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Radiogenic heat production to differentiate source and reservoir rocks of Bahariya formation, Tut oil field, Northwestern Desert, Egypt.

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Abstract.
Differentiation between source and reservoir rocks requires the presence of many geological, petrophysical, and geochemical data. The scope of this research is to evaluate a new approach to distinct source rocks from reservoir rocks by calculating the heat that results from the decaying of radioactive minerals in the rocks. Radiogenic heat production (RHP) values were calculated in ten wells penetrating the studied Bahariya formation in Tut oil field, Northwestern Desert, Egypt. The mean value of (RHP) is calculated as 0.88 μW/ m^3, while the standard deviation value is 0.32 μW/m^3. The zones with average values of more than (0.88) are referred to be the ones that have higher amounts of total organic carbon materials (TOC). The RHP value ranging from an average value from (0.88 μW/ m^3) to the sum of this value plus one standard deviation (1.21) is recorded in low shale content zones which are considered reservoir rocks. The RHP values of more than 1.21 were recorded related to the zones of a moderate and high volume of shale content, which can be considered source rocks.

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I. Introduction.

Radiogenicheat production (RHP) rate in crustal rocks is dominated by contributions from three radioactive elements uranium (U), thorium (Th) and potassium (K). Thesehave long half-lives comparable to the age of the Earth. During radioactive decay, mass is transformedinto energy. The energy of the emitted particles and the gamma radiation associated with different decay processes is absorbed in rocks to be finally transformed into heat (**Clauser,2011**)

It was found through a study conducted by **(Al-Alfy and Nabih, 2013)** that the high radiogenic heat production zones in oil fields are related to zones that have amounts of hydrocarbon accumulations. The first differentiation between source and reservoir rocks using the statistical analysis of radiogenic heat production values was applied by (**Nabih and Al-Alfy, 2021**). The radioactive content of the source rocks (fine grains) as shales is higher than that of the reservoir sandstone rocks (**Ehinola et al., 2005**).

Total organic carbon (TOC) is a measure of the organic richness of rock: that is, the quantity of organic carbon (both kerogen and bitumen) in a rock sample (**Jarvie, 1991; Peters and Cassa, 1994**). TOC is reported as a weight percentage (wt.%) carbon (e.g., 1.0 wt.% carbon means that in 100 g of a rock sample, there is 1 g of organic carbon).

Total organic carbon can be directly calculated from well logging data such as gamma-ray, sonic, neutron, density, and resistivity logs.**Schmoker (1989)**, This study was carried out using different well logging data (Density) logs for Bahariya Formation of ten wells in Tut oil field, north of Western Desert, Egypt (**Fig. 1,2**).

Geologic setting

The Western Desert of Egypt is a part of a Jurassic–Cenomaniancontinental margin, which evolved with the opening and development of the Neo-Tethys Ocean (**El Emam et al., 1990**). The Bahariya Formation is identified at its type locality in Gebel El Dist, Bahariya Oasis (**Norton, 1967**), where the base of the formation was buried and distinguished in the nearby Bahariya-1 well. The Bahariya Formation covers the Kharita Formation conformably and is overlain by the Abu Roash Formation throughout the Western Desert (**Fig. 2**). Bahariya Formation consists mainly of fine sandstone and shale; however, thin limestone interbeds are documented irregularly and not easily correlatable between adjacent wells (**Fig. 3**). It was deposited in a marginal shallow marine to the inner neritic environment (**Mansour and Tahoun, 2018**), which became middle neritic in the extreme north (**Tahoun et al., 2018**). The surface and subsurface structural and stratigraphicalaspects of the Western Desert were the subject of many studies, suchas **Said (1962 and 1990),**

Norton (1967), Elouiand Abdine (1972), Deibis (1978), Parker (1982), Meshref (1982 and 1990), Awad (1985), Wanas and Assal (2020), Farrag et. al, (2021). The common thickness of the Bahariya Formation in the northern part of the Western desert is approximately 1000 ft. (**EGPC, 1992**). The thickness of the Bahariya formation (**Fig. 4**) shows that the thickness range from 149.9 ft. in the middle eastern part to 180.4 ft. in the northwestern part

Tut oil field is located in the Shoushan basin Potential hydrocarbon source rocks in Shoushan Basin are found in the Jurassic and Cretaceous successions (**El Ayouty, 1990; Ghanem et al., 1999; Khaled,1999; Sharaf, 2003; El-Nady et al., 2003 and Alsharhan and Abd El-Gawad, 2008**).

