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Full Length Research Paper

Mineralogical and petrographical characteristics of the Aladag skarn deposit (Ezine/Canakkale-West Turkey)

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The study area located 35 km south of the Çanakkale city center and 8 km southwest of Ezine County (Çanakkale-Turkey) and covers about 80 km^2. The main settlements in the study area are Aladağ, Kemalli, Üsküfçü, Koçali and Gokcebayir villages. Pre(?) Cambrian to Holocene aged magmatic, metamorphic and sedimentary rocks crop out in the study area. The basement of the study area is formed by Lower Cambrian- Pre(?)-Lower Cambrian aged Geyikli formation, comprising primitive alternating sequenced low-grade metamorphic rocks, such as sandstone-claystone-limestone. Geyikli formation is overlaid by the middle-late Permian Bozalan formation, which consists of recrystallized limestones. Cretaceous aged Denizgoren Ophiolites thrusted over the older units. Upper Oligocene-lower Miocene Hallaclar volcanics composed of altered andesite and rhyolite. On the other hand, Kestanbol Pluton, same age with Hallaclar volcanics and represented by mainly quartz-monzonite, monzonite, monzodiorite porphyry, syenite porphyry and quartz-syenite porphyry. Lower- middle Miocene aged Ezine volcanics composed of pyroxene-andesite and trachyte. Plio-quaternary Bayramiç Formation overlaid these units with disconformity and also consists of slightly cemented conglomerate, sandstone and mudstone. In the study area, Hallaclar volcanics and Denizgoren Ophiolites were affected by alteration with the intrusion of Kestanbol Pluton. Skarn type mineralization was developed close to Kestanbol Pluton contacts with the carbonaceous rocks of the Bozalan formation and Denizgoren Ophiolites which is located north of Aladag. Highly dense clay alteration is observed near the contacts of Hallaclar volcanics with the Kestanbol Pluton. Therefore Ca-silicates and some metallic enrichment such as iron, copper, zinc and lead were developed in the skarn zone. Malachite fillings are observed in the fractures of the pluton. Mainly garnet (grossular), tremolite/actinolite, epidote and zoisite/clinozoisite paragenesis were observed while minor amounts of talc, wollastonite, augite, diopside were determined in the thin section samples, taken from skarn mineralization, which is located north of Aladag. In addition, the main ore minerals are represented by magnetite, hematite, chalcopyrite, sphalerite, galenite, cerussite, covellite, digenite, malachite and pyrite in the polished section samples, taken from the same location with thin section samples.

Key words: Skarn-type mineralization, geology, ore deposits, Aladag, Ezine.

INTRODUCTION

The study area located at the north east edge of the Kestanbol Pluton and its environs, covers approximately 40 km^2 of an area in the western edge of the Biga Peninsula (NW Turkey). In addition, the study area is placed 35 km south of the Çanakkale city center and 8 km southwest of Ezine County (Çanakkale-Turkey). The main settlements in the study area are Ezine county and Aladağ, Kemalli, Üsküfçü, Koçali and Gokcebayir villages (Figure 1).

Biga Peninsula (NW Turkey) due to geological and economic importance has been subject to many researches since past (Kalafatçıoğlu, 1963; Doyuran, 1969; Jacopson et al., 1969; Bingöl et al., 1973; Erseçen, 1978; Ercan, 1979; Andıç, 1984; Ercan et al., 1994; Ercan et

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Figure 1. Location map of the study area.

al., 1985; Gevrek et al., 1985; Önal, 1985). In recent years especially because of the economic mineral deposits, the Peninsula was the subject of extensive research (Birkle and Satır, 1995; Ercan et al., 1995; Okay et al., 1996; Yılmaz et al., 1994; Gözler, 1986; Karacık and Yilmaz, 1998). A large number of metallic mineral deposits (lead, zinc, copper, iron, gold) are available in northwestern Turkey, depending on the granitoidic plutonic rocks and young volcanic activities. A lot of base and precious metals, stable isotopes, petrological, genetical and environmental health works were done in the the study area and the immediate vicinity (Okay and Satır, 2000; Yıkılmaz et al., 2002; Beccaletto and Jenny, 2004; Duru et al., 2004; Dönmez et al., 2005; Merdanoğlu and Altınsoy, 2006; Yılmaz Şahin et al., 2010; Örgün et al., 2009; Aydın, 2010; Arık and Aydın, 2010). Earlier generation galleries are available in the north of Aladag. Operation of gold and gold deposits in the region, especially in the production are still controversial. During this study, a number of old production pits have been identified in the study area opened in order to excavate for gold. Therefore, this region is thought to historic periods, mine operated.

This study is aimed at the geological features of an area cover of about 40 km^2 in the region, with the determination of metallic and industrial mineral deposits and mineral enrichments (Figure 2). In addition to finding out the economic characteristics of the skarn zone among the Kestanbol Pluton (Ezine - Canakkale) which is one of the important granitoidic plutons of Turkey and the adjacent ophiolitic rocks of Denizgoren ophiolites and carbonate rocks of Bozalan formation and the conditions of ore deposition.

MATERIALS AND METHODS

The formation boundaries were checked and updated, in light of the previous studies at the year 2008 summer season. During the field studies for determining the mineralogical and petrographical features, 90 sample have been collected from the different formations and skarn zone. 27 of these samples were chemically analyzed in the General Directorate of Mineral Research and Exploration of Turkey (MTA). In order to investigate the mineralogical and petrographical features of the different formations and rock types, 37 thin sections were prepared and investigated

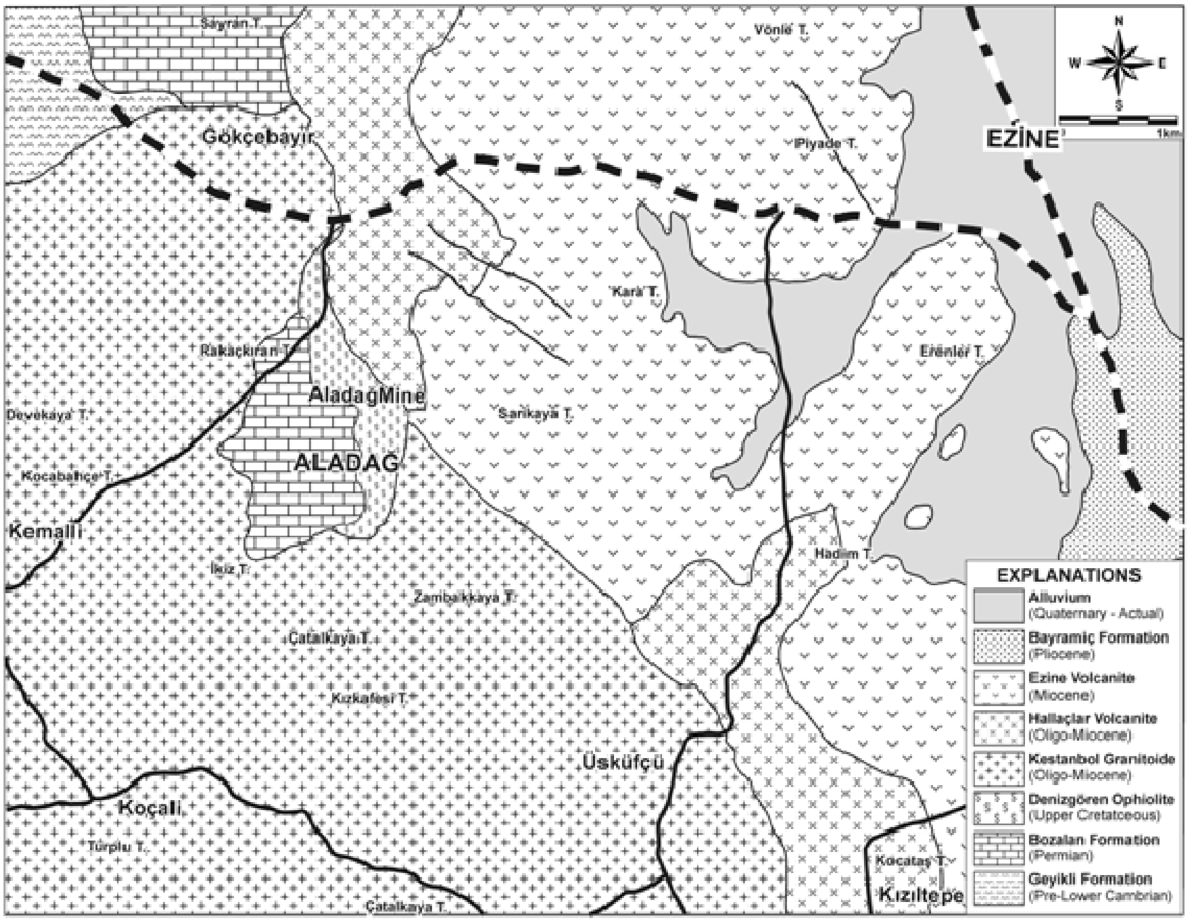

Figure 2. Geological map of the study area.

under polarizan microscobe at the MTA and Geological Engineering Departments of Ankara University and Selcuk University. The rest 27 samples collected from the skarn zone between the Kestanbol pluton and carbonate rocks of Bozalan formation and ophiolitic rocks of the Denizgören ophiolites, were polished and investigated under ore microscoby at the Ore Deposit-Geochemistry Division of the Geological Engineering Department of the Ankara University and MTA Laboratories.

