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Geological and Mineralogical Studies of Uraniferous Microgranites from Ras Abda Area, North Eastern Desert, Egypt

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Abstract. The current study investigates the geology and mineralogy of uraniferous microgranites from Ras Abda area, northeastern Desert, Egypt. The Precambrian basement suites of the studied area comprise older granitoids, microgranite dykes, and post granitic dykes and veins. The microgranite dykes occur as swarms and vary in color from buff and pink to dark red and brown. They are confined to a highly deformed, faulted, and sheared narrow zone, that is more than 1500m long in NE to NNE direction and up to 300 m in width. Several hydrothermal alteration processes, including hematitization, silicification and kaolinitization have varying degrees of impact on the rock. The radioactive mineralizations in the studied area are: (a) uranium minerals (kasolite and uranophane), and b) thorium minerals (thorite, uranothorite and orangite). Occasionally, secondary uranium minerals are found filling micro-fractures or coating joint surfaces.

Keywords: Geology, Mineralogical studies, Ras Abda, North Eastern Desert, Microgranite dykes

1. Introduction

The Arabian-Nubian Shield (ANS) extends across large areas of northeast Africa and Arabia and consists of Neoproterozoic juvenile crust that developed between 900 and 550 million years ago [1, 2]. In the northern Arabian-Nubian Shield, including the Eastern Desert of Egypt, Sinai, Sudan, and northwest Arabia, granitoids constitute nearly 60% of the Neoproterozoic terrain [3]. In contrast, their exposure decreases to about 30% in Ethiopia and Kenya [4]. The basement complex of Egypt's Eastern Desert consists of a series of Cryogenian Island arc assemblages, interspersed with Neoproterozoic granitoid intrusions that formed during different tectonic stages. The older, syn-collisional granitoids (~850–635 Ma) include calc-alkaline diorite, tonalite, and granodiorite, while the younger, late- to post-collisional granites (~630–540 Ma) range from quartz monzonite to alkali granite [5]. Wadi (W.) Ras Abda area is situated in the far southern region of the north Eastern Desert (NED) of Egypt, straight north of Safaga – Qena paved road nearly 20 km southwest of Safaga City at the Red Sea coast. The area is delineated by longitudes 33º 45` 22``and 33º 45` 51`` E and latitudes 26º 43` 15``and 26º 43` 34``N (figure 1a). The area under investigation was studied by many authors [6, 7, 8]. The current study's objective is to determine the variations in geological and mineralogical characteristics along microgranite offshoots.

2. Methods of Study

Fieldwork was carried out during several field trips to collect rock samples representing the different rock units and mineralized types. The collected samples underwent multiple mineral separation processes, including disintegration (crushing and grinding), sizing, and heavy liquid separation using bromoform (density = 2.85). The grains of heavy mineral were manually selected under a binocular microscope. The selected minerals were analysed using scanning electron microscopy (SEM, Philips XL30 model) and X-ray diffraction (XRD) at the Nuclear Materials Authority laboratory. In the field, radioelement measurements were conducted using the RS-230 instrument. Ground γ-ray spectrometric surveys recorded dose rate (D.R.) in nanosieverts per hour (nSv h^{-1}), along with potassium (K%), equivalent uranium (eU ppm), and equivalent thorium (eTh ppm) concentrations.

