An Analysis of Airborne GaSamma Ray Spectrometric Data of Gabal Umm Naggat Granitic Pluton, Central Eastern Desert, Egypt

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Abstract. The present work deals with the analysis of the airborne gamma ray spectrometric data of Gabal Umm Naggat granites, Central Eastern Desert, Egypt. It shows distinct spectral pattern of the radioelement zoning which is related to the associated mineralogical variation of such granitic pluton. The pluton is divided into three spectral domains: northern, middle and southern. The northern domain (A) is characterized by high radioelements contents and high ratios. It is characterized by high Zr, Nb, Y, Th, U and HREE in the most albitized granite varieties. The middle domain (B) is K, Th rich reflects the alkali feldspar rich granite. The southern domain (C) is characterized by high three radioelements contents, but lower than the northern one. Such zonation is evidenced by the results of geochemical analysis of previous works.

To assess the potentiality of the gamma ray spectrometric signatures of areas of change associated with hydrothermal Nb-Ta-Sn occurrences, two approaches such as residual anomaly method on the basis of lithologic normalization (Th-normalized approach) and the F-parameter of Effimov approach are applied. Low anomalous potassium (K\text{d}) that connected with high anomalous uranium variation (U\text{d}), and high F-parameter anomaly strip highlight areas of change associated with hydrothermal Nb-Ta-Sn occurrences.

Keywords: Spectral domains, Th-normalized approach, Umm Naggat granites.
**Introduction**

Early gamma ray spectrometric surveys were used almost exclusively for the direct detection of U and Th orebodies (back to the years following World War II). However, with the development of spectrometers in the 1960s, the scope of the gamma ray method was expanded to include base-metal mineral exploration, geological and environmental mapping. In base-metal mineral exploration the radioelement data can be used for the indirect detection for hydrothermal alteration of host rock that can give measurable gamma spectrometric haloes aiding to such metal deposits. Porphyry Cu-Au deposits (Pires 1995), Pb and Zn deposits (Gnojek and Prichystal, 1985), potash prospecting in Qinghai, Xinjiang, China, (Zhang et al., 1998) and gold in quartz veins (Hoover & Pierce 1990; and Kuosmanen, 1994). These may be detected through potassium alteration, and gold through Au-U associations. The interpretation of K alteration from radioelement data has led to several mineral discoveries (Dickson and Scott 1997; and Shives, et al. 1997& 2000). Further examples are given in other IAEA publications. In addition, it was used for many oil and gas exploration (Saunders & Terry 1985; and Saunders et al., 1987). However, an understanding of how radiometric surveys can be applied to exploration problems requires us to consider the geological sources of radioactivity.

Over the last ten years, several geological/geochemical studies have been undertaken that seek to identify the rare-metal (Li–F) tantalum–tin–tungsten granite deposits in Umm Naggat granites. The present work highlights the role of these results which in turn would assist in analysis of the airborne radiometric signatures of this highly prospective region. Such radiometric signatures are used to provide further insight in the origin of the radioelements zoning pattern of Umm Naggat granites and to assess the potential of the gamma ray spectrometric method characterization of areas of change associated with hydrothermal Nb-Ta-Sn occurrences. This is considered as a step to maximize the potential of the radiometric approach for mineral exploration and to establish a radiometric database reference for geophysical exploration in the Eastern Desert region of Egypt.
Airborne $\gamma$-Ray Spectrometric Survey

Airborne $\gamma$-ray spectrometric data of the G. Umm Naggat area, Central Eastern Desert (CED), Egypt, were obtained as a part of an airborne spectrometric and magnetic surveying programme carried out in 1984, by Aero-Service Division, Western Geophysical Company of America USA. Such surveys were conducted along parallel flight lines that were oriented in a NE-SW direction, at 1.0 km spacing. Meanwhile, the tie lines were flown perpendicularly in a NW-SE direction, at 10 km intervals. Multichannel radiospectrometric measurements were made at 93 m intervals at a nominal sensor altitude of 120 m terrain clearance. A high-sensitivity 256-channel airborne gamma-ray spectrometer (50 l NaI “Tl” crystals) mounted in a tail-stinger configuration, was the primary sensor elements in the Aero-Service CODAS/AGRS 3000F computer-based digital data acquisition system (Aero-Service, 1984). The obtained airborne radiometric survey data were reduced, compiled and finally presented in the form of contour and composite profile maps at a scale of 1:50,000.

