Ground gamma-ray spectrometric studies of El-Sahu area, southwestern Sinai, Egypt

Ahmad M. Abdrabboh
Nuclear Materials Authority, Egypt

1. Introduction

The use of gamma ray spectrometry as a tool for geological mapping, environmental monitoring and exploring radionuclide concentrations has found widespread acceptance over several decades and continues to be developed (IAEA, 2010). It has been observed that airborne geophysical studies carried out in southwestern Sinai area by Abdrabboh (2005) recommended further detailed ground geophysical surveys to map any surface and subsurface extensions of the selected U-mineralized zones. El Sahu area was one of the selected areas that has promising uranium occurrence to be the present target in uranium exploration of the present ground spectrometric study. The studied area is chosen among many interpreted eU anomaly zones located in the interpreted airborne spectrometric zonation map (Fig. 2) and denoted by “U12”.

El Sahu area is located about 60 km. to the east of Abu Zeneima town on the eastern coast of the Gulf of Suez, southwestern Sinai Egypt. It is bounded by Longitudes 33°22'58"–33°23'10"E and Latitudes 28°58'31"–29°58'45"N, covering an area of about 98,371 m².

The northern part of the studied area has a relatively moderate topography relief. Meanwhile, the southern part of the area is relatively high topographic relief, where the elevation nearly 580 m above sea level. In addition, the lowest topographic area located in the course of wadi El Sahu (Fig. 3). The studied area is occupied by upper Proterozoic basement rocks non-conformably overlain by sedimentary successions of Cambro-Ordovician and Carboniferous ages (Fig. 1).

The objective of the present study is to investigate the radioactive anomalies of El Sahu area by applying the ground gamma-ray spectrometric survey. The data were represented as nine image maps, which are: total count (T.C), equivalent uranium (eU), equivalent thorium (eTh), potassium (K%), ratio maps (eU/eTh, eU/K and eTh/K) and two composite image maps.

1.1. Geologic setting

The regional geology of Wadi El Sahu area has been studied and described by several workers as Barron (1907), Abdelmonem et al.
Younger granite is found at the base of the sedimentary succession of the studied area and exposed at G. Adedia that located at the eastern side of studied area. These granites are overlain nonconformably by Paleozoic succession. The Paleozoic outcrops were subdivided by Barron (1907) into: lower sandstone series, Carboniferous limestone series and upper sandstone series. Weissbrod (1969) applied the term Um Bogma Formation to the Carboniferous limestone series of Barron (1907).

Accordingly, the study area was classified stratigraphically into three main stratigraphic units that include from base to top, lower sandstone series of Adadia Formation (Barron, 1907), Carboniferous limestone series (Um Bogma Formation) and upper sandstone series of El Hashash Formation (Wiessbrod, 1980).

Lower sandstone series is classified into three Formations from base to top as Sarabite El Khadim Formation, Abu Hamata Formation and Adedia Formation with the Cambro-Ordovician age. The Carboniferous limestone series (Um Bogma Formation) is Lower Carboniferous age and classified from base to top into three members as lower member, middle member and upper member.

Lower sandy-dolostone member is overlain unconformable of El Adedia sandstone. It contains Fe–Mn ores with shale and ferruginous siltstone which contains high uranium content reaching up to 316 ppm. Middle marl member contains marl and marly-dolostone with shale. Its uranium content reaches to 20 ppm. Upper member is overlies conformably the middle member. It is composed of yellow, pink, and grayish crystalline dolomite and little sandstone.

Upper sandstone series is Lower Carboniferous age and subdivided into three Formations comprise from base to top, El-Hashash, Magharet El-Maiah and Abu Zarab Formations. All these succession covered by basaltic sheet or sill. In the scope of uranium mineralization, Um Bogma Formation has the priority and considered the main target for uranium ore exploration and prospecting.
1.2. Ground gamma-ray spectrometric survey

Variations in the radioactivity of rocks was used for geological mapping and outlining the U-mineralized zones (Aissa and Jubeli, 1997; Gaafar, 2015) and for environmental monitoring (Tauchid and Jubeli, 1991; Gaafar et al., 2016).

Ground γ-ray spectrometric measurements were conducted to cover a variety of lithologies and various degrees of alterations associated with the uranium mineralization in the study area. During the follow up of the recorded high uranium anomaly (U12) as interpreted in previous work at Wadi El Sahu area (Fig. 2); it is located within the lower member of Um Bogma Formation.

