RADIOLOGICAL, GEOCHEMICAL, AND MINERALOGICAL CHARACTERIZATION OF NATURAL STONES USED IN TURKEY

by

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In the study, radiological, geochemical, and mineralogical characterization of natural stone samples used for covering or ornamental purposes collected from different quarries in Turkey was done using gamma spectrometric technique with high-purity germanium detector, X-ray fluorescence spectroscopic technique, X-ray diffraction technique and thin sections. The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were measured in natural stone samples as 28.9, 30.8, and 355.0 Bqkg^{-1}, respectively. The assessment of radiological hazards from utilization of stone samples as covering or ornamental material in building sector was made by estimating activity concentration index, absorbed gamma dose rate and annual effective dose rate. The examined natural stone samples were composed of calcite, dolomite, quartz, orthoclase, albite, biotite, hornblende, oligoclase, olivine and talc.

Key words: natural stone, radioactivity, geochemical characterization, mineralogical characterization, activity concentration, annual effective dose

INTRODUCTION

Turkey is located in the Alpine zone in which the world's richest natural stones deposits are found. Therefore, Turkey has significant natural stone reserves. For instance, Turkey's probable industrial marble reserves are between 5.1- 9.13 billion tons [1]. Turkey is increasing its share in the international markets every year with a variety of natural stones in different colors and texture quality. Natural stones are widely used in Turkey's construction sector as a cheap construction material for large areas – countertops in kitchens and lining of walls and floors. However, natural stones can contain admixture of ^{226}Ra, ^{232}Th, and ^{40}K natural radionuclides and cause direct radiation exposure. Thus the use of such stones in a building can result in the long term exposure to the occupants. There have been numerous scientific studies conclude that countertops, tiles, and other finishes made of stones might emit any level of radiation [2-21]. According to our literature survey a few studies investigating properties of geochemical, mineralogical and radiological of Turkish stone samples are available in the literature [22-24].

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The aim of the study, firstly, is to reveal mineralogical, geochemical, and radiological characteristics of 18 different natural stone samples collected from various geographical regions of Turkey using binocular polarized light (PL) microscopy, spectrometric techniques of X-ray diffraction (XRD), X-ray fluorescence (XRF), and gamma techniques. Secondly, the aim is to assess the potential radiological hazards caused by the usage of stone samples as covering or decorative and countertops tiles in the building sectors by estimating activity concentration index, absorbed gamma dose rate and the corresponding annual effective dose rate.

MATERIAL AND METHODS

Sampling and sample preparation

Eighteen natural stone samples (sedimentary, metamorphic, and magmatic) representing the most popular types were collected from the Aegean (AG), Central Anatolia (CA), East Anatolia (EA), Marmara (MA), Mediterranean (ME), and Southeast Anatolia (SA) geographic regions of Turkey. Firstly, the stone samples were prepared for gamma spectrometric measurements as follows: all samples were air dried,

grounded and screened through a 2 mm sieve. Then the samples were packed and sealed in an impermeable air tight 250 ml PVC container to prevent the escape of radiogenic gases such as radon after the drying process. Before starting the gamma spectrometric measurements, the sealed samples were stored about four weeks to reach the radioactive equilibrium of ^{238}U, ^{232}Th, and their decay products.

Gamma spectrometric measurements

The measurements were carried out using a gamma spectrometer with a coaxial hyper pure germanium (HPGe) detector, having 50% relative efficiency. The detailed information related to gamma spectrometric system was given in the reference [25]. The absolute calibration of the gamma spectrometer was carried out using the IAEA reference materials RGU-1, RGTh-1, RGK-1, and soil 375. The gamma spectra were obtained for each sample placed on top of the detector and background counting for 86400 s. The background spectra were used to get the net gamma-ray peak belonging to the radionuclide in the stone sample. The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the stone samples were computed using the following equation [26]

