POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

URL: http://dergipark.org.tr/politeknik

Distribution of elemental compositions of muscovite quarries in Turkey

Türkiye'deki muskovit ocaklarının elementel bileşimlerinin dağılımı

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Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): E.M.A Krista, Ş. Turhan, A. Kurnaz, A. Hançerlioğullari, "Distribution of elemental compositions of muscovite quarries in Turkey", ***Politeknik Dergisi***, 25(3): 1271-1279, (2022).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.1056220

Distribution of Elemental Compositions of Muscovite Quarries in Turkey

Highlights

- *In this study, the contents of thirty-five elements*
- *Three commercially operated quarries in Manisa province of Turkey*
- *Determine the major and minor oxides and trace elemental of muscovite quarries*
- *The oxides analyzed are listed as SiO_2 > Al_2O_3 > K_2O > MgO > Na_2O > Fe_2O_3 > P_2O_5 > TiO_2 > Ca*
- *In this context, it is recommended to check whether the necessary measures are taken or not for workers working in the stages of extraction, crushing, and sieving of the mica minerals in terms of worker health and work safety.*

Graphical Abstract

The locations of three muscovite quarries (MQ1, MQ2, and MQ3) in the Hisarardı region of the Yatağan district are shown in Figure 1.

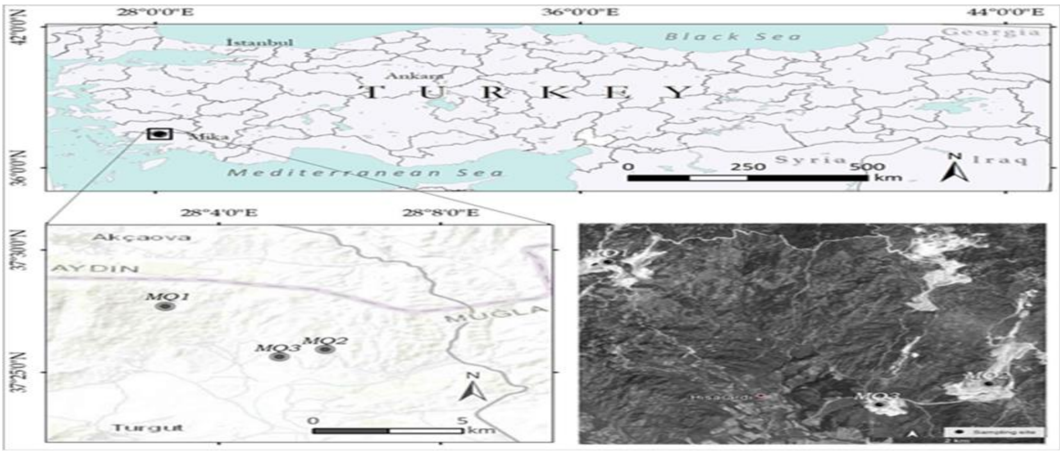

Figure 1. The locations of muscovite quarries

Aim

This study of aim was, the contents of thirty-five elements in eighty-four muscovite samples collected from three commercially operated in Manisa/Turkey were determined using an energy dispersive (EDXRF) spectrometer.

Design & Methodology

The investigation was analysed the major, minor and trace elements in the muscovite samples were performed out by using an EDXRF spectrometer..

Originality

The most important originality of this study is the detailed analysis of mica or muscovite samples used for the first time.

Findings

Until today, detailed analysis of muscovite minerals used in many sectors has not been made. Determining the elemental distribution of muscovite quarries is important to decide how efficient they will be in which sector.

Conclusion

In this study, The first detailed study in which samples taken from commercially operated muscovite quarries in Yatağan district of Manisa province were examined in terms of 9 oxide molecules (SiO_2, Al_2O_3, K_2O, MgO, Na_2O, Fe_2O_3, P_2O_5, TiO_2, and CaO) and 28 trace elements (Cr, Zr, Mn, Zn, Ni, Co, Pb, Cu, Cd, Hg, Sn, Ga, V, Nd, Ta, Nb, Hf, W, Te, Ag, Tl, Th, U, Ba, Cs, Rb, Sr, and Y).

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission..

Distribution of Elemental Compositions of Muscovite Quarries in Turkey

Araştırma Makalesi / Research Article

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(Geliş/Received : 11.01.2022 ; Kabul/Accepted : 26.03.2022 ; Erken Görünüm/Early View : 18.04.2022)

ABSTRACT

In this study, the contents of thirty-five elements (nine major-minor oxides, twenty-one heavy metals, and five other elements) in eighty-four muscovite samples collected from three commercially operated quarries in Manisa province of Turkey were determined using an energy dispersive X-ray fluorescence (EDXRF) spectrometer. The mean concentrations of SiO_2, Al_2O3, K_2O, MgO, Na_2O, Fe_2O_3, P_2O_5, TiO_2 and CaO analyzed in mica samples were determined as 57.1, 32.8, 8.7, 2.9, 1.4, 0.8, 0.3, 0.3 and 0.3%, respectively. The mean concentrations of Cr, Zr, Mn, Zn, Ni, Co, Pb, Cu, Cd and Hg analyzed as primary toxic trace heavy metals in mica samples were found as 136.2, 124.6, 58.7, 19.2, 14.8, 6.8, 6.3, 2.6, 2.0 and 1.2 mg kg^{-1}, respectively.

