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Analysis of Uranium, Thorium and Potassium Radioisotope Content of Muscovite Samples from Turkey

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Abstract: Muscovite, a naturally occurring potassium aluminum silicate mineral, is the most widely used mica type in various industries. In this study, the concentration of uranium, thorium, and potassium radioisotope in fifty muscovite samples collected from commercially operated mica quarries located in Turkey were determined using an energy dispersive X-ray fluorescence (EDXRF) spectrometer. The concentrations of uranium, thorium and potassium radioisotope varied from 0.8 to 4.7 mg/kg with an average of 1.2 mg/kg, 5.5 to 16.7 mg/kg with an average of 11.0 mg/kg g and 7.0 to 10.7 mg/kg with an average of 8.6 mg/kg, respectively. Also, the radiogenic heat generation caused by the emitted ionizing radiation from these natural radionuclides in muscovite samples was estimated. Radiogenic heat generation values of muscovite samples varied from 1.4 to 2.7 μW/m^3 with an average value of 1.8 μW/m^3.

Keywords: Muscovite, Uranium. Thorium, Radiogenic heat generation.

1 Introduction

The fact that superior physical, chemical, and mechanical properties of micas, especially muscovite, compared to other industrial minerals, has made micas indispensable in paint, cement, construction, rubber, plastic, paper, automobile, cosmetics, textile, and fertilizer industry, and welding electrode manufacturing and pearl polishing paint materials [1]. Also, micas can be separated into transparent or optically flat films; and they can be cut or stamped to shape [1]. Micas are plenty in many rocks such as slates, shales, gneisses, schists, and granites [2]. Muscovite [$KAl_2(AlSi_3)O_{10}(OH,F)_2$] is the most commonly used mica and is generally found in igneous and metamorphic rocks [2]. All minerals include radionuclides in the natural decay series of uranium (^{238}U) and thorium (^{232}Th), and radioactive potassium at different activity concentration levels depending on the types of rocks (metamorphic, sedimentary, and igneous) [3]. In general, the concentrations of natural radionuclides in igneous rocks are higher than the activity concentrations of radionuclides in other rocks [3].

To date, many studies were performed on adsorption, sorption, cation exchange capacity and mechanisms (especially for radioisotopes), dissolution and flotation behaviors, and microstructure and mechanical properties of muscovite samples [4-18]. However, according to literature studies, there is no detailed study on the determination of uranium, thorium, and radioactive potassium contents of muscovite. To complete this lack in the literature, in this study, the uranium, thorium, and potassium contents of fifty muscovite samples collected from commercially operated quarries in Turkey were determined by an EDXRF spectrometer. In addition, radiogenic heat generation caused by ionizing radiation emitted from these radionuclides was also estimated.

2 Materials and Methods

2.1 Collection and Preparation of Samples

The muscovite samples were collected from mica quarries located in the Manisa province of Turkey. The samples were brought to the sample preparation laboratory and left to be dried in the atmosphere. The muscovite samples were then dehumidified by drying in the furnace and ground to make them fit the calibrated powder geometry in the EDXRF spectrometer. A maximum of five grams of each muscovite sample was taken for analysis.

2.2 Analysis of Samples

The qualitative and quantitative analysis of major-minor and trace elements contained in the muscovite samples were performed using the EDXRF spectrometer (Spectro

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Xepos, Ametek) in the Central Research Laboratory of Kastamonu University. The EDXRF spectrometer is equipped with an anode X-ray tube (50 W, 60 kV) consisting of a dual thick Pd/Co mixture. The EDXRF spectrometer's target modifier, which optimizes excitation by using polarization and secondary targets, has many different excitation conditions that guarantee the best detection of all elements from Na to U. The spectral resolution of the system is lower than 155 eV. The spectrometer has twelve automatic sampling devices and software to analyze samples at the same time. The spectrometer utilizes sophisticated calibration techniques such as "no-standard" calibration, often based on the basic parameters method. Sample containers prepared for each muscovite sample were placed in an automatic sampler and the analysis procedures were completed by counting for two hours. The total uncertainty of the analytical procedure is between 3% and 12%. The XRF spectrum of each muscovite sample obtained was evaluated with the help of the software installed in the system.

