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Radioactive and Geochemistry Characteristics of the Garnetiferous Granite of Um Sleimat Area, Egypt

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Abstract: This study presents a study of radioactive, geochemical features and radiation dose of garnetiferous granite of Um Sleimat area, which located 80 km south of Marsa Alam on the Red Sea coast. The gamma radiation in samples was measured, employing high-resolution γ-ray spectroscopy. The rock samples were measured in the laboratory with an accumulating time between 10 and 14 h each. From the measured γ-ray spectra, activity concentrations were determined for ^{226}Ra (from 45.5±7 to 130±11 with average 77.9±8.7 Bq kg^{-1}), ^{232}Th (range from 36.7±6 to 77.5±9 with average 52.8±7.2 Bq kg^{-1}) and ^{40}K (from 1299.7±36 to 1521.6±39 with average 1424.9±38 Bq kg^{-1}). To assess the radiological hazard of the natural radioactivity in the samples, the radium equivalent activity, the absorbed dose rate and the external hazard index were calculated. Radium-equivalent activities (Ra_{eq}) for all granite samples were less than the maximum limit 370 Bq kg^{-1}. The total absorbed dose rates in air calculated from the concentrations of the three radionuclides ranged from 98.6 to 158.4 nGy h^{-1}. The external annual effective dose rate of the region was determined to be between 0.56 and 1.42 mSv y^{-1}, with an average value 0.90 mSv y^{-1}. This study provides a baseline map of radioactivity background levels in the Egyptian environment and will be used as reference information to assess any changes in the radioactive background level due to geological processes. The Um Sleimat granite, from uranium mineralization, has normal economic potential.

Key words: Natural radioactivity, granite, geochemical features, absorbed dose

INTRODUCTION

The solid Earth (the mantle and crust) is made of rock. Geologists have developed a way of classifying the various rocks and understand fairly well where they come from and where they go. There are three general types of rocks, those that form from melt (igneous rocks), those that are deposited from air or water (sedimentary rocks) and those that have formed by cooking or otherwise altering another rock (metamorphic rocks). Originally, it was widely believed that granites were formed mainly from magmatic differentiation of basaltic magma, evidence that was considered to indicate a metamorphic origin. However, because of the large quantities of granites that occur in nature, geologists believe now that most of the granites have been formed either by melting, partial melting, or metamorphism of deeply buried shale and sandstone. Granites, therefore, are the result of rapidly injected coalescing sheets of magma, each of which cooled independently of the other sheets (Tzortzis *et al*., 2003).

Granitoid rocks constitute an important rocks group that covers vast areas of the Arabian Nubian Shield in the Eastern Desert of Egypt. They constitute about 60% of the total basement complex terrain (Stren and Hedge, 1985). The Egyptian granitoids are classified according to several ways such as 1-type location; Shaitain and Gattarian granites. 2-relative age of older and younger granites. 3-dominant color (gery and pink granites). 4-Relation to orogeny (Sync-late and post orogenic granites).

Granites, usually suitable as building and ornamental materials for interior and exterior use, are hard natural stones that require harder tools to be cut, shaped and polished, compared to marble. Distinct types of commercial granites have different geological origins and mineralogical compositions and may be either magmatic or metamorphic rocks. Concerning their compositions, granites are mixtures of minerals of visible multicolored grains. One-color grains are typically encircled by grains of other colors, e.g., gray quartzis close to pink orthoclase, white plagioclase and dark mica. Every

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commercial granite contains feldspar of various colors: white, pink, red, yellow, brown, green and gray. Feldspar grains are typically not translucent and have a cleavage. Many granites, especially of light colors, contain quartz with gray (sometimes bluish) color and the grains are glassy translucent without cleavage. Further, there are dark minerals such as hornblende, pyroxene and biotite with black, dark green or dark brown colors. These minerals have larger specific gravity and lower hardness than feldspars and quartz. Some granite contains garnet showing near round shape and brown to dark-red color (Pivko, 2003). Thorium, uranium and potassium concentrations of granitic rocks are intimately related to their mineral compositions and general petrologic features (Doventon and Prensky, 1992).

Uranium and thorium in igneous and metamorphic rocks are usually found in a few accessory minerals such as apatite, sphene and zircon. Other highly radioactive minerals, like monazite, allanite, uraninite, thorite and pyrochlore, are widespread in nature, but they are very minor constituents of rocks. Uranium tends to be highly mobile near the surface whereas thorium is relatively stable. Uranium is easily oxidized to a water-soluble form and can be readily leached from pegmatites and granites and re-deposited in sediments at large distances from the source rock. Thorium is much less soluble than uranium and potassium and does not move except by mechanical means such as wind and erosion processes. Both thorium and uranium contents tend to be high in felsic rocks and to increase with alkalinity or acidity, with their highest concentrations found in pegmatites. The potassium content of rocks also increases with acidity. Potassium is usually found in potash feldspars, such as microcline and orthoclase, or in micas, like muscovite and biotite. Rocks that are free of these minerals have very low K-activity.

External exposures to gamma radiation outdoors arise from terrestrial radionuclides occurring at trace levels in all ground formations. The major sources of external gamma radiation are ^{238}U, ^{232}Th and their decay products and ^{40}K. Therefore, the natural environmental radiation mainly depends on geological and geographical conditions (Florou and Kritidis, 1992). Higher radiation levels are associated with igneous rocks, such as granite and lower levels with sedimentary rocks. There are exceptions, however, as some shales and phosphate rocks have relatively high content of radionuclides (Unscear, 2000). The contribution to absorbed dose in air external gamma radiation emitting from radionuclides change also depending on local geological and geographical conditions.