Geologıcal settıngs

Pre-tertiary geological units outcropped in the Biga Peninsula are Sakarya zone, Çetmi Melange and Ezine zone tectonically-related, ranging from NE-SW at the west of the İzmir-Ankara Zone (Duru et al., 2004). According to Kalafatçıoğlu (1963) geological units cropped out in the vicinity of the Ezine and Bozcaada region from bottom to top are Paleozoic metamorphic rocks, Permian limestone and flysch, Eocene limestone and flysch, tertiary lake sediments, acid intrusion, ophiolitic series rocks, volcanic rocks and alluvial sediments are available. In this investigation, Pre-lower Cambrian to Holocene aged, 8 different geological units were determined in the study area. Pre-lower Cambrian aged Geyikli formation, forms the basement of the study area and represented by the alternation of low-grade metamorphic featured rocks such as calcschists, metasandstones and phyllites. Middle-late Permian Bozalan formation consists of recrystallized limestones and extends over the Geyikli formation by unconformity.

Cretaceous aged Denizgören Ophiolites usually consists of serpentines and emplaced on the other units by tectonic boundary. Upper Oligocene-lower Miocene Hallaçlar volcanics consists of altered andesite and rhyolite. In addition upper Oligocene-lower Miocene aged Kestanbol Pluton, cuts the older units and are mainly represented by quartz monzonite, monzonite, monzodiorite porphyry, monzonite porphyry, syenite porphyry and quartz syenite porphyry. Lower-middle Miocene aged Ezine volcanics consist of pyroxene andesite and trachytes. Plio-quaternary aged Bayramic formation represented by conglomerate, sandstone and mudstone. All of the the older units overlain unconformably by alluvium consist of slightly consolidated and unconsolidated terrestrial clastics (Figures 2 and 3).

Geyikli formation

Geyikli formation is represented by the low-grade metamorphic rocks such as metasandstone, phyllite, calcschists and metacarbonates. The unit crops out in a restricted area on the northwestern side of the study area. Although they spend metamorphosed sandstone, claystone, clayey limestone and limestone the place of the primary sedimentary features can be monitored. The rocks of the Geyikli formation have orientation and weak foliation. In addition, in some places medium-thick sedimentary beddings are seen.

Geyikli formation is the basis of the study area. The unit is unconformably over the younger units. Geyikli metamorphics with

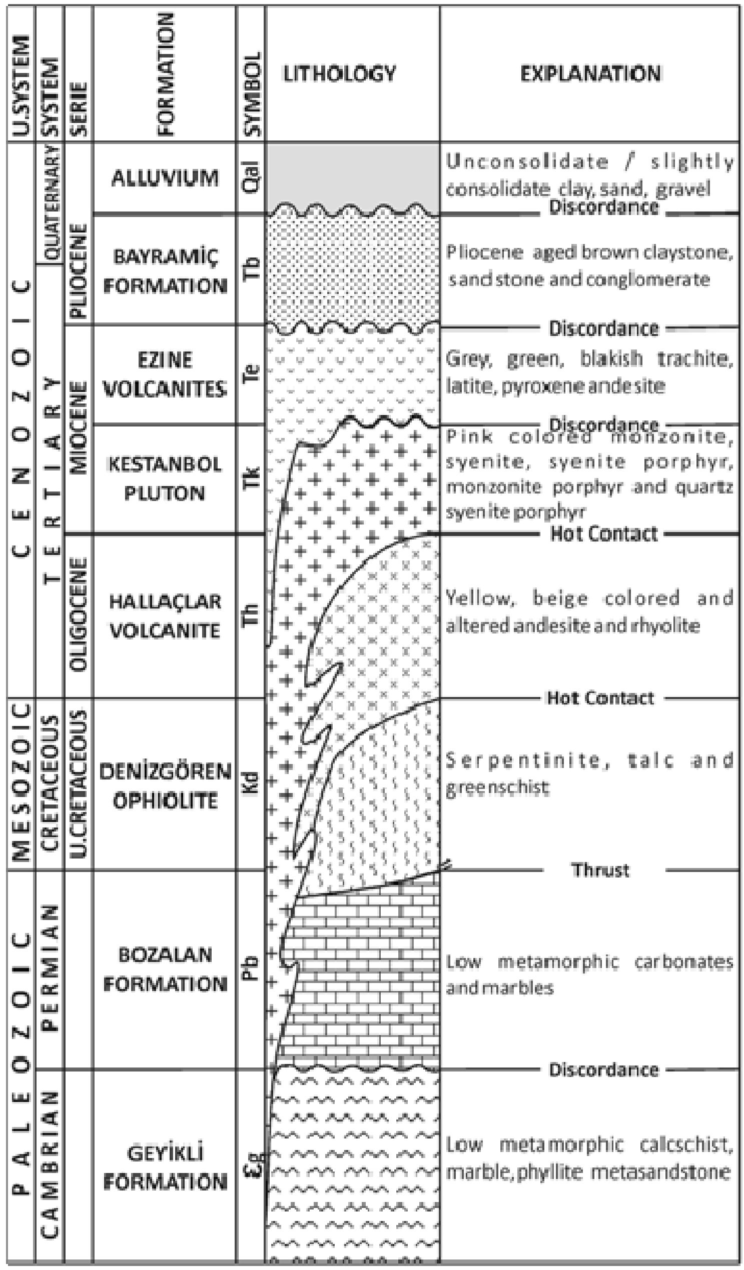

Figure 3. Generalized tectono-stratigraphic columnar section of the study area (no scale).

lithologic features were examined within the epimetamorphics which were defined for all the low-grade rocks in the Biga Peninsula (Bingöl et al., 1973) and Nusretiye formation (Gözler et al., 1984). Metaquartzite and calcschist in the lower levels of the Karadağ Unit, were defined by Okay et al. (1990), corresponds to lower levels of the Geyikli formation defined by Beccaletta and Jenny (2004).

The age of its formation within the unit could not have been found by fossils. In order to determine the age of metamorphism of the unit Donmez et al. (2005) found the 531 ± 86 Ma (Lower Cambrian) with the Rb / Sr radiometric age on muscovites collected from the micaschists samples at the 200 m south of the Geyikli village. Therefore, the formation age of the Geyikli formation, should be Lower and/or Precambrian accordingly Early Cambrian metamorphism age.

Bozalan formation

Bozalan formation consist of mainly low metamorphic carbonate rocks and marbles. From bottom to top, thin quartzite bands at the bottom and phyllite, metasandstone and marbles to the top. The formation is cropp out Aladağ and north of the Gökçebayır village. The unit was called as Permian limestone by Kalafatçıoğlu (1963) for the first time. Unit correspond to Nusretiye formation in a section of the Permian limestones defined by Gözler et al. (1984) and late Permian recrystallized limestones of the Karadağ Unit defined by Okay et al. (1990).

Bozalan formation could be comparable with lithological similarities to upper levels of the Geyikli formation and lower levels of the Karadağ Formation described by Beccaletta and Jenny

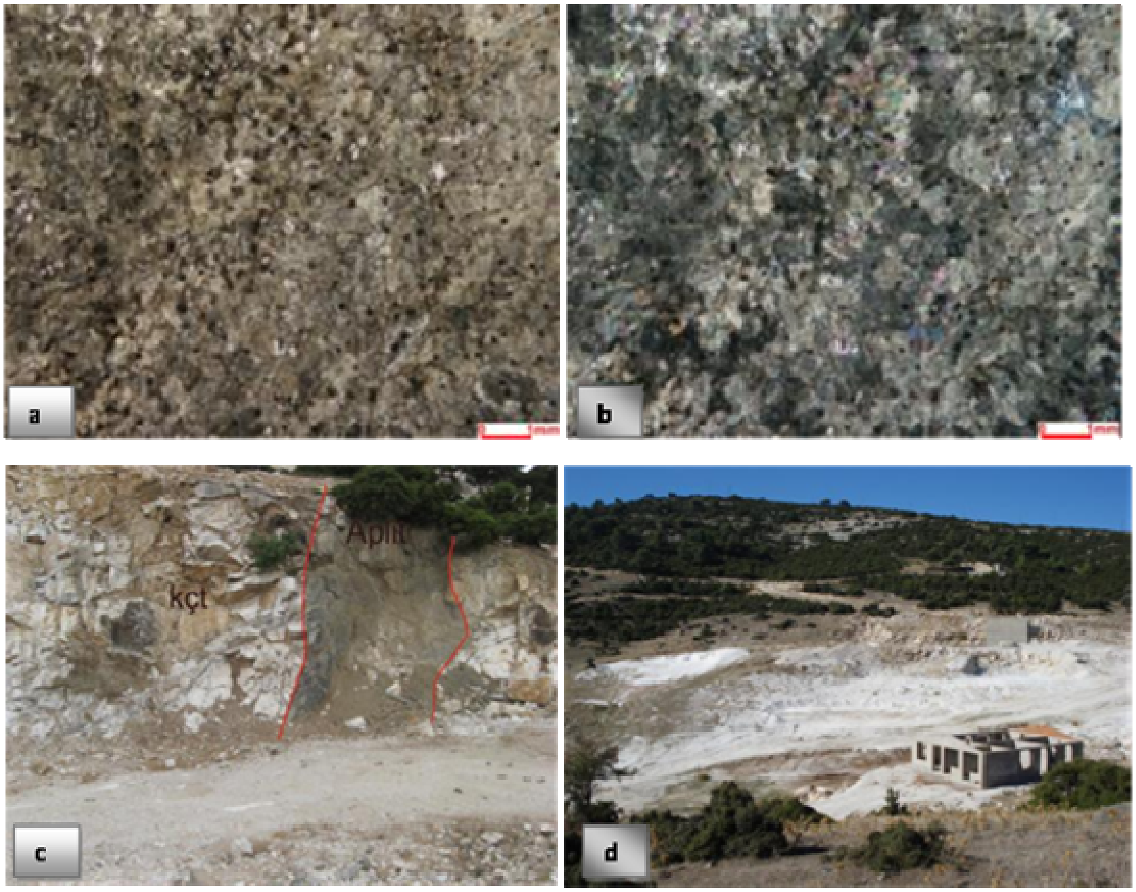

Figure 4. a, b.) Micro photos of the granoblastic texture formed by calcite cyristals in the recyristallized limestones of the Bozalan Formation (a: //N,b: +N), c), c) An aplite vein intruded in the Bozalan Formation b) A marble quarry near the Aladağ.

