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COMPARATIVE ANALYTICAL STUDY ON THE CONTRIBUTION OF AIRBORNE GAMMA RAY SPECTROMETRIC INTERPRETATION TECHNIQUES TO GEOLOGICAL MAPPING

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دراسة تحليلية مقارنة في مساهمة طرق تفسير بيانات المسح الإشعاعي الجامي الطيفي الجوي في التخريط الجيولوجي

الخلاصــة: أستخدم المسح الإشعاعي الطيفي الجوي منذ سنوات عديدة للكشف المباشر عن الخامات المشعة و كذلك للمساعدة في التخريط الجيولوجي السطحي. تتناول الدراسة الحالية تطبيق ثلاث تقنيات أحصائية تحليلية مختلفة لتفسير بيانات المسح الإشعاعي الطيفي الجوي لتقييم مميزات و عيوب كلا منها. كما تم تطبيق هذه التقنيات في محاولة للتخريط الجيولوجي السطحي لمنطقة معروفة جيدا (وادي ساقية بوسط الصحراء الشرقية لمصر) بإستخدام بيانات توزيع كل من البوتاسيوم و اليورانيوم و الثوريوم و نسبهم و ذلك لتوضيح ظواهرها الصخرية و التركيبية. بتطبيق كل تقنية منفرده لم تنجح أي منها في التحديد الكامل للملامح الصخرية لمنطقة الدراسة بينما أعطي التكامل بين هذه التقنيات تخريط جيد للمنطقة بالمقارنة مع الخرائط الجيولوجية المنشورة.

ABSTRACT: *Airborne gamma ray spectrometry has been used for many years for the direct detection of ore bodies and as an aid in surficial lithological mapping. The present work deals with the application of different interpetation techniques, such as multivariate analysis, composite ternary map and zoning, to estimate the relative merit of these three tools, to define their limitations and advantages in different situations. The present work represents a case study which utilizes the information of the distribution of potassium, uranium, thorium and their ratios in the chosen area of Wadi Saqia area, Central Eastern Desert of Egypt for delineating its lithological and structural features. The contribution of aerial gamma-ray spectrometric survey data to surface geological mapping and mineral exploration depends on the extent to which radioelement distribution relates to bedrock differences and the extent to which these are recognizably modified by mineralizing processes. There are cases, however, that these techniques could not successfully identify boundaries and structures.*

INTRODUCTION

The use of gamma ray spectrometry as a tool for mapping radioelement concentrations has benefited from continuing advances in instrumentation, field procedures, calibration and data processing procedures, in order to be used as a geological mapping tool. This work presents an overview and comparison of the common techniques that utilized gamma ray spectrometric data to geological unit delineation and anomalies identification.

An attempt has been made to apply the three published technique in the regional geological mapping on a well-defined area. Wadi (W.) Saqia area, Central Eastern Desert of Egypt. This area was chosen to examine the validity of the three techniques for regional geological mapping.

This paper gives a brief outline of the principles of using gamma rays spectrometric data in geological mapping. This includes a review of the fundamentals of different mapping tools, and their applications to airborne mapping in pre-selected area.

USES OF SPECTROMETRIC DATA IN LITHOLOGICAL MAPPING

Airborne gamma ray spectrometry has been used for many years for the direct detection of mineralization and as a lithological mapping tool. The use of gamma ray spectrometry as a tool for mapping radioelement concentrations has found widespread acceptance in diverse fields. The method has evolved over several decades and continues to be developed. Recent developments include multichannel processing methods and the use of statistical methods to reduce noise in multichannel spectra. Due to this the gamma ray method has been successfully applied to geological mapping, and mineral exploration. The use of spectrometric data as a mapping tool requires an understanding of the geochemistry of the radioelements in rocks and soils, and the processes that affect their distribution and mobility (IAEA, 2003).

Now gamma ray surveys are used in several fields of science, besides being a quantitative geophysical survey method, it has been recognized as a geochemical mapping tool. It is used for geological, geochemical, and environmental mapping, and allows the interpretation of regional features over large areas. It is used in soil mapping and for mineral exploration (IAEA, 2003)..

OUTLINE OF THE TECHNIQUES USED IN REGIONAL GEOLOGIC MAPPING (MAPPING STRATEGY)

Few authors utilized the airborne gamma ray spectrometric data in regional geological mapping. Elserafe (1995) studied the application of image processing techniques and geostatistical methods to the aerial gamma ray spectrometric data of a sample area from the Central Eastern Desert of Egypt as an aid to geological mapping and mineral exploration.

There is no unique strategy for mapping, but many alternatives do exist. Generally, a useful strategy for geological mapping is to first outline the major lithological units and then enhance the radioelement patterns within the individual units as follows:

I- Visual Interpretation: It includes data enhancement to emphasize the overall variations in radioelement concentrations. This includes contrast stretching, pseudo-colour coding, gradient enhancement, and ternary mapping. Arithmetic combinations between the radioelement channels, such as sum-normalized data and ratios, are useful to reduce environmental factors related to water and land soil cover which mask the gamma ray response from rocks and soils. Enhanced products of gamma ray spectrometric data have often assisted in detailed mapping or further subdivision of lithological units (IAEA, 2003).

II- Automatic Edge Detection (Boundaries Hunting): Edge detection is the outlining of spatially continuous radioelement zones, that may associate with the boundaries of lithological and soil units, or geological structures. Zoning technique or other gradient methods can be used perfectly to achieve this goal(Khamies and Abuelnaga, 2002)..

III- Cluster Analysis: Factor analysis can be applied for the outlined units, while mean-differencing, regression, or principle component analyses can be applied within each outlined unit to locally enhance subtle gamma ray responses against the background

I- Visual Interpretation (Image Presentation Techniques)

Image presentations of the data are far easier to visualize than the conventional contour and profile maps, although they lack the absolute quantitative value of the older methods. Lillesand, and Kiefer (1994) give a good general overview of digital image processing. Image presentation technique include:-

I.1. Grey scale images

Gamma ray spectrometric data (T.C., K, eU and eTh) can be rescaled into the dynamic range (typically 256 grey-scale levels between 0 and 255) of the display device. An image histogram can be used to control the enhancement of contrast over the full dynamic range of data, or only over certain intervals of interest. This is called “contrast stretching”. The simplest form of contrast stretching is a linear stretch, where the full dynamic range of the grid values is mapped linearly onto the full output range of the display device. A better enhancement of the overall dynamic range is obtained by excluding the extremes of the data from the contrast-enhanced range. Histogram equalization is a non-linear contrast enhancement technique where the input range is mapped to the output range in such a way that the magnitude of the output range is proportional to the frequency of occurrence of the grid values Lillesand, and Kiefer (1994).