From the ^{232}Th, ^{238}U and ^{40}K activity concentrations obtained for each sample, it is possible to evaluate their respective dose rates in air, when these stones are used as tiling rocks (Unscear, 2000; EC, 1999; Tzortzis *et al*., 2003; Anjos *et al*., 2005). These results are of great interest in the environmental radiological protection

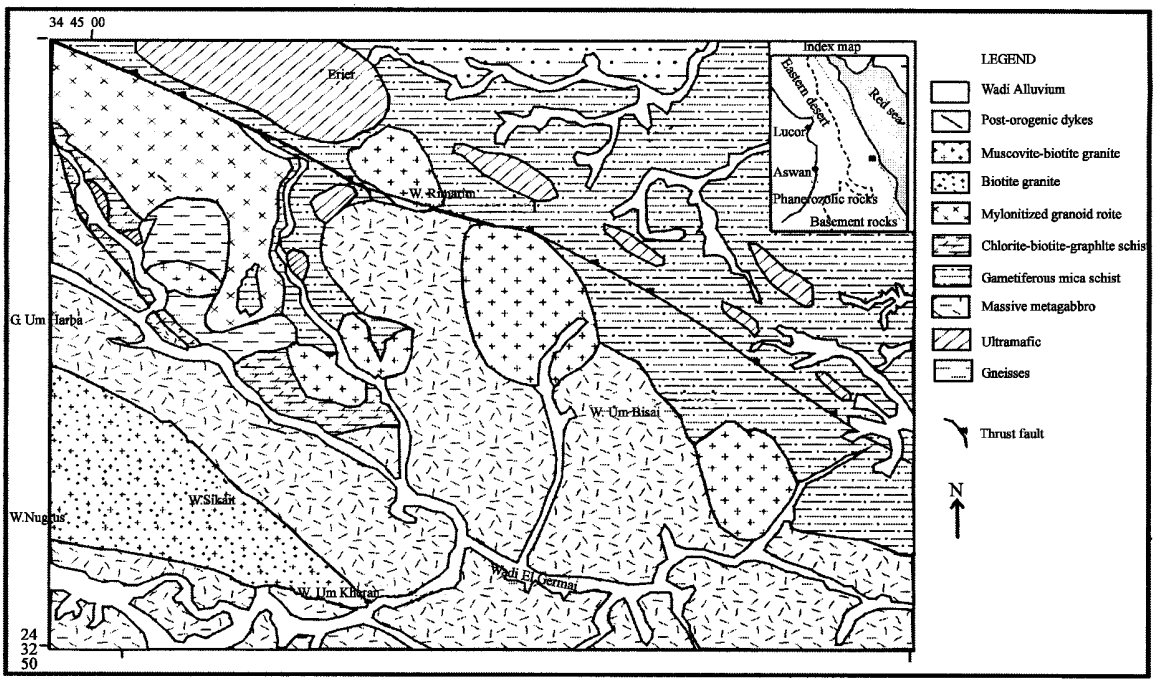

Fig. 1: Geological map of Um Sleimate area (after Akawy 1999)

study, since granites are widely used as building and ornamental materials, including indoor covering.

In this study, the radioactivity and U, Th and K contents in the Um Sleimat area were determined in representative samples by gamma spectrometric techniques, in order to discuss their distribution and geochemistry. This subject is important in environmental radiological protection, since granites are widely used as building and ornamental stones.

Geologic setting and petrography: The studied area is located 80 km Sw of Marsa Alam on the Red Sea coast (Fig. 1). The rock units exposed at Um Sleimat area are ophiolitic melange rocks and arc assemblage that are intruded by late to post orogenic plutonites represented mainly by gneissose granite and garnet leucogranite and younger gabbro.

Garnetiferous granites are located close to the major Nugrus shear zone and the related thrust faults, schist enclaves are sometimes encountered at the granite contacts. This intrusion commonly possesses sharp contacts truncating the schist foliation at high angles. These features coupled with the lack of deformation in these granites, indicate that its emplacement is postdating the main deformational phases and proceeded at shallow levels. El Reedy (1973) reported the ages of 589 and 593 Ma for this granite. Age of Um Kheran granite fall within the range assigned to the post-orogenic younger granites, 410-600 Ma (Hashad, 1980). Hence a post-collision setting can be assigned to the emerald related - leucogranites.

Garnetiferous granite is commonly occurs as dykes-like and small semi-circular masses. They form domal structures around Wadi Um Sleimat and Wadi Sikiat. In some localities it occurs as boudinage layers that well exposed at Um Addebaa and at the mouth of Wadi Abu Rushied. This granite commonly exhibit chilled margin against the melange rocks and associated with network of pegmatiitc veins. Intruded into the surrounding country rocks and e nclosed some of theses. Garnetiferous granite are commonly heterogeneous consisting of two faces diverse mineralogy and variable texture; pegmatite-muscovite granite and biotite-muscovite granite.

MATERIALS AND METHODS

Sampling preparation: Atotal of 20 rock samples were collected from 20 randomly selected locations considered representative of rocks in the area. Before collecting a sample, a big rock is broken into pieces by hammering (Hussain *et al*., 1990) and rock pieces are then packed into black plastic bags. The sample size varied from about 0.5-1 kg. All samples are sedimentary rocks. The rock samples were taken from the collection spots to the laboratory wrapped in black thin-walled plastic bags. Each sample was air dried at about 27°C and 70% relative humidity conditions for 3 days (IAEA, 1989). The dry rock sample was crushed, ground and passed through a sieve 1.0 mm mesh size to separate coarse particles from the needed fine-grained powder. The coarse grains were discarded and the powdered rock was stored 4 week in a cylindrical polyethylene container of size 5.5 cm diameter and 1.3 cm height to allow time for radon and thoron to reach secular equilibrium with their respective decay products before counting (IAEA, 1981). The background was stripped channel by from the count for each rock sample before concentration calculations were done.

