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Borehole Geology and Alteration Mineralogy of Well Bayatcık-1, Bayatcık Geothermal Area, Afyonkarahisar

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Abstract

Bayatçık geothermal field is located 7 km northwest of the Afyonkarahisar. The aim of this study is to determine the borehole geology and hydrothermal alteration mineralogy of Bayatçik-1 well, was drilled in 2013. The well is 925 meters deep. The types of rock that were encountered in this well were alluvium, volcanic and sedimentary sections of the Köprülü volcanosedimanter sequence, basal conglomerate, marble and schist sections. The cover rocks of the geothermal system consisting of volcanic and sedimentary rocks were drilled in the first 528m. Basal conglomerate was observed in 528-558 m level. Marble unit (Mrb1), which is the reservoir rock of the geothermal system at depths of 558-574 m, micaschist (Sch1) between 574-622 m, marble-2 between 622-746 m (Mrb2), micaschist-2 (Sch2) between 746-830 m, marble-3 between 830-890 m (Mrb3) and finally at depths of 890-920 m is a schist unit which acts as the impermeable basement rock of the system. The analyzes such as stereo and polarizing light microscope, x-ray diffractometer (XRD) and scanning electron microscope (SEM) were applied to the clastic samples taken at 2m intervals from Bayatçik-1 well. The result of the study is aimed to reveal the development of the geothermal system in the Bayatcık region by the differences in the hydrothermal alteration mineralogy of the samples. In the study, mineralogical-petrographical data were obtained with the presence of smectite, illite and kaolinite minerals formed at a temperature lower than 200°C.

Keywords
Alteration mineralogy; Borehole geology; Geothermal; Bayatçık; Afyonkarahisar

Bayatcık Jeotermal Sahasında (Afyonkarahisar) Yer Alan Bayatcık-1 Kuyusunun Jeolojisi ve Alterasyon Mineralojisi

Öz

Bayatçık jeotermal sahası Afyonkarahisar ilinin 7 km kuzeybatısında yer almaktadır. Bu çalışmanın amacı 2013 yılında açılan Bayatçik-1 kuyusunun kuyu içi jeolojisi ve hidrotermal alterasyon mineralojisini belirlemektir. 925 metre derinliğindeki sondaj boyunca; Köprülü volkanosedimanter istifinin alüvyon, volkanik ve sedimanter kısımları ile taban konglomerası, mermer ve şist birimleri kesilmiştir. İlk 528 m'de jeotermal sistemin örtü kayaları olan volkanik ve sedimanter kayalar, 528-558 m'lerde taban konglomerası, 558-574 m derinlikte Jeotermal sistemin rezervuar kayası olan mermer (Mrb1), 574-622 m arasında mikasşist (Sch1), 622-746 m arasında mermer-2 (Mrb2), 746-830 m arasında mikaşist-2 (Sch2), 830-890 m arasında mermer-3 (Mrb3) ve son olarak 890-920 m derinliklerde sistemin geçirimsiz temel kayası olan şist birimleri geçilmiştir. Bayatcık-1 kuyusundan 2m aralıklarla alınan klastik örneklere stereo ve polarize mikroskop, x-ışını difraktometre (XRD) ve tarama elektron mikroskobu (SEM) gibi analizler uygulanarak, Bayatcık bölgesindeki jeotermal sistemin gelişimini örneklerin hidrotermal alterasyon mineralojisindeki farklılıklar ile ortaya koymak amaçlanmıştır. Çalışmada 200°C'den düşük sıcaklıkta oluşan simektit, illit ve kaolinit minerallerinin varlığıyla ilgili mineralojik-petrografik verilere ulaşılmıştır.

Anahtar kelimeler
Alterasyon mineralojisi; Kuyu jeolojisi; Jeotermal; Bayatcık; Afyonkarahisar

1. Introduction

Hydrothermal alteration areas are the most important surface signatures of geothermal sources such as fumerols, hot springs and heated areas; they act as the windows of geothermal systems located deep in the earth. The water-rock interaction in geothermal areas changes mineralogical, geochemical, and physical properties of rocks, this is known as hydrothermal alteration. (Henley ve Ellis, 1983; Velde, 1995; Lagat, 2010). Mineralogical changes caused by hydrothermal alteration are very important for the exploration and development of geothermal systems.

Turkey is located on the Alpine-Himalayan geothermal belt and has high geothermal potential. Our country's total geothermal heat capacity (apparent heat amount) has reached 35,500 MWt and total geothermal heat capacity (usable heat amount) has reached 5.000 MWt at the end of 2018 (İnt.Kyn.1). There are around 1000 hot springs and natural mineral water springs in Turkey, where the effects of young tectonism and volcanism are observed intensively. 170 of these water sources have 40°C or higher temperature. 79% of these resources are in Western Anatolia (Denizli, Aydın, İzmir, Çanakkale, Afyonkarahisar, Kütahya etc.), 8.5% in Central Anatolia, 7.5% in Marmara Region, 4.5% Eastern Anatolia and 0.5% in other regions. Most of the geothermal resources in Afyonkarahisar province are located in the Akarçay Basin, Ömer-Gecek, Gazlıgöl, Hüdai, Heybeli and the İscehisar-Susuz regions are the most important geothermal areas in the region (Yıldız et al. 2014). The Bayatçık geothermal area is located on Afyonkarahisar-Eskişehir highway, 8km north of Afyonkarahisar. The thermal waters have Na-Ca-HCO_3-Cl type and have 65°C temperature (Duysak, 2019). 10 wells have been drilled in the region, 8 of them are used as production, and 2 of them are used as reinjection wells. The aim of this study is to determine the borehole geology and hydrothermal alteration mineralogy of Bayatçık-1 geothermal well, which was drilled in 2013 with a depth of 925m.

