ABSTRACT

Ground radiometric survey in Wadi El Reddah area, which represents the north eastern parts of Gabal Gattar batholith in the North Eastern Desert of Egypt, clearly distinguishes two anomalous bodies in the hydrothermally altered alkali feldspar granite. Localized uranium mineralization, formed predominantly of kasolite, is associated with zircon, fluorite, and cotunnite, accompanied by intense hematitization, desilicification, chloritization and K-metasomatism of the original host granite. The geochemical data showing that the mean U (174 ppm) in the mineralized domain is increased in abundances relative to the less altered granite. Mean Th (43 ppm), on the other hand, is relatively remains constant and mean Th/U ratios changes from 2.6 in the less altered granite to 0.27 in the mineralized zones. During mineralization processes, most of major and trace elements are mobilized to some extent where elements such as K, Rb, Zr, Zn and Pb are enriched, while Si, Sr and REE are depleted. The formation of secondary uranium mineralization are generally attributed to wet climatic episodes prevailed at the late Quaternary in Egypt.

Keywords: Gabal Gattar – altered granite - Uranium – Thorium - kasolite – hydrothermal solutions

1. Introduction

The Arabian Nubian Shield (ANS) is considered to be one of the largest preserved exposures of Neoproterozoic juvenile continental crust on Earth (Patchett and Chase, 2002; Stern et al., 2004). The Egyptian Eastern Desert, being a part of the ANS, contains a wide range of granitic rocks exposures (Stern and Hedge, 1985). The granitoid rocks in the ANS include syn- to late-orogenic granitoid assemblages emplaced during the main orogenic stage between 850 and 635 Ma (Fleck et al., 1980; Greenberg, 1981; Jackson et al., 1984; Bentor, 1985; Stern and Hedge, 1985; Harris, 1985; Stern and Gottfried, 1986; Stern et al., 1988; El-Gaby et al., 1988 and Hassan and Hashad, 1990); and post-orogenic to anorogenic granitoid assemblages from 610 to 550 Ma (Greenberg, 1981; Ries et al., 1983; Stern and Hedge, 1985; Bentor, 1985; Hassan and Hashad, 1990; Abdel-Rahman, 1995 and Eliwa et al., 2006). The aforementioned granitoids are previously identified as older granitoids and younger granitoids, respectively (Bentor, 1985).

The Red Sea mountains represent the northern tip of the Arabian Nubian Shield. Gattar batholith is found in the Red Sea mountains to the west of Hurghada City (Fig. 1a). It could be accessed from Hurghada city to Hurghada-Gharib paved road for about 19 km, turning to west through the Pharos Rally desert track to reach the eastern periphery of the mapped area. The Gattar batholith is a post-orogenic granitoid rocks which outcrops over an area ~600Km² representing one of the largest batholiths in the North Eastern Desert of Egypt. The main mass of the Gattar batholith consists of syeno- to alkali feldspar granite that intruded into a number of discrete bodies of metavolcanics and older granitoids (El Rakaiby and Shalaby, 1988; Shalaby, 1990; Roz, 1994 and Bishta, 2004). During the past decades the Gattar batholith has been the site of increasingly intense mineral exploration which has culminated recently in the discovery of a promising U prospect, mainly in the northeastern parts, as well as numerous other showings of this metal (Khalaf, 1995). Numerous radioactive occurrences, reaching or
grade uranium concentrations in some localities, are related to the most abundant alkali feldspar leucogranite (Mahdy et al., 1990; Mahdy, 1999 and Raslan, 2009). In the study region, distribution of U zones are structurally controlled and confined with fracture zones, which are commonly altered and show deposition of various secondary minerals (Abu Zaid, 1995; Hardiy, 1995 and Shalaby, 1996).

The area of the Gattar batholith is of rugged topography and is traversed by few major Wadis. The northeastern peripheries of the Gattar batholith, including Wadi El Reddah area, are the focus for integrated uranium exploration. Wadi El Reddah is filled by alluvial sediments, which locates in the vicinity of mountainous bodies of Gattar alkali feldspar granite. The present work summarizes detailed radiometric investigation on this granitic mass to detect the uranium mineralized zones in this locality and provides details about the mineralogical and geochemical characteristics of the highly radioactive sites.

Fig. 1: (a) Google earth image showing the location of the study area, (b) Geologic map of Wadi El Reddah area (modified after El Dabe, 2004).