Sample counting: The gamma-ray spectrometric analysis was carried out at Radiation Physics Laboratory of the Department of Physics, Faculty of Science, South Valley University, using a coaxial High purity germanium detector (EG and G, ORTEC) with a Relative efficiency of at 1.33 MeV ^{60}Co is 30 %. HPGe resolution (FWHM) at 122 keV ^{57}Co is 1100 eV and at 1.33 MeV ^{60}Co is 2.00 keV. To reduce gamma-ray background, the detector was shielded by a cylindrical lead shield with a fixed bottom and a moving cover, the lead shield contained two inner concentric cylinders of copper and cadmium. The detector was cooled to liquid-nitrogen temperatures and coupled to a PC-based 8K multi-channel analyzer and an ADC (ORTEC model 100U), with appropriate software (Mastero 2.1) for data acquisition and analysis.

The samples were sealed and stored in a tight container to prevent the escape of radiogenic gases ^{222}Rn and ^{220}Rn and to allow the attainment of radioactive equilibrium in the decay chain (El-Arabi, 2005). After attainment of secular equilibrium between ^{226}Ra,^{228}Ra and their daughter products, the samples were subjected to gamma-ray spectrometric analysis. ^{232}Th and ^{238}U are not directly γ-ray emitters, but it is possible to measure γ-rays of their decay products. Decay products for ^{226}Ra (^{214}Pb: 295 and 352 keV; and ^{214}Bi: 609 keV) and ^{232}Th (^{228}Ac: 338 and 911 keV; ^{212}Pb: 239 keV; and ^{208}Tl: 583 keV) were used by assuming the decay series to be in secular equilibrium (Firestone and Shirley, 1998). Weighted averages of several decay products were used to estimate activity concentrations of ^{226}Ra and ^{232}Th. The activity concentrations of ^{40}K were measured directly by its own gamma rays (1460.8 keV). Each sample was measured in the laboratory with an accumulating time between 10 and 14 h live time.

Activity concentrations, calculated from the intensity of several γ-rays emitted by a nuclide, are grouped together to produce a weighted average activity per

nuclide. Errors arise due to a number of factors, like efficiency calibrations, peak area determination and random uncertainties associated with background and sample counts. Radiological concentrations of ^{232}Th, ^{238}U and ^{40}K were then converted to total elemental concentrations of thorium, uranium and potassium in surface soils, as described below. Total thorium and uranium concentrations are reported in units of ppm, while concentrations of potassium are reported in units of percent.

Calculation of elemental concentrations: Radiological concentrations in rocks collected from the Um Sleimat garnetiferous granite are determined from measurements of the gamma rays emitted by specific radionuclides in the decay of uranium, thorium and potassium. These concentrations, while specific only to particular radioisotopes, are used to estimate elemental concentrations in the soil samples. Since the decay progeny of ^{232}Th and ^{238}U are measured, we must rely on the establishment of secular equilibrium in the samples in order to provide an accurate measurement of total thorium and uranium, hence the 30 day in-growth time. A true measure of potassium is taking place since we are measuring ^{40}K directly.

Elemental concentrations are calculated from measured radiological concentrations in the soil samples. First, the radiological concentration of nuclide i, $C_{S,i}$ in units of Bq per gram of sample is calculated using,

$$C_{s,i} = \frac{\dot{C}_i}{Y_i, \varepsilon_i, M_x} \quad (1)$$

where,C_i is the measured count rate [cts/sec], Y_i is the yield of gamma rays per disintegration, å$_i$ is the efficiency [cts/gamma] of the detector at the energy of the nuclide i gamma ray and M_x is the dry mass of the soil sample being analyzed. The fraction of element E in the soil sample, F_E, in units of % or ppm, is then calculated by Hamby and Tynybekov (2002),

$$F_E = \frac{C_{S,i} \bullet M_E}{\lambda_i \bullet N_A \bullet f_{A,i}} \bullet K \quad (2)$$

where M_E is the atomic mass [g/mol]; λ_i is the decay constant [s.1] of the radioisotope being counting; N_A is Avogadro's number [6.023×10^{23} atom/mol]; $f_{A,i}$ is the fractional atomic abundance of ^{232}Th, ^{238}U, or ^{40}K and the constant K, (with a value of 100 or 1 000 000), converts the ratio of the element's mass to soil mass into a percentage or ppm.

RESULT AND DISCUSSION

Whole-rock geochemistry: Twenty selected samples were analyzed for major and trace element from Um Sleimat garnetiferous granite (Table 1 and 2). Chemical analysis of whole sample was performed at the laboratory of Nuclear Material Authority. The studied granite is characterized by their relatively high silica contents (ranging between 73.5 to 75.5%). Its consider as low Ca-granite with an average 0.39%. All major and trace elements show poor linear relation with SiO_2. Only the two faces can be differentiated by their contents of Al_2O_3, Ba and Rb. Pegmatite-muscovite granites show higher content of Al_2O_3 and Rb and lower content of Ba relative to the Biotite-muscovite granites. The ratio of Fe_2O_3/FeO is more than one, indicating that this granite has tendency toward the oxidizing condition (Cox *et al*., 1979). The Na_2O/K_2O ratios of the studied granites range from 0.92 to 1.05 with mean value 0.96 for the biotite muscovite. With respect to pegmatite muscovite granite the range from 0.91 to 0.98 with mean value 0.93.

The element Rb, Sr and Ba are the most useful trace elements in the evaluating the fractional crystallization model because their behavior in these rocks is strongly related to the essential minerals such as feldspar and micas (McCarthy 1976; Neiva *et al*., 1987). The low Sr and high Ba and Rb content indicate that this granite is the product of fractional crystallization. Plagioclase fractionation can account for the low Sr contents.