Keywords: Mica, oxides, heavy metal, Hisarardı, EDXRF.

Türkiye'deki Muskovit Ocaklarının Elementel Bileşimlerinin Dağılımı

ÖZ

Bu çalışmada, Manisa ilinde ticari olarak işletilen üç ocaktan toplanan seksen dört mika örneğinde otuz beş elementin (dokuz ana-minör oksitler, yirmi bir ağır metal ve diğer beş element) içerikleri bir enerji dağıtıcı X-ışını floresan (EDXRF) spektrometresi kullanılarak belirlenmiştir. Mika numunelerinde analiz edilen SiO2, Al2O3, K2O, MgO, Na2O, Fe2O3, P2O5, TiO2 ve CaO'nun ortalama konsantrasyonları sırasıyla %57.1, 32.8, 8.7, 2.9, 1.4, 0.8, 0.3, 0.3 ve 0.3 şeklindedir. Mika numunelerinde birincil toksik eser ağır metaller olarak analiz edilen Cr, Zr, Mn, Zn, Ni, Co, Pb, Cu, Cd ve Hg'nin ortalama konsantrasyonları sırasıyla 136.2, 124.6, 58.7, 19.2, 14.8, 6.8, 6.3, 2.6, 2.0 ve 1.2 mg kg^{-1} olarak belirlenmiştir.

Anahtar Kelimeler: Mika, oksitler, ağır metal, Hisarardı, EDXRF.

1. INTRODUCTION

Industrial minerals (quartz, corundum, hematite, calcite, dolomite, gypsum, fluorite, pyrite, olivine, pyroxene, amphibole, feldspar, orthoclase, anorthite, kaolinite, zeolite, mica, etc.) are of great importance in the life of societies and the economic and cultural development of countries [1].

Therefore, the availability, extraction, and distribution of many minerals of great economic importance have played an important role in history. The importance of mica group minerals, especially muscovite and phlogopite, has gradually increased due to the developments in industrial minerals in recent years [2]. Muscovite, which belongs to the group of potassium aluminum silicate minerals, is phyllosilicate class minerals or sheet silicates with a two-dimensional layer structure [3]. Muscovite, which is white mica, represents the main source of macronutrient K and therefore plays an important role in plant nutrition [4]. Muscovite has been used in various industries such as automotive, construction, paper, plastic, etc. depending on their physicochemical properties. With the prohibition of asbestos against cancer risk by developed countries and the use of alternative materials, including muscovite, instead of asbestos, the importance of dry ground mica has gradually increased, especially in Portland cement production. Muscovite, which can be used as a filler in insulating gypsum plaster and crack cement, has improved its use in this area because it gives a decorative appearance to the buildings, is resistant to cracks that may occur, and is economical [2]. Muscovites, which can be easily supplied as raw materials and pulverized, are used in refractory production, and paper, cardboard, paint, and ceramic industry. Muscovite lamellas and plates do not break easily. They are used as window glass due to their flexible and bending feature, transparent and easy to slice, and they are used in stoves and lamps because they are fire-resistant.

Recently, there are many studies related to the use of mica minerals in different industries in the literature [5-9]. However, few studies have been conducted to determine the elemental composition of micas. Wang et al. [10] analyzed the major-minor oxide components of

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these four mica varieties (muscovite, phlogopites, biotite, and lepidolite) were analyzed using an EDXRF spectrometer to investigate the effects of temperature and chemical composition on irradiation-induced amorphization of these mica samples. Osman et al. [11] determined major-minor oxide analysis of muscovite mineral by ICP-OES to investigate the affinity of alkali metal ions by the ion exchange processes for muscovite. Maslova et al. [12] determined the chemical composition of phlogopite and muscovite samples using ICP-QMS to examine the structural changes and surface properties of phlogopite and muscovite. Ghannam et al. [13] analyzed the chemical components of mica for the synthesis of poly-n-butyl acrylate by in situ nitroxide-mediated polymerizations from the mica surface. Vaculíková and Plevová [14] studied the characterization of clay minerals (crystalline illite, muscovite) using X-ray diffraction and X-ray fluorescence spectroscopy. Ebrahimzadeh [15] measured major-minor oxides in muscovite samples obtained from the Hisarardı mica quarry to examine the oedometric behavior of these mixtures containing mica (muscovite) in different percentages and three different sizes. Seyrekbasan [16] determined the physical and chemical properties of mica samples to investigate the effect of mica fiber used in different proportions on the mechanical properties of new generation composite mortar combinations.

According to literature research, a detailed study related to the analysis of major-minor oxides and trace elements in muscovite samples collected from muscovite quarries in Turkey is not available. This study aims to determine the major and minor oxides and trace elemental contents of eighty-four muscovite samples collected from three commercially operated muscovite quarries (MQ1, MQ2, and MQ3) in the Hisarardı region of Yatağan district of Manisa province in Turkey using an EDXRF spectrometer.