3. Geologic Setting

The Precambrian basement suites in the studied area include; older granitoids, microgranite offshoots in addition to acidic and basic dykes of different attitudes. Granodiorites, tonalite and quartz diorites are among compositions of the older granitoids. The former create low to moderately elevated mounts and hills with gentle slopes covered by debris. Their outcrops display distinct weathering characteristics, such as intensive fracturing, quadrangular and spheroidal detached blocks, weathered surfaces, and exfoliation. They are generally greyish, slightly pinkish when they have a high amount in K-feldspar and occasionally mottled grey to greenish grey. The older granitoids southward of W. Al-Baroud are strongly weathered and possess well- developed planar foliation (gneissosity), predominantly trending northwest, and vertical joints. In many areas especially along and to the south of W. Ras Abda and south of W. Barud El Abiad, the older granitoids are intruded with younger granites and injected by pegmatites, K- feldspars and quartz pockets and veins. As a result, they display a significant variation in transitional composition, with their dark color shifting to dark pink or whitish pink, while most fractures and joints are stained with iron oxides. On the other hand, the older granitoids, which outcrop near or around W. Ras Abda are intruded by the younger gabbros that in many parts contain numerous xenoliths of them and rise them as roof- pendants. Dykes of different compositions that vary from mafic to felsic dissect the older granitoids with different thickness and attitudes. The microgranite offshoots are mainly occupying the middle of the southern part of the studied area north and south of W. Ras Abda. They are mostly found in older granitoids rocks (figure 2a), and also sporadically found in younger gabbros (figure 2b) and older phases of younger granites. They occur as swarms of elongated elliptical-shaped bodies extend from NE to NNE. Their sizes range from a few meters to hundreds of meters in length and from less than a meter to ten meters in width. These rocks are limited to extremely distorted, faulted, and sheared confined zone, reaching to 300 m width and expands southward for more than 1500m to the south of W. Ras Abda. Along W. Ras Abda, a NW-SE left lateral strike- slip fault action causes split the zone into two parts. In general, the microgranite offshoots have an invasive association with the syn-collision granites and their orientation suggests that the forming melts mobilized through the old structures during their ascended. The specific microgranite offshoot generally strikes NE-SW, which is roughly consistent with the predominating structure trend. Conversely, high deformation processes in the microgranite offshoots causes severe joints, fractures and alterations (figure 2c). The microgranite is equigranular, fine- grained rocks, buff to pink, dark red and brown in color. In some places, they are compact and silicified. Different hydrothermal alteration processes, including hematitization, silicification, and kaolinitization, are having varying degrees of impact on the rocks at the two banks of W. Ras Abda.

The most prevalent and significant process is hematitization, which always occurs and intensifies in fractured areas with substantial uranium and thorium mineralizations because ferrous oxides have a high capacity to extract uranium from its carrier solutions [9]. According to [10], there is a geochemical association and connection between uranium and ferric oxides, which causes the staining form of the secondary uranium minerals. The mineralization in the Ras Abda area is largely controlled by structural factors. The exposed rock units are intersected by multiple fault sets, predominantly of the strike-slip type, with normal and thrust dip-slip faults also present. The key tectonic structures influencing mineralization are fault zones, along which metasomatic alterations have occurred. Field observations indicate that NNE-trending strike-slip faults, along with their intersections with NNW-trending structures, played a significant role in the development and localization of mineralization. The microgranite rocks contain diverse mineralized segregations that are strongly ferruginated, highly radioactive, and intensely fractured, displaying black, brownish-black, and reddish-brown hues (figure 2d). They have irregularly formed, measuring up to 0.5x1m, and filling the fracture on the walls of offshoots (figure 2e). Conversely, near the shear zone, irregularly shaped unzoned pegmatite is observed (figure 2f).