Geological Setting of G. Umm Naggat Area

The Gabal Umm Naggat area lies in the central part of the Egyptian Eastern Desert, particularly extends from 25$^\circ$ 25′ 00″ to 25$^\circ$ 32′ 30″ N latitudes and 34$^\circ$ 07′ 30″ to 34$^\circ$ 17′ 30″ E longitudes (Fig. 1).

![Fig. 1. Location map of G. Umm Naggat area, central Eastern Desert, Egypt.](image-url)
The regional geological setting of such an area is depicted in Fig. 2. Exposed Precambrian igneous and metamorphosed rocks constitute most of the terrain in the area. The G. Umm Naggat granite pluton was emplaced at shallow crustal levels in a Pan-African island arc assemblage of calc-alkaline metavolcano-sedimentary association and metagabbro-diorite (Hassanen et al., 2008). In the country rocks and in the Um Naggat massif, as well, Cretaceous-Paleogene dykes of quartz porphyries, felsite porphyries, trachytes, dolerites and basalts are widely distributed. In the central and southern parts of the massif, the granite is cut by trachyte necks associated with relics of trachyte tuffs, tuff and lava breccias. Many of them are located along submeridional faults and in the feathering disturbances (Sabet, 1961).

![Fig. 2. Geological map of G. Umm Naggat area, central Eastern Desert, Egypt (After Sabet et al., 1973).](image)

The internal structure of the massif is complex and considered as an asymmetrical zones of gradual transions for granite facies. Such facies are successively replaced by one another from the northern contact deep into the massif. The most albitized varieties are situated in the immediate vicinity of the northern contact and compose the apical parts of the dome shaped projections. Then follows silicified and less albitized granite which is replaced by the brick red microcllinized varieties. The central and southern parts of the massif are mainly composed of unaltered coarse-grained amphibole granite which may be considered as the
original parent granite (Sabet, 1976a). The Umm Naggat granite is massive coarse-grained (3-4 mm) with a hypidiomorphic granoblastic texture, rarely cataclastic. It is composed of quartz (50%) and microcline (45%) with subordinate amount of amphibole (5%) and biotite in the altered albitized varieties (5%).

The detection of rare metal mineralization in apogranites (alkali feldspar granites which have suffered post magmatic, metasomatic alteration called apogranites in the sense of Beus et al. (1962) of the albitite type in the Central Eastern Desert of Egypt was discovered in 1970 by a group of Soviet and Egyptian geologists (e.g. Baburin et al., 1971; Sabet et al., 1976a, 1976b, 1976c). These geologists have attributed the formation of rare metal mineralization to the metasomatic alteration processes affecting the host granites. However, a zone about 600m, wide of metasomatically altered granite was traced through a distance of about 3 Km along the northern endocontact of Umm Naggat pluton.

In late 2001, Gippsland Limited identified rare-metal (Li–F) tantalum–tin–tungsten granite deposits in the Umm Naggat granite massive, Central Eastern Desert, Egypt with Ta₂O₅ reserves 25 Mt at 0.0151% (Fetherston, 2004).