2. MATERIAL and METHOD

2.1. Sampling

Neogene aged sedimentary rocks are exposed in a wide area around the Yatağan district of Muğla province [17]. These rocks were formed in the part of the Muğla Basin, which is one of the continental basins of Western Anatolia, called the Yatağan sub-basin [17]. There are rocks such as gneiss, mica schist, amphibolite, marble, crystallized dolomite formed in different geological times in this basin and its vicinity [17]. The locations of three muscovite quarries (MQ1, MQ2, and MQ3) in the Hisarardı region of the Yatağan district are shown in Figure 1. These muscovite quarries have been commercially operated since 2011. The muscovite samples collected from these three quarries in numbers representing the quarries were brought to the laboratory and left to be dried in the atmosphere. The muscovite samples were then dehumidified by drying in the furnace for a few hours. Since the major-minor oxide and trace element contents of the muscovite samples will be analyzed using an EDXRF spectrometer, the muscovite samples were ground to make them fit the calibrated powder geometry in the XRF spectrometer. The samples powdered were homogenized with the agate pestle. A maximum of five grams of each mica sample was taken for elemental analysis [18].

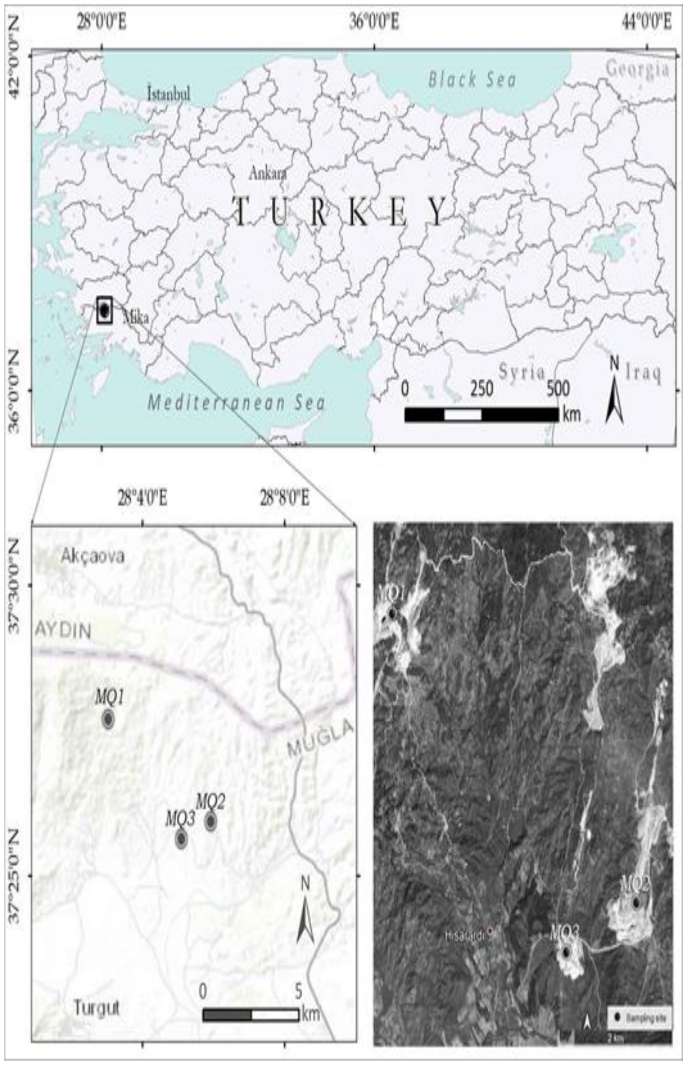

Figure 1. The locations of muscovite quarries

2.2. Analysis of Elemental Concentrations

Analyses of the major, minor and trace elements in the muscovite samples were performed out by using an EDXRF spectrometer (Spectro Xepos). Details of the EDXRF spectrometer are given in the study done out by Turhan et al. The quality assurance for the system was performed using the certified reference material (NIST SRM 2709) [18].

3. RESULTS AND DISCUSSION

3.1. Oxide Contents of Muscovites

Some statistical information related to the oxide concentrations analyzed in the muscovite samples is given in Table 1. The frequency distributions of SiO_2, Al_2O_3, K_2O, MgO, and Na_2O major oxides are shown in Figure 2. In Table 2, the mean concentrations of oxides in muscovite samples were compared with those in sedimentary rock, granite-metamorphic rock, Earth's crust, and mica samples produced in different countries.