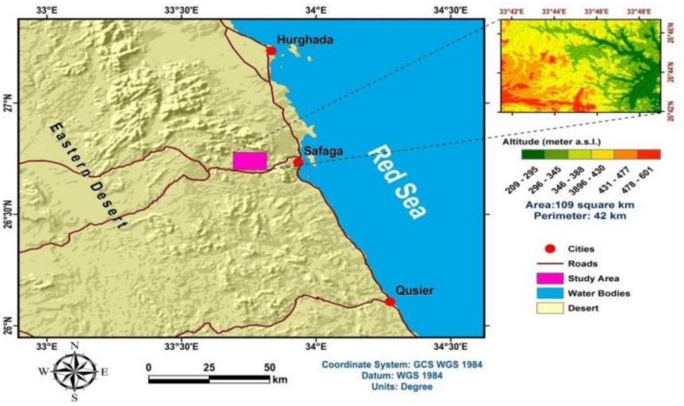

Figure 1a. Location map of W. Ras Abda area, NED, Egypt

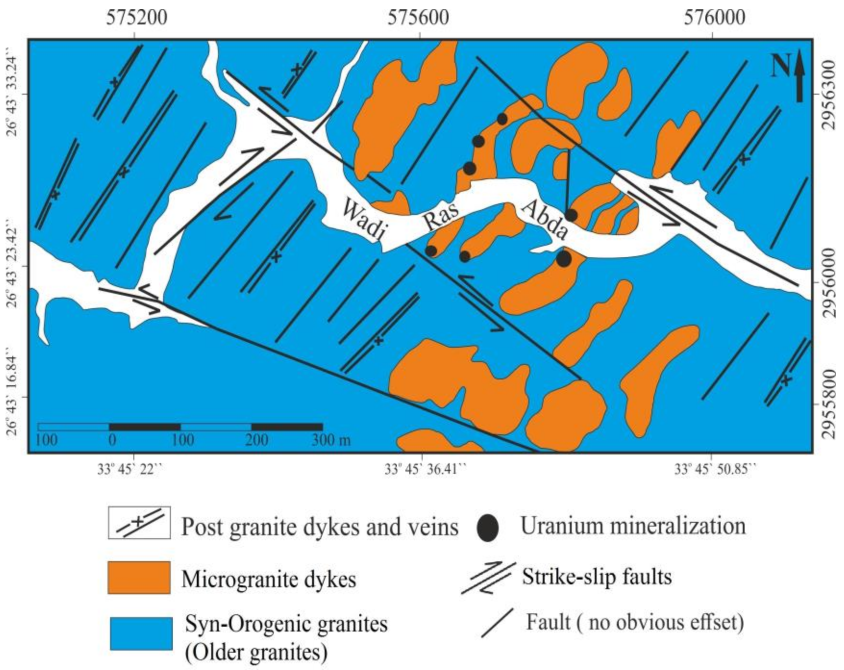

Figure 1b. Geological map of W. Ras Abda area, NED, Egypt

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Figure 2a. Microgranite offshoots intruding older granitoids along W. Ras Abda, NED, Egypt

Figure 2b. Microgranite offshoots intruding younger granites along W. Ras Abda, NED, Egypt.

Figure 2c. Highly deformed microgranites showing intense joints, fractures and various types of alterations, W. Ras Abda area, NED, Egypt

Figure 2d. Mineralized segregation with black, brownish black and reddish-brown color in microgranite offshoots, W. Ras Abda area, NED, Egypt

Figure 2e. Mineralized segregations with black color exist as fracture filling on the wall of the microgranite offshoots, W. Ras Abda area, NED, Egypt

Figure 2f. Irregular shape pegmatite pocket at the contact area of the microgranite offshoots, W. Ras Abda area, NED, Egypt

4. Mineralogical Investigations

The mineralizations in the uraniferous microgranites of Ras Abda area are:

4.1 Uranium minerals

A distinct uranium mineralization is observed, characterized by the existence of secondary uranium minerals. These minerals are present as minute crystals filling micro-fractures or coatings or as encrustations on the rock as in (figure 3). The radioactive minerals mostly appear as mineral skin-deep layers that either freely grow into the open spaces of the microgranites or paint the walls of fissures and fractures.

Kasolite [$Pb(UO_2)(SiO_3)(OH)_2$] crystallizes in a monoclinic system and is made up of silicate, lead, and hexavalent uranium. The yellowish- brown to reddish- orange color of kasolite, which can be seen in a fan-like or radiating shape, and its waxy or greasy sheen are what set it apart [11]. Kasolite can be found on the surfaces of hematitized joints as coatings or as tiny dispersions or microfractures. Kasolite, on the other hand, was identified by its reddish- orange to yellowish- brown hues (figure 4a). X-ray diffraction analysis and the pattern of kasolite are given in (figure 4b).

Uranophane [$Ca\ (UO_2)_2(SiO_3)_2(OH)_2.\ 5H_2O$] is dimorphic with beta-uranophane [12]. It occurs as radiated fibrous grains and has a lemon- yellow to straw- yellow color with waxy or greasy luster and pale-yellow streak (figure 5a). It is less abundant than kasolite. Uranophane was identified using X-ray diffraction (figure 5b).