(2004). Bozalan formation starting with 1 to 2 m thickness and a small (1 to 3 cm), gravelly sandstone and quartzite northeast of the Geyikli village and eastern slopes of the Hacetdede and Bayırgölü hills. Clastics are continuing upward, a regular sequence alternation of metasandstone and phyllites. In the dark brown-gray, pinkish color phyllites clear foliations are observed. In phyllites, light green-gray, brown-colored, thin-bedded, well sorted and binding material are mainly composed of carbonate cement sandstone levels locally. Limestones are limited in the lower levels of the Bozalan formation becomes more dominant towards the top. Commonly observed at the top of the sequence, recrystallized limestones are operated in places. Recrystallized limestone starts with black-and-gray color, thin-bedded micritic limestone-claystone alternation at the bottom and continues upward with into gray beige-colored, medium-thick bedded or massive sparitic limestones (Figures 4a and b).

Bozalan formation locally intruded by basaltic aplite veins (Figure 4a). Pyroxene, plagioclase and biotite phenocrysts are scattered in subofitic textured dough in a porphyritic textured aplite sample derived from Aladağ. Coarse-grained plagioclase minerals are twinning, partially tranform into clay and including opaque mineral inclusions. Pyroxenes are composed of mainly semi- euhedral augites. Pyroxenes formed glomeroporpyritic texture come together in place. Coarse-grained biotite has often-fractured and folded structure. Subofitik textured dough is composed of plagioclase microlites and microgranular pyroxenes. In addition, apatite was found in the sample as an accessory. Aplite subjected to hydrothermal alteration commonly epidote, argillization, carbonation and silicification have been observed. For example, some parts of the very fine-grained biotite minerals are observed clustered together.

Recrystallized limestones of the Bozalan formation transform into saccoroid textured fine, white-colored marbles in the areas affected by granitoid intrusions. This type of marble is seen in the quarries at the north of the Gökçebayır village and around the Aladağ village (Figures 5b and c).

Dönmez et al. (2005) determined late Permian aged fossil assemblages collected from the upper levels of the formation, such as Neoschwagerina old? Ex gr. occidentalis Kochansky Devi and Ramvs, Verbeekina sp. Colania? Sp., Pseudodoliolina? Sp., Afghanella? Sp. and Gymnocodiacean. Middle Permian (Kalafatçioğlu, 1963), middle-late Permian (Gözler et al., 1984), late Permian (Okay et al., 1990; Beccaletta and Jenny, 2004) aged fossil assemblages were determined by previous studies conducted in the same region. Authors received these samples from upper levels of the Bozalan formation. Indeed, there are not any fossil determination about the lower levels of the formation. Therefore, the age of the Bozalan formation was adopted as middle-late Permian.

Denizgören ophiolite

The unit is composed of mainly serpentinized peridotites in khaki green, dark green and blackish-green and light brown colors

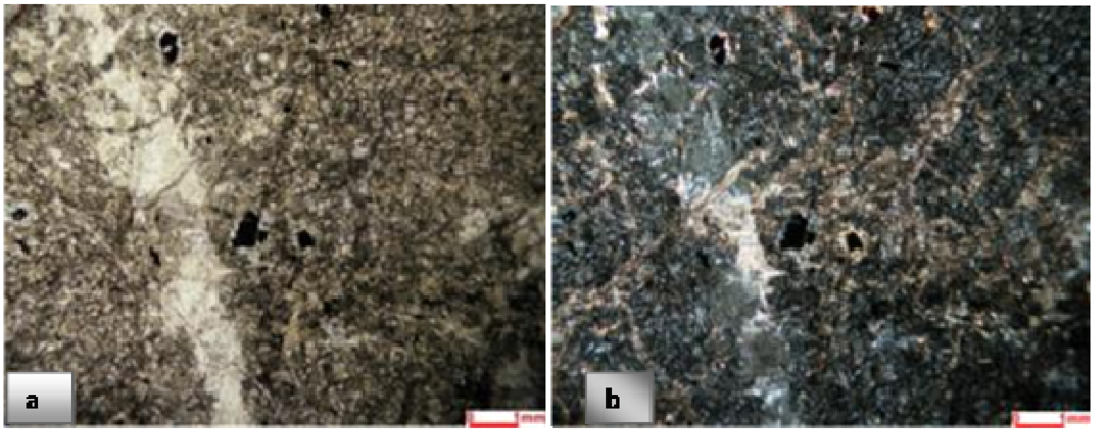

Figure 5. Sieve texture serpentinites in the Denizgören Ophiolites a)Parallel nikol b)Cross nikol

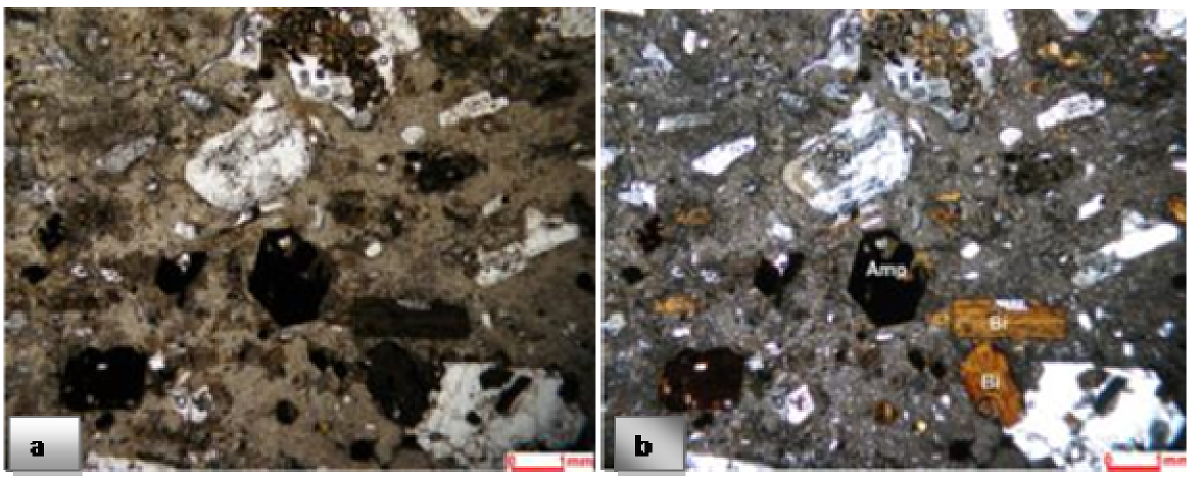

Figure 6. Volcanic glass including amphibole (Amp), plagioclase (Pl) and biotite (Bi) phenocrytals in the rhyolites of the Hallaçlar Volcanics a) Parallel nikol x2,5 b) Cross nikol x2,5

(Figure 7). The ophiolitic rocks are placed over the other units with tectonic contact at the east-northeast of the Aladag in the study area. For the first time, extending approximately in the north-south direction, the unit was named as Denizgören Ophiolite by Okay et al. (1990). Olivine and pyroxenes transform into serpentine minerals and disappearing of textural and mineralogical characteristics belonging to source rocks were observed. Serpentines usually represented by sieve textured cyrisotiles (Figure 5). Fractures and fissures of the highly fractured ophiolites were filled by secondary carbonates. Orthopyroxenes and opaque minerals have been observed in trace amounts in the rocks. Asbestos and talcs occurred in the border between the Denizgören ophiolite and Kestanbol granitoid with contact metasomatism.

The age of the Denizgören ophiolites were indicated as Palaeozoic (Bingöl et al., 1973) and the Permo-Triassic (Okay et al., 1990) by previous studies. Then the age of the metamorphism of the amphibolites derived from the base metamorphics of the unit is 117 Ma (Okay et al., 1996) and 125 Ma (Beccaletto and Jenny, 2004) obtained data based on the Ar / Ar geochronological studies. Accordingly, formation age of the Denizgören ophiolites as Permo-Triassic while metamorphism and settlement age has been considered as upper Cretaceous.

Hallaçlar volcanite

Hallaçlar volcanics are represented by yellow, pink and beige-colored andesite, basalt, spherulitic rhyolite and pyroclastic rocks with same composition. The unit observed that the best was around the Kızıltepe village. Unit were called as Hallaçlar volcanics by Donmez et al. (2005).

