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Major and Trace Element Geochemistry of Bauxites of Ayranci, Karaman, Central Bolkardag, Turkey

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Central Bolkardag (Ayranci, Kucukkoras-Karaman) bauxites are one of the most important bauxite sources of the central Taurus zone. The aim of this study was to determine geological features and major and trace elements of Kucukkoras bauxites based on geochemical data from the bauxite deposits and rocks. To this aim, geochemical features of the region were investigated, a detailed map of the bauxite sites was drawn and chemical analyses of the collected specimens were made with inductively coupled plasma/mass spectrometry (ICP-MS). Kucukkoras diasporic bauxite deposits were located in Jurassicu-upper cretaceous aged uctepeler formation, were formed in the upper cretaceous period, extended in the NW-SE direction and were composed of three types of ores; *i.e.* lenses, karstic fills (sinkhole fills) and veins. Bauxites were found to have the following major oxides: SiO_2 of 3.2005 %, Al_2O_3 of 57.7080 %, Fe_2O_3 of 23.365 %, MgO of 0.1035 %, CaO of 0.3290 %, Na_2O of 0.0800 %, K_2O of 0.0960 %, TiO_2 of 3.1385 %, P_2O_5 of 0.0580 %, MnO of 0.1445 % and CrO_3 of 0.5430 %. Based on the Al_2O_3/SiO_2 ratio of bauxites, the mean module value was found to be 18.04, which indicates that Kucukkoras bauxites were the highest quality bauxites. Geochemical data showed that the bauxites were formed as a result of conversion of limestone into terra rossa and then conversion of terra rossa into bauxite.

Key Words: Diaspore, Bauxite, Bolkardag, Kucukkoras, Geochemistry, Karaman.

INTRODUCTION

Bolkardag, located in the territories of the provinces Konya, Karaman, Mersin, Adana and Nigde in Turkey, is the second most important bauxite source of Turkey preceded by bauxites sources in Seydisehir-Akseki which provides nearly all bauxite needs of Turkey and which plays an important part in the bauxite production of the world. The study area Kucukkoras bauxite deposits are important sources of bauxites in Bolkardag, 15 km away from the southeast of Ayranci (Karaman) and cover an area of almost 300 km^2.

The first large scale studies on geology, stratigraphy and tectonic evolution of the Bolkar mountains were performed by several researchers[1-8]. The first study on sources of mines on the Bolkar mountains was carried out[9]. Calapkulu[10] commented on the geology, formation of mines and mining in the region. Later, Horoz evaluated granodiorites and Pb-Zn sources originating from granodiorites.

Gunalay[11] and Sevgil[12] performed fission tract studies on the Bolkar mountains to determine bauxite reserves and made their tenure calculations. It has been claimed that the sources of bauxites, classified as carbonate rocks, are ophiolite, located in the vicinity of bauxites[13], dendritic sediments such as shale-clay and other magmatic (igneous) rocks[13-15] or carbonate rocks found in their bottom[16-20] was the first to perform a study on bauxites on the Bolkar mountains and suggested that these bauxites were diasporic, developed on unconformity surfaces between Permian and Mesozoic carbonate rocks and filled the karstic spaces of the basement rocks. Temur *et al.*[21] investigated bauxites of Masat mountain (Alanya-Antalya), a Permian and Lower Trias aged carbonate rock and first proposed an intra-karstic model to explain the formation of bauxites and that bauxites were younger than the rocks in which they were found. Petrographic studies of diasporic bauxites on Bolkardag (Ayranci-Karaman) revealed that Bolkardag bauxites were intra-karstic and doline[22-24]. It is important to perform further studies on each bauxite source in that remarkable bauxite deposits have appeared in various parts of the Bolkar mountains. The present study has considerable importance in terms of bauxite deposits in the region.

The aim of this study was to determine the stratigraphy of Kucukkoras bauxite deposits, their importance in terms of regional geology and their weathering degree and environment and their petrology based on analyses of major and trace elements of bauxites and wall rocks collected from the study area. Physco- chemical conditions in which bauxites were formed were evaluated statistically as well.

EXPERIMENTAL

Taking account of the relationships between all rocks and mineralization exposed in the study area, we systematically collected 29 specimens-9 were claystone and 20 were diasporic bauxites- in summer in 2005 and 2006. According to a geology map of the study area at the scale of 1/25.000, locations, tectonics and stratigraphy of bauxite reserves were evaluated. Chemical analyses of the specimens systematically collected from wall rocks and bauxites in the study area were made with ICP-MS by acme analytical laboratories in Canada. Analyses of major and trace elements were made with the 4A + 4B package method. Accordingly, weathering degree, environment and petrology of bauxites and physco- chemical conditions in which bauxites were formed were evaluated statistically. The results of the chemical analyses, made by acme analytical laboratories in Canada, were evaluated with SPSS-11.5 and correlation and regression analyses. Based on the results of correlation analyses, dendrograms for the elements were calculated with EXCELL and drawn with Free-hand 9.0.

Geological setting: The stratigraphic section in the study area started in upper Permian aged Dedekoy formation, made up of dolomite in its lower levels and dolomite limestone and occasional calcite interlayers. Dedekoy formation was conformingly covered by lower Trias aged Gerdekesyayla formation, composed of alternations of phyllite, meta-sandstone, meta-claystone and meta-carbonate with more meta-carbonate towards the top. It was unconformably covered by Jurassic-upper Cretaceous aged Uctepeler formation towards the top. This formation was composed of alternations of crystallized limestone, cherty limestone and oolitic limestone and had the most important bauxite reserves. The formation had occasional dolomite and dolomitic limestone sections. At the uppermost part of the study area was unconformable upper Paleocene aged Guzeller formation, composed of polygenic pebbles at the bottom, limestone towards the top and limestone with occasional clay limestone interlayers.

RESULTS AND DISCUSSION

Stratigraphy of the study area: A very thick unit of limestone forming the top of the Bolkar mountains and alternations of rocks made up of shale and dolomite were called the Bolkar group[2]. This thick carbonate unit consisted of crystallized limestone with occasional shist interlayers and had meta-morphism sufficient to turn into marble. Wippern[13] detected three different types of bauxite on the Taurus ranges. The oldest one was Permian aged, younger one was aged lower-upper cretaceous aged and the youngest one was Eocene aged.

At the base of the study area was the stratigraphic unit upper Permian aged Dedekoy formation composed of dolomite at the bottom and dolomitic limestone towards the top and occasional calcschist interlayers. Dedekoy formation was conformingly overlain by lower Trias aged Gerdekesyayla formation which contained alternations of phyllite, meta-sandstone and meta-carbonates with thicker meta-carbonate towards the top. Towards the top was also unconformable Jurassic-Upper-Cretaceous aged Uctepeler formation made up of crystallized limestone, cherty limestone and oolitic limestone. It also contained occasional dolomite and dolomitic limestone interlayers. At the top of the study area was unconformable upper Paleocene aged Guzeller formation, composed of polygenic pebbles at the bottom, limestone towards the top and limestone with occasional clayey limestone interlayers. The bauxite reserves of Kucukkoras were found in Jurassic-upper cretaceous aged Uctepeler formation. The bauxites were diasporic and filled carbonate rocks, dolines and caves (Fig. 1).

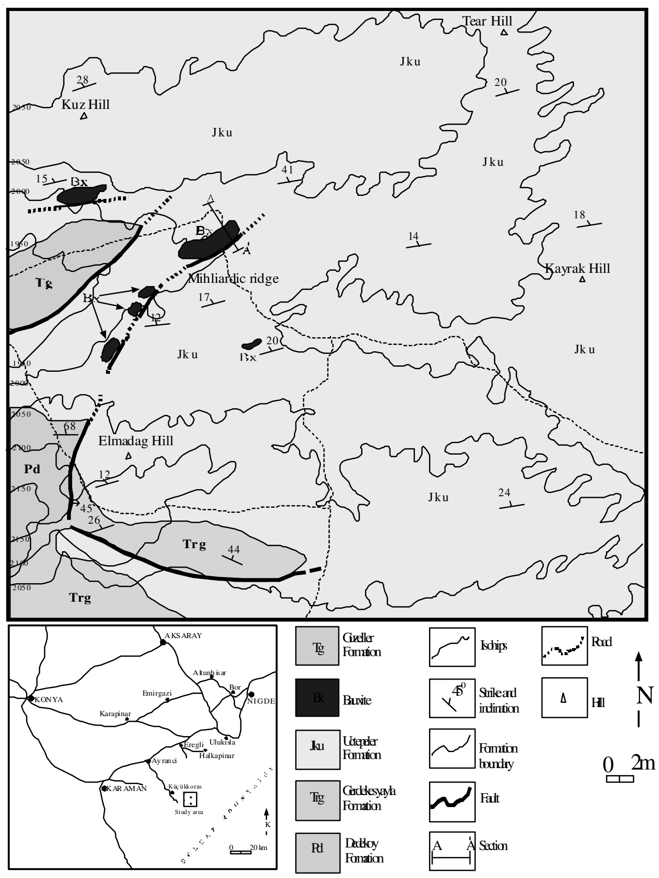


Fig. 1. Stratigraphic columnar section of the study area (no scale)

Dedekoy formation (Pd): Dedekoy formation, the oldest formation of the Bolkar group, was mostly composed of dolomitic crystallized limestone and its alternations[7]. The formation was named after Dedekoy, described as the type section and located in the east of Eregli[7]. The unit was exposed in a narrow area in the southwest of the study area. The lower part of the unit was composed of dolomites which were dark grey, medium-thick-bedded and occasionally blocky and had calcschist interlayers and the upper part of the unit consisted of dolomitic limestone which was grey-beige and thin-medium-bedded (Figs. 1 and 2).

The lower and middle parts of Dedekoy formation were medium-bedded, had a lot of fissures and cracks and melted spaces which were generally made of thin-grained dolomites and occasional interlayers of dar-grey, large crystals of dolomites. There were also occasional calcshist interlayers (Fig. 3).

