



The geology and mineralogical / petrographic features of Umurbabadağ and its surroundings (Eşme, Uşak - Turkey)

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Abstract

Although numerous geological studies have been carried out in many regions of the Menderes Massif, even in areas close to the study area, no detailed geological mapping of the study area has been found. Within the scope of this study, geological, mineralogical-petrographic studies of Umurbabadağ and its vicinity were carried out and detailed 1/25,000 scaled geological mapping of the area was completed. When the findings obtained from the field and mineralogy-petrographic studies are compared with the general geological features of the Menderes Massif, it is understood that the study area is located within the Demirci-Gördes submassif of the Menderes Massif. Paragneisses (fine-grained gneisses) and orthogneisses having shear and/or compatible contact with these rocks belonging to the Latest Proterozoic-Early Cambrian Core of the Menderes Massif crop out in the area. The fine-grained gneiss unit, corresponding to the Pan-African basement, outcrops in a very large area in the field. Amphibolite bodies, meta-aplite and meta leucogranites are present at different locations, generally cutting the fine-grained gneisses. Meta-aplite and meta leucogranites have been interpreted as granite porphyries of granitic augen gneisses, while amphibolites have been interpreted as basic magmatics cutting the Precambrian-Cambrian basement. The second widely observed rocks in the field is granitic augen gneisses (orthogneisses). These rocks are sometimes intermediate levels in fine-grained gneisses and sometimes cut the unit. As a result of the structural analysis performed on the metamorphic rocks in the area, it was observed that the main strike axes of the rocks are N40-50°E and the rocks are affected by a NW-SE trending force pair. It was concluded that the findings obtained were compatible with the properties agreed on the massif.

Keywords: Menderes Massif, Mineralogy/Petrography, General Geology, Eşme-Uşak.

1. Introduction

Perhaps one of the massifs on which the most studies geological studies conducted about the Massif is older than geological studies which have been carried out in Turkey. [1] considered the massif as a nucleus unaffected by Alpine Orogeny and called it "Lydish-Karische Masse" and claimed that it was Precambrian in age. [2] also divided the massif into two as core and cover. [3] carried out detailed geological and petrological studies, in a large area, on the Neogene sedimentary and volcanics covering/cutting the massif in Western Anatolia. [4] divided the massif into three sub-units as the gneiss complex forming the core, the schist complex forming the cover and the marbles overlying them. [5], with their Rb/Sr isotope studies in the Menderes massif, claimed that the age of the massif was 500 ± 10 million years, and that the main metamorphism in the massif was completed 50 Ma ago during the Alpine Metamorphism period, they have also suggested, based on stable isotope studies, that the gneisses in the massif are mainly of para

are carried out is the Menderes massif. Some of the (sedimentary) origin. Kun and Candan [6] conducted studies on basic veins and suggested that these rocks were metamorphic forms of old gabbroic rocks that cut the leptites and their depth conjugate rocks. [7] stated that the main metamorphism of the Menderes Massif was completed in the Upper Paleocene, the tectonic movements accompanying the metamorphism continued until the Eocene, and in the weak zones formed by the effect of tectonic movements, first acidic plutons and then basic plutons were introduced into the lower part of the massif. They consider the garnet-sillimanite paragenesis, which they detected in acidic plutons in particular, as evidence that acidic plutons crystallized in the deep zone and formed as a result of partial melting of the lower crust [8], in their studies on the south of the massif, discussed the Menderes Massif as three main sections with discordance between each, like [4]. They named the Çine Group representing the core, the Kavaklıdere Group

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representing the cover, and the Marçal Group representing the marbles. In fact, although this dialect was expressed in different ways by different researchers in later times, this classification was generally adhered to as a framework. [9] stated that the massif underwent at least two progressive metamorphisms, that the first metamorphism was formed 500 Ma ago at the Cambrian-Ordovician border, and after the first metamorphism, a thick clastic and thick carbonate precipitation occurred in the Ordovician-Paleocene interval. They suggested that the second metamorphism, which they consider to be the main metamorphism of the massif, occurred due to the Lycian nappes with oceanic crust passing over the massif in the Paleocene-Late Eocene

2. Material metot

2.1. General framework of the study area

The study area is a part of the core units of the Gördes-Demirci submassif of the Menderes Massif in Western Anatolia and covers an area of about 145 km² within the borders of Kula, Alaşehir and Eşme (Fig. 1). The detailed geological mapping study in the area subject to this study has not been encountered except for this study conducted by the author within the scope of "Mineral Potential of Western Anatolia Project" of General Directorate of Mineral Research and Exploration of Turkey (MTA). In this study, the detailed geological map of the area was made, and the lithological features and

2.2. Field studies

Within the scope of the study, a large number of rock samples were taken from all lithological units belonging to the metamorphic basement outcropping in the area, using the point sample method and along lines in different directions in places.

Stratigraphic relations observed as a result of field studies and findings obtained from mineralogical-petrographical studies were evaluated together and the geological, stratigraphic and tectonic features of the study area were tried to be correlated with the general features of the Menderes Massif. In this study, it is aimed to present the remarkable

2.3. Laboratory studies

Thin sections of rocks collected from the field were carried out by routine thin section preparation methods in the laboratories of MTA. Mineralogical/petrographic examinations of the prepared thin sections were also carried out in Mineralogy/Petrography Unit of MTA by using facilities the unit (polarizing microscope, etc.).

interval.

As can be understood from the brief summary of the studies on the Menderes massif, especially in the 20th century, the Menderes Massif has been the subject of many geological studies [10–14]. In fact, Western Anatolia, including the Menderes Massif, has hosted many civilizations since antiquity, and since then, the region has been a region where important mining activities have been carried out [15]. Nowadays, the western anatolia in general [16–25] and the Menderes massif in particular [26–30] have been the subject of many mine geology studies.

stratigraphic relationships of the rocks were studied in detail [26, 31, 32]. Within the scope of the MTA project, the geological map of the metamorphic rocks in an area of approximately 600 km² adjacent to the study area was also made by the researcher who carried out this study, but these maps were excluded from this study and were given to the Map Archive of the Geology Department of the General Directorate of Mineral Research and Exploration of Turkey (MTA) and these maps were used as a base for the preparation of İzmir 1/500 000 scaled geological map compilation of Turkey by [33].

geological/lithological features of the region to the attention of the researchers by giving the obtained findings as the details of the lithological features in the area rather than seeing them as the first priority to solve a problem for the Menderes Massif with their current raw state. This study, which has been carried out in the past and is a part of a great effort, has been given in its current raw form as a respect for the labor in the mentioned period, and a very detailed study of the field has been projected for geological purposes, and the findings to be obtained as a result will be shared in future.

XRD examinations of the samples taken from the study area were carried out at the Mineralogy/Petrography Unit of MTA. The instrumental conditions used in XRD examinations are summarized in Table 1.

Table 1. Instrumental conditions used in XRD analysis

Anod	Cu (CuK α =1.541871 Å)	Kağıt Hızı	2 cm/dk
Filtre	Ni	Duyarlılık	4.102
Gerilim	35 kV	Zaman sabiti	1 sn
Ganyometre Hızı	2°/dk	Yarıklar	1°-0.1mm-1°
		Kağıt aralığı	TK 2 θ =2-70° KF 2 θ =2-40°

3. Results and discussions

3.1. Regional geology

With existing position, Turkey is located on the Alpine-Himalayan orogenic system which was formed by the merger of two major continents, Gondwana in the south and Laurasia in the north, and the intervening continental terranes (e.g. Anatolide-Tauride Block, Kırşehir Massif, Sakarya, Istanbul and Strandja zones), with the closure of the different branches of the Tethys Ocean. Izmir-Ankara-Erzincan suture, Turkey's main tectonic line, separates the Sakarya zone in the north from the Tauride-Anatolide Block in the south [34] (Fig.1). The Anatolide-Tauride Block represents the easternmost extension of Apulia. It is claimed that it broke off from Gondwana during the Permo-Triassic period and collided with Pontides in the Paleocene-Early Eocene with the closure of the Neotethys [35]. Anatolids consist of numerous tectonic units, one of which is the Menderes Massif. As stated earlier, these tectonic units are considered to derive from the deep burial of the northern edge of the Taurids during the closure of the northern branch of Neotethys [36]. The Pan-African orogeny represents the general orogenic processes leading to the merger of Gondwana with the multiple closures of individual oceans collages, continental collisions, significant crustal thickening and the development of orogenic belts up to ca.530 Ma [37]. Before the opening of the Eastern Mediterranean in the Triassic, it is recognized that the Taurus Block was actually part of northern Gondwana and connected to Northeast Africa [38]. The base of Tauride exposed in the Menderes and Bitlis massifs is stated to represent the northern continuation of the Neoproterozoic Pan-African basement of Afro-Arabian [39], affected by the "Kadomia" orogeny, and then an Andean type orogenic belt surrounding the northern Gondwana rim at the close of the Precambrian. There is general consensus that Taurus was located on the Northeast African border of Gondwana during the Paleozoic and until the opening of the Eastern Mediterranean. However, the exact geological features of its foundation and whether it is part of the Arab-Nubian

Shield or another Pan-African structure have not been fully reconciled [40].

The Menderes Massif is a widespread (200x300 km dimensions) massif composed of Neoproterozoic-early Cenozoic sedimentary and igneous rocks interlocked with each other during Pan-African and Alpine collisions [41]. The approximately E-W striking Tertiary extensional grabens divide the Menderes massif into northern, central and southern submassifs. The north of the massif is bounded by the İzmir-Ankara zone [42], which consists of marble and ophiolitic masses, and the Lycian nappes to the south (Fig.1). For many years the Menderes massif was seen as a massive with a simple and regular stratigraphy consisting of a Precambrian core in the center and an overlying Paleozoic-Tertiary units [2], however, recent studies have shown that thrust faults produced by the Late Alpine compressional regime have significantly changed the primary structure of the massif and thus it has a very complex structure [43]. As another view, the geological location of the Menderes massif is seen as a Tertiary expansive metamorphic core complex that has overprinted an Alpine nappe pile [44], possibly involving a large recumbent folding [35]. The existence of such different and multi-dimensional views has caused the massif to have a complex structure that makes it difficult to understand. In particular, the border between core and veil is still controversial. Discussions of discordance [2, 39], extensional shear zone [45], detachment with granite intrusion [46], south-dipping thrust [47] or a thrust overprinted by extensional movements [48] have been put forward. In this study, it was aimed to present the general geological/petrographical characteristics of the study area without any interpretation regarding these discussions, and the opinions mostly agreed with the field findings and those that were confirmed about the massif were prioritized in the study. Thus, the geological position of the study area in the Menderes Massif literature has been tried to be clarified.

As a general framework, initially the massive was divided from bottom to top, as Proterozoic gneiss core, Paleozoic schist cover, and Mesozoic-lower Cenozoic carbonate dominant marble cover [2, 8]. Relatively, stratigraphically based on this distinction, the gneiss core consists of poly-metamorphic Neoproterozoic-early Cambrian rocks. These rocks consist of partially migmatized Neoproterozoic metaclastic sequences (paragneiss and overlying it, mica schists) and late Proterozoic-early Cambrian metagranitoid (orthogneiss) intrusions and margins eclogitic metagabbro stocks [49]. The most distinctive feature of orthogneisses in the core is the dominance of augen textures of different shapes and volumes. These augens, which are generally composed of quartz, feldspar, muscovite, biotite and tourmalines in places resemble the leucosome of migmatite. These rocks are generally composed of quartz, feldspar (plagioclase, orthoclase, microcline), muscovite, biotite minerals, less garnet minerals and a few sillimanite minerals as the main minerals. In addition, different types of gneisses and schists in the core series are transitional between migmatites and augen gneisses of sedimentary origin. Granitic augen gneisses cut the other core series. These are settled in the bedrock unit, sometimes as an intermediate level as sills, sometimes as blocks. In some areas, migmatite, gneiss and schist enclaves are encountered within this unit. The core unit is unconformably overlain by the Paleozoic schist cover consisting of meta-conglomerate meta-quartzite, represented by the basal conglomerate of the Supra-Pan-African unconformity in limited locations. The cover group has been subjected to a low degree of metamorphism [8]. Mesozoic-Lower Cenozoic marble cover derived from the Anatolide-Tauride Neotethian platform, begins with a red basal conglomerate horizon, and consists of lower Triassic chlorite schist, upper Triassic-Liassic interbedded marble and schist, Jurassic-lower Cretaceous massive dolomite, upper Cretaceous reddish pelagic limestones, and Eocene wild-flysch [8].

In the core of the massif, different orthogneisses, having S type affinity [46], have been identified according to the primary mineralogical composition and texture. These are from the oldest to the youngest; biotite orthogneiss (570-550 Ma; [50], leucocratic tourmaline orthogneiss (545 Ma; [51], and amphibole orthogneiss (530-525 Ma; [52]. Small volumetric masses of metagabbro were introduced into the core metaclastic sequence. In addition, outside the study area, granulite residue (~585 Ma;

[53] and eclogite facies metamorphism (535-530 Ma; [54] products, which are thought to be related to the final merger of Gondwana, have been reported within the basement series.