The oxides analyzed are listed as $SiO_2 > Al_2O_3 > K_2O >$ $MgO > Na_2O > Fe_2O_3 > P_2O_5 > TiO_2 > CaO$ in descending order according to the mean concentration values (Table 1). The minimum and maximum concentrations of SiO_2 varied from 32 to 59% with an overall mean value of 57%. The mean concentration of SiO_2 from MQ1, MQ2 and MQ3 quarries were found as 53, 57 and 59%, respectively. The highest concentration of SiO_2 was measured in the MQ3 quarry. As can be seen from Figure 2, the frequency distribution of the SiO_2 concentration exhibits a log-normal distribution. Approximately 89% of the SiO2 distribution in muscovite samples is in the concentration range of 55-65%. The mean SiO_2 content of muscovite samples is greater than those in the sedimentary rock, Earth's crust, and micas from Turkey, France, Russia, and Egypt while it is smaller than that in the granite-metamorphic rock. The minimum and maximum concentrations of Al_2O_3 varied from 19 to 40% with an overall mean of 33%. The mean concentrations of Al_2O_3 in the muscovite samples from MQ1, MQ2 and MQ3 quarries were found as 37, 34 and 31%, respectively. The highest concentration of Al_2O_3 was measured in the MQ1 quarry. The frequency distribution of the Al_2O_3 concentration exhibits a distribution close to normal. Approximately 80% of the Al_2O_3 distribution in muscovite samples is in the concentration range of 30 to 40%. The mean Al_2O_3 content of muscovite samples is greater than those in the sedimentary rock, granite-metamorphic rock, Earth's crust, and micas from France and Egypt while it is smaller than those in micas from Russia and Turkey. The minimum and maximum concentrations of K_2O varied from 7 to 11% with an overall mean of 9%. The mean K_2O concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 9.8, 8.5 and 8.3%, respectively. The highest concentration of K_2O was measured in the MQ1 quarry. The frequency distribution of the K_2O concentration exhibits a log-normal distribution. Approximately 99% of the K_2O distribution in muscovite samples is in the concentration range of 9 to 11%. The mean K_2O content of the muscovite samples is greater than those in the sedimentary rock, granite-metamorphic rock, Earth's crust, and mica Egypt while it is smaller than those in micas from Turkey, France, and Russia. The minimum and maximum concentrations of MgO varied from 1.4 to 3.1% with an overall mean of 2.4%.

The mean MgO concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 2.7, 2.4 and 2.2%, respectively. The highest concentration of MgO was measured in the MQ1 quarry. The frequency distribution of MgO concentration shows an abnormal distribution. Approximately 87% of the MgO distribution in muscovite samples is in the concentration range of 1.9 to 2.8%. The mean MgO content of the muscovite samples is smaller than those in the sedimentary rock, granite-metamorphic rock, and Earth's crust while it is higher than those in micas from Turkey, France, Russia, and Egypt. The minimum and maximum concentrations of Na_2O varied from 0.7 to 2.2% with an overall mean of 1.4%.

The mean concentrations of Na_2O in the muscovite samples from MQ1, MQ2 and MQ3 quarries were analyzed as 1.8, 1.6 and 1.3%, respectively. The highest concentration of Na_2O was measured in the MQ3 quarry. The frequency distribution of the Na_2O concentration shows a log-normal distribution. Approximately 82% of the Na_2O distribution in muscovite samples is in the concentration range of 1.3 to 1.9%. The mean Na_2O content is smaller than those in the sedimentary rock, granite-metamorphic, Earth's crust, and black mica from Egypt while it is higher than those in micas from Turkey, France, and Russia. The minimum and maximum concentrations of Fe_2O_3 varied from 0.6 to 2.3% with an overall mean of 0.8%.

The mean Fe_2O_3 concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 0.9, 0.8 and 0.7%, respectively. The highest Fe_2O_3 concentration was measured in the MQ3 quarry. The mean Fe_2O_3 content of the muscovite samples is smaller than those in the sedimentary rock, granite-metamorphic rock, and Earth's crust, micas from Turkey, France, Russia, and Egypt. The minimum and maximum concentrations of P_2O_5 varied from 0.01 to 0.65% with an overall mean of 0.32%. The mean concentrations of P_2O_5 in the muscovite samples from MQ1, MQ2 and MQ3 quarries were analyzed as 0.07, 0.30 and 0.43%, respectively. The highest concentration of P_2O_5 was measured in the MQ3 quarry. The mean P_2O_5 content of the muscovite samples is greater than those in the sedimentary rock, granite-metamorphic rock, and Earth's crust, micas from Turkey, France, Russia, and Egypt. The TiO_2 concentrations in the muscovite samples varied from 0.19 to 0.39% with a mean of 0.29%. The mean TiO_2 concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 0.29, 0.34 and 0.28%, respectively. The highest TiO_2 concentration was measured in the MQ2 quarry. The mean TiO_2 content of the muscovite samples is smaller than those in the sedimentary rock, granite-metamorphic rock, and Earth's crust, mica from Russia while it is higher than that in black mica from Egypt. . The minimum and maximum concentrations of CaO varied from 0.01 to 0.61% with an overall mean of 0.27%.

The mean CaO concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 0.04, 0.24 and 0.37%, respectively. The highest concentration of CaO was measured in the MQ3 quarry. The mean CaO content of the muscovite samples is smaller than those in the sedimentary rock, granite-metamorphic rock, and Earth's crust, mica from France.

