**PERLİT OCAKLARINDAKİ OKSİT VE TOPRAK ALKALİ METAL DAĞILIMLARININ BELİRLENMESİ**

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**ÖZET**

Perlit volkanik kökenli bir kayaçtır. Soğuyan lavların hidrasyonuyla doğal olarak oluştuğu için volkanik cam olarak da isimlendirilir. Perlit minerali nispeten büyük miktarlarda kimyasal olarak bağlı su içerir ve bu özelliği genişlemesine neden olur. Perlitler mineralleri, tavan döşemelerinde, boru izolasyonunda, alçı duvar kaplamasında, kriyojenik izolasyonda, dolgu maddelerinde, filtreleme malzemelerinde, hafif çimento için agregatların hazırlanmasında, ağır metallerin uzaklaştırılmasında ve partiküllerin atmosferden adsorbsiyonunda, ısı yalıtkanlarında, yağın emilmesinde, çatı panellerinde, köpüklerde, yangın geciktiricilerde, tuğla ürünlerinde, bahçecilikte, cam kap üretiminde, mikroorganizma taşıyıcılarında, çimento harcının mekanik ve termal özelliklerini iyileştirilmesinde kullanılan çok yönlü malzemelerdir. Bu minerallerin, hangi sektörde nasıl kullanılacağı kimyasal içeriğine bağlıdır. Bu yüzden Türkiye'deki perlit ocaklarının majör ve minör oksit dağılımlarının belirlenmesi önem arz etmektedir. Bu çalışmada ilk kez Türkiye'nin farklı şehirlerinde bulunan 12 perlit ocağından toplanan 126 perlit örneği ilk defa ayrıntılı olarak analize tabi tutuldu. Perlit örneklerindeki majör-minör oksitlerin ve toprak alkali metallerin (Mg, Ca, Ba ve Sr) seviyeleri,bir enerji dağılımlı X-ışını floresans spektrometresi kullanılarak belirlendi. İncelenen sepiyolit örneklerinde analiz edilen majör ve minör oksitler ortalama derişimlerine (mg/kg cinsinden) göre SiO2 (75.18) > Al2O3 (15.65) > Na2O (5.94) > K2O (3.49) > Fe2O3 (0.94) > CaO (0.71) > MgO (0.56) > TiO2 (0.09) > MnO (0.02) olarak sıralandı. Perlit örneklerinde analiz edilen Ca, Mg, Ba ve Sr’nin ortalama derişimleri, sırasıyla 5099 mg/kg, 3333 mg/kg, 569 mg/kg ve 50 mg/kg olarak bulundu.

**Anahtar Kelimeler:** Perlit, majör ve minör oksitler, toprak alkali metal, EDXRF

**DETERMINATION OF OXIDE AND ALKALINE EARTH METAL DISTRIBUTIONS IN PERLITE MINERALS**

**ABSTRACT**

Perlite is a rock of volcanic origin. It is also called volcanic glass because it forms naturally by the hydration of cooling lava. Perlite mineral contains relatively large amounts of chemically bound water, which causes it to expand. Perlite minerals are versatile materials used in ceiling tiles, pipe insulation, plaster wall cladding, cryogenic insulation, fillers, filtering materials, preparation of aggregates for lightweight cement, removal of heavy metals and adsorption of particles from the atmosphere, thermal insulators, oil absorption, roof panels, foams, fire retardants, brick products, horticulture, glass container production, microorganism carriers, improving the mechanical and thermal properties of cement mortar. How and in which sector these minerals will be used depends on their chemical content. Therefore, it is important to determine the major and minor oxide distributions of perlite quarries in Turkey. In this study, 126 perlite samples collected from 12 perlite quarries in different cities of Turkey were analyzed in detail for the first time. Levels of major-minor oxides and alkaline earth metals (Mg, Ca, Ba, and Sr) in perlite samples were determined using an energy-dispersive X-ray fluorescence spectrometer. The average concentrations (in terms of mg/kg) of the major and minor oxides analyzed in the examined sepiolite samples are listed as SiO2 (75.18) > Al2O3 (15.65) > Na2O (5.94) > K2O (3.49) > Fe2O3 (0.94) > CaO (0.71) > MgO (0.56) > TiO2 (0.09) > MnO (0.02). The average concentrations of Ca, Mg, Ba, and Sr analyzed in perlite samples were found as 5099, 3333, 569 and 50 mg/kg, respectively.

