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Mineralogical characteristics of metamorphic massif units outcropping in Göksun, Afşin and Ekinözü (Kahramanmaraş) region

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Research Article

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ABSTRACT

This study aims to investigate and correlate the mineralogical-petrographic characteristics of Metamorphites in Göksun, Afşin and Ekinözü in the Southeast Anatolian Metamorphic Massifs. In this context, the optical microscopy and XRD investigations were performed on several samples. Göksun Metamorphites are constituted by phyllite, calcphyllite, marble and they contain mainly calcite, dolomite, quartz, feldspar, phyllosilicate. KI and b-cell dimension data reflect high anchizone-epizone and medium pressure conditions. Afşin Metamorphites are represented by phyllite, calcphyllite, calcschist, micaschist, amphiboleschist, marble. Phyllosilicates have consisted of illite/mica, IIb chlorite, mixed-layers, smectite. KI and b-cell dimension data correspond to the subgreenschist-greenschist facies conditions. Ekinözü Metamorphites are made of chloriteschist, amphiboleschist, micaschist, micagneiss in lower parts, while calcitic and/or dolomitic marbles are present in the upper parts. Mica is dioctahedral and trioctahedral, whereas chlorite tends to be trioctahedral. Based on mineral associations, Ekinözü Metamorphites belong to amphibolite facies in the lower parts, but the greenschist facies conditions at the upper parts. The coarse-grained biotite, muscovite and chlorite are accompanied by mixed-layers. According to mineral composition and degrees of metamorphism, Göksun and Afşin Metamorphites are similar to the Keban and Malatya Metamorphites; however, Ekinözü Metamorphites to Pütürge Metamorphites. The data show that metamorphics in the western extension of the Southeast Anatolian Metamorphic Massifs have different origin and/or lithologies according to the regions, increasing temperature-pressure conditions from Göksun to Ekinözü and have groups of rock with different geological evolutions.

1. Introduction

The Taurus Mountain or the Tauride Belt belongs to the Tauride-Anatolian Platform or the Tauride-Anatolian Tectonic Unit and bear traces of the pre-Alpine geological history as inferred from the diagenetic-very low grade metamorphic Paleozoic sequences (Göncüoğlu et al., 1997). The tectono-stratigraphic units forming the Taurides are distinguished by their paleogeographical settings, stratigraphic and structural characteristics as well as their depositional environments and metamorphism characteristics (Özgül, 1976; 1984). It is reported that the Early Paleozoic part of these was deposited in an environment associated with rifting at the northwestern border of Gondwana, and turned into

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the bi-directional nappe system with the closure of the northern and southern branches of Neotethys in the Late Cretaceous (Göncüoğlu, 2010).

Metamorphic massives associated with the Alpine orogeny of the Tauride Belt were referred to under different names in the studies that have been carried out in the last 50 years (Alanya, Malatya, Göksun, Binboğa, Engizek and Keban Metamorphites) and different units (Antalya, Alanya, Geyikdağı, Bozkır, Aladağ, Bolkardağı, Pütürge and Bitlis) (Özgül, 1976, 1984; Yılmaz et al., 1987, 1992, 1993; Yılmaz and Yiğitbaş, 1990; Yılmaz, 1993; Göncüoğlu, 2010). These complexities make their correlation very difficult, especially linking different metamorphic units found within the belt. The same holds true for the understanding of their geological evolution. However, the previous studies related to the Upper Paleozoic-Lower Mesozoic metamorphic units in the Tauride Belt (Bozkaya, 1999, 2001; Bozkaya and Yalçın, 2004; Bozkaya et al., 2007*a*, *b*) were compared with the non-metamorphic units and made significant contributions to the interpretation of the evolution of Tauride tectono-stratigraphic units.

This study aims to investigate the mineralogical-petrographic features of the Upper Paleozoic-Lower Mesozoic metamorphic units defined as the Göksun, Binboğa and Engizek metamorphites. Their geographic positions outline the wide and typical outcrops around Göksun, Afşin and Ekinözü districts in the north of Kahramanmaraş province in the western part of the Eastern Taurus Mountains. In accordance with this goal, equivalent levels of Keban, Malatya and Pütürge metamorphites and in the eastern extension of the same metamorphic belt were compared lithologically, mineralogically and petrographically by determining the degrees of diagenesis/metamorphism and characteristics of the related units. In this context, it is considered that the data obtained from the detailed phyllosilicate mineralogy (associations, illite crystallinity, illite/mica *b*-cell distance, polytype), which is applied first time to the Upper Paleozoic metamorphic units in the study area, will provide additional contributions to the interpretation of the geological evolution of the region.

2. Geological Setting

2.1. Regional Geology

The Taurides cover the units which were deposited in Cambrian-Paleogene period, reflecting different basin conditions, and stratigraphy and metamorphism characteristics and separated from their present structural settings (Özgül, 1976). It was reported that the units commonly referred to as the Bozkır Unit, Bolkardağı Unit, Aladağ Unit, Geyikdağı Unit, Antalya Unit and Alanya Unit from the north to south showed lateral continuities for hundreds of kilometers and mainly were allochthonous with each others (Özgül, 1976). Of these, it is known that Bolkardağı, Aladağ, Geyikdağı and Alanya units contain shelf type carbonate and clastic rocks, whereas Bozkır and Antalya units include the deep sea sediments, ophiolites and submarine volcanics with basic composition (Özgül, 1976). These units were imbricated as a result of the closure of the northern and southern branches of Neotethys in the Late Cretaceous and the collision of the continental micro plates (Şengör and Yılmaz, 1981). Thus, the units (Bozkır, Bolkardağı and Aladağ) in north of the platform thrusted southward and the units (Antalya and Alanya) representing the south of the platform thrusted on the Geyikdağı Unit towards north (Özgül, 1976; 1984) (Figure 1).

In the Southeastern Anatolian Orogenic Belt, where the Metamorphic Massives are located, three tectonic belts were distinguished as the Arabian Platform, the Accretionary Zone and the Nappe Region from south to north by Yılmaz and Yiğitbaş (1990) and Yılmaz (1993) (Figure 2). Of these, the Arabian Platform and Nappe Region are represented by autochthonous sedimentary rocks of the Cambrian-Paleogene range (Southeast Anatolian Autochthonous) and ophiolitic, metamorphic and volcanic-volcanoclastic sedimentary rocks and the study area is located within second zone. The accretionary zone is composed of reverse fault and thrust slices that delimit the northern extension of the Arabian Platform. The relations of these tectonic units with each other are presented in figure 3. The Cambrian-Paleogene sedimentary units of the Eastern Taurus Autochthonous (Geyikdağı Autochthonous) are exposed in northwest of the Nappe Region. These units in the region are unconformably overlain by Neogene-Quaternary sedimentary and volcanic rocks.

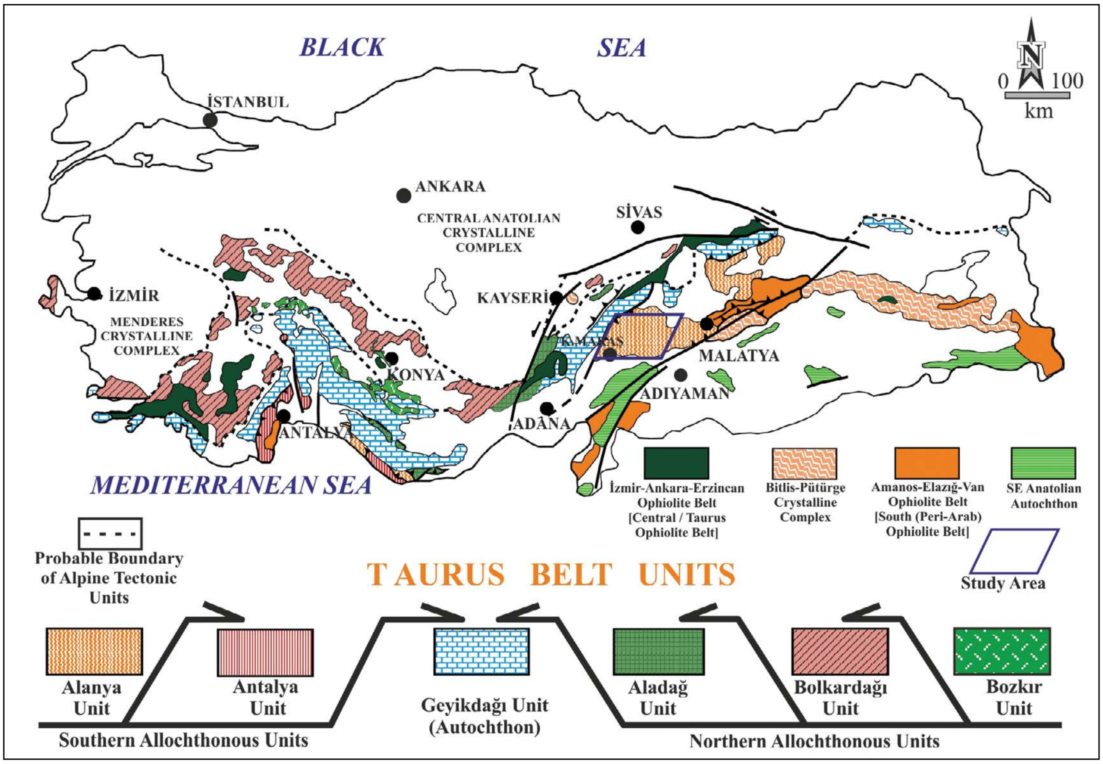

Figure 1- Geographical distribution and tectonic setting of autochthonous and allochthonous units in the Tauride Belt (the nomenclature of tectonic units: Özgül, 1976, 1984; Göncüoğlu et al., 1997; the nomenclature of Ophiolite Belts: Juteau, 1980; the probable boundary of Alpine Tectonic Units: organized from Göncüoğlu et al., 1997; Göncüoğlu, 2010; Bozkaya and Yalçın, 2014).

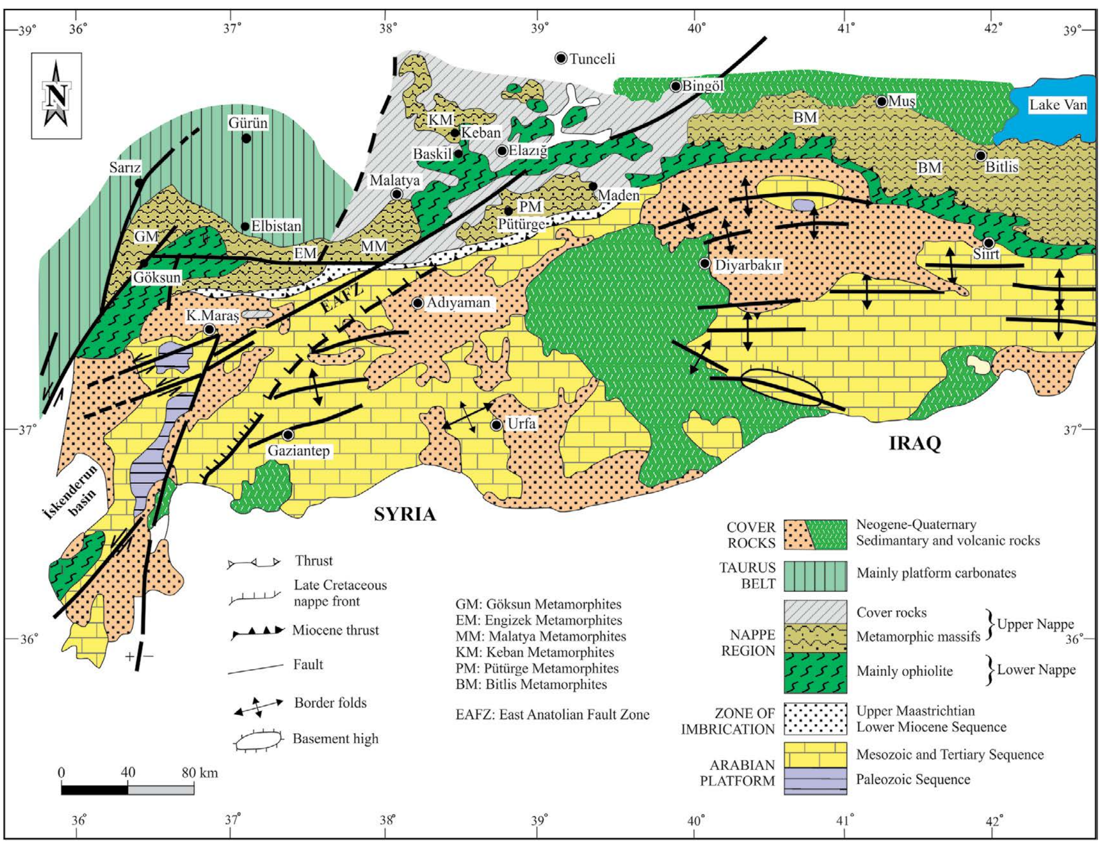

Figure 2- Tectonic units outcropping along the Southeast Anatolian Orogenic Belt (Yılmaz, 1993).

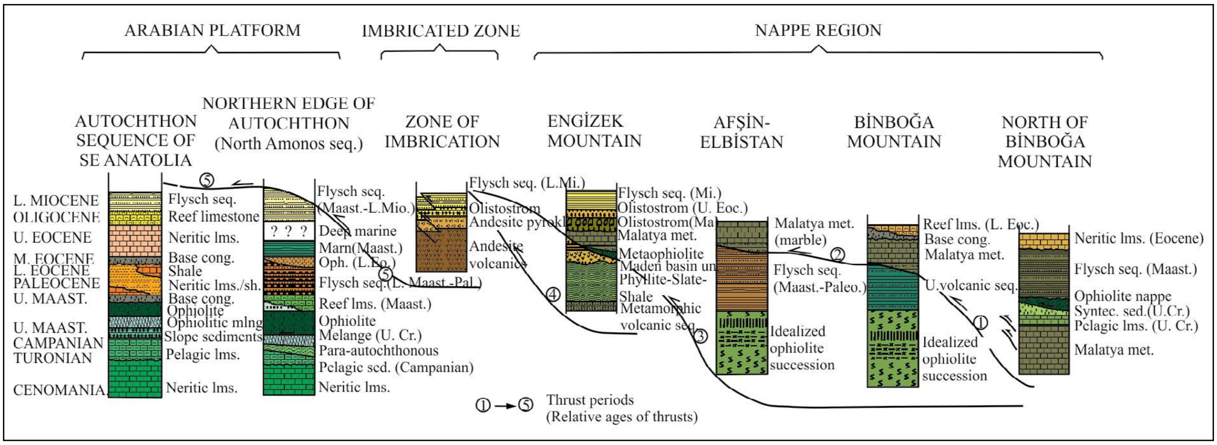

Figure 3- Generalized stratigraphic sections showing different tectonic units of the Southeast Anatolian Orogeny (prepared from Yılmaz and Yiğitbaş, 1990).

2.2. Geology of the Study Area

In the study area, there are east-west trending tectonic units, which are pre-Maastrichtian in age and show different environmental characteristics. These are made up of allochthonous rock assemblages in the northern, central and southern parts of the Eastern Taurus Mountains, respectively (Figure 4, Yılmaz et al., 1993, 1997).

The basement of the study area is constituted by metamorphic rocks of the Upper Paleozoic-Triassic greenschist facies that is the oldest unit in the region (Yılmaz et al., 1993) and the granitic intrusions cutting

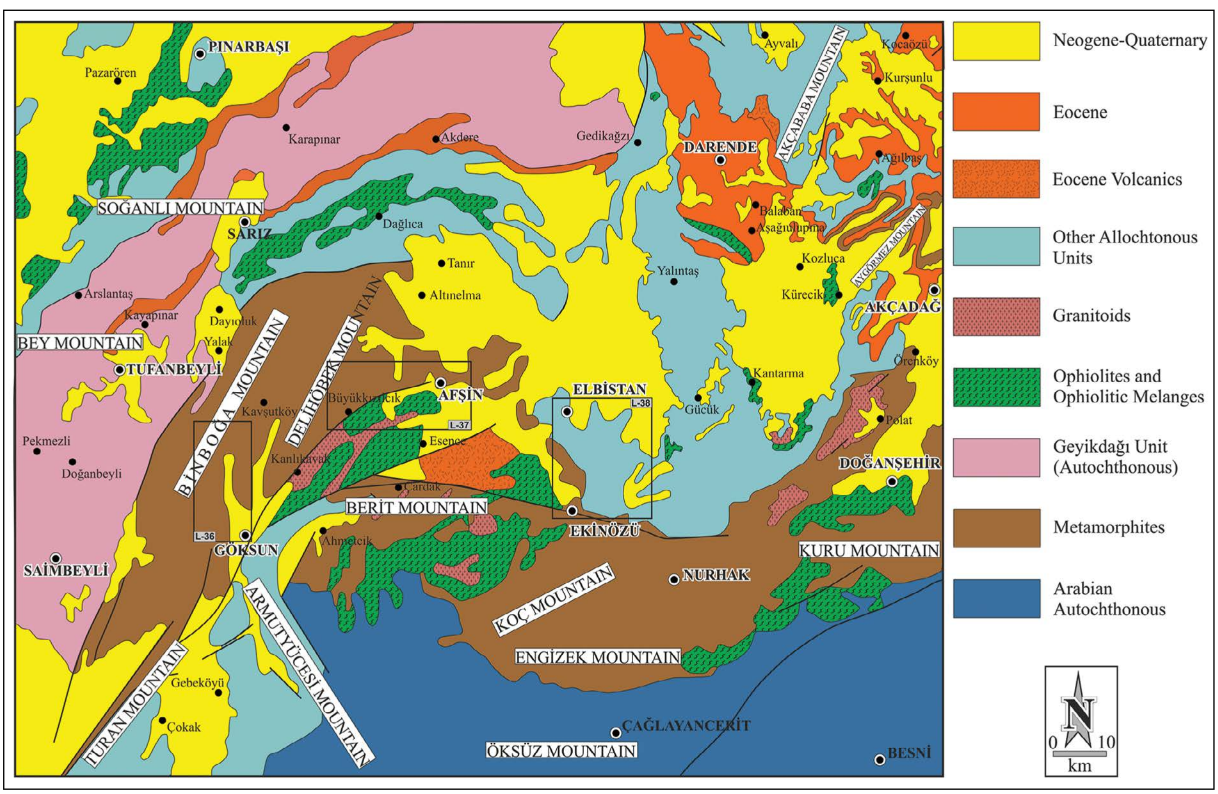

Figure 4- A simplified regional geology map of the study areas and their near surroundings covering three different subareas in the Eastern Taurus Mountains (prepared from Bedi et al., 2005, 2009 and 1/500.000 scale geology map from MTA, 2002).

them. This rock group tectonically passes upwards into the Jurassic-Lower Cretaceous carbonate rocks which are not affected by the metamorphism. The lower parts of metamorphic rocks, which are rich in metapelites, are named as the Yoncayolu formation, however; the upper parts rich in metacarbonates are named as the Çayderesi formation that is located conformably (Figure 5, Özgül and Turşucu, 1984; Yılmaz et al.,

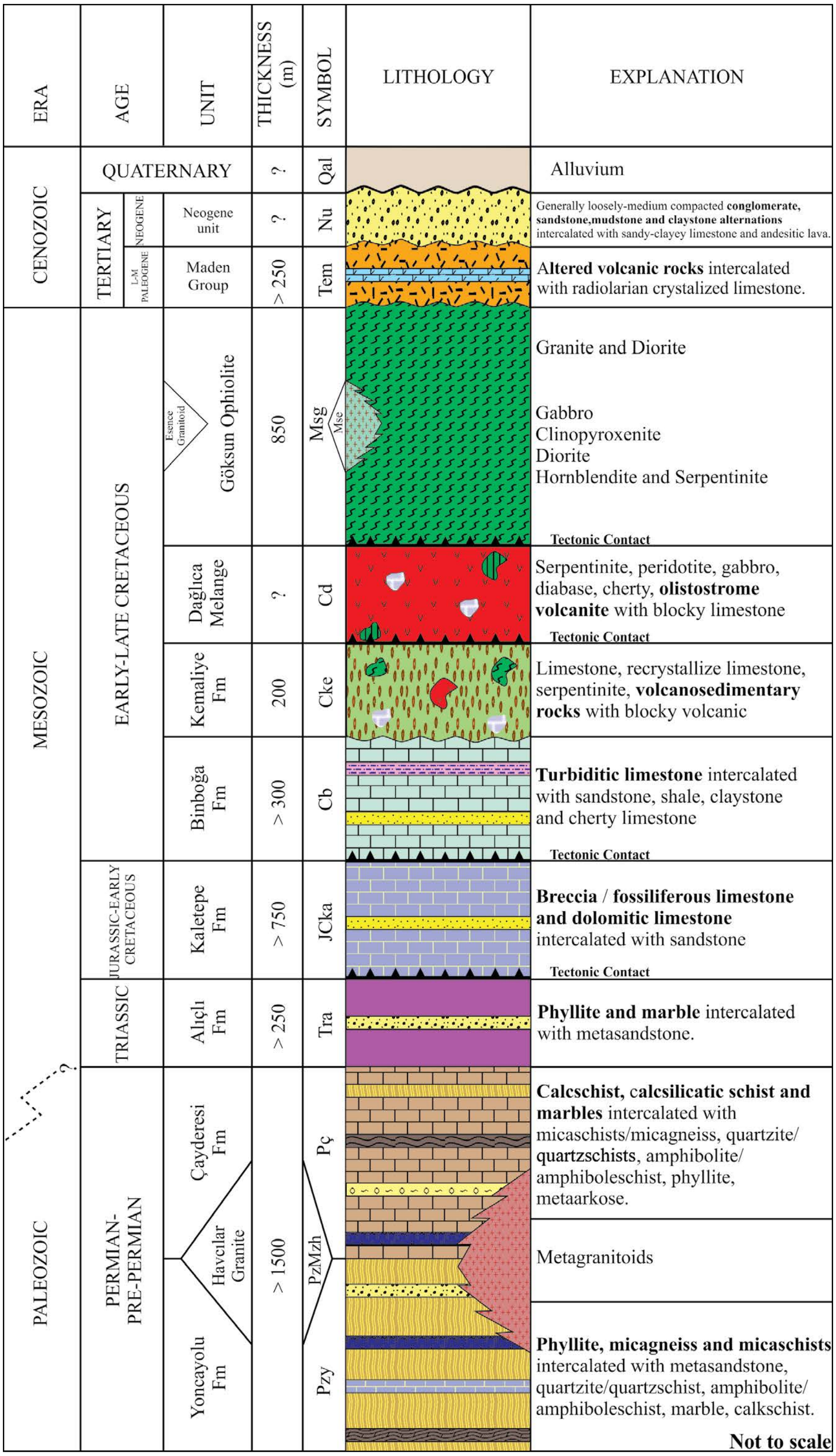

Figure 5- Generalized tectono-stratigraphic columnar section of the southern part of the Eastern Taurus (modified from Yılmaz et al., 1993).

