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DELINEATING Cu-U MINERALIZED ZONE IN WADI EL-REGEITA AREA, SOUTHERN SINAI-EGYPT, USING GAMMA-RAY SPECTROMETRY AND SELF POTENTIAL METHODS

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تحديد نطاق تمعدن النحاس – اليورانيوم بمنطقة وادى الرقيطة، جنوب سيناء – مصر، باستخدام طرق المسح الاشعاعى الطيفى والجهد الذاتى

الخلاصــة: تقع منطقة وادى الرقيطة فى الجزء الجنوبى من سيناء عند تقاطع خط عرض "٢٩ '٣٧ °٢٨ شمالا وخط طول "١٥ '٠٥ °٣٤ شرقا .وقد اكتسبت المنطقة أهميتها لوجود تمعدنات النحاس الناتجة عن محاليل حارمائية محكومة بعوامل تركيبية بالاضافة الى تواجد واضح لشاذات اشعاعية نتيجة لزيادة محتوى اليورانيوم ومرتبطة فى معظم الحالات بشدة تمعدنات النحاس والتحولات الصخرية المصاحبة لها.

يتناول هذا العمل استخدام طرق المسح الاشعاعى الطيفى والجهد الذاتى للتعرف على محتوى العناصر المشعة وتحديد نطاق التمعدن بمنطقة الدراسة بالاضافة الى محاولة ايضاح ما اذا كانت هناك علاقة أو ارتباط لتواجد اليورانيوم مصاحبا لتمعدنات النحاس لما له من أهمية مستقبلية كبيرة فى عمليات البحث والاستكشاف المختلفة.

من خلال التفسير الكمى والكيفى لبيانات المسح الاشعاعى الطيفى وجد تباين ظاهر فى المستويات الاشعاعية بالمنطقة وأن نطاق القص الممتد فى اتجاه شمال غرب – جنوب شرق قد تميز بزيادة محتوى مكافئ اليورانيوم والتى وصلت إلى 130 ppm ، بينما أظهرت نتائج قياسات الجهد الذاتى صورة واضحة لشاذات ضحلة ناتجة لتمعدنات النحاس بامتداد نطاق القص ومائلة فى الاتجاه الجنوبى الغربى. أوضحت الدراسة أيضا وجود ارتباط مكانى قوى لشاذات مكافئ اليورانيوم السطحية وشاذات الجهد الذاتى لتمعدنات النحاس، مما يعكس امكانية استخدام طرق المسح الاشعاعى الطيفى لاستكشاف تمعدنات النحاس بمناطق أخرى.

ABSTRACT: *Wadi El-Regeita area is located in the southern part of Sinai Peninsula, at the intersection of Lat. 28° 37′ 29″ N and Long. 34° 05′ 15″ E. The area acquired its importance since the discovery of significant copper mineralizations associated, in most cases, with some radioactive anomalies related to the increase in the uranium content. These mineralizations are related to intense post-magmatic, structurally controlled, hydrothermal activities in the area and the surroundings.*

This work deals with application of the gamma-ray spectrometry and self-potential methods to identify the content of the radioactive elements and delineate the mineralized zone in the area. The work also aims to explain if there is a relation or association between the mineralizations of uranium and copper, which could be useful in view of the exploratory processes in other areas.

Data of the gamma-ray spectrometry revealed radioactivity levels ranging from 12.0 to 149.0 Ur, 0.3 to 130.0 ppm, 3.0 to 54.0 ppm and 0.5 to 9.8% for the total count of gamma rays, equivalent uranium, equivalent thorium and potassium, respectively. Interpretation of the constructed radioactivity maps, with the equivalent uranium false-color composite image, clearly reflect a sharp increase of the equivalent uranium concentrations along the NW-SE copper-mineralized shear zone in the area. Data of the self-potential survey also revealed a wide range of amplitudes (–106.7 to +55.4 mV), with the highest negative values recorded along the copper-mineralized shear zone. The quantitative interpretation revealed shallow depths to the centers of nine selected anomalies (ranging from 3.3 to 21.0 m and averaging 11.2 m), with half-widths ranging from 8.4 to 61.0 m and moderate dips toward the SW. The spatial distribution of the determined anomalies for equivalent uranium (> 37.5 ppm) and self-potential (> -60 mV) showed an excellent agreement, which indicates a very strong copper-uranium association and, therefore, methods of gamma-ray spectrometry can be considered as effective exploration tools for the copper mineralizations.

INTRODUCTION

Hydrothermal Copper (Cu) and uranium (U) deposits are very attractive targets for exploration and development purposes. These deposits are formed from hydrothermal fluids associated mainly with alkali-rich, felsic to intermediate intrusions and may occur in any type of the host rock. Association of Cu with U was already known in some parts of the world, where Cu-U provinces were investigated using different geological, geochemical and geophysical techniques (e.g., Tschanz et al., 1958; Sarkar, 1985; McLemore and North, 1985; Roberts and Hudson, 2004). Generally, U possess a particular problem regarding the subsurface geophysical exploration and the geophysicists must look for associations between U and other minerals that do alter the petrophysical characteristics of the rocks or fined areas that are structurally favorable for U mineralizations.

In Egypt, the southern part of Sinai Peninsula is mainly covered by different Precambrian basement rocks, which dominated by granites (about 70%, Bentor, 1985) of older and younger types. Some of the younger granite rocks are associated with some mineralizations of Cu (El Shazly, 1955; Gindy, 1966; Bogoch and Zilberfrab, 1979; Hassen, 1987; El Ghawaby et al., 2000) and U (Ibrahim, 1991; Bishr, 2007). These mineralizations are epigenetic, structurally controlled and occur in the form of filling-fault zones, filling-fissures and veins-like. Generally, few geophysical investigations of Cu mineralizations are known (e.g., Ammar et al., 1993; Salem et al., 2013), while there is very limited data on the possible association of radioactive minerals, especially U, with Cu (e.g., Mahdy et al., 2007; Bishr, 2007). For this reason, Wadi El Regeita area, which lies in the southern part of Sinai (Fig. 1), was selected for this study, where the area is of considerable geological interest since the discovery of Cu mineralizations, which attracted the attention of several workers (e.g., Hilmy and Mohsen, 1965; Niazy et al., 1995 and Salem et al., 2013). Besides, the area acquired its importance for the discovery of some radioactive anomalies related to U mineralizations (Bishr, 2007).

