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ARTICLE

Mineralogical and Petrographical Features of Southeast Anatolian Metamorphic Complex (Pütürge Metamorphics, Eastern Taurides-Türkiye)

Abdullah Sar , Mustafa Eren Rizeli, Mehmet Ali Ertürk *

Department of Geological Engineering, Fırat University, Elazığ 23119, Turkey

ABSTRACT

Pütürge Metamorphics, located within the nappe zone in the Southeastern Anatolian Orogenic Belt (SAOB), crop out in large areas in the study area. Pütürge Metamorphics were examined in the Upper Metamorphic and Lower Metamorphic Unit. The Lower Metamorphic Unit; is represented by amphibolite, amphibole schist, biotite schist, granitic gneiss, and augen gneisses, The Upper Metamorphic Unit; with kyanite quartzite veins, muscovite schist, mica schist, garnet mica schist, garnet quartz mica schist, chloritoid chlorite schist, and marbles. Pütürge Metamorphics start with augen gneisses at the base and are overlain by biotite schist-amphibole schist and granitic gneisses. At the top, there are kyanite quartzite veins, muscovite schist, mica schist, garnet mica schist, garnet quartz mica schist, chloritoid chlorite schist, and marbles belonging to the Upper Metamorphic Unit. The main mineral assemblage of the Pütürge Metamorphics consists of quartz, alkali feldspar, plagioclase, biotite, muscovite, sericite, chlorite, garnet, tremolite actinolite, dental, chloritoid, and calcite minerals in varying amounts. As a result, Pütürge metamorphics are divided into Lower and Upper Metamorphic Units, petrographically the rocks belonging to the Lower Metamorphic Unit are represented by amphibolite; nematoblastic texture, biotite schist; lepidoblastic texture, amphibole schist; nematoblastic texture, granitic gneises; granoblastic texture, and augen gneisses; porphyrogranoblastic texture, while the rocks belonging to the Upper Unit represented by kyanite quartzite veins; porphyroblastic texture, muscovite schist; lepidoblastic texture, mica schist; lepidoblastic texture, garnet mica schist; porphyrolepidoblastic texture, garnet quartz mica schist; porphyrolepidoblastic texture, chloritoid chlorite schist; porphyrolepidoblastic texture, and marbles; granoblastic texture.

Keywords: Pütürge Metamorphics; Lower-Upper Metamorphic Unit; Petrography; Kyanite quartzite; Augen gneiss

*CORRESPONDING AUTHOR:
Mehmet Ali Ertürk, Department of Geological Engineering, Fırat University, Elazığ 23119, Turkey; Email: erturkmae@gmail.com

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1. Introduction

Türkiye is located within the Alpine-Himalayan Orogenic Belt, formed by the closure of different branches of the Tethys Ocean and the merging of two large continents, Gondwana in the south and Laurasia in the north [1–4]. Most of the Late Neoproterozoic to Early Paleozoic (600–500 Ma) blocks within the Alpine-Himalayan Orogenic Belt show that magmatic rocks and gneisses were formed by Ediacaran-Cambrian arc-type magmatism or Cadomian events, according to zircon U-Pb age data and paleomagnetic data [1–4].

The Southeastern Anatolian Orogenic Belt (SAOB) has been a key area for studying continental margins' temporal evolution and uplift history during the Alpine-Himalayan orogeny [5–7]. This belt is 400 km long and 70 km wide and was formed due to the convergence and collision of the Eurasian and Asian/African plates. SAOB consists of the Arabian Platform, thrust, and nappe zones [8]. A thick marine sequence represents the Arabian Platform. The thrust zone is a narrow belt sandwiched between the Arabian Platform and the nappes. The content of the nappes, the highest tectonic unit, reveals that from the Late Cretaceous to the Early Tertiary, two continental strips separated by the oceanic environment existed north of the Arabian Plate. Later, they were involved in orogenic development and formed two metamorphic belts: northern (Northern Taurus Mountains; Binboğa-Keban-Malatya metamorphic belt) and southern (Southern Taurus Mountains; Engizek-Pütürge-Bitlis metamorphic belt) metamorphic massifs. SAOB developed due to the geological events that occurred during the closure of the southern branch of the Neotethys, bounded by the Taurus Mountains in the north and the Arabian platform in the south, during the Late Cretaceous-Miocene period. The evolution of the belt proceeded as a relatively southward movement of the nappes towards the Arabian Platform [6, 8–10].

Pütürge Metamorphics, which constitute the subject of the study, are located within the nappe zone in SAOB. The study area is spread over a wide area in and around Pütürge district of Malatya province (**Figure 1**). Pütürge Metamorphics are represented in the study area by amphibolite, biotite schist, amphibole schist, granitic gneiss and augen gneiss, kyanite quartzite veins, muscovite schist, mica schist, garnet mica schist, garnet quartz mica schist, chloritoid chlorite schist, and marbles. Pütürge Metamorphics, which constitute the subject of the study, have been studied by different researchers within the scope of previous studies. With this study, unlike previous studies, we reveal in more detail the mineralogical, petrographic, and textural characteristics of each rock type belonging to both the Lower Metamorphic and Upper Metamorphic Units. This study aims to reveal the distribution of the rocks belonging to the Pütürge Metamorphics in the study area and their mineralogical, petrographic, and textural features.

