Egyptian Geophysical Society
EGS Journal, Vol. 16, No. 1, 187-198 (2018)

APPLICATION OF AIRBORNE SPECTRAL GAMMA-RAY DATA FOR DELINEATING SURFACE DISTRIBUTION OF HEAT PRODUCTION AT GEBEL EL BAKRIYAH – WADI EL BATUR AREA, CENTRAL EASTERN DESERT, EGYPT

R.A.Y. EL QASSAS

Exploration Division, Nuclear Materials Authority, P. O. Box 530 El Maadi- Cairo, Egypt.

تطبيق بيانات أشعة جاما الطيفية الجوية لتحديد التوزيع السطحى للحرارة الناتجة عنها بمنطقة جبل البكرية- وادى الباتور- وسط الصحراء الشرقية- مصر

الخلاصة: تم إنشاء خريطة الحرارة الناتجة عن الاشعاع لمنطقة جبل البكرية - وادي الباتور من بيانات أشعة جاما الطيفية الجوية. وتشتمل هذه المنطقة على تنوع واسع من الصخور النارية والمتحولة والرسوبية التى تتراوح في العمر من عصر ما قبل الكامبرى إلى العصر الرباعى. إن النشاط الاشعاعى الكلى بمنطقة الدراسة يتراوح بين ١,٦ و ٣٣,٥ وحدة قياس، ٠,١% إلى ٣,٧% للبوتاسيوم، ٠,١ إلى ٣٠,١ جزء فى المليون لمكافئ اليورانيوم ، ٠,٨ إلى ٢٨,٩ جزء فى المليون لمكافئ الثوريوم. وتتراوح قيم الحرارة الناتجة عن إشعاع الوحدات الصخرية بالمنطقة من ٠,١٩ إلى ٦,٩٢ ميكرو واط/متر٣. وترتبط أعلى قيم للحرارة الناتجة عن الاشعاع (٢ إلى ٦,٩٢ ميكرو واط/متر٣) ببعض الأجزاء من الجرانيت الحديث الموجود بجبل البكرية، تكوين الداخلة (الطفلة) وتكوين الضوى (فوسفات). وتتوافق القيم المنخفضة للحرارة الناتجة عن الاشعاع بالمنطقة (٠,١٩ إلى ١,٠ ميكرو واط/متر٣) مع تواجدات صخور الرسوبيات المتحولة، البركانيات المتحولة، السيربنتينيت، الميتاجابرو، وتكوين طاريف وبعض أجزاء من تكوينى القصير والداخلة. إتضح أيضا وجود علاقة جيدة بين خريطة الحرارة الناتجة عن الاشعاع وخريطة مكافئ اليورانيوم مما يعكس أن محتوى اليورانيوم من الممكن أن يكون هو العامل الفعال الرئيسى للتوزيع السطحى للحرارة الناتجة عن الاشعاع فى منطقة الدراسة.

ABSTRACT: *The surface radioactive heat production map of Gebel El Bakriyah – Wadi El Batur area is constructed based on the airborne spectral gamma-ray data. This area comprises a wide diversity of igneous, metamorphic and sedimentary rocks ranging in age from Precambrian to the Quaternary. It possesses gamma radiation ranging between 1.6 and 33.5 Ur as a total count, 0.1 to 3.7 % for K, 0.1 to 30.1 ppm for eU and 0.8 to 28.9 ppm for eTh. The radioactive heat production values for the rock units in the study area range from 0.19 $\mu W/m^3$ to 6.92 $\mu W/m^3$, the highest radioactive heat production values (2 $\mu W/m^3$ to 6.92 $\mu W/m^3$) are related to some parts of the younger granites of Gebel El Bakriyah , Dakhla Formation (shale) and Duwi Formation (phosphatic beds). However, the lowest values of the radioactive heat production (0.19 to 1 $\mu W/m^3$) are corresponding to metasediments, metavolcanics, serpentinite, metagabbro, Taref Formation and some parts of Quseir and Dakhla formations. A good correlation is found between the heat production map and equivalent uranium map, which reflects that the uranium content could be the main effective factor for the surface distribution of heat production in the study area.*

1. INTRODUCTION

The Gebel El Bakriyah – Wadi El Batur area is located in Central Eastern Desert of Egypt, north-west to Marsa Alam and south-east to Luxor City (Fig.1). The study area is bounded by latitudes 25° 14′ N and 25° 32′ N; and longitudes 33° 14′ E and 33° 50′ E covering an area of about 2000 square kilometres. The Gebel El Bakriyah – Wadi El Batur area was included in the airborne magnetic and high-sensitivity gamma-ray spectrometric survey conducted by the Aero-Service Division, Western Geophysical Company of America (Aero-Service Report, 1984) over a large segment of the Central and Northern Eastern Deserts of Egypt as a part of the Mineral, Petroleum and Ground Water Assessment Program (MPGAP). The airborne spectral gamma-ray survey was achieved by using the Cessna 404 titan equipment as borne on a craft flown at barometric altitude (terrain clearance) of 120 metres above ground level; traverse flight lines oriented in a NE-SW direction at 1.5 kilometre spacing. The tie lines were oriented NW-SE with 10 kilometre spacing. The collected spectral gamma-ray measurements were corrected, compiled and finally displayed as contour maps (Aero-Service Report, 1984).

Airborne gamma-ray spectrometry used to map the radioelements (potassium, thorium and uranium) rather than the total radiometry of rocks is also widely used in environmental, geological and soil mapping. It is also used to estimate and assess the terrestrial radiation dose to the population and to identify areas of potential natural radiation hazard (IAEA, 2003). Moreover, the airborne gamma-ray survey is used to determine the heat production maps (Richardson and Killeen, 1980; Granar, 1982; Salem et al., 2005).

The measured radioelement concentration is related to the upper few tens of centimetres of the surface. Usually, the computed radioelement concentrations are lower than the actual concentrations in the bedrock. Consequently, a heat production map compiled from airborne data establishes a lower limit on heat production in the bedrock (Richardson and Killeen, 1980).

The purpose of this paper is constructing the surface radioactive heat production map from the airborne gamma-ray data of the Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt. The radioactive heat production can be used for the

