Radioelement anomalous rock types and uranium migration in Wadi Araba area, Northern Eastern Desert, Egypt

Mohamed A. El-Sadek

Nuclear Materials Authority, P. O. Box 530 Maadi, Cairo, Egypt

Abstract: The present study deals with integration between aeroradspectrometric and geologic data to identify significant anomalous rock types of high U, Th and K concentrations in Wadi Araba. Their delineation is based on the technique of computation of uranium favourability index (U_2), three-elemental effective parameter (F) and corroboration factor (C). The "U_2-index", "F- parameter" and "C- factor" were found to vary from 0.28 to 1.29 for "U_2", from 0.13 to 0.30 for "F" and from 8.33 to 14.60 for "C".

The study area was selected to apply these techniques due to its distinct stratigraphic and structural setting which give a good chance to deposit a different types of minerals in it. Investigation of the possibility of identifying rock types, where uranium migration took place, was conducted to delineate the degree of such migration. The estimated contents of eU (ppm), eTh (ppm), K% and eU/eTh (ppm/ppm) ratio for the different rock types were used to study of such mobilization of uranium. The study revealed that uranium migration out was associated with all the rock types of the area except El-Galala formation which still as it is over the time without any change.

Keywords: U_2-index; aeroradspectrometric; uranium migration; gamma-ray

1. Introduction

In 1982, the MPGAP project (cooperation between the Egyptian General Petroleum Corporation (EGPC), the Egyptian Geological Survey and Mining Authority (EGSMA) and (Aero-Service Division, Western Geophysical Company of America) performed an airborne magnetic and spectral gamma-ray survey over a huge part of the Eastern Desert, with a small part in the Central Western Desert of Egypt; in order to provide data to assist in identifying and evaluating minerals, petroleum and groundwater resources of the region. This survey was carried out along traverse flight lines oriented in a NE-SW direction at a 1.5 km spacing, while the tie lines were flown perpendicularly in a NW-SE direction at 10 km intervals[1].

Wadi Araba area is located in the Northern Eastern Desert of Egypt. The area approximates 2800 km2 and is delimited by Lat. 28o 49′ N and 29o 10′ N and Long. 31o 50′ E and 32o 30′ E (**Figure 1**). The present study deals with the integration between the aeroradiospectrometric and geologic data to identify significant rock types of anomalous U, Th and K concentrations.

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Figure 1. Location map of the Wadi Araba area, Northern Eastern Desert, Egypt

2. Geological background

Several authors such as[2-9] studied the lithology, structure and minerals occurrences in the selected area. The exposed rock units in the area under investigation (**Figure 2**) are represented by various lithologic associations ranging in age from Late Paleozoic to Quaternary[10-13]:

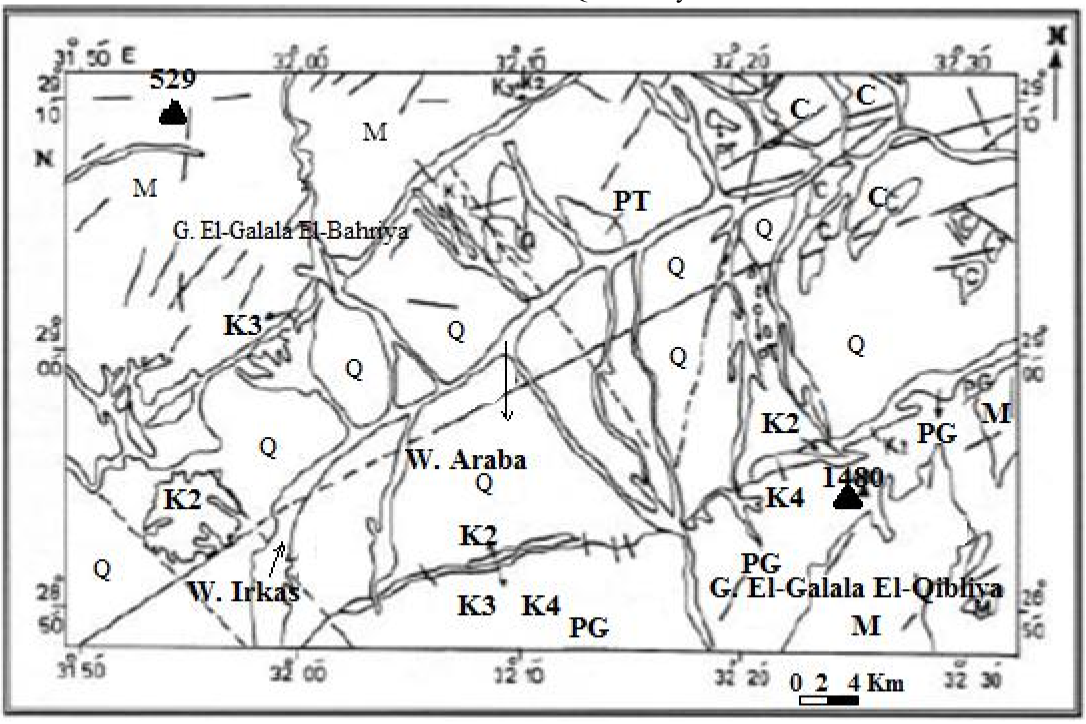

Figure 2. Compiled geological map of the Wadi Araba area, Northern Eastern Desert, Egypt[11,12]

LEGEND

Q	Quaternary Sediments	PT	Qiseib Formation (Permo-Triassic)
M	El-Mokatam Formation (Middle Eocene)	C	Rod El-Hamal Formation (Upper Carboniferous)
PG	Wadi Irkas Formation (Early Eocene)	---	Inferred Fault
K4	Sudr Formation (Late Cretaceous)	▲	Triangulation Point
K3	Duwi Formation (Late Cretaceous)		Fault
K2	El-Galala Formation (Late Cretaceous)		Geological Boundary
K1	Malha Formation (Early Cretaceous)	G.	Gabal (Mountain)

Rod El-Hamal Formation: This formation is of upper Carboniferous age[14,15]. It is essentially constituted of argillaceous and arenaceous beds with some limestone–rich horizons.

Qiseib Formation: This is of Permo-Triassic age. The average thickness of this unit is about 20 m. It is mainly composed of varicolored bleached and thickly bedded sandstone.

Malha Formation: This formation is possibly equivalent to a part of what is called Nubian sandstone and shale. It represents the Early Cretaceous sediments outcropping in the western part of the Gulf of Suez area[16]. This formation has been subdivided into two members: a lower shale, clay, and sandstone with conglomerate member and an upper tabular and cross- bedded sandstone member.

El-Galala Formation: This formation is equivalent to Quseir variegated shale. It conformably overlies Malha formation and represents the first.

Cretaceous Sea transgression in the area under consideration. It is of Late Cretaceous age. It is mainly composed of varicolored shale and silt with sandy limestone interbeds and Oyster limestone.