Accordingly to Assaf *et al*. (1997), the fertile signature of the garnetiferous granite of Um Sleimat is indicated by their lower level of CaO < 0.97%, Sr < 99 ppm and Na_2O/K_2O < 1.11, as well as the higher level of Rb>185 ppm. This concept is supported by the eU/eTh ratios which range between 0.48 and 0.5 for the two granitic facies of Um Sleimat area greater than 0.4 given by Cambon (1994).

U, Th, K are amongst the most incompatible elements and they are concentrated in granitic rocks that are most abundant plutonic rocks in the continental crust. Content of U and Th generally increases with SiO_2 content during differentiation, fractional crystallization, partial melting, etc. in final stage of the magmatic procedures (Mason and Moore, 1982; Wilson, 1989; Rollinson, 1993). The increase of U with both SiO_2 and alkali content is usually more marked than the increase of Th, U and Th enhance mainly in accessory minerals such as orthite or allanite, monazit, zircon, appetite and sphene. These accessory minerals usually concentrate in granitic rocks (Rogers and Adams, 1969; Mason and Moore, 1982; Eisenbud, 1987; Bowie and Plant, 1988; Faure, 1991; Valkovic, 2000). Subsequent hydrogeological processes causing U solution and

Table 1: Chemical analysis of element for the biotite–muscovite granite of Um sleimat area

Element	Sam-1	Sam-2	Sam-3	Sam-4	Sam-5	Sam-6	Sam-7	Sam-8	Sam-9	Sam-10
SiO_2	74.5	75.3	74.5	73.5	75.5	73.5	74.5	74.6	73.3	73.5
TiO_2	0.02	0.03	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.03
Al_2O_3	14.5	14.6	14.7	14.9	14.7	14.8	14.9	14.8	14.7	15.5
Fe_2O_3	0.51	0.53	0.64	0.75	0.74	0.64	0.55	0.65	0.75	0.76
FeO	0.42	0.44	0.46	0.41	0.46	0.44	0.43	0.42	0.45	0.46
MnO	0.03	0.05	0.08	0.06	0.11	0.1	0.08	0.09	0.46	0.01
MgO	0.05	0.06	0.08	0.06	0.06	0.06	0.07	0.06	0.03	0.04
CaO	0.35	0.37	0.41	0.41	0.39	0.36	0.35	0.4	0.41	0.39
Na_2O	4.2	4.1	4	4.2	4.2	4.5	4.4	4.3	4.5	4.6
K_2O	4.4	4.4	4.5	4.5	4.3	4.3	4.8	4.6	4.7	4.5
P_2O_5	0.01	0.02	0.01	0.01	0.03	0.02	0.01	0.03	0.02	0.01
Ba	85	90	95	100	80	90	100	85	90	90
Rb	180	300	200	280	260	225	260	280	280	320
Sr	36	30	40	30	45	60	30	35	50	50
Nb	26	29	27	25	29	28	25	28	28	26
Zr	27	25	25	35	45	25	25	30	25	25
Y	13	16	17	14	15	13	16	17	14	16

Table 2: Chemical analysis of element in pegmatite muscovite granite of Um sleimat area

Element	Sam-11	Sam-12	Sam-13	Sam-14	Sam-15	Sam-16	Sam-17	Sam-18	Sam-19	Sam-20
SiO_2	74.7	74.6	73.6	73.4	73.5	74.5	74.5	73.5	74.6	74.6
TiO_2	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.02
Al_2O_3	15.6	15.7	15.9	15.7	15.8	15.9	15.8	15.9	15.9	15.8
Fe_2O_3	0.52	0.56	0.58	0.51	0.55	0.56	0.57	0.38	0.58	0.58
FeO	0.52	0.48	0.51	0.54	0.55	0.53	0.51	0.52	0.54	0.54
MnO	0.06	0.08	0.06	0.05	0.04	0.05	0.07	0.07	0.06	0.06
MgO	0.05	0.06	0.08	0.06	0.06	0.06	0.07	0.06	0.05	0.05
CaO	0.35	0.37	0.41	0.41	0.39	0.36	0.38	0.41	0.42	0.42
Na_2O	4.1	4.2	4.2	4.2	4.2	4.3	4.3	4.2	4.4	4.5
K_2O	4.5	4.5	4.4	4.5	4.5	4.6	4.7	4.8	4.6	4.6
P_2O_5	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01
Ba	35	40	45	60	50	75	65	70	60	70
Rb	320	360	360	340	350	380	360	380	340	360
Sr	40	40	35	45	50	55	33	40	55	55
Nb	22	25	29	27	25	28	26	28	27	26
Zr	30	20	25	25	40	36	35	35	30	25
Y	12	13	13	15	10	15	12	11	11	12

precipitation and geological phenomena's such as faults, hydrothermal alterations, weathering could have favored further local enrichment in granitic environment (Min *et al*., 2000; Chiozzi *et al*., 2002; Tzortzis and Tsertos, 2004).

In terms of natural radioactivity, igneous rocks of granitic composition are strongly enriched in U and Th (on an average 5 ppm of U and 15 ppm of Th) (Tzortzis and Tsertos, 2004), compared to the Earth's crust (average 1.8 ppm for U and 7.2 ppm for Th) (Mason and Moore, 1982), the upper continental crust (average 2.7 ppm for U and 10.5 ppm for Th) (Rudnick and Gao, 2003) and rocks of basaltic or ultramafic composition (<1 ppm of U and< 2 ppm of Th) (Mason and Moore, 1982; Tzortzis and Tsertos, 2004, Orgun *et al*., 2005).