1993). These units are overlain by Triassic and Jurassic-Lower Cretaceous sedimentary units. The ophiolitic rocks (Göksun Ophiolite), one of the oceanic and arc sections of the allochthonous rock group, tectonically overlie the metamorphics. The Upper Cretaceous allochthonous units, which are located in the south of Gürün Relative Autochthone, which is the local equivalent of the Geyikdağı Unit, and whose positions in the study area are controversial, unconformably overlie the other units. The Maden Group (Yılmaz et al., 1993) and the Neogene-Quaternary sedimentary-volcanic sediments of the Middle Eocene volcano-sedimentary rocks represent the cover units (Figure 5).

3. Stratigraphy and Lithology

Metamorphic successions outcropping along the Tauride Belt are ordered as Paleozoic-Mesozoic Alanya Metamorphics (Işık and Tekeli, 1995), Alanya Massif (Blumenthal, 1951), Alanya Nappe (Öztürk et al., 1996), Alanya Tectonic Window (Özgül, 1984) in the Central Taurides, and as Göksun Metamorphites (Metin et al., 1982, 1986), Devonian Kabaktepe and Çağılhan Metamorphics (Tarhan, 1982, 1984), Jurassic-Lower Cretaceous Engizek formation, Engizek Metamorphites, Engizek Unit (Baydar, 1989; Yılmaz et al., 1992), Pre-Carboniferous(?) Nergile formation (Yıldırım, 1989; Yiğitbaş, 1989), Upper Devonian-Lower Cretaceous Binboğa Metamorphite (Yılmaz et al., 1987; Bedi et al., 2004, 2005), Permo-Carboniferous Malatya Metamorphites (Perinçek and Kozlu, 1984; Yıldırım, 1989; Yiğitbaş, 1989; Karaman et al., 1993), Carboniferous-Permian Keban and Malatya Nappes (Yazgan, 1983), Keban-Malatya Unit (Yılmaz et al., 1993, 1997), Keban Metamorphites (Özgül, 1976; Perinçek, 1979*b*, *c*), Keban Union (Özgül, 1981; Özgül and Turşucu, 1984), Cambrian-Permian Pütürge Metamorphites (Perinçek, 1979*a*; Ricou, 1980) and Devonian-Triassic Mutki Group (Göncüoğlu and Turhan, 1984) from west to east in the Eastern Taurus (Figure 6).

Among these, the Alanya, Göksun, Engizek and Malatya metamorphites were defined as the Alanya Unit by Özgül (1976) and were evaluated within the Taurus orogenic belt. Pütürge and Bitlis metamorphites were excluded from the Tauride Units and were defined as the Misis Unit (Özgül, 1976) or Bitlis Zone (Göncüoğlu et al., 1997).

In order to find an answer to different nomenclature and correlation problems for the same units, one measured stratigraphic section was carried out from each region to determine both the stratigraphic-lithostratigraphic and mineralogical-petrographic changes of metamorphic units in the study area. The relationship of these stratigraphic sequences and their positions from west to east are presented in figure 7.

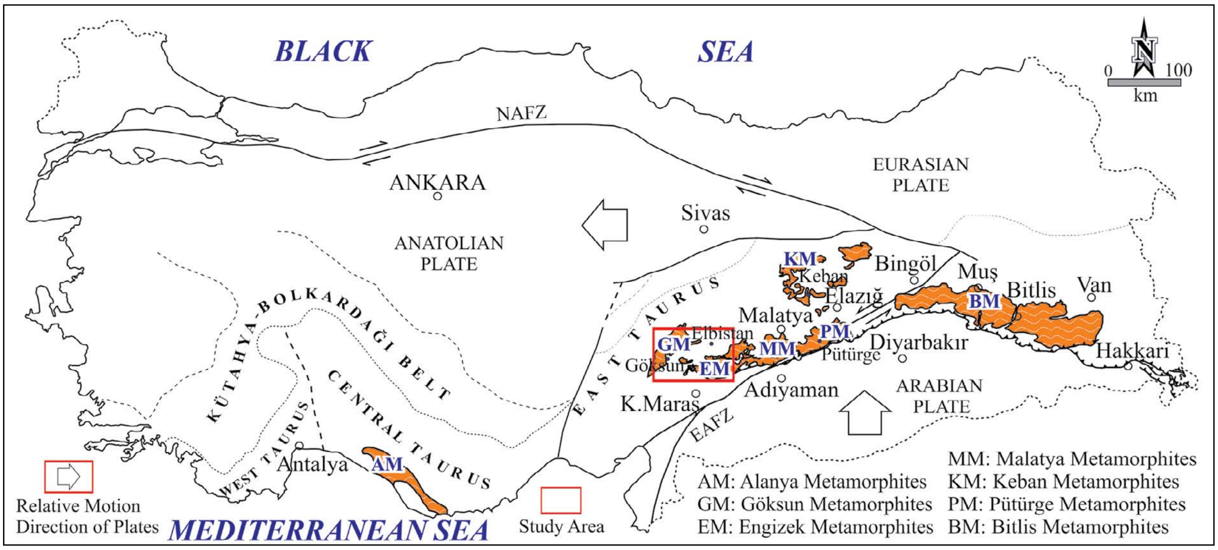

Figure 6- The metamorphic successions outcropping along the Tauride Belt and the location of the study area (modified from Özgül, 1984 and Göncüoğlu et al., 1997; main tectonic boundaries: Schildgen et al., 2014; relative movement direction of the plates: Reilinger et al., 1997; McClusky et al., 2000).

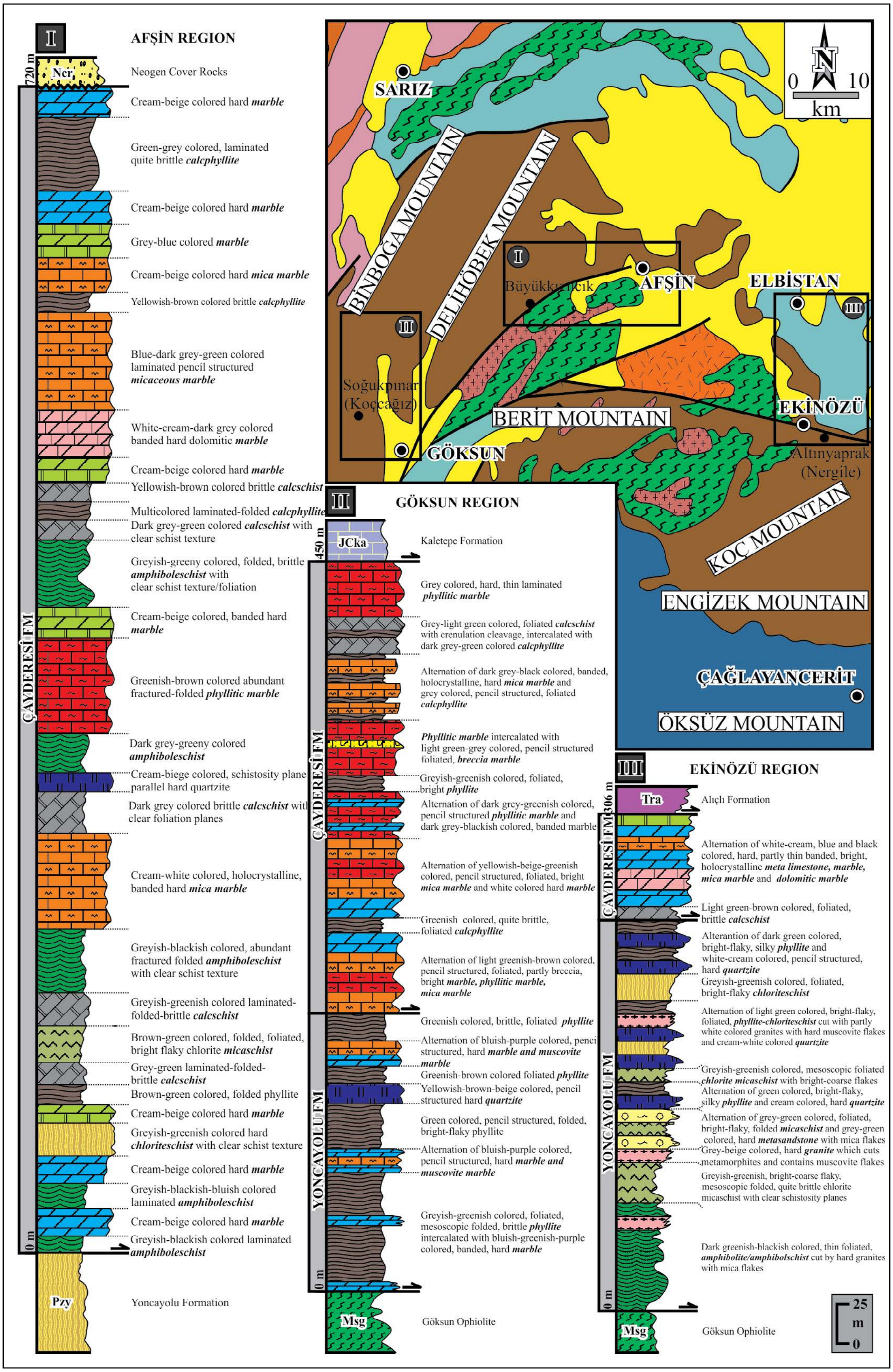

Figure 7- Stratigraphic distribution of the metamorphic sequences from west to east in the study area (The positions of the sequences are II-I-III from west to east; regional geology map: Bedi et al., 2005, 2009 and 1/500.000 scale geology map prepared from MTA, 2002).

3.1. Göksun Region

The unit shows very large outcrops mostly in north-northwestern parts of Göksun and in its immediate vicinity, (in an area of approximately 300 km^2) in the study area (Figure 8). The type section measurement of this region was taken in the northeastern part of Koçcağız/Soğukpınar village in the northwest of Göksun and approximately 450 m thickness was measured (Figure 9a).

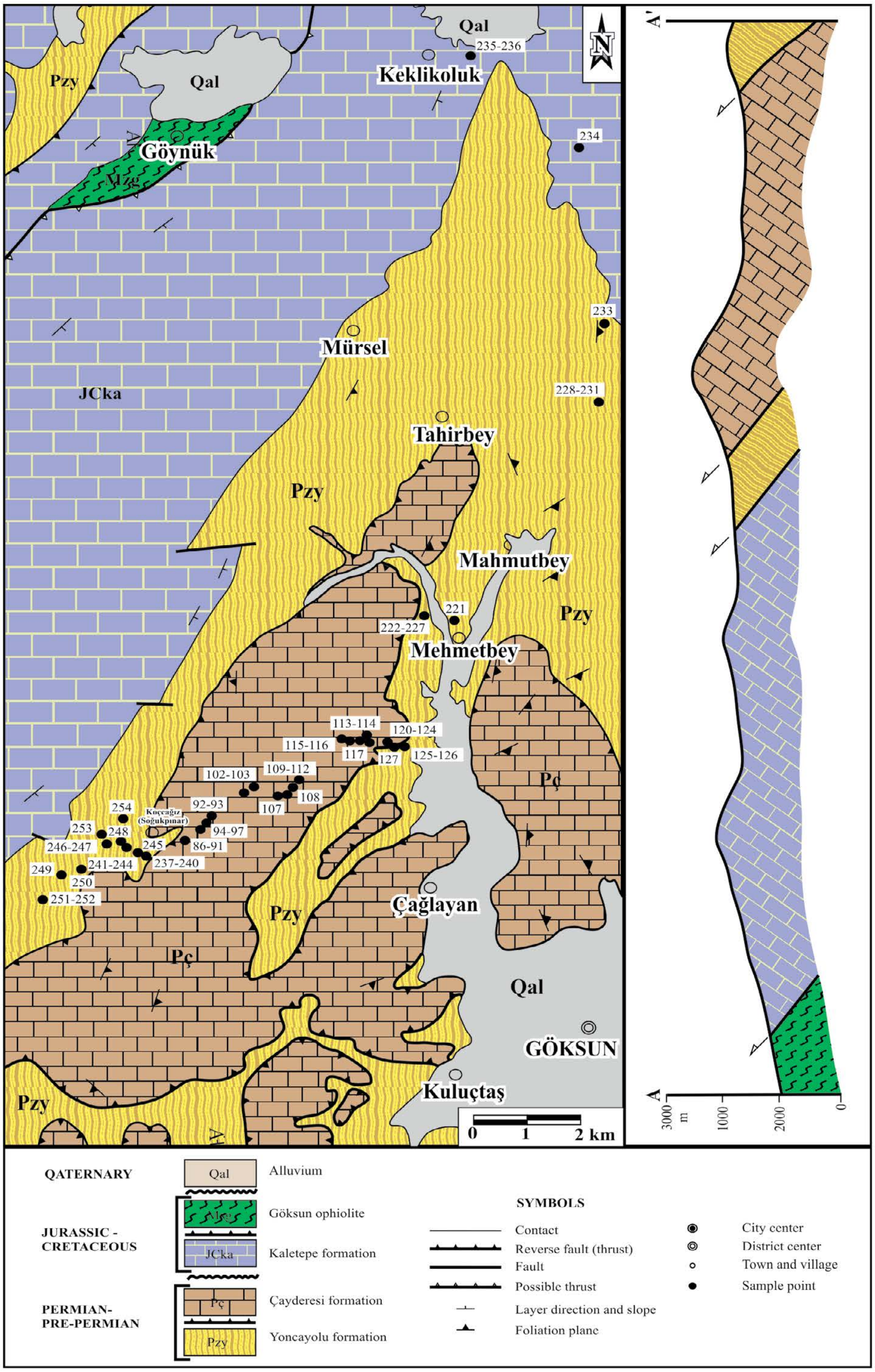

Figure 8- Geological map of the Göksun region (modified from 1/100.000 scale geological map of Turkey, series Elbistan-I22/L-36 sheets, Metin et al., 1989).

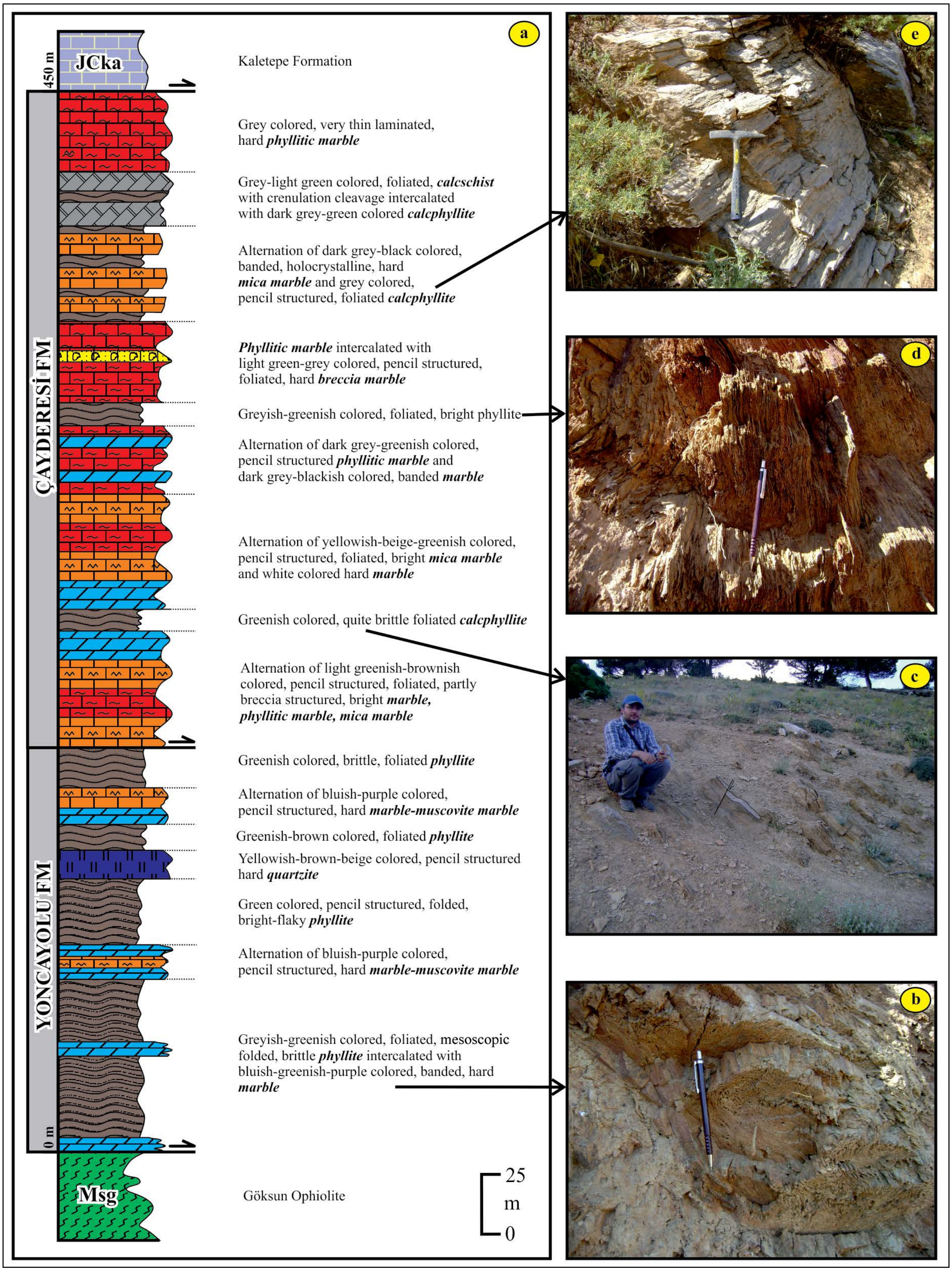

Figure 9- a) Columnar section of the Göksun region (the north of Göksun-Koçcağız/Soğukpınar village). Field views of rock groups b) grayish-greenish colored, pencil structured and banded marbles, c) yellowish-brown colored and foliated phyllites, d) normal faults developed in light brown-green colored calcphyllites and e) yellowish-greenish colored, mesoscopically folded and foliated phyllites.