Blumenthal reported that the unit conformingly transformed into Gerdekesyayla formation[2,12,25] reported that the unit was of upper Permian based on the fossils they found in the unit (*Mizzia Velebitina SCHUB, Mizzia munita, Gymnocodium sp., Nankinella sp., Pacyphloia sp., Fuzulinidae*).

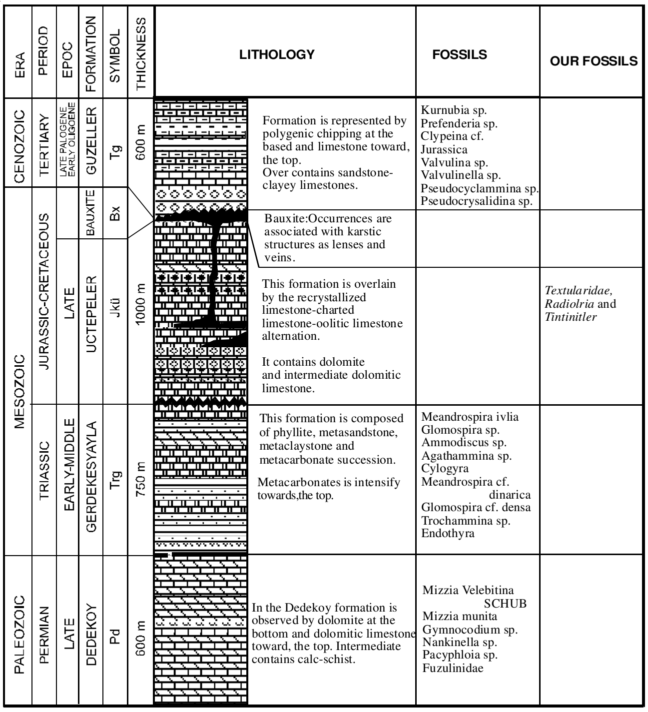


Fig. 2. Geology map of Ayranci bauxite reserves

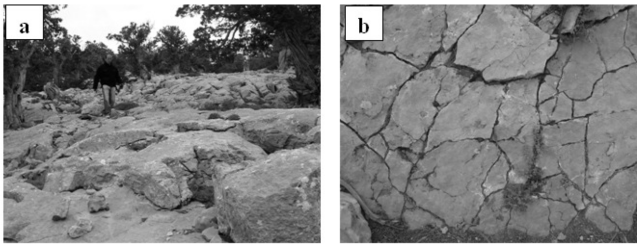


Fig. 3. Views of Dedeköy formation in the west of Elmadag hill (a) Medium-bedded light-grey meta-carbonates (b) Dolomitic limestone with a lot of Fissures and Cracks and melted spaces

Gerdekesyayla formation (Trg): Gerdekesyayla formation was composed of green-yellow-grey-black, foliated, thin-medium bedded phyllite, meta-sandstone, meta-claystone and meta-carbonate alternations (Fig. 4a). Phyllite and meta-sandstones were green, violet and yellow in colour. Phyllites were remarkably foliated and bright due to their rich content of sericite. They were mostly brittled and fragmented. Meta-sandstones were notably bedded. They usually formed alternations with phyllite (Fig. 4b). Since meta-carbonate and meta-sandstone in the formation were stronger than phyllite, they formed processes in the topography (Fig. 4b).

Metacarbonates found in the upper part of Gerdekesyayla formation were generally grey, dark grey and generally thin- and sometimes medium-bedded. They were commonly made up of crystallized limestone and occasionally dolomitic limestone.

Thin sections of the phyllites were made up of sericite (*ca.* 65 %), quartz (*ca.* 20 %), chloride (*ca.* 10 %) and muscovite (*ca.* 5 %). Sericides, which looked scaly crystals, were the main component of the rock. Chloride was green, looked like abnormal double ground coffee and probably made up of ripidolite and picnochlorite. Xenoblast quartz crystals formed alternations with scaly sericides and imparted granolepidoblastic texture to phyllites.

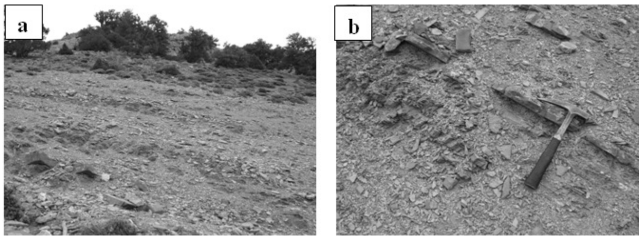


Fig. 4. Views of Gerdekesyayla formation located in the South of Elmadag Hill (a) General view (b) Alternation of Phyllite and Metasandstone

Thin sections of the meta-sandstones contained quartz (*ca.* 25 %), muscovite (*ca.* 5 %) and plagioclase (*ca.* 4 %) crystals in a mixture of calcite, chlorite and sericide (*ca.* 66 %). Calcite, the predominant compound of these rocks, had typically double brieffringes and was xenoblastic. Muscovite had a platelike pattern and unilateral separation. Chlorite was foliated and green. Metasandstones consisted of quartzs with two different dimensions: large quartzs, which were probably residual crystals before metamorphism. Fine-grained quartzs were remarkably rippled and extinctive and must have emerged from meta-morphism. Plagioclases, trace amounts of which were found in meta-sandstones, were striking with their closure and occasionally albite twinned and semi-selfformed (Fig. 5). These types of rock sometimes contain epidote in trace amounts.

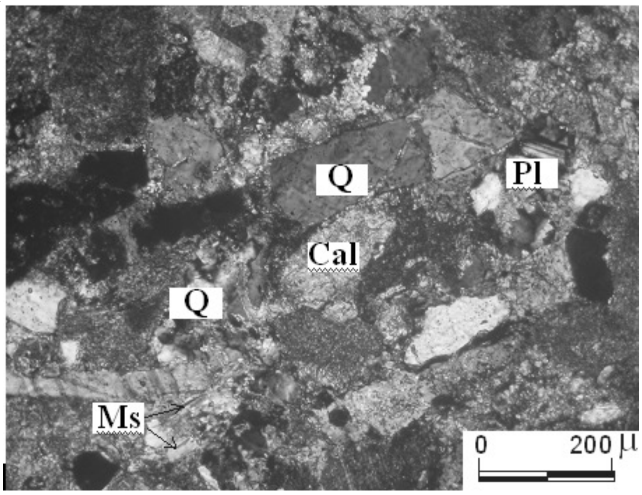


Fig. 5. A general view of meta-sandstones. Q: quartz, Pl: plagioclase, Ms: muscovite, Cal: calcite (double nicol)

Gerdekesyayla formation was concordant with Dedekoy formation at the bottom, but discordant with Uctepeler formation at the top (Fig. 1). Based on the fossils *Meandrospira ivlia, Glomospira sp., Ammodiscus sp., Agathammina sp., Cylogyra, Meandrospira cf. Dinarica, Glomospira cf. Densa, Trochammina sp.* and *Endothyra*[7] reported that the unit was of lower-middle Trias.

Uctepeler formation (J-Ku): Lithologic structures overlying Gerdekesyayla formation and made up of a thick carbonate unit in the study area were named Uctepeler Limestone[7]. Demirtasli *et al.*[7] were observed to be a formation and for this reason they called Uctepeler formation. Covering a large space in the study area, Uctepeler formation was the youngest formation of the Bolkar group.

The formation was composed of dark grey, medium-occasionally thin-bedded oolitic and dolomitic limestone with a lot of cracks at the bottom (Fig. 6a). There was dark grey, thick-bedded dolomite and light grey, medium-bedded, partly pseudoolitic limestone towards the top. The formation had plenty of cherty interlayers at some levels (Fig. 6b). The cherts were yellowish, grey and quite hard and had a sequence paralleling the bedding. Carbonated rocks had crack planes in two directions.

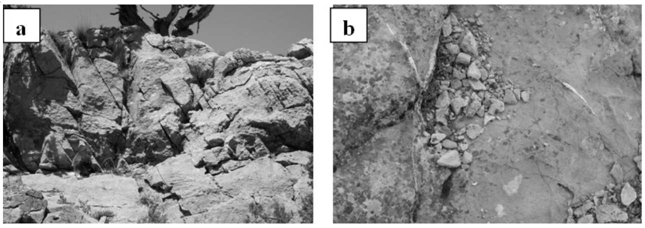


Fig. 6. Views of Uctepeler formation located in the north of Mihliardic Ridge (a) Thin-medium-bedded crystalized limestone with Plenty of Cracks (b) Yellowish, grey and quite hard cherty layers found in limestones

There were quite frequent changes in the direction and inclination at short intervals of crystallized limestone and dolomitic limestone found in the middle and upper parts of Uctepeler formation. This can be attributed to deformations which developed during metamorphism. The degree of metamorphism comparatively increased from the top towards the bottom. Recrystalization was quite common in meta-carbonates found in the lower parts of the formation. The rocks at that level had larger crystals.

Most of the carbonates found in the crystallized limestone in the formation were calcites. They did not have selfforms (*ca.* 85 %), but they had separations in double directions and high double brieffringes. The dolomites found in the rock (-14 %) were mostly romboid in shape. The rock had quartz in trace amounts. The quartzs with no selfforms had double brieffringes. About 99 % of the rock was made from carbonate minerals and 1 % from quartz. Therefore, the lithologic structures were called crystallized limestone. The carbonate minerals found in the rock did not generally have a selfform. They were nearly round and they were found to be crystals in equal sizes. Therefore, these rocks had a granoblastic texture (Fig. 7).