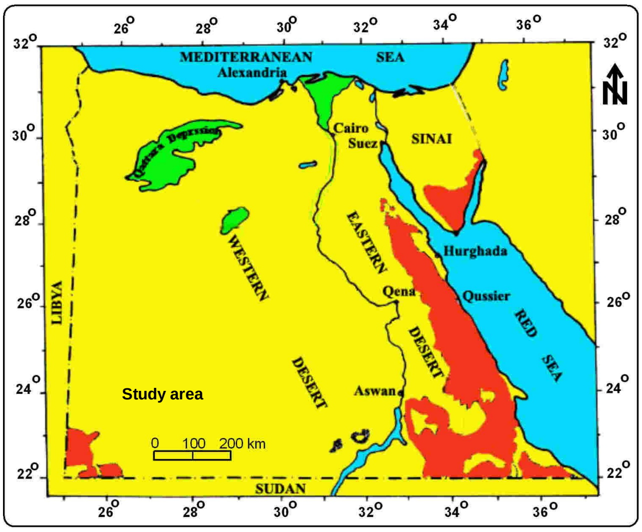

Fig. 1: Location map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

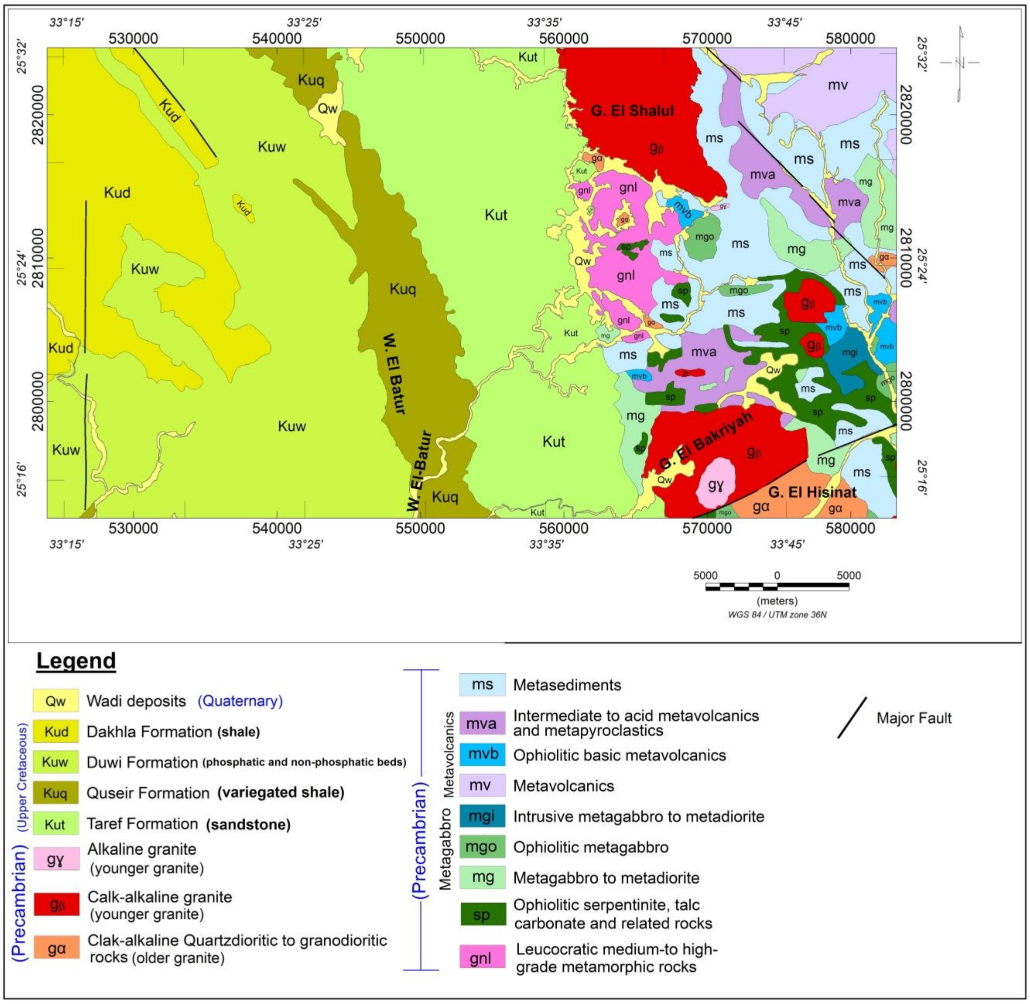

Fig. 2: Simplified geologic map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt (Reproduced after Conoco Coral, 1987).

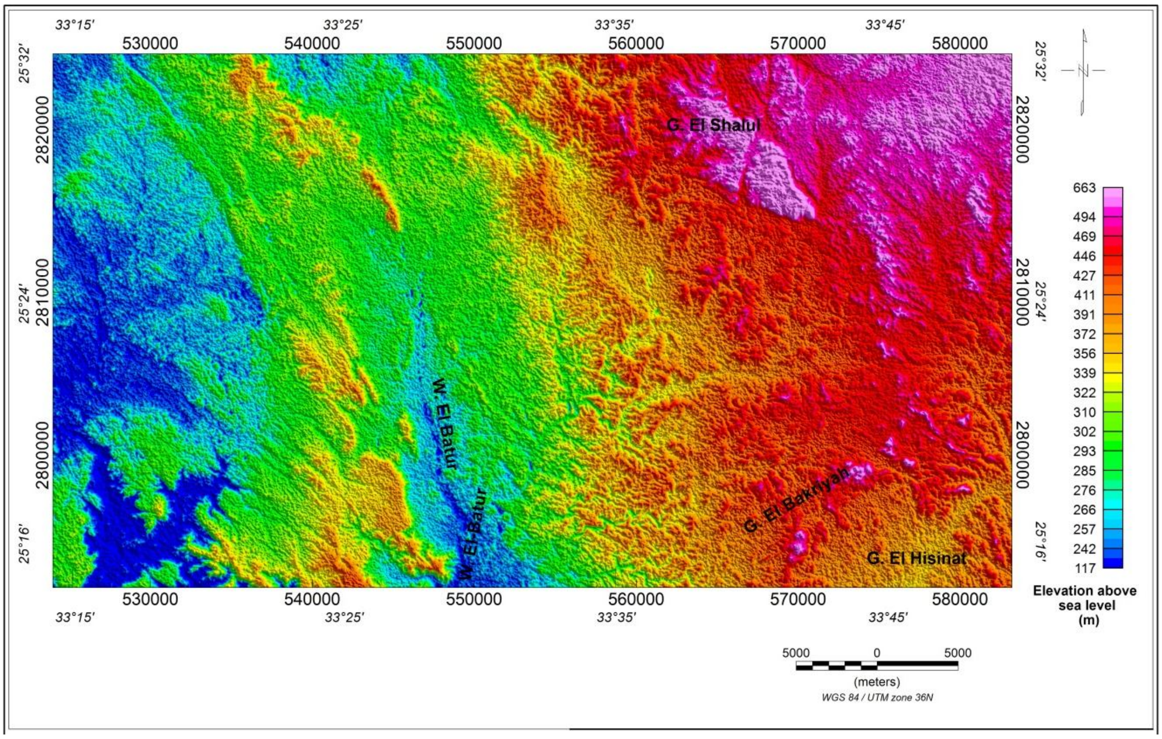

Fig. 3: Shaded colour topographic map from Aster Digital Elevation Model (DEM) at 1.5 arc spacing (about 30 m) of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

prognosis and explanation of temperature variations, for modelling the crustal temperature distributions, interpretation of heat flow variations and modelling the thermal evolution of sedimentary basins (Bücker and Rybach, 1996).

2. GEOLOGIC SETTING

The geology of the study area is based on the geological map of the Gebel Hamata area (Fig. 2) at a scale 1:500000 (Conoco Coral and EGPC, 1987). The study area is characterized by low to high topography (Fig. 3) and comprises a wide diversity of igneous, metamorphic and sedimentary rocks ranging in age from Precambrian to the Quaternary. The Precambrian igneous and metamorphic rocks are represented, from the oldest to the youngest by leucocratic medium-to-high-grade metamorphic, ophiolitic serpentinites, metagabbro to metadiorite, ophiolitic metagabbro, intrusive metagabbro to metadiorite, metavolcanics, ophiolitic basic metavolcanics, intermediate to acid metavolcanics, metasediments, calk-alkaline foliated quartzdioritic to granodioritic, calk-alkaline deformed granitic and alkaline granitic to alkali-feldspar granitic rocks (Fig. 2). The calc-alkaline foliated quartzdioritic to granodioritic rocks (older granites) are represented by the Gebel El Hisinat located at the southeastern corner of the map (Fig. 2). Calk-alkaline deformed granitic (younger granites), and alkaline granitic to alkali-feldspar granitic rocks (younger granites) are represented by the Gebel El Shalul and Gebel El Bakriyah situated at the northeastern and southeastern parts of the map, respectively (Fig. 2). The exposed sedimentary rocks in the study area are of Upper Cretaceous age and are represented by the Taref Formation (sandstone), Quseir Formation (comprising variegated shale), Duwi Formation (containing phosphatic and non-phosphatic beds) and the Dakhla Formation (comprising shale). The Quaternary age deposits are represented by Wadi (valley) deposits (Fig. 2).