The objectives of the present study are: 1) to identify the contents of the radioactive elements U, thorium (Th) and potassium (K), using the ground gamma-ray spectrometry method and delineate any possible spatial association with the Cu-mineralized zone in the area, 2) to follow the anomalous surface mineralizations at deeper depths and obtain information about their lateral and vertical extensions through application of the self-potential (SP) survey method**.**

1.GEOLOGIC SETTING

The study Wadi El-Regeita area lies at the intersection of Lat. 28° 37′ 29′′ N and Long. 34° 05′ 15′′ E (Fig. 1), to the northeast of the well-known Saint Katherine mountain. The area and its surroundings have been described geologically and included within many mapping projects throughout studying of the Precambrian basement rocks in southern Sinai (e.g., Bentor et al., 1974; Shirmon, 1980; El-Shishtawy, 1984; Niazy et al., 1995). It is mainly occupied by a younger granite encloses irregular masses in the form of roof pendants and enclaves of granodiorite, pertaining to an older granitic phase (Fig. 1). The younger granite is also intersected by different post-granitic dykes, followed by pegmatite veins. Structurally, the area is affected by many faults of synthetic and anti-synthetic types, related to the rift systems that reformed the structural pattern of southern Sinai. The synthetic type comprises the faults parallel to the Red Sea grabben while the anti-synthetic types are parallel to the Gulf of Suez and Gulf of Aqaba (Hills, 1963; Salem et al., 2013).

The granodiorite is grayish white in color, medium to coarse-grained and occurs as irregular masses in the form of roof pendants and enclaves in the country younger granite rock. The rock is highly jointed, with predominance of NNE-SSW and ENE-WSW trends, and sometimes exhibits foliation structure along their peripheries. Bishr (2007) defined many enclaves in the granodiorite, with different shapes and size, of mafic rocks.

The younger granite is pale pink in color, medium to coarse-grained and highly fractured and jointed with predominance of NE-SW trend. Based on the petrochemical investigations, Niazy et al. (1995) classified the Wadi El-Regeita younger granite as Perthitic leucogranite of calc-alkaline magma series. It is also considered as two-feldspar younger granite, similar to G-2 granites of Hussein et al. (1982). Structurally, the exposed younger granite is highly affected by fundamental NE-SW fractures as a result of the major faulting parallel to the Gulf of Aqaba (EL-Gammal 1986).

Regarding the post-granitic dykes, they are dominated by the andesite rocks, extruded along the fractures and faults in the NE–SW direction, besides subordinate of NW–SE direction. The rocks are black or very dark grey in color and fine-grained with porphyritic texture. Some of the andesite dykes are associated with Cu mineralizations, and show abundant disseminations of hematite, which is mostly associating the effect of epigenetic Cu-mineralizing solutions. Finally, the post-granitic pegmatite veins are mostly associated with fault planes occupying ENE-WSW and NNE-SSW directions. Pegmatite is very coarse-grained and composed of quartz, alkali feldspar and plagioclase. Some of the pegmatite veins bear green copper staining.

2. MINERALIZATIONS

The study area is intensely sheared and fractured with development of Cu-mineralized shear zone which is mainly associated with andesite dyke. This zone has a general trend of about N65W and a steep dip of about 75º to SW. The length of the shear zone reaches about 600 m and the width ranges from 1.0 m to 3.0 m, with about 0.5 m mineralized area of green copper (Hassen, 1987). The sheared rocks are stained by reddish, brownish and yellowish iron oxides and hydroxides, which marked the horizontal extension of the mineralized zones whereas veins and encrustations of secondary copper minerals are quit common. Besides, Bishr (2007) defined some economic minerals using XRD and ESEM analysis for samples collected from El-Regeita shear zone.

These minerals included wulfenite (lead molybdenum mineral) which is generally associated with Cu minerals malachite and atacamite, sphene (titanite) and some U minerals. The most important U mineral is carnotite, which has a canary or lemon-yellow color and associated with iron oxides and clay minerals in the form of thin films or discrete crystals in vugs. It is present along grain boundaries, cavity fillings and in the high porosity zones, suggesting formation by the action of meteoric or surface waters on the presence of uranyl and vanadate ions.

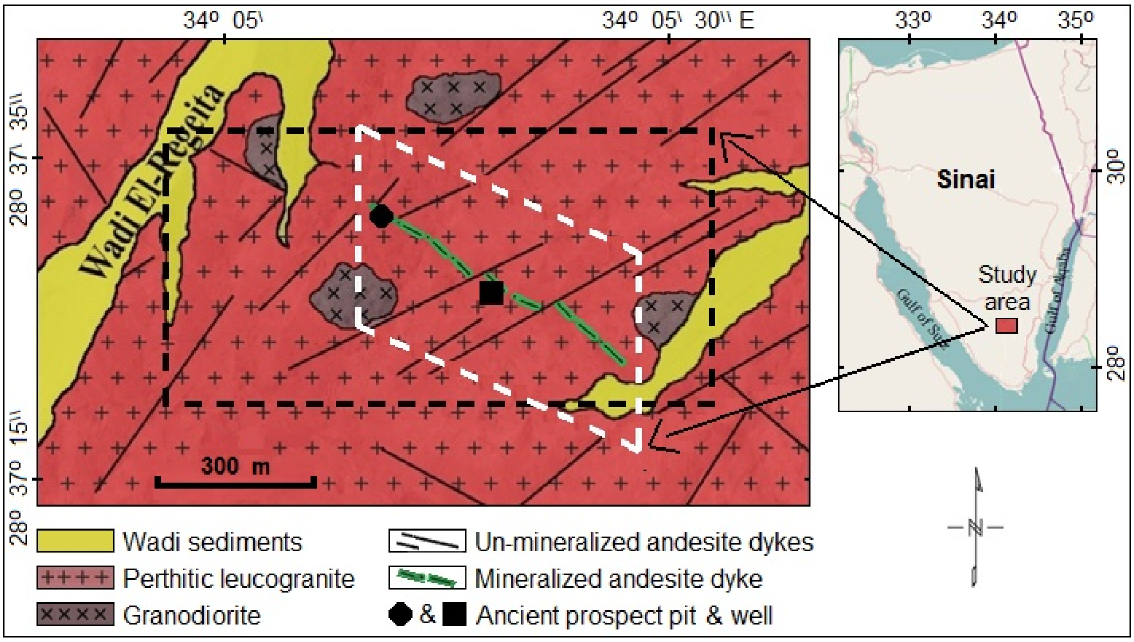

Fig. (1): Location and geologic map of Wadi El-Regeita area, southern Sinai, Egypt (modified after Niazy et al., 1995). The black and white dashed polygons represent the selected areas for ground gamma-ray spectrometry and self-potential surveys, respectively.