Hassanen et al., (2008, pers. Commun.) concluded that the Um Naggat granitic pluton consists of three petrographic types: i) A subsolvus monzo-and syenogranite, ii) a hypersolvus alkali feldspar granite and iii) a subordinate roof facies of albite granite that host greisens and Nb-Ta-Sn mineralization. The least evolved monzogranite is characterized by high K/Rb ratio (880 - 400), moderately fractionated REE pattern (Lan/Ybn = 13 - 3) and negative Eu anomalies (Eu/Eu*=0.3 - 0.6). The alkali feldspar granite has lower K/Rb ratio (350-50) and less fractionated REE pattern (Lan/Ybn = 3) with strong negative Eu anomalies (Eu/Eu*≈0.1 - 0.3). The albite granite is characterized by very low K/Rb ratio (35 - 15) with less fractionated REE patterns (Lan/Ybn < 1). They added that Fluid fractionation was a major differentiation process during the terminal stages of evolution of the pluton. It plays an imptant role in the genesis of the albite granite which is characterized by low K/Rb, Eu/Eu* high Zr, Nb, Y, Th, U and HREE. The parent magma of this granite pluton was formed by fractional crystallization of mantle-
derived mafic magma in a post-orogenic extension-related tectonic environment.

The northern part of Umm Naggat granite massif has suffered extensive post-magmatic metasomatic reworking which results into the development of (Zr, Hf, Nb, Ta, U, Th, F)- and albite-enriched and greisenized apogranite body of 600 m wide, and more than 3 km in the strike length (Fig. 2). Albitization produced an enrichment in Zr (av. 2384 ppm), Hf (61), Nb (419), and U (43). Localization of disseminated mineralization of Zr and Nb is registered in the apical parts of the albitized and greisenized apogranite body (EL–Afandy et al., 2000; Abdalla et al., 2009).

**Interpretation of Gamma Ray Spectrometry**

Unlike the other airborne geophysical methods, there are no mathematical models required to calculate the theoretical radiometric response of a specific source. Interpretation of radiometric data is, therefore, more similar to interpreting the results of a conventional geological survey. It is usually necessary to correlate the results of geological and/or geochemical sampling with, for example, the colour patterns in a radiometric ternary map to achieve a full understanding of the implications of the map. However, an understanding of how radiometric surveys can be applied to exploration problems requires us to consider the geological sources of radioactivity.

The Umm Naggat airborne gamma-ray spectrometric survey dataset are typically displayed as images. Individual radioelements are displayed as pseudocoloured images (Fig. 4, 5 and 6) or combined as false colour composites in ternary radioelement image (Fig. 7). Figures (4, 5 and 6) can be contrast ratioed (e.g. K/eTh, eU/K and eU/eTh) to highlight subtle variations in the data (Fig. 8, 9 and 10).

Low values of total gamma radiation count (Fig. 3) are associated with outcrops of the basic metavolcanic rocks occupied the northeastern and southwestern corners of the mapped area. Areas with high values can be related to the presence of granitic rocks of the Umm Naggat pluton. Intermediate to high values in the areas of east, south and west around the Umm Naggat granitic pluton are associated with outcrops of the Epidiorite Complex.
Equivalent Th, equivalent U and K % coloured maps (Fig. 4, 5 and 6) show a positive correlation between low values and spatial positions of the basic metavolcanic rocks. High values in these maps represent granitic rocks of the Umm Naggat area.
Fig. 5. Equivalent turanium contour map, G. Umm Naggat area, central Eastern Desert, Egypt.

Fig. 6. Potassium percent contour map, G. Umm Naggat area, central Eastern Desert, Egypt.
The ternary (three-component) radioactive element map is an effective method of displaying variations in total radioactivity and in the relative abundances of the three radioactive elements. Areas of the image with the same colour will have similar ratios of $K$, $eU$, $eTh$, and the intensity of that colour is a measure of the total radioactivity. This allows the map to represent the radioactive element distribution better than any of the other single variable maps. The ternary map is often easier to work with to get an overview of the distribution of radioactivity; however, it does not replace the more detailed, quantitative information available on the other 7 maps (total radioactivity, $K$, $eU$, $eTh$, $eU/eTh$, $eU/K$ and $eTh/K$) (Broome et al., 1987). Ternary radioelement maps of airborne gamma-ray spectrometric surveys acquired over exposed granitoid intrusions commonly show a zoning in radioelement concentrations (Ford and O'Reilly, 1985; Broome et al., 1987; Harris et al., 1990; Goossens, 1992; Dickson and Scott, 1997). These zonations have been interpreted as reflecting fractionation in combination with segregation of intercumulus melt (Goossens, 1992), magmatic differentiation, sensu lato (Charbonneau, 1991; Wellman, 1998), or hydrothermal enrichment and alteration (Charbonneau, 1991). An understanding of the processes that give rise to radioelement zoning and the associated mineralogical variation in granites has important implications in the search for mineralization of U, Sn, W, Mo, Cu-Au and rare earth elements (Ford and O'Reilly, 1985; Goossens, 1992; and Dickson and Scott, 1997).

