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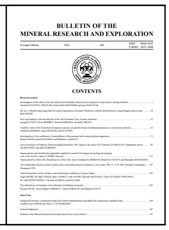

The distribution of elements in the alteration of feldspatic minerals

Kıymet DENİZ[a*], Yusuf Kağan KADIOĞLU[a,b], Tamer KORALAY[c] and Bahattin GÜLLÜ[d]

[a]*Ankara University, Faculty of Engineering, Department of Geological Engineering, Ankara, Turkey*
[b]*Ankara University, Earth Sciences Application and Research Centre (YEBIM), Ankara, Turkey*
[c]*Pamukkale University, Faculty of Engineering, Department of Geological Engineering, Denizli, Turkey*
[c]*Aksaray University, Faculty of Engineering, Department of Geological Engineering, Aksaray, Turkey*

Research Article

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ABSTRACT

Feldspar (alkali feldspar and plagioclases) and in recent years feldspathoid minerals are used as raw materials in the ceramic-glass industries. The igneous rocks such as granite, syenite and foid syenite which mainly contain these minerals have the potential to be raw materials. Some inclusions within the feldspatic minerals affect extremely negatively the desired values for raw material. In this study, the effective processes in the alteration of feldspatic minerals within the Özvatan foid syenites, the effects of alteration minerals in the raw material were evaluated and the effects of the elements released by alteration on the environment were revealed. The foid syenites consist of nepheline, orthoclase, plagioclase, cancrinite, sodalite, amphibole, biotite, pyroxene, melanite with a rare amount of sphene, zircon, apatite and fluorite. The contents of the sericite and kaolinite, which are formed as a result of an alteration of these rocks, increase in direct proportion to alteration degree. As a result of the alteration index values, foid syenites samples show the low degreed decomposed property. According to the calculated mobility index (MI) from chemical analyses, there is a quantitative decrease in the major oxides such as SiO_2, Al_2O_3, Na_2O, K_2O, CaO and Fe_2O_3 in the foid syenites. In accordance with the all data, Özvatan foid syenites have been exposed both weathering and hydrothermal alteration and the effect of hydrothermal alteration are observed more frequently in the altered rock. While the excess of diaclase structures within the rock provides ease of operation, on the other hand, it accelerated the weathering and alteration processes.

1. Introduction

Feldspathic (feldspar and feldspathoid) minerals are found at excess rates in felsic intrusive rocks. Due to representing the main mineral composition in rocks with alkali feldspar granite, alkali feldspar syenite, and foid syenite in composition, these rocks are important in terms of their potential to be industrial raw materials. Nearly all feldspar and feldspathoid minerals are used as raw materials for different purposes in many different fields (glass, ceramic, paint, plastic, rubber industry, etc.) in recent years. With the daily increasing requirements of feldspar and feldspathoid raw materials in different fields, there has been an intensification of geological and technological studies about this topic. For this reason, studies about the assessment of pegmatitic deposits in addition to intrusive rocks that contain abundant feldspathic minerals and may be a source of feldspar and especially altered portions of these rocks have gained importance. However, potential deposits are used in the marble industry due to the

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*Corresponding author: Kıymet DENİZ, kdeniz@eng.ankara.edu.tr

colour homogeneity of fresh intrusive rocks, lack of many fractures, and high block yield. For this reason, determining the usefulness of altered portions with high fracture rates, which cannot be used in the marble sector, for glass and ceramic industries especially and including this in the economy is highly important in terms of the best use of our natural resources. Mineralogy, mineral, and rock chemistry studies are very important to determine the quality and class of feldspar and feldspathoid minerals to be used in the glass and ceramic industry. Enrichment processes for altered intrusive rocks without economic value make it possible to operate them. It is necessary to determine the accompanying impurities in feldspathic minerals with mineralogical and spectroscopic methods and to use the most appropriate and economic separation techniques according to the composition of impurities. It is possible to remove these impurities with physical methods like magnetic separation and flotation.

Many studies were performed about the alteration of magmatic rocks and especially feldspar minerals and the element exchanges within the rocks with alteration (Gürsoy, 1999; Karakaya et al., 2001*a*, 2001*b*; Ng et al., 2001; Piché and Jébrak, 2004; Karakaya et al., 2012; Mathieu, 2016, 2018; Yazar, 2018; Akçe and Kadıoğlu, 2020; Ulusoy and Kadıoğlu, 2021). Feldspar minerals within granitic rocks may transform to kaolin under atmospheric conditions or hydrothermal effects (Gürsoy, 1999). Deniz and Kadıoğlu (2011) stated that smectites within the Buzlukdağ foid syenite (Kırşehir - Kaman) in the Central Anatolia region were derived from the alteration of biotite, amphibole and pyroxene minerals, kaolinite came from alteration of leucite, nepheline and partly from orthoclase and illite formations resulted from alteration of more alkali feldspar and partly feldspathoids (nepheline and leucite).

Enrichment processes are very important in terms of increasing the quality and yield of feldspathic minerals. Process related to purifying feldspathic raw materials includes hand-washing, breaking, grinding, classifying according to size, magnetic or electrostatic separation, and flotation (Gürsoy, 1999). Başıbüyük and Ekincioğlu (2019) performed investigations about the potential of pseudoleucite syenites located in İsahocalı (Kırşehir) as raw material and stated that minerals with potential as raw materials could be enriched using a dry magnetic separator as these rocks were not altered and that they were suitable for raw material. Studies about purifying raw materials by removing accessory minerals found as inclusions within feldspar (apatite, rutile, etc.) or secondary minerals forming as a result of alteration and/or weathering have been performed for many years (Bayraktar et al., 1997, 1999; Gürsoy, 1999; Negm et al., 2000; Erdinç, 2007; Marinov et al., 2010; Başıbüyük and Ekincioğlu, 2019; Ötekaya et al., 2020). A study by Kademli (2004) stated that mica minerals were the main source of iron among feldspar minerals that can be used as raw material in the glass and ceramic industry. They stated that mica can be separated using traditional methods such as flotation and magnetic separation in addition to the spiral enrichment method using the effect of gravity. This technique is much more effective for separation of mica with fine grain size and can be used to reduce flotation stages.

Impurities in feldspathic minerals generally result from the presence of inclusion minerals like hornblende, biotite, chlorite, apatite and sphene. Impurities in feldspathic minerals used in industry are generally determined by examining the content of element values such as Fe, Ti, Mn and Mg. Apart from these elements, when the chemical %K content increases, especially in weathered feldspathic minerals, impurities caused by muscovite and sericite minerals may lead to insidious and hidden contamination. The study area of the Kayseri Özvatan region was chosen due to rocks without silica saturation and foid syenite composition being rich in feldspathic components. The feldspathic minerals from the study area were investigated in mineralogical, textural and chemical senses for components causing impurities. Additionally, the type and ratio of the elements released by the decomposition of feldspathic minerals in the study area and which minerals they contribute to the formation of the environment were determined.

2. Material and Method

Thin sections of 150 samples collected from intrusive rocks that crop out in the vicinity of Özvatan town of Kayseri province have been made and mineralogical and petrographic investigations have been performed by Zeiss brand Axio model polarizing microscope to determine mineralogical compositions, textural features and alteration types of rocks. As a result of result of the petrographic investigations, samples that were not arenised and weathered were prepared for geochemical analyses (major oxide and trace element). Sample preparation and polarised energy distribution X-Ray Fluorescence Spectrometry (PEDXRF) measurement details were completed according to Deniz and Kadıoğlu (2018, 2019). With the aim of determining the chemistry and types of feldspar and feldspathoid minerals found within the rock, electron probe micro analysis (EPMA) analyses performed on polished and carbon-coated thin sections. A JEOL brand JXA 8230 model device with 20 kV voltage and 20 nA current was used for EPMA analyses. Point measurements of feldspathoid minerals had a diameter of 20 µm for the area of the electron beam. Mineral standards used for each element in the measurements are diopside (Mg, Ca), albite (Na), orthoclase (Si, Al, K), fluorite (F), rhodonite (Mn), olivine (Fe), titanium oxide (Ti), and barite (Ba). Detection limits of the standards for each measured element were 150 ppm for Mg, 188 ppm for Na, 242 ppm for Si, 1087 ppm for F, 94 ppm for Mn, 85 ppm for Al, 104 ppm for Fe, 27 ppm for K, 69 ppm for Ti, 176 ppm for Ba and 39 ppm for Ca. The standard deviation of the standards for each measured element were 0.18% for Mg, 0.30% for Na, 0.08% for Si, 0.26% for F, 0.11% for Mn, 0.12% for Al, 0.21% for Fe, 0.08% for K and 0.07% for Ti, Ba and Ca. To determine alteration mineralogy, measurements were taken from samples with different degrees of alteration by using an Inel brand Equinox 1000 model X-Ray Diffractometer (XRD) device at 30 mA and 30 kV using a cobalt (Co) anode. All analytical studies were completed in the Earth Sciences Application and Research Centre (YEBIM) laboratories of Ankara University.

3. Geology of the Study Area

The study area is bounded to the north by the İzmir Ankara Erzincan Suture Zone (IAESZ), to the west by the Tuz Gölü Fault (TGF) and to the east by the Ecemiş Fault Zone (EFZ) and is located in the southeast section of the rough triangle between Ankara, Sivas and Niğde cities in the central Anatolian region. It is located in and around Özvatan (Hayriye - Çukurköy) town located nearly 55 km northeast of Kayseri (Figure 1a). Observed rocks in the study area can be separated into three groups as metamorphic units, magmatic units and cover units. The metamorphic units comprise Palaeozoic schist and Permian marbles belonging to the Central Anatolia Metamorphics (CAM) (Figure 1b). The magmatic units are represented by Upper Cretaceous intrusive (Özvatan foid syenite), sub-volcanic and Cenozoic extrusive rocks.

