PERIODICO di MINERALOGIA
established in 1930

Dipartimento
di Scienze della Terra
Sapienza
Università di Roma

An International Journal of
Mineralogy, Crystallography, Geochemistry,
Ore Deposits, Petrology, Volcanology
and applied topics on Environment, Archaeometry and Cultural Heritage

Mineralogical and Technological Characteristics of Volcanic Rocks around Nevşehir Province of Türkiye

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ARTICLE INFO

Submitted: July 2024
Accepted: October 2024
Available on line: November 2024

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Doi: 10.13133/2239-1002/18577

How to cite this article:
Albayrak M. (2024)
Period. Mineral. 93, 181-198

ABSTRACT

In this study, rock samples were taken from study area, Tuzköy, Gülşehir, Avanos and Ürgüp Units, Nevşehir Province (Türkiye) and their mineralogical and petrographical properties were investigated. In addition, preliminary technological tests of some samples have been made. Physical and chemical analysis, thin section, XRD, SEM-EDX and firing tests were performed on the test samples. Original color and condition of these samples and their water dispersion, plasticity, reaction with dilute acid, firing color and condition were investigated to determine their potential to use as ceramic raw material. The rocks were found to be calc-alkaline, rich in silica and high potassium peralumina, with rhyolitic and dacitic character. Zeolite minerals were identified, including erionite, which poses a health risk. While erionite-free samples exhibited colors and properties suitable for the ceramic industry, their presence necessitates caution in industrial use due to health concerns. As a result, some samples (Nev 25, Nev 31, Nev 43, Nev 47, and Nev 48) are suitable for use at temperatures below 1150 °C while some others (Nev 44, Nev 54, and Nev 61) at temperatures below 1300 °C. In the investigated areas, the distribution of erionite minerals should be identified and mapped, and further detailed investigation of non-erionite-bearing areas in line with the study's objectives is considered important from an economic geology perspective.

Keywords: volcanic rocks; mineralogy and petrography; zeolite group minerals; erionite; mineralogical and technological properties.

INTRODUCTION

Nevşehir is located in Central Kızılırmak part of the Central Anatolia region, Türkiye which is a mountainous and plain terrain and the region is mainly made up of volcanic rocks and it is bordered by Kayseri in the east, Kırşehir in the north and northwest, Niğde in the south, Aksaray in the west and Yozgat in the northeast. In general, volcanic rocks are outcropped in these regions which were formed by extrusion of Hasan, Melendiz and Erciyes Mountains. The margins of the region are given by Strabon as Torids in the South, Aksaray in the West, Malatya in the East and East Black Sea Region in the North. In recent, the area is called as Cappadocian Region which includes the cities of Aksaray, Kayseri, Niğde and Kırşehir (Tuzcuoğlu, 2012). Many studies are present by various researchers about Cappadocian (beautiful horses' country) Region and Nevşehir (Cihat, 2024; Divilioğlu and Orhan, 2023; Güllü and Deniz, 2022; Kolay et al., 2022). The region is a touristic site with its fairy chimneys that are located within the region and many scientific studies were conducted about their geological, volcanological, tectonic and geophysical aspects. In the North and northwest of the region Paleozoic metamorphic massives (Kırşehir massive), in the West Granite Pluton age of Upper Cretaceous which moved upwards by Laremien phase (Ketin, 1963), in the South and Southwest Quaternary aged Acıgöl Lake, Erciyes and Hasan Mountain volcanics are located (Alp, 1978). Geological studies with different aims are conducted in the region in various times. Some of these studies are conducted by

Pasquare (1968); Atabey et al. (1987); Ayhan and Papak (1988); Viereck-Goete et al. (2010); Ercan et al. (1987) and (1990); Göncüoğlu and Toprak (1992); and Albayrak (2008). Along Gülşehir, Avanos and Ürgüp vicinity, Upper Miocene, Pliocene and Quaternary units are observed by forming a discordance on Palaeozoic units while Upper Miocene-Quaternary units are present in Tuzköy and nearby. The youngest volcanic rock is a basalt which sits as a cover on other units below. Folded and faulted rocks in the region are formed by the effect of Alpine Orogenesis (Okut and Güngör, 1972). The volcanic and tuff units which contain zeolites are the main material of this study. The aim of this study is to reveal the general geological characteristics of the advanced zeolitization in the (mainly volcanic) rocks exposed in the Nevşehir Province Tuzköy, Gülşehir, Avanos and Ürgüp surrounding, as well as to perform mineralogical, petrographic, and geochemical evaluations of these units, and to assess their potential as natural resources (especially in the ceramics industry) by conducting certain technological tests on selected samples.

MATERIALS AND METHODS

Materials and study area

The study area is located in the border of Nevşehir city in Cappadocia Region. The study is conducted in two different locations in the 1/100,000 scaled map sheets of Aksaray K32 and Kayseri K33. The first study area is Tuzköy and nearby area (Figure 1), while the second is throughout Gülşehir, Avanos and Ürgüp vicinity in the southern parts of K33 map sheet (Figure 1).

Zeolitic rocks are present in Tuzköy and nearby, on sandstone, conglomerate, tuff, claystone, marl and clayey limestone, while basalts and Quaternary alluvium are present on the upper parts of Tuzköy. Upper Miocene, Pliocene and Quaternary units are present on Pre-Mesozoic (phyllite, schist and marble), Pre-Upper Cretaceous (Gabbro, Granite, Diorite, Granodiorite and Syenite) and Pre-Lutetian units (conglomerate, mudstone, siltstone) along Nevşehir, Avanos and Ürgüp. Conglomerates, sandstones, claystone, siltstones, mudstones and volcanic units are composed of ignimbrite, basalt, lahar and pumice that overlays Upper Miocene-Pliocene units.

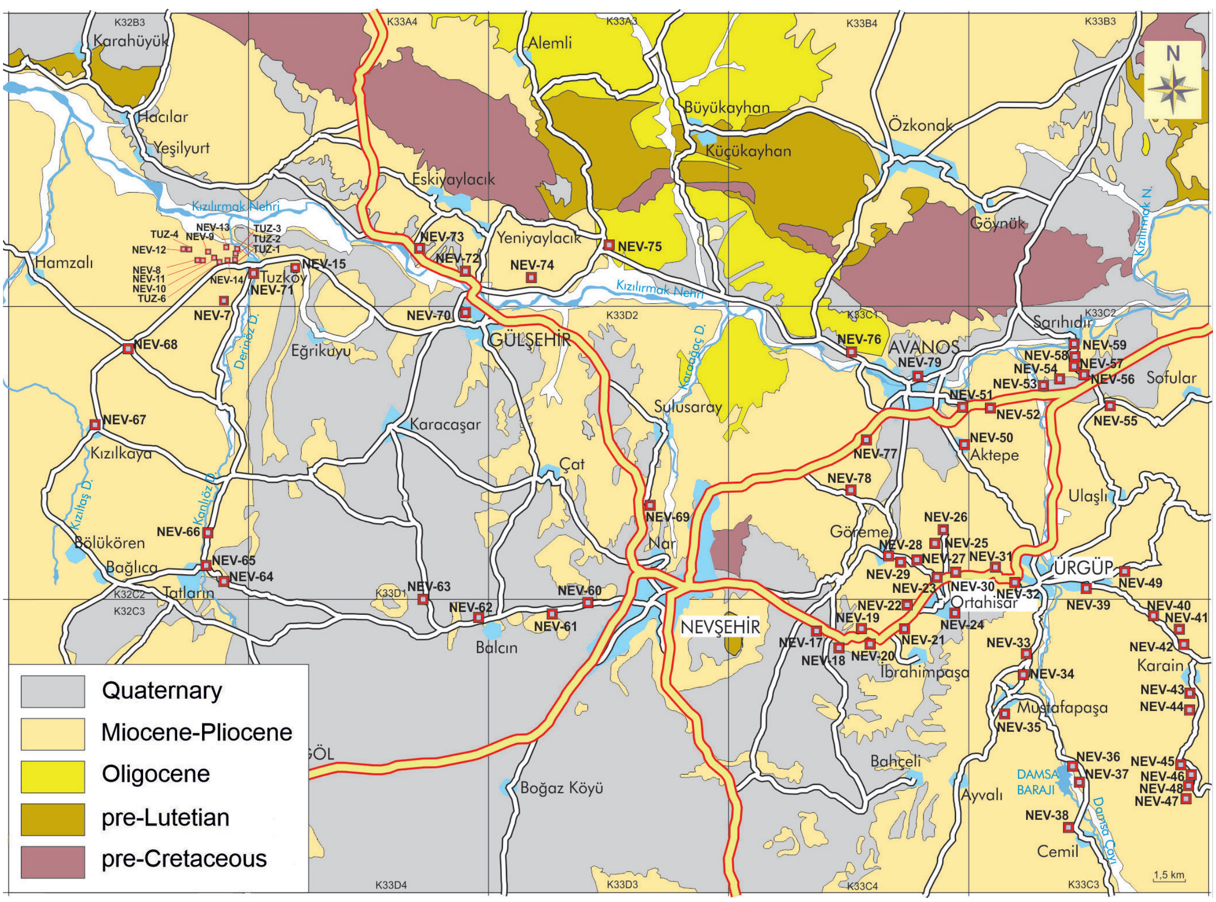


Figure 1. Geological and location map of samples collected from the vicinity of Tuzköy, Gülşehir Avanos and Ürgüp (Nevşehir).(After Şenel, 2002).

Sandstone, travertine, alluvium and talus can be seen on the uppermost parts (Yılmaz, 1991).

Methods

Rock samples are collected from volcanic units outcropped along Tuzköy, Avanos, Ürgüp, Sarıhıdır, Aktepe, Avcılar, Üçhisar, Ortahisar, Karacaören, Mustafapaşa, Karain, Karlık, Yeşilöz ve Cemilköy in the context of field studies (Figure 1). Mineralogical, petrographic, and analytical analyses were conducted to determine the mineralogical, petrographic, and geochemical characteristics of the rocks in the study area. Additionally, certain technological analyses were performed to assess the potential usability of the rocks as raw materials (especially in the ceramics industry).With this aim, thin section, XRD (Bruker, D-8 X-ray Difractometer; Germany), XRF (Thermo Perform X; Switzerland) and SEM+EDS (FEI Inspect F50, USA) analyses are conducted. Primarily, thin sections are prepared in General Directorate of Mineral Research and Explorations (MTA in Turkish), then mineralogical compositions, textural and structural properties of rocks are determined under polarizing microscope in MTA. XRD analyses were carried out on samples which contain clay minerals and such minerals which cannot be determined by petrographic methods. Mineralogical determinations by using instrumental mineralogical methods are conducted on selected samples which collected from outcrops in the study area. Minerals that formed rocks, amounts of minerals, structure and textures are determined as a result of investigation of thin sections under polarized microscope via mineralogical and petrographic studies. Mineralogical/petrographic studies were also conducted to select appropriate samples for detailed studies. Subsequently, the appropriate samples were first crushed in a jaw crusher and then turned into powder by grinding in agate mortar for determination of minerals that cannot determined on thin sections. Mineralogical analyses are conducted on powder samples by using a XRD device. Mineralogical determinations of samples were made by using High Score software and ASTM cards at the same time or later.