The nappe stacking in the Menderes massif and the ages between 62-25 Ma obtained from muscovite and biotite using Rb-Sr and Ar-Ar methods [39, 55] are seen as evidence of continental collision during Cenozoic period [56]. In the South of the Menderes massif, the lower Triassic metaconglomerates, at 45 Ma, cover the HP/LT assemblage series (up to 12-14 kbar/450–500°C; [57] preserved under low green schist facies conditions. Therefore, Tertiary metamorphic evolution of HP/LT metamorphized cover of South of the Menderes Massif is correlated with Cycladic complex [47]. These explanations define the southern sub-massif more clearly, and it is stated that the central sub-massif is formed as isolated clips on the underlying imbricated tectonic layer, showing similarity to the basement of the southern sub-massif, but due to this nappe structure it shows an inverted metamorphic field gradient and reverse stratigraphic sequence [58]. Based on the lowest tectono-stratigraphic unit, lithology and low grade metamorphism of the central sub-massif, it is associated with the paleozoic cover of the southern sub-massif and is considered to be para-autochthonous [35, 39]. Considering the data on the core of the massif and the findings in the metagabbros within the core, it is suggested that the basement of the Menderes Massif was exposed to at least 3 metamorphic facies (granulite, eclogite and amphibolite facies) during/or after the Late Neoproterozoic magmatic activity period, the Phanerozoic cover sediments on the basis of the massif were not affected by any of these metamorphic processes [54]. The Paleozoic cover section mainly presents mineralogy belonging to the greenschist facies. In studies conducted by various researchers, Alpin [39] or Early Triassic [4] age was given for the greenschist facies metamorphism of cover section of the massif. As a general consensus, significant magmatic activity in the Menderes massif (nappes) occurred in the Proterozoic/Cambrian border [50], middle Triassic [59] and Miocene [60]. Recent findings on the Menderes massif show that the main metamorphic events that shaped the Precambrian basement of the massif are associated with the Kuunga orogeny, however Alpine metamorphism also led to limited retrograde events in these basement rocks [11, 61].

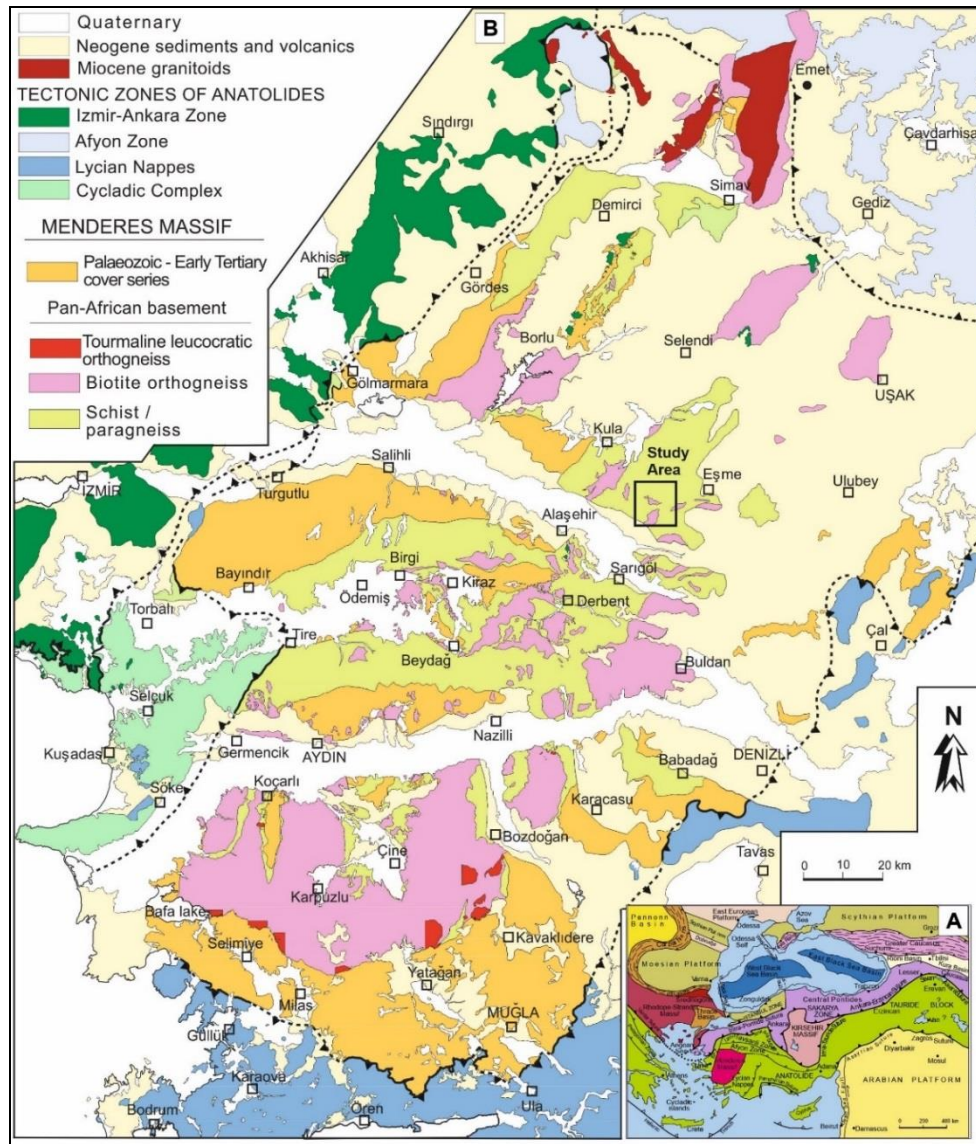


Figure 1. (a) The geological map of the Menderes Massif in particular and the western Anatolia in general and location of the study area (from [62, 63]), the filled triangles indicate the polarity of subduction b) Inset shows tectonic map of Turkey and surrounding (from [64]).

3.2. Geology of the study area

The rocks exposed in the study area are within the Demirci-Gördes submassif of the Menderes Massif, which is accepted as the core of the massif by various authors studying in the region. In a large part of the area, rocks called paragneisses of the massif crop out. The units were defined as fine grained gneiss units in [26]'s master thesis and in [27]. This unit has been named paragneiss in different parts of the Menderese Massif by different researchers [8, 9, 33, 49, 65, 66] and it corresponds to the Pan-African basement. Granitic augen gneisses take place in the unit as intermediate levels and sometimes cut the unit in different places (Narıncaail, Uzuntarla, Hacıyeşiller, Battallar locations). Abundant amphibolite bodies are encountered in fine grained gneisses (paragneisses),

especially stratigraphically towards the upper levels of the series. Again, within the fine-grained gneisses belonging to the core series, a metaaplite unit is also observed in the west of the study area and further west outside the area. In the southern part of the study area, metaleucogranite unit cutting the fine grained gneiss unit was detected. Both metaaplite and metaleucogranite units have been interpreted as granite porphyries of granitic augen gneisses [26]. A small sized serpentinite slice in the form of boudinage was encountered within the fine grained gneiss unit in the southern part of the study area. Continuity of this serpentinite in the same unit was observed outside the area. The serpentinite was interpreted as the sign of the guidance of a large

thrust line and the remnant of the Lycian nappes. On top of all these metamorphites in the area are the alluvial fan (Kürtköy formation) [67], unit consisting of pebbles of augen gneiss, fine-grained gneiss and

metaapilites, belonging to the massif, south of the area, and the Quaternary Asartepe formation consisting of orange sandstone, claystone and tuffite [26, 67] (Fig. 2, 3).

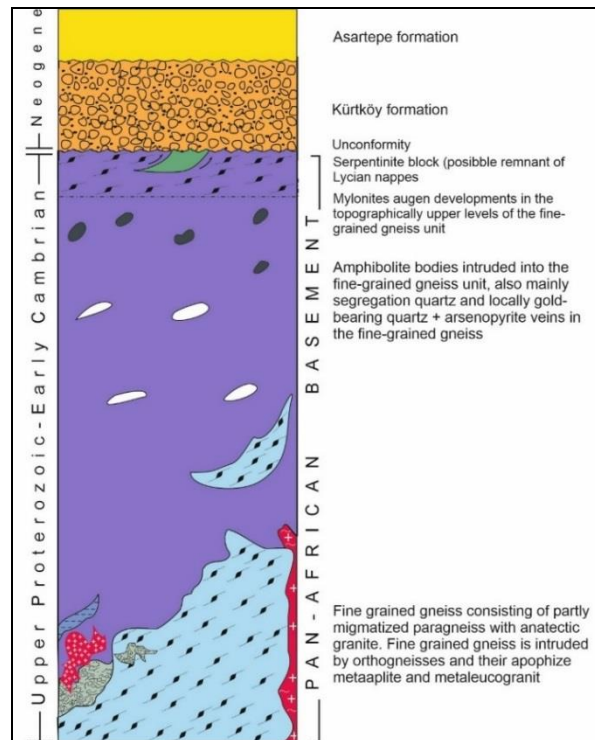


Figure 2. Generalized column section of the study area

3.2.1. Fine grained gneiss

Fine grained gneiss unit outcrops about 2/3 of the area. Especially in the northern part of the area, this unit is seen as more uniform. Considering the field observations, the unit stands out with its dark color and well developed foliation feature. The unit has mostly NE-SW strikes. When struck with a hammer, centimeter-sized breaks develop. Abundantly garnet, muscovite, quartz, biotite minerals can be seen in the unit macroscopically. The unit takes its color mainly from the biotite minerals, it contains. The unit is the equivalent of paragneisses belonging to the Pan-African basement of the Mendere Massif. The fine grained gneiss unit is cut by augen gneisses of orthogneiss character around Narıncalı, Hacıyeşiller, Uzuntarla districts in the southwest of the study area. In the middle and the NE part of the study area, in the upper levels of the fine-grained gneiss unit, tiny augen developments are encountered. This unit (s), which was called as the Umbabadağ augen-developed unit by [26], was accepted as the protomylonite level due to the movement of the Lycian nappes over the fine grained gneiss. In the west of the study area, west of the Battallar location, an intermediate level metaapilite is observed within the fine-grained unit. When the unit is viewed from a

distance, it resembles quartzite and mica schist units, and when viewed closely, fine-grained feldspars with quartz and muscovite are easily observed with the naked eye. The unit is light brown in color and it is hardly broken in decimeter size when hit with a hammer. The main mineral composition constituting the unit is especially albite type feldspar and quartz minerals. The extension of the unit towards the west is also observed outside the field. Granitic gneiss (ortho gneiss) and the primary sill of granitic gneiss were encountered in the fine-grained gneiss unit around Güneyköy in the south / southeast of the study area. In the fine-grained gneiss, quartz veins (segregation quartz) and amphibolite bodies are also encountered in different areas, sometimes parallel to foliation and sometimes cutting foliation. Although the fine-grained gneiss unit does not show much change in mineralogical content terms, it does not show a homogeneity in the area in terms of mineral ratios. While the amount of muscovite increases in some areas within the unit, there is an increase in the amount of biotite in other areas. In some areas, there are graphitic layers within the unit. In addition, in some areas the unit is petrographically observed in the character of garnet and biotite fine-grained

gneiss, while in some areas it takes on the character of micaschist. However, these changes were not encountered in scales to be mapped (Fig. 4). In addition, the metaleucogranite unit bearing rich in light colored minerals in the south of the study area cuts the fine grained gneiss unit.

In petrographic examinations (Fig.4a), the general mineral composition of fine-grained gneisses consists of garnet, plagioclase, biotite, muscovite and quartz minerals. Zircon, epidote and opaque minerals were determined as secondary minerals. The dominant minerals are biotite and muscovite. The unit shows lepidoblastic, lepidoporphroblastic in some areas and nematoblastic in some areas. This unit is petrographically named as garnet, epidote, biotite, muscovite, quartz, feldspar fine-grained gneiss.

Minerals in the units are garnet, quartz, biotite, muscovite and feldspars. Garnets in the unit are found in some areas in the field. They are observed as euhedral crystals, sometimes rounded and conforming to schistosity and sometimes as subhedral or anhedral. In the unit, garnets are surrounded by muscovites. Quartz, chlorite and opaque mineral inclusions are abundant in the garnets. The inclusions show a decrease in the central parts of the garnets, the more towards the edges. These inclusions in garnet are not very compatible with schistosity. Quartz found as inclusions in garnets show undulating extinction. In areas where garnets are not seen, zoisite and clinozoisite minerals are found. It is also observed that garnets are subjected to chloritization in places. When all petrographic data were evaluated together, it was concluded that garnets probably occurred after the pre-tectonic stage.

