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Investigation of Cappadocia Volcanic Tuffs by X-ray Diffraction (XRD) Method

Zeliha Atioğlu[*1]

[*1] Kapadokya Üniversitesi Uygulamalı Bilimler Yüksekokulu Havacılık Elektrik ve Elektroniği, NEVŞEHİR

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Keywords
Volcanic Tuff,
XRD Method,
Qualitative Analysis

Abstract: In this study, stone samples taken from volcanic tuffs at seven different locations in the Cappadocia region were examined. In order to obtain the powder diffraction pattern of the samples, they were pulverized by grinding in agate mortar. Diffraction patterns were taken on a Bruker AXS D8 Advance Model diffractometer. Qualitative analysis of the pattern data was performed using the XRD Evolution program. The most common compounds as a result of the analysis: it has been identified as Silicon Oxide [SiO_2], Magnesium Silicate Hydroxide [$Mg_3(Si_2O_5)(OH)_4$], Sodium Calcium Aluminum Silicate [$(Na_{0.45}Ca_{0.55})(Al_{1.55}Si_{2.45}O_8)$], Sodium Calcium Magnesium Aluminum Iron Titanium Aluminum Silicon Oxide Hydroxide Hydrate [$(Mg_{2.46}Al_{0.3}Fe_{0.22}Ti_{0.021})_2(Mg_{0.38}Ca_{0.03}Na_{0.02})_2((Si_{2.83}\ Al_{1.17})O_{10})_2\ (OH)_4(H_2O)_{3.4}$], Potassium Aluminum Silicate Hydroxide [$(K, Ca, Na)(Al, Mg, Fe)_2(Si, Al)_4O_{10}(OH)_2$], Sodium Magnesium Aluminum Iron Silicon Oxide Hydroxide Hydrate [$Na_{0.930}Mg_{2.810}Fe_{0.065}Al_{1.185}Si_{2.895}O_{10}(OH)_2\ (H_2O)_3$], Calcium Magnesium Aluminum Silicate Hydroxide Hydrate [$Ca_{0.2}\ (Al, Mg)_2Si_4O_{10}(OH)_2.xH_2O$].

Kapadokya Volkanik Tüflerinin X-ışını Difraksiyon (XRD) Yöntemi ile İncelenmesi

Anahtar Kelimeler
Volkanik Tüf,
XRD Metod,
Nitel Analiz

Öz: Bu araştırmada Kapadokya bölgesinde yedi farklı konumdaki volkanik tüflerden alınmış olan taş örnekleri incelenmiştir. Toz kırınım desenini elde edebilmek için numuneler, agat havanda öğütülerek toz haline getirildiler. Bruker AXS D8 Advance Model difraktometrede kırınım desenleri alındı. XRD Evolution programı kullanılarak desen verilerinin nitel analizi yapıldı. Analiz sonucunda en sık rastlanan bileşikler; Silikon Oksit [SiO_2], Magnezyum Silikat Hidroksit [$Mg_3(Si_2O_5)(OH)_4$], Sodyum Kalsiyum Alüminyum Silikat [$(Na_{0.45}Ca_{0.55})(Al_{1.55}Si_{2.45}O_8)$], Sodyum Kalsiyum Magnezyum Alüminyum Demir Titanyum Alüminyum Silikon Oksit Hidroksit Hidrat [$(Mg_{2.46}Al_{0.3}Fe_{0.22}Ti_{0.021})_2(Mg_{0.38}Ca_{0.03}Na_{0.02})_2((Si_{2.83}\ Al_{1.17})O_{10})_2(OH)_4\ (H_2O)_{3.4}$], Potasyum Alüminyum Silikat Hidroksit [$(K, Ca, Na)(Al, Mg, Fe)_2(Si, Al)_4\ O_{10}(OH)_2$], Sodyum Magnezyum Alüminyum Demir Silikon Oksit Hidroksit Hidrat [$Na_{0.930}Mg_{2.810}Fe_{0.065}Al_{1.185}Si_{2.895}\ O_{10}(OH)_2(H_2O)_3$], Kalsiyum Magnezyum Alüminyum Silikat Hidroksit Hidrat [$Ca_{0.2}(Al, Mg)_2Si_4O_{10}(OH)_2.xH_2O$] olarak tespit edilmiştir.

***İlgili Yazar:** zeliha.atioglu@kapadokya.edu.tr

1. Introduction

Cappadocia is one of Turkey's most popular historical and tourist sites, rock formations millions of years of geological processes appeared in the results. Ancient volcanic eruptions covered the area with thick ash and later turned into a soft rock called 'tuff'. With the effect of natural forces such as wind and water, 'fairy chimneys' were formed, reaching a height of 130 feet from the ground, leaving only harder elements [1]. Tuff is an extraordinary type of volcanic rock composed of volcanic ash compacted as a light but extremely strong stone. Volcanic tuff has an attractive range of shades in the form of red, light brown, dark brown, yellow buff, black. The varieties bearing tuff pieces of different sizes have 'porphyritic' texture. Tuffs contain quartz, feldspar crystals, biotite and volcanic rock particles as minerals [2].

Tuff is the name of the pyroclastic volcanic material that contains a lot of pores and has a large surface area. Volcanic rocks are examined in three groups according to their silica content: 1- Rhyolitic (if the percentage of silica in the solid phase is more than 65), 2- Andesitic (if the percentage of silica in the solid phase is 50-65) and 3- Basaltic (if the percentage of silica in the solid phase is less than 50). 1- Rhyolitic lavas are formed at relatively low temperatures (800 °C - 1000 °C) during the eruption and therefore contain mainly light elements such as Si and Al but Fe, Mn, Ca and Mg contents are low. These rocks have high viscosity and light color. 2-Basaltic lavas are formed at high temperatures (over 1000 °C) and therefore contain higher Fe, Mn, Ca and Mg, low viscosity and dark colored. 3- Andesitic lavas are formed at intermediate temperatures and have an intermediate color between rhyolitic and basaltic lavas. Primary minerals cannot be formed due to the rapid cooling of the magma during the explosion, and as a result pyroclastic materials contain vesicular, volcanic glass. Physical and chemical properties of tuff are determined according to its mineralogical composition and decomposition stages. There are different types of tuffs (in black, red and yellow colors), all erupting from the same volcano and having approximately the same chemical composition but with a different primary mineral composition and decomposition stage [3].

Cappadocia volcanism has positive and negative effects on the region [4]. The data obtained so far indicate that volcanic activity in the Cappadocia region has continued without a major interruption until today. Thus, unique geological structures have emerged in Cappadocia and its surroundings [5]. The products of the common acidic volcanism (volcano glass) in the Cappadocia region were processed and used as tools by primitive people in archaeological settlements. Thus, they dug rock churches and underground cities in ignimbritic tuffs [6]. In addition, as a result of the existence of important clay deposits formed as a result of the decomposition of tuffs in the region, the art of ceramics and pottery processing has developed very much and has become a source of livelihood for people. The presence of very young rhyolitic domes (~ 70-20 thousand years) in the Cappadocia volcanic complex and the presence of extensive hot springs indicate that this region is a potential geothermal area. Reservoir rocks of thermal water are basement rocks in the region, and cover rocks are pyroclastic rocks. Young rhyolitic domes play a role as warmer. It has been suggested that the thermal waters to be obtained from the region should be used in city heating, greenhouse management and health facilities [7]. On the other hand, volcanic tuffs in the Cappadocia region pose a risk to human health. Especially the risk of cancer is the acicular erionite, which is one of the zeolite minerals found in the volcanic tuffs accompanying the rock salt. The centers most affected by the erionite mineral in the region are Tuzköy, Karain and Sarıhıdır villages of Nevşehir [8].