The Egyptian phosphate deposits were subjected to many geological and radiometric investigations. For example, the phosphate deposits East Luxor area were studied by Sadek (1972), El Shazly et al. (1972), Abdel Hadi (1972) Salman (1974), Ammar et al. (1982, 1988), Gharieb (1995), Salahel-Din (2009) and Abbady (2010). The results of these studies show that the phosphates contain economic concentrations of uranium.

The Gebel El Bakriyah was subjected to geological and radiometric studies by many authors e.g. El Shazly and El Ghawaby (1974), El-Amin (1975), Abdel Hadi (1978), El Shazly et al. (1981), Hussein (1990), Abd-Elmonem et al. (2000), Hanafy (2002) and Abd El Nabi (2009). The important conclusion of these studies is that the U-mineralization in the Gebel El Bakriyah region is mainly concentrated at the northern and central parts of Gebel El Bakriyah, which were considered as promising areas for radioactive mineralization.

3. DESCRIPTION OF AIRBORNE SPECTRAL GAMMA-RAY MAPS

The interpretation of airborne spectral gamma-ray data of the Gebel El Bakriyah – Wadi El Batur area based on total count (TC in Ur) and the apparent surface concentration of radioelements potassium (K in %), equivalent uranium (eU in ppm), and equivalent thorium (eTh in ppm) in addition to their ratios of eU/eTh, eU/K and eTh/K (Figs. 4 to 10). The total-count (TC) radiometric contour map (Fig. 4) is divided into three levels of radioactivity. The low level ranges from 1.6 to 6.8 Ur and is recorded over the serpentinites and on some parts of metagabbro, metavolcanics, metasediments, Taref Formation (sandstone), Quseir Formation (variegated shale) and Dakhla Formation (shale) at the eastern, central and extreme northwestern parts of the map. The moderate levels range from 6.8 to 13 Ur and are recorded over some parts of leucocratic metamorphics, older granites, younger granites, Duwi Formation (phosphatic and non-phosphatic beds), Dakhla Formation (shale) and Quseir Formation (variegated shale) at the northern, southeastern and western parts of study area. The highest level of radioactivity has values varying between 13 Ur and 33.5 Ur, observed over the younger granites of the Gebel El Bakriyah and Gebel El Shalul and some parts of Duwi Formation (phosphatic and non-phosphatic beds) which covers the southeastern, northern and western parts of the map.

Potassium (K %) contour map (Fig. 5) reflects three levels of radioactivity. The first level is less than 0.5 % and is recorded over the Taref Formation (sandstone) and in some parts of the Dakhla Formation (shale), in serpentinites and metavolcanics, and over the Duwi Formation (phosphatic and non-phosphatic beds). The second level (0.5 - 1.3 %) is encountered over the Quseir Formation (variegated shale) and on some parts the metasediments, metavolcanics, metagabbro and Duwi and Dakhla formations. The third level is the highest level with values of more than 1.3 %. This level covers the eastern part of the map, which is represented geologically by older granites, younger granites, leucocratic metamorphic rocks and some parts of metasediments and metavolcanics. The increase of potassium values to this level is due to the presence of alkali-feldspars and hydrothermal alteration represented by chloritization, kaolinization and carbonization (Abd-Elmonem et al., 2000).

The uranium content ranges from 0.1 ppm over metasediments to 30.1 ppm over the Duwi Formation (phosphatic and non-phosphatic beds) (Fig. 6). The younger granites of the Gebel El Bakriyah, Dakhla and Duwi formations exhibits the highest uranium content (6 ppm to 30.1 ppm) on all the rock units in the study area. The moderate uranium values (2.3 to 6 ppm) are mainly associated with some parts of leucocratic metamorphic rocks, Taref Formation (sandstone), Quseir Formation (variegated shale), older granites, younger granites, Dakhla and Duwi formation. The lowest uranium content (< 2.3 ppm) is limited to metavolcanics, serpentinite, metagabbro and some parts of metasediments and Taref Formation.

The study area possesses a wide range of eTh content varying from 0.8 ppm to 29 ppm (Fig. 7). The

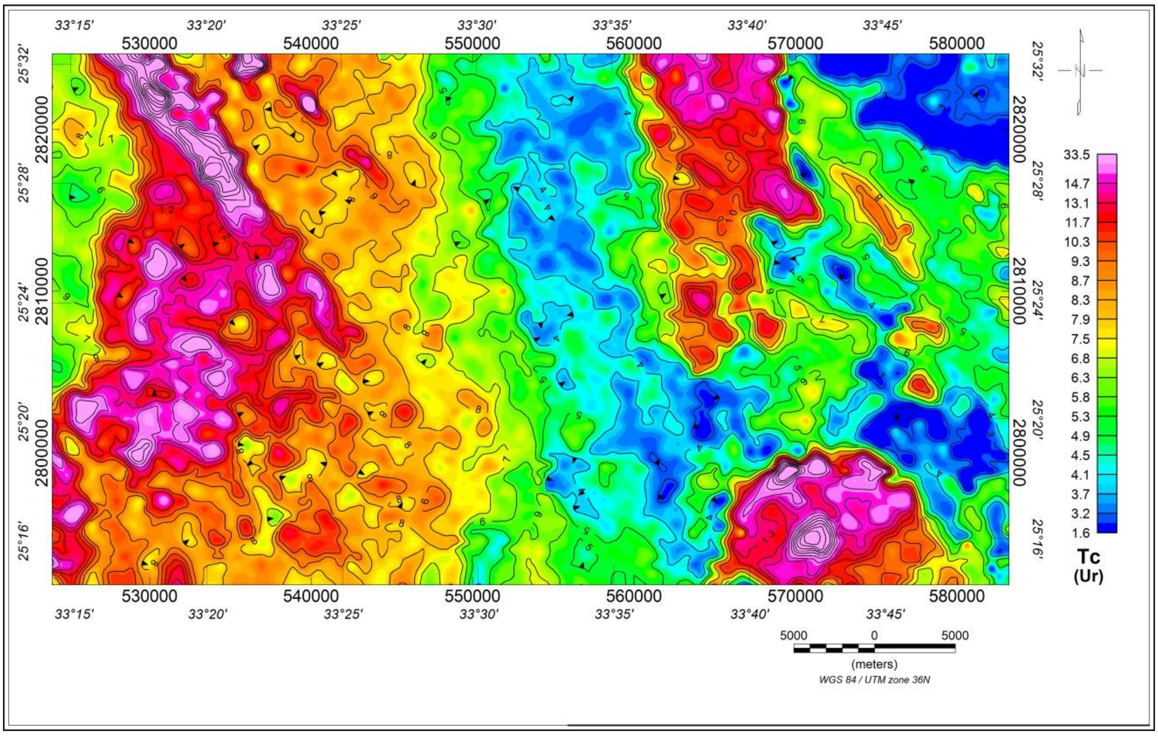

Fig. 4: Airborne total-count (TC in Ur) radiometric contour map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt (Aero-Service, 1984).