The dominant lithology of the unit consists of the rock assemblages that are Upper Paleozoic (Özgül and Turşucu, 1984) Yoncayolu formation at the bottom and Çayderesi formation of the same age with a tectonic contact. From these units, Yoncayolu formation tectonically overlies the Middle-Upper Cretaceous Göksun Ophiolite, and as for the Jurassic-Lower Cretaceous Kaletepe formation, it tectonically overlies the Çayderesi formation.

At the bottom of the Yoncayolu formation, which is approximately 163 m thick and located in lower parts of the unit, the phyllites with banded marble intercalations are present. They have bluish/purple-greenish, hard, grayish-greenish-yellowish, foliated/cleavaged, mesoscopically folded, very fragile and bright in appearance (Figure 9b). Towards the upper parts of the unit, the yellowish-brown-beige colored, hard, pencil-structured quartzites with a thickness of about 1 m are followed. At the top of the formation, the bluish-purple colored, pencil structured, hard, marble-muscovite marble intercalated and/or alternated greenish colored, brittle, foliated phyllites transit into the tectonically overlying Çayderesi formation.

The basement of the Çayderesi formation, which has a thickness of approximately 287 m in the unit, consists of the alternation of light greenish-brown, pencil structured, bright marble, phyllitic marble and mica marble containing distinctive foliation planes with brecciated appearance in places. Towards the upper parts of the unit, there is observed a grayish-greenish phyllite-calcphyllite alternation, with distinct schistosity planes in the form of stratifications of 10-30 cm in thickness that have very fragile, foliated and bright colored crenulation folds and show small scale normal faulting (Figure 9c-d). Metacarbonates, which form the common lithology of the formation, are composed of pencil structured, foliated, banded, coarse-crystalline, bright-looking, hard marble (Figure 9e), phyllite marble, mica marble and calc-schist intercalations offering yellowish-beige-greenish and grayish-blackish colors.

3.2. Afşin Region

The unit outcrops in an area of approximately 250 km^2 in western-southwestern and eastern parts of Afşin within the study area (Figure 10). Type section measurements in the region were taken in the southwestern parts of the Büyükkızılcık village in the southwest of Afşin and a thickness of approximately 720 m was measured (Figure 11a).

The dominant rock group of the unit belongs to Upper Paleozoic Çayderesi formation (Özgül and Turşucu, 1984). While this unit tectonically overlies the same aged Yoncayolu formation, the Neogene units unconformably overlie the Çayderesi formation.

In lower parts of the unit, there are observed amphiboleschist levels with a thickness of approximately 0.5-1 m, exhibiting a grayish-blackish-purplish color and prominent schistosity plane alternating with cream-beige, hard marbles (Figure 11b). The foliated and shiny-flaked chloriteschists, which contain grayish-green, distinct schistosity planes, are another metapelitic rocks in lower parts of the unit.

Towards the intermediate levels of the formation, the cream-beige colored hard marbles, and greyish-greenish, laminated, foliated and brittle calcschists, and brown-green colored micaschists with distinct schistosity planes and foliated and shiny-flaked appearance (Figure 11c), and grayish blackish colored, heavily jointed, foliated amphiboleschists with distinct schistosity planes show an alternated structure. The metacarbonate levels, which increase markedly towards the upper levels of the unit, begin with creamy-white, coarse crystalline, banded, thick layered and hard micaceous marbles and continue with brittle calc-schists showing dark gray colored distinct foliation planes. Dark grayish-greenish, foliated and brittle amphiboleschist levels with distinct schist-texture/cleavage are regularly observed which continue until upper levels from the middle parts of the formation within these metacarbonate levels. In some places, cream-beige, thin-bedded, hard quartzite levels parallel to the schistosity plane are also observed. Towards the upper levels of the unit, the dark gray-greenish and schist textured calcschists alternate with pied colored, thin-bedded and foliated calcphyllites.

In the upper levels of the formation, the dark gray-cream-beige, sporadically banded, hard, pencil-structured and very thick-layered marble (Figure 11d), dolomitic marble and marble with mica intercalate with light green-gray colored, very brittle, thin layered calcphyllites containing distinct schistosity planes (Figure 11e), and the succession is completed.

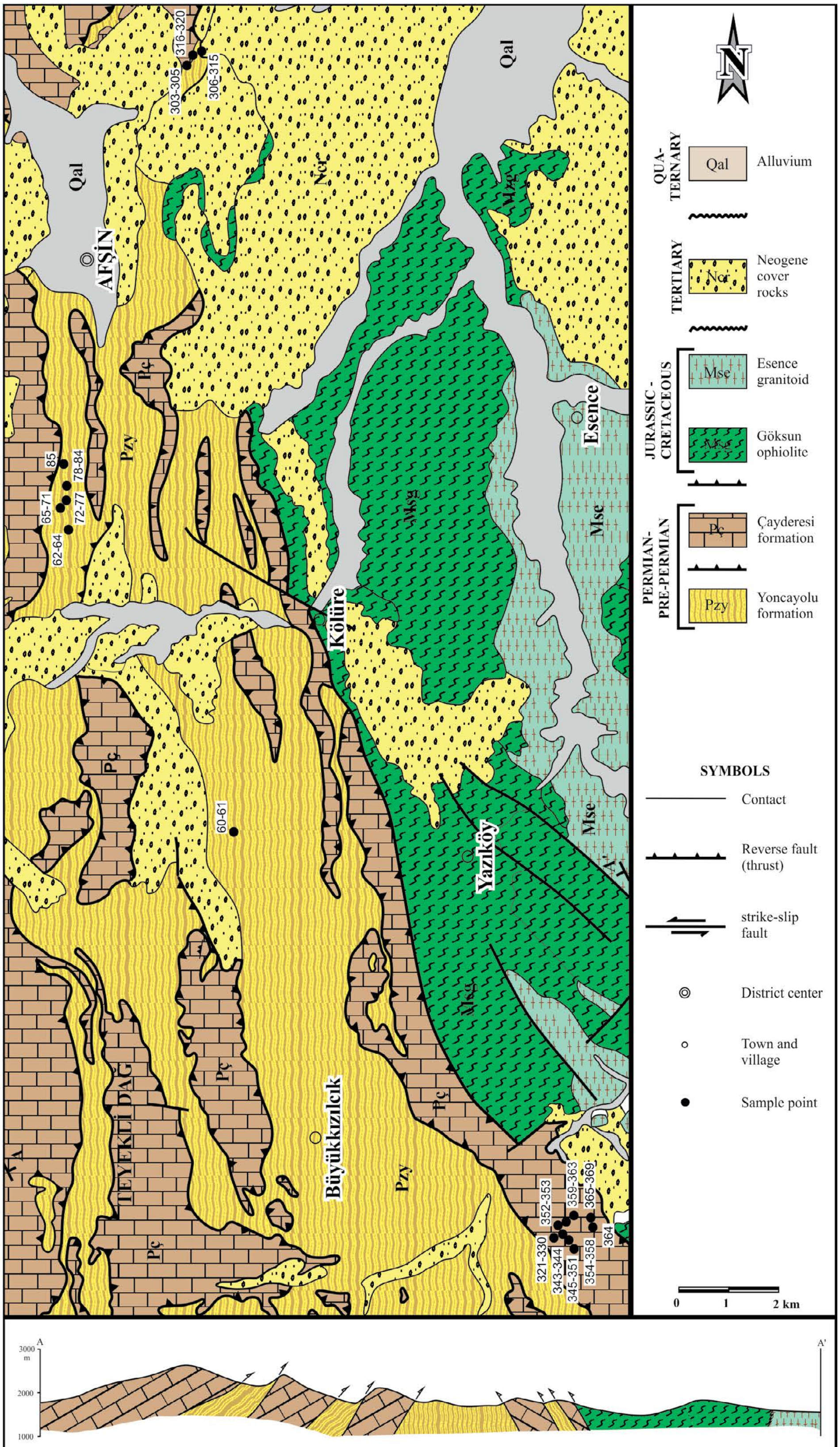

Figure 10- Geological map of the Afşin region (prepared from 1/100.000 scale geological map of Turkey, series Elbistan-I23/L-37 sheet, Yılmaz et al., 1997; age data of Paleozoic rocks taken from Özgül and Turşucu, 1984).

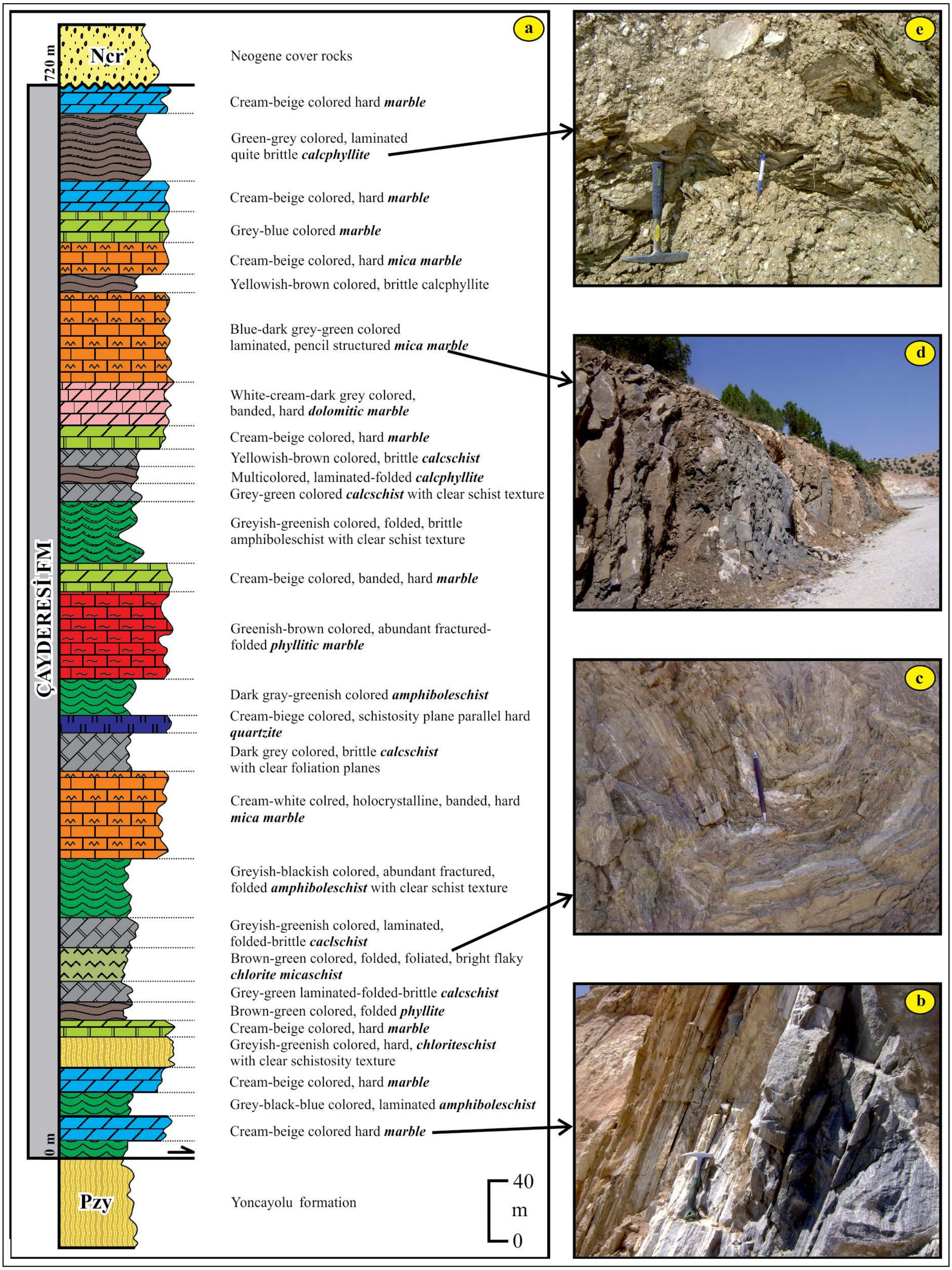

Figure 11- a) Columnar section of the Afşin region (the south of Afşin-Büyükkızılcık Village). Field views of rock groups, b) whitish-cream and purple colored, hard, medium-thick layered and banded marbles, c) folded structures in gray-green colored mica schists, d) grayish-purplish-greenish colored and thick-layered marbles, e) mesoscopic foliations in grayish-greenish colored phyllites/calcphyllites.

3.3. Ekinözü Region

The unit within the study area has very large outcrops in an area of approximately 250 km² in south-southeast of Elbistan and north, south-southeast of Ekinözü and in its close vicinity (Figure 12). The type section measurement of the units was taken in the northwestern parts of Altınyaprak/Nergile village in the southeast of Ekinözü and a thickness of more than 300 m was measured (Figure 13a).

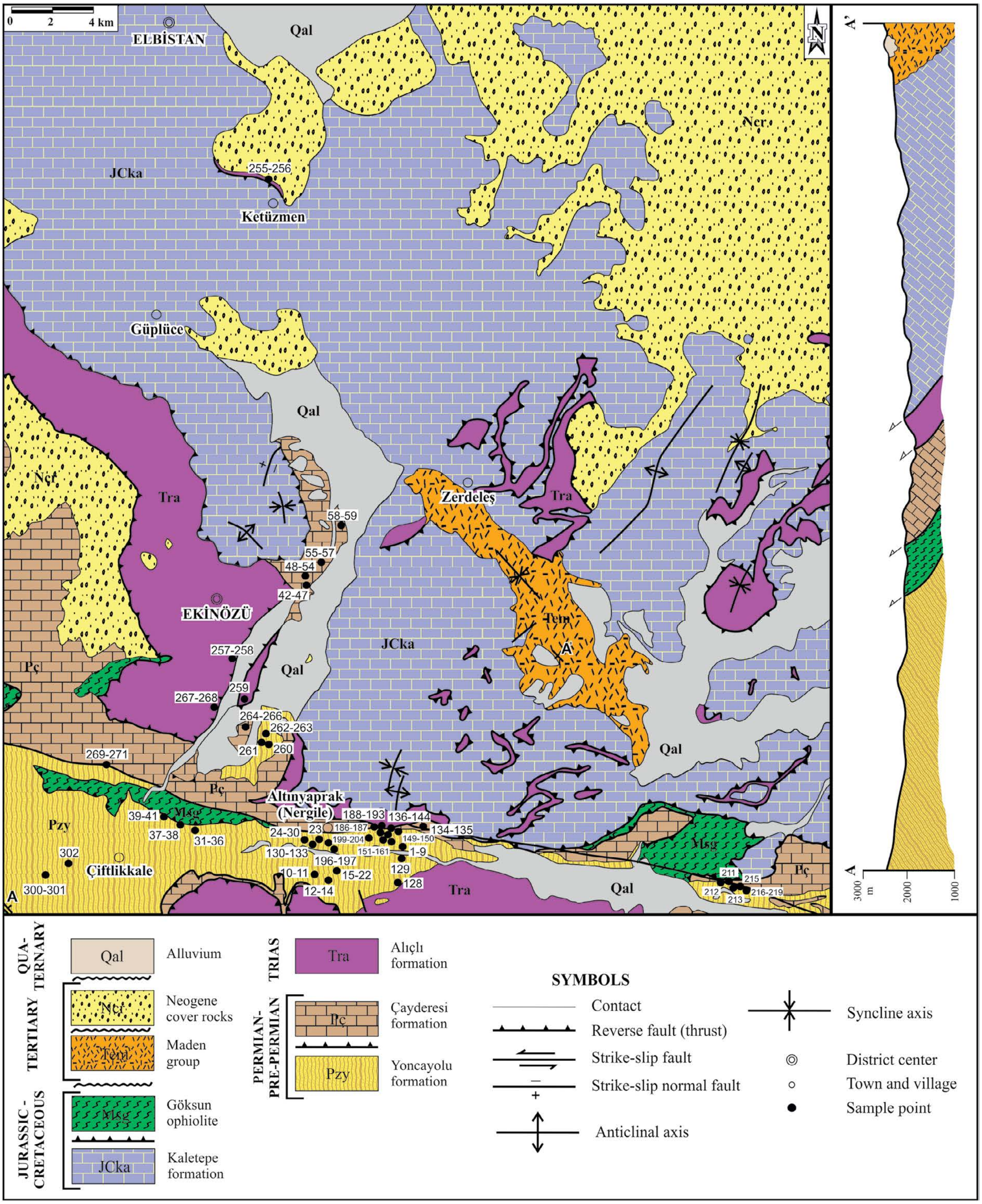

Figure 12- Geological map of the Ekinözü region (prepared from 1/200.000 scale of Kahramanmaraş province geology map, MTA, 2008).

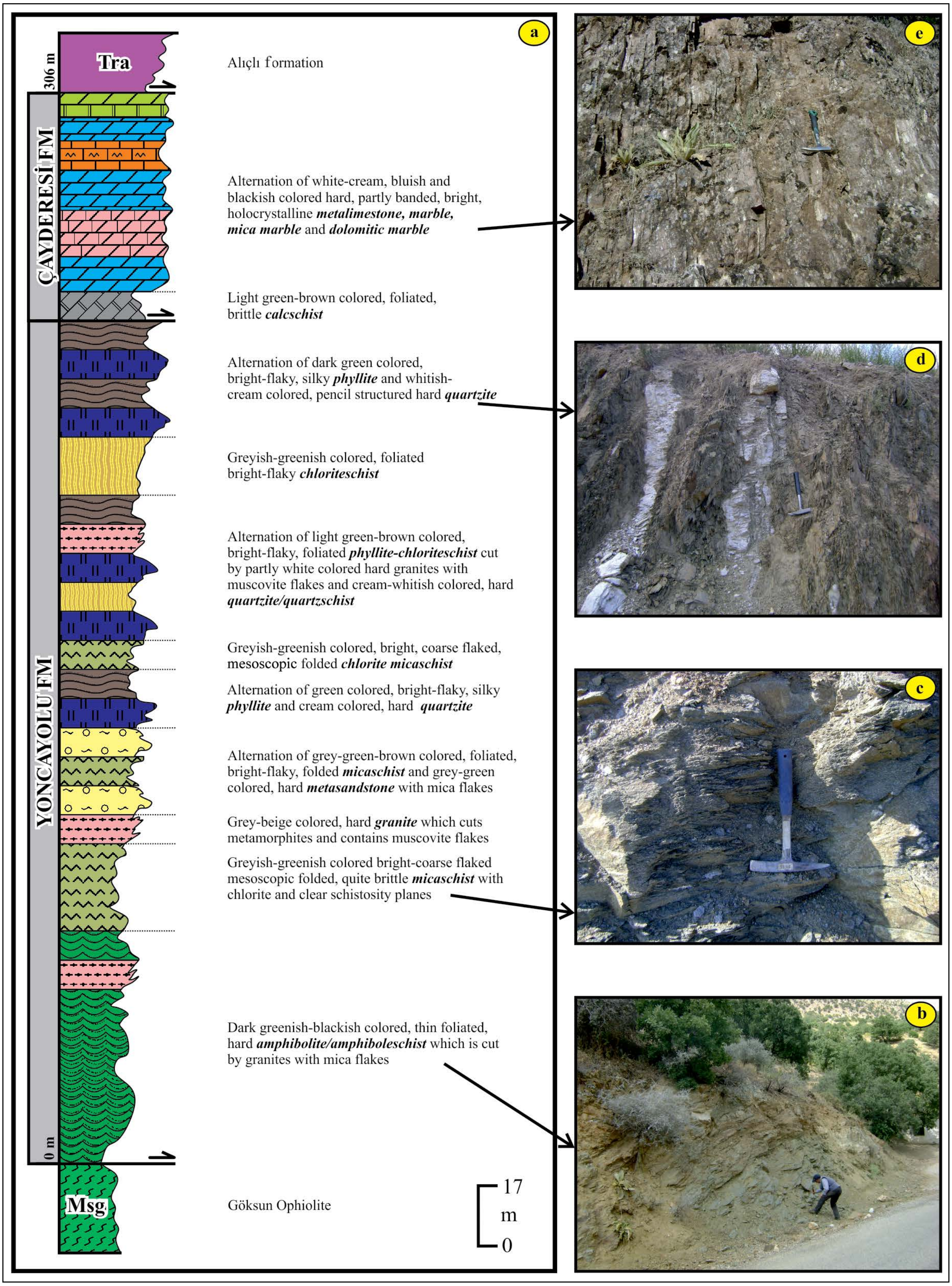

Figure 13- a) Columnar section of the Ekinözü region (the north of Ekinözü-Altınyaprak/Nergile village). Field views of the rock groups, b) greenish-blackish colored and thin-medium bedded amphiboleschists), c) grayish-greenish colored and micaschists with coarse flakes, d) perpendicularly developed phyllite-quartzite alternation and e) gray-white colored and thin-medium bedded marbles.