4.2 Thorium minerals

It comprises thorite, uranothorite and orangite. They were found near zircon revealing the effect of the hydrothermal fluids. Thorite Th (SiO_4) is now an important thorium mineral and has the potential to replace uranium in nuclear power generation. It is believed to be three times more frequent in granitic rocks than uranium [13]. In the study area, thorite appears as metamictized short prismatic crystals with a deep brownish tint. Metamictization makes thorite isotropic (figure 6a). In the investigated area, some thorites are close to ideal thorite with some U in the crystal lattice that is confirmed by XRD as in (figure 6b). The orange and the yellowish white variety crystallized later by replacement of primary thorite supported by the relict rims similar to thorite of primary origin or by direct precipitation from hydrothermal fluid. Such thorites incorporate REEs in their structure; zircon may be the reason for their partitioning of REEs. The ochre yellow assemblage retains a large fraction of radiogenic Pb as Pb U $(SiO_4)_2$ during recrystallization [11]. Uranothorite [(Th, U, Y) SiO_4] vary in color from dark brown, greyish yellow, deep brown to deep yellowish green. It is worthy to mention that the U replaces Th producing uranothorite (figure 7a) and it is confirmed by ESEM (figure 7b). Orangite (Th, Y, Ce) SiO_4 is an orange tinted variety of thorite (figure 8a). It has the same chemical formulae with some traces of U, Y and Ca as shown in figure (8b). It is characterized by the presence of U besides Th and orange color [11].

Figure 3. Visible uranium mineral along fractures of uraniferous micrograntes from Ras Abda area, NED, Egypt

Figure 4a. Stereophotograph of kasolite grains separated from, uraniferous microgranites, Ras Abda area, NED, Egypt, (C.N., X=10)

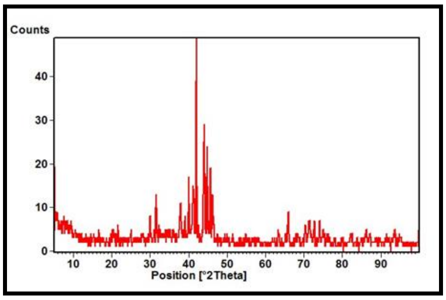

Figure 4b. X-ray diffractogram of kasolite, uraniferous microgranites from Ras Abda area, NED, Egypt

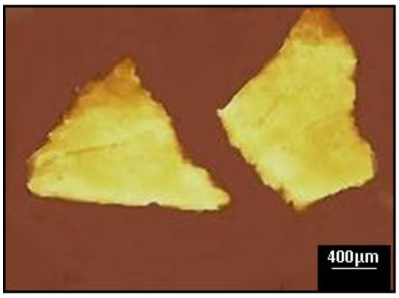

Figure 5a. Stereophotograph of uranophane mineral separated from uraniferous microgranites, Ras Abda area, NED, Egypt

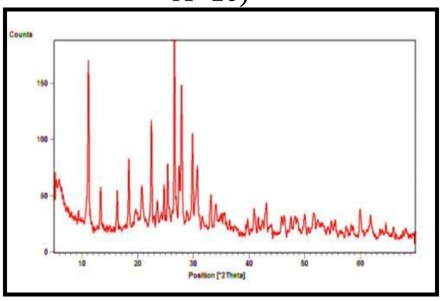

Figure 5b. X-ray diffraction pattern of uranophane, uraniferous microgranites from Ras Abda area, NED, Egypt

Figure 6a. Stereophotograph of thorite minerals separated from uraniferous microgranites from Ras Abda area, NED, Egypt

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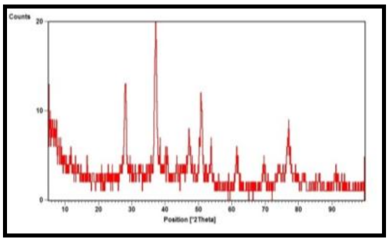

Figure 6b. X-ray diffraction pattern of thorite, uraniferous microgranites from Ras Abda area, NED, Egypt

Figure 7a. Stereophotograph of uranothorite separated from uraniferous microgranites, Ras Abda area, NED, Egypt