Duwi Formation: This formation includes the phosphate-bearing sediments in Wadi Araba[17]. It is classified into two members, lower and upper. The lower member is mainly composed of snow-white chalky limestone, while the upper member comprises thin-bedded limestone, phosphatic sandstone with marl, and conglomeratic phosphate. It is of Late Cretaceous age.

Sudr Formation: This formation unconformably overlies Duwi Formation and is composed of thickly bedded chalk and chalky limestone. It belongs to the Late Cretaceous.

Wadi Irkas Formation: This is a newly introduced rock unit representing the Early Eocene sediments[17]. The sediments belonging to this formation are mainly composed of well-dedded sandstone, conglomeratic sandstone, and sandy limestone.

Mokattam Formation: This formation forms the main bulk of Northern and Southern Galala plateaux, and extends to the Nile Valley. It increases in thickness towards the north and west. This formation is composed mainly of crystalline limestone at the lower horizon and hard thickly bedded limestone in the upper horizon. It is of Middle Eocene age.

Quaternary Sediments: These sediments cover the most considerable part of Wadi Araba area. They are mainly composed of clastic sediments of different textures ranging from silt to boulder. Wadi sediments comprise various particles of gravel, sand, and silt and are present in the main courses of the wadis.

3. Aerospectrometric levels

3.1 Radiopotassium (^{40}K) spectrometric levels

The radiopotassium (^{40}K) contour map (**Figure 4**) was divided and coloured into five separate levels. These levels range in intensity from 0.01% to 1.1% and in colour from deep blue (very low intensity), green (low intensity), yellow (intermediate intensity), orange (high intensity) to red (very high intensity) to help the lithological interpretation of the radiospectrometric survey data. These five levels could be described in the following:

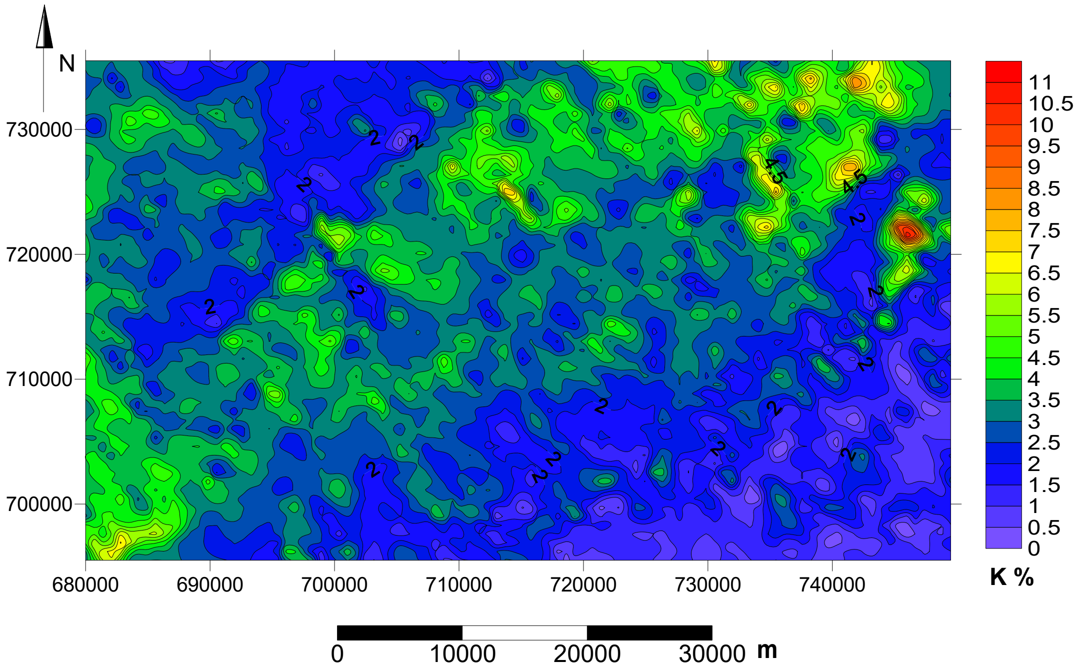

Figure 4. Coloured contour map of Potassium (K) aeroradiospectyrometric data, in % *10, Wadi Araba area, Northern Eastern Desert, Egypt[1]

3.1.1 Very low ^{40}K level (less than 0.2%)

This level coincides with W. Irkas and Mokattam formations in the southeastern part of the area under consideration as well as with some parts of Mokattam formation at G. El-Galala El-Bahariya located at its northwestern part. Besides, some scattered spots are encountered over the Quaternary Sediments. This level ranges in intensity from 0.01% to 0.2% (Figure 4).

3.1.2 Low 40K level (0.2%-0.5%)

It is encountered as zones with different shapes that are distributed allover the study area. It is registered over most of the Mokattam formation at G. El-Galala El-Bahariya in the northwestern part, G. El-Galala El-Qibliya in the southeastern part, some parts of the W. Irkas formation, Quaternary Sediments, El-Galala formation, Duwi and Sudr formations, and as well as parts of Rod El-Hamal formation in the central part of the area under study. This level ranges in intensity from 0.2% to 0.5% (Figure 4).

3.1.3 Intermediate 40K level (0.5%-0.7%)

This level extends over the northern and northeastern parts of the area under investigation. It is registered over Rod El-Hamal, Malha and Qiseib formations, as well as some parts of the Duwi formation and Quaternary Sediments in the southwestern parts of the study area. This level ranges in intensity from 0.5% to 0.7% (Figure 4).

3.1.4. High 40K level (0.7%-0.9%)

This level is met with over Rod El-Hamal and Malha formations. It possesses nearly circular or elongated shapes, and is encountered in the northeastern parts of the area under consideration. The intensity of this level ranges from 0.7% to 0.9% .

3.1.5. Very high 40K level (more than 0.9%)

This level possesses an intensity reaching to more than 0.9%. It is encountered as mass of nearly circular shape, associated with the Rod El-Hamal formation north W. Ragaba in the eastern part of the area under study (Figure 4). The intensity of this level varies from 0.9 to 1.1% .

