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Radioelements and Uranium Migration in Granites, El-Missikat Tunnels, Central Eastern Desert, Egypt

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Abstract. Fracture-filling uranium mineralization, connected mainly to black and jasperoid silica veins, occupying shear and fracture zones, was detected in 1968-1969 at the northern margin of El-Missikat post-tectonic granite, Central Eastern Desert, Egypt. Tunnels and excavations were executed, nearly at Wadi level, following these shear zones, in order to determine extensions of parts of the tunnels and evaluate their potentiality. Excavation works revealed the existence of disseminated pitchblende, as well as its secondary association, in some drifts of the explored shear zones. The granite along the shear zone is intensely altered. The main alteration features are silicification, sericitization and kaolinization. An extensive gamma-ray spectrometric survey was carried out on some of the mineralized parts. The obtained data were statistically treated in order to outline the radiolithological features of the different rock units in the prospect area. The original uranium content and uranium migration rate were calculated in order to identify the migration trends in the granite and its alteration products.

The study shows that there is a close relationship between the distribution of radioelements and lithology, in which the silica veins and silicified granites posses the highest radioelement contents. The migration of uranium took place inward in the brecciated jasperoid silica, massive silica and silicified granite. Meanwhile, the migration is outward in the case of pink (unaltered), kaolinized, and sericitized granites. The results show that, the pink granite has the highest outward uranium migration rate (–148), followed by the sericitized granite (up to –123). The kaolinized granite has the lowest outward uranium migration (up to –67). Meanwhile, both silica types the silicified granite and jasperoid silica show inward uranium migration rate reach up to 56 and 77, respectively. These results reflect the similarity between uranium migration in the granitic rocks of El-Missikat prospect and the nearby El-Erediya prospect, located about 30 km to the south.

Introduction

The gamma-ray spectrometric method is a powerful tool in geological mapping. It is possible, when using this method, to determine the individual concentrations of the three naturally-occurring radioelements in the ground. The method depends upon the fact that the absolute and relative concentrations of the radio-elements (K, U, and Th) vary measurably and significantly with lithology (Darnley and Ford, 1989). The distribution of these radio-elements at the surface is controlled by bedrock composition and modified by a variety of geologic processes, the most dominant being weathering, erosion, and transportation (Pitkin and Duval, 1980). Ong and Mior Shallehhuddin, 1988, indicated that using maps of eTh, eU and K permit better analysis of petrographic differentiation according to spectral response, and the parameters of radioelements ratios eU/eTh, eU/K and eTh/K reflect the radioactive characters of the rocks. They reported that: if $eTh/K \geq 2*10^{-4}$, the rock is thorium rich, if $eTh/K \leq 1*10^{-4}$, the rock is potassium rich and if $eU/eTh \geq 1$ and $eU/K \geq 1*10^{-4}$, the rock is uranium rich. The U/Th ratio is highly affected by the oxidizing processes that can lead to U-migration and consequently its loss or gain. This ratio is an important parameter in determining the oxidizing environment in which uranium was transported (Naumov, 1959).

El-Missikat prospect is located in the Central Eastern Desert of Egypt. It is situated about 3 km south of the landmark "km 85" on the asphaltic road connecting Qena, on the Nile Valley and Safaga, on the Red Sea coast (Fig. 1). The area of El-Missikat has been covered by a combined aeroradiometric-aeromagnetic survey resulted in the discovery of an interesting radioactive zone in the northern part of G. El-Missikat (Ammar, 1973). The subsequent ground radiometry revealed the presence of some uranium mineralization mainly connected to the jasperoid silica veins which dissect G. El-Missikat granites (Bakhit, 1978).

The main objective of this work is to study the distribution of the radio-elements in El-Missikat granites in order to clarify their relation to the different alterations and detect some radiospectrometric parameters related to the uranium mineralization and migration.

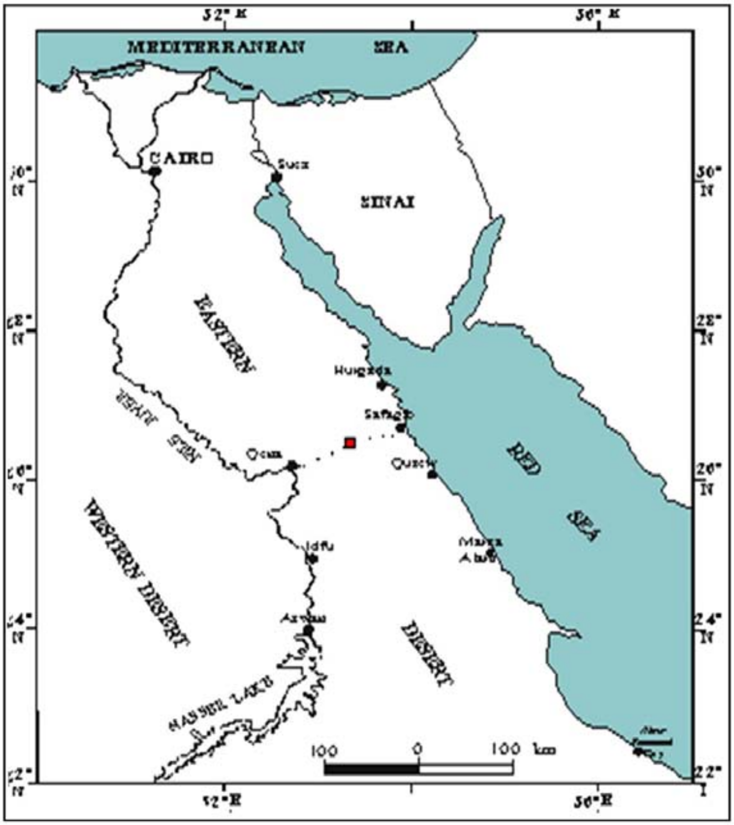

Fig. 1. Location map of El-Missikat area, Central Eastern Desert, Egypt.

Geologic Setting

El-Missikat post-tectonic granite is intruded mainly into older granites and older rocks. Dykes and veins of aplites, porphyries, pegmatite and quartz as well as few basaltic ones dissect the granite (Fig. 2). It has been emplaced during the post-tectonic episode in Egypt, about 600 Ma (Greenberg, 1981). The age of the pluton is 568 ± 17 Ma, Rb/Sr age, (Fullagar, 1980).

The granite of El-Missikat is described as an epizonal undeformed leucocratic mass displaying a good degree of uniformity in both texture and mineral composition (Nagy, 1978). Some degree of geochemical variation between its northwestern part, where the tunnels were dug and the rest of the pluton was reported by Abu-Deif, (1999). The northwestern part forms the highly differentiated and more sodic supplementary phase of this composite granitic pluton. This phase includes the most important secondary silicified, and mineralized shear zones that include the majority of the radioactive anomalies and uranium occurrences (Abu-Deif, 1999).

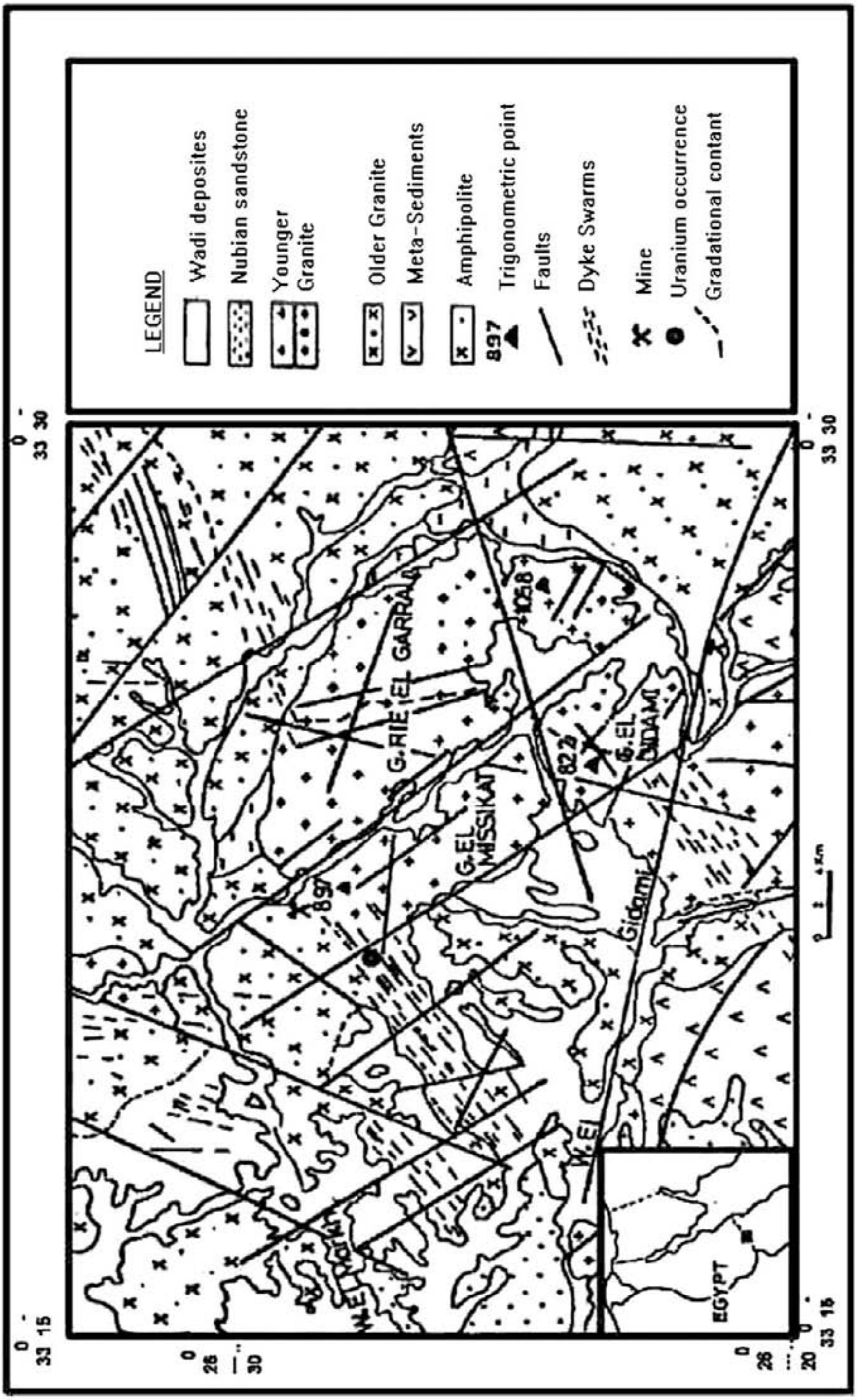

Fig. 2. Geologic map of El-Missikat area.