Gamma radiation levels and distribution of ^{238}U and ^{232}Th and ^{40}K in granite: Calculations of count rates for each detected photopeak and radiological concentrations (activity per mass unit or specific activity) of detected radionuclides depend on the establishment of secular equilibrium in the samples. Since secular equilibrium was reached between ^{232}Th and ^{238}U and their decay products, the ^{232}Th concentration was determined from the average concentrations of ^{212}Pb and ^{228}Ac in the samples and that of ^{238}U was determined from the average concentrations of the ^{214}Pb and ^{214}Bi decay products (Hamby and Tynybekov, 2002; Tzortzis, *et al*., 2003 and Abbady *et al*., 2005). Thus, an accurate radionuclide concentration of ^{232}Th and ^{238}U was determined, whereas a true measurement of ^{40}K concentration was made.

The obtained results show that the minimum and maximum values of the measured specific gamma ray activities due to ^{226}Ra from the biotite-muscovite granite and pegmatite muscovite granite areas are 45.5, 130 and 70.5, 91 Bq kg^{-1}, respectively. The minimum and maximum ^{232}Th and ^{40}K activities in biotite-muscovite granite are 36.7, 77.5 and 1299.7, 1521.6 Bq kg^{-1}, respectively, while the corresponding values in pegmatite muscovite granite are 44.9, 61.2 and 1361.1, 1518.6 Bq kg^{-1}. The mean activities of the ^{226}Ra (^{238}U) series, ^{232}Th series and ^{40}K in biotite-muscovite and pegmatite muscovite granite are recorded in units of Bq kg^{-1} in Table 3.

Table 3: Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K (Bq.kg^{-1}) for all samples under study.

Sample	^{226}Ra (Bq.kg^{-1})	^{232}Th (Bq.kg^{-1})	^{40}K (Bq.kg^{-1})	U ppm	Th ppm	K %	Th/URatio
1	78.0±9	44.9±7	1363.1±37	6.3	11.0	4.5	1.7
2	52.0±7	40.8±6	1394.8±37	4.2	10.0	4.6	2.4
3	45.5±7	36.7±6	1331.4±36	3.7	9.0	4.4	2.4
4	97.5±10	77.5±9	1426.5±38	7.9	19.1	4.7	2.4
5	130.0±11	73.4±9	1299.7±36	10.5	18.1	4.3	1.7
6	45.5±7	36.7±6	1363.1±37	3.7	9.0	4.5	2.4
7	84.5±9	61.2±8	1521.6±39	6.8	15.1	5.0	2.2
8	78.0±9	53.0±7	1458.2±38	6.3	13.0	4.8	2.1
9	114.4±11	77.5±9	1489.9±39	9.3	19.1	4.9	2.1
10	45.5±7	49.0±7	1390.8±37	3.7	12.1	4.6	3.3
11	71.5±8	49.0±7	1422.5±38	5.8	12.1	4.7	2.1
12	72.8±9	44.9±7	1394.8±37	5.9	11.0	4.6	1.9
13	70.2±8	53.0±7	1361.1±37	5.7	13.0	4.5	2.3
14	71.5±8	49.0±7	1422.0±38	5.8	12.1	4.7	2.1
15	88.4±9	49.0±7	1455.2±38	7.2	12.1	4.8	1.7
16	80.6±9	49.0±7	1486.9±39	6.5	12.1	4.9	1.8
17	80.6±9	61.2±8	1518.6±39	6.5	15.1	5.0	2.3
18	91±10	40.8±6	1423.5±38	7.4	10.0	4.7	1.4
19	88.4±9	61.2±8	1456.2±38	7.2	15.1	4.8	2.1
20	71.5±8	49.0±7	1421.5±38	5.8	12.1	4.7	2.1

In granitoid rocks U and Th tend to concentrate in accessory minerals such as zircon, monazite, apatite, sphene and allanite (Rogers and Adams, 1969). Some may also occur as an impurity in fluorite, apatite, haematite and mica. It is also possible for Th to be adsorbed onto clays and onto Fe oxides and hydroxides. The Th content generally increases with the SiO_2 content and closely follows U during differentiation or partial melting. Th increases with the alkali content in comagmatic suites, the K/Th ratio remaining fairly constant in a large variety of igneous rocks. Some alkali-rich igneous rocks are especially rich in Th. However, the increase in U with both SiO_2 and alkali contents is usually more marked than the increase in Th. In high temperature processes, U may crystallize directly from silicate magmas (as uraninite, for example). Other accessory minerals, such as allanite, monazite, apatite, sphene, zircon, xenotite, thorite, thorianite, euxenite, pyrochlore and brannerite, often intimately associated with biotite, may also contain uranium. Granitic rocks rich in U (and Th) are sometimes referred to as, hot granites' on account of their high rates of heat production (Abbady *et al*., 2006).

Both thorium and uranium contents tend to be high in felsic rocks and to increase with alkalinity or acidity, with their highest concentrations found in pegmatites. The potassium content of rocks also increases with acidity. Potassium is usually found in potash feldspars, such as microcline and orthoclase, or in micas, like muscovite and biotite. Rocks that are free of these minerals have very low K-activity (Anjos *et al*., 2005).

Concentrations of ^{238}U, ^{232}Th and ^{40}K are usually given in equivalent ground concentrations: K (%), eU (ppm) and eTh (ppm), respectively. The specific parent activity of a sample containing 1 ppm of ^{232}Th and 1 ppm of natural U is 4.08 and 13.0 Bq kg^{-1}, respectively. For natural potassium, a concentration of 1% by weight of sample corresponds to a ^{40}K-specific activity of 317 Bq kg^{-1}.