The magmatic rocks in the study area were called Atdere foid syenite by Özkan (1987) and Hayriye pluton by Kadıoğlu et al., (2006). In this study, it was appropriate to call the syenitic composition rocks outcropping near Özvatan town with different degrees of weathering the Özvatan foid syenite (Figure 1b and 2a, Deniz et al., 2018*a*). Previous studies (e.g., Kraeff and Pasquare, 1966) mentioned the presence of silica-saturated and silica-unsaturated rocks in the region, while previous studies by the authors and this study only observed the presence of syenite composition rocks that were not silica saturated (e.g., Deniz et al., 2018*a*, *b*). Syenites containing quartz in the region were determined to have secondary quartz forming with the effect of silicification due to hydrothermal alteration. Syenitic composition intrusive rocks have intruded into schist and marble composition rocks in the study area. Dykes with felsic and mafic composition cut the syenitic units with sharp contacts and hydrothermal veins containing calcite, fluorite and barite are present (Deniz et al., 2018*a*). Volcanic rocks with basalt composition were observed in the southern sections of the study area (Deniz et al., 2018*b*). The cover units, which are not included in the research topic, are represented by Eocene - Upper Miocene continental clastics. The youngest formation in the study area is Quaternary alluvium (Özaksoy and Göktan, 1996).

4. Mineralogy and Petrography

Özvatan foid syenites are light grey, grey, and pinkish-grey colour with phaneritic texture (Figure 2b - 2g). The unit with diaclase structure (Figure 2b) displays different rates of alteration (Figure 2c, d, and e). The degree of alteration is more pronounced along with diaclase structures, with the colour of the rock displaying variation from grey to pink linked to the severity of alteration (Figure 2g). In hand samples, nepheline, K-feldspar, garnet, biotite, amphibole and fluorite crystals are very visible (Figure 2f, g). The Özvatan foid syenites have holocrystalline hypidiomorphic texture, with main mineralogic composition of 20 - 50% nepheline, 70 - 90% orthoclase, 20 - 30% plagioclase, 1 - 5% cancrinite, 1 - 3% sodalite, 0 - 3% amphibole, 0 - 4% biotite, 1 - 3% pyroxene, 1 - 6% melanite and lower rates of 0 - 1%

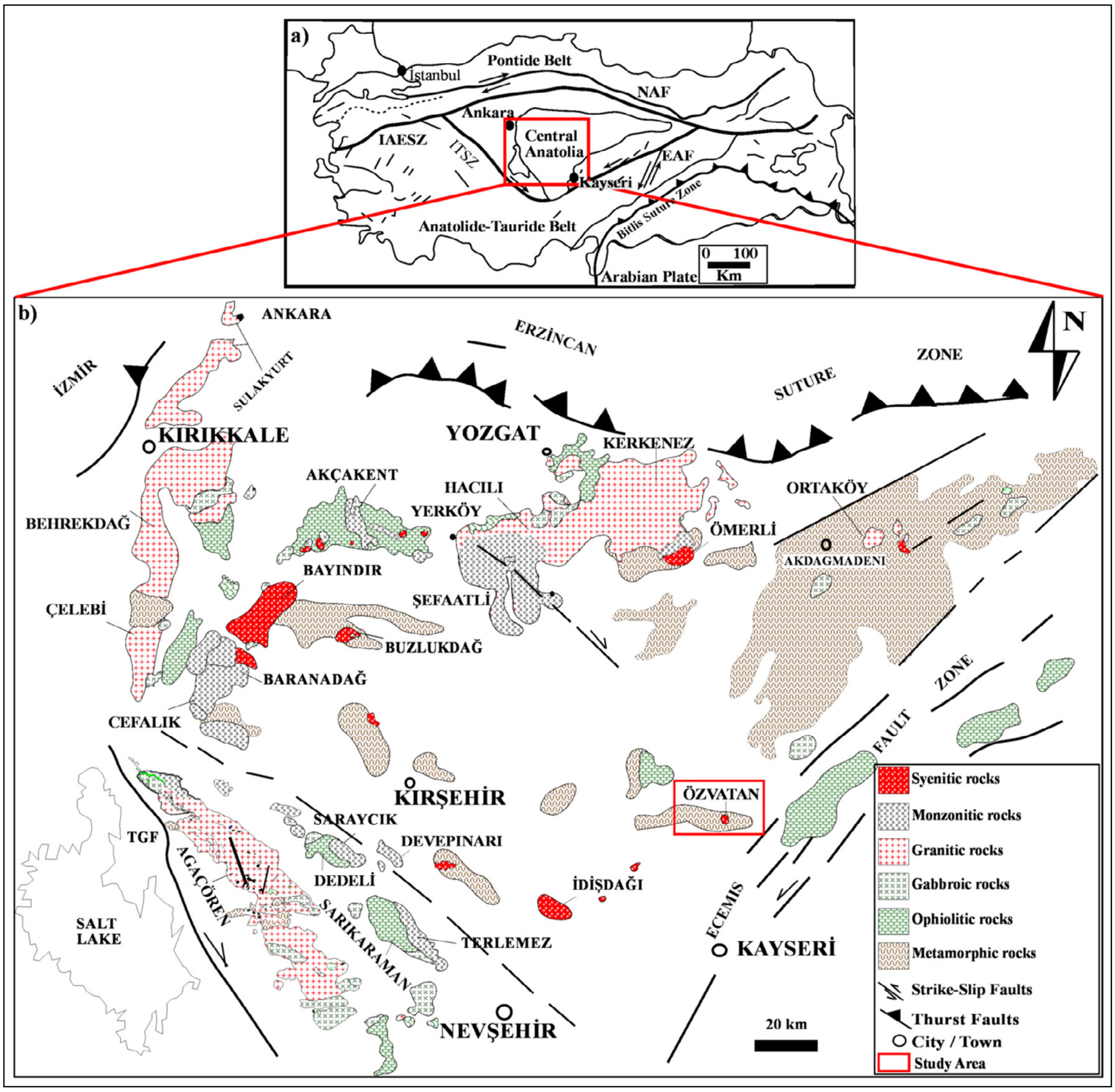

Figure 1- a) Map showing location of central Anatolia in Turkey (modified from Bozkurt and Mittwede, 2001), b) geological map showing location of the study area (modified from Kadıoğlu et al., 2006).

for other minerals (titanite, zircon, apatite and fluorite) (Figure 3a - d). Syenite rocks may be divided into sub-groups according to the abundance of minerals like cancrinite, sodalite, amphibole, biotite, pyroxene, and melanite in the rock. According to Confocal Raman Spectroscopy (CRS) performed to determine types in the group minerals, amphibole minerals are actinolite; pyroxene minerals are diopside; cancrinite minerals are vishnevite; mica minerals are biotite and phlogopite; feldspathoid minerals are nepheline and sodalite and garnet minerals have melanite composition.

Alteration types including argillisation, sericitization, carbonation, albitisation, uralitisation, opacification and iron hydroxidation are commonly observed in the altered samples (Figure 3e - i). As the degree of alteration increases, the secondary alteration products within the rock naturally increase (Figure 3e - i). Sericite and kaolinite minerals were detected from XRD analyses for identification of alteration products (Figure 4).

Within the Özvatan foid syenites, low proportions of mafic magmatic enclaves (MME) and magma segregation enclaves were observed. The composition of MMEs are foid gabbro and foid monzogabbro. Magma segregation enclaves formed as a result of clustering of biotite and amphibole minerals (Kadıoğlu and Güleç, 1996, 1999).

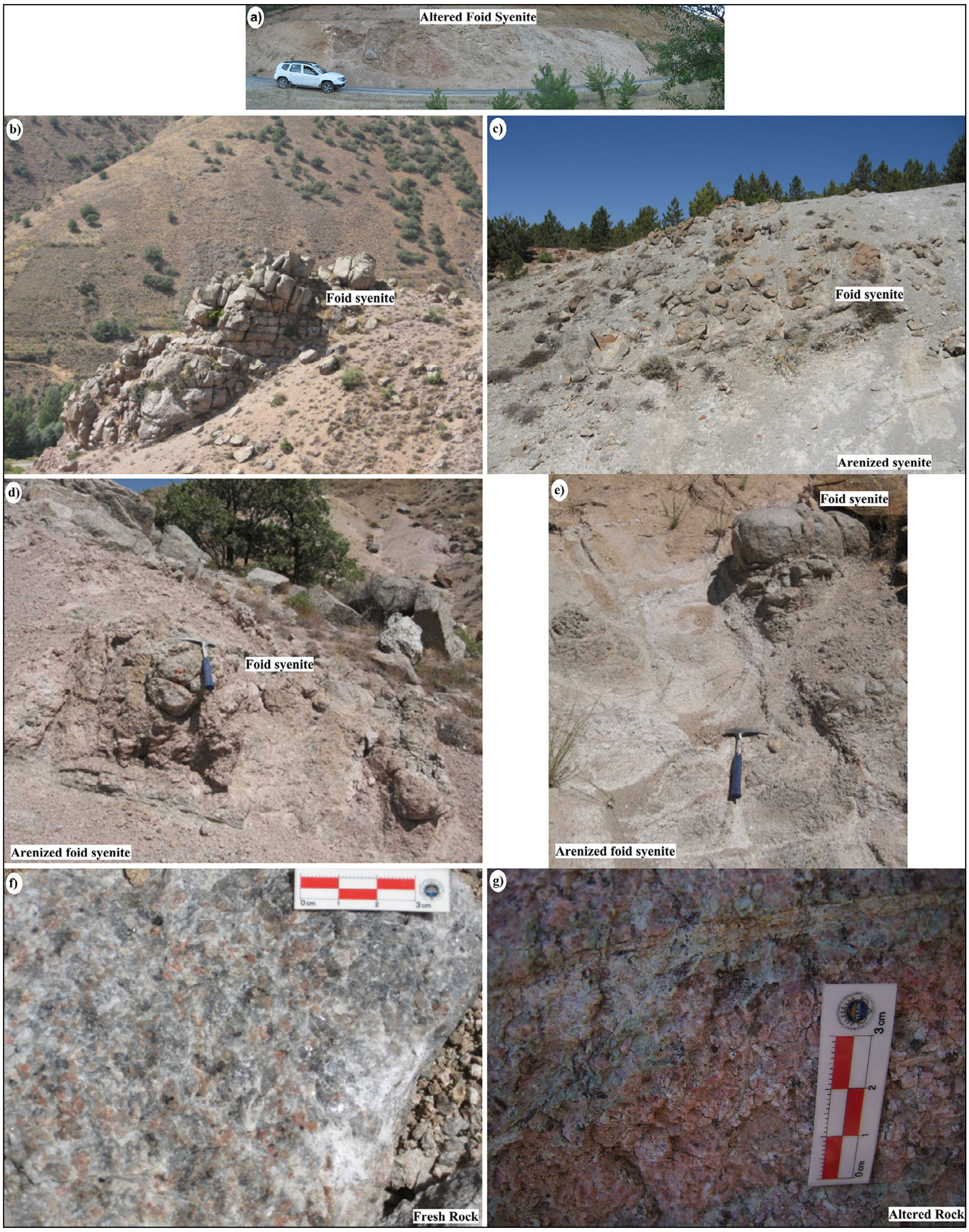

Figure 2- Field appearance of Özvatan foid syenites; a) general altered syenite outcrop, b) diaclase structures in altered syenites, c), d), e) appearance of arenitised syenite, f) macroscopic appearance of fresh syenite and g) macroscopic appearance of altered syenite.