X-ray wavelengths are on the order of the distance between atoms (≈0.1 nm) in solid bodies [9]. Therefore, the diffraction pattern formed by scattering in all directions as the X-ray passes through a place where it can match the wavelength of a particle, is used to examine the crystal structure. Diffracted, with the scattering in all directions from the atom of the incoming beam, when the diffracted X-rays fall on the film, interference occurs when the two waves join each other in different paths. If the path difference is a multiple of the wavelength, it creates constructive interference, and half of it creates destructive interference.

Since crystals represent the symmetrically repeating solid form of atomic arrangement, the pattern of diffractive X-rays that arise after passing through such a material exhibits distinct regular spacing and symmetry properties peculiar to the crystal. X-ray crystallography is used to determine the atomic and molecular structure of a crystal, basically, it is based on the diffraction of crystalline atoms in different directions from an X-ray beam [10]. Volcanic tuff stones in the Cappadocia region were studied using X-ray diffraction (XRD) method. The structure of volcanic tuff stones was illuminated by analyzing powder crystals that had not been studied before. Thus, the literature has been contributed with the results obtained.

2. Material and Method

Stone samples taken from volcanic tuffs at seven different locations in the Cappadocia region (Figure 1) were ground to a quality powder in agate mortar in order to be examined by X-ray powder diffraction method (Figure 3). Diffraction patterns of stone samples taken from pulverized volcanic tuffs were taken on a Bruker AXS D8 Advance Model diffractometer (Figure 2). In the X-ray diffractometer, the generator voltage was kept at 45 kV and the generator current at 40 mA. Due to the use of copper anode, the wavelength became 1.54060 Å. The X-ray diffraction patterns were obtained between 5^o - 90^o angle. Placed in a powdered sample holder so that X-rays can irradiate. The detector was placed on the other side of the sample and X-rays that were diffracted from the diffractometer were detected.

A special advantage of diffraction analysis is that it explains the existence of an object not in terms of its components consisting of chemical elements, but in the way that it actually exists in the sample. For example, if a sample contains the compound A_xB_y, the diffraction method explains A_xB_y as it is, but chemical analysis indicates that the A and B elements are present. XRD allows us to determine the orientation of a single crystal and measure the size and shape of small crystals [11]. XRD is generally useful for nanoscale crystallites with diameters below 100-200 nm. When the crystal is irradiated with X-rays, a constructive and destructive interference of the scattered X-ray beam results in a diffraction pattern consisting of several sharp points known as Bragg diffraction peaks. The diffraction of X-rays by a crystal is described by Bragg's law, which relates the wavelength of X-rays to the inter-atomic spacing [12].

Thus, the diffraction pattern of the sample was obtained. The diffraction pattern containing the angular position and relative intensities of the Bragg reflections was recorded by the detector and sent to the computer. The evaluation processes of the diffraction pattern data collected using the package program named "XRD Evaluation" installed on the computer were performed. Background correction, $K_{\alpha 2}$ correction and system error correction were performed on these patterns. The X-ray tube contains the strong K_α line as well as the K_β line. Since nickel filter is used, K_β component absorbs more than K_α. There were exposed peaks that could not be indexed. Some of these peaks could not be indexed because their intensity was so low that they disappeared in the background and could not be determined. Some peaks were observed but could not be indexed, and it was decided that they could not be indexed due to impurities or within error limits. Peak position (d), positions of diffraction peak angles (2θ) and intensity values (I) were determined from the diffraction pattern data for suitable peaks. Qualitative analyzes were performed by comparing the unknown XRD dust pattern data with PDF files, which are a collection of diffraction files of many objects loaded on the computer. Thus, the substances in the stone samples taken from volcanic tuffs were detected [13].

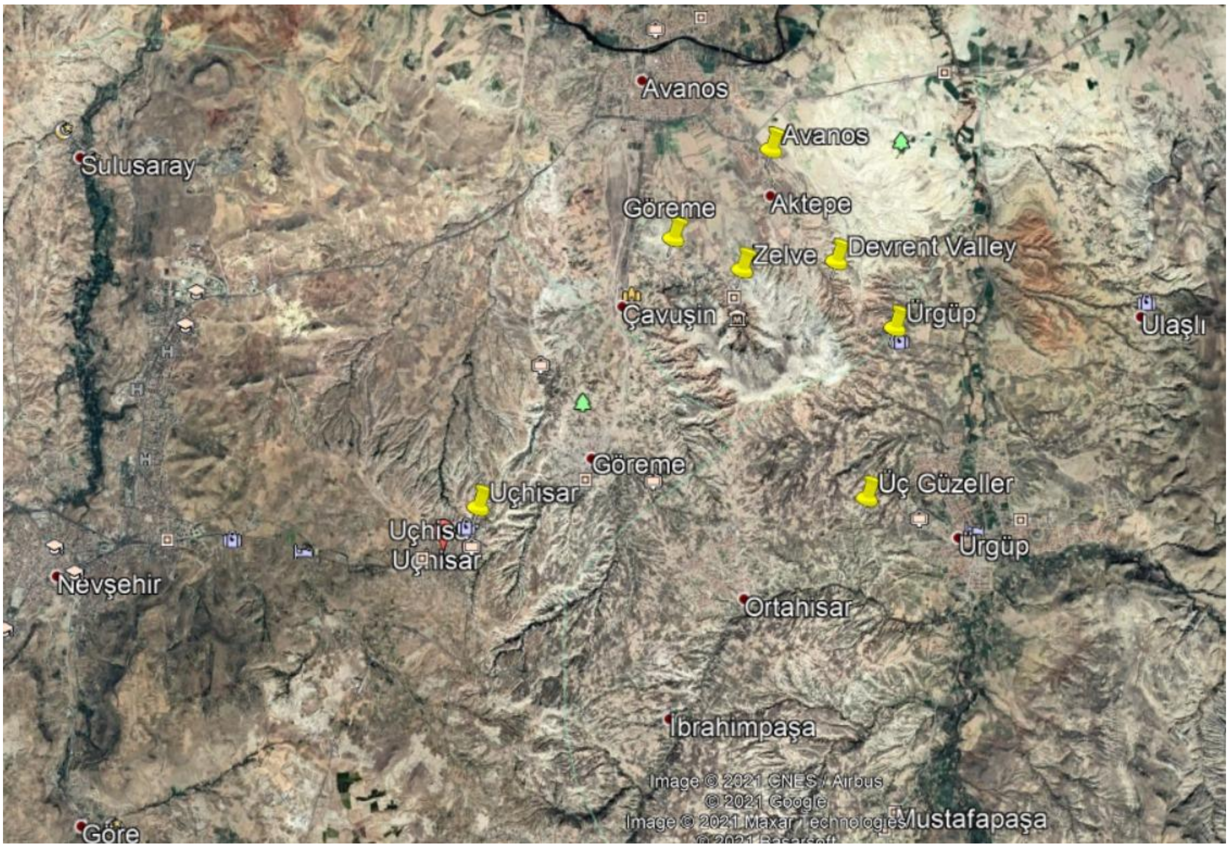


Figure 1. Location of Cappadocia volcanic tuff Stones on Google Earth.