2. Geological setting

The mapped area is bounded by longitudes 33° 19' 02" - 33° 22' 46" E and latitudes 27° 05' 28" - 27° 08' 15" N covering an area of about 32 Km² (Fig. 1b). The rocks occupying the area are mainly consisting of post-collisional magmatism represented by Gabal El Reddah biotite granite and Gabal Gattar perthitic leucogranite (El Dabe, 2004). The country rocks consist of Hammamat sedimentary rocks of molasses-type (585±15 Ma; Willis et al., 1988) confined to the northern parts of the study area. Small exposures of the older granitoids (700-750 Ma; Dixon, 1981) are situated at the eastern parts of mapped area and extend beyond it.

The older granitoids are represented by quartz diorite and locally diorite. They occur as small masses of low relief around Gabal El Reddah and extend out beyond the study area (Fig. 2a). They
intruded by Gabal Gattar and Gabal El Reddah younger granites with intrusive sharp contacts dipping away from them. The Hammamat sedimentary rocks occur as isolated outcrops intruded by Gabal Gattar younger granite with sharp intrusive contact (Fig. 2b). The Hammamat sedimentary rocks are composed mainly of greywacke with thin layers of siltstones (Abu Zeid, 1995).

Gabal El Reddah biotite granite forms a semicircular to oval body with moderate to high relief and smooth slopes (Fig. 2c). It is composed of medium-to-coarse-grained massive and hydidiomorphic biotite monzogranite variety.

On the other hand, Gabal Gattar younger granite, the aim of the present work, is characterized by high relief and widely spaced joints (Fig. 2d). It encloses numerous Hamammat xenoliths of different shapes and sizes. The rock is leucocratic red to pinkish red color, massive and composed mainly of medium-grained, equigranular alkali feldspar granite. It is characterized by high values of radioactivity, especially in the highly altered fractured zones.

Various hydrothermal alteration features such as hematitization, kaolinitization, episyenitization (disilication) and fluoritization are affecting on the rocks with different degrees of intense. The hematitization is the most common and the most influential process and always exists and increases in the fractured and sheared zones accompanied with high uranium mineralization due to the high ability of iron oxides for uranium adsorption from its bearing solutions (Hussein et al., 1965). Dawson (1956) suggested that iron and uranium are geochemically related and the ferric oxide is abundantly found with uranium. Kamineni et al. (1986), Casas et al. (1994) and Drot et al. (2007) had documented sorption of the uranyl ion on iron oxides and montmorillonite.

Faults represent the main structural features in the study areas. The NE and NW trends comprise both left-lateral and right lateral strike-slip faults (Fig. 1b). On the other hand, the area is dissected by major joints generally trending in the N20°W and N70°E directions.

![Field photographs](image)

**Fig. 2:** Field photographs showing: (a) small masses of low relief of the older granitoids, looking southeast, (b) the Hammamat sedimentary rocks intruded by Gabal Gattar granite with intrusive sharp contact, looking northwest. (c) Gabal El Reddah biotite granite forms moderate to high mountains with smooth slopes looking east and (d) Gabal Gattar granite forms high rough mountains with sharp rugged peaks, looking west.
3. Uranium Mineralization and Alterations

Generally, the granitoid rocks are possessing higher gamma ray values than the other rock types due to the high proportion of their contained natural radioactive elements (Harb et al., 2012). Uranium is a redox-sensitive element that is highly mobile under oxidizing conditions and forms mineralization through the entire geological cycle in magmatic, metamorphic, and sedimentary rocks (Dahlkamp, 1993, 2016 and Cuney and Kyser, 2015). Uranium is leached and carried downward as soluble uranyl complexes and precipitated under reducing conditions along fractures to form their own minerals in veins or adsorbed on the surface of clay minerals and iron oxy-hydroxides. On the other hand, the stability of Th$^{4+}$ complexes, especially those with carbonates (Mernagh and Miezitis, 2008), and the persistence of Th under oxidizing conditions, allows Th to be used as a reference concentration in order to evaluate the original U concentration, prior to the formation of an oxidizing environment (Rogers and Adams, 1969 and Stuckless and Ferreira, 1976).

An extensive ground gamma-ray spectrometric survey was carried out on the exposed younger granites in the studied area using RS-230 Spectrometer (103 cm$^3$) with higher density Bismuth Germanate Oxide (BGO) detector makes it also an ideal portable instrument for Potassic Alteration measurements. Particular attention was paid to structural features such as contacts, shear zones and faults as well as hydrothermally altered zones. Radioactive measurements in the field indicated erratic variations of U and Th across the highly altered rocks in the study area.