$$A \quad \frac{C_R}{\varepsilon P M} \tag{1}$$

where A is the activity concentration of a radionuclide (in Bqkg^{-1}), C_R – the net count rate of a specific gamma emission (in counts per second), ε – the absolute efficiency, P – the emission probability, and M – the mass of the sample (in kg). The activity concentrations of ^{226}Ra were determined from the gamma-ray peak of ^{214}Pb (352 keV) and ^{214}Bi (609 keV). The gamma-ray peak of ^{228}Ac (911 keV) and ^{208}Tl (583 keV) were used to determine the activity concentrations of ^{232}Th. The ^{40}K activity concentration was determined from the 1460.8 keV emission gamma-ray line. The mean values of the minimum detectable activity concentrations for ^{226}Ra, ^{232}Th, and ^{40}K were determined as 0.3, 0.4, and 3.3 Bqkg^{-1} for the marble samples. The uncertainty of the activity concentration is estimated using the following equation [26]

$$\frac{\Delta A}{A} \quad \sqrt{\left(\frac{\Delta C_R}{C_R}\right)^2 \quad \left(\frac{\Delta P}{P}\right)^2 \quad \left(\frac{\Delta \varepsilon}{\varepsilon}\right)^2 \left(\frac{\Delta M}{M}\right)^2} \tag{2}$$

where ΔA is the activity uncertainty, ΔC_R – the count rate uncertainty, ΔP the emission probability uncertainty, $\Delta \varepsilon$ – the efficiency uncertainty, and ΔM – the weighing uncertainty.

Geochemical measurements

The X-ray fluorescence (XRF) spectrometer has been a valuable experimental tool for determining the chemical composition of the natural stone samples. The geochemical compositions of the samples were determined using an energy dispersive X-ray fluorescence (EDXRF) spectrometer (PW4030) which consists of air cooled X-ray tube having a rhodium anode and a liquid nitrogen cooled Si(Li) detector.

Mineralogical measurements

The X-ray diffraction (XRD) technique makes the mineralogical identification of the stones possible. Mineralogical measurements of the samples were carried out using a Rigaku Miniflex system (XRD system with CuK radiation). The XRD pattern of grounded powder samples was recorded at room temperature in powder mode. Samples were run from 20° to 50° 2θ with a step size of 0.02°. Thin sectioned samples were examined by a binocular polarized light (PL) microscopy (Kyowa). An optical microscope with transmitted and reflected light was used to further examine the thin section samples.

RESULTS AND DISCUSSION

Activity concentrations

As can be seen from tab. 1, the activity concentrations of the stone samples vary from site to site because of large variations in chemical and mineralogical properties of the samples. The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K measured in the samples varied from 2.0 Bqkg^{-1} to 190.2 Bqkg^{-1} with a mean of 28.9 10.8 Bqkg^{-1}, <MDA* to 245.1 Bqkg^{-1} with a mean of 30.8 15.1 Bqkg^{-1}, and <MDA to 1278.7 Bqkg^{-1} with a mean of 355.0 118.3 Bqkg^{-1}, respectively. The highest activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were observed in the sample of S17 (Aksaray 1/Central Anatolia). The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are lower than the mean values of 32, 45, and 412 Bqkg^{-1} for ^{226}Ra, ^{232}Th, and ^{40}K, respectively, measured in the Earth's crust [27]. In tab. 2 the average concentration values of these radionuclides in the natural stone samples are compared with those in European stone samples used superficial materials and classified according to their geological origin (igneous plutonic, igneous volcanic, and metamorphic) [28]. It is seen from tab. 2 that the average values of the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the metamorphic stone sample are significantly lower than those in European metamorphic stone samples. Also, the average values of the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the magmatic stone sample are 3-6 times lower than those in European igneous plutonic and volcanic.