SEM-EDS analyses were conducted on the samples to obtain detailed morphological and compositional data on the minerals, with three-dimensional imaging carried out at MTA, METU, and ÇMB. During to process, chemical analyses were also carried out on samples. The chemical change on the sample as point, linear and areal were determined by energy dispersive X-ray micro analysis. All analyses (XRD analyses, chemical analyses, SEM-EDS analyses and technological analyses) were performed on both raw and processed samples (see following paragraph). The samples to be analyzed were selected and firstly anchored on sample holders with two-sided tape. They were coated with Au-Pd and then subjected to SEM-EDS analysis. The samples prepared for analysis were photographed on the SEM device. EDS analysis of the selected points was carried out also.

Preliminary technological studies have been made to evaluate the potential usage of the samples in the ceramic industry. Whether the original sample dispersed in water was examined by the water dispersion tests. The behavior of the sample gives information about the grain size. If the sample disperses in water quite easily, that means the sample can be readily grinded, thus the grinding cost of the sample is reduced.

To determine whether there are some carbonate minerals in the sample and the mineral types {calcite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$] or magnesite $MgCO_3$} of carbonates, samples were treated with 10% HCI acid. Determination of carbonate in the sample is important because the carbonate mineral causes cracks during the firing of the sample. According to petrographical investigations, correlation of XRD diagrams with ASTM cards and treatment with hot and cold 10% HCl acid show that carbonate minerals are present within the samples. It is possible to determine the presence of siderite ($FeCO_3$), smithsonite ($ZnCO_3$) and cerussite ($PbCO_3$) with other carbonate determination methods.

The samples were generally fired in the oven at 1150 °C. The colors of the sample are checked after these processes. Some samples were prepared at 1300 °C and 1430 °C and it was observed whether there was a phase change in the sample at these temperatures.

Technological characteristics

Technological analyses were performed on the samples of Nev 25, Nev 27, Nev 31, Nev 46, Nev 47, Nev 48 and Nev 61. All samples were dried at 105 °C until stable weight. Different processes were applied on the samples in the experiments.

Ceramic preliminary technological review

Preliminary technological analyses give information about the original color and condition of the sample, water dispersion, plasticity, reaction with dilute acid, firing color and condition.

The original color and condition of the sample

The original color and condition of the samples were determined by using color determination device and visual inspection.

Dispersion in water

The aim of the water dispersion experiment is to simulate the resistance of schist and similar soft rocks used in construction applications such as landfill to the wetting-drying cycle. The samples were spun in the drum, half immersed in water and dried. Water dispersion tests were applied to large and small samples (Nev-25, Nev-31, Nev-47 Nev-48, Nev-54 and Nev-61) but not in powder forms (Nev-43 and Nev-44).

Plasticity

Plasticity is based on manually measuring the plasticity of the sample taken from the ground sample by adding water. The plasticity of the test samples was determined by examining them manually and visually.

Reaction process with dilute acid

During the reaction process with dilute acid, dilute HCl acid solution was dropped on the sample to see if there is foaming, or gas release and the result was observed.

The firing color and condition

The samples were fired at 1150 °C, 1300 °C, and 1430 °C in order to determine the firing color and condition then checked. For this purpose, high temperature furnace was used.

Bleaching ability of the original sample

It is determined in two different ways as the bleaching ability of the original sample and the determination of the bleaching ability of the activated sample. The sample was dried to a stable mass at 55±5 °C using drying oven and then ground and sieved with 200 mesh (74 µm) sieve. A 1 g sample was placed in a tube, and 20 ml of a fuel oil-benzole mixture was added and shaken for 10 minutes. After 24 hours, %T (permeability) value was read from the calorimeter and tonsil equivalence was determined.

Determination of bleaching ability of activated sample

The samples are dried to a stable mass at 55±5 °C and then ground under a 200 mesh (74 µm) sieve. 100 ml of distilled water is placed in a beaker and 20 g of sample is added. Mix well with a glass stirrer and carefully add 12.5 ml of 98% concentrated H_2SO_4. When it reaches the boiling point, it is left on a hot plate for 1.5 hours. It is left to stand for 24 hours from the beginning of the experiment when the boiling time is over. Then it is drained under vacuum until there is no acid in the filtrate and left to dry. The sample in the form of a dried cake is ground again and sieved. The bleaching process applied to the original sample is repeated.

RESULTS AND DISCUSSION

Petrographic and mineralogical evaluations via polarizing microscope and XRD

It is determined that the analyzed rocks are generally composed of volcanic rocks and show volcanic glassy texture. Flat and long, totally, or partly rounded pumices are also determined in volcanic rock fragments. Clay formations are clear due to alteration of rocks. It is noticeable that various zeolite minerals, alteration minerals and carbonate minerals are also present. Glass shards are very common in matrix and porphyritic texture is also common. The mineralogical compositions of collected samples which were determined in thin section and XRD are presented in Table 1.

Nev-17, Nev-18, Nev-19 and Nev-20 samples from Kermil Mountain, Nevşehir Ürgüp Road, are analysed in thin section and XRD. The sample Nev-17 is rich in silica and composed of quartz and feldspar minerals (Plagioclase). Amorphous structure is clear on XRD patterns. The Nev-18 sample from the same location have hypocrystalline texture. Sample is composed of pumice, glass shards, plagioclase, quartz, biotite, volcanic rock fragments and opaque minerals in thin section. Rounded and flat pumice fragments are present in rock. All two type pumices are quite vesicular, and the dense clay formation is the matrix is observed. Rod-like, needle-shaped, Y-shape glass shards are very common. Plagioclases are clear and sometimes fractured in the edges. Edges of some anhedral and subhedral quartz minerals are embayed. Some of subhedral biotites show zonation. Totally rounded volcanic rock fragments are also present in the sample. These rock fragments contain very small feldspar and biotite phenocrystals. The rocks are named as Vitritic Tuff under this information. Ca and Na feldspars are present in sample. CaO concentration in the sample is 2.25%. Due to this information, feldspar minerals could probably be Ca-feldspars. Na_2O composition of 1.8% indicate that feldspar composition could be albite. Sample Nev-19 have hypocrystalline texture and includes plagioclase, quartz, biotite phenocrystals, rock fragments and glass shards respectively. Many prolonged and flatted rock fragment are present in the rock. Feldspar and biotite enclaves are present. Plagioclases are clear, zonated and fractured from edges. Quartz crystals are rounded and embayed by magma corrosion. Biotite crystals are deformed, and alterations can be seen along their slices. Rock components are in a totally clayed matrix. In addition, very thin and rounded rock fragment are also present in rock. The rock is named as vitritic tuff. The CaO composition of 3.13% indicates feldspar minerals could be Ca-feldspar and Ca could also be related to clinoptilolite and heulandite minerals. Nev-20 sample is generally enriched in feldspar and amorphous material and formed from quartz, smectite clays and zeolite minerals.

Nev-21 sample which was collected from İnmeobası region that is located in the entrance of Nevşehir–Ürgüp road Ortahisar is composed of amorphous material together with feldspar, quartz and smectite clays while

Table 1. Locations and mineralogical composition of samples from study area which are determined by mineralogical studies.

Sample no	Minerals
TUZ-1	Clinoptilolite-heulandite, amorphous material
TUZ-2	Quartz, kaolinite
TUZ-3	Gypsum, ankerite
TUZ-4	Clinoptilolite, amorphous material
TUZ-5	Chabasite, gypsum
TUZ-6	Gypsum, erionite, amorphous material, chabasite
NEV-7	Calcite, amorphous material, smectite group clay mineral, feldspar, quartz, very few kaolinite
NEV-8	Chabasite, amorphous material
NEV-9	Clinoptilolite, erionite, mordenite, amorphous material
NEV-10	Chabasite, amorphous material
NEV-11	Chabasite, amorphous material, erionite
NEV-12	Chabasite, amorphous material, erionite
NEV-13	Chabasite, amorphous material
NEV-14	Chabasite, amorphous material, erionite
NEV-15	Calcite, very few smectite group clay mineral
NEV-17	Amorphous material, quartz, feldspar, smectite group clay minerals, illite
NEV-18	Amorphous material, feldspar, mica(biotite), smectite group clay mineral
NEV-19	Amorphous material, quartz, feldspar, zeolite(clinoptilolite-heulandite), illite, smectite group clay mineral
NEV-20	Amorphous material, feldspar, quartz, smectite group clay mineral, zeolite(clinoptilolite-heulandite)
NEV-21	Amorphous material, feldispar, quartz, smectite group clay mineral, kaolinite
NEV-22	Amorphous material, feldspar, smectite(montmorillonite), mica(biotite)
NEV-23	Amorphous material, feldspar, smectite(montmorillonite), quartz, mica(biotite)
NEV-24	Feldspar, amorphous material, huntite?, smectite group clay mineral, ankerite
NEV-25	Feldspar group mineral, amorphous material
NEV-26	Amorphous material, smectite group clay mineral, feldspar, quartz
NEV-27	Smectite group clay mineral, amorphous material
NEV-28	Amorphous material, smectite(montmorillonite), mica(muscovite), feldspar, quartz
NEV-29	Amorphous material, feldspar, mica(biotite+muscovite), quartz
NEV-30	Amorphous material, smectite(montmorillonite), quartz
NEV-31	Amorphous material, feldspar group mineral, smectite group clay mineral
NEV-32	Amorphous material, smectite group clay mineral, very few feldspar
NEV-33	Amorphous material, feldspar, smectite group clay mineral
NEV-34	Smectite(montmorillonite), feldspar, quartz
NEV-35	Amorphous material, very few feldspar, very few smectite group clay mineral, very few cristobalite
NEV-36	Amorphous material, smectite group clay mineral., feldspar, calcite, tridymite
NEV-37	Smectite(montmorillonite), amorphous material, feldspar
NEV-38	Amorphous material, smectite(montmorillonite), quartz, feldispar, kaolinite
NEV-39	Smectite(montmorillonite), feldspar, amphibole group mineral, quartz
NEV-40	Calcite
NEV-41	Amorphous material, smectite group clay mineral, feldspar, quartz, cristobalite
NEV-42	Erionite, clinoptilolite, amorphous material
NEV-43	Amorphous material, feldspar group mineral