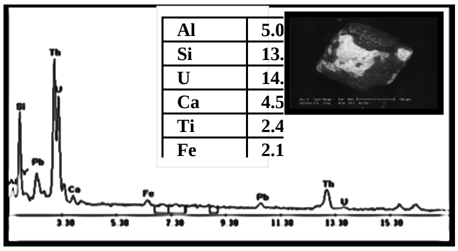

Figure 7b. ESEM image and EDX analysis data of uranothorite, uraniferous microgranite from Ras Abda area, NED, Egypt

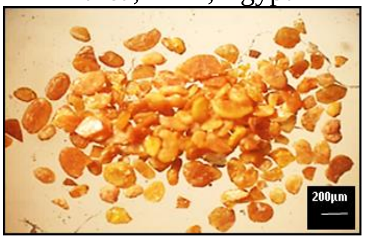

Figure 8a. Stereophotograph of orangite separated from uraniferous microgranites from Ras Abda area, NED, Egypt.

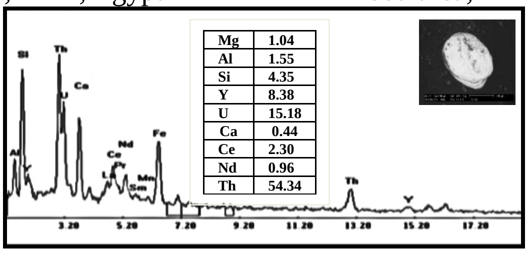

Figure 8b. ESEM image and EDX analysis data of orangite, uraniferous microgranites from Ras Abda area, NED, Egypt

5. Spectrometric Prospecting

The RS-230 instrument was used in the field to measure the dose rate (D.R.), potassium (K%), equivalent uranium (eU), and equivalent thorium (eTh). Uranium mobilization (eUm) is calculated as the difference between the measured equivalent uranium (eU) and the expected original uranium content. The original uranium is estimated by dividing the measured equivalent thorium (eTh) by the average eTh/eU ratio in crustal acidic rocks, which are 3.5 according to [14]. This calculation is expressed as ($eUm = eU - eTh/3.5$). Positive eUm values indicate uranium enrichment due to mobilization, while negative values suggest uranium depletion through leaching. If the surface uranium distribution is lower than the expected hypothetical distribution, it implies uranium leaching, resulting in negative mobilization values [15].

5.1 Distribution of the radioelements in uraniferous microgranites at Ras Abda area

The minimum, maximum and average of the different radioelement values of uraniferous microgranites in Ras Abda area are illustrated in (figure 9). The uraniferous microgranites in the Ras Abda area are enriched in uranium, which is linked to post-magmatic processes, the leaching of uranium from country rocks. The correlation between elements and their ratios at Ras Abda area are illustrated in (figure 10). The eU with Th, K, and eU/eTh correlation reflects a strong relation. The diagram (figure 10d) shows the strong relation between eU vs. (eU - eTh/3.5) reflects slight uranium mobilization.

5.2 Variation diagrams of the radioelements in some trenches at Ras Abda area

Eight box-cut exploratory trenches with variable shapes and sizes were excavated in the studied uraniferous micrograntes offshoots to follow the extension of the radioelement mineralization at depth and to find out the nature of its occurrence. The trenches were excavated by using a compressed air hammer with the aid of primitive tools such as pickaxes, hammers and punching nails. The excavation process was achieved at a slow rate due to the hardness of the rocks.

Detailed geologic study as well as spectrometric surveys had been carried out for each trench through a regular spatial grid with 20 cm space interval. The survey had been carried out for each part of the

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trench (foot, front, back, right and left limbs) if present. Results of study in the different mined trenches revealed that the radioelement mineralization occur either as disseminations within the granitic dykes rocks or as fracture fillings associated with various types of alterations which are mainly represented by ferrugination, silicification, kaolinitization, chloritization and manganese dendrites.

The minimum, maximum and average of the different radioelement values are illustrated in figure 11. The variation diagrams of the uraniferous micrograntes (Trenches) at Ras Abda area (figures 12 and 13) show that, there are strongly positive relations between D.R. with eU, eTh, and K%. There is a strong positive relation among eU with eTh and K%. While there is a moderate positive relation between eU and eU/eTh. The diagram (figure 13d) shows the strong relation between eU vs. (eU - eTh/3.5) reflects slight uranium mobilization.