The major rock forming minerals are quartz, sodic plagioclase, alkali feldspar (mainly perthite) and biotite. Accessories are apatite, fluorite, rutile, chlorite, muscovite, magnetite, tantalum-bearing minerals and zircon. Very rare uraninite as well as allanite, uranothorite, xenotime and monazite are also present (Nagy, 1978; Attawiya, 1984; Abu-Deif, 1985 and 1992; Mohammed, 1988; Oraby, 1999, and Ibrahim, 2002). The granite is, more or less, altered especially along the structural lines. The main alteration features are silicification, green alteration (sericitization), ferrugination, kaolinization, and manganese dendritic staining. The U-minerals in the silica veins are represented essentially by disseminated pitchblende and uranphane as its main secondary alteration product (Abu-Deif *et al.*, 1985; Hussein *et al.*, 1992 and Amer *et al.*, 2005). They are always found in association with some sulphides and gangue minerals. The sulphides are mainly represented by pyrite, chalcopyrite, galena, sphalerite and molybdenite. The gangue minerals are mainly represented by fluorite and, iron and manganese oxides.

The uranium deposit at El-Missikat pluton represents a case of siliceous vein-type deposit (Hussein *et al.*, 1986), and is related to polymetallic vein type, probably formed in a reducing condition (Abu-Deif *et al.*, 1997).

Tunnels Geology and Uranium Mineralization

Tunneling works have commenced early in 1980, at the northern part of El-Missikat mass. These works were started by a straight adit (main adit) with a gentle slope in the direction of S33ºE, was driven perpendicular or nearly so to the general strike of the shear zones. At the points of the interceptions, drifts (D) were driven following the extensions of some mineralized shear zones. These works showed that the explored drifts DI, DII, DII$^{\backslash}$ and DIII are uranium-hosting zones. Some of the mineralized parts, of about 230 m total length (Fig. 3), were selected for the present study; beside a section of about 135 m length in the main adit, which represents the less-altered granite (pink granite). The other drifts of mine (DIV, DV and DVI) are not significant from the point of view of exploration. Therefore, they are excluded in the present work.

The explored rocks in the tunnels are represented mainly by unaltered biotite granite (pink granite) which forms the main bulk of the tunneling works, especially at the main adit away from the shear zones. The explored rocks in the drifts include jasperoid veins and veinlets filling fractures of the shear zones. Zonally arranged around the jasperoid veins, are the alteration products of the granite. The wall-rock alteration is represented mainly by silicified granite, sericitized granite and kaolinized granite (Abu-Deif, 1985; Bakhit *et al.*, 1985 and Hussein *et al.*, 1992). Hematitization as well as black manganese and iron oxides and some argillaceous materials are also common. Some microscopic arrangements of the alteration zones are observable. All gradations from intensely altered to unaltered granite were detected. Near the fractures, which are occupied by silica, especially at their contacts, the granite is more siliceous and stained by hematite. This causes the rock to be very hard and flinty and acquire a characteristic red colour. The silicification decreases gradually away from the fractures. The sericitized zones (green alteration) occur directly in contact with the siliceous veins. In sericitized granite, the feldspars are mostly altered to sericite and the rock has a green colour. The kaolinized zones follow the sericitized zones outward and pass gradually to the unaltered granite. In kaolinized granite, the feldspars are mostly altered to kaolin, and the rock becomes light in colour and more brittle.

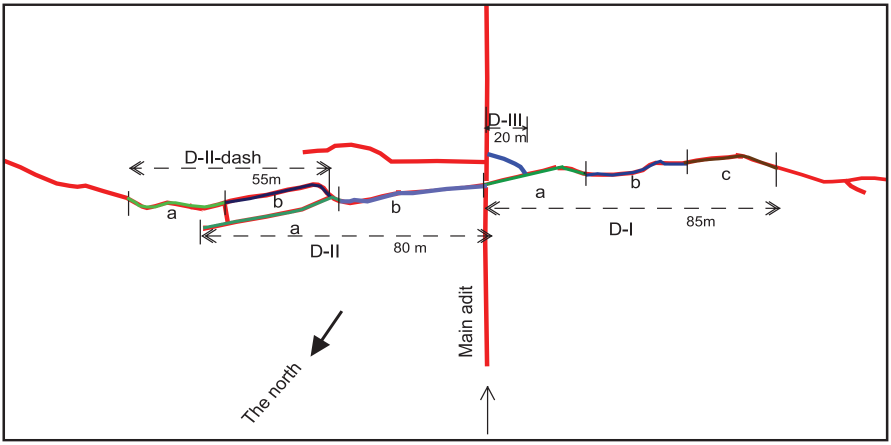

Fig. 3. A sketch for El-Missikat tunnels, Central Eastern Desert, Egypt.

Uranium mineralization is found, connected to the faults and the fractures occupied by jasperoid materials. The uranium minerals occur as stains on the walls of the jasperoid veins, and as disseminations in the micro-fractures. Figure 4 (A, B and C) shows the recorded geological rock units in El-Missikat drifts (Abu-Deif, 1985).

Gamma-Ray Spectrometric Studies

A detailed ground gamma-ray spectrometric survey was carried out on the four drifts of El-Missikat tunnels (I, II, DII\ and III, Fig. 2b), beside a considerable part in the main adit. The present γ-ray spectrometric survey was carried out using a GS-256 spectrometer (with sodium-iodide thallium-activated crystal detector, 3" diameter by 3" height). The GS-256 spectrometer was calibrated in equivalent uranium (eU) in part per million (ppm), equivalent thorium (eTh) ppm, and potassium (K-40%), as well as total count (T.C) in Ur (unit of concentration of radioactivity). The measurements were taken through a uniform grid

