DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

KINEMATICS OF THE NAPPES IN THE SULTAN MOUNTAINS AND THE BEYŞEHİR-HOYRAN NAPPES

by
Efe Can UNGUN

October, 2015
İZMİR

KINEMATICS OF THE NAPPES IN THE SULTAN MOUNTAINS AND THE BEYŞEHİR-HOYRAN NAPPES

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"KINEMATICS OF THE NAPPES IN THE SULTAN MOUNTAINS AND BEYŞEHİR-HADİM NAPPES"** completed by **EFE CAN UNGUN** under supervision of **Prof. Dr. Talip GÜNGÖR** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Prof. Dr. Talip GÜNGÖR

Supervisor

Prof. Dr. Sacit ÖZER

(Jury Member)

Prof. Dr. Suha ÖZDEN

(Jury Member)

Prof.Dr. Ayşe OKUR

Director

Graduate School of Natural and Applied Sciences

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KINEMATICS OF THE NAPPES IN THE SULTAN MOUNTAINS AND THE BEYŞEHİR-HOYRAN NAPPES

ABSTRACT

In the Central Taurides, tectonic slices of the Beyşehir-Hoyran nappes of the Bozkır unit occupy the structurally uppormost position on the autochthons of the Anamas and Sultan Mountains. These tectonic slices of the Bozkır unit crop out in a NW-SE trending zone between the Beyşehir and Hoyran lakes, and are known as the Beyşehir-Hoyran nappes. These are composed of serpentinites, sole metamorphics represented by amphibolites, huge limestone blocks in sandstone-shale matrix, spilites and olistostromal conglometares. These allochthons thrust over the Lutetian Celeptaş formation that forms the stratigraphically uppermost unit both the Anamas and the Sultan Mountains autochthons made up of platform sequences. The contact of the Beyşehir-Hoyran nappes with the Anamas autochthon is a dextral strike-slip fault striking in NW-SE direction, whereas their contact with the Sultan Mountains autochthon is a thrust fault. This SE-striking dextral strike-slip contact represent a lateral-wall between the Beyşehir-Hoyran allochthons and the Anamas autochthon. Along the boundaries between the Beyşehir-Hoyran nappes and the autochthons the kinematic indicators such as S/C relation, s-clasts and imbrication of beds both in amphibolites of the sole metamorphics, strongly sheared serpentinites and sandstone-shale alternation in the Celeptaş formation clearly indicate a top-SE sense of shearing/movement during the Lutetian nappe emplacement. After the correction of post-emplacement clockwise 40^{o} rotation defined by palaeomagnetic studies in the Central Taurides, The Lutatian emplacement direction of the Beyşehir-Hoyran nappes come to light as E-W with top-E sense of movement.

Keywords: Kinematic analysis, Eocene emplacements, Beyşehir-Hoyran nappes

SULTAN DAĞLARI VE BEYŞEHİR-HOYRAN NAPLARININ KİNEMATİK ÖZELLİKLERİ

ÖZ

Orta Toroslar`da Beyşehir-Hoyran napları (Bozkır Birliği), Anamas ve Sultan Dağları otoktonlarının üzerinde tektonik dilimler halinde bulunmaktadır. Bozkır Birliği'nin bu tektonik dilimleri KD-GB doğrultulu bir kuşak boyunca Beyşehir ve Hoyran Gölleri arasında bulunmaktadır ve Beyşehir-Hoyran napları olarak bilinmektedir. Bu naplar; serpantinitler ve amfibolitler ile temsil edilen taban metamorfikleri, kumtaşı-şeylden oluşan bir matriks içinde büyük boyutlu kireçtaşı blokları, spilitler ve olistostromal çakıltaşlarından meydana gelmektedir. Bu allokton birimler Anamas ve Sultan Dağları otoktonlarını meydana getiren platform istifinin stratigrafik olarak en üst birimini oluşturan Lütesiyen yaşlı Celeptaş formasyonu'nun üzerine bindirmiştir. Beyşehir-Hoyran napları'nın Anamas otoktonu ile dokanağı KB-GD doğrultulu sağ doğrultu atımlı faylıdır. Ancak Sultan Dağı otoktonu ile dokanağı bindirme faylıdır. Bu sağ doğrultu atımlı fay, Beyşehir-Hoyran alloktonları ile Anamas otoktonu arasında bir yanal duvara karşılık gelmektedir. Beyşehir-Hoyran napları ile otoktonların dokanağı boyunca amfibolitlerden oluşan taban metamorfiklerinde, yapraklı serpantinitlerde ve Celeptaş formasyonu'nun kumtaşı-şeyl ardalanmasında gözlenen S/C yapıları, σ-klast, mezoskopik ölçekli ters faylar gibi kinematik belirteçler napların Lütesiyen'de GD yönünde hareket ettiğini göstermektedir. Orta Toroslarda Lütesiyen sonrası saat yönünde yaklaşık 40^{o}'lik rotasyon düzeltildiğinde, Beyşehir-Hoyran naplarının Lütesiyen'de batıdan doğuya doğru ilerlediği ortaya çıkmaktadır.

