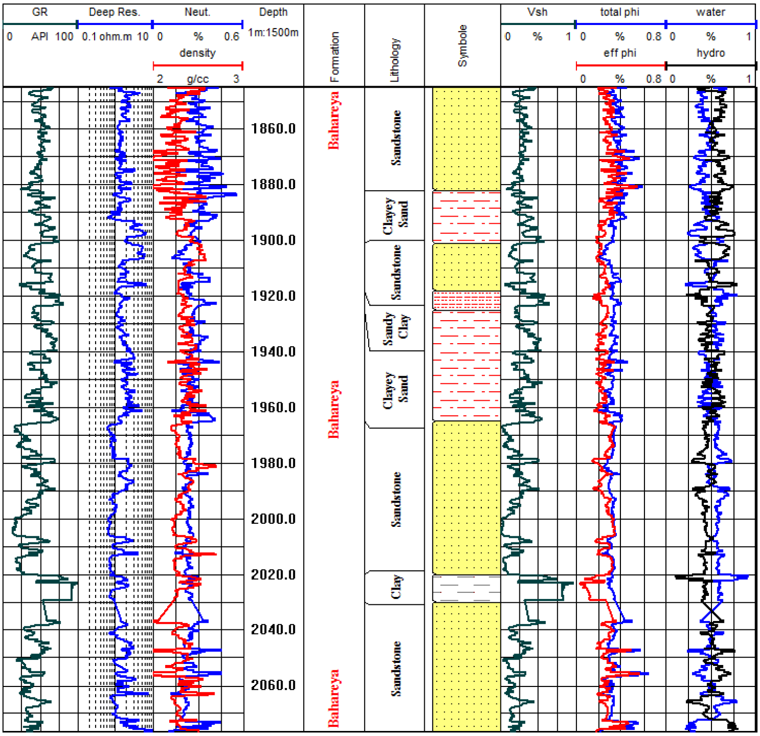

Fig. 3. Calculated reservoir parameters using conventional logs of Bahareya Formation, Hayat-1x well, Hayat oil field, Northwestern Desert, Egypt.

lithological composition of Bahareya Formation in the studied well was derived depending on the petrophysical parameters of the rocks.

It is clear from Fig. 3 that sandstones, as well as clay sandstones, sandy mudstones and clays are associated with the range in which the volumes of shale percentage range from 0 to 25%, 25 to 50%, 50 to 75% and more than 75%, respectively.

Figure 4 illustrates that, the DRAD values, which are calculated from the spectral gamma-ray logs (K, eU and eTh) range from −2 to 2, where positive DRAD values, indicating hydrocarbon accumulations are seen in zones varying in depth from 1850 to 1880 m, 1950 to 1960 m and 1985 to 2015 m. Meanwhile, negative DRAD values indicating hydrocarbon-free zones are observed in zones ranging in depth 1895 to 1915 m, 1960 to 1975 m and 2055 to 2075 m.