2. Geology

2.1 Geology of study area

Paleozoic Afyon metamorphics are the basement rocks of the study area. This formation consists of Bayramgazi schists and Oyuklutepe marbles. Middle-Upper Miocene aged Ömer-Gecek formation unconformably overlies the basement rocks. The unit is composed of Başçakmaktepe conglomerate and Köprülü volcano-sedimentary sequence. Middle-Upper Miocene aged Seydiler tuff and agglomerate shows lateral and vertical transitions with Ömer-Gecek formation. The Upper Miocene Kocatepe trachyte is the last product of the volcanism. Quaternary alluvial deposits are the youngest units in the study area (Metin et al., 1987; Ulutürk, 2009; Yıldız et al., 2014) (Figure 1).

Bayramgazi schists comprise albite-chlorite-muscovite-biotite-quartzschist, calcschistand quartzites are also observed in cracks. Mineral paragenesis of low grade greenschist facies was determined in this unit. Oyuklutepe marbles occur stragraphically the upper section of Afyon metamorphics. and display violet, sugar and gray colored textures (Metin et al., 1987; Öktü et al., 1996; Kibici et al., 2001; Ulutürk, 2009; Yıldız et al., 2010; Yıldız et al., 2011), (Figure 1).

The Başçakmaktepe conglomerate unit of Ömer-Gecek formation, has dark yellow, reddish color, and thick bedded, contains sedimentary structures such as cross-bedding, hollow-fill and channel structures, drying cracks, and traces of currents. The Köprülü volcano-sedimentary (KVS) sequence includes volcanic intercalations of lava and pyroclastic type and epiclastic sediments. In the upper sections of these unit, clayey limestones, tuff, ash discharge, and opalite silica layers are observed. The Upper Miocene Erkmen volcanics are the final product of volcanism in the region. This unit consists of agglomerated pyroclastics and lava flows and formed during pre-caldera activities during the physical development process of the Afyon stratovolcano. Pyroclastics are generally gray, dark gray colored, and contain trachytic, trachyandesitic blocks and lithic fragments. The another unit of Erkmen volcanics are trachyte and trachyandesite lavas. The unit forms the highest elevations in the region in the form of dome structures, it is characterized by gray, dark gray, and brownish. Quaternary travertine and alluvium are the youngest units in the study area.