Quartz within the unit is generally seen as anhedral. They are arranged parallel to the schistosity in their long axis direction. The majority of quartz are in certain grain sizes. It is observed that the grain sizes vary between medium and small in the samples taken from some areas. Some of the quartz are associated with albite type plagioclases. Feldspar and very few opaque mineral inclusions are found in quartz. Biotites are arranged parallel to the schistosity in their long axis direction. They show a brownish-reddish brown pleochroism, in some sections greenish dirty brown. There are also fluctuating flashing developments due to deformation. Opaque minerals are observed in the cleavage of biotites, around and in the vicinity. Biotites are arranged parallel to the schistosity in their long axis direction. They show a brownish-reddish brown pleochroism,

in some sections greenish dirty brown. There are also fluctuating flashing developments due to deformation. Opaque minerals are observed in the cleavage of biotites, around and in the vicinity. Opaque minerals in the cleavage have been subjected to deformation. There are also noticeable apatite inclusions with high relief in biotites. While biotites are completely chloritized in some areas, muscovite and chloritization are also observed in some areas. Muscovite is found in flakes surrounding garnet minerals and mostly together with biotite minerals. They are lined up parallel to the schistosity. Most of the muscovites are primary and their association with biotites is typical. In some parts of this unit, muscovite minerals are less common than biotite minerals, while in some parts biotite minerals are less common than muscovite minerals. Opaque mineral inclusions are observed in the cleavage of muscovites.

Feldspars are composed of alkali feldspar and plagioclase. Locally, albite twins are encountered in the unit accompanying quartz. Alkali feldspar and plagioclase minerals, reaching large grain sizes in places, are encountered in areas with augen development in the unit. In alkali feldspars, perthitic textures are also abundant. In some samples, it is observed that plagioclases vary between albite-oligoclases by looking at extinction angles of twin individuals. Widespread sericitizations are found in feldspars in the form of augens. Plagioclases are seen in different grading in the rock. Plagioclases show polysynthetic twinning, especially in samples taken from areas close to granitic gneiss. Augen developments are also seen in areas close to granitic gneiss. Zoisite-Clinzoisite minerals are known for their ink-blue colors and prismatic shapes, which are optical anomalies in sections. They are mostly found around mica minerals, especially with biotites. In some areas, the amount of zoisite-clinozoisite minerals reaches higher rates than garnet. Secondary minerals are tourmaline, rutile and opaque minerals. Tourmaline mineral shows a proportional increase especially in areas where the fine-grained gneiss unit approaches its border with granitic gneiss. There is also a significant growth in tourmalines in these areas. Tourmalines are of the schorl type and rounding is observed in most of them. Rutile minerals are less common in the unit. They are found in biotites along their cleavage. Opaque minerals, in the unit, are mostly found as inclusions in muscovites and biotites or around and/or near biotites. Pyrite, chalcopyrite and ilmenite minerals are found in hand samples of the rock. In addition, sphene, apatite and zircon minerals are found as accessories in the unit.

XRD analysis was carried out from a sample taken from a fine-grained gneiss unit close to granitic gneiss, and quartz, lepidolite, albite minerals were determined (Fig. 4b).

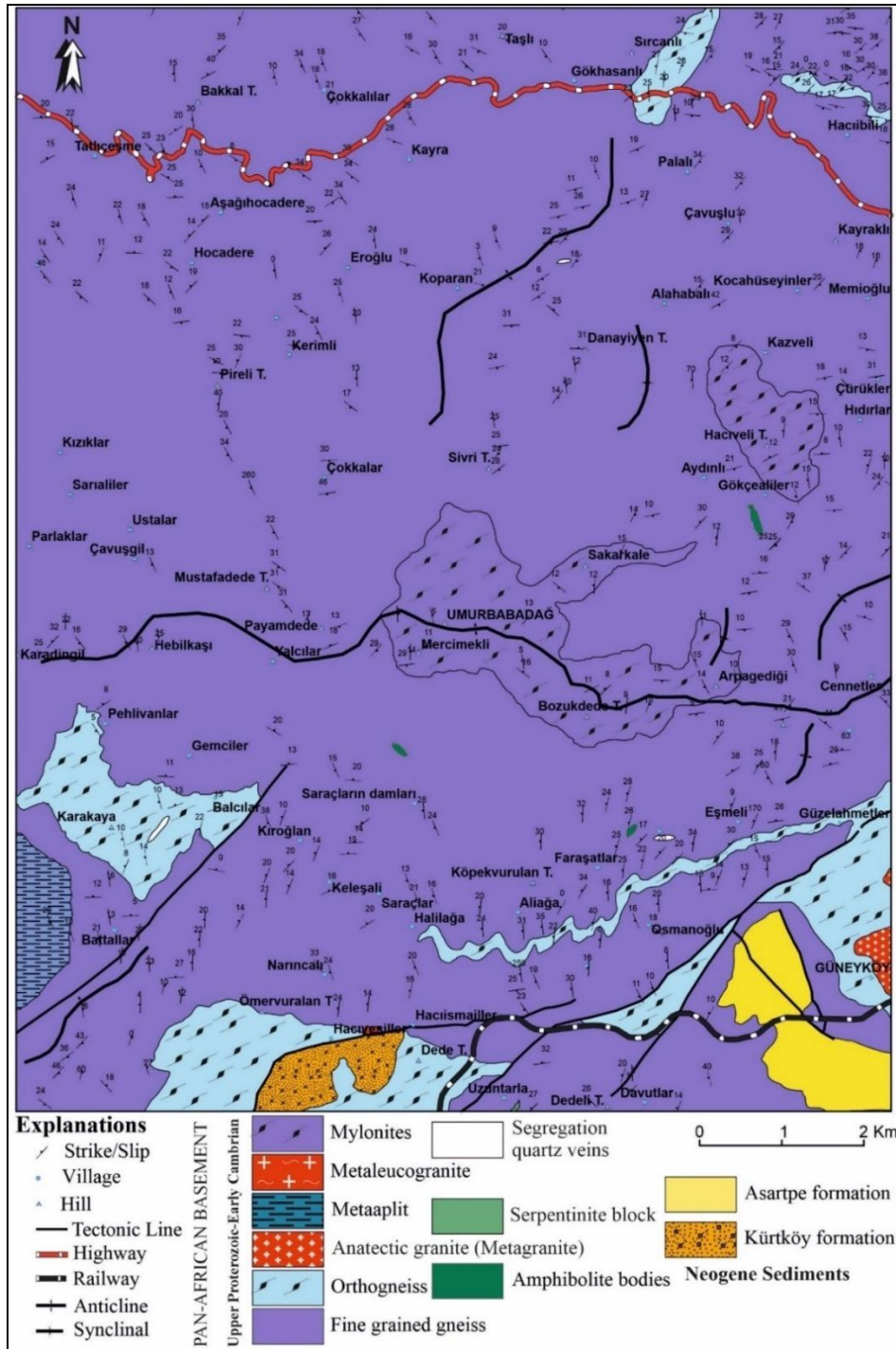


Figure 3. Geological map of the study area.

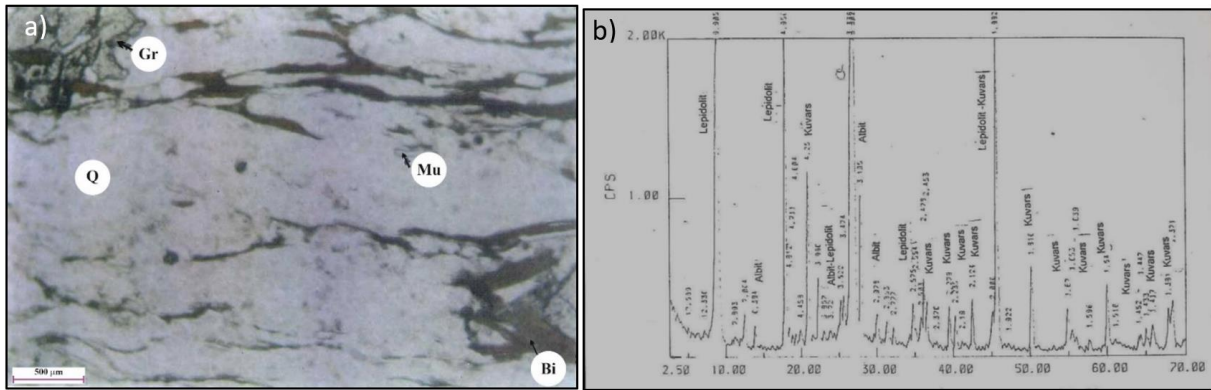


Figure 4. a) Garnet, quartz, muscovite and biotite minerals are seen in the fine-grained gneiss unit. Gr: garnet, Bi: biotite, Mu: muscovite, Q: quartz. (Plane light), b) Quartz, lepidolite, albite minerals were determined by XRD diffractogram carried out in a sample taken from a fine-grained gneiss unit close to the granitic gneiss unit.

3.2.1.1. Amphibolite bodies

A large number of amphibolite bodies are encountered in different regions within the fine-grained gneiss unit, especially on the Faraşatlar, Meryemoğlu, Güneyköy road route and around the Hacıveli Tepe-Aydınlı neighborhoods. Apart from these, there are amphibolite bodies with larger masses in size both in the east and west of the field outside the study area. These bodies within the fine-grained gneiss unit are sometimes observed to cut schistosity in different areas, and sometimes in accordance with schistosity of the fine-grained

gneiss. Marks of metamorphism are occasionally observed in amphibolite bodies in some locations and they can be immediately distinguished from fine-grained gneisses with their typical dark green color. Alteration effects are also observed in the rock due to the weathering effect (Fig. 5). When amphibolites are examined macroscopically, abundant amphibole group minerals are encountered. Besides, garnet and quartz minerals can also be seen. The green color of the rock is derived from amphibole group minerals



Figure 5. Photo of amphibolite bodies (Amph) cutting the fine-grained gneiss unit just west of Faraşatlar location (looking NE)

These amphibolite bodies were defined by [63] as basic magmatic bodies in the form of stock and vein cutting the paragneiss and schist units belonging to the core, and these rocks are distinguished as Precambrian/Cambrian biotite gabbro, olivine gabbro, noritic gabbro, norite rocks and eclogite and amphibolite in their peripheral zones. According to Candan [61], it was stated that the relationship between amphibolite and gabbroic rocks is uncertain due to complete recrystallization. The existence of a large number of eclogitic metagabbros and eclogite lenses within the core series of the Menderes Massif

has been also stated by the [63]. [63, 65] suggested that, due to high pressure metamorphism, these microgabbro and basaltic rocks in the fine-grained gneiss unit were recrystallized and transformed into eclogites and by subsequent medium pressure metamorphism, the eclogites were converted to garnet amphibolites.

The rock shows nematoblastic texture in petrographic examinations and has been named amphibolite. Amphibole group minerals, garnet, feldspar, quartz, epidote group minerals and biotites are abundant in

the rock. Garnets show a poikiloblastic texture and are mostly subhedral, anhedral and with a lot of fractures and cracks. They are optically isotropic. There are veinlets consisting of opaque minerals and possibly biotite in the cracks of garnets. In some areas, hornblende inclusions are also found. Chloritization is also encountered in places.

Plagioclase minerals, in which abundant albite twinning developed, are encountered as feldspar minerals. Plagioclases are subhedral, anhedral and zoned structures are also observed. They show undulating extinction due to the deformation they have undergone. Epidote Group Minerals are composed of epidote and clinozoisite minerals. They are found in the third abundance in the rock. Clinozoisite are ink blue in color and are found in hornblende minerals and in garnet minerals. Biotite minerals are observed in small amounts in the rock. They are green, dirty brown in color and show chloritization. In thin sections, under cross-polarized light, there are also gray colored, thinly sliced, radially distributed platy minerals in which pleochroism is not evident, but biotite is observed in the marginal zones of them. These are probably chlorite minerals. The most common minerals in the rock are amphibole group minerals, and these minerals are in the type of hornblende. Hornblendes are green in color. They offer mostly rod-like and prismatic crystal shapes. There are small and large ones. Typical head sections are also encountered in places. Quartz and opaque mineral inclusions are observed in them. Rutile and sphene minerals are found as secondary minerals. Rutilites are seen as high relief, anhedral and grain assemblages. In addition to these minerals, opaque minerals possibly thought to be ilmenite are encountered. Sphene minerals are in the form of small grains and are found with rutilites. Opaque minerals are observed in disseminated form, subhedral to anhedral in places.

3.2.2. Orthogneisses gneisses (Metagranites)

The fine-grained gneiss unit with paragneiss character has been intruded by orthogneisses of different volumes in different parts of the study area. In different regions of the massif, orthogneisses, which are distinguished as biotite orthogneiss, leucocratic tourmaline orthogneiss and amphibole orthogneiss by different researchers [66] according to their mineralogical composition and textural properties, were observed in the study area in the character of biotite orthogneisses. The U/Pb and Pb/Pb ages, which are clustered around 500 Ma, have been accepted as the intrusion age of the precursors

of orthogneisses in the Menderes Massif and based on these data, they have been interpreted as sin and/or post Pan-African intrusions in relation to the latest Neoproterozoic final amalgamation of Gondwana [50].