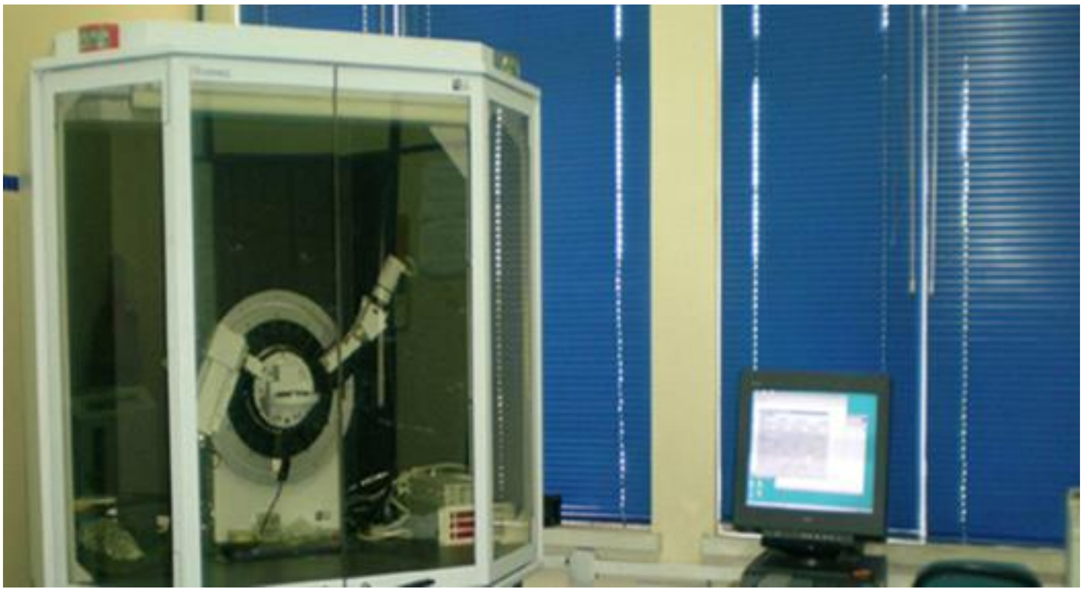
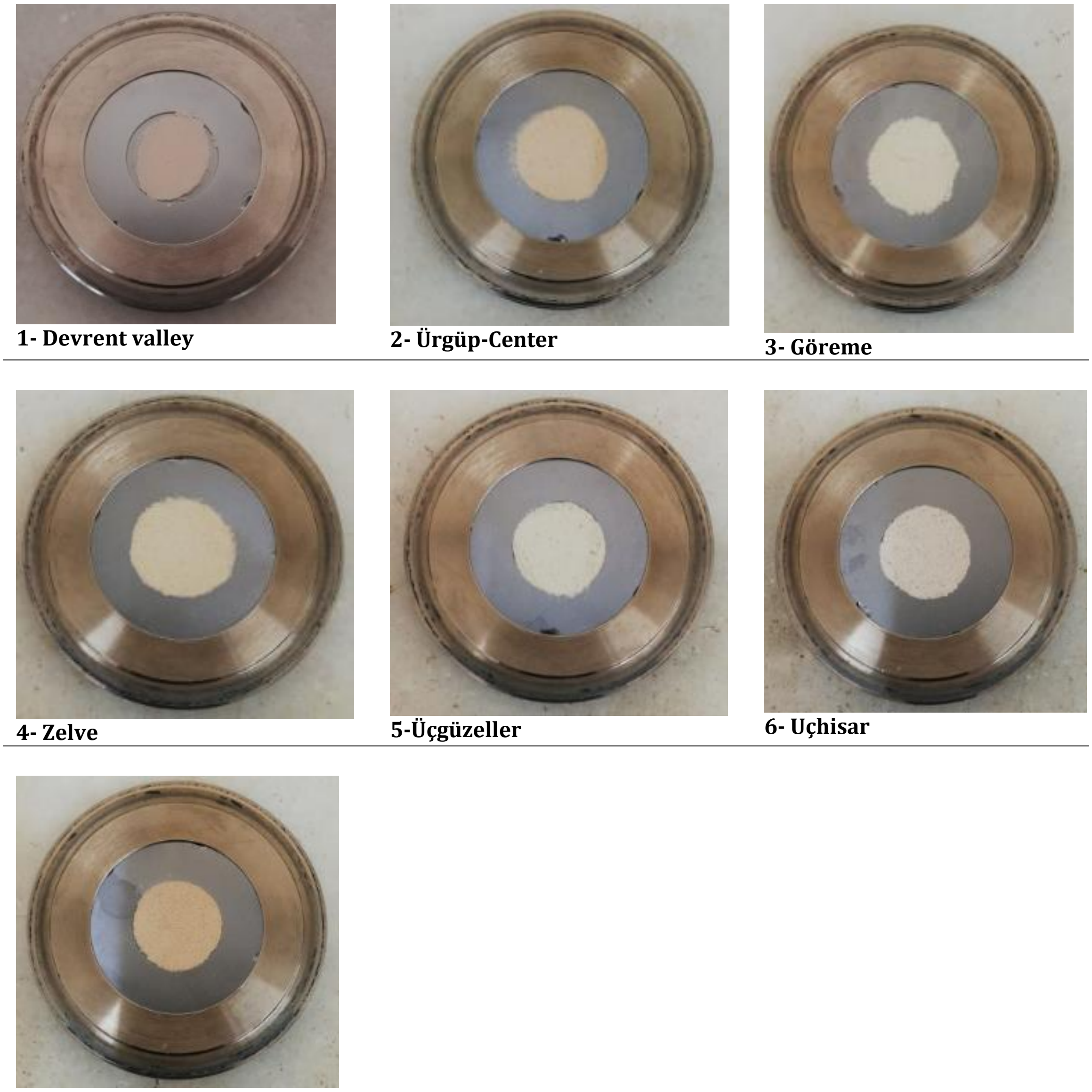


Figure 2. Bruker AXS D8 Advance Model diffractometer where diffraction pattern data are collected

3. Results

Powdered photographs of stone samples taken from seven volcanic tuffs examined in this study are given in Figure 3. The substances in the stone samples were determined with the help of the diffraction pattern data obtained from the X-ray diffractometer, d, I and 2θ values [14]. As an example, the powder diffraction pattern drawn according to the intensity (counts) I intensity values on the vertical and (2θ) the plane angle on the horizontal axis of the stone sample taken from the volcanic tuff found in Avanos is shown in Figure 4. Determination of compounds with indexable peaks is given in Figure 5. In Table 1 measurement conditions and in Table 2 the analysis result of the sample taken from Avanos is given. The list of compounds detected in volcanic tuffs is given in Table 3 in full. On the other hand, in Table 4, commonly detected compounds in volcanic tuff locations are listed.



1- Devrent valley
2- Ürgüp-Center
3- Göreme
4- Zelve
5-Üçgüzeller
6- Uçhisar
7- Avanos

Figure 3. Powdered image of volcanic tuff samples.

