

The Mineropetrographic and Geochemical Properties of Reservoir Rocks (Ömer-Gecek/ Afyonkarahisar Geothermal Field)

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Abstract

The most important elements of the geothermal system are fluid, reservoir-cover rock, heat source, and fault lines. In geothermal basins, it is necessary to have a reservoir rock of sufficient thickness with high porosity and permeability. This study aims to determine the mineralogic-petrographic and geochemical features of the marbles, which are the reservoir rocks of Ömer-Gecek geothermal region. In this scope, the samples taken from both the outcrops and the geothermal drillings made in the region were investigated and the possible effects of water-rock interaction were determined. There are low and medium temperature (45-128°C) fluids produced from Ömer-Gecek region, the most important geothermal field in Afyonkarahisar (Western Turkey). Afyon metamorphics, which are composed of Bayramgazi schists and Oyuklu Tepe marbles, are the basement rocks of the study area and the marble lenses/bands form the reservoir rock. As a result of the analyses, it has been determined that the samples are mainly composed of calcite and dolomite minerals, and these minerals are accompanied by quartz and mica minerals with secondary minerals and kaolinite minerals as alteration minerals. The granoblastic textured outcrop marble samples gained breccia texture due to alteration and secondary manganese and iron-rich solutions were deposited into the pores and micro-cracks. According to the geochemical analysis results, while the CaO is the most important component in outcrop samples, it is significantly depleted in drilling samples, while MgO, Al₂O₃, and SiO₂ levels are enriched.

Keywords

Reservoir rock; Marble;
Mineralogy-
petrography;
Geochemistry;
Afyonkarahisar

Ömer-Gecek (Afyonkarahisar) Jeotermal Sahası Rezervuar Kayaçlarının Mineropetrografik ve Jeokimyasal Özellikleri

Öz

Jeotermal sistemin en önemli elemanlarını akışkan, rezervuar kayaç, örtü-ısıtıcı kayaç ve fay hatları oluşturmaktadır. Jeotermal havzalarda her şeyden önce yüksek porozite ve permeabiliteye sahip olan yeterli kalınlıkta rezervuar kayacın bulunması zorunludur. Bu çalışmanın amacı Ömer-Gecek jeotermal bölgesinin rezervuar kayacı olan mermerlerin mineralojik-petrografik ve jeokimyasal özelliklerinin belirlenmesidir. Bu kapsamda hem mostra yüzeylerinden, hem de bölgede yapılmış olan jeotermal sondajlardan alınan kırıntı numuneler üzerinde incelemeler yapılarak, su-kayaç etkileşiminin muhtemel etkileri belirlenmiştir. Afyonkarahisar ilindeki en önemli jeotermal saha olan Ömer-Gecek bölgesinden düşük ve orta sıcaklıkta (45-128°C) akışkan üretilmektedir. Bayramgazi şistleri ve Oyuklu Tepe mermerlerinden oluşan Afyon metamorfikleri inceleme alanının temel kayaçları olmakla birlikte, bu istif içerisinde yer alan mermer mercer ve bantları akışkanların ana rezervuarını oluşturmaktadır. Yapılan analizler sonucunda örneklerin başlıca kalsit ve dolomit minerallerinden oluştuğu, bu minerallere tali oranda kuvars ve mika mineralleri ile alterasyon minerali olarak kaolinit mineralinin eşlik ettiği görülmektedir. Makroskobik olarak şekerimsi doku gösteren mermerler alterasyonun etkisiyle breşik yapı kazanmış ve sekonder mangane ve demir bakımından zengin eriyikler kayaç içindeki boşluk ve mikro çatlaklara yerleşmiştir. Jeokimyasal sonuçlara göre, mostra örneklerinde CaO kimyasal bileşimindeki en önemli bileşen olarak göze çarpmakta iken kırıntı örneklerde CaO önemli derecede azalmakta ve MgO, Al₂O₃ ve SiO₂ miktarlarında artış gözlenmektedir.

Anahtar kelimeler

Rezervuar kayaç;
Mermer; Mineraloji-
petrografi; Jeokimya;
Afyonkarahisar

1. Introduction

In our country, high enthalpy geothermal fields are concentrated in Western Anatolia, especially in Aegean Region. In this region, Denizli, Aydın, Kütahya and İzmir provinces as well as Afyonkarahisar contain important geothermal fields. Ömer-Gecek, Gazlıgöl, Heybeli-Çay-Çobanlar, Hüdai and Susuz-İscehisar are the most important geothermal areas in Afyonkarahisar (Figure 1). The study area is located in the Aegean Region, 16 km northwest of Afyonkarahisar. The closest settlements to the study area are Bayramgazi, Köprülü, Demirçevre, Sadıkbey, İsmailköy, Saraydüzü villages and Fethibey and Erkmen Towns.



Figure 1. Geothermal fields in Afyonkarahisar.

2. Materials and Method

2.1. Geology Studies

In the first stage of the study, the geological and minero-petrographical properties and the geological properties of important parts of the geothermal system such as reservoir rock, cover rock and tectonic lines were investigated.

2.2. Mineralogical Studies

Mineralogical investigations were carried out in three sections: polarizing microscope studies, scanning electron microscope (SEM) studies and X-ray diffractogram (XRD) analysis. The experimental procedure of the analyses is given below.

2.2.1. Polarizing Microscope Studies

Polarizing microscope studies concentrated on the main rocks of the alteration zones associated with

geothermal waters were carried out within the scope of the project. Leica DM2500P model polarizing microscope was used for petrographic investigation at the Geological Engineering Department of the Faculty of Engineering.