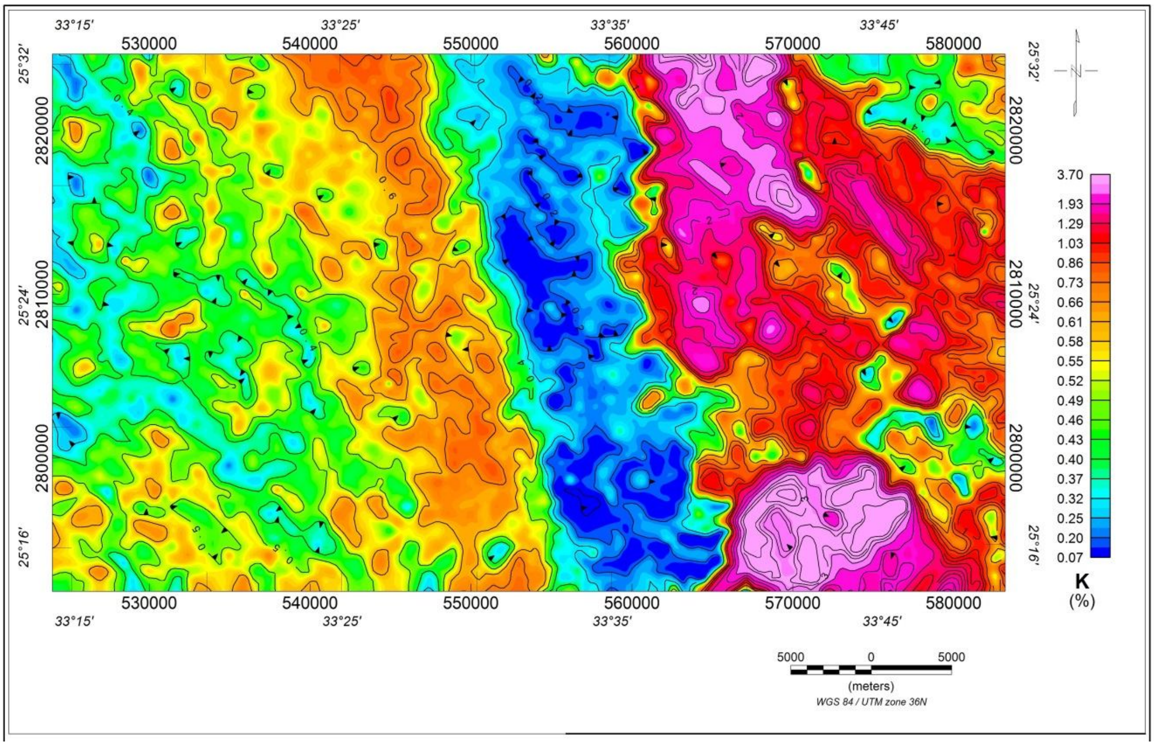

Fig. 5: Airborne potassium (K in %) contour map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt (Aero-Service, 1984).

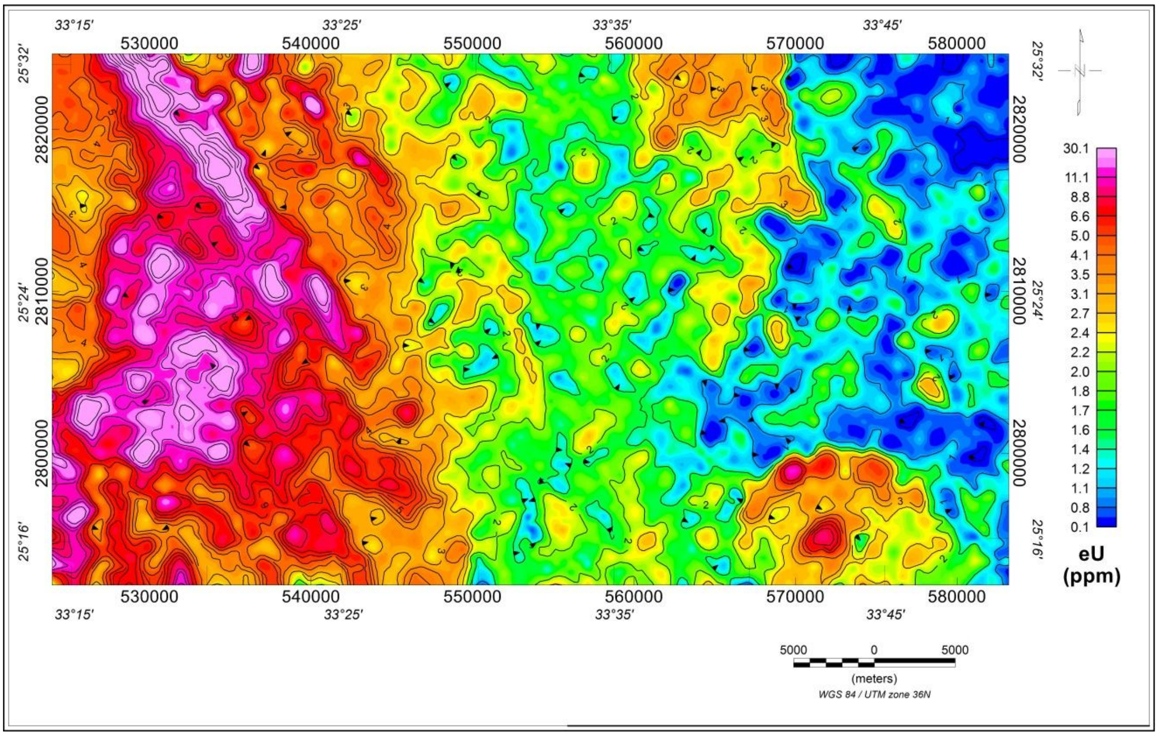

Fig. 6: Airborne equivalent uranium (eU in ppm) contour map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt (Aero-Service, 1984).

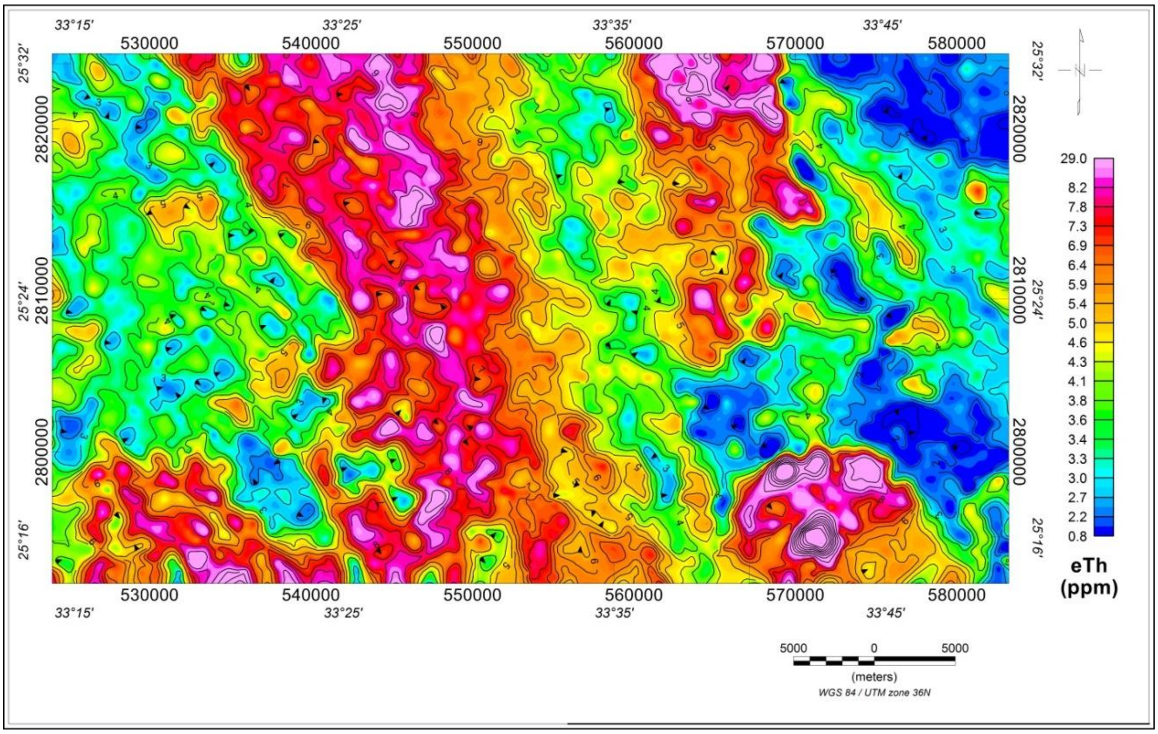

Fig. 7: Airborne equivalent thorium (eTh in ppm) contour map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt (Aero-Service, 1984).