The Shushan and Matruh basins were initiated during the Permo-Triassic as single rift-basins and developed into broad down warp structures as a collapsed crest of a territorial high developed during the Late Cimmerian Orogeny in Late Jurassic until Early Cretaceous (**Kerdany and Cherif, 1990; EGPC, 1992**). Additionally, the Shushan Basin is bounded by WSW-ENE oriented faults, whereas the Matruh Basin is bordered by NNE-SSW trending faults (**Sultan and Halim, 1988**).

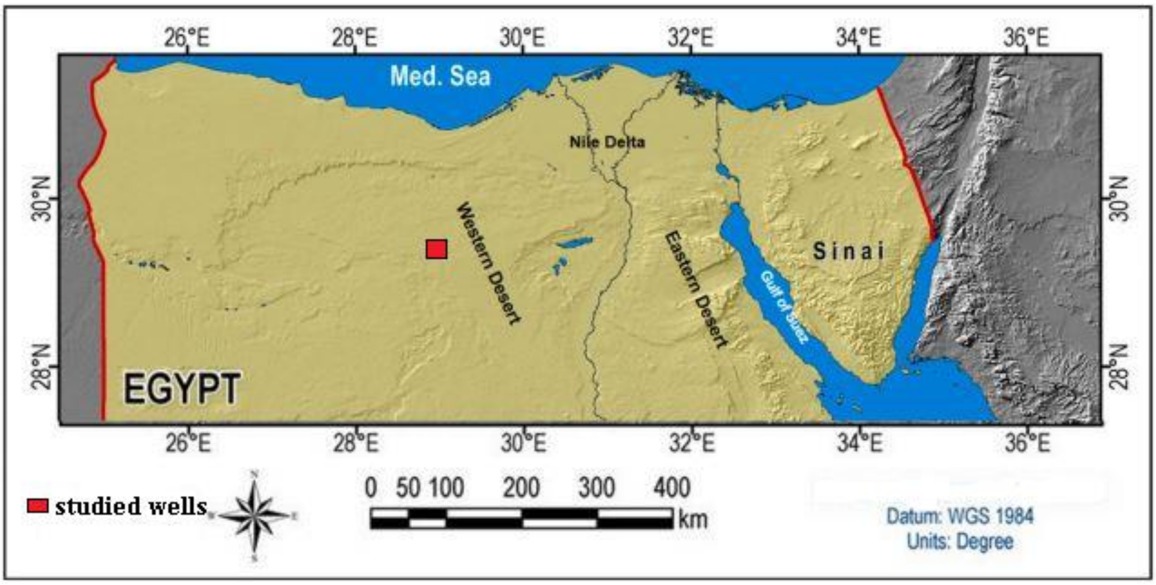

Fig. (1): location map of Tut oil field, Northwestern Desert, Egypt

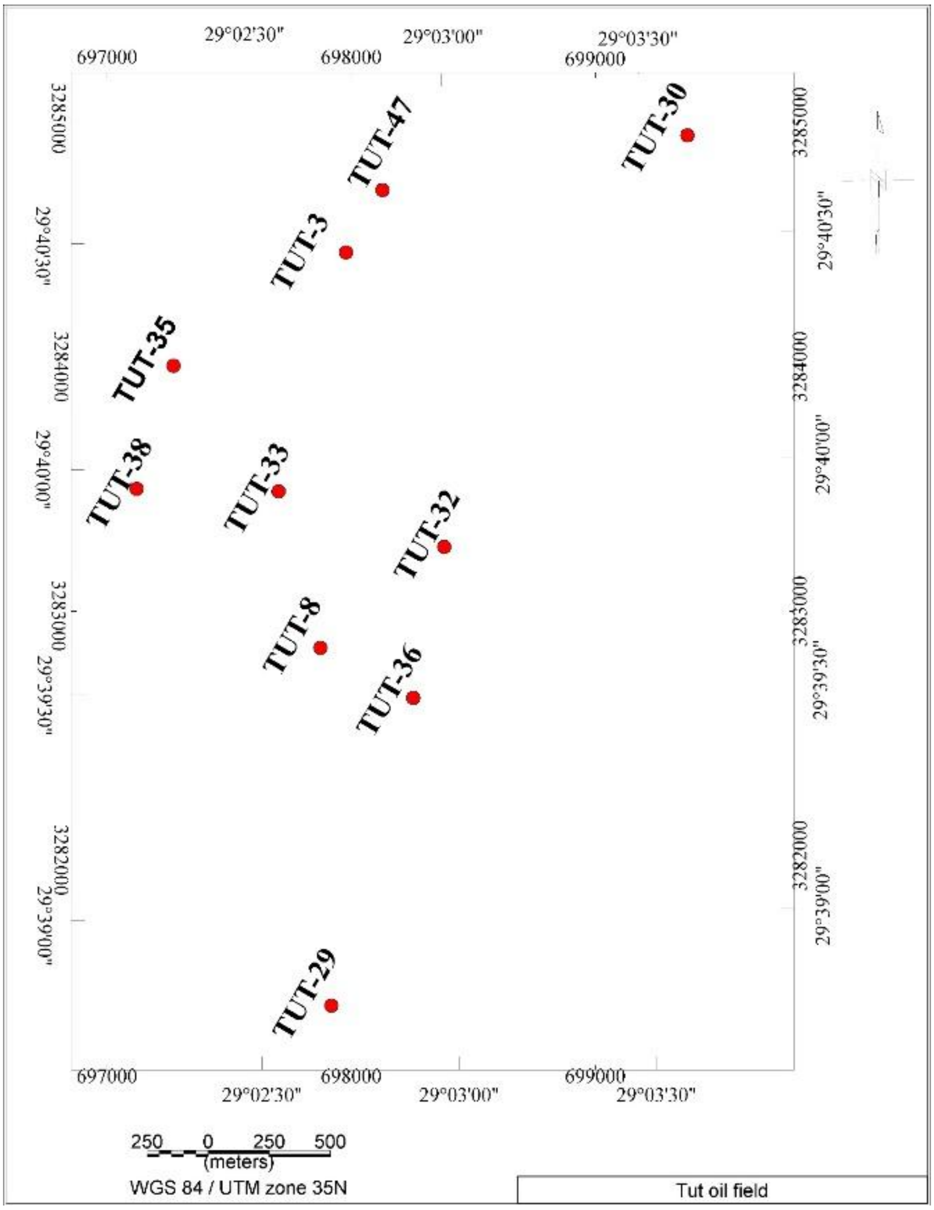

Fig. (2): location of studied ten wells in Tut oil field, Northern Western Desert, Egypt.