Table 1. ... Continued

Sample no	Minerals
NEV-44	Amorphous material, feldspar group mineral
NEV-45	Smectite(montmorillonite), amorphous material, feldspar, quartz
NEV-46	Smectite group clay mineral
NEV-47	Amorphous material, feldspar group mineral
NEV-48	Feldspar group mineral, smectite group clay mineral, cristobalite
NEV-49	Smectite(montmorillonite), feldspar
NEV-50	Amorphous material, smectite group clay mineral, feldspar, quartz, illite
NEV-51	Amorphous material, smectite group clay mineral
NEV-52	Dolomite
NEV-53	Ankerite
NEV-54	Ankerite, quartz
NEV-55	Amorphous material, dolomite, smectite group clay mineral, tridymite, feldspar, mixed layer clay mineral, quartz
NEV-56	Dolomite, amorphous material
NEV-57	Dolomite
NEV-58	Chabasite, philippsite, amorphous material, erionite
NEV-60	Amorphous material, tridymite, very few feldspar
NEV-61	Dolomite
NEV-62	Amorphous material, cristobalite, feldspar
NEV-63	Amorphous material, cristobalite, feldspar, quartz
NEV-64	Feldspar, smectite group clay mineral., amorphous material, illite, calcite
NEV-65	Smectite group clay mineral, amorphous material, feldspar, mica(biotite)
NEV-66	Feldspar (plagioclase), quartz, amorphous material, smectite group clay mineral, cristobalite, illite
NEV-67	Smectite(montmorillonite), amorphous material, feldspar, cristobalite, illite
NEV-68	Quartz, smectite group clay mineral, cristobalite, amorphous material, feldspar, mixed layer clay mineral
NEV-69	Smectite group clay mineral, feldspar, amorphous material, quartz, illite, mica(muscovite)
NEV-70	Amorphous material, smectite group clay mineral, feldspar, quartz, mica(muscovite), amphibole group mineral
NEV-71	Chabasite, amorphous material, quartz, feldspar
NEV-72	Calcite, amorphous material, smectite group clay mineral, feldspar, mixed layer clay mineral
NEV-73	Smectite group clay mineral, feldspar, amorphous material, quartz, mica(muscovite), calcite
NEV-74	Smectite group clay mineral, amorphous material, quartz, feldspar
NEV-75	Amorphous material, smectite(montmorillonite), quartz, feldspar, cristobalite, illite
NEV 76	Smectite(montmorillonite), gypsum, feldspar, quartz, ankerite
NEV-77	Clinoptilolite, tridymite, smectite group clay mineral
NEV-78	Quartz, kaolinite
NEV-79	Amorphous material, feldspar, smectite group clay mineral, quartz, calcite, cristobalite

Nev-22 sample have hypocrystalline texture. Primarily, pumice, glass shards, crystal fragments, rock fragments and opaque minerals are present in rock. Crystal fragments in rock is composed of biotite, quartz, feldspar (plagioclase and orthoclase) minerals. Plagioclase crystals are anhedral, subhedral, platy and prismatic. Many crystal fragments are present beside phenocrystals. Biotites are anhedral, subhedral, needle-like and prismatic. Many of them are fractured and fragmented. Arrow shape can be seen on some of them. Many pumice fragments and glass shards have formed the glassy matrix of rock. Two type pumices are present in rock as round and flat. Round pumices are very vesicular and includes plagioclase, quartz and biotite enclaves. Flat pumices are non-vesicular. Includes plagioclase and biotite enclaves. In addition, volcanic rock fragments which include feldspar microcrystals are present in rock. The crystals and rock fragments in sample is in densely clayed glassy matrix. Opaque minerals are also present in rock. The rock is named as vitritic tuff with this information. The sample is primarily composed of glass and feldspar (plagioclase), smectite clays (montmorillonite) and mica minerals (biotite) are also present.

The Nev-23 sample which is collected from Aşarkaya region entrance of Ortahisar is composed of amorphous material, feldspars, quartz and mica minerals (biotite). Nev-24 sample from Ortahisar is composed of feldspars, smectite clays, amorphous material, mica minerals and ankerite. The Fe_2O_3 composition of 3.50% and CaO composition of 3.30% indicate ankerite. Nev-25 sample collected from the church of Akdağ Ortahisar-Üzümlü composed of feldspar (plagioclase), amorphous material and smectite clays. The brown melt color of sample which is heated to 1150 °C is indicates the smectite clay is nontronite. Another evidence is the Fe_2O_3 composition of %1.82. Smectite clays, quartz and feldspars are obtained respectively from the mineralogical analyses of Nev-26 sample from the Akdağ Üzümlü Church. Small amounts of zeolite minerals are also present in the sample. It can be said that the smectite mineral is nontronite due to Fe_2O_3 composition of 3.58%.

SEM-EDS analyses

Zeolite formations have developed within the units outcropping in the studied area and its surroundings. SEM-EDS analysis results of samples no. Tuz-5 and Tuz-6 is shown in Figure 2. As seen in Figure 2, there are chabazite minerals in Tuz-5 sample and EDS graph taken over the same sample. Also, there are chabazite minerals and needlelike erionite minerals in Tuz-6 sample and EDS graph taken over the same sample (Figure 2).

SEM micrographs of Nev-8 and Nev-9 samples are shown in Figure 3. As seen in Figure 3, there are chabazite minerals in Nev-8 sample. There are needle-like erionite

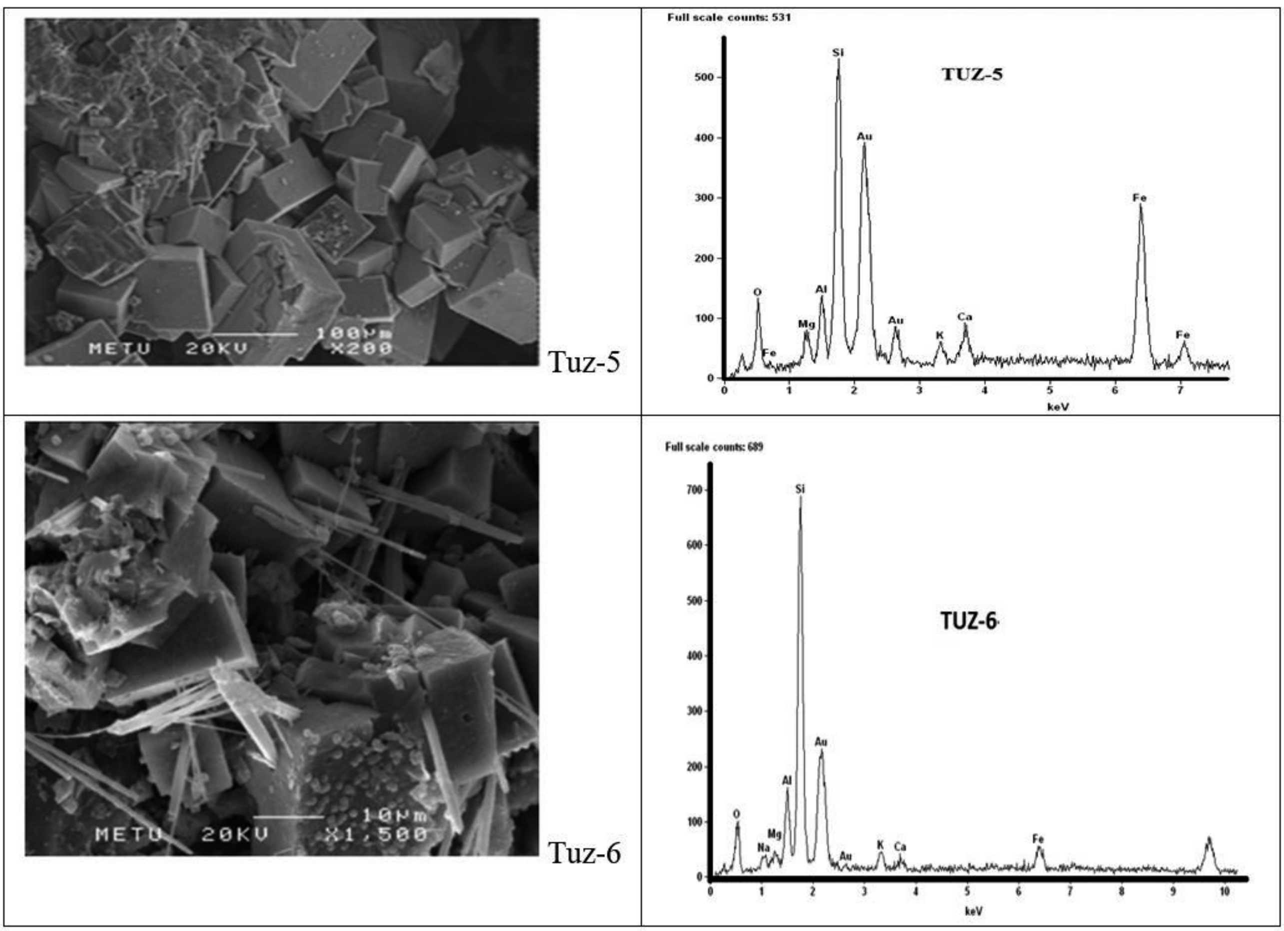


Figure 2. SEM micrographs and EDS graphs of sample Tuz-5 and Tuz-6.

minerals and tabular clinoptilolite minerals in Nev-9 sample.

SEM micrographs of Nev-10 and Nev-42 samples are shown in Figure 5 and Figure 6. As seen in Figure 5, there are mainly chabazite minerals in Nev-10 sample. On the other hand, there are erionite minerals determined in Nev-42 sample in Figure 6a and Figure 6b and also clinoptilolite minerals determined in Nev-42 sample in the Figure 6c.

50 natural and more than 200 artificial zeolite types of minerals are known. Most of them are used for industrial purposes. There are only studies on very limited species such as needle-like erionite and morderite, indicating that they are harmful to human health and pose environmental risks. No studies have been reported regarding the negative effects of zeolite minerals other than these on human health (Vural et al., 2016; Vural and Albayrak, 2020, 2016, 2005).

Geochemical Analysis Results

Oxide values obtained from geochemical analysis of samples collected from the two different studied regions are given in Table 2. The geochemical analysis results of samples collected from Tuzköy, Ürgüp, Avanos and Gülşehir regions were evaluated in Harker, TAS, SiO_2 and K_2O, rock classification and formation environment classification diagrams.

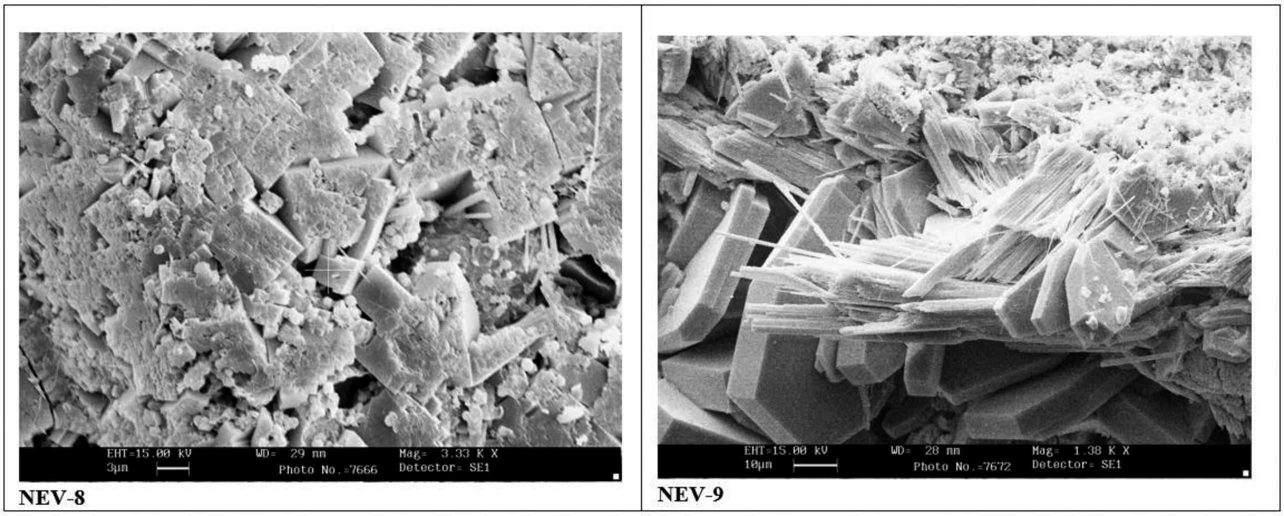


Figure 3. SEM micrographs of sample NEV-8 and NEV-9.

