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Stratigraphy of the Kuloğlu–Yaka Area and Petrographic Properties of Boyabat Metamorphites and Volcanic-Pyroclastic Rocks of Yemişliçay Formation, the Boyabat-Sinop-Turkey

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Abstract **–** The study area is located between Kuloglu and Yaka Villages in the north of Boyabat District of Sinop Province. Paleozoic-Triassic aged Boyabat metamorphites are observed at the bottom of the study area. These metamorphites are composed of phyllite, sericite-chlorite schist and metasandstones which contain intense greenschist, glaucophanitic greenschist, metagabbro and metadiabase interlevels at the bottom levels. This unit is overlain unconformably by the Lower Jurassic aged Akgöl formation, which consists of alternation of sandstone-milestone-shale. Higher up, Middle-Upper Jurassic aged Bürnük formation which consist of conglomerate is observed unconformably. The Bürnük formation is overlain by the lateral-vertical transition by Middle-Upper Jurassic aged the Akkaya formation which contain limestones. The Lower Cretaceous aged Çağlayan formation, which is composed of marls and shales with sandstone-sandy limestone interlevels, unconformably overlies the Akkaya formation. Higher up, Upper Cretaceous aged Kapanboğazı formation which consist of cherty limestones and micritic limestones is observed unconformably. This formation is conformably overlain by the Upper Cretaceous aged Yemişliçay formation which consists of basaltic-andesitic lavas, tuffs and agglomerates which contain sandstone-marl interlevels. At the top, the Upper Cretaceous aged Cankurtaran formation, which consist of alternation of sandstone-marl-shale-mudstone-limestone and contain tuff-agglomerate interlevels at the bottom levels, is conformably observed.

The following mineral assemblages have been observed in metapelitic, metapsammitic and metabasic rocks belonging to Boyabat metamorphites. Phyllites and sericite-chlorite schists contain mineral assemblage which are composed of *sericite + chlorite (ripidolite-picnochlorite) + quartz ± calcite ± plagioclase (albite) ± muscovite ± epidote ± zoisite / clinozoisite ± microcline ± biotite (green) ± sphene*. The mineral assemblage which are composed *sericite + quartz + muscovite ± epidote ± plagioclase (albite) ± microcline ± chlorite ± calcite ± biotite (green) ± apatite* are observed in metasandstones. The mineral assemblage observed in greenschists are *tremolite + actinolite + chlorite (ripidolite-picnochlorite) + plagioclase (albite) + epidote + zoisite / clinozoisite ± quartz ± calcite ± microcline ± relict clinoproxene (diopside / augite) + sphene*. Glaucophanitic greenschists observed as interlevels and sometimes blocks in metapelitic schists show mineral assemblage which are composed of *chlorite + glaucophane + epidote + plagioclase (albite) + phengite ± actinolite + zoisite / clinozoisite ± stilpnomelane ± calcite ± quartz + sphene*. Metagabbro and metadiabases consist of mineral assemblages which are composed of *actinolite + plagioclase (albite-oligoclase) + chlorite (penninite-clinochlore) ± relict clinoproxene (diopside / augite) ± zoisite / clinozoisite + quartz ± epidote ± sphene*. Boyabat metamorphites initially underwent to metamorphism in quartz-albite-muscovite-biotite subfacies of greenschist facies at 425-450 ºC temperature and 2-3 kbar pressure conditions. Later, these metamorphites underwent the second metamorphism in the glaucophanitic greenschist (epidote-blueschist) facies at 400-500 ºC temperatures and 6-12 kbar pressure conditions with increased pressure in the environment. The effects of these metamorphism are observed in the metabasites within the Boyabat metamorphites.

Basalts and basaltic andesites belonging to the Yemişliçay formation show aphanitic porphyritic texture. Basalts contain common plagioclase and olivine phenocrysts and plagioclase microliths. The phenocrystalline phase of basaltic andesites consists of plagioclase, clinoproxen (diopside/augite) and very few olivine. Plagioclase microlites and volcanic glass are observed in matrix of these rocks. The tuffs observed in Yemişliçay formation include plagioclase, clinoproxene (diopside augite), amphibole (hornblende), volcanic glass and litic fragments. These rocks are *andesitic tuff* "according to composition and grain size" and *lapilli stone* "according to grain size" and *lapilli tuff and lapilli stone* "according to% distribution of grains" and *vitric tuff* "according to the volcanic glass-crystal-litic fragments compound.

Keywords – Boyabat (Sinop), Stratigraphy-petrography, Yemişliçay formation, Volcanic-Pyroclastic rocks, Boyabat metamorphites, High pressure metamorphism

I. Introduction

The study area is 96 km^2 that covers Kuloğlu, Göktepe, Kayadibi, Paşalıoğlu, Akman and Yaka villages in the north of Boyabat district of Sinop province (Figure 1). As a result of this study, it was aimed to determine the stratigraphic characteristics of the region. In addition, the petrographical

properties of Boyabat metamorphites bearing high pressure metamorphism and volcanic-prolastic rocks in Yemişliçay formation, which is one of the volcanics around Sinop, is the another objective of this study.

The study area is located in the middle part of Pontide tectonic belt belonging to tectonic units of Turkey (Figure 1). The region is characterized by the presence of a thick subduction-accretion complex developed during the closure of the Paleotethys and Neotethys oceans and oceanic lithospheric segments mixed with these tectonically [1].

The first regional study recorded in Boyabat region was conducted by [3]. Later, [4] made a 1 / 100 000 scale geological map of the region and distinguished metamorphic, volcanic and sedimentary units from Paleozoic to Eocene. Detailed studies on the formation level in the region were carried out by [5], [6], [7] and [8]. These researchers indicate that Liassic aged shales are the oldest sedimentary unit of the region, higher up, Upper Jurassic-Lower Cretaceous aged massive limestone, Lower Cretaceous aged shale, Upper Cretaceous aged flysch (Cankurtaran formation) and Upper Cretaceous aged volcanic rocks (Hamsaros formation) are observed. The researchers metioned that these units are covered by Upper Cretaceous-Paleocene aged Akveren formation (limestone, marl), Eocene aged Ayancık and Kusuri formations and Neogene aged Sarıkum formation.

The petroleum opportunites in the Sinop-Ayancık region by [9], the geomorphology of the Sinop peninsula by [10], sediments and palaeocurrent in the Sinop-Ayancık region by [11], Neogene formations in the region by [12], petroleum potential of the region by [13], detailed stratigraphy of Daday-Devrekani (Kastamonu) region by [14] and the detailed geology of Cide (Kastamonu) - Kurucaşile (Bartın) region by [15] are examined. Reference [16] investigated the geology of the Middle Black Sea (Sinop-Samsun) basin and the petrology of the volcanic rocks observed in the region. In addition, [17] and [18] made studies on the geology of Sinop basin and on petroleum opportunities. Reference [19] studied the geology of the north of Boyabat and the geochemical properties of volcanic rocks.

Reference [20] determined that there are volcanic rocks with calc-alkaline island arc property around Sinop and they are related to the subduction settled in the south. Reference [21] argued that the subduction zone that caused the Late Cretaceous volcanism emphasized by [20] was not located in the south but in the north.

Reference [22] divided the Pontides into three tectonic zones: Eastern Pontides, Middle Pontides and Western Pontides. In addition, Paleotethys system of the Middle Pontides [23], high pressure-low temperature metamorphism in the Middle Pontides [24] and the Late Cretaceous-Paleocene period of the Middle Pontides [25] are investigated.

Reference [26] named the volcanic rocks as Dodurga volcanics and Akyörük volcanics in Boyabat region in south of Sinop. The researcher stated that the Dodurga volcanics are composed of andesitic rocks, dacitic rocks and volcanoclastic rocks, and the Akyörük volcanics are made of basaltic rocks. She also stated that the main propagation center of the Dodurga magmatics is Sülüdağ. Reference [27] stated that the Upper Cretaceous (?) Volcanic rocks (Hamsaros volcanics) outcropping around Sinop consist of basaltic-andesitic lavas, dykes and their pyroclastics. The researcher stated that the volcanic rocks in the region are composed of basalt, trachybasalt, basaltic andesite, basaltic trachyandesite, trachyandesite and andesite, and they are both subalkaline and slightly alkaline. Reference [28] investigated the microfacies characteristics of the Upper Jurassic - Lower Cretaceous İnaltı formation outcropping in Boyabat (Sinop).

Reference [29] indicated that the volcanic activity observed in the south of Sinop was effective in two periods: Late Cretaceous (~ 71 million years, reverse isochron age) and Eocene (~ 48 million years, plateau age). Asan, Late Cretaceous volcanics are the product of an aged volcanism coinciding with the Yemişliçay formation,It indicates that the Eocene volcanics intersecting this formation as shallow intrusions are equivalent of the Tekkeköy formation volcanics.



Fig. 1. a) The map showing Turkey tectonic units (from [2]), b) The map of the study area

II. Materials and Method

In the field studies, detailed geological map of the study area was prepared by utilizing the geological map made by [18] on topographic maps of 1/25 000 scale numbered Sinop E 33-c1, Sinop E 33-c4 (Figure 2-a). The stratigraphic cross section of the region was made by considering the lower-upper relationships of the lithologies in the study area (Figure 2-b).