2.2.2. Scanning Electron Microscope (SEM) Studies

To determine the surface morphology and mineralogical composition of the samples belonging to different rocks, Scanning Electron Microscope (SEM) was used. For scanning electron microscopy (SEM) studies carried out in parallel with X-Ray Diffractogram analysis, fragments of approximately 1 cm in diameter were broken from the separated samples with different mineralogical composition. Thus, fresh surfaces representing rock structure and texture were obtained. SEM samples were coated with thin gold film at 250-300 Å in Technology Application Research Center (AKU-TUAM) by using LEO VP-1431 model scanning electron microscope.

2.2.3. X-Ray Diffractography (XRD) Studies

For XRD investigations, different rock samples, which are considered as main rocks, were prepared for analysis. XRD analysis was carried out in 2 sections as all rock and clay size investigations. XRD analyses were carried out by using Shimadzu XRD-6000 model X-ray diffractometer (Ni filter, CuK α radiation) in AKU Technology Application Research Center (TUAM). All rock samples were ground to -250 μ m grain size for XRD investigations. As a result of all rock XRD investigations, clay size investigations were performed in samples showing different mineralogical composition. Guided samples were prepared from the broken samples for clay size investigations.

2.3. Geochemistry Studies

Differentiated specimens determined by field observations and polarized microscope and XRD studies and some samples of rocks that are thought to be the main rocks are reserved for geochemical studies. Main, trace and rare earth elements of the samples prepared for geochemical investigations were determined by ICP-MS device in ACME

(Canada) Laboratory. After all the rock samples were crushed and ground, it was brought to -0,106 mm grain size for determination of main, trace and rare earth elements.

3. Results and Discussion

3.1. Geology of the Study Area

3.1.1. Stratigraphy

Paleozoic aged Afyon metamorphics form the basis of the study area. The formation consists of Bayramgazi schists and Oyuklu Tepe 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. The Upper Miocene Erkmen volcanics are the last products of volcanism in the region. Quaternary travertine and alluvium are the youngest units in the study area (Figure 2).

3.1.1.1. Afyon Metamorphics

a) Bayramgazi Schists

This unit is usually brown, grey, green in color and has a very fold structure determined that it includes mineral paragenesis of low-grade greenschist facies Öktü et al (1996). The schists are composed of albite-chlorite-muscovite-biotite-quartz schist and calc-schists. Quartzite and quartz veins are occasionally found within the schists (Metin et al., 1987; Kuşcu et al., 1999; Kibici et al., 2001).

b) Oyuklu Tepe Marbles

The unit forms the upper levels of Afyon metamorphics (Ulutürk, 2009) (Figures 3a, b). In the unit, violet, sugarish and grey colored textures are observed. It is similar in texture to İsehisar marbles. It is possible to see the alteration effects of geothermal waters in this unit. The unit is reservoir rock of the geothermal system.

3.1.1.2. Ömer-Gecek Formation

a) Başçakmaktepe Conglomerate

The unit is dark yellow, reddish colored, thick-bedded and contains sedimentary structures, which represent terrestrial formations such as cross-bedding, embossment filling and channel structures, drying cracks, discharge traces. The unit consists of rounded pebbles of old rocks. The pebbles are in sizes ranging from 2 mm to 20 cm.

b) Köprülü Volcano-sedimentary sequence

The Köprülü volcanic-sedimentary sequence includes volcanic and pyroclastic lavas and epiclastic sediments (Ercan et al.,1987). The level of lava is yellowish, greenish colored with onion peel, pillow and plate structures. The upper parts of the lava level are lubricated and sometimes have gas pockets. Above this level, there are tuff, marl and conglomerate units. These rocks distinguish different lava flows in the Köprülü volcano-sedimentary sequence.

3.2. Alteration in Reservoir Rocks

One of the most important data indicating the presence of geothermal waters in the field is the alteration zones in the rocks. For this reason, the distribution of different alteration zones in the Ömer-Gecek geothermal basin has been examined in detail. In the study area, the effectiveness of hydrothermal alteration, which is related to geothermal waters, is monitored intensively in two regions. The first is between Ömer-Gecek and Köprülü Village, and the other is between Erkmen own and Çakırköy (Figure 2). The distribution of the alteration zones is fracture controlled and is in line with the direction of major faults in the region. The geological characteristics of the important hydrothermal alteration areas in the study area are given below according to their stratigraphic levels. One of the important alteration zones in the area are seen in Oyuklu Tepe marbles.