I.2. Band ratios

Any arithmetic combination of radioelement grids can be represented as grey-scale images. $C\ r_{[K/Th]}$ = (CK/Th) where C is an optional scaling. If C is chosen to be 2.83, the values range from 0 to 255, facilitating direct display across the full dynamic range of the display device (Grant, 1998).

I.3. Colour coding techniques

Single radioelement channels can be mapped in pseudo-colour, which enables the interpreter to better recognize the regional distribution of radioelement concentrations. Radioelement channels can be combined in a colour composite image, commonly referred to as a ternary radioelement map (Drury, 1992).

I.4. Colour spaces

A colour space is a model that facilitates the specification and visualization of colour. One way of representing the range of colours displayable on a computer monitor is the Red-Green- Blue (RGB) colour space. While, the Cyan-Magenta-Yellow (CMY) colour space is based on the “subtractive” system of colours used in printing and painting (Milligan and Gunn, 1997)**.**

I.5. Pseudo-colour and shaded relief images

Pseudo-colour, through the use of colour look-up tables, can be used as an alternative to grey-scale presentation. Pseudo-colour coding can be combined with relief-shaded presentations of grids Lillesand, and Kiefer (1994).

Shaded relief (or gradient enhancement) incorporates a sun shading algorithm to artificially illuminate the image from a specific direction Milligan and Gunn, (1997).

I.6. Ternary radioelement maps

A ternary radioelement map is a colour composite image generated by modulating the red, green and blue phosphors of the display device or yellow, magenta and cyan dyes of a printer in proportion to the radioelement concentration values of K, Th, U and TC grids Broome et al. (1987). The use of red, green and blue for K, Th and U, respectively, is a standard for displaying gamma ray spectrometric data. Blue is used to display the U channel, since this is the noisiest channel and the human eye is least sensitive to variations in blue intensity. Areas of low radioactivity, and consequently low signal to noise ratios, can be masked by setting a threshold on the total count grid. This reserves more colour space and ensures a better colour enhancement for the remaining data. Sum-normalization can be used to compute relative concentrations of K, Th and U prior to imaging as follows:

Kn=K/(K+U+Th)

Un=U/(K+U+Th)

Thn=Th/(K+U+Th)

A similar normalization technique was used by Broome et al. (1987) for printing ternary radioelement maps in the CMY colour space. The radioelement channels are scaled as follows:

Kn=K/(K+U+Th/4)

Un=U/(K+U+Th/4)

Thn=Th/(K+U+Th/4)

Table (1) Combinations of the three primary colours (red, green and blue)

Composite color	Red	Green	Blue
Red	255	0	0
Green	0	255	0
Blue	0	0	255
Cyan	0	255	255
Magenta	255	0	255
Yellow	255	255	0
Black	0	0	0
White	255	255	255

As shown in Table (1), there are two systems both based on the combination of RGB colour in the RGB system. The three radioelements (K, eU & eTh) can be displayed through combinations of the three primary colours (red, green and blue). If all are 255, the result colour is white. If all are zeros, the result colour is black. Yellow is generated by equal intensity of the red and green, while blue is zero. Equal amounts of red, green and blue give achromatic (grey scale) colours ranging from black to white.

In the Cyan-Magenta-Yellow (CMY), the three radioelements (K, U & Th) can be displayed through combinations of the three primary colours (Cyan, Magenta and Yellow).Cyan is generated by equal intensity of the green and blue, while red is zero. Magenta is generated by equal intensity of the red and blue, while green is zero (Broome et al., 1987).

II- Automatic Edge Detection (Zoning Technique)

Edge detection is the outlining of spatially continuous radioelement zones, that may associate with the boundaries of lithological and soil units, or structures. Zoning technique is the dividing of a radioelement map into zones relatively uniform in geochemical characteristics and lithologically according to mathematical basis. This technique or other gradient methods can be used perfectly to achieve this goal (Khamies and Abuelnaga, 2002).

Zoning technique in this manner is different from the other conventional techniques, such as multivariate analysis and composite ternary maps in that:

1- In these techniques, the end product of the transform equation, the actual measurements have been substituted by an equivalent values (i.e., factor scores in the case of factor analysis and the radioelemental concentration values are rescaled to 256 displayed in pseudo-colour levels in ternary maps) while zoning technique keeps the map values as it is.
2- These techniques concern the interrelation of the radioelements throughout the grid, while zoning concerns the boundaries of these units.
3- These techniques may be achieved automatically, while zoning technique is performed by compiling the different radioelement zoning maps.

III- Cluster Analysis (Factor Analysis)

Factor analysis can be applied for the outlined units while the mean-differencing, regression, or principle component analysis can be applied within each outlined unit to locally enhance subtle gamma ray responses against the background. Factor analysis has been used for many years as a tool in surface geologic mapping and proved its significance in delineation of the different rock units. It proved to be a powerful tool for direct differentiation of all rock units. The sharp rock boundaries on score maps clearly define any discontinuities.

A detailed discussion of factor analysis was given by Harman (1960) and Comrey (1973) among others. However, it is a technique by which variables on a set of samples are linearly combined giving rise to new fundamental quantities (factors), which can be named and simply interpreted in the light of sound geologic reasoning. The resultant three factor scores (F_1, F_2 and F_3) are subjected to what we simply called clustering. The method consists of considering each data point from factor analysis as a point in the X, Y, Z coordinate system, where X is F_1, Y is F_2 and Z is F_3.

IV- Integration of Gamma Ray Spectrometry Data with Complimentarily Data Sets.

Gamma ray spectrometric mapping applications typically rely on an integrated approach. So, the output should be integrated into a unit map with all the available geological and geophysical data. This can be archieved by superimposing the basic unit boundaries map with other data overlays.

CASE STUDY

The study area is located in the Southern Eastern Desert of Egypt, between lat. $26^{o}\ 15^{/}$ and $26^{o}\ 40^{/}$ N and long. $33^{o}\ 30^{/}$ and $33^{o}\ 58^{/}$ E (Fig. 1). It is composed mainly of crystalline basement rocks and phanerozoic sediments. Its topography ranges from gentle to rough topography and is traversed by many dry valleys (Wadis), which trend mostly in a NW-SE and NE-SW directions. In addition, local wadis follow the N-S direction.

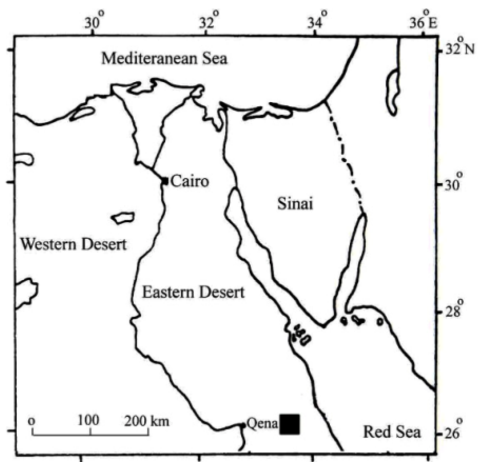

Fig. (1): Location map of the study area.

