Data Article

Radiometric and mineralogical dataset of microgranite dykes and stream sediments of Ras Abda area, north Eastern Desert, Egypt

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ABSTRACT

Ras Abda Area is located in the north part of the Eastern desert, and is characterized by a rugged topography and high relief. The main exposed rock units in the area comprise older granites, younger gabbros and granites as well as several types of post granite dykes (rhyolite, basic and microgranite dykes). Radiometric measurements indicated that the microgranite samples are characterized by anomalous concentrations of the radioelements which mean that the rocks originated from radioelements-bearing magma and may be subjected to epigenetic processes of leachability and migration of uranium. The stream sediments samples show low levels of radioactivity where eU ranges from 4.0 to 7.0 ppm with an average of 5.3 ppm, and eTh ranges from 6.0 to 18.0 ppm with an average of 10.65 ppm. The eTh/eU ratio ranges from 1.2 to 3.6 where the samples distal from the microgranite dykes are characterized by the highest eTh/eU ratio (3.6) while those close to the dykes have the lower eTh/eU ratios. Generally, the average eTh/eU ratio (~2.08) is lower than the world ratio (3.5) implying that uranium probably enriched from an adjacent source may be the microgranite dykes. The calculated factors of equilibrium (P and D) indicated disequilibrium state for both rocks types (microgranite and stream sediments) and referred to incomplete U-decay series. Mineralogical studies revealed that the heavy minerals could be classified into: a) radioactive minerals comprising uranophane, kasolite, sklodowskite, thorite and...
uranothorite, and b) radioelements-bearing minerals comprising columbite, fergusonite, samarskite, pyrochlore, allanite, monazite, zircon and fluorite. The heavy minerals are mostly concentrated upstream rather than downstream; meandering portions of the stream may act as natural traps for the heavy minerals.

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1. Specifications Table

| Subject                  | Earth science                                      |
|--------------------------|----------------------------------------------------|
| Specific subject area    | Mineralogy, Radioactivity                          |
| Type of data             | Tables, Plots, Figures                             |
| How data were acquired   | Satellite images, Analysis using NaI, ICP-MS, Microscope, SEM, XRD. |
| Data format              | Raw and Analyzed                                   |
| Parameters for data collection | The satellite images have been used to delineate the radiometric anomalous locations. The studied samples undergo radiometric measurements using a multichannel gamma-spectrometer (NaI Detector). Radioelements concentrations were also measured chemically using (ICP-MS). The samples were prepared for mineralogical investigation with using dense media separation and magnetic separation. The separated minerals were recognized by stereomicroscope, identified by XRD and confirmed by electron scanning microscope (ESEM). |
| Description of data collection | Radiometric dataset were determined and plotted by ArcGIS, ENVI, Sigma plot programs. |
| Data source location     | Ras Abda area, Northern Eastern Desert, Egypt. The area is located between latitudes 26°43′43″ & 26°43′33″ N and longitudes 33°45′31″ & 33°45′49″ E. |
| Data accessibility       | Data are available inside this article.            |

**Value of the Data**

Is to achieve more additional radiometrical and mineralogical data for the microgranite offshoots and the wadi deposit of the area through using different techniques

- The data can be used to understand the radiometry of Ras Abda area.
- The radiometric dataset can provide a proposal for the magma type of Ras Abda microgranites.
- The mineralogical dataset can provide insights on the microgranites dykes and stream sediments of Ras Abda area.
- The data could serve as useful indicators for mineral exploration project to assess the ore potential of an unknown microgranites offshoot.
- The dataset is very useful to other researchers for geochemical exploration.

1. Data

The data set of this article provides more additional radiometrical and mineralogical data for the microgranitic offshoots and the wadi deposits of the area through using different techniques.

The geology of the study Ras Abda area shown in Fig. 1. The results obtained from the satellite imagery are showed in Figs. 2 and 3, and the radiometric maps are displayed in Figs. 4–6. Radiometric measurements on samples indicated that the microgranite dykes are characterized by a high radioactivity as shown in Tables 1 and 3. The high radioactivity of microgranite can be attributed to the presence of several radioactive minerals (uranophane, kasolite, sklodowskite, thorite and uranothorite) in addition to radioelements-bearing minerals (columbite, fergusonite, samarskite, pyrochlore, allanite, monazite, zircon and fluorite) as shown in Fig. 7.
The stream sediments are characterized by low radioactivity (average of eU = 5.3 ppm and eTh = 10.65 ppm, Table 2). Their radioactivity is attributed mainly to the radioelements-bearing minerals. Diagenetic processes such as mobility, leachability and migration of uranium played an
Fig. 3. Landsat false composite color image with band ratios (4/2, 5/6 & 6/7) in RGB colors for Ras Abda area.

Fig. 4. Variation diagrams of U–Th concentrations for the microgranite of Ras Abda showing: a) eU vs eTh b) eU vs Uc.

Fig. 5. Variation diagrams of eTh/eU ratio vs eU for the studied rocks of Ras Abda showing: a) eU vs eTh/eU for the microgranite, b) eU vs eTh/eU for the stream sediments.
essential role in lowering the radioactivity of these sediments. The average eTh/eU ratio (about 2.08) is lower than the world ratio (3.5). The low radioactivity of the stream sediments is attributed to development of the sediments under condition where uranium content was removed due to continuous leaching of rock detritus.