*MDA is mean directional accuracy

Table 1. The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K measured in the natural stone samples

Sample code	Commercial name/geographical region	Activity concentration [Bqkg^{-1}]		
		^{226}Ra	^{232}Th	^{40}K
S1	Konya/CA	2.6 0.4	2.0 0.5	17.9 0.6
S2	Afyon sugar/AG	3.0 0.3	1.2 0.4	3.0 0.1
S3	Mugla sugar/AG	3.5 0.4	2.2 0.5	24.9 0.8
S4	Mut Traverten/ME	3.4 0.4	1.2 0.4	3.5 0.1
S5	Sivas/CA	12.4 0.7	1.6 0.5	<MDA[b]
S6	Sirnk black/SA	22.8 0.8	5.1 0.7	146.8 3.1
S7	Adryaman emperador/SA	20.3 0.8	0.9 0.4	14.8 0.6
S8	Elazig cherry/EA	12.2 0.7	2.1 0.6	15.5 0.6
S9	Kirsehir black/CA	45.3 1.3	7.5 1.0	107.6 2.6
S10	Diyarbakir beige/SA	6.1 0.7	<MDA[a]	<MDA[b]
S11	Malatya beige/SA	6.7 0.7	<MDA[a]	<MDA[b]
S12	Silifke white/ME	2.6 0.5	1.9 0.7	<MDA[b]
S13	Aksaray Dark/CA	43.3 2.1	54.6 3.6	978.6 13.1
S14	Aksaray 2/CA	66.7 1.9	95.8 5.3	1025.8 12.9
S15	Marmara pajamas/MA	2.0 0.3	1.7 0.6	<MDA[b]
S16	Aksaray Light/CA	69.4 1.7	67.6 3.7	991.0 11.9
S17	Aksaray 1/CA	190.2 4.3	245.1 12.4	1278.7 15.7
S18	Misis white/ME	7.9 0.6	2.7 0.7	7.5 0.3
Min		2.0	<MDA[b]	<MDA[b]
Max		190.2	245.1	1278.7
Mean SE		28.9 10.8	30.8 15.1	355.0 118.3

[a] MDA is 0.4 Bqkg^{-1} and [b] MDA is 3.3 Bqkg^{-1}

Table 2. Comparison of the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the natural stone samples with those in European stone samples

Stone type	Activity concentration [Bqkg^{-1}]			References
	^{226}Ra	^{232}Th	^{40}K	
Igneous plutonic	78	89	1049	[20]
Igneous volcanic	160	163	1295	[20]
Metamorphic	27	21	395	[20]
[a]Sedimentary	9	2	23	This study
[b]Metamorphic	13	3	35	This study
[c]Magmatic	26	26	318	This study
All stones	29	31	355	This study

[a] Samples of S1, S4, S5, S6, S7, S10, S11, S12, and S18, [b] Samples of S2, S3, S9, and S15, [c] Samples of S8, S13, S14, S16, and S17

Assessment of radiological hazards from utilization of the stone samples

Activity concentration index

The external radiation exposure due to the use of building materials is caused by the direct gamma radiation emitted from natural radionuclides. Enhanced or elevated levels of natural radionuclides in building materials may cause annually doses of the order of several mSv. Therefore, a control on the radioactivity of building materials is to limit the radiation exposure due to materials with enhanced or elevated levels of natural radionuclides [28]. As well as the criterion for controlling was established to consider the overall nations circumstances, it is recommended that the controls should be based on an annual effective dose in the range 0.3-1 mSv [28]. The activity concentration index has been used for practical controlling purposes. Taking into consideration more than one radionuclide contributions to the radiation dose, the activity concentration index was calculated for building as [28]

$$I \quad \frac{A_{\mathrm{Ra}}}{300\,\mathrm{Bqkg}^{-1}} \quad \frac{A_{\mathrm{Th}}}{200\,\mathrm{Bqkg}^{-1}} \quad \frac{A_{\mathrm{K}}}{3000\,\mathrm{Bqkg}^{-1}} \tag{3}$$

where I is the activity concentration index, A_{Ra}, A_{Th}, and A_{K} are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in terms of Bqkg^{-1}, respectively. For covering materials (tiles and natural building stones), I 2 corresponds to an annual effective dose less than or equal 0.3 mSv, while $I \leq 6$ corresponds to an annual effective