**Keywords:** Perlite, major and minor oxides, alkaline earth metal, EDXRF

**1. INTRODUCTION**

Perlite is one of the natural volcanic aluminosilicate glasses formed by the rapid cooling of viscous rocks in lava or magma (Reka et al. 2019). Perlite is a volcanic glass with an acidic character. The main feature of perlite is its chemically bound water content. Perlites are divided into three types according to their water content: obsidian (water content less than 2% by weight), perlite (2-5% by weight), and pitch (water content > 5% by weight) (Reka et al. 2019). Perlite is a rock that has the property of expanding with heat and becomes very light and porous when expanded. The word perlite is used for both raw perlite and the product obtained by expanding it. Various perlite rocks may differ from each other in terms of color and structure (DPT 2001). The color of raw perlite can vary from transparent light gray to shiny black. When it expands, the color becomes completely white. The most important feature of perlite is the water it contains as a compound of 2.5% in the hydrated glassy silica structure, and this water ensures the stability of perlite (DPT 2001). The physical and chemical properties of perlite are given in Table 1 (DPT 2001). Moist perlite reserves in the world are concentrated in Tertiary-Early-middle Quaternary volcanic regions. Perlite mines are located in many countries of the world. USA, Armenia, Japan, Italy, Türkiye, Greece, and Hungary are countries rich in perlite resources (DPT 2001; Reka et al. 2019). Turkey's visible perlite reserve is 30 million tons and its total possible perlite reserve is 4.5 billion tons (DPT 2001). Perlite ore is generally produced by blasting using the open-pit mining method. Then, following the crushing, grinding, and classification processes, the expansion process is carried out. Perlite is mostly used in the construction industry (DPT 2001). For this reason, perlite demand is parallel to the developments and stagnation in the construction sector. Climate conditions are another factor that affects the development of insulation systems in buildings and therefore the use of perlite. Approximately 70% of the perlite used in construction production products in the world is used in insulation plates and ceiling tiles (DPT 2001). The most important feature that gives expanded perlite commercial value is its low density in small volumes, physical flexibility, chemical stability, low sound permeability, and fire resistance (DPT 2001). The usage or consumption areas of perlite are presented in Table 2 (DPT 2001).

**Table 1**. Physical and chemical properties of perlite

|  |  |
| --- | --- |
| **Physical properties** | |
| Description: | Glassy volcanic rock with conchoidal, spheroidal fractures |
| Color | White, gray and its shades, completely white when expanded |
| Hardness (Mohs) | 5-6 |
| Specific gravity | 2200-2400 kg/m3 |
| Loose density | 32-400 kg/m3 |
| Softening point | 871-1093 °C |
| Melting point | 1260-1343 °C |
| Specific heat | 0.2 cal/g °C |
| Refractive index | 1.5 |
| pH | 6.5-8 |
| Free moisture (%) | Maximum 0.5 |
| Acid soluble property | It dissolves in concentrated hot alkali and hydraulic acid  It is slightly soluble in concentrated mineral acids. (%2)  It dissolves very little in dilute minerals or concentrated weak acids (0.1%) |
| **Chemical properties** | |
| Perlite is essentially volcanic glass with a special texture, containing a certain amount of water in its internal structure, and acid composition. It does not have a fibrous structure. It does not contain nitrate sulfate, phosphorus, heavy metals, radioactive elements, and organic matter. Therefore, it is chemically quite pure. | |

It is important to know the chemical composition of perlite well so that both raw and expanded perlite can be used more effectively and efficiently in the usage areas given in Table 2. This study aims to determine the chemical component distributions of perlite quarries in Turkey. For this purpose, major-minor oxide and alkaline earth metal concentrations of one hundred and twenty-six perlite samples collected from twelve separate perlite quarries were analyzed using an energy-dispersive X-ray fluorescence (EDXRF) spectrometer.