The amount of dolomite increased to about 60 % and the amount of calcite decreased to *ca.* 40 % in specimens of some carbonate rocks. Such rocks were named dolomitic limestone. Specimens of some rocks had micrite of *ca.* 80 %, fossil of *ca.* 10 % and sparite of *ca.* 10 %. We found such fossils as textularidae, radiolria and tintinitler in the specimens. Such rocks were named biomicrite[26] (Fig. 8a and b). The type section thickness of Uctepeler formation was about 1000 m. Crystallization in the limestones increased towards the north of the formation, but it was less likely to contain microfossils. Uctepeler formation was unconformably covered Gerdekesyayla formation at the bottom. At the top was also unconformable Guzeller formation (Fig. 1).

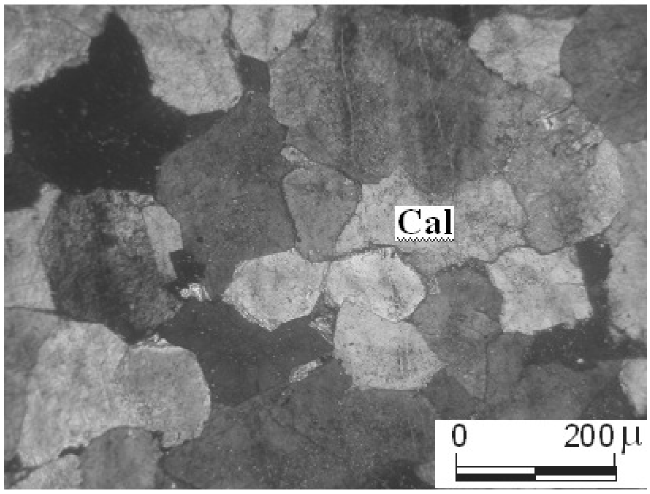


Fig. 7. View of crystalized limestone from uctepeler formation. Cal: calsit (double nicol)

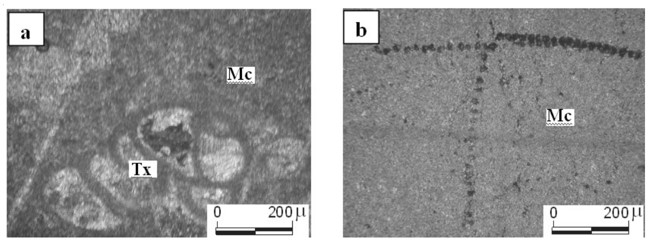


Fig. 8. Thin sections of Uctepeler limestone: (a) Micrite (Mc) and textularidae (Tx) in biomicrite (single nicol), (b) Micrite (Mc) and radiolarya va tintinitler in biomicrite (single nicol)

We first detected the fossils textularidae, radiolria and tintinitler in limestones of Uctepeler formation in the study area. Demirtasli *et al.*[7] had observed the fossils *Kurnubia sp., Prefenderia sp., Clypeina cf., Jurassica, Valvulina sp.* and *Valvulinella sp.* in the area before. In the light of these data, the formation must be of Jurassic-upper cretaceous. Bauxites were encountered in crystallized limestones of Uctepeler formation. The geological position of these diasporic bauxites and their meta-morhosis degree revealed that they were formed in the late Createous period, developed on Jurassic-upper createous aged carbonate rocks, traveled to fill dolines and caves of carbonate rocks (Fig. 9). There were both large and small bauxite reserves and outcrops especially in the middle and west part of the study area (Fig. 2). Some of them, likely to be mapped, were really mapped but in an exaggerated way. The largest bauxite reserve in the study area was near Kucukkoras (Fig. 2). This bauxite reserve (Kucukkoras bauxite reserve), started to be operated after the onset of the present study, extended in the NW-SE direction and it was in the form of cave filling. In the same region, there were also bauxite outcrops in the form of veins and filling the fractures and cracks in the limestones (Fig. 8).

There were also large and small bauxite reserves and outcrops in the formation. The largest of these outcrops, mostly of lens geometry, was 50 m in length and 15 m in width and the smallest was 2 m in length and 0.5 in width. The dolines where bauxites accumulated varied in diameter, reaching maximum 20-25 m (Fig. 10).

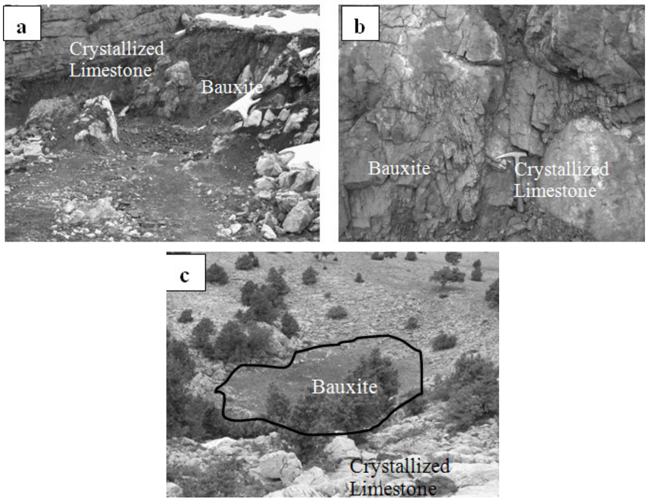


Fig. 9. Bauxite reserves in Uctepeler formation in the mines on Mihliardic Ridges (a) Bauxite in crystalized limestonest, (b) Bauxite filling the spaces of crystalized limestones, (c) Bauxites in the Dolines in Körkuyu in the southeast of Mihliardic ridge

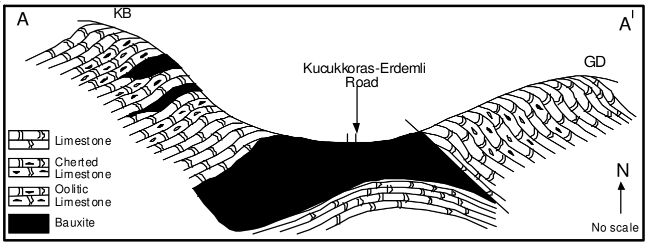


Fig. 10. Horizontal geological sections of Uctepeler formation around the village Kucukkoras and bauxite reserves

Guzeller formation (T_g): Guzeller formation was located in the west and southwest of the Bolkar mountains and covered the formation of the Bolkar group and ophiolite nappe. It was composed of Paleosen-Eosen aged clastic rocks and carbonates. Guzeller formation was first defined by Demirtasli *et al.*[27]. It was made up of polygenic pebbles at the bottom and white-cream, medium-thick-bedded biogenic calcerenite towards the top. These limestones transformed into limestones alternating with greenish, grey limestones marls and sandstones. Demirtasli *et al.*[7] showed that the formation was upper Paleosen-lower Oligosen aged based on the fossils *Discocyclina sp., Lacazina sp., Missisipina sp.* and *Ranikothalia sp.*

Wallrock geochemistry (carbonate rocks): Kucukkoras bauxite reserve in the study area is a carbonate rock which belongs to Uctepeler limestone. Therefore, we determined major element, trace element and rare earth element contents of nine specimens collected from Uctepeler limestone (Table-1). The mean Al concentration of Uctepeler limestone in the study area was 2699.05 ppm (0.26 %) ranging from 370.46 ppm to 6879.95 ppm (Table-1). There was a strong positive correlation between Al and Fe, Si, Ti, Cr, Mn and Sc, a strong negative correlation between Al and Na and a negative correlation between Al and Mg and Ca (Table-2). This may indicate that Al may be bound to clay, feldspar minerals and opaque minerals rarely found in the rocks. In addition, the source of Al may be different from that of Mg and Ca. Al, Fe and Si formed a group in the dendrogram based on the correlation coefficients of the elements, which confirms the relation between Al and silicates (Figs. 11 and 12).

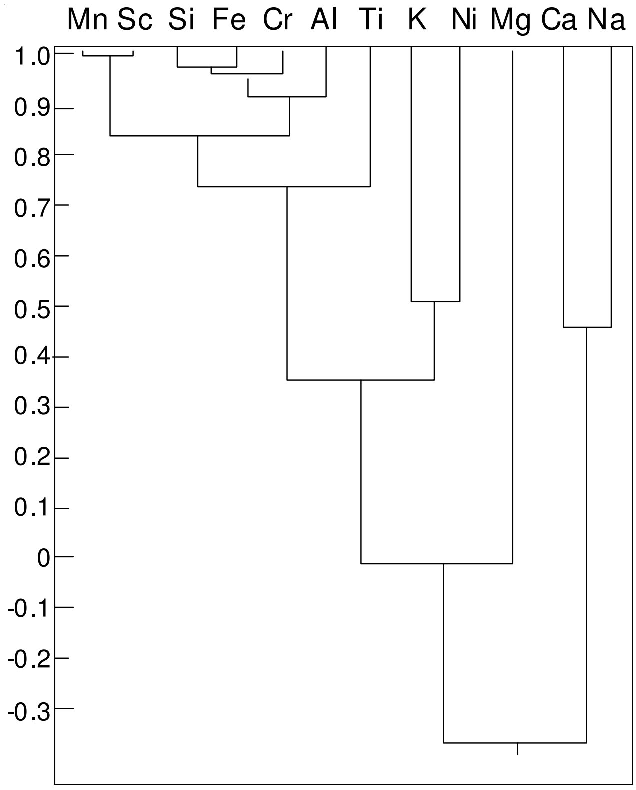
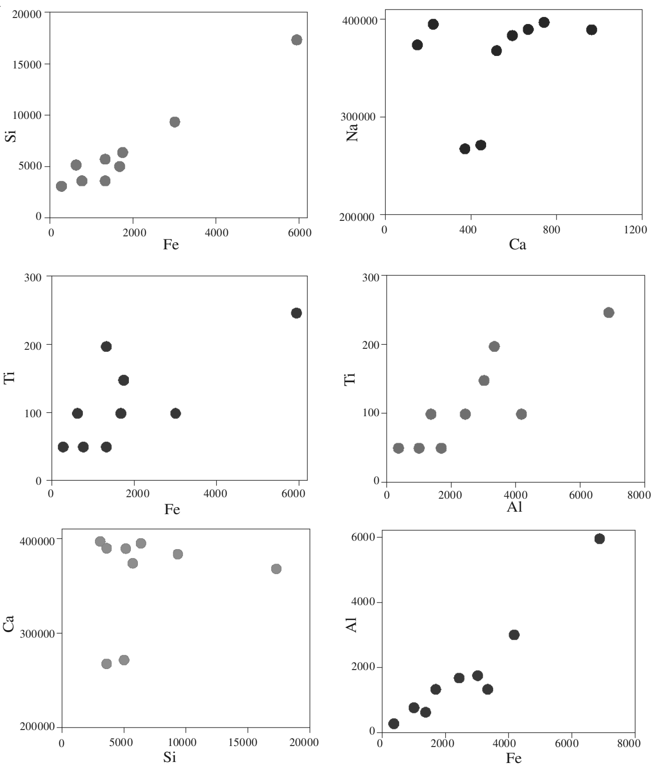