3- SURVEYING METHODS

3.1. Gamma-ray Spectrometry Method:

Ground gamma-ray spectrometry survey is a rapid effective quantitative method of mapping variations of radioelements concentrations within the different rock types. It is a powerful tool for locating U deposits (e.g., Bowie, 1972) and even associated metalliferous deposits (Moxham, et al., 1965). The applications of this method as a geological mapping and exploration tool are well developed, mainly through the work of the Geological Survey of Canada (e.g., Grasty and Darnley, 1971), the Danish Atomic Energy Commission (e.g., Lovborg, 1973) and the International Atomic Energy Agency (e.g., IAEA, 1974).

In the present study, a systematic ground gamma-ray spectrometry survey has been carried out for an area of 500 x 1000 m, on a grid pattern of 20 m station separation through 51 NS parallel profiles of 500 m length for each. The measurements were carried out using a 512-channel portable gamma-ray spectrometer (GS-512, Geofyzika Brno) with a NaI scintillation detector activated by thallium. The measurement depends on recording of the gamma-ray associated with characteristic peaks in the decay spectra of Th, U, and K at selected energy windows of 2.62 MeV for ^{208}Tl, 1.76 for ^{214}Bi and 1.46 for ^{40}K, which represent the equivalent thorium (eTh), equivalent uranium (eU) and potassium (K), respectively. The data have been corrected for the background and stripping ratios to obtain the net concentrations of the radioelements eU (ppm), eTh (ppm) and K (%), as well as the total count of gamma rays, TC (Ur).

Finally, the measurements were presented as color radioactivity maps of TC, eU, eTh, K, eU/eTh, eU/K and eU-index as well as a false-color composite image of eU, using Geosoft package (Geosoft, 2010). Besides, some statistical analysis and graphical presentations were also carried out for the different gamma-ray measurements to enhance the qualitative and quantitative interpretations.

3.2. Self Potential (SP) Method:

The SP method is based upon measuring the natural potential developed in the earth by electrochemical actions between minerals and subsurface fluids or by electrokinetic processes involving the flow of ionic fluids. As the method offers relatively rapid field data acquisition, it often is cost-effective for reconnaissance or initial investigation of an area prior to more intensive studies using other geophysical and geochemical techniques (Telford et al., 1990; Parasins, 1997). The required equipment merely includes two non-polarizing type electrodes (porous pots), wire and a high-input-impedance voltmeter (>10 mega ohms). The electrodes are placed in 10 cm holes, which made at each station on a grid pattern, to reduce the source of noise from the topsoil. Watering of these holes may improve contact consistency (Semenov, 1974). A high-input-impedance voltmeter is used to read the potential in the millivolt range. The resolution of the voltmeter should be less than 1.0 mV.

In the present study, the SP survey was conducted along 14 NS profiles, with profile spacing of 40 m, 20 m station separation and 360 m length for each, beside one selected profile (tie line) of about 560 m length. One station was selected as a base station, located at a calm SP potential point as possible, and all potentials were referenced to that point. At the base station, the instrument was adjusted to zero value by connected it to the non-polarizing electrodes staying at the same station. All the base stations were reduced to the zero value of the general base station for the whole surveyed area. The other electrode (rolling electrode) was moving on the grid stations. Field measurements were taken using an Auto–Ranging Digital Multimeter Model HP 972A (U.S.A made).

The corrections of the obtained SP measurements have been carried out by subtracting the base station value of each profile from the reading of each station on the same profile. Also, any differences in potential between the electrodes were subtracted from the reading of each station. The corrected SP data were used to construct SP contour map to enhance the qualitative interpretation. In terms of the quantitative interpretation, the corrected readings along some selected anomalies were plotted against the distances on millimeter papers to produce reduced SP anomaly profiles for determination of some anomaly parameters with a more accuracy.

4. ANALYSIS AND INTERPRETATIONS

4.1. Gamma-ray Spectrometry Data:

The visual examination of Table 1 exhibits a fairly wide range for TC (12.0 – 149.0 Ur) and eU (0.3 – 130.0 ppm). As observed from the constructed TC and eU maps (Fig. 2 (a & b)), and indicated from the field observations of the surveyed area, the highest values were spatially associated, to a large extent, with the Cu mineralizations and wall rock alterations in the eastern part of the study area, and mainly along the NW–SE Cu-mineralized shear zone, which steeply inclined to the south-west direction. Away from the area of alteration and Cu mineralization, the rocks are marked by low radioactivity levels, where the recorded values for TC and eU fall on the range of about 12.0 – 35.0 Ur and 0.3 – 13.0 ppm, respectively, very close to the normal radioactivity levels of the granitic rocks. There is also a good agreement between TC and eU maps as concerning the highest and lowest levels and the distribution of the radioactive anomalies, which indicates that the radioactivity in the study area is mainly related to eU. This is also confirmed from the estimated very strong positive relation between TC and eU (r = 0.82), whereas insignificant relations exhibit between TC and both of eTh (r = 0.12) and K (r = 0.14), as illustrated in Figure 3 (a, b & c).

Regarding the eTh, the recorded measurements exhibit a relatively wide range (3.0 - 54.0 ppm), with an average of 12.8 ppm (Table 1). As indicated from the constructed map (Fig. 2c), together with the field observations, the lower eTh values are generally associated with the wadi sediments, in the northwestern part of the study area, and along the NW–SE andesite dyke, located within the Cu-mineralized shear zone, which characterized by lower thorium content than the hosting granitic rock. In terms of the higher eTh values, they are associated, to some extent, with the anomalously high eU parts in the eastern side of the area and along the Cu-mineralized shear zone. Despite this distribution, there is no any relation between eU and eTh (r = 0.002), as illustrated in Figure 3d, which can be explained in two ways. The first is the probability of some association of U with Th-rich accessory minerals and there was a mobilization and redistribution of uranium in the area. The second more plausible explanation is the presence of different hydrothermal episodes for the formation of U and Th mineralizations along the same deformation trends in the area, which seems to be consistent with explanation of Ibrahim (1991), where he defined two episodes for the formation of U and Th at the nearby wadi Zaghra area.

