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ESTIMATION AND INTERPRETATION THE RADIOGENIC HEAT PRODUCTION, USING THE GAMMA-RAY LOGGING DATA OF THE LOWER CRETACEOUS ALAM EL-BUEIB FORMATION, NORTH WESTERN DESERT, EGYPT

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تقدير وتفسير الحرارة الإشعاعية الناتجة عن استخدام بيانات تسجيلات الآبار لأشعة جاما الكلية للطباشيرى الأسفل لتكوين علم البويب بشمال غرب الصحراء الغربية، مصر.

الخلاصـــة: تهدف الدراسة الى دراسة الخواص الاشعاعية والحرارة الناتجة من هذا النشاط الاشعاعى. تمت دراسة الخواص الاشعاعية لهذه الصخور عن طريق استخدام تسجيلات اشعة جاما الكلية فى عشر آبار لتكوين علم البويب، شمال الصحراء الغربية بمصر. الهدف الرئيسى من البحث معرفة الوضع الحرارى لمنطقة أمتياز خالدة. تم تعيين الحرارة الناتجة من النشاط الاشعاعى من بيانات اشعة جاما الكلية وتبين من خلالها ان حرارة النشاط الاشعاعى تتراوح بين ٠,١ الى ٢,٦ ميكرو وات لكل متر مكعب بقيمة متوسطة تبلغ ٠,٩ ميكرو وات لكل متر مكعب. ومن تحليل العلاقات البيانية والتراكمية، نجد أن ٧٢% من قيم ABR تتراوح من ٠,٤ إلى ١,٢ ميكرو وات لكل متر مكعب.

كما تم عرض نتائج الحرارة الناتجة من النشاط الاشعاعى فى شكل ثلاثى الأبعاد مما زاد من دقة عرض البيانات وتحديد افضل الأماكن لتواجدات الحرارة الاشعاعية فى أبعاد الخزان الثلاثة كما ان تشريح الخزان لتتبع التغير فى خاصية الحرارة الاشعاعية مع كل محور على حدة فى الاتجاهات الثلاثة أعطى صورة تفصيلية وواضحة للخزان. ومن خلال تشريح الخزان تبين ان النطاقات الغربية والشمالية الغربية تحتوى على أعلى قيم للحرارة الاشعاعية بالمقارنة لباقى النطاقات بتكوين علم البويب بمنطقة الدراسة، ووجد أن الحرارة الإشعاعية الناتجة تؤثر على الإمكانات الهيدروكربونية لعلم البويب من خلال نضوج صخر المصدر.

ABSTRACT: *Subsurface total count gamma-ray (GR) data were recorded of ten wells, from Alam El-Bueib Formation, north Western Desert, Egypt. The radiogenic heat production (RHP) was constructed with the three-dimensional block diagram from the subsurface well logging total gamma-ray data recorded within Alam El-Bueib Formation. The studied rocks possess a range of radiogenic heat production estimated from the GR logs (A_{BR}), is varying from 0.10 μWm^{-3} to 2.6 μWm^{-3}, the average value is 0.9 μWm^{-3}, with standard deviation of 0.53 μWm^{-3}.*
The radiogenic heat production of the sandstone rocks of Alam El-Bueib Formation is relatively higher than the average RHP of the crustal sedimentary rocks. The data distribution illustrate that, about 72.09 % for A_{BR} values, that ranged from 0.4 to 1.2 μWm^{-3}. The three dimensional slicing of Alam El-Bueib Formation shows that, the northwestern and western portions of the study Formation have the highest radiogenic heat production. The estimated RHP in Alam El-Bueib Formation produces heat, this heat causes an effect on the hydrocarbon potential.

INTRODUCTION

Khalda offset new concession of oil field is located in the northern province of the Western Desert (Fig. 1). It is delimited by latitudes 30°40′ and 30°50′ N and longitudes 26°25′ and 27°00′ E. The subsurface Lower Cretaceous Alam El-Bueib Formation in the northwestern desert Basin, including ten studied wells, have attracted the attention, because of their large thickness, wide areal distribution and varying facies characteristics. Mohamed et al., (2016) reported that, the estimated RHP in Rudeis Formation of Belayim marine oil field, Gulf of Suez, Egypt, may produce enough heat for the maturation process of the hydrocarbon products.

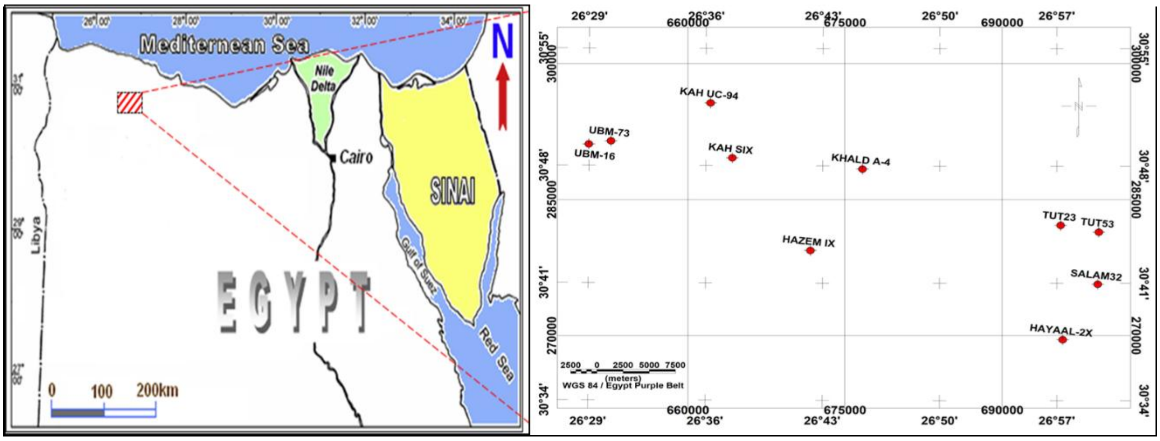

Fig. 1: Base map showing the studied wells in the North Western Desert, Egypt.