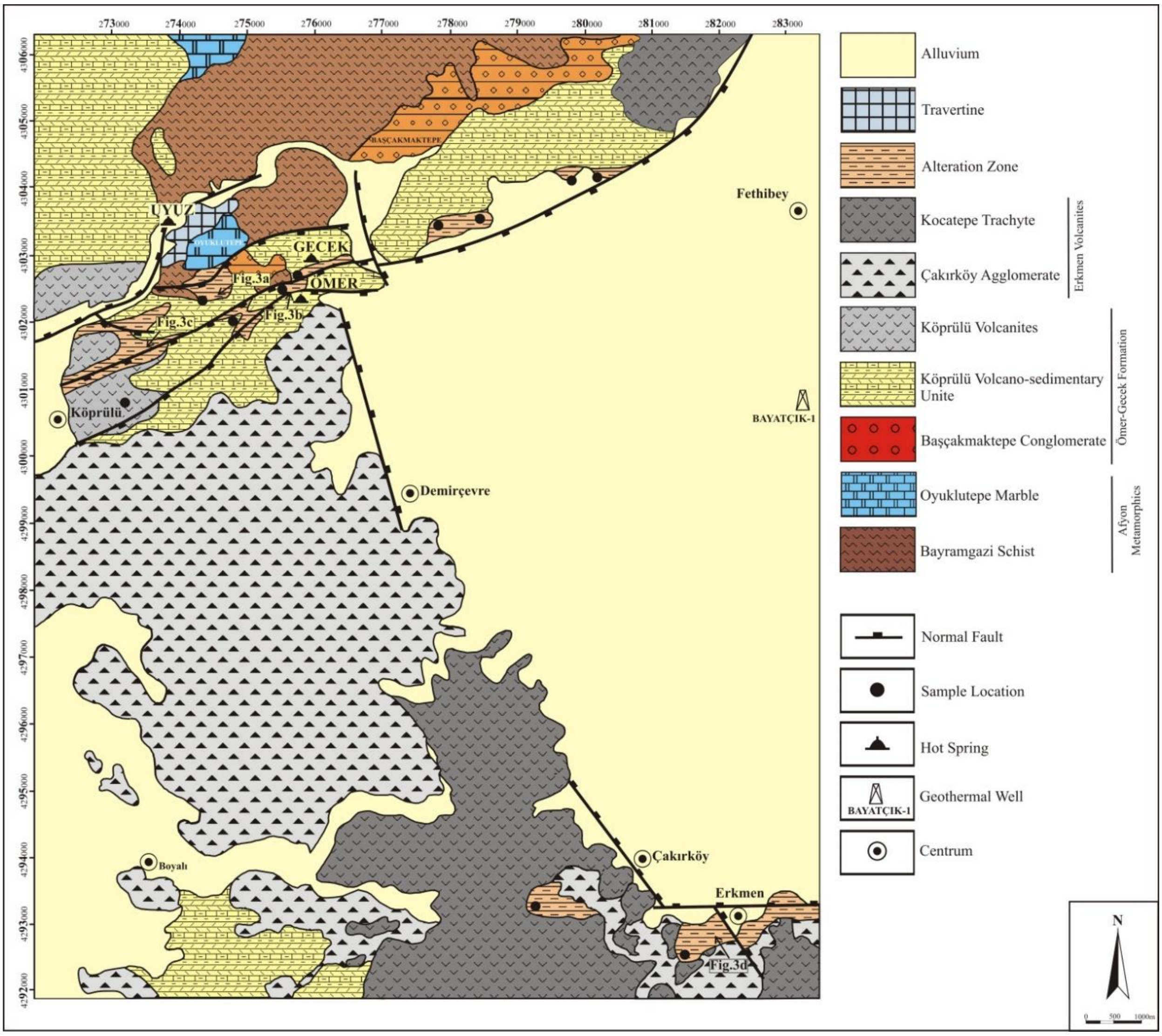

Figure 1. The geology map of study area (Ulutürk, 2009; Yıldız et al., 2011).

2.2 Borehole Geology

The well Bayatçik-1 is located 7 km northwest of the Afyonkarahisar city center. The coordinates (ED50 system) of well are: X = 283315 and Y = 4300156 and Z = 1012m. The well was drilled in 2013 by Afyon Geothermal Facilities Tourism, Industry and Trade Inc. (AFJET), is 925 m in depth and a temperature of 65°C. The types of rocks that were encountered in this well were alluvium, volcanic and sedimentary units from the Köprülü volcano-sedimentary (KVS) sequence, basal conglomerate, marble and schists. The lithological description of rocks is based on binocular observations. The columnar section of Bayatçık-1 well is shown in Figure 2.

Alluvium was drilled in the first 102 m of the well. Volcanic and sedimentary units of the Köprülü volcano-sedimentary (KVS) sequence appear at depths of 102-526 m. There are pyroclastics and lavas in 102-134 m (Pr1), 146-150 m (Pr2), 164-178 m (Pr3), 202-208 m (Pr4), 244-278 m (Pr5-Pr7), 290-300 m (Pr8).), 331-336 m (Pr9), 352-366 m (Pr10), 368-410m (Lv1; Pr11; Lv2; Pr12), 424-466m (Lv3; Pr13). Pyroclastic rocks have trachy andesite composition, are glassy in texture and consists of sanidine, plagioclase, biotite and hornblende phenocrystals.

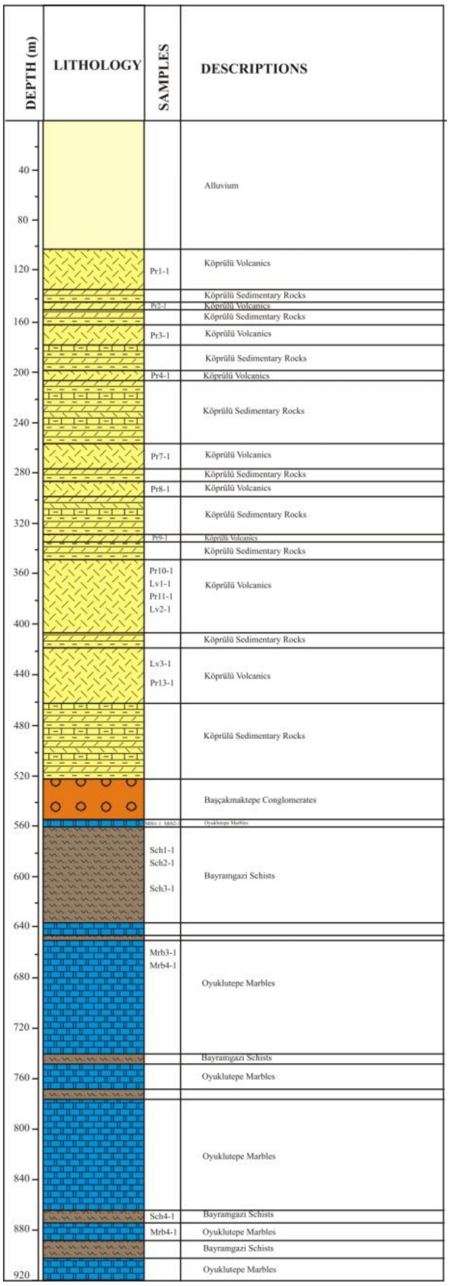

Figure 2. The borehole geology of Bayatçik-1 well.