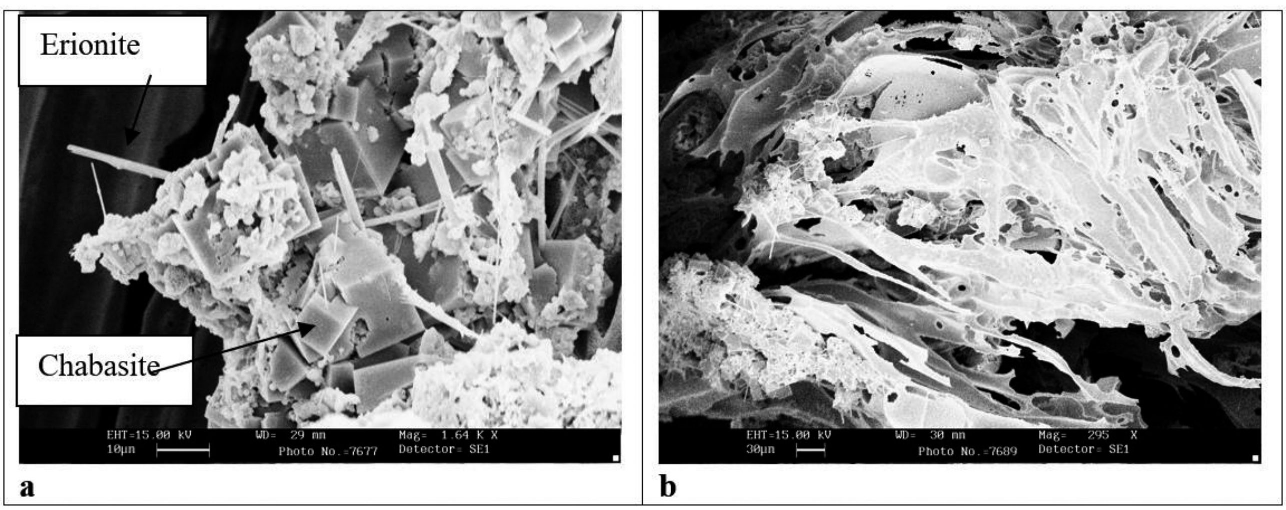


Figure 4. SEM micrographs of sample Nev-11 and Nev-12. a) Chabasite and needle-like erionite minerals in sample numbered Nev-11, b) Development of new zeolite minerals from amorphous glass in Nev-12 sample.

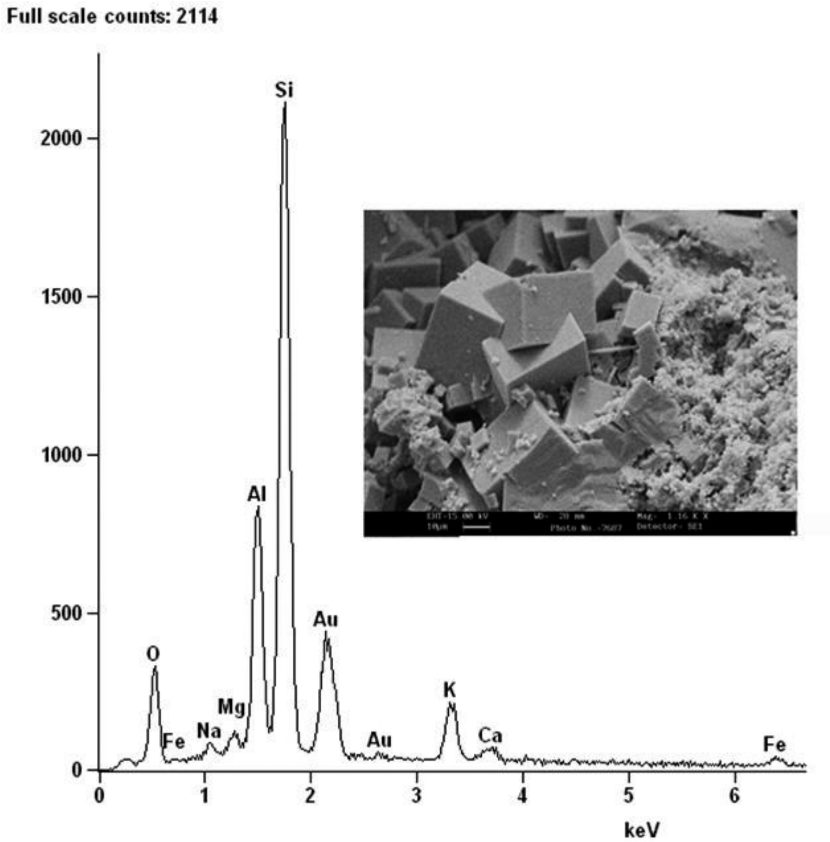


Figure 5. SEM-EDS analysis results of sample number Nev-10. Two different views of chabasite minerals and the EDS graph of the mineral.

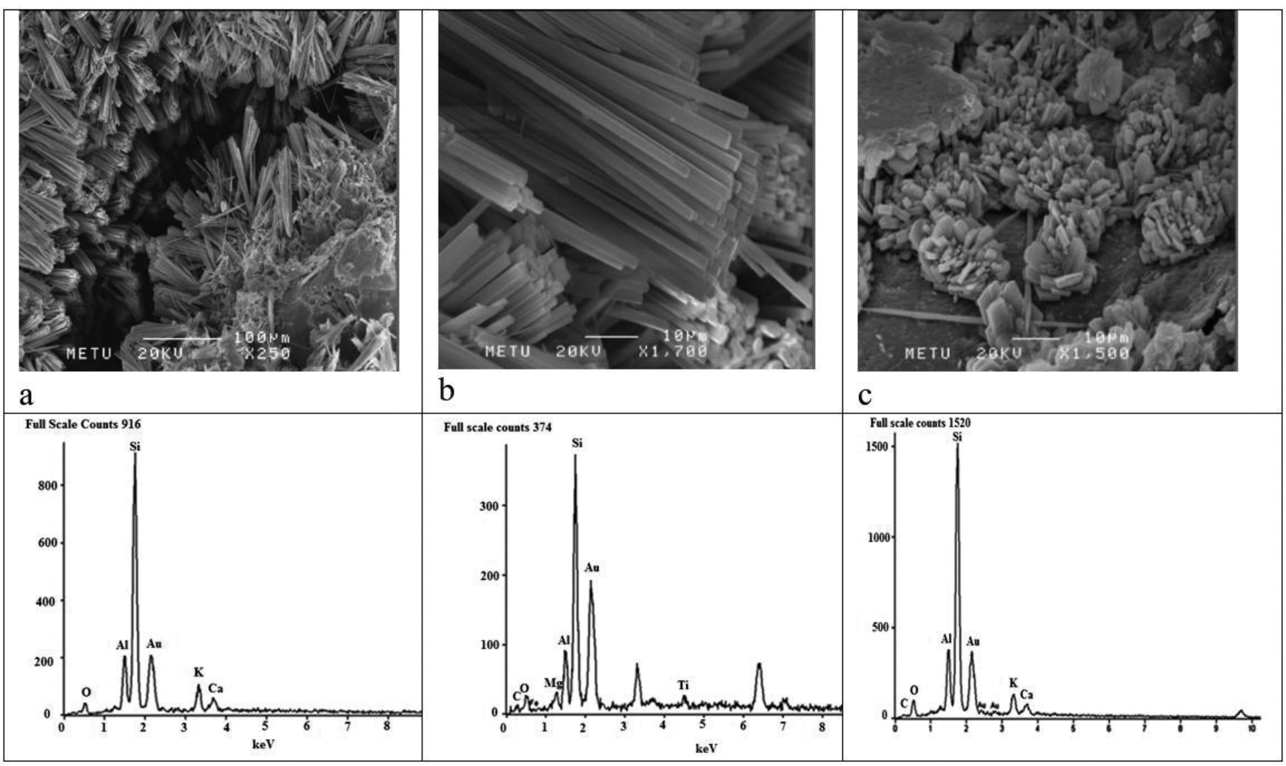


Figure 6. SEM micrographs and EDS graphics of the erionite and clinoptilolite minerals determined in the sample numbered NEV-42. a) and b) characterized the erionite minerals, c) characterized clinoptilolite and very few erionite minerals.

Table 2. Chemical analysis results of the samples.