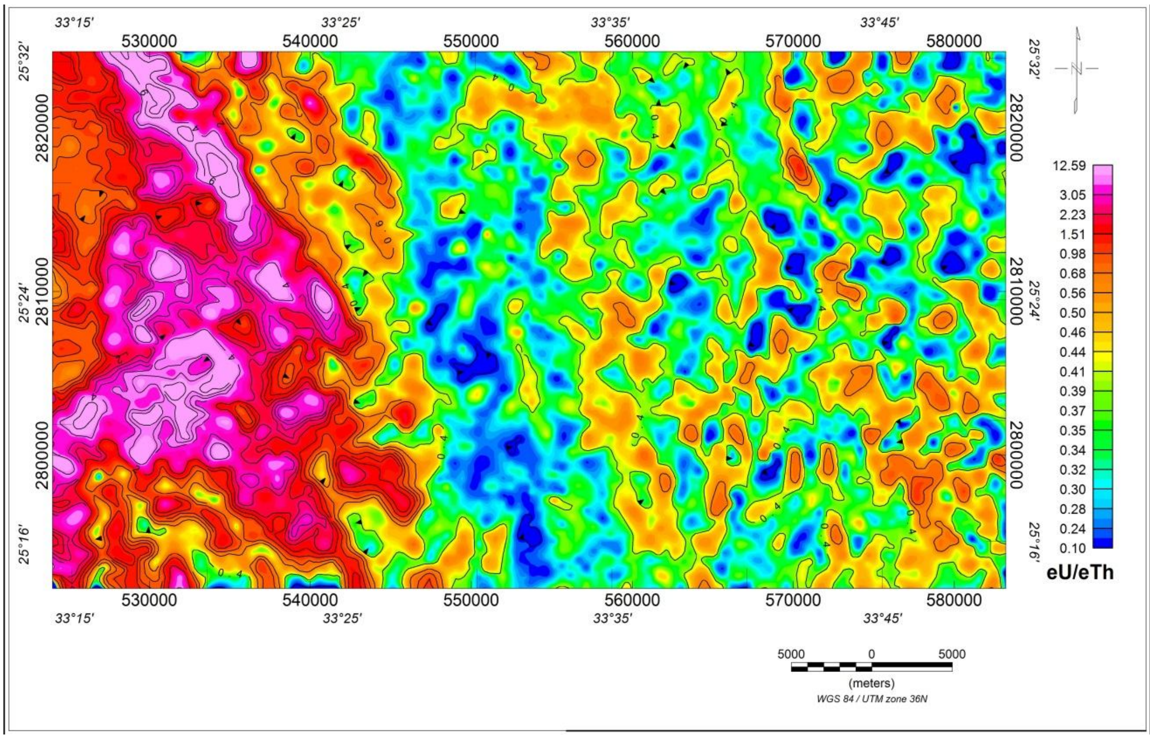

Fig. 8: Airborne eU/eTh ratio contour map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

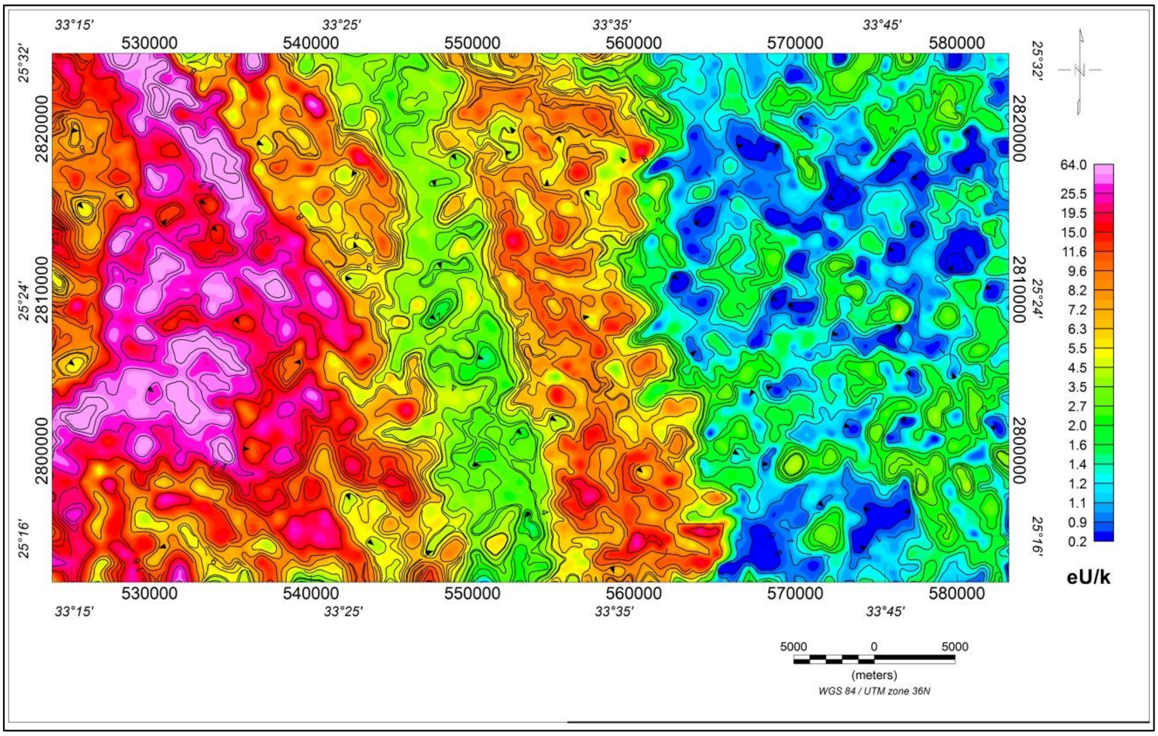

Fig. 9: Airborne eU/K ratio contour map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

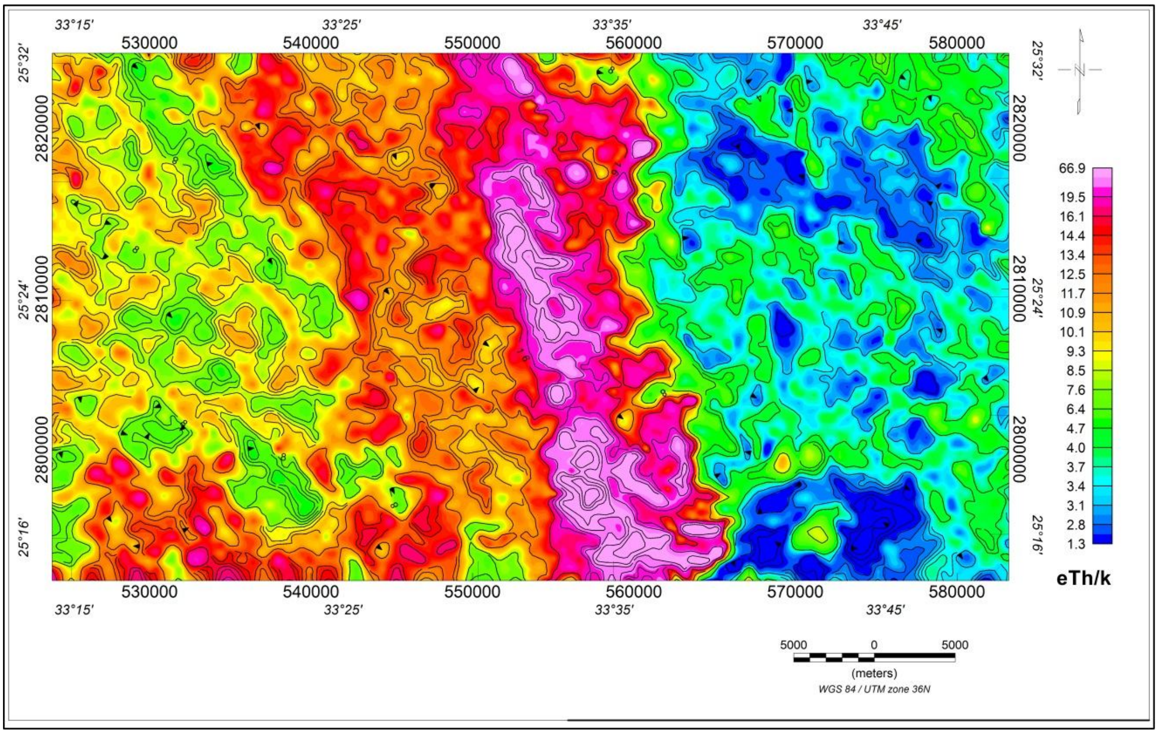

Fig. 10: Airborne eTh/K ratio contour map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