Orthogneisses are exposed in a large area in Güneyköy and its surroundings in the southwestern part of the study area, and in a smaller but in mapped sizes near Battallar, Mollasüleymanlı and Hacıbilibi locations. Orthogneiss observed in Güneyköy and its surroundings cuts the fine grained gneiss unit whereas in the vicinity of Battallar, Mollasüleymanlı and Hacıbilibi districts, are observed as intrusions in the form of interlayer in fine-grained gneisses. The orthogneiss unit in Güneyköy and its surroundings crops out in a very large area in the east of the village and can be easily distinguished from the fine-grained gneiss unit by its morphology (Fig. 6).

Their distant appearance is dark brown in color and can be easily distinguished by their primary granitic-looking morphology. They have a well developed foliation due to metamorphism. In locations close to fine-grained gneisses, very large and coarse feldspar and quartz augens are found, a granitic texture becomes dominant towards the center of orthogneiss. Macroscopically, it consists of quartz, muscovite, biotite, and feldspar group minerals, towards the center, although the same mineral composition is preserved, there is a transition to a granitic texture.

Within the fine grained gneiss unit, a sill interbed of orthogneiss starts from the north of Güneyköy and extends from Eşmeli Village to southwest direction and disappears near the Halılağa neighborhood (Fig 3 and 7). This sill unit is also shifted by faults in some areas along its extension. Its best exposure is in the roadcut near Osmanoğlu district. The dark brown unit has foliation development. The unit, which shows a fracture parallel to the foliation when struck with a hammer, has a thickness of 10-15 m, the augen developments in the unit are small chickpea size and give the unit more a mottled texture. These augens are mostly composed of feldspar and quartz.

When the orthogneiss unit around Güneyköy was examined petrographically, it was determined that the rock had a lepidoporphroblastic texture and contained mainly muscovite, quartz, feldspar minerals. The unit in the relevant location and its vicinity is named petrographically as garnet, biotite, muscovite, quartz, feldspar orthogneiss (Fig. 8 a, b). Garnets are semi-euhedral and occasionally observed in skeletal texture and contain schörl type tourmaline inclusions. Biotite and muscovite coexist, encircle quartz and plagioclase and form the schistosity of the

unit. Biotites are brown and dirty in appearance and sericitizations have developed on their edges. Quartz minerals sometimes appear parallel to the schistosity in their long axis direction, sometimes they have formed augen textures by getting larger. Feldspars are large K-feldspar augens in the thin section. These

feldspars have an anhedral, perthitic property. There are also perthitic plagioclases in the rock. However, these plagioclases are not very common. Sericitic alteration is encountered in especially K-feldspars. Plagioclase minerals are anhedral and have polysynthetic twins.

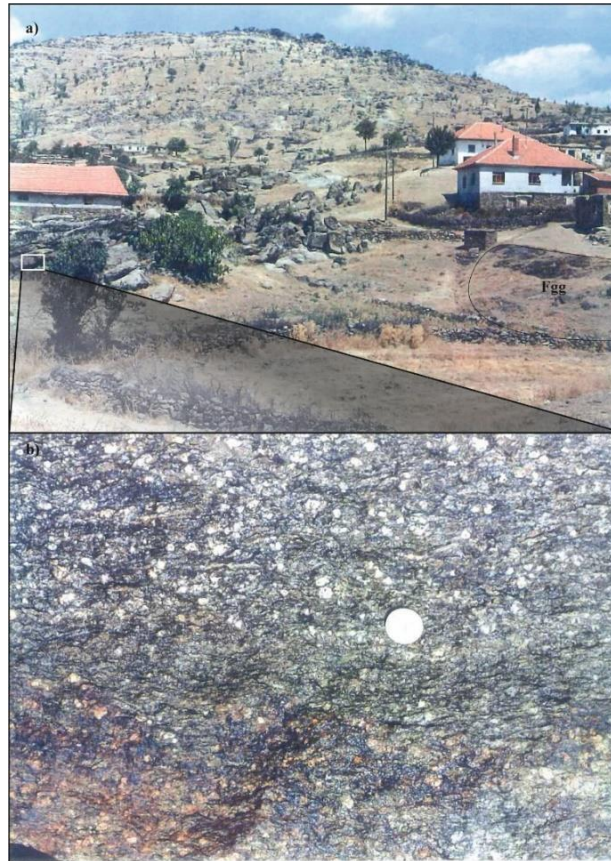


Figure 6. a) In and around Güneyköy, orthogneisses cutting the fine-grained gneiss unit and fine-grained gneiss (Fgg) trapped in orthogneisses. They are clearly observed with their morphology near Güneyköy. b) Small augens surrounded by biotite and muscovite minerals.

As secondary minerals, tourmalines are found as inclusions in garnet minerals. They are semi-euhedral and of the schörl type. Tourmalines are sometimes found in biotites. The color of the rock is mainly derived from biotite and tourmaline minerals. As the epidote-zoisite group minerals, zoisite and clinozoisite minerals have been found in the rock as

small grains. Opaque minerals are mostly associated with biotites.

Kaolinite, illite, quartz and abundant albite minerals were found in XRD analysis performed in orthogneisses around Güneyköy (Fig. 8c).

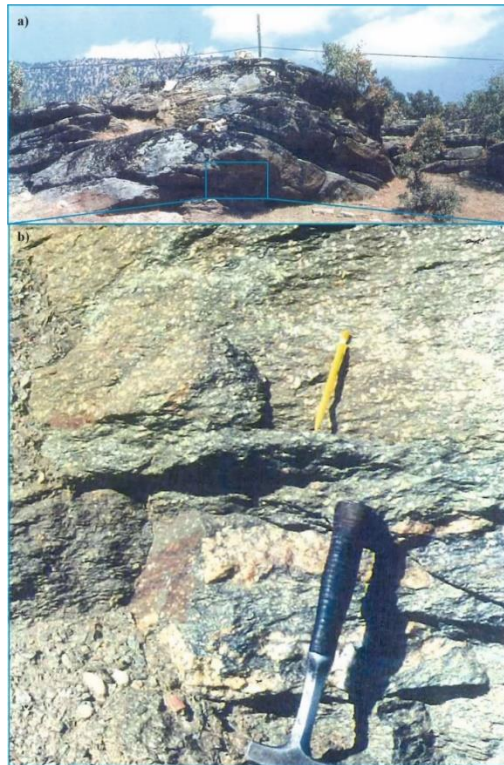


Figure 7. a) Sill layer of orthogneiss within the fine-grained gneiss in Osmanoğlu District (viewed from a distance, looking north). b) Close-up view of the sill with a mottled texture, augens consists of mostly quartz and feldspar.

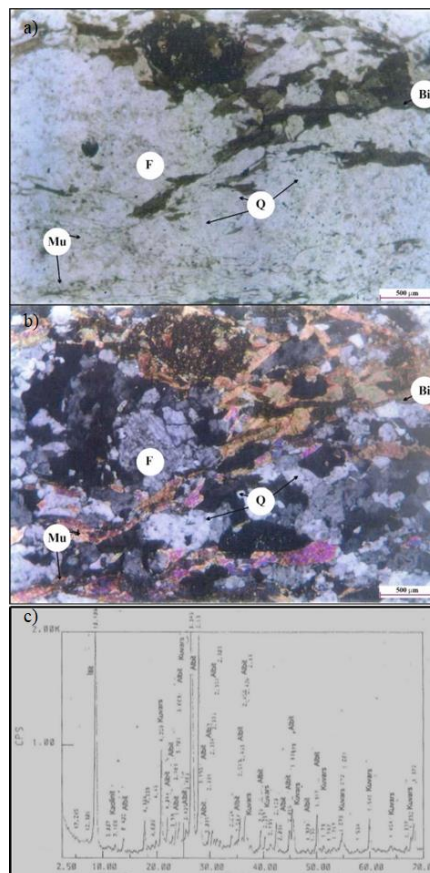


Figure 8. Microphotograph of the orthogneiss unit around Güneyköy. Biotite and muscovite minerals show orientation and surround quartz and feldspar minerals. a) plane light, b) crossed polar. Bi: biotite, Mu: muscovite, Q: quartz, F: K-feldspar. c) XRD diffractometer of the orthogneiss

The sills (Fig. 3) in the fine grain gneiss belonging to the orthogneiss unit have a lepidoporphyroblastic texture in the thin sections and consist of garnet, quartz, feldspar, muscovite, biotite minerals (Fig. 9), petrographically named as garnet, quartz, feldspar, muscovite, biotite gneiss. Garnets have been catalyzed and show skeletal texture. Quartzes are partly coarse, in places in the form of small grains and their long axis is aligned parallel to the schistosity. As feldspar minerals plagioclases and predominantly alkali feldspar minerals are found in the sill layer. Alkali feldspar and plagioclases form heaps mostly in the form of augen development.

Perthitic textures are observed in alkali feldspars. Sericitizations are also encountered in places in feldspars. Feldspar minerals are arranged parallel to the schistosity of the unit. Biotite and muscovite minerals are found together in the rock. Biotites are dirty green-brown, with pronounced pleochroism. Both biotites and muscovites are lined up parallel to the schistosity. Biotites are proportionally more abundant than muscovites. Opaque and epidote mineral inclusions are also found in biotites. As secondary minerals, small-grained, clustered epidotes, opaque minerals and sphene minerals are encountered.

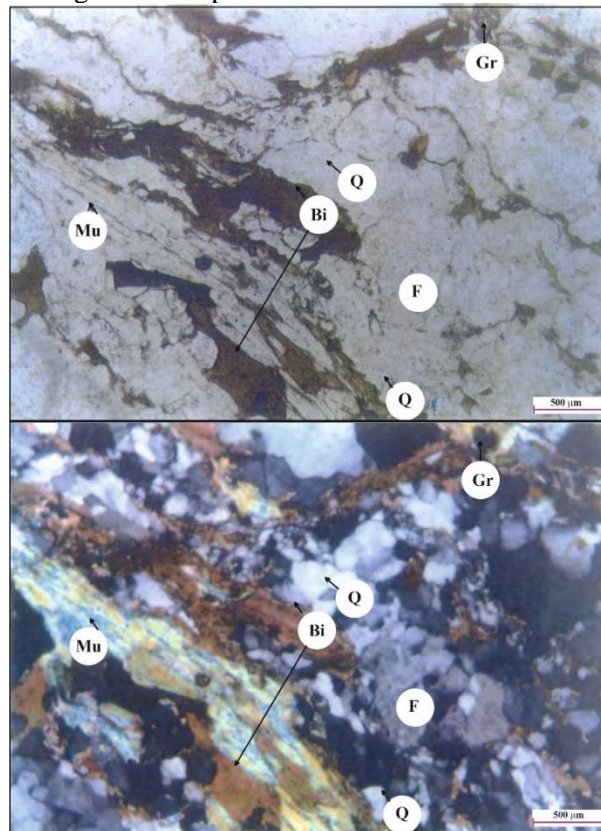


Figure 9. Microphotograph of the sill level in fine grained gneiss. a) Plane light, b) crossed polar. Gr: garnet, Bi: biotite, Mu: muscovite, Q: quartz, F: feldspar

In the west of the study area (Fig. 3), within the fine-grained gneiss unit, another orthogneiss unit crops out with its distinctive morphology as an intermediate level in Karakaya Tepe locality between Battallar and Pehlivanlar district. There are aplites and quartz veins at the cutting position of this orthogneiss unit. The unit contains quartz, feldspar, biotite and muscovite minerals macroscopically.

When evaluated petrographically, this orthogneiss unit shows lepidoblastic texture and contains quartz, feldspar, biotite muscovite minerals. The unit is named as quartz, feldspar, biotite muscovite-eyed up parallel to the schistosity. Biotites are

gneiss (Fig. 10). Quartzes are partly coarse, in places in the form of small grains and their long axis is aligned parallel to the schistosity. Feldspars are found in rock's thin sections as large alkali feldspar augens. They are anhedral and have perthitic character. There are also perthitic plagioclases in the unit, although not much. Sericitic alteration is common in feldspars. Polysynthetic twins are developed in plagioclase minerals and they are anhedral. Biotite and muscovite minerals are found together in the rock. Biotites show dirty green-brown pleochroism. Both biotites and muscovites are lined proportionally more abundant than muscovites.

Opaque and epidote mineral inclusions are also found in biotites. As the secondary mineral, epidotes in small-grained clusters, opaque minerals and sphene minerals are encountered.