The main purpose of this paper is to get new insights on the geothermal setting of Khalda offset new concession oil field area, north Western Desert, Egypt, using the total count gamma-ray logs. The RHP in Alam El-Bueib Formation is estimated by applying the method of Bucker and Rybach (1996) technique. The well log datawere used to study RHP which has an effect on the hydrocarbon maturation. The RHP estimation in Alam El-Bueib Formation allows the recognition of new sites suitable for conducting heat measurements, explaining the temperature variations with depth and interpreting the presence of heat flow changes. Additionally, heat production can be used for modelling the temperature distribution in the study Formation.

GEOLOGIC SETTING

The Western Desert province constitutes approximately 66 % of the surface area of Egypt. The study area subjected to different tectonic regimes, since the Paleozoic, as a result many sedimentary basins and sub-basins, ridges, troughs and platforms are formed. The study of the Cretaceous rocks in Egypt (in general) and in the northern part of the Western Desert (in particular) is interesting, due to its high hydrocarbon potentiality. This province consists of a number of sedimentary basins, that received a thick succession of Mesozoic sediments. Several authors, such as Schlumberger (1984 & 1995), Barakat (2017) and Temraz et al. (2017), showed the most important geologic characteristics of these sedimentary basins, which include stratigraphy, facies distribution and tectonic framework.

Alam El Bueib Formation is considered one of the main conventional rock units producing hydrocarbon. It is mainly composed of fine to coarse clastic sediments, which conformably overly the carbonates of Masajed Formation (Upper Jurassic) and conformably underly the Alamein Dolomite (Fig. 2). Bore hole data show that, Alam El Bueib Formation is composed mainly of sandstone, siltstone and calcareous shale. These facies reflect shallow marine environments of deposition (Ramadan et al., 2012 and Temraz et al., 2017). They recognized that, Alam El Bueib Formation has mature source rocks, derived from mixed organic sources which has fair to good capability to generate gas. The current study aims to evaluate the radiogenic heat production resulted from the shale content distributed within Alam El Bueib Formation, through the interpretation of gamma-ray log data.

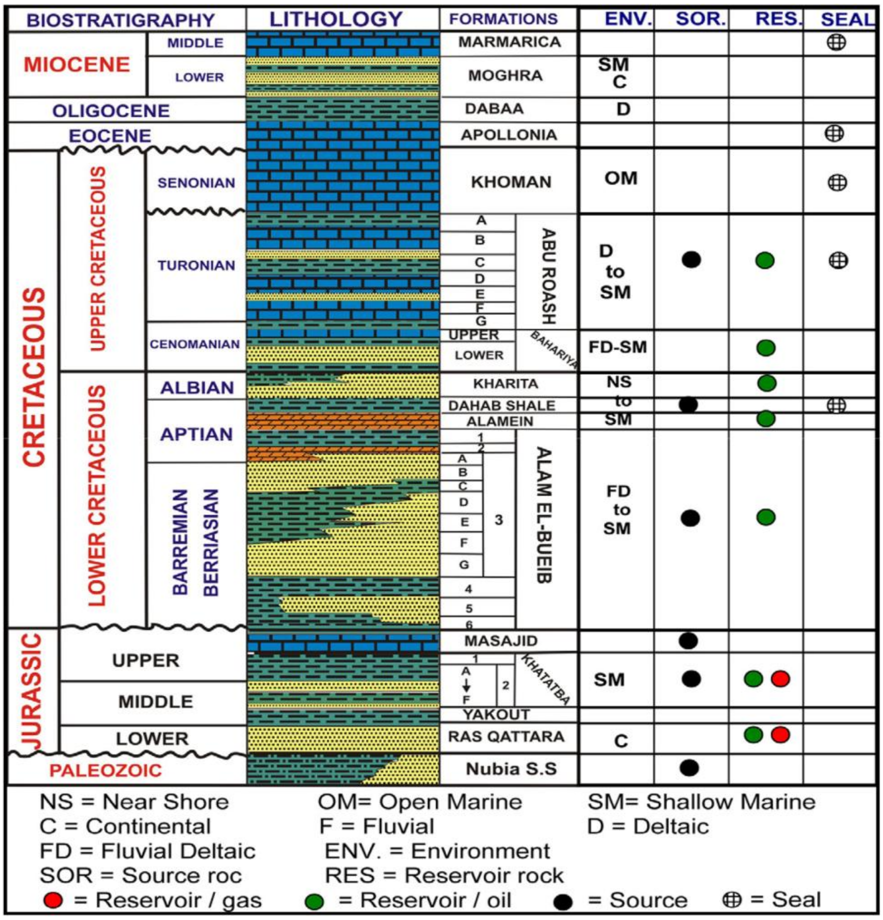

Fig. 2: Simplified stratigraphic column of the Western Desert, Egypt (modified after Schlumberger 1984, 1995).