Table 1. Measurement Conditions

Table 1. Measurement Conditions

Dataset Name	avanos
Comment	Configuration=Reflection-transmission spinner 3.0, Owner=User-1, Creation date=10/24/2018 2:24:31 PM
Goniometer=Theta/Theta; Minimum step size 2Theta:0.0001; Minimum step size Omega:0.0001	
Sample stage=Reflection-transmission spinner 3.0; Minimum step size Phi:0.1	
Diffractometer system=EMPYREAN	
Measurement program=Manual, Owner=User-1, Creation date=11/9/2020 9:09:24 AM	
PHD Lower Level = 4.02 (keV), PHD Upper Level = 11.27 (keV)	
Measurement Start Date/Time	11/11/2020 2:14:00 PM
Operator	DELL
Raw Data Origin	XRD measurement (*.XRDML)
Scan Axis	Gonio
Start Position [°2θ]	5.0104
End Position [°2θ]	89.9784
Step Size [°2θ]	0.0260
Scan Step Time [s]	147.3900
Scan Type	Continuous
PSD Mode	Scanning
PSD Length [°2θ]	3.35
Offset [°2θ]	0.0000

Divergence Slit Type	Fixed
Divergence Slit Size [°]	0.3599
Specimen Length [mm]	10.00
Measurement Temperature [°C]	25.00
Anode Material	Cu
K-Alpha1 [Å]	1.54060
K-Alpha2 [Å]	1.54443
K-Beta [Å]	1.39225
K-A2 / K-A1 Ratio	0.50000
Generator Settings	40 mA, 45 kV
Diffractometer Type	0000000011224171
Diffractometer Number	0
Goniometer Radius [mm]	240.00
Dist. Focus-Diverg. Slit [mm]	60.50
Incident Beam Monochromator	No
Spinning	Yes

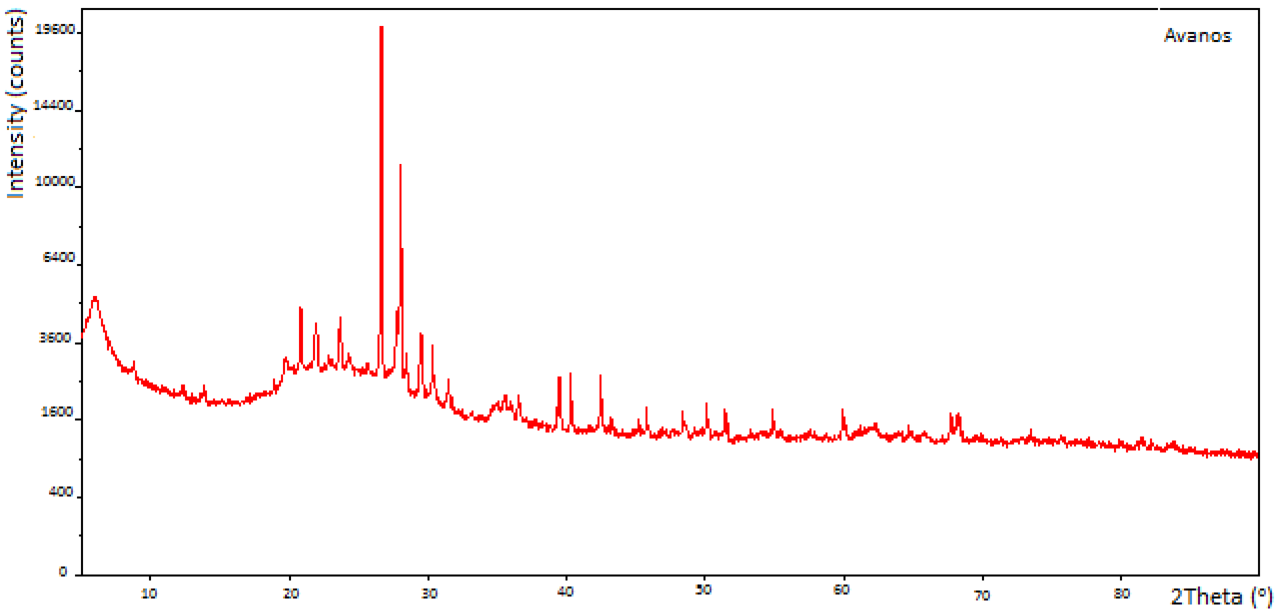


Figure 4. Diffraction pattern of a volcanic tuff stone sample taken from Avanos.

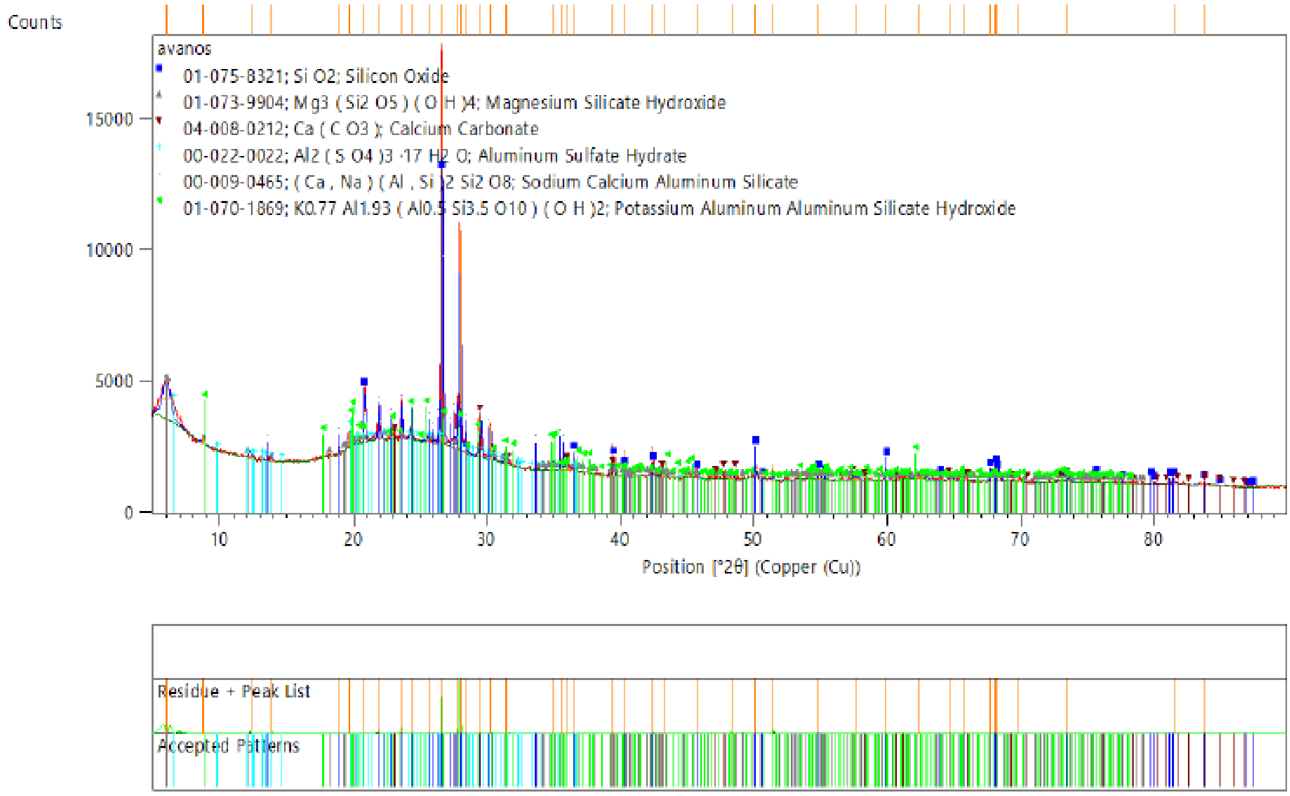


Figure 5. Identifying compounds with indexable peaks.