Anahtar kelimeler: Kinematik analiz, Eosen nap hareketleri, Beyşehir-Hoyran napları

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CHAPTER ONE
INTRODUCTION

1.1 Location and Accessibility

In Central Turkey, the study area is located in the area between the Hoyran and Beyşehir Lakes along which the Beyşehir-Hoyran and SultanDağları nappes expose (Figure 1.1).The main town in the study area are Yalvaç, Şarkikaraağaç and Gelendost. The minor earth roads connect to towns and villages. The Anamas Mountains and the Sultan Mountains are located in the SW and NE of the study area respectively.

The study area includes the 1/25000 scale topographic sheets of Isparta I26-c3, c4 and d3, M26-a2, b1 and b3 and covers an area of approximately 200 square kilometer.

Figure 1.1 Map showing the location of the study area.

1.2 Purpose and Methods of the Study

The purpose of this study is the describe themovement direction of the Eocene nappe emplacement in the area between the Lakes of Beyşehir and Hoyran. The tectonic slices found in the Central Taurides and known as Beyşehir-Hoyran nappes (Blumental 1947, Andrew and Robertson 2002, Ozgul 1976). These nappes emplaced on the platform carbonates of Anamas and Sultan Mountains, and are located to the eastern subsection of the Isparta Angle (Figure 1.2). Due to the tectonic setting of the Beyşehir-Hoyran nappes, the kinematic analysis is crucial to reveal tectonic evolution of the Central Taurides.