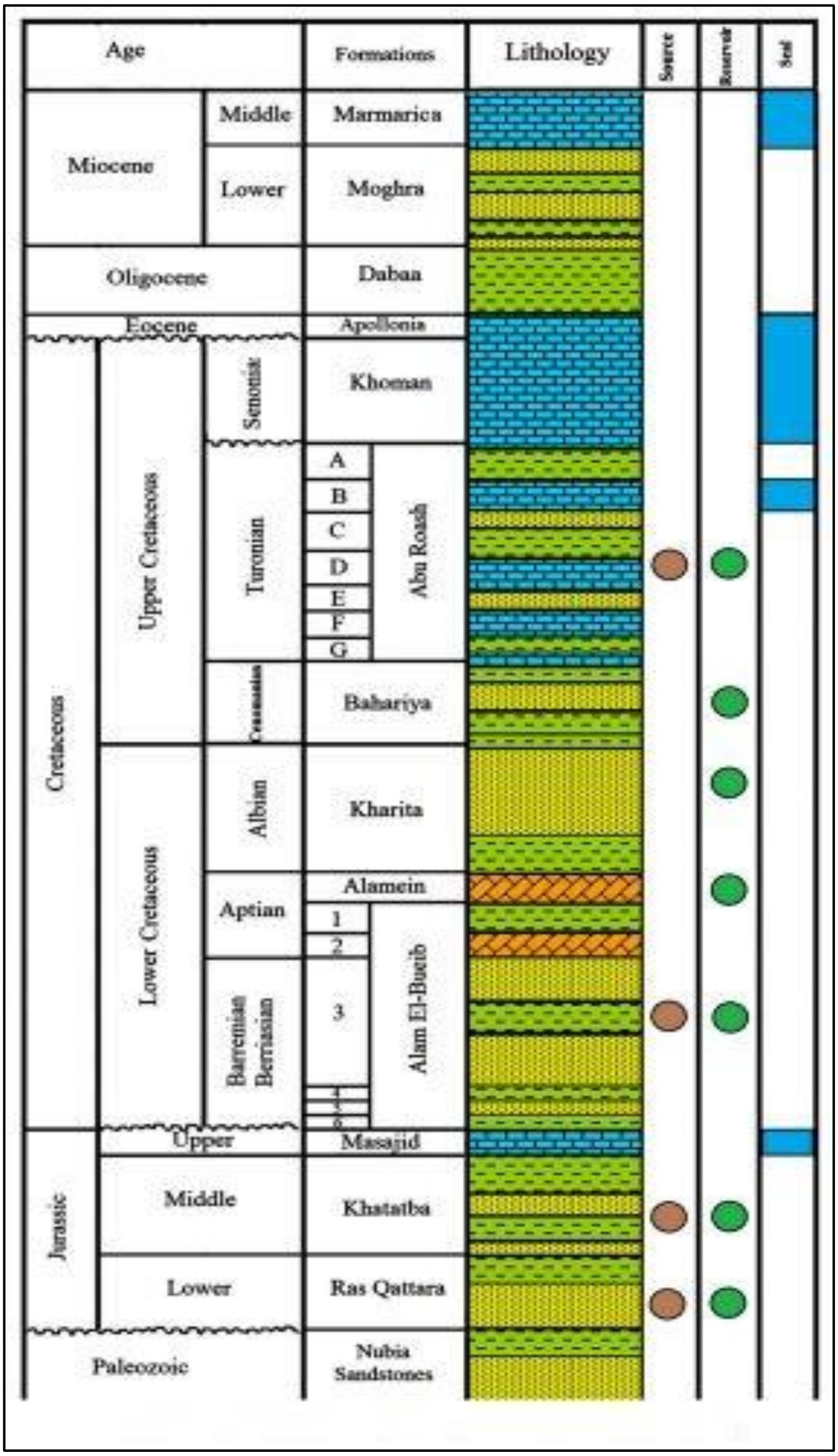

Fig. (3): Generalized stratigraphic column of Northern Western Desert, Egypt

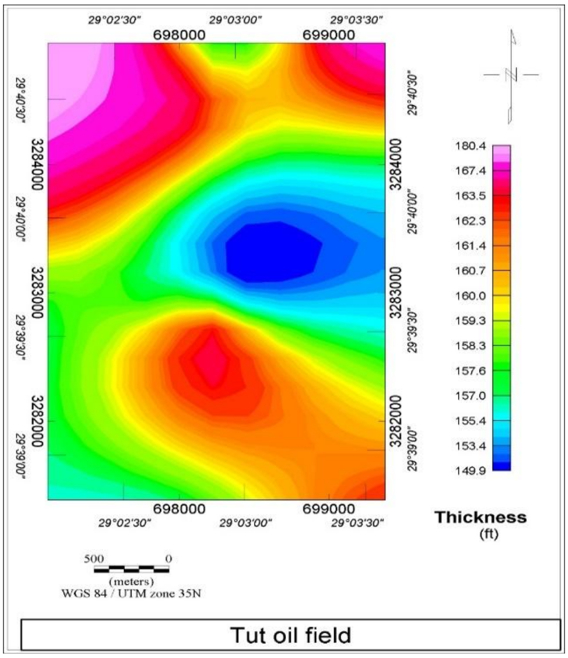

Fig. (4): Filled colored map of subsurface Bahariya Formation thickness, Tut oil Field, Northwestern Desert, Egypt.

II. Methodology

Bucker and Rybach (1996) determined the RHPfrom GR logs using the empirical equation:

$$A[\mu W/m^3] = 0.0158(GR[API] - 0.8)(1)$$

Where GR: is the total gamma-ray logs that are scaled in American Petroleum Institute (API) units.

Schmoker (1989) derived an equation to calculate the Total Organic Carbon from the density log (TOCD) depending on the fact that, the average density of clay minerals is 2.7 g/cc.considering the densities of other rock components, this equation can be used as

$$TOC_D = \frac{157}{\rho \text{b}} - 58.3 \qquad (2)$$

While, **Passeyet, .. al. (1990)** processed an advanced method to calculate the TOC % in the rocks using (sonic/resistivity, density/resistivity, and neutron/resistivity) methods depending on the log separation between the resistivity and the other three used logs. When using the sonic/resistivity method (TOC_R), the equation which can be used is:

$$TOC_R = \Delta \log \text{R} * 10^{[2.297 - (0.1688 * LOM)]} \qquad (3)$$

while LOM (Level of Organic Maturity) is derived from maturity formation at Ro value.