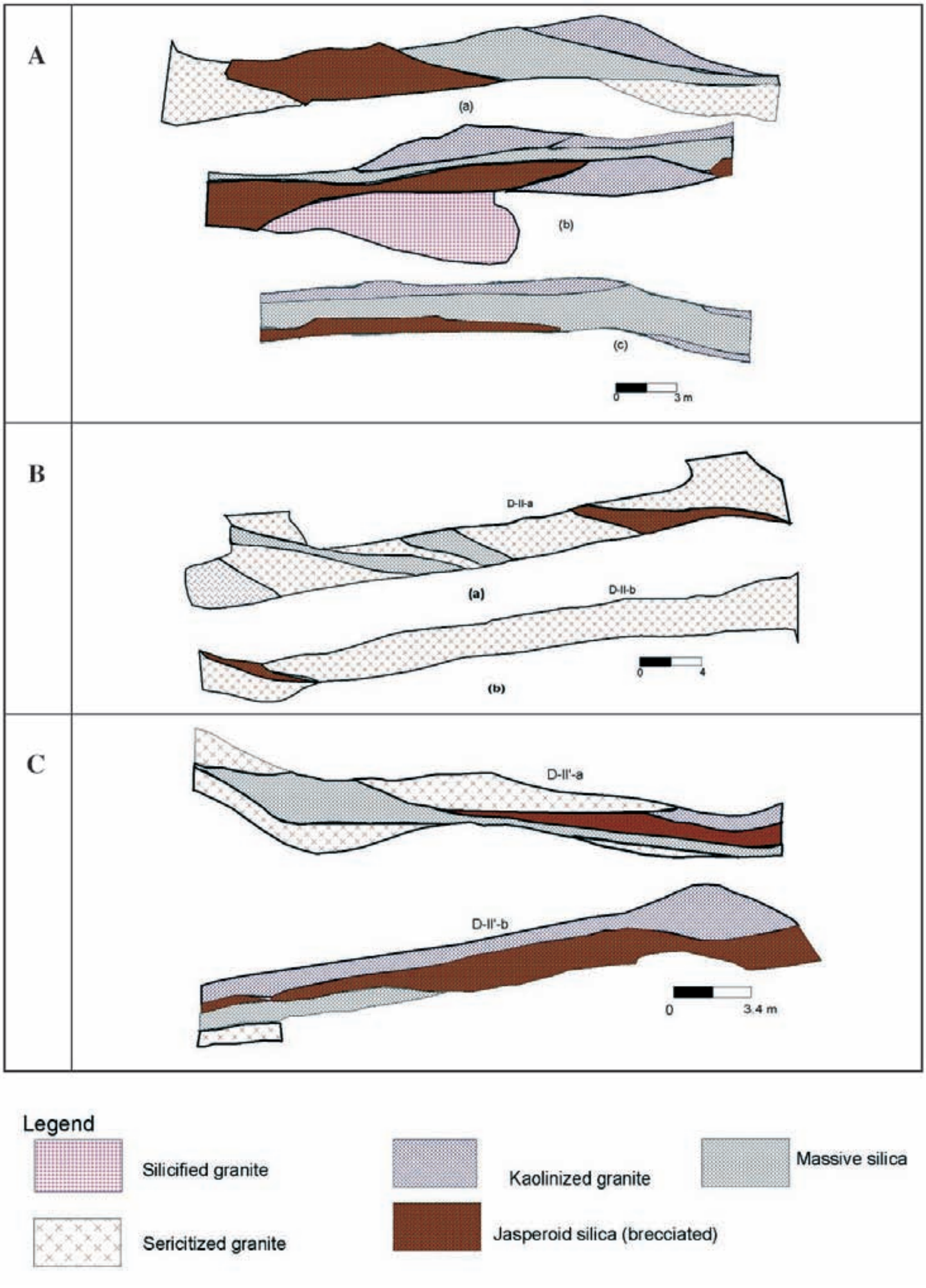

Fig. 4. Geological maps of the drifts, El-Missikat tunnels, Central Eastern Desert, Egypt (A). Drift No. I (a, b and c), (B). Drift No. II (a and b), and (C). Drift No. II\ (a and b).

pattern of 50 cm interval along the drifts (Fig. 4). The data of the total-count (T.C.) radiometry of the four drifts are represented as contour maps (Fig. 5-8). The γ-ray spectrometric data was subjected to statistical analysis using a computer program in order to delineate the distribution pattern of the radioelements in the granite and its alteration products. Generally, there is a strong relationship between the different lithologic units of the tunnels and the levels of the gamma-ray spectrometric measurements. Therefore, the γ-ray spectrometric data were divided into a number of units, each of which is related to one of the lithologic units with the same radiospectrometric signature. In this study, statistical computations were applied on the original data, without employing any type of transformation. This is in accordance with the work of Sarma and Koch (1980), who recommended the performance of statistical computations on the original data.

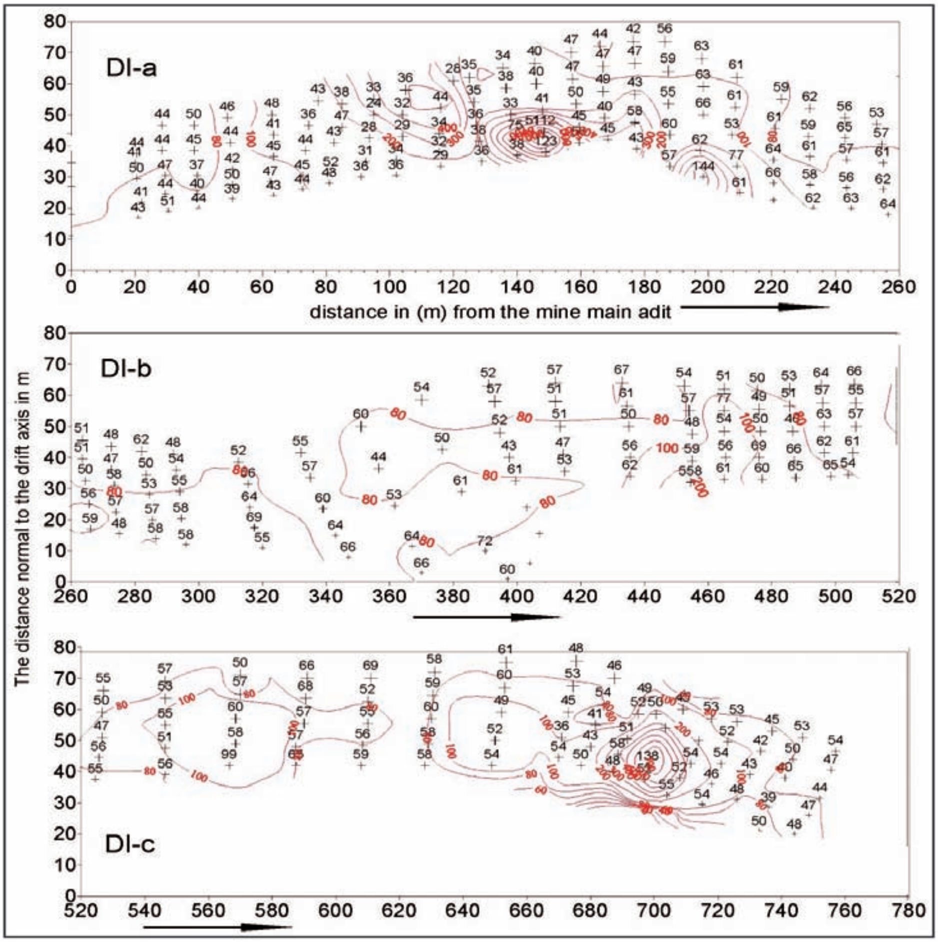

Fig. 5. T.C. radiometry of Drift I, El-Missikat tunnels.

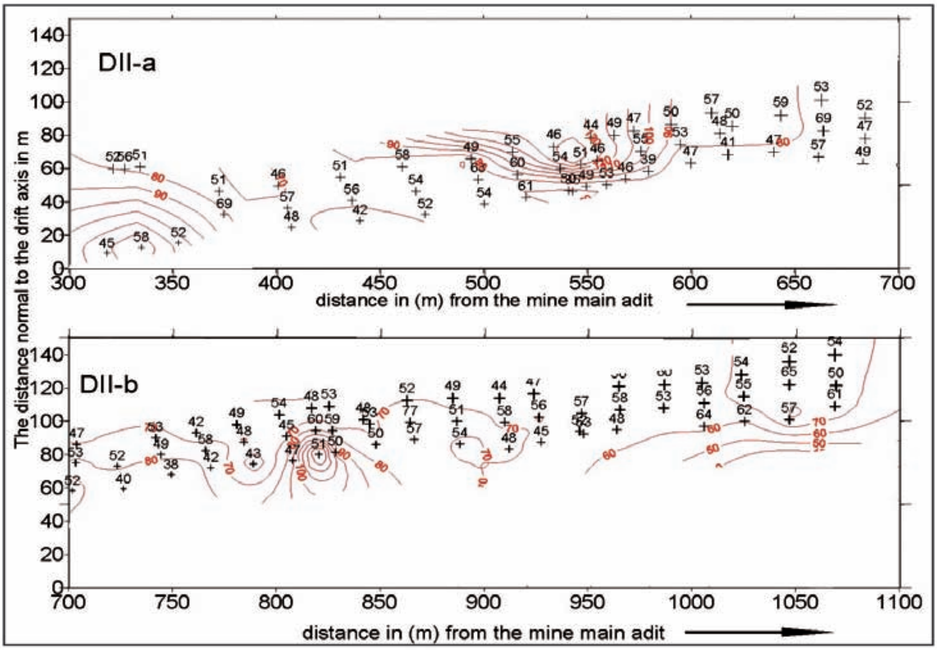

Fig. 6. T.C. radiometry of Drift-&II, El-Missikat tunnels.

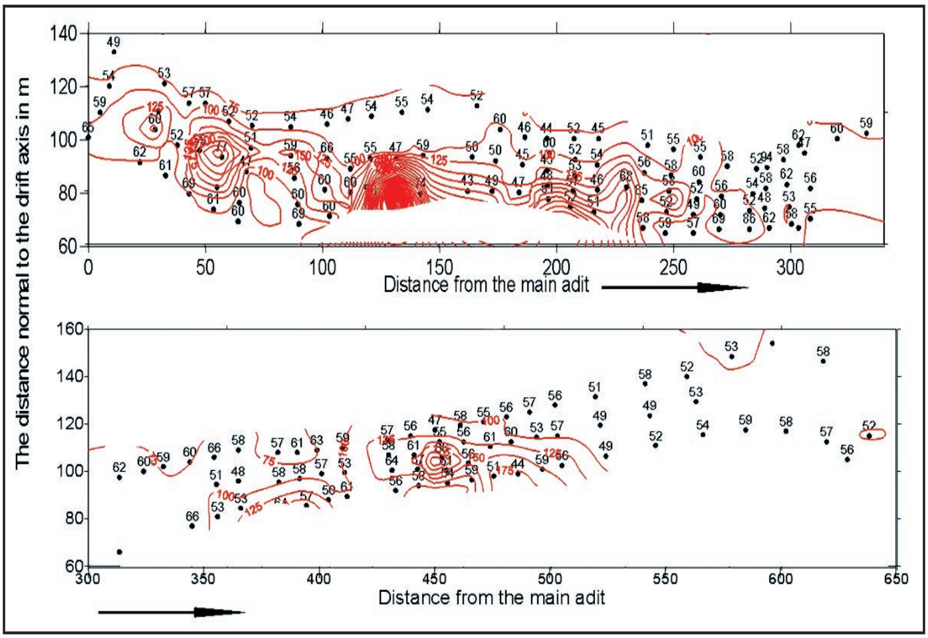

Fig. 7. T.C. radiometry of Drift-II$^{\backslash}$, El-Missikat tunnels.