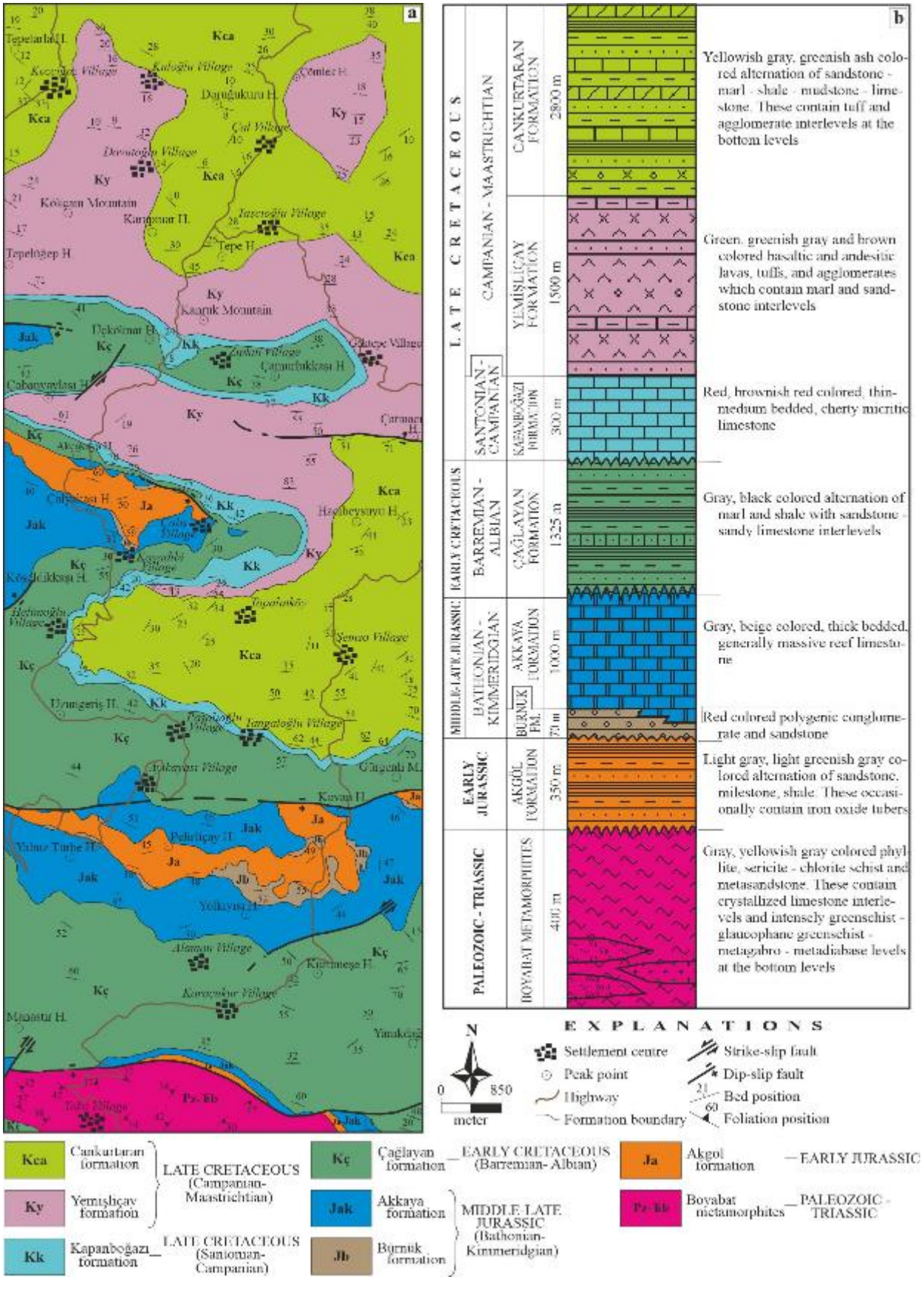


Fig. 2. a) Geological map of the study area (partially modified from [18]), b) Cross section of the study area

Thin sections of 80 rock samples collected during field studies were made in Thin Section Laboratory of Geological Engineering Department, Konya Technical University Faculty of Engineering and Natural Sciences. Pyroclastic rocks have been named considering their mineralogical composition, grain size, volcanic glass and rock fragments. Volcanic rocks were classified in [30] double triangular diagrams according to their mineralogical composition, and these rock nomenclatures were supported by geochemical analysis of these rocks. Metamorphic rock nomenclature is made considering mineralogical composition, texture-structure properties and sometimes characteristics of origin. In the nomenclature of "phyllite", "quartzite" and "greenschist as metamorphic rocks, classification diagrams of low- and high-temperature metamorphic rocks prepared by [31] were used. Metamorphic rocks, called "meta-" prefixes, show traces of metamorphism, while preserving the origin rock textures. These rocks were taken into consideration according to mineralogical composition and texture-structure properties, and "meta-" prefix was added to these names.

III. STRATIGRAPHY

A. Boyabat Metamorphites

First, Boyabat metamorphites named by [17] are observed in the south of the study area around Yaka Village (Figure 2-a). It is generally composed of phyllite, sericite-chlorite schist and metasandstone. In the lower levels of the unit, dense greenchist, glaucophane greenchist, metagabbro and metadiabase bands-lenses and blocks are observed (Figure 2-b). Crystallized limestone interlevels are encountered in the unit. Phyllite, sericite-chlorite schist and meta- sandstone are gray-yellowish gray-greenish in color. Phyllites should be fine grained and foliated. Due to the excess of sericite mineral, it has a silky shiny appearance (Figure 3-a). If the amount of chlorite increases and the amount of sericite decreases, the grain size of the rock becomes visible, and the rock transitions to chloritschists. Green color is dominant in these rocks. Metasandstones are layered and their thickness varies between 5-15 cm.

Green schists, glaucophanous green schists, metagabbros and metadiabases, which are commonly encountered in the bottom levels of the unit, are prominent with their green-blackish green colors. Foliation (schistosity) is very prominent especially in green schists. In some green schist samples, chlorites and fibrous tremolite-actinolites are quite prominent. Metabasites encountered in the unit are generally massive, sometimes they make weak schists (Figure 3-b). Phyllites, green schists, metabasites and metacarbonates belonging to Boyabat metamorphites are observed in places.

The unit shows an apparent thickness of approximately 400 m. The bottom surface of Boyabat metamorphites is not observed in the study area. It is unconformably overlain by the Upper Jurassic aged Akgöl formation. According to [14], the age of the unit is pre-Liassic. Reference [32] gave the age of Triassic (?) - Liassic to these lithologies, which are called Bekirli formation. When they are considered that the unit is unconformably covered by the Lower Jurassic Akgöl formation in the study area, and the regional correlations, the Boyabat metamorphics are considered to be Paleozoic-Triassic in age. The Boyabat metamorphites are comparable with the Bekirli formation [32], which outcrops between Ayancık-Erfelet-Boyabat (Sinop).

B. Akgöl Formation

The Akgöl formation was named by [9]. It is observed in the northern part of Kayadibi Village (Figure 4) and around Pelirliçay Hill (Figure 2-a). Akgöl formation is composed of light gray, light greenish gray, blackish gray colored of alternation sandstone-milestone-shale. Iron oxide tubers are observed in places within the unit. In the bottom levels of the formation, blackish gray colored, fine to very fine grained shales are observed. Towards the top, alternation of sandstone-milstone-shale takes place. Sandstones are gray-yellowish-brownish in color, thick-very thick bedded. Micritic limestones and argillaceous limestones occur at the upper levels of the formation (Figure 4-b).

The Akgöl formation presents a visible thickness of approximately 350 m in the study area. The Akgöl formation unconformably overlies the Boyabat metamorphics from the bottom. It is unconformably overlied by the Bürnük formation and by the Akkaya and Çağlayan formations where this formation are not observed from the top (Figure 2-b). Reference [33] gave Liassic (Lower Jurassic) age to the unit according to *Arietites latisulcatus* Quenst, *Phylloceras? Sp.*, *Belemnites cf.*, and *Clavatus* Elb. in the limestones intercalated with the black shales of the formation on the İnebolu-Küre road. In addition, [34] gave the Liassic age to the unit based on the *Involutina liassica* Jones fossil in the black shales of the unit [32]. Therefore, the age of the Akgöl formation should be Liassic (Lower Jurassic). The Akgöl formation is a sedimentary range of deep submarines deposited in increasingly shallow environments [32].



Fig. 3. Phyllites (a) and metagabbros (b) belonging to Boyabat metamorphites observed around Yaka Village

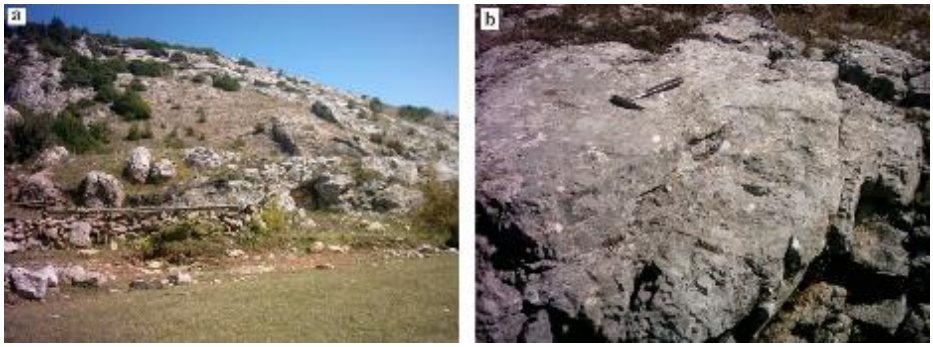


Fig. 4. Akgöl formation observed north of Kayadibi Village (a), and micritic limestone belonging to this formation (b)

C. Bürnük Formation

The Bürnük formation, firstly named by [9], is observed to the north of Kayadibi Village and Yolkıyısı Hill in the study area (Figure 2-a). The Bürnük formation consists of conglomerates and sandstones in red, purple and brownish colors (Figure 5). The gravel are poorly sorted, well rounded and several cm in size. It is not well cemented. Most of the gravel are derived from the underlying metamorphic basement. They also contain fragments of granite, shale and volcanic gravel. Gravel do not show significant bedding. The bedding is significant at sandstone levels. The sandstones showing cross-bedding are poorly sorted, and their grains are well-rounded. In the study area, in the outcrops of the Bürnük formation, red colored alternation of conglomerate-sandstone is obserfved frequently.