The ternary radioelement map of the Umm Naggat granite (Fig. 7), with $\% K$ modulating green-magenta, ppm $eTh$ modulating red-cyan, and ppm $eU$ modulating yellow-blue, shows three spectral domains (A, B and C). However, it shows an inward transition from blue and magenta hues in the northern marginal zone (domain A) to reddish and brownish hues in the middle (domain B), then blue and magenta hues in the southern marginal zone of the pluton (domain C). Table (1) shows the three spectral domains signatures of the Umm Naggat granitic pluton. Also, the zoning is mainly reflected in the thorium channel (Fig. 4). Such zonation is evidenced by the results of geochemical analysis carried out by Hassanen et al. (2008) which will be discussed in section 5. White and black hues in the image correspond to high or low abundances, respectively, of all three of the radioelements. Mixture of $K$, $eU$ and $eTh$ appear as magenta-blue and cyan hues.
Fig. 7. Ternary radioelement map, G. Umm Naggat area, central Eastern Desert, Egypt.

Table 1. Spectral domains of the Umm Naggat granitic pluton as assigned in Fig. 7.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Ternary map hue</th>
<th>Radioelements</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| Northern domain   | Strong blue-magenta and white coloured hues | -High eU, eTh.  
- Low K relative to eU & eTh.  
| (A)               |                                        |                                                                               |                                                                                              |
| Middle Domain     | Reddish and brownish hues              | -High K, relatively high eTh, eU.  
| (B)               |                                        |                                                                               |                                                                                              |
| Southern domain   | Blue and magenta hues                  | -High eTh, K.  
- relatively high eU.  
| (C)               |                                        |                                                                               |                                                                                              |

In addition, ternary radioelement map (Fig.7), provides additional information where low Th values are associated with the basic metavolcanic complexes (Fig. 4) also appear as low values in the ternary
map (dark colours). The northern domain A of the granitic pluton appears in light blue tones and white coloured areas, indicating a relative predominance of U content; although it shows high absolute values for the three channels. Such enrichment of the three elements can be interpreted as evidence for hydrothermal alteration, where a change in chemical conditions led to enrichment in these radiometric elements. It is also possible to detect areas of predominant Th (red tones in domain B), which indicates an enrichment of this element in the alkaline feldspar granite which is cut by trachyte dykes and necks. Domain B is prevailed in the central parts of the granitic pluton. Then light blue tones appear again in the southern domain C of the granitic pluton which is associated with trachyte necks (Fig. 7).

It can be noticed from the airborne gamma-ray spectrometric survey dataset (Fig. 3, 4, 5, 6 & 7) that, the Umm Naggat younger granite is more radioactive than their country rocks. This may be due to its mineral content; where it is characterized by high Zr, Nb, Y, Th, U and HREE, particularly the northern part of the granite massif (EL–Afandy et al., 2000; Hassanen et al., 2008; and Abdalla et al., 2009). Hussein and Sayyah (1992) recorded that, generally younger granites in several localities of Eastern Desert are more radioactive than their country rocks (5 to 15 times) due to their relative high uranium and thorium contents.