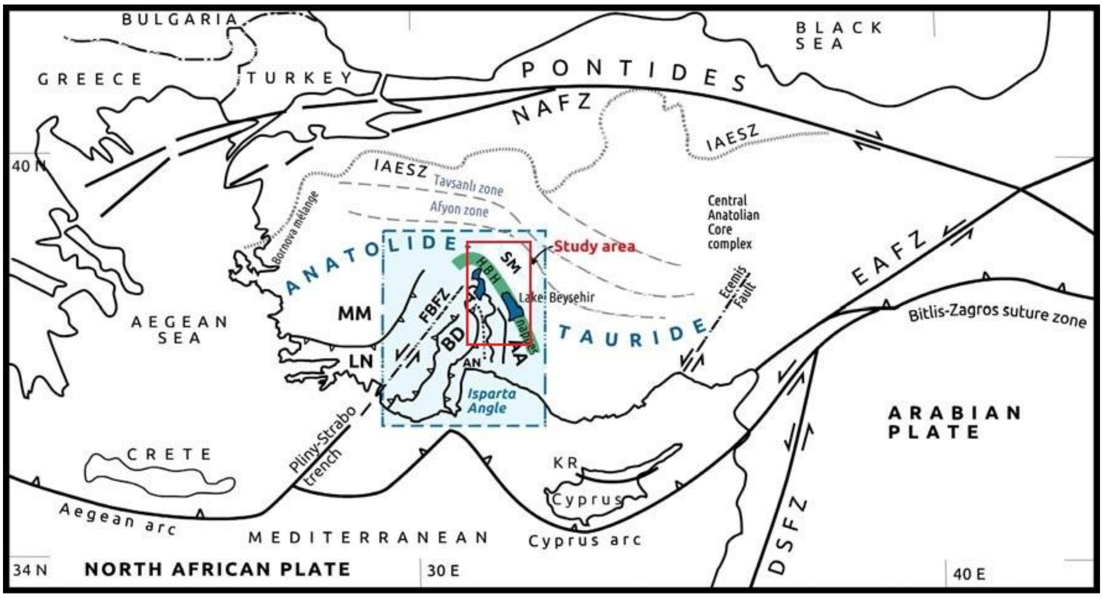

Figure 1.2 Map showing the location of the study area and tectonostratigraphic units in Central Taurides. AN Antalya Nappes, DSFZ Death Sea Fault zone, EAFZ East Anatolian Fault Zone, FBFZ Fethiye-Burdur Fault Zone, HBH Hoyran-Beyşehir-Hadim nappes, IAESZ İzmir-Ankara-Erzincan suture zone, KR Kyrenia Range, LN Lycian nappes, MM Menderes Massif, NAFZ North Anatolian Fault zone, SM Sultan Mountains (after Güngör, 2013).

Details of the main objective of this thesis are:

1. To study and map the structures along the contact between the Anamas Mountains and Beşehir-Hoyran nappes to figure out the tectonic direction of the Eocene nappe movement.

2. To describe deformation of the nappes Beyşehir-Hoyran and Sultan Mountains by examining mesoscale and microscale structures.

3. To compare the structural data obtained from this study in the structural features and then to show the evolution of the Isparta Angle.

During the field studies, structural elements in the rocks of the Beyşehir-Hoyran nappes and the Anamas autocthonous were systematically measured and mapped. In the first stage of the study the contact between the limestones of the Anamas autochthon and ophiolitic melange around the Yenicekale Village were studied to determine the proper outcrops for structural analysis. During the field studies 1/25.000 scale topographic maps were used. After the most suitable areas decided, detailed observations were done along treverses. Systematic structural measurements were carried out in the metamorphic sole rocks, ophiolites of the Behşehir-Hoyran nappes and Eocene rock units of the Anamas autochthon. Measurements about the ductile deformation were done along surfaces parallel to the stretching lineation and perpendicular to the foliaton at each outcrop (Figure 1.3).

The microstructural studies were also carried out synchronously to the field measurements. For these goal the oriented samples were collected from metamorphic sole rocks and the Eocene Celeptaş formation. A particular notice had been taken during the collection of oriented samples. Figure 1.3 explains the preparation of an oriented thin section from an oriented sample.

Samples from the Beyşehir-Hoyran nappes are generally collected from metamorphic sole rocks represented by serpantinites, amphibolites and schists. They generally show prominent lineation and mostly preserve prominent foliation. The amphibolites and serpantinites preserve numerously asymmetic structures. They are suitable for thin section studies.

During the collecting samples the strike and dip of the foliations and the trend and plunge of the lineations are drawn on the surface of the sample (Figure 1.3). Also to avoid mistakes, all locations was photographed and simple drawing of the outcrop was sketched on the field notebook.

Oriented samples were cut perpendicular to the foliation and parallel to the stretching or mineral lineation to get maximal information about the kinematic indicators (Figure 1.3). These surfaces might show asymmetric structures such as S/C, sigma clast, relation between foliation and porphyroblast/porphyroclast.