CALCULATION METHODOLOGY

RHP was calculated, using the empirical equation developed by Bucker and Rybach (1996), which requires only the GR logs. GR log is often recorded, as a fundamental geophysical measurement in most logging runs. The total GR emission can be measured and conducted either by logging tools in boreholes or in the laboratory. The RHP from GR logs determined by Bucker and Rybach (1996), using the following empirical equation:

$$A_{BR}\ [\ \mu W\ m^{-3}\ ] = 0.0158(GR[API]-0.8)$$

where: A_{BR} is the radiogenic heat production and has a unit (μWm^{-3}); GR is the total gamma-ray log, which is scaled through the American Petroleum Institute (API) units. The total gamma-ray log data obtained from ten wells penetrating Alam El Bueib Formation were digitized and converted to regular intervals of 0.5 ft, using the common statistical package SPSS program. The total GR data were normalized before processing, using the histogram normalization technique (Gadallah et al., 1998 and 2009).

The process of normalization was used to ensure the homogeneity, field-wide consistency and for the reservoir description. This was necessary, because most fields were drilled over long time span, by different logging companies and with varring drilling parameters. The multi-well normalization correction tasks were applied on the GR log data as follow:

1. Preparation of the multi-well data distribution for GR log data recorded in all available wells.
2. Preparation of the individual well data distribution for the corrected logs in every well.
3. Normalization of the corrected logs in every well

RESULTS AND DISCUSSION

Figure (3) shows the ouput of the normalization process. The standard histogram of the total GR log data for all the used wells was generated (Figure 3a). The individual GR histogram of Hazem-IX well before the normalization is shown in Figure (3b). Comparison of the individual histogram of GR log data, with the standard multi-wells histogram of the same GR log data, was performed. The process of normalization was implemented on the low GR side of the histogram. A shift of –12 API was required to ensure good matching between the individual GR histogram of well Hazem-IX and the standard multi-wells as shown in Figure (3c).

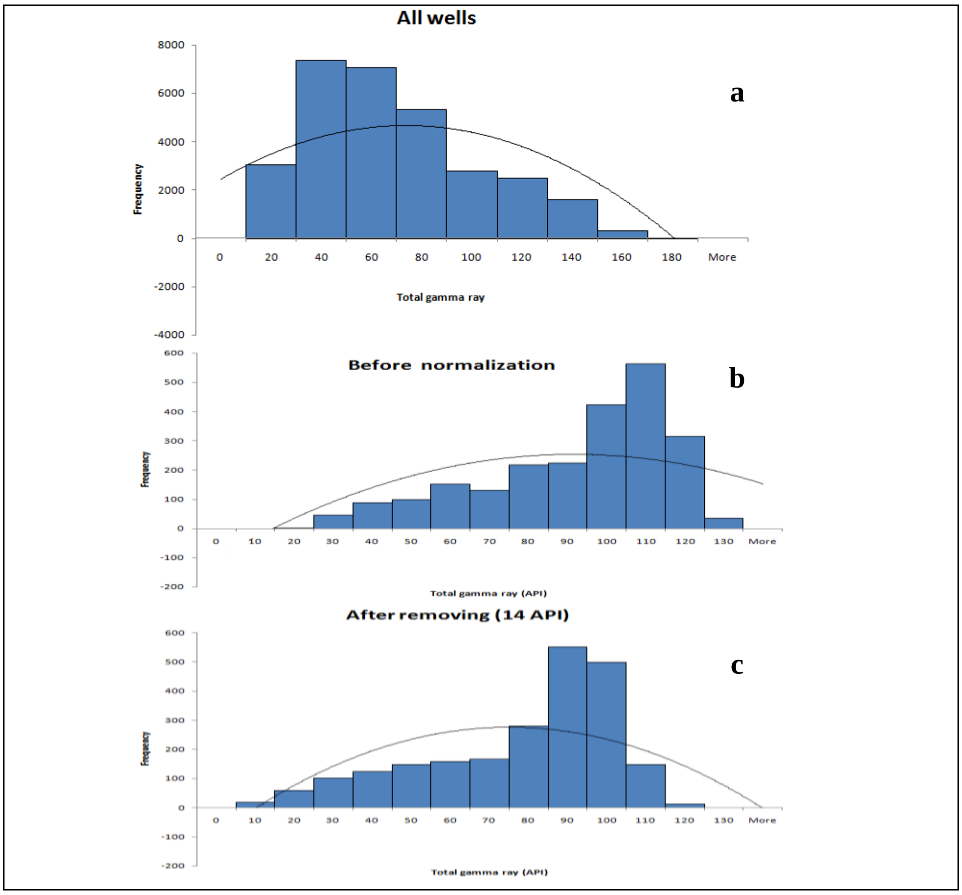

Fig. 3: Normalisation histograms of the GR log in Hazem-IX well, Alam El Bueib Formation, (a) Standard histogram of total GR log data for all wells. (b) The individual GR histogram of well BM-35. (c) Anormalised histogram of the GR log.