3 Results and Discussion

3.1 Elemental Concentration

Some statistical data related to the concentrations of uranium (U), thorium (Th), potassium (K), and potassium radioisotope (^{40}K) analyzed in the muscovite samples is given in Table 1. The frequency distributions of U, Th, and ^{40}K are shown in Fig. 1. In Table 2, the average concentrations of uranium, thorium, and potassium analyzed in the muscovite samples are compared with those in basic rock, acid rock, and Earth's crust [20].

Table 1: Some statistical data for uranium, thorium, potassium, and potassium isotope concentration analyzed in muscovite samples.

	Concentration (mg/kg)			
	U	Th	K	^{40}K
Average	1.2	11.0	73370.3	8.6
Standard error	0.1	0.3	1058.5	0.1
Median	1.0	10.6	71831.5	8.4
Standard deviation	0.6	2.3	7484.7	0.9
Kurtosis	16.8	-0.02	-0.1	-0.1
Skewness	3.5	0.3	0.7	0.7
Min	0.8	5.5	60166.1	7.0
Max	4.7	16.7	91855.2	10.7

It can be seen from Table 1 that the elements analyzed in the muscovite samples are listed as Th > ^{40}K > U in descending order according to the average concentration values. The concentrations of uranium in the muscovite samples varied from 0.8 to 4.7 mg/kg with an average of 1.2 mg/kg. As can be seen from Fig. 1, the frequency distribution of the U concentration exhibits a log-normal distribution. Approximately 78% of the U concentrations in the muscovite samples are in the range of 0.8 to 1.5 mg/kg. As can be seen from Table 2, the average U concentration in the muscovite samples is 24 times higher than that in the basic rock while the average U concentration is 3 and 2 times lower than those in the acidic rock and Earth's crust, respectively.

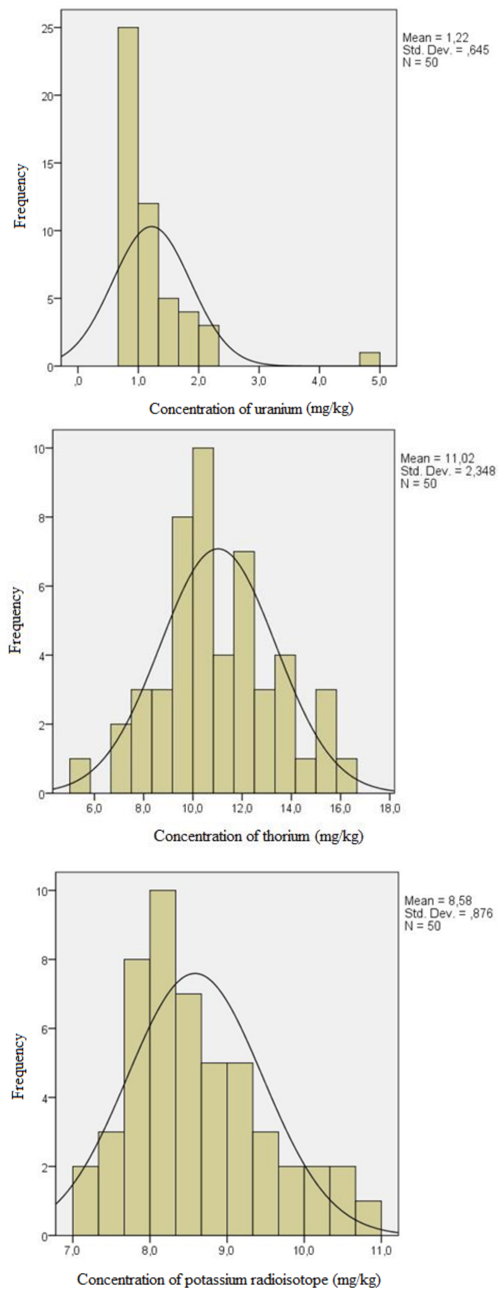

Fig. 1: Frequency distribution of U, Th, and ^{40}K analyzed in muscovite samples.