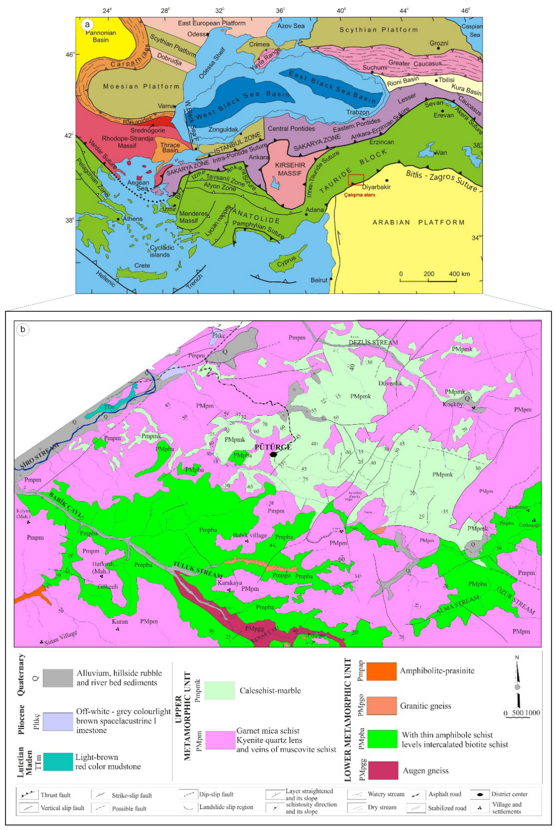

Figure 1. (A) Türkiye tectonic units map (b) geological map of the study area (used and modified from Erdem).

Source: [11,14].

2. Materials and Methods

A total of 30 metamorphic rock samples were collected for the Lower Metamorphic Unit, including

5 amphibolites, 7 biotite schists, 7 amphibole schists, 5 granitic gneiss, and 6 augen gneiss. A total of 53 metamorphic rock samples were collected for the Upper Metamorphic Unit, including 5 kyanite quartzite veins, 12 muscovite schist, 15 mica schist, 12 garnet mica schist/garnet quartz mica schist, 5 chloritoid chlorite schist and 4 marble samples. The samples of Pütürge Metamorphics, which constitute the subject of investigation within the scope of petrographic studies, were cut in 0.5x2x4 cm dimensions in Fırat University, Department of Geological Engineering, Thin Section Laboratory. After smoothing one surface, they were glued on glass in 2.5x4.5 cm dimensions (25 units of Epoxy resin, three units mixed with epoxy hardener). After the glued metamorphic rock piece was cut to a size of approximately 0.5 mm, it was thinned to a thickness of 0.025 mm with the help of abrasives and was prepared for petrography examinations.

3. Regional Geology and Field Observations

The study area within SAOB is located in Pütürge district of Malatya province and its surroundings. Lithological units cropping out in the region are represented by Paleozoic-aged Pütürge Metamorphics, Middle Eocene-aged Maden Complex, and Quaternary-aged alluviums. Pütürge Metamorphics are seen as a thick stack in the study area due to the tectonic morphology caused by dip-slip reverse and strike-slip faults. Metamorphic rocks cropping along the valley slopes are generally divided into Upper and Lower Metamorphic Units [11]. Lower Metamorphic Unit: The Upper Metamorphic Unit is represented by amphibolite, biotite schist, amphibole schist, granitic gneiss and augen gneisses, kyanite quartzite veins, muscovite schist, mica schist, garnet mica schist, garnet quartz mica schist, chloritoid chlorite schist, and marbles. Pütürge Metamorphics start with augen gneisses at the base, and are overlain by biotite schist-amphibole schist and granitic gneisses. A shear zone containing profillite levels is observed above these units. At the top, there are kyanite quartzite veins, muscovite schist, mica schist, garnet mica schist, garnet quartz mica schist, chloritoid chlorite schist, and marbles belonging to the Upper Metamorphic Unit (**Figure 2**). Foliation is observed in metamorphics, and several different foliations are observed. These are schistosity, gneiss banding, and cleavage. The Middle Eocene-aged Maden Complex crops out around the Şiro stream in the study area and is represented by basalt, basaltic andesite, and diabase-type rocks [12,13]. Volcanics belonging to the Maden Complex transgressively cover the Pütürge Metamorphics.