In addition to the interpretation of ternary radioelement, ratio images are useful for identifying the overall radioelement variations. In general the ratio maps indicate a relative enrichment of one or more elements. In turn, enrichment of potassium and (or) uranium can be indicative of alteration processes that are associated with various types of mineralization. Enrichment of thorium can be indicative of the presence of the heavy mineral monazite, which may contain rare earth elements. In particular, the eTh/K ratio can be a sensitive indicator of K alteration associated with mineralization and can be used as a direct indicator of mineralization (Broome et al., 1987). The ratio maps of the study area (Fig. 8, 9 & 10) depict the highest eTh/K, eU/K and eU/eTh ratio values that reach 10.4, 5.5 and 0.7, respectively, over the northern portion of the Umm Naggat granite. Such high ratio values are considered as indicator of K alteration and/or metasomatism associated with Nb-Ta-Sn mineralization at the northern margin of such granitic pluton.
One of the modern applications of gamma ray spectrometry is the possibility of identifying areas of hydrothermal alteration and establishing its relationship with processes forming base metal mineralization (Cu-Pb-Zn), and gold and silver in various geological environments (e.g. Shives et al. 2000). The research has a methodological and focuses on a series of tools used in mineral exploration, with emphasis on gamma ray spectrometry, with the main purpose of testing them in the study of Nb-Ta-Sn mineralization and determination of areas favorable to its occurrence in the Umm Naggat granite pluton. To assess the potential of the gamma ray spectrometric method characterization of areas of change associated with hydrothermal Nb-Ta-Sn occurrences and propose new targets exploration, two approaches such as residual anomaly method on the basis of lithologic normalization (Th-normalized approach) and the F-parameter of Efimov approach are applied.
Fig. 9. eU/k% ratio contour map, G. Umm Naggat area, central Eastern Desert, Egypt.

Fig. 10. eU/eTh ratio contour map, G. Umm Naggat area, central Eastern Desert, Egypt.
The Th-Normalized Approach (Saunders et al., 1987)

Geochemically, the variations in concentration of various elements reflect factors. The surface lithology is the main factor influencing the variation of the content of the rocks radioelements. So it is necessary to suppress the effects caused by variations lithology and soil types and environmental conditions before evaluating any other side effects (Foote 1969). Several procedures have been proposed in order to remove the lithological and environmental effects (Saunders et al. 1978, 1987, 1993, 1994, and Galbraith & Saunders 1983). Most of these studies aimed at identifying accumulations of oil and no identification of deposits vent from the analysis of gamma-spectrometric data. Normalizing data for thorium would eliminate the primary effects of all undesirable variables. The basic premise of this approach is that thorium, which is relatively stable in the near surface of the Earth and a sensitive indicator of lithology, can well reflect the original distribution of rock and soil. However, in normal rocks, correlations exist between Th, U and K (linear or logarithmic), while geological and geochemical activities (such as the formation of oil and gas reservoirs, hydrothermal alteration associated with mineralization, etc.) can cause local changes in the contents of K and U, the content of Th remains relatively stable.

According to Saunders et al. (1987), who proposed an 'ideal' content of K and U can be calculated from that of Th and used as the background value for various rocks in an area. By subtracting the 'ideal' contents of U and K from the contents determined from the survey, a residual content of U and K can be obtained which can be considered as having the interference of removed lithology. They applied normalization of potassium and uranium by thorium, in prospecting for oil and gas fields in east Texas and Australia (Saunders et al. 1993, 1994) and normalization calculated as follows:

\[
K_i = \text{mean } K_s / \text{mean } Th_s \times Th_s; \quad K_d = (K_s - K_i) / K_i
\]

\[
U_i = \text{mean } U_s / \text{mean } Th_s \times Th_s; \quad U_d = (U_s - U_i) / U_i,
\]

Where, \( K_i \) and \( U_i \) indicate the optimal values determined from the report, \( K_d \) and \( U_d \) are the deviations from the ideals and values represent the \( K_s \) and \( U_s \) original data.

Pires (1995) first used this approach in mineral prospecting, identifying areas of hydrothermal change successfully in Crixás Guarinos
in the state of Goias, Brazil through anomalous potassium (Kd). The awareness of the value of such normalization approach in mineral exploration is rapidly increasing Ferreira et al. (1998), Blum (1999), Carvalho (1999), Biondi et al. (2001), Cainzos (2001), Fornazzari et al. (2001), among others.