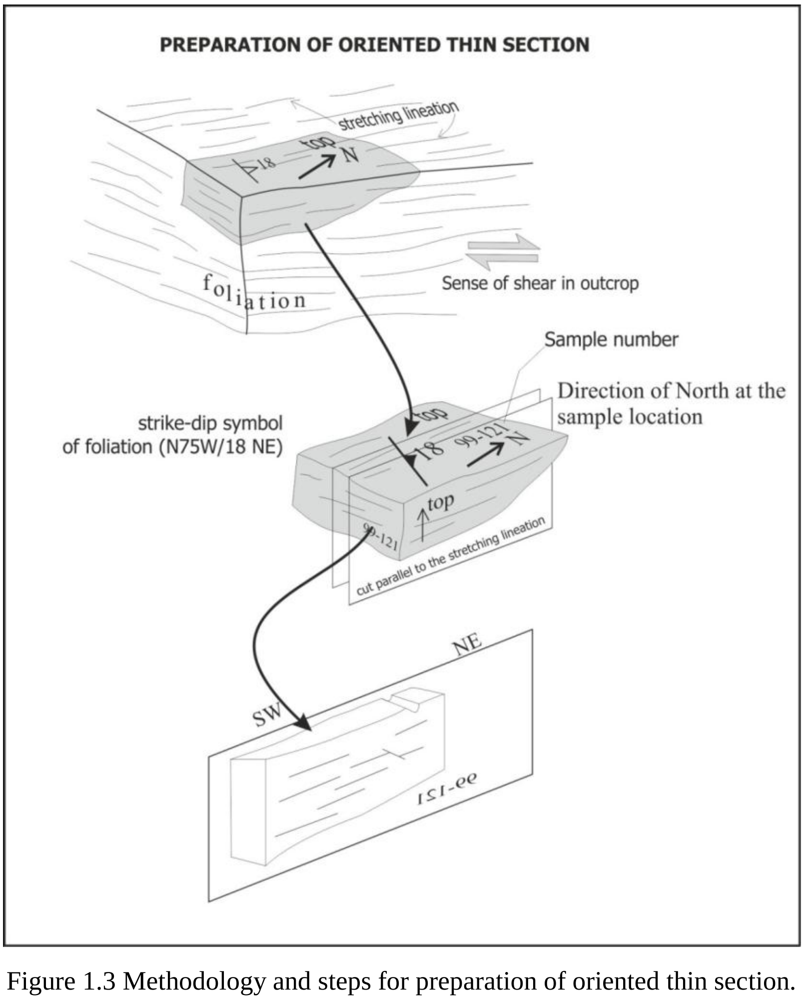

Figure 1.3 Methodology and steps for preparation of oriented thin section.

1.3 Layout of this Thesis

This thesis was arranged according to the rules of the Graduate School of Natural and Applied Sciences of Dokuz Eylül University. This thesis occurs three chapters. The first chapter introduces the location and accessibility of the study area and defines objectives and methods used in this study. Furthermore, it outlines the geological properties of the study area and surrounding area defined by the previous studies. In the second chapter, tectonostratigraphic units of the Sultan Mountains and Beyşehir-Hoyran-Hadim nappes are briefly described after Özgül et al., (1997) and Güngör (2013). The second chapter also present the structural features related to the Eocene nappe movement in the Sultan Mountains and Beyşehir-Hoyran nappes. Final chapter consists a further discussion considering the previous studies on the Central Taurides and the Isparta Angle, and concluding remarks reached by this study.

1.4 Previous Studies

Central Taurides has been studied by Blumental (1947), Özgül (1976), Demirkol and Yetiş (1983), Demirkol (1986), Akay and Uysal (1988), Ersoy (1990), Varol and Tunay (1996), Özgül (1997), Parlak and Delaloye (1999), Elitok (2000), Andrew and Robertson (2002), Robertson et al., (2003), Çelik et al., (2006), Moix et al., (2008), Güngör (2013) that have importance from many others.

Özgül (1976) studied the Taurus mountains comprising the tectonographic units which were deposited from Cambrian to Teriary, and described the following units due to their stratigraphic position, metamorphic features and the structural position of the rock units: Bolkardağı, Aladağ, Geyik Dağı, Alanya, Bozkır and Antalya Units. These structural units laterally strikes about hundreds of kilometers and mostly tectonically cover over each other. Bolkardağı, Aladağ, Geyik Dağı and Alanya units are chacarterized by shelf carabonates and clastic rocks. The Bozkır and Antalya units are characterized by deep sea sediments, ophiolites and submarine basic volcanic rocks.

Demirkol and Yetiş (1983) studied the stratigraphy of rock units cropped out of the Western Taurides (southern Turkey). They distunguished the stratigraphic units as “allochthon and autochthon” due to the their lithologic and structural proporties. Stratigraphy of the autochthon starts at the base with the Upper Cambrian-Lower Ordovician Sultandede Formation. Liasic sequence overlies the Sultandede Formation along an unconformity marked by basal conglomerates. This sedimentary sequence is made up Pre-Maastrichtian platform carbonates and Maastrichtian-Middle Eocene pelagic deposits as well as neritic deposits. While sedimentary basin was deepening, flysch facies was deposited during the Middle Eocene. Also, during this time interval the Sultan Mountains were occupied by allochthons named as the Hoyran unit. This area was uplift by the end of the Pliocene. The authors also metioned that when the Mesozoic and Senozoic formations has been folding by Alphin orogeny, the Paleozoic Sultandede formation has been folding not only Caledonian but also Alpine orogeny.