XRD analyses were performed on fresh samples and differentially altered samples. On XRD diffractograms, nepheline and orthoclase minerals are dominant in the fresh rock (Figure 4). Sericite is mostly observed as an alteration mineral and when the degree of alteration in the rock increases, the proportion of this mineral in the rock increases (Figure 4). In addition to sericite, kaolin was also observed as the dominant alteration mineral in rocks with IV Group alteration degree (Figure 4). Sericite and kaolin minerals are more dominant in weathered rocks compared to fresh rock. (Figure 4).

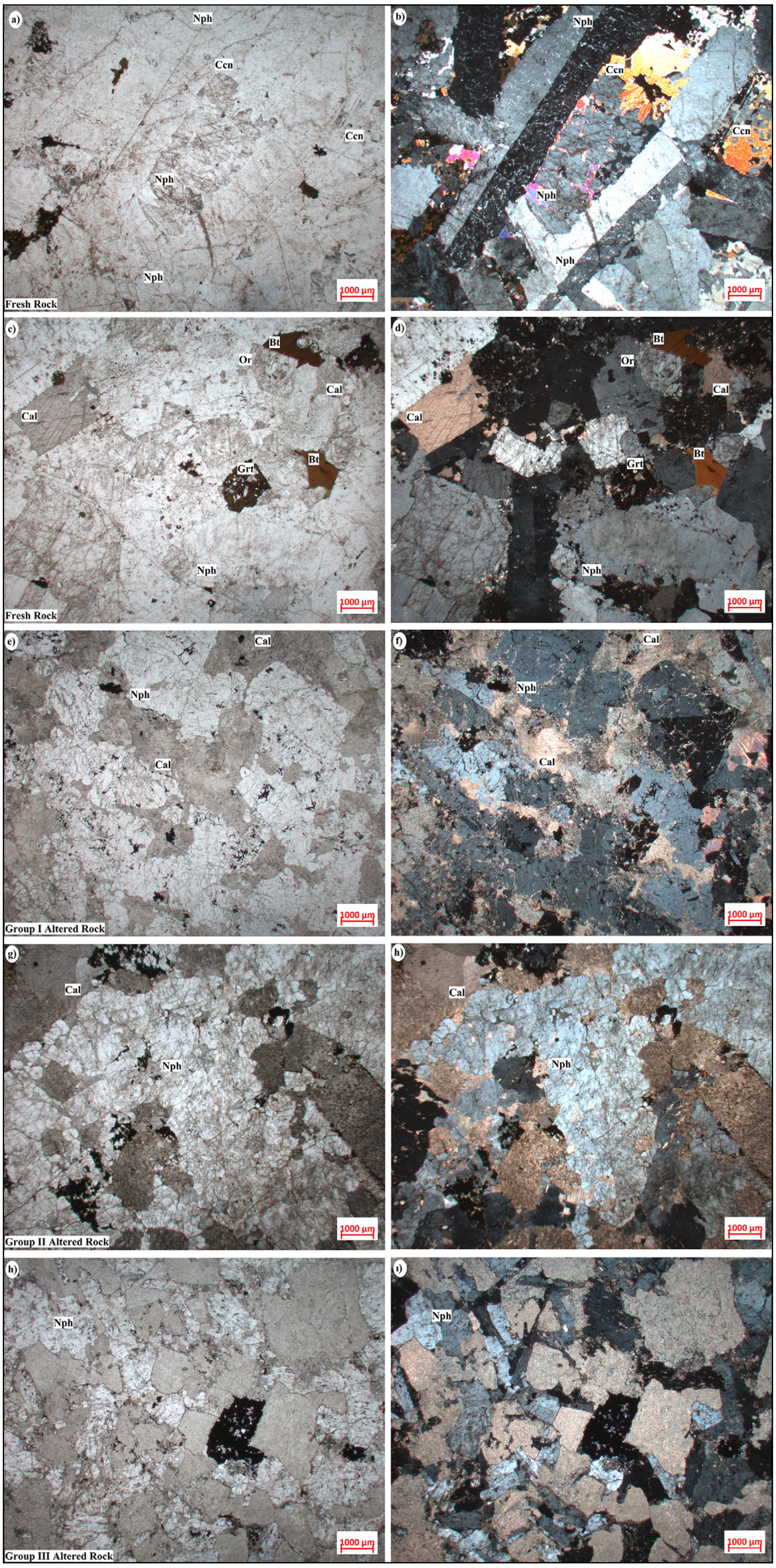

Figure 3- a), b), c), d) Özvatan foid syenites microphotographs of fresh rock, e), f), g), h), i) microphotographs of altered rock (a, c, e, g, h: parallel Nicol images, b, d, f, h, i: cross Nicol images and Bt: biotite, Cal: calcites, Ccn: cancrinite, Grt: garnet, Kln: kaolinite, Nph: nepheline, Or: orthoclase, Ser: sericite).

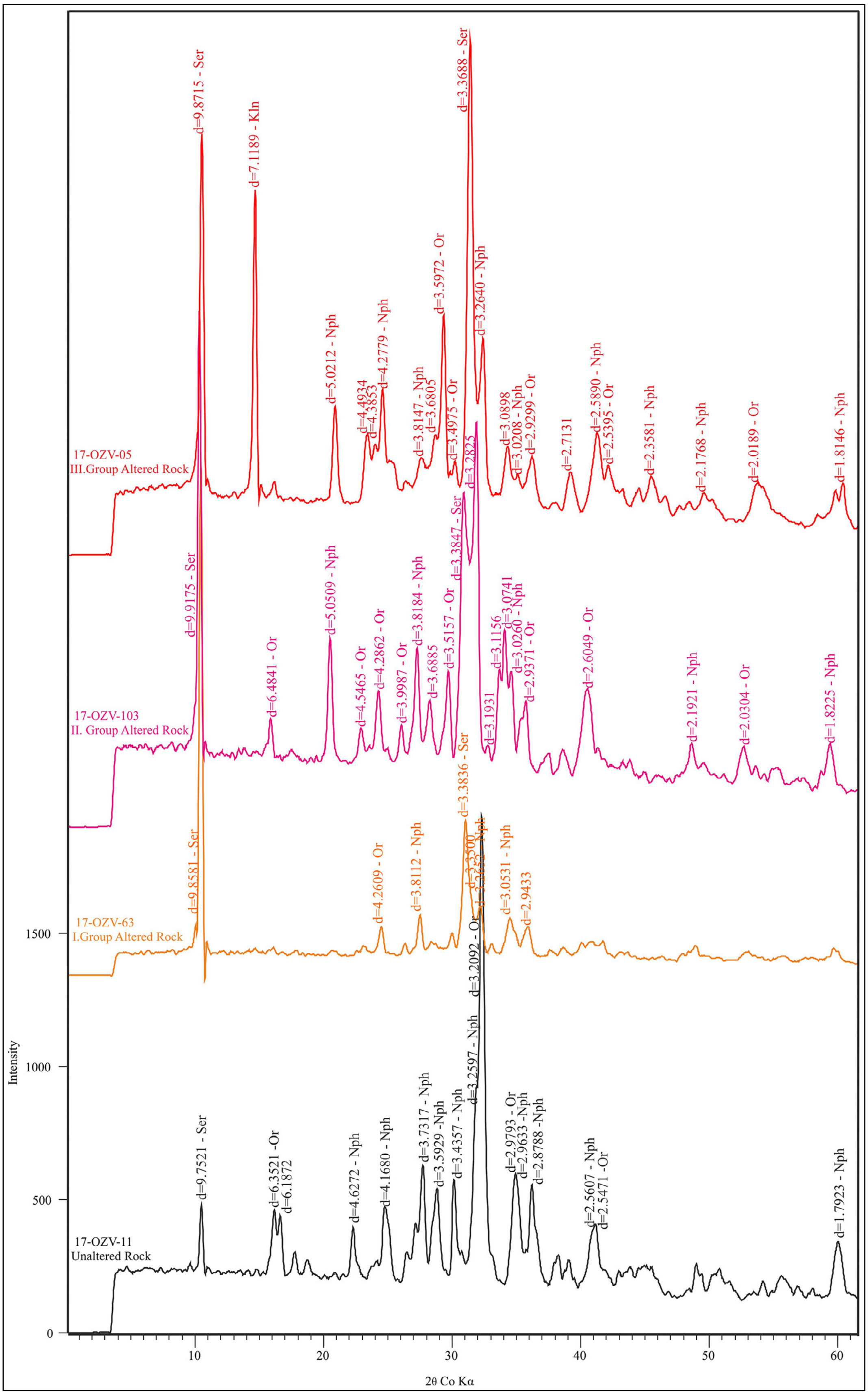

Figure 4- XRD diffractograms for fresh and altered Özvatan foid syenites.

5. Feldspar and Feldspathoid Chemistry

Mineral chemistry analysis results for minerals of the feldspar (alkali feldspar, plagioclase) and feldspathoid (nepheline, cancrinite, sodalite) groups are given in Tables 1 and 2. Accordingly, nephelines contain 41 - 45% SiO_2, 31 - 32% Al_2O_3, 14 - 16% Na_2O, 5 - 7% K_2O and 0.3 - 0.5% FeO (Table 1). The composition of cancrinite group minerals within syenites was determined as vishnevite (Deniz et al., 2017).

The feldspar minerals contain 62 - 65% SiO_2, 18 - 22% Al_2O_3, 0.6 - 10.6% Na_2O, 0.1 - 16.1% K_2O, 0.01 - 3.13% CaO and 0.01 - 0.16% FeO (Table 2). Alkali feldspar minerals within syenite rocks were orthoclase and plagioclase minerals were oligoclase with bitownite composition in core sections determined in mineral chemistry studies (Table 2). This situation is a marker that a magma mixing process was effective during formation of the rocks.