3.2 Equivalent Uranium (eU) spectrometric levels

The Equivalent Uranium (eU) contour map (**Figure 5**) was divided and coloured into five recognizable levels ranging from deep blue (very low intensity) to red (very high intensity) as in the radiopotassium (^{40}K) contour map (Figure 5) to help also in the lithological interpretation of the radiospectrometric survey data. These five levels of equivalent uranium range in intensity from 0.1 to 3.9 ppm and could be described in the following:

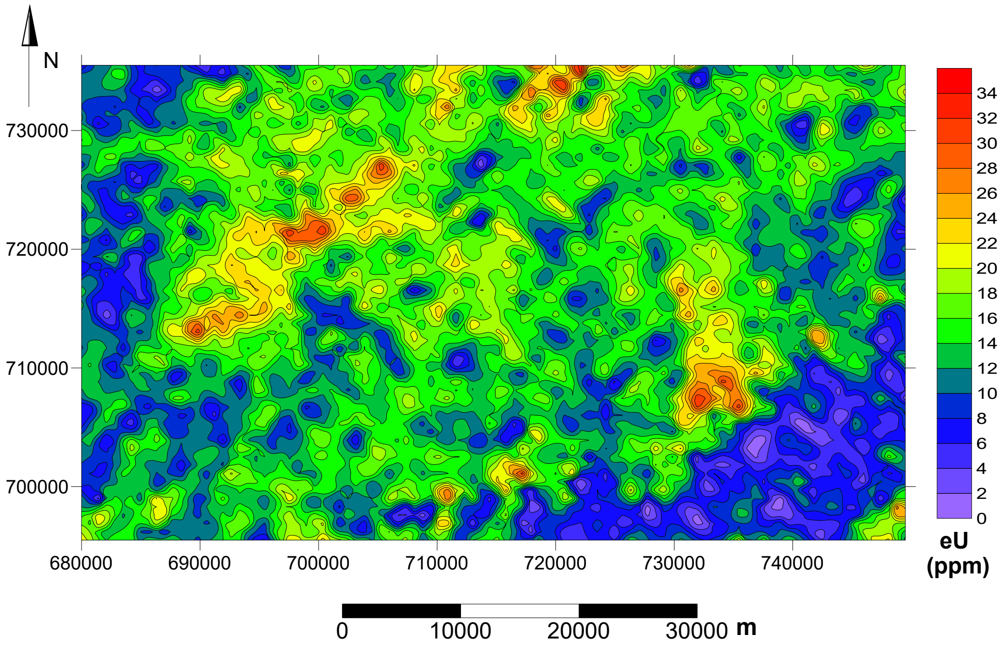

Figure 5. Coloured contour map of equivalent uranium (eU) aeroradiospectyrometric data, in (ppm*10) Wadi Araba area, Northern Eastern Desert, Egypt[1]

3.2.1. Very low eU level (less than 1.0 ppm)

This level ranges in intensity of aerial equivalent uranium from 0.1 to 1.0 ppm. In the south and southeastern parts, it coincides with W. Irkas and Mokattam formations. It is also associated with G. El-Galala El-Bahariya and El-Galala formation in the northwestern, western and southwestern parts of the area under study. Moreover, some parts of Rod El-Hamal and Malha formations as well as Quaternary Sediments are connected with this level.

3.2.2. Low eU level (1.0-1.6 ppm)

It is encountered as zones with different shapes distributed allover the area under study. It coincides with Quaternary Sediments, some parts of Rod El-Hamal, W. Irkas, Sudr and El-Galala formations in the eastern and southeastern parts of the study area as well as Qiseib formation in the northern part and Mokattam formation in the northwestern part. This level varies in intensity from 1.0 to 1.6 ppm (Figure 5).

3.2.3. Intermediate eU level (1.6-2.4 ppm)

This level corresponds with some parts of Quaternary Sediments as well as Mokattam and Rod El-Hamal formations. It also coincides with the Malha, El-Galala, Duwi and Sudr formations on the two cliffs of El-Galala El-Bahariya and El-Galala El-Qibliya as well as some parts of the Qiseib formation in the northern part of the area under investigation. This level ranges in intensity from 1.6 to 2.4 ppm (Figure 5).

3.2.4. High eU level (2.4-3.2 ppm)

It is mainly encountered with the southeastern and northwestern parts of the study area (along the southern and the northern escarpments of G. El-Galala El-Bahariya and G. El-Galala El-Qibliya respectively). It coincides with Malha, El-Galala, Duwi and Sudr formations. Besides, some parts of the Quaternary Sediments in the central part, and W. Irkas formation in the southern part of the area under consideration. This level ranges in intensity from 2.4 to 3.2 ppm (Figure 5).

3.2.5. Very high eU level (more than 3.2 ppm)

This level possesses nearly circular shapes. It is registered over some parts of Sudr formation in the southeastern part, Rod El-Hamal formation in the northern part, and Duwi formation in the northwestern part of the area under investigation. The intensity of this level varies from 3.2 to about 3.9 ppm (Figure 5).

3.3 Equivalent Thorium (eTh) spectrometric level

The patterns of the eTh contour map (**Figure 6**) reflect much of the regional geology. Besides, many local changes in the regional trend of rocks are marked by corresponding changes in the contours of this map. This map is separated into five remarkable levels ranging in intensity from less than 1.4 (0.1) ppm to more than 5.6 (7.0) ppm and in colour from deep blue (very low intensity) to red (very high intensity to help in the lithologic interpretation of the aerial radiospectrometric survey data. These five levels could be described in the following:

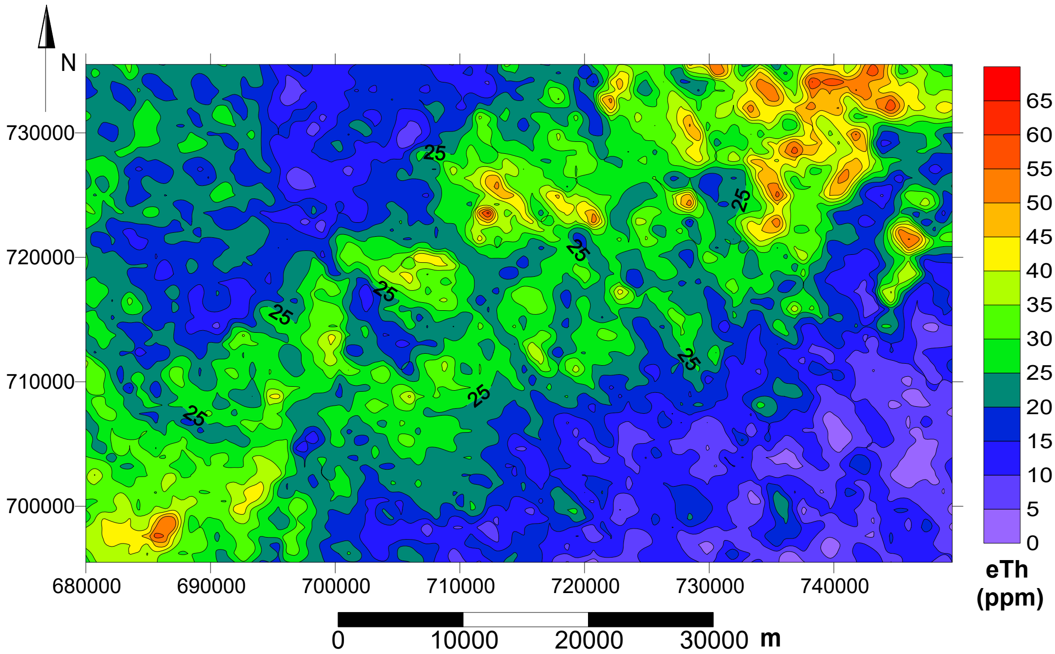

Figure 6. Coloured contour map of equivalent Thorium (eTh) aeroradiospectyro-metric data, in (ppm*10),Wadi Araba area, Northern Eastern Desert, Egypt[1]

3.3.1 Very low eTh level (less than 1.4 ppm)

This level mainly encountered within the southern, southeastern, eastern and northwestern parts of the area under study. It coincides with W. Irkas, some parts of Mokattam, Duwi, Sudr and El-Galala formations in the southern and southeastern parts and Quaternary Sediments in the eastern part as well as the Mokattam formation in the northwestern part of the area under consideration. This intensity of this level varies from 0.1 to 1.4 ppm (Figure 6).