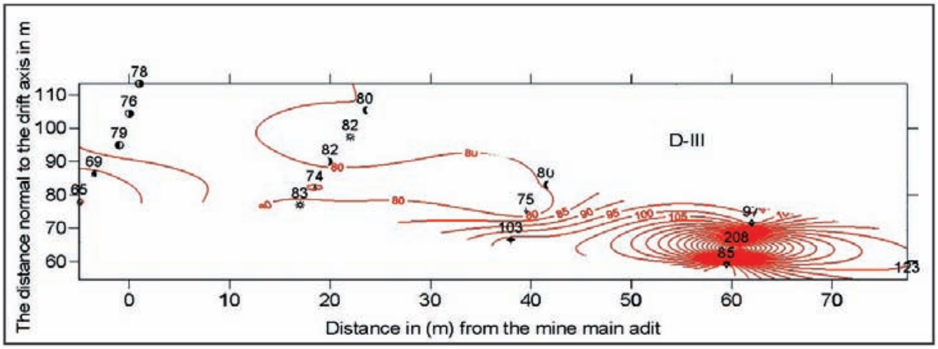

Fig. 8. T.C. radiometry of Drift-III, El-Missikat tunnels.%

The computed statistical parameters (Min., Max., S, $X^{\backslash}$ and C.V %) for each of T.C. radioactivity, absolute K, eU, and eTh concentrations as well as the eU/eTh ratio in the drifts DI, DII, DII$^{\backslash}$ and DIII are shown in Table (1). The coefficient of variability (C.V%) was calculated for the T.C., and K-40, eU and eTh data to define the degree of variability of the data of the main adit and drifts. If the C.V% of certain group of data is more than 100, these groups of data include anomalous values. In addition, the normal probability plot (NPP) is used to evaluate the normality of the distribution of the total-count radiometric survey data, that is, whether and to what extent the distribution of this variable follows the normal distribution. The observed variables were plotted on a standard normal probability plot according to Geigy, 1962.

The a and b diagrams of Fig. 9-12, represent the histograms and normal probability plots (NPP) for the drifts (I, II, DII$^{\backslash}$ and III). These diagrams show that the total count radiometric data of each drift is abnormal distribution. The test of normality, by using normal probability plot used to classify the data of each drift into normally distribution sets of data. Each of these sets corresponds to one interpreted radiolithologic (IRL) unit. Each of these IRL units possesses a different radiometric level corresponding to one of the rock units which are included in each drift. Accordingly, Fig. 9(c, d, e and f) reveal that DI is divided into four different IRL units (DI-IRL1, DI-IRL2, DI-IRL3 & DI-IRL4). Also, Fig. 10(c and d) shows that DII could be divided into two IRL units (DII-IRL1 & DII-IRL2) and Fig. 11(c, d and e) delineates that DII$^{\backslash}$ could be divided into three IRL units (DII$^{\backslash}$-IRL1 & DII$^{\backslash}$-IRL2 & DII$^{\backslash}$-IRL3). Due to the limited extension of DIII, the anomalous readings were excluded to get one normal IRL unit (Fig. 12.c). The resultant outlines of the normally-distributed IRL units are shown on Fig. (13-15). The computed statistical parameters (Min., Max., S, $X^{\backslash}$ and C.V%) for each of T.C. radioactivity, absolute K-40, eU, and eTh concentrations as well as the eU/eTh ratio of the units of drifts DI, DII and DII$^{\backslash}$ are shown in Tables 2-4).

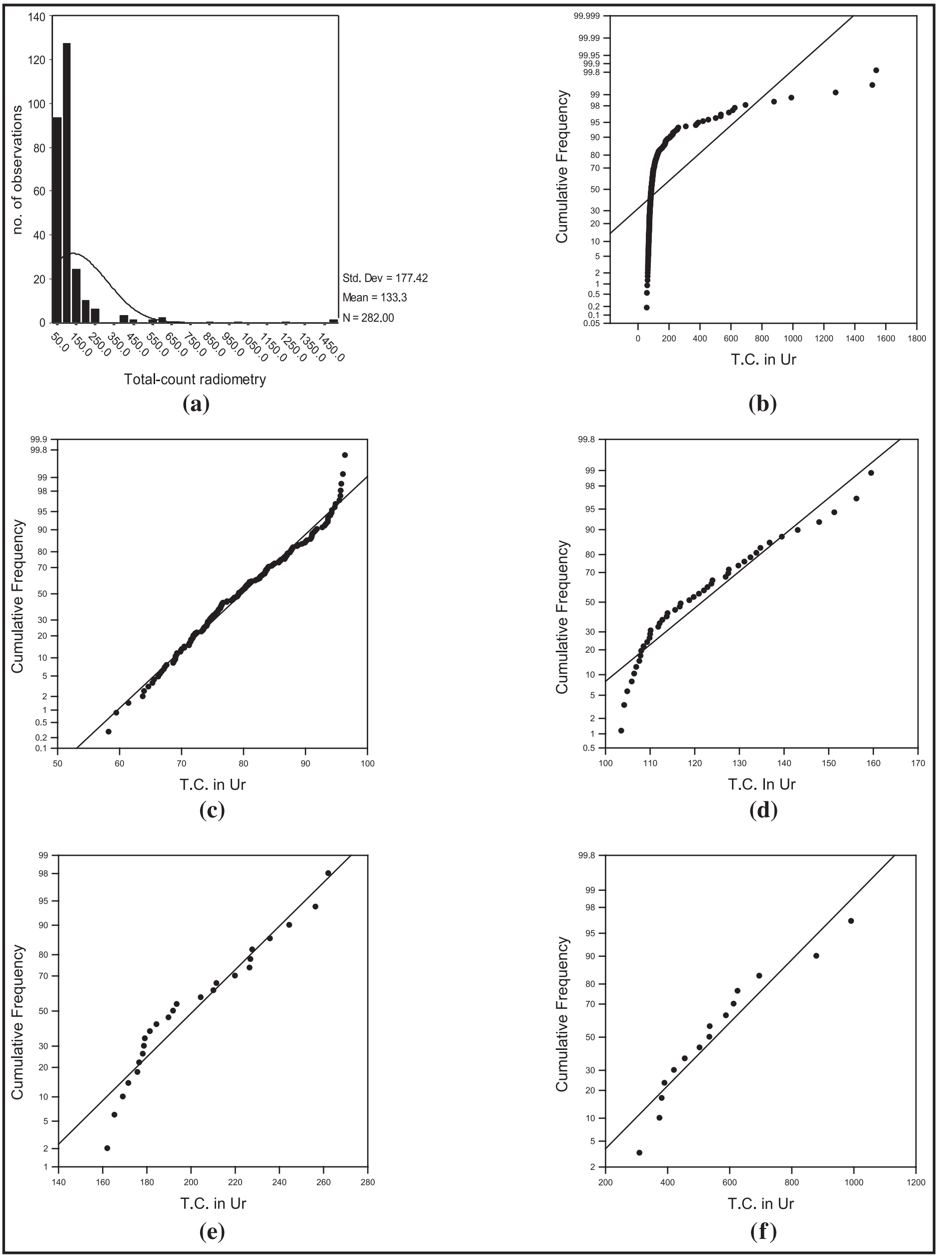

Fig. 9. Histogram and normal probability plots (NPP) for T.C. radiometry of Drift I. (a): Histogram of Drift I, (b): NPP of Drift I, (c): NPP of Drift I- unit-1, (d): NPP of Drift I-unit-2, (e): NPP of Drift I-unit-3, (f): NPP of Drift I-unit-4.