1.3. Field procedure

Ground radioelement concentration measurements were carried out over the studied area in the form of random pattern with stations interval ranging from 5 to 10 m according to high U-anomalies. The measurements were conducted using a high sensitive portable gamma-ray spectrometer of model RS-230. The spectrometer is well calibrated on artificial concrete pads of NMA, containing known concentrations of K, U and Th. The radiation energy spectrum depicts the relative count rates in the range between 0.12 and 3.0 MeV. U, Th and K were determined by analyzing the γ-radiations from $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$, recorded at different windows (Chiozzi et al., 2002). For the determination of eU and eTh, the selected peaks and energy values were $^{214}\text{Bi}$ at 1.76 MeV and $^{208}\text{Tl}$ at 2.62 MeV, respectively. Potassium was directly determined from the window centered at 1.46 MeV corresponding to the primary decay of $^{40}\text{K}$.

1.4. Gamma-ray spectrometric results

The high U-content found with some facies as ferruginous siltstone, carbonaceous shale, Fe-Mn ore, ferruginous sandstone of lower member and sandyclaystone of upper member of Um Bogma Formation. The obtained data (total count, K, eU, and eTh) as well as their ratios (eU/eTh, eU/K and eTh/K) were prepared and subjected to detailed interpretations and represented as colored image maps (Figs. 4–9). This examination aims to classify the study area into zones based on the contrast in their spectral γ-ray emission response levels.

1.5. Statistical treatments of the spectrometric data

The ground gamma-ray spectrometric data were treated statistically using the computer programs. The computed values of minimum, maximum, mean (X) and standard deviation (Std. Dev.) for the eU (in ppm), eTh (in ppm) and K (in%) concentrations as well as their ratios (eU/eTh, eU/K and eTh/K) for El Sahu area are summarized in Table 1. The main results of the statistical treatment, as illustration in Table 1, are showing that Um Bogma Formation has the highest values of radioactive concentrations. The eU content ranges between 1.7 ppm (Wadi sediments) and 316 ppm (Um...
Bogma Formation), and its average abundance reaches about 31.8 ppm (Table 1). The eTh content reaches 40.4 ppm as a maximum value in Um Bogma Formation and diminishes to 0.9 ppm as a minimum value in El Hashash sandstone (Table 1). The average of eTh content in the study area attains about 10.3 ppm. Besides, there is a high variability in the computed values of eU/eTh and eU/K ratios which shows high anomalous values in Um Bogma Formation reaching to 45.5 and 234 respectively (Table 1). The average value (3.1) is considered higher more than 10 times the average of crustal rocks (0.25). Potassium concentrations reach their highest values (2.8%) in the course of wadi El Sahu sediments due to the accumulation of clay minerals eroded from the surrounding rocks.

The spectrometric image maps (Figs. 4 to 12) emphasize the surface distribution of the radioelements on the surveyed area.

Consequently, the relationship of the radioelement pattern and the distribution of the major lithologic units, including the anomalous zones, have formed the basis for the present interpretation.

1.6. Total count distribution map

The examination of the total-count (T.C) radiometric image map (Fig. 4) shows that the radioactivity levels vary widely from 2.8 Ur to 326.5 Ur with an average of about 38.6 Ur classified into three relative zones of radioactivity. Low radioactivity zone, (less than 20 Ur), this level is encountered at the northwestern part of the study area, coincides with El Hashash sandstone and Wadi sediments of the course of wadi El Sahu, trending EW trend in the central part of the study area and colored by blue to green.

Intermediate radioactivity level, (from 20 to 50 Ur), is recorded over ferruginous sandstone of lower member of Um Bogma. It is colored by yellow to red (Fig. 4).

The high radioactivity level extends over some parts of Um Bogma Fm. (upper and lower members). It is represented by an elongated and rounded anomaly zones located in the southern and east northern parts of the study area. These anomaly as a whole arranged in WNW, NW and NNW direction trends. It is colored by yellow to red (Fig. 4).

1.7. Potassium (K) surface distribution map

The potassium content in El Sahu area ranges from 0.1% to 2.8% with an average value of about 0.7%. Most of the area is characterized by low level of potassium content (less than 0.5%). Relatively high potassium concentrations are associated with the course of wadi El Sahu due to high concentrations of clay minerals eroded from the surrounding rocks (Fig. 5).

The low K zone concentrated with the northern and southern parts of the area. It ranges in K concentration from 0.1 to less than 0.5%. It occupies the most southern and northeastern parts of the studied area. El Hashash Formation and some parts of Um Bogma Formation are occupied with this level. The intermediate K (0.5–1.5%) is encountered as zones of irregular shape expands on the entire area.
The high K zone varies in concentrations from 1.5 to 2.8% and mainly associated with claystone of upper Um Bogma Formation. The anomalies are exposed as scattered spots mainly elongated in the two main structural trends in the study area (NNW-SSE and ENE-WSW).