The Upper Paleozoic (Özgül and Turşucu, 1984) Yoncayolu formation at the bottom and tectonically overlying same aged Çayderesi formation consist of mainly dominant units of the region. Of these, the Yoncayolu formation and the Triassic Alıçlı formation tectonically overlie the Middle-Upper Cretaceous Göksun Ophiolite and the Çayderesi formation, respectively.

The bottom of Yoncayolu formation with totally 240 m thickness consists of bright-looking, greenish-black decomposition colored, thinly foliated amphibolite/amphiboleschists (Figure 13b) with 25-30 cm thick quartz bands and partly with mica flakes. These rocks are cut by hard granites. In the middle levels of the formation, there are grayish-greenish, bright-coarse flaked, mesoscopically folded, highly brittle chlorite micaschists with distinct schistosity planes (Figure 13c). Inside of this unit, gray to beige colored granitic intrusions with muscovite flakes are observed. Above these levels, the gray-green-brown distinctively foliated and flaky micaschists alternate with purplish-gray-green, 25-40 cm thick, medium-bedded, hard metaclastic sandstones containing moderately thick muscovite flakes. In the formation, partly whitish, thin-bedded phyllite-quartzite alternations with muscovite flakes are observed towards the upper layers (Figure 13d). In this alternated structure, the grayish-greenish, bright-coarse flaked chloritic micaschists and chlorite schists, which show distinct wrinkle folds and cut by hard granitic intrusions, intercalate with each others. Phyllites are generally light greenish-grayish, bright-flaked and silky-like in appearance, however; the quartzites are hard, cream-colored and developed parallel to the foliation plane.

At the bottom of the Çayderesi formation, which tectonically overlies the Yoncayolu formation and presents a thickness of approximately 70 m in the region, there are light green-brown calcschists exhibiting cleavage and brittle structure. The sequence ends with the intercalation of whitish cream, bluish, blackish, hard, exhibiting occasionally thin banded structure, bright, coarse crystalline metalimestone, marble, mica marble and dolomitic marble (Figure 13e).

4. Material and Method

Totally 369 rock and mineral samples with each weighing approximately 1 kg were collected from points and measured sections in the field study. In addition, the mesoscopic structures developed in the units and their relations with each others were observed and photographed in detail. The samples were washed with distilled water, cleaned from surface dusts, dried and then made ready for analyses.

The optical microscopy (OM), X-ray diffraction (XRD)-whole rock (WR) and clay fraction (CF) investigations were performed by using binocular polarizing microscope on thin sections and X-ray diffractometer devices. These analyses were carried out in Crushing-Grinding-Sieving, Clay Separation and Mineralogy-Petrography and Geochemistry Research Laboratories (MIPJAL) in Geological Engineering Department of Sivas Cumhuriyet University.

The optical microscope studies were carried out on a LEICA brand binocular polarizing microscope. Thin sections were prepared especially by cutting cleavage planes perpendicularly in low-medium grade metamorphic (slate, phyllite and schist) rock samples, and thus the petrographical properties developed depending on metamorphism by determing the textural relationships within mineral and matrix were interpreted. With this method, both the components and textural properties were defined. In addition to the nomenclature of the rocks, the weathering and alteration products, indirectly the origin of the minerals and textural and mineralogical properties developed by the effect of metamorphism were clarified.

XRD has been the most widely used method to determine the whole rock and clay size mineralogical compositions of the rocks with very small (submicroscopic) grain size and also to detect polymorphic changes in minerals. Hard specimens to be used in XRD studies were first crushed in 3-5 cm pieces with hammer, crushed in FRITISCH jaw crusher as granules smaller than 5 mm, and then the rocks were milled for 0.5-3.0 min. using an ÜNAL brand tungsten bowl ring mill. XRD analyses were carried out in Rigaku brand DMAX IIIC model X-ray diffractometer (Anode = Cu (CuK_a = 1.541871 Å), Filter = Ni, Voltage = 35 kV, Current = 15 mA, Goniometer speed = 2°/min., Paper speed = 2 cm/min., Time constant = 1 sec., Slits = 1° 0.15 mm 1° 0.30 mm, Paper range = 2q = 5-35°). The whole rock and clay fraction components (< 2 mm) were defined (J.C.P.D.S., 1990) and semi-quantitative percentages were calculated based on the external standard method

(Brindley, 1980) in rocks collected from units in the study area. The mineral intensity factors were used in whole rock and clay fraction calculations and the reflections were measured in mm. In this method, the dolomite for the whole rock and the kaolinite for the clay fraction were taken as the reference from glycol preparations (Yalçın and Bozkaya, 2002). Quartz was used as an internal standard for measuring d-spacings. The definition of clay minerals was made based on their (001) basal reflections.

The necessary clay separation process for XRD-CF analyses generally are; chemical dissolution (removal of non-clay fraction), centrifugation - decantation/ resting and washing, suspension - sedimentation in the first step and siphon - centrifugation and bottling in the second stage. 10 % HCl in dolomite and 10 % CH_3COOH in calcite bearing samples were used to dissolve carbonate minerals. In the absence or long duration of the suspension process, a small amount of calgon (sodium hexametaphosphate) was added to accelerate this process. The centrifugation process was performed in HERAEUS SEPATECH brand VARIFUGE 3.2 S centrifuge with 5600 rpm and 200 cc metal codes. Three oriented slide preparations were prepared in suspension from each of the separated clay mud by plastering, and they were dried at room temperature. The clay fraction diffractograms were obtained by normal-N (air-dried), glycolation-EG (retention in ethylene glycol vapor at 60° C for 16 hours in desiccator) and heating-H (heating at 490° C for 4 hours in oven). The goniometer speed as 1°/min and the recording interval was set as 2q = 2-30° (error amount ± 0.04°).

The width of the 10-Å illite and 7-Å chlorite peaks at half-height in D°2q (Kübler index - KI: Kübler, 1968, Arkai index - AI: Árkai, 1991 and Guggenheim et al., 2002) was used in the crystallinity measurements of illite and chlorite. As a result of peak analysis by means of WINFIT (Krumm, 1996) software (http://xray.geol.uni-erlangen.de/html/software/soft.html), the calibration was made based on (Full Width Half Maximum - FWHM) Kisch (1980) and Warr and Rice (1994) standards from peak widths determined sensitively. Since the measurements taken at different universities were performed on different brand XRD devices, the separate calibration equations were used for the patterns at each university. The obtained CIS-calibration values were re-converted to the original KI_{Basel} values by means of the equation proposed by Warr and Ferreiro-Mählmann (2015) (KI_{CIS} = 1.1523 x KI_{Basel} + 0.036, R^2 = 0.986).

Polytype studies were made on illite, chlorite, biotite and muscovite. Recording range applied from non-oriented preparations is between 2q = 5-65°, 16-36° and 31-52°, respectively. The diagnostic peaks suggested by Bailey (1988) were used to determine the polytypes. $2M_1$, $1M$ and $1M_d$ ratios were determined according to the peak area (A) ratios proposed by Grathoff and Moore (1996) and listed below. WINFIT software was used to determine peak areas (Bozkaya and Yalçın, 2007). The b_0 parameter (Sassi and Scolari, 1974) was measured by taking the quartz (211) peak (2q=59.97°, d=1.541 Å) as an internal standard from the reflection of $d_{(060)}$.

The analysis of peaks of d_{002} and d_{003} reflections in order to measure the d_{001} values of paragonite, and the crystalline sizes (*N* nm) of illite/mica were determined by applying the WINFIT software.

5. Mineralogy-Petrography

5.1. Optical Microscope Studies

The metamorphic rocks in the Göksun area consist mostly of metacarbonates (muscovite, biotite, chlorite and/or tremolite-bearing marble) and less metapelitics (phyllite, tourmaline-garnet phyllite, calcphyllite) and rarely metapsammitic rocks (metasandstone, phyllitic quartzite). The main texture of metamorphites is consisted by the rock assemblages that have grano-lepido-nemato-fibroblastic and blastopsammitic texture with respect to the ratio of granular, platy, rod and fibrous minerals. The main mineralogical compositions of the rocks are represented by quartz, feldspar (plagioclase, orthoclase), mica (muscovite, biotite, and sericite), chlorite, calcite, dolomite, and tremolite and hematite minerals. These are accompanied by index minerals such as garnet and tourmaline and secondary minerals such as hematite and zircon.

Calcite or rarely observed dolomite in metacarbonates are bright pearly gray in color and very fine grained (0.063-0.25 mm) and there are polysynthetic twinnings with single or double directions in some coarse grained parts (0.5-2 mm) (Figure 14a). In some sections of these marbles, the

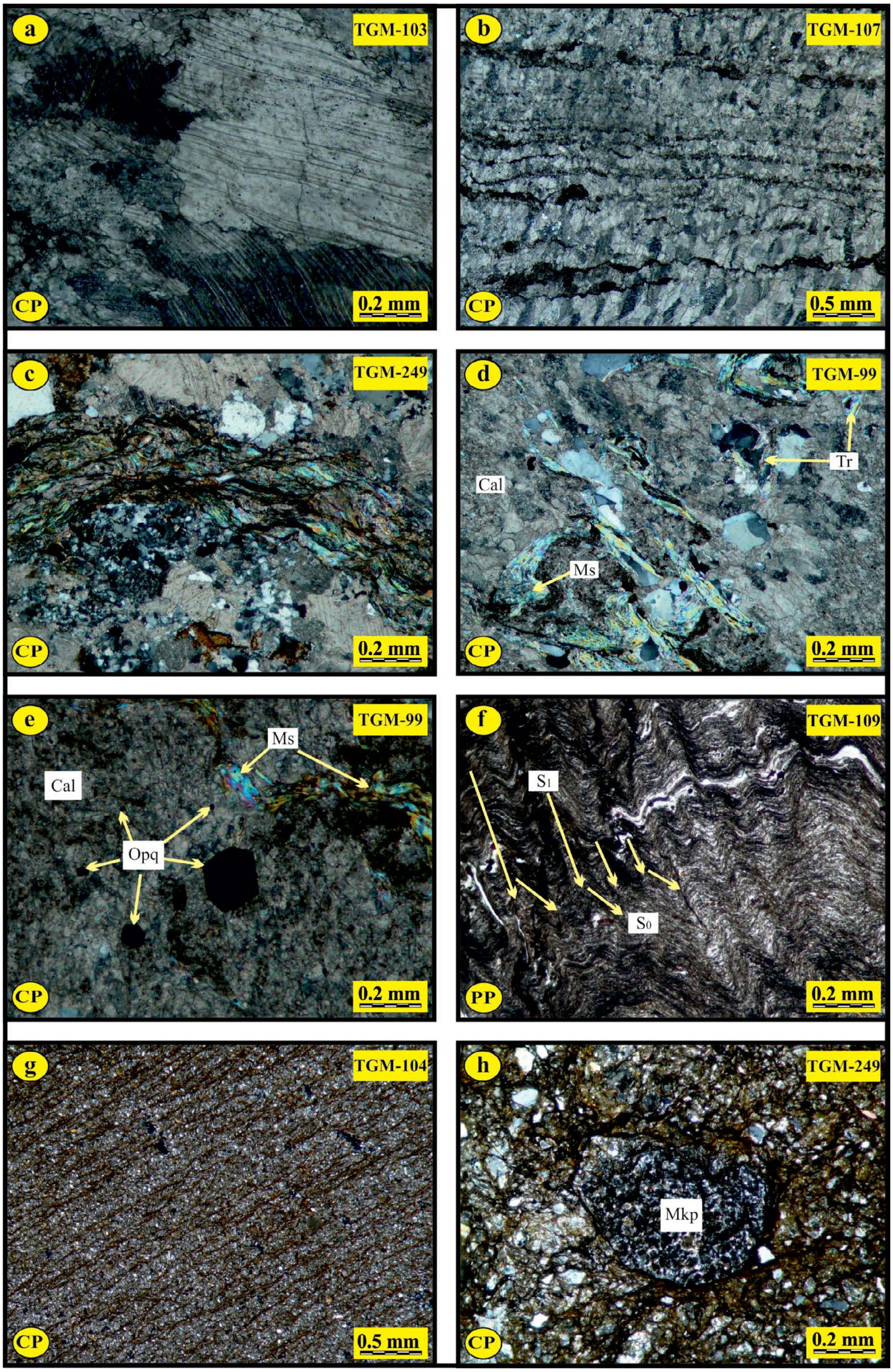

Figure 14- The optical microscopic views of metamorphic rocks in the Göksun region (CP: Cross polarised, PP: Plane polarised, Cal: Calcite, Ms: Muskovite, Tr: Tremolite, Opq: Opaque mineral, Mrf: Magmatic rock fragment, S0: Primary bedding plane, S1: Slate cleavage), a) coarse calcites with single and double polysynthetic twinning, b) remarkable banding in marbles, c) microfolded and oriented opacifications developed from phyllosilicates, d) folds and orientations in the minerals of tremolite-muscovite marbles, e) euhedral opaque minerals and folded muscovites in the marbles, f) clear slate type of crenulation cleavage and planes developed in the phyllites, g) weak folding and orientations in the phyllites and h) Magmatic rock fragment observed in the metasandstones.

coarse grained (0.5-2 mm) secondary crack fillings are observed in addition to significant banding (Figure 14b). The most common and prominent feature observed in metacarbonates is crenulaton cleavage (Figure 14c) and banding (Figure 14d). The euhedral Fe-oxide (hematite) rich levels are also observed in these rocks (Figure 14e).

The most distinctive feature of phyllitic rocks is the observation of the crenulation-type slaty cleavage and the microfoliation/banding and the angle between the primary bedding or primary cleavage plane (S_0) and the later developed cleavage planes (S_1) vary between 90-135° (Figure 14f). In these rocks, where Fe-oxide rich levels are commonly observed, porphyroblastic textures composed of coarse grained (0.5-2 mm) quartz in places are also found. While some phyllites do not show crenulation cleavage, they often contain continuous or smooth with intermittent (Powell, 1979), and sometimes partly weak and discontinuous slaty cleavages (Figure 14g). In these, (S_0) and (S_1) are approximately parallel to each others or intersect at an angle of less than 10-40°.

Metasandstones have fine to medium grained (0.063-0.25 and 0.25-0.5 mm) and they have the mineral orientation and crenulation cleavages as well as primary sedimentary foliation. In addition, the metamorphic, magmatic (Figure 14h) and sedimentary rock fragments were occasionally distinguished in these rocks.

In phyllitic quartzite rocks, the pale greenish chlorite appears in the fan form and phyllitic lamination and folding and orientations are typical for mica. There are opaque mineral laminations in these rocks, where large mica pods/stacks are occasionally observed.

The metamorphic rocks located in Afşin area are mostly; metacarbonate (marble, tremolite/actinolite marble, mica marble, dolomitic marble, tremolite/actinolite-muscovite marble, phyllitic marble and chlorite epidote marble), schist (calcschist, garnet calcschist, calcsilicatic schist, chlorite micaschist, biotite chloriteschist), less metapelite (phyllite, calcphyllite), metabasite (amphiboleschist, epidote amphiboleschist, garnet epidote amphiboleschist, epidote clinopyroxene amphiboleschist) and metapsammite (feldspar quartzite).

The main texture of metamorphites are consisted by the rock assemblages that have granoblastic, lepido-granoblastic, nemato-granoblastic, lepido-nemato-granoblastic, nemato-lepido-granoblastic, and nematoblastic textures according to the ratio of granular/platy/rod/ fibrous minerals.

The major mineralogical compositions of the rocks that form the metamorphites in the region are mainly; quartz, feldspar (plagioclase, orthoclase), mica (muscovite and/or sericite, biotite), chlorite, calcite, dolomite, amphibole (tremolite/actinolite, antophyllite), clinopyroxene (diopside), epidote and hematite minerals. In addition to these minerals, the index minerals such as scapolite and garnet are also present. All these mineral assemblages are accompanied by accessory minerals such as apatite, titanite and/or xenotime and zircon.

Calcite and dolomite, which are commonly observed in granoblastic textured metacarbonates, exhibit a bright pearly grayish color and generally have evidently relief, single or double directed polysynthetic twinnings with medium to coarse grains (0.25-0.5 mm) (Figure 15a). The orientation, banding/lamination, zig-zag/kink and band structures are clearly observed in these rocks (Figure 15b). While quartz is observed as polycrystalline and thick veins in places, the orthoclases present a euhedral structure and show intense argillizations. In rocks rich in mica minerals, which are widely observed in metacarbonates, clear micro folds and orientations (Figure 15c), schistosity plane and phyllitic laminations, mica pods (Figure 15d) and chloritizations developed from mica minerals. Amphibole in the form of tremolite/actinolite and anthophyllite generally shows a needle-rod like form (Figure 15e-f), but are also occasionally observed as rhombus clevage. In calcsilicatic schists, which are rarely observed in metacarbonates, there are viable interference colored scapolites and clinopyroxene containing typical parallel lines (Figure 15g).