The histogram of the GR log, as observed from Figure 3a illustrates that, the main GR values varies from 10 to 160 API, which suggests the presence of shale zones of varying volumes within Alam El Bueib Formation. Generally, the shale has been noted to have high radioactive elements as compared to other rock types (Serra, 1984; Iyer et al., 1996 and Wang et al., 2000). Table (1) shows the total GR values, which must be either added to or removed from the GR data recorded in the ten wells.

The summary of statistical analysis of the calculated RHP values of the ten wells in Alam El Bueib Formation are illustrated in Table (2). The RHP values, derived from the GR logs (A_{BR}), vary between 0.10 and 2.61 μWm^{-3}, with an average of 0.90 μWm^{-3} and a standard deviation of 0.53 μWm^{-3}. The data distribution and cumulative frequency curve of the calculated RHP from the total count GR, are represented in Figure (4). The trend line illustrates that, the RHP values, ranging between 0.4 and 1.2 μWm^{-3}, which are ~72.09% of the total GR values.

Table 1: Shifts required for the GR data normalization of Alam El Bueib Formation wells.

Well name	Hazem-IX	KHALDA-4	KAH UC-94	KAH S-IX	HAYAT-2X	SALAM-32	TUT-23	TUT-53	UMB-73
Value (API)	14	3	23	5	7	5	14	30	36

Table 2: Statistical analysis of the RHP, corresponding to AEB Formation within the study area (μWm^{-3}).

Method	Number of samples	Mean μWm^{-3}	Minimum μWm^{-3}	Maximum μWm^{-3}	Std dev. μWm^{-3}
A_{BR}	30100	0.90	0.10	2.6	0.5

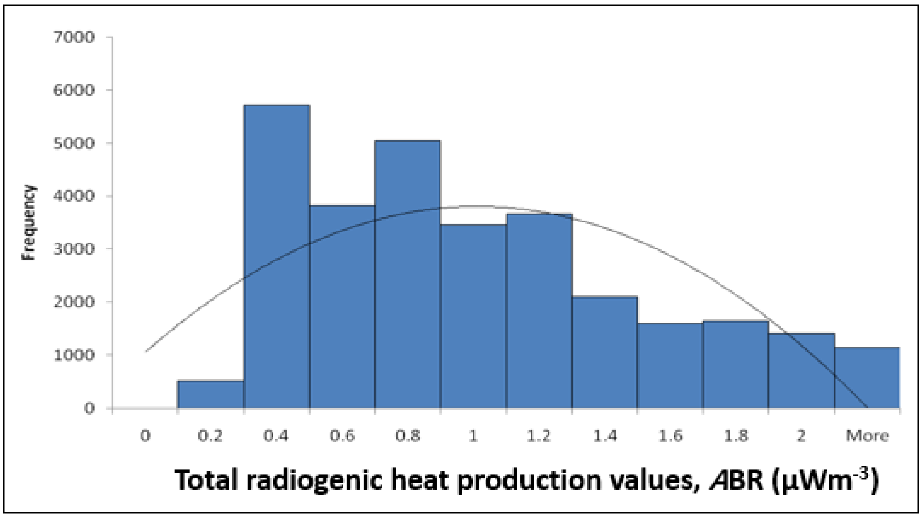

Fig. 4: Histogram and cumulative frequency of RHP, *A*BR, of the Alam El Bueib Formation from all ten wells.

Figure 5 shows a log of calculated RHP from the recorded Gamma ray data (ABR) with depth in well Hayat2X; the calculations shows good agreement downhole. RHP equation has been successfully tested on several well logging data in the Alam El Bueib Formation where GR logs are available.

The log-derived reservoir parameter was interpolated in three-dimensions, to construct a three-dimensional (3D)-slicing. Python computer software was used to construct the 3D-slicing, to show the variation and distribution of the calculated RHP in Alam El Bueib Formation. The data were displayed in the form of volume coverage by an interpolation process, in which new values were estimated for the locations, with no recorded data, based on the spatial patterns within the real data (Ghoneimi, 2002).

RHP (A_{BR}) is visualized within the Alam El Bueib Formation. The exterior RHP distribution of the reservoir (Figure 6a) represents the outer three faces.