Table 1. Some statistical data on oxides analyzed in muscovites

	Concentration (%)								
	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3
Average	1.44	2.38	32.76	57.05	0.32	8.74	0.27	0.29	0.78
SE*	0.04	0.04	0.46	0.61	0.02	0.09	0.02	0.00	0.02
Median	1.36	2.40	33.60	55.95	0.37	8.60	0.32	0.29	0.75
SD*	0.32	0.35	4.17	5.57	0.18	0.84	0.17	0.04	0.20
Kurtosis	-0.27	-0.27	0.54	3.99	-1.19	0.33	-1.24	-0.28	40.16
Skewness	0.45	-0.33	-0.75	-0.66	-0.25	0.78	-0.17	0.11	5.41
Min	0.74	1.38	18.58	31.67	0.01	7.25	0.01	0.19	0.55
Max	2.19	3.10	40.12	68.96	0.65	11.07	0.61	0.39	2.30
N*	84	84	84	84	84	84	84	84	84

**SE: standard error; SD: standard deviation; N: number of samples*

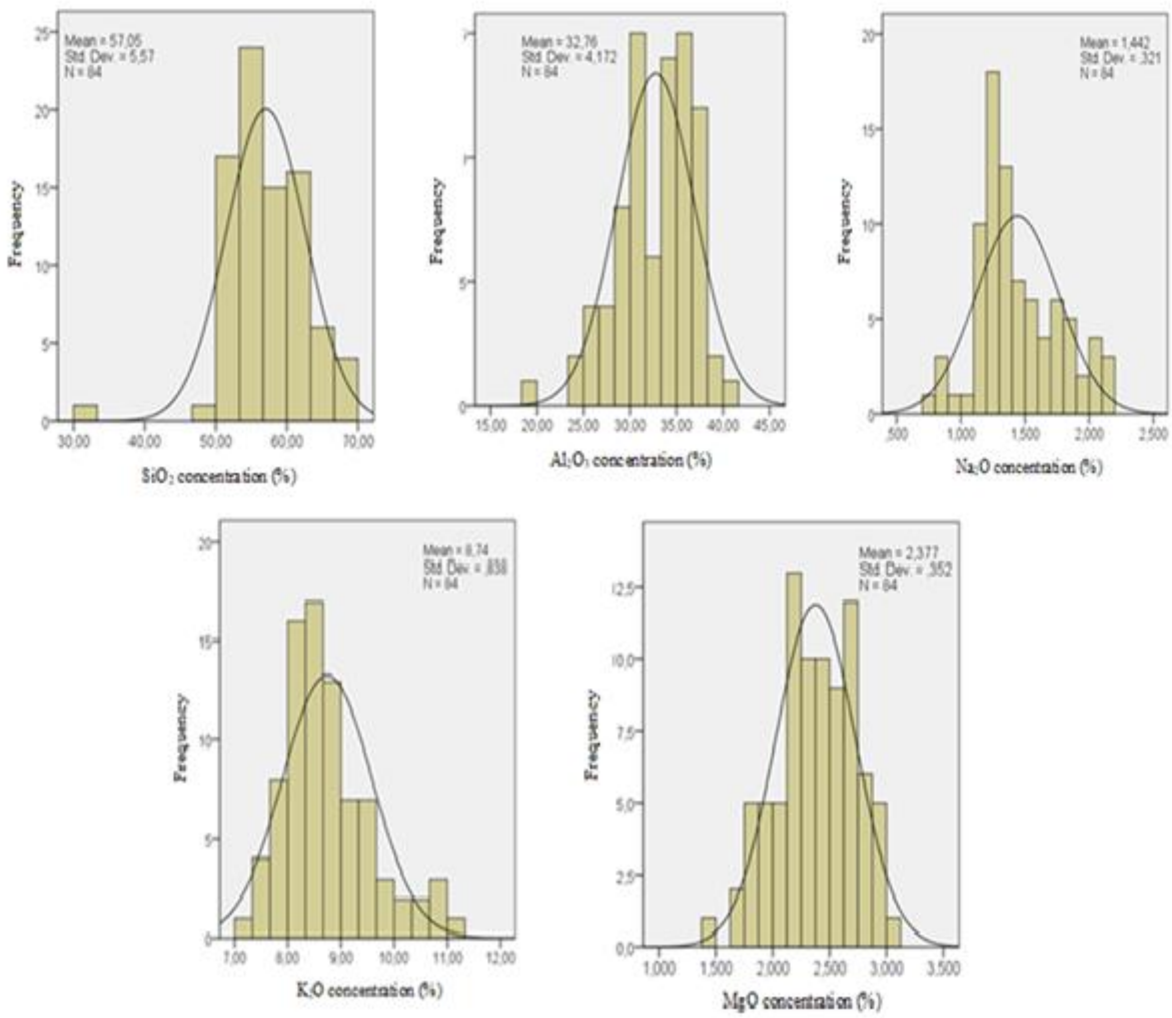

Figure 2. Frequency distribution of SiO_2, Al_2O_3, K_2O, MgO, and Na_2O analyzed in muscovites

Table 2. Comparison of average concentrations of oxides in muscovites with those in rocks, Earth's crust, and micas from different countries