Fig. 5. Gravel of Bürnük formation observed north of Kayadibi Village

The Bürnük formation has a visible thickness of approximately 70 m. The unit is unconformably overlain by the Akgöl formation. It shows lateral-vertical transition with the Akkaya formation consisting of limestones. Where Akkaya formation disappears, it is unconformably overlain by Çağlayan formation (Figure 2-b). Reference [35] suggested that the Bürnük formation is of Upper Jurassic aged according to *Pseudocyclammina cf., Virguliana* Koechlin, *Paalzowella sp., Rectocyclammina sp., Bramkampella sp.* and *Mesoendothyra sp.* in the samples taken from the upper levels of the Bürnük formation [32]. In the study area, Bürnük formation unconformably overlies the Liassic (Lower Jurassic) aged Akgöl formation from the bottom, and it shows a lateral-vertical transition with the Dogger-Malm (Middle-Upper Jurassic) aged Akkaya formation from the top. Therefore, the age of the Bürnük formation should be Middle-Upper Jurassic. Bürnük formation is correlated with the Muzrup formation [14], Ahlatcık formation [36] and the upper surfaces of the Mevrandere formation [37] in the vicinity of Dadak-Devrekani. The Bürnük formation shows the characteristics of old river sediments in terrestrial facies with its typical red color and lithology. The formation was deposited in terrestrial, deltaic and shallow marine environments.

D. Akkaya Formation

The unit is made of limestones. It named by [17]. In study area, the unit covers in Çalyakası Hill and Köseldikkaşı Hill arounds, northeast of Kayadibi Village, Çalış Village around, north of Pelirliçay Hill, Yalnız Türbe Hill, Yolkıyısı Hill and Kovan Hill arounds (Figure 2-a). The Akkaya formation is composed of gray-beige colored, generally medium-thick bedded and abundant fossiliferous limestones (Figure 6). At levels where the clay content increases, the limestone layers become lumpy. The limestones are abundantly cracked, and these cracks have filled with secondary calcite minerals. Fossils consist of form gastropod shells, corals and alga.

The limestones of the Akkaya formation show a visible thickness of 1000 m in the study area. The unit shows lateral-vertical transition with conglomerates and sandstones of Bürnük formation from bottom. From the top, it is unconformably overlain by the Çağlayan formation and by the Yemişliçay formation where Çağlayan formation is not observed (Figure 2-b). The age of the unit according to foraminiferas and algas observed in limestones is given as Dogger-Malm (Middle-Upper Jurassic) [18]. The Akkaya formation is comparable to the Kestanedağ limestone described by [15] in Cide-Kurucaşile around and Yukarıköy formation described by [38] in Daday-Devrekani around. The fossil assemblage and lithological characteristics of the formation and its reef characteristics in places indicate that the formation has deposited in a shallow marine environment [18].



Fig. 6. The limestones belonging to the Akkaya formation observed northeast of Kayadibi Village

E. Çağlayan Formation

It was named by [9]. Çağlayan formation is observed in the vicinity of Zıpkın Village, Üçköknar Hill, Çamurlukkaşı Hill, Akçakaya Hill, Kayadibi Village, Helimoğlu Village, Uzungeriş Hill, Paşalıoğlu Village, Ayıkayası Village, Gürgenli Mountain, Yanıkdağ, Alaman Village and Manacık Hill in the study area (Figure 2-a). Çağlayan formation is generally composed of gray-black colored alternation of marl and shale. Sandstone and sandy limestone interlayers and limestone olistoliths are observed within the unit (Figure 7). Laminated sandstones are observed at the bottom levels of the formation. Gravelly sandstones are located towards the top.

Çağlayan formation is a visible thickness of 1325 m in the study area. The Çağlayan formation unconformably overlain by Akkaya formation from the botom and by the Kapanboğazı formation from the top (Figure 2-b). It is given Barremian-Albian (Lower Cretaceous) age to this formation according to *Nodosaria sp*. and *Lentioulena sp*. from Foraminiferas, *Parhaodolithus* embergru, *Coccollthui cf.* and *Cribrosbhaepalla* ehrenbergi from Nannoplanktons and *Eulioplites sp*. from Ammonoides [18]. The Çağlayan formation is correlated with the Ulus formation described by [15] and Çatak formation described by [38] in the vicinity of Cide-Kurucaşile. The formation was deposited in a marine environment according to its lithological and sedimentological characteristics. That the presence of fine-grained, black colored, organic-rich pyritic shales indicates that this formation were deposited in an aneorobic environment. In addition, the presence of olistolitic and sandy levels, the presence of imbricates that only shales and marls dominate together with alternation of sandstone-shale-marl and the presence of various sedimentary structures shows that the formation is deposited at marine, turbiditic and variable paleotopographic depth [18].

F. Kapanboğazı Formation

It is mainly composed of cherty limestones and micritic limestones. The Kapanboğazı formation was named by [9]. In the unit study area, it is observed along a narrow strip in the southern and northern parts of Zıpkın Village and Çalış Village and in around Tangaloğlu Village (Figure 2-a). The Kapanboğazı formation is composed of red, brownish red, sometimes green cherty limestone and marl intercalated micritic limestones (Figure 8). Limestones are generally medium bedded and sometimes chert banded. Upward, clayey limestones are observed. It passes into the Yemişliçay formation with the formation of clastic materials and volcanic materials at the upper levels of the Kapanboğazı formation.

The Kapanboğazı formation, which is generally observed as a thin belt in the study area, offers a visible thickness of approximately 300 m where the thickest outcrops occur. The Kapanboğazı formation covers the Çağlayan formation in conformity. It is overlain by the Yemişliçay formation from the top (Figure 2-b). The age of this formation was determined as Santonian-Campanian (Upper Cretaceous) according to *Globotruncana* cf. *arca* (Cushman), *Globoruncana* cf. *concavata* Brotzen, *Globotruncana* cf. *bulloides* Vogler and *Globoruncana tricarinata* (Quereau) fossils by [18]. In addition, [39] said that the age of the unit is Santonian-Lower Campanian (Upper Cretaceous) according to *Globotruncana linneiana* (d'Orbigny), *Marginotruncana sp*., *Globotruncana carinata* Dalbiez, *Globigerinellodies sp*., *Ticinella sp*. and *Dicarinella sp*. The Kapanboğazı formation is comparable to the Unaz limestone described by [15] in around Cide-Kurucaşile and Kirensökü formation described by [38] in around Daday-Devrekani. The Kapanboğazı formation was deposited in a deep marine environment.

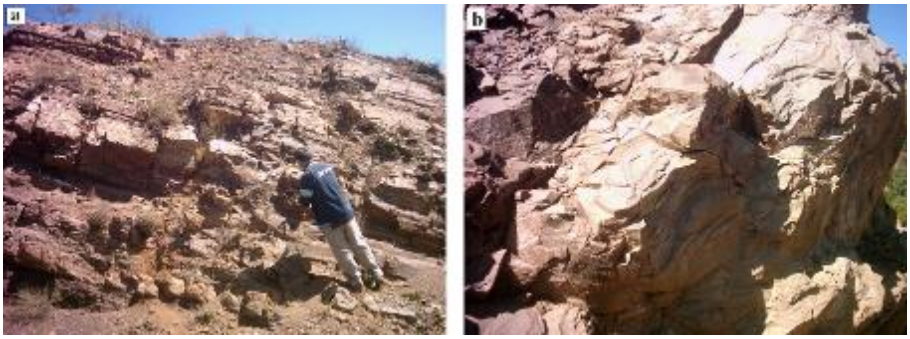


Fig. 7. The alternation of marl-shale with the sandstone interlayer observed around Uzungeriş Hill (a) and the marls observed south of Gürgenoğlu Village (b) belonging to the Çağlayan formation



Fig. 8. The limestones of the Kapanboğazı formation observed northeast of Vayisoğlu Village

G. Yemişliçay Formation

The unit, named by [9], covers in a large area in the vicinity of Kuloğlu Village, Davutoğlu Village, Kökçam Mountain, Kanruk Mountain and Göktepe Village (Figure 2-a). The Yemişliçay formation is composed of basaltic-andesitic lava, tuff and agglomerates containing green, greenish gray and brown colored marl, shale, sandstone interlevels (Figure 9). The lavas in the formation are blackish green-green in color and have basalt and basaltic andesite composition (Figure 9-a). They are generally observed as lava flows in the study area. In these lavas, cooling cracks are observed from time to time. Lava levels are generally characteristic with aphanitic porphyritic texture. Green-greenish brown tuffs and agglomerates in the Yemişliçay formation are more common than lavas (Figure 9-c). They should be alternated with sandstone, shale and marls. High amounts of feldspar phenocrysts are encountered in tuffs. The agglomerates are formed by attaching lapilli - block size grains to a ash - like volcanic matrix. Blocks are sometimes observed angular. They form a volcanic breccia. At the marl-shale-sandstone levels within the formation, flute structures, load molds and sometimes channel fills are observed. In these lithologies, layer thicknesses are quite variable. They offer layer thicknesses from thin to very thick. It is also possible to find layered structures at some tuff levels within the formation.