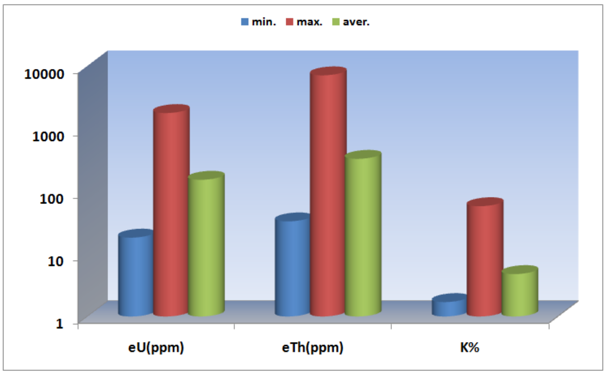

Figure 9. Bar diagram showing the average contents of eU, eTh and K- for the studied uraniferous microgranites from Ras Abda area, NED, Egypt

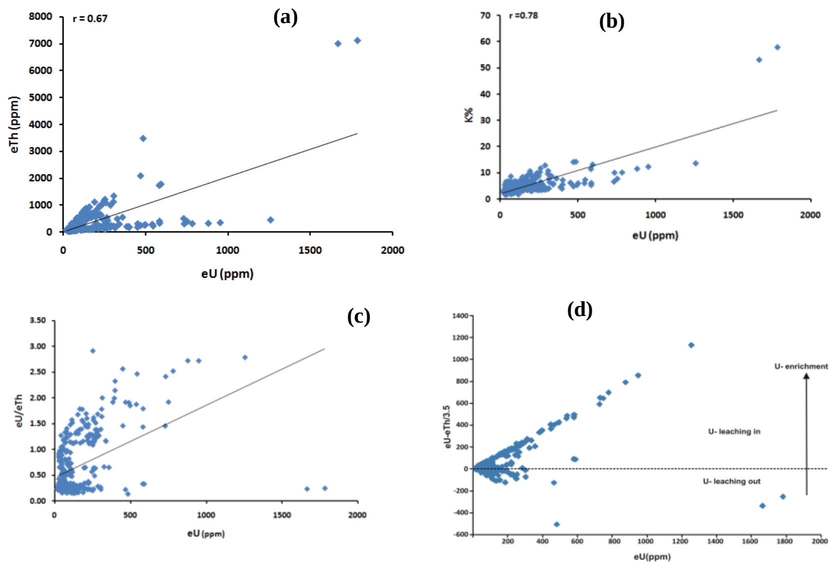

Figure 10. The correlation between a) eU-eTh, b) eU-K%, c) eU-eU/eTh, and d) eU-(eU-eTh/3.5) for the studied uraniferous microgranites from Ras Abda area, NED, Egypt

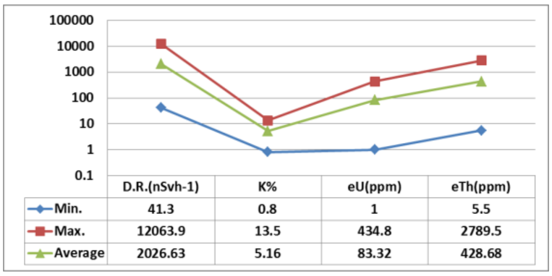

Figure 11. Profile line diagram showing the minimum, maximum and the average of D.R.(nSvh-1), K%, eU(ppm) and eTh(ppm) in uraniferous microgranites (Trenches) at Ras Abda area, NED, Egypt