In metapelites; the microlamination, microfracture and orientations are typical. In these rocks, where distinct schistosity planes are observed, in addition to opaque mineral laminations, alterations such as epidotization and in occasion porphyroblastic textures are observed (Figure 15h-i-j). Another feature observed in this rock group is the stack structures in different paragenesis such as biotite-muscovite (BMS), chlorite-muscovite (CMS) and/or chlorite-

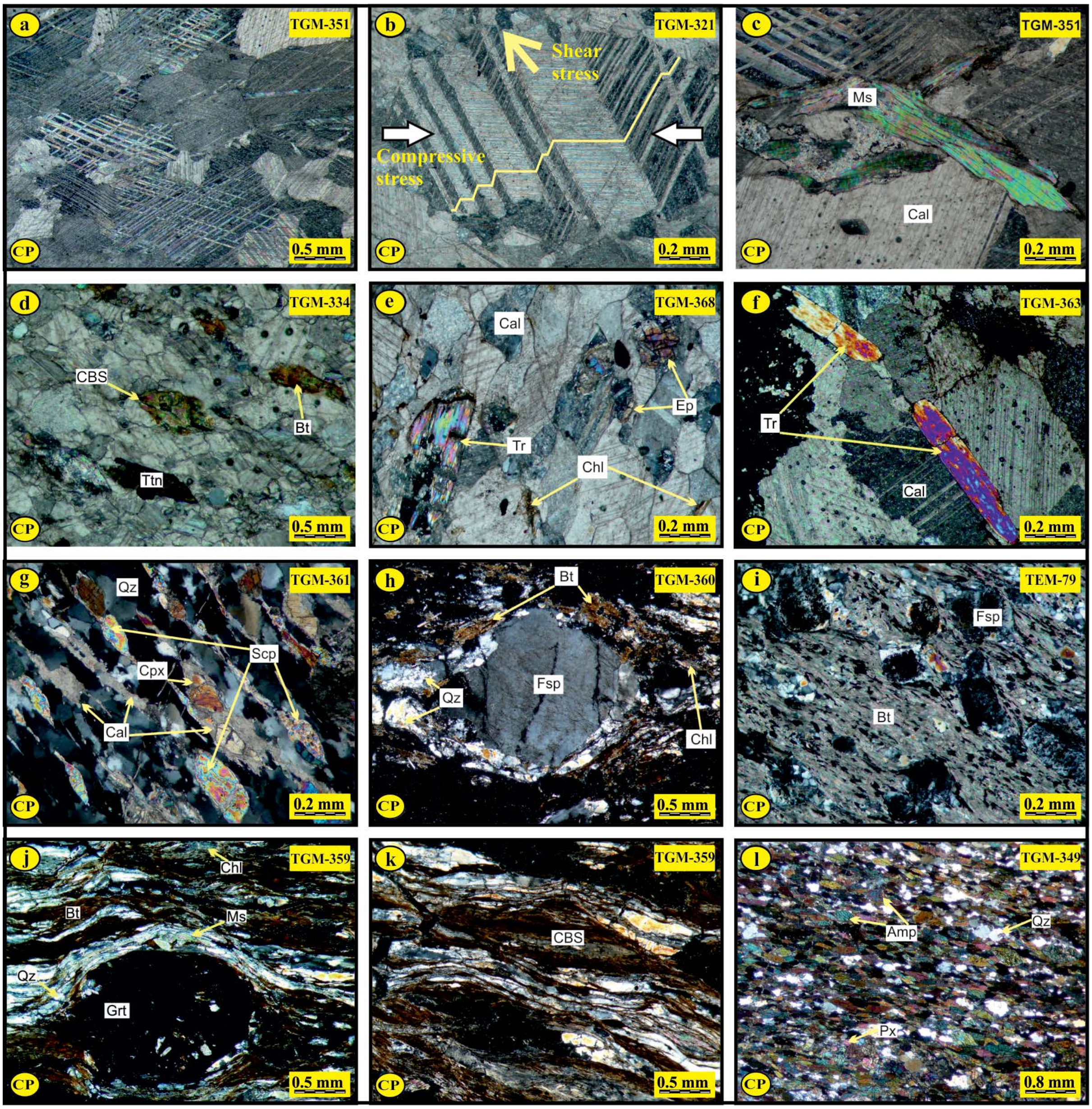

Figure 15- Optical microscopic wiews of metamorphic rocks in Afşin region (CP: Cross polarised, PP: Plane polarised, Cal: Calcite, Ms: Muscovite, Bt: Biotite, Chl: Chlorite, Qz: Quartz, Fsp: Feldspar, Ep: Epidote, Amp: Amphibole, Cpx: Clinopyroxene, Scp: Scapolite, Grt: Garnet, Tr: Tremolite, Ttn: Titanite, Opq: Opaque mineral, Mrf: Magmatic rock fragment, CBS: Chlorite-biotite stack), a) single and double directional polysynthetic twinning in the calcites forming marbles, b) high shear stresses in asymmetric monoclinal kinking folds in marbles (arrows indicate the direction of stress), c) significant orientation and weakly folded structure in the mica marbles, d) biotite-chlorite stack in the mica marbles, e) platy chlorites, rod-needle tremolites and epidote with crack and high optical relief in the chlorite-tremolite-epidote marbles, f) tremolite orientations in the tremolite/actinolite marbles, g) distinct diallag type divisions in the clinopyroxenes in the calcsilicate schists, h) polycrystalline quartzs developed around highly argillized and sericitized feldspar porphyroblasts in the micaschists, i) lepidoporphyroblastic texture formed by greenish colored biotites in the micaschists, j) garnet porphyroblast in the garnet-chlorite micaschists, k) chlorite-biotite stack in the garnet-chlorite micaschists and l) significant schistosity planes and orientations in the amphiboleschists.

biotite (CBS) formed by mica and chlorite (Figure 15k).

In metabasics, distinct schistosity planes developed from amphibolites are one of the most typical features (Figure 15l). Opaque mineral orientations, titanites exhibit a semi-rounded to rounded appearance and porphyroblastic texture in some places reflect other features of these rocks.

The metamorphic rock assemblages in the Ekinözü region based on the amount of abundance are; metapelitic and quartz-feldspar bearing rocks (granitic augen gneiss/mica gneiss, phyllite, micaschist, chlorite micaschist, garnet micaschist, tourmaline micaschist, tourmaline sillimanite micaschist, sillimanite kyanite micaschist, tourmaline staurolite garnet micachist, staurolite garnet micaschist, chlorite schist, actinolite chloriteschist, kyanite actinolite chlorite schist), metacarbonates (marble, mica marble, epidote mica marble, biotite marble, chlorite marble, tremolite chlorite marble), metabasics (amphibolite/amphiboleschist, hornblendeschist, garnet hornblende schist, chlorite actinolite schist), metapsammites (quartzschist/quartzite, tremolite quartzschist, biotite chlorite quartzschist, chlorite quartzschist, tourmaline garnet mica quartzschist, epidote muscovite quartzschist, chlorite quartzschist, metasandstone).

The main texture of metamorphics are nematoblastic (lepido-nematoblastic), lepidoblastic (nemato-lepidoblastic and fibro-nemato-lepidoblastic), granoblastic (lepido-granoblastic, nemato-granoblastic and nemato-lepido-granoblastic), rarely blastopisamitic texture, morter and mylonitic in occasion.

The main mineralogical compositions of the metamorphic rocks are; quartz, feldspar (plagioclase, orthoclase), mica (muscovite, biotite, sericite), chlorite, calcite, dolomite, amphibole (hornblende, tremolite/actinolite and antophyllite/gedrite), pyroxene, epidote and hematite. In addition to these major minerals, the index minerals such as sillimanite, kyanite, staurolite, garnet and tourmaline, which can reflect the type and intensity of metamorphism, are also present. All these mineral assemblages are accompanied by accessory minerals such as apatite, titanite/xenotime, beryl, rutile and zircon. Sillimanite and kyanite minerals were observed together in the same rock in some samples, indicating that the temperature and pressure conditions during the metamorphism of the rock exceeded 500°C and 4 kbar conditions (Deer et al., 1992; Pattison, 1992).

In addition to chloritic alteration in mica minerals, where distinct schistosity planes, microfolds, orientations (Figure 16a) and also the porphyroclastic textures (Figure 16b) are typically observed in metapelitics, the muscovite cuts biotite in occasion and biotite is sometimes at a perpendicular to schistosity plane as a result of granitic intrusion. The quartz has generally undulatory and microfractured phyllosilicate fillings were perpendicular to the schistosity plane. In the feldspar, while excessive argillization and partly sericitization developed, the pleochroic zircon grains and garnet with poikiloblastic texture (Figure 16c) were partially rounded.

The staurolite porphyroblasts (Figure 16d), containing poikiloblastic quartz inclusions, were formed under regional metamorphism conditions from pelitic rocks and reflect the intermediate grade metamorphism conditions corresponding the upper parts of amphibolite facies. The kyanite formed by the medium-high pressure metamorphism of Al rich pelitic rocks have been transformed into sericite by retrograde metamorphism (Figure 16e). In metapelitic rocks where sillimanite is observed in the form of fibrous-needle and perpendicular to the c-axis (Figure 16f), the tourmaline has also sections with perpendicular to the c-axis. Opaque oxide minerals are abundant occasionally, mostly euhedral, partly anhedral/semihedral and sometimes microfolded and oriented. According to petrographic observations, the accessory mineral defined as beryl is in trace amount and rarely observed as coarse porphyroblasts. Rutile, which offers a color ranging from reddish to brownish due to the increased iron content, has a very high optical relief.

In metabasics, there are observed hornblends (Figure 16g), which are considered as chermakitic with distinct schistosity planes and occasionally rod-prismatic (Figure 16h), both single and double directed cleavages and/or separations (Figure 16i). The traces of cataclasm in feldspar and quartz were rarely seen, as well as common argillization and sericitization in the feldspar. In pyroxene, where single and double directional cleavages are typically being followed and the alterations such as uralitization are present.

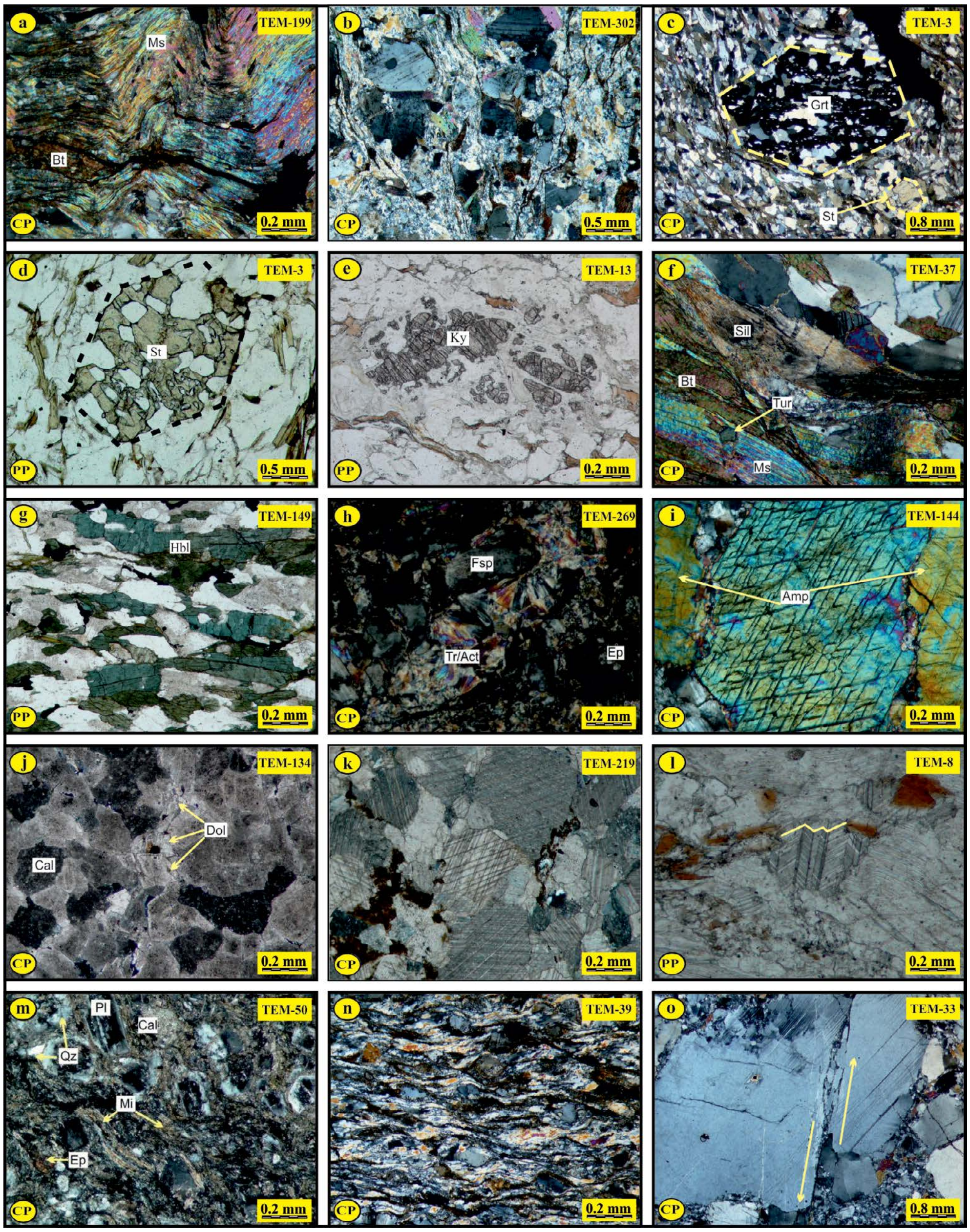

Figure 16- Optical microscopic views of the metamorphic rocks in the Ekinözü region (CP: Cross polarised, PP: Plane polarised, Cal: Calcite, Dol: Dolomite, Mi: Mica, Ms: Muscovite, Bt: Biotite, Qz: Quartz, Fsp: Feldspar. , Pl: Plagioclase, Ep: Epidote, Amp: Amphibole, Hbl: Hornblende, Tr: Tremolite, Act: Actinolite, Sil: Sillimanite, Ky: Kyanite, St: Staurolite, Grt: Garnet, Tour: Tourmaline, a) significant schistosity planes, folds and orientations in the micaschists, b) porphyroclastic texture in the granitic augen gneisses, c) poikiloblastic texture developed in the euhedral garnets and staurolites, d) euhedral staurolite porphyroblast containing poikiloblastic quartz inclusions in the micaschists, e) kyanite porphyroblasts surrounded by sericites in the kyanite micaschists, f) fibrous sillimanite and associated minerals developed in the micaschists, g) chermakitic hornblends observed in the amphiboleschists, h) fan-shaped tremolite/actinolites and associated minerals in the tremolite/actinolite epidotefels, i) double directional cleavages developed in the perpendicular section to the c-axis of the amphiboles in the amphibolites, j) euhedral dolomite crystals developed in the dolomitic marbles, k) distinct single and double directional polysynthetic twinning in the calcites from marbles, l) kinking band structures developed from calcite minerals in the biotite marbles, m) argillization and sericitizations in the metaarcoses, n) lenticular feldspar and quartz porphyroclasts in the mylonite/protomylonites and o) shear traces caused by cataclasm effect in the morter textured amphibolites.

In addition to distinct polysynthetic twinnings (Figure 16j), mostly in fine grained (0.063-0.25 mm) calcite or occasionally euhedral dolomite in metacarbonates, there are cracks that developed perpendicular to the microlaminations (Figure 16k). They are partly mesh/porous in texture, micro-faulted and kinking band structures are remarked (Figure 16l). The chloritization type of alterations is observed in occassion in the mica minerals. Biotite and epidote minerals are rarely found as the crack filling. Chlorite is fan-shaped and occasionally opacitized; as to tremolite, they have been fibreous and needle forms. Rare quartz and opaque minerals are generally found as in cavities or crack fillings.

The quartz in metapsammites, whose origin is mostly the quartz sandstones are partly fine grained (0.063-0.25 mm), generally with undulatory and polycrystalline (Figure 16m). In feldspar, the intense argillization and partly sericitization are seen. Chloritizations in phyllosilicate minerals in some places and slate and/or phyllite foldings are observed, while in some parts muscovite cuts biotite. While the folds are occasionally observed in rod, needle-like tremolite, the zircon is generally rounded and opacities are in the form of cavities and crack fillings.

Mylonite and/or protomylonites, which are among the products of the cataclastic metamorphism, rarely observed in the region, exhibit a lenticular appearance with porphyroclast grains (Figure 16n). In addition, there are traces of slip formed by the cataclasm effect in these rocks (Figure 16o).

5.2. X-Ray Mineralogy

5.2.1. XRD-WR and XRD-CF Analyses

The metamorphic rocks located in the Göksun region are represented mostly by metacarbonate, less metapelitic and partly by metapsammitic rock groups (Figure 17). In metacarbonates (TGM-98), which constitute the dominant lithology in the region, the calcite and dolomite are the dominant minerals, whereas the metapelitic rocks (TGM-254) mainly contain phyllosilicate, feldspar, quartz and hematite. Metapsammitic rocks on the other hand are represented by quartz, feldspar and phyllosilicate minerals.

The clay minerals in metacarbonates are mainly formed of illite, chlorite and partly smectite and kaolinite. However, in metapelitic rocks (TGM-122, 124, 230) illite, less chlorite, paragonite, smectite, kaolinite and mixed layers (C-V and I-C) are observed (Figure 18-19).

The metamorphic rocks located in the Afşin region according to abundance order are; metacarbonate, metapelite and metabasics (Figure 20). Calcite and dolomite are the most abundant minerals in metacarbonate rocks (TGM-358, 365), followed by less quartz, feldspar, phyllosilicate and rare epidote. Metapelitic rocks (TEM-60, 84, 303); are consisted by phyllosilicate, quartz, feldspar, partly hematite and rare paragonite, epidote, scapolite and pyroxene minerals. Metabasic rocks according to abundance are; mainly amphibole, feldspar, and less calcite and phyllosilicate. The clay mineral components of the metacarbonate rocks (TEM-84, 85) in the region are composed by illite, chlorite, smectite and mixed layers (C-V, C-S and I-C). The clay minerals of the metapelitic rocks (TEM-71) are formed mainly by illite, then chlorite, smectite, paragonite, kaolinite and mixed layers (C-V, C-S and I-C). Clay minerals of the metabasic rocks in the abundance order are represented by chlorite, smectite and mixed layers (C-V and C-S) (Figure 21-22).

The metamorphic rocks in the Ekinözü region are mainly metapelitic and metabasic, less metacarbonates and rare metapsammitic rock groups (Figure 23). The rock assemblages forming the metapelitics (TEM-136, 159) in abundance order are represented by phyllosilicate, feldspar, quartz, amphibole, calcite, dolomite and hematite, and index minerals such as pyroxene, epidote and tremolite. Calcite, quartz, feldspar, phyllosilicate, amphibole, hematite, pyroxene and epidote constitute the whole rock association of metabasic rocks (TEM-171, 270). Whole rock compositions of the marble and calcschist rocks in the unit are either completely pure or close to pure calcite and/or dolomite, or in each sample, calcite + quartz + feldspar + mica + chlorite in different amounts and numbers. This paragenesis is accompanied by very few specimens and a small amount of amphibole and hematite. Quartz + feldspar + phyllosilicate in trace amount accompanied by hematite forms the whole rock association of the metapsammitic rocks which are the least available in the unit.

When clay mineral associations of rocks in the region are examined, of the phyllosilicate association

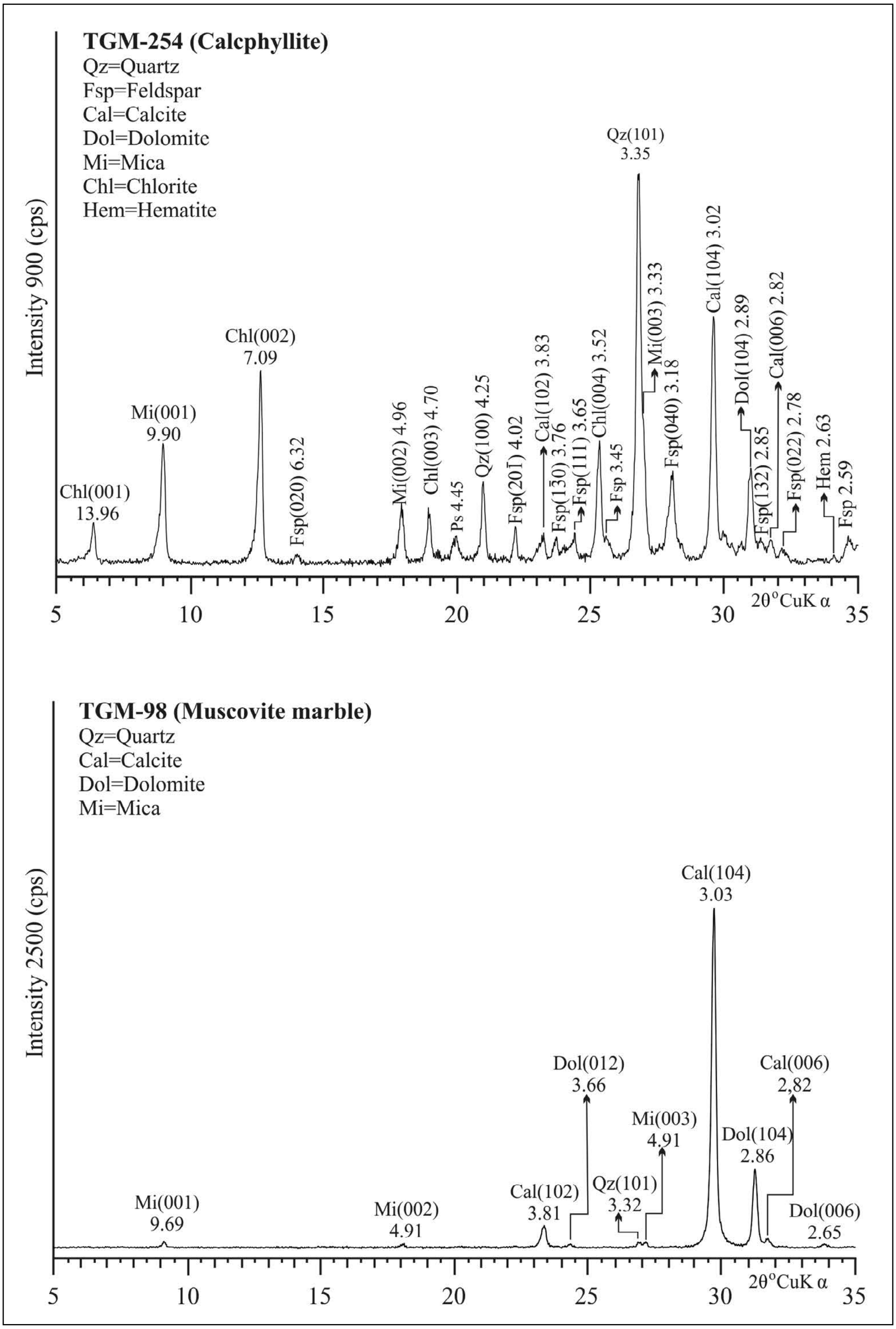

Figure 17- XRD-WR diffractograms of the metamorphites from Göksun region.