3.3.2 Low eTh level (1.4-2.8 ppm)

It is distributed allover the study area and corresponds with Quaternary Sediments, W. Irkas, some parts of Mokattam, Sudr and Duwi formations in its southeastern part. Besides, it coincides with some parts of Rod El-Hamal formation in the central part and Mokattam, Duwi, Malha and El-Galala formations in the northwestern part of the area under study. This level ranges in intensity from 1.4 to 2.8 ppm (Figure 6).

3.3.3 Intermediate eTh level (2.8-4.2 ppm)

It coincides with Rod El-Hamal formation, and Quaternary Sediments in the northeastern and central parts, Malha, Qiseib and El-Galala formations in the northwestern and southwestern parts of the area under study. This level ranges in intensity from 2.8 to 4.2 ppm (Figure 6).

3.3.4 High eTh level (4.2-5.6 ppm)

It is encountered and associated with Rod El-Hamal, Qiseib, Malha and some parts of El-Galala formations. This level ranges in intensity from 4.2 to 5.6 ppm (Figure. 6). It is mainly encountered within the north and northeastern parts of the area under study.

3.3.5 Very high eTh level (more than 5.6 ppm)

This level possesses nearly circular or elongated shapes and is encountered in the northern, northeastern and southwestern parts of the area under investigation. It is registered over Rod El-Hamal, Qiseib, Malha and El-Galala formations. This level possesses an intensity reaching to about 7.0 ppm starting from 5.6 ppm (Figure 6).

3.4 eU/ eTh ratio spectrometric levels

The eU/eTh ratio contour map (**Figure 7**) can be divided into five different levels ranging in intensity from 0.05 to 2.5 and in colour from deep blue (very low intensity) to red (very high intensity) to help in the lithologic interpretation of the aeroradiospectrometric survey data. The five levels could described in the following:

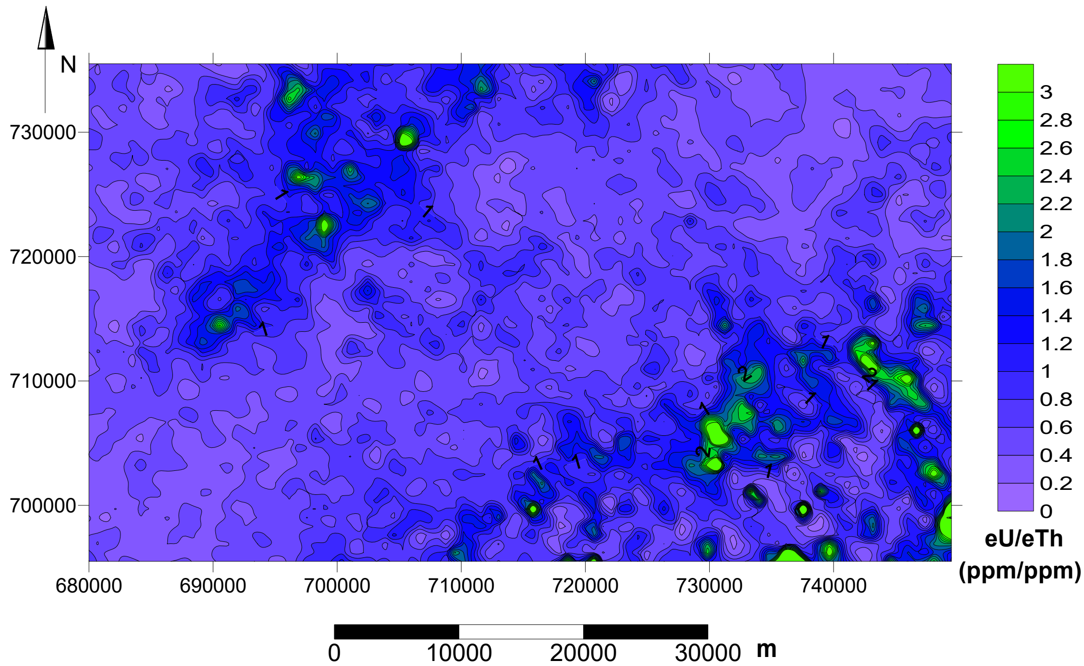

Figure 7. Coloured contour map of equivalent uranium / equivalent thorium (eU/eTh) aeroradiospectyrometric data, in (ppm/ppm), Wadi Araba area, Northern Eastern Desert, Egypt[1]

3.4.1 Very low eU/eTh (less than 0.5)

It is encountered as zones with different shapes which are distributed allover the study area especially in its northeastern and southwestern parts. It coincides with Rod El-Hamal, Qiseib, Malha and El-Galala formations as well as some parts of W. Irkas and Mokattam formations beside the Quaternary Sediments. This level ranges in intensity from 0.045 to 0.5 (Figure 7).

3.4.2 Low eU/eTh level (0.5-1.0)

It is also encountered and distributed allover the area under investigation. It coincides with great parts of the Quaternary Sediments, as well as Duwi, Malha, Sudr, Mokattam and El-Galala formations. This level ranges in intensity from 0.5 to 1.0 (Figure 7).

3.4.3 Intermediate eU/eTh (1.0-1.5)

This level is mainly encountered within the northwestern and southeastern parts of the area under study. It corresponds with Mokattam, some parts of W. Irkas, Duwi, El-Galala and Sudr formations. Besides, some scattered spots are encountered over the Quaternary Sediments. This level oscillates in intensity from 1.0 to 1.5 (Figure 7).

3.4.4 High eU/eTh level (1.5-2.0)

This level is encountered as zones with different shapes that are distributed along the southern escarpments of El-Galala El-Bahariya and the northern escarpments of El-Galala El-Qibliya. It is registered over some parts of the Mokattam, Duwi, W. Irkas, El-Galala and Sudr formations, as well as the Quaternary Sediments. This level ranges in intensity from 1.5 to 2.0 (Figure 7).

3.4.5 Very high eU/eTh level (more than 2.0)

This level extends over the northwestern and southeastern parts of the area under study. It possesses mainly circular or elongated shapes and is encountered over small parts of the Mokattam, Duwi and W. Irkas formations, besides the Quaternary Sediments. This level shows an intensity reaching to more than 2.5 beginning from 2.0 (Figure 7).