Sample No	(%)										
	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	LOI
NEV-7	1.38	2.52	10.36	54.02	0.06	2.52	13.05	0.34	0.08	3.02	87.35
NEV-8	1.65	1.35	12.58	65.46	0.03	2.57	3.20	0.28	0.06	2.35	89.53
NEV-9	2.26	1.62	15.71	64.05	0.02	5.15	1.99	0.48	0.06	2.55	93.89
NEV-10	1.85	2.25	13.00	64.00	0.03	1.91	4.29	0.30	0.03	2.50	90.16
NEV-11	2.13	1.37	12.03	64.21	>0.01	2.74	3.20	0.24	0.07	2.50	88.49
NEV-12	2.08	1.51	13.09	67.55	>0.01	2.41	2.21	0.30	0.05	2.01	91.21
NEV-13	2.01	1.00	13.34	68.10	0.02	3.12	2.64	0.28	0.06	2.49	93.06
NEV-14	2.85	1.80	11.61	62.53	>0.01	2.91	3.90	0.22	0.07	2.56	88.45
NEV-18	1.80	0.55	14.52	70.88	>0.01	3.07	2.25	0.20	0.06	1.45	94.78
NEV-19	1.42	0.97	14.04	71.35	0.05	2.80	3.13	0.25	0.05	1.64	95.70
NEV-25	1.55	0.57	13.53	70.33	0.02	4.06	1.75	0.25	0.07	1.82	93.95
NEV-26	2.00	0.81	13.02	68.29	0.03	3.34	1.86	0.32	0.12	3.58	93.37
NEV-27	1.58	1.35	13.57	67.50	0.02	3.23	2.46	0.18	0.06	1.71	91.66
NEV-28	1.74	0.39	13.24	70.89	0.03	4.49	1.79	0.21	0.06	1.67	94.51
NEV-30	1.79	0.43	13.15	70.23	0.03	3.87	1.83	0.25	0.05	1.99	93.62
NEV-31	1.91	0.90	14.13	69.20	0.02	3.35	2.19	0.22	0.06	1.50	93.48
NEV-32	1.56	0.58	12.96	68.53	0.02	3.53	1.77	0.26	0.06	2.63	91.90
NEV-33	1.53	0.61	13.01	71.07	0.03	3.80	1.77	0.22	0.06	1.72	93.82
NEV-34	1.08	1.56	14.75	64.80	0.03	2.11	2.25	0.46	0.05	4.57	91.66
NEV-35	1.50	0.37	13.46	70.25	0.04	3.85	1.84	0.24	0.06	1.78	93.39
NEV-36	0.64	2.70	4.64	73.97	0.03	1.35	7.21	0.19	0.03	1.86	92.62
NEV-37	1.96	1.01	12.75	68.53	0.02	3.41	1.36	0.22	0.11	3.00	92.37
NEV-38	1.59	0.45	12.80	70.71	0.02	4.00	1.20	0.19	0.09	2.23	93.28
NEV-41	2.05	0.51	12.43	70.53	0.04	4.14	2.14	0.22	0.10	2.49	94.65
NEV-42	1.01	2.10	13.09	63.18	0.01	3.53	4.81	0.43	0.05	3.10	91.31
NEV-43	2.82	0.42	15.74	66.80	0.11	3.24	3.35	0.35	0.05	1.57	94.45
NEV-44	2.17	0.29	12.50	72.02	0.04	4.28	1.99	0.20	0.05	1.41	94.95
NEV-46	0.42	1.36	7.51	78.83	0.09	0.59	1.63	0.32	0.02	2.23	93.00
NEV-47	0.74	2.59	8.75	51.45	0.05	1.21	17.10	0.40	0.07	2.54	84.90
NEV-49	0.45	1.54	8.04	65.81	1.00	0.42	4.71	0.63	0.05	10.01	92.66
NEV-50	1.95	0.46	12.82	69.92	0.03	3.99	1.56	0.25	0.07	2.02	93.07
NEV-54	0.26	14.53	5.31	29.77	0.10	1.86	18.55	0.25	0.04	2.58	73.25
NEV-57	0.28	15.60	2.24	20.89	0.03	0.48	22.18	0.17	0.05	1.09	63.01
NEV-58	2.65	0.95	13.58	67.75	0.04	4.07	1.51	0.33	0.08	2.88	93.84
NEV-61	0.37	14.92	5.13	36.92	0.04	0.91	13.16	0.11	0.14	1.26	72.96
NEV-63	3.65	0.18	13.02	71.94	0.02	4.18	0.98	0.12	0.07	1.87	96.03
NEV-64	2.54	1.79	14.54	63.84	0.09	3.05	3.80	0.25	0.20	2.20	92.30
NEV-67	1.61	1.31	13.35	67.81	0.03	3.98	1.99	0.25	0.08	2.00	92.41
NEV-71	2.94	1.15	11.18	59.95	0.03	5.00	3.93	0.22	0.05	2.19	86.64
NEV-74	2.18	2.00	13.79	67.15	0.02	2.63	2.42	0.25	0.07	2.06	92.57
NEV-75	2.50	0.54	13.10	70.35	0.04	3.17	1.70	0.20	0.06	1.32	92.98
NEV-80	0.26	14.59	5.01	28.24	0.07	1.34	17.39	0.24	0.06	2.16	69.36

LOI: Lost of Ignition.

When the results are examined, it can be seen that the values of SiO_2 ratios are between 20.89 and 78.83 and Al_2O_3 ratios are between 2.24 and 15.74 (Table 2). It was determined that the total major oxide values of the rocks ranged from 63.01% to 96.03%, with a median value of 92.64%. Consequently, the Loss on Ignition (LOI) values ranged from 3.97% to 36.99%, with a median LOI value of 7.36%. High Loss on Ignition (LOI) values indicate that the rocks in the study area have undergone extensive zeolitization (Vural et al., 2016). Samples generally have high content of silica and show felsic character. In the diagrams (Irvine and Baragar, 1971; Peccerillo and Taylor, 1976), most of the rocks are plotted in the calcalkaline field (Figure 7a) and in SiO_2 and K_2O rock classification diagram, samples generally plot in high K and calcalkaline area (Figure 7b). The geochemical results obtained are consistent with the literature (Di Giuseppe et al., 2018; especially consistent with Ertek and Öner, 2008), although some minor deviations are present. The main reason for these deviations is that, due to the scope of the study, samples that have mostly undergone zeolitization (alteration) were selected for this work.

In the Harker diagrams of the samples, K, Al and Na increases compatible with silica around Avanos, Ürgüp and Gülşehir, while K and Na, which disrupts the acidic magma trend around Tuzköy, also decreases (Figure 8 a-f). On the other hand, there was a slight decrease in Ca, Mg and Fe. These reductions show that the rocks in the region are the products of an acidic magma source.

The increase in SiO_2, along with the rise in K_2O, Al_2O_3, and Na_2O, generally indicates potassium and sodium enrichment. Considering the felsic and acidic character of the rocks in the field, the consistency of the findings is evident. The decrease in CaO, Fe_2O_3, and MgO along with SiO_2 is associated with the magma becoming more acidic during volcanic activity. This suggests that minerals containing Ca, Fe, and Mg, such as olivine, pyroxene, and amphibole, were depleted during the crystallization processes of the minerals. Given these trends, along with the high LOI values of the studied rocks, it is expected that zeolite minerals such as mordenite, clinoptilolite, and erionite would form in these volcanic rocks, which have indeed been identified in our samples.

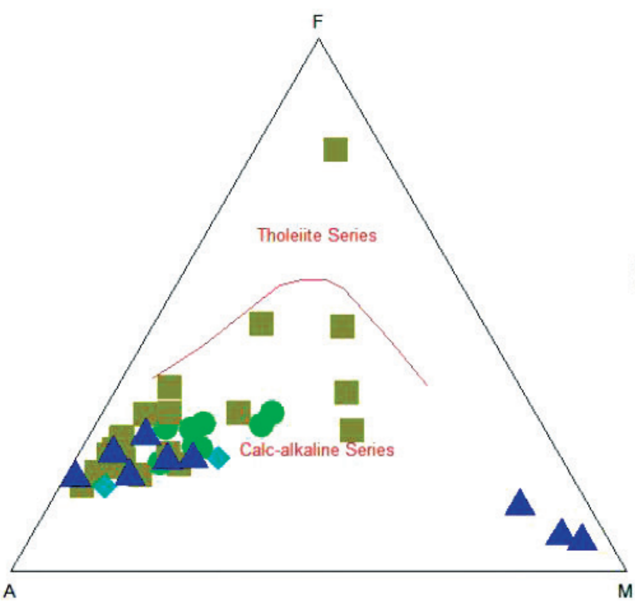
It is determined that the samples show a rhyolitic and dacitic character in the total alkali silica diagram, but rather a rhyolitic character. In the TAS (Cox et al., 1979) diagram, rocks are mostly plotted in a dacitic and rhyolitic area (Figure 9).

In the A/NK vs A/CNK diagram (A/CNK-A/NK), most of the samples are plotted in the peraluminous area (Figure 10a).

In the FeO, MgO and Al_2O_3 triangle, most of the samples are located in the post orogenic region (Figure 10b). In Ca+Mg, Na, K triangle (Demant et al., 1998), analyzed zeolite samples are situated in upper Chabazite region with group of heulandite zeolites (Figure 11).

Preliminary technological evaluation

According to the preliminary technological evaluation results, the original color and condition, dispersion in



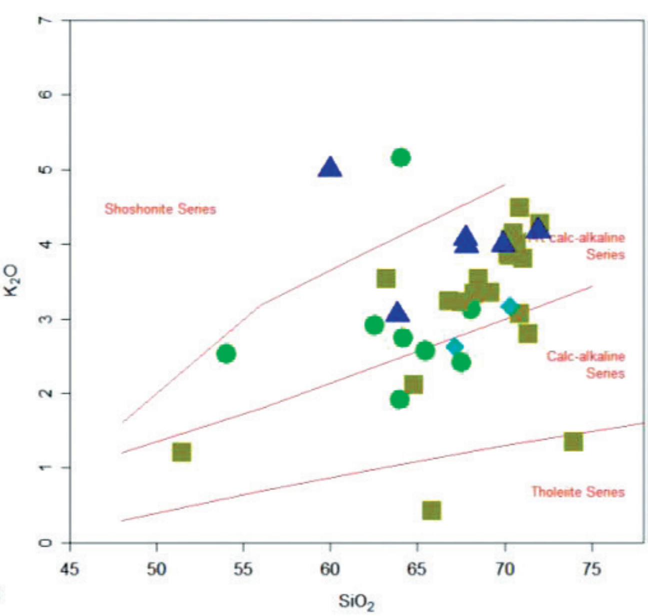


Figure 7. Irvine and Baragar (1971) a) and Peccerillo and Taylor (1976) b) classification diagrams.