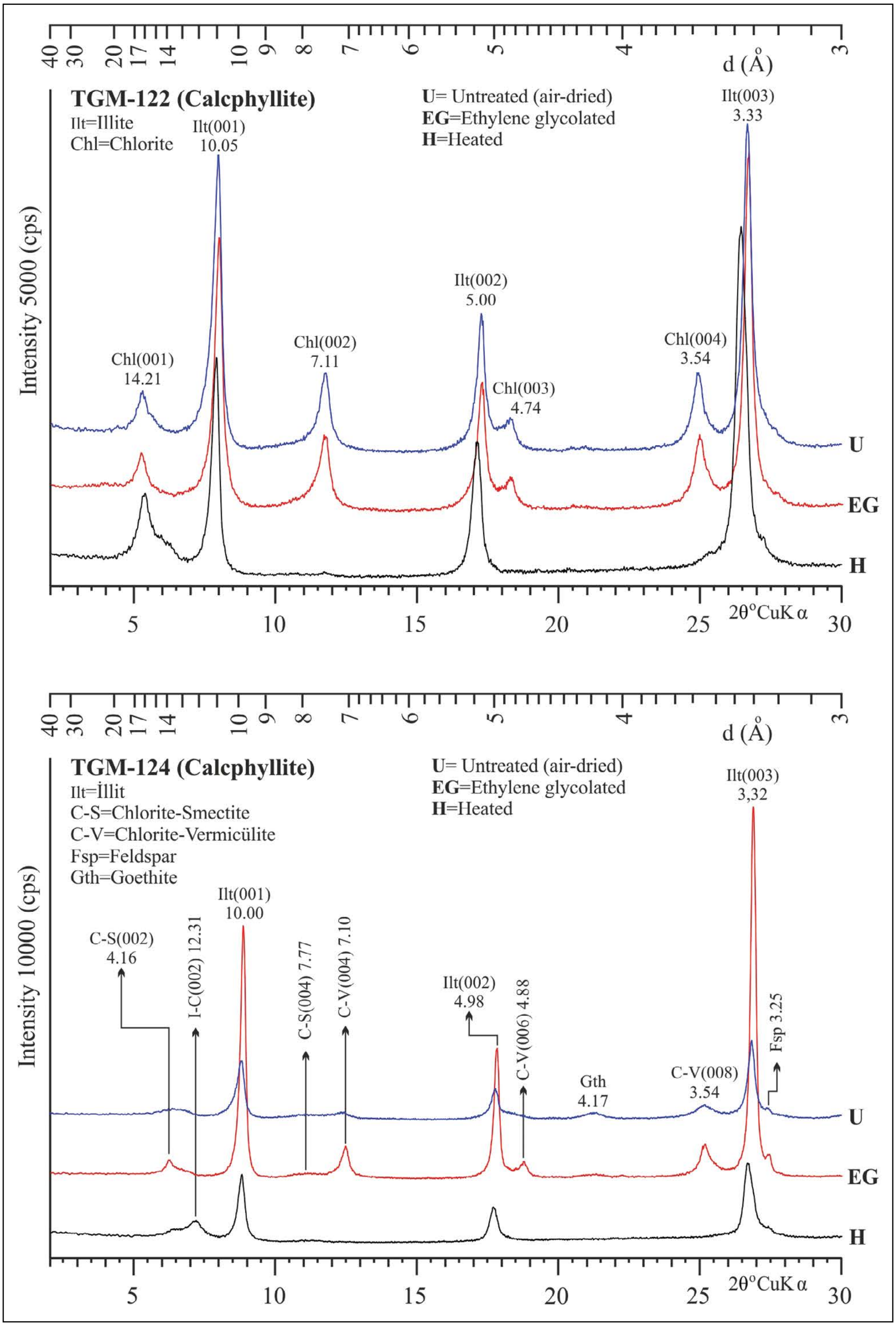

Figure 18- XRD-CF diffractograms of the metamorphites from Göksun region.

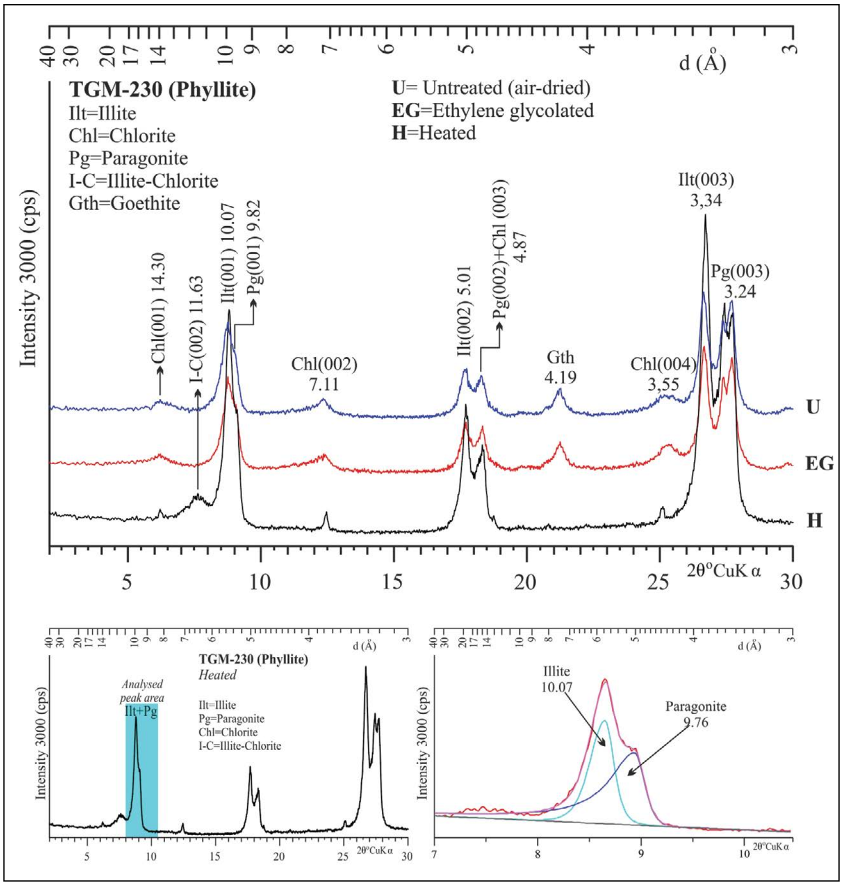

Figure 19- The analysis of complex peaks belonging to illite + paragonite association in XRD-CF diffractograms using WINFIT software from the metamorphites in the Göksun region.

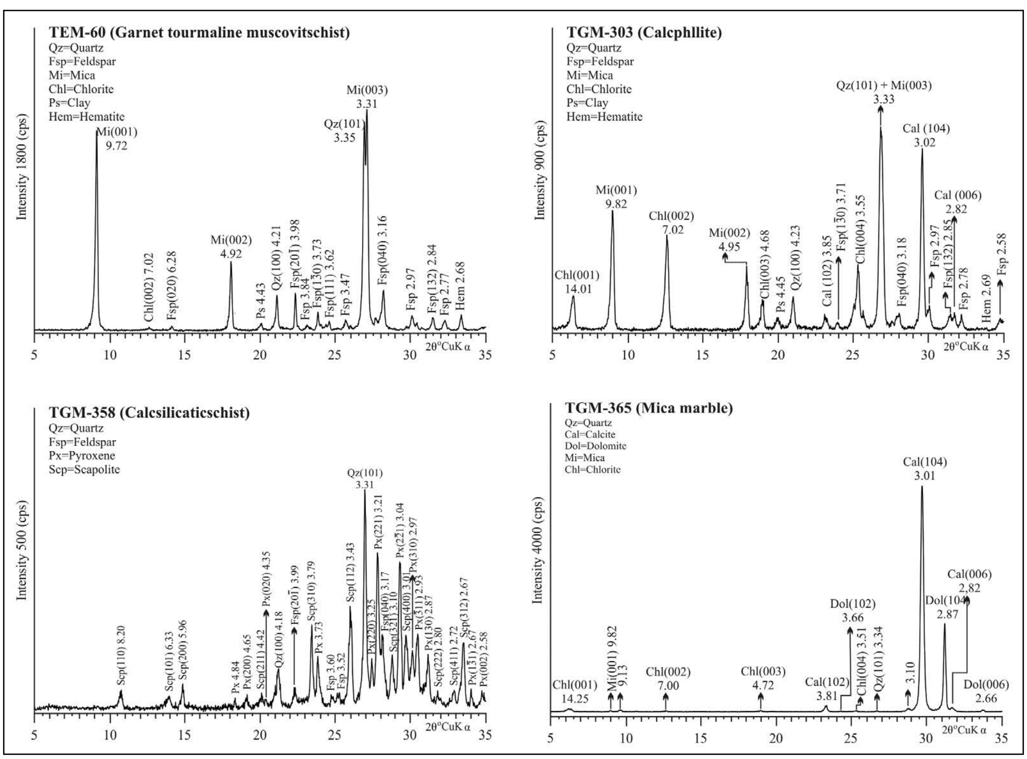

Figure 20- XRD-CF diffractograms of the metamorphites from Afşin region.

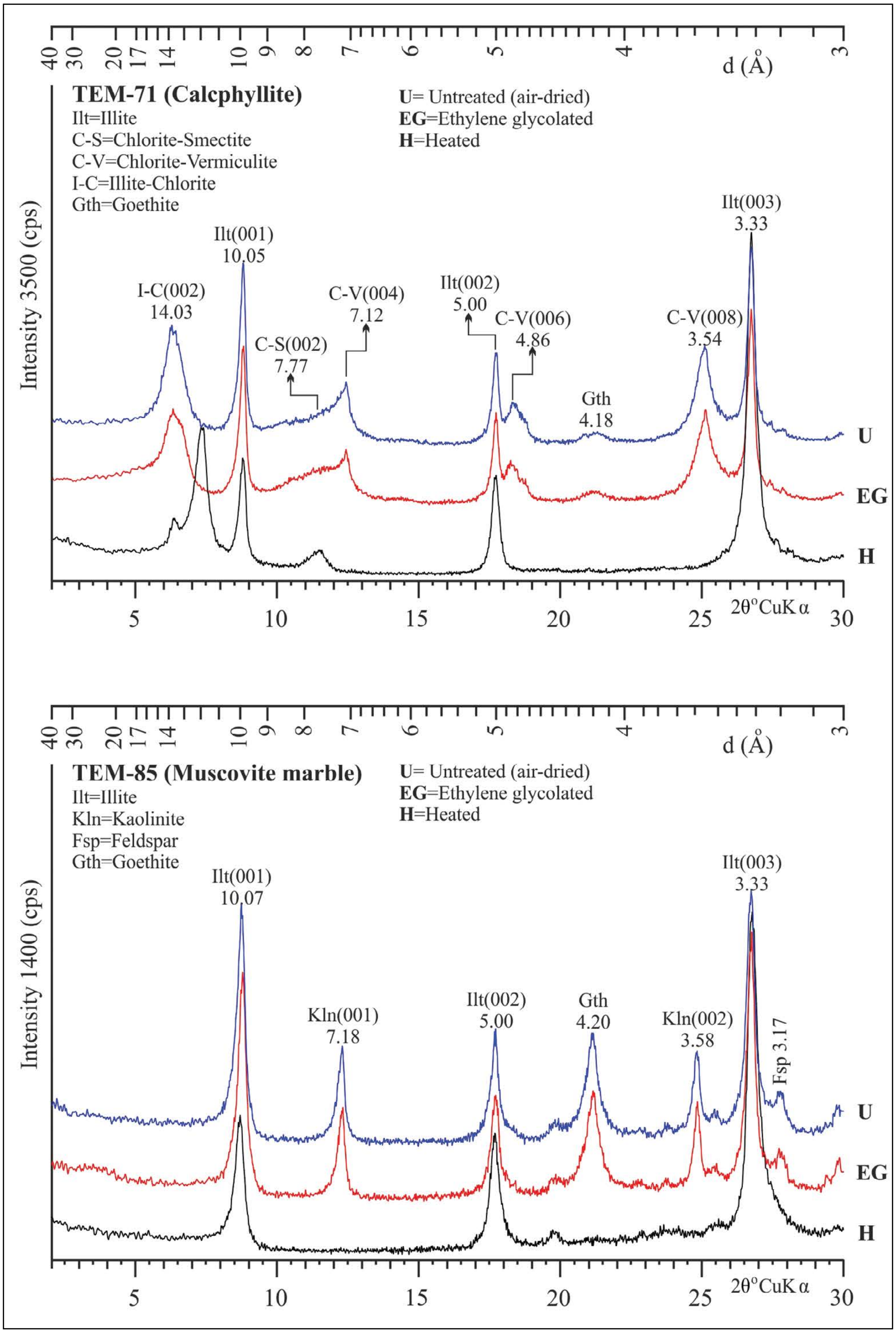

Figure 21- XRD-CF diffractograms of the metamorphites from Afşin region.

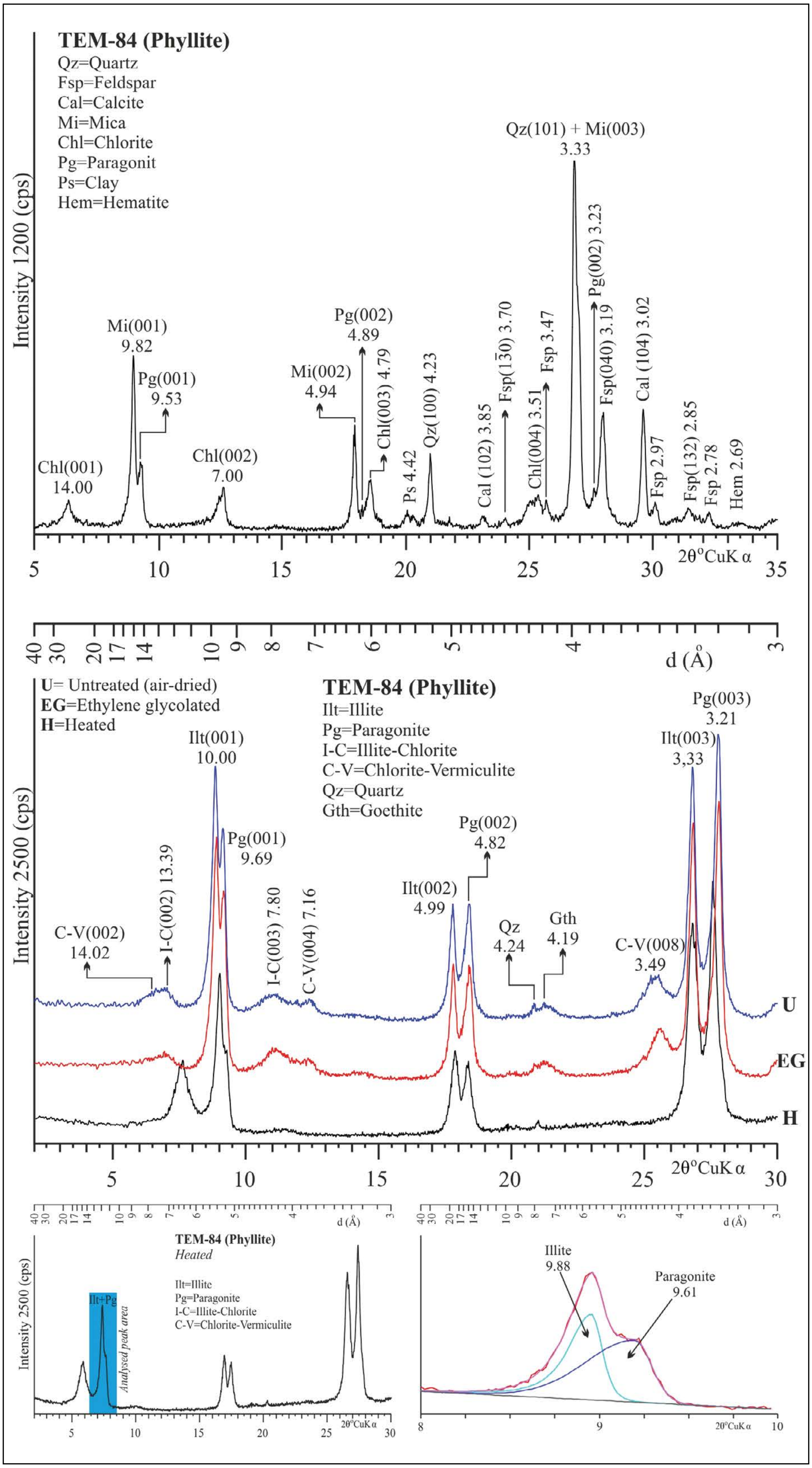

Figure 22- XRD-WR-CF diffractograms and WINFIT analysis of complex peaks of the metamorphites from Afşin region.

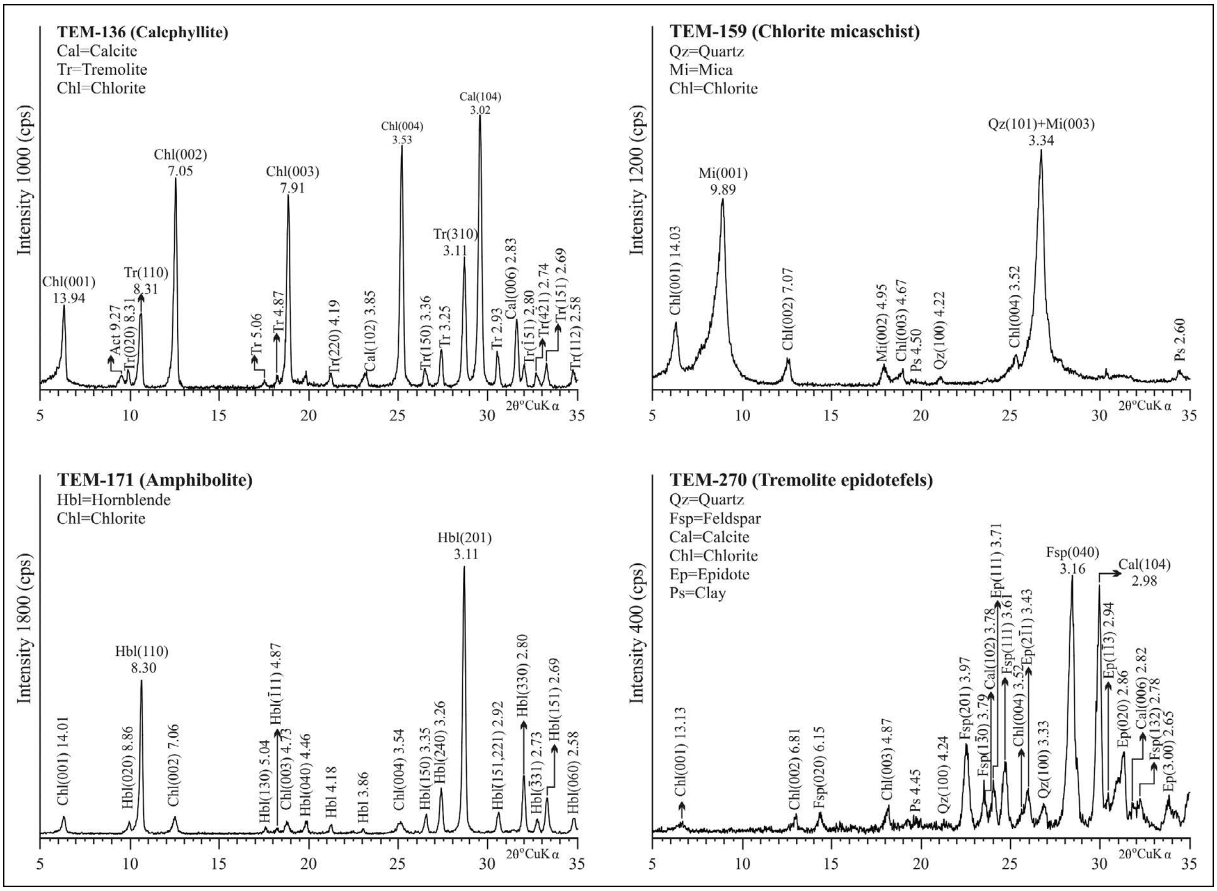

Figure 23- XRD-WR diffractograms of the metamorphites from Ekinözü region.

of metapelites (TEM-203, 209, 218, 265, 299) are composed of C-V, I-C, I-V and C-S types of mixed-layered clay minerals, in addition to smectite, illite, chlorite, vermiculite, kaolinite. The phyllosilicate association of metabasics is represented by smectite, illite, chlorite and mixed layers (C-V, I-C, I-V and C-S). In the phyllosilicate association of metacarbonates, the illite, chlorite and C-S mixed layered clay minerals were determined. The phyllosilicate compositions of metapsammitics are consisted of illite + chlorite + C-V + I-C association (Figure 24-25). Illite peak intensity of 5 Å in TEM-203 sample indicates that they are biotite.