Table 1
Radiometric measurements of eU, eTh, Ra (ppm) & K40% for Ras Abda microgranite.

| S. No. | Latitude  | Longitude | eU   | eTh  | Ra  | K40% | eTH/eU | eU/Ra |
|--------|-----------|-----------|------|------|-----|------|--------|-------|
| T1     | 26.72444  | 33.76278  | 175  | 875  | 111 | 5.7  | 5.0    | 1.6   |
| T2     | 26.723889 | 33.7625   | 483  | 1724 | 183 | 0.6  | 3.6    | 2.6   |
| T3     | 26.723889 | 33.7599   | 615  | 1999 | 240 | 12.1 | 3.3    | 2.6   |
| T4     | 26.72361  | 33.759722 | 820  | 5730 | 342 | 0.6  | 7.0    | 2.4   |
| T5     | 26.72361  | 33.7644   | 33   | 143  | 17  | 2.7  | 4.33   | 1.9   |
| T6     | 26.725    | 33.776    | 29   | 310  | 27  | 0.8  | 10.7   | 1.1   |
| Average| 267       | 1010.2    | 115.6| 3.7  | 5.6 | 1.9   |         |       |

Fig. 6. Geochemical maps showing distribution of the radioelements in the rock units of Ras Abda area. a) eU(ppm), b) eTh(ppm), c) 40K(ppm) and d) Ra(ppm).
Fig. 7. ESEM spectrograph, BSE image and stereophotograph for (a) Uranophane, (b) Kasolite, (c) Sklodowskite, (d) Thorite, (e) Uranothorite, (f) Columbite, (g) Fergusonite, (h) Samarskite, (i) Pyrochlore, (j) Allanite, (k) Monazite, (l) Zircon and (m) Fluorite minerals from Ras Abda studied samples.
The SEM and EDX data were shown in Fig. 7 and Table 4, and the XRD data were shown in Tables 5 and 6.

2. Experimental design, materials, and methods

Radioactivity is a natural phenomenon exhibited by rocks due to the presence of natural radioactive isotopes and their radioactive daughter products. Naturally radioactive is contributed by several sources comprising naturally occurring radioactive isotopes (K⁴⁰, Th²³², U²³⁵ and U²³⁸).

Geological maps, and satellite images have been used to delineate the radiometric anomalous locations in the study area. Landsat Multispectral Scanner (MSS) and thematic Mapper (TM) images enable the investigation of land systems and geological terrains over large areas. The discrimination potential of multispectral image data depends mainly on the wavelength range and spectral resolution of remote sensing instrument.

Six samples from the microgranite dikes were collected beside ten grab samples from the stream sediments were selected to measure the Uranium (eU), thorium (eTh), radium (Ra) and potassium (K⁴⁰) contents radiometrically.

Stream sediment samples were prepared for analyses by drying to remove the water content, splitting using the John’s splitter and rotary splitter to obtain a representative batch. Rock samples are crushed to about 1mm grain size, a portion of the sample weighting about 300–400 g stored in plastic containers, sealed well and left for 30 days to accumulate free radon to attain radioactive equilibrium [1].

Uranium (eU), thorium (eTh), radium (Ra) and potassium (K⁴⁰) are measured by using four energy regions representing Th-234, Pb-212, Pb-214 and K-40 at 93Kev, 239Kev, 352Kev, and 1460Kev for U, Th, Ra and K⁴⁰ respectively.

The measurements were carried out in the laboratories of the Nuclear Material Authority (NMA) of Egypt, using a multichannel gamma-spectrometer. The instrument consists of a hermetically sealed Bicron Scintillation Detector NaI (TI) 76 × 76 mm, with the photomultiplier tube in an aluminum housing. The tube is protected by a copper cylinder protection 0.6 cm thick against induced X-rays, and

Table 2
Radiometric measurements of eU, eTh & Ra (ppm) and K⁴⁰ for Ras Abda stream sediments.

| S. No. | Latitude | Longitude | eU  | eTh  | Ra  | K⁴⁰ | eTh/eU | eU/Ra |
|--------|----------|-----------|-----|------|-----|-----|--------|-------|
| S1     | 26.7283  | 33.7811   | 5.0 | 14.5 | 4.0 | 1.3 | 2.9    | 1.3   |
| S2     | 26.7267  | 33.7783   | 5.0 | 18.0 | 6.0 | 1.9 | 3.6    | 0.8   |
| S3     | 26.7236  | 33.7732   | 5.0 | 11.0 | 3.0 | 2.0 | 2.2    | 1.7   |
| S4     | 26.7197  | 33.7725   | 5.0 | 15.0 | 2.0 | 1.5 | 2.5    | 3.0   |
| S5     | 26.7214  | 33.7686   | 5.0 | 6.0  | 2.0 | 1.2 | 1.2    | 2.5   |
| S6     | 26.7211  | 33.7658   | 5.0 | 7.0  | 1.0 | 1.5 | 1.4    | 5.0   |
| S7     | 26.7228  | 33.7658   | 5.0 | 10.0 | 5.0 | 1.2 | 2.0    | 1.0   |
| S8     | 26.7239  | 33.7639   | 4.0 | 8.0  | 2.0 | 1.7 | 2.0    | 2.0   |
| S9     | 26.7242  | 33.76189  | 7.0 | 7.0  | 2.0 | 1.4 | 1.0    | 3.5   |
| S10    | 26.7242  | 33.7589   | 6.0 | 12.0 | 3.0 | 1.7 | 2.0    | 2.0   |
| Average|          |           | 5.3 | 10.65| 3.0 | 1.54| 2.08   | 2.28  |