	Concentration of oxides (%)									
	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3	Reference
Sedimentary rock	1.96	3.32	12.89	51.82	0.16	2.23	9.93	0.66	2.50	[19]
Granite-metamorphic rock	3.02	2.83	14.93	63.81	0.14	2.84	4.08	0.54	1.75	[19]
Earth's crust	2.66	5.44	15.87	53.84	0.19	1.09	9.41	0.97	1.11	[19]
Mica (Turkey)	-	-	39.85	47.24	-	12.08	-	-	-	[10]
Mica (Turkey)	1.00	1.50	33.00	50.00	-	9.00	0.30	0.30	0.90	[15]
Mica (Turkey)	0.88	1.72	29.67	52.41	0.07	9.65	0.1	0.35	1.14	[16]
Mica (France)	0.80	-	28.30	49.20	-	9.80	1.00	-	6.90	[13]
Muscovite (Russia)	0.63	1.32	34.00	46.40	0.01	10.50	<0.10	0.37	2.32	[12]
Black mica (Egypt)	3.00	0.23	11.4	55.6	0.04	4.52	0.29	0.12	11.50	[9]
Mica (Turkey)	1.44	2.38	32.76	57.05	0.32	8.74	0.27	0.29	0.78	This study

3.2. Trace Element Contents of Muscovites

Some statistical information on the trace element concentrations were analyzed in the muscovite samples (Table 3). In Table 4, the mean concentrations of elements analyzed in the muscovite samples are compared with those in basic rock, acid rock, and Earth's crust [19]. According to the mean concentration values, the primary toxic heavy metals in the samples are listed (in descending order) as Fe > Cr > Zr > Mn > Zn > Ni > Co > Pb > Cu > Cd > Hg. The Fe concentrations varied from 3874 to 16060 mg kg^{-1} with a mean of 5439 mg kg^{-1}. The mean Fe concentrations from MQ1, MQ2 and MQ3 quarries were found as 5988, 5659 and 5182 mg kg^{-1}, respectively. The mean Fe content is significantly lower than those in the basic rock, acid rock, and Earth's crust (Table 4). The Cr concentrations varied from 7 to 3819 mg.kg^{-1} with a mean of 136 mg kg^{-1}. The mean Cr concentrations from MQ1, MQ2 and MQ3 quarries were found as 9, 11 and 207 mg kg^{-1}, respectively. The mean Cr content is higher than those in the acid rock and Earth's crust, while it is smaller than that in the basic rock. The Zr concentrations varied from 27 to 258 mg kg^{-1} with a mean of 125 mg kg^{-1}. The mean Zr concentrations of the muscovite samples from MQ1, MQ2 and MQ3 quarries were found as 56, 143 and 150 mg kg^{-1}, respectively. The mean Zr content of the muscovite samples is lower than those in the acid rock and Earth's crust while it is higher than that in the basic rock. The Mn concentrations varied from 30 to 452 mg kg^{-1} with a mean of 59 mg kg^{-1}. The mean Mn concentrations of the muscovite samples from MQ1, MQ2 and MQ3 quarries were analyzed as 39, 46 and 69 mg kg^{-1}, respectively. The mean Mn content is significantly lower than those in the basic rock, acid rock, and Earth's crust.

The Zn concentrations varied from 4 to 62 mg kg^{-1} with a mean of 19 mg kg^{-1}. The mean Zn concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 6, 15 and 25 mg kg^{-1}, respectively. The mean Zn content is lower than those in the basic rock, acid rock, and Earth's crust. The Ni concentrations varied from 6 to 527 mg kg^{-1} with a mean of 15 mg kg^{-1}. The mean Ni concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 8, 8 and 18 mg kg^{-1}, respectively. The mean Ni content is lower than those in the basic rock and Earth's crust, while it is higher than that in the acid rock.

The Co concentrations varied from 3 to 46 mg kg^{-1} with a mean of 7 mg kg^{-1}. The mean Co concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 7.0, 6.5 and 6.8 mg.kg^{-1}, respectively. The mean Co content is lower than those in the basic rock and Earth's crust, while it is higher than that in the acid rock. The Pb concentrations varied from 2 to 16 mg kg^{-1} with a mean of 6 mg kg^{-1}. The mean Pb concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 3, 5 and 8 mg kg^{-1}, respectively. The mean Pb content is lower than those in the basic rock, acid rock, and Earth's crust.

The Cu concentrations varied from 0.6 to 39.1 mg kg^{-1} with a mean of 2.6 mg kg^{-1}. The mean Cu concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 1.7, 1.7 and 3.1 mg kg^{-1}, respectively. The mean Cu content is significantly lower than those in the basic rock, acid rock, and Earth's crust. The concentrations of Cd varied from 0.8 to 6.8 mg kg^{-1} with a mean of 2.0 mg kg^{-1}. The mean Cd concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 3.7, 1.4 and 1.4 mg kg^{-1}, respectively. The mean Cd content is approximately fifteen times higher than those in the basic rock, acid rock, and Earth's crust. The concentrations of Hg varied from 0.6 to 2.2 mg kg^{-1} with a mean of 1.2 mg kg^{-1}. The mean Hg concentrations from MQ1, MQ2 and MQ3 quarries were analyzed as 1.2, 1.0 and 1.2 mg kg^{-1}, respectively. The mean Hg content is approximately thirteen times higher than those in the basic rock, acid rock, and Earth's crust.