Fig. 11. Dendrogram based on correlation coefficients between major element concentrations of Uctepeler formation



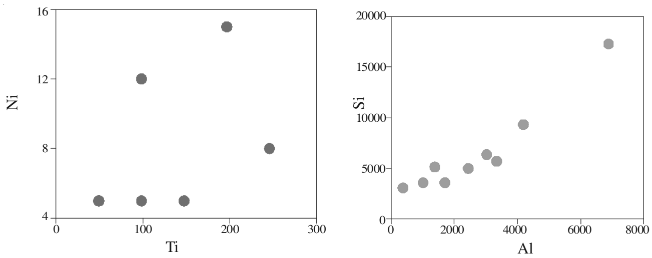


Fig. 12. Regression analyses of major elements of Uctepeler formation

The mean Mg concentration of limestones was 24357.58 ppm (2.43 %) and ranged from 0.2 to 9.23 % (Table-1). Magnesium carbonate was found to be 8.43 %. Therefore, Mg may have been originated from dolomites. There was a weak negative correlation between Mg, Si and Ca (Table-2). Magnesium did not form a group in the dendrogram based on the correlation coefficients of the elements (Fig. 11).

The mean Fe concentration was 1857.39 ppm ranging between 279.77 and 5945.21 ppm (Table-1). Secondary iron hydroxides may have increased the mean Fe concentration. There was a very strong positive correlation between Fe and Si, Al, Mn, Cr and Sc, a strong positive correlation between Fe and Ti and a negative correlation between Fe, Na and Ca (Table-2). Iron formed a group with Si in the dedrogram and Cr and Al also joined this group (Figs. 11 and 12). Therefore, Fe, Si and Al may have resulted from the same source.

The mean Cr concentration was 6.93 ppm (Table-1), quite lower than its Clark concentration of 200 ppm[28]. The mean Cr concentration determined by the acme laboratories[29] was slightly higher than the mean Cr concentration of 5 ppm in carbonate rocks[30]. It ranged between 5.2 and 15.6 ppm in the rocks of the study area. This wide range of Cr concentration can be attributed to an increased heterogeneity of the limestones. There was a very strong positive correlation between

TABLE-1
CONCENTRATIONS OF MAJOR, TRACE AND RARE EARTH ELEMENTS OF UCTEPELER FORMATION IN THE STUDY AREA (ppm)

Sample	Limestone											
	K-1	K-2	K-3	K-4	K-5	K-6	K-7	K-8	K-9	min	max	mean
Si	17296.22	9349.31	3599.48	5703.08	5142.12	3085.27	3599.48	5001.88	6357.53	3085.27	17296.22	6570.486
Al	6879.95	4180.89	1693.53	3334.13	1375.99	370.46	1005.53	2434.44	3016.59	370.46	6879.95	2699.057
Fe	5945.21	3007.58	1328.93	1328.93	629.49	279.77	769.38	1678.65	1748.59	279.77	5945.21	1857.392
Mg	10433.22	5246.76	92330.96	10975.99	3316.92	2834.46	3859.69	85335.28	4884.92	2834.46	92330.96	24357.58
Ca	368067	383575.9	267366.8	373927.5	389436.4	397012.1	389793.7	271369	395082.5	267366.8	397012.1	359514.5
Na	519.3	593.48	370.93	148.37	964.41	741.85	667.67	445.11	222.56	148.37	964.41	519.2978
K	830.15	332.06	332.06	1411.25	581.1	332.06	415.07	1079.19	1328.24	332.06	1411.25	737.9089
Ti	245.91	98.36	49.18	196.73	98.36	49.18	49.18	98.36	147.55	49.18	245.91	114.7567
P	43.64	43.64	43.64	43.64	43.64	43.64	43.64	43.64	43.64	43.64	43.64	43.64
Mn	154.89	77.45	77.45	77.45	77.45	77.45	77.45	77.45	77.45	77.45	154.89	86.054
Cr	15.6	10.4	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	15.6	6.93
Ni	8	12	5	15	5	5	5	12	5	5	15	8
Sc	3	1	1	1	1	1	1	1	1	1	3	1.2
Mo	0.1	0.2	1.3	0.8	0.5	0.2	1.1	2.7	1.8	0.1	2.7	0.96
Cu	5.1	2.9	1.2	1.4	0.6	0.4	0.5	0.4	0.3	0.3	5.1	1.42
Pb	0.4	0.4	0.3	1.3	1.1	0.3	0.6	0.8	1.1	0.3	1.3	0.7
Zn	6	4	6	9	5	2	5	4	6	2	9	5.2
As	4.1	1	1.2	3.6	2.1	1.3	3.8	2.5	4.6	1	4.6	2.68
Cd	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.12
Sb	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.12
Bi	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ag	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Au	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Hg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Tl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Se	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Ba	9.3	5.2	9.9	11.4	4.9	4.8	6.8	6.1	9.8	4.8	11.4	7.57
Be	1	1	1	1	1	1	1	1	1	1	1	1
Co	3.8	2.4	1.3	1	0.5	0.5	0.5	0.5	0.6	0.5	3.8	1.23
Cs	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.6	0.1	0.6	0.18
Ga	1	0.8	0.5	0.9	0.5	0.5	0.5	0.8	0.7	0.5	1	0.68
Hf	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Nb	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.7	0.5	0.7	0.53
Rb	2.8	0.9	0.8	5.5	2.3	0.6	1.4	3.1	4.4	0.6	5.5	2.42
Sn	1	1	1	1	1	1	1	1	1	1	1	1
Sr	127.1	157.4	163.1	155.1	172.4	206.9	163.4	161.1	206.3	127.1	206.9	168.08
Ta	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Th	0.1	0.1	0.1	0.7	0.2	0.1	0.4	0.8	0.3	0.1	0.8	0.31
U	0.8	1.1	2.3	1	1	2.3	3.3	1.5	2.1	0.8	3.3	1.71
V	25	10	11	10	6	6	5	11	10	5	25	10.44
W	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.11
Zr	2.4	1.4	1.3	6.2	3	1.4	3.4	5.3	6.3	1.3	6.3	3.41

Sample	Limestone											
	K-1	K-2	K-3	K-4	K-5	K-6	K-7	K-8	K-9	min	max	mean
Y	1.3	0.7	0.7	1.5	0.8	0.8	2.4	2.6	1.9	0.7	2.6	1.41
La	0.7	0.5	0.5	1.7	1.3	0.5	1.7	2.3	2.2	0.5	2.3	1.26
Ce	1	0.5	0.5	2.9	1.3	0.5	2.6	4.4	3.1	0.5	4.4	1.86
Pr	0.17	0.12	0.09	0.36	0.17	0.1	0.36	0.56	0.5	0.09	0.56	0.27
Nd	0.7	0.4	0.4	1.2	0.6	0.4	1.5	2.2	1.6	0.4	2.2	1
Sm	0.2	0.1	0.1	0.3	0.1	0.1	0.3	0.5	0.4	0.1	0.5	0.23
Eu	0.05	0.05	0.05	0.05	0.05	0.05	0.3	0.5	0.4	0.05	0.5	0.16
Gd	0.31	0.22	0.18	0.28	0.21	0.14	0.38	0.44	0.32	0.14	0.44	0.27
Tb	0.05	0.02	0.01	0.04	0.02	0.02	0.05	0.06	0.07	0.01	0.07	0.037
Dy	0.19	0.1	0.07	0.13	0.09	0.07	0.28	0.39	0.28	0.07	0.39	0.17
Ho	0.05	0.05	0.05	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.054
Er	0.13	0.08	0.05	0.15	0.05	0.06	0.14	0.22	0.17	0.05	0.22	0.116
Tm	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Yp	0.18	0.11	0.07	0.12	0.08	0.05	0.13	0.17	0.15	0.05	0.18	0.117
Lu	0.02	0.01	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.01	0.03	0.02

TABLE-2
CORRELATION COEFFICIENTS OF MAJOR ELEMENTS IN UCTEPELER FORMATION

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cr	Ni	Sc
Si	1.00												
Al	.950**	1.00											
Fe	.976**	.958**	1.00										
Mg	-.244	-.126	-.068	1.00									
Ca	.524	-527	-.620	-.560	1.00								
Na	-.535	-.707*	-.618	-.181	.460	1.00							
K	.180	.397	.215	.061	-.267	-.783*	1.00						
Ti	.789*	.856**	.732*	-.274	-.393	-.738*	.680	1.00					
P	-	-	-	-	-	-	-	-	1.00				
Mn	.905**	.793*	.888**	-.142	-.627	-.518	.114	.707*	-	1.00			
Cr	.964**	.880**	.955**	-.226	-.491	-.415	-.017	.625	-	.884**	1.00		
Ni	.227	.437	.252	.101	-.256	-.389	.518	.445	-	.000	.178	1.00	
Sc	.905**	.793*	.888**	-.142	-.627	-.518	.114	.707*	-	1.000**	.884**	.000	1.00

*Correlations is significant at the 0.05 level; **Correlations is significant at the 0.01 level

Cr and Si, Al, Fe, Mn and Sc and a negative correlation between Cr and Mg, Ca and Na Table-2). Cr formed a group with Si and Fe and Al joined this group (Fig. 11).