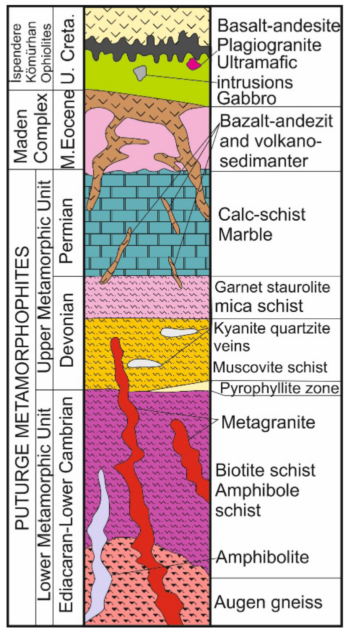

Figure 2. Tectono-stratigraphic strut section of the study area (used modified from Beyarslan et al.)

Source: [4].

3.1. Lower Metamorphic Unit

The Lower Metamorphic is represented by amphibolite, biotite schist, amphibole schist, granitic and augen gneisses (**Figure 3(a)**, **Figure 4(a)**). Augen gneisses belonging to the Lower Metamorphic Unit constitute the basement rocks of the Pütürge Metamorphics. Amphibole schists and biotite schists lie on the augen gneisses. Garnet mica schists and occasionally granitic gneisses located between them are located on these units. Pyrophyllite levels are observed above all these units in certain parts of the study area. Above these are muscovite schist, mica schist and garnet mica schist. At the highest levels, calcschist and marbles are observed.

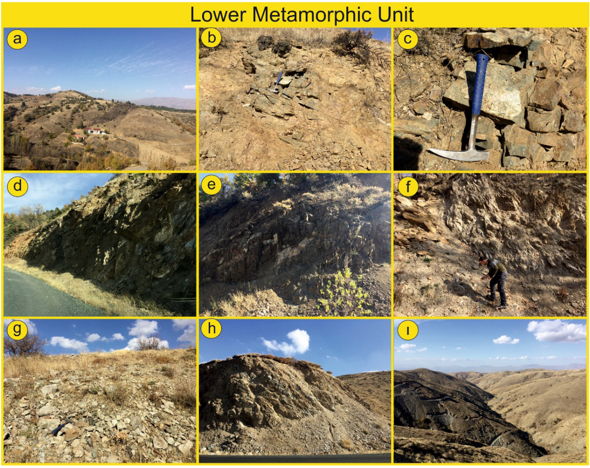

Figure 3. Field views of rocks belonging to the lower metamorphic unit (a-c) amphibolite (d-e) biotite schist (f) amphibole schist (g-h) granitic gneiss (i) augen gneiss.

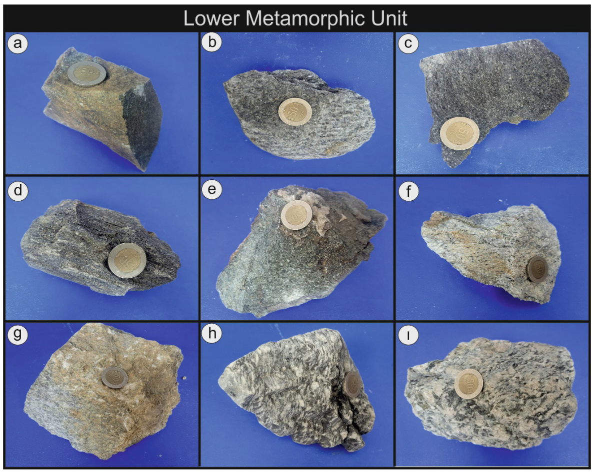

Figure 4. Macroscopic views of rocks belonging to the lower metamorphic unit (a) amphibolite (b) biotite schist (c-e) amphibole schist (f-h) granitic gneiss (i) augen gneiss.

Amphibolite

Amphibolites black colours in hand specimens, and in the outcrop, they are generally display in brown tones on surfaces affected by alteration (**Figure 5(a-c), Figure 6(a)**). Even though poorly developed schistosity is observed in amphibolite, it appears massive It outcrops in a limited area compared to other units on the land. Crack levels are observed intensively. It shows nematoblastic texture.

Biotite Schist

It is observed in dark brown and black bright colours in the study area (**Figure 5(d-e), Figure 6(b)**). It lies intrusively on the augen gneisses at the base, and thin layers of amphibole schist levels are observed inside this unit. Alteration is at variable degrees and is observed at low-high levels. The dominant foliation type is schistosity. It has well-developed schistosity levels. It is characteristic of its plate-like structure and shows lepidoblastic texture.

Amphibole Schist

It is observed in black shiny tones in hand specimens, similar to biotite schists (**Figure 3(f), Figure 4(c-e)**). Generally, it is observed as thin layers among biotite schists. The schistosity level is lower than biotite schists. Alteration is observed at low-medium levels. The dominant texture in the rock is the nematoblastic texture.

Granitic Gneiss

It is observed in grey and white tones in the study area (**Figure 3(g-h), Figure 4(f-h)**). Specimens affected by alteration are observed in brown tones. It has poorly developed schistosity levels, and the dominant foliation type is gneiss banding. It shows granoblastic texture.