Özgül (1997) studied in detail the stratigraphy and tectonic settings of Geyik Dağı, Aladağ, Bolkar Dağı and Bozkır units in the area between Bozkır, Hadim and Taşkent towns (Southern Turkey). The Geyik Dağı unit is the structurally lowest unit and is tectonically overlain by Bolkar Dağı, Aladağ and Bozkır Units. The author described the Dipsiz Göl Ophiolitic melange found as a tectonic slice above the Geyik Dağı Unit and below the Aladağ and Bolkar Dağı Units. This melange is characterized by ophiolites, pelagic limestones with spilitic volcanic intercalations and distal turbidites. The origin of this melange is probably a basin located in the Neotethys between the Geyik Dağı and Aladağ units and existed from the Late Senonian to the Early Tertiary.

Elitok (2000) studied mineralogical and petrographical properties of the rock units crop out between Şarkikaraağaç and Yalvaç in the Central Taurides. He examined the allochthon and autochthon rock units. The author described middle Jurassic volcanic rocks found as intercalations in the Hacıalabaz formation represented by platform carbonates. He determined that the emplacement age of the Kızıldağ ophiolite is the upper Eocene.

Andrew and Robertson (2002) described emplacement events of the Beyşehir-Hoyran-Hadim Nappes in the Central Taurides. They summarized Beyşehir-Hoyran-Hadim Nappes units from NW to SE listed below in Central Taurides: Dinar area, Beyşehir area, Bozkır area and Ermenek-Karaman area. They explained that during the Late Eocene time the autochthons subsided as a flexural foredeep in front of the Beyşehir-Hoyran nappes. According to the authors, the emplacement of the Hoyran-Beyşehir nappes evolved in two phases: First, ophiolites from the Northern Neotethys emplaced on the Geyik Dağı unit during the Latest Cretaceous and after than, southward translation of the nappe pile on the platform carbonates of the Geyik Dağı unit occurred during the Early-Middle Eocene.

Robertson et al., (2003) outlined the development of the Isparta Angle in its regional context. They mainly focused on the core part of the Isparta Angle. According to the authors three allochthon systems are found in Isparta Angle. These are represented by the Antalya, Lycian and Hoyran-Beyşehir-Hadim nappes. These allochthons orginated from paleogeographically contrasting areas of Neotethys. They exclaimed the Beyşehir-Hoyran-Hadim nappes root far to the northeast within a northerly branch of the Neotethys. Authors mentioned that the Hoyran-Beysehir-Hadim nappes initally emplaced southwards during latest Cretaceous.

Çelik and Delaloye (2006) described petrography, tectonic setting and geothermobarometry of the amphibolites situated along the sole of serpantinites in the Beyşehir-Hoyran nappes. Authors determined that ophiolite-related metamorphic rocks in the Beyşehir ophiolitic melange exhibit four mineral parageneses and show mainly granoblastic, grano-nematoblastic, porphyroblastic or poikiloblastic textures. These amphibolites show an alkaline to subalkaline characters and a typical ocean island basalts affinity. Age dating data from these amphibolites show $^{40}Ar/^{39}Ar$ ages between 90,7±0,5 and 93,8±1,7 Ma in hornblendes, and 91,2 ±2,3 and 93,6 ± 0,8 Ma in white micas. These radiometric dating data point out an obduction started at Late Cretaceous.

Güngör (2013) described kinematics of the nappes in the Sultan Mountains, Central Taurides. The Sultan Mountains contain in ascending order the Çimendere unit as relative autochthone, and the Akşehir, Doğanhisar, Çay nappes as allochthons (Figure 1.4). The Çimendere unit occupies the structurally lowermost position. The author indicated that the latest nappe emplacement occured during the Middle Eocene kinematic data along the Sultan Mountains, he interpreted tectonic models for the Central Taurides. According to the previous tectonic models nappe translation occurred from north to south over the Anatolide-Tauride platform. The kinematic data was obtained from the structural elements formed during the Mid-Eocene all around the Sultan Mountains. These kinematic data related to the Mid-Eocene nappe emplacement reveal a top-NE shear sense in the northwest part and a top-SE shear sense in the southeast part of the Sultan Mountains. Besides, in consideration of exiting paleomagnetic data (Kissel et al., (1993) and Tatar et al., (2000)) which showed that the west and east subsections of the Isparta Angle were subjected to post-Eocene 30^0 and 40^0 anticlockwise and clockwise rotations, respectively, the kinematic measured along the Sultan Mountains might be restored into E-W trending linear fabric associated with a top-E shear sense related to the Mid-Eocene nappe emlacement. Also, the author reported that there is no kinematic data indicating N-S nappe translation along the Sultan Mountains.