Table 3
Chemical analysis of U-concentration and Uc/eU for Ras Abda microgranite.

| Sample No. | Uc     | Uc | Uc/eU |
|------------|--------|----|-------|
| T1         | 291.3  | 175.0| 1.7   |
| T2         | 638.7  | 483.0| 1.3   |
| T3         | 780.6  | 615.0| 1.3   |
| T4         | 929.4  | 820.0| 1.1   |
| T5         | 65.4   | 33.0 | 2.0   |
| T6         | 42.5   | 29.0 | 1.5   |
| Average    | 363.7  | 267 | 1.5   |
the chamber is made of lead bricks to protect for environmental radiation hazards. The detector is covered by a lead cover (5 cm thick), and is connected to an amplifier, (model NE-4658) with a high voltage power supply, (model TC 952) with the high voltage display. It is also connected with a nucleus PCA-8000 computer based on an 8192 multichannel analyzer, with color graphic display of spectra and high level technical operation features, and an Epson FX-80 (Printer).

Uranium concentrations were also measured chemically using the Inductive Coupled Plasma Mass Spectrometer (ICP-MS) of ACME Lab in Vancouver, Canada with a detection limit ranges between (0.1–4000 ppm).

Two conventional heavy liquids were used to concentrate the heavy economic minerals. Bromoform (specific gravity of 2.8 g/cm3) was used to separate the quartz and feldspars from the total heavy minerals. Then Methylene Iodide (di-iodomethane) (specific gravity of 3.3 g/cm3) was used to reduce the size of the obtained heavy fractions to facilitate the magnetic separation, besides removal of part from green silicate (olivine, pyroxenes, epidote, kyanite, hornblend, and amphiboles). Then Magnetite grains (ferromagnetic mineral) were removed from each concentrate with a hand magnet. Finally the magnetic field strengths were chosen to separate the sample into five fractions: together with the magnetite fraction, ilmenite and garnet were separated in the highly magnetic fraction (0.2Mag.), the rest of garnet, columbite, and monazite separated in the next magnetic fraction (0.5Mag.), the rest of monazite separated in the third fraction (1.0Mag.), the brown rutile separated in fraction (1.5Mag.), and the last

| Table 4 |
|----------------|
| Chemical analysis of (a) Uranophane, (b) Kasolite, (c) Sklodowskite, (d) Thorite, (e) Uranothorite, (f) Columbite, (g) Fergusonite, (h) Samarskite, (i) Pyrochlore, (j) Allanite, (k) Monazite, (l) Zircon and (m) Fluorite minerals separated from Ras Abda samples. |
| (a) Uranophane |
| (b) Kasolite |
| (c) Sklodowskite |
| (d) Thorite |
| (e) Uranothorite |
| (f) Columbite |
| (g) Fergusonite |
| (h) Samarskite |
| (i) Pyrochlore |
| (j) Allanite |
| (k) Monazite |
| (l) Zircon |
| (m) Fluorite |
| (n) Total |

| Element | Wt % | Element | Wt % | Element | Wt % | Element | Wt % | Element | Wt % | Element | Wt % |
|---------|------|---------|------|---------|------|---------|------|---------|------|---------|------|
| Al      | 2.92 | Si      | 15.89| Mg      | 6.46 | Al      | 1.42 | Al      | 0.83 | Al      | 1.09 |
| Si      | 11.06| Pb      | 54.87| Al      | 2.53 | Si      | 10.53| Si      | 6.27 | Si      | 3.06 |
| Ca      | 7.53 | U       | 29.24| Si      | 13.13| Pb      | 2.03 | Ca      | 3.65 | Y      | 2.43 |
| Ti      | 6.64 | P       | 3.29 | U       | 13.31| Nd      | 0.82 | Ti      | 3.01 |
| Fe      | 1.57 | K       | 1.61 | Ca      | 0.42 | Fe      | 2.03 | Fe      | 2.85 | Fe      | 4.44 |
| Pb      | 7.88 | Fe      | 1.71 | Ti      | 1.71 | Th      | 64.16| Th      | 67.04| Ta      | 2.84 |
| U       | 62.41| U       | 70.86| Zr      | 5.83 | U       | 11.66| Nb      | 70.61| Zr      | 5.08 |
| Nb      | 3.13 | Si      | 3.76 | Al      | 3.96 | Si      | 19.49| Al      | 0.55 | Al      | 1.9  |
| Si      | 3.44 | Y      | 1.59 | Si      | 3.87 | Ca      | 3.46 | Si      | 5.07 | Si      | 23.32|
| Th      | 6.55 | Th     | 3.75 | U       | 5.86 | Ti      | 14.45| P      | 18.17| Fe      | 4.68 |
| U       | 5.6  | Ca     | 9.34 | Ca      | 1.62 | La     | 14.41| U      | 2.25 | Hf      | 2.22 |
| Ca      | 1.92 | Ti     | 12.35| Ti      | 0.56 | Ce     | 22.42| Ca      | 2.59 | Zr      | 67.87|
| Ti      | 0.8  | Nd     | 1.88 | Ce     | 1.68 | Pr     | 1.53 | La     | 15.09| Total   | 100  |
| Nd      | 0.39 | Mn     | 1.99 | Nd     | 2.68 | Nd     | 8.64 | Pr     | 3.43 | (m) Fluorite | Element | Wt % |
| Dy      | 5.76 | Fe     | 2.31 | Fe     | 1.95 | Sm     | 1.11 | Nd     | 10.59| Total   | 100  |
| Er      | 5.5  | Ta     | 3.85 | Co     | 2.76 | Gd     | 0.93 | Ce     | 28.67| F      | 29.45 |
| Yb      | 6.94 | U      | 23.48| Yb     | 12.58| Fe     | 13.55| Sm     | 1.87 | Si      | 0.81 |
| Ta      | 1.84 | Nb     | 35.7 | Ta     | 3.05 | Gd     | 1.21 | Y      | 2.07 |
| Y       | 17.39| Th     | 5.63 | Fe     | 1.2  | Ca      | 67.67|
| Nb      | 41.51| Y      | 18.54| Th     | 9.3  | Nb     | 35.25|
| Total   | 100  | Total  | 100  | Total  | 100  | Total  | 100  | Total  | 100  | Total  | 100  |
Table 5
X-ray diffraction data of (a) Uranophane, (b) Kasolite, (c) Sklodowskite, (d) Thorite and (e) Uranothorite minerals separated from Ras Abda samples.