Figure. (2) shows a simplified geological map of the study area, drawn from the published maps. The compiled geological map was used in correlation with different radioelement maps traced from the application of the three techniques. Aeroservice Division, Western Geophysical Company of America in 1984, had carried out gamma ray spectrometric and magnetic surveys of a great part of the Eastern Desert of Egypt including the selected area, scale 1:50,000. The survey was conducted along parallel flight lines that were oriented in a NE-SW direction at 1km spacing, while the tie lines were flown in NW-SE direction at 10km intervals.

GEOLOGIC SETTING

The geology, structure and radioactivity of W. Saqia area have been studied through the regional geological and structural mapping of the Eastern Desert of Egypt by many authors (El-kassas, 1974; Bakheit, 1978; Hussein et al., 1986; and Rabie, et al, 1994).

The geological map (Fig. 2) was constructed from a false colour composite (FCC) image (1:100,000), previous work and field check. This map delineates the main rock units, structural lineaments and wadis with their tributaries of the investigated area. The exposed rocks in the study area are chronologically grouped into the following tectonic-stratigraphic units, according to the classification of Takla and Hussein (1995):

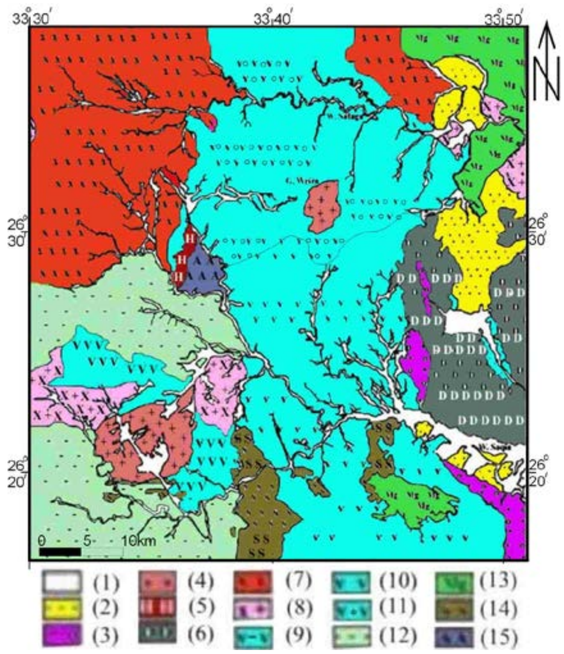

Fig. (2) Geological map of the case study area.

Legend

1-Alluvial sediment 2-Phanerozoic sediments 3-Alkali feldspar granites 4-Monzogranites 5-Hammamat sediments 6-Dokhan volcanics 7-Grey granites 8-Granodiorites 9- etavolcanics(type-I) 10-Metavolcanics(type-II) 11-Metavolcanics(type-III) 12- Metasediments 13-Metagabbros 14-Serpentinites 15-Amphiboliites

I-Gneisses, migmatites, amphibolites and high grade schists

These rocks are represented in the study area by amphibolites located northeast of Gabal (G.) Semna and north and east of G. Kab Amiri, and high grade schists situated to the south of G. Kab Amiri (Fig.2).

II- Ophiolitic mélange and island arc association

In the study area, these rocks are represented by metaultramafites, ophiolitic metagabbros, and serpentinites represented in the southwestern part while, metagabbros are found to the south of G. Elhimeiyir and north of W. Safaga (Fig. 2). The metasediments form low relief and are exposed at the west central and the southwestern parts of the study area. The metavolcanics cover a vast area at the northern, central and southern parts of the study area. These rocks generally form huge bodies and range in composition from ultrabasic (type I), intermediate (andesites (type II)), to acidic (dacites or even rhyolites (type III)), and may be island arc volcanics (Elshazly, 1977).

III- Arc granitoids (Older granitoids, G1)

These types of rocks include diorites, tonalites, and granodiorite association. Diorites cover a wide area in the northwestern part of the study area, while tonalites, granodiorites and grey granites are exposed in the northwestern and northeastern parts of the study area. Besides, the grey granites which are located between G. Kab Amiri and G. Elabsi and invade the metavolcanic country rocks (Fig. 2).

IV- Continental margin-within plate magmatism and sedimention

These rocks includes :-*Younger volcanics* (basaltic andesite, andesite, and rhyolite association) which are known as Dokhan Volcanics.The Dokhan volcanics form large outcrops cutting metavolcanics at the eastern part of the study area (Fig. 2) between G. Gassous and G. Abu-Aqarib and they take a NNW and NW trends. These rocks are fine-grained; greyish green to dark grey, partly to completely altered and mostly formed of plagio-andesites (Osman, 1996).- *Clastic molasses sediments* (Hammamat clastics sediments),these sediments are derived from the erosion of the older rocks. They are composed of conglomerates interbedded with sandstones, siltstones and mudstones**.** These rocks occur as a small exposure in the west central part of the study area. - *Younger gabbros*: these rocks are not represented in the study area. -*Younger granites (G2):* (The Intrusive Rocks). These intrusive rocks are exposed in the southwestern, northwestern and northeastern parts of the study area. and invade the metavolcanic country rocks (Fig. 2). Granodiorites occur at the northeastern parts of the study area. Younger granites are encountered in the southwestern part, in G. Kab-Amiri and in the northern part of G. Abu Muraywat. The youngest granitic intrusions (post granitic dykes) of the study area are the alkali - feldspar granites, which occur, in the eastern part of the study area.

V- Phanerozoic sediments

The Phanerozoic sediments of the study area are represented by Mesozoic and Cenozoic sediments as well as the Quaternary alluvial sediments. These sediments are located at the extreme northern and northeastern parts of the study area and unconformably cover the Basement rocks (Fig. 2).

I- Image Presentation Techniques

I.1. Potassium non-normalized composite map (Fig. 3): This map reflects the potassium content in acidic rocks and it could trace the boundaries of monzogranite of Kab Amiri and the isolated granitic bodies (pink colour), beside the boundaries of granodiorite monzonite, Phanerozoic sediments and Dokhan volcanics which occur in the eastern part of the study area. It could also distinguish the diorites in the northwestern part of the area (red colour). The green colour which covers most of the area represents the basic rocks. The blue colour reflects the ultrabasic rocks and the third type of metavolcanics (dacitic rock varieties, Type III).