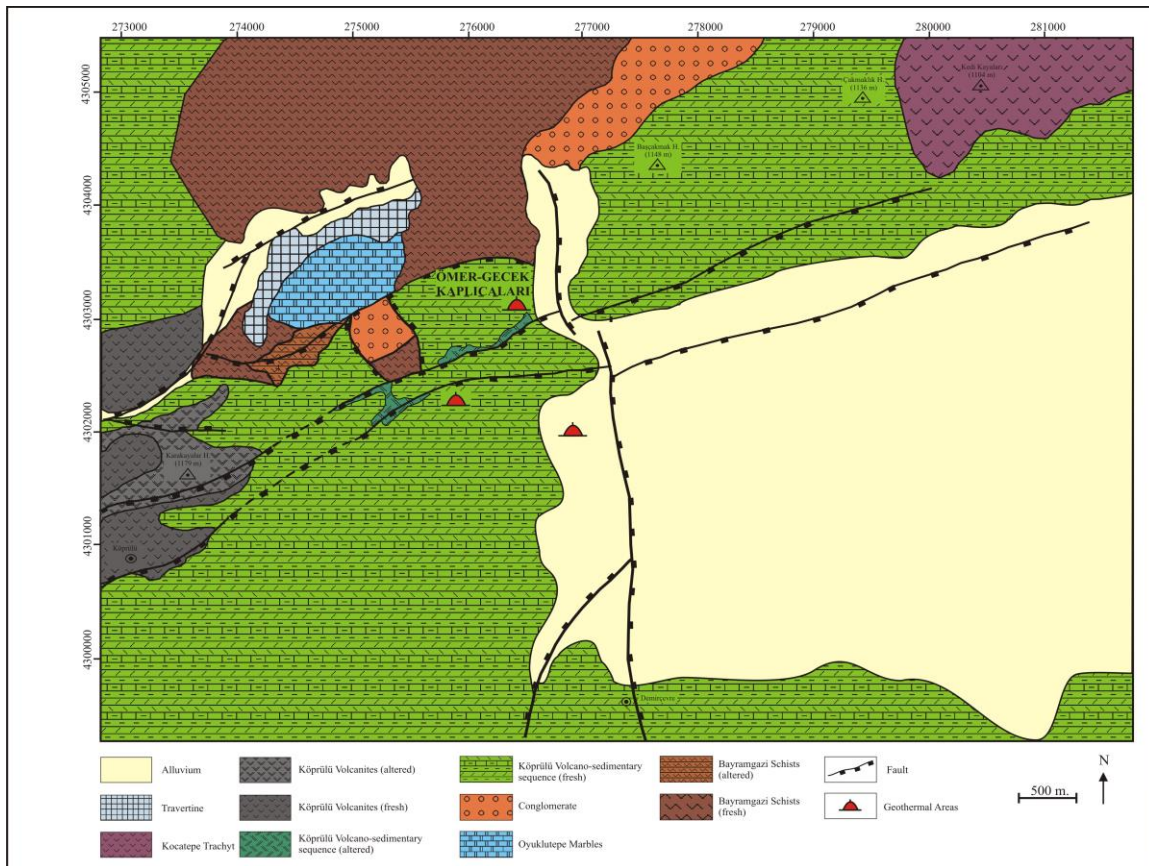


Figure 2. The geology map of study area (modified after Ulutürk, 2009).



Figure 3: Oyuklu Tepe marbles; (a): General view of the abandoned marble quarry; and (b): Violet texture in marble.

White-colored and yellow-veined, sugar-textured marbles became brecciated by the effect of tectonism, and manganese and iron-rich solutions were deposited in the fractured parts and melting cavities and the rock crystallized again. As a result, marbles with sugar-like texture have gained a violet appearance (Figure 4).

This change is consistent with the K60°B fault in the marble quarry. In the intense melting gaps observed near the fault zone, a dark blue colored manganese aragonitic zone, yellow colored iron zone, manganese, iron rich violet zone, and sugarish textured zone are observed.

3.3. Mineralogical Properties of Alteration Zones

Mineralogical properties of the rocks were determined by Polarizing microscope, scanning electron microscope (SEM) and X-Ray Diffractogram (XRD) method and the results were summarized below.

3.3.1. Polarising Microscope Investigations

Quartz, muscovite and calcite minerals were determined in the Bayramgazi schists where

granolepidoblastic texture shape was observed in polarizing microscope studies (Figures 5a-d). Calcite is the most important mineral in the reservoir rock with granoblastic texture, secondary calcite crystals along the microcracks and muscovite minerals and dark colored minerals were formed (Figures 5b-c). The block sizes in the unit are quite low due to the effect of extensional tectonics prevailing in the region. The mining operation to operate the marble at Oyuklu Tepe was terminated soon after due to its low block size.

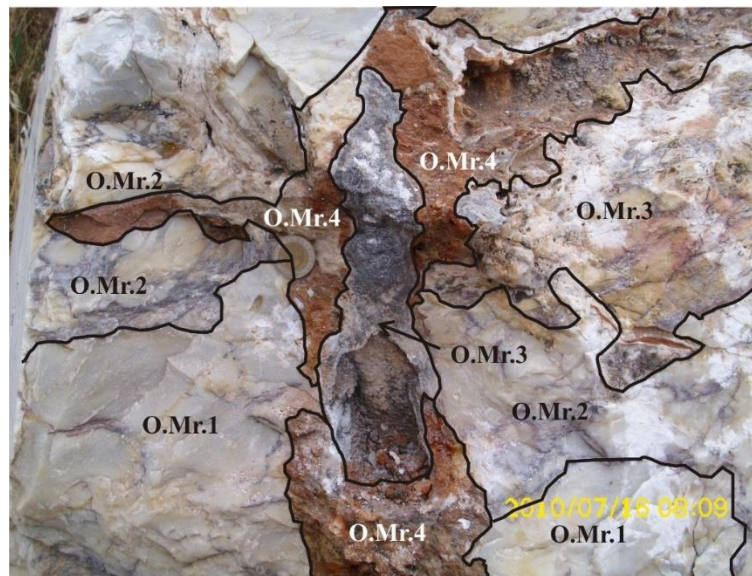


Figure 4. Different alteration zones observed in Oyuklu Tepe marbles. (O.Mr.1): Sugarish textured zone, (O.Mr.2): Violet appearance zone, (O.Mr.3): Manganese zone and (O.Mr.4): Iron zone.