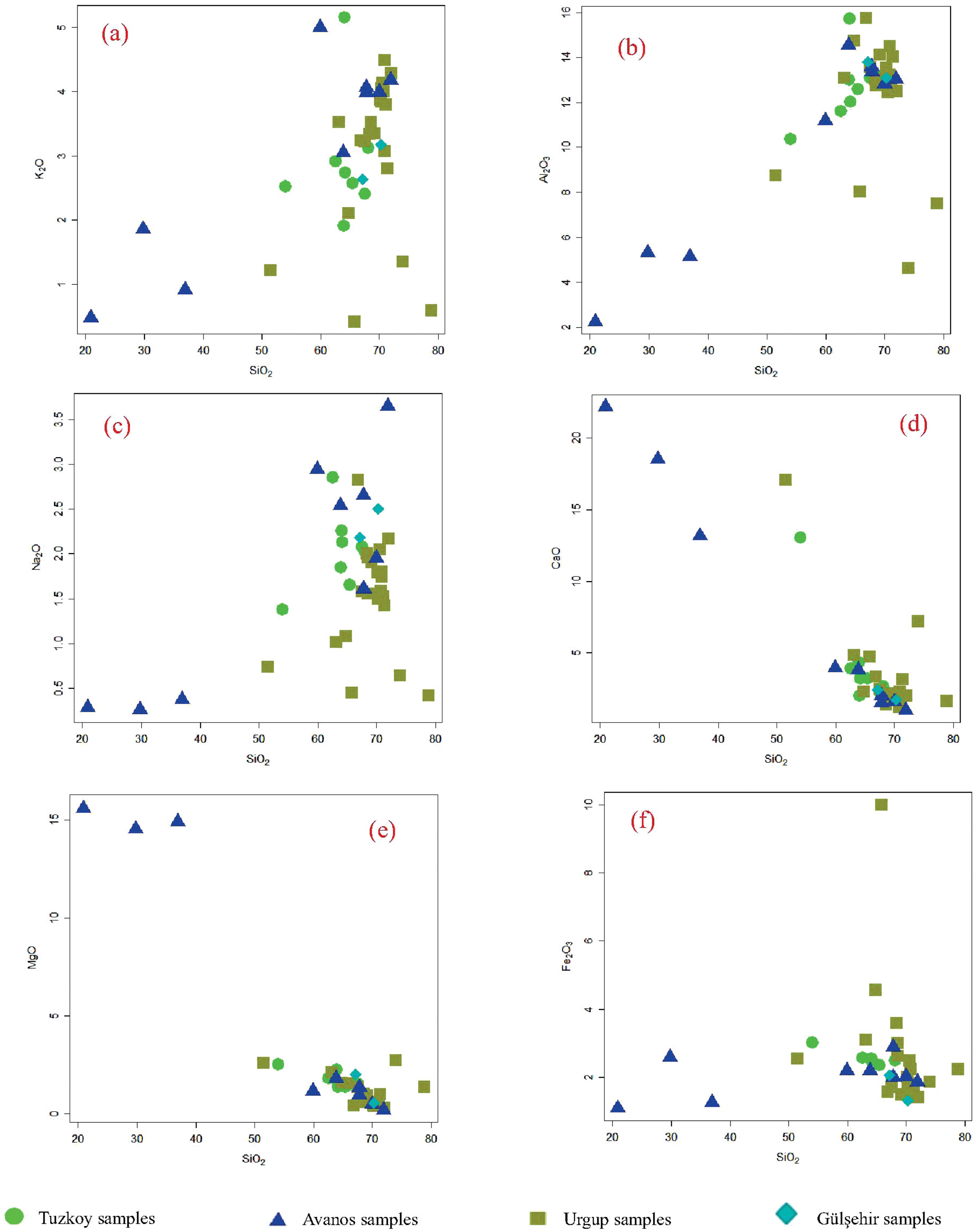


Figure 8. Harker diagrams: a) SiO_2 vs K_2O, b) SiO_2 vs Al_2O_3, c) SiO_2 vs Na_2O, d) SiO_2 vs CaO, e) SiO_2 vs MgO, f) SiO_2 vs Fe_2O_3.

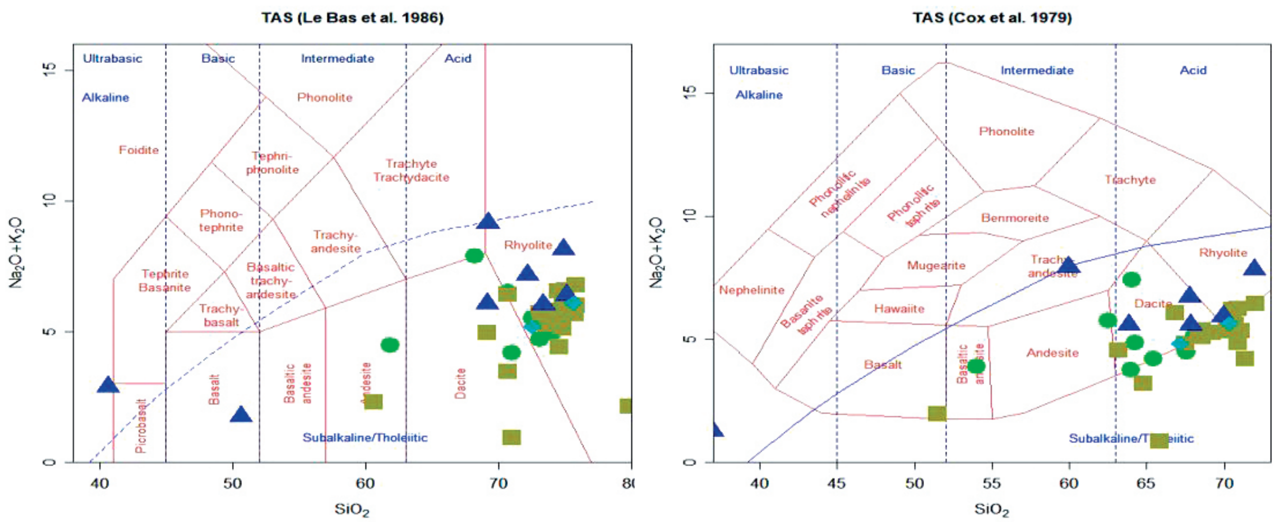


Figure 9. Total Alkali (Na_2O+K_2O) vs SiO_2 (TAS) diagrams according to Le Bast et al. (1986) and Cox et al. (1979).

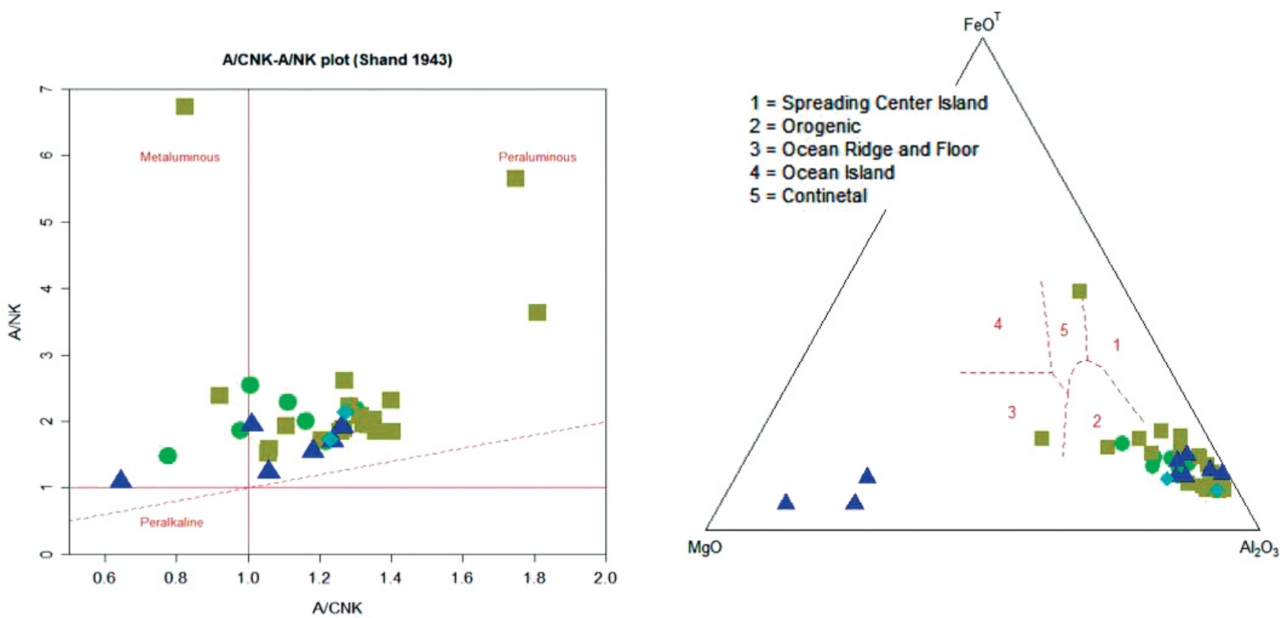


Figure 10. A/CNK-A/NK (Maniar and Piccoli, 1989; Shand, 1943) and FeO, MgO, Al_2O_3 Triangular diagrams (Pearce et al., 1977).

water, plasticity, reaction with dilute acid, firing color and condition of the samples were examined and given obtained results in Table 3.

The samples are divided into two groups according to the preliminary technological experiments. The first group includes Nev-25, Nev-31, Nev-43, Nev-47 and Nev 48 samples. The second group consists of samples Nev-44, Nev-54 and Nev-61 (Table 3). As seen in Table 3, it was determined that the colors of the samples examined were beige, cream, dark cream, greenish beige and green with black. It was observed that some of the samples were dispersed in water, and some were not. Plasticity is determined that whether the sample whose plasticity is determined can be mixed with other plastic raw materialsureand thus can be used. It was determined that the samples except Nev 54 sample had no plasticity in Table 3. It was also determined that some samples reacted with dilute acid, and some did not. It can be said that the first group samples are suitable for use at temperatures below 1150 °C and the second group samples below

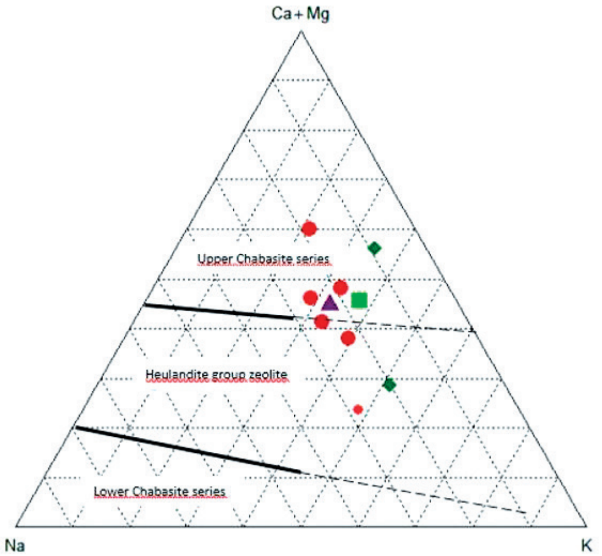


Figure 11. Ca+Mg, Na, K triangle diagram (Demant et al., 1998).

1300 °C (Table 3). It is widely believed that the samples of Nev-25, Nev-31, Nev-43, Nev-44, Nev-47, Nev-48, Nev-54 and Nev-61 given their original color and water conditions, water dispersion, plasticity, reaction with dilute acid, firing color and conditions, can be used in the ceramics industry due to the colors they show.

Ceramic, heat treatment and firing test results

New mineral developments were observed by applying heat treatments on the test samples. The color of the fired sample that is expected in traditional uses is light white, close to white or close to cream color. However, in recent years, dark colored fired samples in the firing cone can be used in ceramics. Kuczynski et al. (1967) and Su and Johnson (1996) were described heat treatments above 1000 °C as firing. Sintering develops with the fusion of particles touching each other during firing. It is expected that the shape of the cone formed during firing will not

Table 3. Preliminary technological evaluation results of analyzed samples.