4. Methodology

4.1 Uranium favourability index (U_2)

Saunders and Potts[18] attempted to determine a general "uranium favourability index" by plotting histograms of various possible indices such as the eU/eTh ratio for about 30 different areas, where existing mines and occurrences were known to be favourable. Based on the observation yhat high mean uranium content indicates that there is sufficient uranium for possible geochemical concentrating processes to work, and that low mean eU/eTh and eU/K values indicate these processes took place, they derived the index U_2 for uranium $U_2 = MeTh * MK/MeU$ ………..........……(1)

4.2 Three- Elemental Effective Parameter (F)

The Three-Effective Parameter (F) seems to be very useful, because it comprises two important characteristics of the rock environment, i.e., the potassium (K) abundance to the eTh/eU ratio and eU abundance to the eTh/K ratio as expressed by the following relation[19]:

$F = MeU * MK/ MeTh$……………….. (2)

F-parameter can acquire values up to 1.2 or 1.3 in common fresh rocks, while altered rocks may reach 2.0 or even 5.0, exceptionally 10.0.

4.3 Corroboration factor (C)

[4] were attempting to relate the three-radioelements K, eU and eTh in a different way than the two other parameters known as “U2”[18] and “F”[19]. This factor was nominated by[4] as the Corroboration factor (C), which may be useful in delineation of anomalies of radiospectrometric zones. It may also contain some important and recognized qualities of the rock environment, i.e., the eU abundance relative to the K/eTh ratio and the eTh abundance relative to the K/eU ratio. This factor can be expressed in the following relation:

$C = MeU * MeTh / MK$…………………(3)

4.4 Uranium migration in geologic units

Uranium and thorium are often associated in geologic units due to their similar ionic radii. Uranium is easy to mobilize and migrate under the action of oxygen from underground water and atmosphere during its evolution. Meanwhile, thorium is relatively stable in oxidation zone, and stay in place, i.e., the present Th-high area could be considered as the original U-high area. The eU/eTh ratio is a very important geochemical index for U migration. It is an approximate constant in some rock types or geologic rock units in a relatively closed environment. Uranium migration (in or out) occur, within some probability, in geologic units with relatively closed environments. Besides, the half-life times of U and Th elements are very long (4.47×10^9 for U^{238} & 1.41×10^{10} for Th^{232}). So, the present eU/eTh ratio can be considered as an original ratio, to account for uranium migration[20].

The migration rate of uranium could be calculated as follows[20]:

Paleo-uranium background (i.e., the original uranium content U_O) is calculated by multiplying the average eTh content detected in each geologic unit by the average regional MeU/MeTh ratio[20].

$U_O = MeTh * M (eU/eTh)$……………..(4)

Where MeTh is the average eTh content in a certain geologic unit (in ppm), and M(eU/eTh) is the regional average of (eU/eTh) ratio in different geologic units. The amount of mobilized uranium (i.e., the amount of uranium migration “Um”) can be calculated by the following relation:

$U_m = U_p – U_o$…….….........………(5)

where U_p is the present average uranium content in a certain geologic unit. If $U_m > 0$, uranium migration is in the geologic body during late evolution (i.e., +ve value) and ,

If "U_m" < 0, uranium migration is out of the geologic body during late evolution (i.e., -ve value).

The mobilized uranium migration rate (P) can be calculated by the following relation :

$P = (U_m/U_p) * 100$………………(6)

This value (in %) can be either positive or negative, according to the direction of uranium migration, where it can be "in" or "out" of the geologic body respectively.

This method was applied in the in Bahariya Oases, Western Desert, Egypt by[21]. According the results attained in this study, the source rocks (migration out) can be basalt, Sand dunes, Bahariya formation and Sabkha sediments. Meanwhile, the rock units which received uranium (migration in) cab be Qazzun formation.

5. Results and interpretation

Statistical characteristics of the aeroradiospectrometric data were calculated for all lithologic units in the study area. The arithmetic mean (X), standard deviation (S) and coefficient of variability (C.V., in %) for the radioelements and one ratio (K, eU, eTh and eU/eTh) for each rock unit were computed (**Table 1**).

Lithologic unit (Fig. 2)	**K %**			**eU (ppm)**			**eTh (ppm)**			**eU/eTh (ppm/ppm)**		
	X	**S**	**C.V. %**	**X**	**S**	**C.V. %**	**X**	**S**	**C.V. %**	**X**	**S**	**C.V. %**
RH	0.50	0.11	22.0	1.54	0.28	18.2	3.98	0.65	16.3	0.41	0.11	0.27
Qb	0.47	0.10	21.3	1.50	0.24	16.0	3.76	0.72	19.2	0.41	0.09	0.22
Ml	0.47	0.09	19.1	1.83	0.42	23.0	3.75	0.82	21.9	0.51	0.22	0.43
Gl	0.36	0.05	13.9	1.10	0.22	20.0	3.05	0.27	8.9	0.36	0.80	2.22
WI	0.16	0.06	37.5	1.15	0.39	33.9	1.17	0.37	31.6	1.01	----	----
Mk	0.22	0.05	22.7	1.16	0.38	32.8	1.58	0.39	24.7	0.84	----	----
QtS	0.33	0.06	18.2	1.50	0.33	22.0	2.70	0.49	18.2	0.61	0.22	0.36
Regional Average										0.59		

Table 1. Summary of the statistical characteristics of various rock types from Aeroradiospectrometric data of Wadi Araba, North Eastern Desert, Egypt

5.1 Discussion of aeroradiospectrometric parameters

Two main aeroradiospectrometric statistical parameter, i.e., the arithmetic mean (X) and the standard deviation (S), beside the coefficient of variability (C.V., %) for the three radioelements and one ratio (K, eU, eTh and eU/eTh) were computed for all lithologic units in the area study (Table 1), except Duwi and Sudr formation which have low data to compute the statistical characteristics for each. The arithmetic means (X) for all geologic units and formations were compiled, drawn, presented and arranged according to their relative ages (**Figure 8**).