Table 3. The values of the activity concentration index (*I*), the indoor absorbed gamma dose rate *D*, and the annual effective dose *E*

Sample code	*I*	*D* [nGyh^{-1}]	*E* [mSv]
S1	0.02	0.8	0.004
S2	0.02	0.6	0.003
S3	0.03	1.0	0.005
S4	0.02	0.6	0.003
S5	0.05	1.7	0.009
S6	0.15	4.9	0.024
S7	0.08	2.7	0.013
S8	0.06	1.9	0.009
S9	0.22	7.5	0.037
S10	0.02	0.8	0.004
S11	0.03	0.9	0.004
S12	0.02	0.6	0.003
S13	0.74	22.2	0.109
S14	1.04	31.3	0.153
S15	0.02	0.5	0.003
S16	0.90	27.3	0.134
S17	2.29	69.4	0.341
S18	0.04	1.4	0.007
Min	0.02	0.5	0.003
Max	2.29	69.4	0.341
Mean SE	0.32 0.14	9.8 4.2	0.048 0.021

dose less than or equal to 1 mSv [28]. The values of the activity concentration index calculated for the stone samples are given in the second column of tab. 3. It is observed, from tab. 3, that all values of *I* are lower than the criterion of 2 corresponding to the annual effective dose 0.3 mSv, except for S17 (Aksaray 1). The mean values of *I* estimated for the magmatic and metamorphic samples are compared with those reported for different countries in tab. 4. From tab. 4 the mean values of *I* for the metamorphic samples examined in the present study are lower than those reported by other studies, except for Austria.

Absorbed gamma dose rate and the annual effective dose rate

The absorbed gamma dose rate in indoor air was evaluated using data and formulae provided by the EC report [28].

$$D \quad CF_{\mathrm{Ra}} A_{\mathrm{Ra}} \quad CF_{\mathrm{Th}} A_{\mathrm{Th}} \quad CF_{\mathrm{K}} A_{\mathrm{K}} \qquad (4)$$

where D is the absorbed gamma dose rate (in nGyh^{-1}); A_{Ra}, A_{Th}, and A_{K} are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K (in Bqkg^{-1}), respectively; CF_{Ra}, CF_{Th}, and CF_{K} are dose conversion factors estimated as 0.12 nGyh^{-1} per Bqkg^{-1} for ^{226}Ra, 0.14 nGyh^{-1} per Bqkg^{-1} for ^{232}Th and 0.0096 nGyh^{-1} per Bqkg^{-1} for ^{40}K, respectively. These factors were calculated from the center of the room. The dimensions of the room are 4 m 5 m 2.8 m. The thickness of tiles on all walls and the density of the structures are 3 cm and 2600 kgm^{-3}, respectively. The values of D evaluated for the stone samples are given in the third column of tab. 3. As can be seen from tab. 3, all values of D are lower than the world mean indoor absorbed gamma dose rate of 84 nGyh^{-1} [27].

The corresponding annual effective dose was calculated as [27]

$$E \quad DF_{\mathrm{c}} ET \; 10^{\;6} \qquad (5)$$

where E is the annual effective dose (in mSv), D is the absorbed gamma dose rate (in nGyh^{-1}), F_{c} is the conversion factor of 0.7 SvGy^{-1} from indoor absorbed gamma dose in air to effective dose received by adults and ET is annual exposure time of 7000 h, implying that 80 % of time is spent indoors [27]. The values of E are given in the fourth column of tab. 3. All values of E are below than the exemption dose criterion of 0.3 mSv, except for S17 (Aksaray 1).