6. Geochemistry of Whole Rock Alteration

Geochemical analysis results for Özvatan foid syenite samples are given in Table 3 and Table 4. When the whole-rock geochemistry of foid syenite samples with negligible degree of weathering as a result of petrographic investigation are examined, SiO_2 contents varied from 49 - 61%, K_2O content from 4 - 11%, Na_2O amounts were 3 - 8%, Al_2O_3 contents were 19 - 26% and Fe_2O_3 amounts were 1 - 7%. Total alkali (Na_2O+K_2O) amounts vary between 7 - 19%. Similarly, the content of SiO_2, Al_2O_3, Na_2O, K_2O, CaO, and Fe_2O_3 in the foid syenite samples with advanced degree of alteration change between 41 - 78% , 10 - 26%, 0.04 - 4.70%, 4.0 - 12.4%, 0.9 - 16.4% and 0.7 - 14.3%, respectively (Table 3).

The LOI values were calculated because of identifying whether rocks in the study area were altered and the number of volatile compounds (Table 3). For the LOI calculations, powdered samples were weighed to 2 g and placed in heat-resistant porcelain crucibles and were left in an ash oven at 1050 °C for 24 hours. The samples were taken out of the oven after they were weighed again and mass loss was calculated for LOI values as a percentage. Rocks with feldspathoid content contain minerals rich in terms of volatile compounds, so the LOI values were higher than magmatic rocks not containing feldspathoid minerals. Accordingly, it is seen that the LOI values of altered samples is more higher compared to fresh rock samples.

During weathering processes, significant changes may occur in rock and/or mineral chemistry. The degree of alteration of a rock may be determined according to alteration indexes proposed by a variety of researchers. The Özvatan foid syenite samples with

Table 1- Mineral chemistry results for representative nepheline minerals of Özvatan syenites (OZV: Özvatan, NPHL: nepheline).

	17-OZV-26-1-NPHL1					
No.	**1**	**3**	**5**	**7**	**10**	**12**
SiO_2	45.38	46.79	41.47	41.53	44.21	41.94
Al_2O_3	32.37	31.18	31.63	32.30	31.10	31.91
FeO	0.50	0.43	0.50	0.30	0.53	0.54
CaO	0.23	0.10	0.08	0.11	0.17	0.17
Na_2O	15.29	14.99	16.24	15.52	15.63	15.44
K_2O	5.29	6.31	7.32	7.36	7.01	7.41
Total	99.07	99.81	97.25	97.11	98.66	97.44
Cation values calculated according to oxygen 32						
Si	8.70	8.93	8.31	8.29	8.64	8.35
Al	7.32	7.01	7.46	7.60	7.17	7.49
Fe^{+2}	0.08	0.07	0.08	0.05	0.09	0.09
Ca	0.05	0.02	0.02	0.02	0.04	0.04
Na	5.68	5.54	6.31	6.01	5.93	5.96
K	1.30	1.53	1.87	1.87	1.75	1.88

Table 2- Mineral chemistry results for representative feldspar minerals of Özvatan syenites (OZV: Özvatan, ORT: orthoclase, PLG: plagioclase).

	17-OZV-11-3-ORT1	**17-OZV-29-1-ORT1**										**OZV-12-16-4-PLG1**
No.	**1**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**4**
SiO_2	64.59	63.86	64.15	63.73	64.59	62.27	63.34	65.30	64.18	64.13	64.37	64.30
Al_2O_3	18.69	19.02	19.47	19.17	18.57	19.10	18.09	18.14	18.79	18.53	18.28	22.22
FeO	0.16	0.12	0.13	0.01	0.11	0.08	0.08	0.09	0.08	0.12	0.12	0.03
CaO	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.02	3.13
Na_2O	1.36	0.80	0.79	0.62	0.82	0.81	0.65	0.79	0.81	0.82	0.93	10.61
K_2O	15.09	15.70	15.92	16.01	15.83	15.94	16.04	15.92	15.59	16.08	15.87	0.07
BaO	0.02	0.61	0.51	0.66	0.85	0.65	0.76	0.65	1.11	0.62	0.64	0.01
Total	99.95	100.13	101.00	100.23	100.80	98.87	98.99	100.92	100.59	100.30	100.23	100.39
Cation values calculated according to oxygen 32												
Si	10.36	10.06	10.11	10.08	10.18	9.94	10.26	10.17	10.20	10.21	10.28	11.40
Al	4.00	4.00	4.09	4.04	3.90	4.06	3.91	3.77	3.98	3.93	3.89	5.25
Fe	0.05	0.04	0.04	0.00	0.03	0.03	0.02	0.03	0.02	0.04	0.04	0.01
Ca	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	1.11
Na	0.73	1.39	0.83	0.97	0.97	1.41	0.25	1.61	0.55	0.62	0.57	0.31
K	9.68	9.90	10.04	10.13	9.98	10.17	10.40	9.92	9.92	10.24	10.14	0.05
Ba	0.01	0.19	0.16	0.21	0.27	0.21	0.24	0.20	0.35	0.20	0.20	0.00
Orthoclase	92.92	87.66	92.29	91.19	91.10	87.78	97.56	86.04	94.68	94.24	94.63	3.51
Albite	7.00	12.29	7.66	8.72	8.84	12.18	2.37	13.92	5.28	5.72	5.31	21.31
Anorthite	0.07	0.06	0.06	0.09	0.07	0.04	0.07	0.03	0.04	0.04	0.06	75.18

chemical analyses performed had the Ruxton ratio (R), Chemical Index of Alteration (CIA), Chemical Index of Weathering (CIW), Plagioclase Index of Alteration (PIA), Ishikawa Alteration Index (AI), Chlorite-Carbonate-Pyrite Index (CCPI), Advanced Argillic Alteration Index (AAAI), Sesquioxide Content Index (SOC), Leach Factor (LC), and Residue Factor (Rc) calculated (Table 5) and results are given in Table 6 (Ruxton, 1968; Parker, 1970; Roaldset, 1972; Nesbitt and Young, 1982; Harnois and Moore, 1988; Li et al., 1995; Fedo et al., 1995; İrfan, 1996; Souri et al., 2006; Fiantis et al., 2010).

The R (SiO_2/Al_2O_3) is a simple weathering index used for acidic and intermediate rocks (Ruxton, 1968; Fiantis et al., 2010). The R value for an altered rock is >10 and this value reduces when the degree of weathering increases. For the foid syenite samples, the R values vary from 2.0 to 6.6 and the samples were determined to be partially weathered (Tables 5 and 6). The relatively high values may be due to the abundant amounts of feldspar minerals within the rocks which are easily affected by weathering.

The CIA is used to measure the degree of transformation of feldspars to clay minerals (Nesbitt and Young, 1982; Fiantis et al., 2010). The CIA values increase in parallel to the increase in clay minerals within the rock. The CIA values for the Özvatan foid syenites vary from 44 to 78 and CIA values for magmatic rocks without weathering are below 50 (Tables 5 and 6).

The CIW proposed by Harnois (1988) is also defined as the A/CN ratio. There appear to be high rates of similarity and compatibility between CIW values and CIA values. The CIW calculations ignore the K_2O value. The CIW values for syenites in the study area were 38 - 96 and feldspar minerals in the rocks were determined to partly transform to clay minerals based on weathering (Tables 5 and 6). The CIW values of magmatic rocks vary from ≤50 - 100 and the CIW values of foid syenite samples changes 38 to 96 (Tables 5 and 6).

The PIA is calculated as an alternative to CIW. Plagioclase minerals commonly found in silicate rocks

Table 3- Major element oxide chemical analysis results of Özvatan syenites (LOI: loss on ignition).

Identification	Group	Element	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Cr_2O_3	V_2O_5	Cl	LOI	Total
		Unit	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Fresh Foid Syenite		17-OZV-11	56.80	0.08	23.29	2.37	0.02	0.10	3.55	10.08	9.13	0.08	1.30	0.02	0.01	0.44	2.49	99.67
Altered Foid Syenite	I	17-OZV-04	53.77	0.12	26.58	4.49	0.45	0.09	1.45	0.04	7.36	0.04	0.11	0.00	0.00	0.01	5.32	99.83
		17-OZV-05	55.84	0.12	25.76	4.26	0.35	0.07	0.93	0.04	6.19	0.01	0.09	0.00	0.01	0.01	6.36	99.99
		17-OZV-93	53.81	0.07	25.56	2.03	0.22	0.08	2.95	0.50	10.01	0.03	0.06	0.01	0.00	0.00	5.02	99.85
	II	17-OZV-06	46.97	0.53	19.90	6.42	2.58	0.26	5.93	0.05	8.71	0.09	0.09	0.01	0.01	0.01	8.46	99.99
		17-OZV-07	43.27	2.08	12.81	14.34	10.07	0.84	3.72	0.05	8.01	0.03	0.10	0.15	0.02	0.01	4.54	100.00
		17-OZV-18	55.75	0.04	22.29	1.92	0.14	0.09	4.28	4.77	8.99	0.04	0.41	0.00	0.01	0.01	5.47	99.46
		17-OZV-60	51.65	0.07	24.59	2.02	0.25	0.07	4.67	0.04	10.12	0.09	0.20	0.00	0.01	0.00	5.97	99.73
		17-OZV-62	55.08	0.16	21.77	2.43	0.24	0.08	5.71	0.04	9.87	0.09	0.17	0.00	0.01	0.00	4.40	100.02
		17-OZV-85	55.22	0.11	21.35	2.43	0.29	0.12	4.61	4.17	9.44	0.05	0.17	0.01	0.01	0.01	5.32	99.14
		17-OZV-90	55.77	0.09	23.88	2.50	0.15	0.11	2.47	0.57	11.75	0.02	0.06	0.01	0.01	0.01	2.99	99.83
		17-OZV-102	56.25	0.01	23.69	1.32	0.10	0.05	3.04	0.04	12.37	0.06	0.07	0.00	0.01	0.01	3.00	99.97
		17-OZV-103	55.37	0.10	23.26	2.71	0.13	0.13	4.03	0.04	11.63	0.07	0.06	0.00	0.01	0.01	2.52	100.02
		17-OZV-106	62.89	0.17	21.51	2.41	0.70	0.10	3.16	4.58	4.30	0.03	0.31	0.00	0.01	0.00	4.08	99.68
		17-OZV-107	78.65	0.01	11.87	0.78	0.34	0.03	1.84	4.34	4.81	0.00	0.07	0.00	0.00	0.00	1.46	99.88
	III	17-OZV-57	42.29	0.07	20.21	2.74	0.10	0.12	14.39	0.05	8.03	0.14	0.13	0.00	0.01	0.00	10.98	99.22
		17-OZV-81	47.88	0.04	20.56	1.68	0.10	0.09	10.60	0.04	10.02	0.11	0.14	0.00	0.01	0.00	8.46	99.70
		17-OZV-84	41.86	0.09	20.10	1.80	0.19	0.13	15.61	0.04	7.88	0.14	0.10	0.02	0.01	0.01	11.45	99.39
		17-OZV-100	46.06	0.18	20.86	3.56	0.16	0.19	10.79	0.05	10.85	0.09	0.06	0.00	0.01	0.01	7.16	99.98
		17-OZV-13	46.61	0.96	14.45	8.01	5.44	0.17	8.20	0.70	6.13	0.70	0.09	0.03	0.02	0.02	8.61	99.43
		17-OZV-16	42.20	1.26	11.48	7.73	6.74	0.18	13.92	0.79	5.11	1.20	0.14	0.08	0.03	0.01	9.43	99.51
		17-OZV-20	54.57	0.27	10.18	2.46	0.07	0.25	16.44	0.05	8.21	0.11	0.08	0.02	0.01	0.02	7.34	100.04
		17-OZV-54	41.00	0.03	18.74	2.82	0.41	0.15	16.32	0.04	7.15	0.17	0.12	0.01	0.01	0.02	13.01	99.95
		17-OZV-56	41.91	0.01	19.48	1.77	0.11	0.13	16.10	0.05	7.79	0.14	0.06	0.00	0.01	0.00	11.68	99.21
		17-OZV-58	51.19	0.07	19.31	3.25	0.56	0.14	7.69	0.05	9.87	0.12	0.29	0.02	0.02	0.02	7.08	99.62
		17-OZV-63	47.17	0.67	15.70	8.98	4.39	0.15	5.87	0.05	10.06	0.08	0.08	0.03	0.05	0.00	6.75	99.99
		17-OZV-101	53.80	0.13	17.51	4.83	0.12	0.16	9.29	0.04	9.72	0.07	0.05	0.00	0.01	0.00	4.33	100.02