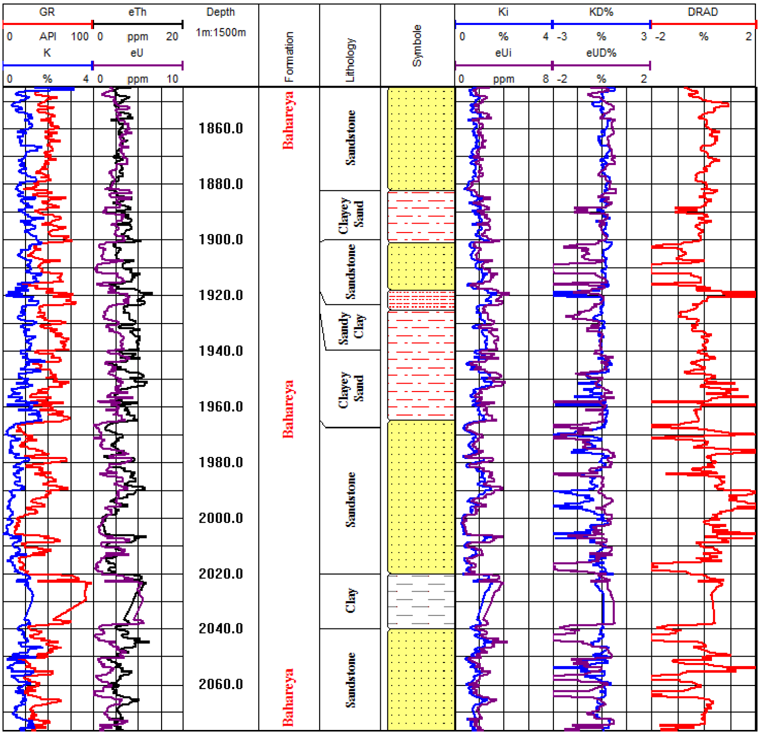

Fig. 4. Results of thorium normalization technique of Bahareya Formation, Hayat-1x well, Hayat oil field, the NW Desert, Egypt.

The radiogenic heat production (RHP) values were found to range from 0.2 to 2.3 μW/m^3 for clastic sediments of Bahareya Formation along the studied well. The statistical analysis of RHP values illustrates that there arithmetic mean ($\bar{X}$) reaches 0.98 μW/m^3, and the standard deviation (D) value attains 0.37 μW/m^3.

Figure 5 shows that the RHP values reach more than 0.98 μW/m^3, indicating the presence of hydrocarbon-bearing zones similar to the zones oscillating in depth from 1845 to 1874 m, 1928 to 1967 m and 2020 to 2039 m. The values of RHP ranging from 0.98 to 1.35 μW/m^3 indicate that the reservoir rocks are found as in zones changing depth from 1845 to 1874 m, 1928 to 1967 m. Meanwhile the RHP values reaching more than 1.35 μW/m^3, indicate source rocks, such as in the zone varying in depth from 2020 to 2039 m, which is associated with clay sediments. From the cal-

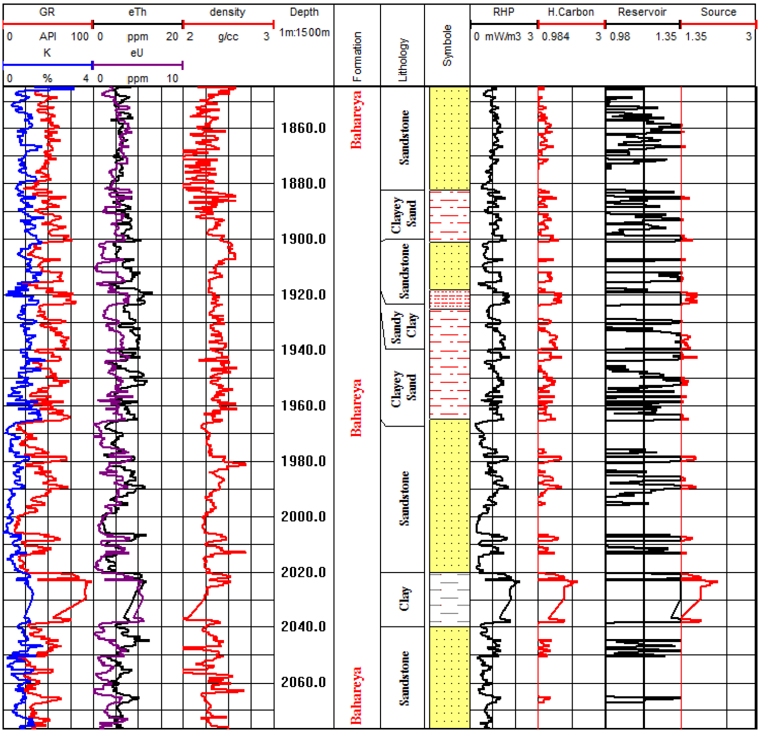

Fig. 5. Results of Radiogenic Heat Production (RHP) technique of Bahareya Formation, Hayat-1x well, Hayat oil field, Northwestern Desert, Egypt.

culations of RHP values, differentiation between source and reservoir zone can be reached easily.