The Yemişliçay formation has a visible thickness of approximately 1500 m in the study area. The Yemişliçay formation is conformably observed on the Kapanboğazı formation. It is conformably overlain by the Cankurtan formation (Figure 2-b). At the outcrops of this formation which are observed in the northeast of Vayisoğlu Village, they are sometimes followed by lateral-vertical transitions at transitions with Cankurtaran formation. Reference [18] said that the age of the unit is Campanian - Maestrichtian (Upper Cretaceous) according to *Broinsonia parca* (Stradner), *Litraphidites quadratus* Bramlette and Martini, *Watznauerla barnesae* (Black), *Zygulithus consinnus* Martini, *Discolithus numerosus* Gorka, *Arkangelskiella parca* Stradner and *Globutruncana sp*. that they found in the shale interlevels of the Yemişliçay formation. Reference [29] determined ~ 71 million years (Campanian) age in the volcanics within the Yemişliçay formation by the method of 40Ar/39Ar. The Yemişliçay formation is comparable to the Yeniceköy tuffite member and Cambu agglomerated member described by [15] in the vicinity of Cide-Kurucaşile and the Mesudiye formation described by [40] in the vicinity of Ordu. The Yemişliçay formation has emerged as a product of volcanic activities intensified during the deposition stage of the Cankurtaran formation, which is deposited in the shelf ahead - slope environment [32]. The volcanites of the Yemişliçay formation were formed in an fore-arc environment in the Pontide magmatic arc [29].

H. Cankurtaran Formation

The unit was named as "Üst Cankurtaran member" by [5] and as "Gürsökü formation" by [9]. Whereas, It was named as the Cankurtaran formation by [17]. In the study area, it surfaces arounds Tepetarla Hill, Doruğukuru Hill, Kozciğaz Village, Çal Village, Hacıbeysuyu Hill, Topalınköy and Semso Village (Figure 2-a). The Cankurtaran formation consists of alternations of sandstone, marl, shale, mudstone and limestone (Figure 10). In bottom levels, it includes tuff and agglomerate interlevels. The unit presents thin-medium stratification. The flute structures and the load molds are observed in the formation. In the upper levels of the formation, black shale levels up to 60 m thick are found. Fine grained alternation of shale-marl-sandstone are typically observed at these levels.

The Cankurtaran formation presents a visible thickness of approximately 2800 m in the study area. The unit covers conformity the Yemişliçay formation and Kapanboğazı formation where it is not observed. The upper limit of the Cankurtaran formation was not observed in the study area (Figure 2-b). Reference [39] said that the age of the unit is the Campanian - Maestrichtian (Upper Cretaceous) according to *Globotruncana ventricosa* (White), *Globotruncana fornicata* (Plummer), *Stomiosphaera sp*. and *Lagena sp*. that they found in the Cankurtaran formation. Reference [18] gave Campanian - Lower Maestrichtian (Upper Cretaceous) age the unit by detecting the *Globotruncana lapparenti* (Brotzen), *Globotruncana conica* (White), *Globotruncana linneiana* (d'Orbigny) and *Globotruncana tricarinata* (Quereau) fossils within the unit. The Cankurtaran formation is correlated with the Üst Cankurtaran member described by [5] and the Hisarköy formation described by [15] in the vicinity of Cide-Kurucaşile. Cankurtaran formation is a submarine fan sediment formed by turbiditic currents in shelf ahead and in an area where volcanic activities sway [32].



Fig. 9. The lavas (east of Kökçam Mountain) (a), alternation of lava-sandstone-marl-shale (around Çömlek Hill) (b) and tuffs (northwest of Davutoğlu Village) (c) belonging to Yemişliçay formation

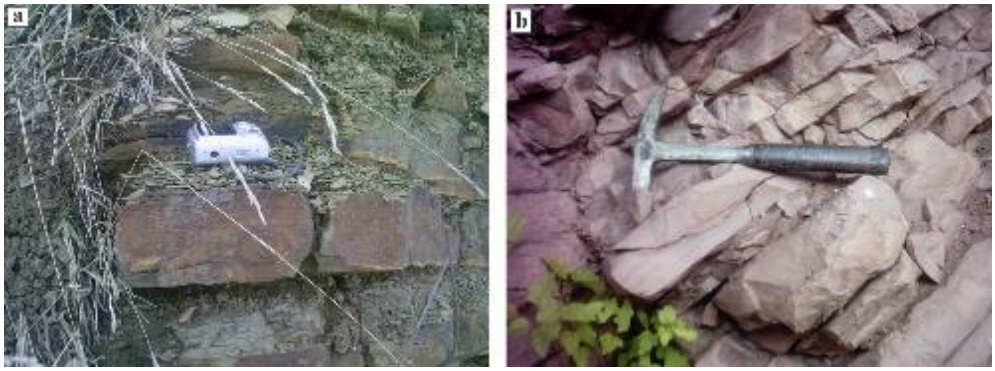


Fig 10. The alternation of shale - sandstone (north of Taşçıoğlu Village) (a) and marls containing shale interlayers (around Tepetarla Hill) (b) belonging to the Cankurtaran formation

IV. PETROGRAPHY

A. Boyabat Metamorphites

Phyllites and sericite-chlorite schists belonging to Boyabat metamorphics contain *sericite + chlorite (ripidolite-picnochlorite) + quartz ± calcite ± plagioclase (albite) ± muscovite ± epidote ± zoisite / clinozoisite ± microcline ± biotite (green) ± sphene* as mineralogical composition (from high to low) (Figure 11). While the main component in phyllites is sericite, the sericite amount decreases relatively in the sericite-chlorite schists whereas the amount of chlorite increases. In these rocks, sericites are prominent with pulsed crystals and they give a directional texture to these rocks together with chlorite. Chlorites are dark brown birefringence colored, leafy shaped and dark green colored (Figure 11). With these properties, chlorites are thought to be in the "ripidolite-picnochlorite" composition. These rocks are characterized by lepidoblastic and granolepidoblastic textures. In these metapelitic rocks, plagioclases observed in minor amounts are albite ($Ab_{96}An_{04}$, $Ab_{92}An_{08}$) according to extinction angle determination.

The *metasandstones* observed in Boyabat metamorphites contain *sericite + quartz + muscovite ± epidote ± plagioclase (albite) ± microcline ± chlorite ± calcite ± biotite (green) ± apatite* mineral paragenesis. The rocks are composed of quartz, muscovite, epidote, albite, microcline, chlorite and calcite minerals in a matrix with sericite showing pulsed shapes. Sericites in metasandstones were probably formed from clay minerals by low grade metamorphism. Two different sizes of quartz crystals are found in metasandstones. The coarse-grained quartzs are angular-round and are formed before metamorphism. Interlocking quartz with small grains and strong wave extinction are autogenically exposed by metamorphism.

Within the metapelitic rocks of Boyabat metamorphites, *greenschists* are observed as lenses and interlayers parallel to schistosity. They were named as "*epidote-actinolite schist*", "*actinolite-chlorite schist*" and "*epidote-tremolite schist*" according to the dominant mineralogical composition. The dominant mineralogical composition in *greenschists* are *tremolite + actinolite + chlorite (ripidolite-picnochlorite) + plagioclase (albite) + epidote + zoisite / clinozoisite ± quartz ± calcite ± microcline ± clinoproxene (diopside / augite) (relict) + sphene* (Figure 12). The greenschists are characteristic of granofibroblastic and nematoblastic textures.

Amphiboles seen in greenschists are in the composition of "tremolite" and "actinolite". Actinolites are fibrous and acicular forms, while tremolites are prismatic forms (Figure 12-a and b). Actinolites show green color, while tremolites show colorless or very pale green color. Actinolite schists show granofibroblastic texture, while tremolite schists are prominent with nematoblastic textures (Figure 12-b). These amphiboles together with chlorites gave the greenschists a directional texture.

Chlorites found in greenschists are green colored, leafy-platy-shaped, abnormal brown birefringence colored. They are probably in Mg-Fe chlorite (ripidolite-picnochlorite) composition (Figures 12-a and c). They form the main component of chlorite schists. The feldspars in the greenschists are in the composition of plagioclase and microcline. Mostly plagioclases, which have abundant inclusions, rarely have twinning. According to extinction angle, plagioclases were found to be albite ($Ab_{95}An_{05}$, $Ab_{93}An_{07}$).