|                        | (a) Uranophane | (b) Kasolite | (c) Sklodowskite | (d) Thorite | (e) Uranothorite |
|------------------------|----------------|--------------|------------------|-------------|-----------------|
| Analyze sample         | ASTYM card (08–442) | ASTYM card (08–0297) | ASTYM card (29–0875) | ASTM card (11–419) | ASTM card (08–393) |
| $d$ (Å)                | $l/lo$         | $d$ (Å)      | $l/lo$           | $d$ (Å)      | $l/lo$           | $d$ (Å)      | $l/lo$           | $d$ (Å)      | $l/lo$           | $d$ (Å)      | $l/lo$           |
| 7.90                   | 95             | 7.88         | 100              | 6.50        | 20              | 6.61         | 60              | 8.49        | 100             | 8.42         | 100             |
| 6.61                   | 25             | 6.61         | 40               | 6.11        | 9               | 6.19         | 20              | 6.43        | 13              | 6.37         | 20              |
| 5.40                   | 35             | 5.42         | 40               | 5.25        | 6               | 5.31         | 40              | 5.93        | 18              | 5.91         | 50              |
| 4.82                   | 30             | 4.76         | 50               | 4.20        | 21              | 4.19         | 80              | 4.84        | 6               | 4.82         | 40              |
| 4.27                   | 16             | 4.29         | 20               | 3.53        | 34              | 3.53         | 70              | 4.35        | 12              | 4.33         | 40              |
| 3.93                   | 75             | 3.94         | 90               | 3.35        | 14              | 3.38         | 10              | 4.20        | 34              | 4.19         | 80              |
| 3.59                   | 19             | 3.60         | 40               | 3.25        | 100             | 3.26         | 100             | 4.06        | 15              | 4.00         | 50              |
| 3.51                   | 25             | 3.51         | 40               | 3.06        | 32              | 3.07         | 50              | 3.54        | 41              | 3.52         | 50              |
| 3.21                   | 35             | 3.20         | 50               | 2.92        | 40              | 2.93         | 90              | 3.26        | 31              | 3.27         | 70              |
| 3.00                   | 74             | 2.99         | 80               | 2.73        | 13              | 2.73         | 30              | 3.00        | 16              | 3.00         | 60              |
| 2.91                   | 60             | 2.91         | 80               | 2.64        | 4               | 2.64         | 30              | 2.89        | 17              | 2.87         | 50              |
| 2.70                   | 19             | 2.69         | 40               | 2.36        | 6               | 2.73         | 20              | 2.79        | 10              | 2.80         | 20              |
| 2.63                   | 14             | 2.63         | 50               | 2.18        | 14              | 2.18         | 30              | 2.12        | 13              | 2.13         | 30              |
| 2.20                   | 9              | 2.20         | 40               | 1.96        | 12              | 1.69         | 50              | 2.09        | 6               | 2.09         | 30              |
| 2.10                   | 11             | 2.10         | 50               | 1.74        | 10              | 1.74         | 40              | 1.97        | 5               | 1.98         | 20              |
| 1.97                   | 25             | 1.96         | 70               | 1.86        | 3               | 1.68         | 50              | 1.97        | 5               | 1.98         | 20              |

M. Hassan et al. / Data in brief 27 (2019) 104711
Table 6
X-ray diffraction data of (a) Columbite, (b) Fergusonite, (c) Samarskite, (d) Pyrochlore, (e) Allanite, (f) Monazite, (g) Zircon and (h) Fluorite minerals separated from Ras Abda samples.