Geochemical composition

The geochemical compositions of the stone samples determined by XRF are presented in tab. 5. Major and minor element contents of the samples are expressed in % weighted. From tab. 5, the values of SiO_2, Al_2O_3, Fe_2O_3, MgO, and CaO varied from <0.01 to 72.30, <0.05 to 15.80, 0.08 to 11.46, <0.05 to 18.90 and 2.02 to 55.55, respectively. However, the chemistry results show that the granite samples of S13, S14, S16, and S17 contain a high proportion of TiO_2, K_2O, and ZrO_2.

Table 4. Comparison of the mean values of the activity concentration index with European stone samples

Country	Mean value of the activity concentration index				References
	Igneous plutonic	Igneous volcanic	Metamorphic	Magmatic	
Austria	0.61	0.33	0.04	–	[20]
Greece	1.12	1.49	0.19	–	[20]
France	–	–	0.60	–	[20]
Germany	0.81	0.58	0.25	–	[20]
Italy	1.21	2.29	0.80	–	[20]
Poland	1.10	–	0.51	–	[20]
Portugal	1.79	–	0.56	–	[20]
Slovakia	0.72	–	0.11	–	[20]
Spain	0.85	–	–	–	[20]
Turkey	–	–	0.07	1.01	This study

Table 5. The geochemical composition of the natural stone samples

Sample code	% SiO_2	% Al_2O_3	% Fe_2O_3	% MgO	% CaO	% Na_2O	% K_2O	% TiO_2	% MnO	% Cr_2O_3	% ZrO_2	% LOI
S1	2.27	0.50	0.41	<0.05	53.03	<0.01	<0.01	0.05	0.01	0.03	<0.01	43.70
S2	<0.01	0.13	0.13	<0.05	51.96	<0.01	<0.01	0.05	0.02	0.01	<0.01	44.48
S3	<0.01	0.18	0.17	<0.05	55.34	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	44.09
S4	<0.01	0.18	0.11	0.34	55.46	<0.01	<0.01	0.07	<0.01	0.01	<0.01	43.60
S5	<0.01	0.28	0.20	0.41	55.20	<0.01	<0.01	0.09	<0.01	<0.01	<0.01	43.10
S6	10.45	2.80	1.50	<0.05	45.33	<0.01	0.34	0.19	0.08	0.02	<0.01	38.65
S7	<0.01	<0.05	0.10	10.71	49.75	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	39.40
S8	25.00	<0.05	11.46	18.90	23.84	<0.01	<0.01	<0.01	0.11	0.92	<0.01	18.75
S9	36.70	<0.05	2.64	13.92	24.91	<0.01	0.31	0.32	0.06	0.05	<0.01	19.56
S10	2.63	0.53	0.49	1.50	52.77	<0.01	<0.01	0.09	0.01	0.02	<0.01	41.30
S11	<0.01	0.29	0.23	<0.05	55.55	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	42.75
S12	<0.01	0.16	0.13	0.42	55.48	<0.01	<0.01	0.04	<0.01	0.02	<0.01	42.85
S13	69.30	15.10	3.82	<0.05	2.02	2.30	4.51	0.34	0.11	0.00	0.14	0.65
S14	72.30	14.70	2.36	<0.05	2.06	2.10	4.31	0.21	0.06	0.06	0.14	0.58
S15	<0.01	0.13	0.08	0.20	52.52	<0.01	<0.01	0.01	<0.01	0.01	<0.01	45.01
S16	69.50	14.90	3.85	<0.05	2.19	2.15	4.43	0.31	0.13	0.01	0.15	0.68
S17	61.60	15.80	6.99	1.30	3.77	1.90	4.63	0.69	0.17	0.05	0.12	0.71
S18	<0.01	0.32	0.16	<0.05	54.40	2.10	<0.01	<0.01	0.09	0.03	<0.01	44.98

Stone type and mineralogical composition

A typical X-ray diffractograms from the powdered stone samples are shown in fig. 1. The XRD pattern denotes that all samples are in highly crystalline nature. The XRD results show that limestone, travertine, and dolomitic limestone are composed of calcite and dolomite, granitic rocks are including biotite, albite, orthoclase, quartz, and hornblende and the metamorphic rocks are dominated by quartz, biotite, hornblende, and oligoclase which show schist textures. Ophicalcite dunite is formed by olivine, talc, calcite, anorthite, chrysotile.