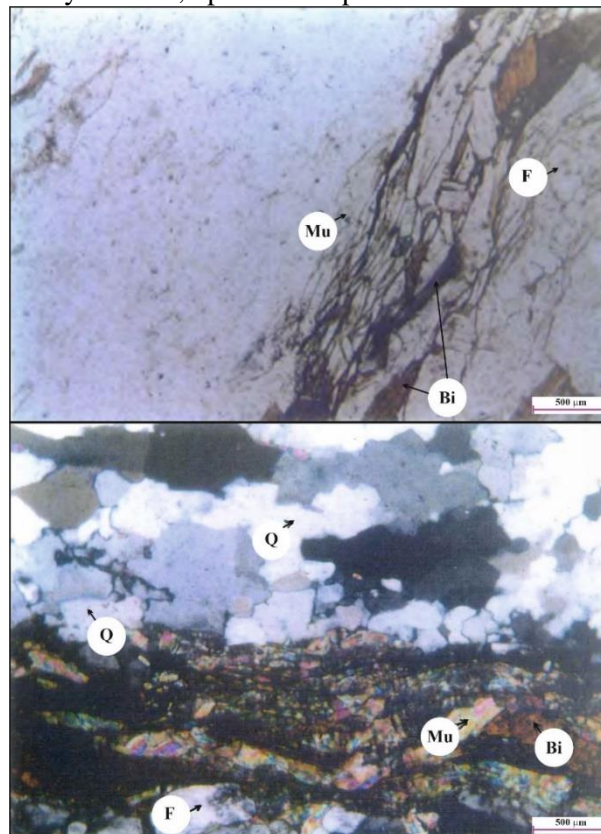


Figure 10. Microphotograph of Battallar and Pehlivanlar district and their surrounding orthogneisses. While biotite and muscovite minerals show orientation, it is observed that they also enclose quartz and feldspar minerals. a) Polar light, b) crossed polar. Bi: biotite, Mu: muscovite, Q: quartz, F: feldspar

Another orthogneiss unit was found in the fine grained gneiss unit in the south of the study area, between the south of Narıncalı and the east of Uzuntarla (Fig. 3, 11 a). Although it was stated by [26] that the unit came over the fine-grained gneiss unit with a thrust relationship, when the unit was evaluated from a new perspective, it was concluded that orthogneiss was located in fine-grained gneiss as a stock. At the contact of orthogneiss-fine-grained gneiss, which coincides with the edge zones of the primary granite, small-sized porphyroblasts consisting of light-colored minerals are encountered, and in the more central parts of the orthogneiss, these light-colored minerals turn into larger-augen textures and resemble typical orthogneisses of the Mendere Massif (Fig. 11b). When the rock was examined petrographically, it was observed that it had lepidoporphyroblastic texture, consisted of garnet, muscovite, biotite, alkali feldspar and quartz minerals, and was named as garnet, muscovite, biotite, alkali feldspar, quartz orthogneiss. In garnets, biotitization and chloritization are common (Fig 11b). Garnets with remarkable cataclasm also contain quartz inclusions. The proportional abundances of muscovite and biotite minerals in the rock vary according to each other. Muscovite minerals are arranged parallel to schistosity. Opaque mineral separation is observed in its cleavage. Biotites have red brown-greenish and brownish pleochroism. They are arranged parallel to the schistosity. They are in very small flakes. Biotites are separated into a muscovite and some of them into opaque minerals. Primary biotite inclusions are also found in plagioclases. The association of biotites with opaque minerals is very evident. Feldspars, especially alkali feldspars, are abundant. Alkali feldspars form augens that show graphic texture development, presumably these are primary formations. Feldspar grains are larger than quartz ones. Feldspars also show undulating extinction due to the deformation of the rock. Most of the feldspars are aligned parallel to the schistosity. There are muscovite, biotite and opaque mineral inclusions in feldspars. In addition, perthitic orthoclase, microcline and plagioclase are also observed. quartz mineral is abundant. They are aligned parallel to the schistosity in their long axis direction, meanwhile the coarse-grained quartz has become rounded. Inclusions are seen in quartz. These inclusions are mostly composed

of muscovite, biotite and opaque minerals. Apatite and zircon minerals are also found as secondary minerals in the rock.

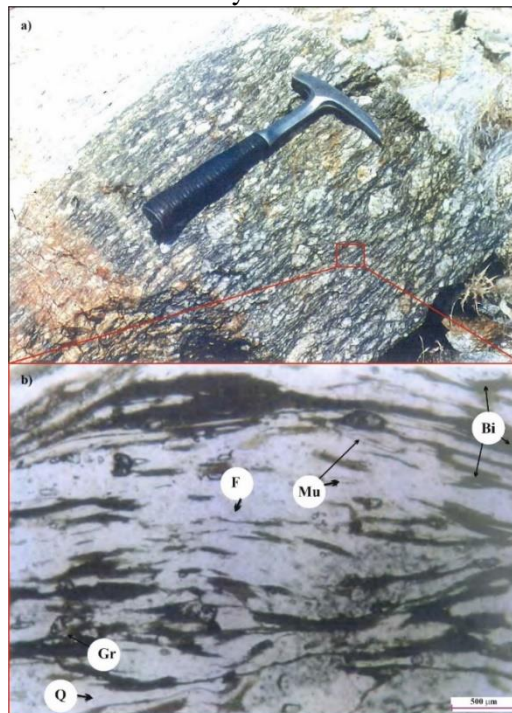


Figure 11. a) Orthogneisses outcropping in Narıncalı-Uzuntarla locality, and augens that have almost gained a boudinage texture in orthogneisses, b) Microphotograph of the orthogneiss unit outcropping in Narıncalı, Uzuntarla locality. Biotite and muscovite present a fibrous texture, Gr: garnet, Bi: biotite, Mu: muscovite, Q: quartz, F: feldspar (Plane light)

3.2.3. Mylonites

In the study area, a unit with augens development is encountered in Umurbabadağ and its close vicinity (Fig. 3 and 12). This unit is topographically and stratigraphically located in the upper levels of fine-grained gneisses in the area. It crops out at many

points, topographically on the upper levels, on the tops of the hills in and outside of the study area. In the study area, it is widely observed around Umurbabadağı, Bozukdede H., Mercimekli H and Sakarkale H.

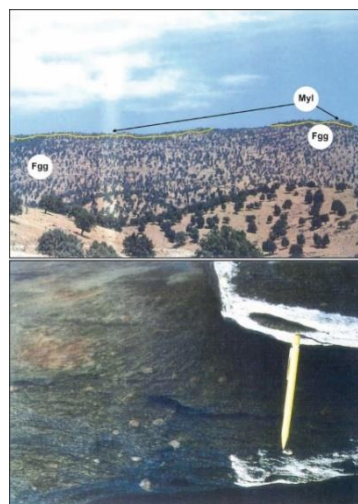


Figure 12. Photographs of mylonites bearing biotite, quartz, feldspar, and muscovite on the fine-grained gneiss unit (Fgg) in the upper parts of Umurbabadağ (Remote view, North view) b: Sparse augens surrounded by biotite and muscovite (closer look).

Although the unit cannot be distinguished from the fine-grained gneiss unit very distinctly, it can be

more or less separated by presenting its a hard topography. It lies on the fine grained gneiss unit. However, the border between them is not clear and they show a transition. Moving from the bottom to the top, it is passed from small augens formations to larger augens formations. However, the augens are very sparse, and are composed of quartz, feldspar and tourmaline minerals.

Mylonites have lepidoporphyroblastic texture. Garnet, muscovite, quartz, biotite, feldspar minerals are observed in the thin sections (Fig. 13). Garnet minerals are in the form of subhedral crystals or skeletal texture. Transformation into epidote-zoisite minerals is observed in garnets. Garnets have been chloritized from the edges.

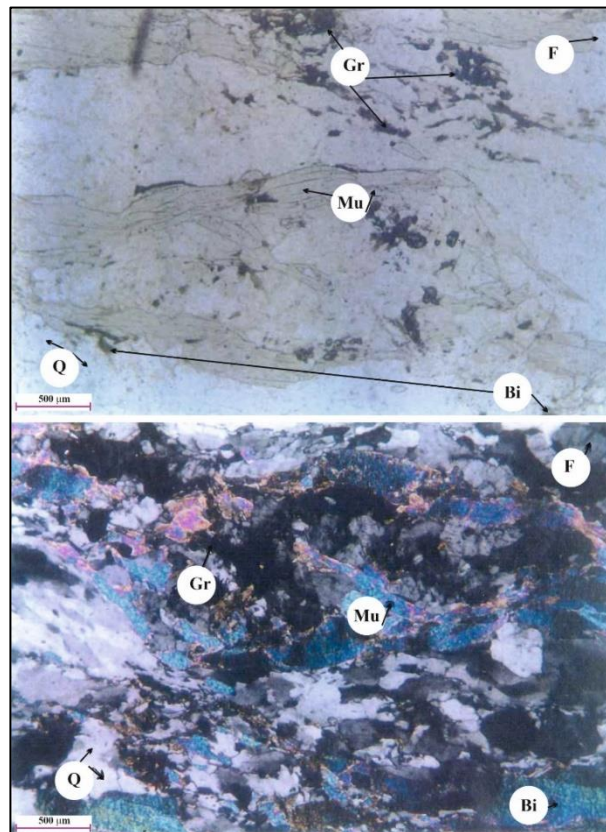


Figure 13. Microphotograph of mylonites a) The orientation of muscovites is seen very well (plane light) b) garnet, biotite, muscovite, quartz and feldspar minerals are observed. Gr: garnet, Bi: biotite, Mu: muscovite, Q: quartz, F: feldspar.

Biotites are relatively abundant than muscovites. Their association with muscovites and opaque minerals is evident. They show redish and dirty brown pleochroism. Opaque mineral inclusions in them are observed as separations from cleavage. Also, opaque minerals are found around them. Biotites are probably iron-rich species. Chloritization is also encountered in biotites. Muscovites are observed with their slightly greenish colors and light pleochroism. They show fluctuating extinction due to pressure effect. Opaque mineral inclusions are also found in muscovites. Quartz minerals show compatibility with schistosity, parallel to schistosity along their long axes. There are also recrystallizations in the form of belt texture in quartz. Although the grain sizes of quartz minerals are

generally equal, differences are observed in some areas. Feldspar minerals are generally in the form of coarse crystals and show abundant perthitic texture development. Polysynthetic twins and zoned structures are found in plagioclases. Deformation effects are clearly observed in plagioclases. Due to deformation, deformation twins are encountered in plagioclases. Sometimes resistance and sometimes breaks are observed in the direction of schistosity in plagioclases. Feldspars have formed augen developments among mica minerals. Inclusions have also developed in them. Sericitic alteration developments are also observed. Perthite textures were formed towards the edges of microcline minerals. Tourmaline, epidote-zoisite and zircon minerals are found as secondary minerals, and apatite

minerals are found as accessories. Tourmaline minerals are of schorl species and subhedral. Opaque Minerals are encountered together with biotite and

muscovites, sometimes in disseminated form. XRD analysis was made from mylonites, quartz, muscovite, albite minerals were determined (Fig. 14)

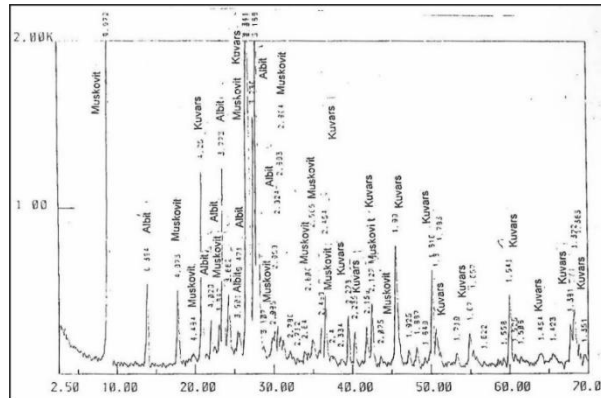


Figure 14. XRD diffractometer of mylonites, quartz, muscovite, albite minerals were found.

3.2.4. Metaleucogranite

Metaleucogranite crops out in a fine-grained gneiss unit in a stream, 5x25 m in size, near Hacıyeşiller neighborhood in the south of the study area (Fig. 15a). When viewed from a distance, it immediately draws attention with its dirty yellow color. This unit cuts the fine grained gneiss unit. Abundant joint cracks have developed in the unit and has foliation. When viewed from a distance, it immediately draws attention with its dirty yellow color. This unit cuts

the fine grained gneiss unit. Abundant joint cracks have developed in the unit. It has foliation. When struck with a hammer, it hardly breaks, and irregular fractures occur. There are abundant quartz, feldspar and tourmaline minerals in the rock macroscopically. Metaleucogranites are exposed in a wide area, outside-west of the study area showing a well developed foliation (Fig. 15b).