Many outcrops of the Hallaçlar volcanics were altered and colors of rocks have been transformed into white, yellow, brown and red (Figure 6). Finding of clean and unaltered samples are very difficult because of the intense alteration in the unit. Collected samples of the volcanics are named as andesite and rhyolite. Hyalopolitic textured rhyolites are mainly composed of plagioclase, sanidine and biotite crystals. Plagioclase is subhedral-euhedral zoning and sieve texture shows in places. Sanidines are anhedral and clean. Subhedral biotites have some rod-shaped opacification. Dough of the rhyolites are consist of volcanic glass and microlites of the plagioclase. Also sferulites are available in the dough. Chloritization has been observed in some places of the biotites. Chemical analysis of the rhyolite samples have been identified 67.8% SiO_2, 2.2% Na_2O, 2.9% K_2O and 2.9% Fe_2O_3 have been identified.

Geochronological ages of the biotites in the andesites from the

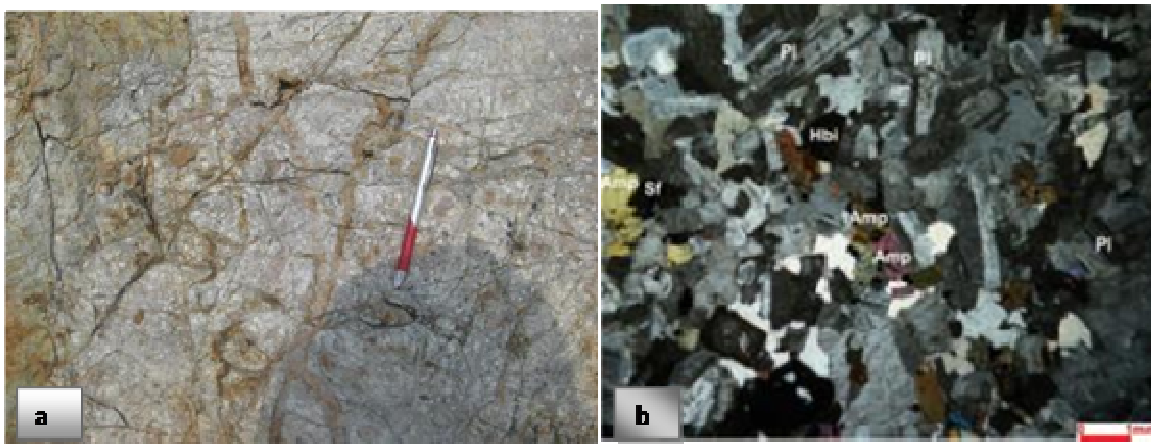

Figure 7a. Green and light Brown colored monzonites of the Kestanbol Pluton, b) Holocrystalline and granular textured monzonites of the Kestanbol Pluton (Amp: Amphibole, Pl: Plagioclase, Hbl: Hornblende, Sf: Sphene) (Parallel nikol)

northeast of Edremit, outside the study area are found 23.6 Ma by Krushensky (1976) while 26.5 ± 1.1 million years by Donmez et al. (2005) by using K / Ar isotope method.
Therefore, volcanism has become effective in upper Oligocene to lower Miocene time. The unit is equivalent to Çan and Kirazli volcanics determined by Ercan et al. (1995) and Hallaçlar formation called by the Krushensky (1976).

Kestanbol pluton

Kestanbol Pluton is represented by intense fractured and cracked, dirty yellow and pink quartz-monzonites, together with basic enclaves such as monzonite, monzodiorite porphyry, monzonite porphyry, syenite porphyry and quartz syenite porphyry. The pluton is cut from 1–2 cm to 1–2 m thicnesses, a set of dykes such as aplite, pegmatite and mafic lamprophyre and porphyritic latite. The Unit widely and typically exposed around the villages of Kestanbol (Uluköy), Koçali and Aladağ, at the east of the study area and took its name of Kestanbol village. Pluton, is emplaced into the regionally metamorphosed basement rocks such as Geyikli and Bozalan formations.

Thus, locally a contact-metamorphic zone occured between the pluton and older units. The Kestanbol Pluton consists of monzonitic rocks and was derived from crustal melts that mixed with mantle-derived mafic magma (Yılmaz et al., 2010). The main components of the Kestanbol Pluton are green, grey, light brown, pinkish and beige colored, coarse grained quartz monzonites and lesser amount monzogranite, syenite porhyr (Figure 8a). Sometimes, fine grained porphyritic textured monzonites and monzogranites include coarse grained K-feldspar and abundant plagioclase phenocyrsts. In addition, pluton includes mafic microgranular enclaves (MME) that are products of mixing of felsic and mafic magmas (Yılmaz et al., 2004).

Monzonites are generally holocrystalline and granular textured having medium to coarse grain sizes (Figure 8b). They are uncommonly porphyritic textured, due to existence of K-feldspar megacrystals. The porphyritic monzonites medium-coarse grained subhedral-anhedral groundmass consisting of 20 to 75% orthoclase, 10 to 45% plagioclase, 12 to 35% quartz, 5 to 15% hornblende, 2 to 10% biotite, 2 to 5% pyroxene, together accessory minerals (1 to 2%) such as titanite, apatite, zircon, allanite, epidote, sphene and opaque minerals (magnetite, ilmenite, pyrite and rutile) including 20 to 75% euhedral, orthoclase megacrystals (Örgün et al., 2007). Secondary minerals are chlorite, sericite, muscovite and iron-oxide minerals. K-feldspars have euhedral and subhedral and micro-cracks. They contain biotite and plagioclase inclusions and weak-moderate argillization places available. Plagioclases are euhedral-subhedral, shows zoned texture in places and some of them have biotite inclusions. Biotites euhedral and subhedral some of them has feldpar inclusions. Anhedral cyristallized hornblendes are partly replaced by biotite. Mean chemical analysis of samples examined monzonite 68.2% SiO_2, 16.8% Al_2O_3, 4.04% Fe_2O_3 and 2.85% K_2O were identified.

Quartz monzonite samples taken near the Kestanbol village is porphyritic textured and the components are K-feldspar (24 to 30%), plagioclase (35 to 40%), amphibole (10 to 12%), biotite (5 to 10%), quartz (10 to 20%) and opaque minerals (3 to 5%). K-feldspars consist mainly of coarse-grained pertitic textured orthoclases in place, showing Carlsbad twins and partly argillized. Plagioclases are twinning, in the form of coarse and fine grains of albite-oligoclases (Figure 8). Amphiboles in places consist of euhedral and twinning hornblendes. Fine to coarse grained biotites spread to the entire thin-sections. Quartz is anhedral, fine-grained and lesser amount. In addition, small amounts of opaque minerals are available in the samples. Quartz monzonites have 68.1 to 69.3% SiO_2, 15.9 to 16.5% Al_2O_3 and 3.2 to 3.5% Fe_2O_3.

Kestanbol Pluton is cut by fine- to medium-grained, equigranular and locally porphyritic textured aplite, pegmatite, granophyr, leucogranite and lamprophyr dykes that are commonly found around Aladağ village. Dykes consist of pertitic K-feldspar, plagioclase, quartz with minor amount of biotite and accessory minerals such as apatite, zircon, sphene and opaque minerals. Mafic dykes have lamprophyre, leucite porphyry and microdioritic compositions. They have sharp contacts with felsic host rocks.

All of these dykes were injected after the crystallization of the pluton (Yilmaz et al., 2010). Association of vein rocks, faults and hydrothermal alteration in these zones has created high radioactivity concentrations (Örgün et al., 2007). Mafic lamprophyre samples are porphyritic textured and composed mainly of plagioclase, biotite and pyroxenes (Figure 9). Carbonate and epidote alterations are observed in places. Biotites are dark brown and euhedral and subhedral. Pyroxenes are euhedral-subhedral and minor amount of chloritization is observed. Some of the fractures in the pryroxenes filled carbonate and the other filled by opaque minerals. The groundmass of the lamprophyres is composed of fine-grained feldspars, opaque minerals and minor amount quartz. Main chemical compositions of lamprophyres are

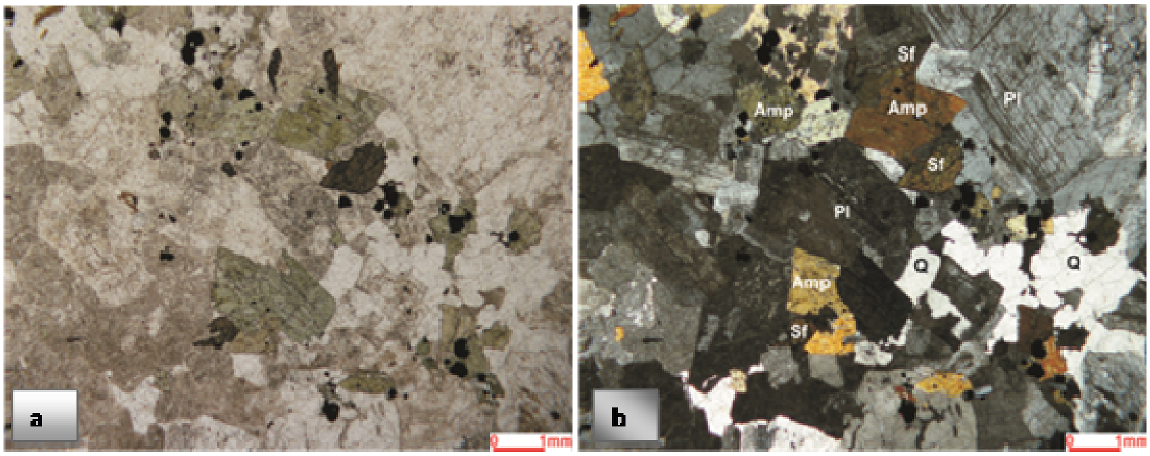

Figure 8. Porphyritic textured quartz-monzonites of the Kestanbol Pluto (Amp: Amphibole, Pl: Plagioclase, Q: Quartz, Sf: Sphene a) Parallel nikol x2,5 b) Cross nikol x2,5