The fresh surface of this unit are gray and the altered surface have light gray to yellowish gray color. The alteration occurs in the matrix and the feldspars of the rock. Lava have dark gray color and contain intense cooling spaces, they are composed of plagioclase, sanidine, mica and hornblende minerals. As a result of alteration, the color of hornblende changed to light gray and milky brown.

The sedimentary sequence of KVS were drilled at 136-144 m (Sd1), 152-162 m (Sd2), 180-200 m (Vs1), 210-242 m (Vs2), 280-288 m (Vs3), 302-330 m (Vs4), 338-350 m (Vs5), 412-420 m (Vs6), 412-422 m (Vs6) and 468-526 m (Vs7). Sd coded levels sections are dominated by cream colored marl, otherwise the Vs coded levels are volcanic rock, marl, and clay type sedimentary rock. The red colored basal conglomerate (Tk) is found between 528 and 560m and separates the covered and reservoir rocks.

Afyon metamorphics, comprise marble and schist intercalation, were drilled at 560-920 meters. Marbles are generally gray, light gray, cream and light yellow colors. Calcite and dolomite are the main minerals in the marbles and they contain small amounts of muscovite minerals. At the altered marbles, the crystallized texture is changed and the color is lightened. Secondary iron minerals, hematite and limonite, were also formed along the crystal boundaries and cracks. The marble were observed at 560-564 m (Mrb1; Mrb2), 642-744 m (Mrb3; Mrb4), 754-772 m, 830-866 m, 880-890 m (Mrb5) levels. The thickness of marbles vary between 2-84 m.

The Bayramgazi schists contain muscovite-schist calc-schist and show gradual transitions to marble. The schists are mostly composed of feldspar, quartz, muscovite, and small amounts of calcite and dolomite minerals. The secondary iron minerals (probably hematite) formed due to alteration along the fracture and schistosity planes. The schists were found at 564-640 m (Sch1; Sch2, Sch3), 746-780 m, 770-786 m (Sch4) and 894-904 m.

2.3 Geological Properties of Geothermal System in Bayatcık Area

The Bayatcık geothermal field in the Akarçay basin was formed due to the effect of the extensional tectonics of Western Anatolia. The Afyonkarahisar region is located on a second degree earthquake zone. There is also the active Erkmen (Demirçevre) and Gecek faults of Afyon-Akşehir graben system observed in the area.

The Paleozoic Oyuklutepe marble is the reservoir rock of geothermal system, the impermeable units of volcano-sedimentary units are cover rocks and Bayramgazi schists are impermeable basement rocks. The recharge involves surface and underground waters infiltrating the basin. The geothermal fluid ascends to the productive aquifers through the major faults and ascend to the surfave via by Afyon-Akşehir Graben faults after being heated at greater depth.

According to the geothermal model; meteoric waters falling on to the high elevation areas of the Ömer-Gecek region percolate into the reservoir rocks along faults and fracture zones, they are then heated at depth, ascend to the surface by convection. Some of the waters, which are Na-Cl type due to deep circulation and high temperature, are obtained by drilling in the Ömer-Gecek region. Some of the waters also circulate towards the southeast, along the crack-fault zones, where it becomes enriched in Ca and HCO_3 due to a possible mixture-cooling effect, and are finally observed the in Bayatcık region (Duysak, 2019).

3. Methods

Drill cutting samples from well Bayatçık-1 were collected at every 2 m interval during the drilling operations. The wet cuttings from the rig site were washed to remove dust particles and later dried in electric ovens at 60 ± 5°C, archived and stored in clearly labelled containers with lids.

In order to reveal the alteration degree, alteration type, abundance of alteration minerals, and bedrock relationships with the lithological descriptions of the samples, stereo microscope studies were carried out using Leica DM300 digital microscope at Afyon Kocatepe University Department of Geological Engineering. Mineralogical properties of the altered samples were determined by using a stereo microscope and an X-ray diffractometer (XRD). XRD analysis were carried out on bulk samples and clay fraction. The bulk mineralogy conducted on -250µm grain size samples.