| (a) Manganese-Columbite | (b) Fergusonite | (c) Samarskite | (d) Pyrochlore |
|-------------------------|---------------|---------------|--------------|
| Analyze sample ASTM card (45–1360) | Analyze sample ASTM card (09–0443) | Analyze sample ASTM card (10–398) | Analyze sample ASTM card (13–0254) |
| $d_A$ | $I/I_0$ | $d_A$ | $I/I_0$ | $d_A$ | $I/I_0$ | $d_A$ | $I/I_0$ |
| 7.14 | 5 | 7.13 | 2 | 3.14 | 100 | 3.12 | 100 | 4.04 | 8 | 4.03 | 20 |
| 3.66 | 44 | 3.65 | 79 | 3.00 | 35 | 3.01 | 20 | 3.23 | 20 | 3.23 | 30 |
| 2.97 | 100 | 2.97 | 100 | 2.97 | 28 | 2.96 | 90 | 3.15 | 15 | 3.13 | 40 |
| 2.86 | 6 | 2.86 | 25 | 2.70 | 39 | 2.74 | 40 | 2.98 | 100 | 2.98 | 100 |
| 2.49 | 14 | 2.49 | 24 | 2.52 | 29 | 2.53 | 10 | 2.93 | 20 | 2.92 | 90 |
| 2.38 | 6 | 2.37 | 5 | 2.15 | 5 | 2.16 | 6 | 2.58 | 22 | 2.59 | 6 |
| 2.24 | 7 | 2.24 | 2 | 1.92 | 46 | 1.90 | 50 | 2.52 | 13 | 2.52 | 20 |
| 2.21 | 8 | 2.21 | 8 | 1.84 | 15 | 1.86 | 30 | 1.92 | 9 | 1.91 | 20 |
| 1.77 | 8 | 1.77 | 9 | 1.64 | 39 | 1.65 | 10 | 1.87 | 7 | 1.86 | 20 |
| 1.73 | 13 | 1.737 | 16 | 1.49 | 8 | 1.50 | 6 | 1.83 | 39 | 1.83 | 20 |
| 1.72 | 12 | 7.72 | 17 | | | | | 1.71 | 5 | 1.71 | 20 |
| | | | | | | | | 1.56 | 30 | 1.56 | 30 |

| (e) Allanite | (f) Monazite | (g) Zircon | (h) Fluorite |
|-------------|-----------|--------|--------|
| Analyze sample ASTM card (21–146) | Analyze sample ASTM card (11–0556) | Analyze sample ASTM card (06–0266) | Analyze sample ASTM card (04–0864) |
| $d_A$ | $I/I_0$ | $d_A$ | $I/I_0$ | $d_A$ | $I/I_0$ | $d_A$ | $I/I_0$ |
| 9.32 | 20 | 9.2 | 40 | 4.18 | 13 | 4.17 | 25 | 4.47 | 25 | 4.43 | 45 |
| 8.12 | 12 | 8.0 | 40 | 3.50 | 22 | 3.51 | 25 | 3.32 | 100 | 3.30 | 100 |
| 3.54 | 46 | 3.53 | 50 | 3.30 | 83 | 3.30 | 50 | 2.66 | 3 | 2.65 | 8 |
| 3.30 | 36 | 3.32 | 20 | 3.09 | 100 | 3.09 | 100 | 2.53 | 35 | 2.52 | 45 |
| 2.93 | 100 | 2.92 | 100 | 2.87 | 25 | 2.87 | 70 | 2.34 | 10 | 2.34 | 10 |
| 2.89 | 30 | 2.83 | 10 | 2.19 | 10 | 2.19 | 18 | 2.22 | 2 | 2.22 | 8 |
| 2.72 | 52 | 2.71 | 60 | 2.15 | 18 | 2.15 | 25 | 2.07 | 24 | 2.07 | 20 |
| 2.63 | 41 | 2.63 | 50 | 2.10 | 7 | 2.13 | 25 | 1.91 | 9 | 1.91 | 14 |
| 2.56 | 9 | 2.56 | 20 | 1.97 | 29 | 1.961 | 25 | 1.76 | 14 | 1.75 | 12 |
| 2.14 | 17 | 2.14 | 20 | | | | | 1.72 | 34 | 1.71 | 40 |
| 1.90 | 8 | 1.893 | 20 | | | | | 1.65 | 19 | 1.65 | 14 |
| 1.64 | 12 | 1.639 | 50 | | | | | 1.48 | 5 | 1.48 | 8 |
| | | | | | | | | 1.38 | 11 | 1.38 | 10 |
fraction represent the rest of reddish rutile and zircon (1.5 Non Mag.) [2]. The separated minerals were recognized by stereomicroscope, identified by XRD and confirmed by electron scanning microscope (ESEM) in the labs of Egyptian Nuclear Materials Authority.

2.1. Geological setting

The Eastern Desert of Egypt is occupy the north part of the Arabian-Nubian Shield [3]. It is dissected by two major shear zone into north, center and south Eastern desert [4]. Ras Abda area is located at the extreme southern part of the northern Eastern Desert of Egypt at, about 20 km westward Safaga City at the Red Sea coast. The area can be easily accessed via a newly established part of Qena-Safaga asphaltic road, along Wadi Barud Al Abyad, which runs directly to the north of the area. The study area is bound by latitudes 26° 43' 20" & 26° 43' 33" N and longitudes 33° 45' 31" & 33° 45' 49" E (Fig. 1). The area is characterized by moderate to high topography relative to its surroundings.

The area is mostly dominated by the older granitoid rocks ranging in composition from granodiorite to quartz diorite. They are intruded by younger gabbro in the northern part. The younger granites are present as small bodies intruding the older granite in the southern part and as a microgranitic offshoots outcropping in the central part of the area and extending southward (Fig. 1).