Figures (6 & 11) show the airborne gamma-ray spectrometry K content and residual Kd % content contour maps over the Umm Naggat granitic pluton. From the maps it can be seen that the mineralized zone is within the area of low K. But from the original K contour map, it is very difficult to mark the range of the mineralized zone which is shown very clearly on the residual K map obtained from Th-normalization. Besides, Kd % map of the study area (Fig. 11) highlights the anomalously low adjusted potassium anomalies over areas favorable to Nb-Ta-Sn mineralization in the northern part, as well as areas of trachyte necks in the southern part of the Umm Naggat granite pluton. Through the weak anomalous potassium (Kd), (Fig. 11) that connected with anomalous uranium variation (Ud), (Fig. 12) the Umm Naggat mineralization can be highlighted.

Fig. 11. Deviations from the K ideals (Kd%) contour map, G. Umm Naggat area, central Eastern Desert, Egypt.
Fig. 12. Deviations from the U ideals (Ud%) contour map, G. Umm Naggat area, central Eastern Desert, Egypt.

**The F-Parameter of Efimov Approach**

Another indicator factor, the F-parameter of Efimov (1978), is used in conjunction with the normalization approach to delineate the Nb-Ta-Sn mineralized alteration zone of Umm Naggat granite. The expression for the F-parameter is $K^* U/Th$ or $K/(Th/U)$ or $U/(Th/K)$, which can be thought of as the ratio of potassium abundance and Th/U or as the ratio of uranium abundance and Th/K. The F-parameter is an important alteration index of rocks. Usually, for unaltered rocks, the F-parameter value is no more than 1.2-1.3, but for altered rocks, it can be 2-5 and sometimes above 10 (Gnojek and Prichystal, 1985). The F-parameter has been very useful for locating potassic alteration zones related to gold, copper and polymetallic mineralization in China (Zhang et al. 1998), to new Zn mineralization in Czechoslovakia (Gnojek and Prichystal, 1985), to Cu, Ni mineralization in Abu Swayel, Egypt (Abd El Nabi 1993). Over the Umm Naggat granitic pluton there exists an obvious F-parameter anomaly strip having values more than 1.6 (Fig. 13), which shows the potassic alteration metasomatism associated with ore zone mineralization along the northern endocontact of Umm Naggat pluton and the dykes of
quartz porphyries, felsites porphyries, trachytes, dolerites and basalts and trachyte necks which are widely distributed in the central parts of the massif.

Fig. 13. F-parameter of Efimov contour map, G. Umm Naggat area, central Eastern Desert, Egypt.

**Statistical Aspect**

Three histograms for each Umm Naggat granitic pluton portion show the concentration of eU, eTh, and K % (Fig. 14.a, .b, & .c). Correlation the similar histograms in the three portions reveal a significant difference between their radiometric properties. However, Fig. (14.a, .b, & .c) and Table 2 show that the concentrations differ considerably in the three portions for examples the mean K concentration of 2.49 %, 2.90 %, 2.66 % for the northern, central and southern portions of the granite respectively. The depletion of K content in the northern portion with respect to the other granite portions may be due to the increase of Na in the apogranite (albitized variety) and the presence of trachyte necks associated with relics of trachyte tuffs, tuff and lava breccias in the central and southern parts of the massif (Sabet, 1961). In contrary, eU and eTh contents are higher in the northern portion; 10.29 ppm, 20.65 ppm than both the central and the southern portions. The central portion has eU content of equal 5.47 ppm, eTh content of equal 11.90 ppm and the southern portion has the lowest eU and eTh contents;
3.65 ppm and 10.72 ppm respectively. The highest eU and eTh contents in the northern portion are due to its mineral content; where it is characterized by high Zr, Nb, Y, Th, U and HREE in the most albitized varieties, particularly in the vicinity of the northern endocontact (EL–Afandy et al., 2000; Hassanen et al., 2008; Abdalla et al., 2009). As well as, the highest values of the three ratios eU/eTh, eU/K and eTh/K of the northern portion (Table 2) indicate to areas of favorable to the metasomatic processes associated with Nb-Ta-Sn mineralization occurrence in the Umm Naggat granite pluton.