Table 4- Trace element chemical analysis results of Özvatan syenites.

Identification	Group	Element	Co	Ni	Cu	Zn	Ga	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb
		Unit	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
Fresh Foid Syenite		17-OZV-11	18.30	7.70	3.30	97.00	20.80	6.40	179.50	2333.00	0.70	213.00	44.60	5.30	0.90	0.90
Altered Foid Syenite	**I**	17-OZV-04	12.60	4.40	0.90	187.50	69.50	20.30	297.90	712.90	0.80	1165.00	262.00	4.90	0.90	9.10
		17-OZV-05	21.60	2.10	1.10	148.40	73.20	9.60	257.30	341.20	0.70	1907.00	243.10	5.70	2.30	11.40
		17-OZV-93	26.20	1.80	0.90	93.50	29.20	4.20	219.10	1576.00	0.70	164.10	58.50	3.00	0.60	0.80
	II	17-OZV-06	16.50	42.80	1.10	292.70	28.80	2.00	276.80	2132.00	8.60	384.00	115.90	4.00	1.00	1.00
		17-OZV-07	40.60	408.20	1.50	970.70	30.20	0.80	522.60	418.20	1.20	185.60	262.60	5.00	1.90	1.00
		17-OZV-18	16.70	5.80	1.20	85.90	20.10	7.90	201.00	5211.00	0.90	514.00	69.80	4.40	1.00	1.00
		17-OZV-60	14.60	6.10	4.90	77.30	19.40	5.40	284.00	2627.00	0.80	199.00	31.70	3.80	0.90	0.90
		17-OZV-62	20.60	5.70	7.80	88.00	21.20	4.10	278.50	3014.00	0.90	167.00	52.30	3.80	0.90	0.90
		17-OZV-85	27.60	8.20	2.40	74.80	24.70	5.60	229.90	3718.00	0.80	433.00	38.50	3.30	1.00	1.20
		17-OZV-90	9.70	3.60	0.80	145.30	32.30	3.10	308.60	783.80	0.70	13.00	25.70	2.60	0.80	0.80
		17-OZV-102	20.70	1.20	0.60	46.40	19.50	5.40	407.20	1711.00	0.90	153.40	29.60	3.60	0.90	1.00
		17-OZV-103	13.60	3.00	2.20	80.10	19.70	1.80	453.90	2133.00	1.00	170.00	31.80	3.90	1.00	1.00
		17-OZV-106	27.90	14.30	36.60	53.90	31.90	0.60	85.30	769.40	1.40	132.10	226.30	3.30	0.80	6.60
		17-OZV-107	13.10	3.20	0.80	20.00	18.50	0.50	72.00	99.50	0.40	13.70	8.30	2.40	0.80	0.70
	III	17-OZV-57	13.00	5.40	1.20	112.70	17.60	5.20	189.30	4515.00	0.90	207.00	34.40	3.60	1.10	1.00
		17-OZV-81	22.90	6.00	1.20	48.10	17.90	4.50	276.00	3455.00	0.90	394.00	37.70	6.50	0.50	1.10
		17-OZV-84	10.80	5.30	1.00	58.60	16.40	4.10	342.70	2971.00	0.90	141.00	69.40	3.40	0.90	1.00
		17-OZV-100	31.10	2.30	1.40	63.00	13.40	0.70	424.20	3019.00	5.20	309.00	41.30	4.50	1.10	1.20
		17-OZV-13	43.90	56.00	7.20	145.80	17.20	6.20	278.90	566.20	19.50	277.20	21.50	3.80	1.80	1.00
		17-OZV-16	34.90	86.20	37.60	104.40	20.80	2.90	173.80	1255.00	23.70	567.00	36.90	5.00	1.20	1.00
		17-OZV-20	15.60	8.90	2.20	43.60	22.70	4.50	161.50	1792.00	47.70	639.00	169.50	4.90	1.10	1.00
		17-OZV-54	23.30	4.80	1.00	37.00	16.10	5.60	373.30	3931.00	3.60	223.00	21.10	4.00	1.10	1.10
		17-OZV-56	14.80	6.50	1.10	20.80	18.00	5.00	213.50	3763.00	0.90	260.00	29.30	4.00	1.10	1.10
		17-OZV-58	17.70	10.20	4.70	87.80	15.50	5.30	272.50	3130.00	4.90	175.00	37.00	4.00	1.00	1.00
		17-OZV-63	66.70	36.60	1.00	149.10	17.70	2.40	513.00	1205.00	5.80	79.30	66.10	3.70	0.90	0.90
		17-OZV-101	12.00	4.00	0.90	89.90	15.50	4.30	371.20	1771.00	0.90	186.00	42.60	3.80	1.00	1.00

Table 4- Trace element chemical analysis results of Özvatan syenites (continued).

Identification	Group	Element	Cs	Ba	La	Ce	Hf	Ta	W	Hg	Tl	Pb	Bi	Th	U
		Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Fresh Foid Syenite		17-OZV-11	3.70	409.10	278.50	406.10	2.20	3.40	241.80	1.70	2.30	37.10	1.30	112.30	30.00
Altered Foid Syenite	**I**	17-OZV-04	3.50	125.20	78.80	100.80	15.30	11.70	68.90	1.10	3.70	117.60	1.60	42.90	50.50
		17-OZV-05	6.40	69.40	93.20	115.10	20.40	13.00	35.20	0.90	3.20	71.80	0.80	101.20	41.80
		17-OZV-93	3.10	106.90	305.90	405.70	3.20	6.00	89.20	0.90	3.70	33.80	0.50	85.90	17.70
	II	17-OZV-06	4.10	1659.00	75.00	134.70	6.90	2.70	86.10	1.40	1.40	52.40	1.40	50.40	52.10
		17-OZV-07	12.40	838.20	177.60	333.90	3.90	4.50	21.60	1.20	1.70	31.70	0.90	50.80	33.60
		17-OZV-18	6.10	2307.00	243.80	338.50	2.80	4.00	152.00	1.60	4.70	68.10	1.30	99.90	34.40
		17-OZV-60	3.90	1527.00	126.30	214.60	5.10	4.40	99.80	1.20	2.50	25.60	1.40	115.90	58.60
		17-OZV-62	4.10	2138.00	112.30	187.10	3.20	3.80	143.20	2.20	2.10	22.60	0.70	96.10	63.10
		17-OZV-85	3.20	489.40	249.60	355.90	2.40	2.50	133.70	1.40	2.70	30.20	0.70	90.50	29.90
		17-OZV-90	2.70	27.70	28.80	40.10	1.40	1.80	80.00	1.10	4.20	23.50	0.50	16.80	12.20
		17-OZV-102	4.20	2382.00	80.70	123.70	2.20	4.20	157.40	1.40	3.70	50.60	0.70	14.00	8.20
		17-OZV-103	5.50	3599.00	102.80	161.20	2.20	2.40	104.50	1.30	4.70	40.50	1.10	79.90	16.80
		17-OZV-106	3.50	156.80	266.60	329.90	2.70	13.50	54.60	1.00	1.20	62.40	2.40	42.30	86.70
		17-OZV-107	6.00	157.30	27.60	32.20	1.50	4.10	422.50	1.80	1.50	5.00	0.50	3.60	12.50
	III	17-OZV-57	4.30	2943.00	103.50	165.00	2.90	2.50	33.40	1.20	1.70	32.30	1.20	65.60	21.20
		17-OZV-81	4.60	3310.00	107.70	191.40	6.50	4.10	60.10	1.50	3.50	28.30	0.40	95.80	21.00
		17-OZV-84	4.30	2509.00	102.80	176.20	2.50	2.40	72.20	1.20	1.50	40.00	1.90	73.80	22.90
		17-OZV-100	4.70	3262.00	346.40	465.90	2.70	5.50	105.50	1.50	3.50	39.00	0.90	82.20	9.70
		17-OZV-13	31.40	1862.00	77.20	169.10	9.50	3.70	30.80	1.00	1.00	24.50	0.70	37.20	8.80
		17-OZV-16	4.30	1787.00	99.60	222.70	9.60	4.20	24.60	1.10	0.50	22.90	0.70	29.80	58.90
		17-OZV-20	4.40	1982.00	430.80	594.90	9.00	2.40	113.30	1.40	2.10	50.60	1.10	145.90	64.30
		17-OZV-54	4.70	3860.00	342.20	568.50	2.80	2.40	29.40	1.10	2.20	28.20	0.90	142.70	15.40
		17-OZV-56	4.40	4293.00	201.30	305.50	2.80	2.60	55.30	1.10	2.40	31.20	0.80	89.10	10.20
		17-OZV-58	4.50	3454.00	273.30	432.00	2.60	2.80	148.00	1.60	2.60	26.20	1.30	139.30	44.00
		17-OZV-63	20.10	470.10	35.20	71.40	3.00	2.70	95.60	1.50	3.60	26.70	0.80	7.40	49.70
		17-OZV-101	4.40	2584.00	152.50	264.90	1.80	2.50	118.90	1.50	2.70	42.40	0.50	77.60	15.10

Table 5- Alteration indexes, calculate formulas and classification values used in this study.