Table 2. Analysis result of the sample taken from Avanos

Pos.[°2θ]	Height[cts]	FWHM Left [°2θ]	d-spacing [Å]	Rel. Int. [%]
6.0197	1510.98	0.6140	14.68238	10.36
8.7918	307.90	0.1535	10.05817	2.11
12.3432	290.21	0.1535	7.17106	1.99
13.8806	311.24	0.1535	6.38008	2.13
18.9595	208.19	0.0768	4.68090	1.43
19.7607	579.38	0.2558	4.49287	3.97
20.8622	2172.26	0.0768	4.25807	14.90
21.9720	1400.88	0.1535	4.04544	9.61
23.6633	1583.74	0.1023	3.75999	10.86
24.3121	444.17	0.2047	3.66110	3.05
25.6658	215.92	0.3070	3.47099	1.48
26.6571	14580.92	0.1023	3.34413	100.00
27.7788	2109.05	0.0768	3.21159	14.46
28.0389	8520.65	0.1023	3.18239	58.44
28.4332	973.34	0.0768	3.13914	6.68
29.5271	1703.52	0.2047	3.02530	11.68
30.3024	1369.51	0.1023	2.94964	9.39
31.4574	672.81	0.1023	2.84392	4.61
34.9259	289.49	0.5117	2.56903	1.99
35.5705	468.68	0.1535	2.52394	3.21
36.0613	295.33	0.2047	2.49071	2.03
36.5383	469.63	0.1279	2.45928	3.22
39.4646	1098.83	0.0768	2.28341	7.54
40.2994	1016.72	0.0768	2.23801	6.97
42.4256	1132.71	0.0768	2.13064	7.77
43.2620	244.25	0.2047	2.09137	1.68
45.7871	481.18	0.0768	1.98174	3.30
48.3574	455.91	0.0768	1.88225	3.13
50.1226	613.01	0.0768	1.82002	4.20
51.4324	547.77	0.0768	1.77671	3.76
54.8708	537.58	0.0768	1.67323	3.69
57.6183	86.59	0.6140	1.59981	0.59
59.9335	569.65	0.1023	1.54343	3.91
62.3741	143.19	0.8187	1.48877	0.98
64.7609	135.39	0.3070	1.43955	0.93
65.7890	117.18	0.3070	1.41953	0.80
67.7345	551.65	0.0936	1.38227	3.78
68.1255	489.22	0.0936	1.37529	3.36
68.3177	548.65	0.1023	1.37302	3.76
69.7579	50.19	0.6140	1.34816	0.34
73.5019	134.40	0.3070	1.28846	0.92
81.5447	78.31	0.4093	1.18051	0.54
83.6831	49.10	0.6140	1.15570	0.34

Pos.[°2θ]: Positions of peaks, **Height[cts]:** Peak heights **FWHM:** Calculate the Full Width At Half Maximum for the peaks in the XRD pattern. **d-spacing:** Distance between planes, **Rel. Int.:** Relative X-ray intensity on percent ratio**.**

Table 3. Compounds detected in volcanic tuff locations

Location	Reference Code	Score	Name of the Detected Compound	Chemical Formula
Avanos	01-075-8321	60	Silicon oxide	SiO_2
	01-073-9904	27	Magnesium silicate hydroxide	$Mg_3(Si_2O_5)(OH)_4$
	04-008-0212	25	Calcium carbonate	$Ca\ (CO_3)$
	00-022-0022	16	Aluminum sulfate hydrate	$Al_2(SO_4)_3 \cdot 17H_2O$
	00-009-0465	32	Sodium calcium aluminum silicate	$(Ca, Na)(Al,Si)_2\ Si_2O_8$
	01-070-1869	Unmatched strong	Potassium aluminum aluminum silicate hydroxide	$K_{0.77}Al_{1.93}(Al_{0.5}Si_{3.5}O_{10})(OH)_2$
Devrent Valley	00-046-1045	65	Silicon oxide	SiO_2
	00-010-0393	40	Sodium aluminum silicate	$Na\ (\ Si_3\ Al\ )\ O_8$
	00-026-0911	16	Potassium aluminum silicate hydroxide	$(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$
	04-007-5008	10	Sodium aluminum silicate	$NaAlSi_3O_8$
	01-078-4316	14	Sodium calcium magnesium Aluminum iron titanium aluminum silicon oxide hydroxide hydrate	$(Mg_{2.46}Al_{0.3}Fe_{0.22}Ti_{0.021})_2(Mg_{0.38}\ Ca_{0.03}\ Na_{0.02}\ )_2\ ((Si_{2.83}\ Al_{1.17})O_{10})_2(OH)_4(\ H_2O)_{3.4}$
Göreme	01-079-6238	46	Silicon oxide	SiO_2
	05-001-0865	38	Sodium calcium aluminum silicate sodium calcium	$Ca_{0.41}Na_{0.59}Si_{2.59}Al_{1.41}O_8$
	01-078-4316	17	Magnesium aluminum iron titanium aluminum silicon oxide hydroxide hydrate	$(Mg_{2.46}Al_{0.3}Fe_{0.22}Ti_{0.021}\ )_2(Mg_{0.38}\ Ca_{0.03}Na_{0.02})_2((Si_{2.83}Al_{1.17})\ O_{10})_2(OH)_4(H_2O)_{3.4}$
	00-022-0022	16	Aluminum sulfate hydrate	$Al_2(SO_4)_3 \cdot 17H_2O$
	00-025-0649	19	Potassium aluminum silicate hydroxide	$(K, Ca, Na\ )(\ Al, Mg, Fe)_2(Si, Al)_4O_{10}(OH\ )_2$
	00-013-0259	9	Sodium magnesium aluminum silicate hydroxide hydrate	$Na_{0.3}(Al, Mg)_2Si_4O_{10}(OH)_2 \cdot x\ H_2O$
Üç Güzeller	01-085-1054	49	Silicon oxide	SiO_2
	04-023-4719	43	Potassium sodium aluminum silicate	$K_{0.08}Na_{0.92}AlSi_3O_8$
	01-075-8323	11	Magnesium silicate hydroxide hydrate	$Mg_8(Si_{12}O_{30}(OH)_4)(H_2O)_{11.82}$
	05-001-0866	36	Potassium sodium calcium aluminum silicate	$Ca_{0.421}Na_{0.559}\ K_{0.02}\ Si_{2.58}\ Al_{1.42}O_8$
	00-026-0911	19	Potassium aluminum silicate hydroxide	$(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$
	01-082-3729	7	Potassium sodium magnesium aluminum iron silicon titanium oxide hydroxide	$(K_{0.92}Na_{0.08}\ )(Al_{1.86}\ Fe_{0.07}Mg_{0.07}\ Ti_{0.02})(Si_{3.03}Al_{0.97})O_{10}(OH)_2$
Uçhisar	01-086-1630	49	Silicon oxide	SiO_2
	05-001-0864	41	Sodium calcium aluminum silicate	$Ca_{0.4}Na_{0.6}\ Al_{1.4}Si_{2.6}O_8$
	04-017-7291	17	Sodium magnesium aluminum iron silicon oxide hydroxide hydrate	$Na_{0.930}Mg_{2.810}Fe_{0.065}Al_{1.185}Si_{2.895}\ O_{10}(OH)_2(H_2O)_3$
	01-083-1604	14	Potassium aluminum silicate	$KAlSi_3O_8$
	00-025-0649	14	Potassium aluminum silicate hydroxide	$(K, Ca, Na\ )(Al, Mg, Fe)_2(Si, Al)_4O_{10}(OH)_2$
Ürgüp	04-005-4718	61	Silicon oxide	SiO_2
	01-071-0748	32	Sodium calcium aluminum silicate	$(Na_{0.45}Ca_{0.55})(Al_{1.55}Si_{2.45}O_8\ )$
	01-073-9904	24	Magnesium silicate hydroxide	$Mg_3(Si_2O_5)(OH)_4$
	00-058-2007	14	Calcium magnesium aluminum silicate hydroxide hydrate	$Ca_{0.2}(Al,Mg)_2\ Si_4O_{10}(OH)_2.xH_2O$
	01-078-4316	24	Sodium calcium magnesium aluminum iron titanium	$(Mg_{2.46}Al_{0.3}Fe_{0.22}Ti_{0.021}$

			aluminum silicon oxide hydroxide hydrate	$)_2(Mg_{0.38}Ca_{0.03}Na_{0.02})_2((Si_{2.83}Al_{1.17})O_{10})_2(OH)_4(H_2O)_{3.4}$
Zelve	04-006-1757	41	Silicon oxide	SiO_2
	01-073-9904	37	Magnesium silicate hydroxide	$Mg_3(Si_2O_5)(OH)_4$
	00-010-0393	41	Sodium aluminum silicate	$Na(Si_3Al)O_8$
	00-058-2007	19	Calcium magnesium aluminum silicate hydroxide hydrate	$Ca_{0.2}(Al, Mg)_2Si_4O_{10}(OH)_2.xH_2O$
	04-017-7291	24	Sodium magnesium aluminum iron silicon oxide hydroxide hydrate	$Na_{0.930}Mg_{2.810}Fe_{0.065}Al_{1.185}Si_{2.895}O_{10}(OH)_2(H_2O)_3$

Table 4. Commonly detected compounds in volcanic tuff locations.