The studied granite shows eTh/eU ratio less than 2.3, suggesting post magmatic addition of uranium to this granite (Rogers and Adams, 1969). The relationships of eU/eTh increase with eU and inversely with eTh. This Suggests that the distribution of uranium is partially magmatic and mainly due to the late magmatic processes. This was clearly conformed from the positive correlation between eU with Rb as well as the negative correlation between eU and Zr/eU ratios.

The highest concentrations normally occurring in the youngest, most potassium-rich and most silica-rich members. The high temperature metamorphism and partial melting of silica crust that leads to the formation of granites also appears to mobilize uranium, which becomes concentrated in pegmatites. There is often an associated increase in Th, Zr, Nb, Ta and Rare Earth elements. Among less silcic rocks, some kimberlites and lamprophyres may be enriched in uranium. As high uranium levels are often accompanied by a high alkali content, alkali syenites and carbonatites are often rich in uranium (Durrance, 1986).

The week correlation between uranium and thorium and uranium with U/Nb (Fig. 2a, b) suggests mobilization of uranium after crystallization. This conclusion could be supported by the relationship of uranium with Th/K ratios, which shows weak correlation. The weak to negative correlation between U vs SiO_2 and Al_2O_3 and Th vs SiO_2 (Fig. 2c-e) show that there is no relation between the concentration of uranium and thorium and the degree of fractionation of the two granitic faces at Um Sleimat.

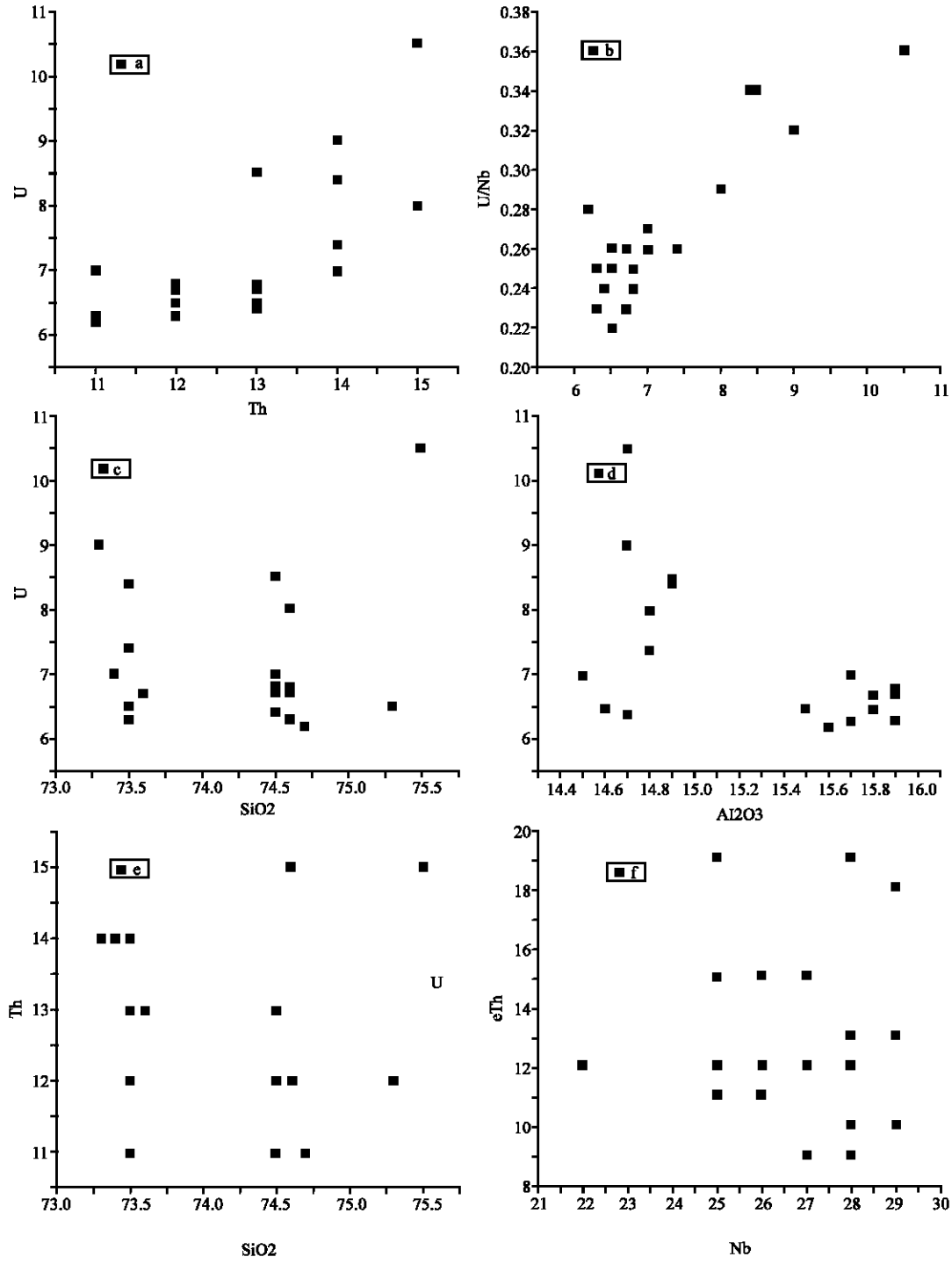

Fig. 2: Correlation diagrams between trrace and mijor elements for samples under studies

The positive correlation between eTh and Nb as well as Y (Fig. 2f) indicates that the granitic magma from which the granitic masses developed were emplaced at shallow depths (Briqueu *et al.*, 1984).

The results of U and Th analyses (Table 3) showed that U averaged 6.2 ppm and Th 4.6 ppm in biotite-muscovite granite. The corresponding values for pegmatite muscovite granite are 6.4, 4.7 ppm, respectively.