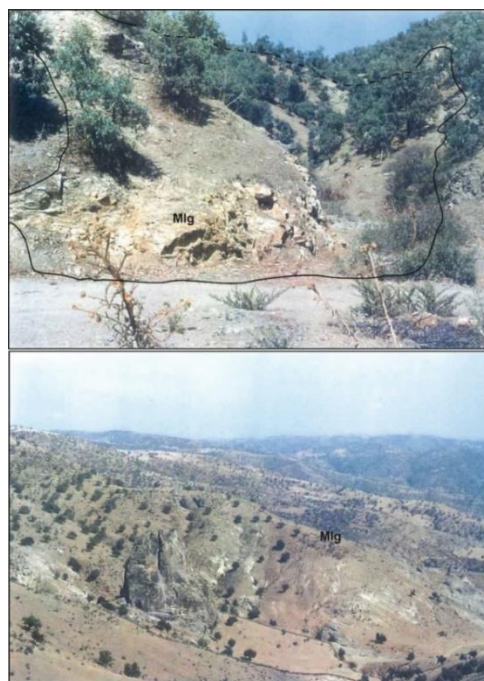


Figure 15. a) Metaleucogranite (Mlg) unit cutting the fine grained gneiss unit (looking to NW) b) Metaleucogranite exposed in large areas near Ballıkaya village, outside the study area (Looking east)

There is still no consensus for the meta leukogranites encountered in the Menderes Massif [14, 66]. Based

on the general geological characters and kinematic indicators, a "Tertiary" protolith age has been also

proposed by [14]. According to [68], these rocks of Pan-African age were intruded in a relatively later magmatic phase. Much larger sizes of these rocks, their off-white colors, leucocratic character and their high content of tourmaline (\pm biotite) as mafic minerals are characteristically observed in many regions in the Menderese Massif, especially in the Çine Submassif. It is also observed in Ödemiş - Kiraz submassif, in Kula and Alaşehir regions [68]. These rocks, which are encountered in large sizes in different regions within the Menderes massif, were found in the study area in much smaller size as stock. There are feldspar phenocrysts of a few mm in a very fine grained ground, tourmaline as the mafic mineral is the common mineral and the rocks are thought to

be the end products of leucocratic magmatic activity. The rock petrographically shows lepidoporphyroblastic and granoblastic texture (Fig. 16a). Orientation is observed in mica, and radial tourmaline heaps are found in them. Tourmalines are mostly schorl and dravite types and together. Microclines are anhedral, enlarged in places, but generally in the form of small grains. Orthoclase minerals are also found. Some of these are perthitized. Plagioclases in rock are less than alkali feldspars and show polysynthetic twinning. In addition, anhedral, medium-fine-grained opaque minerals are also determined. XRD analysis was also carried out on metalucogranite and quartz, lepidolite, albite minerals were determined (Fig. 16b).

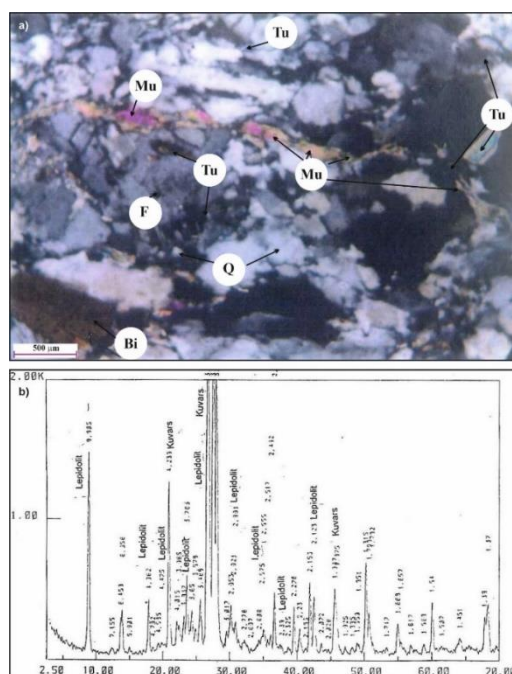


Figure 16. a) Microphotography of metalucogranite. Tu: tourmaline, F: K-Feldspar, Q: quartz, Mu: muscovite. Bi: biotite. crossed polar. b) XRD diffractogram of the metalucogranite.

3.2.5. Serpentinite

In the south of the study area, in the Uzuntarla/Topallar locations locality, a small boudinage-shaped serpentinite slice was encountered within the fine-grained gneiss unit (Fig. 17 a). The unit extends along a tectonic line outside the field. Serpentine minerals in the unit have very small grain sizes and the unit consists almost entirely of serpentine group minerals.

On the scale of the field, the unit is immediately noticed and attracts attention with its bluish green color from a distance. A great tectonic effect can be seen on the unit easily. It has a cryptocrystalline texture. Although talcifications are encountered in places in the serpentinite, it is very difficult to break

with a hammer. The fracture surfaces are smooth and show breaks in the form of mussel shells. Dark-colored metallic minerals are encountered in the unit, and these minerals macroscopically consist of chromite and magnetite. The unit is 1x1.5 m. in size. This serpentinite stock is thought to be the remains of the Lycian nappes in the field.

When the rock is examined petrographically (Fig. 17 b), it consists of 95% serpentine group mineral and abundant opaque minerals are found in it. Opaque minerals are probably chromite or magnetite minerals. Additionally, XRD analysis was performed from the serpentinite unit and antigorite (serpentine group mineral) and talc minerals were determined (Fig. 17c).

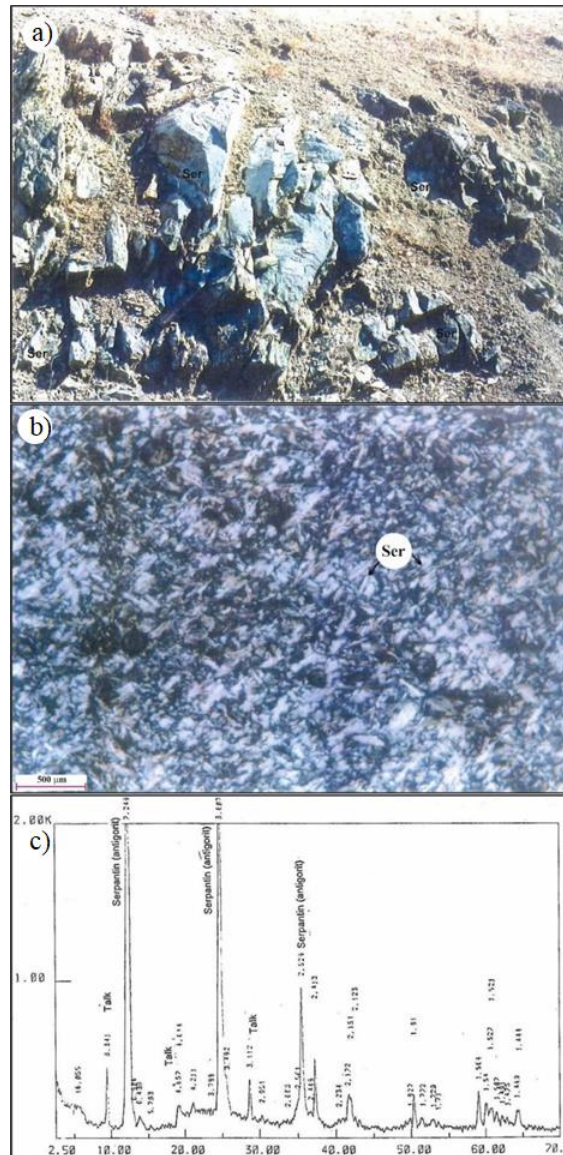


Figure 17. a) Photograph of the serpentinite in the form of boudinage in the fine-grained gneiss unit north of Topallar/Uzuntarla locations (North view). b) Microphotograph of serpentinite, the rock consists of almost fine grains of serpentine minerals. Opaque minerals are seen in the form of scattering in the rock. Ser: serpentine (crossed polar) c) XRD diffractogram of the serpentinite.

3.2.6. Neogene sedimentary units

In the area, sediments which are named as Miocene aged Kürtköy formation in the studies of [67] are encountered. The unit contains gravels varying in size from large blocks to small pieces at the bottom (Fig. 3 and 18a). Its material is derived from augen gneisses, meta aplites and fine-grained gneisses. It is badly sorted and without fossils. It is observed in the field in the west and south of Hacıyeşiller village. It has a thickness of about 15-20 meters. Alluvium is the youngest unit in the field (Asartepe

formation) (Fig. 18b). It is in various colors, usually red and orange, and occasionally white. It is clay cemented, and consists of an alternation of loose lime, tuff, medium thick bedded, multi-origin, semi-rounded conglomerate sandstone. They are sediments formed in a stream environment and contain thin marly calcareous levels in places. It also includes canal fillings in the form of lenses. It was observed in the south of Güneyköy in the study area (Fig. 3).

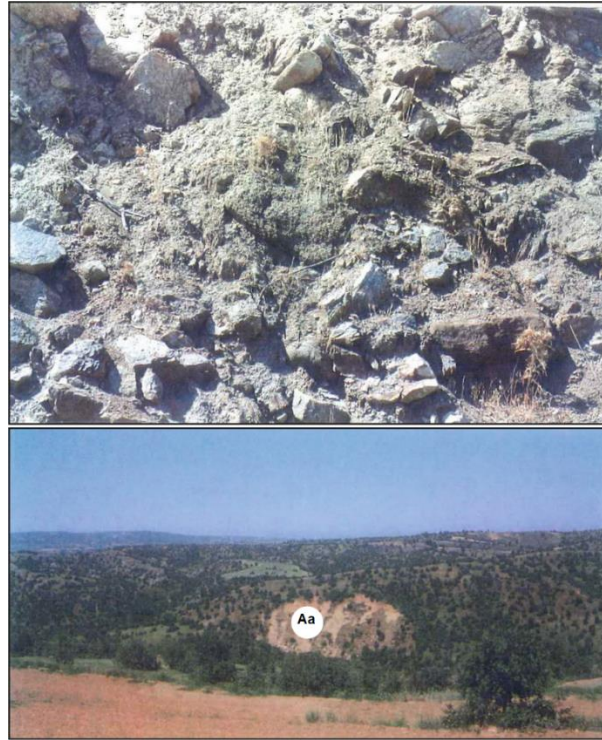


Figure 18. a) Alluvial fan (Kürtköy formation) overlying granitic gneisses (augen gneisses) in the west of Hacıyeşiller village and containing pebbles belonging to augen gneiss, metaaplite and fine-grained gneiss (looking west). b) Alluvial unit (Aa) containing clay, tuff and sand south of Güneyköy (looking west).

4. Structural Geology

As detailed geological features of the Menderes massif are given in the general geology section; The Menderes Massif consists of the late Neoproterozoic-Early Cambrian basement and the Paleozoic-early Cenozoic rocks unconformably overlying them [68]. Based on the geological and geochronological findings of recent studies, a consensus has been reached on the existence of three main magmatic activities in the massif: (i) Neoproterozoic-Cambrian, (ii) Triassic and (iii) Miocene [11, 12]. Neoproterozoic-Cambrian magmatic activities are the most common in the mass. These include orthopyroxene-bearing orthogneisses (charnockites), metagabbros-metanorites, anatectic granites and orthogneisses. These magmatic activities are generally accepted as developed during and / or after the late Neoproterozoic amalgamation of Gondwana [66]. Triassic magmatic activities are the second common magmatism in the massif and are generally represented by leucocratic orthogneisses cutting the Precambrian and Permo-Carboniferous rocks [4]. This magmatic activity has been associated with regional tectonic events that Anatolia is in. The Miocene magmatic activities observed in the massif are represented by granitoid intrusions and volcanic rocks and are associated with low angle normal faults which occurred during the exhumation of the

Menderes massif [69].

According to recent studies carried out on the massif, main metamorphic events shaping the Precambrian basement of the Menderes massif are associated with the Kuunga orogeny, and that the Alpine metamorphism to which the region is exposed, causes limited retrograde events in the basement rocks of the massif [66].

The Menderes Massif shows a continuous uplift, although this uplift has continued by slowing down until today [67]. The evidences of this rise are;

- Terrestrial deposits folded and dipped, especially in the Miocene. The fact that the slopes are near horizontal in the Pliocene indicates that the uplift rate decreased.
- The grabens (Salihli-Alaşehir graben) formed in Tertiary are still active today.
- There are many fault systems in the region.
- There is an extreme activity in the region in terms of earthquakes and volcanism.
- The streams scraped deep their beds very quickly compared to the lateral erosion.
- Although the massive region is not very high compared to its surroundings, a large amount

of Mesozoic cover has been exhausted by erosion.

It is observed that a lot of faults have developed in the massif due to uplift events. There are also vertical slip faults in the study area. In addition, there is a main fold with an E-W direction and its axis passing over Umurbaba Mountain, and there are also small NE-SW trending folds on the flanks of this fold. These fold developments are mostly observed in the north and west of Güneyköy around Eroğlu, Alahabalı and Hıdırlar neighborhoods. The faults detected in the field, on the other hand, have developed mostly on the folds wings. The strike/slip rose diagrams of the foliations of the metamorphites in the area were drawn and the relationships of the units were tried to be interpreted with their help. Foliation strike/slip rose diagrams were obtained

separately for each unit and each unit was first evaluated within itself and then correlated with the general of the site. The foliation positions of the rocks in the study area where the core units of the Menderes Massif are in harmony with the general condition of the massif and they extend in NE-SW direction (Fig. 19).