Commonly Detected Compound Name	Volcanic Tuff Location	Reference Code	Score	Chemical formula
Silicon oxide	Avanos Devrent Valley Göreme Üç Güzeller Uçhisar Ürgüp Zelve	01-075-8321 00-046-1045 01-079-6238 01-085-1054 01-086-1630 04-005-4718 04-006-1757	60 65 46 49 49 61 41	SiO_2
Magnesium silicate hydroxide	Avanos Ürgüp Zelve	01-073-9904 01-073-9904 01-073-9904	27 24 37	$Mg_3(Si_2O_5)(OH)_4$
Sodium calcium aluminum silicate	Avanos Göreme Uçhisar Ürgüp	00-009-0465 05-001-0865 05-001-0864 01-071-0748	32 38 41 32	$(Ca, Na)(Al, Si)_2Si_2O_8$ $Ca_{0.41}Na_{0.59}Si_{2.59}Al_{1.41}O_8$ $Ca_{0.4}Na_{0.6}Al_{1.4}Si_{2.6}O_8$ $(Na_{0.45}Ca_{0.55})(Al_{1.55}Si_{2.45}O_8)$
Sodium calcium magnesium aluminum iron titanium aluminum silicon oxide hydroxide hydrate	Devrent Valley Göreme Ürgüp	01-078-4316 01-078-4316 01-078-4316	14 17 24	$(Mg_{2.46}Al_{0.3}Fe_{0.22}Ti_{0.021})_2(Mg_{0.38}Ca_{0.03}Na_{0.02})_2((Si_{2.83}Al_{1.17})O_{10})_2(OH)_4(H_2O)_{3.4}$
Potassium aluminum silicate hydrate	Göreme Üç Güzeller Uçhisar	00-025-0649 00-026-0911 00-025-0649	19 19 14	$(K, Ca, Na)(Al, Mg, Fe)_2(Si, Al)_4O_{10}(OH)_2$ $(K, H_3O)Al_2Si_3AlO_{10}(OH)_2$
Sodium magnesium aluminum iron silicon oxide hydroxide hydrate	Uçhisar Zelve	04-017-7291 04-017-7291	17 24	$Na_{0.930}Mg_{2.810}Fe_{0.065}Al_{1.185}Si_{2.895}O_{10}(OH)_2(H_2O)_3$
Calcium magnesium aluminum silicate hydroxide hydrate	Ürgüp Zelve	00-058-2007 00-058-2007	14 19	$Ca_{0.2}(Al, Mg)_2Si_4O_{10}(OH)_2.xH_2O$

Score: Indicates the number of compatible files as a result of comparing the PDF file of the unknown sample with the PDF files of the known sample patterns loaded on the computer. **Reference code:** Shows the detected PDF number. ***Note:*** The items in the table were scanned from the pdf file using a computer program.

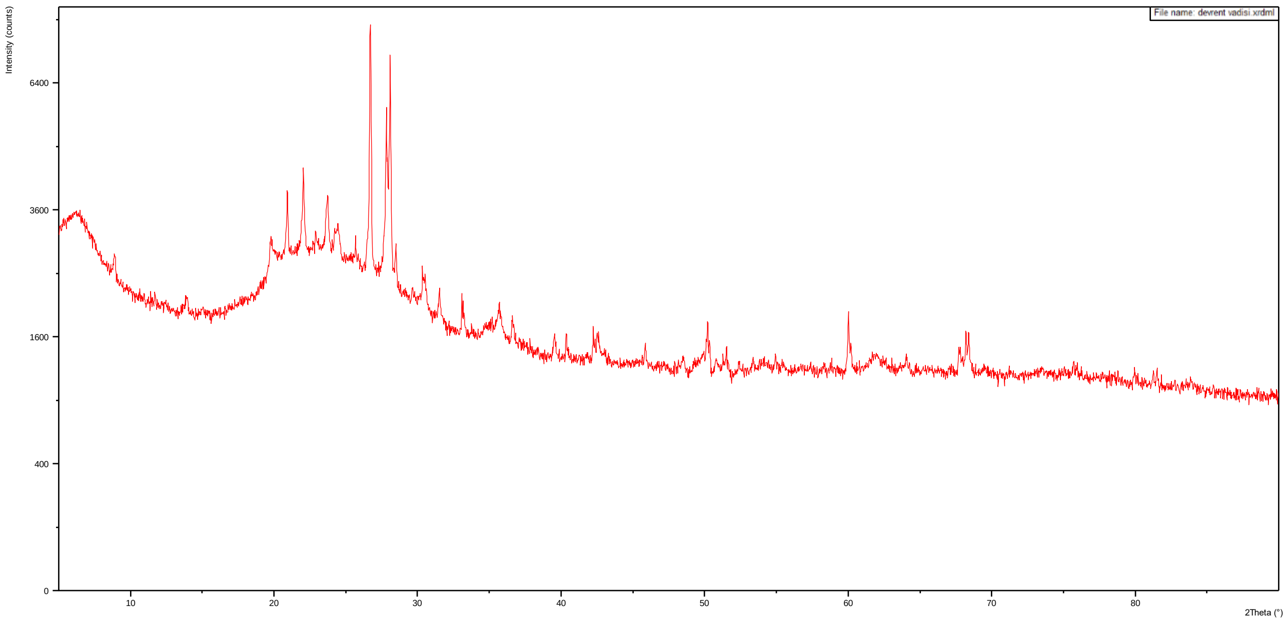


Figure 6. Diffraction pattern of a volcanic tuff stone sample taken from Devrent.