Finally, the recorded K concentration values showed narrow range (0.5 – 9.8%), with an average value of 3.9% (Table 1 & Fig. 3d). Except for the relatively high K concentrations along the mineralized shear zone, which could related to the rock alterations, the recorded values fall within the normal range of the granitic rocks. As illustrated in Figure 3 (e & f), there is no any correlation between K and eU (r = 0.00), while there was an insignificant positive correlation between K and eTh (r = 0.12). This lack of relations, with the observed homogeneity of K concentrations in the area, appears to coincide with the fact that K is a wide spread element in the crustal rocks, since it is considered as a major element in the rock forming minerals.

It is known that the radioelement ratio maps are particularly useful in interpretation of the ground gamma-ray spectrometry surveys, since they are frequently more indicative of lithological units or geological-geochemical environments than the absolute intensity and concentration maps alone. This is because they are less affected by surface geometry, percentage of outcrop, inversion trapping of radon and various absorbers such as soil moisture and vegetation. From an exploration viewpoint, maps of U/Th and U/K are diagnostic for identification of the anomalous U concentration zones (Darnely, 1973; Boyle, 1982). Accordingly, the eU/eTh and eU/K ratios were calculated and represented by color ratio maps for the study area. As illustrated in Table 1, values of the eU/eTh ratios range from 0.02 to 10.5, with a mean value of 0.6. According to Darnely and Ford (1989), the eU/eTh value of productive uraniferous rock is around one or more. As illustrated in Figure 2e, the anomalous parts, with eU/eTh values more than unity and attained a maximum value of 10.5, occur mainly along the NW-SE Cu-mineralized shear zone. The calculated eU/K ratios, together with their constructed map (Table 1 & Fig. 2f), on the other hand, confirm most of the anomalous eU/eTh parts in the area and show very high values (up to 0.30) along the Cu-mineralized shear zone. These observations, together with the very good positive relation between eU and eU/eTh (r = 0.77), and insignificant relation between eTh and eU/eTh (r = - 0.06), as illustrated in Figure 3 (g & h), confirm a strong post-magmatic hydrothermal activities and mobilization in favor of excessive U (Bostock, 1981 and Charbonneau, 1982).

Table (1): Some statistical analysis of the gamma-ray spectrometry data, Wadi El-Regeita area, southern Sinai, Egypt.

Variables	Statistical parameters				
	Range		X	S	*CV%*
	Min.	Max.			
TC (Ur)	12.0	149.0	27.1	10.7	39.5
eU (ppm)	0.3	130.0	6.3	9.8	155.6
eTh (ppm)	3.0	54.0	12.9	4.6	35.7
K (%)	0.5	9.8	3.9	0.8	20.5
eU/eTh	0.02	10.5	0.6	0.9	150.0
eU/K	0.8	30.0	1.7	2.8	164.7

X: Arithmatic mean, S: Standard deviation and CV: Coefficient of variability.

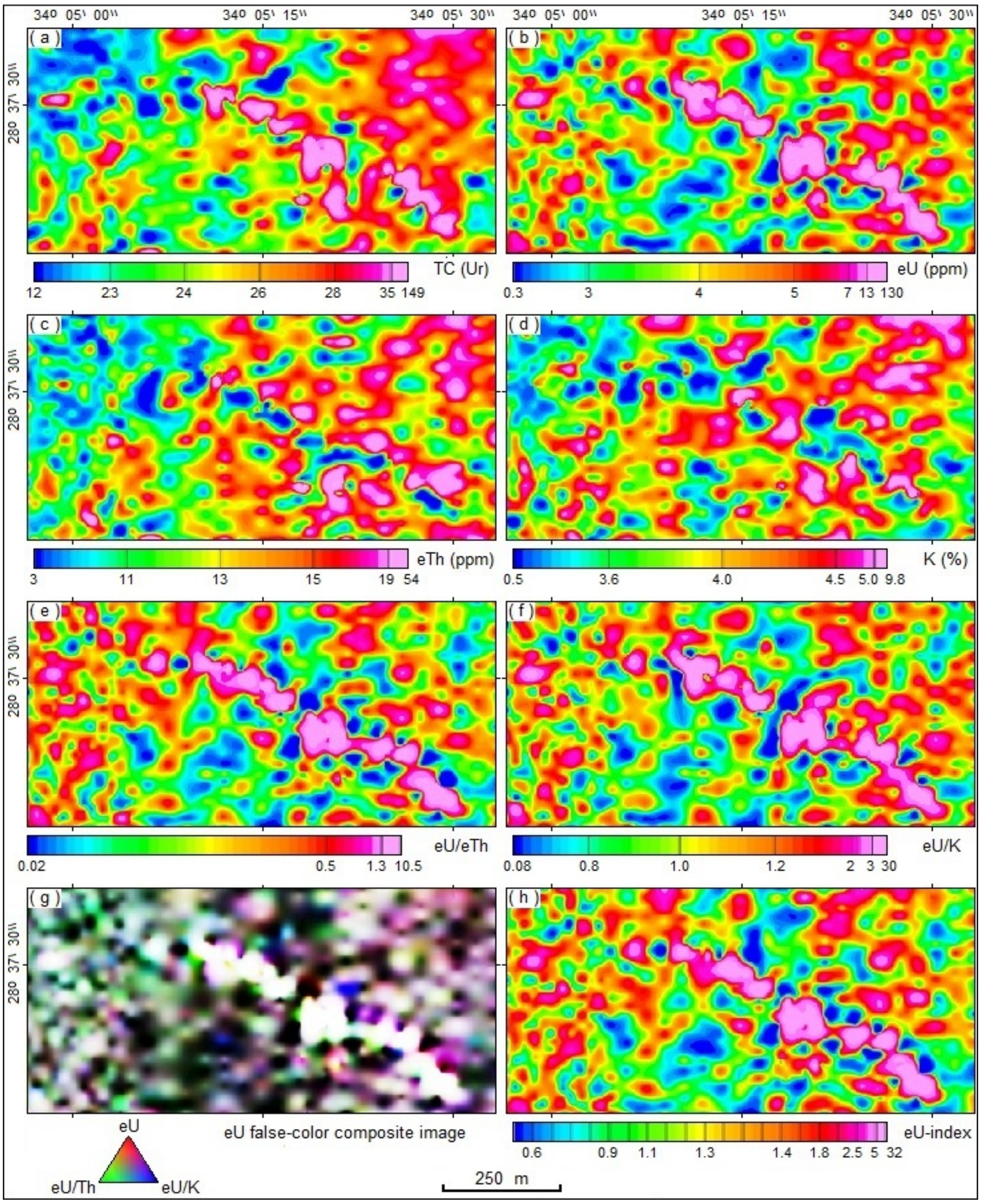

Fig. (2): Gamma-ray spectrometry maps showing the distribution of TC, eU, eTh, K, eU/eTh and eU/K as well eU false-color composite image and eU-index map for Wadi El-Regeita area, southern Sinai, Egypt.