highest eTh values (7 - 29 ppm) are mainly observed at the southeastern, northern, central and southwestern parts which are associated with younger granites, leucocratic metamorphic rocks, Quseir Formation and some parts of Duwi Formation. The lowest values (0.8 – 3 ppm) are situated at the eastern, western and some scattered parts all over the area.

The eU/eTh ratio contour map exhibits values varying from 0.1 to 12.6 (Fig. 8). This ratio is important for uranium exploration because it delineates the relatively uranium-enriched areas. The high eU/eTh values (> 1 to 12.6) are observed at the western part of the area. The highest values (> 4) are mainly restricted to some parts of Duwi and Dakhla formations at the western part of the area under study. The highest values of eU/eTh may have been produced by highly enriched formations in uranium, which have higher mobilization than thorium.

The eU/K ratio contour map (Fig. 9) confirms the highest eU/eTh anomalies which are located at western part of the map (Fig. 8). The eU/K map agrees well with eTh/K map in delineating the lowest values at the eastern part of the map (Figs. 9 and 10).

The high values of eTh/K (19.5 to 67) are concentrated over Taref Formation (sandstone) at the central part of the area (Fig. 10). The intermediate eTh/K values (10 to 19.5) are recorded over Quseir Formation, Duwi Formation and some scattered parts of Dakhla Formation. The low eU/K values (< 10) are related to the basement rocks (younger granites, older granites, metasediments, leucocratic metamorphic, metagabbro, metavolcanics and serpentinites) at the eastern part of the map. The eTh/K map clearly defines the contact between the basement and sedimentary rock units, which has a NNW to N-S direction.

4. ESTIMATING AND DELINEATING THE RADIOACTIVE HEAT PRODUCTION

Radioactive heat production (***A***) mainly depends on the amount of uranium (U), thorium (Th) and potassium (K) present in the rock (Vedanti, et al., 2011). U and Th are normally presented as trace elements and their concentrations don't exceed a few tens of parts per million (ppm), while K is presented as a major oxide. It is known that the heat production is highest in acidic rocks and lowest in ultrabasic rocks (Vedanti, et al., 2011). Accordingly, radioactive heat production (***A***) is given in microwatt per cubic meters ($\mu W/m^3$) and can be calculated using the following formula (Bücker and Rybach, 1996):

$$\boldsymbol{A}\ (\mu W/m^3) = 10^{-5}\,\rho\,(9.52\ C_U + 2.56\ C_{Th} + 3.48\ C_K)$$

Where ρ is rock density (Kg/m^3), and C_U (ppm), C_{Th} (ppm) and C_K (%) are the radioactive element contents of uranium, thorium and potassium, perspectively.

In order to get the best results for delineating the surface radioactive heat production in the study area, the geologic map is prepared and re-projected by outlining different rock units and subsequently estimating the radioactive heat production of each rock unit. The average density of each rock unit used in this study (Table 1) are derived from Telford et al. (1990); Sharma (1997) and O'Dowd and Eaton (2005). The Surface radioactive heat production map (Fig. 11) represents the final product, which displays the anomalous radioactive heat production zones in the study area.

Figure 11 exhibits considerable variations of heat production with rock types. The preliminary investigation shows a good similarity between the airborne equivalent uranium map (Fig. 6) and the radioactive heat production map (Fig. 11). The estimated values of radioactive heat production for the rock types are summarized in table 1. The radioactive heat production values for the rock units of the study area range from 0.19 to 6.92 $\mu W/m^3$ (Fig. 11 and Table 1). The highest radioactive heat production values (2 to 6.92 $\mu W/m^3$) are encountered over some parts of the younger granites of the Gebel El Bakriyah, in the Dakhla (shale) and Duwi Formations exposed in the southeastern and western parts of the area, respectively (Figs. 2 and 11). The Duwi Formation (phosphatic and non-phosphatic beds) and Dakhla Formation (shale beds) show relatively high values of radioactive heat production (6.92 and 6.38 $\mu W/m^3$) compared with the other rock units of the study area (Table 1). The relatively high values could be produced due to the higher content of uranium in phosphate and shale. A significant difference in the radioactive heat production values between the younger granites (0.32 - 4.83 $\mu W/m^3$) and older granites (0.49 - 1.92 $\mu W/m^3$) can be easily noticed. Relatively moderate values of radioactive heat production range from 1 to 2 $\mu W/m^3$ are associated with some parts of leucocratic metamorphic rocks, older granites, younger granites, Quseir Formation, Duwi and Dakhla formations. The radioactive heat production values of the leucocratic metamorphic rocks vary from 0.61 to 1.64 $\mu W/m^3$ with an average of about 1.07 $\mu W/m^3$. This can be attributed to the increase of uranium content with the metamorphic grade (Table 1). The lowest values of the radioactive heat production (0.19 to 1 $\mu W/m^3$) cover a vast areal extent (Fig. 11), which is corresponding to metasediments, metavolcanics, serpentinite, metagabbro, Taref Formation and some parts of Quseir and Dakhla formations (Fig. 2). The lowest values of radioactive heat production for these rock units may be related to low uranium contents in these rocks.

A good correlation is found between the heat production map and equivalent uranium map, which reflects that the uranium content could be the main effective factor for the surface distribution of heat production in the study area (Figs. 6 and 11). The correlation between heat production and equivalent uranium maps has been proved by the relations between the radio-elements (eU, K and eTh) and heat production (***A***) (Fig. 12). Table 2 shows a high positive correlation between heat production (***A***) and the three radiometric

Table (1): Airborne spectral gamma-ray data, average density and estimated radioactive heat production values for the different rock units of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

Rock Units	TC (Ur)		K (%)		eU (ppm)		eTh (ppm)		Average Density (ρ) (Kg/m^3)	Estimated Radioactive Heat Production (A) ($\mu W/m^3$)		
	Min	Max	Min	Max	Min	Max	Min	Max		Min	Max	Average
Dakhla Formation	4.5	28.14	0.20	0.70	2.10	27.0	2.20	6.20	2400	0.75	6.38	2.05
Duwi Formation	6.27	33.50	0.20	0.80	2.10	30.1	2.00	12.0	2350	0.91	6.92	2.09
Quseir Formation	4.00	11.25	0.30	0.85	0.70	6.00	3.30	12.0	2400	0.56	1.87	1.06
Taref Formation	2.73	9.32	0.07	1.30	0.70	3.80	2.20	10.1	2350	0.36	1.30	0.74
Granite (Younger)	3.54	30.55	0.30	3.70	0.50	11.8	2.00	28.9	2670	0.32	4.83	1.50
Granite (Older)	4.50	12.86	0.80	3.00	0.70	3.90	2.80	9.50	2670	0.49	1.92	1.07
Metasediments	1.66	10.29	0.20	2.20	0.10	3.40	1.20	5.70	2720	0.19	1.45	0.61
Metavolcanics	1.77	11.10	0.30	1.85	0.20	2.50	1.20	5.50	2790	0.21	1.24	0.56
Metagabbro	1.93	8.04	0.10	1.40	0.20	2.80	1.40	7.10	3030	0.29	1.31	0.68
serpentinite	1.6	6.27	0.20	1.25	0.30	2.20	0.80	4.40	2780	0.21	0.90	0.47
leucocratic metamorphic	4.18	14.80	0.40	2.70	0.50	3.50	3.70	9.80	2740	0.61	1.64	1.07