**Table 2**. Usage areas of perlite

|  |  |
| --- | --- |
| Sector or industry | Usage |
| Construction | Shaped insulation materials (roof and floor insulation)  Perlite Plasters  Lightweight insulation concrete with perlite aggregate (cement or gypsum binder)  Lightweight building elements with perlite aggregate, ceiling tiles, pipe insulation, etc.  As loose filling material (as insulation material in attics, floor, and wall cavities; in foam form after being subjected to a special treatment with silicone)  In surface flooring (as heat and sound insulator)  Perlite concretes for special purposes made with binders other than cement and gypsum |
| Agriculture | It is used in field agriculture, horticulture, and greenhouse cultivation as a "substrate" substance that increases the physical properties of the soil, provides the necessary appropriate soil conditions, reduces water drainage, and preserves moisture by helping to increase the compactness of the soil, to create a breeding environment for seedlings and to aerate the soil. |
| Food | Filtering fruit juices, vegetable cooking oils, sugar syrup, corn syrup, filtering beer, wine and liquors |
| Pharmaceutical and chemical | Infiltration of dyes, filtration of antibiotics, filtration of pectin  in citric acid filtration, filtration of soda ash solutions, sulfuric acid filtration, and phosphoric acid filtration  As a filler in the pharmaceutical and chemical industries |
| Metallurgy | As an additive to foundry sand, as a metallurgical flux in the foundry, to protect molten metal in the crucible, to control molten metal in the iron and steel industry, in forging or hot rolling, ceramic binder refractory bricks, aluminum phosphate bound perlite refractory bricks or concretes, perlite refractory mortars. |

**2. MATERIAL AND METHODS**

**2.1. Collection and preparation**

A total of 126 perlite samples were obtained from 12 perlite quarries (PERQs) located in Erzurum, İzmir, Ankara, and Nevşehir provinces of Turkey (Table 3). The perlite samples were carried to the laboratory of sample preparation and dried in a temperature–controlled furnace at 110 °C for 15 h to remove moisture. Then, the samples were crushed and pulverized to get the calibrated powder geometry. A few grams of each perlite sample were taken for analysis.

**Table 3.** Information on perlite quarries

|  |  |  |
| --- | --- | --- |
| Quarry code | Number of sample | Location |
| PERQ1 | 10 | Erzurum (Pasinler) |
| PERQ2 | 10 | Erzincan (Mollaköy) |
| PERQ3 | 10 | İzmir (Mezarkaya) |
| PERQ4 | 10 | Ankara (Çubuk) |
| PERQ5 | 7 | Nevşehir (karapınar) |
| PERQ6 | 10 | Nevşehir (Acıgöl) |
| PERQ7 | 10 | Nevşehir (Göllü Dağı) |
| PERQ8 | 8 | İzmir (Bergama, Koyuneli) |
| PERQ9 | 15 | İzmir (Bergama, Pınar köyü) |
| PERQ10 | 10 | Nevşehir (Nenezi Dağı) |
| PERQ11 | 10 | İzmir (Bergama, Örlemiş) |
| PERQ12 | 16 | İzmir (Bergama) |

**2.2. Analysis technique**

Elemental analysis of perlite samples was performed by an EDXRF spectrometer (Spectro Xepos, Ametek) with a thick binary Pd/Co alloy anode X-ray tube (50 kV, 60 W), in the Central Research Laboratory of Kastamonu University. The EDXRF spectrometer was equipped with a thick binary Pd/Co end-window tube (50 W, 60 kV) and a Peltier-cooled Si drift detector. The EDXRF spectrometer uses the “standardless” calibration based on the Fundamental Parameters method. (Turhan et al. 2020; Turhan et al. 2022; Altıkulaç et al. 2022). NIST SRM 2709 reference material was utilized for quality assurance of the EDXRF spectrometer (Turhan et al. 2020). Perlite samples were placed in the automatic sampler and counted once for two hours, and the analysis processes were completed.

**3. RESULTS AND DISCUSSION**

**3.1. Major and minor oxides of perlite samples**

Some descriptive statistical data such as average, standard error (SE), standard deviation (SD), median, etc. on the concentrations of oxides analyzed in all perlite samples are presented in Table 4. A comparison of average concentrations of major and minor oxides analyzed in Turkish perlites with Earth’s continental crust is shown in Fig. 1. The average and range (min-max) values of oxides analyzed in perlite quarries are given in Table 5.