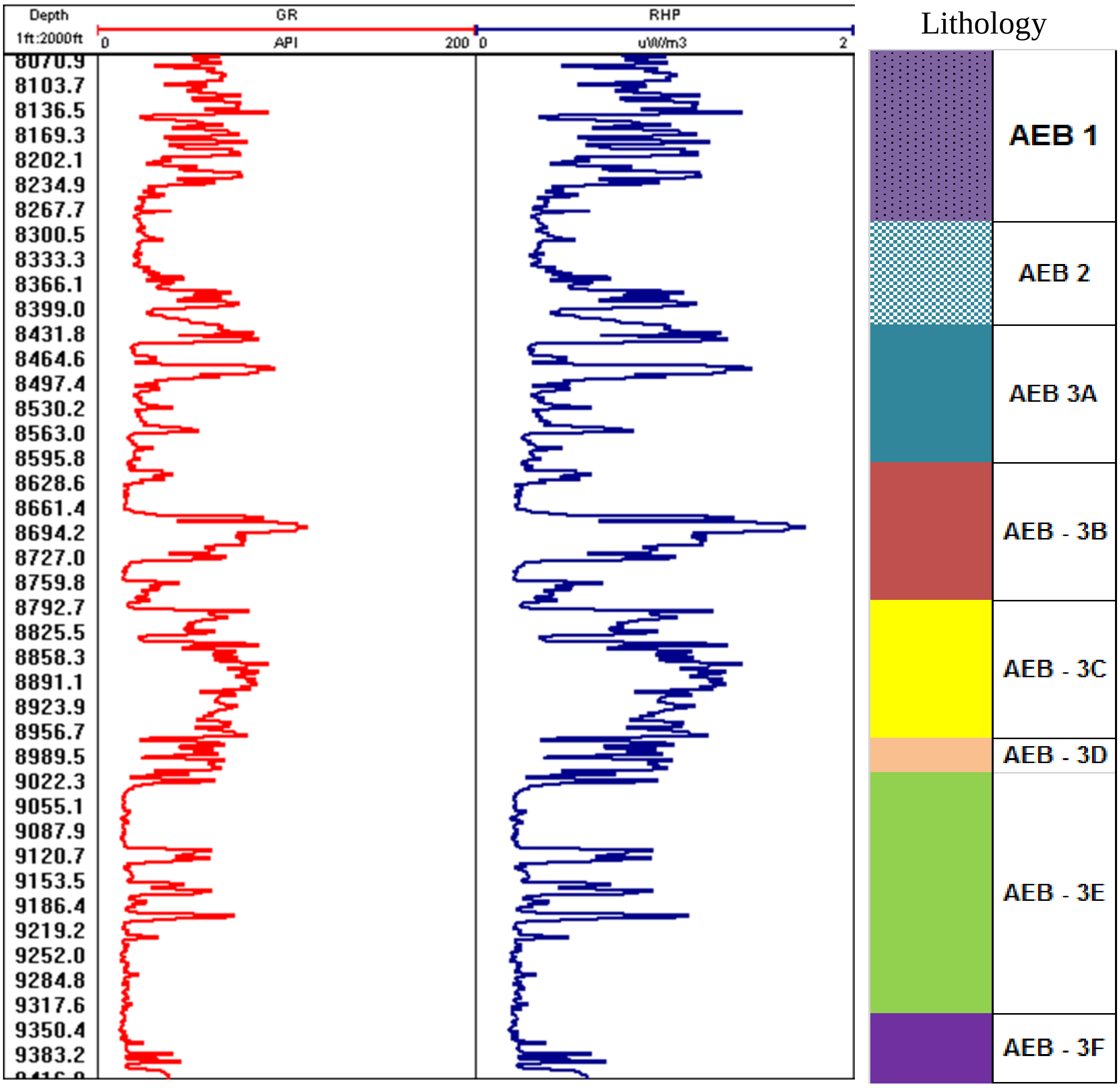

Fig. 5: The calculated *A*BR for AEB Formation with depth in well Hayat 2X.

On the top face, the lower RHP values (below 0.55 μWm^{-3}) appear in the east southern part, while the higher values (over 0.8 μWm^{-3}) appear in the north part. In the front face, higher RHP values (over 1 μWm^{-3}) appear in the north, extending to the northwestern part, while the lower values (under 0.8 μWm^{-3}) spread toward the south part of the face. In the left side face, RHP values over 1 μWm^{-3} appear in the north part and increase gradually to more than 1.5 μWm^{-3} in the central part, before decreasing again to 1.0 μWm^{-3} in the southern part. Figure (6b) illustrates the change of RHP in the x-direction, with a moderate value of 1.2 μWm^{-3}. This value is common in all the ten planes, especially in the western ones. The RHP values, in the x-direction planes, reach its highest value with about 2 μWm^{-3} in the northwestern part of the study area. The variation of the radiogenic heat production in the y-direction, illustrated on Fig. (6c), as the minimum value (0.6 μWm^{-3}), is recorded in the southern part of the study area, while the maximum value (1.73 μWm^{-3}) is reported in the northern and northwestern parts.

The variation of RHP in the z-direction is illustrated in Figure (6d). The higher values (over 1 μWm^{-3}) appear in the northern and northwestern parts of AEB Formation. The anatomy of the studied Formation in the three dimensions is illustrated in Fig. (7a), where the minimum value of 0.5 μWm^{-3} is recorded at the south part of the reservoir. It increases toward the northwestern and northern portions of the reservoir, reaching the maximum value of 2 μWm^{-3}. The cut-off for the radiogenic heat production (Figs. 7b - 7d) were applied at three different values, with 0.7 μWm^{-3}, 1 μWm^{-3} and 1.2 μWm^{-3}.

Figure (7) shows the RHP distribution within Alam El Bueib Formation, the RHP is less than 0.6 μWm^{-3} in the south part of the reservoir. While, the RHP is more than 0.7 μWm^{-3} at the northwestern and northern portions of the reservoir.