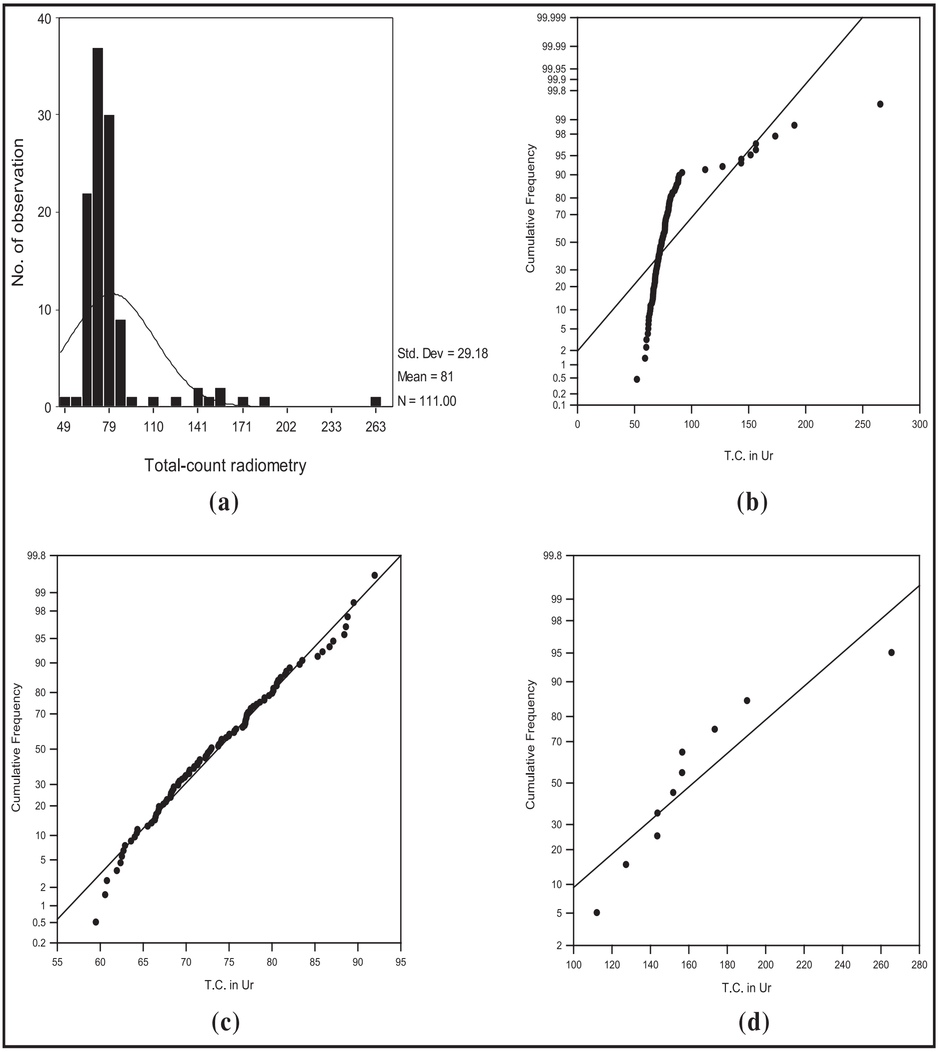

Fig. 10. Histogram and normal probability plots (NPP) of T.C. radiometry for Drift II. (a): Histogram for Drift-II, (b): NPP of Drift-II, (c): NPP of Drift II-unit-1, (d): NPP of Drift II-unit-2.

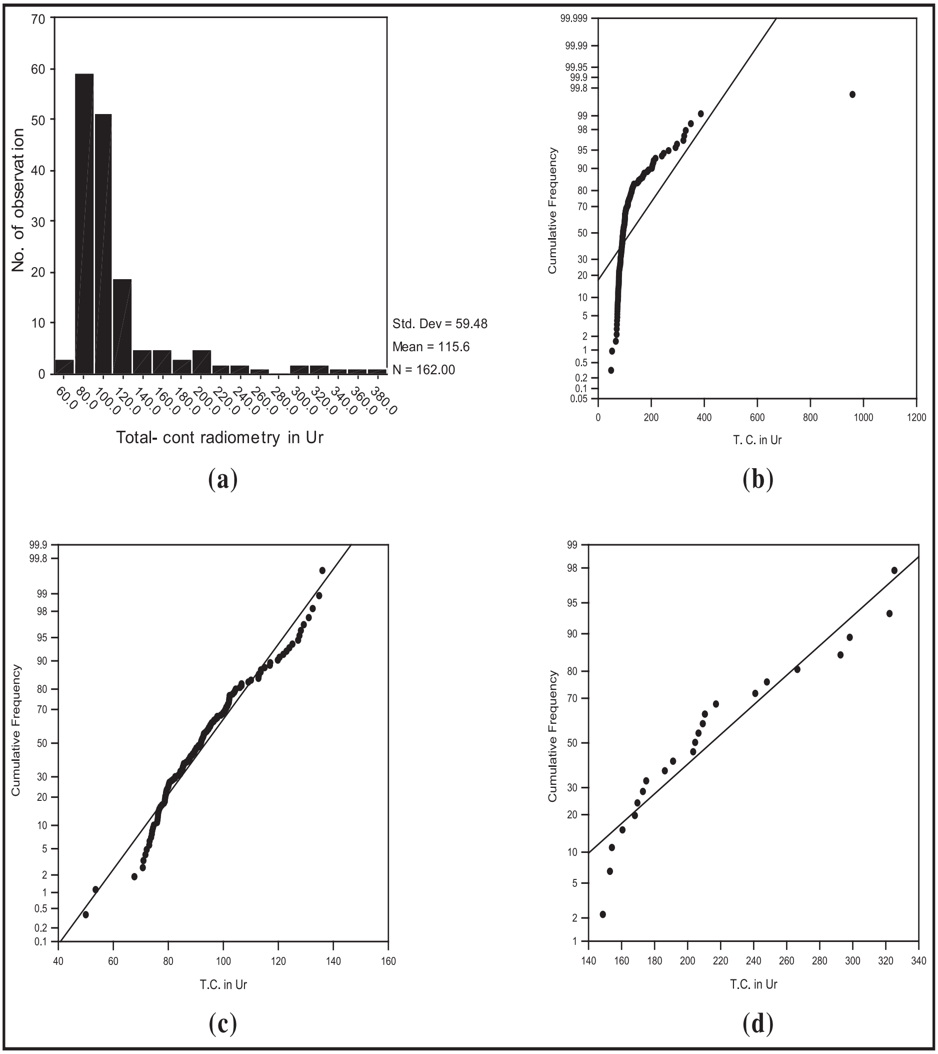

Fig. 11. Histogram and normal probability plots of T. C. radioactivity data of Drift II\\.
a): Histogram of Drift II\\, (b): NPP of Drift II\\,
c): NPP of Drift II\\ - unit-1, (d): NPP of Drift II\\ - unit-2.

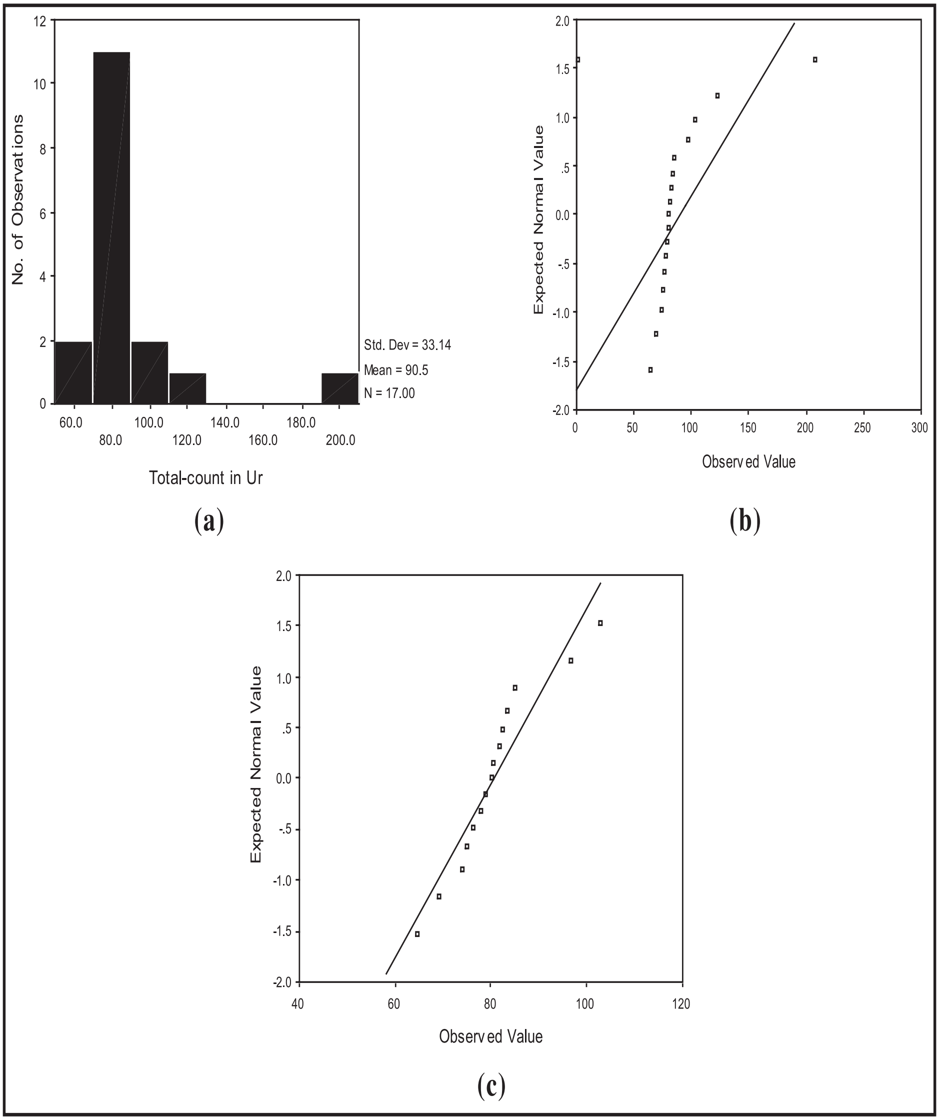

Fig. 12. Histogram and normal probability plots (NPP) of T. C. radioactivity data of Drift III.
(a): Histogram of Drift III,
(b): NPP of Drift III,
(c): NPP of Drift III without anomalous values.