Alshakhs and Rezaee, (2017) calculated TOC from both laboratory and well logging data. When the estimated TOC values were cross-plotted against the Laboratorymeasured TOC values, the best relation resulted between measured values and the estimated TOC values from (GR, sonic, and density) logs (TOCGSD) as follows:

$$\text{TOC}_{\text{GSD}} = 8.24 + 0.0195 * GR + 0.12 * Sonic + 0.3 * density(4)$$

Król, (1996); Klaja and Dudek, (2016) stated that a very good relation between uranium content in ppm and the calculated TOC values couldbe introduced when **Klaja and Dudek (2016)** applied this relation to two wells. They found that

TOC (%) =(0.1063 * U (ppm)) – 0.009 with r =0.94 (5)

The gamma ray logs and bulk density logs were obtained from ten wells penetrating Bahariya Formation in the studied area. The data were digitized and converted to a regular interval of 0.5 ft.

III. Results.

Applying equations (1) for the ten wells shows the calculated RHP (µW/m³) for all the ten wells.The calculated Total organic carbon for the ten wells (Table 1) shows that the Bahariya formation in well Tut-32 has the uppermost TOC percent 45.7%, and the minimum percent was 12.13 % in Tut 35. Table (2) shows that RHP mean value equals to 0.88µW/m³and the slandered deviation is 0.23 for all ten wells. The maximum calculated RHP in Bahariya Formation was2.4 µW/m³ in well Tut-38, also the minimum was 0.14 µW/m³ in this well.

Table (1): Statistical analysis of TOC calculated from ten studied wells, Bahariya Formation, Tut Oil Field, Northwestern Desert, Egypt

Well No	Min.	Max.	Average	St. D.
Tut – 3	0	33.8	8.9	4.3
Tut – 8	0	17.8	7.2	3.5
Tut - 29	0	44	7	4.2
Tut - 30	0	26.4	7.5	3.7
Tut - 32	0	45.7	8.7	5.1
Tut - 33	0	14.6	6.4	2.97
Tut - 35	0	12.13	5.6	2.5
Tut - 36	0	17.9	6.7	2.94
Tut - 38	0	22.8	7.7	3.3
Tut - 47	0	37.7	7	3.7

Table (2): Statistical analysis of RHP calculated from ten studied wells, Bahariya Formation, Tut Oil Field, Northwestern Desert, Egypt

Well No	Min.	Max.	Average	St. D.
Tut – 3	0.21	1.46	0.73	0.24
Tut – 8	0.23	1.8	0.9	0.33
Tut – 29	0.41	1.71	1.06	0.26
Tut – 30	0.31	1.56	0.82	0.22
Tut – 32	0.24	1.87	0.88	0.27
Tut – 33	0.34	1.54	0.87	0.26
Tut – 35	0.46	1.86	1.14	0.28
Tut – 36	0.27	1.77	0.96	0.25
Tut – 38	0.14	2.4	0.72	0.36
Tut – 47	0.32	2.24	1.15	0.32
All	0.14	2.40	0.88	0.32

Fig. (5) illustrates the vertical distribution of different gamma ray which indicate shale volume, TOC, and RHP) logs of Bahariya Formation in Tut 29 well. The total organic carbons curve of the Bahariya formation shows that TOC values oscillate around 10 % and reach a maximum value of 44% at a depthof 6170 ft.

From the statistical analysis of RHP values, it results that, the average RHP value calculated is equal to 0.88 (µW/m³) and a standard deviation (St.Dv.) value of 0.32 (µW/m³). A noticeable agreement ratio of more than 95% exists between the zones having RHP values of more than the average (0.88µW/m^3) with those having high amounts of TOC.) The values of RHP which range between the average value (0.88) and average value plus one standard deviation value (0.88 +0.32 =1.2) are related to the zones of low gamma-rays and low volume of shale values zones (6091ft - 6135 ft.), (6415ft-6460ft.), (6620ft-6665ft) which can be classified as sandstone and shaly sand deposits.

Thus, these zones can be defined as reservoir rocks. When RHP values of more than 1.2 are recorded in the zoneshavingmoderate to high volume of shale values, these zones can be classified as source rocks in **fig (5)** thecurve of Value RHP>1.2 shows source rock.

From the composite log of (GR, Lithology, TOC_D and RHP) logs (fig 6) in well Tut - 32 TOC curves show that organic carbon percentage ranges from 5% to 12% in majority of Bahariya Formation in this well. The maximum TOC percent was 45.7 at a depth of 6765 ft. The values of RHP which range between the average value (0.88) and average value plus one standard deviation value (0.88 +0.32 =1.2) are related to the zones of low gamma-rays and low volume of shale values zones (5880ft - 6010 t), (6370ft-6540ft) (6630ft-6690ft) which can be classified as sandstone and shaly sand deposits, so these zones can be considered as reservoir rocks as it has calculated TOC ranges from 5% to 15 %. Zones that have RHP >1.2 are related to sandy clay, and clay can be considered as a source roc in well Tut-32 (Fig 6).