Saunders and Potts (1976) concluded that the most promising U anomalies should have a high U abundance coinciding with high U/Th and U/K ratios, which indicates U enrichment over Th and K. Accordingly, the three parameters U/Th, U/K and U can be combined in one false-color composite image, using three different colors for the used parameters. In this study, a false-color composite image of eU was constructed to the surveyed area through a combination of red, green and blue color, representing eU, eU/eTh and eU/K, respectively (Fig. 2g). This image is used to identify and outline the anomalous eU concentration zones, which displayed as white light portions resulting from an equal color mixture for the used parameters. As illustrated from the image, the white light portions (high eU anomalies) are mainly associated with the Cu-mineralized shear zone. According to Duval (1983), this zone can be interpreted as reflecting good geochemical environment favorable for the formations of U deposits and can, therefore, be used as exploration guides to search for additional surface and subsurface U mineralizations in the area.

Assessment of the U potential within the area is also based on the calculated values of the statistical parameter coefficient of variability (*CV*) as recommended by Saunders and Potts (1976) and the U favorability index (U-index), which was proposed by Efimov (1978). Saunders and Potts (1976) concluded that, the calculated *CV* values of the radioactive elements are generally increased with increasing U potentiality. As indicated in Table 1, the calculated *CV* values of K and eTh concentrations are 20.5% and 35.7%, respectively, reflecting a relatively low variability distribution within the study area. The eU, on the other hand, exhibits very high *CV* value (156%), which was very close to the calculated value for both eU/eTh (150.0%) and eU/K (164.7%). These values reflect very strong variability distributions and, consequently, high potentiality of eU in the study area.

Regarding the U favorability index (U-Index), it seems to be very useful parameter because the calculated value comprises the three radioactive elements U, Th and K. This index distinguished between the altered and unaltered rocks, and through light on the favorable areas for U exploration. In common non-altered rocks, value of U-index is about 1.2 or 1.3, while in altered rocks, there is a general increase in U-index value with the increase of the degree of rock alteration (Efimov, 1978). As illustrated from the constructed eU-index map of the study area (Fig. 2h), and on the basis of Efimov's (1978) quantification, the shear zone area revealed very high U-Index values, which attain about 32.0, reflecting intense alterations and mineralization processes. Thus, this zone is considered of high potential, favorable for U exploration.

In conclusion, the study Wadi El-Regeita area recorded significant radioactivity levels which were, to a large extent, spatially associated with Cu mineralizations along a NW-SE shear zone located in the eastern part of area. Abundance of the radioactive elements were independent of differentiation processes, but were related to the favorable combination of structural conditions and post-magmatic hydrothermal processes, which have clearly altered the rocks and modified their radioactive element concentrations, especially uranium. Therefore, the area could be considered significant and promising in view of Cu-U mineralization and extraction.

4.2. Self Potential (SP) Data:

Qualitative Interpretation:

The constructed SP color map of the surveyed area (Fig. 4a) exhibits a wide range of amplitudes varies from -106.7 to +55.4 mV, with the highest negative values recorded mainly along the NW-SE shear zone and at the southeastern part of the mapped area. The high negative amplitudes (from about -60.0 to -106.7 mV) along the shear zone can be related to the strong surface Cu mineralizations or shallow depths to top of the ore bodies, while in the southeastern part of the mapped area, the high SP negative amplitudes represent the wadi sediments in the area (Fig. 1) and can be related to the groundwater, where many of wells are found within and close to the Wadi area. In terms of the scattered moderate negative SP amplitudes (-30 to -60 mV) allover the mapped area, they are largely related to the fracture fillings mineralizations, as confirmed from the field observations, where the area is intensely sheared and fractured. On the other hand, the relatively weak negative SP values could be related to clay or poor conductive materials within the surface fractures and drainage lines, while the positive SP values are mainly associated with the resistant unmineralized granitic rocks in the area.

In order to obtain a good insight into the Cu-U association in the investigated area, the statistical parameters arithmetic mean (X) and standard deviation (S) have been used to calculate the threshold value for eU, which was considered the beginning of the high anomalous eU concentration in the area. This value, which was considered as three standard deviation above the calculated mean (X + 3S), was used to outline the high eU anomalies in the area. As illustrated in the constructed anomaly map (Fig. 4b), there is a very good agreement in the spatial distribution between the determined eU anomalies (above 37.5 ppm) and the strong negative SP anomalies (> -60 mV), which is directly related to the intensity of Cu mineralization and relevant alteration in the study area. The anomalies are elongated mainly in the NW-SE direction, with some NE-SW trends. This, with the field observations, is consistent with the major structural lines affecting the prospect area.

It is also noticed that most of the Cu-eU anomalies located at the intersections of faults and andesite dyke along the shear zone, which is coincide with Hassen (1987), that the enrichment of Cu mineralizations increase at the intersections between faults.