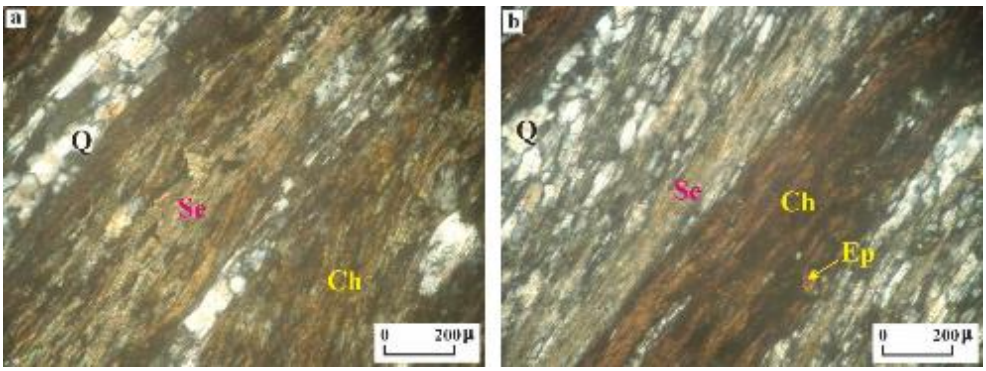


Fig. 11. Chlorite phyllite (a) and sericite-chlorite schist (b) belonging to Boyabat metamorphites. Se: Sericite, Ch: Chlorite, Ep: Epidote and Q: Quartz, // Nicol

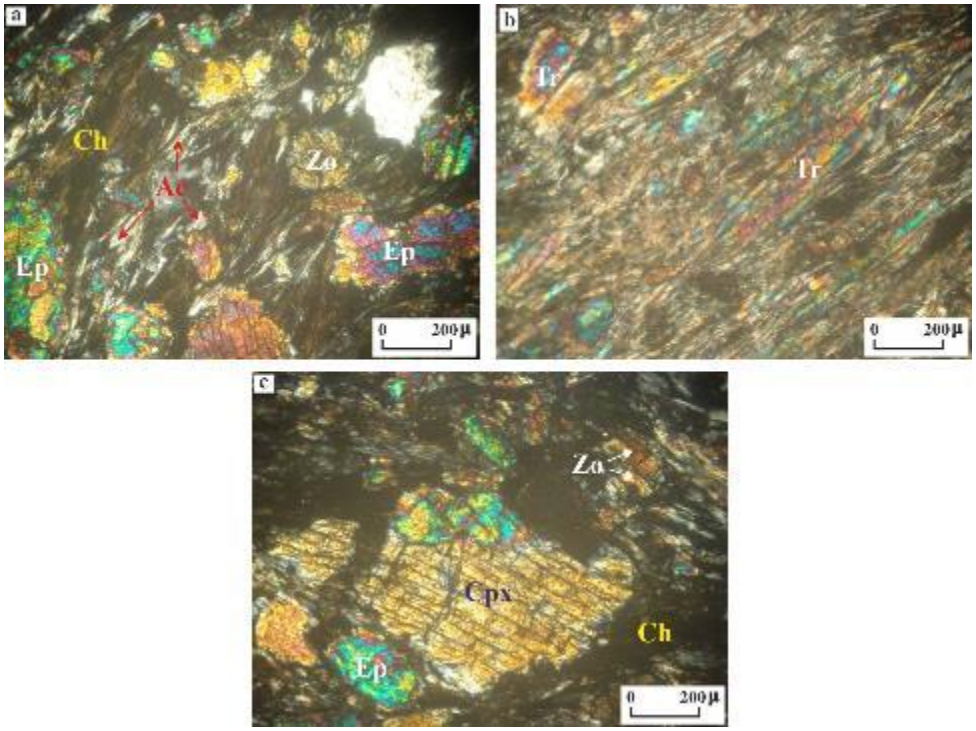


Fig. 12. Epidote-actinolite schists (a and c) and epidote-tremolite schist (b) belonging to Boyabat metamorphites. Ac: Actinolite, Tr: Tremolite, Ch: Chlorite, Ep: Epidote, Zo: Zoiside / Clinozoisite and Cpx: Relict Clinoproxene, // Nicol

Clinoproxenes, which are observed as remnants of magmatic rocks before metamorphism in greenschists, have long-short prismatic shape, oblique extinction between 40º-45º and very pale green color (Figure 12-c). With these properties, clinoproxenes are probably in diopsite / augite composition. Epidotes and zoisite / clinozoisites are characterized by very high relieves, generally semi-euhedral prismatic crystals and colorless-yellow-pale greenish yellow colors.

Glaucophanitic greenschists which are intensely observed in the bottom levels of Boyabat metamorphites are light bluish gray colored and fine grained in macro samples. These are observed as generally interlevels and sometimes blocks in metapelitic rocks. *Chlorite + glaucophane + epidote + plagioclase (albite) + phengite ± actinolite + zoisite / clinozoisite ± stilpnomelane ± calcite ± quartz + sphene* mineral paragenesis are observed in *glaucophanitic greenschists* (Figure 13). These rocks are characterized by granolepidoblastic and granonematoblastic textures. Considering the mineral abundance, these rocks are called *epidote-glaucophane-chlorit schist (glaucophanitic greenschist).*

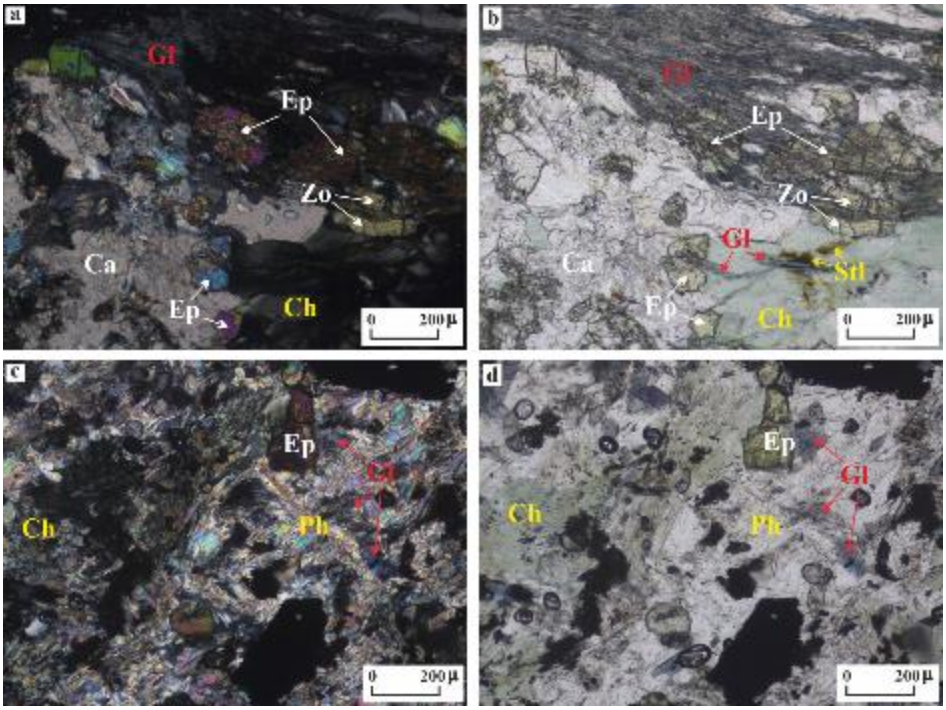


Fig. 13. Epidote-glaucophane-chlorite schists (Glaucophanitic greenschists). Ch: Chlorite, Gl: Glaucophane, Ep: Epidote, Zo: Zoisite / Clinozoisite, Ph: Phengite and Stl: Stilpnomelane, a and c) / Nicol, b and d) // Nicol

Chlorites observed in glaucophane greenschists are distinctly green colored and elongated leafy - plate crystals in one direction (Figure 13). The glaucophanes should be blue-violet colored, long prismatic shaped and 5°-angle oblique extinction (Figure 13). Considering the mineral paragenesis in glaucophane greenschists and greenschists, it is thought that glaucophanes are formed from albite and possibly chlorite due to increased pressure with deep burial. Albites are mostly porphyroblasts and contain inclusions. The inclusions are epidotes, zoisites and opaque minerals. These rarely show polysynthetic twinning. Phengites have plate-shape, with high birefringence and flat extinction (Figures 13-c and d). Stilpnomelanes observed in glaucophane greenschists are in the form of plate-radial crystals. Stilpnomelanes showing markedly flat extinction are prominent with their high reliefs and golden yellow-brown colors (Figure 13-b).

In *metagabbro* and *metadiabases*, which are seen as blocks in the bottom levels of Boyabat metamorphites; *actinolite + plagioclase (albite-oligoclase) + chlorite (pennin-clinochlorine) ± relict clinoproxene (diopside / augite) ± zoisite / clinozoisite + quartz ± epidote ± sphen* are observed (Figure 14). These rocks show blastoporphic and blastoophytic textures.

Actinolite crystals observed in metagabbros and metadiabases are green colored, prismatic and sometimes fibrous shaped and 10°-13° angle oblique extinction (Figure 14). These actinolites were formed from relict clinoproxenes by progressive reactions. Plagioclases are mostly observed as porphyroblasts (Figure 14). These is usually abundant and sometimes shows twinning. Plagioclases are in the composition of albite ($Ab_{97}An_{03}$) and oligoclase ($Ab_{77}An_{23}$). In metagabbros and metadiabases, clinoproxenes are observed as relicts and small crystals (Figure 14). They show prismatic shape and very pale green color. They show an oblique extinction between 43°-47°. With these properties, clinoproxenes are probably in diopside / augite composition. Clinoproxenes were transformed into chlorite and actinolite by progressive reactions.

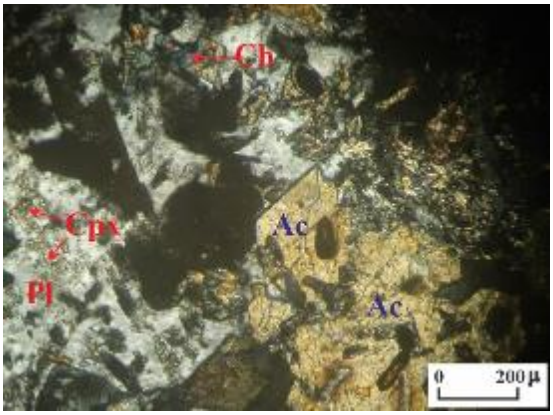


Fig. 14. Actinolite (Ac), plagioclase (P1), clinoproxene (Cpx) and chlorite (Ch) crystals seen in metagabbro // Nicol

The minerals, percentage values of minerals and rock names of nine samples belonging to phyllite, sericite-chlorite schist, metasandstone, greenschist, glaucophanitic greenschist, metagabbro and metadiabase from Boyabat metamorphites are given in Table 1.