The mean concentration of Si resulting from microscopic quartz and other silicate minerals such as chloride, epidote, feldspar and clay minerals commonly found in limestones was 6570.48 ppm (0.65 %) (Table-1).

Silicon concentrations in the limestones ranged between 3085.24 ppm (0.30 %) and 17296.22 ppm (1.72 %) (Table-1). There was a very strong positive correlation between Si and Al, Fe, Mn, Cr and Sc, a strong positive correlation between Si and Ti, a positive correlation between Si and Ca and a weak negative correlation between Si and Mg and Na (Table-2). This may suggest that Si may have originated from secondary silica formations and other silica minerals. Silicon formed a group with Al and Fe in the dendrogram (Figs. 11 and 12).

The mean Ti concentrations in the limestones of Uctepeler formation was 114.75 ppm and ranged from 49.18 ppm to 245.91 ppm (Table-1). There was a strong negative correlation between Ti and Na, a negative correlation between Ti and Ca, a very strong positive correlation between Ti and Al and a positive correlation between Ti and Si, Fe, Mn and Sc (Table-2). It may be due to silicates containing Ti. Titanium was the member of the group (Si-Fe-Cr-Al)-(Mn-Sc) in the dendrogram (Figs. 11 and 12).

The mean Ca concentration was 35.95 % and ranged between 26.73 % and 39.70 %. The mean $CaCO_3$ concentration of the limestones was 89 %. These results were consistent with the results of petrographic observations. There was a negative correlation between Ca and Al, Fe, Mg, Mn and Sc (Table-2). This can be attributed to increased concentrations of Ca and decreased concentrations of Mg due to dolomitization. There was a positive correlation between Ca and Si and Na (Table-2). Calcium also formed a group with Na in the dendrogram (Figs. 11 and 12).

The mean Ni concentration was 8 ppm and ranged between 5 and 15 ppm (Table-1). It was quite lower than the Clark concentration reported[28] (80 ppm), but 2.5 times higher than the mean Ni concentration of carbonate rocks reported[30] (20 ppm). Nickel had a weak positive correlation with Si, Al, Fe, Ti and K and a weak negative correlation with Ca and Na (Table-2). Nickel formed a group with K and joined the group of (Mn-Sc)-(Si-Fe-Cr-Al)-Ti in the dendrogram (Fig. 11).

The mean Na concentration was 519.29 ppm and ranged from 148.37 ppm to 964.41 ppm. (Table-1). Sodium had a strong negative correlation with Al, Ti and K, a negative correlation only with Fe, Mg, Si and Cr and a positive correlation with Ca (Table-2). Sodium might have been enriched by silicates. As a result, pyroxenes found in the limestones might be a source of Na. Sodium formed a group with Ca in the dendrogram (Fig. 11).

TABLE-3
CORRELATION COEFFICIENTS OF TRACE AND RARE EARTH ELEMENTS IN UCTEPELER FORMATION

	Mo	Cu	Pb	Zn	Ni	As	Cd	Sb	Ba	Co	Cs	Ga	Nb	Rb	Sr	Th	U	V	W	Zr	Y	La	Ce
Mo	1.000																						
Cu	-.544	1.000																					
Pb	.324	-.372	1.000																				
Zn	.073	.197	.588	1.000																			
Ni	.054	.642	.169	.565	1.000																		
As	.270	.031	.515	.535	.650	1.000																	
Cd	-.072	-.005	.581	.737*	.211	.247	1.000																
Sb	-.338	.645	.220	.672*	.792*	.466	.661	1.000															
Ba	.173	.215	.309	.867**	.542	.570	.566	.621	1.000														
Co	-.465	.944**	-.555	-.030	.512	-.071	-.320	.383	.070	1.000													
Cs	.524	-.365	.519	.250	-.022	.614	.026	-.136	.388	-.318	1.000												
Ga	.439	-.504	.507	.167	-.508	-.192	.482	-.208	.026	-.596	.316	1.000											
Nb	.306	-.249	.639	.491	.045	.580	.354	.134	.577	-.037	.912**	.389	1.000										
Rb	.332	-.026	.847**	.737*	.493	.707*	.676*	.574	.632	-.241	.572	.370	.728*	1.000									
Sr	.181	-.743*	.141	-.410	-.697*	-.071	-.194	-.609	-.250	-.620	.513	.278	.447	-.078	1.000								
Th	.677*	-.376	619	.354	.145	-379	.530	.109	.219	-.542	.260	.611	.239	.647	-.110	1.000							
U	.291	-.380	-.490	-.414	-.398	.034	-.487	.554	-.104	-.178	.236	-.137	-.038	-.485	.397	-.145	1.000						
V	-.162	.864**	-.234	.286	.823**	.305	-.028	.673	.436	.831**	-.098	-.526	-.040	.217	-.650	-.159	-.317	1.000					
W	.751*	-.239	.097	-.238	.031	-.022	-.125	-.189	-.219	-.196	.026	.327	-.177	.149	-.104	.676*	-.004	.035	1.000				
Zr	.624	-.232	.609	.501	.232	.673	.505	.294	.567	-.359	.725	.518	.729	.821**	.093	.469*	.020	.058	.358	1.000			
Y	.728*	-.299	.348	.121	.231	.641	.045	-.008	.139	-.317	.491	.223	.254	.436	-.041	.756*	.327	-.035	.601	.739*	1.000		
La	.769*	-.504	.749*	.295	.134	.641	.219	-.051	.198	-.560	.685*	.464	.548	.694*	.177	.810**	.025	-.212	.523	.810**	.852**	1.000	
Ce	.883**	-.564	.658	.230	.002	.474	.279	-.099	.153	-.628	.573	.610	.442	.615	.167	.907**	.077	-.289	.649	.820**	.858**	.960**	1.000

*Correlations is significant at the 0.05 level; **Correlations is significant at the 0.01 level

The mean Cu content was 1.42 ppm, ranging between 0.3 ppm and 5.1 ppm. It was quite lower than the Clark concentration of 70 ppm[28] (Table-1). Copper had a very strong correlation with V and a strong positive correlation Ni and Sb (Table-3). Copper also formed a group with V, Ni and Sb in the dendrogram (Fig. 13).

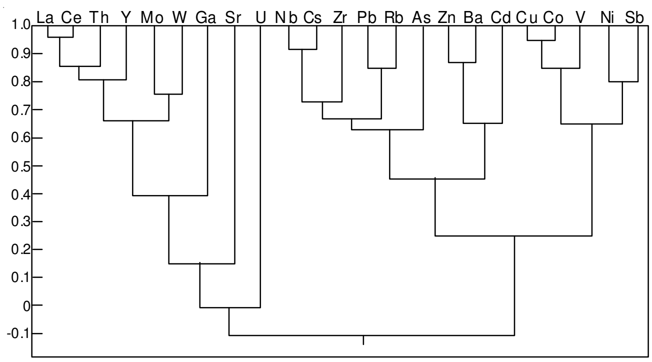


Fig. 13. Dendrogram based on the correlation coefficients of trace and rare earth elements of Uctepeler formation

The mean Mo concentration was 0.96 ppm and ranged between 0.1 ppm and 2.7 ppm (Table-1). Molybdenum had a very strong positive correlation with Ce, a strong positive correlation with Th, W, Y and La and a negative correlation with Cu and Co (Table-3). Molybdenum formed a group with W and united with (La-Ce)-Th-Y in the dendrogram (Fig. 13).

The mean Pb content of the carbonate limestones was was 0.7 ppm and ranged between 0.3 and 1.3 ppm (Table-1). It was quite lower than the Clark concentration of 16 ppm[31]. Lead had a very strong positive correlation with Rb, a strong positive correlation with La and a negative correlation with Cu and Co (Table-3). Lead formed a distinctive group with Rb and joined the group (Nb-Cs)-Zr (Fig. 13).

The limestone specimens had a mean Zn of 5.22 ppm (range: 2-9 ppm) (Table-1). It was nearly equal to the the mean concentration of Zn in the carbonate rocks reported (5 ppm)[30]. The Clark concentration of Zn was 130 ppm. Zinc had a very strong positive correlation with Ba, a strong positive correlation with Cd, Sb and Rb and a negative correlation with Sr, U and W (Table-3). Zinc formed a group with Ba and Cd joined this group in the dendrogram (Fig. 13).

The mean Ga concentration was 0.68 ppm (range: 0.5-1 ppm) (Table-1). Gallium had a positive correlation with Pb, Th, Zr and Ce and a negative correlation with Cu, Ni and Co (Table-3). There was no significant correlation with Ga and the other elements (Figs. 13 and 14).

The mean V concentration was 10.44 ppm, the Clark concentration of V was 150 ppm[28] (Table-1) and the mean V concentration of carbonate rocks was reported to be 20 ppm[30]. In other words, the mean V concentration in the study area was nearly half of its concentration in the carbonate rocks reported. V had a very strong positive correlation with Cu, Ni and Co and a negative correlation with Ga and Sr (Table-3). Vanadium also took part in the group Cu-Co in the dendrogram (Figs. 13 and 14).

The mean Sr was 168.08 ppm (127.1-206.9 ppm) (Table-1). The Clark concentration of Sr in the carbonate rocks was reported to be 610 ppm[32].

The mean Th concentration in the limestones was 0.31 ppm (Table-1). Its Clark concentration in the carbonate rocks was reported to be 1-7 ppm[33]. The mean U concentration was 17 ppm (Table-1) and its Clark concentration in the carbonate rocks was reported to be 1-2 ppm[34].