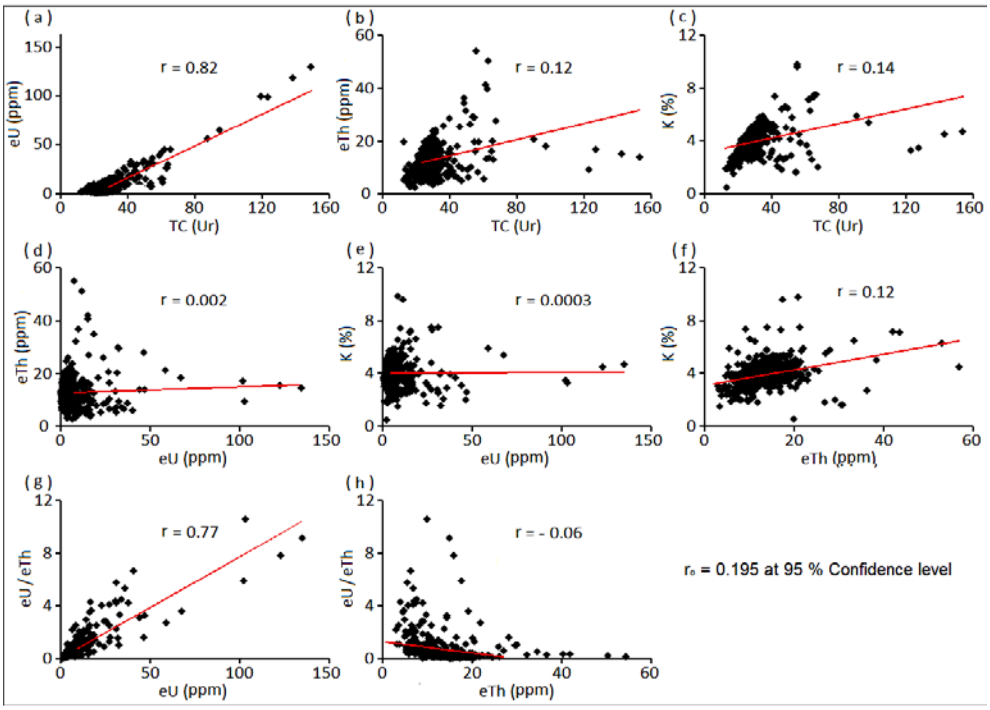

Fig. (3): The relationships of TC-eU, TC-eTh, TC-K, eU-eTh, eU-K, eTh-K, eU-eU/eTh and eTh- eU/eTh for Wadi El-Regeita area, southern Sinai, Egypt.

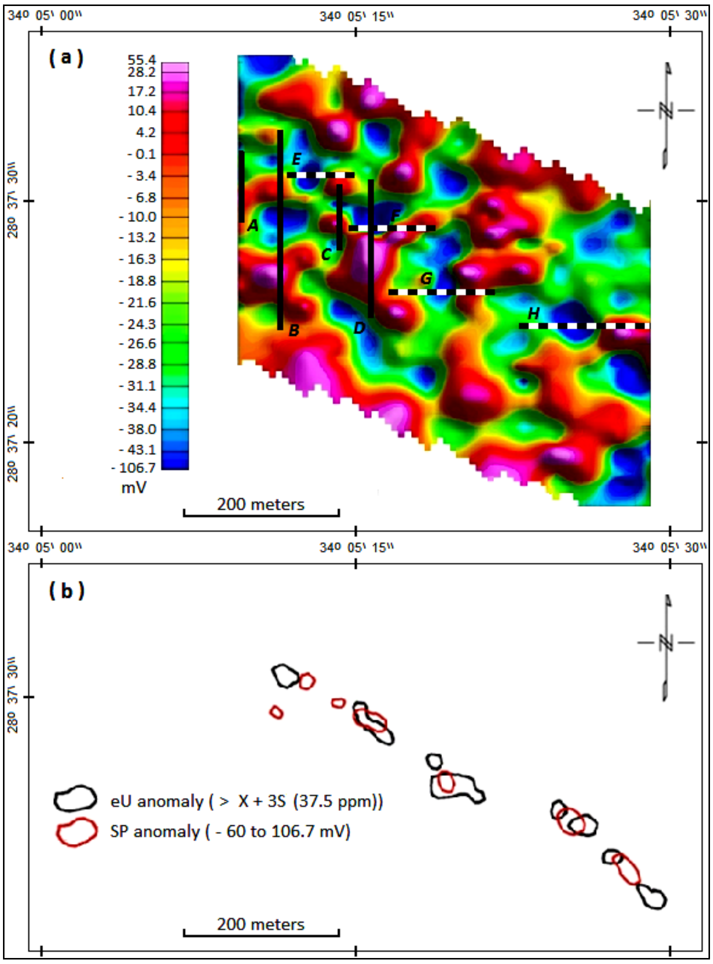

Fig. (4): a- Self-potential filled color contour map, and b- Equivalent uranium and self-potential anomaly map, Wadi El-Regeita area, southern Sinai, Egypt.