I.2. Uranium non-normalized composite map (Fig. 4): This map is nearly similar to the uranium map where it could trace the boundaries of acidic rocks in pink colour but it shows the difference between Kab-Amiri mass and the granitic mass which lies to its northeast. The blue color shows the lowest parts in uranium content, where this colour describes the leached lithologic parts of Wadi sediments and takes a NW direction. The red colour describes only the northwestern part of diorite, this means that this part differs from the mother diorite mass and shows higher uranium content than the eastern part of this mass.

I.3. Thorium non-normalized composite map (Fig. 5):, There is a similarity between this map and the previous two maps of K and eU, but in this map the boundaries of diorite located in its northwestern part, they can be traced easily from the surrounding rocks. The blue colour reflects the areas of low content of thorium and does not describe any lithologic contacts.

I.4. Radioelements non-normalized composite map (Fig. 6): This image map could split the granitic mass of Kab Amiri into two parts different in their elemental and mineralogical compositions. The northern part (Red colour) is similar to the eastern part of the area which is related to granodiorite monzonite and alkali feldspar granite. The white colour traces the boundaries of the southern part of G. Kab Amiri, beside the Dokhan volcanics to the east of G. Abu-Aqarib. The blue colour traces the boundaries of metavolcanics (andesitic rock varieties or Type II). The Phanerozoic sediments are reflected the blue colour also. The grey colour reflects the interferences of low K, eU, and eTh concentrations. This zone displays a sharp colour contrast with the white and red colored zones associated with the younger granites, Dokhan volcanics, granodiorite monzonite and alkali feldspar granite. This reflects the great difference in the radioelement contents of these zones. Finally, this map could split the granitic part north of G. Kab Amiri (the RGB normalized map (Fig. 10) from the true mass of G.

Kab Amiri. It could also split the oval mass of G. Kab Amiri into two parts: northern (red colour) and southern (white colour) (Fig. 2).

I.5. Potassium normalized composite map (Fig. 7): This map shows two sets of pink colour. The first one lies in the northern part area and takes a NE trend. Its discriminates the southern part of G. Waira and extends towards the southwest to describe the ophiolitic assemblages as serpentinites, metabasalts and amphiboles. The other set lies in the southern part area and traces the contact between metagabbros and metavolcanics rocks.

The red colour traces the diorite boundaries in the northern part area with some spots which show high normalization of potassium.

The blue colour describes the lowest parts of normalized K as Phanerozoic sediments in the northeastern part area and schists and metabasalts to the south of G. Kab Amiri.

I.6. Uranium normalized composite map (Fig. 8): This map shows high anomalies of uranium with pink colour and reflects the Phanerozoic and Foreland sediments of Wadis, especially north G. Gasous, east W.Safaga and east G. Waira. Wadi sediments take the NW and NE directions. The other colours on this map are confused and did not provide clear discrimination for any lithologic contacts.

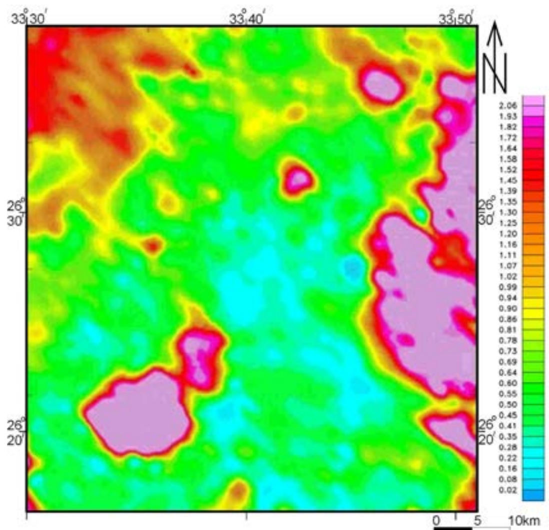

Fig. (3): Potassium Non-Normalized Composite Map..

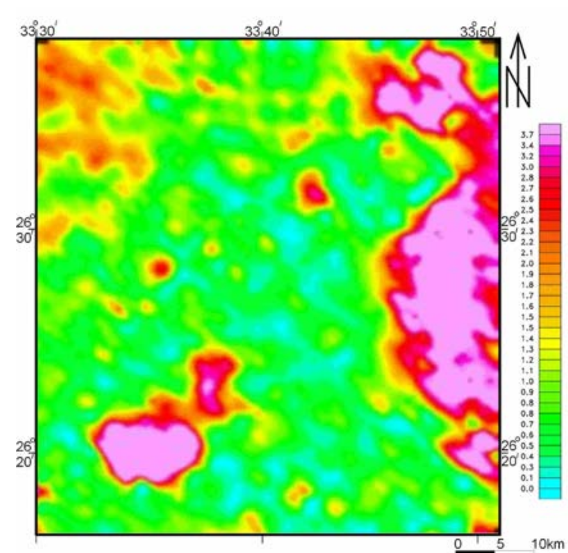

Fig. (4): Uranium Non-Normalized Composite Map.

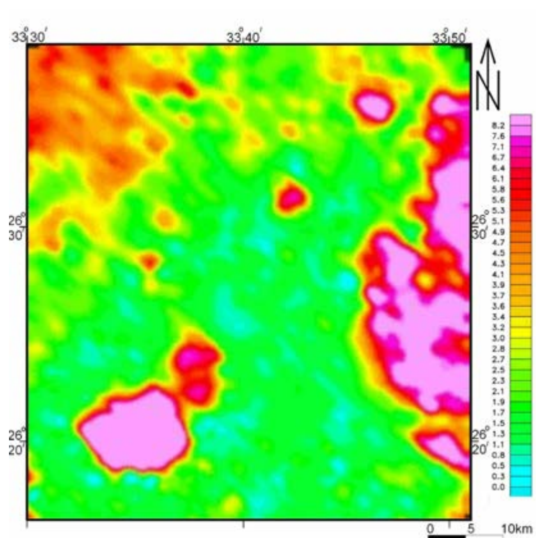

Fig. (5): Thorium Non-Normalized Composite Map.

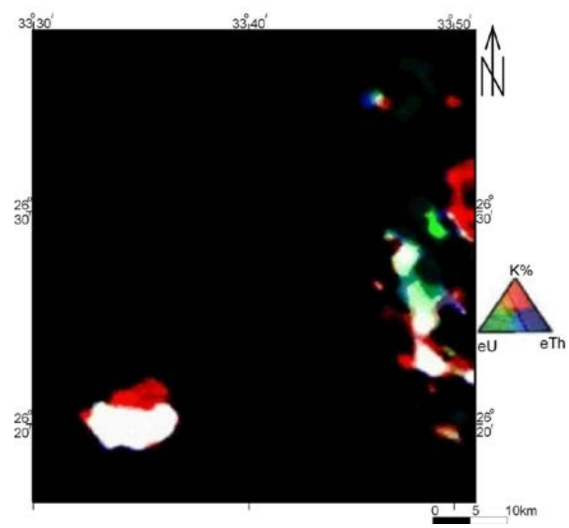

Fig. (6): Radioelements Non-Normalized Composite Map.