Gabal Gattar granite displays the highest level of gamma activity among the other granitic types in the study area. This granite is characterized by intensive wall-rock alterations, especially in highly deformed parts, which used as guide for locating the uranium mineralization. Two radioactive anomalies (RAD-1 and RAD-2) were identified, with reference to the background values of eU (11 ppm) and eTh (31 ppm).

The radioactive anomaly (RAD-1) is located along a major shear zone trending N25$^\circ$E and dipping 75$^\circ$ to the SE (Fig. 3a). The granite at this occurrence is disilicified accompanied by many alterations features especially hematitization and kaolinitization besides fluoritization. Frequent presence of cotunnite is noticed in this occurrence (Fig. 3b).

Fig. 3: (a, b) Location and alteration features of the radioactive anomaly RAD-1 (c, d) Location and alteration features of the anomaly RAD-2.
The disilicified granite occurs as thin body surrounding the anomaly. The anomalous zone is about 5m long and 3m width controlled essentially by the intersection zone of the NNE-SSW and NW-SE fractures. The radioactive measurements illustrated that the U contents are ranging from 150 to 250 ppm with spots reach 400 ppm.

The radioactive anomaly (RAD-2) is located in the vicinity of basic dike trending NE and the intersection zone of two major shear zones (Fig. 3c). The major one is trending NNE and dipping 75° to SE, whereas the second one is trending E-W and dipping 70° to the S. The radioactive granite is showing alteration features represented by hematitization, kaolinitization and disilicification (Fig. 3d)). The size of this anomaly is about 6m long and 2m width. The uranium contents vary between 100 ppm and 180 ppm with spots reach 250 ppm.

4. Materials and Methods

Seven altered samples representing the two radioactive zones were analyzed quantitatively for U, Th, major constituents, trace and REE using inductively coupled plasma mass spectrometry (ICP-MS) at the Acme laboratory, Vancouver, Canada. Thin sections were examined by transmitted and reflected light optical microscopy in order to characterize mineral textural relationships. The radioactive samples were prepared, then separating their contained accessory minerals by the standard heavy liquid method using bromoform (SG 2.89). Back scattered electron (BSE) imaging and energy dispersive spectroscopy (EDS) analyses were conducted over the picked mineral grains with a Phillips XL 30 Scanning Electron microscope at the laboratory of the Nuclear Materials Authority of Egypt.

5. Petrography and Mineralogy

The studied granite is classified as alkali feldspar granite according to El Dabe (2004). It is medium-grained with heterogeneity in color, ranging from pink to red. It consists mainly of k-feldspar and quartz as essentially minerals with subordinate plagioclase and biotite and displays hypidiomorphic equigranular texture. The accessory phases comprise, muscovite, zircon, fluorite and iron oxides, while chlorite, sericite, epidote and calcite are secondary minerals. It was affected by more than one cycle of hydrothermal solutions causing many mineralogical changes in the essentially rock-forming minerals accompanied by precipitation of newly secondary uranium minerals.

The k-feldspar is somewhat clouded by minute hematite inclusions. Plagioclase is partially altered to sericite and stained with iron oxides. The disilicified samples show two types of quartz occur in variable proportion. The first is the magmatic quartz (Qz1) and occurs as anhedral to subhedral crystals. The second is newly formed amorphous quartz (Qz2), occurring occasionally in the interstitial spaces between feldspars and/or surround the magmatic quartz (Qz1) (Fig.4a).

Chloritization of biotite occurs together with carbonatization in many parts throughout the hydrothermally altered rock.

The uranium minerals are precipitated as facture and vug-filling uranium minerals of secondary origin (Fig. 4b). They appear to have formed within the secondary pore spaces between feldspars or fill the cracks throughout the minerals. In some instances, they filling vugs formed by dissolution of the magmatic quartz. These secondary uranium minerals are always associated with large amounts of amorphous quartz (Qz2).

Zircon, apatite and fluorite, which represent the most important accessory minerals in the least altered granite, were affected by hydrothermal solutions. The petrographic studies of the altered rocks indicated that the zircon and apatite are partially affected by hydrothermal fluids where hydrothermal fluids partially coated zircon crystals with secondary radioactive minerals (Fig.4c). Fluorite is changed to blue-violet and purple colors as the result of radiation effect (Fig. 4d).

Mineralogical studies of the heavy minerals show reasonable amounts of the radioactive minerals such as secondary uranium minerals and zircon associated with fluorite and cotunnite.