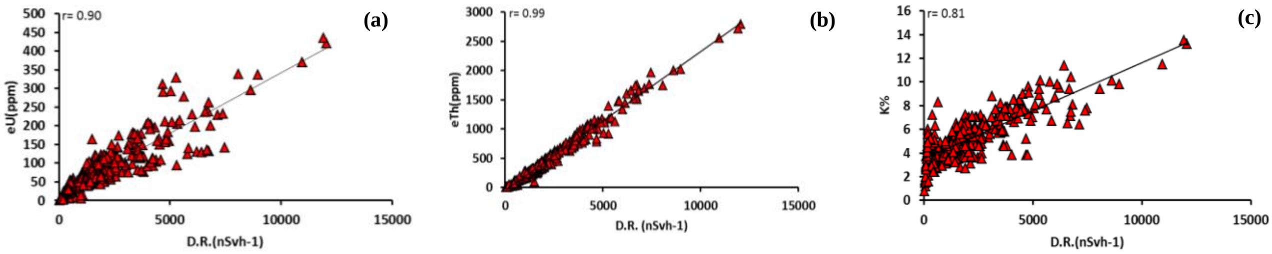

Figure 12. The correlation between a) D.R.-eU, b) D.R.-eTh, and c) D.R.-K% for the studied uraniferous microgranites (Trenches) from Ras Abda area, NED, Egypt

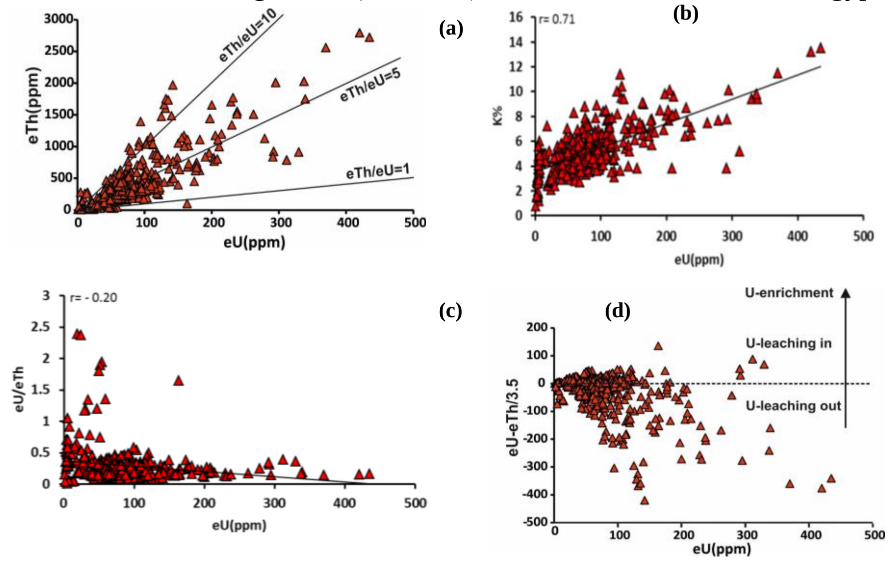

Figure 13. The correlation between a) eU-eTh, b) eU-K%, c) eU-eU/eTh, and d) eU-(eU-eTh/3.5) for the studied uraniferous microgranites (Trenches) from Ras Abda area, NED, Egypt

6. Summary and Conclusions

The W. Ras Abda area is composed of Precambrian basement suites, primarily consisting of older granitoids intruded by microgranite dykes, as well as basic and acidic dykes with varying orientations. The older granitoids, included tonalite, granodiorite, and quartz diorite. The microgranite dyke swarms exhibiting high radioactivity and poly-metallic mineralization. They are confined to a highly deformed, faulted, and sheared confined zone, which extends over 1500 m in a NE to NNE direction and reaches up to 300 meters in width. This zone has been divided into two sections due to the influence of a NW-SE left-lateral strike-slip fault. The elongated bodies of uraniferous microgranites various in their sizes and intruded the older granitoids, and suggests that the magma ascended along

pre-existing structural weakness. Individually, the uraniferous microgranite dykes predominantly follow a NE-SW trend, which closely aligns with the dominant structural fabric. Furthermore, these dykes have been subjected to significant deformation, leading to extensive jointing, fracturing, and associated alteration. The radioactive mineralizations in the uraniferous microgranites rocks of the studied area are:- kasolite, uranophane, thorite, uranothorite and orangite.
The study area exhibits a relative enrichment of uranium compared to thorium, which may be attributed to the presence of accessory minerals or secondary processes that played a key role in uranium concentration. Additionally, uranium may have been introduced into these granitic sites through post-magmatic processes.

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