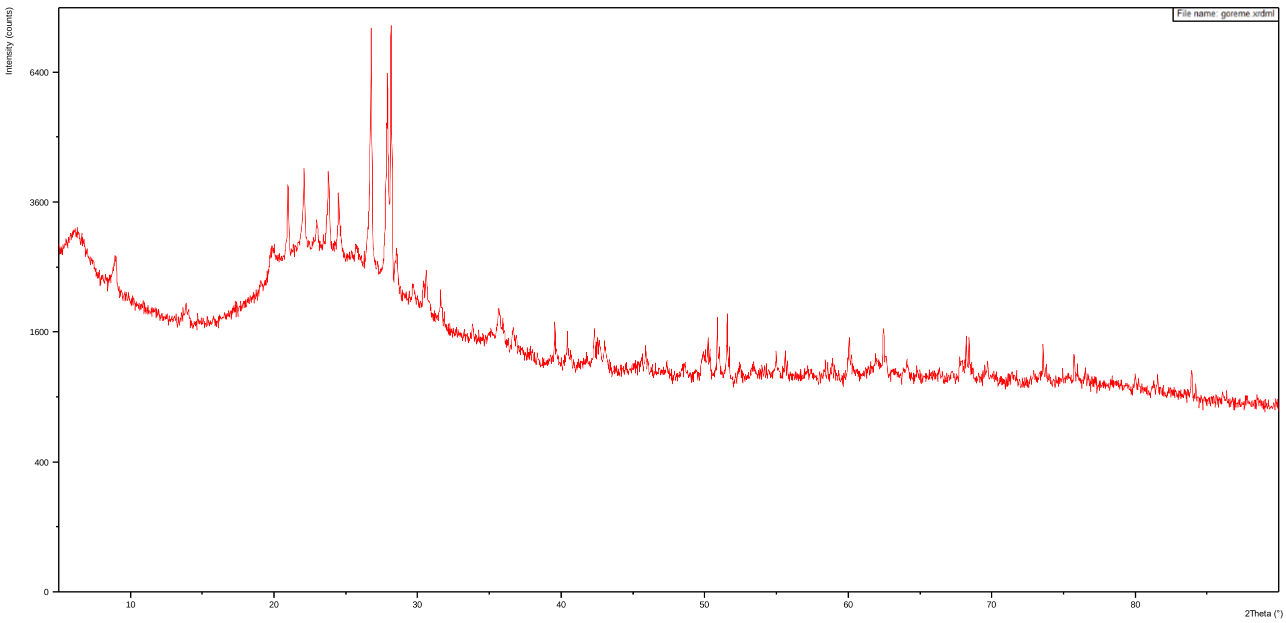


Figure 7. Diffraction pattern of a volcanic tuff stone sample taken from Göreme.

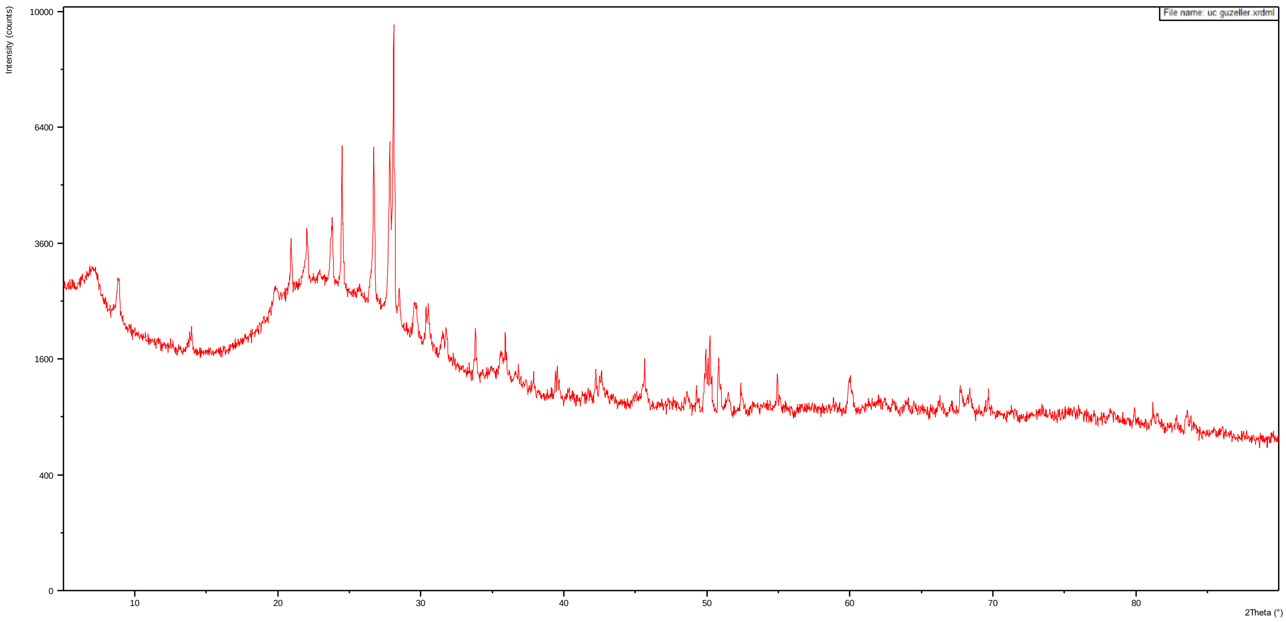


Figure 8. Diffraction pattern of a volcanic tuff stone sample taken from Üç Güzeller.

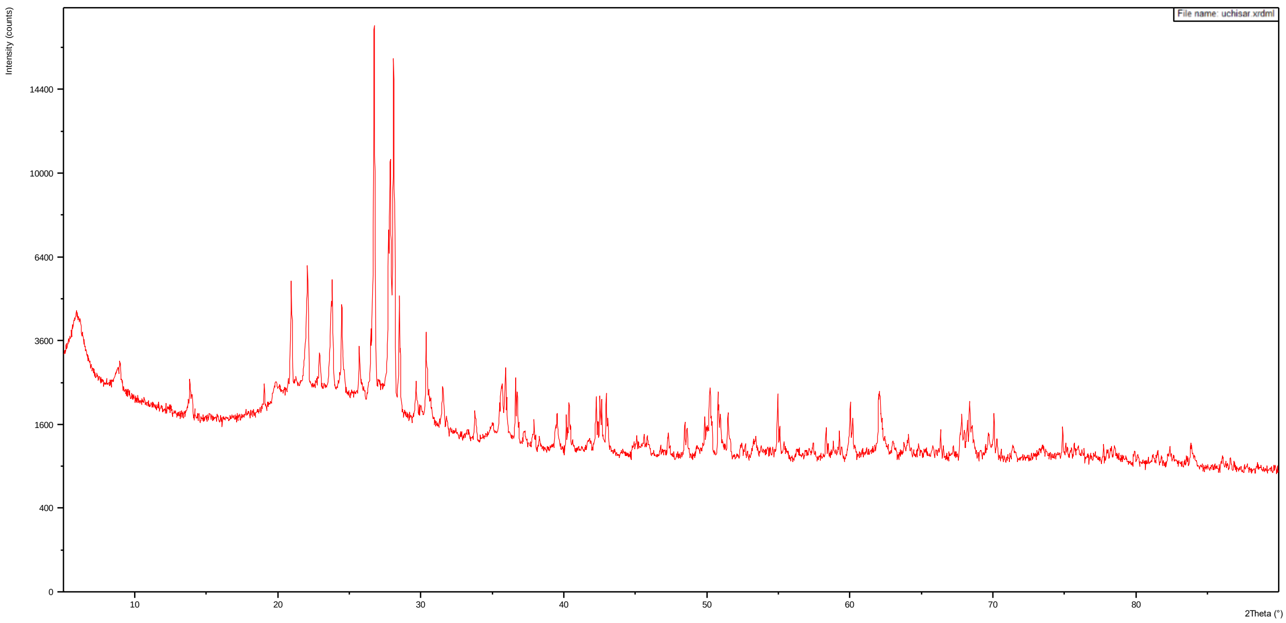


Figure 9. Diffraction pattern of a volcanic tuff stone sample taken from Uçhisar.