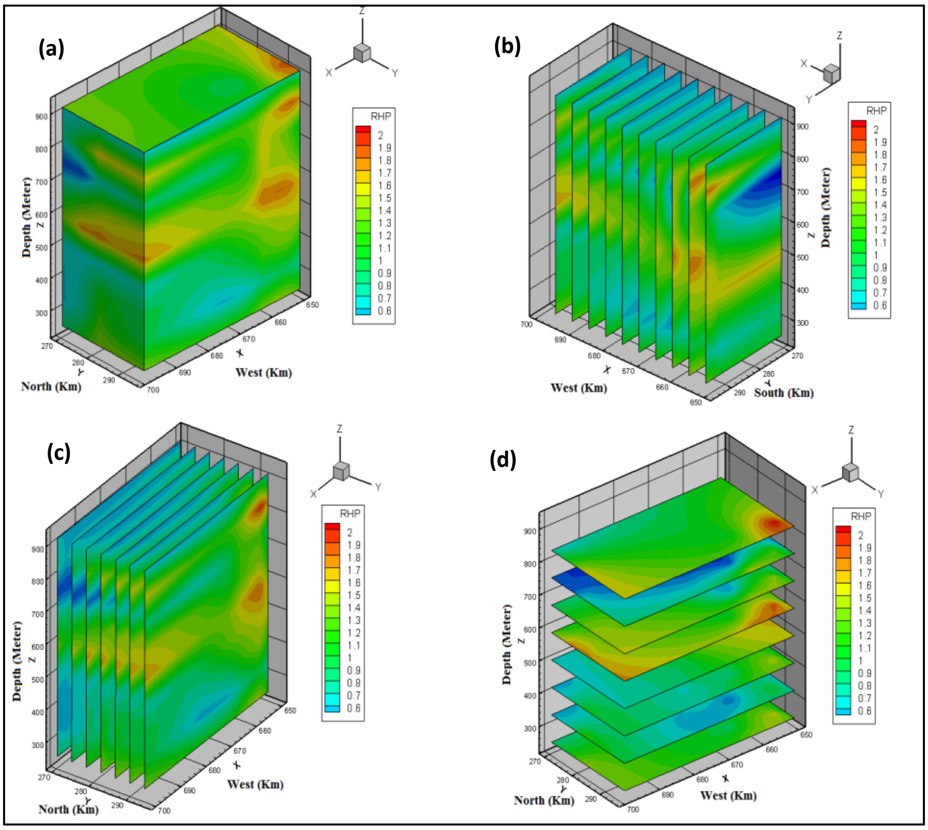

Fig. 6: (a) Exterior view, (b) 3D-slicing in the western direction, (c) 3D-slicing in the northern direction and (d) 3D-slicing with the depth direction of Alam El Bueib Formation.

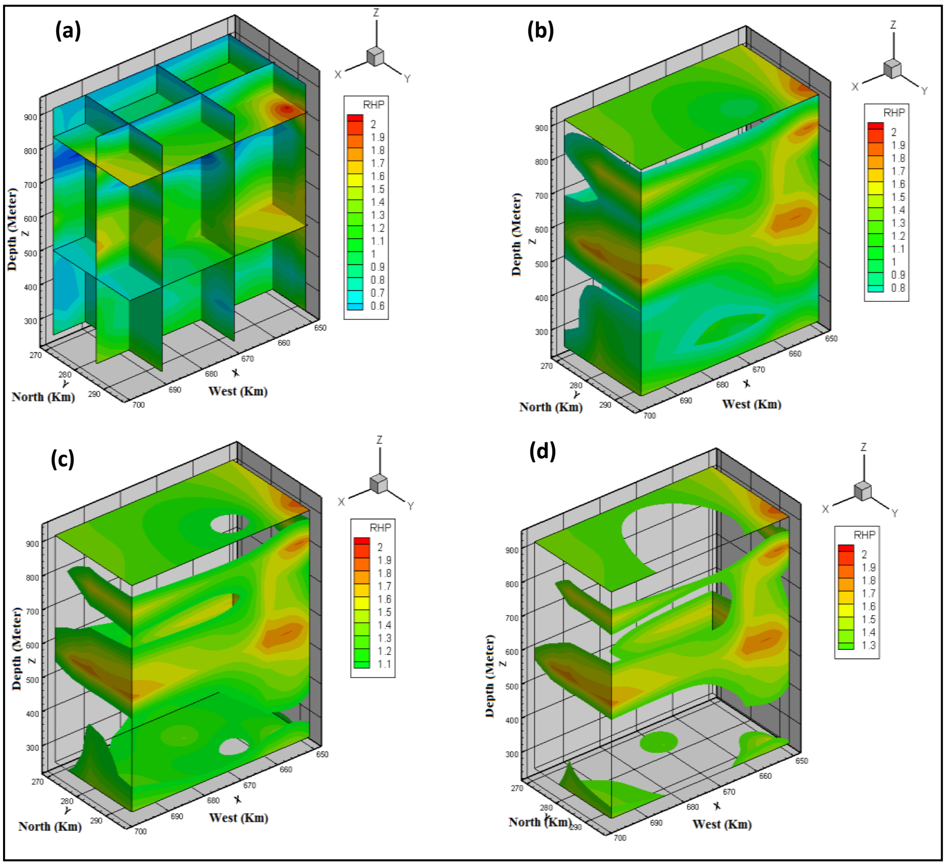

Fig. 7: Interior view and cutoff for radiogenic heat production, ABR of the Alam El Bueib Formation

Figures (8a, to 8d) illustrate the highest and lowest horizontal distributions of the RHP in AEB-1 Member, AEB-2 Member, AEB-3A Unit and AEB-3C Unit, respectively. In AEB-1 Member, the RHP values increase toward the northwestern direction, where the maximum value of 1.9 μWm^{-3} is recorded at UMB-37 and KAH UC-94 wells. High RHP values are observed at the central portion of AEB-2 Member near Khalda-4 and Hazem-IX wells. In AEB-3A Unit, the RHP values decrease toward the northcentral and southeastern portions of the Alam El Bueib Formation, meanwhile AEB-3C Unit shows the minimum values (<0.6 μWm^{-3}), as recorded at the south part of the study area, around Hayat-2X well.