Thin sections from each sample were prepared for the microscopic study. In order to make structural and textural analyses, including identification and classification of the samples, microscopic analysis of thin sections and XRD results have been combined and shown in tab. 6. The results were evaluated in three groups: firstly, the stone samples of S13 (Aksaray dark), S14 (Aksaray 2), S16 (Aksaray light), and S17 (Aksaray 1) are magmatic rocks. These samples are granitic rocks which have quartz, biotite, albite, orthoclase, and sphene crystals. The granitic rocks included in K-feldspar megacrysts (fig. 2A-D). The stone sample of S8 (Elazig cheery) is identified as ultramafic rock which contains over serpantinized olivine, chrysotile, and calcite crystals (fig. 2E). Secondly, the stone samples of S3 (Mugla sugar), S15 (Marmara pajamas), S2 (Afyon sugar), and S9 (Kirsehir black) are identified as metamorphic rocks. The S3, S15, and S2 rocks are occurred by calcite and dolomite crystals (fig. 3A-D). The sample of Kirsehir black (S9) shows very clear structure of schistosity and include hornblende, calcite, mica, minor amounts of quartz, plagioclase, sphene, and opaque minerals (fig. 3C). Thirdly, the stone samples of S1 (Konya), S10 (Diyarbakir beige), S11 (Malatya beige), S12 (Silifke white), and S18 (Misis white) are identified as biomicritic limestone in sedimentary rocks (fig. 3E). The group of limestone has the S5 (Sivas), S6 (Sirnak black), and S4 (Mut) travertine units which are mainly occurred by thin calcite, rare quartz crystals, a large amount of fossils and iron oxides (fig. 3F). The S7 sample (Adryaman emperador) is named dolomitic limestone because of dolomite and the large amount of calcite.

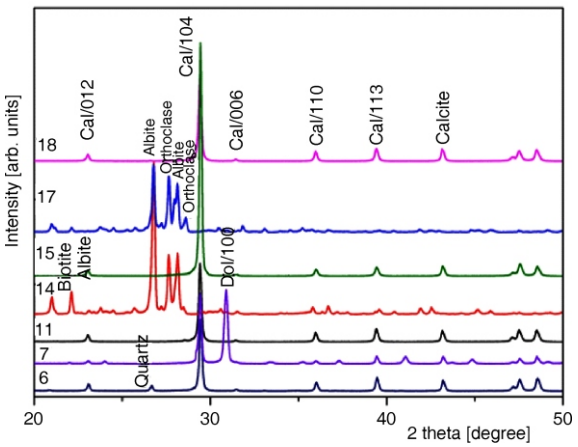

Figure 1. XRD patterns of the selected natural stone samples; sample numbers are indicated on the each pattern

CONCLUSION

Radiological, geochemical, and mineralogical characterization of the natural stone samples from different geographical regions of Turkey was determined by the gamma-ray spectrometry with HPGe detector, XRF, XRD, and binocular polarized light (PL) microscope. The mean activity concentrations of ^{226}Ra,

Table 6. Thin section and XRD mineralogical composition of the natural stone samples