1.8. Equivalent thorium (eTh) distribution map

The equivalent thorium content in the study area attains its maximum value reaching about 47.5 ppm, which coincide with Um Bogma Formation. Some of the delineated high eTh anomalies are circular in shape and others are elongated, which trends in the NE, NS and NNW directions (Fig. 6). The lowest eTh value, of about 0.9 ppm, is associated with El Hashash sandstone located in at the northwestern and south-central parts of the studied area. The average values of about 10.7 ppm are associated with Adedia Formation.

1.9. Equivalent uranium (eU) distribution map

The equivalent uranium content attains its maximum value reaching about 316 ppm at the central northern part of the study area (Fig. 7). The minimum eU value, of about 1.7 ppm is situated at Wadi El Sahu and El Hashash sandstone. The eU image map can be separated into three remarkable and relative zones ranging in concentration from less than 1.7 ppm eU to more than 316 ppm eU described as the following.

- The low eU zone, varies in eU concentration from (1.7–10) ppm, is encountered at the elongated shape coincides with Wadi El Sahu and the northwestern parts of the studied area at El Hashash sandstone.
- The intermediate eU zone varies in eU concentration from

| T.C (Ur) | K (%) | eU (ppm) | eTh (ppm) | eU/eTh | eTh/K | eU/K |
|---------|-------|----------|-----------|--------|-------|------|
| Mini.   | 2.8   | 0.0      | 1.7       | 0.9    | 0.1   | 2.6  |
| Max.    | 326.5 | 2.8      | 316       | 40.4   | 45.5  | 49.3 |
| Mean    | 38.5  | 0.7      | 31.8      | 10.3   | 3.1   | 21.3 |
| Std Dev | 50.6  | 0.6      | 48.3      | 7.8    | 4.5   | 10.7 |
| Mean + 3SD | 190.3 | 2.5      | 176.7     | 31.3   | 16.6  | 53.4 |

Fig. 10. eTh/K image map of El Sahu area, Southwestern Sinai, Egypt.

Fig. 11. Radioelements ternary map of El-Sahu area, Southwestern Sinai, Egypt.

Fig. 12. eU ternary map of El-Sahu area, Southwestern Sinai, Egypt.
Meanwhile, Wadi sediments located at the central part of the studied area is clearly discriminated its high eTh/K values from 10 to 40 ppm and associated with wadi sediments and Adadia sandstone (Fig. 7). The high eU zone extends over most parts of Um Bogma Formation (upper and lower). It is represented by an elongated and rounded small spot at the northeastern and southern parts of the studied area. This zone trends nearly in WNW, NW and NNW directions. It varies in eU concentration from 40 to 316 ppm (Fig. 7).

### 1.10. eU/eTh ratio surface distribution map

The eU/eTh ratio is important for uranium exploration because it depends mainly on the mobility of uranium. Therefore, it outlines the most promising areas of uranium migration and accumulation and hence it determines the uranium-enriched zones. eU/eTh image map (Fig. 8) confirms the presence of very high eU/eTh ratio zones reflecting increased uranium content superimposed on constant thorium content. These anomalies may have been produced due to invagination of solutions that highly enriched with uranium. These solutions may lead to the mobilization and the re-concentration of uranium in Um Bogma Formation.

The general view of the surface eU/eTh ratio distribution map of the study area (Fig. 8) indicates that the ENE-WSW trend shows promising elongation anomalies in the northern and southern parts of the study area, which coincide with Um Bogma Formation. These strong anomalies show raised amplitudes reaching to 46, resulting in obvious exploration targets. Meanwhile, the N-S and NNW trends show slightly high content of eU over eTh levels that located mostly at the southern part of the studied area and associated also with Um Bogma Formation. Therefore, Um Bogma Formation possesses higher U-content many times greater than Adedia and El Hashash Formations, leading to an increase in the U-potentiality and possibly local uranium entrapment in this Formation of the study area.

### 1.11. eU/K ratio surface distribution map

Ratios between radioelement concentrations (eTh/K and eU/K) are often used to reduce the effect of terrain geometry on the radioelement concentration (Boyle, 1982). The studied area is associated with conspicuous and elongated high eU/K anomalies attaining values reaching 40–234 (Fig. 9). This can be attributed essentially to the uranium mineralized zones of Um Bogma Formation, without any contribution from adjacent rocks leading to an increase in its U-potentiality. The main trends of these anomalies are ENE and NW directions. The second high level of eU/K ranging from 10 to 40 is encountered as zones with different shapes, distributed over the Adedia Formation. Wadi sediments indicate low level of eU/K ratio due to its relatively moderate K-content and low eU concentration.