## Table 4. Some descriptive statistical data on the concentrations of oxides

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Concentration of oxides in perlite samples | | | | | | | | | |
| Na2O | MgO | Al2O3 | SiO2 | P2O5 | K2O | CaO | TiO2 | MnO | Fe2O3 |
| Average | 5.941 | 0.557 | 15.653 | 75.184 | 0.024 | 3.487 | 0.710 | 0.087 | 0.049 | 0.937 |
| SE | 0.139 | 0.034 | 0.077 | 0.151 | 0.001 | 0.049 | 0.023 | 0.003 | 0.001 | 0.020 |
| Median | 6.596 | 0.415 | 15.635 | 75.290 | 0.025 | 3.622 | 0.693 | 0.086 | 0.049 | 0.894 |
| SD | 1.563 | 0.386 | 0.861 | 1.696 | 0.006 | 0.550 | 0.258 | 0.034 | 0.009 | 0.221 |
| Kurtosis | -1.582 | -1.148 | 4.058 | 18.690 | -0.828 | 0.586 | -0.708 | -0.745 | -1.132 | -1.094 |
| Skewness | -0.094 | 0.588 | -1.000 | -2.389 | -0.408 | -0.958 | 0.157 | -0.299 | 0.117 | 0.231 |
| Min | 3.300 | 0.052 | 11.320 | 63.280 | 0.011 | 2.022 | 0.245 | 0.020 | 0.033 | 0.560 |
| Max | 8.505 | 1.334 | 17.260 | 79.090 | 0.037 | 4.268 | 1.203 | 0.139 | 0.066 | 1.349 |

According to their average, the oxides analyzed in perlite samples are listed as SiO2 > Al2O3 > Na2O > K2O > Fe2O3 > CaO > MgO > TiO2 > MnO.

The SiO2 concentrations in Turkish perlites varied from 63.28 (perlite sample from PERQ4) to 79.09% (perlite sample from PERQ8) with a mean of 75.18%. As shown in Fig. 1, the average SiO2 concentration is 1.4 times higher than the average value of Earth's continental crust of 54.55% (Yaroshevsky 2006). From Table 5, the highest SiO2 concentration was analyzed in the PERQ3. The average SiO2 concentrations in perlite quarries are summarized in descending order as follows: PERQ3 > PERQ8 > PERQ5 > PERQ1 > PERQ7 > PERQ9 > PERQ4 > PERQ12 > PERQ2 > PERQ6 > PERQ10 > PERQ11.

The Al2O3 concentrations in Turkish perlites varied from 11.32 (perlite sample from PERQ4) to 17.26% (perlite sample from PERQ12) with a mean of 15.65%. The average Al2O3 concentration is very close to the average value of Earth's continental crust of 15.87% (Yaroshevsky 2006). However, the average Al2O3 concentrations analyzed in perlite samples from PERQ12, PERQ9, and PERQ1 are above the average value of Earth's continental crust. The highest Al2O3 concentration was analyzed in the PERQ12. The average Al2O3 concentrations in perlite quarries are summarized in descending order as follows: PERQ12 > PERQ9 > PERQ1 > PERQ10 > PERQ11 > PERQ6 > PERQ2 > PERQ7 > PERQ4 > PERQ3 > PERQ8 > PERQ5.