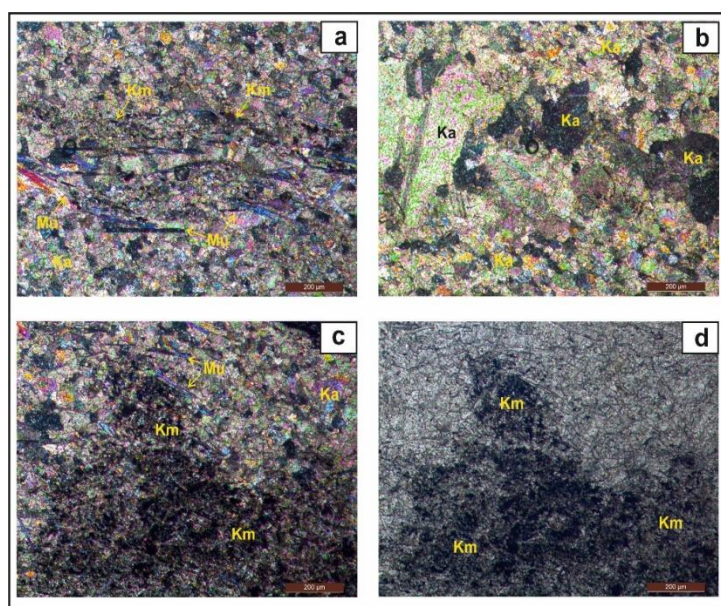


Figure 5. Primary calcite crystals (Ka), secondary muscovite (Mu) and dark minerals (Km), (a), (b) and (c) (Ç.N.x10) and d) (TN x10).

3.3.2. Scanning Electron Microscope (SEM) Investigations

To examine the morphological properties of the samples belonging to different alteration zones in the study area, the samples were examined by scanning electron microscopy (SEM). The Oyuklu Tepe marble structure is generally observed in the OMR-4 code belonging to the dark yellow alteration zone in Bayramgazi schists (Figures 6 a, b,), while muscovite (Mu) minerals are the dominant minerals in the sample (Figures 6 e; f). Muscovite minerals accompanied quartz and feldspar minerals. In some parts of the rock, worm-shaped kaolinite crystal clusters (vermiform) and euhedral alunite crystals are observed along the contact of muscovite and lesser feldspar minerals (Figures 6c, d). SiO_2 , Al_2O_3 , K_2O peaks obtained in EDX measurements indicate muscovite minerals (Figure 7a). In addition to the major oxides such as SiO_2 , Al_2O_3 , K_2O in cubic crystals observed near the feldspar minerals, the SO_3 value of 1.33 % supports the amount of alunite in this rock (Figure 7a). 31.88-41.25% Al_2O_3 and 41.18-48.15 % SiO_2 values obtained in the EDX measurements made in the sections containing worm-shaped kaolinite crystals reflect the chemical composition of the kaolinite mineral (Figures 7b; c).

3.3.3. X-Ray diffraction (XRD) Investigations

Bayramgazi schists consist of mica, quartz, feldspar and calcite (Figure 8 a; b; c). Oyuklu Tepe marbles, which are affected by alteration, are mostly composed of calcite and the rock contains dolomite in places (Figure 9a). On the other hand, there are mica and quartz minerals in addition to these minerals in the composition of violet textured marble (Figure 9b). The yellow colored carbonate zone observed along the fracture and fault lines in the Oyuklu Tepe marbles and the calcite and dolomite minerals in the aragonitic zone and a small amount of quartz minerals were observed (Figure 9c).

3.4. Geochemical Investigations

The results of major, trace and rare earth (REE) analysis are given in Table 1. In order to reveal the behavior of the elements during the alteration, the

main, trace and rare earth elements (REE) contents of the samples belonging to different stratigraphic levels of alteration zones were compared according to the origin rock and the changes in the amount of these elements were investigated. In Bayramgazi schists, Fe_2O_3 , MnO , MgO , CaO and K_2O were lost in different zones from the bedrock to the weathered zone, while SiO_2 , TiO_2 and Al_2O_3 were enriched during the alteration (Table 1). This behavioral pattern in the elements is clearly marked from top to bottom and this behavior shows that the alteration occurs in the form of hydrothermal alteration associated with geothermal waters. The most important alteration mineral at this level was determined as kaolinite in the XRD investigations, whereas it was observed that kaolinite was mostly formed along the contact of the muscovite mineral. The effect of hydrothermal alteration associated with geothermal waters was also observed in Oyuklu tepe marbles so that the main rock texture, which has a sugar-like appearance, was first transformed into violet with the effect of alteration and the gaps in the rock were filled with secondary manganese and iron-rich solutions. The main mineral in the composition of the marbles is calcite. In relation to the mineralogical composition, CaO is the most important component in the chemical composition of the marbles and the change in the amount of CaO is an important guide for the degree of alteration in the marbles. While the CaO decreases in Oyuklu Tepe marbles due to alteration, SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , Na_2O , K_2O , P_2O_5 and Cr_2O_3 are enriched (Table 1). In the Bayramgazi schists, alteration in Oyuklu Tepe marbles in the form of lenses occurs in relation to the schists. During the alteration, the elements which are separated from the structure of the minerals such as muscovite and feldspar in the composition of the schists, are deposited in the melting cavities formed in the marbles by the effect of tectonism and alteration and crystallize secondary here. In fact, with increasing amounts of illite-mica, quartz and dolomite minerals at the violet textured level compared to the sugar-textured level, kaolinite mineral observed in the iron zone was formed as a result of the elements enriched at these levels.