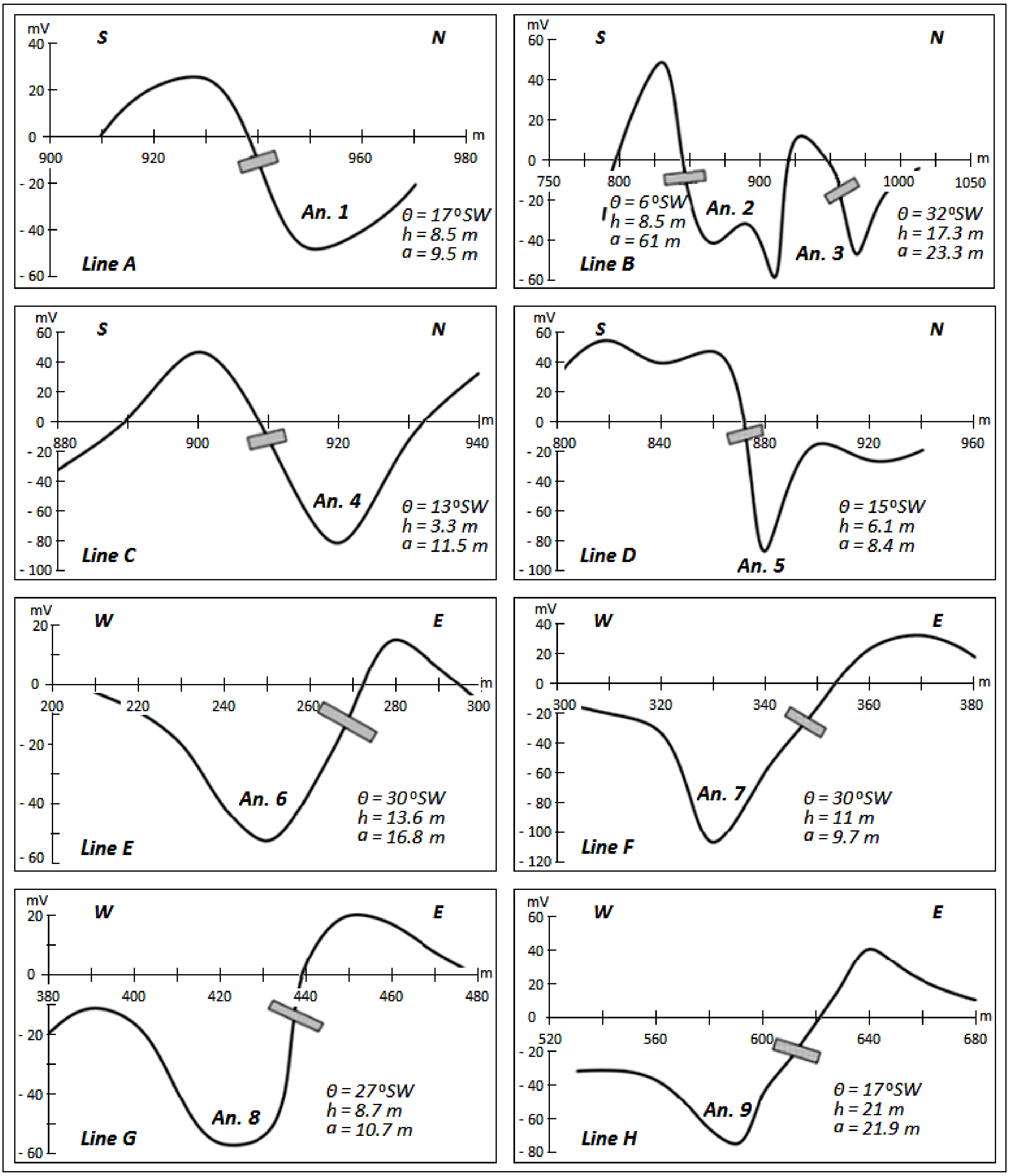

Fig. (5): Characteristic curves, with the calculated parameters, of SP lines (profiles) along N-S and E-W directions for nine SP anomalies, Wadi El-Regeita area, southern Sinai, Egypt. (θ° = Polarization angle in degrees, h & a = Depth to the center & Half-width of the anomalous body in meters in meters).

Quantitative Interpretation:

The quantitative interpretation of SP data depends usually on transformation of the SP anomaly to a physical model of simple geometric shape and determine the model parameters (shape, depth, polarization angle and electric dipole moment) using several graphical methods. The methods include, for example, use of characteristic points, distances, curves and nomograms. In the present study, eight SP anomaly lines (profiles), representing nine anomalies, were selected for the quantitative interpretations. Four of these lines have N-S direction, and the other four lines were conducted in the E-W direction (Fig. 4a). The parameters of the source anomaly were evaluated using method of the characteristic curves of Ram Babu and Atchuta Rao (1988), where the field profile can be interpreted in a very short time with ease and accuracy.

The obtained results from the selected SP anomalies are illustrated in Figure 5. From these results, it can be deduced that:

a) The calculated depths to centers of the selected SP anomalies are shallow, varying from 3.3 m to 21.0 m and averaging about 11.2 m.

b) The half-widths of the anomalous bodies range between 8.4 m and 61 m, with a mean value of 19.2 m.

c) All the anomalous bodies have moderate dips (ranging between 6º and 32º) toward the SW.

CONCLUSIONS

The integration between the ground gamma-ray spectrometry and self-potential methods enabled the determination of the concentrations and distributions of the radioactive elements in the study Wadi El-Regeita area and delineation of the Cu-U mineralized zone, with obtaining important information about the lateral and vertical extensions for some selected Cu-U anomalies in the area. In general, results of the study can be outlined in the following:

1- Data of the gamma-ray spectrometry revealed radioactivity levels ranging from 12.0 to 149.0 Ur, 0.3 to 130.0 ppm, 3.0 to 54.0 ppm and 0.5 to 9.8% for TC, eU, eTh and K, respectively. Interpretation of the different radioactivity maps, with the false-color composite image of eU, clearly reflect the sharp increase of eU content along the NW-SE Cu-mineralized shear zone in the area.

2- Abundance of the radioactive elements were independent of differentiation processes, but were related to the favorable combination of structural conditions and post-magmatic hydrothermal processes, which have clearly altered the rocks and modified their radioactive element concentrations, especially eU.

3- The SP measurements exhibit a wide range of amplitudes (–106.7 to +55.4 mV), with the highest negative values along the Cu-mineralized shear zone.

4- Quantitative interpretation of the SP data revealed shallow depths to the centers of nine selected anomalies, ranging from 3.3 m to 21.0 m and averaging 11.2 m, while the half-widths of the anomalous bodies range from 8.4 m to 61 m, with a mean value of about 19.2 m. All the anomalies have moderate dips to the SW.

5- There was a very good agreement in surface spatial distribution between the determined eU anomalies (above 37.5 ppm) and the SP anomalies (> -60 mV), which is directly related to the intensity of Cu mineralization and relevant alteration in the area. Therefore, methods of gamma-ray spectrometry can be considered as an effective exploration tools for the copper mineralizations.

6- Based on the results of gamma-ray spectrometry and SP surveys, the Wadi El-Regeita area is of considerable significant in view of the Cu-U mineralizations, and can be considered as a promising target for exploration and extraction processes.

REFERENCES

Ammar, A.A., El Sirafe, A.M. and El Kattan, E.M. (1993): Airborn geochemical and structural investigations of the Precambrian copper-bearing rocks, Hammash district, south Eastern Desert, Egypt. Annals Geol. Surv. Egypt, Vol. XIX, pp. 467-486.

Bentor, Y.K. (1985): The crustal evolution of the Arabo-Nubian Massif with special reference to the Sinai Peninsula, Precambrian Res., 28, 1-74.

Bentor, Y. K., Bogoch, R., Eyal, M., Garfunkel, Z. and Shimron. A. (1974): Bishr, A. H. A. (2007): Factors contro-lling mineralizations of some shear zones in granites, South Sinai, Egypt. Ph.D. Thesis, Fac. Sci., Zagazig Univ., Egypt.

Bogoch, R. and Zilberfrab, A. (1979): Reevaluation of the Wadi Remthi copper prospect. Geol. Survey of Israel, Report no. M. P. B. K. 417/79.

Bostoc, H.H. (1981): A general diaper of batholithic dimensions at the west mar-gin of the Churchill Province, In: Current Research, Part B, Geological Survey of Canada, Paper 81, 1B, pp. 73-82.

Bowie, S.H.U. (1972): In uranium prospecting handbook, Bowie, S.H.U. (ed), Inst. Mining and Metallurgy London, pp. 1-16.

Boyle, R.W. (1982): Geochemical prospecting for thorium and uranium deposits. Elsevier, Amsterdam and New York, 488 p.