I.7. Thorium normalized composite map (Fig. 9): The high scores of this map (pink colour) reflect some spots, which lie along the geologic contact (litho-geochemical contact) between the different types of rocks as the contact between ophiolitic mélange and metavolcanics in the southern part of the area or along the boundaries of Wadis as in the case of type II and type III of metavolcanics, which take the NW trend. The blue colour reflects the lowest score on this map and can discriminate only the Phanerozoic sediments in the northeastern part area, as in G. Gasous and east of W. Safaga. The other colours are not differentiated on the map, because the thorium contents are nearly similar in these rocks.

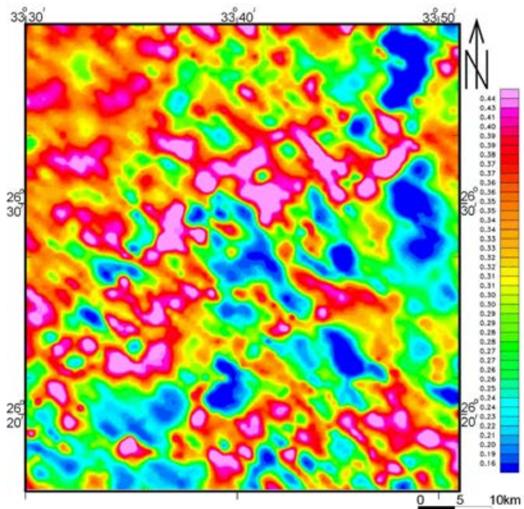

Fig. (7): Potassium Normalized Composite Map.

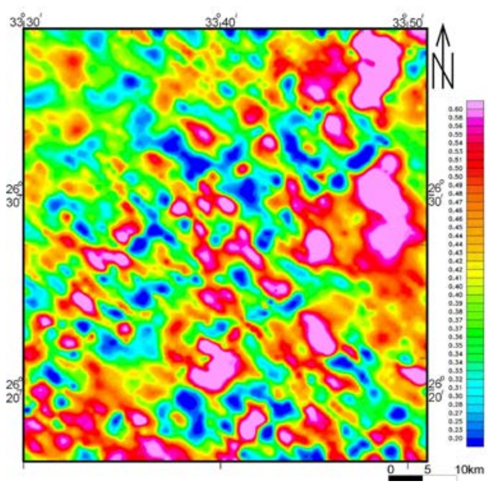

Fig. (8): Uranium Normalized Composite Map.

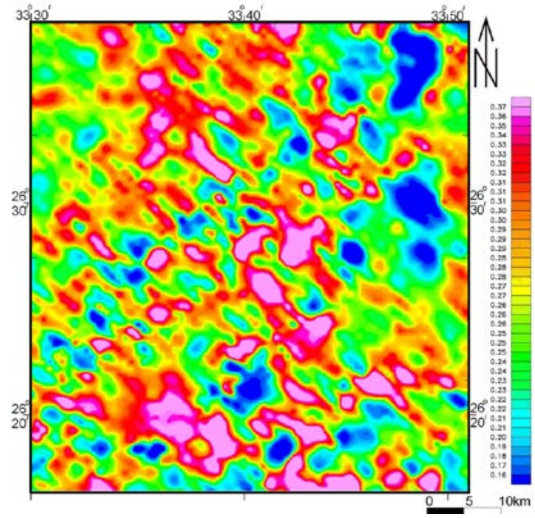

Fig. (9): Thorium Normalized Composite Map.

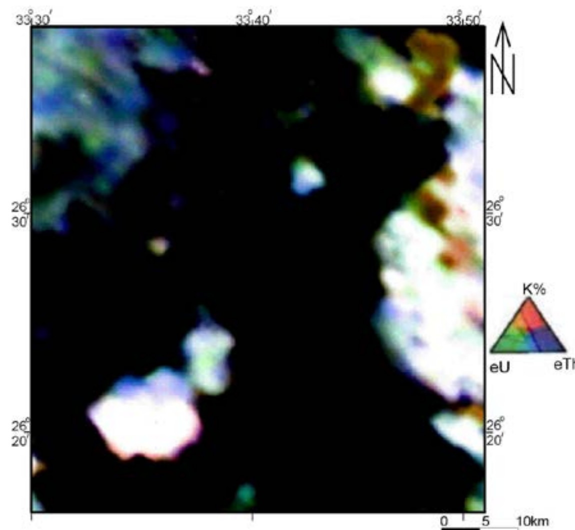

Fig. (10): Radioelements Normalized Composite Map RGB.

I.8. Radioelements normalized composite map RGB (Fig. 10): The composite image map from these colours could trace the boundaries of some masses. The white colour describes the granitic mass of G. Kab Amiri, Phanerozoic sediments in the northeastern part area. Dokhan volcanics to the north of W. Saqia and the granodiorite monzogranite mass north of G. Gasous. The blue colour in the northwestern part area describes the diorites rocks and could show the boundaries between this mass and its surrounding rocks. The grey colour reflects the other lithologic units without any differentiation. In general, the white colour on this map separates the southern part of Kab Amiri granitic mass from its northern part. This means that the two parts differ in their chemical and mineralogical composition. The variation of the white colour could differentiate between Dokhan volcanics, Phanerozoic sediments and granodiorite monzonites rocks.

I.9. Radioelements normalized composite map CMY (Fig. 11): This composite image map could trace the boundaries of some masses having a relatively high radioactivity. The white colour describes the granitic mass of G. Kab Amiri and the three small isolated granitic intrusions to the north west of G. Kab Amiri, in NW direction, beside the acidic rocks in the eastern part area without any differences between the rock boundaries in this part. The dioritic rocks, in the northeastern part area reflected by magenta colour, whose strength is proportional to the radioactivity contents in these rocks. Yet, the external boundaries are interfaces with the surrounding rocks, which possess very low radioactivities that take black colour and describe mostly the basic rocks in the study area. The green colour mainly shows Phanerozoic sediments.

II- Automatic Edge Detection

II.1. The Total count zoning map (Fig. 12): This map displays an overall picture of the radioelement distributions in the study area. This zoning offers much in terms of lithologic discrimination based on colour differences. The pink colour reflects the high radioactive rocks of Kab Amiri granites, and Phanerozoic sediments of G. Gassous. The intermediate radioactive rocks like diorites in the northwestern part of the area can be traced and isolated into two kinds of diorites, which take the red colour with some Phanerozoic sediments in the east ern part of the area. The yellow colours describe most of the low radioactive rocks collectively as ophyolitic assemblages, metasediments, and metavolcanics.