The clay mineralogy was determined by studying <2 mm particles. After dispersing the samples in distilled water overnight, the <2 mm size fraction was separated by sedimentation and subsequent centrifugation. Oriented samples were prepared from the clay fraction spread on glass slides and allowed to dry under atmospheric conditions. The dried samples were saturated with ethylene-glycol vapor at 60ºC and heated at 550ºC for 2 h. The X-ray diffraction (XRD) analyses of the oriented samples were performed on air-dried, ethylene glycol-solvated, and heated samples (Brown, 1972; Brown and Brindley, 1980) to identify the mineral abundances in the studied samples. XRD analysis of samples were performed by using Shimadzu XRD-6000 model X-ray diffractometer (Ni-filtered, CuKα radiation) at Afyon Kocatepe University Technology Application Research Center (TUAM). In the analysis, 40 kV (voltage) and 30 mA (current) diffraction values were selected. The scanned range was 2-70o2θ in bulk samples and 2-30o2θ in oriented samples at a scanning speed of 2θº/min for all samples

Scanning electron microscope (SEM) was utilized to determine the mineralogical composition, surface morphology of the samples and to make microchemical analysis. For SEM investigations, decomposed samples with different mineralogical composition are coated with thin gold film to control the excess electrical charge from the SEM, thus obtaining a better quality image from the samples. The surface morphology and microchemical analysis with thin gold film of 250-300 Å thickness were carried out on an electron microscope with EDX equipped with LEO VP-1431 model at Afyon Kocatepe University Technology Application Research Center (TUAM).

4. Hydrothermal Alteration

Hydrothermal alteration is a geological process that changes the mineralogical, chemical, and physical properties of the original rock by the effect of hot water called "hydrothermal fluids", steam and gas. As a result of water-rock interaction, the primary minerals turn into alteration minerals. The composition and permeability of the reservoir rocks, the chemical composition of the fluid, temperature, pressure and pH conditions of the rock during fluid interaction, and reservoir processes such as mixing and boiling, and duration of activity, are several of the most important factors controlling the type of alteration minerals (Henley and Ellis, 1983; Reyes, 2000).

4.1 The distribution of alteration minerals

Illite and smectite occur in Köprülü volcanics at the upper 528 m of the Bayatçık-1 well, and dolomite occurs in the Oyuklutepe marbles and kaolinite found in Bayramgazi schists as a most important alteration minerals deeper parts 560 m depth (Figure 3). The first peak of illite is considered to be d(001) 10Ǻ, the second peak is d(002) 5Ǻ and the third peak is d(003) 3.33Ǻ (Karakaya, 2006). In the XRD patterns of the clay fraction, d(001) peaks of illite ranged between 10.05-10.79Ǻ and d(002) peak of 5.02-5.19Ǻ in air dried samples (AD). The *d*(001) spacing, reflect c-axis length of smectite, exhibits 12.53-12.87Å, expanded to 16.79-17.50Å after saturation with ethylene glycol (EG), and collapsed to 10.04-10.12Å after heating at 550°C (Figure 4).

d(001) peak in 7.18-7.22Å remain unchanged by the ethylene glycol treatment. This peak collapsed completely after heating at 550°C due to dehydroxylation (Brindley and Brown, 1980).