Table 3. Some statistical data on trace elements analyzed in muscovites

Element	Concentration (mg kg^{-1})							
	Average	SE	Median	SD	Kurtosis	Skewness	Min	Max
Cd	2.0	0.1	1.5	1.4	2.7	1.9	0.8	6.8
Co	6.8	0.5	6.6	4.7	57.7	7.0	3.0	45.5
Cr	136.2	66.0	10.1	604.9	25.5	5.0	6.7	3819.0
Cu	2.6	0.5	1.8	4.2	72.8	8.3	0.6	39.1
Hg	1.2	0.04	1.2	0.3	0.2	0.5	0.6	2.2
Mn	58.7	7.1	46.4	64.8	24.9	4.9	30.1	452.4
Ni	14.8	6.2	8.8	56.6	83.9	9.2	6.1	527.0
Pb	6.3	0.3	5.8	3.0	0.6	1.0	2.2	15.6
Zn	19.2	1.5	15.5	14.1	0.7	1.2	4.2	62.0
Zr	124.6	5.8	124.6	53.4	-0.5	0.1	26.7	257.7
Ag	3.2	0.3	1.8	2.9	1.6	1.6	0.5	12.8
Ga	31.7	0.4	32.1	4.1	-0.2	-0.4	20.5	40.1
Hf	5.6	0.2	5.6	2.1	-0.6	0.4	2.1	10.7
Nb	5.9	0.1	5.7	1.1	0.9	0.4	3.2	8.7
Nd	22.7	0.7	21.1	6.7	-0.3	0.7	11.7	39.2
Sn	135.1	6.6	112.3	60.5	1.8	1.6	72.3	315.0
Ta	20.4	0.3	20.3	2.9	0.5	0.4	14.2	29.4
Te	3.9	0.3	2.6	2.8	0.8	1.4	0.5	11.3
Tl	1.2	0.0	1.1	0.3	0.8	1.2	0.7	2.0
V	28.5	0.8	26.9	7.1	2.1	1.4	17.0	52.1
W	4.0	0.1	3.9	1.1	0.2	0.1	1.3	6.8
Ba	587.9	23.6	668.4	216.0	-0.8	-0.8	145.4	839.1
Cs	22.1	1.7	24.6	15.6	-0.6	0.3	3.1	68.4
Rb	315.9	5.2	316.6	47.7	0.9	0.4	194.8	461.5
Sr	17.3	0.6	15.1	5.3	0.1	1.1	8.7	31.1
Y	6.7	0.4	7.2	3.7	-0.2	-0.1	0.5	15.4

The Pearson correlation matrix of primary toxic heavy metals analyzed in the samples is given in Table 5. As can be seen from the bold numbers in Table 4, a significant positive correlation between toxic heavy metals ($p \leq 0.01$; greater than 0.4).

As can be seen from Table 3, the other heavy metals analyzed in the muscovite samples are listed as Sn > Ga > V > Nd > Ta > Nb > Hf > W > Te > Ag > Tl in descending order according to the mean concentration values. The mean concentrations of Sn, Ga, V, Nd, Ta, Nb, Hf, W, Te, Ag and Tl analyzed in the samples were found as 135, 32, 29, 23, 20, 5.9, 5.6, 4, 3.9, 3.2 and 1.1 mg kg^{-1}, respectively.

The mean concentrations of Ba, Cs, Rb, Sr and Y analyzed in the samples were found as 588, 22, 316, 17 and 7 mg kg^{-1}, respectively.

Table 4. Comparison of the average concentration of the elements in muscovites with those in some rocks and Earth's crust

Element	Concentration of elements (mg kg^{-1})						
	Basic rock	Acid rock	Earth's Crust	MQ1	MQ2	MQ3	Mica
Cd	0.19	0.1	0.13	3.7	1.4	1.4	2.0
Co	45	5	18	7.0	6.5	6.8	6.8
Cr	200	25	83	9.0	11.3	206.6	36.2
Cu	100	20	47	1.7	1.7	3.1	2.6
Fe	85600	27000	46500	5988.0	5658.8	5182.4	5438.8
Hg	0.09	0.08	0.083	1.2	1.0	1.2	1.2
Mn	200	600	1000	38.7	45.5	68.8	58.7
Ni	160	8	58	8.1	8.3	18.4	14.8
Pb	8	20	16	3.2	4.8	7.8	6.3
Zn	130	60	83	5.8	14.8	25.4	19.2
Zr	100	200	170	56.4	143.3	149.5	124.6
Ag	0.1	0.05	0.07	7.1	1.3	1.9	3.2
Ga	18	20	19	30.5	33.1	32.0	31.7
Hf	1	1	1	3.9	6.2	6.3	5.6
Nb	20	20	20	5.0	7.6	6.0	5.9
Nd	20	46	37	17.3	23.5	24.8	22.7
Sn	1.5	3	2.5	216.7	136.6	101.7	135.1
Ta	0.48	3.5	2.5	21.6	21.3	19.7	20.4
Te	0.001	0.001	0.001	7.7	2.5	2.6	3.9
Tl	0.2	1.5	1	1.6	1.1	1.0	1.2
V	200	40	90	37.0	24.5	25.6	28.5
W	1	1.5	1.3	3.0	5.7	4.2	6.0
Ba	300	830	650	254.6	671.9	711.3	587.9
Cs	1	5	3.7	11.8	28.0	25.4	22.1
Rb	45	200	150	353.1	303.7	302.5	315.9
Sr	440	300	340	25.2	17.4	14.0	13.3
Y	20	34	29	2.3	9.3	8.1	6.7