The basic dykes are intersected by acidic ones. The acidic dykes are less abundant but the largest in terms of size and space compared to the basic ones. They are mainly of rhyolite, and microgranite composition. They are encountered at the northeastern part and extend to the southwestern part of the area. Also, the rhyolite dykes occupy the middle area and extend from the extreme southwest to the northeast. They form high and huge blocks, with irregular shapes [5,6].

At the western part of wadi Ras Abda, the microgranitic dykes are present as swarms of abnormal high radioactivity and poly-mineralization. They are restricted to a highly deformed, faulted, and sheared narrow zone. The zone has been split into two parts under the action of a NW-SE left lateral strike-slip fault (Fig. 1).

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. 1). The NW-trending faults are the oldest fracture planes, followed by the NE orientations. On the other hand the area is dissected by joints generally trending in the N 20°W and N70°E directions [7].

2.2. The satellite imagery data

Multispectral remote-sensing has been successfully used for lithological and mineral mapping especially with the development of the remote-sensing sensors and mathematical algorithms that provided detailed information about the mineralogy of the different rock types comprising the earth’s surface [8]. The detection of hydrothermally altered areas, which are potential sites for mineral deposits using multispectral or hyper-spectral remote sensing was discussed by many authors [9].

For the image analysis of the Landsat-8 (TM) images, a false color composite RGB images were made of bands 7, 6 and 1 and with band ratio 4/2, 5/6 and 6/7, to discriminate the boundary of rock units depending on the color difference and photo geological characteristics of rocks. On the 7, 6, 1 image, the Quaternary deposits of the wadi sediments have a light white color, the older granites are greenish brown, while the younger granites have brown color and the younger gabbro have blue color (Fig. 2). Based on the band ratio image, reddish areas are rich with iron oxide and represent granites, dark greenish areas are rich with (Fe & Mg) minerals as olivine and represent gabbro, light greenish areas represent stream sediments and bluish area represent volcanic rocks (Fig. 3).

2.3. Radioactivity

2.3.1. Radiometric measurements

The microgranite samples are characterized by anomalous concentrations of the radioelements: eU varies from 29 to 820 ppm, with an average 267 ppm, and eTh ranges between 143 and 5730 ppm with an average 1010 ppm (Table 1) [10]. suggested 3.5 to 4 for the Th/U ratios in the world granites. In the
present study the ratio $e_{\text{Th}}/e_{\text{U}}$ fluctuates between natural ($3.3 \pm 3.6$) and high ratios ($4.33 \pm 10.7$) with general average about 5.6 higher than the world average of granitic rocks (3.5) indicating that the rock originated from radioelements-bearing magma and may be subjected to epigenetic processes of leachability and migration of uranium. They are considered as the source of radioactive minerals like zircon, monazite, columbite, fergusonite, thorite and uranathorite.

The stream sediment samples show low level of radioactivity where $e_{\text{U}}$ ranges from 4.0 to 7.0 ppm with an average 5.3 ppm, and $e_{\text{Th}}$ ranges from 6.0 to 18.0 ppm with an average 10.65 ppm (Table 2). The $e_{\text{Th}}/e_{\text{U}}$ ratio ranges from 1.2 to 3.6; the sample distal from the microgranite dykes characterized by the highest ratio (3.6) while those close to the dykes have the lower ratios (1.0–2.9). Generally, the average $e_{\text{Th}}/e_{\text{U}}$ ratio (about 2.08) is lower than the world ratio (3.5) indicating that uranium may be enriched from the adjacent source.

Radioactivity is mostly restricted in the inner parts of coarse rock fragments containing detrital radioactive minerals like zircon, monazite, columbite, fergusonite, thorite and uranathorite that may be transported from the adjacent microgranite dykes.

[11] stated that uranium mineralization is affected by different processes (leaching, mobility and redistribution of uranium). These processes are affected by hydrothermal solution and/or supergene fluids, which cause disequilibrium in the radioactive decay series in the U-bearing rocks. The activity ratio (AR) can be used to ascertain the equilibrium state: if the value is around the unity (1), there is an equilibrium state. When the value is more or less than the unity, it would indicate a state of disequilibrium [12]. The radioactive equilibrium of any rock can be determined by the calculation of activity ratio (AR) or equilibrium factor ($P_{\text{factor}}$) which is the ratio of radiometric uranium contents ($e_{\text{U}}$) to the radium content $Ra$, ($P_{\text{factor}} = e_{\text{U}}/Ra$) [13].

The ratio calculated for the studied microgranite ranging between 1.1 and 2.6 with an average about 1.9 (Table 1), which is higher than (1) indicating disequilibrium in U-decay series.

The stream sediments of Ras Abda are characterized by disequilibrium state with $P_{\text{factor}}$ ranging between 0.8 and 5.0 with an average about 2.28 (Table 2). Nine samples with $P_{\text{factor}}$ more than the unity and only one approaching the unity indicate that they are recent deposits; and uranium ($U^{238}$ series) may attain the equilibrium state in nearly 1.5 M.a. according to Ref. [14].

2.3.2. Geochemistry of $U$ and $Th$

ICPMS uranium concentrations ($U_{c}$) of the studied microgranites show that $U_{c}$ (average 363.7 ppm) is higher than $e_{\text{U}}$ (267 ppm) that measured radiometrically (Table 3), indicating that U-decay series is incomplete.