Sample No	Original Color and Condition	Dispersion in Water	Plasticity	Reaction with Dilute Acid	Firing Colour and Condition
Nev-25	In large and small pieces, greenish beige	No	No	No	1150 ºC: Melted, L 42.99; a+9.20; b+13.14 1300 ºC: - 1430 ºC: -
Nev-31	In large and small pieces, beige	No	No	No	1150 ºC: Melted, L 50.91; a+3.08; b+6.13 1300 ºC: - 1430 ºC: -
Nev-43	In powder form, dark cream	-	No	No	1150 ºC: Melted, L 58.22; a+3.71; b+11.03 1300 ºC: - 1430 ºC: -
Nev-47	In large and small pieces, beige	Yes	No	Yes	1150 ºC: Melted, L 53.28; -1.05; b+13.35 1300 ºC: - 1430 ºC: -
Nev-48	In large and small pieces, cream	Yes	No	No	1150 ºC: Melted, L 35.59; a+10.38; b+9.88 1300 ºC: - 1430 ºC: -
Nev-44	In powder form, dark cream		No	No	1150 ºC: Incipient melting, L 58.22; a+1.81; b+8.44 1300 ºC: Melted, L 35.53; a-0.46 ; b+9.27 1430 ºC: -
Nev-54	In large and small pieces, green with black	Yes	Yes	Yes	1150 ºC: Sintering, L 51.54; a+0.41; b+12.89 1300 ºC: Melted 1430 ºC: -
Nev-61	Large pieces, cream	No	No	Yes	1150 ºC: Beginning of sintering, L 72.29; a+3.18; b+22.87 1300 ºC: Melted 1430 ºC: -

Note: "L" demonstrates white color value, "a" demonstrates from "0" to "+100" red color, from "0" to "-100" green color value and "b" demonstrates from "0" to "+100" yellow color, from "0" to "-100" blue color value.

deteriorate. Cracks occurring in the cones during the firing of the sample are caused by the fact that carbonate mineral in the sample, the sample not being placed in the mold properly or the sample not being fired sufficiently (not sintered) due to the small air gap in the sample. Since the samples Nev-25, Nev-27, Nev-31, Nev-43, Nev-47, Nev-48 melted at 1150°C, there was no need to fire at 1300 °C and 1430 °C. After the samples were fired, they turned into an amorphous structure. The minerals determined together with the amorphous material are given in the diffractograms (Figure 12). The samples can be used at temperatures below 1150 °C.

The shape of the firing cone at 1150 °C in Nev-47 was distorted. As seen in Figure 12, in the diffractograms obtained in XRD analysis, it is seen that the samples mostly have an amorphous structure. On the other hand, Nev-46 sample was fired at 1150 °C, 1300 ºC, and 1430 °C. While the sample consists of cristobalite, spinel and quartz minerals at 1150°C, cristobalite, mullite and a couple of tridymite minerals were developed at 1300 °C. Cristobalite and amorphous material (glass) was formed as a result of firing the sample at 1430 °C (Figure 13).

The samples marked as Nev-44, Nev-54, and Nev-61 started to melt at 1150 °C and completely melted at 1300 °C. It is seen that the firing cone of the samples has deteriorated at 1300 °C and has become melted from the cone state (Figure 14).

In addition to the change in the melting cone in these samples, color changes were observed depending on their chemical composition (Figure 14). The firing cone and color of the sample Nev-46 at 1300 °C did not change much, but the crack was observed at the base of the cone.

As a result of the firing of Nev-44 sample at 1150 °C, quartz and plagioclase minerals were developed along with amorphous material (glass). In addition, plagioclase peak collapsed at 1300 °C and very few quartz minerals have developed together with amorphous material. Nev-61 sample was examined in terms of whiteness (%) (L: 84,94; a: -0,06; b: +5,90) and refractory industry as usage and filling material in paper industry. The samples are not suitable for using in the refractory industry according to the chemical analysis results. Likewise, due to its high Fe_2O_3 ratio, the samples are not suitable for using in the glass industry. The bleaching ability of the sample Nev-27 (g Sample / g Tonsil) is higher than 3.5 and the bleaching ability of the activated sample (g Sample/g Tonsil) is 3.4. In original sample, it is very good if the values are between 1.0-1.25 and can be used if they are between 1.50-2.5. In the activated sample 1.25-1.50 are good and values above 2.5 are worthless. According to these results, the sample is not suitable for use as bleaching earth in its original and activated form (Table 4).

When the sample is considered as drilling mud agent, the efficiency is less than 51.4 Bbl/metric ton. The sample is not suitable for using as drilling mud agent. Because it must be less than <Bbl/metric ton to be considered as an agent. If the sample is taken into consideration as foundry sand cement, the gel index should be less than 8.3. Therefore, there is no gelation. While the swelling capacity of sample should be over 25 ml, this sample is 11 ml. So, the sample is not suitable for use as foundry sand cement with these values (Table 4). In the sample Nev-46, the bleaching ability of the original sample (g Sample/g Tonsil) is 2.72 and the bleaching ability of the activated

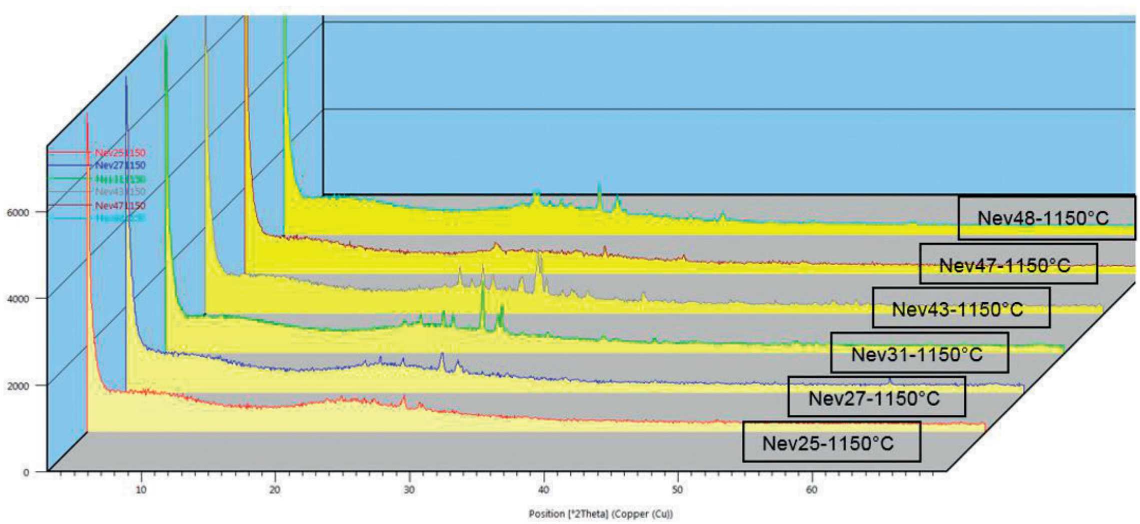


Figure 12. X-Ray diffractograms of the samples Nev-25, Nev-27, Nev-31, Nev-43, Nev-47, and Nev-48 after firing at 1150 °C.

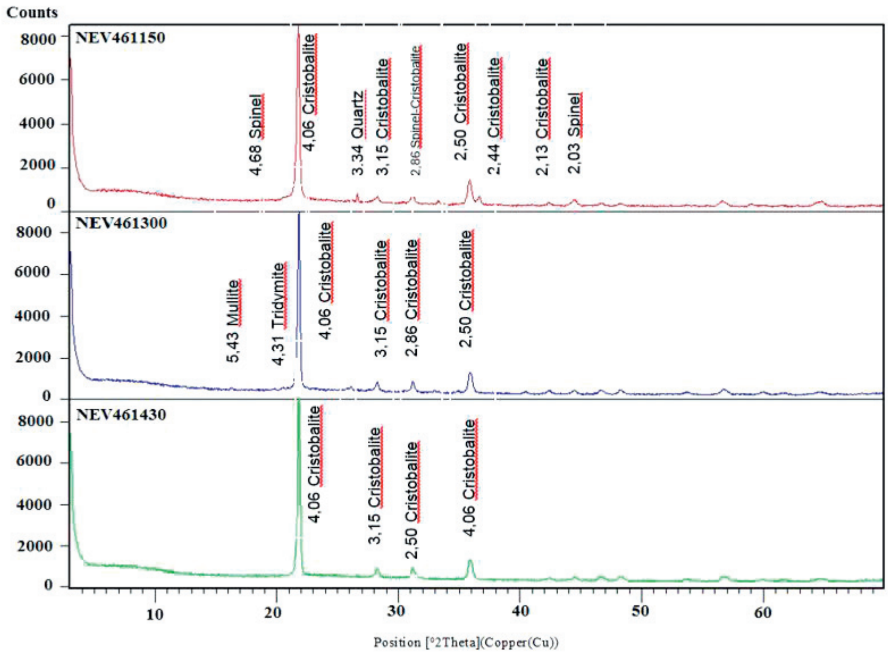


Figure 13. Comparison of X-Ray diffractograms obtained by firing the sample Nev-46 at 1150 °C, 1300 °C and 1430 °C and developing minerals.

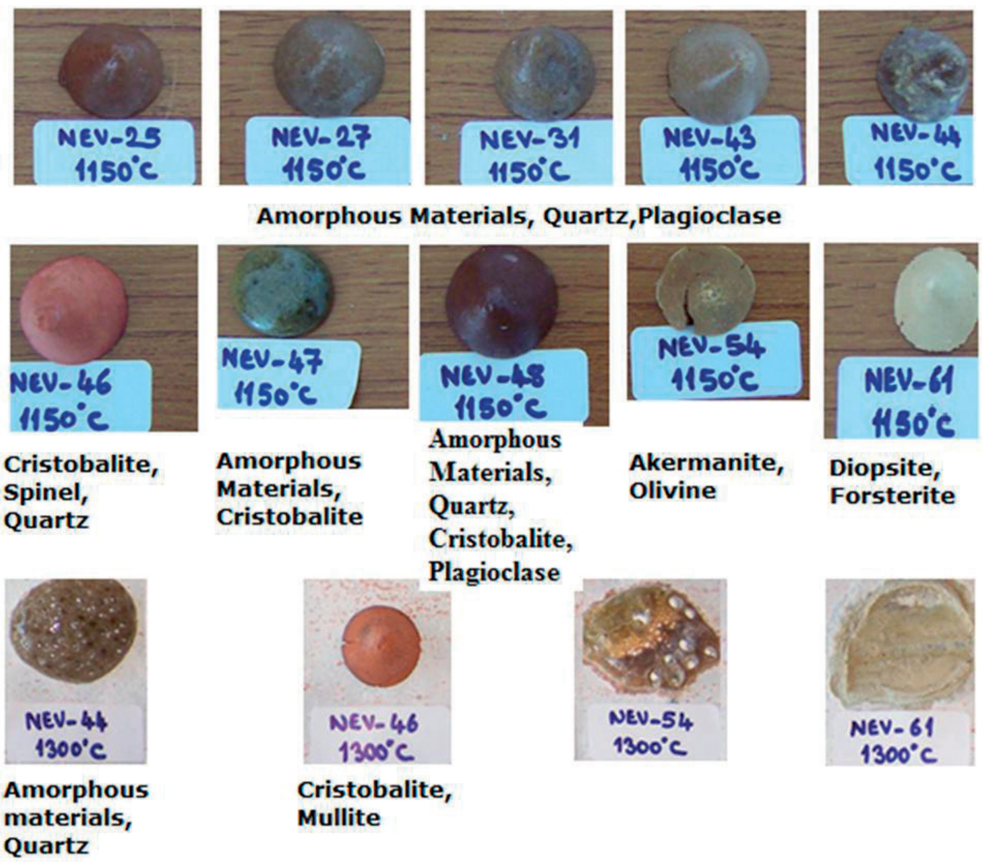


Figure 14. Firing conditions, colors and mineral developments of samples fired at 1150 °C and 1300 °C.

sample (g Sample/g Tonsil) is 1.26. Considering these values, the sample, which cannot be used as bleaching earth in its original form, is suitable for use in activated form. When the sample is considered as drilling mud agent, the efficiency is less than 51.4 Bbl/metric ton. Thus, it was observed that the sample was not suitable for using as drilling mud agent. Because it must be less than <Bbl/metric ton to be considered as an agent. Since the sample gel index is less than 8.3 and the swelling capacity is 12 ml, it is not suitable to be used as foundry sand cement (Table 4).