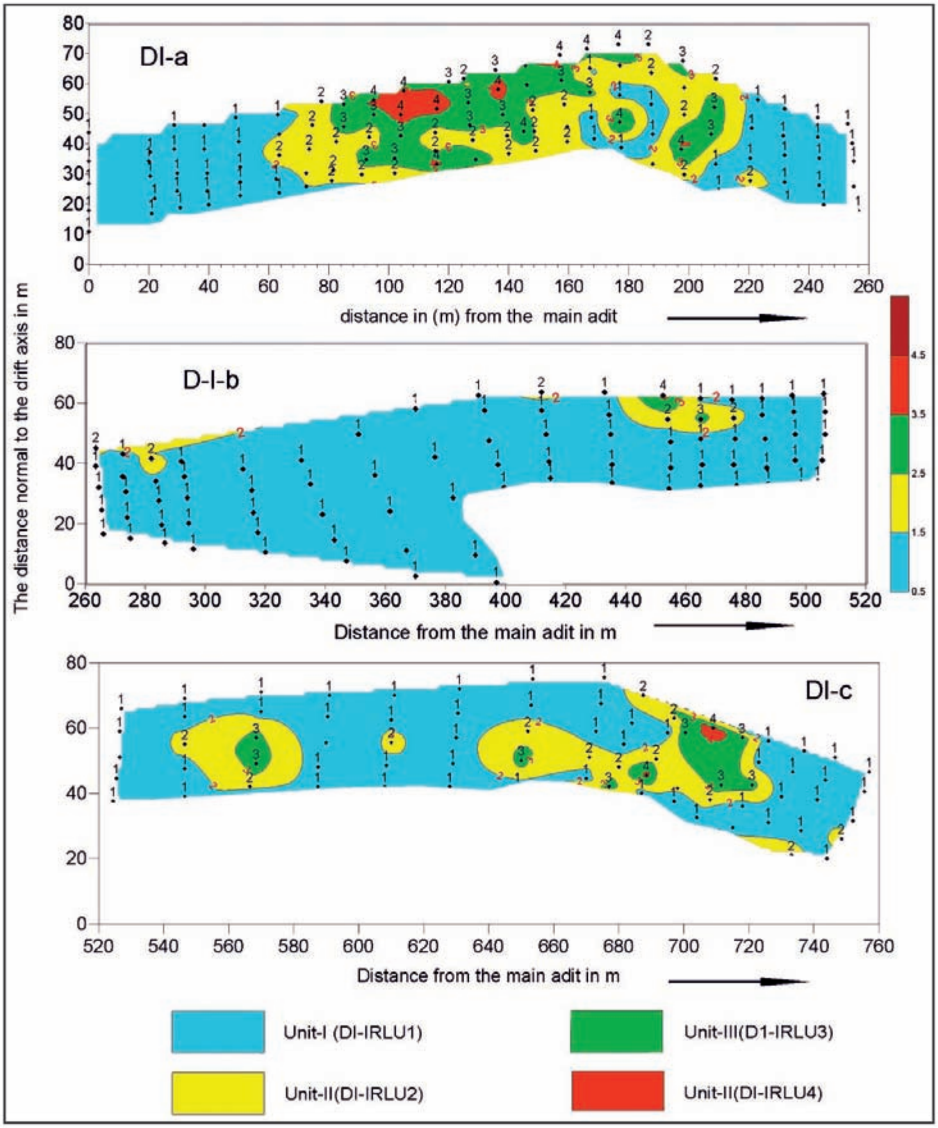

Fig. 13. Radiolithologic (IRL) units of Drift I.

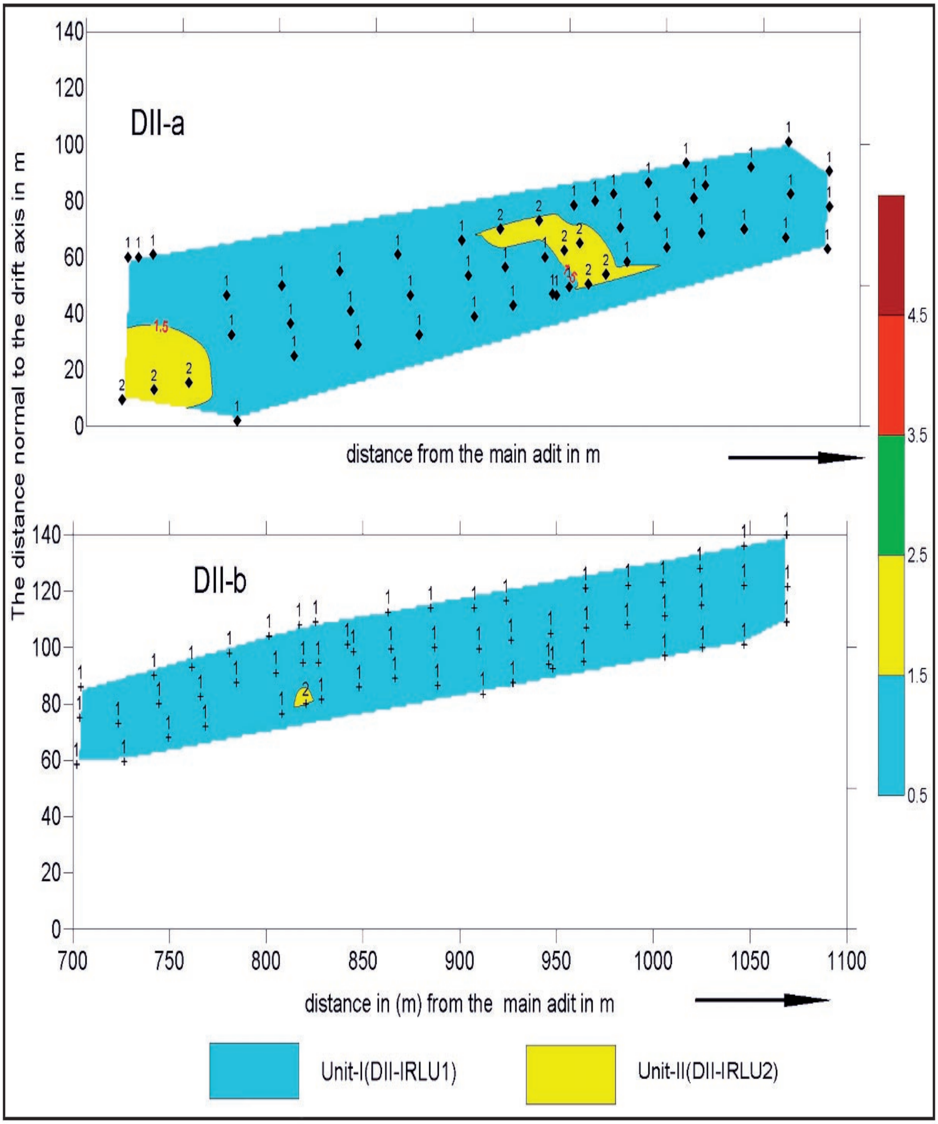

Fig. 14. Radiolithologic (IRL) units of Drift II.

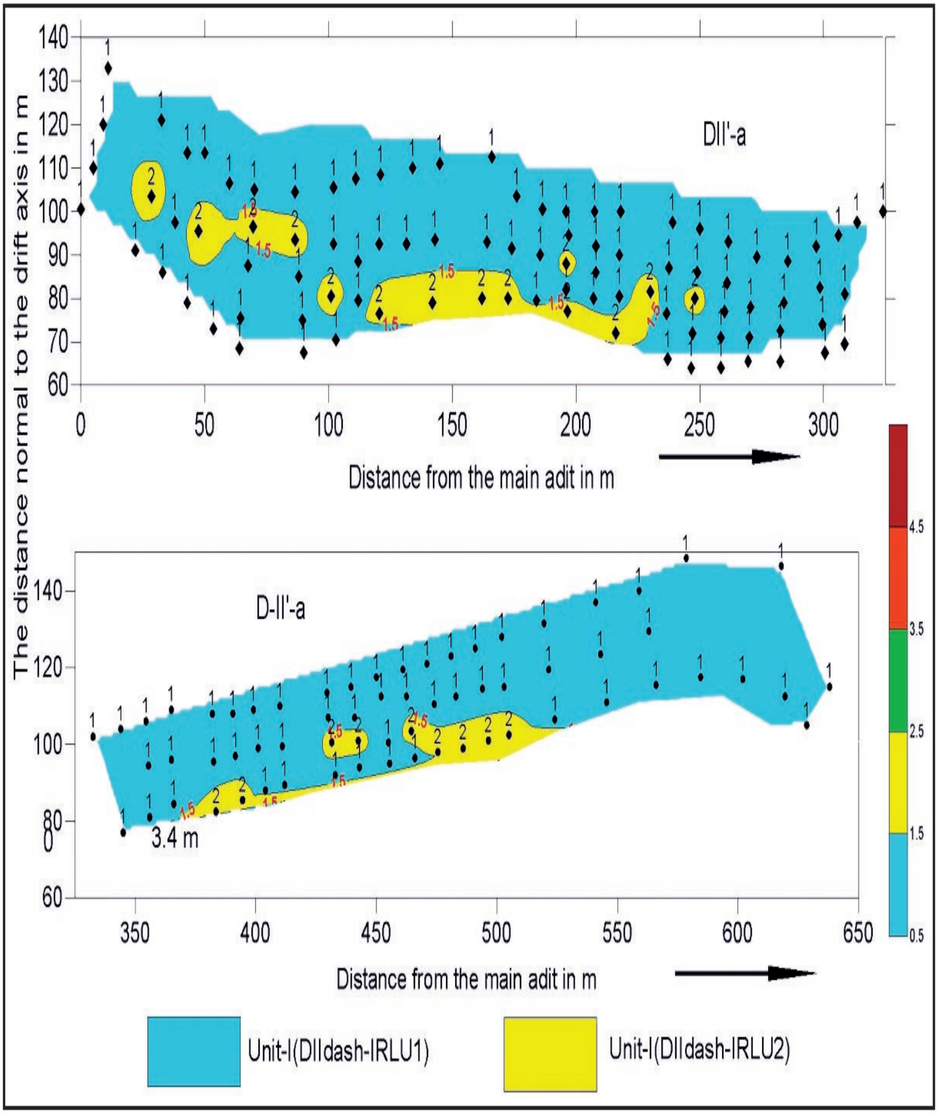

Fig. 15. Radiolithologic (IRL) units of Drift II\.