Weathering Index	Abbreviation	Formula	Fresh value	Weathered value	I degree altered rocks	I degree altered rocks	III degree altered rocks	IV degree altered rocks
					This study			
Chemical Index of Alteration	CIA	$100[(Al_2O_3/Al_2O_3+CaO+Na_2O+K_2O)]$	≤50	100	50-55	55-78	65-78	>78
Chemical Index of Weathering	CIW	$100[(Al_2O_3/Al_2O_3+CaO+Na_2O)]$	≤50	100	50-65	65-88	88-96	>96
Plagioclase Index of Alteration	PIA	$100[(Al_2O_3-K_2O/Al_2O_3+CaO+Na_2O-K_2O)]$	≤50	100	50-55	55-80	80-95	>95
Ishikawa Alteration Index	AI	$100[K_2O+MgO)/(K_2O+MgO+Na_2O+CaO)]$	20-65	>60	60-65	65-75	75-87	>87
Chlorite-Carbonate-Pyrite Index	CCPI	$100[(MgO+FeO)/(MgO+FeO+Na_2O+K_2O)]$	15-85	>65	60-65	65-75	75-85	>85
Advanced Argillic Alteration Index	AAAI	$100[(SiO_2)/(SiO_2+10*MgO+10*CaO+10*Na_2O)]$	20-60	>60	60-65	65-70	70-80	>80
Sesquioxide Content Index	SOC	$Al_2O_3+Fe_2O_3$	-	-	20-25	25-30	30-40	>40
Leach factor	Lc	$SiO_2/(K_2O+Na_2O+CaO+MgO)$	-	-	1,5-2,5	2,5-5,0	5,0-7,5	>7,5
Residue factor	Rc	$(Al_2O_3+Fe_2O_3)/(K_2O+Na_2O+CaO+MgO)$	-	-	0,5-1,5	1,5-2,0	2,0-4,0	>4,0
Mobility Index	MI	$R_pR^i_w/R_wR^i_p$	-	-	-	-	-	-

rapidly alter compared to other minerals (Fiantis et al., 2010). For this reason, the PIA is used with the aim of finding an approach to weathering status of plagioclase minerals. The optimum weathering degree is 100 and considering fresh samples should have values lower than 50, the plagioclase minerals in syenites appear to be partly weathered (Tables 5 and 6).

The AI, CCPI and AAAI are associated with changes due to hydrothermal alteration (Ishikawa et al., 1976; Large et al., 2001; Williams and Davidson, 2004). The calculated AI values of the Özvatan foid syenites vary between 31 - 87 (Tables 5 and 6). This rate should be higher than 60 in the samples that underwent both mineralogical and chemical changes by undergoing hydrothermal alteration (Ishikawa et al., 1976). Accordingly, it was revealed that the Özvatan foid syenites were exposed to hydrothermal alteration and were heavily affected by these hydrothermal solutions. The CCPI values were 10 - 75 and AAAI values were 16-80 for the Özvatan foid syenites (Tables 5 - 6). Considering the CCPI values for altered rocks are >65 and AAAI values are >60, some samples appear to be above these limit values (Tables 5 and 6).

While calculating the SOC, major oxides such as Al_2O_3 and Fe_2O_3 with oxygen and metal ratio 3:2 are used. Due to the insoluble content of these major oxides, an increase in SOC value indicates excess leaching or intense oxidation resulting in enrichment of ferric iron due to oxidation of ferrous iron (Ng et al., 2001). The SOC values vary from 12 to 31 in weathered foid syenite samples (Tables 5 and 6). When compared with values for the fresh rock, some samples show high SOC values (Tables 5 and 6). A similar situation exists for Lc and Rc values (Tables 5 and 6). The Lc values were 1.6 - 7.4 and the Rc values were 0.5 - 4.0 on the weathered samples (Tables 5 and 6). In the light of all these assumptions, it was determined that rocks were significantly altered (Tables 5 and 6).

7. Discussion

Class I feldspars/feldspathoids for usage in ceramic production should have 9.00% K_2O content, 3.00% Na_2O amount, 10.00% total alkali (Na_2O + K_2O) and 0.10% Fe_2O_3 amount (TSE 11325, 1994). When the mineral chemistry results for feldspars are examined, % K_2O and total alkali content are much above the estimated limit values and iron content appears to

Table 6- Calculated alteration indexes of Özvatan syenites (abbreviations are given in Table 5).

Identification	Group	Element	CIA	CIW	PIA	AI	CCPI	AAAI	SOC	Lc	Rc
Fresh Foid Syenite		17-OZV-11	50.58	63.08	50.95	40.16	11.07	29.38	25.66	2.49	1.13
Altered Foid Syenite	**I**	17-OZV-04	75.01	94.68	92.78	83.94	40.04	73.44	31.08	5.78	3.34
		17-OZV-05	78.24	96.38	95.29	87.11	42.46	80.96	30.01	7.44	4.00
		17-OZV-93	65.50	88.11	81.84	74.78	17.60	59.48	27.59	3.93	2.02
	II	17-OZV-06	57.54	76.90	65.18	65.38	50.68	35.43	26.32	2.72	1.52
		17-OZV-07	52.10	77.27	56.01	82.75	75.18	23.82	27.15	1.98	1.24
		17-OZV-18	55.26	71.12	59.50	50.22	13.02	37.76	24.22	3.07	1.33
		17-OZV-60	62.37	83.91	75.43	68.74	18.26	51.00	26.62	3.42	1.76
		17-OZV-62	58.21	79.09	67.39	63.73	21.20	47.87	24.19	3.47	1.52
		17-OZV-85	53.96	70.87	57.58	52.58	16.69	37.83	23.79	2.98	1.28
		17-OZV-90	61.74	88.70	79.95	79.66	17.69	63.60	26.38	3.73	1.76
		17-OZV-102	60.52	88.49	78.60	80.19	10.23	63.92	25.01	3.62	1.61
		17-OZV-103	59.71	85.11	74.08	74.28	19.62	56.84	25.98	3.50	1.64
		17-OZV-106	64.12	73.54	68.98	39.25	26.00	42.68	23.92	4.94	1.88
		17-OZV-107	51.91	65.74	53.30	45.46	10.95	54.65	12.65	6.94	1.12
	III	17-OZV-57	47.35	58.32	45.75	36.03	26.04	22.53	22.95	1.87	1.02
		17-OZV-81	49.87	65.89	49.75	48.74	15.04	30.82	22.25	2.31	1.07
		17-OZV-84	46.06	56.21	43.83	34.00	20.08	20.90	21.90	1.76	0.92
		17-OZV-100	49.03	65.81	48.01	50.40	25.49	29.52	24.42	2.11	1.12
		17-OZV-13	49.02	61.88	48.32	56.52	66.33	24.53	22.45	2.28	1.10
		17-OZV-16	36.68	43.83	30.22	44.62	71.04	16.44	19.21	1.59	0.72
		17-OZV-20	29.19	38.18	10.68	33.43	23.44	24.79	12.65	2.20	0.51
		17-OZV-54	44.35	53.38	41.46	31.60	31.00	19.65	21.56	1.71	0.90
		17-OZV-56	44.86	54.67	41.98	32.85	19.38	20.49	21.25	1.74	0.88
		17-OZV-58	52.31	71.40	54.96	57.42	27.73	38.17	22.55	2.82	1.24
		17-OZV-63	49.57	72.64	48.82	70.96	56.97	31.40	24.68	2.32	1.21
		17-OZV-101	47.91	65.25	45.53	51.33	33.63	36.29	22.34	2.81	1.17

be far below the desired limit value (Table 3). When mineral chemistry is investigated, the feldspathic minerals in the region may have class I feldspar features and can be said to be very appropriate raw materials for the ceramic industry (Tables 1 and 2). The K_2O, Na_2O and total alkali contents of nepheline minerals within the rock are much above the estimated values and appear to be higher quality raw materials compared to feldspar minerals (Tables 1 and 2). Alkali element contents determine and affect the usage area of feldspathic (feldspar and feldspathoid) raw materials in the glass and ceramic industries (Lewicka, 2010). For example, feldspathic raw materials to be used for glass and ceramic tile production need to have Na_2O content higher than 7%, for use in the production of white ceramic goods, K_2O amount should be larger than 10%, while colourizing oxides like Fe_2O_3 and TiO_2 should have low values such as 0.15% and 0.05%, respectively (Lewicka, 2010). Accordingly, it is understood from the analysis results that the nepheline minerals in the Özvatan foid syenites are appropriate for both glass and ceramic tile production and white ceramic goods production. However, it is necessary to investigate secondary formations like sericite, kaolinite, and illite within these rocks.