5.2.2. Crystalo-Chemical Analyses of the Phyllosilicates

The results of polytype analysis of pure K-mica fractions belonging to the rocks in Göksun, Afşin and Ekinözü regions are given in table 1, and the polytype and d_{060} measurements are given in figure 26. Illite has mainly $2M_1$ white K-mica (muscovite) and $1M$ biotite polytypes, however; chlorite minerals are entirely composed of IIb polytype. According to d_{060} values octahedral (Mg + Fe) compositions in all three regions (Göksun d_{060} 1.4972-1.5093 Å, average 1.5032 Å and (Mg + Fe) 0.18-0.77 and average 0.47, Afşin d_{060} 1.5007-1.5106 Å, average 1.5051 Å and (Mg + Fe) 0.35-0.84 and average 0.56, Ekinözü d_{060} 1.4977-1.5088 Å, average 1.5040 Å and (Mg + Fe) 0.20-0.75 and avergae 0.51), illite is completely dioctahedral in composition.

Crystallinity values obtained by calibrating the half-height peak width (FWHM) values of illite and chlorite minerals of the Göksun, Afşin and Ekinözü regions by WINFIT software (Kübler Index-KI: Kübler, 1968, and Arkai Index-Al: Árkai, 1991; Guggenheim et al., 2002 for illite and chlorite, respectively), the peak intensity ratios and the calculation results of the crystalline sizes of illite determined by two different methods (Merriman et al., 1990 and WINFIT software) are given in table

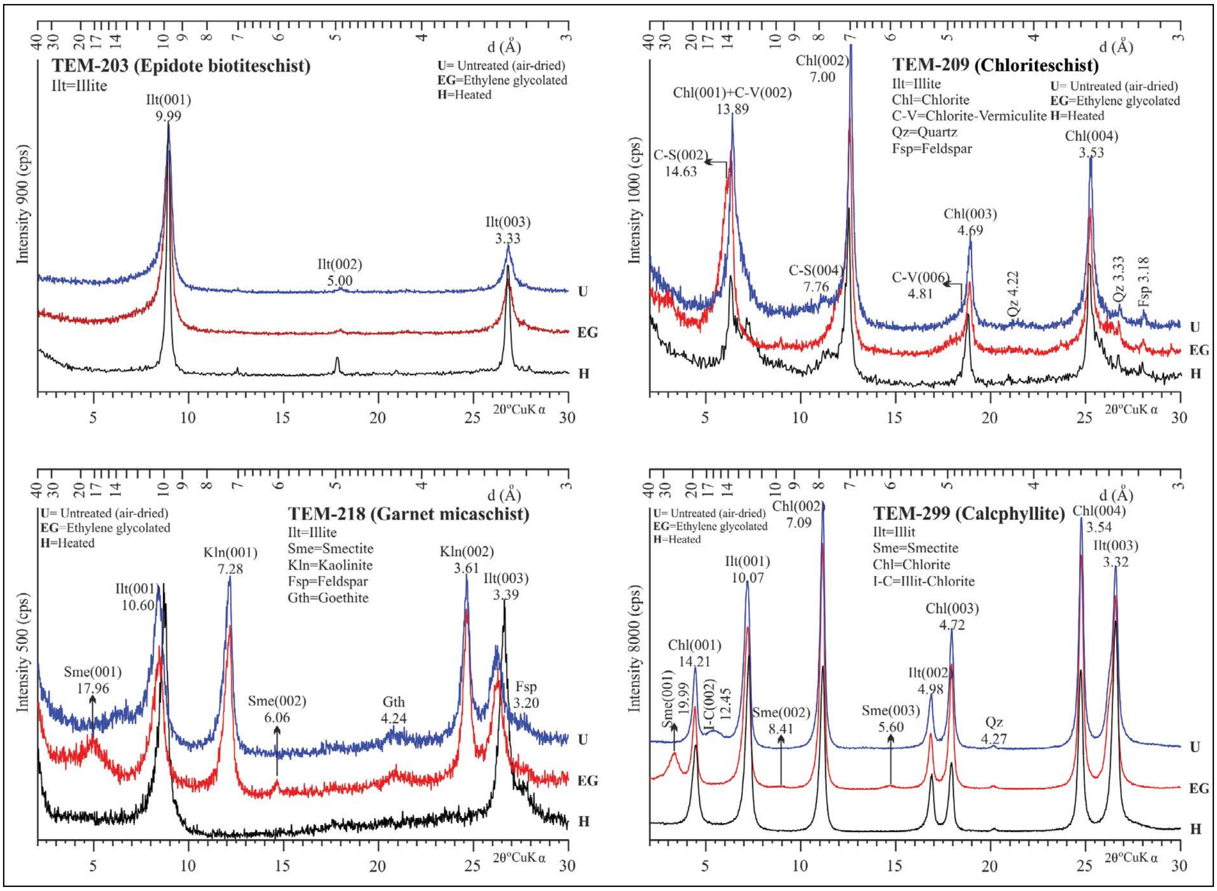

Figure 24- XRD-WR diffractograms of the metamorphites from Ekinözü region.

2. The sizes of illite crystallites range between 15-96 nm (average 53 nm) in the Göksun region, 13-128 nm (average 57 nm) in the Afşin region and 11-96 nm (average 29 nm) in the Ekinözü region based on the formula suggested by Merriman et al. (1990) (N001 = 8.059 / β; β = 1.038949) x KI-0.08250323).

The crystallinity measurement values for each region are evaluated in KI-I (002)/(001) diagrams (Figure 27). According to these, it is seen that the Göksun region has 0.16-0.58 Δ˚2θ and with the average value of 0.26 Δ˚2θ corresponding mostly to epizone, partially anchizone and rarely diagenesis, the Afşin region has 0.14-0.67 Δ˚2θ with the average value of 0.24 Δ˚2θ mainly corresponding to epizone, rarely anchizone and diagenesis, and the Ekinözü region has 0.07-0.77 Δ˚2θ and with the average value of 0.40 Δ˚2θ corresponding mostly anchizone, partially epizone and diagenesis values.

The b_0 results together with average values and standard deviations of illite/K-mica of the Göksun, Afşin and Ekinözü regions are presented in table 3. All three regions were evaluated as a whole and the b_0 vs cumulative frequency (%) distribution of illite/K-mica minerals were given in figure 28. Thus, it is seen that the b cell parameters of illite/K-mica varies between 8.9912-9.0574 Å and their average values with 9.0271 Å, represent mostly the medium pressure, and low and high pressure facies series in less ratios. On the other hand, it was seen that b_0 values of illite/K-mica were reached to typical low pressure and high pressure and glaucophanitic greenschist facies conditions for Barrovian type of regional metamorphism conditions given for Wales (Sassi and Scolari, 1974) and Sanbagawa (Robinson and Bevins, 1986).

6. Conclusions

Lithological, mineralogical and petrographical investigations of the Upper Paleozoic-Lower Mesozoic metamorphic units outcropping around the Göksun, Afşin and Ekinözü districts in the north

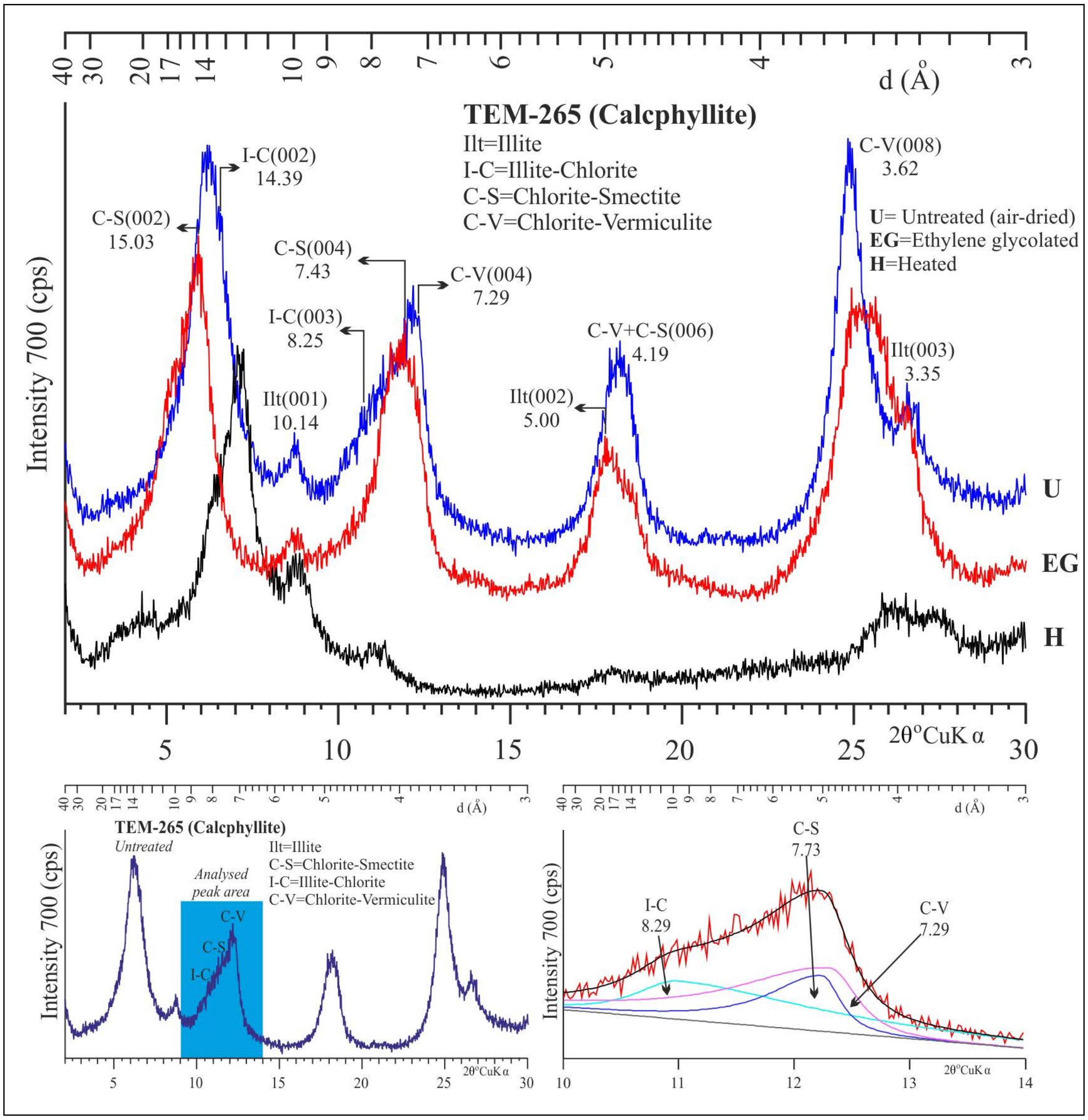

Figure 25- XRD-WR-CF diffractograms and WINFIT analysis of complex peaks of the metamorphites from Ekinözü region.

Table 1- Results of polytype analysis of illite/K-mica and biotite minerals in Göksun, Afşin and Ekinözü regions.

GÖKSUN		AFŞİN		EKİNÖZÜ			
Sample No	Illite/K-mica	Sample No	Illite/K-mica	Sample No	Illite/K-mica	Biotite	Chlorite
TGM-100	$2M_1$	TEM-60	$2M_1$	TEM-24			*II*b
TGM-112	$2M_1$	TEM-75	$2M_1$	TEM-28			*II*b
TGM-121	$2M_1$	TEM-79	$2M_1$	TEM-37	$2M_1$	1*M*	
TGM-125	$2M_1$	TEM-81	$2M_1$	TEM-40		1*M*	
TGM-222	$2M_1$	TEM-304	$2M_1$	TEM-42		1*M*	
		TEM-312	$2M_1$	TEM-43		1*M*	
				TEM-48		1*M*	
				TEM-57	$2M_1$	1*M*	
				TEM-59	$2M_1$	1*M*	
				TEM-299			*II*b
				TEM-302	$2M_1$		

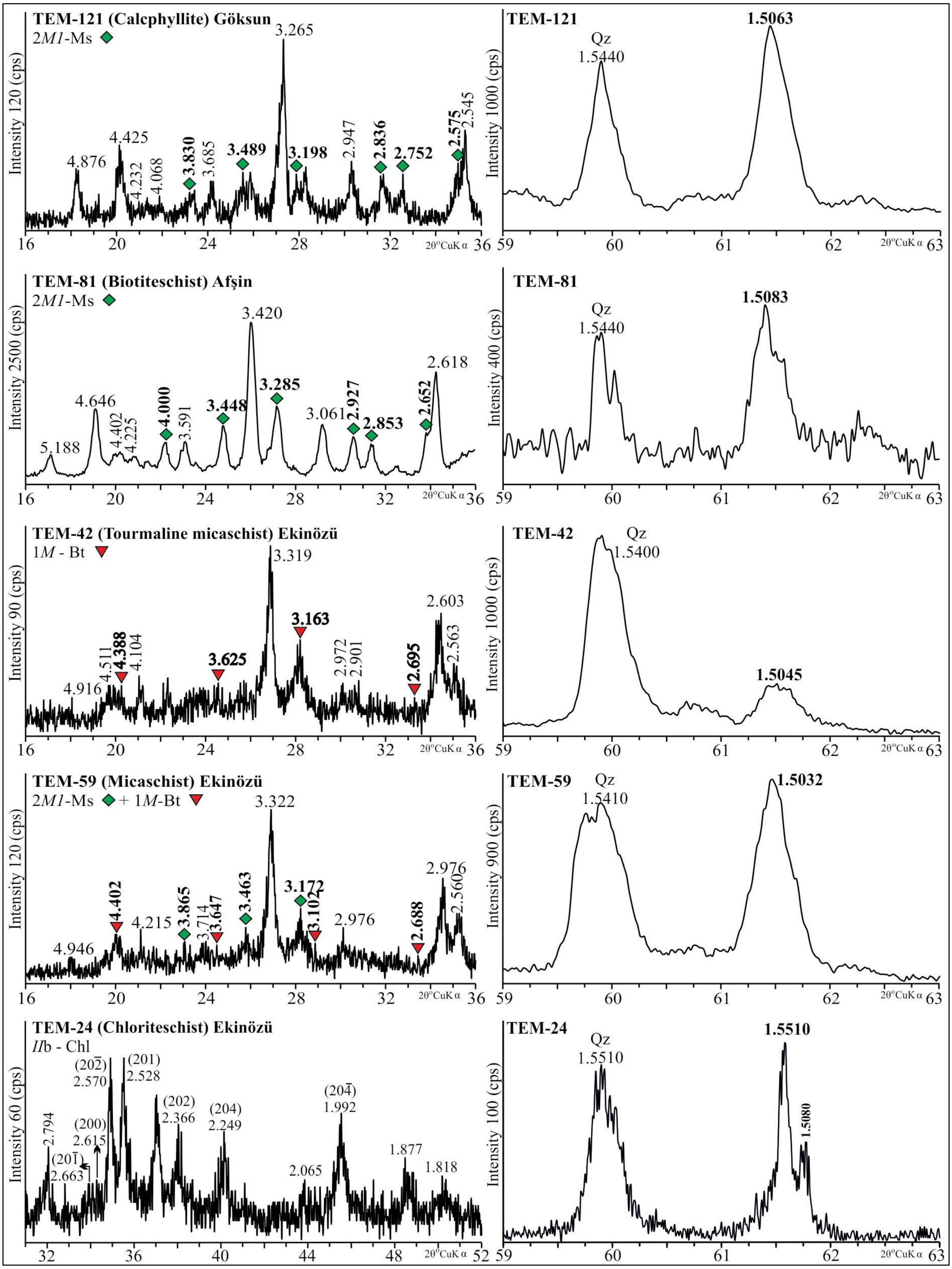

Figure 26- Polytypes and d_{060} XRD diffractograms of illites and chlorites in the Göksun, Afşin and Ekinözü regions.

Table 2- Results of crystallinity analysis of K-mica and chlorite minerals in Göksun, Afşin and Ekinözü regions and crystallite sizes (*N*, nm) determined by Merriman et al. (1990) and WINFIT methods (KI:Kubler Index, AI:Arkai Index).

GÖKSUN						AFŞİN					
Sample No	KI	AI	I(002)/I(001)	N(*)	N(**)	Sample No	KI	AI	I(002)/I(001)	N(*)	N(**)
TGM-86	0.23	0.24	0.54	52	11	TEM-60	0.19		0.29	70	19
-87	0.23	0.29	0.52	52	16	-63	0.24		0.67	48	20
-90	0.21	0.28	0.57	59	18	-66	0.25		0.67	45	15
-91	0.24	0.30	0.52	48	19	-68	0.21		0.55	59	22
-93	0.20	0.35	0.53	64	19	-69	0.19		055	70	22
-100	0.17		0.61	86	24	-70	0.23		0.48	52	16
-102	0.21		0.60	59	19	-71	0.20		0.53	64	21
-109	0.21		0.62	59	21	-72	0.22		0.48	55	19
-112	0.16		0.70	96	24	-74	0.17		0.61	86	19
-117	0.34	0.48	0.56	30	13	-75	0.18	0.28	0.57	77	20
-119	0.20	0.18	0.59	64	17	-79	0.20		0.29	64	20
-120	0.18		0.50	77	21	-81	0.20		0.32	64	19
-121	0.16		0.51	96	24	-82	0.23		0.55	52	17
-122	0.29	0.36	0.46	37	15	-83	0.25		0.45	45	19
-124	0.27		0.53	41	16	-84	0.21		0.47	59	15
-125	0.16		0.54	96	25	-85	0.29		0.49	37	14
-126	0.25		0.49	45	16	TGM-303	0.30	0.46	0.54	35	21
-127	0.20		0.60	64	21	-304	0.14		0.64	128	23
-222	0.24		0.46	48	18	-305	0.26		0.73	43	18
-223	0.38	0.71	0.64	26	13	-306	0.21		0.65	59	20
-224	0.16	0.38	0.63	96	15	-310	0.23		0.66	52	19
-229	0.58		0.25	15	11	-312	0.21		0.42	59	27
-230	0.50		0.54	18	11	-314	0.24	0.41	0.79	48	18
-231	0.48		0.45	19	14	-316	0.17	0.31	0.56	86	22
-237	0.30	0.73	0.51	35	15	-322	0.67	0.48	0.33	13	8
-238	0.20		0.86	64	16	-359	0.45		0.30	21	9
-241	0.23	0.42	0.60	52	16						
-242	0.23	0.30	0.42	52	23						
-243	0.22	0.35	0.86	55	16						
-245	0.30		0.54	35	21						
-246	0.27		0.57	41	16						
-247	0.26		0.80	43	17						
-248	0.25		0.91	45	16						
-254	0.25	0.24	0.60	45	16						

Table 2- Continue.