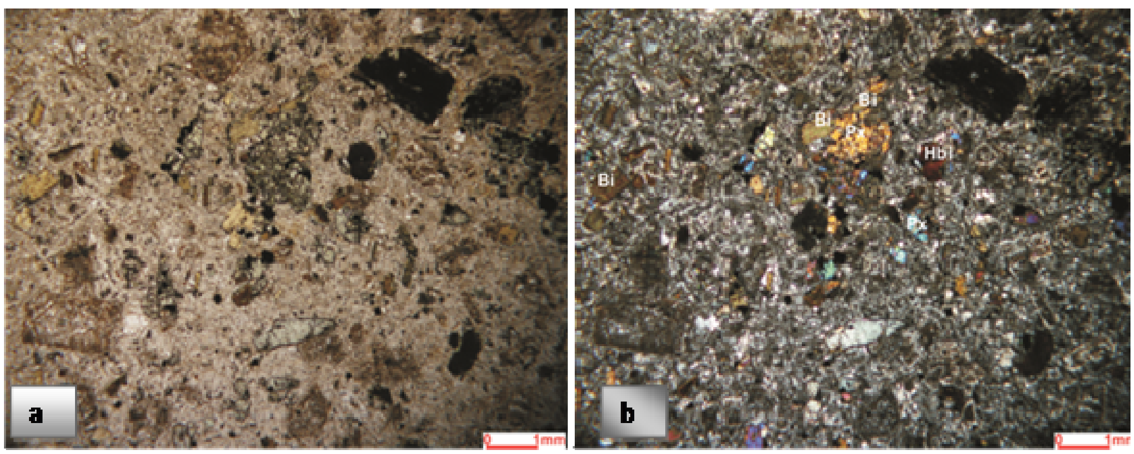

Figure 9. Porphyritic textured lamprophyres cut the Kestanbol Pluton (Amp: Amphibole, Pl: Plagioclase, Sf: Sphene) a) Parallel nikol x2,5 b) Cross nikol x2,5

54.2 to 65.4% SiO_2, 15.7 to 19.8% Al_2O_3, 4.3 to 8.3% Fe_2O_3 and 1.7 to 5.1% MgO.

Kestanbol Pluton, intrudes the regional metamorphic rocks. The age of the pluton was found to be 28 ± 0.88 My by Fytikas et al. (1984) by using the K / Ar method, 21 ± 1.6 My on the biotites by Birkle and Satır (1995) by using Sr86/Sr87 method. Accordingly, the age of magmatism in the upper Oligocene-middle Miocene has been adopted.

Various ages and compositions calc-alkaline and I-typegranitoid rocks display extensive evidence of interactions between mafic and felsic magmas In the western Anatolia (Birkle and Satır, 1995, Örgün et al., 2007). According to obtained data from field, petrographic, mineralogical and geochemical investigations, the Kestanbol Pluton must have formed relevant to mafic and felsic magmatic processes such as magma mixing and magma mingling. (Yılmaz et al., 2010).

Ezine volcanites

Ezine volcanites consist mainly of gray, dark gray, black and greenish-black color, coarse crystalline K-feldspar andesite, trachyandesite, dacite, rhyodacite and andesitic, rhyolitic pyroclastics. This unit cropped out approximately in the north-south direction, near the west of the Ezine County and was called Ezine volcanites.

Hypocrystalline porphyritic textured pyroxene andesites received from the Kara Tepe composed of plagioclase, pyroxene, biotite and hornblende (Figure 10). Plagioclases subhedral and shows zoned structure. Medium-intense degree carbonate alteration has been observed in some plagioclases. Biotites are subhedral, dense opacification was observed in the perpendicular sections to the axis-C and corrosion also observed in places. The types of the pyroxenes are subhedral clinopyroxenes and carbonatization from the cracks. Hornblendes are large crystallized, subhedral-anhedral and opacificated from edges, cracks and cleavages. Weakly argillized dough is made up of very fine-grained plagioclase and opaque mineral microlites. In addition, some sections of the rock is painted by ferrous opaque minerals. Pyroxene andesites have 63.25% SiO_2, 17.64% Al_2, 5.35% Fe_2O_3, 2.94% K_2O 2.45% Na_2O, 1.84% MgO and 4.01% CaO.

The porphyritic textured trachytes were derived from the 500 m north of the Kara Tepe; consists mainly of feldspar, biotite and pyroxene phenocyristals in a microlitic groundmass (Figure 11).

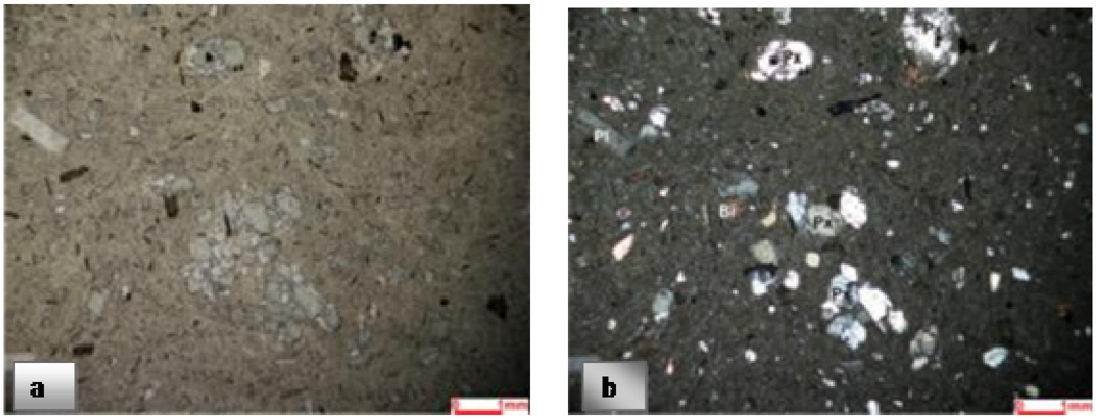

Figure 10. Hypocyristalline porphric textured pyroxene andesites belonging to Ezine Volcanites (Px: Pyroxene, Pl: Plagiyoclase, Bi: Biotite)e a) Parallel nikol x2,5 b) Cross nikol x2,5

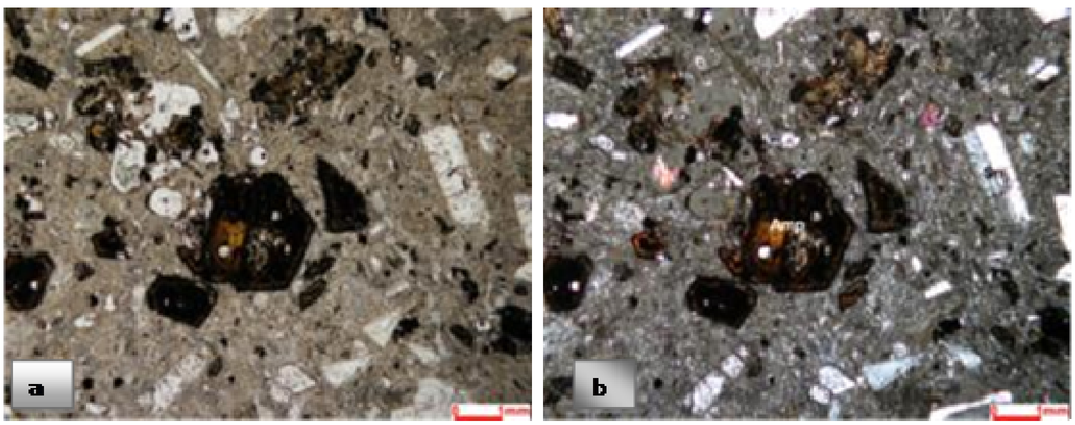

Figure 11. Porphyritic textured trachytes of the Ezine Volcanites (Amp: Amphibole, Sn: Sanydyne) a) Parallel nicol b) Cross nicol

Feldspar minerals are composed of alkali feldspar and plagioclases. Alkali feldspars are coarse-grained, Carlsbad twinning sanidines. Some of them include biotite and albite inclusions. Plagioclases are twinning-zoned albite-oligoclasses. Biotites are brown euhedral and exposed opacification in some places. Pyroxenes are partly euhedral; green-colored altered spinning augites. Microlitic textured dough contains plagioclase microlites. Also intensive argillization and lesser amount of silicification were observed in the dough. In the example as an accessory with a small amount of opaque minerals and apatite were found. Trachytes have 65.6% SiO_2, 17.4% Al_2O_3, 4.98% Fe_2O_3 and 4% K_2O.