|  |
| --- |
| a) |
| b) |

**Fig. 1.** Comparison of major (a) and minor (b) oxides averages with the Earth's crust average

## Table 5. Concentrations of major and minor oxides in perlite quarries

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample code |  | Concentration of oxides (%) | | | | | | | | | |
| Na2O | MgO | Al2O3 | SiO2 | P2O5 | K2O | CaO | TiO2 | MnO | Fe2O3 |
| PERQ1 | Average | 4.74 | 0.42 | 16.18 | 76.09 | 0.02 | 4.01 | 0.36 | 0.08 | 0.04 | 0.95 |
|  | Min | 4.50 | 0.41 | 15.92 | 75.97 | 0.02 | 3.62 | 0.29 | 0.07 | 0.03 | 0.82 |
|  | Max | 5.07 | 0.44 | 16.60 | 76.26 | 0.03 | 4.27 | 0.41 | 0.09 | 0.04 | 1.02 |
| PERQ2 | Average | 7.70 | 0.15 | 15.29 | 74.48 | 0.01 | 3.49 | 0.68 | 0.02 | 0.05 | 1.01 |
|  | Min | 7.41 | 0.14 | 15.12 | 74.09 | 0.01 | 3.10 | 0.58 | 0.02 | 0.04 | 0.88 |
|  | Max | 8.30 | 0.18 | 15.71 | 74.70 | 0.01 | 3.65 | 0.73 | 0.03 | 0.05 | 1.12 |
| PERQ3 | Average | 4.25 | 0.41 | 14.96 | 77.15 | 0.03 | 4.04 | 0.77 | 0.08 | 0.04 | 1.14 |
|  | Min | 3.97 | 0.33 | 14.73 | 76.96 | 0.02 | 3.59 | 0.52 | 0.07 | 0.03 | 0.97 |
|  | Max | 4.76 | 0.46 | 15.41 | 77.28 | 0.04 | 4.25 | 0.90 | 0.09 | 0.04 | 1.22 |
| PERQ4 | Average | 5.66 | 0.99 | 15.19 | 75.10 | 0.02 | 2.37 | 0.66 | 0.07 | 0.05 | 0.78 |
|  | Min | 3.30 | 0.63 | 11.32 | 63.28 | 0.02 | 2.02 | 0.53 | 0.06 | 0.04 | 0.62 |
|  | Max | 7.54 | 1.21 | 16.14 | 78.99 | 0.02 | 2.81 | 0.78 | 0.09 | 0.06 | 0.93 |
| PERQ5 | Average | 7.84 | 0.08 | 14.55 | 76.13 | 0.01 | 3.09 | 0.28 | 0.03 | 0.06 | 0.79 |
|  | Min | 7.38 | 0.05 | 14.11 | 75.91 | 0.01 | 2.78 | 0.25 | 0.03 | 0.05 | 0.68 |
|  | Max | 8.26 | 0.11 | 14.83 | 76.47 | 0.01 | 3.45 | 0.32 | 0.04 | 0.07 | 0.90 |
| PERQ6 | Average | 7.66 | 0.17 | 15.29 | 73.90 | 0.03 | 3.42 | 0.94 | 0.08 | 0.05 | 1.26 |
|  | Min | 7.35 | 0.16 | 15.08 | 73.62 | 0.02 | 3.02 | 0.79 | 0.07 | 0.05 | 1.06 |
|  | Max | 8.26 | 0.18 | 15.79 | 74.09 | 0.03 | 3.58 | 0.99 | 0.09 | 0.06 | 1.35 |
| PERQ7 | Average | 6.78 | 0.21 | 15.24 | 75.82 | 0.02 | 3.48 | 0.39 | 0.06 | 0.06 | 0.80 |
|  | Min | 6.39 | 0.19 | 14.98 | 75.48 | 0.02 | 3.10 | 0.34 | 0.05 | 0.05 | 0.68 |
|  | Max | 7.29 | 0.24 | 15.65 | 76.03 | 0.02 | 3.75 | 0.44 | 0.07 | 0.06 | 0.90 |
| PERQ8 | Average | 6.53 | 0.54 | 14.60 | 76.58 | 0.02 | 2.55 | 0.69 | 0.08 | 0.05 | 0.80 |
|  | Min | 4.11 | 0.45 | 13.41 | 75.19 | 0.01 | 2.02 | 0.53 | 0.06 | 0.04 | 0.59 |
|  | Max | 8.51 | 0.59 | 15.35 | 79.09 | 0.02 | 3.10 | 0.85 | 0.10 | 0.06 | 1.02 |
| PERQ9 | Average | 3.91 | 0.99 | 16.60 | 75.77 | 0.03 | 3.98 | 0.63 | 0.10 | 0.04 | 0.65 |
|  | Min | 3.69 | 0.95 | 16.21 | 75.58 | 0.02 | 3.49 | 0.52 | 0.09 | 0.03 | 0.56 |
|  | Max | 4.25 | 1.07 | 17.17 | 76.00 | 0.03 | 4.26 | 0.69 | 0.12 | 0.04 | 0.75 |
| PERQ10 | Average | 6.88 | 0.40 | 15.81 | 73.60 | 0.03 | 3.56 | 1.11 | 0.13 | 0.06 | 1.19 |
|  | Min | 6.51 | 0.37 | 15.60 | 73.36 | 0.03 | 3.15 | 0.95 | 0.11 | 0.05 | 1.00 |
|  | Max | 7.37 | 0.45 | 16.33 | 73.96 | 0.03 | 3.75 | 1.20 | 0.14 | 0.06 | 1.28 |
| PERQ11 | Average | 6.92 | 0.38 | 15.74 | 73.54 | 0.03 | 3.63 | 1.13 | 0.13 | 0.06 | 1.21 |
|  | Min | 6.68 | 0.36 | 15.58 | 73.31 | 0.03 | 3.24 | 0.97 | 0.11 | 0.05 | 1.03 |
|  | Max | 7.39 | 0.42 | 16.22 | 73.71 | 0.04 | 3.75 | 1.20 | 0.14 | 0.06 | 1.27 |
| PERQ12 | Average | 4.79 | 1.20 | 16.73 | 74.65 | 0.03 | 3.59 | 0.75 | 0.12 | 0.05 | 0.81 |
|  | Min | 4.61 | 1.11 | 16.45 | 74.04 | 0.03 | 3.16 | 0.63 | 0.10 | 0.04 | 0.68 |
|  | Max | 5.21 | 1.33 | 17.26 | 74.93 | 0.03 | 3.80 | 0.82 | 0.14 | 0.05 | 0.89 |