Augen Gneiss

Augen gneisses are observed in grey, pink and greenish colours in hand specimens and brown tones in samples affected by alteration (**Figure 3(i), Figure 4(i)**). Large K-feldspar crystals of pegmatitic sizes are observed in these rocks, which form the base of the Pütürge Metamorphics. The sizes of the crystals vary between 2–5 cm on average. It has an intrusive contact relationship with biotite schists and amphibole schists in the study area. The dominant foliation type in the unit is gneiss banding. Alteration in the rocks is observed at a moderate level. Porphyrogranoblastic texture dominates throughout the rock.

3.2. Upper Metamorphic Unit

Upper Metamorphic Unit: It is represented by kyanite quartzite veins, muscovite schist, mica schist, garnet mica schist, garnet quartz mica schist, chloritoid chlorite schist and marbles (**Figure 5(a-i), Figure 6(a-i)**).

Kyanite Quartzite Veins

Quartzite veins in whitish tones are observed within the garnet mica schist levels in the study area. Kyanite crystals are observed within the veins. The knuckles are in light-dark blue tones and have an average size of 7–8 cm (**Figure 5(a-b), Figure 6(a-b)**). Quartzite veins are observed in the study area in lengths ranging from 3 to 15 meters. Their width varies between 30–60 cm. The alteration rate is high in the garnet mica schists it contains. Garnet minerals are seen separated from the main mass in areas where alteration is intense. Garnets are observed in the region with an average size of 5–7 mm. Schistosity is not observed in the quartzite veins, but well-developed schistosity is observed in the garnet mica schists it contains. It shows porphyroblastic texture.

Muscovite Schist

It is observed in light, bright greyish colours in the study area (**Figure 5(c), Figure 6(c)**). In samples where alteration is intense, it is seen in brown tones. Well-developed schistosity is observed. Texturally, lepidoblastic texture dominates. It is the most commonly observed unit in the study area.

Mica Schist

Mica schists are generally observed in greyish-brown tones. The unit, which has very well-developed schistosity, shows lepidoblastic texture texturally (**Figure 5(d), Figure 6(d)**).

Garnet Mica Schist

It outcrops in large areas in the study area. It is generally observed in greyish colours, and in parts where alteration is intense, it appears in earthy colours (**Figure 5(e-f), Figure 6(e)**). It contains garnet minerals in varying sizes and proportions. Garnets are in light-dark brown tones and have sizes up to 0.3–1.5 cm. It is characteristic of its crystallized structure in the cubic system and its alteration-resistant structure. For this reason, mica is observed as protrusions of varying sizes in schists. Alteration varies regionally. Garnet minerals are seen in forms separated from the main rock in regions where alteration is intense. It has very well-developed schistosity. Texturally, porphyrolepidoblastic texture dominates.

Garnet Quartz Mica Schist

Garnet mica shows similar properties to schists (**Figure 5(g), Figure 6(f-g)**). It contains quartz lenses/veins of different sizes (approximately 10 cm). Texturally, porphyrolepidoblastic texture dominates.

Chloritoid Chlorite Schist

It is observed in dark green colours in the study area. It contains chloritoid minerals with an average size of 0.3–0.8 cm (Figure 5(h), Figure 6(h)). Chloritoids appear in shades of black. Chloritoids have oval shapes within the rock and are observed as cavities on the outer surface. It has poorly developed schistosity. Porphyrolepidoblastic texture is dominant throughout the rock.

Marble

It is observed in grey-white tones in hand specimens (**Figure 5(i), Figure 6(i)**). It constitutes the uppermost unit of the Pütürge Metamorphics. Marbles conformably overlie garnet-bearing mica schists and muscovite schists in the study area. It has more massive features, and schistosity is not observed. Texturally, granoblastic texture dominates.

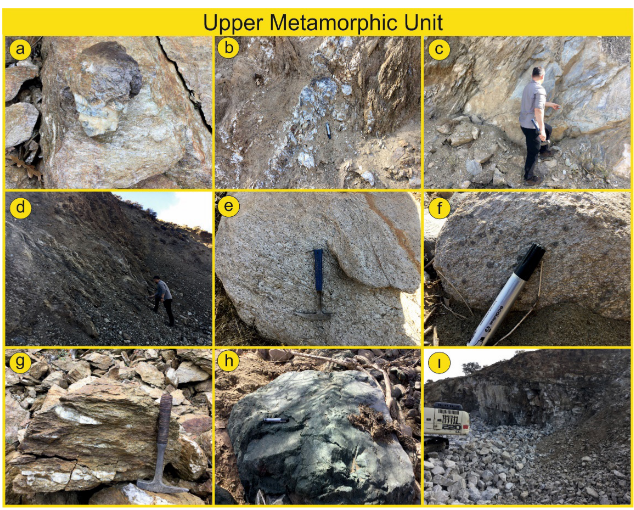

Figure 5. Field views of rocks belonging to the upper metamorphic unit (a-b) kyanite quartzite veins (c) muscovite schist (d) mica schist (e) garnet mica schist (g) garnet quartz mica schist (h) chloritoid chlorite schist (i) marble.