The age of the andesitic and trachyandesitic rocks are lower-middle Miocene and 22.3 to 13.6 Ma ages were measured by Ercan et al. (1994) by using radiometric age determinations. Upper Miocene volcanism in the Biga Peninsula has changed character, before the kind of black basalt lava trachyandesite-looking and then the alkaline olivine basalts were formed. The radiometric age of these rocks are 11.0 to 8.4 My were measured. Therefore these rocks must have been formed in the middle to upper Miocene time (Dönmez et al., 2005; Aydın, 2010).

Bayramiç formation

Bayramic formation is made up of red-brown colored conglomerate, sandstone and mudstones. These Plio-quaternary fluvial deposits were called Bayramic formation by Siyako et al. (1989), the best observed place around the Bayramic River. Unit has spread around Çukurtarla creek west of the study area.

Alluvium

Alluvium mainly represented by slightly consolidated and unconsolidated gravel, sand and mud deposits. Formation was observed in river beds, old pits and coastal plains at the northeast of the study area.

Aladağ Cu, Pb, Zn and Fe mıneralization

Distribution and location of mineralization

Aladağ Cu, Pb, Zn and Fe mineralization is at the Aladağ near the Kiremitoba village (Figures 12, 13 and 14). There is a contact metamorphic and skarn zone among the Kestanbol Pluton and carbonate rocks of Bozalan formation and altered peridotites of the Denizgören Ophiolites. These formations were developed by the intrusion of the Kestanbol Pluton in the Oligo-Miocene time. Therefore Pb, Zn, Cu and Fe enrichments occurred in the skarn

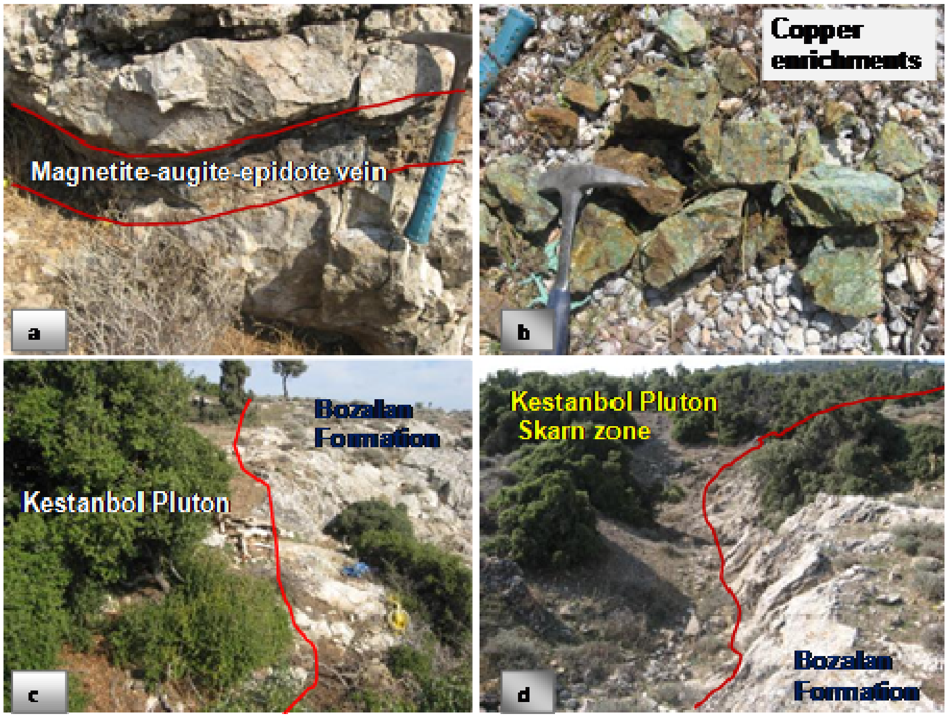

Figure 12. Aladağ skarn zone between the Kestanbol Pluton and Bozalan Formation a)A magnetite-augite and epidote vein in the marbles of Bozalan Formation, b) Copper enrichments in the Bozalan Formation, c-d) General view of the skarn zone between the pluton and Bozalan Formation

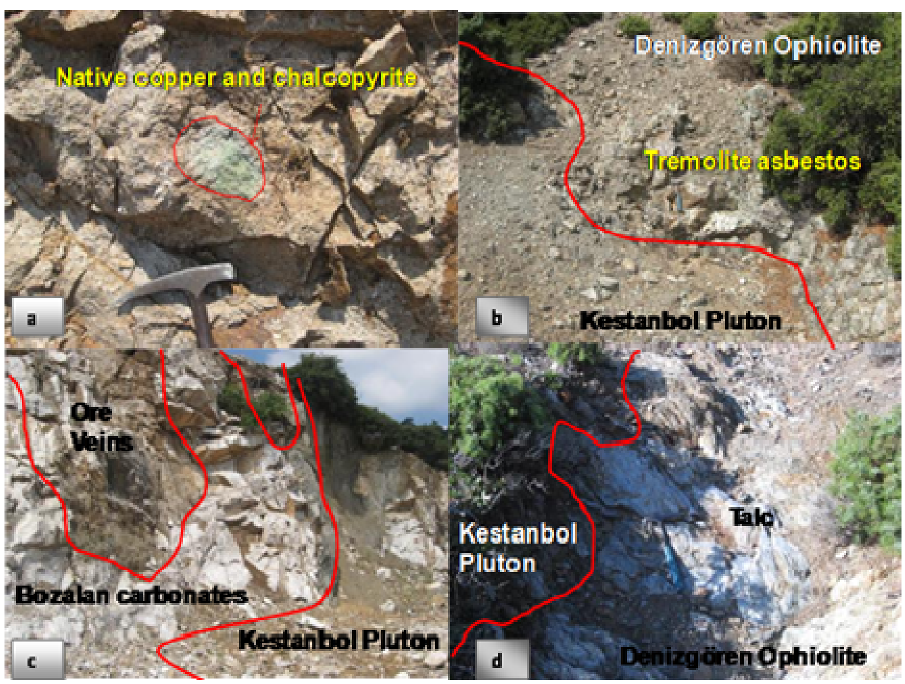

Figure 13. Aladağ contact metamorphic and skarn skarn zone a) Native copper and chalcopyrites in the skarn zone b) Tremolite asbestos formation in the contact metamorphiz zone between the ophiolitic rocks of the Denizgören Ophiolites and Kestanbol Pluton, c) An ore vein enriched Cu, Fe, Pb and Zn in the skarn zone d) Talc formation in the contact metamorphiz zone between the ophiolitic rocks of the Denizgören Ophiolites and Kestanbol Pluton.

Figure 14. Sampling points of the ore Aladağ contact metamorphic and skarn skarn zone

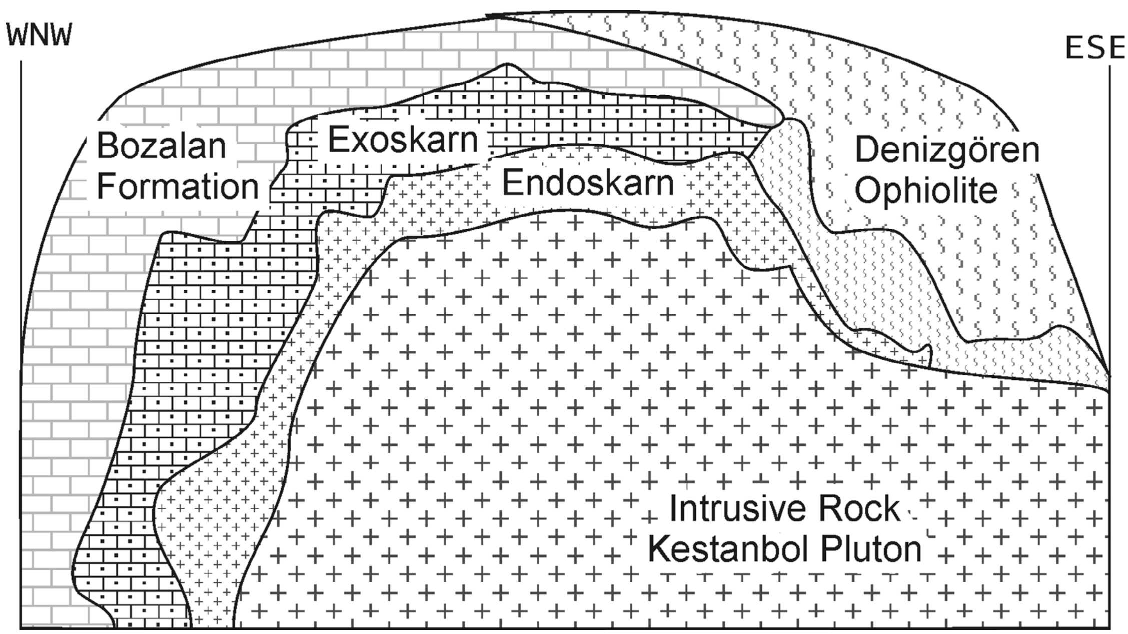

Figure 15. Schematic cross section model of Aladağ skarn zone

zone between the Kestanbol Pluton and Carbonaceous rocks of Bozalan formation (Figures 13 and 14). In addition, some talc and asbestos formation developed in the contact metamorphic zone between the pluton and basic-ultrabasic rocks of Denizgören Ophiolites. Previously, chimney shaped galleries opened in the skarn zone and some ore production were run because of filled with water, undetectable when the work of the gallery (Figure 14). Therefore, samples were collected from only old production waste and skarn zone rocks at the surface.