Zircon is abundant in all collected samples. It occurs as subhedral crystals of prismatic and dipyramidal forms. Their colors are principally brown although dark brown and yellow are also encountered. The studied zircon grains show cracks due to deuteric alteration, indicating that they are metamict zircon (Geisler et al. 2003, 2007; Xu et al. 2012). The ESEM image and EDS analysis of the picked zircon grains indicated that it consists mainly of Zr, Si and Y with minor Al, Ca, Fe and Hf (Fig. 5a).
Fig. 4: Photomicrographs showing the main mineralogical changes in the altered granite: (a) Generation of secondary quartz (Qz 2) at the expense of the magmatic quartz (Qz 1), C.N., (b) Uranium minerals are precipitated as fracture and vug-filling materials, C. N., (c) Hydrothermal fluids partially coated zircon crystal with secondary radioactive minerals, C. N. and (d) Violet fluorite crystallized interstitially together with radioactive minerals (U), P. L.

Fig. 5: Microphotographs illustrate the accessory phases picked from the radioactive altered samples, (a) ESEM image and EDS spectrum of zircon, (b) ESEM image and EDS spectrum of kasolite, (c) ESEM image and EDS spectrum of fluorite and (d) ESEM image and EDS spectrums of cotunnite.
Table 1: Major and trace elements concentrations of selected samples from anomalous radioactive occurrences in the study area.

| Elements          | Less altered alkali feldspar granite of Gabal Gattar area (Mahdy et al. 2015) | Radioactive anomaly (RAD-1) | Radioactive anomaly (RAD-2) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | Average |
|-------------------|-----------------------------------------------------------------------------|-----------------------------|-----------------------------|-----|-----|-----|-----|-----|-----|-----|--------|
| SiO₂              | 76.63                                                                       | 71.87                       | 72.89                       | 71.64 | 70.86 | 73.91 | 73.05 | 74.16 | 72.63 |
| TiO₂              | 0.05                                                                        | 0.09                        | 0.09                        | 0.07 | 0.1  | 0.1  | 0.1  | 0.12 | 0.10 |
| Al₂O₃             | 12.73                                                                       | 15.71                       | 14.47                       | 15.64 | 15.25 | 13.47 | 13.7  | 14.83 | 14.72 |
| Fe₂O₃             | 0.55                                                                        | 1.63                        | 1.87                        | 1.27 | 2.15 | 1.14 | 1.42 | 1.25 | 1.73 |
| FeO               | 0.69                                                                        | 0.18                        | 0.23                        | 0.13 | 0.22 | 0.25 | 0.14 | 0.19 | 0.19 |
| MnO               | 0.02                                                                        | 0.11                        | 0.18                        | 0.12 | 0.21 | 0.11 | 0.15 | 0.15 | 0.15 |
| MgO               | 0.04                                                                        | 0.1                         | 0.08                        | 0.11 | 0.09 | 0.07 | 0.09 | 0.08 | 0.09 |
| CaO               | 0.35                                                                        | 0.26                        | 0.42                        | 0.27 | 0.22 | 0.33 | 0.38 | 0.43 | 0.33 |
| Na₂O              | 4.32                                                                        | 3.36                        | 3.44                        | 3.71 | 2.89 | 3.97 | 3.31 | 3.82 | 3.5  |
| K₂O               | 4.17                                                                        | 5.74                        | 4.96                        | 6.03 | 6.43 | 5.41 | 5.42 | 4.18 | 5.45 |
| P₂O₅              | 0.02                                                                        | <0.01                       | <0.01                       | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| L.O.I             | 0.84                                                                        | 1.37                        | 0.92                        | 1.64 | 1.19 | 0.72 | 0.77 |       |       |

Major oxides (wt. %)