The mean Nb concentration in the study area was 0.3 ppm (0.5-0.7 ppm) (Table-1). Niobium had a strong positive correlation with Ga, Rb and Cs and a negative correlation with Cu and W (Table-3). Niobium formed a group with Cs and Zr joined this group in the dendrogram (Figs. 13 and 14).

The total concentrations of Bi, Hg, Ag, Tl and Se were 0.1 ppm. It was attributed to a mistake in the analyses and considered insufficient to detect. The result was found to be insignificant and was not included in the analysis.

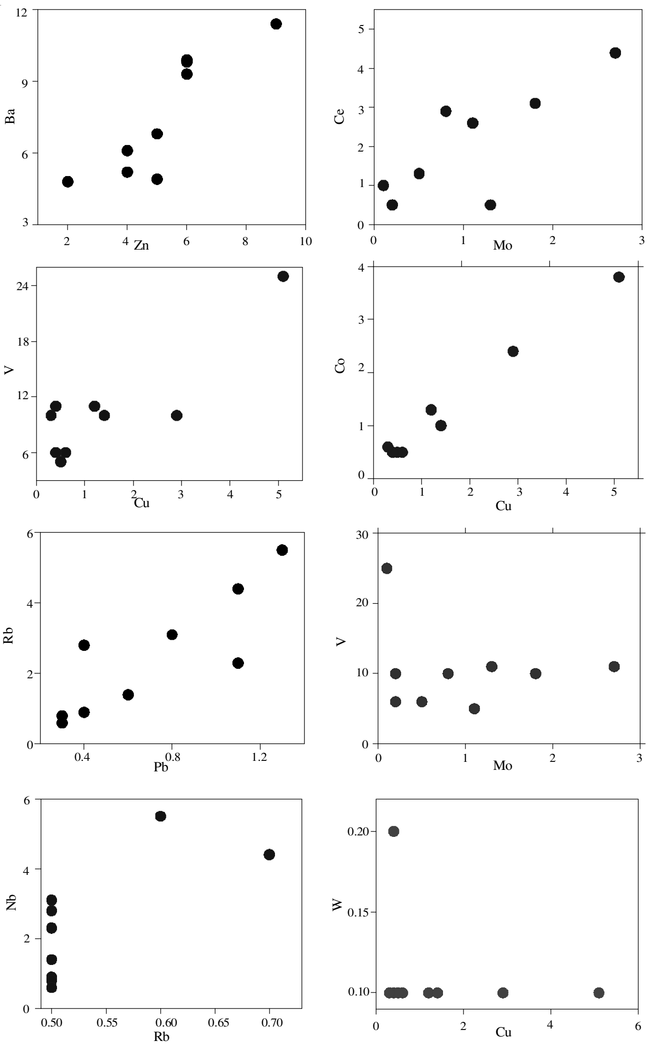


Fig. 14. Regression analyses of trace elements in the study area

Geochemistry of bauxites: The concentrations of major elements, trace elements and rare earth elements in 20 specimens collected from Kucukkoras diasporic bauxite reserves are shown in Table-4.

The mean Al_2O_3 concentration of Kucukkoras bauxite reserves was 57.70 % and ranged between 52.1 % and 62.1 % (Table-4). The mean Al content of Kucukkoras bauxite reserves (30.53 %) was slightly higher than that of the world bauxite reserves (Al_2O_3 of 54.40 %). It was 3.71 times higher than that of the crust (8.22 %) and 117.4 times higher than that of the limestones in the study area and 2.15 times higher than that of the terra rossa in the study area. Therefore, it seems unlikely that the mean Al content of Kucukkoras bauxite reserves might have resulted from the limestones with a very low Al concentration. In fact, bauxites may have originated from terra rossa.

The mean Fe_2O_3 concentrations of the bauxites was 23.4 % and ranged between 14.0 % and 31.8 % (Table-4). The mean Fe_2O_3 concentration of Kucukkoras bauxite reserves was 1.6 times higher than that of the world bauxite reserves (14.43 %). The mean Fe concentration of the bauxites 16.36 %, which was 2.7 times higher than that of the crust (6.14 %), 90 times higher than that of the limestones in the study area and 1.9 times higher than that of the terra rossa.

The mean SiO_2 concentration of Kucukkoras bauxite reserves was 3.2 % and ranged from 0.9 to 11.0 % (Table-4). It was about half of the mean SiO_2 concentration in the world bauxite reserves (6.37 %). The mean Si concentration of the bauxites was 1.49 %, which was 0.05 times higher than that of the crust (27 %), 2.48 times higher than that of the limestones in the region and 0.08 times higher than that of the terra rossa in the region. The Si content of Kucukkoras bauxites was 1.12 times higher than that of the world (2.86 %).

The mean TiO_2 concentrations of the bauxites was 3.1 % with a very low standard deviation (0.1) (Table-4). The TiO_2 contents of Kucukkoras bauxites was higher than that of the world bauxite reserves (2.78 %). The mean Ti element concentration of the bauxites was 1.52 %, which was 4.9 times higher than that of crust (0.63 %). It was 310 times higher than the mean Ti concentration of the limestones and 4.42 times higher than that of terra rossa in the study area.

The triangular diagrams based on the major oxide contents of Kucukkoras bauxite reserves (Al_2O_3-Fe_2O_3-SiO_2) (Al_2O_3-Fe_2O_3-TiO_2) (Al_2O_3-SiO_2-TiO_2) (Fe_2O_3-SiO_2-TiO_2) (Fig. 15) showed that the bauxite reserves were rich in iron, but poor in silicate. Iron was observed to cluster along the side of Al_2O_3-Fe_2O_3 and more in the corner of Al_2O_3 in the Al_2O_3-Fe_2O_3-SiO_2 triangle. Only a very small proportion of bauxite specimens or iron bearing bauxite specimens approached the corner of Fe_2O_3 and depicted the features of iron bearing bauxites.

The Al_2O_3/SiO_2 ratio of bauxites is called a module and plays an important part in determination of the parameters for operation of bauxite reserves. The module values of Kucukkoras diasporic bauxite specimens ranged from 5 to 63.8 with a mean of 31.96. The module based on the mean values was 18.04. As a result, Kucukkoras bauxites could be considered high quality bauxites according to the classification made[35].

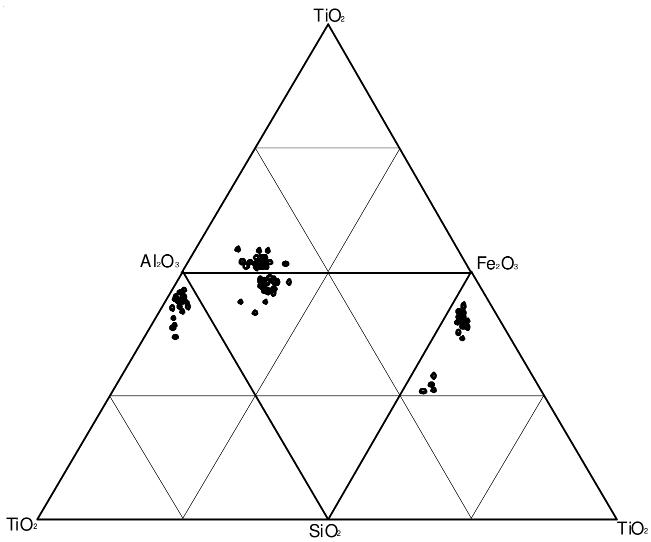


Fig. 15. Triangular diagrams of Kucukkoras bauxite specimens based on their major oxide compositions

As for the concentrations of the major elements in the bauxites and their correlations with each other, the mean Al concentrations of all 20 specimens was 30.54 % and ranged

TABLE-4
CONCENTRATIONS OF MAJOR ELEMENTS. TRACE ELEMENTS AND RARE EARTH ELEMENTS IN THE STUDY AREA (ppm)