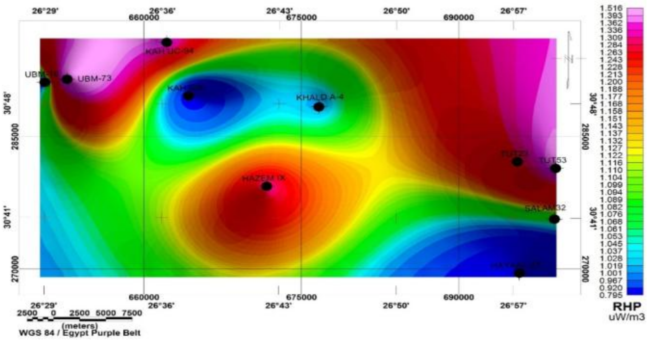

Fig. 8a: Horizontal distribution to the RHP in AEB-1 Member.

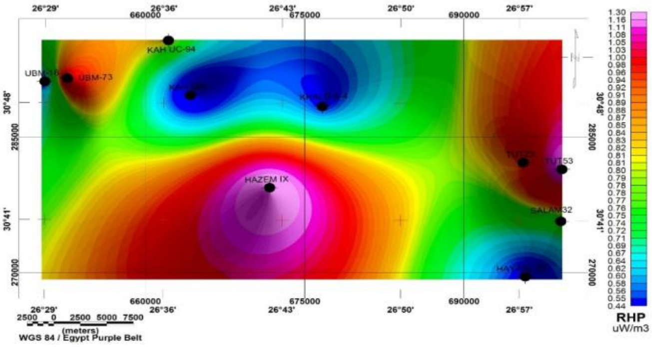

Fig. 8b: Horizontal distribution to the RHP in AEB-2 Member.

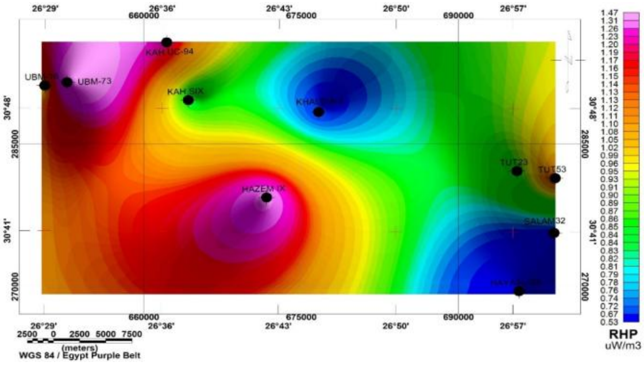

Fig. 8c: Horizontal distribution to the RHP in AEB-3A Unit.

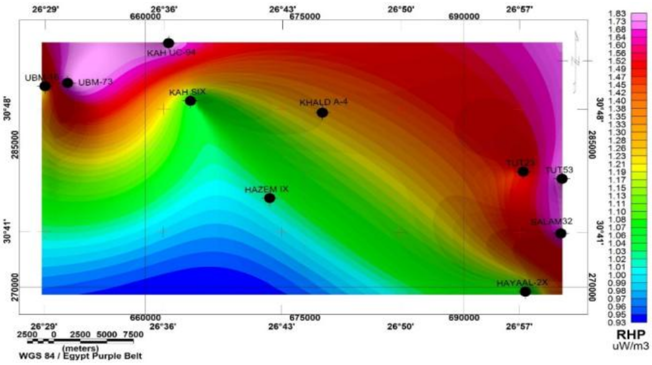

Fig. 8d: Horizontal distribution to the RHP in AEB-3C Unit.

The interpretation of these results indicate the major occurrence of clay minerals and the minor shale content in the north and west northern portions of the Alam El Bueib Formation. The total RHP of the Alam El Bueib Formation can be calculated, by using the average value of 0.9 μWm^{-3}, the Alam El Bueib Formation covers ~13 km^2 and the average formation thickness is ~ 900 m; the volume of the Alam El Bueib Formation can be calculated as:

Volume (m^3) = covered area (m^2) × average formation thickness (m)

Volume (m^3) =13 ×10^6 (m^2) × 900 average formation thickness (m)

The total radiogenic heat production (TRHP) for the Alam El Bueib Formation can be calculated as:

TRHP = (Volume (m^3)) × (Average TRHP (μWm^{-3}))

TRHP = (117 ×10^8 m^3) × (0.9 μWm^{-3}) =1.053 kW.