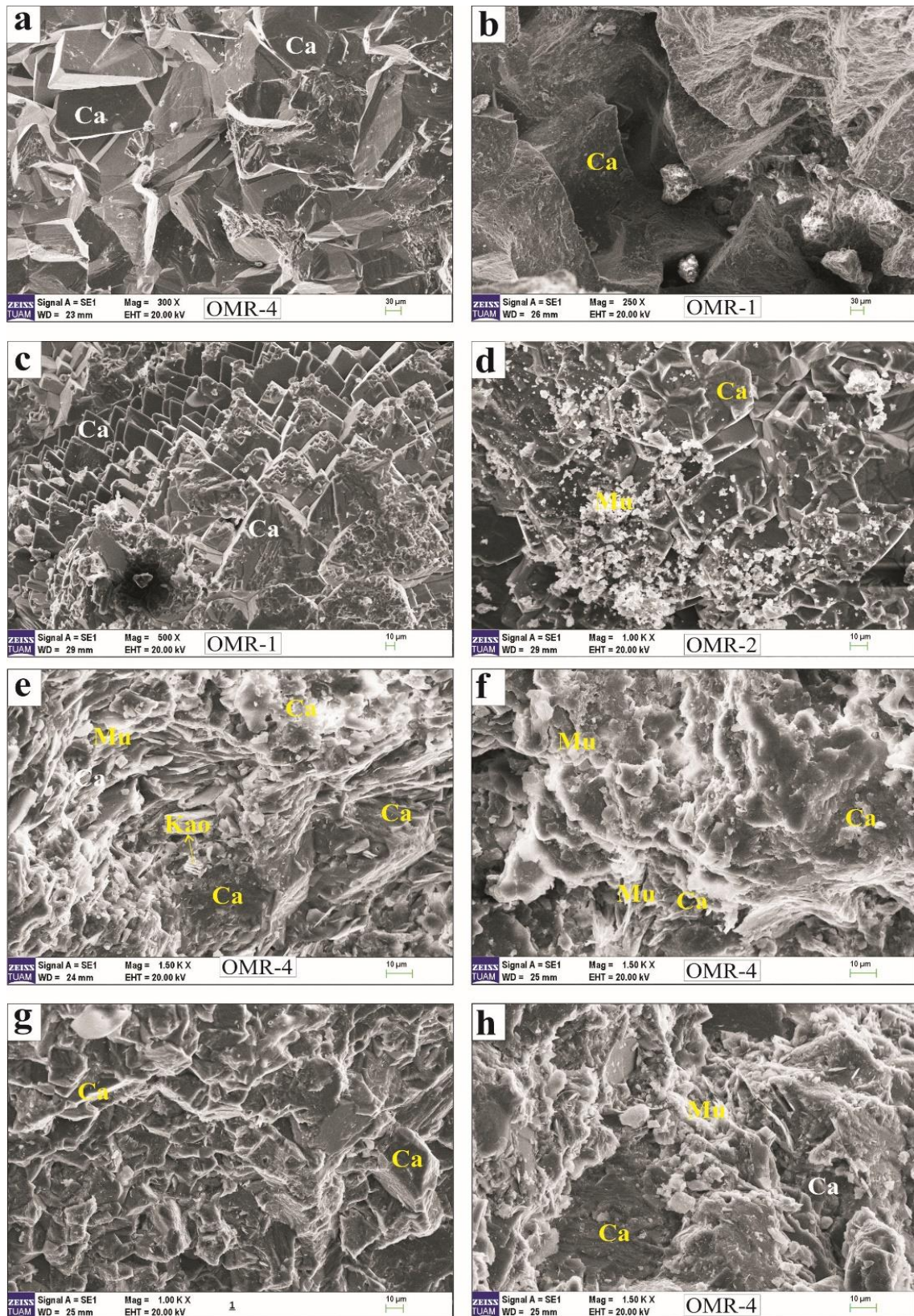
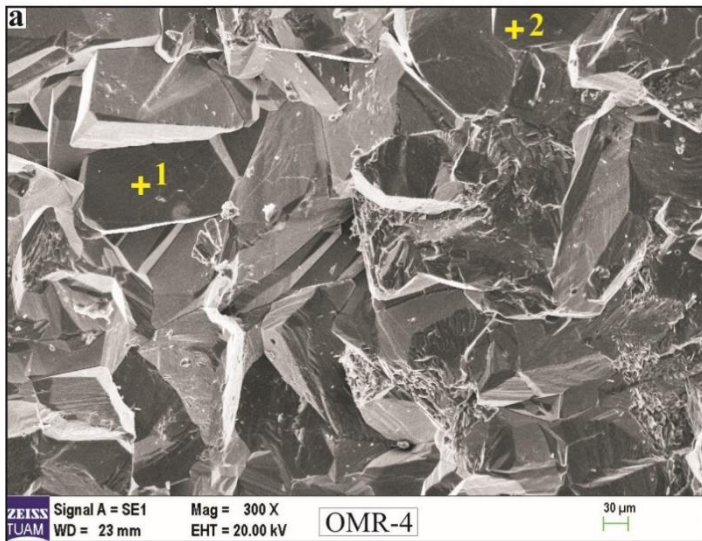
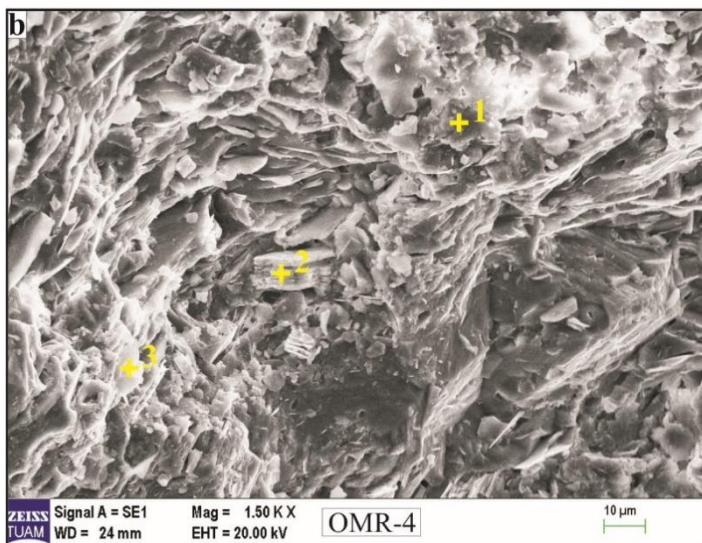