Table 1. The components, % values of the components and rock names of nine rock samples taken from Boyabat metamorphites

	The Name of Rock								
The Name of Mineral	**Chlorite phyllite**	**Sericite-chlorite schist**	**Meta sandstone**	**Epidote-tremolite schist**	**Epidote-actinolite schist**	**Actinolite-chlorite schist**	**Epidote-glaucophane-chlorite schist**	**Meta gabbro**	**Meta diabase**
Sericite	32	28	27	-	-	-	-	-	-
Actinolite/ Tremolite	-	-	-	89	31	24	6	44	34
Chlorite (ripidolite-picnochlorite)	27	34	9	2	18	39	32	-	-
Chlorite (penninite-clinochlore)	-	-	-	-	-	-	-	8	7
Quartz	25	28	47	1	2	2	3	3	2
Calcite	5	-	2	-	5	6	2	-	-
Plagioclase (albite)	3	2	-	2	7	8	4	-	-
Plagioclase (albite-oligoclase)	-	-	-	-	-	-	-	16	26
Microcline	1	-	3	-	2	-	-	-	-
Glaucophane	-	-	-	-	-	-	22	-	-
Epidote	2	1	3	5	24	14	15	6	7
Zoisite / Clinozoisite	1	1	-	-	6	4	6	4	4
Stilpnomelane	-	-	-	-	-	-	2	-	-
Muscovite	3	4	8	-	-	-	-	-	-
Phengite	-	-	-	-	-	-	7	-	-
Relict clinoproxene	-	-	-	-	3	2	-	18	19
Biotite (green)	-	2	-	-	-	-	-	-	-
Apatite	-	-	1	-	-	-	-	-	-
Sphene	1	-	-	1	2	1	1	1	1
TOTAL	100	100	100	100	100	100	100	100	100

A.1. Metamorphism properties of Boyabat Metamorphites

Boyabat metamorphites are generally composed of phyllites, sericite-chlorite schists and metasandstones. The bands-lenses and blocks of greenschists, glaucophanitic greenschists, metagabbros and metadiabases are observed intensively in the bottom levels of the unit. When geochemical analyzes are also taken into consideration [41], it can be said that the unit was made of pelitic and psammitic rocks, basic magmatites and carbonated rocks before metamorphism.

Depending on the origin rock composition, chlorite, glaucophane, epidote, plagioclase (albite), phengite, actinolite, zoisite / clinozoisite, stilpnomelane, calcite, quartz and sphene minerals were observed in the glaucophanitic greenschists belonging to Boyabat metamorphites.

According to this, *in glaucophanitic greenschists*;

As a product of low grade (greenschist facies) metamorphism;

Chlorite + actinolite + epidote + zoisite / clinozoisite + albite + calcite

As a product of high pressure / low temperature metamorphism;

Glaucophane + albite + stilpnomelane + phengite

mineral assemblages are seen.

In phyllites and sericite-chlorite schists;

Sericite + chlorite (ripidolite-picnochlorite) + quartz + calcite + plagioclase (albite) + muscovite + epidote + zoisite / clinozoisite + microcline + biotite + sphene,

in metasandstones;

Sericite + quartz + muscovite + epidote + plagioclase (albite) + microcline + chlorite + calcite + biotite + apatite,

in greenschists;

Tremolite + actinolite + chlorite (ripidolite-picnochlorite) + plagioclase (albite) + epidote + zoisite / clinozoisite + quartz + calcite + microcline + clinoproxene (diopside / augite) (relict) + sphene,

in metagabbros and metadiabases;

Actinolite + plagioclase (albite-oligoclase) + chlorite (pennin-clinochlorine) + relict clinoproxene (diopside / augite) + zoisite / clinozoisite + quartz + epidote + sphene

mineral assemblages have been identified.

According to this that the observation of mineral paragenesis and index minerals released under different metamorphism conditions indicates that Boyabat metamorphites undergo at least two stages of metamorphism when we look at the metapelitic, metapsammitic and metabasic rocks of Boyabat metamorphites.

In Metapelites belonging to Boyabat metamorphites;

Muscovite + Chlorite (Ripidolite-Picnochlorite) + Biotite + Quartz (Figure 15- (1))

Muscovite + Biotite + Microcline + Albite + Quartz (Figure 15- (2))

Biotite + Microcline + Epidote + Albite + Quartz (Figure 15- (3))

in Metapsammites;

Quartz + Muscovite + Microcline + Biotite + Albite (Figure 15- (2))

Quartz + Muscovite + Albite

in Metabasites (in Greenschists);

Chlorite + Actinolite + Epidote + Albite (Figure 15 - (4)

Actinolite + Epidote + Calcite + Albite (Figure 15 - (5)

Chlorite + Epidote + Muscovite + Albite + Quartz

in Metabasites (in Metagabbros and Metadiabases);

Actinolite + Chlorite + Epidote + Albite (Figure 15 - (4)

Actinolite + Epidote + Zoicite / Clinozoisite + Albite + Quartz

paragenesis shows that the formation initially underwent metamorphism in "quartz-albite-muscovite-biotite subfacies" of greenschist facies (Abukama type) (Figure 15).

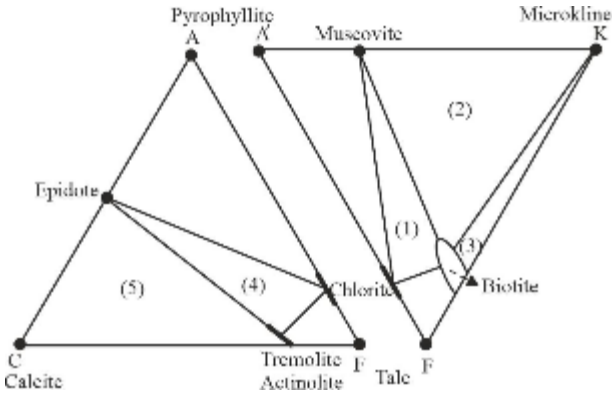


Fig. 15. The view in ACF and A'FK diagrams [42] belonging to "quartz-albite-muscovite-biotite subfacies" of greenschist facies of the mineral paragenesis observed in metapelitic, metapsammitic and metabasic rocks belonging to Boyabat metamorphites

The metamorphism conditions of the greenschist facies can be expressed as approximately a temperature of 350–500 ºC and a pressure of 2–10 kbar. The pressure-temperature conditions of the initial metamorphism in the greenschist facies observed in Boyabat metamorphites can be interpreted with the help the pressure-temperature diagram that show the stability of the chloritoid prepared by [43] (Figure 16). Chloritoid and phyrophyllite that are index minerals of the greenschist facies were not found in the Boyabat metamorphites. The absence of chloritoid in Boyabat metamorphites, it shows that the effective pressure in the environment is less than 3 kbar when it is considered in conjunction with Reaction 2 in Figure 16. The absence of phyrophyllite and chloritoid in metapelitic rocks of Boyabat metamorphites indicates that the lower temperature limit of the metamorphism in greenschist facies that is effective in environment is approximately 450 ºC when it is considered in conjunction with Reaction 1 and Reaction 2 in Figure 16. Actinolite was observed instead of hornblende in metabasites of Boyabat metamorphites. There is no hornblende in these rocks. Thus, it is seen that the effective temperature in the environment is lower than 500 °C when it is considered Andalusite ⇆ Hornblend reaction in Figure 16. Therefore, according to these data, it can be said that the metamorphism in the greenschist facies, which is effective in Boyabat metamorphites, occurs under temperature conditions between 450-500 ºC (Figure 16). As a result, Boyabat metamorphites initially underwent metamorphism in "quartz-albite-muscovite-biotite sub-facies" of greenschist facies at temperatures of 450-500 ºC and pressure of 2-3 kbar.

In the glaucophanitic greenschists belonging to the Boyabat metamorphites, albites formed as a result of the first stage metamorphism (greenschist facies) has changed into glaucophane with pressure increase.

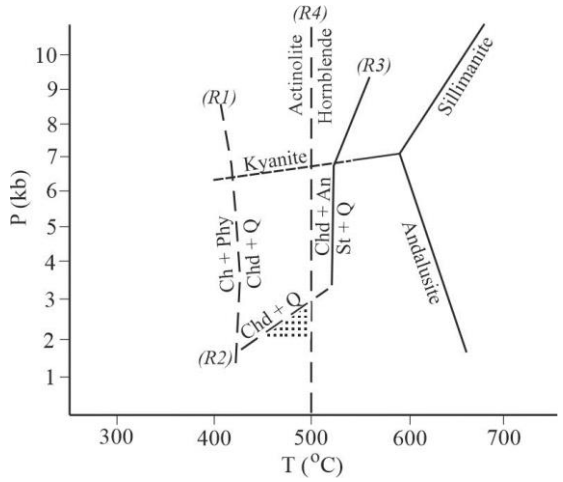


Fig. 16. The diagram showing the effective pressure (P) - temperature (T) conditions on chloritoid stability [43]. Straight lines indicate phase boundaries that are determined experimentally. Dashed lines indicate indicate phase boundaries that are predicted by virtue of both experimental data and petrographic observations. The triple point in the Al_2SiO_5 system was taken from [44], and the Actinolite ⇆ Hornblend reaction line was taken from [45]. The shaded area shows the pressure-temperature conditions that are effective in metamorphism in greenschist facies observed in Boyabat metamorphites. An: Andalusite, Ch: Chlorite, Chd: Chloritoid, Q: Quartz, Phy: phyrophyllite, St: Staurolite, R: Reaction

The glaucophane formations that are formed from the edges of chlorites are observed in some metabasite samples. These transformations must be carried out by the following reactions:

Albite + Chlorite + Quartz → Glaucophane + Paragonite + H_2O (5)

Tremolite + Chlorite + Albite → Glaucophane + Clinozoisite + Quartz + H_2O (6)

These data show that Boyabat metamorphites undergo the second metamorphism with increasing pressure after the initial metamorphism in greenschist facies.