The Na2O concentrations in Turkish perlites varied from 3.30 (perlite sample from PERQ4) to 8.51% (perlite sample from PERQ8) with a mean of 5.94%. The average Na2Oconcentration is approximately 2 times higher than the average value of Earth's continental crust of 2.66% (Yaroshevsky 2006). The highest Na2O concentration was analyzed in the PERQ5. The average Na2Oconcentrations in perlite quarries are summarized in descending order as follows: PERQ5 > PERQ2 > PERQ6 > PERQ11 > PERQ10 > PERQ7 > PERQ8 > PERQ4 > PERQ12 > PERQ1 > PERQ3 > PERQ9.

The K2O concentrations in Turkish perlites varied from 2.02 (perlite sample from PERQ4) to 4.27% (perlite sample from PERQ1) with a mean of 3.49%. The average K2Oconcentration is approximately 3 times higher than the average value of Earth's continental crust of 1.09% (Yaroshevsky 2006). The highest K2O concentration was analyzed in the PERQ3. The average K2O concentrations in perlite quarries are summarized in descending order as follows: PERQ3 > PERQ1 > PERQ9 > PERQ11 > PERQ12 > PERQ10 > PERQ2 > PERQ7 > PERQ6 > PERQ5 > PERQ8 > PERQ4.

The Fe2O3 concentrations in Turkish perlites varied from 0.56 (perlite sample from PERQ9) to 1.35% (perlite sample from PERQ6) with a mean of 0.94%. The average Fe2O3 concentration is lower than the average value of Earth's continental crust of 1.11% (Yaroshevsky 2006). However, the average Fe2O3 concentrations analyzed in perlite samples from PERQ6, PERQ11, PERQ10, and PERQ3 are slightly higher than the average value of Earth's continental crust. The highest Fe2O3 concentration was analyzed in the PERQ6. The average Fe2O3 concentrations in perlite quarries are summarized in descending order as follows: PERQ6 > PERQ11 > PERQ10 > PERQ3 > PERQ2 > PERQ1 > PERQ12 > PERQ8 > PERQ7 > PERQ5 > PERQ4 > PERQ9.

The CaO concentrations in Turkish perlites varied from 0.25 (perlite sample from PERQ5) to 1.20% (perlite sample from PERQ10) with a mean of 0.71%. The average CaOconcentration is lower than the average value of Earth's continental crust of 9.41% (Yaroshevsky 2006). The highest CaO concentration was analyzed in the PERQ11. The average CaO concentrations in perlite quarries are summarized in descending order as follows: PERQ11 > PERQ10 > PERQ6 > PERQ3 > PERQ12 > PERQ8 > PERQ2 > PERQ4 > PERQ9 > PERQ7 > PERQ1 > PERQ5.