Sample	Bauxite																						
	BX-1	BX-2	BX-3	BX-4	BX-5	BX-6	BX-7	BX-8	BX-9	BX-10	BX-11	BX-12	BX-13	BX-14	BX-15	BX-16	BX-17	BX-18	BX-19	BX-20	min	max	mean
SiO_2	38000	17500	21300	23600	12000	13300	16300	9600	19500	28100	9000	11900	10200	17400	93400	63500	13000	89600	110600	22300	9000	110600	32005
Al_2O_3	549000	585400	585900	582700	592200	583100	572800	599500	580200	572100	574600	521700	596300	621700	556400	621100	580300	551900	559600	555100	521700	621700	577080
Fe_2O_3	234500	246400	227200	235100	232000	242900	259400	233900	250300	249100	264000	318900	243400	260300	177400	140600	256900	189800	154500	270700	140600	318900	234365
MgO	4700	1500	1600	1400	700	800	900	500	1100	1300	500	500	500	500	900	700	400	700	900	600	400	4700	1035
CaO	19500	2900	7700	4900	6100	8400	2500	2400	1300	1200	1000	1100	700	900	900	900	700	1000	900	800	700	19500	3290
Na_2O	2200	400	1100	300	200	100	200	100	200	200	300	100	200	100	3700	1000	300	1500	3600	200	100	3700	800
K_2O	500	< 400	< 400	< 400	< 400	< 400	< 400	< 400	< 400	< 400	< 400	< 400	< 400	< 400	1400	500	< 400	1000	1400	< 400	500	1400	960
TiO_2	29900	30700	31800	30500	33200	31800	30700	34500	30200	30900	31100	27300	31500	34600	30900	33100	31700	29700	30400	33200	27300	34600	31385
P_2O_5	300	400	400	600	500	400	600	1300	400	600	400	900	300	900	800	700	200	600	700	600	200	1300	580
MnO	1400	1400	1500	1600	2300	1800	1400	2100	1600	1400	2000	1400	1900	2100	400	500	1400	300	400	2000	300	2300	1445
Cr_2O_3	4500	4600	5200	4800	5700	5200	5600	6100	5200	5700	5800	6200	5100	6100	4900	6600	5400	5200	5300	5400	4500	6600	5430
Ni	80	114	95	128	118	92	162	64	111	157	145	107	115	110	48	64	100	51	56	104	48	162	101.05
Sc	56	69	63	62	88	55	70	68	64	65	67	69	67	78	56	58	64	54	57	71	54	88	65.05
Mo	0.6	0.3	0.4	0.7	0.9	1	0.6	0.9	0.6	0.8	0.7	3.7	0.6	1	4.1	2	0.7	4.9	4.4	0.9	0.3	4.9	1.49
Cu	21.7	59.6	46.4	50.5	56.7	53	71.3	26.3	121	18.9	63.2	51.9	36.7	83.7	52.4	142.4	62	56.8	51.5	47.6	18.9	142.4	58.68
Pb	38.9	55.8	52.6	67.6	29.3	58	55.9	47.8	52.9	54.6	56.9	74.4	51.8	62	60.1	50.9	62.8	69.1	46.9	52.8	29.3	74.4	55.055
Zn	136	68	77	73	70	90	78	42	63	104	41	105	57	96	19	23	50	34	31	91	19	136	67.4
Ni	57.1	69	58.4	89.7	70.8	68.5	107.5	34.4	86.5	110.7	75.5	79.6	77.1	77.8	25.6	35	66.1	33.4	29.2	73.1	25.6	110.7	66.25
As	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.4	0.5	0.5	0.5	5.3	0.5	0.5	9.2	0.9	0.5	9.7	5.7	0.5	0.5	9.7	1.96
Cd	0.3	0.5	0.6	1.5	0.4	1.3	0.5	0.3	0.2	0.2	0.4	0.7	0.4	0.3	0.2	0.2	0.5	0.4	0.3	0.5	0.2	1.5	0.485
Sb	3.5	2.7	3.2	3.4	3.5	4	2.5	5.7	3.1	4.1	2.4	5.4	2.3	3.6	4.4	3.4	4.4	5.3	4.5	5.5	2.3	5.7	3.845
Bi	1.5	1.6	1.7	1.6	1.8	1.6	1.5	1.7	1.4	1.6	1.4	1.5	1.4	2	1.8	1.9	1.4	1.8	2.1	1.6	1.4	2.1	1.645
Ag	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Au	0.0018	0.0038	0.0022	0.0036	0.002	0.0024	0.0007	0.002	0.003	0.0041	0.0031	0.002	0.0013	0.0016	0.0013	0.0006	0.0019	0.0015	0.0013	0.0025	0.0006	0.0041	0.002135
Hg	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.01	0.02	0.01	0.02	0.05	0.05	0.01	0.02	0.02	0.01	0.01	0.05	0.0185
Tl	0.1	0.1	0.2	0.3	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.3	0.15
Se	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Ba	47.9	33.5	39.2	51.6	35.3	40.3	29.4	34	35.9	26.4	40	44.4	32	23.2	24.2	24.5	29.6	22.7	18.5	31.4	18.5	51.6	33.2
Be	6	7	10	10	9	6	8	6	9	7	9	6	9	6	5	5	7	6	6	6	5	10	7.15
Co	28.3	28.2	25.8	37	39.4	33.1	29	16	25.8	34.6	31.3	38.1	31.5	41.3	10.2	21	28.8	18.3	10.3	27.2	10.2	41.3	27.76
Cs	0.1	0.2	0.1	0.3	0.1	0.3	0.1	0.1	0.2	0.4	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.8	0.3	0.2	0.1	0.8	0.21
Ga	63.1	66.4	66.9	65.4	65.9	57.2	65.8	67.4	65.6	63.1	68	59.9	66.5	72.6	64.8	80.4	67.7	67.7	63.9	69.3	57.2	80.4	66.38
Hf	17	17.3	17.2	17.1	16.2	16.9	15.7	16.3	14.6	16.9	16.1	14.1	16.2	17.7	16.5	18.5	15.9	16.3	17	18.9	14.1	18.9	16.62
Nb	66.6	67.1	70.6	66.7	69.8	68.8	65.9	67.3	63.3	65.7	65	56.4	66.4	73.9	66.7	77	66.7	67.4	68.8	74.3	56.4	77	67.72
Rb	2	1.2	1.1	1.2	0.5	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.4	1.4	0.5	2.2	2.4	0.6	0.5	2.4	1.01
Sn	14	13	13	14	13	14	13	13	13	12	11	12	13	14	11	15	12	12	12	13	11	15	12.85
Sr	41.7	44.2	50.1	46.5	28.7	30.1	43.8	27.4	47.2	42.9	29.8	33.5	30.1	22.7	116.6	133	27.9	97.3	106.2	37	22.7	133	51.835
Ta	5.1	5.2	5.6	5.3	5	4.9	5	5.2	4.7	5	5	4.1	4.5	5.3	5.1	5.5	5.1	4.8	5.2	5.3	4.1	5.6	5.045
Th	50.5	47.3	49.8	47.4	47.7	48.5	45.6	50.4	48.2	48.6	49.4	42.5	43.4	51.6	4439	56.5	46.5	47.2	47	55.9	42.5	4439	268.15
U	8	7.6	9.2	8.9	9.5	8.2	9	7.7	8	7.5	8.2	7.8	7.5	8.5	9.8	10.5	8	10.1	9.4	9.6	7.5	10.5	8.65
V	573	604	619	627	680	595	593	667	535	590	653	706	572	787	574	711	651	609	635	736	535	787	635.85
W	5.6	6.5	5.7	5.8	6.4	5.8	5.4	5.8	5.1	5.9	5.2	5.3	5.3	5.8	5.9	7	5.9	5.9	6.4	5.7	5.1	7	5.82
Zr	551.8	545.8	567.1	555	577.4	558.8	536.8	549	509.5	554.4	538.3	481.3	536.9	629	596.7	637.2	557.2	558.5	582.4	636.3	481.3	637.2	562.97
Y	64.9	67	78.7	77.1	84.3	66.6	88.4	49.9	77.8	70.8	69	63.2	68.2	58.6	54.6	58.4	65.4	55.1	52.3	67.3	49.9	88.4	66.88
La	82.3	110.5	111.1	128.4	173.9	81.1	163.9	67.7	114.4	104.3	113	74.6	112.1	74.2	72.7	91.3	113	93.4	83.5	95.5	67.7	173.9	103.045
Ce	293	329.2	308.3	367	648.9	370.1	441.5	303.6	267.4	300.3	338.2	229.7	345.8	299.6	295.6	373.7	350.6	335.3	334	441	229.7	648.9	348.64
Pr	16.56	23.04	22.21	28.27	41.72	46.06	35.32	13.75	24.81	20.63	25.38	15.95	24.66	15.25	14.48	17.6	24.86	18.47	16.36	20.57	13.75	46.06	23.2975
Nd	58.2	77	78	98.6	150.4	55.8	124.2	45.1	87.9	68.6	84.6	57.5	81.5	52.6	50.3	57.5	86.8	64.3	53.9	67.2	45.1	150.4	75
Sm	11.7	15.4	16.1	21.2	32.3	12.8	25.5	9.3	18.3	14.3	18.5	12.7	17.6	11.4	8.6	9.6	18.1	11.2	9.1	13.4	8.6	32.3	15.355
Eu	2.37	3.27	3.23	4.28	6.5	2.57	5.02	2.11	3.85	2.97	3.48	2.83	3.63	2.34	1.8	1.81	3.54	2.31	1.62	2.92	1.62	6.5	3.1225
Gd	9.47	11.8	12.29	15.72	21.41	10.45	18.34	7.59	14.64	11.73	13.78	12.5	13.63	9.78	5.89	7.12	13.55	8.6	5.53	9.95	5.53	21.41	11.6885
Tb	2.03	2.26	2.47	2.9	3.76	1.9	3.19	1.57	2.66	2.16	2.59	2.37	2.45	1.86	1.31	1.61	2.56	1.85	1.39	2.21	1.31	3.76	2.255
Dy	11.65	13.66	14.66	15.91	20.24	12.01	17.03	9.68	15.65	13.97	14.58	13.43	13.99	11.07	8.08	9.6	14.46	10.09	8.36	12.64	8.08	20.24	13.038
Ho	2.49	2.77	3.16	3.21	3.51	2.33	3.33	2.09	3.11	2.72	3.06	2.53	2.84	2.39	1.74	2.02	2.95	2.07	1.76	2.64	1.74	3.51	2.636
Er	7.78	8.9	9.46	9.89	0.82	7.68	10.44	6.61	9.8	8.85	9.34	8.37	9.3	7.43	6.34	6.82	8.89	6.83	6.17	8.28	0.82	10.44	7.9
Tm	1.22	1.49	1.55	1.67	1.73	1.15	1.61	1	1.6	1.45	1.58	1.33	1.47	1.22	1.02	1.17	1.43	1.09	1	1.35	1	1.73	1.3565
Yp	8.38	9.37	9.79	11.64	11.26	7.89	10.74	7.48	10.52	9.46	10.74	8.67	10.29	8.07	7.42	7.88	9.77	7.81	7	8.92	7	11.64	9.155
Lu	1.26	1.49	1.49	1.78	1.8	1.14	1.65	1.19	1.61	1.41	1.65	1.23	1.56	1.26	1.12	1.26	1.48	1.13	1.16	1.26	1.12	1.8	1.3965

TABLE-5
CORRELATION COEFFICIENTS OF THE MAJOR AND TRACE ELEMENTS IN THE STUDY AREA

	Al	Cr	Ca	Fe	Cu	Mg	K	Ni	P	Si	Ti	Zn	Ga	Co
Al	1.00													
Cr	-.147	1.00												
Ca	.179	-.387	1.00											
Fe	-.506*	.556*	-.130	1.00										
Cu	-.441	.490*	-.266	.664**	1.00									
Mg	.077	-.583**	.884**	-.096	-.141	1.00								
K	-.332	-.229	-.140	-.176	.104	.007	1.00							
Ni	.390	.065	-.125	-.105	-.096	-.182	-.655**	1.00						
P	-.380	.314	-.343	.185	.554*	-.244	.376	-.047	1.00					
Si	-.427	-.175	-.085	.065	.243	.090	.926**	-.682**	.366	1.00				
Ti	-.101	.184	.076	.262	-.003	-.006	-.364	.301	-.129	-.457*	1.00			
Zn	.301	-.159	.585**	-.217	-.334	.444	-.540*	.455*	.023	-.524*	.188	1.00		
Ga	-.231	-.003	-.006	.227	.134	.056	.074	-.352	.168	.189	-.009	.057	1.00	
Co	.323	-.014	.205	-.285	-.317	-.038	-.370	.340	.008	-.476*	.062	.545*	-.238	1.00

*Correlations is significant at the 0.05 level; **Correlations is significant at the 0.01 level

from 27.6 to 32.9 %. Aluminium had a positive correlation with Zn, Ni and Co and a negative correlation with Si and K (Table-5). There was very strong correlation between Al and Fe, which was unusual for bauxites because Al and Fe exhibit similar features under surface conditions. The coefficient correlations between the elements revealed that Al partook in Zn-Ni-Co group (Fig. 16).