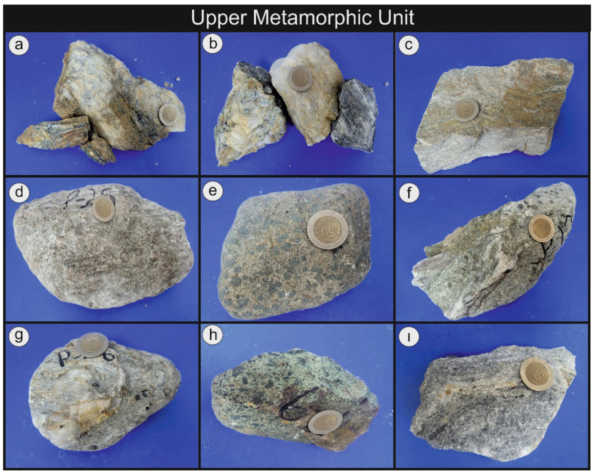

Figure 6. Macroscopic views of rocks belonging to the upper metamorphic unit (a-b) kyanite quartzite (c) muscovite schist (d) mica schist (e) garnet mica schist (f-g) garnet quartz mica schist (h) chloritoid chlorite schist (i) marble

4. Petrography

4.1. Lower Metamorphic Unit

Amphibolite

The main mineral parageneses in amphibolites are plagioclase, amphibole, biotite and quartz minerals (**Figure 7(a-c)**), and the rock has no obvious orientation. Plagioclase generally appears as prismatic, small crystals. Due to mineral sizes, most minerals cannot clearly observe twinnings. Nematoblastic texture is observed throughout the rock (**Figure 7(a-c)**). Amphibole minerals, generally observed as euhedral crystals, are characteristic of their pleochroism in green tones in one light. Biotite and quartz minerals are seen in very small amounts in the rock. Quartz minerals are observed as euhedral crystals, while biotite minerals are observed as plate-like crystals and are characteristic of their brown pleochroism.

Biotite Schist

The unit was examined as a biotite schist because more than 85% of the mica minerals contain biotite. The main mineral assemblage in the rock consists of biotite, quartz, muscovite, plagioclase and opaque minerals (**Figure 7(d-e)**). Biotites are in the form of long, prismatic, plate-like crystals. It offers vivid interference colors in dual nicol. It has pleochroism in brown tones in plane-polarized light (PPL). It forms a lepidoblastic texture in the rock. It generally shows a regular arrangement around the plagioclase crystals parallel to the schistosity plane (**Figure 7(d-e)**). Muscovite, the other mica mineral in the rock, shows vibrant interference colours in shades of pink, yellow and orange. It has perfect cleavages and is observed transparently in a plane-polarized light (PPL). Plagioclase minerals with low birefringence colours are generally observed in the rock as prismatic, subhedral crystals. It forms a porphyroblastic texture in the rock (**Figure 7(d-e)**). Quartz, biotite and muscovite minerals are inclusions within the plagioclase poikiloblasts. Quartz, which appears as euhedral crystals of different sizes, forms the granoblastic texture with plagioclase in the rock.

Amphibole Schist

The main mineral parageneses in amphibole schists are amphibole, plagioclase, alkali feldspar and quartz. Amphiboles appear as subhedral and euhedral prismatic crystals (**Figure 7(f)**). It shows vivid interference colours in cross-polarized light (XPL). It is characteristic of its single-coloured green pleochroism. Amphibole minerals are arranged parallel to the schistosity plane around plagioclase and alkali feldspar poikiloblasts. It forms a nematoblastic texture in the rock (**Figure 7(f)**). Plagioclases are observed as prismatic crystals. It has low birefringence colours in cross-polarized light (XPL). Biotite quartz and opaque minerals are observed as inclusions within plagioclase and alkali feldspar poikiloblasts. Plagioclase and alkali feldspars form the porphyroblastic texture in the rock.

Granitic Gneiss

The main mineral parageneses in granitic gneisses are alkali feldspar, plagioclase, biotite, muscovite and quartz minerals (**Figure 7(g)**). Alkali feldspars have low birefringence colours in grey-white tones at cross-polarized light (XPL). It is seen in earthy colours in a plane-polarized light (PPL). Quartz, biotite, muscovite and opaque minerals are observed as mineral inclusions in alkali feldspar poikiloblasts. Alkaline feldspars form porphyroblastic texture within the rock (**Figure 7(g)**). Plagioclases appear as euhedral, prismatic crystals. Albite twinning is observed in some crystals. Biotites are characteristic with their vibrant interference colours, well-developed cleavages and brown pleochroism in plane-polarized light (PPL). Muscovites with vibrant interference colours are observed as plate-like crystals. Biotite and muscovite form the lepidoblastic texture in the rock.