Charbonneau, B.W. (1882): Radiometric Study of Three Radioactive Granites in the Canada Shield: Elliot Lake, Ontario; Fort Smith; and Fury and Hecla, N.W.T," In: Y.T. Maurice, Ed., Uranium in Granites. Geological Survey of Canada, pp. 91-99.

Darnely, A.G. (1973): Airborne gamma-ray techniques--present and future; Uranium Exploration Methods: International Atomic Energy Agency, Proc. of a Panel, Vienna, 1972, pp. 67-108.

Darnely, A.G. and Ford, K.L. (1989): Regional airborne gamma-ray surveys, a review. Proceedings of Exploration, 87, Third Decennial International Conference on Geophysical and Geochemical Exploration for Minerals and Ground-water, edited by G.D. Garland, Ontario, Canada, Geol. Sur., Can., Special V.3, pp. 229-240.

Duval, I.S. (1983): Composite color images of aerial gamma-ray spectrometric data. Geophysics, Vol. 48, No. 6, pp. 722-735.

Efimov, A. V. (1978): Multiplikativnyi pokazatel dlja vydelenija endogennych rud po aerogamma - spektrometriceskim dannym. In "Metody rudnoj geofiziki, Naucnoproizvodatvennoje objedinenie "Geofizika" (ed), Leningrad, USSR.

EL-Gammal S.A. (1986): Geology of the granitoid rocks of the northern western part of the basement rocks in Sinai, Egypt. Ph.D thesis, Department of Geology, Faculty of Science, Al Azhar University, Egypt.

El-Ghawaby, M.A., Hegazi, A.M., Khalifa, I.H. and Arnous, M.O. (2000): Tectonic and mineralization style of Saint Catherine Environs, South Sinai, Egypt. M.E.R.C. Ain Shams Univ., Earth Sci. v. 14: p. 40-55.

El-Shazly, S.M. (1955): Recent investigations on Egyptian copper deposits, Geol. Survey of Egypt, Cairo, Egypt.

El-Sheshtawy, Y.A. (1984): Petrographical and geochemical studies of granitic rocks around Wadi El-Sheikh, southwest Sinai, Egypt. Ph. D. Thesis, Al-Azhar Univ., Cairo, Egypt. 213 p.

Geosoft Inc (2010): Geosoft mapping and processing system. Geosoft Inc., Toronto, Canada.

Gindy, A.R. (1966): The origin of copper mineralization in central Sinai, Egypt. The Fourth Arab Sci. conference.

Grasty, R.L., and Darnley, A.G. (1971): The calibration of gamma-ray spectrometers for ground and airborne use. Geological Survey of Cartada Paper 71-17.

Hassen, O.S. (1987): Geology and mineralization of El-Regeita area, Central south Sinai, Egypt. M.Sc. Thesis, Fac. Sci., Suez Canal Univ., Ismailia, Egypt.

Hills, E.S. (1963): Elements of structural geology. Methuen and Co. Ltd, London.

Hilmy, M.E., and Mohsen, L.A. (1965): Secondary copper minerals from West Central Sinai. J Geol., UAR, pp. 91–12.

Hussein, A.A., Ali, M.M. and El-Ramly, M.F. (1982): A proposed new classification of the granites of Egypt. J. Volc. Geoth. Res., 14, pp. 187-198.

International Atomic Energy Agency, I.A.E.A., (1974): Recommended instrumentation for uranium and thorium exploration. International Atomic Energy Agency Technical Report 158.

Ibrahim, M.E. (1991): Geology and radioactivity of Wadi Zaghra area, south central Sinai, Egypt. PH.D. Thesis, Mansoura Univ., Egypt, 181p.

Lovborg, L. (1973): Future development in the use of gamma-ray spectrometry for uranium prospecting on the ground. Uranium Exploration Methods, International Atomic Energy Agency, Panel Proceedings Series, pp. 14-153.

Mahdy, A.I., El-Sankary, M.M. and Shalaby, M.H. (2007): Gamma-ray spectrometry and mineralogical characteristics of Wadi Dara Cu-mineralization, north Eastern Desert, Egypt. J. Appl. Geophys., Vol. 6, No. 1, pp. 1-20.

McLemore, V.T. and North, R.M. (1985): Copper and uranium mineralization in east central New Mexico. New Mexico Geological Society Guidebook, 36th Field Conference, Santa Rosa, 12 p.

Moxham, R.M., Footh, R.S. and Bunker, C.M. (1965): Gamma-ray spectrometer studies of hydrothermally altered rocks. Economic Geology, 60(4), pp. 653-671.

Niazy, E.A., Shalaby, I.M., Abdel Rahim, S.H. (1995): Wallrock alteration associated with the copper mineralization of Wadi El-Regeita, Southern Sinai, Egypt. Annals Geol. Survey. Egypt, V.XX. pp. 433-450.

Parasnis D.S. (1997): Principles of applied geophysics. ISBN 0 – 412 – 64080 -5, Chapman & Hall, London, 429 p.

Ram Babu, H.V., and Atchuta, D. (1988): A rapid graphical method for the interpretation of the self-potential anomaly over a two-dimensional inclined sheet of finite depth extent: Geophysics, Vol. 5, pp. 1126-1128.

Roberts, D.E. and Hudson, G.R.T. (2004): The Olympic Dam copper-uranium-gold deposit, Roxby Downs, South Australia. Economic Geology, v. 78, pp. 799-822.

Salem, S.M., Arafa, S.A., Ramadan, T.M. and El Gammal, E.A. (2013): Exploration of copper deposits in Wadi El Regeita area, Southern Sinai, Egypt, with contribution of remote sensing and geophysical data. Arab J. Geosci., 15 p.

Sarkar, S.C. (1985): Geology and ore mineralisation of the Singhbhum copper-uranium belt, Eastern India. INA Press, Kolkata.

Saunders, D. F. and Potts, M. J. (1976): Interpretation and application of high sensitivity airborne gamma ray spectrometric data. In: IAEA Symp. Exploration for Uranium Ore Deposits, Vienna, pp. 107-124.

Semenov, A. S. (1974): Elektrorazvedka metodom estestvennovo elektricheskovo polya. 2nd ed. St Petersburg: Nedra.

Shimron, A. E. (1980): Proterozoic island arc volcanism and sedimentation in Sinai, Precamb. Research, 12, pp. 437-458.

Tachanz, C. M., Laub, D. C., and Fuller, G. W. (1958): Copper and uranium deposits of the Coyote distrect, Mora Contry, New Mexico: U.S. Geological Survey, Bulletin 1030-L, pp. 343-398.

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