| Trace elements (ppm) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Average |
|----------------------|---|---|---|---|---|---|---|---------|
| Ba                   | 165 | 171 | 155 | 225 | 95 | 108 | 91 | 144     |
| Rb                   | 408 | 375 | 438 | 445 | 390 | 410 | 366 | 404     |
| Sr                   | 3.3 | 3.7 | 2.7 | 3.3 | 4.2 | 3.6 | 4.8 | 3.6     |
| Ca                   | 28.9 | 24.8 | 28.6 | 27.1 | 23.5 | 23.9 | 25.6 | 26.2     |
| Ta                   | 6.1 | 4.8 | 4.2 | 4.1 | 4.3 | 3.8 | 4.1 | 3.8 | 4.2 |
| Nb                   | 80.4 | 51.4 | 47.3 | 62.6 | 41.2 | 43 | 41.7 | 50.8 |
| Hf                   | 8.18 | 8.5 | 7.6 | 7.2 | 7.9 | 6.8 | 6.3 | 6.1 | 7.2 |
| Zr                   | 128 | 184 | 145 | 128 | 165 | 121 | 135 | 123 | 143 |
| Y                    | 78.4 | 15.4 | 16.1 | 13.6 | 15.3 | 17.6 | 16.9 | 15.2 | 15.7 |
| Ni                   | 1.9 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Cr                   | 27 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Co                   | 0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 0.6 | <0.5 | 0.6 | 0.6 |
| V                    | 1.6 | 18 | 10 | 12 | 14 | 6 | 7 | 7 | 11 |
| Cu                   | 4.5 | 72 | 45 | 43 | 76 | 21 | 18 | 20 | 42 |
| Pb                   | 22.8 | 1247 | 834 | 820 | 920 | 55 | 35 | 28 | 563 |
| Zn                   | 84.2 | 2873 | 1569 | 1378 | 2530 | 475 | 368 | 321 | 1359 |
| Th                   | 23.5 | 55 | 45 | 41 | 48 | 39 | 38 | 33 | 43 |
| U                    | 9.8 | 256 | 209 | 185 | 241 | 124 | 105 | 95 | 174 |
| Th/U                | 2.6 | 0.21 | 0.22 | 0.22 | 0.20 | 0.31 | 0.36 | 0.35 | 0.27 |

Fluorite is found as anhedral, angular to subangular grains with irregular outlines and sharp edges and has vitreous luster. It shows a wide range of colors from rose, violet to deep violet and colorless crystals are also observed. The semi-quantitative analysis of fluorite indicates that it mainly contains F and Ca (Fig. 5c).

Cotunnite is the natural mineral form of lead (II) chloride with formula PbCl₂. Cotunnite is documented within the studied samples, associated with zircon and the U-bearing accessory minerals. ESEM image and EDX analysis of cotunnite is shown in figure (5d).

6. Geochemistry

The list of major and trace elements concentrations for seven samples of the altered alkali feldspar granite of Wadi El Reddah is presented in table (1).
These data are compared to the less altered average composition of the alkali feldspar granite from other occurrences in Gabal Gattar area (Mahdy et al. 2015). The altered samples plotted in the Na$_2$O-K$_2$O diagram of Cuney et al. (1984); most of the samples showing intensive potassic metasomatism and shifted towards the higher K$_2$O values and desilicification (Fig. 6).

Most major elements show a general decrease in the altered samples compared to the less-altered rock (Table 1). Exceptions to this are K$_2$O, Fe$_2$O$_3$, and MnO, which are important elements incorporated into the highly altered rock due to sericitization of feldspars, chloritization and epidotization, respectively. The formation of typical Sr-bearing Ca minerals (e.g. fluorite, calcite, epidote) were identified in some samples but overall Ca and Sr are depleted. Cobalt, Ni, V and Cr are under the detection limit in most of the altered samples and is depleted in the less altered rock. Primitive mantle-normalized plots (Sun and McDonough, 1989) of the altered granite are shown in Figure (7a). Like the unaffected granite, the studied altered samples show negative anomalies with Ti, P, Sr, and Ba. Marked enrichment of elements such as U, Th, Zr, and Pb due to the mineralization processes is noticed along the studied samples.

Concentrations of REEs are shown in table (2). The REE contents of the altered samples (av. = 104 ppm) are lower than the average contents of the less altered rock (av. = 152 ppm). Chondrite normalized patterns (Sun and McDonough, 1989) (Fig. 7b) indicate that the altered samples show similar REE patterns with depletion in MREE and HREE, and partial depletion in LREE. The REE patterns of all samples are characterized by a negative Eu anomaly and a slightly positive Ce anomaly.