Table 4: Mean concentration of U, Th and K% Granite rocks compared with other published data

	Mean concentration				
Type of rock	U (ppm)	Th (ppm)	K%	Th/U Ratio	Reference
Biotite-muscovite granite (10)	6.2	4.6	4.7	2.3	Present study
Pegmatite muscovite granite (10)	6.4	4.7	4.8	2.0	Present study
Granite,Turkey (14)	24.8	61	4.2	2.46	Orgun *et al*., 2005
Granite	4-7	15-40	3.4-4	...	Helbig and Treitel 1996
Granite South Africa	6.5	21.6	4.15	3.3	Cermak *et al*., 1982
Granite	5.4	24.6	3.73	4.6	Haack 1982
Granodiorite Bir El-Sid, eastern desert, Egypt (3)	3.7	10.3	3.6	2.8	Abbady *et al*., 2006
Granodiorite	2.1	8.3	2.3	4.0	Helbig and Treitel 1996
Granodiorite	6	16	2.25	2.7	Simov 1989
Granodiorite	3.1	12.4	2.34	4.0	Haack 1982
Granite Wadi El-Gemal Eastern desert, Egypt (10)	3.2	11.8	3.4	3.7	Abbady *et al*., 2006
Granite gebal El-Erediya, Eastern desert, Egypt (35)	30.5	21.1	3.6	0.7	Abbady *et al*., 2006
Gable gattar II,north eastern Desert, Egypt	13.4-2255.9	17.5-67.4	3.5-4.1	1.31-0.03	El-Shershaby, 2002
Gabel El Majal,central eastern desert, Egypt. (10)	16.1	7.5	2.3	0.46	Arafa,W., 2004
Homret waggat south,central eastern desert, Egypt. (10)	63.8	47.4	7.6	0.74	Arafa, W., 2004

Note: Number of samples in parentheses

If we compare this data with the reported ranges and averages of Adams *et al*. (1959), Turekian and Wedepohl (1961), Clark *et al*. (1966), Adams and Gasparini (1970) and Rogers and Adams (1969), it is clear that biotite and pegmatite muscovite granite exhibits normal contents of U, where the other studied granite plutons are enriched in U in various degrees. During late magmatic stages, residual hydrothermal solutions may become enriched in U and form U-rich veins. Also at those stages large proportions of U are precipitated in the intergranular spaces or in late stage alteration minerals associated with silicification and hematitization of the host rocks (Abdel-Monem *et al*., 1996).

When the results of this study are compared to the results of some of the previous studies (Abdel Hady *et al*., 1994; Abdel-Monem *et al*., 1996; Walley El-Dine *et al*., 2001; El-Shershaby, 2002; Arafa, 2004; Orgun *et al*., 2005; Abbady *et al*., 2006), it is clear that the results, are smaller than to those from others references and from different areas Egypt plutons, which are known as having high radionuclide concentrations. The concentration of U, Th (ppm) and K% Granite rocks in biotite-muscovite, pegmatite muscovite granite and the available in other countries in the world are given in (Table 4).

Derivation of the radiation hazard indices: In order to compare the specific activities of samples, which contain ^{226}Ra, ^{232}Th and ^{40}K, the radium equivalent activity as a common index was used to obtain the sum of activities. The radium equivalent activities (Ra_{eq}) have been calculated on the estimation that 370 Bq g^{-1}(10 pCi g^{-1}) ^{226}Ra, 259 Bq kg^{-1} (7 pCi g^{-1}) ^{232}Th or 4810 Bq kg^{-1} (130 pCi g^{-1}) ^{40}K produce the same gamma-ray dose rate (Krieger, 1981; Beretka and Mathew, 1985). Therefore, the Ra_{eq} of a sample is given by

$$Ra_{eq} = A_{Ra} + (A_{Th} \times 1.43) + (A_K \times 0.077) \quad (3)$$

where A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra,^{232}Th and ^{40}K, respectively, in Bq kg^{-1}.

Another radiation hazard index called the representative level index, Iγr, is defined as follows (NEA-OECD, 1979)

$$I_{\gamma r} = \left(\frac{A_{Ra}}{150\ Bq/kg} + \frac{A_{Th}}{100\ Bq/kg} + \frac{A_K}{1500\ Bq/kg} \right) \quad (4)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Bq kg^{-1}.

If naturally occurring radioactive nuclides are uniformly distributed, dose rates, D, in units of nGy h^{-1} can be calculated by the following formula (Beck *et al*., 1972):

$$D = A_{ei} \times C_F \quad (5)$$

where A_{ei} is the activity concentration measured in Bq kg^{-1} and C_F is the dose conversion factor (absorbed dose rate in air per unit activity per unit of soil mass, in units of nGy h^{-1} per Bq kg^{-1}). In the recent (UNSCEAR, 2000) reports, a value of 0.7 Sv Gy^{-1} was used for the conversion coefficient from absorbed dose in air to effective dose received by adults and 0.8 for the indoor occupancy factor, implying that 20% of time is spent

Table 5: Values of radiation hazard parameters of the rock types from Um Sleimat area, Egypt

Sample	Ra_{eq} Bq kg^{-1}	Abs. dose rate nGy h^{-1}	AGDE μSv y^{-1}	Representative level index I_{yr}
1	247.2	119.9	147.1	1.88
2	217.7	106.7	130.9	1.68
3	200.5	98.6	121	1.56
4	318.2	151.1	185.4	2.38
5	335	158.4	194.3	2.47
6	202.9	99.9	122.6	1.58
7	289.2	139.3	170.9	2.19
8	266.1	128.7	157.9	2.02
9	339.9	161.6	198.2	2.53
10	222.7	108.5	133.1	1.72
11	251.1	121.8	149.4	1.92
12	244.4	118.8	145.7	1.86
13	250.8	121	148.5	1.91
14	251.1	121.8	149.4	1.91
15	270.5	131	160.7	2.05
16	265.2	128.7	157.9	2.02
17	285	137.3	168.5	2.16
18	259	125.9	154.5	1.96
19	288	138.3	169.7	2.17
20	251	121.8	149.4	1.91

outdoors, on average, around the world. The effective dose rate outdoors, H_E, in units of mSv per year, is calculated by the following formula:

$$H_E = DTF \quad (6)$$

where D is the calculated dose rate (in nGy h^{-1}), T is the outdoor occupancy time (0.2×24 h×365.25 d ˜ 1753 h y^{-1}) and *F* is the conversion factor (0.7×10^{-6} Sv Gy^{-1}).