Figure 6. SEM images of the alteration zones Oyuklu Tepe Marble, (Mu): Muscovite, (Kao): Kaolinite, (Alu): Alunite, (Ca): Calcite.



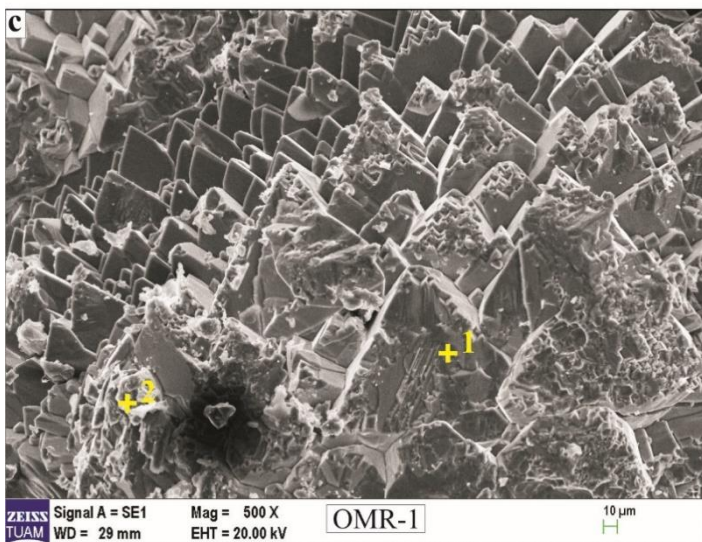
Sample No: OMR-4

Oxide (%)	Spectra: 1	Spectra: 2
Na ₂ O	*	*
MgO	*	*
Al ₂ O ₃	*	*
SiO ₂	*	*
K ₂ O	*	*
CaO	100.00	100.00
Total:	100.00	100.00



Sample No: OMR-4

Oxide (%)	Spectra: 1	Spectra: 2	Spectra: 3
Na ₂ O	1.72	*	*
Fe ₂ O ₃	16.73	1.52	1.57
Al ₂ O ₃	31.88	42.35	*
SiO ₂	41.18	48.85	4.75
K ₂ O	2.82	0.70	19.40
CaO	1.40	7.57	56.06
Cl ₂ O	0.50	*	18.20
MgO	1.15	*	*
SO ₃	1.31	*	*
TiO ₂	1.26	*	*
Total:	100.00	100.00	100.00



Sample No: OMR-1

Oxide (%)	Spectra: 1	Spectra: 2
MgO	*	*
Al ₂ O ₃	*	1.54
SiO ₂	*	2.03
CaO	100.00	96.43
K ₂ O	*	*
Total:	100.00	100.00

Figure 7. EDX data of the alteration zones of Oyuklu Tepe Marble, (Mu): Muscovite, (Kao): Kaolinite, (Ca): Calcite.