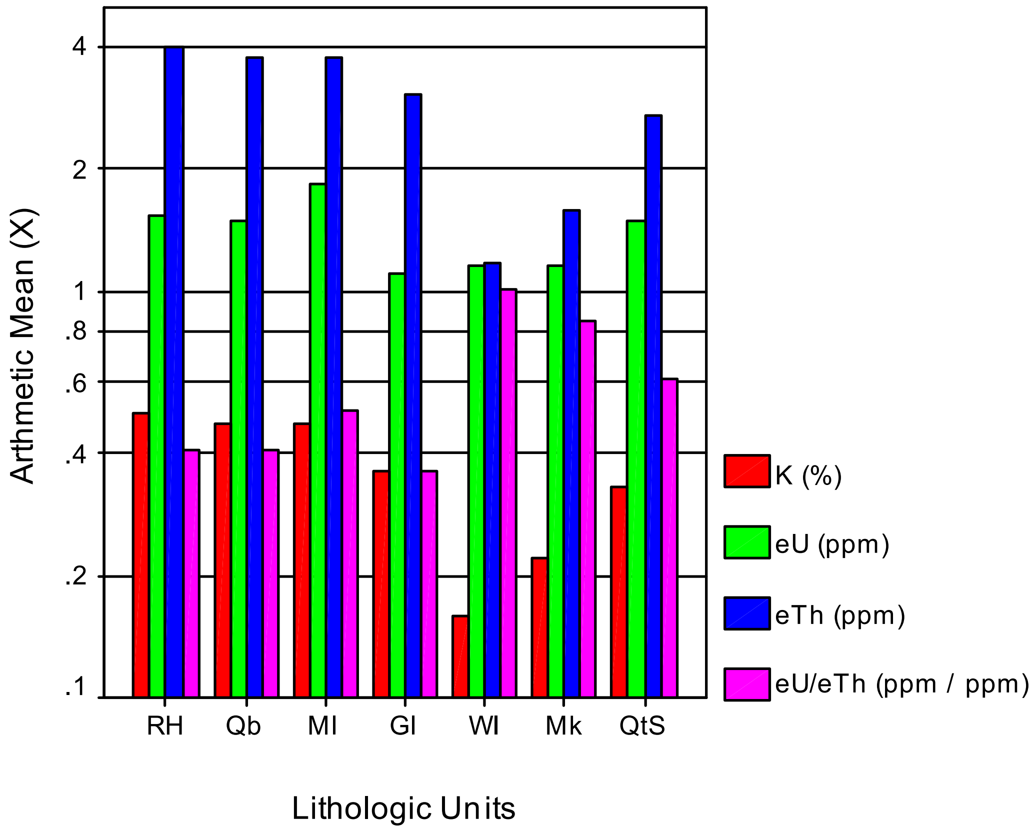

Figure 8. Relation between the lithologic units arranged according to their relative ages and their computed arithmetic means (X) for K, eU, eTh and eU/eTh, Wadi Araba area, Northern Eastern Desert, Egypt

These results ascertain that the maximum arithmetic means of aeroradio-spectrometric data are associated with Rod El-Hamal, Qiseib and Malha Formations. The minimum values are connected with Wadi Irkas and Mokattam Formations. The intermediate values are correlated with El-Galala, Duwi and Sudr Formations as well as Quaternary Sediments.

The highest (X) values of aeroradiospectrometric potassium data (Table 1 and Figures 4&8) are associated with Rod El-Hamal (0.50%), Qiseib (0.47%) and Malha (0.47%) Formations. The intermediate values are correlated with El-Galala (0.36%), Mokattam (0.22%) Formations and Quaternary Sediments (0.33%). The lowest values are related to Wadi Irkas Formation (0.16%).

The highest (X) values of aeroradiospectrometric "eU" data (Table 1 and Figures 5&8) are related to Malha (1.83 ppm), Rod El-Hamal (1.54 ppm) and Qiseib (1.50 ppm) Formations as well as Quaternary Sediments (1.50 ppm). The intermediate values are correlated with Mokattam (1.16 ppm) and Wadi Irkas (1.15 ppm) Formations. The lowest values are connected to El-Galala Formation (1.10 ppm).

The Highest (X) values of aeroradiospectrometric eTh data (Table 1 and Figures 6&8) are correlated with Rod El-Hamal (3.98 ppm), Qiseib (3.76 ppm), Malha (3.75 ppm) Formations. The intermediate values are correlated with El-Galala Formation (3.05 ppm) and Quaternary Sediments (2.70 ppm). The lowest values are connected to Mokattam (1.58 ppm) and Wadi Irkas Formations (1.17 ppm).

The Highest (X) values of aeroradiospectrometric (eU/eTh) data (Table 1 and Figures 7&8) are related to Wadi Irkas (1.01) and Mokattam (0.84) Formations as well as Quaternary Sediments (0.61). The intermediate values are associated with Malha (0.51), Rod El-Hamal (0.41) and Qiseib (0.41) Formations. The lowest values are connected to El-Galala Formation (0.36).

5.2 Discussion of the results of favourability indices

Althogh the principle of the three favourability indices was based on data obtained from areas known to have workable uranium deposits in Canada, there is some logic for using it to throw light on areas without such high economic uranium contents. The histograms (**Figures 9**, **10** and **11** & **Table 2**) show vertical bar charts of the three radioelement favourability indices (U2, F and C) for all lithologic formations forming Wadi Araba areaand its surroundings.

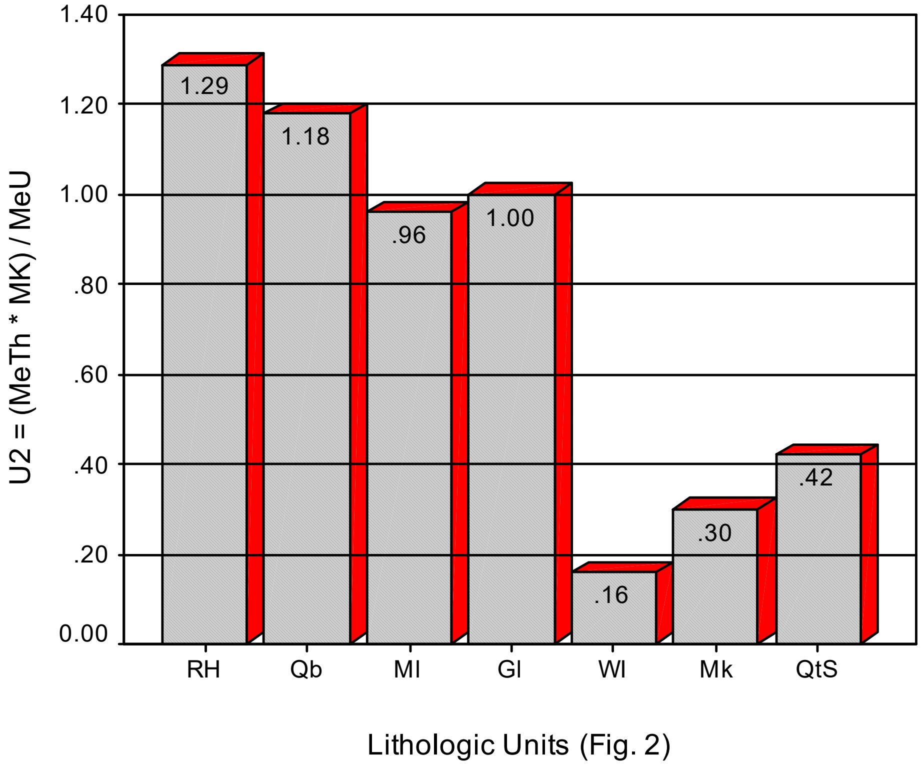

Figure 9. Vertical bar chart showing the uranium favourability index (U_2) for the different rock units forming Wadi Araba area, Northern Eastern Desert, Egypt

Lithologic Units (Fig. 2)	**Uranium favourability index (U_2)**	**F – parameter (F)**	**C – factor (C)**
RH	1.29	0.19	12.26
Qb	1.18	0.19	12.00
Ml	0.96	0.23	14.60
Gl	1.00	0.13	9.32
WI	0.16	0.16	8.41
Mk	0.30	0.16	8.33
QtS	0.42	0.18	12.27