CONCLUSIONS

In the context of this study, detailed mineralogical, chemical and technological properties of the samples collected from the Tuzköy, Gülşehir, Avanos and Ürgüp area were determined and also scientific evaluations have been made. In addition, new mineral developments were observed by applying heat treatment on the samples. Considering the results of mineralogical, petrographic and geochemical studies, volcanic rocks in the study areas are characterized by calc-alkaline rich in silica and high potassium peralumina, and they also have rhyolitic and dacitic character. They have also, according to chemical analysis, generally have high content of silica and show an acidic character. Analyzed zeolite samples are also situated in upper chabazite region with group of heulandite zeolites. According to XRD and SEM-EDS analysis, the erionite mineral (a kind of zeolite group) is detected from the samples Tuz-6, Nev-9, Nev-11 and Nev-42. and chabazite minerals were determined in Tuz-5, Nev-8 and Nev-10 via detailed SEM-EDS analysis. Erionite type zeolites pose a serious risk to human health. Since zeolitic rocks containing erionite occur in a wide area in especially Tuzköy and its immediate surroundings, it is not suitable for industrial use of rocks containing such minerals. According to technological evaluations (except for those containing erionite mineral), it was determined that the colors of the samples examined were beige, cream, dark cream, greenish beige and green with black. According to today's market trends and end user demands, these colors have been found to be suitable for use in the ceramic industry. It was observed that some of the samples were dispersed in water, and some were not. It was determined that the samples except Nev 54 sample had no plasticity. It was also determined that some samples reacted with dilute acid, and some did not. As a result of technological analysis, Nev 25, Nev 31, Nev 43, Nev 47 and Nev 48 samples are suitable for use in ceramic industry at temperatures below 1150 °C and Nev 44, Nev 54 and Nev 61 samples at temperatures below 1300 °C.

ACKNOWLEDGEMENTS

This study is a part of the field and laboratory studies during the preparation of the Mineralogical Data Book of Western Anatolia, Thrace, Cappadocia Zeolites under the MAT Department of the MTA (General Directorate of Mineral Research and Explorations). Therefore, the author thanks all project staff who contributed to the study. Furthermore, author thanks to the Geological Engineer Candan Üçkardeşler, who helped with the map drawings, to the Geological Engineer Cumhur Özcan Kılıç, who helped with the diagrams, and to Abdullah Mete Özgüner for reviewing the manuscript in terms of scientific content and English language. The author also thanks the anonymous reviewers for their contributions and the editor for their assistance in managing the review process.

Declaration of Competing Interest

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Albayrak M., 2008. Batı Anadolu, Trakya, Kapadokya Yöresi Zeolitleri Mineralojik Veri Kitabı. Ankara.

Alp İ., 1978. Nevşehir İli Avanos İlçesi Civarındaki Alüminyum (%30 dan fazla Al_2O_3 havi Kaolen) Yataklarının Değerlendirme Raporu. Ankara, Türkiye.

Atabey E., Papak İ., Tahran N., Aksu B., Taşkıran M., Adil A., 1987. Ortaköy Niğde-Kesikköprü (Kırşehir) Yöresinin Jeolojisi. Ankara, Türkiye.

Ayhan A. and Papak İ., 1988. Aksaray-Taşpınar-Altınhisar-Çiftlik-Delihebil (Niğde) Civarının Jeolojisi. Ankara-Türkiye.

Cihat A., 2024. Su İtici Kimyasal Kaplama Malzemesinin Nevşehir Taşının Mekanik Özelliklerine Etkisinin İncelenmesi. Online Journal of Art and Design 12, 21-34.

Cox K.G., Bell J.D., Pankhurst R.J., 1979. The Interpretation of Igneous Rocks. Allen & Unwin, London.

Demant A., Romeuf P., Morata D., 1998. Distribution and chemistry of secondary minerals (zeolites and clay minerals) from Hole 917A, southeast Greenland Margin. Ocean Drilling Program (ODP), Leg 152 Scientific Results, sites 914-919.

Di Giuseppe P., Agostini S., Manetti P., Savaşçın M.Y., Conticelli S., 2018. Sub-lithospheric origin of Na-alkaline and calc-alkaline magmas in a post-collisional tectonic regime: Sr-Nd-Pb isotopes in recent monogenetic volcanism of Cappadocia, Central Turkey. Lithos 316-317, 304-322. doi: 10.1016/j.lithos.2018.07.018.

Divilioğlu E. and Orhan A., 2023. Avanos (Nevşehir, Orta Anadolu) Yöresindeki Geç Kretase Yaşlı Alkalen Plütonik ve Subvolkanik Kayaçların Jeokimyası, Mineral Kimyası ve Kristallenme Koşulları. Türkiye Jeoloji Bülteni-Geological Bulletin of Turkey 66, 159-188. doi: 10.25288/tjb.1212341.

Ercan T., Fujitami T., Matsuda J.I., Tokel S., Notsu K., Ul T., Can B., Selvi Y., Yıldırım T., Fişekçi A., Ölmez M., Akbaşlı A., 1990. Hasandağı-Karacadağ (Orta Anadolu) dolaylarındaki Senozoik yaşlı volkanizmanın kökeni ve evrimi. Jeomorfolojik Araştırmalar Dergisi 18, 39-54.

Ercan T., Yıldırım T., Akbaşlı A., 1987. Gelveri (Niğde)-Kızılcin (Nevsehir) arasındaki Volkanizmanın Özellikleri. Jeomorfolojik Araştırmalar Dergisi 15, 27-36.

Ertek N. and Öner F., 2008. Mineralogy, geochemistry of altered tuff from Cappadocia (Central Anatolia) and its use as potential raw material for the manufacturing of white cement. Appl. Clay Sci. 42, 300-309. doi: 10.1016/j.clay.2008.01.020.

Göncüoğlu M.C. and Toprak V., 1992. Neogene and Quaternary volcanism of central Anatolia: a volcano-structural evaluation. Bulletin de la Section de Volcanologie Société Géologique De France 26, 1-6.

Güllü B. and Deniz K., 2022. Nature and crystallization stages of spherulites within the obsidian: Acıgöl (Cappadocia-Nevşehir, Turkey). Turkish Journal of Earth Sciences 31, 545-562. doi: 10.55730/1300-0985.1819.

Irvine T.N. and Baragar W.R.A., 1971. A guide to the chemical classification of the common volcanic rocks. Canadian Journal of Earth Sciences 8, 523-548.

Ketin İ., 1963. 1/500,000 ölçekli Türkiye Jeoloji Haritası, Kayseri Paftası İzahnamesi. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara, Türkiye.

Kolay E., Karakoç G., Temiz U., 2022. Investigation of the anisotropic structure of travertine in terms of geological and physico-mechanical properties: Sarıhıdır (Avanos-Nevşehir) travertine quarry. Environmental Earth Sciences 81, 1-14. doi: 10.1007/s12665-022-10457-y.

Kuczynski G.C., Hooton N.A., Gibbon C.F., 1967. Sintering and Related Phenomena. Gordon and Breach, New York.

Le Bas M.J., Le Maitre R.W., Streckeisen A., Zanettin B., 1986. A chemical classification of volcanic rocks based on the total alkali-silica diagram.Journal of Petrology 27, 745-750.

Maniar P.D. and Piccoli P.M., 1989. Tectonic discrimination of granitoids. Geological Society of America Bulletin 101, 635-643.

Okut M. and Güngör M., 1972. Nevşehir İli Ürgüp-Avanos ve Gülşehir İlçelerindeki Kükürt Zuhurlarının Jeolojisi. Ankara, Türkiye.

Pasquare G., 1968. Geologie of the Senozoic volcanic area of Central Anatolia. Atti della Acad. No delince menorie Ser. VIII 9, 55-204.

Pearce T.H., Gorman B.E., Birkett T.C., 1977. The relationship between major element chemistry and tectonic environment of basic and intermediate volcanic rocks. Earth and Planetary Science Letters 36, 121-132. doi: 10.1016/0012-821X(77)90193-5.

Peccerillo A. and Taylor S.R., 1976. Geochemistry of eocene calc-alkaline volcanic rocks from the Kastamonu area, Northern Turkey. Contributions to Mineralogy and Petrology 58, 63-81. doi: 10.1007/BF00384745.

Şenel M., 2002. Türkiye 1/500.000 Jeoloji Haritaları, Kayseri 1/500.000'liği. Ankara, Türkiye.

Shand S.J., 1943. Eruptive rocks. Their genesis, composition, classification and their relation to ore-deposits, Second. ed. John Wiley & Sons, New York.

Su H. and Johnson D.L., 1996. Master Sintering Curve: A Practical Approach to Sintering. Journal of the American Ceramic Society 79, 3211-3217. doi: 10.1111/j.1151-2916.1996.tb08097.x.

Tuzcuoğlu S., 2012. Kapadokya. Duru Yayınları.

Viereck-Goette L., Lepetit P., Gürel A., Ganskow G., Çopuroğlu İ., Abratis M., 2010. Revised volcanostratigraphy of the upper Miocene to lower Pliocene Ürgüp Formation, Central Anatolian Volcanic Province, Turkey. Geolological Soc. Amsterdam 464, 85-112.

Vural A. and Albayrak M., 2020. Evaluation of Gördes zeolites in terms of mineralogical, geochemical and environmental effects. Journal of Engineering Research and Applied Science 9, 1503-1520.

Vural A. and Albayrak M., 2016. Geochemical and Mineralogical Properties of Zeolites from Gördes (Manisa) and its Near Vicinity, in: 2nd International Conference on Engineering and Natural Sciences (ICENS 2016).

Vural A. and Albayrak M., 2005. Gördes ve Civarı Zeolitlerinin Mineralojisi, in: 58. Türkiye Jeoloji Kurultayı. Ankara, Türkiye, 140-141.

Vural A., Corumluoglu O., Asri İ., 2016. Exploring Gördes Zeolite Sites by Feature Oriented Principle Component Analysis of LANDSAT Images. Caspian Journal of Environmental Sciences 14, 285-298.

Yılmaz Ş., 1991. Nevsehir İli ve Civarının Zeolit Aramaları Prospeksiyon Raporu. Ankara, Türkiye.