7. Th-U VARIATION

The uranium contents of the analyzed altered samples show enrichment, which ranging from 95 to 256ppm. Uranium enrichment is associated with a relatively weak increase in Thorium from a mean of 23.5ppm in the less altered rock to a mean of 43 ppm in the altered samples (Table 1). The average of Th/U ratios is 0.27 in the altered samples highly lower than the average of the less altered rock (2.6). Figure (8) demonstrates that the decrease in Th/U ratio with increasing uranium concentration results from the accumulation of secondary U minerals in the altered zone. The distribution and variation of U and Th contents show a strong linear decrease in the Th/U ratio with increasing U concentrations. The Th/U ratio appears to be independent of U concentration. These relationships indicate that uranium has been added within the altered zone while thorium has remained relatively fixed.

| Elements | Less altered alkali feldspar granite of Gabal Gattar area (Mahdy et al. 2015) | Radioactive anomaly (RAD-1) | Radioactive anomaly (RAD-2) |
|----------|--------------------------------------------------------------------------|-----------------------------|-----------------------------|
|          |                                                                          | 1  | 2  | 3  | 4  | 5  | 6  | 7  | Average |
| La       | 13                                                                       | 42 | 33 | 30 | 38 | 26 | 21 | 19 | 30       |
| Ce       | 39                                                                       | 71 | 65 | 52 | 61 | 48 | 41 | 38 | 54       |
| Pr       | 7.1                                                                      | 6  | 3.9| 4.1| 4.1| 3.8| 3.1| 2.9| 4.0      |
| Nd       | 29.2                                                                     | 12 | 8.7| 9  | 8.7| 8.3| 7.8| 5.4| 8.6      |
| Sm       | 11                                                                       | 1.5| 1.3| 1.04| 1.1| 1.1| 1.14| 1.12| 1.19   |
| Eu       | 0.13                                                                     | 0.05| 0.07| 0.04| 0.08| 0.07| 0.06| 0.05| 0.06   |
| Gd       | 12.16                                                                    | 0.8 | 0.75| 0.66| 0.6 | 0.68| 0.75| 0.68| 0.70   |
| Tb       | 2.52                                                                     | 0.2 | 0.16| 0.15| 0.15| 0.14| 0.13| 0.13| 0.15   |
| Dy       | 15.18                                                                    | 1.4 | 1.34| 1.15| 1.1 | 1.02| 0.86| 0.84| 1.09   |
| Ho       | 3.3                                                                      | 0.8 | 0.4 | 0.37| 0.3 | 0.31| 0.26| 0.22| 0.38   |
| Er       | 9.2                                                                      | 1.7 | 1.4 | 1.58| 1.4 | 1.2 | 1.1 | 0.95| 1.33   |
| Tm       | 1.49                                                                     | 0.35| 0.31| 0.36| 0.34| 0.34| 0.22| 0.25| 0.31   |
| Yb       | 8.86                                                                     | 3.1 | 3.1 | 3.4 | 2.9 | 2.5 | 2.12| 2.3 | 2.77   |
| Lu       | 1.17                                                                     | 0.56| 0.54| 0.62| 0.52| 0.48| 0.38| 0.44| 0.51   |
| ∑REE     | 152                                                                      | 141| 120| 104| 120| 94 | 80 | 72 | 104     |
Fig. 6: Na$_2$O-K$_2$O variation diagram of Cuney et al. (1984) applied to altered radioactive granite of the study area. +: Average of less altered Gattar granite, ◊: Radioactive anomaly RAD-1, ▲: Radioactive anomaly RAD-2.

Fig. 7: (a) Primitive mantle normalized multi-element diagram and (b) chondrite-normalized REE pattern diagram for the studied altered samples. Normalization according to Sun and McDonough (1989).
8. Conclusions

The data presented indicated that the Gattar granite at Wadi El Reddah area has affected by post-
magmatic hydrothermal solutions, which causing significant changes in their mineralogical, chemical
and radiometrical characteristics. Two radioactive anomalies were documented along brittle structures
in the hydrothermally altered parts of Gattar granite. The metasomatic overprint is characterized by
intense hematitization, desilicification, chloritization and K-metasomatism. The U mineralization is
occurred in disseminated form, represented mainly by kasolite associated with zircon, fluorite and
cotunnite. Major and trace element data revealed enrichment of the elements K, Rb, Zr, Zn and Pb, and
depletion of Si, Sr, and REE. Uranium (av. 174ppm) is enriched during the alteration of granite, while
Th (av. 43ppm) is more stable than U under the effect of hydrothermal fluids. During the late
Quaternary, wet climatic episodes are known to have prevailed in the Egyptian Sahara several times.
This paleoclimate was favorable for leaching and transportation of uranium from the uranium-bearing
minerals in the alkali feldspar granite. Thus, the secondary processes are related to superheated solutions
and meteoric water rather than hydrothermal solutions because the hydrothermal solutions add both U
and Th, but the studied altered granites show enrichment in U with very restricted increase in Th
contents.

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