Bahariya Formation in well Tut 35(Fig. 7) has TOC ranges from 2 to 12% zones (5850 ft. -5860 ft.), (5955 ft-5965 ft.), (6160 ft-6170 ft.), (6220ft-6250ft) have RHP ranges from 0.8 to 1 µW/m³ and could be considered as reservoir rock, the majority of this well could be considered as source rock as it has RHP over than 1.2µW/m³.

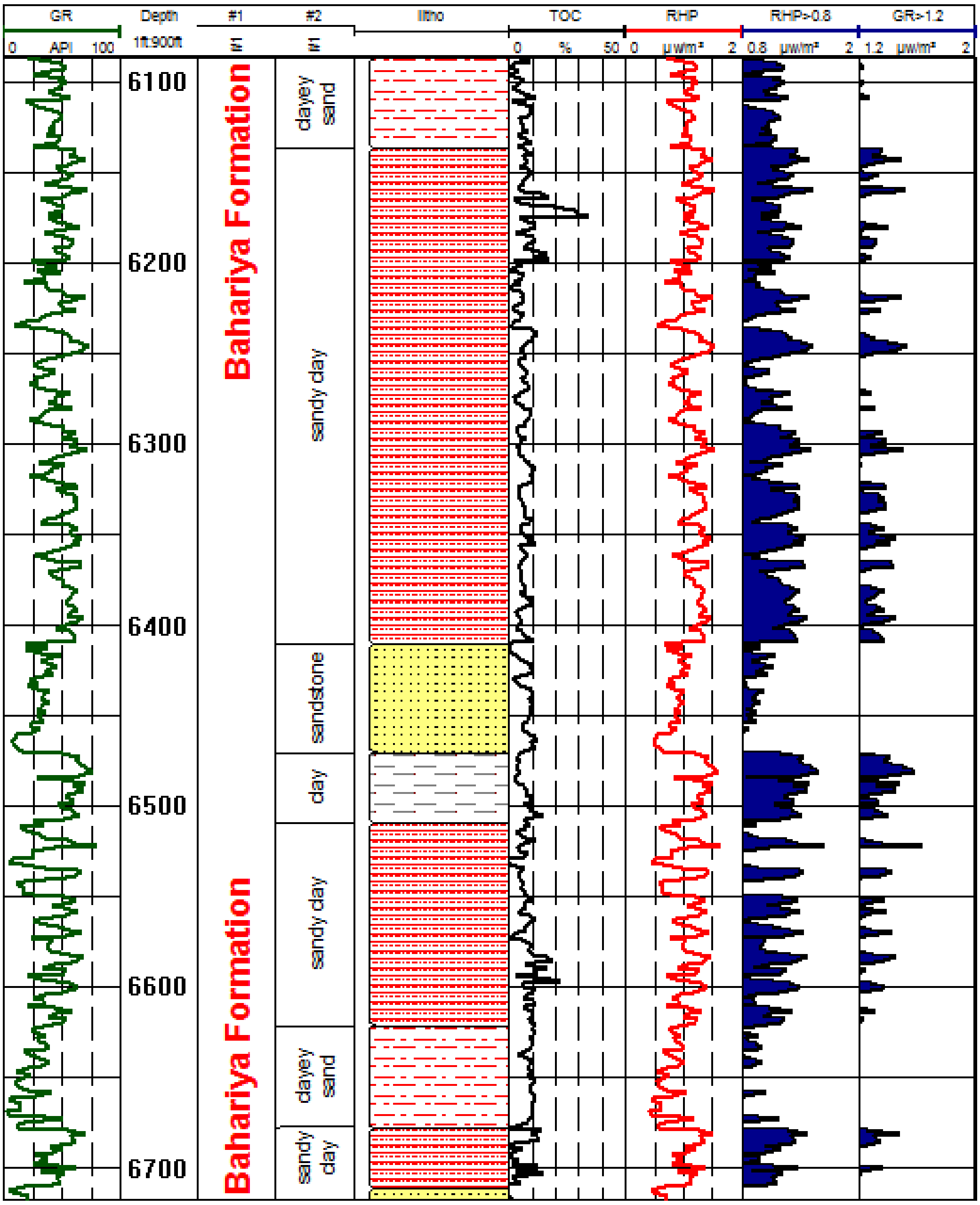

Fig. 5. Composite log of (GR, Lithology, TOC_D and RHP) logs in well Tut - 29, Tut oil field, Northwestern Desert, Egypt