II.2. Potassium zoning map (Fig. 13): This map shows much information about the lithologic contacts, where it could discriminate the monzogranites of Kab Amiri and the sediments drived from granites, which contain high percentage of potassium. This map could isolate the boundaries of the granodiorite monzonite mass which occurs in the eastern part area under study. It could also discriminate the diorites in the northwestern part of the area into two kinds, which differ in mineralogical and chemical compositions, where they have different concentrations of potassium (Fig. 2). The yellow colour reflects the boundaries of low potassium content. It could especially trace the boundaries of the third type of metavolcanics (dacitic rock varieties, Type III).

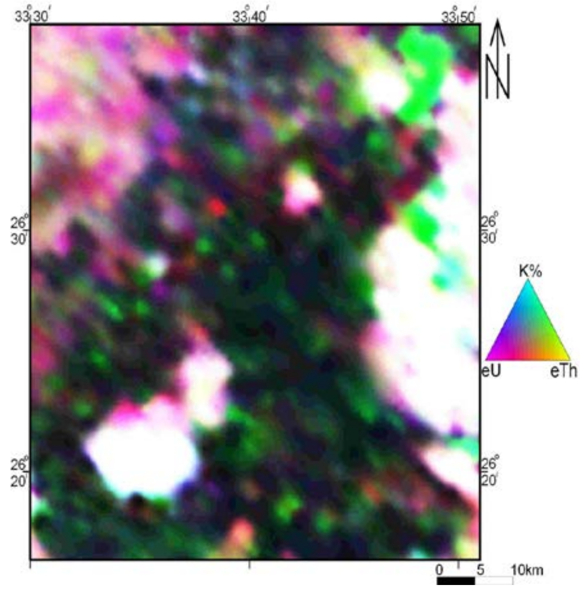

Fig. (11): Radioelements Normalized Composite Map CMY.

II.3. Uranium zoning map (Fig. 14): This map reflects the high radioactive mass of G. Kab Amiri in pink colour together with the acidic metavolcanics and Phanerozoic sediments. Granodiorite and basic rocks of similar intermediate radioactivity are included in this pink colour, which makes it very difficult to discriminate between them. The Wadis take the NW and NE directions and can be distinguished as they show low radioactivity levels (Fig 2).

II.4. Thorium zoning map (Fig. 15): This map is similar to the T.C. zoning map, where the high radioactive rocks as granites and Phanerozoic sediments could be traced. It could also show the drainage lines, especially in the basic rocks (yellow colour) which take two main trends: NW and NE directions.

III- Cluster Analysis

The correlation matrix (Table 2) shows that there is a high positive correlations between T.C. and the three variables (eU, eTh and K) reaching 85%, 95% and 95% respectively. The eU/eTh ratio is correlated positively with uranium and eU/K and negatively with the other variables. The negative correlation distinguishes between eU/K and Tc and K, while it is correlated positively but moderately, with eU and very poorly with eTh. Weak correlation between eTh/k ratio and the other variables is noticed except with eU/K, where the correlation is relatively moderate (49%).Instead of discussing the intercorrelations between these variables, factor analysis provides a way of thinking about these interpretation types.

Table (2): Correlation coefficients between the seven data variables, W. Saqia area.

Variables	T.C.	eU	eTh	K	eU/eTh	eU/K	eTh/K
T.c in Ur							
U ppm	0.85						
Th ppm	0.95	0.78					
K%	0.95	0.72	0.89				
eU/eTh	-0.05	0.44	-0.07	-0.08			
eU/K	-0.06	0.46	0.02	-0.12	0.85		
eTh/K	0.03	0.18	0.18	-0.14	0.11	0.49	

Table (3) shows the three principle factors F1, F2, and F3 after being rotated using the verimax method. It can be concluded form this Table that factor one (F1) has an appreciably high positive loading with the four variables T.C., eU , eTh and K, attaining 99%, 85 %, 96 % and 96 % respectively. F1 exhibits a weak loading with eU/eTh, eTh/K and eU/K as positive values attaining 1% and 2 % and 2 % respectively. Therefore, F1 can be identified as the total radioactivity factor. The second factor (F2) is highly loaded with eU/eTh and eU/K reaching 98 % and 91 % respectively, and is inversely loaded with (Th and K) as 8 % and 10 % respectively. F2 is also moderately loaded with T.C, eU, and eU/K by 39 %, 46 % and 15% respectively. Therefore F2 refers mainly to Phanerozoic sediments, which are mainly derived from granites and acidic volcanic rocks. The third factor (F3) is highly loaded with the ratio eTh/K reaching 98% and is moderately loaded with eU/K ratio, and very poorly loaded with eU, eTh and inversely loaded with T.C, K% and eU/eTh ratio, this factor explains the locations of volcanic rocks. These factor scores which characterize different rock units in the study area are best summarized in table (2). These units are named in the light of the published geological map (Fig 2).

Table (3): Loading of factors (Varimax rotated), in W. Saqia area.

Factor Variables	F1	F2	F3
T.C. (Ur)	0.993	0.390	-0.001
eU(ppm)	0.847	0.462	0.097
eTh(ppm)	0.963	-0.081	0.176
K (%)	0.961	-0.104	-0.160
eU/eTh	0.012	0.982	-0.053
eU/K	0.027	0.907	0.370
eTh/K	0.023	0.149	0.984

III.1. Factor 1 map (Fig. 16): This map could discriminate granite rocks (G1) as G. Kab Amiri with sharp pink colour. However, some other types of the older rocks could be confused with them, because of similarities in gamma-ray responses (e.g., Dokhan volcanics, north of W.Saqia and Phanerozoic sediments of G.Gasus). The red colour reflects the Arc granitoid (Older granitoid, G2) which include diorites , granodiorites and grey granites. The Phanerozoic sediments are confused also in this colour. The green colour which covers a large surface of the area reflects low K, eU, and eTh concentrations (representing ophiolitic mélange and island arc association). These rocks include metaultamafites. ophiolitic mafic metavolcanics intermediate to felsic metavolcanics (G. Waeira, W. Safaga, W. Saqia, G. Semina), metapyroclastics and metasediments (dacite origin) beside ophiolitic assemblage around G. Kab Amiri. The blue colour could discriminate metavolcanic rocks especially the third type (dacitic rock varieties) which occur in Abu Aqarib and Kab Elabssi (Fig. 2).