The MgO concentrations in Turkish perlites varied from 0.05 (perlite sample from PERQ5) to 1.33% (perlite sample from PERQ12) with a mean of 0.56%. The average MgOconcentration is lower than the average value of Earth's continental crust of 5.44% (Yaroshevsky 2006). The highest MgO concentration was analyzed in the PERQ12. The average MgO concentrations in perlite quarries are summarized in descending order as follows: PERQ12 > PERQ9 > PERQ4 > PERQ8 > PERQ1 > PERQ3 > PERQ10 > PERQ11 > PERQ7 > PERQ6 > PERQ2 > PERQ5.

The TiO2 concentrations in Turkish perlites varied from 0.02 (perlite sample from PERQ2) to 0.14% (perlite sample from PERQ11) with a mean of 0.09%. The average TiO2 concentration is lower than the average value of Earth's continental crust of 0.97% (Yaroshevsky 2006). The highest TiO2 concentration was analyzed in the PERQ11. The average TiO2 concentrations in perlite quarries are summarized in descending order as follows: PERQ11 > PERQ10 > PERQ12 > PERQ9 > PERQ6 > PERQ3 > PERQ1 > PERQ8 > PERQ4 > PERQ7 > PERQ5 > PERQ2.

The MnO concentrations in Turkish perlites varied from 0.03 (perlite sample from PERQ3) to 0.07% (perlite sample from PERQ5) with a mean of 0.05%. The average MnOconcentration is lower than the average value of Earth's continental crust of 0.16% (Yaroshevsky 2006). The highest MnO concentration was analyzed in the PERQ11. The average MnO concentrations in perlite quarries are summarized in descending order as follows: PERQ11 > PERQ10 > PERQ5 > PERQ7 > PERQ6 > PERQ8 > PERQ2 > PERQ4 > PERQ12 > PERQ1 > PERQ3 > PERQ9.

The P2O5 concentrations in Turkish perlites varied from 0.01 to 0.04% with a mean of 0.02%. The average P2O5 concentration is lower than the average value of Earth's continental crust of 0.19% (Yaroshevsky 2006). The highest P2O5 concentration was analyzed in the PERQ11. The average P2O5 concentrations in perlite quarries are summarized in descending order as follows: PERQ11 > PERQ10 > PERQ12 > PERQ6 > PERQ3 > PERQ9 > PERQ1 > PERQ7 > PERQ4 > PERQ8 > PERQ5 > PERQ2.

**3.2. Alkaline earth metals of perlite samples**

The average and range (min-max) values of alkaline earth metals analyzed in all perlite quarries are given in Table 6. From Table 6, alkaline earth metals analyzed in perlite samples are ranked in descending order as follows: Ca > Mg > Ba > Sr according to their average concentration.

The Ca concentrations in the perlite samples varied from 1752 to 12030 mg/kg with an average value of 5099 mg/kg, which is lower than the Earth's continental crust average of 29600 mg/kg (Yaroshevsky 2006). The highest Ca concentration was analyzed in the PERQ11. The average Ca concentrations in perlite quarries are summarized in descending order as follows: PERQ11 > PERQ10 > PERQ6 > PERQ3 > PERQ12 > PERQ8 > PERQ2 > PERQ4 > PERQ9 > PERQ7 > PERQ1 > PERQ5.

The Mg concentrations in the perlite samples varied from 313 to 8044 mg/kg with an average value of 3373 mg/kg, which is lower than the Earth's continental crust average of 18700 mg/kg (Yaroshevsky 2006). The highest Mg concentration was analyzed in the PERQ12. The average Mg concentrations in perlite quarries are summarized in descending order as follows: PERQ12 > PERQ9 > PERQ4 > PERQ8 > PERQ1 > PERQ3 > PERQ10 > PERQ11 > PERQ7 > PERQ6 > PERQ2 > PERQ5.