Table 2. Results of the computed three favourability indices, Wadi Araba area, Northern Eastern Desert, Egypt

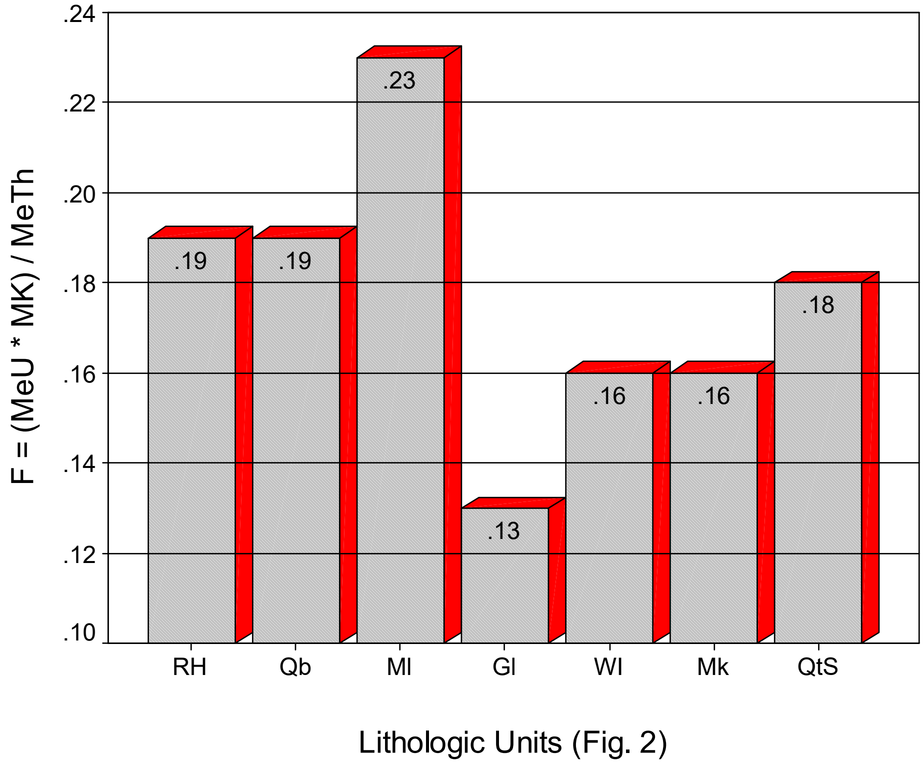

Figure 10. Vertical bar chart showing the three elemental effective – parameter (F) for the different rock units forming Wadi Araba area, Northern Eastern Desert, Egypt.

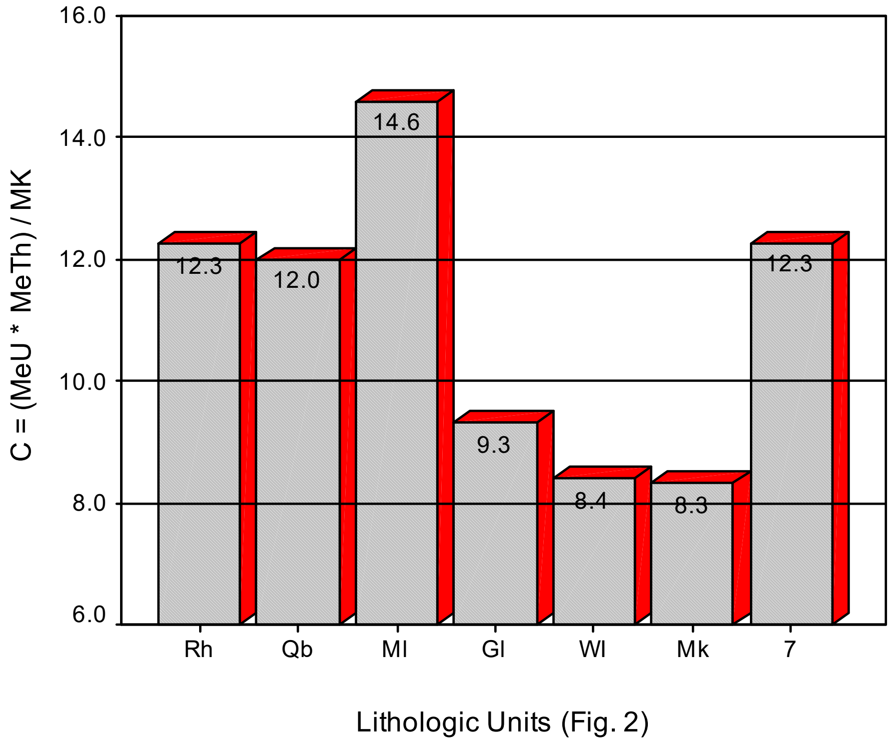

Figure 11. Vertical bar chart showing the Corroboration–factor (C) for the different rock units forming Wadi Araba area, Northern Eastern Desert, Egypt

5.2.1 U2 index

The equation derived by[18], for uranium favourability index (U2) was computed. The geologic formations forming Wadi Araba area can be classified, based on their calculated U2 index values, into three main groups of relatively minor, intermediate and major potentials (Figure 10), which require further verification and research.

a. Minor Potential: The minor or least potential values, where U2 ranges from 0.16 to 0.42, are associated with Wadi Irks, Mokattam Formations as well as Quaternary Sediments.

b. Intermediate Potential: The intermediate potential values, where U2 index values range from 0.42 to 1.0, include Malha and El-Galala Formations.

c. Major Potential: The major or most potential values, where U2 index values reach more than 1.0, include Rod El-Hamal and Qiseib Formations.

5.2.2 F parameter

The equation derived by[19], for the three-element effective parameter (F) was also computed, established and drawn for each lithologic formation (Figure 10) in the study area. It was found that F values oscillate between 0.13 (El-Galala Formation) and 0.23 (Malha Formation). The area can be classified, based on their calculated "F" parameter values, into three main groups of relatively minor, intermediate and major potentials (Figure 10).

a. Minor Potential: The minor or least potential values (ranging from 0.13 to 0.16) are associated with El-Galala, Wadi Irkas and Mokattam Formations.

b. Intermediate Potential: The intermediate potential values (varying from 0.18 to 0.19) are associated with Quaternary Sediments, Rod El-Hamal and Qiseib Formations.

c. Major Potential: The major or most potential values (reaching more than 0.19) include only Malha Formation.

5.2.3 C factor

The equation derived for the corroboration factor (C) was also computed, established and drawn for all lithologic formations (Figure 11). It varies in value between 8.33 (Mokattam Formation) and 14.60 (Malha Formation). The area can be classified, based on their calculated "C" factor -or values, into three main groups of relatively minor, intermediate and major potentials (Figure 11).

a. Minor Potential: The minimum values (oscillating from 8.33 to 9.32) could be correlated with Mokattam, Wadi Irkas and El-Galala Formations.

b. Intermediate Potential: The intermediate values (changing from 12.0 to 12.27) includes Qiseib, Rod El-Hamal Formations as well as Quaternary Sediments.

c. Major Potential: The maximum values (attaining 14.60) involve Malha Formation.