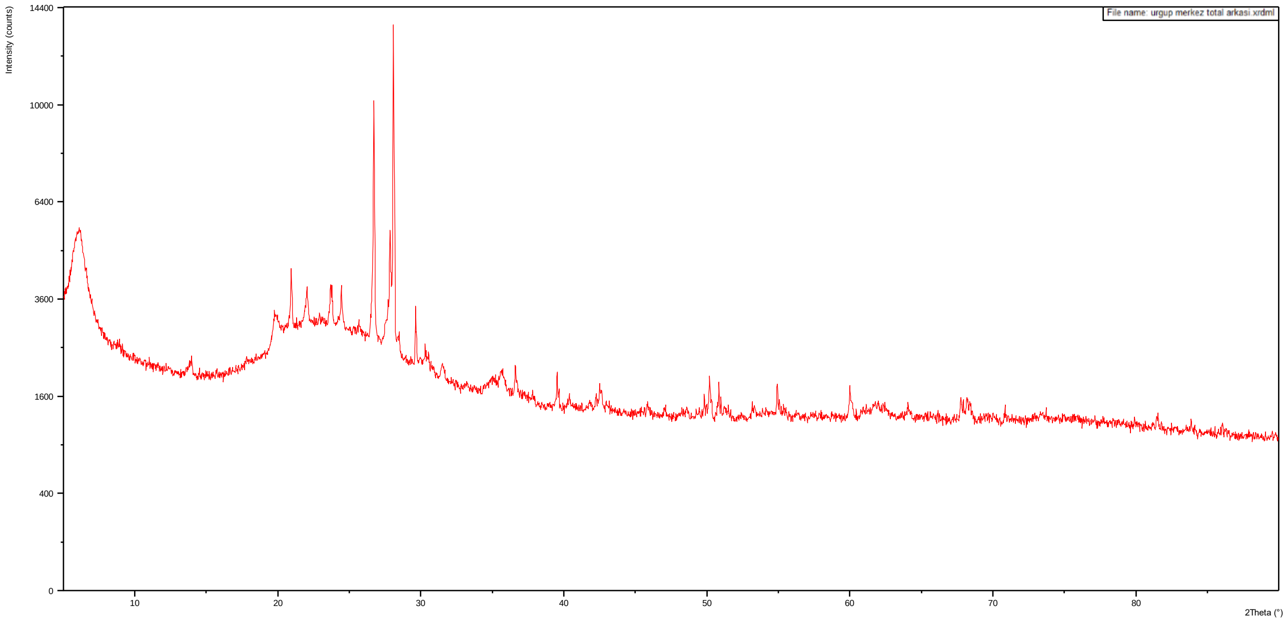


Figure 10. Diffraction pattern of a volcanic tuff stone sample taken from Ürgüp.

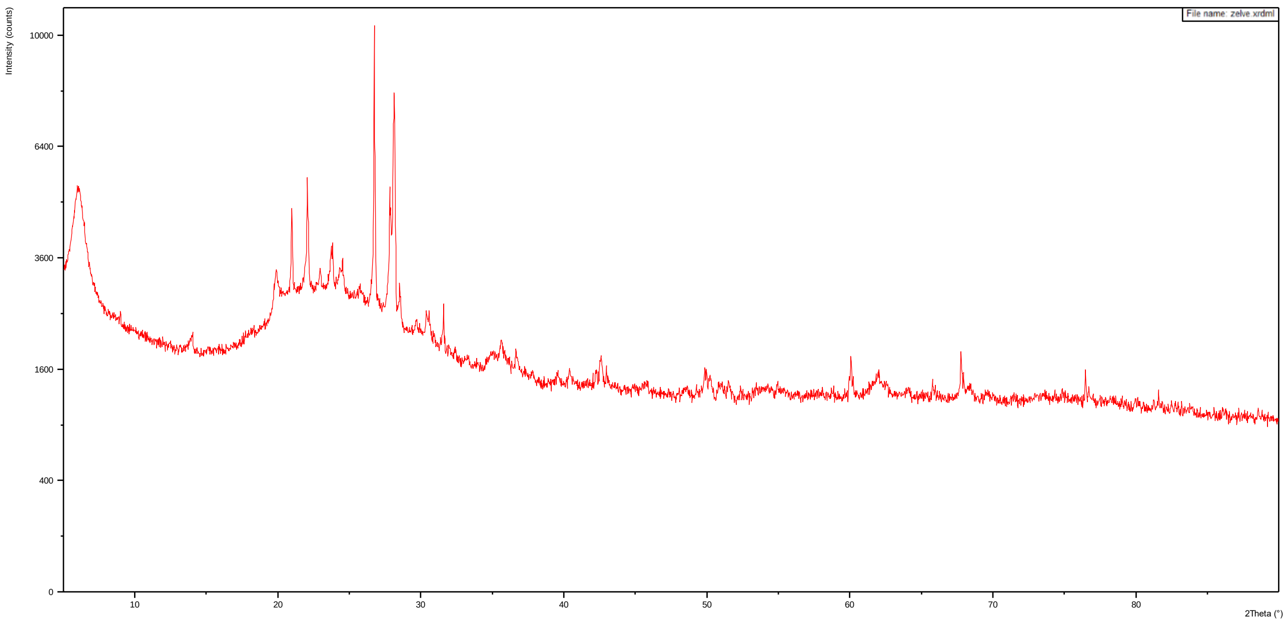


Figure 11. Diffraction pattern of a volcanic tuff stone sample taken from Zelve.

4. Discussion and Conclusion

Volcanic tuff is formed when magma, which contains very rich dissolved gases, erupts onto the earth. Igneous rocks are mainly composed of silicate minerals. Chemical analysis shows that silicon and oxygen are the most abundant components of igneous rocks. In addition to two elements, magma is a melt composed of large amounts of aluminum (Al), calcium (Ca), sodium (Na), potassium (K), magnesium (Mg) and iron (Fe) ions. In addition, it contains small bonds of many other elements, including magma, titanium, and manganese, and trace amounts of much more rare elements such as gold, silver, and uranium.

In this study, stone samples taken from volcanic tuffs located at seven different locations in the Cappadocia region were analyzed by X-ray powder diffraction method. In the examined stones mainly; Silicon Oxide [SiO_2], Magnesium Silicate Hydroxide [$Mg_3(Si_2O_5)(OH)_4$], Sodium Calcium Aluminum Silicate [$(Na_{0.45}Ca_{0.55})(Al_{1.55}Si_{2.45}O_8)$], Sodium Calcium Magnesium Aluminum Iron Titanium Aluminum Silicon Oxide Hydroxide Hydrate [$(Mg_{2.46}Al_{0.3}Fe_{0.22}Ti_{0.021})_2(Mg_{0.38}Ca_{0.03}Na_{0.02})_2((Si_{2.83}Al_{1.17})O_{10})_2(OH)_4\ (H_2O)_{3.4}$], Potassium Aluminum Silicate Hydroxide [$(K, Ca, Na)\ (Al, Mg, Fe)_2(Si, Al)_4O_{10}(OH)_2$], Sodium Magnesium Aluminum Iron Silicon Oxide Hydroxide

Hydrate [$Na_{0.930}Mg_{2.810}Fe_{0.065}Al_{1.185}Si_{2.895}O_{10}(OH)_2(H_2O)_3$], Calcium Magnesium Aluminum Silicate Hydroxide Hydrate [$Ca_{0.2}(Al, Mg)_2Si_4O_{10}(OH)_2.xH_2O$] was detected.

Diffraction patterns of the remaining six volcanic tuff stone samples are also given for comparison [Figure 6-11].The list of compounds detected in volcanic tuffs is given in Table 3. These compounds are similar in samples taken from different locations [Table 4]. Compounds and elements detected in tuff samples are in agreement with the literature. When these results we obtained are compared with similar studies, it is seen that the studied volcanic tuff samples contain a high amount of SiO_2. Volcanic tuffs containing aluminum silicate alkali are frequently seen in the structures in the Cappadocia region. Thus, volcanic tuffs can be used in the building materials industry both as rocks and in the preparation of masonry or concrete mortar [15,16-19]. This research contributes to the literature on the formation of natural structures in the Cappadocia region.

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