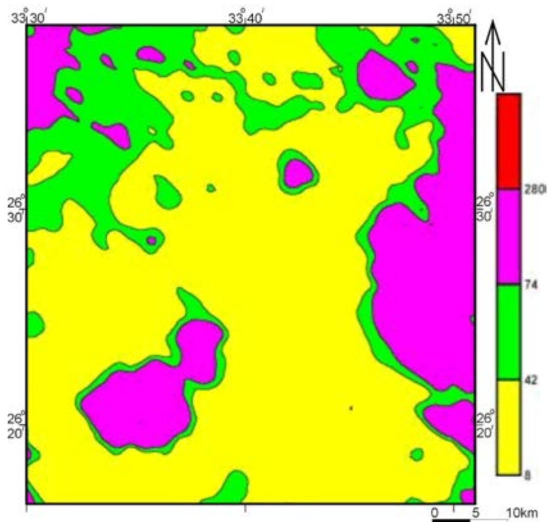

Fig. (12): Total Count radiometric Zoning Map.

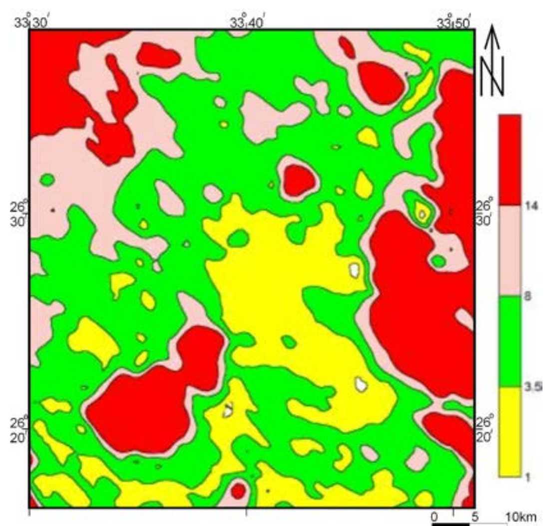

Fig. (13): Potassium Zoning Map

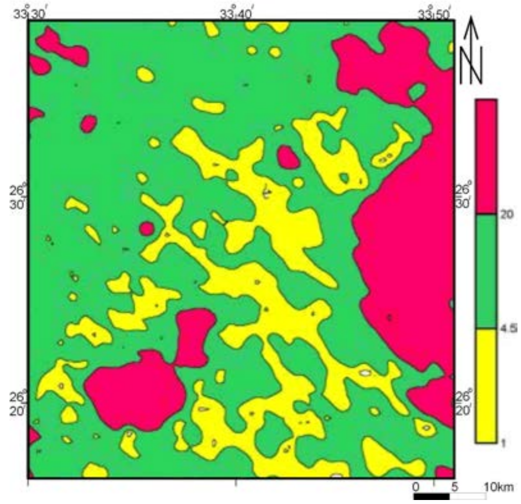

Fig. (14): Uranium Zoning Map.

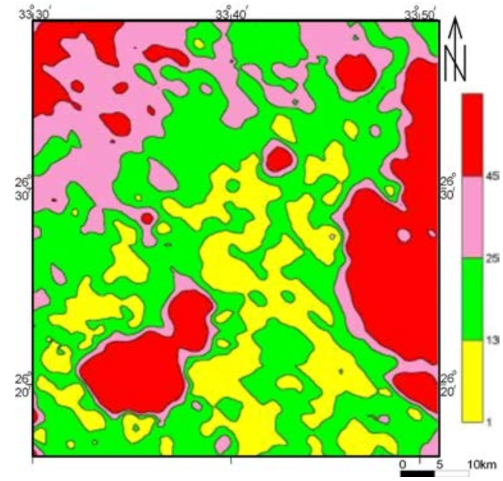

Fig. (15): Thorium Zoning Map

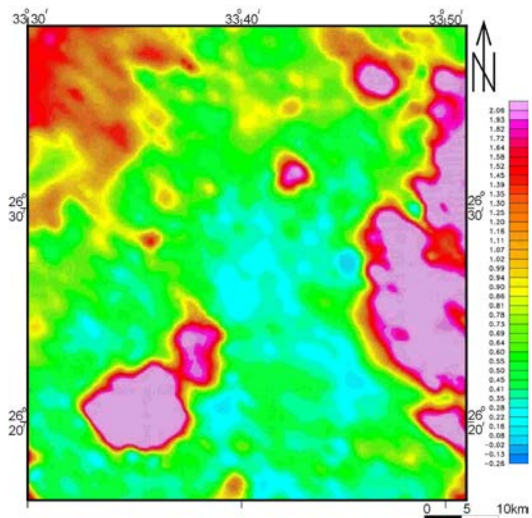

Fig. (16): Factor 1 Map.

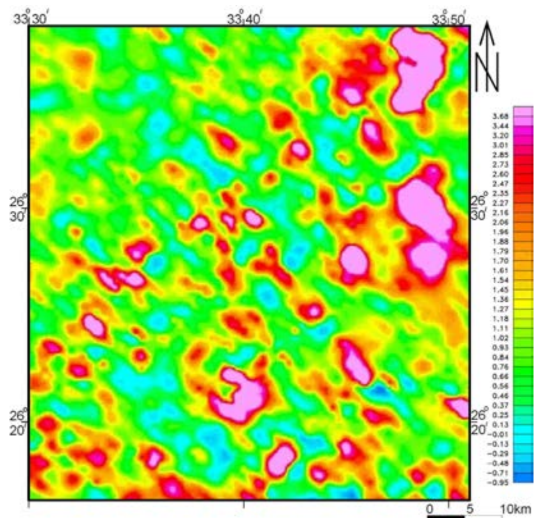

Fig. (17): Factor 2 Map.

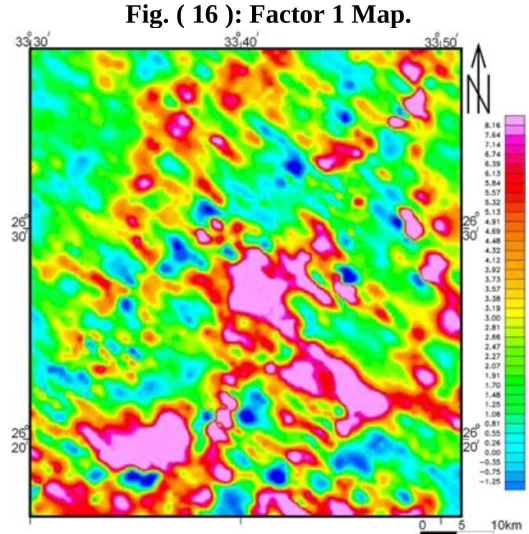

Fig. (18): Factor 3 Map.