A total of 337 foliation direction and slope measurements were made in the fine-grained gneiss unit covering a large area in the field. In the measurements made, the N40-50°E strike and a slip between 10-30 were determined. There is a secondary density in the direction of N40-50°B. The force pair affecting the unit is in the NW-SE direction (Fig. 20).

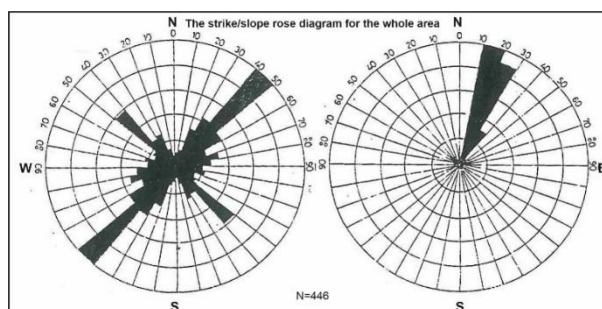


Figure 19. Rose diagram obtained from the strike/slip measurements of fine-grained gneiss area.

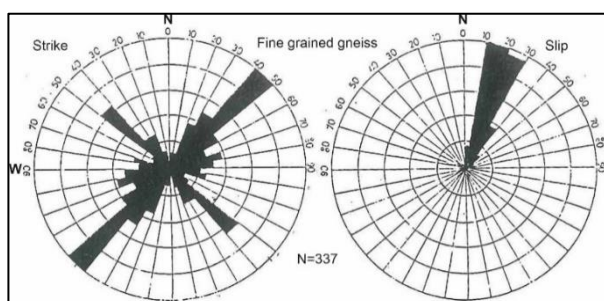


Figure 20. Rose diagram obtained from the strike/slip measurements of fine-grained gneiss.

Mylonite zones in the area were studied separately. In this context, 33 foliation strike/slip measurements were made from the mylonite zone at Umurbaba Mountain. In these measurements, the N40-50°E, 10-20° strike /slip values were determined. These values are parallel to the above mentioned Fine-grained gneiss unit, and this shows that the Umurbaba Mountain mylonite unit is affected by a NW-SE trending force pair (Fig. 21a).

A total of 25 foliation strike/slip measurements were made in the mylonite unit observed in Hacıveli location. The measurements made generally show a strike in the N40-50°E/10-20° strike/slip values. In

the unit, there is also a second density in the N60-70°W direction, but the actual gravity is in the NE-SW direction (Fig. 21b). So, Hacıveli location mylonite unit is also affected by a NW-SE trending force pair, as in fine grained gneiss and Umurbaba Mountain mylonite units.

Strike/slip measurements of orthogneisses in the area were evaluated separately for each area (Battalar/Balcılar/Karakaya, Narıncalı, Mollasüleymanlı locations). In the orthogneisses in the Battalar location, a total of 15 strike/slip measurements were made from foliation planes. It has been observed that the measurements are compatible with the general of the study area (Fig.

22a).

In the foliation planes in orthogneisses near Molla Süleymanlı location, which is located in the north of the study area, a total of 14 direction/slope measurements were taken. It was concluded that the strike/slip measurements of the unit here are parallel to the overall area and the unit is affected by a force pair in the NW-SE direction (Fig 22b).

A total of 22 foliation strike/slip measurements were made in the orthogneiss unit of Narıncalı location,

which is located in the southwest of the study area. An inconsistency is observed in these measurements when compared to the general of the field (Fig. 22c). The directions are generally in the K20-30°B position. A second concentration is in the direction of N10-20°E. The reason for this discrepancy in terms of the overall area may be the effect of a different pair of tectonic forces at this location. However, the amount of slope observed in the unit is parallel to the general of the region and varies between 10-20.

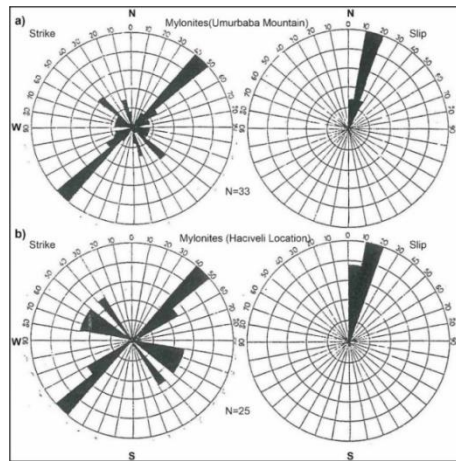


Figure 21. a) Rose diagram produced from the strike/slip of the foliations belonging to the Umurbaba Mountain mylonite unit b) Rose diagram produced from the strike/slip of the foliations belonging to the Hacıveli location mylonite unit.

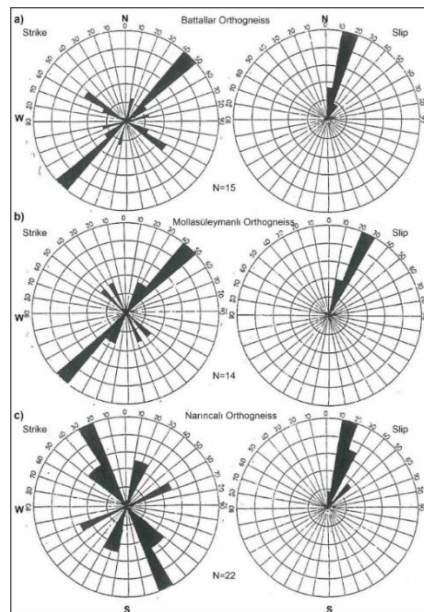


Figure 22. Strike/slip rose diagrams of orthogneisses a) orthogneisses in Battallar / Balçılar / Karakaya locations b) orthogneisses in Narıncalı location c) orthogneisses in Mollasüleymanlı location

5. Conclusion

Although many geological studies have been carried out throughout the Menderes Massif, no detailed

geological map has been found, except for the geological map of the study area made within the

scope of this study. The 1/25.000 scaled detailed geological mapping of the area was carried out by the responsible author within the scope of the master's thesis. In the same period, 1/25.000 scaled geological maps of the immediate surroundings of the area were also made by the responsible author. The originals of these maps are in the Archive of the General Directorate of Mineral Research and Exploration (MTA), Geological Research Department. These maps were also used in the preparation of the 1/500 000 scaled Geology map of the region.

Neoproterozoic-Cambrian aged core rocks of the Menderes Massif belonging to the Demirci-Gördes sub-massif were encountered in the field within the scope of this study. The most common rock group in the field is the paragneiss unit, defined as fine-grained gneiss. Amphibolite bodies were found in different locations and sizes in the fine grained gneiss unit. These rocks are thought to be basic rocks of Precambrian / Cambrian age intruded into the core rocks of the massif. However, it is thought that a more detailed study of the amphibolite bodies in the study area will contribute to the overall massif. In addition, in the fine-grained gneiss unit, it has been identified to the serpentinite stock in the form of boudinage along a tectonic line, and this serpentinite is thought to be the remnant of the Lycian nappes passing through the region.

Orthogneisses were determined as the second common unit in the area. Orthogneisses are

considered to be Pan-African intrusions that occurred during or after the last amalgamation process of Gondwana in Latest Neoproterozoic. Dyke, sills and metalucogranite stocks, which have been intruded in the fine grained gneiss unit and anatexis granites, belonging to orthogneisses are exposed in different parts of the area. Although similar rocks are frequently encountered in different parts of the massif, a complete consensus has not been reached among researchers regarding their origins and ages. Although it is not found in large sizes in the field, it is thought that detailed isotope studies to be made with these rocks will contribute to the understanding of the Menderes Massif.

As a result of the structural analysis of the measurements of many strikes, slip and lineaments taken from the metamorphic rocks in the area, it was determined that the main strike axes of the metamorphic rocks in the area are N40-50°E and a second density is in the N40-50°W direction. The general slip of the rocks is between 10-20° and the second trend is between 20-30°. It was concluded that all rocks in the field, except for orthogneisses in the Narıncalı location, were mainly affected by a force pair in the NW-SE direction, in line with the general tectonics of the region. It is thought that a more detailed study should be done for orthogneisses in Narıncalı location.

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References

- [1] Philipson A. Reisen und Forschungen in Newstlichen Kleinasien. *Pet Mitt Erg M* 1915; 167,173.
- [2] Schuiling RD. Türkiye'nin Güneybatısındaki Menderes Masifi Migmatitik Kompleksinin Petrolojisi, Yapısı ve Yaşı Hakkında. *Bulletin of Mineral Research and Exploration* 1962; 58:71-84.
- [3] Ercan T, Dinçel A, Metin S, Türkecan A, Günay E. Uşak Yöresindeki Neojen Havzalarının Jeolojisi. *Türkiye Jeoloji Kurumu Bülteni* 1978; 21:97-106.
- [4] Akkök R. Structural and metamorphic evolution of the northern part of the Menderes

- Massif: New data from the Derbent area and their implication for the tectonics of the massif. *Journal of Geology* 1983; 91:342–350.
- [5] Satır M, Friedrichsen H. Interpretation of Geochronological and Stable Isotope Data from Menderes Massif (W.Turkey). *European Council of Geological Soc. VII. Terra Cognita*. 1984.
- [6] Kun N, Candan O. Menderes Masifindeki erken Paleozoyik yaşlı bazik damar kayaları. *Yerbilimleri/ Earth Sciences* 1987; 14:121–132.
- [7] Dora OÖ, Faküttesi MM, Bölümü JM, Fakültesi MM. Kiraz-Birgi yöresinde (Ödemiş-Menderes Masifi) metavolkanitlerin (leptitlerin) varlığı 1988:21–28.
- [8] Konak N, Akdeniz N, Öztürk EM. *Geology of South Menderes Massif Guide Book for Field Excursion along Western Anatolia, Turkey*. Ankara, Türkiye: 1987.
- [9] Dora OÖ, Kun N, Candan O. Menderes Masifi'nin metamorfik tarihçesi ve jeotektonik konumu. *Türkiye Jeoloji Bülteni / Geological Bulletin of Turkey* 1992; 35:1–14.
- [10] Seyitoğlu G, Işık V. Meaning of the Küçük Menderes graben in the tectonic framework of the central Menderes metamorphic core complex (western Turkey). *Geologica Acta* 2009; 7:323–331.
- [11] Candan O, Dora OÖ, Oberhänsli R, Koralay E, Çetinkaplan M, Akal C, Satır M, Chen F. Menderes Masifinin Pan-Afrikalı Temelinin Stratigrafisi Ve Gondvana'nın Geç Neoproterozoyik / Kambriyen Evrimi ile ilişkisi. *Bulletin of Mineral Research and Exploration* 2011; 142:25–68.
- [12] Seyitoğlu G, Işık V. Late cenozoic extensional tectonics in western anatolia: Exhumation of the menderes core complex and formation of related basins. *Bulletin of the Mineral Research and Exploration* 2015; 2015:47–106.
- [13] Roche V, Bouchot V, Beccaletto L, Jolivet L, Guillou-Frottier L, Tuduri J, Bozkurt E, Oguz K, Tokay B. Structural, lithological, and geodynamic controls on geothermal activity in the Menderes geothermal Province (Western Anatolia, Turkey). *International Journal of Earth Sciences* 2019; 108:301–328.
- [14] Bozkurt E, Winchester AJ, Mittweide S, Ottley C. Geochemistry and tectonic implications of leucogranites and tourmalines of the southern Menderes Massif, southwest Turkey. *Geodinamica Acta* 2006; 19:363–390.
- [15] Vural A, Kaya S, Başaran N, Songören OT. *Anadolu Madencilğinde İlk Adımlar*. Ankara, Türkiye: Maden Tetkik ve Arama Genel Müdürlüğü, MTA Kültür Serisi-3; 2009.
- [16] Vural A, Albayrak M. Gördes ve Cıvırı Zeolitlerinin Mineralojisi. 58th Geological Congress of Turkey. 2005:140–141.
- [17] Vural A, Aydal D. Determination of Lithological Differences and Hydrothermal Alteration Areas by Remote Sensing Studies: Kısacık (Ayvacık-Çanakkale, Biga Peninsula, Turkey). *Journal of Engineering Research and Applied Science* 2020.
- [18] Aydal D, Vural A, Polat O. Definition Of The Base Metal And Gold Bearing Hydrothermally Altered Areas In Volcanic Rocks Using By Landsat 7 TM Imagery: Case Study From Bayramiç (Çanakkale). *Abstracts of 57th Geology Congress, Turkey*, Turkey: 2004:89–90.
- [19] Vural A, Corumluoglu O, Asri İ. Exploring Gördes Zeolite Sites by Feature Oriented Principle Component Analysis of LANDSAT Images. *Caspian Journal of Environmental Sciences* 2016; 14:285–298.
- [20] Vural A. Soil geochemistry study of the listvenite area of Ayvacık (Çanakkale, Turkey). *Caspian Journal of Environmental Sciences* 2020; 18:205–215.
- [21] Aydal D, Vural A, Taşdelen-Uslu İ, Aydal, Emine G. Crosta Technique Application On Bayramic (Alakeçi-Kısacık) Mineralized Area By Using Landsat 7 ETM+ Data. *J FacEngArch Selcuk Univ* 2007; 22:29–40.
- [22] Vural A, Aydal D. Soil geochemical prospecting at listvenite area, Bayramiç, (Çanakkale Turkey). 34th National and the 2nd International Geosciences Congress proceedings book. 22-24 Feb. 2016 Tehran, Iran. 2016.
- [23] Vural A, Corumluoglu O, Asri I. Zeolitleşmelerin Uzaktan Algılama Metodlarıyla Tespit Edilmesi: Gördes (Manisa) Örneği. 14. Türkiye Harita Bilimsel ve Teknik Kurultayı. 2013.
- [24] Aydal D, Vural A, Taşdelen-Uslu İ, Aydal, Emine G. Investigation of Kuşçayırı-Kartaldağı (Bayramiç-Çanakkale) mineral enhancement region by Crosta technique with LANDSAT 7 ETM+ bands. *Technical University of İstanbul, First Remote Sensing Workshop and panel book*, 11p in Turkish with English abstract. 2006.
- [25] Vural A, Aydal D, Akpınar İ. A low sulphur epithermal gold mineralization in Kısacık-Ayvacık area (Çanakkale-Turkey). *Goldschmidt Conference Abstracts*. Prague, Czech Republic: 2011:2105.