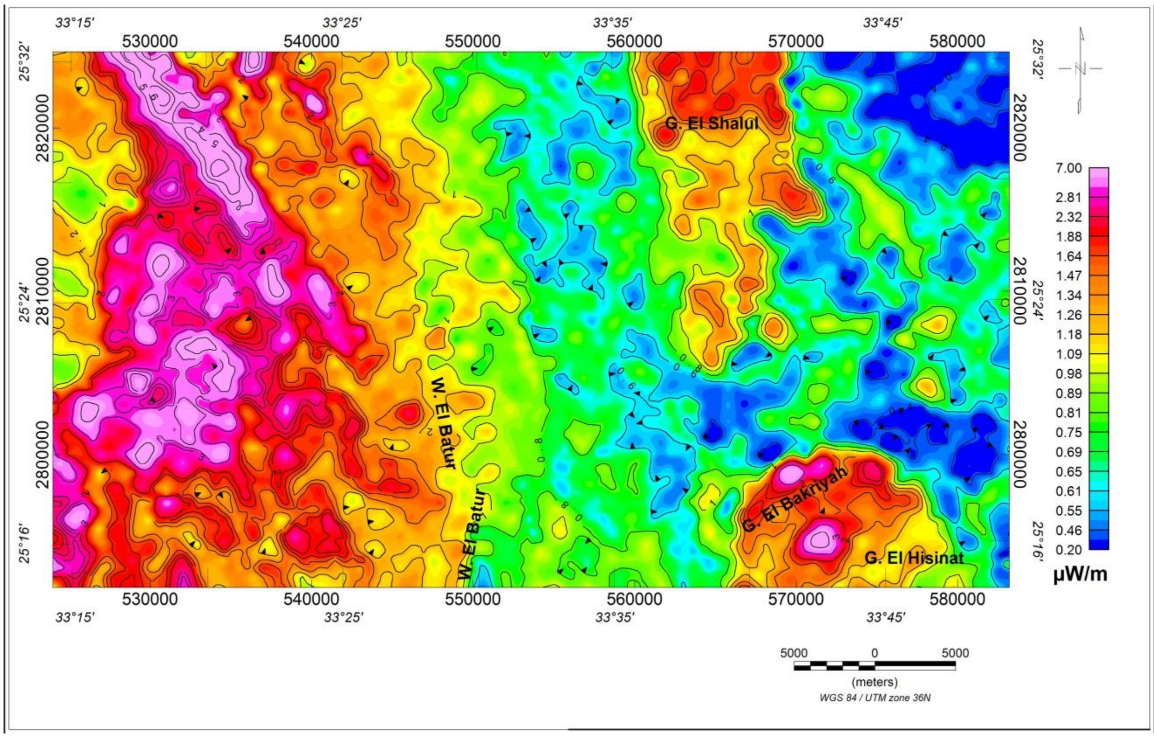

Fig. 11: Surface radioactive heat production contour map of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

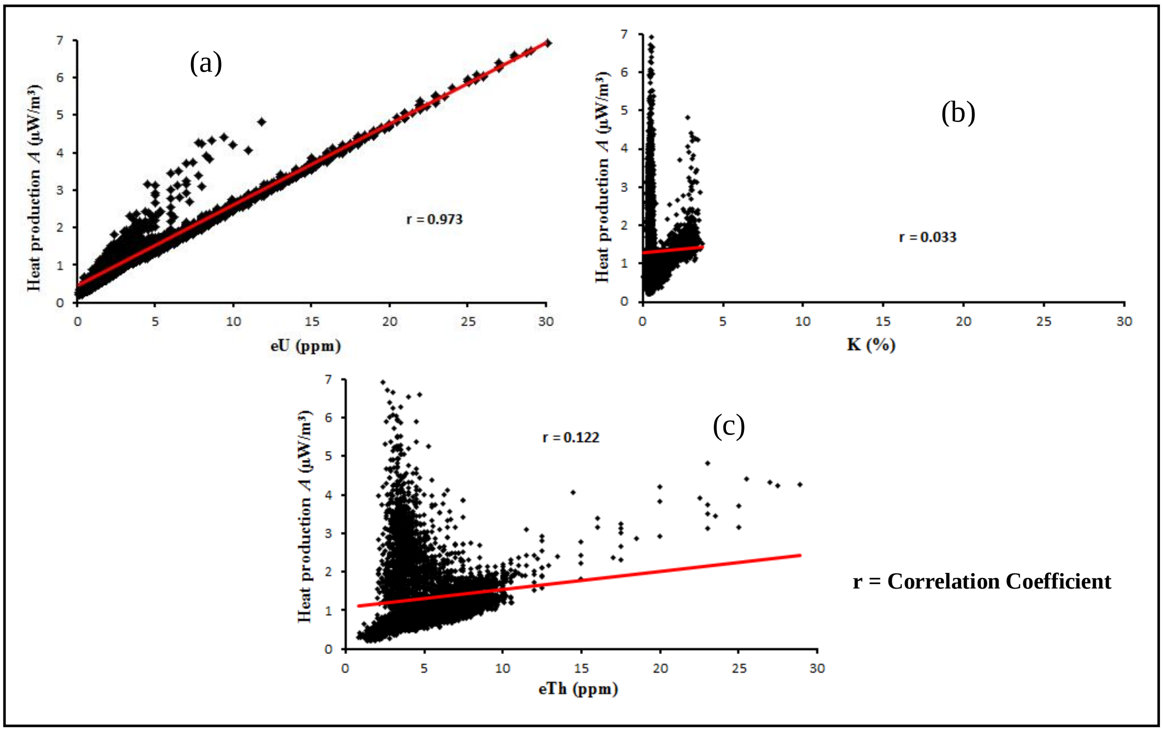

Fig. 12: Relations of heat production A with eU (a), K (b) and eTh (c) of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

Table 2: Correlation Coefficient matrix of the airborne spectral gamma-ray and heat production variables of Gebel El Bakriyah – Wadi El Batur area, Central Eastern Desert, Egypt.

	TC	K	eU	eTh	eU/eTh	eU/K	eTh/K	*A*
TC	1							
K	0.397	1						
eU	0.793	-0.155	1					
eTh	0.341	0.423	-0.074	1				
eU/eTh	0.676	-0.225	0.946	-0.304	1			
eU/K	0.589	-0.388	0.920	-0.233	0.926	1		
eTh/K	-0.250	-0.533	-0.060	0.199	-0.114	0.179	1	
A	0.895	0.033	0.973	0.122	0.877	0.840	-0.104	1

parameters (eU, eU/eTh and eU/K), that have values of about 0.973, 0.877 and 0.84, respectively. This might be due to the high content of uranium. The correlation coefficient matrix (Table 2) displays a very weak positive correlation between heat production (***A***) and the two radio-elements (K and eTh) with values of about 0.033 and 0.122 respectively. The above-mentioned results suggest that the total-count (TC) radiations contents mostly come from the uranium content rather than the other two elements (K and Th), which might be due to the fact that uranium is more leachable than potassium and thorium.