CONCLUSIONS

The radiogenic heat production of the Alam El Bueib Formation (A_{BR}) ranges from 0.10 to 2.6 μWm^{-3}, with an average of 0.9 μWm^{-3}. Generally, the higher RHP values exist in the northern and north-western parts of the study area, as shown on the 3D-slicing and cut-off figures. The areal distribution maps reflect the highest and lowest part for the different Members and Units of AEB. In AEB-1 Member, the RHP values increase toward the northwest direction, meanwhile high RHP values are observed at the central portion of AEB-2 Member. In AEB-3A Unit, The RHP values decrease toward the northcentral and southeastern parts of the study area, meanwhile AEB-3C Unit shows the lowest values of RHP at the southern part of the study area. As well as a major occurrence of clay minerals and the minor shale content are noticed at the northern and northwestern portions of the study area and the TRHP for the study area is estimated of 1.053 kW.

REFERENCES

Abdine A.S., Deibis S., 1972, Oil potentialities of Lower Cretaceous sediments in northern Western Desert: 8th Arab petroleum conference, Cairo, Egypt, 10-12 March 1972, p 24

Abu El Naga M., 1984, Paleozoic and Mesozoic depocenters and hydrocarbon generating areas, north Western Desert: 7th Egyptian general petroleum corporation exploration seminar, Cairo, Egypt, 22-24 November 1984, p 8

Barakat, M.K., 2017, Reservoir Modeling of Alam El Bueib Formation in the TUT Oil Field, Western Desert, Egypt, International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-3, Issue-2, pp: 21-43.

Bucker, C. and Rybach, L., 1996, A simple method to determine heat production from gamma-ray logs: Marine and Petroleum Geology, 13,373-375. doi:10.1016/0264-8172(95)00089-5

Clauser, C., 2011, Radiogenic heat production of rocks, in H. K. Gupta, ed. Encyclopedia of solid earth geophysics: Springer Verlag, pp: 1018–1024.

Gadallah, M.M., El-Terb, R.A., El-Kattan, E.S.M., and El-Alfy, I.M., 2009, Spectrometry and reservoir characteristics of Rudeis Formation in Belayim marine oil field, Gulf of Suez, Egypt: Journal of King AbdulAziz University, Earth Sciences, 21, 171–199.

Gadallah, M.M., Samir, A., Holditch, S.A. and Ghoneimi, A.E., 1998, Multiwell normalization: an example of application to the Nubia sandstone, Gulf of Suez, Egypt: EGS Proceedings of the 16th Annual Meeting, 105–122.

Ghoneimi, A.E., 2002, Reservoir 3-D slicing of log-derived parameters of Lower Bahariya pay zones in Hayat-Yasser oil fields, Western Desert, Egypt: Journal of Applied Geophysics, 1, 129–142.

Hassan, M., Mizunaga, H., Abou Ashour, N., Elterb, R., Elalfy, Elsayed, A.S., 2016, Radiogenic heat production in Rudeis Formation, Lower Miocene, Belayim marine oil field, gulf of suez, Egypt**,** exploration geophysics, doi: 10.1071/EG15021.

Iyer, S.S., Babinski, M., and Hamza, V.M., 1996, Radiogenic heat production in sedimentary rocks of the Bambui Group: implications for thermal history and hydrocarbon generation: Proceedings of the 39th Brazilian Congress on Geology, 5, 335–338.

Meshref, W.M., Abdel Baki S.H., Abdel Hady H.M., Soliman S.A., 1980, Magnetic trend analysis in northern part of Arabian-Nubian Shield and its tectonic implications. Ann Geol Surv Egypt 10 pp: 939-953.

Pollack, H.N., and Chapman, D.S., 1977, On the regional variation of heat flow, geotherms and lithospheric thickness: Tectonophysics, 38, pp: 279–296. DOI: 10.1016/0040-1951(77)90215-3.

Ramadan, F.S., Metwalli, F.I., El-Khadragy, A. A., Afify, W., 2012, The subsurface geology and source rocks characteristics of some Alam El Bueib reservoirs in Tut oil field, north Western Desert, Egypt. J Appl Sci Res 8(11):5388–5409

Rybach, L., 1986, Amount and significance of radioactive heat sources in sediments, in J. Burrus, ed., Collection colloques seminares 44, Thermal modelling in sedimentary basins: Paris Editions Technip, 311-322.

Rybach, L., 1988, Determination of heat production rate, in R. Hanel, L. Rybach, and L. Stegena, eds., Handbook of terrestrial heat flow density determination: Kluwer, 125142.

Schlumberger, 1984, Well Evaluation Conference, Egypt. Geology of Egypt, pp: 1-64.

Schlumberger, 1995, Well Evaluation Conference, Egypt. Schlumberger Technical Editing Services, Chester, pp: 58-66.

Serra, O., 1984, Fundamentals of well-log interpretation, I, the acquisition of logging data: Elsevier.

Temraz, M.G., Mosa D.A., Lofty M.A., 2017, Evaluation of the shale beds within Alam El Bueib Formation as an unconventional reservoir, Western Desert, Egypt, Journal of Petroleum Exploration and Production Technology, pp: 1-7 DOI: 10.1007 s13202-017-0353-z

Youssef, M.A.S., 2015, Estimating and interpretation of radioactive heat production using airborne gamma-ray survey data of Gabal Arrubushi area, Central Eastern Desert, Egypt, Journal of African Earth Sciences, V. 114 pp: 67-73.