In Table 5, the results obtained for radium equivalent activity (Bq kg^{-1}), representative level index, the total absorbed dose rate in air due to gamma radiation, as well as the outdoor effective dose assessment for samples under investigations are presented. In biotite–muscovite granite and pegmatite muscovite granite the Ra_{eq} average values were 263.9±14.9 and 261.6±47.7 Bq kg^{-1}. The average I_{yr} values for the corresponding rocks were 2±0.1 and 1.99±0.33, respectively. The calculated Ra-equivalent activities of the samples under study are less than the recommended maximum value of 370 Bq kg^{-1} suggested for building materials as shown in Table 5.

The absorbed dose rates due to ^{226}Ra, ^{232}Th and ^{40}K in biotite-muscovite granite and pegmatite muscovite granite were varied in the range 98.6-158.4, 121-138.3 nGy h^{-1} with average values 127.3±21.2 and 126.6±26.8 nGy h^{-1}, respectively.

Taking the indoor occupancy factor of 0.8 and a conversion factor of 0.7 Sv Gy^{-1} (Unscear, 2000) to convert the γ-ray absorbed dose to effective equivalent, the above-mentioned average dose rate corresponds to an annual average effective dose 497.2 and 499.9 μSv y^{-1}.

In order to evaluate the Annual Gonadal Dose Equivalent (AGDE) for a resident of a house built with a material with given specific activities of radium, thorium and potassium. the model described by Eq. 5., of Mamont-Ciesla *et al.* (1982) was used:

$$D\ (\mu Sv\ y^{-1}) = 3.09A_{Ra} + 4.18\ A_{Th} + 0.314\ A_K \quad (7)$$

This model considers a house as a cavity with infinitely thick walls. It facilitates a comparison of AGDEs of a house containing concentrations of ^{226}Ra, ^{232}Th and ^{40}K equal to the world average values in soil (25, 25 and 370 Bq kg^{-1}, respectively) with those obtained using a given material. If building materials contain less radioactivity than these concentrations, they will shield the resident from the terrestrial radiation. On the other hand, if their radioactivity is higher than that of the soil the exposure will increase. The average concentrations would produce an AGDE of 0.91 mSv y^{-1}. The annual gonadal dose equivalents generated by the use of granite as a construction material were calculated with this model as shown in Table 5.

Basic approaches to radiation protection are consistent all over the world. The ICRP-60 (1990) recommends that any exposure above the natural background radiation should be kept as low as reasonably achievable -*ALARA*- but below the individual dose limits, which for radiation workers averaged over 5 years is 100 mSv and for members of the general public is 1 mSv y^{-1}. These dose limits have been established on the prudent approach by assuming that there is no threshold dose below which there would be no effect. This means that any additional dose will cause a proportional increase in the chance of a health effect. This relationship has not yet been established in the low dose range where the dose limits have been set. A factor of 3 to 10 lower would now be needed to satisfy most regulations (Iqbal *et al.*, 2000).

CONCLUSION

The area under investigation was affected by various cycles of hydrothermal solutions having various compositions, which causes the different alteration types of the granite. The circulation of the hydrothermal fluids through the granite played an important role in concentrating the uranium. The radioactivity concentrations measured in Um Sleimat can be explained by the mineralogical and geochemical composition of the pluton that derived from the magma undergone fractional crystallization and contaminated by continental crust. In addition, metasomatic activities such as alteration and weathering and geological structure of the region were affected on the radioactivity levels of the Um Sleimat. The garnetiferous rocks of Um Sleimat area are characterized by their relatively high silica contents (ranging between 73.5 to 75.5%). They are chemically classified as calc-alkaline, peraluminous, syn-collision fractionated I-type granites emplaced at depth roughly about 30 km which may indicate their possible emplacement from the lower crust and the upper mantle.

The ^{238}U activity concentrations of the plutons are between 45.5±7 and 130±11 Bq kg^{-1}. The ^{232}Th activity concentrations of the plutons range from 36.7±6 to 77.5 ±9 Bq kg^{-1}.The activity obtained for ^{40}K ranged from 1299.7±36 to 1521.6±39 Bq kg^{-1}. The absorbed dose rates for the plutons ranged from 98.6 to 158.4 nGy h^{-1}. According to the recent Unscear reports, the mean absorbed dose rate in air outdoors from the Um Sleimat area are almost two and three times higher than that of the worldwide average value, respectively. The calculated Ra-equivalent activities of the Um Sleimat (ave. 263.1 Bqkg^{-1}) are smaller than the recommended maximum value of 370 Bq kg^{-1}. The calculated average external hazard index value is higher than unity and it may be harmful to people in the region. The activity of the radionuclides in Um Sleimat as determined in this study gives rise to an effective dose equivalent value that is higher than the world's soil average value. Nevertheless, the health burden due to natural background radiation from rocks on the inhabitants of this areas is low and hence carriers insignificant health hazards. The data obtained in this study will serve as baseline data for the proper assessment of radiation exposure of the dwellers. In this case, the pluton can be used as building materials.

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