Table 5. Pearson's correlation coefficient matrix between toxic heavy metals

Quarry code		Toxic heavy metals										
MQ1		Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	Zr
	Cd	1.0										
	Co	**0.5**	1.0									
	Cr	0.2	0.1	1.0								
	Cu	0.4	0.4	**0.6**	1.0							
	Fe	0.4	0.1	**0.7**	**0.6**	1.0						
	Hg	**0.6**	0.4	0.1	0.3	**0.5**	1.0					
	Mn	0.4	0.2	**0.8**	**0.6**	**0.9**	**0.5**	1.0				
	Ni	**0.7**	0.4	**0.6**	0.4	**0.7**	0.4	**0.7**	1.0			
	Pb	**0.6**	0.4	**0.5**	**0.7**	**0.7**	**0.8**	**0.8**	**0.6**	1.0		
	Zn	**0.6**	0.3	**0.7**	**0.8**	**0.9**	**0.6**	**0.9**	**0.8**	**0.9**	1.0	
	Zr	0.1	0.2	0.3	0.3	0.0	0.2	0.0	0.3	0.2	0.3	1.0
MQ2		Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	Zr
	Cd	1.0										
	Co	-0.5	1.0									
	Cr	-0.1	-0.4	1.0								
	Cu	-0.6	0.3	**0.5**	1.0							
	Fe	-0.2	-0.1	**0.8**	0.2	1.0						
	Hg	-0.1	0.3	-0.2	-0.2	-0.3	1.0					
	Mn	-0.2	-0.3	**0.9**	0.4	**0.9**	-0.3	1.0				
	Ni	-0.1	-0.4	0.3	**0.6**	-0.2	0.02	0.1	1.0			
	Pb	0.4	-0.3	-0.3	-0.2	-0.7	**0.5**	-0.5	0.4	1.0		
	Zn	0.4	0.1	-0.6	-0.2	-0.8	**0.5**	-0.7	0.2	**0.9**	1.0	
	Zr	0.1	-0.5	-	-0.0002	-0.4	0.4	-0.2	**0.7**	**0.9**	**0.7**	1.0
MQ3		Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	Zr
	Cd	1.0										
	Co	-0.2	1.0									
	Cr	0.1	0.4	1.0								
	Cu	-0.2	**0.9**	0.4	1.0							
	Fe	-0.2	**0.9**	0.4	**0.9**	1.0						
	Hg	0.1	-0.1	-0.2	-0.1	0.1	1.0					
	Mn	0.1	0.4	**1.0**	0.4	0.4	-0.2	1.0				
	Ni	-0.2	**0.9**	0.4	**1.0**	**1.0**	-0.1	0.4	1.0			
	Pb	0.1	-0.2	-0.1	-0.2	-0.2	-0.04	-0.04	-0.2	1.0		
	Zn	0.02	-0.2	-0.1	-0.2	-0.2	-0.1	-0.05	-0.2	**0.8**	1.0	
	Zr	-0.2	-0.1	-0.2	-0.1	0.0	0.3	-0.2	-0.1	0.2	0.1	1.0

4. CONCLUSIONS

This study is the first detailed study in which samples taken from commercially operated muscovite quarries in Yatağan district of Manisa province were examined in terms of 9 oxide molecules (SiO_2, Al_2O_3, K_2O, MgO, Na_2O, Fe_2O_3, P_2O_5, TiO_2, and CaO) and 28 trace elements (Cr, Zr, Mn, Zn, Ni, Co, Pb, Cu, Cd, Hg, Sn, Ga, V, Nd, Ta, Nb, Hf, W, Te, Ag, Tl, Th, U, Ba, Cs, Rb, Sr, and Y). It has been revealed that muscovites contain cadmium and mercury, which are important and primarily poisonous heavy metals for human and environmental health. In this context, it is recommended to check whether the necessary measures are taken or not for workers working in the stages of extraction, crushing, and sieving of the mica minerals in terms of worker health and work safety.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

ACKNOWLEDGEMENT

This study is carried out within the framework of a master thesis conducted at Kastamonu University and supported by The Scientific Research Projects Coordinator of Kastamonu University (Research Project codded of KÜ-BAP01/2020-11

AUTHORS' CONTRIBUTIONS

Eman M.A. KRISTA: Performed the experiments and analyse the results.

Şeref TURHAN*:* Literature review and wrote the article and made statistical analysis**.**

Aslı KURNAZ: The analysis of the data and the writing of the article in scientific terms**.**

Aybaba HANÇERLİOĞULLARI: The analysis of the data and the writing of the article in scientific terms**.**

CONFLICT OF INTEREST

There is no conflict of interest in this study

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