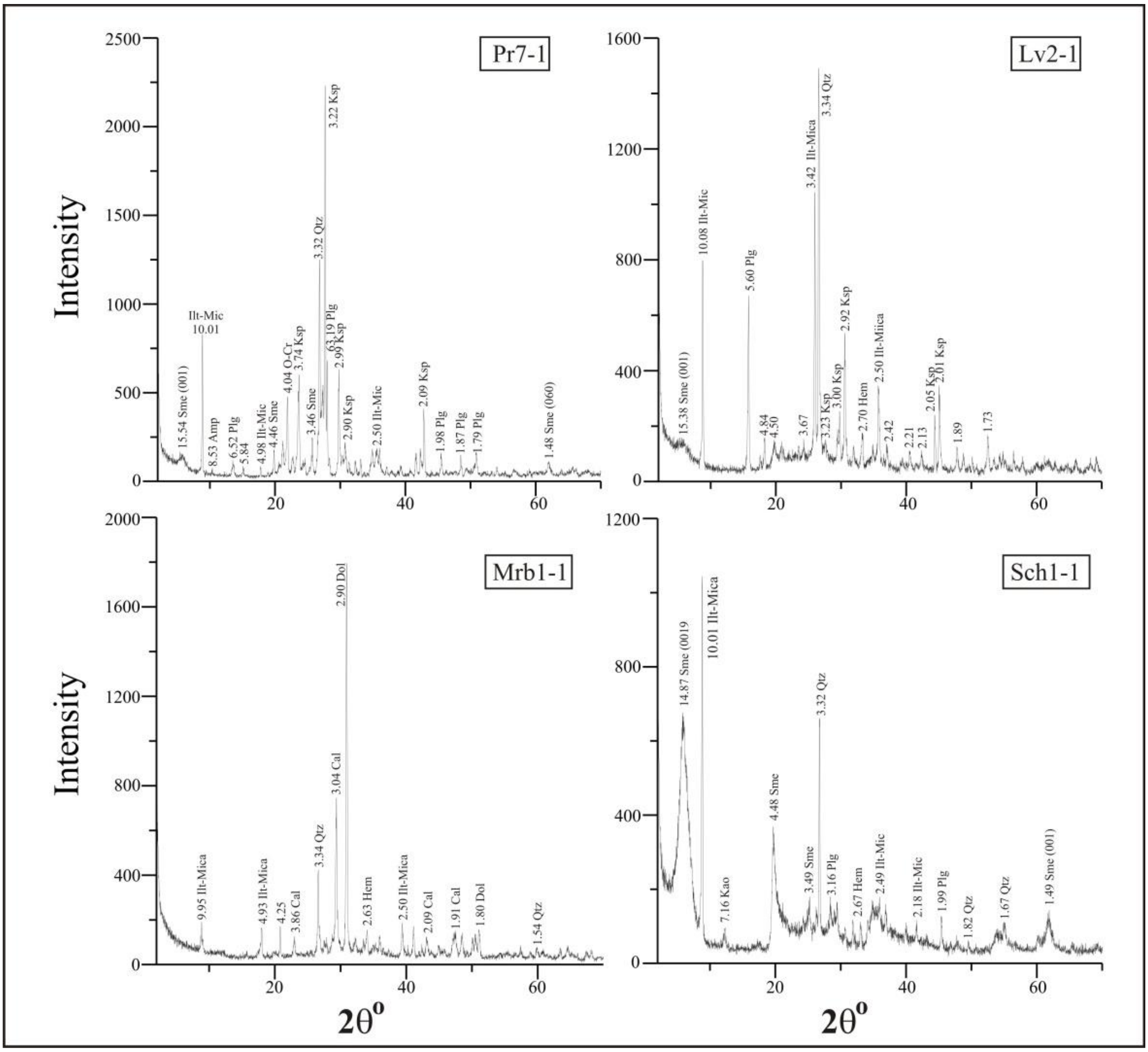

Figure 3. The whole rock XRD diagrams of representative samples from the BAYATCIK-1 well. (Sme): Smectite, (Ilt-Mic): Illite-Mica, (Amp): Amphibole, (Plg): Plagioclase, (Kao): Kaolinite, (Qtz): Quartz, (Ksp): Alkali feldspar, (Hem): Hematite, (Cal): Calcite, (Dol): Dolomite