Augen Gneiss

The main mineral assemblage in the augen gneisses, which are easily recognized with their afferent texture in the study area, consists of alkali feldspar (orthoclase), plagioclase, biotite, amphibole and quartz minerals (**Figure 7(h-i)**). Alkaline feldspars, which form the eye structures in augen gneisses, are the minerals with the highest ratio in the rock (**Figure 7(h-i)**). Sericitization is observed in some alkali feldspar crystals. Dense mineral inclusions, including quartz, biotite and muscovite, are observed within the alkali feldspar poikiloblasts. Alkaline feldspars form a porphyroblastic texture in the rock (**Figure 7(h-i)**). Biotites present vibrant interference colours in cross-polarized light (XPL) and show brown pleochroism in single chromaticity. Muscovites offer vibrant interference colours. Biotite and muscovite form the lepidoblastic texture in the rock and cause the formation of eyes by surrounding alkali feldspar crystals.

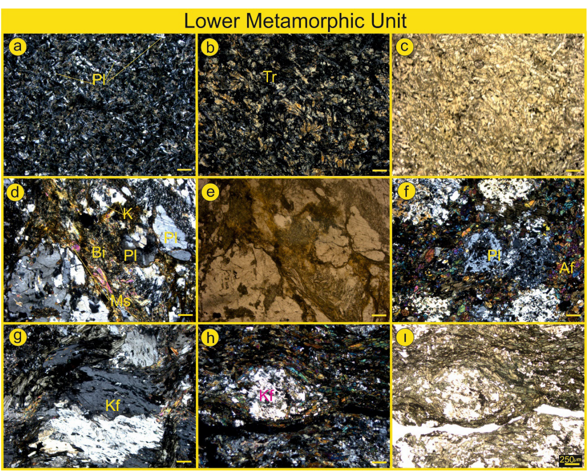

Figure 7. Thin section views of rocks belonging to the lower metamorphic unit (a-c) amphibole and plagioclase minerals in amphibolites (d-e) porphyroblastic texture seen in biotite schists (f) nematoblastic and porphyroblastic textures observed in amphibole schists (g) porphyroblastic texture observed in granitic gneisses (h-i) augen texture observed in augen gneisses (pl: plagioclase, tr: tremolite-actinolite, af: amphibole, k: quartz, ms: muscovite, bi: biotite, kf: alkali feldspar).

4.2. Upper Metamorphic Unit

Kyanite Quartzite Veins

In the study area, garnet mica crops out through lenses and veins within the schists (**Figure 5(a-b)**). In thin sections, Kyanite quartzites show porphyroblastic and granolepidoblastic textures (**Figure 8(a-b)**). The main mineral assemblage of the rock consists of quartz, kyanite and, to a lesser extent, muscovite. Quartz minerals are in the form of fine-coarse-grained amorphous crystals. It has low birefringence colours in cross-polarized light (XPL). Quartzes are the most common minerals observed in rocks and constitute 65–75% of the rock. Kyanites forming the porphyroblastic texture in the rock are observed in dark blue-blue colours in hand specimens (**Figure 6(a-b)**). It has low birefringence colours in cross-polarized light (XPL) in thin sections. It is characteristic of its perfectly developed unidirectional cleavages in a plane-polarized light (PPL). Its proportion in the rock varies between 15–20%.

Muscovite Schist

The main mineral assemblage of muscovite schists consists of muscovite, quartz, and opaque minerals. The texture observed throughout the rock is granolepidoblastic texture (**Figure 8(d)**). Quartzes are observed as amorphous crystals of similar shapes and sizes and constitute the most common mineral phase in the rock. It shows wavy extinction. It forms a granoblastic texture within the rock. Muscovite minerals have vivid interference colours in cross-polarized light (XPL) (**Figure 8(d)**). It shows colourless and well-developed segments in single chromatography. It is observed as long, prismatic, plate-like crystals of different shapes and sizes. These crystals have a regular arrangement parallel to the schistosity plane in the rock, and in some cases, they show a folded structure. Muscovites form lepidoblastic texture in the rock. Muscovites and quartzes are folded harmoniously with each other. It can be said that muscovite and quartz are affected by the same deformation forces since quartz exhibits wavy extinction and participates in folding.

Mica Schist

It consists of quartz, muscovite and biotite as the main minerals and opaque as secondary minerals. Secondary chlorite and sericite formations are observed in some sections (**Figure 8(e-g)**). Lepidogranoblastic texture is dominant throughout the rock. Quartzes are unaffected by colourless alteration in plane-polarized light (PPL) and are characteristic with their interference colours in grey-white tones in cross-polarized light (XPL) and approximately equal-sized, euhedral amorphous crystals. They mostly show schistosity and elongation in the direction of foliation (**Figure 8(e-g)**). They form a granoblastic texture in the rock. Muscovites offer vibrant interference colours in cross-polarized light (XPL). It is in the form of plate-like, long prismatic crystals and has very well-developed cleavages. Biotites are characteristic with their pleochroism varying in brown tones in plane-polarized light (PPL). It is observed as plate-like, long prismatic crystals similar to muscovite minerals. Together with Muscovites, it forms the main foliation of the rock. Chloritization is observed in some biotite minerals. Muscovite and biotite minerals form the lepidoblastic texture in the rock (**Figure 8(e-g)**). Biotite and muscovite constitute 25–35% of the rock composition.