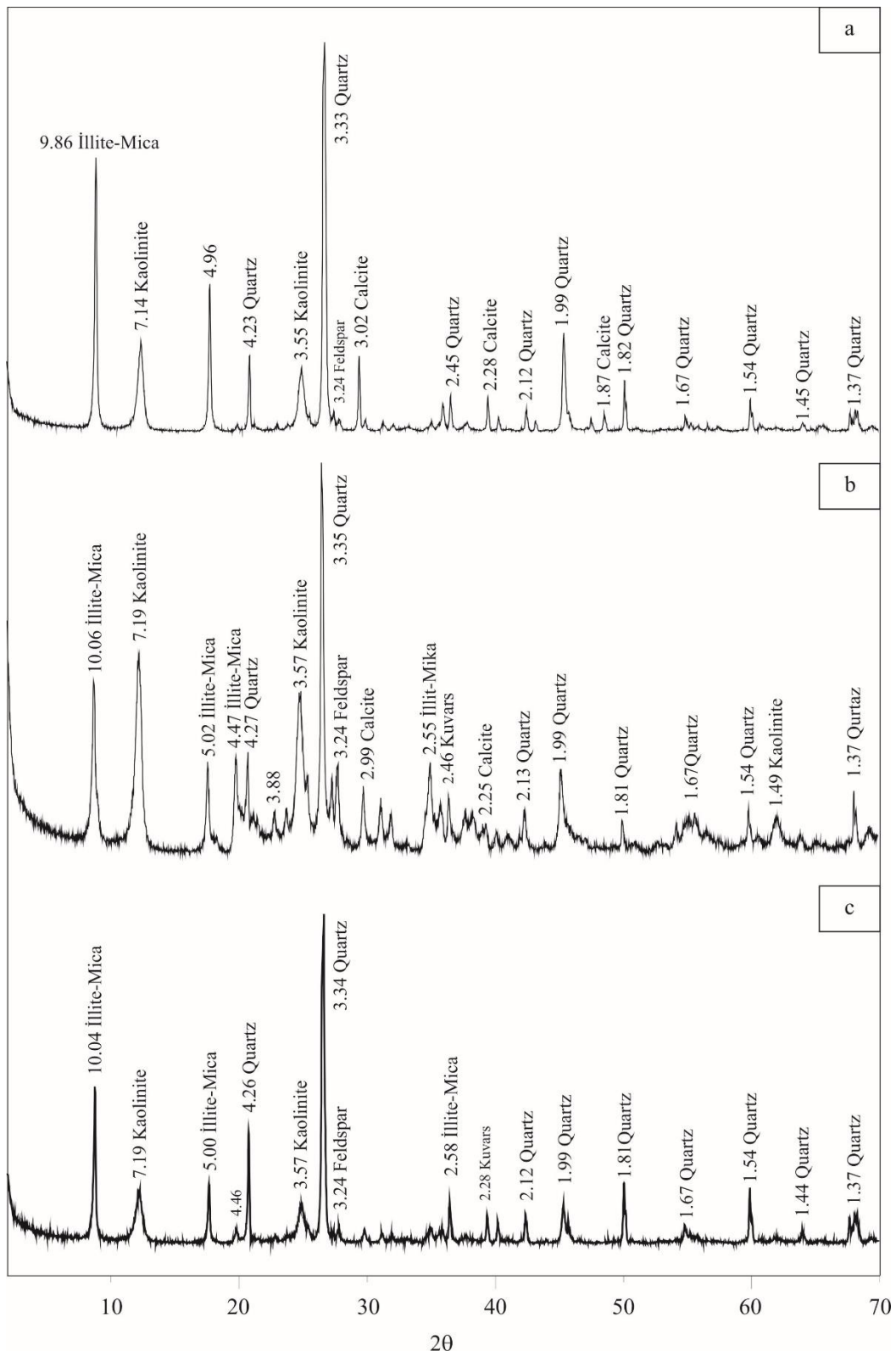


Figure 8. All rock XRD graphs of samples of different alteration zones in Bayramgazi schists, (a): O.Ş.1, (b): O.Ş.3, (c): O.Ş.4.

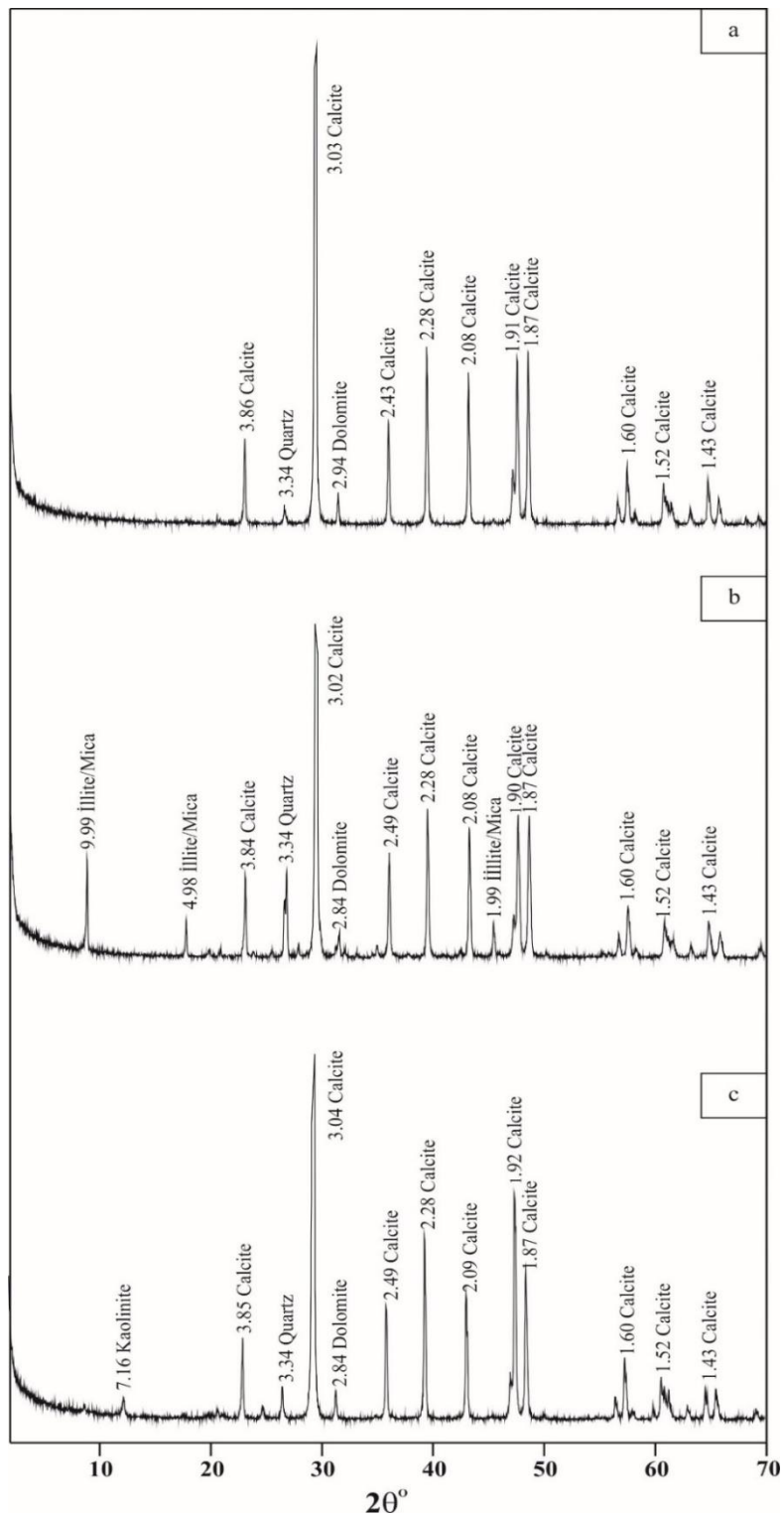


Figure 9. XRD graphs of all samples of different alteration zones in Oyuklu Tepe Marbles, (a): O.Mr.1, (b): O.Mr.2 and (c): O.Mr.4