On the MFW diagram, M represents the mafic source, F is the felsic source and W is the altered/

weathered products (Ohta and Arai, 2007). When the plot of the Özvatan foid syenite samples on the MFW diagram is examined, it appears they plot outside the area for fresh magmatic rock (Figure 5a) (Ohta and Arai, 2007). The majority of samples plot in the Fe-saponite and nontronite (smectite) fields on the MFW diagram with some close to the montmorillonite field and some close to the illite field (Figure 5b). There may be a transformation of mafic minerals within the rock (amphibole, pyroxene and biotite) into Fe-

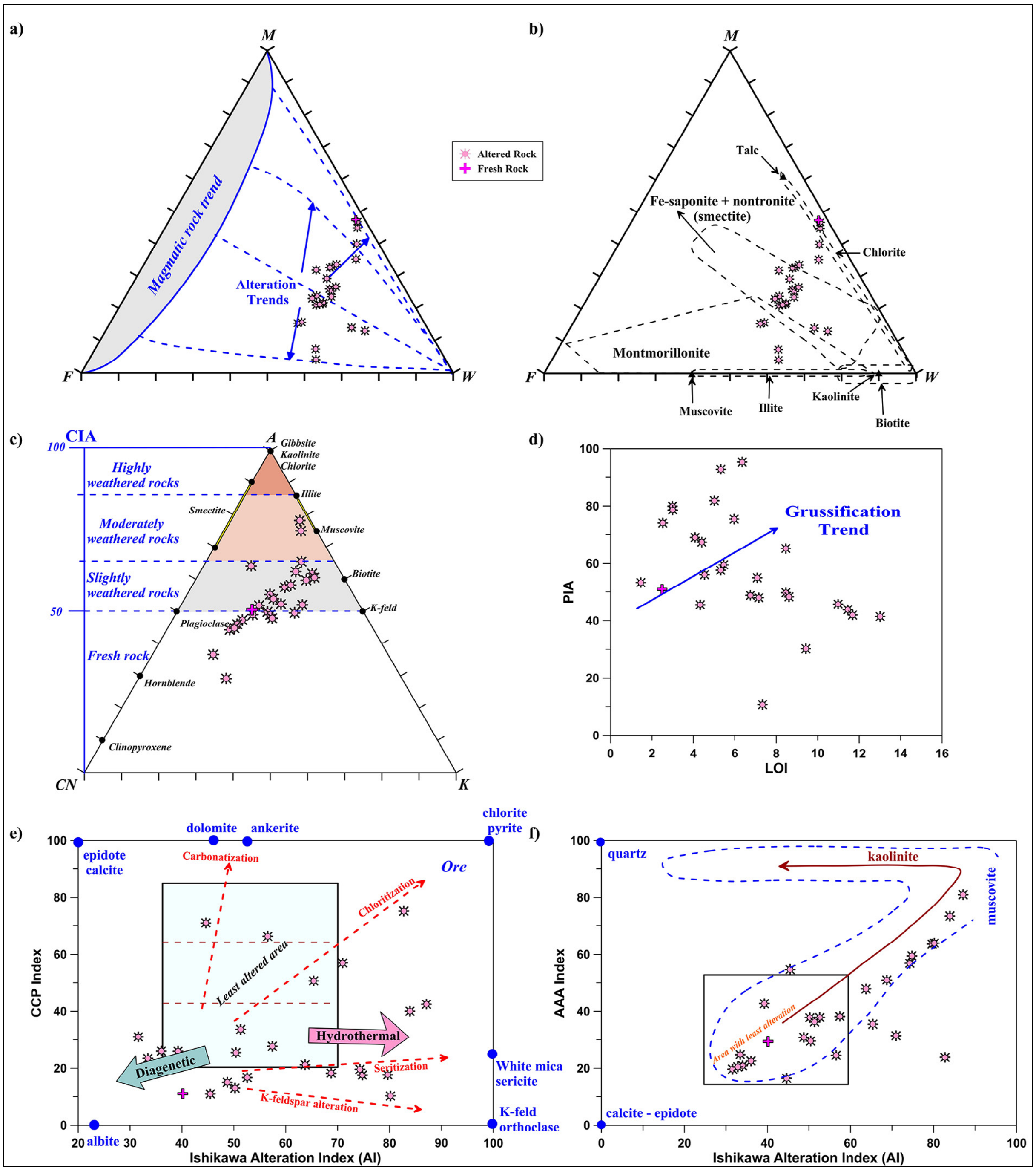

Figure 5- Özvatan foid syenites; a), b) plots on MFW pyramid diagram (Ohta and Arai, 2007), c) plot on ACNK diagram and classification according to CIA (Nesbitt and Young, 1982), d) variation diagram for PIA against LOI values (Fedo et al., 1995), e) plot on variation diagram for CCPI against AI (Large et al., 2001; Mathieu, 2018), f) plot on variation diagram of AAAI against AI (Williams and Davidson, 2004).

saponite and nontronite (smectite). Sericite and illite transformation of K-feldspar minerals may be present. Due to weathering of minerals within the rock, changes occur in the colour of the rock. While light dirty white and greyish colours in the rock are mostly due to clay minerals like kaolinite formed as a result of weathering in the feldspathic minerals, pinkish colours can be associated with iron hydroxide (limonite) minerals.

The $CaO + Na_2O$ - Al_2O_3 - K_2O (CNAK) triangle classification diagram was used with chemical components to determine the degree of weathering and alteration of foid syenite samples in the study area (Figure 5c). On the CNAK diagram, the Özvatan foid syenites plot in three different areas of unweathered (fresh rock), slightly weathered (partly altered rock) and moderately weathered (moderately altered rock) (Figure 5c). The correlation between the increase in LOI values and PIA for the rocks displays regular variation (Figure 5d).

In order to reveal whether the alteration is due to the effect of surface conditions or the effect of deep solutions, the AI versus the CCPI was drawn (Large et al., 2001). It was observed that the Özvatan foid syenites were altered mostly by the effect of hydrothermal solutions (Figure 5e). The samples degraded with the effect of hydrothermal alteration show trends toward orthoclase and sericite points on the diagram indicating sericitization of K-feldspars (Figure 5e). Against AI, it can be stated in the AAAI variation diagram that the degree of alteration of the rocks is variable and has a trend toward muscovite formations to argillisation (Figure 5f) (Williams and Davidson 2004).

According to the CNAK diagram, syenites can be divided into three groups and the degrees of alteration for these groups were determined and interpretations were made. Accordingly, the stages/degrees I, II and III were used for unweathered (fresh rock), slightly weathered (rock with a mild degree of alteration) and moderately weathered (rocks with a moderate degree of alteration), respectively (for definitions of weathering stages/degrees see GCO 1988). Moving from the degree I to III, alteration and weathering increase. The CIA, CIW, PIA, AI, AAAI, SOC, Lc and Rc values increase with the alteration from the degree I to III, while the LOI values reduce and the CCPI values display a similar relationship (Figure 6). With

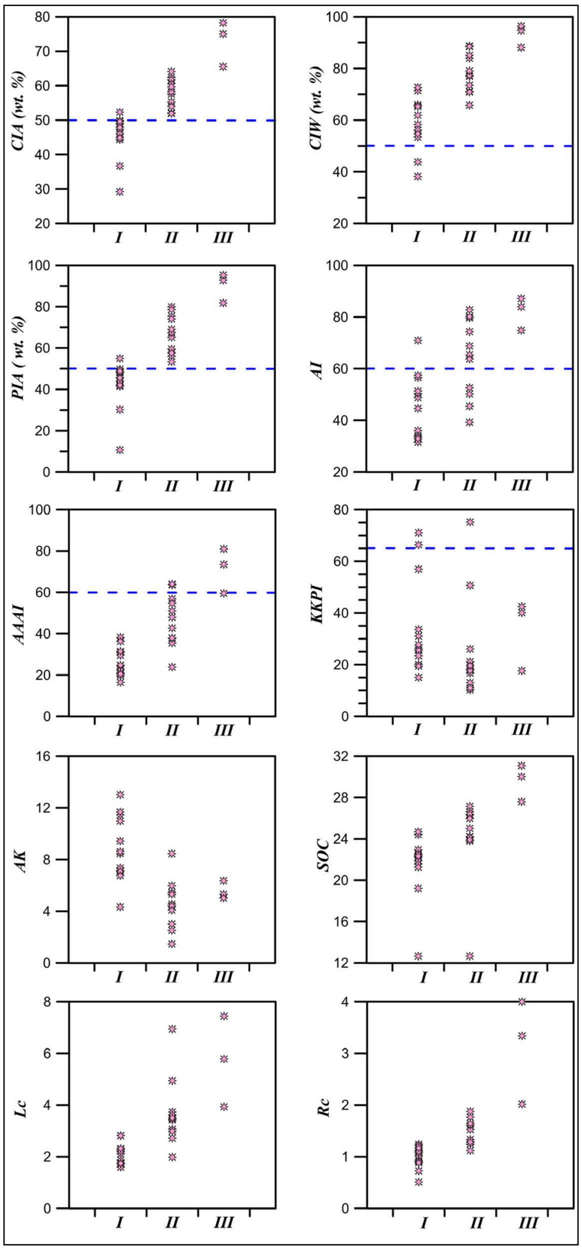

Figure 6- Variation diagrams for degree of alteration of altered Özvatan foid syenites against some alteration indexes (CIA: chemical index of alteration, CIW: chemical index of weathering, PIA: plagioclase index of alteration, AI: Ishikawa alteration index, AAAI: advanced argillic alteration index, CCPI: chlorite-carbonate-pyrite index, LOI: loss on ignition, SOC: sesquioxide content index, L_C: leach factor, R_C: residue factor).

weathering, the proportions of sericite, kaolinite and illite are determined with XRD increase which allows these alteration degrees to be determined.

In order to better understand weathering processes and to find an approach to element mobility, the MI was calculated (Ng et al., 2000, 2001).

$$R_pR^i_w/R_wR^i_p \quad (1)$$

In the equation, R_p is the percentage of stable components in major (fresh) rock, R^i_p is the percentage of unstable components (i) in the major (fresh) rock, Rw is the percentage of stable components in the altered rock and R^i_w is the percentage of unstable components in the altered rock (Ng et al., 2000, 2001).

In the calculations, MgO is taken as a stable component, and the mobility of Na_2O, K_2O, Al_2O_3, SiO_2, CaO, Fe_2O_3 and LOI values are investigated. For each alteration degree, the mean values for MI, major oxides and LOI were taken and the diagram of MI against alteration degree was drawn (Figure 7). As the amount of the component increases, the gain or loss proportions (X_{gp}) are positive and MI>1; contrary to this as the amount of component reduces the X_{gp} value is negative and MI<1 (Ng et al., 2001). According to the diagram of MI against alteration (weathering) degree, Na_2O, K_2O, Al_2O_3, SiO_2, CaO, Fe_2O_3 and LOI had MI values lower than 1 (Figure 7). For the Özvatan foid syenites, the K_2O, Al_2O_3, SiO_2 and Fe_2O_3 amounts show a similar relationship during weathering processes, with a severe reduction from fresh rock to degree I alteration and then a slight reduction moving toward degree III alteration (Figure 7). This situation can be associated with the formation of kaolin. The increase in Fe_2O_3 amounts moving from degree II to degree III is related to the oxidation of FeO and transformation to Fe_2O_3 during alteration. The CaO amount shows a clear reduction moving from degree I to degree III alteration (Figure 7).On the other hand, LOI values reduce as the degree of alteration increases. While the opposite situation is expected to be observed in felsic intrusive rocks, this situation in magmatic rocks including foid may be associated with the presence of volatile components like excess halogen elements within feldspathoid minerals. The amount of Na_2O shows an irregular correlation from the fresh rock to the altered rock. The amount of K_2O, Al_2O_3, and SiO_2 reduces with the alteration of feldspar minerals. This reduction must have occured mainly by the separation of illite and [$K_{0.65}Al_{2.0}(Al_{0.65}Si_{3.35}O_{10})(OH)_2$] and kaolinite [$Al_2(Si_2O_5)(OH)_4$] from the feldspars.