### 1.12. eTh/K ratio surface distribution map

As thorium is immobile element generally and does not accompany potassium during hydrothermal alteration processes, eTh/K ratio provides an excellent tool to determine the alteration zones related to the K-metasomatism. The normal ratio of crustal material is approximately $5 \times 10^{-6}$ (Galbraith and Saunders, 1983).

The eTh/K image map (Fig. 10) shows that the southern part of the studied area is clearly discriminated its high eTh/K values reaching to about 49 and trending in the ENE direction. These highest anomalies of eTh/K ratio are mostly associated with Um Bogma Formation and having high eTh values relative to low K-content. Another high anomaly, reaching to about 12, coincides also with Um Bogma Formation at the northern part of the studied area. Meanwhile, Wadi sediments located at the central part of the studied area has low eTh/K ratio, due to its moderate potassium content compared to low eTh content.

### 1.13. Composite color images maps

Composite color images are created by combining information from three data sets into a single display. These images are generated by quantizing data intensity or another attribute, assigning a different primary color to each data set, and then superimposing the results. Using primary colors (Red, Green, Blue), the number of data sets that can be combined is limited to three “ternary” (Duval, 1983). In this study it was producing two ternary images: (1) the radioelement composite image combines the data of K (in green), eTh (in blue), and eU (in red) as shown in Fig. 11, (2) the uranium composite image combines the data of eU (in red) with the ratios eU/eTh (in blue) and eU/K (in green) as shown in Fig. 12.

The radioelement composite image map Fig. 11 shows a rounded zone of red color associated mainly with Um Bogma Formation in the northern part of the studied area due to its high content of uranium concentrations. The southern part of the studied area is characterized with elongated zone in the EW direction of red color that coincide also with Um Bogma Formation in the southern part of the studied area which reflect high concentration of eU compared to low eTh and K content. There are scattered small white spots, located in the northern and southern parts of the studied area reflect high concentration of three radioelements. The green color covers Wadi El Sahu reflecting high K concentration than eU and eTh radioelements due to the detrital of K-feldspars that derived from the nearby granite. There are small scatter blue spots reflect high concentration of eTh than the eU and K that coincides with outcrop of Adedia Formation.

The eU composite image map (Fig. 12) can provide useful information regarding the identification of anomalous zones of enriched uranium concentration. This map combines eU (in red) with the two ratios eU/K (in green) and eU/eTh (in blue). Uranium anomalous zones, displayed as white portions on the uranium composite image map. These uranium-enriched offer good prospects for uranium, since their relatively high concentrations of uranium with respect to both potassium and thorium are important diagnostic factors in the recognition of possible uranium deposits (IAEA, 1988). This map shows white (high) regions are mainly associated with the outcropping of Um Bogma Formation. Uranium anomalies in the study area can reflect favorable geochemical environments for forming uranium deposits that can, therefore, be used as exploration guides to additional uranium deposits (Duval, 1983).

### 2. Conclusion

The stratigraphic section within the investigated area has three main stratigraphic units that include Lower sandstone series, Carboniferous limestone series (Um Bogma Formation) and upper sandstone series.

The ground gamma-ray spectrometric survey has been conducted along El Sahu area in order to outline the radioactive zones as recommended from the previous airborne studies carried out in southwestern Sinai area. The resultant image maps show different radioactivity levels, which reflect contrasting radioelement contents for the exposed various rock types in the studied area. They are mainly associated with Um Bogma Formation. The study area possesses total count ranging from 2.8 Ur to 326.5 Ur, 1.7 to 316 ppm eU, 0.9 to 47.5 ppm eTh and 0.1 to 2.8 Ks. The high K ratio located in the course of wadi El Sahu sediments. The highest U-anomalies are located in the north central and southern parts of the studied area.

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The eU/eTh, eU/K ratios distribution maps and composite image maps indicate that the Um Bogma Formation shows promising U-anomalies. These high anomalies are elongated in the ENE and NNW directions, in the northern and southeastern parts of the studied area. These spectrometric signatures indicate that Um Bogma Formation are characterized by higher U-content many times greater than the other rocks in the studied area, leading to an increase in the U-potentiality and possibly local uranium entrapment.

The composite image maps for eU reveal that there are two important anomalies, located in the southern and northern parts of the study area; both are connected to the Um Bogma Formation. The southern anomaly seems to represent the highest one in the study area and, hence, is considered very important from the eU point of view and needs more detail studies.

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