Uranium Migration

Uranium and thorium are usually accompanied together during magmatic differentiation, due to the similarity in their ionic radii. During evolution of the crust, U^{+4} is easy to oxidize and migrate. This means that uranium can be separated from thorium and transported by fluids into the surroundings. Migration of uranium depends on the permeability of rocks, the type of uranium accessory minerals, the U content in the source rock and the physico-chemical characteristics of the solutions.

Thorium is stable in the oxidation zone, so we can consider Th as a reference to study the U-migration. Thorium is about three times as abundant as uranium in granitic rocks (Rogers and Adams, 1969). Any disturbance in this ratio suggests post-magmatic redistribution of U. Therefore, U/Th ratio is a very good geochemical index for U-migration; it is approximately constant in the same type of rock in a relatively closed environment. The uranium migration (out or in) has the same probability within rock units in a relatively closed geologic environment. The half-life times of uranium and thorium are very long, so the present regional U/Th ratio can be considered as original U/Th ratio, in a closed environment (NMA, 1999).

According to the Nuclear Materials Authority of Egypt (NMA, 1999), the migrated uranium value (Um) for a certain rock unit can be obtained by subtracting the original uranium content Uo (or paleo-uranium background) from the present uranium content Up, where Um = Up-Uo. The original uranium content (Uo) can theoretically be calculated according to the equation: Uo = eTh*(regional eU/eTh), where eTh is the average thorium content (in ppm) in a certain rock unit; the regional eU/eTh means the average regional eU/eTh ratio in different rock units (tunnel rocks). Then, the U-migration rate (Umr %) can be obtained by using the relation (Umr % = Um*100/Up). The rate of uranium migration is also a good indicator for determining type and degree of migration. If it is positive; the migration is in, and if it is negative; the migration is out. If (Um) > 2, this indicates that a considerable amount of uranium has been migrated into the rock unit, if (Um) < –2, this indicates that a considerable amount of uranium has been migrated outside, and if –2 > (Um) > 2, this points to the probability that migration is equal in and out the rock unit.

Interpretation and Discussion

The geologic maps of drifts I, II and II$^{\backslash}$ are presented on Fig. 4(a, b and c) and their T.C. contour radiometric maps are presented on Fig. 5(a, b and c), 6(a & b), 7(a & b) and 8, respectively. The main results obtained from analysis of the gamma-ray spectrometric data of the main adit and the four drifts are given in Tables (1-4, respectively).

Table 1. Characteristic radiospectrometric statistics of the main adit (pink granite), and the four drifts (I, II, II\ and III), El-Missikat tunnels, Central Eastern Desert, Egypt.

Drift no.	Statistical parameter	No.	Min.	Max.	X\	S	C.V%	Average eU/eTh ratio
The main adit	T.C (Ur)	79	68	91	78	5.5	7.0	0.67
	K-40%		5.5	7.9	6.6	0.6	9.0	
	eU (ppm)		19	41	29	4.5	16	
	eTh(ppm)		29	60	43	6.7	16	
Drift I	T.C (Ur)	281	58.3	1515	129	151	117	2
	K-40%		0.2	6.3	3.3	1.3	39	
	eU (ppm)		25	1477	98	149.4	152	
	eTh(ppm)		24	558	54	33	61	
Drift II	T.C (Ur)	111	52	266	82	29.1	35	0.9
	K-40%		1.4	8.5	4.5	1.0	22	
	eU (ppm)		22	228	47	29.5	63	
	eTh(ppm)		35	77	52	6.6	13	
Drift II\	T.C (Ur)	163	50	960	121	88.8	73	1.5
	K-40 %		0.5	9	3.5	1.7	49	
	eU (ppm)		19	896	87	87.3	100	
	eTh(ppm)		43	94	56	7.3	13	
Drift III	T.C (Ur)	17	64.5	208	91	33	36	1.0
	K-40%		2.2	6.9	4.7	1.6	34	
	eU (ppm)		28	175	55	35.4	64	
	eTh(ppm)		43	66	54	7.2	13	

Table 2. Characteristic radiospectrometric statistics of the drift No. I units (IRL1-IRL4), El-Missikat tunnels, Central Eastern Desert, Egypt.

Unit code	Statistical parameter	No.	Min.	Max.	X\	S	Average eU/eTh ratio
DI-IRLU1, (Massive silica)	T.C (Ur)	177	5 8	96	80	8.6	0.9
	K-40 %		0.2	5.8	3.6	1.2	
	eU (ppm)		25	70	47	8.9	
	eTh(ppm)		37	77	54	7.6	

Table 2. Contd.

Unit code	Statistical parameter	No.	Min.	Max.	X\	S	Average eU/eTh ratio
DI-IRLU2, (Kaolinized granite)	T.C (Ur)	44	104	160	122	14.7	2.1
	K-40%		0.3	6	2.9	1.4	
	eU (ppm)		56	142	94	18.8	
	eTh(ppm)		28	99	48	12.6	
DI-IRLU3, (Silicified granite)	T.C (Ur)	25	162	262	201	29.5	4.1
	K-40%		0.6	5.3	2.1	1.1	
	eU (ppm)		141	238	176	30.5	
	eTh(ppm)		24	77	46	12.9	
DI-IRLU4, (Jasperoid silica)	T.C (Ur)	14	880	310	522	152	9.7
	K-40%		6.3	0.9	2.8	1.6	
	eU (ppm)		804	49	474	178	
	eTh(ppm)		558	32	94	138	

Table 3. Characteristic radiospectrometric statistics of drift No. II, El-Missikat tunnels, Central Eastern Desert, Egypt.

Unit code	Statistical parameter	No.	Min.	Max.	X\	S	Average eU/eTH ratio
DII-RL1, (Sericitized granite)	T.C (Ur)	100	60	92	74	7.3	0.8
	K-40%		2.4	8.5	4.5	0.9	
	eU (ppm)		22	63	39	7.9	
	eTh(ppm)		35	7	52	6.7	
DI-IRL2, (Silica)	T.C (Ur)	10	112	266	162	42.4	2.6
	K-40%		1.4	6.3	4.1	1.8	
	eU (ppm)		89	228	129	40.5	
	eTh(ppm)		45	58	50	4.4	

Table 4. Characteristic radiospectrometric statistics of drift No. II\, El-Missikat tunnels, Central Eastern Desert, Egypt.

Unit code	Statistical parameter	No.	Min.	Max.	X\	S	Average eU/eTH ratio
D II\-IRL1, (Kaolinized granite)	T.C (Ur)	136	50	136	94	16.8	1.1
	K-40 %		0.7	6.8	3.6	1.6	
	eU (ppm)		19	107	60	17.6	
	eTh(ppm)		44	86	56	6.3	
D II\-IRL2, (Brecciated jasperoid silica)	T.C (Ur)	23	149	325	214	54.5	3.3
	K-40%		0.5	8.1	3.2	1.9	
	eU (ppm)		110	301	181	55.7	
	eTh(ppm)		43	74	56	7.4	

1. *The Main Adit*

The total count radiometric intensities measured in the main adit that mainly represent the unaltered pink granite, range from 68 to 91 Ur, with an average value of 78 Ur. The average contents of the three radio-elements (K-40, eU and eTh) are 6.6%, 29 ppm and 43 ppm respectively, with eU/eTh of 0.67 (Table 1). It is worth to mention that, the measurements were taken inside the tunnels; this causes a relative increase in spectrometric measurements.

2. *Drift No. I*

This drift has a wide range of T.C. radioactivity (DI, Fig. 5) from 58 Ur to 1515 Ur, with an average of 129 Ur (Table 1). The average eU/eTh ratio is the highest among all other drifts (2.6). The histogram and NPP plot of this drift (Fig. 9a and b); show that the distribution of the T.C. radiometric data is not normal. It could be divided into four populations corresponding to four IRL radiolithologic units (DI-IRL1, DI-IRL2, DI-IRL3 and DI-IRL4. Each of these units shows normal distribution (Fig. 9c, d, e and f) and has its own radio-spectrometric features (Fig. 13a &, b). The four IRL units are roughly corresponding to the geologic map of this mineraralized section (Fig. 4a). These four units are represented by silicification (brecciated jasperoid and massive silica), kaolinized and silicified-granites, respectively. The main results of the statistical treatment of the data of these four units are given in Table 2.

The DI-IRL4 has the highest average uranium content among all other units in all drifts (474 ppm). It has also, the highest eU/eTh ratio (9.7). This silica is highly brecciated and highly jasperized, with deep brown to black colours. The increasing of radioactivity at DI-RL3 and DI-IRL4 is due to fracturing, brecciation and ferrogination of silicieous rocks which permit uranium fixation.