5. Data integration

The results of different calculations as thorium normalization technique, radiogenic heat production (RHP) and total organic carbon (TOC) were integrated to ensure the hydrocarbon-bearing zones and the hydrocarbon-free zones (Fig. 6). From this figure, it can be shown that the depth ranges from 1845 to 1874 m, containing high TOC, positive DRAD and RHP values higher than arithmetic mean are related to sandstone reservoir rocks. Meanwhile the depth ranging from 2020 to 2039 m containing high TOC, positive DRAD, and RHP values higher than arithmetic mean (+1 St.D.)

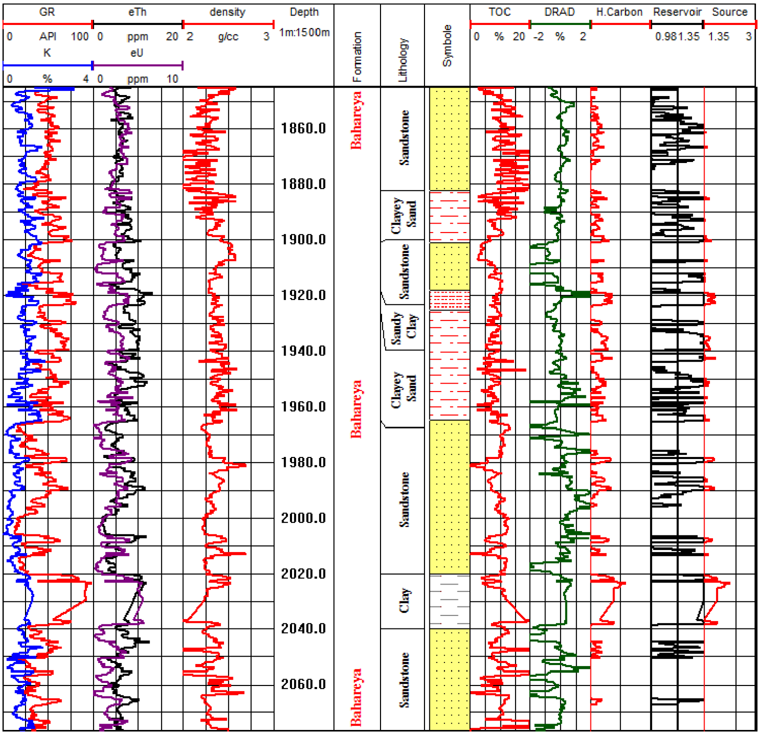

Fig. 6. Integration of thorium normalization, Radiogenic Heat Production (RHP) and Total Organic Carbon (TOC) techniques of Bahareya Formation, Hayat-1x well, Hayat oil field, the NW Desert, Egypt.

are related to clay sediments as source rocks. But, for depth range 1900 to 1910 m contains low TOC, negative DRAD and less than arithmetic mean of RHP values, are related to sandstone hydrocarbon-free zone.

6. Conclusions

The lithological composition of Bahareya Formation consists of different clastic rocks as sandstone, clayey sandstone, sandy clay and clay sediments.

The results of thorium normalization technique indicate that Bahareya Formation contain hydrocarbon bearing zones and other hydrocarbon-free zones.

Radiogenic heat production (RHP) values of Bahareya Formation range from 0.2 to 2.3 μW/m^3, with arithmetic mean value 0.98 μW/m^3 and a standard deviation of the values reaching more than 0.98 μW/m^3 indicate hydrocarbon-bearing zones. Depending on the calculated arithmetic mean and standard deviation values of RHP, differentiation between source and reservoir rocks can be easily seen.

The total organic carbon (TOC) percentage in Bahareya Formation sediments ranges from 0% to 20%. The high TOC values are observed to be related to positive DRAD and RHP values, reaching more than 0.98 μW/m^3.

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