A second method for determining the radioactive equilibrium is using the ratio between chemically and radiometric measurements of uranium or $D_{\text{factor}}$, where $D_{\text{factor}} = U_{c}/e_{\text{U}}$ [15]. The factor calculated for the microgranite samples ranges between 1.1 and 2.0 with an average 1.5 indicating that the $U_{c}$ is greater than the $e_{\text{U}}$ reflecting a disequilibrium state (Table 3).

The relation between U and Th is helpful to know if there is enrichment or depletion of U and Th. The geochemical behavior of U and Th in the studied microgranitic rocks are examined by plotting a number of variation diagrams. The variation diagrams of resp. $e_{\text{U}}$ and $e_{\text{Th}}$ with their ratios are used to indicate the amount of U remobilization that occurred within the magmatic plutons [16].

The variation diagram of $e_{\text{U}}$ and $e_{\text{Th}}$ for the studied microgranitic rocks (Fig. 4a) shows positive correlation which, indicates that magmatic processes played an important role in the concentration of radioelements [17].

The relation between $e_{\text{U}}$ and $U_{c}$ for the studied microgranites rocks (Fig. 4b) shows strong positive correlation, which indicates that both magmatic processes and hydrothermal solutions played an important role in the concentration of radioelements [17].

The variation between $e_{\text{U}}$ content and $e_{\text{Th}}/e_{\text{U}}$ ratios of the microgranites and stream sediments (Fig. 5a,b) shows negative correlation, which suggests that, the distribution of radioactive elements is not only magmatic but also due to hydrothermal redistribution of radioelements [17].

2.3.3. Radiometric distribution maps

Using Arc GIS program Version, 10.2, four geochemical distribution maps for the concentration of $e_{\text{U}}$, $e_{\text{Th}}$, $K^{40}$ and $e_{\text{Ra}}$ were constructed (Fig. 6).
From the obtained results of the satellite imagery and the radiometric maps, it is clear that, the highest radioactive zone in the study area is associated with the presence of granitic rocks especially the microgranitic rocks. The low radioactivity of the stream sediments suggests that the sediments may developed under condition where uranium content was removed due to continuous leaching of rock detritus.

3. Mineralogy

The heavy minerals separated from the studied microgranite and stream sediments could be categorized in two groups: A) Radioactive minerals and B) Radioelements-bearing minerals.

3.1. Radioactive minerals

This group comprises uranium and thorium bearing minerals and is represented mainly by uranophane, kasolite, sklodowskite, thorite and uranothorite.

1 Uranophane \([\text{Ca (UO}_2\text{) 2SiO}_3\text{ (OH)}_2\text{ 5(H}_2\text{O)}]\]

Uranophane is found in the microgranite samples. The separated grains occur as massive with granular forms ranging in color from yellow to pale canary yellow with dull and greasy luster. The EDX/BSE images (Fig. 7a), the EDX chemical analysis data indicates the presence of U (62.41 wtWt. %), Ca (7.53 Wt. %), Si (11.06 Wt. %), Ti (6.64 Wt. %) and Pb (7.88 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of uranophane is shown in Table 5.

2 Kasolite \([\text{Pb (UO}_2\text{) (SiO}_4\text{)( H}_2\text{O)}]\]

This mineral occurs as small prismatic aggregates ranging in color from yellow to yellowish orange with resinous luster recorded in the microgranite samples, The EDX/BSE images (Fig. 7b), the EDX chemical analysis data indicate the presence of U (29.24 Wt. %), Pb (54.87 Wt. %) and Si (15.89 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of kasolite is shown in Table 5.

3 Sklodowskite \([\text{Mg (UO}_2\text{)2 (SiO}_3\text{)2 (OH)}_2\text{ 6H}_2\text{O]}\]

Sklodowskite is recorded in the microgranite samples. The separated grains occur as massive with granular form ranging in color from pale yellow to brownish yellow with dull and earthy luster. The EDX/BSE images (Fig. 7c), the EDX chemical analysis data indicate the presence of U (70.86 Wt. %), Si (13.13 Wt. %), and Mg (6.46 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of sklodowskite is shown in Table 5.

4 Thorite \([\text{ThSiO}_4]\]

Thorite recorded in stream sediment samples and microgranite rock samples, it has black to brown color and euhedral to subhedral crystals. The EDX/BSE images (Fig. 7d), the EDX chemical analysis data indicate the presence of Th (64.16 Wt. %), U (13.31 Wt. %), Si (10.53 Wt. %) and Zr (5.83 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of thorite is shown in Table 5.

5 Uranothorite \([\text{(Th, U) SiO}_4]\]

Uranothorite in the studied area occurs as subhedral to anhedral grains. The majority of uranothorite grains are angular to subrounded prismatic. It recorded in microgranite samples and stream sediment samples beside the microgranite rocks samples. The EDX/BSE images (Fig. 7e), the EDX
chemical analysis data indicate the presence of Th (67.04 Wt. %), U (11.66 Wt. %), Si (6.27 Wt. %) and Zr (5.08 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of uranothorite is shown in Table 5.