Sample code	Commercial name/ geographical region	Rock type	Q	B	A	H	O	AN	OR	O	CH	T	C	D	Others
S1	Konya/CA	Sedimentary/limestone	–	–	–	–	–	–	–	–	–	–	A	–	Fossil-M
S2	Afyon sugar/AG	Metamorphic/marble	–	–	–	–	–	–	–	–	–	–	A	–	–
S3	Mugla sugar/AG	Metamorphic/marble	–	–	–	–	–	–	–	–	–	–	A	–	–
S4	Mut traverten/ME	Sedimentary/travertine	–	–	–	–	–	–	–	–	–	–	A	–	Fossil-M
S5	Sivas/CA	Sedimentary/limestone	–	–	–	–	–	–	–	–	–	–	A	–	Fossil-M
S6	Sirnak black/SA	Sedimentary/limestone	M	–	–	–	–	–	–	–	–	–	A	–	Fossil-L
S7	Adryaman emperador/SA	Sedimentary/dolomitic limestone	–	–	–	–	–	–	–	–	–	–	A	A	
S8	Elazig cherry/EA	Magmatic/ophicalcite dunite	–	–	–	–	–	L	–	M	A	M	A	–	Opaque-M, Chlorite-L
S9	Kirsehir black/CA	Metamorphic/schist	A	L	–	M	M	–	–	–	–	–	MA	–	Sphene-S, Opaque-L
S10	Diyarbakir beige/SA	Sedimentary/limestone	–	–	–	–	–	–	–	–	–	–	A	–	Fossil-M
S11	Malatya beige/SA	Sedimentary/limestone	–	–	–	–	–	–	–	–	–	–	A	–	Fossil-M
S12	Silifke white/ME	Sedimentary/limestone	–	–	–	–	–	–	–	–	–	–	A	–	Fossil-MA
S13	Aksaray dark/CA	Magmatic/granite	A	MA	MA	M	–	–	MA	–	–	–	–	–	Opaque-L
S14	Aksaray 2/CA	Magmatic/granite	A	MA	MA	M	L	–	MA	–	–	–	–	–	Opaque-L, Chlorite-L
S15	Marmara pajamas/MA	Metamorphic	–	–	–	–	–	–	–	–	–	–	A	–	–
S16	Aksaray Light/CA	Magmatic/Granite	A	MA	MA	–	L	–	MA	–	–	–	–	–	Opaque-L, Chlorite-L, Hornblende-S
S17	Aksaray 1/CA	Magmatic/granite	A	MA	MA	–	L	–	MA	–	–	–	–	–	Opaque-L, Chlorite-L, Hornblende-S
S18	Misis white/ME	Sedimentary/limestone	–	–	–	–	–	–	–	–	–	–	A	–	Fossil-MA

Q: quartz, B: biotite, A: albite, H: hornblende, AN: anorthite, OR: orthoclase, O: olivine, CH: chrysotile, T: talc, O: oligoclase, C: calcite, D: dolomite, A: abundant, MA: moderately abundant, M: moderate, L: low, and S: sparse

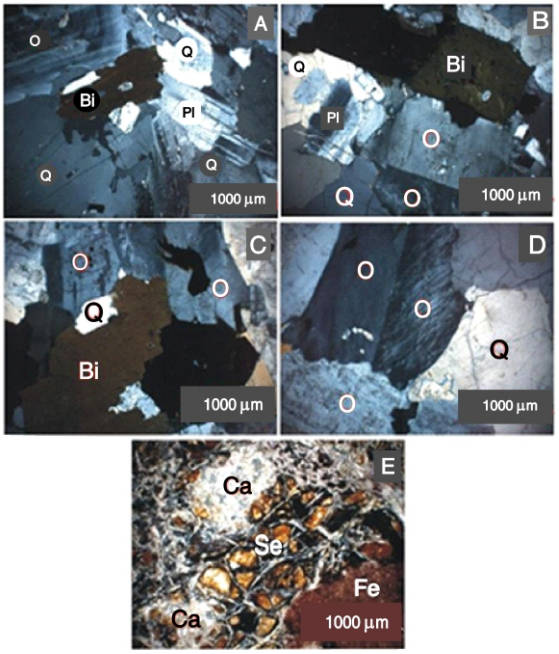

Figure 2. Thin section microphotograph of magmatic rock samples (crossed polars), A-B-C-D: granite (Aksaray), O: orthoclase; Q: ouartz; Bi: biotite; Pl: plagioclase (Albite); (E): ophicalcite dunite (Elazig cherry); Ca: calcite; Se: serpentine (Chrysotile); Fe: iron alteration