Garnet Mica Schist/ Garnet Quartz Mica Schist

The main mineral assemblage in these rocks, common in the study area, consists of garnet, quartz, muscovite, biotite and opaque minerals. Garnets are characteristic of their isotropic properties (**Figure 8(h-i)**). It has black in cross-polarized light (XPL), high optical roughness in single nacre, well-developed cleavages, and commonly observed fractures and cracks. It forms a porphyroblastic texture within the rock. It is generally subhedral and euhedral and is observed in crystalline forms in the cubic system. The garnets are mostly surrounded by biotite and muscovite minerals (**Figure 8(h-i)**). Quartz poikiloblasts are observed in some garnet crystals. Biotite and muscovite, which constitute the phyllosilicate minerals in the rock, are observed in the form of plate-like crystals. Micas observed that surrounded garnet minerals present vivid interference colours in double fluorescence. It forms a lepidoblastic texture in the rock. Quartz, mostly observed around garnet minerals and micas, is an amorphous, approximately equal-sized mineral. It forms a granoblastic texture in the rock (**Figure 8(h-i)**).

Chloritoid Chlorite Schist

The main mineral assemblage in chloritoid chlorite schists consists of quartz, plagioclase, chlorite and chloritoid minerals (**Figure 8(k-i)**). Lepidogranoblastic texture is observed throughout the rock. Quartzes appear as amorphous crystals of different sizes. Albite twinnings characterize plagioclases. Plagioclases are mostly euhedral or subhedral, and transformation into sericite minerals is observed in some plagioclase minerals. Amorphous plagioclase minerals and quartz form the granoblastic texture in the rock. Chloritoids are characteristic with their pleochroism, which is observed in dark-dark blue colors in cross-polarized light (XPL) and light green tones in plane-polarized light (PPL) (**Figure 8(k-i)**). They form a porphyroblastic texture within the rock.

Marble

The marbles that form the uppermost part of the Upper Metamorphic Unit contain more than 90% calcite mineral (**Figure 8(m)**). The granoblastic texture is observed throughout the rock. Calcites have perfect cleavages developed in the lateral direction in thin sections. It is colourless in plane-polarized light (PPL).

5. Discussion and Conclusion

Pütürge Metamorphics cropping out along SAOB are considered the western extension of the Precambrian-Paleozoic aged Bitlis Massif [4,10,11,15–17]. Researchers [11,15,16,18] stated that the Alpine Metamorphism was the first active phase in the metamorphism of the Bitlis-Pütürge Metamorphics and that this metamorphism took place in the Campanian with the arc-continent collision and overlay of ophiolites, and formed Barrovian-type regional metamorphism from greenschist to upper amphibolite facies in the massif. Erdem [11] examined the Pütürge Metamorphics in the Upper Unit and Lower Unit. He said that the

Upper Unit is represented by Kyanite quartzite veins, muscovite schist, mica schist, garnet mica schist, and marbles, and the Lower Unit is characteristic of amphibolite, amphibole schist, biotite schist, granitic gneiss and augen gneisses. He suggested that augen and granitic gneisses belonging to the Lower Unit were originally collision granites. The researcher states that amphibole and amphibole schists are formed due to the metamorphism of basic rocks of magmatic origin. He stated that the schists of the Upper Unit were derived from marine clays of sedimentary origin, and the kyanite quartzite veins were formed due to hydrothermal melts rich in aluminum and silica that occurred due to friction during the metamorphism process. Erdem [11] petrographically defined the rocks belonging to the Upper Metamorphic Unit in the region as kyanite quartzite veins, staurolite muscovite schist, garnet mica schist, calcschist, and marbles. In this study, different rock types such as mica schist, garnet quartz mica schist, and chloritoid chlorite schist were also defined. Erdem (1994) stated that the Kyanite Quartzite veins belonging to the Upper Unit are located within mica schists and muscovite schists, while Güngör [18] stated that they are located within mica schists and fine-medium grained gneisses. In this study, Kyanite quartzite veins were detected in the garnet mica schists containing garnet minerals with an average size of 0.5 cm in the study area. The alteration rate is high in garnet mica schist units and garnet minerals are observed in separate forms from the main mass. Güngör [18] stated that pressure and temperature did not remain the same in the formation of kyanite quartzite veins in the Pütürge Metamorphics and that structural factors played an active role during the rise of the metamorphics. The researcher stated that large kyanite crystals in kyanite quartzite veins might form due to aluminum migration from host rocks or fracture zones during metamorphism and that the origin of these rocks may be magmatic. According to [16], Şahin and Işık stated that the index minerals (e.g. sillimanite) in the Pütürge Metamorphics were formed under 600–700 °C temperature and 7–9 kbar pressure conditions.