In Boyabat metamorphites,

in Metabasites (in Glaucophanitic greenschists);

Glaucophane + albite + stilpnomelane + phengite,
Albite + epidote + chlorite + phengite + glaucophane,
Epidote + chlorite + albite + glaucophane

paragenesis shows that these metamorphites undergo high pressure - low temperature metamorphism with increasing pressure after metamorphism in greenschist facies. When this *high pressure - low temperature* metamorphism is evaluated in the pressure - temperature diagram of [46] (Figure 17), the following can be said about the conditions of metamorphism:

The absence of lavsonite in the metabasites of Boyabat metamorphites indicates a temperature that is higher than 400 °C. Observation of glaucophane in these metabasites, on the other hand, the absence of garnet and / or clinoproxene limits the upper limit of temperature as 500 ° C (Figure 17). There aren't aragonites in the metabasites. When this situation is considered together with the stability area of the glaucophane, it indicates a pressure of 6-12 kbar (Figure 17). In this study, other index minerals that limit this pressure range weren't found in the metabasites of Boyabat metamorphites. Therefore, Boyabat metamorphites underwent metamorphism in glaucophanitic greenschist (epidote-blueschist) facies at 400-500 °C temperature and 6-12 kbar pressure conditions after greenschist facies metamorphism (Figure 17).

As a result, Boyabat metamorphites in the study area initially underwent metamorphism in "quartz - albite - muscovite - biotite subfacies" of greenschist facies under 450-500 °C temperature and 2-3 kbar pressure conditions. These metamorphites then underwent a second metamorphism, whose effects are observed in the metabasites within the unit, in the glaucophanitic greenschist (epidote-blueschist) facies at 400-500 °C temperature and 6-12 kbar pressure conditions with increasing pressure in the environment.

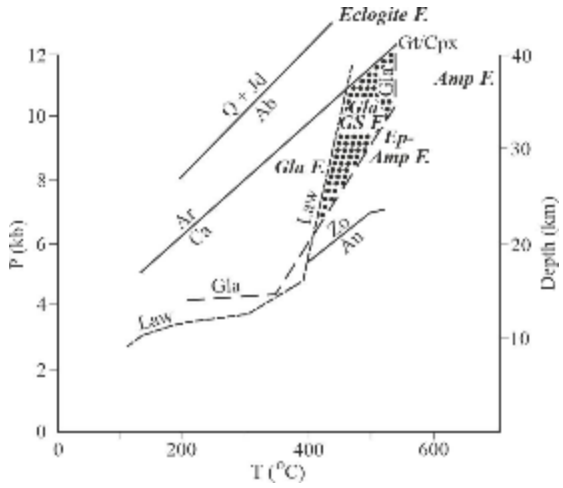


Fig. 17. Pressure (P) - Temperature (T) conditions of glaucophanitic greenschist (epidote-blueschist) metamorphism (scanned area with dots) observed in Boyabat metamorphites.The diagram has taken from [46]. Gla F .: Glaucophanite facies, Gla GS F .: Glaucophanitic greenschist (epidote blueschist) facies, Ep-Amp F.: Epidot-amphibolite facies, Amp F.: Amphibolite facies, Q: Quartz, Jd: Jadeite, Ab: Albite, Ar: Aragonite, Ca: Calcite, Law: Lavsonite, Gla: Glaucophane, Zo: Zoisite, An: Anortite, Gt: Garnet, Cpx: Clinoproxen

B. Yemişliçay Formation

Yemişliçay formation is composed of basaltic-andesitic lava, tuff and agglomerates containing marl, shale, sandstone interlevels (Figure 9). In this section, petrographic properties of volcanic and pyroclastic rocks observed in Yemişliçay formation will be introduced.

B.1. Volcanic and pyroclastic rocks

The lavas observed in the Yemişliçay formation were found to be in basalt and basaltic andesite composition according to geochemical analysis [41] and thin section observations. The components and % values of these components in these rocks are given in Table 2.

Basalts contain *plagioclase + clinoproxene (diopside / augite) + olivine + opaque mineral* as phenocrystals. The matrix consists of *plagioclase microlites* (Figure 18-a, Table 2). *Basaltic andesites* have *plagioclase + clinopyroxene ± olivine + opaque mineral* mineral composition in phenocrystalline phase. The matrix of these rocks consists of *plagioclase microlites + volcanic glass* (Figure 18-b, Table 2). Plagioclase phenocrysts and plagioclase microliths observed in these rocks show prismatic shape, albite and albite-pericline twin and zoned texture. Plagioclases in the basalts are in the composition of andesine ($Ab_{53}An_{47}$, $Ab_{56}An_{44}$) and labrador ($Ab_{32}An_{68}$, $Ab_{43}An_{57}$). Plagioclases in the composition of andesin ($Ab_{61}An_{39}$, $Ab_{59}An_{41}$) are seen in basaltic andesites. The olivines, which are commonly observed in basalts, are generally subhedral and sometimes euhedral. Abundant cracked structures are typical in some olivine crystals. Clinoproxenes, characterized by their prismatic shapes, very pale green colors and oblique extinction of 44°-48°, are probably in diopside / augite composition. Basalts commonly

show holocrystalline porphyritic texture. Basaltic andesites are hypocrystalline porphyritic textures (Figure 18).

Table 2. The components, % values of the components and rock names of four basalt and basaltic andesite samples belonging to Yemişliçay formation

Property	The Name of Component	The Name of Rock			
		Basalt	**Basalt**	**Basaltic andesite**	**Basaltic andesite**
Phenocryst	Plagioclase	24	21	22	22
	Clinopyroxene	6	2	28	24
	Olivine	28	30	2	1
	Opaque mineral	1	2	1	1
Matrix	Plagioclase microlites	41	45	23	25
	Volcanic glass	-	-	24	27
	TOTAL	100	100	100	100

The *tuffs* belonging to the Yemişliçay formation include *plagioclase, clinoproxene (diopside / augite), amphibole (hornblende), sphene, opaque mineral* in the phenocrystalline phase and *volcanic glass* in the matrix. Also these tuffs include *lithic fragments*. The components, % values of these components, grain sizes and classifications of the tuffs belonging to Yemişliçay formation are shown in Table 3.

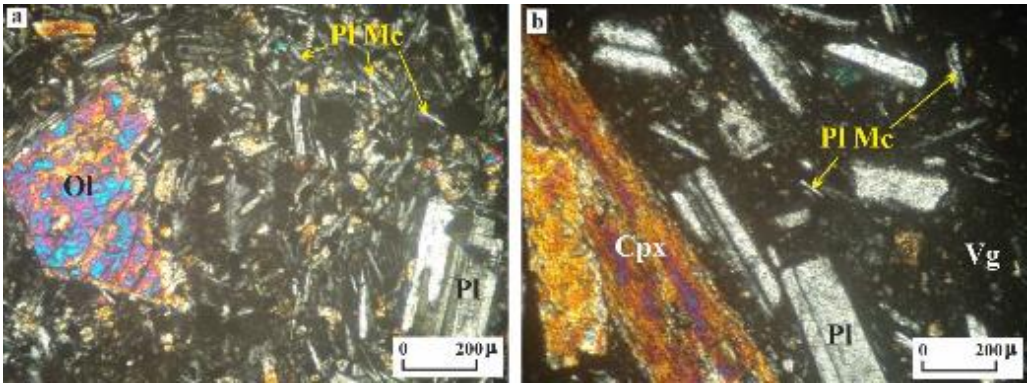


Fig. 18. Basalt (a) and basaltic andesite (b) belonging to Yemişliçay formation. Ol: Olivine, Pl: Plagioclase, Cpx: Clinoproxen, Pl Mc: Plagioclase microlites, Vg: Volcanic glass, // Nicol

Table 3. The Components,% values of the components, grain sizes and classifications of tuffs of Yemişliçay formation

			Sample Number		
			S-35	**S-38**	**S-41**
The Name of Component	**Phenocryst**	Plagioclase	% 25	% 22	% 26
		Clinopyroxene (Diopside/Augite)	% 9	% 12	%8
		Amphibole (Hornblende)	% 3	-	% 2
		Sphene	% 1	-	% 1
		Opaque mineral	% 1	% 1	% 1
	Matrix	Volcanic glass	% 56	% 57	% 59
		Litic fragments	% 5	% 8	% 3
Grain Size (in macro sample)		Size (mm)	mostly 2-64 mm	mostly 2-64 mm	mostly 2-64 mm
Distribution of percentage of grains (in macro sample)		< 2 mm	% 10	% 43	% 39
		2 – 64 mm	% 88	% 54	% 58
		> 64 mm	% 2	% 3	% 3
Classification		**According to Grain Size**	*Lapillistone*	*Lapillistone*	*Lapillistone*
		According to Composition and Grain Size	*Andesitic tuff*	*Andesitic tuff*	*Andesitic tuff*
		According to Percentage Distribution of Grains	*Lapillistone*	*Lapilli tuff*	*Lapilli tuff*
		According to Glass-Crystals-Litic Fragments Composition	*Vitric tuff*	*Vitric tuff*	*Vitric tuff*

The tuffs belonging to the Yemişliçay formation have mostly grain sizes of 2-64 mm (Table 3). Therefore, these rocks were defined as "lapillistone" when they are evaluated in *the grain size classification diagram of the proclasts* of [47]. Also, according to their mineralogical composition, these rocks (Table 3) are in the "andesitic" composition in the Q-A-P-F diagram prepared by [30]. These tuffs are named as "lapillistone"and "lapilli tuff" when they is used in the triangular diagram for classification *according to percentage distribution of grains in pyroclastic rocks* of [48] (Figure 19-a). Tuffs are seen in the area of "vitric tuff" in *glass-crystals-lithic fragments* diagram of [49] (Figure 19-b).