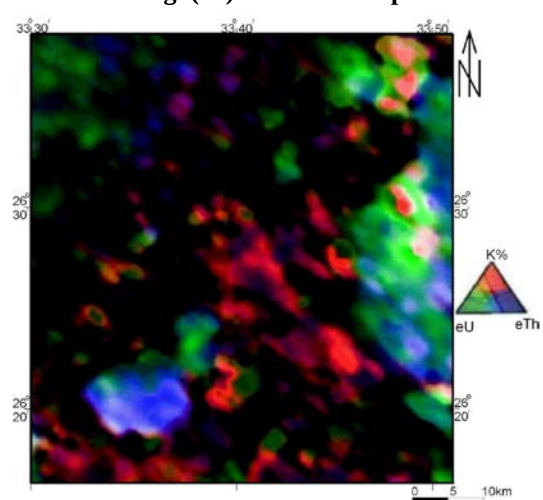

Fig. (19): Composite Factors Map.

III.2. Factor 2 map (Fig. 17): This map is loaded in eU/eTh and eU/K which reflect Phanerozoic sediments by a pink colour in the northeastern part of the study area. Other spots of this colour reflect some anomalies along the drainage lines of Wadis. The red colour is remarkable to areas dominated by ophiolitic assemblage, grey granite, metadiabase, metabasalt (very low radioactive rocks). The green and blue colours are confused and they couldn't distinguish between any of the lithologic boundaries.

III.3. Factor 3 map (Fig. 18): This map is loaded in eTh /K by a high score which discriminates the southern part of G. Kab Amiri by a pink colour, beside the metasediments rocks (metamudstone, granitized metamudstone), metagabbro and Phanerozoic sediments. The green colour reflects the diorites in the northwestern part of the area. The contacts are not well defined by this colour in the case of metavolcanics and ophyolitic assemblage.

III.1. Composite factors map (Fig. 19): This map shows valuable information and could differentiate between different rock units, which have similarity in their radioactive mineral contents. An example of these cases, the granitic mass of Kab Amiri (blue colour in the south of the area), the southern part is isolated from the northern part as well as from the granitic mass, which lies in the northeastern part of this pluton. Besides, the granitic mass of Kab Amiri is discriminated from the surrounding other small isolated granitic bodies. The acidic rocks in the east of the area are differentiated into blue, green and red colours, and each colour reflects rock units which differ in their lithologic content. The red colour in the centeral, northeastern and southeastern parts of the area reflects the high ultramafic rocks and the leached parts from the radioactive contents. The black colour reflects the intermediate and low radioactivity rocks of intermediate and basic rocks.

IV- Integration of Gamma Ray Spectrometric Data with Complementary Data Sets

The integrated interpretation of gamma ray data with complementary data sets provides an excellent approach for geological mapping. This integration was performed using the results of the three techniques used in this study. The final defined geologic boundaries which are traced to identify the unit boundaries on the map (Fig. 20). These boundaries could be correlated with the published geological map of the area under study (Fig. 2). The integration of tracing started as follows:

IV.1. Non-normalized maps:

Potassium map reflects the acidity of rock units. It could trace the boundaries of the known isolated masses in the study area. The increase of K content greatens the percentage of discrimination in the rock. Uranium map could classify one type of acidic rocks as granites to more than one type of rocks. Thorium map could describe the boundaries of acidic and intermediate rocks only.

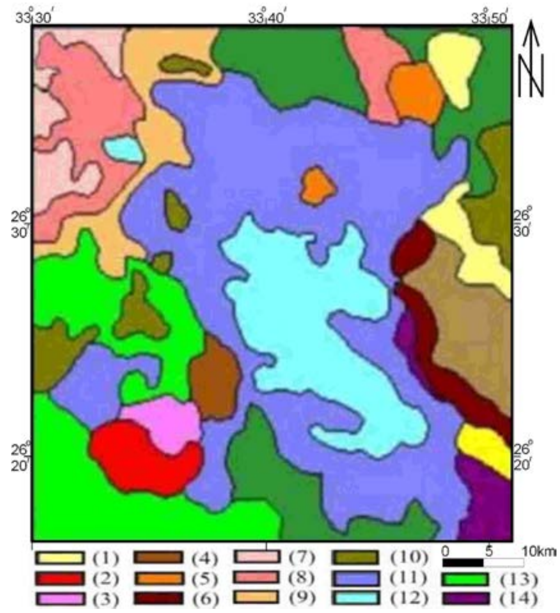

Fig. (20): Integrated units boundaries map

Legend

1- Phanerozoic sediments 2- Monzogranites 3- Granodiorites 4- Alkali feldspar granites 5- Grey granites I 6- Serpentinites 7- Grey granites II 8-Diorites I 9- Diorites II 10-Gabbros 11- Acidic metavolcanics 12-Basic metavolcanics 13- Ultrabasic rocks 14-Dokhan volcanics

IV.2. Normalized maps:

Potassium, Uranium and Thorium maps reflect the variations in the anomalous zones, but the lithologic boundaries are confused. The normal composite map could trace the boundaries of acidic rocks but could not discriminate the other rocks.

IV.3. Zoning maps:

Potassium map could trace the boundaries of many rock units (acidic or basic). Uranium and Thorium maps could trace the boundaries of acidic rocks, beside the locations of the drainage lines and structures. The total count map could differentiate between acidic and basic rocks, but it couldn't differentiate between intermediate and basic rocks.

IV.4. Factor analysis maps: F1 map could trace the boundaries of the high radioactive rocks, while the rough **F2** map could trace the boundaries of the Phanerozoic sediments and the trends of Wadis which are shown as spots of anomalies. **F3** map could trace the boundaries of the areas of high eTh and low K as at the southern part of G. Kab Amira and acidic metavolcanics.

SUMMARY AND CONCLUSIONS

The gamma ray method has been successfully applied to geological mapping, and mineral exploration. The use of spectrometric data as a mapping tool requires an understanding of the geochemistry of the radioelements in rocks and soils, and the processes that effect their distribution and mobility. This paper gives a brief outline of the principles of using gamma ray spectrometric data in geological mapping. This includes a review of the fundamentals of different mapping tools, and their applications to airborne mapping in a selected area.

It was found through this field example that, there is no unique strategy for mapping, but there are many alternative strategies. Generally, the useful strategy for geological mapping is first to outline the major lithological units and then enhance the radioelement patterns within the individual units. This can be achieved through data enhancement; unit and anomaly identification using edge detection–visual interpretation and factor analysis. Finally, integrating all data sets (units on the geological maps and anomalies) was conducted to contribute efficiently to the mapping of the study area. At the end, the integrated unit map is compared with the published geological map of the area to assess their successfulness in geological mapping and good correlations were achieved.

Gamma ray mapping precision depends on the survey parameters, quality of the data, and the characteristics of survey area. The mapping scale depends strongly on (flight) line separation and station separation along profiles and other survey parameters. The most important factors determining the efficiency of contribution of gamma- ray survey to geological mapping are: the contrasts in radioelement content between lithological assemblages and the nature and type of weathering and transported materials. This integration can give good geological mapping taking into consideration the other important points mentioned.

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