3. Drift No. II

The total counts of the radiometric data of this drift (Fig. 6) show a wide variation, ranging from 52 Ur to 266 Ur, with an average value of 82 Ur. It has the lowest average eU/eTh ratio among all other drifts (about 0.9). The average abundances of the three radioactive elements in this drift are 4.5%, 47 ppm and 52 ppm for K-40, eU and eTh respectively (Table 1). This drift can be divided into two IRL units (Fig. 14), DII-IRL1 and DII-IRL2. Each of them has its own characteristic features in both lithology and radiospectrometry. The first unit consists of the main bulk of the drift represented by sericitized granite and corresponds to (DII-IRL1). The second one has a limited extension and represented by jasperoid brecciated silica (DII-IRL2). They are conformable with the two main geologic units shown on the geologic map (Fig. 4b).The main results of the statistical treatment of the data of these two units are given in Table 3.

4. Drift No. II\

The total counts of the radiometric data of this drift (Fig. 7) show a wide variation, ranging from 50 Ur to 136 Ur, with an average value of 94 Ur. The average abundances of the three radioactive elements in this drift are 3.5%, 87 ppm and 56 ppm for K-40, eU and eTh respectively, with average eU/eTh ratio of 1.5 (Table 1). The main structures can be detected easily on the gamma-ray spectrometric maps. This drift can be divided into two IRL units (Fig. 15), D II\-IRL1 D II\-IRL1, which differ in their lithology and radioelement contents. These IRL units are conformable with the two main geologic units on the geologic map (Fig. 4.c). These units correspond to the altered granite (kaolinized and/or sericitized granite) and silica (jasperoid and massive silica) respectively. The main results of the statistical treatment of the data of these two units are given in Table 4.

5. Drift No. III

In spite of the limited data of this drift, a wide variation in the total counts of the raw radiometric data is recorded (ranging from 65 Ur to 208 Ur), with an average content of 91 Ur. The average abundances of the three radioelements in this drift are 4.7%, 55 ppm and 54 ppm for K-40, eU and eTh respectively, with an average eU/eTh ratio of 1 (Table 1). This drift is considered as one unit due to its limited extension. The normality of the data of DIII occurred when two anomalous measurements were neglected. So, the NPP of this drift indicates one IRL unit only (Fig. 12.c). The main results of the statistical treatment of the data of this drift are given in Table 1.

6. Uranium Migration

Statistical treatment of γ-ray spectrometric data of the four drifts (DI, DII, DII$^{\backslash}$ and DIII, Fig. 3) and the main adit gave a regional eU/eTh ratio of 1.35 (Table 1). The calculated original uranium content (Uo), migrated uranium (Um) and uranium migration rate (Umr) for the different IRL units in the main adit and drifts are shown in Table (5). It shows that, the pink granite (the main rock of the main adit) has the highest outward uranium migration (–148). This outward migration is shown also by the unit (DI-IRL2) in the drift I, which is represented by the kaolinized granite (–67). The other two unites (brecciated jasperoid silica, and silicified granite) of this drift (DI) show inward uranium migration. The second drift (DII) as a whole, shows outward uranium migration (–85), but the two IRL units do differ in uranium migration, where the DII-IRL1 (sericitized granite) shows outward uranium migration (–123) and DII-IRL2 (jasperoid silica) shows inward U-migration (35). The third drift (DII$^{\backslash}$) comprises two different units. The first is DII$^{\backslash}$-IRL1 (sericitized granite), shows outward uranium migration (–8), while the DII$^{\backslash}$-IRL2 is represented by silicified granite, which shows inward uranium migration (48). The fourth drift (D III), mainly kaolinized granite, shows also outward uranium migration (–64).

The main rock units which show outward uranium migration (Table 5) are pink granite, kaolinized granite and sericitized granite. The inward migration is clearly indicated in jasperoid silica, massive silica, and silicified granite in most IRL units. The rate of inward uranium migration increases with the increase of silicification and fracturing, beside its association with jasperoid veins.

Conclusion

Number of tunnels were driven at the northern periphery of the younger granitic mass of El-Missikat pluton, located about 3 km south the landmark “km 85" on the asphaltic road connecting Qena and Safaga towns, Central Eastern Desert of Egypt. The explored rocks in the tunnels are biotite granite (pink granite) which is exposed mainly at the main adit away from the shear zones. The exposed rocks in the drifts include jasperoid veins and veinlets. Zonally arranged around the jasperoid veins, are the alteration products of the granite. The wall-rock alteration is represented mainly by silicified-, sericitized-, and kaolinized granites. A detailed ground gamma-ray spectrometric survey was

Table 5. Uranium migration in the different interpreted radiolithologic (IRL) units, El-Missikat tunnels. Central Eastern Desert, Egypt.

Rock type	Unit	Up (ppm)	Uo (ppm)	Um (ppm)	Umr (%)	M.T
Pink granite	Main adit	29	72	–43	–148	↑
Drift I (DI)	All units	98	90	8	8	↓
Massive silica	DI-IRL1	47	90	–43	–91	↑
Kaolinized granite	DI-IRL2	142	237	–95	–67	↑
Silicified granite	DI-IRL3	176	77	99	56	↓
Jasperoid silica	DI-IRL4	474	157	317	77	↓
Drift II(DII)	All units	47	87	–40	–85	↑
Sericite granite	DII-IRL1	39	87	–48	–123	↑
Jasperoid silica	DII-IRL2	129	84	46	35	↓
Drift II\	All units	87	94	–7	–8	↑
Sericite granite	DII\-IRL1	60	94	–34	–56	↑
Silicified granite	DII\-IRL2	181	94	87	48	↓
Drift III Kaolinized granite	DII-IRL1	55	90	–35	–64	↑

Up = Present Uranium, Uo = Original Uranium, Um = Migrated Uranium, Umr % = U-migration rate
Uo = eTh*(regional eU/eTh), Um = Up-Uo, (Umr %) = Um *100/ Up,
M.T = Migration trend, ↓= Inward migration, ↑= Outward migration

carried out on the drifts and main adit of El-Missikat tunnels. The γ-ray spectrometric data was subjected to statistical analysis in order to delineate the distribution pattern of the radioelements in the exposed rocks. The original uranium content and uranium migration rate were calculated in order to identify the migration trends in the granite and its alteration products. Generally, there is a strong relationship between the different lithologic units of the tunnels and the levels of the gamma-ray spectrometric measurements. El-Missikat tunnels show some uranium enrichment. The jasperoid and silica veins, as well as the silicified granite show inward uranium migration characters. Meanwhile, the pink-, sericitized-, and kaolinized granites indicate outward uranium migration characters. In general, El-Missikat prospect show high probability for uranium potentiality. The rate of inward migration (%) increases with the increase of silicification processes and fracturing, beside the relative increase in jasperoid products.

The study also indicates the similarity in uranium migration in these prospects and El-Erediya prospect, 30 km to the south, which was studied previously by the same authors (Abu-Dief *et al.*, 2001). In both cases (El-Missikat and El-Erediya, Central Eastern Desert, Egypt.), the source of U-mineralization is probably the granite itself. The enrichment of uranium in the mineralized shear zones (drifts) in the two prospect areas is probably due to uranium migration that took place during different alteration processes from rock units of outward migration characters (the pink granite, sericitized granite and kaolinized granite), into the rock units which show some degree of inward migration characters (silica veins and silicified granite). This process led to deposition of uranium in its present locations within the sheared and fractured zones.

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العناصر المشعة وهجرة اليورانيوم في صخور الجرانيت، أنفاق المسيكات، الصحراء الشرقية الوسطى، مصر

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المستخلص. اكتشفت تمعدنات لليورانيوم مصاحبة لعروق الجاسبر الموجودة فى نطاقات القص والشقوق بكتلة الجرانيت بعد البنائي لجبل المسيكات بالصحراء الشرقية الوسطى لمصر عام ١٩٦٨ / ١٩٦٩م. حفرت الأنفاق الاستكشافية بمستوى الوادى متتبعة نطاقات القص لتحديد امتدادات الأجزاء المتمعدنة وتقييم إمكانياتها بالمستكشف. كشفت أعمال حفر الأنفاق عن وجود معادن اليورانيوم في نطاقات القص المستكشفة. وجد أن الجرانيت على طول نطاقات القص غالبا ما يكون متغيراً، ومن الظواهر الأساسية لهذا التغيرالسلكته ، وتكوين معادن السيريسيت، والتغيرالطيني. مسحت الأجزاء المتمعدنة فى بعض الأسراب والقواطع، بالإضافة إلى الجرانيت غير المتغير الموجود فى السرب أو النفق الرئيسى مسحا إشعاعيا طيفيا مكثفا. عولجت البيانات إحصائيا لتقييم تواجدات اليورانيوم وتحديد اتجاهات هجرته. أوضحت الدراسة وجود علاقة قوية بين توزيع العناصر المشعة ونوع الصخور وتحولاتها. بينت الدراسة كذلك حدوث هجرة لليورانيوم إلى الداخل في نطاق الجاسبر والسيليكا والجرانيت السليكاتى وإلى الخارج في الجرانيت الوردى الأقل تغيراً والجرانيت السيريسيتى والكاوليني. وجد أن هناك تشابها فى هجرة اليورانيوم بين كتلتى الجرانيت بهذه المنطقة ومنطقة العرضية الواقعة إلى جنوب المسيكات بمسافة تقارب الثلاثين كيلومتراً.