6. Discussion

Table 3 shows the computed statistics of uranium migration (U_p, U_o, U_m and P) of the different rock units and formations in the study area. Close examination of Table 3 shows that the six lithologic possessing negative amount of uranium migration (out) rates are as follows: Rod El-Hamal (RH), Qiseib (Qb), Malha (Ml), Wadi Irkas (WI) and Mokattam (Mk) Formations as well as Quaternary Sediments (QtS). These types of rocks which have negative amounts of uranium migration rates can be considered as uranium source bodies, which provide uranium and hence mineralization to other rock types in the area. According to the results which are illustrated in Table 3, The Mokattam Formation shows an average amount of uranium that migrated out attaining about -0.17 ppm, with a uranium migration out reaching -14.66%. These values represent the maximum amount of uranium migration out rate in the study area. Meanwhile, the minimum value of uranium migration out rate reaches about -2.61%, which is associated with Wadi Irkas Formation.

Rock Unit (Fig. 2)	Present U Content (U_p) (in ppm)	Original U Content (U_o) (in ppm)	Amount of U Migration (U_m) (in ppm)	U Migration Rate (P) (in%)
RH	1.54	1.63	- 0.09	- 5.84 %
Qb	1.50	1.54	- 0.04	- 2.67 %
Ml	1.83	1.91	- 0.08	- 4.37 %
Gl	1.10	1.10	0.0	0.0
WI	1.15	1.18	- 0.03	- 2.61 %
Mk	1.16	1.33	- 0.17	- 14.66 %
QtS	1.50	1.65	- 0.15	- 10.0 %

Table 3. Statistics for uranium migration in different rock types in Wadi Araba area, Northern Eastern Desert, Egypt

The first rock unit (Rod El-Hamal Formation "RH") has uranium content (U_p) value of about 1.54 ppm as indicated from the equivalent uranium map (Figure 5). Its original uranium content (U_o) is about 1.63 ppm, as calculated from equation (4). The amount of uranium migration (U_m) reaches -0.09 ppm. This value is negative and, therefore, the migration is outward. Consequently, uranium migration rate attains -5.84%.

The second lithologic unit, i.e., the Qiseib Formation (Qb) reflects an amount of uranium migration rate (P) of about -2.67 %, uranium content (U_p) of about 1.50 ppm, original uranium content (U_o) of 1.54 ppm, and (U_m) of about -0.04 ppm. The negative (P) value indicates that the migration in Qiseib Formation in the study area is also outward.

The third lithologic unit, i.e., the Malha Formation (Ml), has a uranium content (U_p) value of about 1.83 ppm, as indicated from the equivalent uranium map (Figure 5). Its original uranium content (U_o) is about 1.91 ppm, as calculated from equation (4). The amount of uranium migration (U_m) reaches about -0.08 ppm. The uranium migration rate attains -4.37%. This value is negative and therefore, the migration is also outward.

The fourth lithologic unit, i.e., the Wadi Irkas Formation (WI) reflects an amount of uranium migration rate (P) -2.61%, uranium content (U_p) of about 1.15 ppm, original uranium content (U_o) of 1.18 ppm, and (U_m) of about -0.03 ppm. This indicates that the migration of U in Wadi Irkas Formation in the study area is also outward.

The fives lithologic unit, i.e., the Mokattam Formation (Mk) has a uranium content (U_p) value of about 1.16 ppm, as indicated from the equivalent uranium map (Figure 5). Its original uranium content (U_o) is about 1.33 ppm, as calculated from equation (4). The amount of uranium migration (U_m) reaches about -0.17 ppm. The uranium migration rate attains -14.66%. This value is negative and therefore, the migration is also outward.

The sixes lithologic unit, i.e., the Quaternary Sediments (QtS) reflects an amount of uranium migration rate (P) of about -10.0 %, uranium content (U_p) of about 1.50 ppm, original uranium content (U_o) of 1.65 ppm, and (U_m) of about -0.15 ppm. The negative (P) value indicates that the migration in Quaternary Sediments in the study area is also outward.

Table 3 shows that Rod El-Hamal, Qiseib, Malha, Wadi Irkas and Mokattam Formations as well as Quaternary Sediments have uranium migration out rates reaching -5.84%, -2.67%, -4.37%, -2.61%, -14.66% and -10% respectively. These rates of uranium migration out indicate that these rocks could be considered as major U-source bodies as far as the area under investigation is concerned.

The last lithologic unit, i.e., the El-Galala Formation (Gl), has a uranium content (U_p) value of about 1.10 ppm, as indicated from the equivalent uranium map (Figure 5). Its original uranium content (U_o) is about 1.10 ppm, as calculated from equation (4). The amount of uranium migration (U_m) reaches about 0.0 ppm. The uranium migration rate attains 0.0%. This value indicates that this formation has not changed over the time.

7. Summary and conclusion

The exposed rocks of the Wadi Araba area and its surrounding plateaus range in age from Late Paleozoic to Quaternary. The arithmetic mean (X), standard deviation (S) for the three aeroradiospectrometric elements (K, eU and eTh) as well as eU/eTh ratio wer computed for the seven rock units and formations exposed in the area. The present work is dedicated fundamentally to identify significant rock types of anomalously high U, Th and K concentrations. Their delineation were based mainly on the computation of the uranium favourability index (U_2), three elemental effective parameter (F) and corroboration factor (C).

The (U_2) index was found to oscillate between 0.16 (Wadi Irkas Formation) and 1.29 (Rod El-Hamal Formation). The F-parameter and C-factor were found to vary from 0.13 (El-Galala Formation) to 0.23 (Malha Formation) for "F" and from 8.33 (Mokattam Formation) to 14.60 (Malha Formation) for "C". The high values of F-parameter and C-factor were found to be correlated with Malha Formation. Meanwhile, high values of (U_2) index were found to correlate well with Rod El-Hamal Formation. These results ascertain previous findings by various authors [11,22,1,3,4]. The three favourability indices are very important in identifying the most significant rock types. Nevertheless, the most important between them is C-factor, which delineated the three rock types showing the highest radioelement contents in the area under study (Figure 2).

Investigation of the possibilities of identifying rock types where uranium migration took place was conducted to delineate the rate and direction of such migration. This study revealed that uranium migration was outward in Rod –Hamal,Qiseib, Malha, Wadi Irkas and Mokattam Formations as well as Quaternary Sediments. Their uranium migration rates are negative and reached -5.84%, -2.67%, -4.37%, -2.61%, -14.66% and -10% respectively. The El-Galala Formation has the uranium migration rate attains 0.0%. This value indicates that this formation has not changed over time (stable contents of uranium).

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