Table 2: Comparison of average concentrations of elements in muscovite samples with those in some rocks and Earth's crust.

	Concentration (mg/kg)			Reference
	U	Th	K	
Basic rock	0.05	2	8300	[19]
Acid rock	3.5	18	33400	[19]
Earth's Crust	2.5	13	25000	[19]
Muscovite	1.2	11.0	73370	This study

The concentrations of thorium in the muscovite samples varied from 5.5 to 16.7 mg/kg with an average of 11.0 mg/kg. As can be seen from Fig. 1, the frequency distribution of the Th concentration exhibits a near-normal distribution. Approximately 76% of the Th concentrations in the muscovite samples are in the range of 1.5 to 12.5 mg/kg. As can be seen from Table 2, the average Th concentration in the muscovite samples is higher than those in the basic rock and Earth's crust while the average Th concentration is lower than those in the acidic rock.

Natural potassium consists of three isotopes: two stable forms, ^{39}K (93.3%) and ^{41}K (6.7%), and a very long-lived radioisotope ^{40}K (0.0117%). The concentrations of potassium in the muscovite samples varied from 60166 (6%) to 91855 (9%) mg/kg with an average of 73370 (7%) mg/kg. As can be seen from Table 2, the average K concentration in the muscovite samples is higher than that in the basic rock, acidic rock, and Earth's crust. The concentrations of potassium radioisotope (^{40}K) in the muscovite samples varied from 7.0 to 10.7 mg/kg with an average of 8.6 mg/kg. As can be seen from Fig. 1, the frequency distribution of the ^{40}K concentration exhibits a near-normal distribution. Approximately 90% of the ^{40}K concentrations in the muscovite samples are in the range of 6 to 10 mg/kg.

3.2 Radiogenic Heat Generation

Radiogenic heat is produced by the ionizing radiations (α-, β-, X-, and γ-ray) emitted by radionuclides belonging to natural radioactive series of ^{238}U, ^{232}Th, and ^{40}K in the Earth's crust after radioactive decay. During radioactive decay, the kinetic energies of the emitted ionizing radiation are absorbed in rocks and soils and transformed into heat. In general, the radiogenic heat generation (RHG, in terms of W/m^3) of any rock or mineral is estimated by the formula given below [20]:
The radiogenic heat production (RHG in μW/m^{-3}) of any rock is estimated by the following formula [20]:

$$RHG = 10^{-5} \cdot \rho \cdot (9.52 \cdot C_U + 2.56 \cdot C_{Th} + 3.45 \cdot C_K) \qquad (1)$$

where ρ is the bulk density of the muscovite (in kg/m^3), C_U, C_{Th} and C_K are the concentration of uranium (in mg/kg), thorium (in mg/kg), and potassium (%) measured in the muscovite samples, respectively. The values of RHG estimated for the muscovite samples varied from 1.4 to 2.7 μW m^{-3} with an average of 1.8 μW m^{-3}. The contribution of uranium, thorium and potassium to this average RHG value was 18%, 43% and 39%, respectively. The comparison of the average value of RHG estimated for muscovite samples with those estimated for different materials is given in Table 3 [21]. As can be seen from Table 3, the average RHG value of the muscovite is two times higher than the average RHG value of the Earth's crust, while it is lower than the average RHG value of granite (Egypt and South Africa), schist, acid rock, and zeolite.

4 Conclusions

The study is a detailed study related to the analysis of uranium, thorium, and potassium in fifty muscovite samples collected from commercially operated mica quarries in the Yatağan district of Manisa province were analyzed by the EDXRF spectrometer. Muscovite samples contain an average of 1.2 mg/kg U, 11.0 mg/kg Th and 73370 mg/kg K. The average U and Th content of the muscovite samples is lower than the average U and Th content of Earth's crust. The average K content of the muscovite samples is approximately three times higher than the average K of the Earth's crust.

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