4. Conclusions

Paleozoic Afyon metamorphics form the basis of the study area. The formation consists of Bayramgazi schists and Oyuklu Tepe 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. The Upper Miocene Erkmen volcanics are the last crops of volcanism in the region. The most important signs of hydrothermal alteration observed in all schists, marbles and volcanic rocks in the area are the

distribution of the alteration zones in conformity with the fault lines in the region, the increase of the alteration intensity from the ceiling to the base and the presence of different alteration zones in a lateral direction. The mega gypsum crystals observed in the basal zones of Bayramgazi schists are mineralogical data supporting the alteration of acidic composition. Kaolinite crystals were also related to muscovite and feldspar in Bayramgazi schists, ascites in ash-flow and sanidine and smectite minerals in Erkmen volcanics. In the Ömer-Gecek geothermal basin, Paleozoic aged Oyuklu Tepe marbles are primary reservoirs, Paleozoic aged quartzites, Başçakmaktepe conglomerate and

Köprülü tracts are secondary reservoirs. The quaternary alluvium, the Miocene aged Köprülü volcano-sedimentary sequence are covered by impermeable units such as clay and marl and schists of the Paleozoic aged Afyon metamorphics. Volcanism products that continued throughout the Miocene and Pliocene in and around Afyonkarahisar province were considered as heating rocks. Geothermal fluids are rising up along the Fethibey Fault Zone, Demirçevre Fault Zone and Karahisar fault and the secondary faults intersecting them in different directions (Koçyiğit, 1984; Koçyiğit et al., 2000).

Table 1. Major, trace and rare earth element analysis results of samples belonging to Bayramgazi schists and Oyuklu Tepe marbles.

	O.Ş.1*	O.Ş.2	O.Ş.3	O.Ş.4	O.Mr.1*	O.Mr.2*	O.Mr.3*	O.Mr.4
SiO ₂	57.75	49.22	65.76	66.52	1.63	8.9	0.5	6.78
TiO ₂	0.86	2.13	1.16	0.88	0.01	0.18	0.01	0.14
Al ₂ O ₃	18.1	29.47	16.94	18.77	0.23	4.76	0.12	3.01
Fe ₂ O ₃	7.08	1.32	6.86	4.13	0.18	2.74	0.14	1.21
MnO	0.05	0.01	0.01	0.01	0.01	0.01	0.47	0.02
MgO	0.34	0.27	0.12	0.23	0.54	0.74	0.39	0.39
CaO	3.82	0.82	0.16	0.22	53.91	43.6	55.35	48.18
Na ₂ O	0.49	2.14	0.69	0.63	0.02	0.1	0.05	0.07
K ₂ O	3.26	3.74	1.86	3.2	0.07	1.53	0.04	0.32
P ₂ O ₅	0.16	0.21	0.11	0.12	0.01	0.07	0.04	0.09
Cr ₂ O ₃	0.018	0.034	0.016	0.014	0.002	0.003	0.002	0.003
LOI	7.9	10.2	6.2	5.1	43.4	37.3	42.9	39.7
SUM	99.84	99.55	99.87	99.86	99.96	99.91	99.95	99.95
Ba	600	754	470	658	9	138	161	86
Hf	4.7	18.7	8.2	6	0.1	1.1	<0.1	1.2
Nb	16.4	101	21.3	16.6	0.6	4.3	0.4	4.3
Rb	131.7	228.3	84.1	148.4	2	36.3	1	10
Sr	165	380.4	75.9	77	204.7	306.8	147.3	79.9
Th	14.5	49.6	9.6	15.1	0.2	3.7	0.2	5.6
Zr	170.8	642.3	290.2	215.2	4	40.1	5.1	38.4
Y	29.5	276.1	15.2	35.3	1.8	5.5	0.6	9
La	37.8	239.6	22.4	42.8	1	9.4	0.5	13.1
Ce	84.8	471.1	48	90.3	1.7	18.5	0.8	24.5
Pr	9.26	50.93	5.4	10.07	0.23	2.2	0.09	2.78
Nd	36	182.4	21.4	38.9	1	8.2	0.5	10.5
Sm	6.71	24.72	4.18	7.07	0.2	1.4	0.06	1.77
Eu	1.34	3.87	0.81	1.59	0.05	0.29	0.02	0.42
Gd	5.33	24.38	3.17	5.84	0.24	0.98	0.07	1.44
Tb	0.91	5.3	0.52	1.05	0.04	0.17	0.01	0.24
Dy	5.05	34.18	2.78	5.97	0.25	0.94	0.05	1.24
Ho	0.98	7.51	0.54	1.13	0.04	0.19	0.02	0.24
Er	2.73	22.02	1.6	3.4	0.12	0.58	0.03	0.68
Tm	0.44	3.21	0.27	0.53	0.02	0.09	0.01	0.1
Yb	2.63	18.93	1.8	3.16	0.1	0.59	0.05	0.57
Lu	0.41	2.73	0.27	0.49	0.02	0.1	0.01	0.08

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