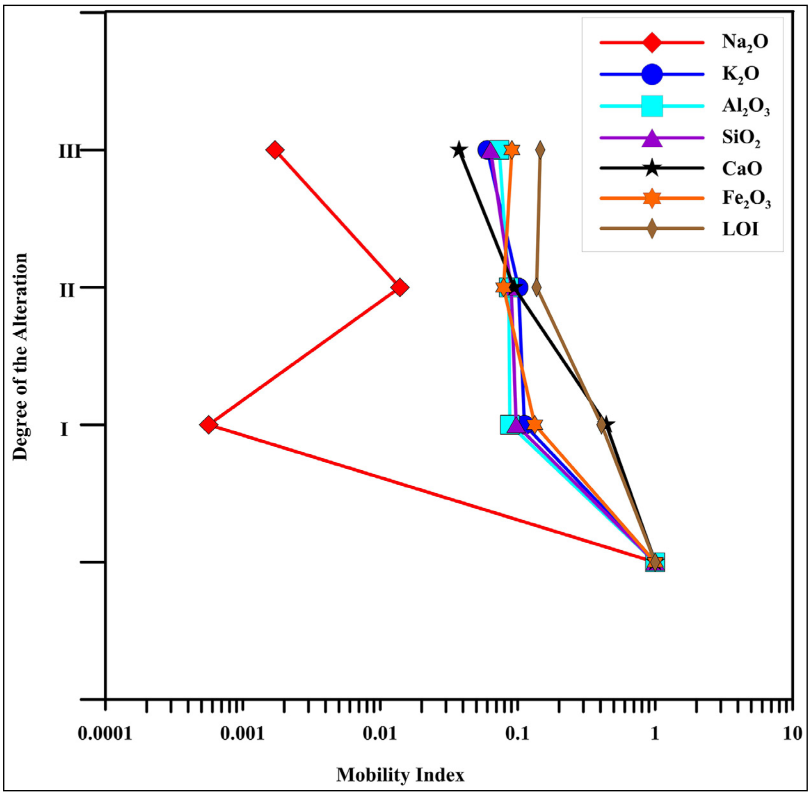

Figure 7- Diagram showing variation in mobility index (MI) values for major oxide elements and loss on ignition values for altered Özvatan foid syenites linked to degree of alteration (Ng et al., 2001).

Feldspathic minerals are chosen in the ceramic production due to high Na and K content. The raw material used in all ceramic operations is chosen by direct examination of chemical composition. For this reason, the quality of the raw material is determined by looking at the total Na and K content rather than mineralogy of the analysed material. Thus, all minerals containing K within the rock contribute to this calculation. Muscovite and sericite minerals which are formed as a result of the alteration, are poor in iron and rich in K so they contribute to this proportion and increase the K content ratio of the raw material. However, these minerals negatively affect the impurity of feldspathic minerals. For this reason, ceramic raw material processing stages should be planned by determining the mineralogical, alteration type and rates of the raw material in detail. Mathieu (2018), in his study for the determination of hydrothermal alteration, stated that Ca and Na reduced with sericitization whereas K increased or decreased (Equations 2 and 3). Due to the effect of this fluid with low temperature, sericite mineral formation is more common than muscovite. Sericite and muscovite are found in such igneous rocks as weathering products. Both muscovite and sericite contain K so they cause an increase in the K content in whole rock analyses as well as feldspathic minerals.

$3KAlSi_3O_8$ (Orthoclase) + $2H^+$ (Fluid) <==> $KAl_3Si_3O10(OH)_2$ (Sericite) + $2K^+$ (Fluid) + $6SiO_2$ (Quartz) (2)

$4(Na,K)AlSi_3O_8$ (Alkali Feldspar) + $2H^+$ (Fluid) <==> $NaAlSi_3O8$ (Albite) + $KAl_3Si_3O10(OH)_2$ (Sericite) + $6SiO_2$ (Quartz) + $2Na^+$ (Fluid) (3)

As shown in the equations, K elements released from feldspathic minerals as a result of alteration cause sericite and additionally kaolinite formation according to XRD results. Some of the released Na becomes albite while some remains free and is removed and may form evaporate minerals (halite and globerite) in evaporitic environments. For this reason, the abundance of ions in free form occurring with alteration of feldspathic minerals and physicochemical conditions cause formation of appropriate evaporitic rocks. This situation provides an important contribution to form Tuzla lake located in the study area.

In the diagram drawn by using K_2O and Na_2O in order to approach the Özvatan foid syenites as raw materials, it is seen that the alkali oxide values are desired for the raw materials (Figure 8).

Feldspathic minerals are used as a melter in the ceramic industry and lower the melting point when compared to other ceramic raw materials (Gürsoy, 1999). Due to strong fluxing features, Na-rich feldspars or Na-rich feldspathoid minerals are more preferred in modern rapid-firing technologies and glazes (Gürsoy, 1999; Levin et al., 1969; Ehlers, 1972; Lewicka, 2010). Considering the results of geochemical analysis, the amount of Na_2O severely reduces with alteration (Table 3). It has been determined that the lack of observation of fresh mineral or mineralization linked to Na values in the region indicates it may have leached and been removed from the environment. With the reduction of the Na content of the rock or minerals, it will increase the melting temperature of raw material during ceramic production, in this case, it will cause slow melting and reduce work efficiency and increase the amounts of fuel (Harben and Kuzvart, 1997; Abouzeid and Negm, 2014). Feldspars with high Na amount have lower viscosity and glazing temperature compared to feldspars with high potassium (K) and are more predisposed to shrinkage during firing (Ryan, 1978; Köprülü, 1997; Tayçu, 2009). Therefore, in the glazing phase, products with Na content are more preferred compared to minerals containing K.

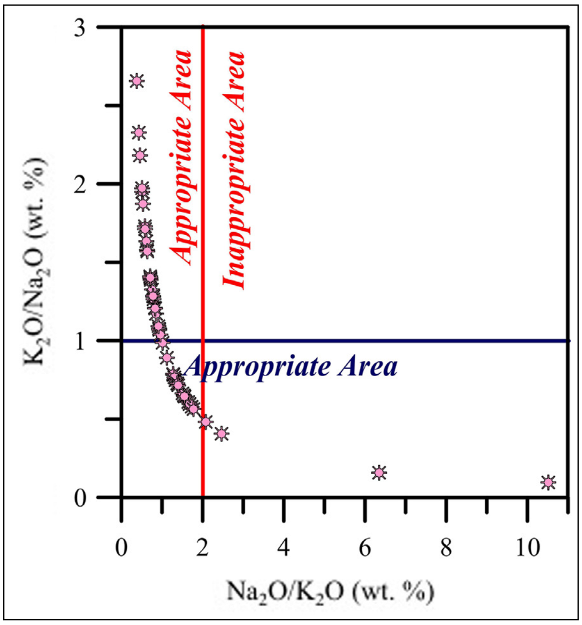

Figure 8- Variation diagram for Na_2O/K_2O against K_2O/Na_2O for altered Özvatan foid syenites (wt. : weight, Deniz and Kadıoğlu, 2018).

In this context, it has been revealed that the fresh samples of Özvatan syenites were determined to enter the more useful rock group for the glazing stage, while altered samples are more useful for the major ceramic paste. With the use of K-rich feldspars a melt with high viscosity will be formed and its resistance against deformations (cracking, etc.) that may occur during firing will increase. Since the plagioclase minerals found at very low rates in the rock have very close softening and melting degrees, and may cause deformation during firing, it will be more appropriate to use them in glaze production. Additionally, crushing and grinding stages in processing before they are offered for sale will facilitate the use of sections of the Özvatan foid syenite with excess arenisation as raw material. This is because the feldspar to be used in ceramic paste must be grinded very well to increase the melting ability and to ensure better mixing with other components (Gürsoy, 1999). For this reason, reducing the processing stages of the rock that has weathered in a certain grain size will save both time and money.

8. Results

Due to the distinctive diaclase structure and highly fractured in terms of structural elements in the region, it was determined that the Özvatan foid syenite were altered at different rates. According to the field and laboratory results obtained, as the degree of alteration of the Özvatan foid syenites increased, the transformation rates of feldspathic minerals to sericite and kaolin minerals increased. According to the whole-rock geochemistry and mineral chemistry results, the percentage of Na_2O in the rock has reduced significantly as a result of weathering processes. This situation occurred in association with the loss of alkali components from feldspar and feldspathoid minerals especially as a result of weathering and alteration due to atmospheric effects (air), and surface waters and hydrothermal solution and their transformation into sericite and kaolinite minerals. Mineralogical and geochemical data shows that the alteration of the rock due to both the effect of weathering and hydrothermal conditions is clearly observed. The K and Na (alkali) elements emerging with weathering of the Özvatan syenites appear to provide an important contribution to new mineral formations (kaolinite and sericite) and evaporitic mineralisation by transported elements (Na).

The excess diaclase structures in the rock provide convenience for processing, while they affect the chemical composition of feldspar and feldspathoid minerals in the rock. The variation in element ratios in the rock and minerals with alteration will play an effective role in determining the area of use for feldspar and feldspathoid minerals. Minerals such as sericite and muscovite may cause impurities by forming small inclusions in feldspathic minerals which are insidious contaminants in raw materials. It is necessary to remove these minerals from the product with the flotation method. The excess presence of iron or oxide minerals in the form of inclusions may provide an advantage for the flotation (metal oxide flotation) and magnetic separator stages. Due to the release of very small size color-giving impurities contained, the Özvatan altered foid syenite does not represent high-quality ceramic raw material in terms of both yield and concentration quality.

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