## Table 6. Concentrations of alkaline earth metals in perlite quarries

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sample code |  | Concentration of alkaline earth metals (mg/kg) | | | |
| Mg | Ca | Sr | Ba |
| PERQ1 | Average | 2534.7 | 2544.4 | 6.6 | 35.3 |
|  | Min | 2446.0 | 2100.0 | 5.9 | 20.9 |
|  | Max | 2643.0 | 2912.0 | 7.6 | 48.3 |
| PERQ2 | Average | 919.7 | 4878.1 | 16.3 | 46.4 |
|  | Min | 818.0 | 4179.0 | 13.8 | 31.4 |
|  | Max | 1102.0 | 5218.0 | 18.3 | 64.2 |
| PERQ3 | Average | 2446.9 | 5514.9 | 15.7 | 101.7 |
|  | Min | 1999.0 | 3750.0 | 12.9 | 87.9 |
|  | Max | 2786.0 | 6449.0 | 17.8 | 118.9 |
| PERQ4 | Average | 5964.7 | 4717.9 | 26.3 | 214.9 |
|  | Min | 3791.0 | 3756.0 | 20.7 | 201.5 |
|  | Max | 7303.0 | 5541.0 | 31.8 | 237.6 |
| PERQ5 | Average | 462.4 | 2032.6 | 6.6 | 41.5 |
|  | Min | 313.0 | 1752.0 | 4.7 | 23.2 |
|  | Max | 634.0 | 2317.0 | 9.5 | 74.3 |
| PERQ6 | Average | 1037.0 | 6692.8 | 59.7 | 350.4 |
|  | Min | 961.0 | 5637.0 | 49.0 | 284.3 |
|  | Max | 1105.0 | 7088.0 | 63.7 | 384.2 |
| PERQ7 | Average | 1294.4 | 2818.3 | 17.8 | 157.6 |
|  | Min | 1175.0 | 2457.0 | 15.1 | 140.8 |
|  | Max | 1446.0 | 3144.0 | 19.5 | 187.2 |
| PERQ8 | Average | 3239.5 | 4957.5 | 32.6 | 194.6 |
|  | Min | 2694.0 | 3810.0 | 23.2 | 154.1 |
|  | Max | 3533.0 | 6109.0 | 43.1 | 237.7 |
| PERQ9 | Average | 5982.5 | 4478.9 | 83.9 | 1764.4 |
|  | Min | 5735.0 | 3728.0 | 68.7 | 1244.0 |
|  | Max | 6469.0 | 4933.0 | 94.7 | 2042.0 |
| PERQ10 | Average | 2538.3 | 8310.5 | 85.5 | 517.4 |
|  | Min | 2218.0 | 6769.0 | 68.8 | 438.7 |
|  | Max | 3915.0 | 12030.0 | 107.0 | 565.2 |
| PERQ11 | Average | 2319.2 | 8067.0 | 86.4 | 525.9 |
|  | Min | 2186.0 | 6953.0 | 72.0 | 407.5 |
|  | Max | 2535.0 | 8555.0 | 91.2 | 577.9 |
| PERQ12 | Average | 7224.1 | 5375.2 | 100.5 | 1490.9 |
|  | Min | 6705.0 | 4529.0 | 80.5 | 1050.0 |
|  | Max | 8044.0 | 5890.0 | 109.3 | 1701.0 |

The Sr concentrations in the perlite samples varied from 5 (perlite sample from PERQ5) to 109 mg/kg (perlite sample from PERQ12) with an average value of 50 mg/kg, which is lower than the Earth's continental crust average of 340 mg/kg (Yaroshevsky 2006). The highest Sr concentration was analyzed in the PERQ12. The average Sr concentrations in perlite quarries are summarized in descending order as follows: PERQ12 > PERQ11 > PERQ10 > PERQ9 > PERQ6 > PERQ8 > PERQ4 > PERQ7 > PERQ2 > PERQ3 > PERQ1 > PERQ5.

The Ba concentrations in the perlite samples varied from 21 (perlite sample from PERQ1) to 2042 mg/kg (perlite sample from PERQ9) with an average value of 569 mg/kg, which is lower than the Earth's continental crust average of 650 mg/kg (Yaroshevsky 2006). The highest Ba concentration was analyzed in the PERQ9. The average Ba concentrations in perlite quarries are summarized in descending order as follows: PERQ9 > PERQ12 > PERQ11 > PERQ10 > PERQ6 > PERQ4 > PERQ8 > PERQ7 > PERQ3 > PERQ2 > PERQ5 > PERQ1.

**CONCLUSIONS**

The study is the first detailed research on the determination of oxides and alkaline earth metals in perlite samples obtained from 12 perlite quarries located in different provinces of Türkiye. The results of this study provide guiding information for the more effective and efficient use of perlite minerals in different sectors.

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