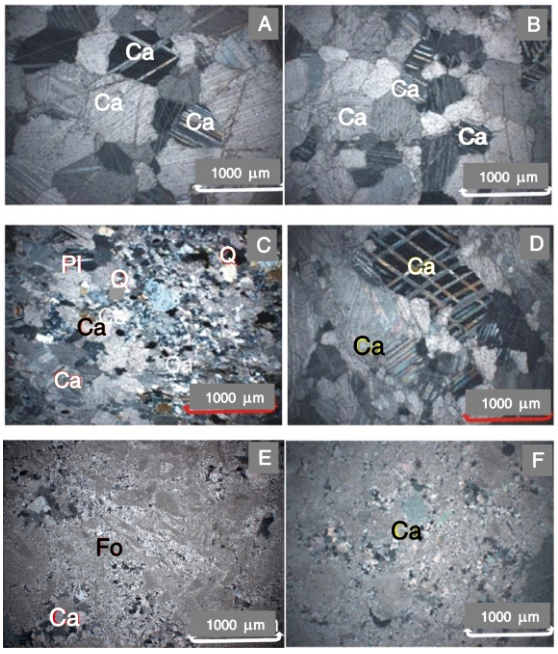

Figure 3. Thin section microphotograph of metamorphic rock samples (crossed polars); (A): afyon sugar, Ca: calcite, (B): mugla Ca: calcite, (C): kirsehir Pl: plagioclase (Oligoclase), Ca: calcite, Q: quartz, (D): marmara, Ca: calcite, (E): silifke, Ca: calcite, Fo: fossil, (F): mut travertine, Ca: calcite; the grain boundaries are regular in samples A and B while C and D showed highly irregular grain boundaries

^{232}Th, and ^{40}K measured in the samples are lower than those with mean values measured in the Earth's crust and natural building stones utilized in the European Union countries. For each stone sample the activity concentration index, the absorbed gamma dose rate and the annual effective dose were estimated to assess the possible radiological hazard for external radiation exposure of the members of the public from the usage of the samples as ornamental or covering material in the building sector. The results show that all stone samples with the exception of one sample (Aksaray 1) meet the exemption annual dose criterion of 0.3 mSv. The natural stone samples examined contained majorly silicon oxide, calcium oxide, magnesium oxide and aluminum oxide. A large number of the samples are from metamorphic and sedimentary rocks.

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AUTHORS' CONTRIBUTIONS

The idea for the study was put forward by Y. Ufuktepe. The experiments and calculations were carried out by N. Yapici, F. Gezer, and N. Nurlu. The results were analyzed and manuscript was prepared jointly by all authors.

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РАДИОЛОШКА, ГЕОХЕМИЈСКА И МИНЕРАЛОШКА КАРАКТЕРИЗАЦИЈА ПРИРОДНОГ КАМЕНА У ТУРСКОЈ

У овом раду, применом метода гама спектрометрије са германијумским детектором високе чистоће, спектроскопије флуоресценцијом X-зрачења, дифракцијом X-зрачења и танких пресека, извршена је радиолошка, геохемијска и минералошка карактеризација узорака природног камена који се користи за облагање или украшавање, прикупљених у различитим каменоломима у Турској. Средње концентрације активности ^{226}Ra, ^{232}Th и ^{40}K измерене у узорцима природног камена износиле су 28.9, 30.8 и 355.0 Bqkg^{-1}, респективно. Процена радиолошког ризика од примене узорака камена за облагање или украшавање у грађевинарству извршена је оценом индекса концентрације активности, апсорбоване дозе гама зрачења и годишње ефективне дозе. Испитани узорци камена састављени су од калцита, доломита, кварца, ортоклаза, албита, биотита, хорнбленде (амфибола), олигоклаза, оливина и талка.

Кључне речи: природни камен, радиоактивност, геохемијска карактеризација, минералошка карактеризација, концентрација активности, годишња ефективна доза