Aladağ skarn zone formed by the intrusion of the Kestanbol Pluton during Oligocene and Miocene times. Thus skarn zones and mineralization well developed from intrusive rocks to endoskarn zone, exoskarn zone and wall-rocks (Figure 15).

Intrusive rocks: Intrusive rocks of the Kestanbol Pluton and the wall rocks such as marble and carbonaceous rocks of Bozalan formation and altered peridotites of Denizgören Ophiolites are as explained earlier. Intrusive rock represented mainly by monzonite, Q-monzonite and synite. Monzonites composed of mainly placioglase, alkali feldspar, quartz, biotite, hornblende and minor amount sphene while syenites are composed of mainly alkali

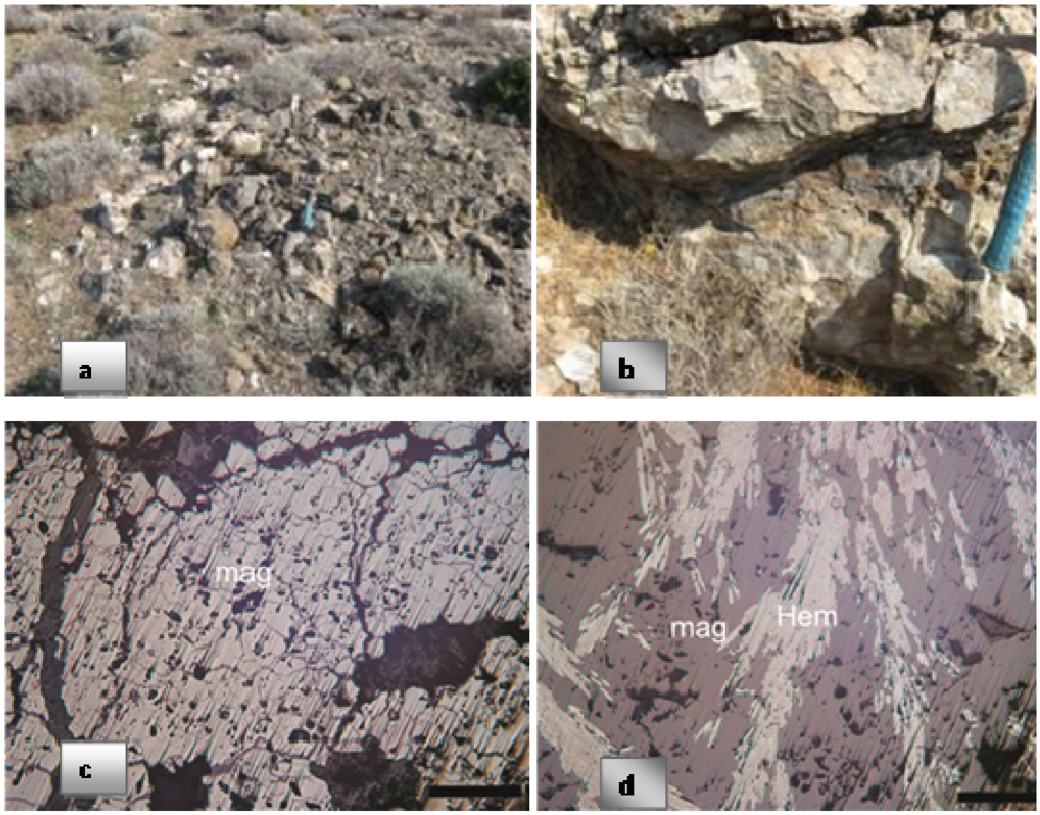

Figure 16. Iron mineralization in the carbonate rocks at the Aladağ ore deposit. a) Old production of Fe Mineralization, b) An iron vein in the Bozalan Formation, c) Microphoto of a magnetite in the Fe minerazliation d) Magnetite (mag) and hematite (hem) in the iron mineralization of the Aladağ ore deposit (x10)

feldspar, placioglase, quartz, biotite, hornblende and minor amount of sphene.

There are some coarse grained K-feldspar, biotite, quartz, pyroxenes (diopside, augite) in the endoskarn zone. Some magnetite enrichments in the same zone.

There are epidote, grossular, tremolite/actinolite, augite, diopside and talc formations in the exoskarn zones with galena, sphalerite.

Aladağ skarn zone (ore mineralization)

Magnetite, hematite, galena, sphalerite, chalcopyrite, cerussite, covellite, malachite, azurite, pyrite, limonite (goethite and lepydocrosite) were observed in the polished section of ore samples magnetite and hematites observed in the endoskarn zone and near the pluton contact. These minerals in the same section. So hematites were formed by the alteration of magnetites.

The most common ore minerals are magnetites in the endoskarn zone (Figures 16a and b). Coarse crystalline generally anhedral magnetite grains are often observed as fractured and fragmented (cataclastic) texture. Relatively small-sized magnetites occur as islets in some areas. Magnetites are encountered and often transformed into hematite (martitization) in the samples. Some of the magnetite relicts are monitored in the martitized areas. Usually euhedral, acicular prismatic rod-shaped and / or semi-euhedral grains form. Cyristal sizes vary between 10-50 µ. (Figure 16c). Sometimes hematites are transformed into mangnetites and they form branched bouquet of flowers, as a typical (mişketofitleşme) structure of re-crystallization was observed (Figure 16d). Therefore these textures may point to re-crystallization. Galena, cerussite, sphalerite, chalcopyrite pyrite and covellite were observed in the outer zone of the skarn mineralizations. Chalcopyrite, pyrite and covellite near the magnetite mineralizations. Galena and sphalerite mineralizations are near the carbonate rocks. Some galena and sphalerite veins in the marbles and recrystallized limestones. Sphalerite and magnetite were observed in the same sections in some places.

Galena is usually in the form of free grain and triangularly (wedge) shaped by the traces of cleavage and can be easily distinguished (Figure 17). Subhedral galena mineral sizes range from 10 to 500 µ in some places and over 600 µ galena sizes were also identified. Minerals such as galena were observed in some cases completely transformed cerussite. Sometimes galena relicts were observed in the cerussites. Cerussites can be easily distinguished by their yellowish-brown and brown internal reflection (Figure 17). The relict galenas are usually subhedral or partly anhedral, relatively small grain sizes vary between 10 to 150 µ. Sphalerites usually 600 µ in size are commonly observed in the samples having galena and sphalerites.

Covellites were observed as crystal stacks along the grain boundaries in the border between the galena and cerussite. Covellite bluish-greenish-bluish-gray in color and typically pleocroism show purplish blue in places (Figure 18a). Covellite stacks especially in the form of cerussite grain and settled along the grain boundaries and cracks of the galenas. In addition, although relict minerals centers in places digenite minerals is galena

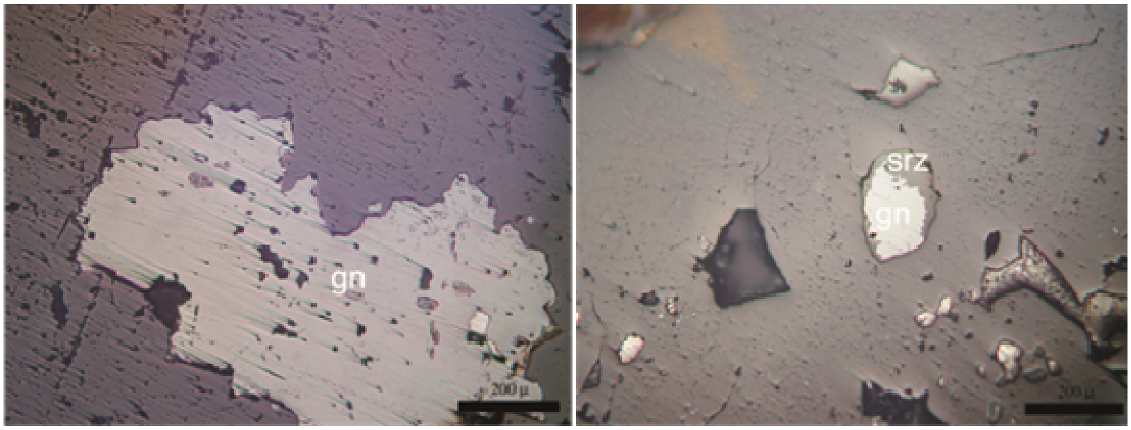

Figure 17. Galena (gn) and cerussite (srz) in the Aladağ mineralization

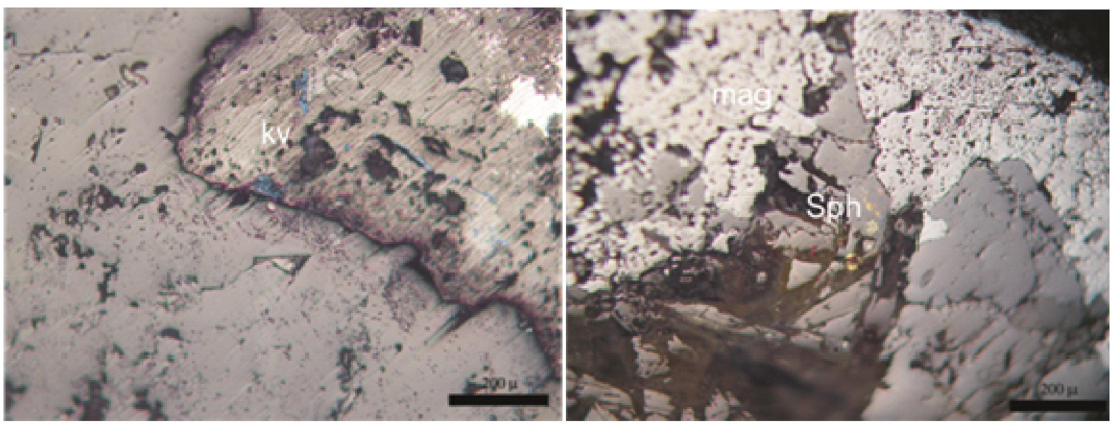

Figure 18a. Covellite (kv), b) sphalerite (Sph) and magnetite in the Aladağ mineralization.