EKİNÖZÜ											
Sample No	KI	AI	I(002)/I(001)	N(*)	N(**)	Sample No	KI	AI	I(002)/I(001)	N(*)	N(**)
TEM-3	0.34	0.28	0.10	30	11	TEM-154	0.42		0.25	23	4
-4	0.53	0.37	0.21	17	10	-155	0.38		0.13	26	8
-5	0.37	0.28	0.12	27	12	-157	0.35		0.05	29	8
-10	0.16	0.29	0.69	96	27	-159	0.77	0.28	0.33	11	8
-12		0.25				-161	0.68		0.41	13	8
-13	0.30	0.18	0.45	35	13	-162	0.38		0.44	26	13
-17		0.18				-163	0.18		0.16	77	8
-18		0.24				-164	0.46		0.53	20	11
-20		0.15				-165	0.22		0.83	55	22
-21		0.21				-175		0.33			
-24		0.22				-176		0,21			
-27	0.41	0.21	0.23	23	11	-177		0.35			
-28		0.25				-194	0.44		0.11	22	13
-29	0.45	0.22	0.33	21	11	-195	0.52		0.48	18	11
-31		0.21				-197	0.32	0.21	0.20	32	15
-37	0.30		0.15	35	14	-198	0.39	0.08	0.57	25	13
-40	0.56		0.05	16	7	-199	0.51	0.12	0.31	18	11
-42	0.38		0.10	26	11	-200	0.56	0.38	0.39	16	9
-43	0.43		0.21	22	10	-201	0.16		0.16	96	12
-44	0.28		0.10	39	14	-202	0.49		0.21	19	10
-46	0.33		0.41	31	14	-203	0.30		0.04	35	12
-48	0.32		0.09	32	11	-209		0.32			
-49	0.27		0.07	41	14	-210		0.55			
-50	0.07	0.20	0.17	24	11	-215		0.24			
-52	0.42	0.23	0.24	23	11	-218	0.57		0.12	16	8
-53	0.38		0.22	26	13	-220	0.51		0.08	18	13
-54	0.37		0.34	27	12	-277	0.32	0.36	0.08	32	17
-56	0.30		0.23	35	16	-279	0.39	0.44	0.20	25	11
-57	0.51		0.15	18	10	-280	0.59	0.35	0.20	15	16
-59	0.37		0.13	27	12	-281	0.33	0.36	0.46	31	12
-133	0.35		0.36	29	13	-283	0.51		0.39	18	11
-139		0.40				-284	0.47	0.51	0.50	20	11
-140		0.36				-286	0.45		0.23	21	13
-142		0.28				-299	0.24	0.16	0.35	48	18
-148		0.41				-300	0.39		0.09	25	14
-150	0.55		0.35	16	4	-301	0.51		0.20	18	9
-151	0.31		0.27	34	10	-302	0.57		0.16	16	7
-153	0.52		0.15	18	8						

N*= Merriman et al. (1990) N (nm), N**= WINFIT N (nm), N_{001}=8.059/β; β=1.038949) x KI-0.08250323

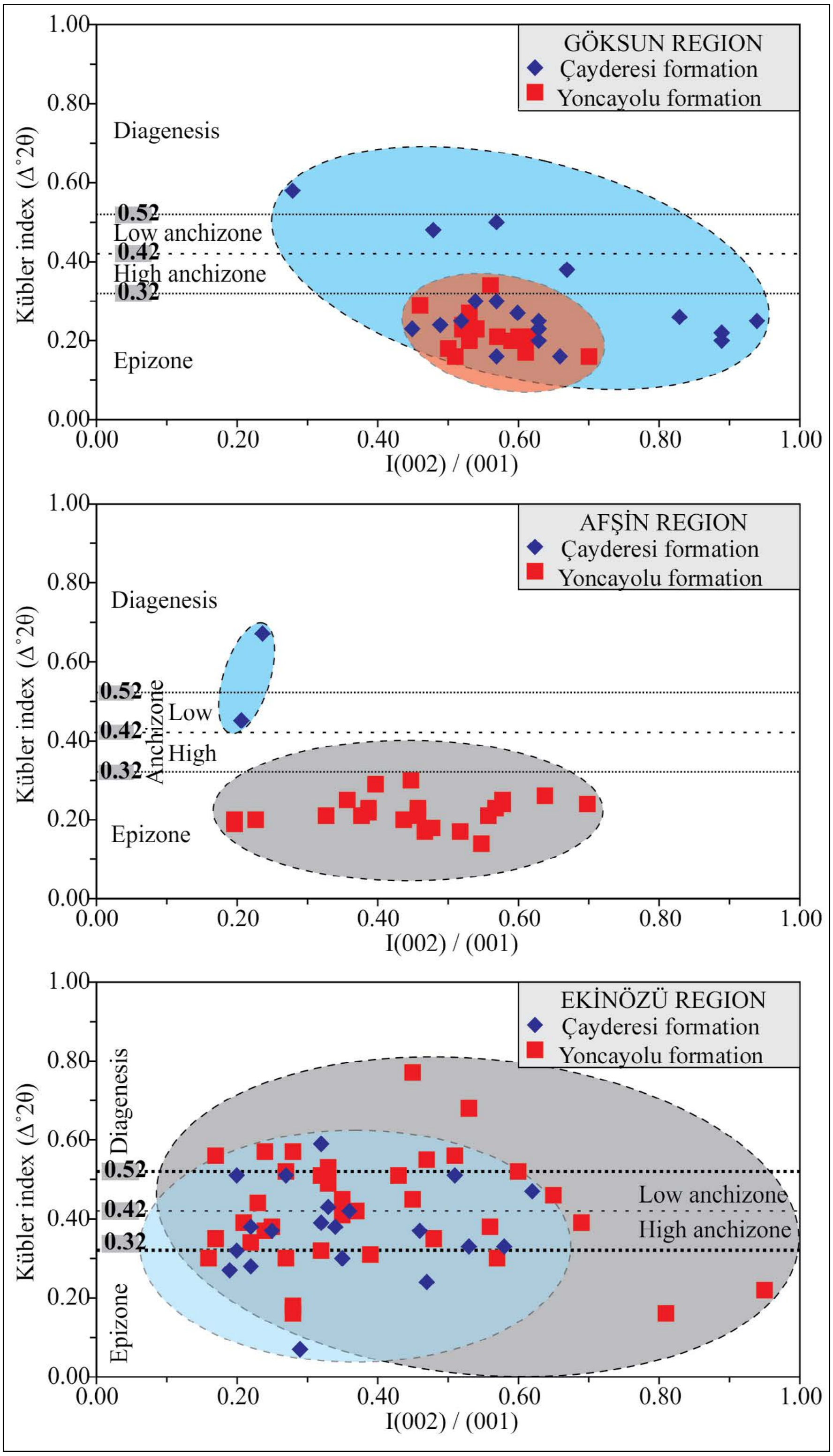

Figure 27- Distribution of illite/K-mikas in Göksun, Afşin and Ekinözü regions according to KI-I(002)/I(001) peak intensity ratios.

of Kahramanmaraş province, the western part of the Eastern Taurus Mountains, are presented below.

The Upper Paleozoic - Triassic metamorphites and crosscutting granitic intrusions constitute the oldest rock units outcropping in these regions. These rock assemblages are tectonically overlain in upward direction by non-metamorphosed allochthonous units, while the cover units are unconformably located on all units.

In the upper levels of the Göksun region, the very thick layered phyllitic or mica marbles bearing distinct foliation planes with pencil structure exhibit an alternating appearance, however; in lower levels mainly the banded marble with pencil structure, mesoscopically folded phyllites/calcphyllites, foliated and intercalated with metasandstone and quartzite are observed. In upper levels of the Afşin region, the medium-thick bedded, hard marbles intercalate with calcphyllite and phyllitic schists, whereas in lower-middle levels, the phyllite/calcphyllites with distinct schistosity planes and highly brittle structures present an alternation with marbles. In upper levels of the Ekinözü area, the foliated calcschists form an alternating structure with thin banded metalimestone, marble, mica marble and dolomitic marbles in places. The lower levels consist of quartzite and metasandstone intercalating with marble, gneiss, phyllite/phyllitic schist, micaschist, chloriteschist, amphibolite/ amphiboleschist and calcschist lithologies that are occassionally cut by granitoid intrusions.

Metamorphic rocks around Göksun mainly contain calcite, dolomite, quartz, feldspar and phyllosilicate minerals ($2M_1$ illite / K-mica, IIb chlorite, paragonite, kaolinite, C-V and I-C). The metamorphic rocks around Afşin are mainly represented by calcite, dolomite, quartz, feldspar, garnet, chlorite, epidote, and amphibole and tremolite association. The phyllosilicates on the other hand numerate illite/mica ($1M$ biotite; $2M_1$ muscovite, paragonite), IIb chlorite, mixed layers (C-V, I-C and I-S) and smectite. The metamorphic rocks around Ekinözü are composed of feldspar, quartz, amphibole, chlorite, garnet, sillimanite, staurolite and kyanite in the lower levels; and by calcite, dolomite, tremolite, actinolite, biotite, muscovite and chlorite associations in the upper levels. The phyllosilicate minerals of the region are accompanied by smectite, illite/mica ($1M$ biotite, $2M_1$ muscovite), IIb chlorite, vermiculite and kaolinite as well as C-V, C-S, I-C and I-V indicating very low-grade retrograding metamorphism. Of these, especially the index minerals such as sillimanite (T > 500 ± 50 °C), kyanite (P > 4 ± 0.5 kbar), staurolite (P > 1.5 kbar and T 500-700 °C), garnet (T < 785°C) correspond to high-grade metamorphism (Deer et al., 1992). The association of Al_2SiO_5 polymorphs was also observed in metamorphic rocks of the Sivrihisar (Eskişehir) region and it was reported that this paragenesis was caused by the effect of successive metamorphism factors (counter clockwise P-T evolution) (Whitney, 2002). In authors' opinion, transformations of the andalusite-kyanite as a result of burial during subduction causing an increase of pressure in the first stage occurred and the kyanite-sillimanite with post collisional heating.

Illite, chlorite, paragonite, mixed layers (C-V, I-C, C-S, C-V and I-V), smectite, kaolinite and vermiculite types of phyllosilicates are identified in the abundance order. The mixed layers indicate advanced diagenesis conditions of vertical diagenesis/metamorphism transition (e.g., Frey, 1987). Smectite, kaolinite and vermiculite represent the weathering and/or hydrothermal alteration products.

K-mica has $2M_1$ muscovite polytype in Göksun and Afşin regions, and $2\ M_1$ muscovite, $1\ M$ biotite or $2\ M_1$ muscovite + $1\ M$ biotite polytypes in the Ekinözü region. Chlorite is represented by IIb polytype in all regions.

In the Göksun region, the KI values of illite and AI values of chlorite vary between 0.16-0.58 $\Delta°2\theta$ (mean 0.26 $\Delta°2\theta$) and 0.18-0.73 $\Delta°2\theta$ (mean 0.37 $\Delta°2\theta$), respectively. The specimens mostly point out epimetamorphic, less anchimetamorphic, and rarely diagenetic grades. The KI values in the Afşin region were detected as 0.14-0.67 $\Delta°2\theta$ (mean 0.24 $\Delta°2\theta$) and AI values as 0.28-0.48 $\Delta°2\theta$ (mean 0.40 $\Delta°2\theta$). Almost all of the samples are located in the epizone, partly in the low anchizone and diagenesis zones. The KI values in the Ekinözü region were estimated as 0.07-0.77 $\Delta°2\theta$ (mean 0.40 $\Delta°2\theta$) and AI values as 0.08-0.55 $\Delta°2\theta$ (mean 0.28 $\Delta°2\theta$). Illite/K-mica in the Ekinözü region, where the metamorphism degree is the highest, to have KI data indicating lower degrees of metamorphism according to the petrographic studies is because they contain biotite (Frey, 1987).

Table 3- Results of b_0 analysis of illite/K-mica minerals in Göksun, Afşin and Ekinözü regions (N.S.: Number of samples, S.D.: Standard deviation).

GÖKSUN		AFŞİN		EKİNÖZÜ	
Sample No	*b0 (Å)*	Sample No	*b0 (Å)*	Sample No	*b0 (Å)*
TGM-86	9.0324	TEM-60	9.0618	TEM-1	9.0306
-87	9.0294	-63	9.0084	-3	8.9862
-90	9.0306	-65	9.0084	-5	9.0528
-91	9.0312	-66	9.0054	-8	9.0192
-95	9.0366	-67	9.0342	-9	9.0246
-96	9.0540	-68	9.0210	-12	9.0438
-99	9.0222	-69	9.0300	-13	9.0408
-105	9.0156	-70	9.0042	-18	9.0264
-106	9.0012	-72	9.0300	-21	9.0048
-109	9.0360	-74	9.0492	-29	9.0450
-110	9.0390	-75	9.0486	-38	9.0048
-111	9.0246	-76	9.0252	-42	9.0270
-112	9.0348	-78	9.0504	-43	9.0486
-113	9.0558	-79	9.0636	-44	9.0276
-114	9.0426	-80	9.0360	-46	9.0120
-115	9.0474	-81	9.0498	-48	9.0024
-117	9.0300	-82	9.0180	-49	9.0150
-119	9.0180	-83	9.0480	-50	9.0414
-120	9.0360	-85	9.0204	-51	9.0186
-121	9.0378	TGM-303	9.0102	-52	9.0312
-122	9.0378	-304	9.0198	-53	9.0324
-123	9.0462	-306	9.0312	-54	9.0108
-124	9.0456	-310	9.0084	-56	9.0066
-125	9.0042	-312	9.0324	-59	9.0192
-126	9.0246	-313	9.0468	-277	9.0198
-127	9.0174			-280	9.0252
-222	9.0462			-281	9.0270
-229	8.9952			-283	9.0186
-231	9.0096			-284	9.0180
-238	9.0204			-299	9.0342
-242	9.0150			-300	9.0156
-247	8.9832				
-248	9.0222				
-254	9.0174				
N.S.	34	N.S.	25	N.S.	31
Smallest b0 (Å)	8.9832	Smallest b0 (Å)	9.0042	Smallest b0 (Å)	8.9862
Biggest b0 (Å)	9.0558	Biggest b0 (Å)	9.0636	Biggest b0 (Å)	9.0528
Average b0 (Å)	9.0272	Average b0 (Å)	9.0307	Average b0 (Å)	9.0233
S.D.	0.0161	S.D.	0.0184	S.D.	0.0150

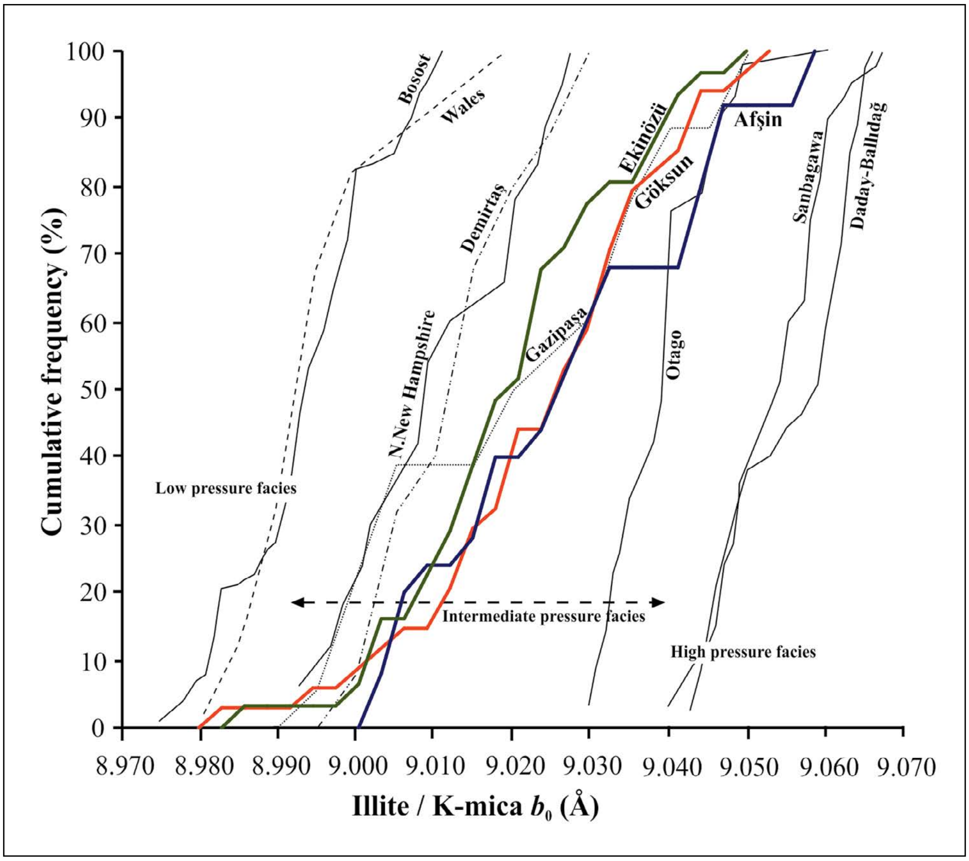

Figure 28- The relationship between the cumulative frequency and b_0 values in Göksun, Afşin and Ekinözü regions (Demirtaş, Gazipaşa b_0 values: Bozkaya and Yalçın, 2005; Wales: Robinson and Bevins, 1986; others: Sassi and Scolari, 1974).

In the Göksun region, the b_0 values of dioctahedral illite range from 8.9832 to 9.0558 Å (mean 9.0272), mostly indicating the medium-pressure (lower greenschist facies). These obtained values reflect the series of pressure facies less than 4 kbar (Buchan type; Turner, 1981) and Barrovian type regional metamorphism conditions between the borders represented by Wales (Sassi and Scolari, 1974) and Otago (Robinson and Bevins, 1986). The b_0 values of dioctahedral illite in the Afşin region, vary between 9.0042-9.0636 Å (average 9.0307 Å), corresponding to the medium-high pressure (lower greenschist-greenchist facies) and represent the glaucophanitic greenschist facies conditions mostly between the boundaries of Wales and Sanbagawa (Sassi and Scolari, 1974). The b_0 values of dioctahedral illite in the Ekinözü region are between 8.9862-9.0528 Å (mean 9.0238 Å) and have medium-high pressure (amphibolite facies in lower levels rich in metabasic and metapelites, and greenschist facies in upper levels rich in metacarbonates). Most of the rocks in the region show typical Barrovian metamorphism between the border lines of Wales and Otago (Sassi and Scolari, 1974). Furthermore, according to the cumulative frequency curves of b_0 values for illite/K-mica formed for three regions, it can be stated that Afşin region has higher *b* cell parameters than those of Göksun and Ekinözü regions.

Metamorphites in the Göksun, Afşin, Keban and Malatya regions are of Carboniferous-Triassic; however, the metamorphites in the Ekinözü and Pütürge Metamorphites are of Permian and pre-Permian. The metamorphic rocks in the Göksun and Afşin regions contain the characteristic paragonite mineral for Malatya Metamorphites, however; the rocks in the Ekinözü region contain 1*M* biotite, sillimanite and kyanite minerals characteristic for the Pütürge metamorphics. These differences are related to the fact that these metamorphic sequences have different histories of metamorphism (Bozkaya et al., 2007*a*) and also show that the metamorphites of Göksun and Afşin regions developed in the opposite direction of P-T, however the metamorphites in the Ekinözü region developed in the direction of P-T. The similar evaluations were made for Keban, Malatya, Pütürge metamorphites (Bozkaya et al., 2007*a*) in the Eastern Taurus Belt, and Alanya Nappes (Bozkaya and Yalçın, 2004) in the Central Taurus Belt, and the clockwise P-T and anti-clockwise P-T represent the environments related with continental collision (Alpine collision) and extensional basins in passive continental margins, respectively (e.g., Robinson, 1987; Merriman and Frey, 1999).

When textural and mineralogical data are evaluated together, the metamorphic units in the Afşin and Göksun regions are similar to the Malatya Metamorphites and the ones in the Ekinözü region show similarity to the Pütürge Metamorphites (Bozkaya et al., 2007*a*, *b*). The Pınarbaşı and Kalecik formations of the Malatya Metamorphites (Karaman et al., 1993) correspond to those of Göksun and Afşin regions, however, the metapelitic and metacarbonate units named as without rule of the Pütürge Metamorphites (Yazgan et al., 1986, 1987) are the equivalent of the Yoncayolu and Çayderesi formations in the Ekinözü and Afşin regions. In the light of the findings obtained from this study, it was detected that the metamorphic rocks representing the western extension of the Southeast Anatolian Metamorphic Massifs had different origin rocks and/or lithologies depending on the regions and exhibited increasing temperature and pressure conditions from the west (Göksun) to the east (Ekinözü) and each of them were rock assemblages having different geological evolution.

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