- [26] Vural A. Güneyköy ve Çevresi (Eşme-Uşak) Arsenopirit Cevherleşmelerinin Maden Jeolojisi/Mining Geology of Arsenopyrite Mineralizations in Güneyköy and Surroundings (Eşme-Uşak). Ankara University, 1998.
- [27] Vural A, Ünlü T. Güneyköy ve Çevresindeki Kalıntı Altınlı Arsenopirit Cevherleşmelerinin Maden Jeolojisi Açısından İncelenmesi (Investigation of Residual Gold-Bearing Arsenopyrite Mineralization in Güneyköy and its Vicinity in Terms of Mining Geology). 69. Türkiye Jeoloji Kurultayı 11-16 Nisan 2016. Ankara-Türkiye: 2016:374–375.
- [28] Vural A, Albayrak M. Geochemical and Mineralogical Properties of Zeolites from Gördes (Manisa) and Its Near Vicinity. 2nd International Conference on Engineering and Natural Sciences (ICENS 2016). 2016.
- [29] Sönmez FN, Yılmaz H, Çiçek M, Koralay OE, Niedermann S, Kirk J. Age and source of the Küre/Ödemiş arsenopyrite-gold mineralization (Menderes Massif, Turkey) determined by Re-Os-He isotopes. *Ore Geology Reviews* 2020; 118:103333.
- [30] Sönmez FN, Yılmaz H, Güngör T. Uşak/Eşme (Menderes Masifi) Sahasında Altın İçeren Arsenopirit-Kuvars Damarlarının Mineralojisi, Sıvı Kapanım ve Cevherleşme Yaşı (187Re/188Os) Üzerine Bir Çalışma. 67th Geological Congress of Turkey. Ankara, Turkey: 2014:522–523.
- [31] Vural A, Çorumluoğlu Ö, Asri İ. Investigation of Litologic structures and Alterations in Hazine Cave and Dere Mine regions in Turkey by Remote Sensing Techniques. TUFUAB VI. Technical Symposium, 21th February, Antalya (in Turkish with English abstract). 2011.
- [32] Corumluoglu O, Vural A, Asri I. Determination of Kula basalts (geosite) in Turkey using remote sensing techniques. *Arabian Journal of Geosciences* 2015; 8:10105–10117.
- [33] Konak N, Akat U, Afşar ÖP, Akay E, Akçaören F, Akçay AE, Akçay Y, Akdeniz N, Akıncı H, Akkök R, Akyol Z, Akyürek B, et al. İzmir, 1/500 000'lik Jeoloji Haritası (Kompilasyon). Ankara, Türkiye: Maden Tetkik ve Arama Genel Müdürlüğü; 2002.
- [34] Okay AI, Tüysüz O. Tethyan sutures of northern Turkey. In: Durand B, Jolivet L, Horvath L, Serranne M (eds.), *The Mediterranean Basins: Tertiary Extension within the Alpine Orogeny*. London: Geological Society, Special Publications 156; 1999:475–515.
- [35] Okay AI, Tansel I, Tüysüz O. Obduction, subduction and collision as reflected in the Upper Cretaceous-Lower Eocene sedimentary record of western Turkey. *Geological Magazine* 2001; 138:117–142.
- [36] Okay AI, Harris NBW, Kelley SP. Exhumation of blueschists along a Tethyan suture in northwest Turkey. *Tectonophysics* 1998; 285:275–299.
- [37] Meert JG. A synopsis of events related to the assembly of eastern Gondwana. *Tectonophysics* 2003; 362:1–40.
- [38] Şengör A, Yılmaz Y. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics* 1981; 75:181–241.
- [39] Şengör AMC, Satır M, Akkök R. Timing of tectonic events in the Menderes Massif, western Turkey: implications for tectonic evolution and evidence for Pan-African basement in Turkey. *Tectonics* 1984; 3:693–707.
- [40] Zlatkin O, Avigad D, Gerdes A. Evolution and provenance of Neoproterozoic basement and Lower Paleozoic siliciclastic cover of the Menderes Massif (western Taurides): Coupled U-Pb-Hf zircon isotope geochemistry. *Gondwana Research* 2013; 23:682–700.
- [41] Bingöl E. Batı Anadolunun Jeotektonik Evrimi. *Bulletin of the Mineral Research and Exploration* 1976; 86:14–34.
- [42] Brinkmann R. Geotektonische Gliederung von Westanatolien. *Neues Jahrbuch Fur Geologie Und Palaontologie - Abhandlungen* 1966:603–618.
- [43] Konak N, Çakmakoğlu A, Elibol E, Havzoğlu T, Hepşen N, Karamandereci İH, Keskin H, Sarıkaya H, Sav H, Yusufoglu H. Menderes Masifi'nin orta kesimlerindeki bindirmeli yapıların gelişimi. 47. Türkiye Jeoloji Kurultayı, Ankara. 1994:34.
- [44] Bozkurt E, Oberhansli R. Menderes Massif (Western Turkey): structural, metamorphic and magmatic evolution—a synthesis. *International Journal of Earth Sciences* 2001; 89:679–708.
- [45] Bozkurt E, Park RG. Southern Menderes Massif: an incipient metamorphic core complex in western Anatolia, Turkey. *Journal - Geological Society (London)* 1994; 151:213–216.
- [46] Bozkurt E, Winchester JA, Park RG. Geochemistry and tectonic significance of augen gneisses from the southern Menderes Massif (west Turkey). *Geological Magazine* 1995; 132:287–301.
- [47] Ring U, Gessner K, Güngör T, Passchier C. The Menderes Massif of western Turkey and

- the Cycladic Massif in the Aegean-do they really correlate? *Journal of Geological Society London* 1999; 155:3–6.
- [48] Lips ALW, Cassard D, Sözbilir H, Yilmaz H, Wijbrans JR. Multistage exhumation of the Menderes Massif, Western Anatolia (Turkey). *International Journal of Earth Sciences* 2001; 89:781–792.
- [49] Dora O, Candan O, Kaya O, Koralay E, Dürr S. Revision of “Leptite-gneisses” in the Menderes Massif: A supracrustal metasedimentary origin. *International Journal of Earth Sciences* 2001; 89:836–851.
- [50] Hetzel R, Reischmann T. Intrusion age of Pan-African augen gneiss in the southern Menderes Massif and the age of cooling after Alpine ductile extensional metamorphism. *Geological Magazine* 1996; 133:505–572.
- [51] Candan O, Koralay OE, Akal C, Kaya O, Oberhänsli R, Dora OÖ, Konak N, Chen F. Supra-Pan-African unconformity between core and cover series of the Menderes Massif/Turkey and its geological implications. *Precambrian Research* 2011; 184:1–23.
- [52] Koralay OE, Candan O, Akal C, Dora OÖ, Chen F, Satır M. The Geology and Geochronology of the Pan-African and Triassic Metagranitoids in the Menderes Massif, Western Anatolia, Turkey. *Bulletin Of The Mineral Research and Exploration* 2011; 142:69–119.
- [53] Koralay OE, Chen F, Oberhänsli R, Wan Y, Candan O. Menderes Masifi’ndeki (Batı Anadolu/Türkiye) Granulit Fasiyesi Metamorfizmasının Yaşı: SHRIMP U–Pb Zirkon Yaşlandırması. *Türkiye Jeoloji Kurultayı* 2006; 59:28–29.
- [54] Oberhänsli R, Candan O, Wilke F. Menderes Masifinin orta kesimindeki Pan-Afrikan eklojitlerine ait jeokronolojik veriler. *Turkish Journal of Earth Sciences* 2010; 19:431–447.
- [55] Satır M, Friedrichsen H. The Origin and Evaluation of the Menderes Masiff (W.Turkey), A Rubidium Strontium and Oxigene Isotop Study. *Geologische Rundschau* 1986; 753:703–714.
- [56] Régnier JL, Ring U, Paschier CW, Gessner K, Güngör T. Contrasting meta-morphic evolution of metasedimentary rocks from the Çine and Selimiye nappes in the Anatolide belt, western Turkey. *Journal of Metamorphic Geology* 2003; 21:699–721.
- [57] Rimmelé G, Oberhänsli R, Goffé B, Jolivet L, Candan O, Çetinkaplan M. First evidence of high-pressure metamorphism in the “Cover Series” of the southern Menderes Massif. Tectonic and metamorphic implications for the evolution of SW Turkey. *Lithos* 2003; 71:19–46.
- [58] Hetzel R, Romer RL, Candan O, Passchier CW. Geology of the Bozdag area, central Menderes massif, SW Turkey: Pan-African basement and Alpine deformation. *Geologische Rundschau* 1998; 87:394–406.
- [59] Dannat C. Geochemie, geochronologie und Nd-Sm Isotopie der granitoiden Kerngneiss des Menderes Massivs, SW-Turkey. , Johannes Gutenberg Universität Mainz, 1997.
- [60] Seyitoğlu G, Scott BC. Age of Alaşehir graben (west Turkey) and its tectonic implications. *Geological Journal* 1996; 31:1–11.
- [61] Candan O, Koralay OE, Topuz G, Oberhänsli R, Fritz H, Collins AS, Chen F. Late Neoproterozoic gabbro emplacement followed by early Cambrian eclogite-facies metamorphism in the Menderes Massif (W. Turkey): Implications on the final assembly of Gondwana. *Gondwana Research* 2016; 34:158–173.
- [62] Dora OÖ, Üniversitesi DE, Bölümü JM, Dora C. Menderes Masifi ’nde granulit , eklojit ve mavi şist kalıntıları : Pan-Afrikan ve Tersiyer metamorfik evrimine bir yaklaşım 1998; 41:1–35.
- [63] Candan O, Dora O, Oberhänsli R, Çetinkaplan M, Partzsch JH, Warkus FC, Dürr S. Pan-African high-pressure metamorphism in the Precambrian basement of the Menderes Massif, western Anatolia, Turkey. *International Journal of Earth Sciences* 2001; 89:793–811.
- [64] Okay AI, Tüysüz O. Tethyan sutures of northern Turkey. *Geological Society Special Publication* 1999; 156:475–515.
- [65] Candan O. Petrography and metamorphism of the meta-gabbros at the northern part of Alaşehir; Demirci-Gördes submassif of the Menderes Massif. *Türkiye Jeoloji Bülteni / Geological Bulletin of Turkey* 1994; 37:29–40.
- [66] Candan O, Oberhänsli R, Dora OÖ, Çetinkaplan M, Koralay E, Rimmelé G, Chen F, Akal C. Polymetamorphic Evolution of the Pan-African Basement and Palaeozoic–Early Tertiary Cover Series of the Menderes Massif. *Bulletin Of The Mineral Research and Exploration* 2011; 142:121–163.
- [67] Ercan T, Türkecan A, Dinçel A, Güney E, Küçükayman A. Uşak Yöresinin Petrolojisi. Ankara-Türkiye: 1977.
- [68] Koralay E, Candan O, Akal C, Dora OO, Chen F, Satır M, Oberhänsli R. Menderes

- Masifi'ndeki Pan-Afrikan Ve Triyas Yaş [69] Bozkurt E, Satir M. The southern Menderes Metagranitoidleri Jeolojisi ve Jeokronolojisi, Batı Anadolu, Türkiye. Bulletin of the Mineral Research and Exploration 2011; 142:69–121. Massif (western Turkey): Geochronology and exhumation history. Geological Journal 2000; 35:285–296.