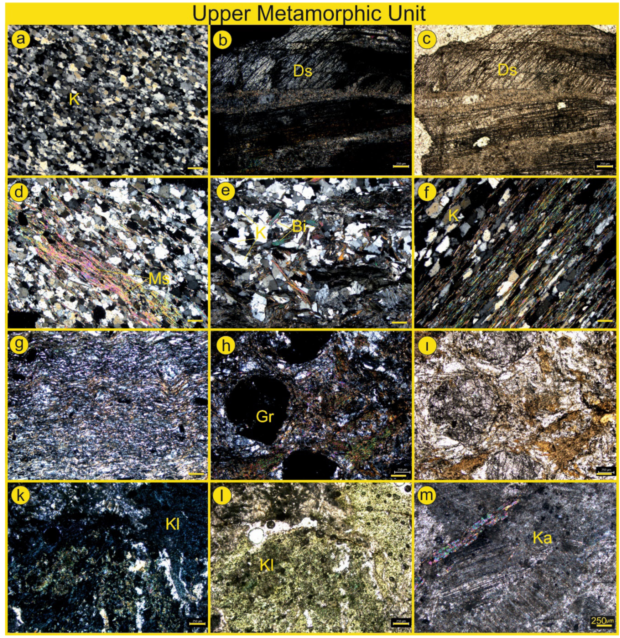

Figure 8. Thin section views of rocks belonging to the upper metamorphic unit (a-c) porphyroblastic texture observed in kyanite quartzite veins (d) lepidogranoblastic texture seen in muscovite schists (e-g) lepidoblastic texture seen in mica schists (h-i) porphyrolepidoblastic texture observed in garnet mica schists (k-l) porphyroblastic texture observed in chloritoid chlorite schists m. calcite crystals observed in marbles (K: quartz, Ds: kyanite, ms: muscovite, Bi: biotite, Gr: garnet, Kl: chloritoid, Ka: calcite)

Within the scope of this study, field observations and petrographic features of the Pütürge Metamorphics were examined in detail. Accordingly, metamorphics are divided into Upper and Lower Metamorphic Units. The Lower Metamorphic Unit is composed of amphibolite (plagioclase ± amphibole ± biotite ± quartz)), amphibole schist (plagioclase ± amphibole ± alkali feldspar ± quartz), biotite schist (biotite ± quartz ± muscovite ± plagioclase), granitic gneiss (alkaline feldspar ± plagioclase ± biotite ± muscovite ± quartz) and augen gneisses (alkaline feldspar ± plagioclase ± biotite It is represented by ± muscovite ± quartz). Upper Metamorphic Unit; kyanite quartzite veins (kyanite ± quartz), muscovite schist (quartz ± muscovite ± opaque minerals), mica schist (quartz ± muscovite ± biotite ± sericite ± chlorite), garnet mica schist (garnet ± quartz ± muscovite ± biotite ± sericite ± chlorite) , quartz garnet mica schist (garnet ± quartz ± muscovite ± biotite ± sericite ± chlorite), chloritoid chlorite schist (quartz ± plagioclase ± chlorite ± chloritoid) and marbles (calcite). The characteristics of regional metamorphism are observed in these metamorphic rocks examined. Texturally, these rocks show lepidoblastic, granoblastic, nematoblastic, and porphyroblastic textures, depending on their minerals.

In conclusion, Lower Metamorphic Unit;

Amphibolites contain plagioclase, amphibole, biotite and quartz minerals; nematoblastic texture.

Biotite schists consist of biotite, quartz, muscovite, plagioclase and opaque minerals; lepidoblastic texture.

Amphibole schist is composed of amphibole, plagioclase, alkali feldspar, and quartz; nematoblastic texture.

Granitic gneiss consists of alkali feldspar, plagioclase, biotite, muscovite, and quartz minerals; granoblastic texture.

Augen gneiss contains alkali feldspar (orthoclase), plagioclase, biotite, amphibole, and quartz minerals; porphyrogranoblastic texture.

Upper Metamorphic Unit;

Kyanite quartzite veins consist of quartz, kyanite, and, to a lesser extent, muscovite; porphyroblastic texture.

Muscovite schist contains muscovite, quartz and opaque minerals; lepidoblastic texture.

Mica schist is composed of quartz, muscovite, biotite, chlorite, and sericite; lepidoblastic texture.

Garnet Mica Schist/Garnet Quartz Mica Schist consists of garnet, quartz, muscovite, biotite, and opaque minerals; porphyrolepidoblastic texture.

Chloritoid Chlorite Schist consists of quartz, plagioclase, chlorite, and chloritoid minerals; porphyrolepidoblastic tissue.

Marble contains calcite mineral; granoblastic texture.

Author Contributions

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Conflict of Interest

The authors declare no conflicts of interest financial or otherwise.

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