![Fig. 14. F-Histogram for radioelements of G. Umm Naggat granite pluton.](image)

**Table 2. Summary statistics of eU, eTh, K for: a) Northern-, b) Central- and c) Southern Umm Naggat Pluton.**

<table>
<thead>
<tr>
<th>Pluton area</th>
<th>No. of observations</th>
<th>eU ppm</th>
<th>eTh ppm</th>
<th>K %</th>
<th>eU/eTh</th>
<th>eU/K</th>
<th>eTh/K</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Umm Naggat Pluton</td>
<td>n=102</td>
<td>10.29</td>
<td>20.65</td>
<td>2.49</td>
<td>0.49</td>
<td>4.42</td>
<td>8.59</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>05.39</td>
<td>07.76</td>
<td>0.42</td>
<td>0.12</td>
<td>2.88</td>
<td>3.69</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Central Umm Naggat Pluton</td>
<td>n=194</td>
<td>5.47</td>
<td>11.90</td>
<td>2.90</td>
<td>0.46</td>
<td>1.89</td>
<td>4.10</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.24</td>
<td>4.16</td>
<td>0.39</td>
<td>0.09</td>
<td>0.75</td>
<td>1.32</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Southern Umm Naggat Pluton</td>
<td>n=49</td>
<td>3.65</td>
<td>10.72</td>
<td>2.66</td>
<td>0.35</td>
<td>1.36</td>
<td>4.00</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.16</td>
<td>3.78</td>
<td>0.36</td>
<td>0.07</td>
<td>0.33</td>
<td>1.19</td>
<td>Standard Deviation</td>
</tr>
</tbody>
</table>

Additional insight into the relationships between the K, eTh and eU airborne concentrations and the associated spectral trends may be
obtained by analysing their interrelationships in K-eTh-eU space (Kuosmanen, 1994; and Wellman, 1998). Bivariate diagram eTh-K plot (Fig. 15) shows that K values of central portion have a higher concentration than that of the northern and southern portions. Also, it shows that the northern portion has a higher eTh concentration than the central and southern portions of the Umm Naggat granite. According to Muecke and Chatterjee (1983), who reported that bodies which show a thorium enrichment trend with increasing differentiation appear to be more favourable exploration target than spatially associated bodies in which thorium is depleted. As a consequence, the northern apogranite is considered more favourable for exploration than the central and southern portions of the Umm Naggat granites.

![Fig. 15. Bivariate diagram eTh Vs. K plot of G. Umm Naggat granitic pluton.](image)

**Geochemical Aspect**

Spatial interpretation of the airborne gamma ray spectrometric data requires correlation with additional data, such as geology, geochemistry and other airborne or ground geophysical data. From geochemical point of view, rare metal granites have been identified as those with high concentrations of normally dispersed elements such as F, Li, Rb, Cs, Sn, Ta, Nb, Zr, and REE (Tauson, 1974; and Kovalenko, 1978). To distinguish the granitoids with mineralization potential from barren ones, geochemical indicators have been used, such as Rb, Li, F, Zr, Ba and Sr proposed by Dall Agnol et al., (1994); Scheepers, (2000). The available geochemical results carried out by Hassanen et al. 2008; Abdalla et al. 2009 are used to provide further insight in the origin of the zoning pattern.
which is assigned by gamma spectrometric maps (Fig. 3-7). Besides, the northern Umm Naggat albite granite has suffered extensive post-magmatic metasomatic reworking that lead to development of Zr, Hf, Nb, Y, Ta, U, Th, F (EL–Afandy et al., 2000). Hassanen et al. (2008); Abdalla et al. (2009) reported that it is characterized by very low K/Rb, Eu/Eu, high Zr, Nb, Y, Th, U and HREE. In addition, Hassanen et al. (2008, pers. Commun.) reported that the southern monzogranite part of the Umm Naggat pluton is characterized by high K/Rb ratio (880-400), the central alkali feldspar granite has lower K/Rb ratio (350-50) and the northern albite granite is characterized by very low K/Rb ratio (35-15). Consequently, low values for the ratios, K/Rb correspond to the fertile granites of Um Naggat granite pluton such as the subordinate roof facies of albite granite that host greisens and Nb-Ta-Sn mineralization at the northern margin of such granitic pluton.