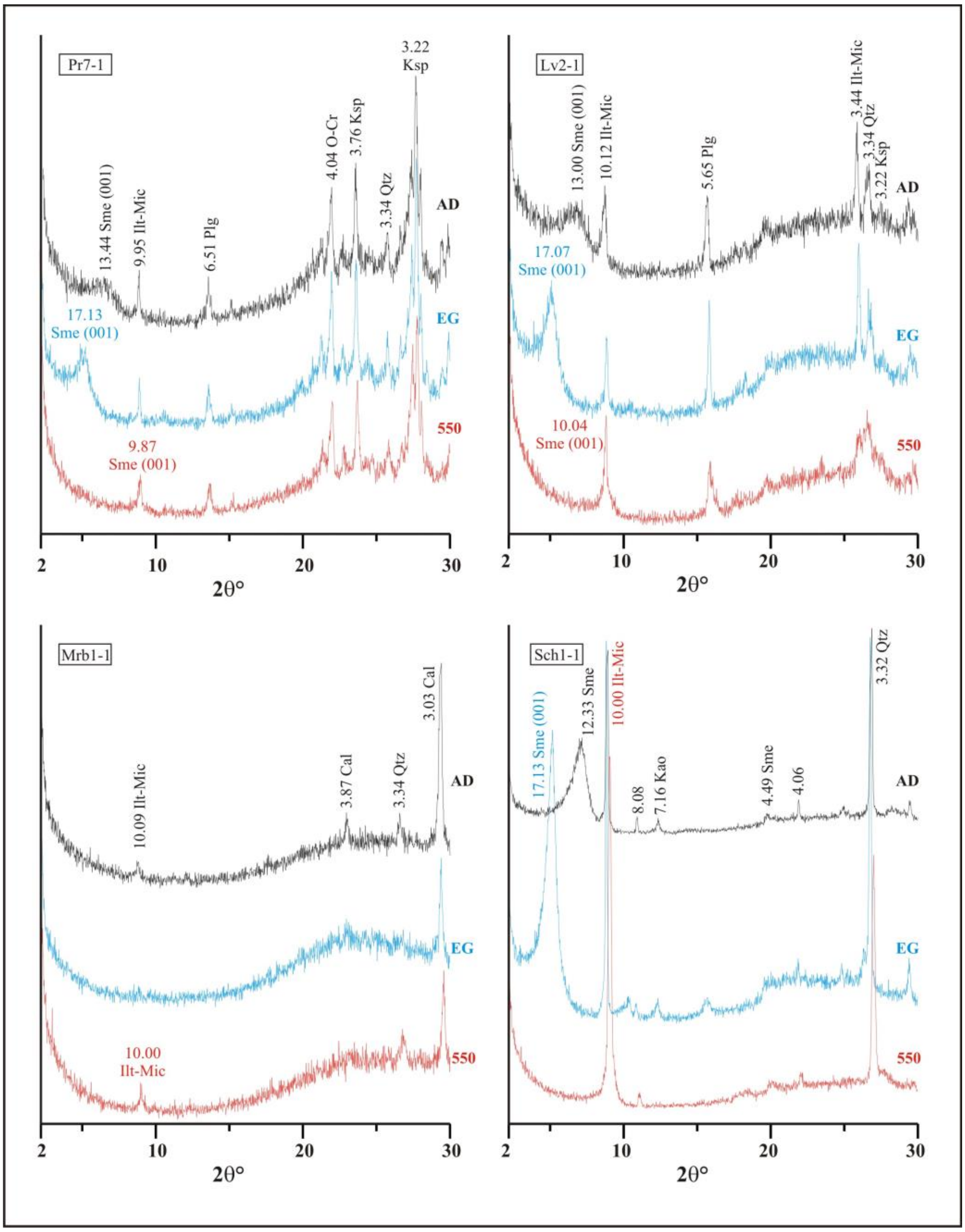

Figure 4. Representative XRD patterns of clay fraction of samples from the Bayatcık-1 well. Key to the symbols: (AD): Air dried, (EG): Ethylene glycolated, (550): Heated at 550 oC.

Hydrothermal alteration in Bayatçık geothermal area systems has been described in zones with respect to temperature (Figure 5). The sequence of alteration minerals depends on the temperature of the geothermal system (Franzson et al., 2008). In the mineral alteration temperature diagram developed by Franzson (1998), smectite, illite and kaolinite minerals indicate temperatures less than 200°C (Figure 6). Low temperature hydrothermal dioctahedral smectites has been referred close to the surface of the geothermal fields (Cole, 1988; Mizoto, 1998; Mas, 2003).

4.2. Hydrothermal alteration of primary minerals

Alteration was observed Köprülü volcanites, Oyuklutepe marbles, and Bayramgazi schist in Bayatçik-1 well. Alteration occurs as a result of the dissolution of primary minerals and precipitation of alteration minerals along the fractures and voids. Sanidine, plagioclase, biotite, quartz, hornblende and opaque minerals are the most important primary minerals in glassy matrix of volcanic rocks.

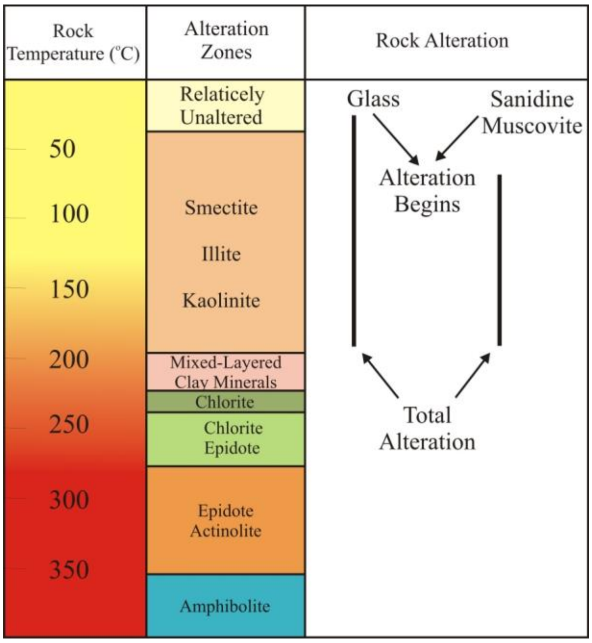

Figure 5. The temperature diagram of mineral alteration (Franzson, 1998).

The morphological and microchemical data related to the alteration of volcanic glass and feldspar were obtained SEM studies of Köprülü volcano-sedimentary sequence. The glassy matrix and feldspar of the volcanites altered to smectite and illite minerals in the form of flakes (Figure 3). The impoverishments in sodium, silicon, potassium and increaments in magnesium, aluminum, calcium, titanium and iron were measured in smectite formation. The conversion of feldspar to illite is characterized by impoverishment of sodium, silicon and calcium and enrichment of magnesium, aluminum and iron (Figure 6; Table. 1).

Table 1. The main alteration minerals from BAYATÇIK-1 well.

Primary Minerals	Alteration Minerals
Volcanic Glass	Simectite
Volcanic Glass	Illite
Sanidine	Illite
Calcite	Dolomite
Muscovite	Kaolinite
Muscovite	Illite

The coexistence of calcium and magnesium in the marbles was proved that the marbles have dolomitic composition. The magnesium content increased due to the progressive alteration, thus the marbles have dolomitic composistion. The schists comprise mica, quartz and calcite minerals. The presence of magnesium and iron together with aluminum and potassium in mica minerals indicated biotite. Sodium, magnesium, silicon and potassium are lost decreased, aluminum remains immobilized, and calcium, titanium and iron are enriched during the alteration of biotite to kaolinite (Figure 6).

5. Conclusions

The following results were obtained in the study to determine the borehole geology and alteration mineralogy of Bayatcik-1 well in Bayatçık (Afyonkarahisar) geothermal area.

Alluvium, volcanic and sedimentary units of Köprülü volcano-sedimentary sequence, basal conglomerate, marble and schist levels drilled respectively in Bayatcık-1 well. In the upper parts 528m of the well, the cover rocks of the geothermal system consisting of volcanic and sedimentary rocks were observed. Basal conglomerate was passed between 528-558m. At the levels of 558-920m, Oyuklutepe marble, which is the reservoir rock of the geothermal system, and Bayramgazi schist, the impermeable basement rock are also found.