CONCLUSIONS

The Gebel El Bakriyah – Wadi El Batur area possesses gamma radiation ranging between 1.6 and 33.5 Ur as a total count, 0.1 to 3.7 % for K, 0.1 to 30.1 ppm for eU and 0.8 to 28.9 ppm for eTh. The surface radioactive heat production map of the study area is produced from the spectral gamma radiation data. The estimated radioactive heat production values for the different rock units in the study area range from 0.19 to 6.92 $\mu W/m^3$. The Duwi and Dakhla formations show relatively high values of radioactive heat production that range from 6.38 and 6.92 $\mu W/m^3$. The younger granites of the Gebel El Bakriyah possess values of radioactive heat production varying from 0.32 to 4.83 μW/m^3, while older granites show values ranging between 0.49 and 1.92 μW/m^3.

The uranium content represents the main responsible factor for the distribution of heat production in the study area. The relationship between the radio-elements (eU, K and eTh) and heat production (***A***) showed high correlation between heat production and equivalent uranium map, which is also supported by the high positive correlation between heat production (***A***) and the three radiometric parameters (eU, eU/eTh and eU/K) with values of about 0.973, 0.877 and 0.84, respectively. This may reflect that the total-count (TC) radiations mostly come from the uranium content in the study area.

Acknowledgments

I would like to thank Prof. Dr. Assran Sayed Mohamed for his comments on this work. Thanks are also due to Prof. Dr. Salah Hanafy, for fruitful discussions during this research. I am also grateful to Prof. Dr. Abdelmohsen Galal Gharieb and Dr. Ragaa Abdelgawad Mahmoud for their fruitful discussion.

REFERENCES

Abbady, A.G.E. (2010): Evaluation of heat generation by radioactive decay of sedimentary rocks in Eastern Desert and Nile Valley, Egypt. Appli. Radiat. and Isot. 68, pp. 2020–2024.

Abd-Elmonem, A.A., Abd-Elkader, Z.M., Mansour, S.I., Hassanein, Sh.M.M. and Mohamed, N.A.A. (2000): Application of alpha-track mapping to genesis of U-mineralization, G. El Bakriyah. Eastern Desert, Egypt; 5th Radiation Physics Conference, Cairo, Egypt.

Abd El Nabi, S.H. (2009): Airborne γ-ray spectrometric signatures - a case study, El-Bakriyah granitic plutons, Central Eastern Desert, Egypt, JKAU. Earth Sci. 20 (1): pp.19–33

Abdel Hadi, H.M. (1972): Interpretation of the geology of the East Luxor area in the light of aerial radiometric mapping. M. Sc. thesis Fac. of Sc. Cairo Univ., 124 p.

Abdel Hadi, H.M. (1978): Aeroradiometric data and its relation to the regional geology of Bakriya area, Eastern Desert (Corroborated with aeromagnetic survey). Ph. D. thesis Fac. of Sc. Cairo Univ., Cairo, 250 p.

Aero-Service. (1984): Final report on airborne magnetic and radiation survey in Eastern Desert, Egypt. Work completed for the Egyptian General Petroleum Corporation (EGPC). Six volumes, Aero -Service, Houston, Texas, USA.

Ammar, A.A., Meleik, M.L. and Fouad, K.M. (1982): Tectonic analysis of Central Eastern Desert of Egypt, applying aeromagnetic and aeroradiometric data. F. E. S. research series, No. 13, First symposium, I. G. C. P. 194, Jeddah Saudi Arabia.

Ammar, A.A., Abdel Hadi, H.M., Soliman, S.A. and Sadek, H.S. (1988): Aerial radioactivity of phosphates in the Western Central Eastern Desert of Egypt. JKAU. Earth Sci., vol. 1, pp. 181–203.

Bücker, C., and Rybach, L. (1996): A simple method to determine heat production from gamma-ray logs, Marine and Petroleum Geology Vol. 13, No. 4, pp. 373-375.

Conoco Coral Corporation and the Egyptian General Petroleum Corporation (EGPC). (1987): Geological map of Egypt, Scale 1: 500000 –NG 36 SE- GEBEL HAMATA.

El-Amin, H. (1975): Radiometric and geological investigations of El-Bakriya area, Eastern Desert, Egypt. Ph.D. Thesis, Cairo Univ., 244 p.

El Shazly, E.M., El Hazek, N. and El Mahrouky, F. (1972): Geochemistry of East Luxor phosphate as a basis for its technology. Abstract Vol. XXVII No. 2 from the transformation of the Arab Mining and Petroleum Association, Cairo, ARE.

El Shazly, E.M. and El Ghawaby, M.A. (1974): Tectonic analysis of Wadi Zeidun area and its application in localizing radioactive mineralizations in the Central Eastern Desert, Egypt. The 2nd Arab, Conf. Miner. Res., Jeddah. pp. 20–43.

El Shazly, E.M., Abd-Elkhalek, L.M., Hafez, A. and El-Amin, H. (1981): Geological and radiometric study of G. El-Bakriya area, Eastern Desert, Egypt, J. Geol. 25 (1-2). pp. 1-20.

Gharieb, A.G. (1995): Characterization of phosphate belts in the Central Eastern Desert of Egypt by management of geological and geophysical databases. M. Sc. Thesis, Faculty of Science, Ein Shams University, Cairo, Egypt., 179 p.

Granar, L. (1982): The Impression of Computer-Made oloured Geophysical Maps, Abstract, 8th European Geophysical Society Meeting, Uppsala, 119 p.

Hanafy, S.M. (2002): Contribution of airborne magnetic and spectral gamma-ray survey data to mineral exploration and geological mapping at Wadi Al Miah- wadi Ash Shalul area, Central Eastern Desert, Egypt; aided with the application of geostatistical methods of analysis. Ph.D. Thesis, Faculty of Science, Ein Shams University, Cairo, Egypt, 144 p.

Hussein, H.A. (1990): Mineral deposits, In: R. Said (Ed), The Geology of Egypt, A. A. Balkema/ Rotterdam/ Brookfield., pp. 511-566.

International Atomic Energy Agency "IAEA", (2003): Guidelines for radioelement mapping using gamma ray spectrometry data. IAEA-TECDOC-1363, 173 pp.

O'Dowd, C. and Eaton, D. (2005): Field and laboratory measurements of magnetic properties and density, Central Metasedimentary Belt, Ontario; Geological Survey of Canada, Current Research 2005-D2. 12 p.

Richardson, K.A. and Killeen, P.G. (1980): Regional radiogenic heat production mapping by airborne gamma-ray spectrometry; in Current Research, Part B, Geological Survey of Canada, Paper 80-1B, pp. 227-232.

Sadek, H.S. (1972): Regional aeroradiometric survey of East Luxor area and its relation to stratigraphy and regional geology. M.Sc. thesis Fac. of Sc. Cairo Univ., 131 p.

Salahel-Din, K. (2009): Estimation of heat generation by radioactive decay of some phosphate rocks in Egypt. Appli. Radiat. and Isot. 67, pp. 2033–2036.

Salem, A., ElSirafy, A., Aref, A., Ismail, A., Ehara, S. and Ushijima, K. (2005): Mapping Radioactive Heat Production from Airborne Spectral Gamma-Ray Data of Gebel Duwi Area, Egypt. Proceedings World Geothermal Congress, Antalya, Turkey, pp. 24-29.

Salman, A.B. (1974): Structures and radioactivity of some phosphate deposits, East Luxor area, Eastern Desert Egypt. Ph. D. thesis, Fac. of Sci. Ain Shams Univ., 322 p.

Sharma, P.V. (1997): Environmental and engineering geophysics, Cambridge University Press, 475 p.

Telford, W.M., Geldart, L.P. and Sheriff, R.E. (1990): Applied geophysics. Second Edition, Cambridge University Press, 770 p.

Vedanti, N., Srivastava, R.P., Pandey, O.P. and Dimri, V.P. (2011): Fractal behavior in continental crustal heat production. Nonlin. Processes Geophys., 18, pp. 119–124.