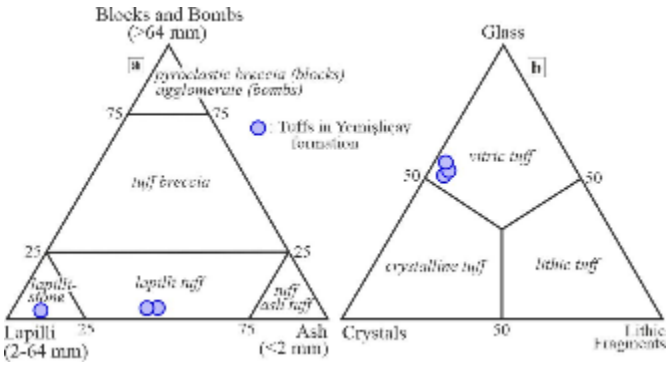


Fig 19. Classification diagrams according to percentage distributions of grains (a) and according to the compositions of glass-crystals-lithic fragments (b) for tuffs belonging to Yemişliçay formation. The diagram a : from [48], and the diagram b : from [49]

Plagioclases observed in tuffs are seen as subhedral prismatic crystals (Figure 20). These represent polysynthetic and karlsbad twins. Sericitization is sometimes observed in plagioclases. Clinoproxenes are probably in diopside / augite composition with very pale green colors, prismatic shapes and 44º-47º angled oblique extinction. Hornblendes are prismatic shaped, brown colored and 22º-25º angled oblique extinction. Oxidation and opacification are observed in the proxene and hornblendes in tuffs. The litic fragments in the tuffs are Volcanic litic fragments. Volcanic glasses observed in the matrix are sometimes silicified (Figure 20).

Tuffs consist of phenocrystals, volcanic glass and litic fragments. Therefore, tuffs show porphyritic texture. Since the matrix consists entirely of volcanic glass, the tuffs also have vitrophyric porphyritic texture (Figure 20).

V. DISCUSSION

In this study, stratigraphy of around Kuloğlu - Yaka Villages in the north of Boyabat (Sinop) and petrographic properties of Boyabat metamorphites and volcanites and proclastites belonging to Yemişliçay formation observed in this region were investigated. The metamorphic units constituting the basement in the region are named as pre-Liassic aged Boyabat metamorphites that contain low-grade metapelitic rocks by [18]. They stated that these metamorphics are unconformably overlain by Liassic aged Akgöl formation consisting of alternation of shale-marl with turbiditic sandstone-milestone interlevels with dunite and gabbro blocks. Reference [32] named metamorphic rocks at the bottom as Triassic-Liassic aged Bekirli formation. The researchers stated that these metamorphites are made of phyllite, schist, gneiss and that serpentinite, metadiabase, metagabbro, metachert blocks are observed in these metamorphites. Reference [32] said that basic volcanic clastics contained albite, chlorite, epidote, glaucophane, garnet and muscovite. Reference [1] said that metamorphites, which are named as Boyabat (Bekirli) metamorphites, in the basement, contain schists and phyllites and that metabasics-metalavas-metatuffs are abundant in the base. They stated that the base levels of Boyabat metamorphites undergo metamorphism in high-pressure conditions and that the upper levels of these undergo metamorphism in glaucophanitic greenschist facies in low-medium pressure conditions.

In this study, it was determined that Boyabat metamorphites were formed the base in the region. These metamorphites consist of metapelitic and metapsammitic rocks. It is determined that Boyabat metamorphites contain intensely greenschist, glaucophanitic greenschist, metagabbro and metadiabase bands-lenses and blocks in the bottom levels. Also, it is determined that these metamorphites are exposed to two phase metamorphism with increasing pressure in the environment.

The volcanic units observed in the study area are showed in the Upper Cretaceous aged Yemişliçay formation by [18]. The researchers stated that this unit is composed alternation of tuff-tuffite-agglomerate intercalations with sandstone-marl interlevels and contains dacitic lava levels. These volcanic units are named as "volcanite members" at the base levels of the Campanian aged Cankurtaran formation by [32]. The researchers said that the volcanic member is composed of basaltic-andesitic lava, tuff and agglomerate. Reference [26] determined that Dodurga volcanics (102.2+2.7 my. - Cretaceous aged volcanics), which are composed of andesitic rocks (trachyandesite, andesite), dacitic rocks (dacite, trachydacite) and volcaniclastic rocks, and Akyürek volcanics (15.4 + 0.6 my. - Middle Miocene aged volcanics), which are composed of basaltic rocks (trachybasalt and basalt), compose the volcanic units in the vicinity of Boyabat. In this study, the volcanic and proclastic rocks observed in the region have been shown in the Upper Cretaceous aged Yemişliçay formation. It has been determined that Yemişliçay formation is composed of basaltic-andesitic lavas, tuffs and agglomerates containing marl, shale, sandstone interlevels.

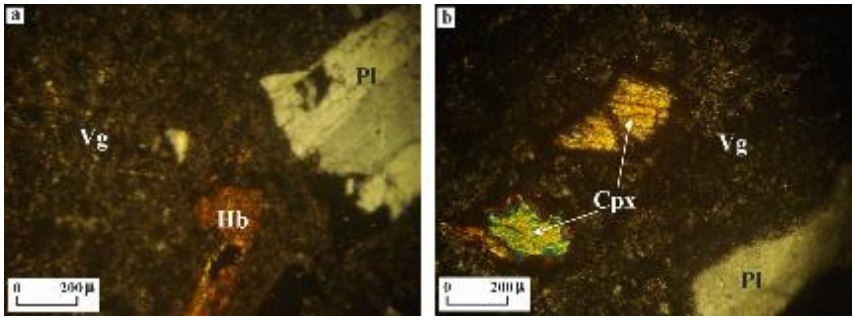


Fig. 20. Tuffs belonging to Yemişliçay formation. Hb: Hornblend, Pl: Plagioclase, Cpx: Clinoproxen, Vg: Occasionally silicified volcanic glass, // Nicol

VI. CONCLUSION

Paleozoic-Triassic aged Boyabat metamorphites consisting of phyllite, sericite-chlorite schist and metasandstones containing greenschist, glaucophanitic greenschist, metagabbro and metadiabase interlevels are observed at the base in the study area. Higher up, the Upper Jurassic aged Akgöl formation, which consists of alternation of sandstone-milestone-shale, is unconformably located. Middle-Upper Jurassic aged Bürnük formation consisting of conglomerates unconformably overlies Akgöl formation. The Akkaya formation, which is made of Middle-Upper Jurassic aged limestones, is observed with lateral-vertical transition on the Bürnük formation. Higher up, the Lower Cretaceous aged Çağlayan formation, which is composed of marls and shales with sandstone-sandy limestone interlevels, is unconformably located. The Çağlayan formation is unconformably overlain by the Upper Cretaceous aged Kapanboğazı formation. Kapanboğazı formation is composed of cherty limestones and micritic limestones. This formation is covered by the Upper Cretaceous aged Yemişliçay formation, which is composed of basaltic-andesitic lavas, tuffs and agglomerates containing sandstone-marl interlevels. Upper Cretaceous aged Cankurtaran formation consisting of sandstone, marl, shale, mudstone and limestone interlevels and including tuff and agglomerate interlevels at the bottom levels is observed at the top of the study area.

Boyabat metamorphites initially underwent metamorphism in the "quartz-albite-muscovite-biotite subfacies" of the greenschist facies under 450-500 ^{o}C temperature and 2-3 kbar pressure conditions. Afterwards, these metamorphites then underwent a second metamorphism, whose effects are observed in the metabasites within the unit, in the glaucophanitic greenschist (epidote-blueschist) facies at 400-500 ^{o}C temperature and 6-12 kbar pressure conditions with increasing pressure in the environment.

Basalts of Yemişliçay formation contain plagioclase and olivine phenocrysts and plagioclase microlites. Basaltic andesites consist of plagioclase, clinoproxene (diopside/augite), very few olivine, plagioclase microlites and volcanic glass. Tuffs in this formation include plagioclase, clinoproxene (diopside / augite), amphibole (hornblende), volcanic glass and litic fragments. Tuffs are called as *andesitic tuff* "according to composition and grain size". Tuffs are called as *lapillistone* "according to grain size". Tuffs are called as *lapilli tuff* and *lapillistone* "according to percentage distribution of grains". Tuffs are called as *vitric tuff* "according to glass-crystals-litic fragments compositions".

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