In the SEM investigations, it was observed that smectite and illite minerals in flaky morphology occur from the alteration of the volcanic glass and sanidine crystals. Moreover, the dolomitization of calcites in marbles and the conversion of biotite to kaolinite in schists are the most important alteration process at this level.

Illite and smectite occur in Köprülü volcanics at the upper 528m of Bayatcık-1 well, and dolomite in Oyuklutepe marbles and kaolinite in Bayramgazi schists are important alteration minerals at the deeper parts 560m.

The mineral alteration temperature diagram developed by Franzson (1998), show that the alteration mineral geothermometer indicates temperatures below 200°C for Bayatcık-1 well.

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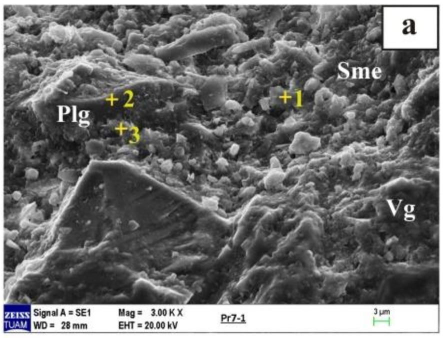
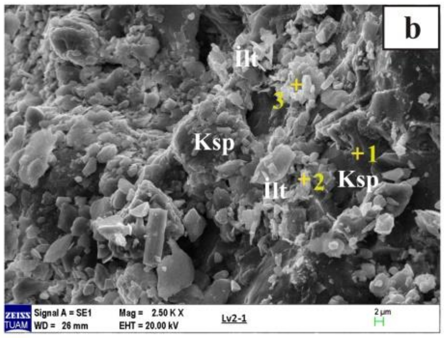
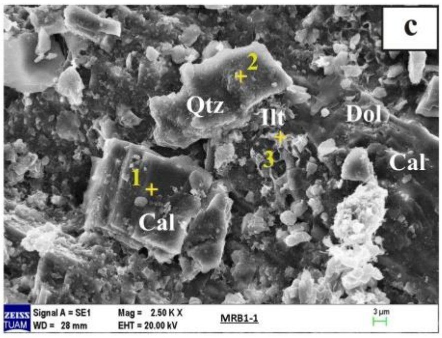


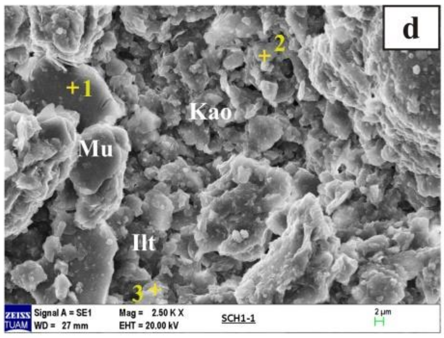
Oxides (%)	Spectrum: 1	Spectrum: 2	Spectrum: 3
Na_2O	0.59	1.38	2.29
MgO	2.98	6.29	4.91
Al_2O_3	14.67	11.43	15.99
SiO_2	57.80	57.57	59.04
K_2O	3.46	1.62	3.00
CaO	8.35	14.83	8.97
Fe_2O_3	10.34	6.52	5.61
TiO_2	1.80	0.36	0.19



Oxides (%)	Spectrum: 1	Spectrum: 2	Spectrum: 3
Na_2O	3.71	2.76	3.86
MgO	0.88	2.00	1.95
Al_2O_3	14.18	16.57	21.95
SiO_2	65.61	53.61	54.17
K_2O	5.08	4.26	4.19
CaO	1.44	11.24	5.54
Fe_2O_3	5.67	6.92	6.29
TiO_2	3.42	2.64	2.06



Oxides (%)	Spectrum: 1	Spectrum: 2	Spectrum: 3
Na_2O	-	0.43	2.00
MgO	31.60	0.51	18.95
Al_2O_3	0.94	2.53	9.50
SiO_2	1.23	91.67	24.63
K_2O	-	0.34	0.90
CaO	65.02	0.78	41.61
Fe_2O_3	1.21	3.75	2.41



Oxides (%)	Spectrum: 1	Spectrum: 2	Spectrum: 3
Na_2O	1.36	1.19	0.71
MgO	1.46	4.06	1.43
Al_2O_3	33.36	19.91	15.69
SiO_2	49.85	51.48	70.63
K_2O	9.04	3.94	3.73
CaO	-	11.09	2.14
Fe_2O_3	4.28	6.71	4.84
TiO_2	0.65	1.62	0.83

Figure 6. The semi-quantitative EDS results of alteration minerals. (Qtz): Quartz, (Ksp): Alkali feldspar, (Plg): Plagioclase, (Mu): Muscovite, (Sme): Smectite, (Ilt): Illite, (Kao): Kaolinite, (Cal): Calcite, (Dol): Dolomite and (Vg): Volcanic glass.

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