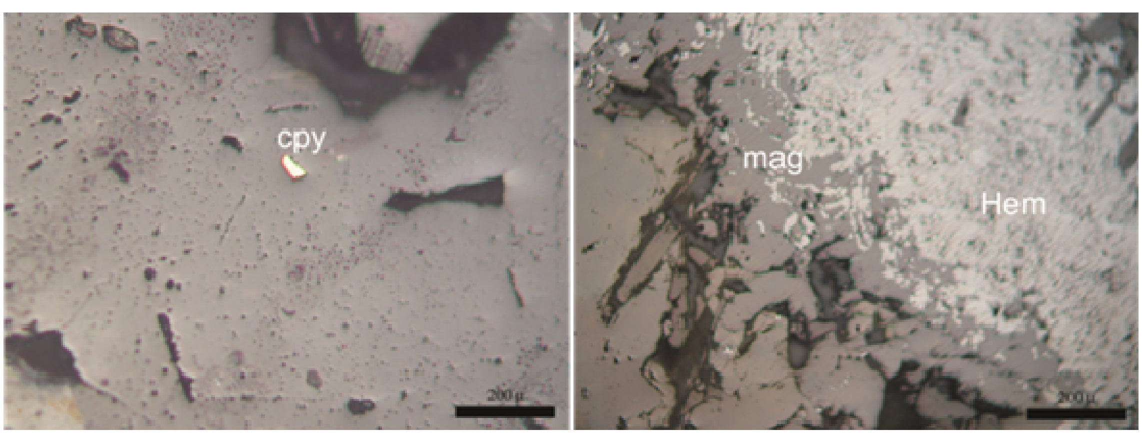

Figure 19. Chalcopyrite (cpy), magnetite (mag) and hematite (hme) in the Aladağ mineralization.

followed. Sphalerites include previously formed magnetite inclusions in some examples (Figure 18b).

There are minor amounts of pyrites and chalcopyrites in the rocks. The sizes of pyrites are from 5 to 50 µ and chalcopyrites 10 µ and smaller sizes (Figure 19). Some of the pyrites were limonitization from the edges. Chalcopyrites are free grains and seetled as cracks and / or cavities in the magnetites and / or in the form of inclusions (Figure 19).

Cavity filling and / or veins in the form of limonite (lepidocrocite and goethite) were observed in some polished sections. Goethite

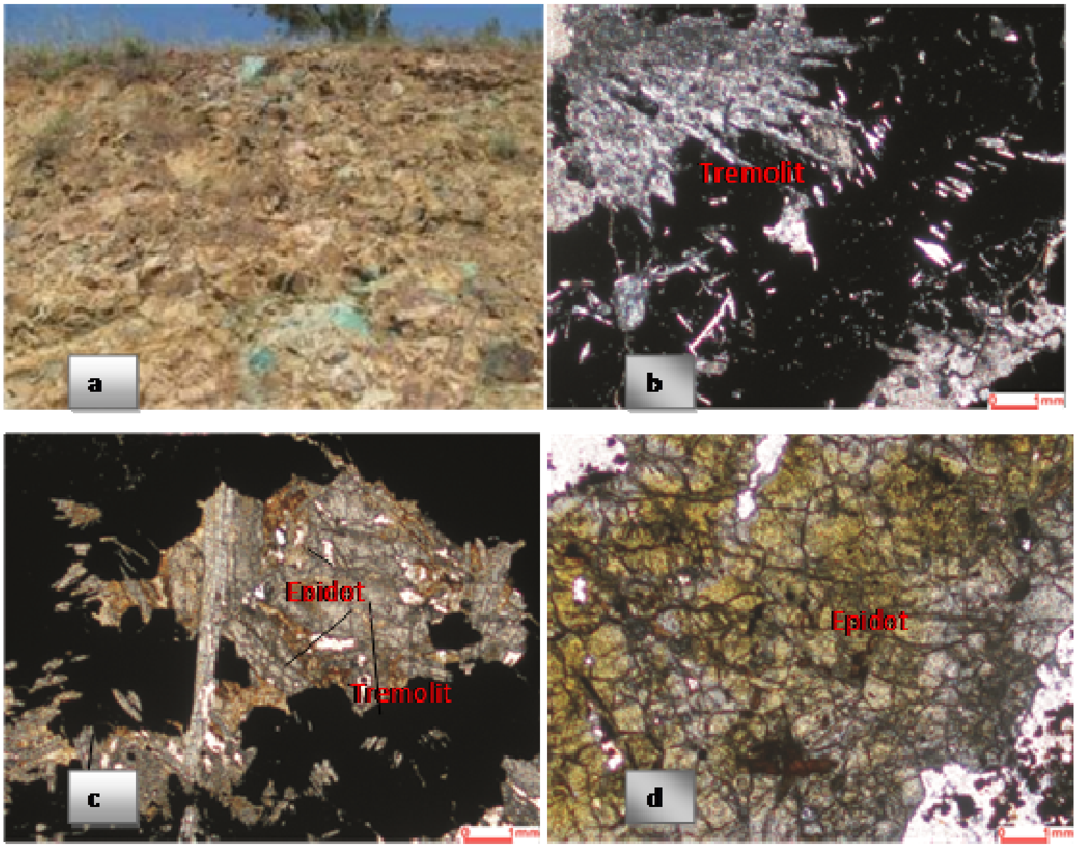

Figure 20a. Malachite and azurite formations 1 km to the west of the Aladağ mineralization, b-c-d). Epidote and tremolites in the exoskarn zone of Aladağ mineralization

and lepidocrocite were observed side by side and enlarged intertwined. Limonite minerals are pyrite formation in places. Limonites are thought to be likely from pyrites.

Talc and asbestos formation contact between the pluton and ophiolites. There are malachite, azurite and native copper formations around the Skarn Zone in the Kestanbol Pluton and near environs (Figure 20a). Some Ca-silicate mineral gormed in the contact metamorphic zone such as tremolite, actinolite, augite, epidote etc. (Figures 20 b, c and d).

RESULTS

Tectono-stratigraphic sequence of the units cropping out in the study area, developed in the following way. The Pre(?)-lower Cambrian aged Geyikli formation comprising low-grade metamorphic rocks, such as sandstone-claystone-limestone and forms the basement of the study area. Middle-late Permian Bozalan formation consisting of recrystallized limestones, overlay the Geyikli formation with disconformity. Cretaceous Denizgoren Ophiolites made up of serpentinites and thrusted over the older units. Upper Oligocene-lower Miocene Hallaclar Volcanics composed of altered andesite and rhyolite. In addition, same aged with Hallaclar volcanics, Kestanbol Pluton represented by mainly quartz-monzonite, monzonite mafic enclaves and cuts the older units. Lower- Middle Miocene Ezine Volcanics composed of pyroxene-andesite and trachyte. Plio-quaternary Bayramiç formation overlaid these units with disconformity and also consists of slightly cemented conglomerate, sandstone and mudstone.

Bozalan formation and Denizgoren Ophiolites were affected by alteration with the intrusion of Kestanbol Pluton. Skarn type mineralization was developed close to Kestanbol Pluton contacts with the carbonaceous rocks of the Bozalan formation and Denizgoren Ophiolites which is located north of Aladag. As a result of the intrusion of the Kestanbol Pluton, Ca-silicates and some metallic mineral enrichments such as iron, copper, zinc and lead were developed in the skarn zone. Skarn zones are discussed under four main headings such as intrusive rocks, endoskarn, eksoskarn and wall rocks. Intrusive rocks are Q-monzonites and monzonites of the Kestanbol Pluton. In the endoskarn zone, some coarse-grained K-feldspar, biotite, quartz, pyroxenes (diopside, augite) were formed. In addition, iron mineralizations are developed such as primary magnetites and secondary hematites in the endoskarn zone. There are ca-silicate minerals formed such as epidote, grossular, tremolite/ actinolite, augite, diopside and talc formations in the exoskarn zones with galena, sphalerite. The main wall-rocks are carbonate rocks of Bozalan formation and low-metamorphic detricious rocks of Geyikli formation. Malachite and azurite fillings are observed in the fractures of the pluton near the skarn zone. Main ore minerals are represented by magnetite, hematite, chalcopyrite, sphalerite, galenite, cerussite, covellite, digenite, malachite and pyrite. Also talc and amphibole (tremolite) asbestos are developed in the contact between the Kestanbol Pluton and Denizgören Ophiolites.

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