**Conclusion**

Gamma-ray spectrometry data acquired over the G. Umm Naggat granitic pluton show a conspicuous and complex radioelement zoning, in particular eTh, which in turn reflects mineralogical associations in the pluton. The pluton is divided into three northern, middle and southern spectral domains. The geochemical results of previous works are used to provide further insight in the origin of this zoning pattern. The integrated analysis of the gamma-ray spectrometry and geochemical data provides a tool to map the regional extent of the compositional patterns within the pluton, and provides insight into the most probable differences in mineralogy associated with the radioelement zoning.

Normalization approach in conjunction with the F-parameter approach are used to assess the potential of the gamma ray spectrometric method characterization of areas of change associated with hydrothermal Nb-Ta-Sn occurrences. Low anomalous potassium (K$_d$) connected with high anomalous uranium variation (U$_d$), and high F-parameter anomaly strip highlight such areas. This is considered as a step to maximize the potential of the radiometric approach for mineral exploration.

**References**

An Analysis of γ-ray spectrometry of G. Um Naggat granitic pluton...


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تحليل بيانات أشعة جاما الطيفية المحمولة جوًا للتدخلات الجرانيتية لجبّل أم ناقط، ووسط الصحراء الشرقية، مصر

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المستخلص. يتناول العمل الحالي تحليل بيانات أشعة جاما الطيفية المحمولة جوًا للتدخلات الجرانيتية لجبّل أم ناقط، ووسط الصحراء الشرقية، مصر. وقد أظهرت هذه التداخلات الجرانيتية نمطًا طيفيًا متميزًا للعناصر المشعة والمرتبطة بالتغامرات المعقدة لتمثيل هذا الحالة. وقد تم تقسيم الجرانيتات إلى ثلاثة نماذج طيفية: الشمالية والأوسط والجنوبية. وتمثل النماذج الشمالية (A) بمحتميات ونسب عالية من العناصر المشعة. وتمثل هذا النماذج أيضاً وجود عالي لعناصر الزركونيوم، والنوبيوم، والنيتيروم، والثوريوم، والبيرونيوم، والعناصر الأوضاعية النادرة الثقيلة في معظم أصناف الجرانيت الألبيتي. ويعكس النماذج الأوسط (B) الغني بالبوتاسيوم والثوريوم طبيعة الجرانيت الغني بالفلسفات الثقيلة. وتمثل النماذج الجنوبي (C) بمحتميات عالية من كل العناصر المشعة الثلاثة، ولكن أقل من النماذج الشمالية. وتم الاستدلال على تقسيم مثل هذه النماذج بنتائج التحليل الجيوفيزيائي من الدراسات السابقة.

وتقييم بخصائص أشعة جاما الطيفية لمناطق التغاير المصاحبة لوجود البيرونيوم والتنتالوم والقصدير ذات الأصل الحرومي، تم تطبيق نهجين: نهج الطريقة الشاذة المنقية على أساس التطبيع الصخري (Th-normalized approach)، ونهج معامل (F-parameter of Efimov). وقد أدى انخفاض شاذات البيرونيوم (F) والمرتبطة بتفاعل البيرونيوم الشاذ العالي (K_B) إلى إقلاع الضوء لمناطق التغاير الحرومي والمصاحبة لأماكن وجود البيرونيوم والتنتالوم والقصدير.