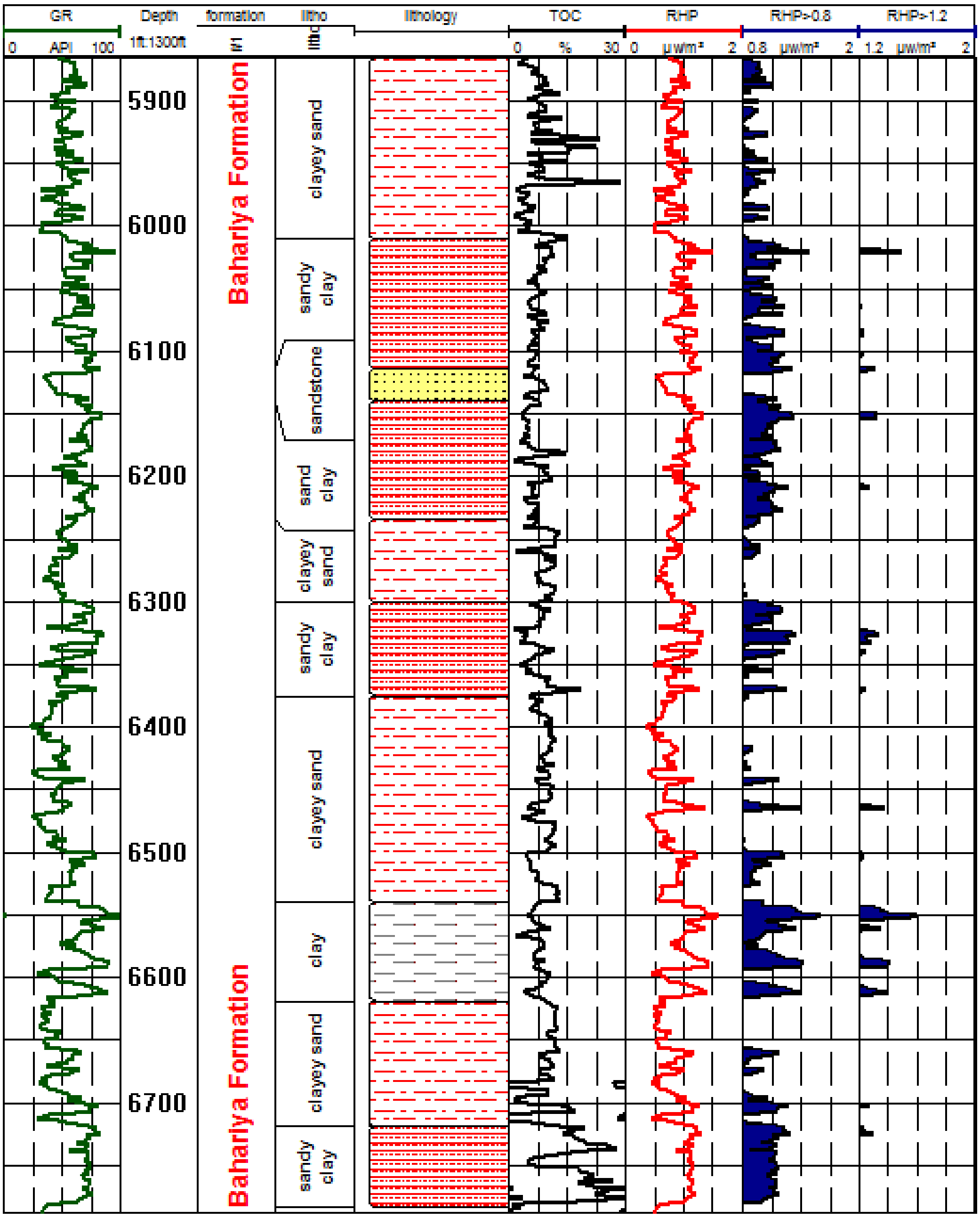

Fig. 6. Composite log of (GR, Lithology, TOC_D and RHP) logs in well Tut - 32, Tut oil field, Northwestern Desert, Egypt