The mean Cu concentration of Kucukkoras bauxites was 60.67 ppm and ranged from 18.9 to 142.4 ppm (Table-4). The mean Cu concentration of the bauxites was nearly the same as in the crust (68 ppm). The bauxites were 43 times richer in Cu than the limestones (1.42 ppm) and 1.2 times richer in Cu than the terra rossa (50.89 ppm). There was a strong positive correlation between Cu and Fe and Cr and there was a negative correlation between Cu and Al (Table-5). Copper also formed a group with Fe and Cr in the dendrogram (Fig. 16).

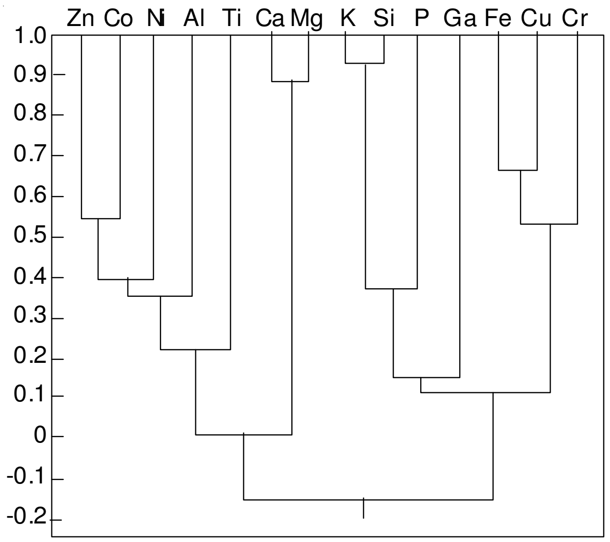


Fig. 16. Dendrogram based on coefficient correlations between concentrations of the trace elements in the bauxites

The mean Fe concentration of the bauxites was 16.2 %, ranging between 9.8 and 22.3 %. Iron had a very negative correlation with Al and a very strong positive correlation with Cr and Cu (Table-5). In the dendrogram, Fe formed a group with Cu and Cr joined this group (Fig. 16).

The mean K concentration of the bauxites was 448 ppm, ranging between 332 and 1162 ppm. The limestones were 0.6 times richer in K (737 ppm) and the terra rossas were 0.03 times richer in K (14021 ppm) than the bauxites. It seemed that K in the terra rossas was still bound to silicate and was not carried away. It was dissolved during bauxite formation. Potassium had a strong positive correlation with Si and a strong negative correlation with Ni and Zn (Table-5). In the dendrogram, K formed a distinctive group with Si and P joined this group (Fig. 16).

The mean Ga concentration of the bauxites was 66.6 ppm (Table-4) and was a little higher than that of the world (55 ppm)[22]. The mean Pb concentration of the bauxites was 54.7 ppm, which was much lower than that of the world. This suggested that Kucukkoras bauxites were similar to lateritic bauxites which originated from magmatic rocks. The mean Ni concentration of the bauxites was 101.05 ppm, which was nearly equal to that of the crust (99 ppm).

Origin of Kucukkoras bauxites: Kucukkoras diasporic bauxites were in and on the carbonate rocks of Jurassic-upper cretaceous uctepeler formation. For this reason, the bauxites were of upper cretaceous. The margins of the wallrock bauxites were irregular had a zizag pattern. Pieces of wallrocks were found to be blocky in the bauxites. This may suggest a lateritic or karstic sedimentation.

The bauxite ores were found in the form of lens, dolines and vessels. The bauxite ores with a lens-shaped geometry extended from the NW to the SE and were 3 m in width and 5 m in thickness. The doline bauxites had present-day structure and were 20-25 m in diameter. The bauxites ores in the form of vessels were 1-10 m in length.

Mineralizations in the region were diasporic and can be classified as in the following: brown (hematite), black (magnetite), oolitic and clayey (reddish, yellowish, greyish, colourful) bauxites[22,24]. This suggests that aluminum hydroxide, iron hydroxide, clay minerals, pieces of rocks and thin-grained sediments may have traveled and accumulated in various places when bauxites were carried and stored. These types of mineralizations which depicted lateral and vertical transitions into each other may have appeared in intra-karstic environments.

All bauxites were in the carbonate rocks. There were detachment zones, indicative of lateritic enrichment. But there were meta-morphic grading depending on detachment of silicate minerals. It indicated that lateritic enrichment may not have occurred in place but that the bauxites may have come from another place and stored.

Abundance of oolitic structures in the bauxites showed that the sedimentary environment had high energy. Presence of Fe in the nuclei of the oolites suggested that the source rocks might have high amounts of Fe. However, oolitic parts were gradually transferred into massive bauxite or clayey parts at 10-15 m intervals. It may indicate that environmental conditions might have changed at short intervals.

Abundance of boehmite in the lateritic bauxites shows that this mineral developed under surface conditions[35]. Gibbsite is stable in the Al_2O_3-H_2O system at low temperatures, but turns into boehmite and diaspore when temperature and water vapour increases. In this system, transformation of gibbsite to boehmite occurs under water vapour pressure at 140-200 ºC. Accordingly, gibbsite changes into boehmite under 200 ºC and boehmite turns into diaspore at 300 ºC.

It is expected that pH should be 4.5-6.5 under surface conditions so that gibbsite, the primitive bauxite mineral, can be formed. Under atmospheric conditions, pH should be higher than 7 and Eh should be higher than 0.2 for sedimentation of hematite and psilomelane. Under atmospheric conditions, pH should be higher than 7 and Eh should be lower than -0.2 for sedimentation of magnetite. Magnetites in Kucukkoras bauxites may have developed from transformation of chloritoides and these transformations can be seen microscopically.

Abundance of rutile in the bauxites can be enriched from wallrocks. Besides, abundant rutile shows that the bauxites may not have traveled long distances.

We thought that the carbonate rocks and terra rossas found around Kucukkoras bauxite reserves may have been sources of the bauxites. Terra rossas were considered as the sign of an intermediary stage in the formation of the bauxites and the rates of changes were estimated according to the carbonate rocks. Besides, Kasir diabase, which was located around the Bolkar Mountains, not in the study area, might have had an influence in the formation of the bauxites.

The bahaviours of the elements detected in the rocks exposed around Kucukkoras bauxite reserves and likely to be sources of the bauxites were as in the following: there were positive correlations between Al and Fe, between Al and Ti, between Al and Mn, between Fe and Mn, between Cr and Mn, between Cr and Sc, between Al and Si and between Al and Cr, but there were negative correlations between Al and Mg, between Al and Ca, between Al and Na, between Na and K, between Fe and Ca and between Mg and Cr in carbonate rocks. This can be explained by presence of metallic elements and the compounds which form rocks in the carbonate rocks. In the dendrogram, there were two main groups: Si-Fe-Cr-Al-Mn-Sc-Ti *vs.* K-Ni-Mg.

In the terra rossas, there were positive correlations between Al and Si, between Al and Ti, between Al and N, between Al and Sc, between Si and Ti, between Ti and Ni and between Mg and Fe, but there were negative correlations between Al and Fe, between Al and Mg, between Fe and Ti, between Ti and Mg, between Na and Ti and between Si and Fe. The negative correlation between Al and Fe remains unexplained. Although Al and Fe act together under surface conditions, there was a negative correlation between these two elements. In the dendrogram, there were two main groups: Al-Sc-Ti-Ni-Si *vs.* Mg-P-Fe-Na-Ca.

Conclusion

There were bauxite outcrops, large and small, in Kucukkoras. These outcrops were in the form of eroded surfaces or wells in the same karstic system. The bauxite reserves of the region were located Jurassic-upper cretaceous aged uctepeler formation. Stratigraphically, they may have been formed in the upper cretaceous period. Kucukkoras bauxite reserves lied in the direction of NW-SE. There were three types of bauxite ores: lens, karstic fills (doline fills) and veins. The biggest bauxite outcrops, mostly of lens geometry, was 50 m in length and 15 m in width and the smallest was 2 m in length and 0.5 m in width. The bauxites in the form of vessels were 1-10 m in length. Dolines were 20-25 m in diameter at maximum and filled with bauxite.

Geochemical investigations revealed that limestones and terra rossas could be the sources of bauxites. Kasir diabase, which was located around the Bolkar mountains, not in the study area, may have affected the bauxite formation as well. The bauxites did not stay in place after they were formed. The bauxites rose and the rocks on their top were eroded and exposed. Based on the analyses of the specimens collected from Kucukkoras bauxite reserves, Al_2O_3/SiO_2 ratio of the bauxites was calculated and their module value was 18.04. As a result, Kucukkoras bauxites were found to be the first grade bauxites according to the classification made[36].

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