3.2. Radioelements-bearing minerals

This group comprises the minerals that are composed mainly of trace elements including the radionuclides as substantial constituents. They are represented by the minerals of Nb–Ta series (columbite, fergusonite and samarskite) in addition to pyrochlore, allanite, zircon, fluorite and monazite.

1 Columbite [(Fe, Mn) Nb2O6]

The mineral recorded in both stream sediment samples and microgranite rock samples as small black, flattened, short prismatic crystal habit with smooth surface. The mineral have semi-resinous luster. The EDX/BSE images (Fig. 7f), the EDX chemical analysis data indicate the presence of Nb (70.61 Wt. %), Mn (12.51 Wt. %), Fe (4.44 Wt. %), Ti (3.01 Wt. %) and Ta (2.84 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of mangano-columbite is shown in Table 6.

2 Fergusonite [(Y, Er) (Nb, Ta) O4]

Fergusonite have brown color with no specific crystal shape but usually metamictized. The origin of the mineral is considered as the pegmatites and microgranite and it recorded in stream sediment samples and microgranite rock samples. The EDX/BSE images (Fig. 7g), the EDX chemical analysis data indicate the presence of Nb (41.51 Wt. %), Y (17.39 Wt. %), Yb (6.94 Wt. %), Th (6.55 Wt. %), Dy (5.76 Wt. %), U (5.6 Wt. %) and Er (5.5 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of fergusonite is shown in Table 6.

3 Samarskite [(Ca, REE, U, Th) (Nb,Ta,Ti)2 O8]

Samarskite is generally massive with a granular form. They are characterized by a splendid vitreous or resinous luster. They are mainly of velvet - reddish brown to bloody red in color. They are generally translucent, compact, metamict and hard. Samarskite is usually found in stream sediment samples and microgranite rock samples in appreciable amounts and distributed in all size fractions with a tendency to increase with decreasing grain size. The EDX/BSE images (Fig. 7h), the EDX chemical analysis data indicate the presence of Nb (35.7 Wt. %), U (23.48 Wt. %), Ti (12.35 Wt. %), Ca (9.34 Wt. %), Ta (3.85 Wt. %) and Th (3.75 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of samarskite is shown in Table 6.

4 Pyrochlore [(Na, Ca, U) (Nb, Ta)2 O6 (OH, F)]

The pyrochlores have a general formula A2B2O6(O,OH,F), where U4+ (or U6+) occurs in the A site and B = Ta, Nb [18,19]. Pyrochlore is present in the microgranite rock samples. The separated grains shown massive metamict brownish red color with adamantine luster. The EDX/BSE images (Fig. 7i), the EDX chemical analysis data indicate the presence of Nb (35.25 Wt. %), Y (18.54 Wt. %), Yb (12.58 Wt. %), U (5.86 Wt. %) and Th (5.63 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of pyrochlore is shown in Table 6.

5 Allanite [Ca (Ce, Ca) Al (Al, Fe) (Fe, Al) (Si2O7) (SiO4) O (OH)]

Allanite recorded in the microgranite rock sample and present in rare percentage in stream sediment samples. It shows a translucent brownish black color, euhedral to subhedral crystals with
vitreous luster. The EDX/BSE images (Fig. 7j), the EDX chemical analysis data indicate the presence of Ce (22.42 Wt. %), Si (19.49 Wt. %), Ti (14.45 Wt. %), La (14.41 Wt. %), Fe (13.55 Wt. %) and Nd (8.64 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of allanite is shown in Table 6.

6 Monazite [(Ce, La, Nd, Th) PO4]

It is a rare earth phosphate of highly variable composition. Monazite is widely disseminated in all rocks as well as the detrital sediments. It exhibits high content from thorium and uranium, therefore, it documented as radioactive mineral. Monazite exhibits shape varies from rounded to oval. Their color ranges from honey to yellowish brown to blue (Fig. 7k). They occur as accessory mineral in the fine sand size fractions in the stream sediments and microgranite. The EDX/BSE images (Fig. 7k), the EDX chemical analysis data indicate the presence of Ce (28.67 Wt. %), P (18.17 Wt. %), La (15.09 Wt. %), Nd (10.59 Wt. %), Th (9.3 Wt. %) and U (2.25 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of monazite is shown in Table 6.

7 Zircon [ZrSiO4]

Zircon is a common accessory mineral in the study samples. It has grain size lies in the medium and fine sand sizes. They variable in its appearance, their color varies from colorless, pale yellow, reddish yellow and honey with vitreous luster (Fig. 7l). The variation in the color of zircon may be attributed to the density of fine inclusions as well as the degree of iron oxides staining. Zircon separated in the magnetic field 1.5A, using the Frantz Isodynamic Separator. The EDX/BSE images (Fig. 7l), the EDX chemical analysis data indicate the presence of Zr (67.87 Wt. %), Si (23.32 Wt. %), Fe (4.68 Wt. %) and Hf (2.22 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of zircon is shown in Table 6.

8 Fluorite [CaF2]

The separated grains occur as massive form ranging in color from colorless to deep violet with vitreous luster. A positive relation between color of fluorite and the accompanying uranium minerals or to the presence of Y in particular [20]. The EDX/BSE images (Fig. 7m), the EDX chemical analysis data indicate the presence of Ca (67.67 Wt. %), F (29.45 Wt. %) and Y (2.07 Wt. %) as shown in Table 4, and the X-ray diffraction analysis data of fluorite is shown in Table 6.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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