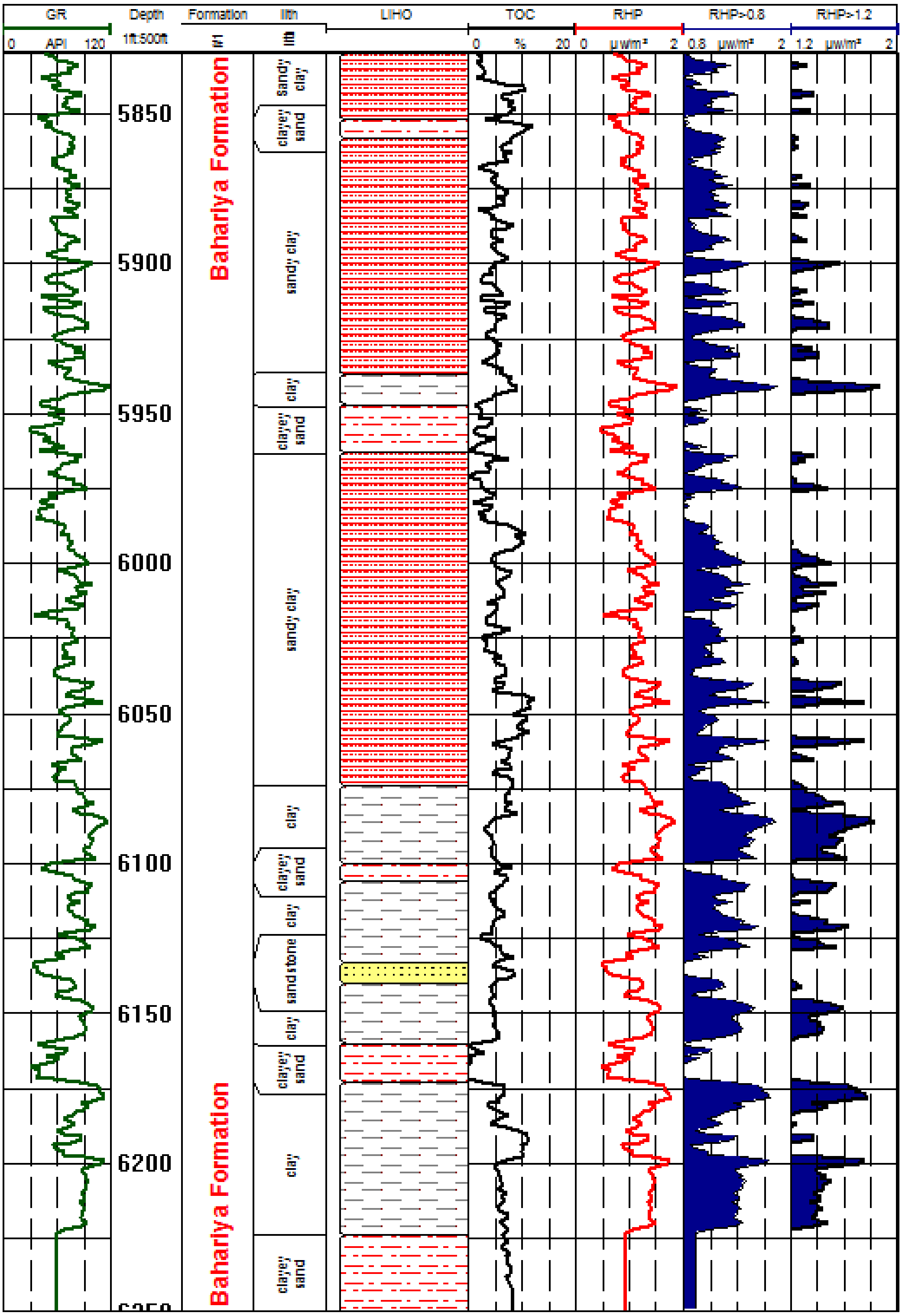

Fig. 7. Composite log of (GR, Lithology, TOC_D and RHP) logs in well Tut - 35, Tut oil field, Northwestern Desert, Egypt

IV. Conclusion

It is necessary to differentiate reservoir from source rock especially when the formation has a good percentage of TOC.

According to the results of the statistical analysis for radiogenic heat production properties, Bahariya Formation can be classified as source and reservoir rocks.

Sandstone and shaly sand (reservoir rocks), which is characterized by low content of shale volume and high TOC values, were in Bahariya formation related to the zones which have RHP values ranging from average value 0.88 to 1.2(average +St.Dv.) ($\mu W/m^3$).

Source rock zones can be determined from the RHP curve as they have RHP more than 1.2 (average+ St. Dv**.)**

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