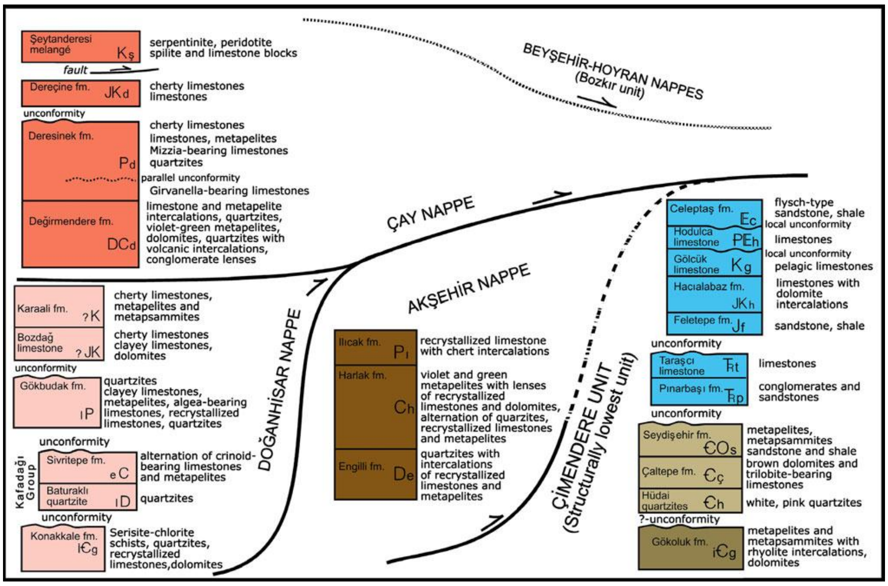

Figure 1.4 Simplified stratigraphic sequences and tectonic positions of the nappes in the Sultan Mountains (after Güngör, 2013).

CHAPTER TWO
TECTONOSTRATIGRAPHY AND KINEMATIC ANALYSIS

The Beyşehir-Hoyran nappes is a part of the Bozkır Unit of Özgül (1976). Tectonic slices of the Beyşehir-Hoyran nappes trends in NW-SE direction in the area between Beyşehir and Hoyran lakes. The Anamas and Sultan Mountains autochthons are located to the southwest and northeast of these tectonic slices respectively. The stratigraphic sequences of these autochthons are represented by platform carbonates in the lower part and sandstone-shale intercalation in the upper part. The Beyşehir-Hoyran nappes are composed of sole metamorphics, serpantinites, huge limestone blocks, spilites and olistostromal conglomerates.

2.1 Stratigraphy of Sultan Mountains Autochthon (Geyik Dağı unit)

In the Sultan Mountains, the Early Paleozoic sedimantary rocks are unconformably covered by the Triassic limestones along a basal conglomerate (Özgül et al., 1991) (Figures 2.1 and 2.2). The Triassic Pınarbaşı formation overlies the Cambro-Ordovician Seydişehir formation represented by sandstone-shale alternation with limestone and brown dolomite lenses along an unconformity identified by basal conglomerates. This unconformity between the Paleozoic and Mesozoic sequences has no much angular difference, i.e. it is more or less parallel in the Central Taurides.

The upper part of the sequence is represented by platform carbonates with local diastems. Around Şarkikaraağaç, the platform sequence is composed of dark gray, thickly bedded limestones. The beds of these limestones form an homocline and moderately dip to west and southwest. In the Kızıldağ National Park located to the south of the Şarkikaraağaç, these limestones contains aboundant bioclasts and milliolid fossils (Figure 2.3). In addition to the millioid fossils, well preserved rudists fossils are also found. In these beds, *Radiolites* sp., *Bournonia excavata* and *Jofia* cf. *cappadociensis* indicate that the age these levels of the carbonate sequence is the Campanian-Maastrichtian (Figure 2.4).

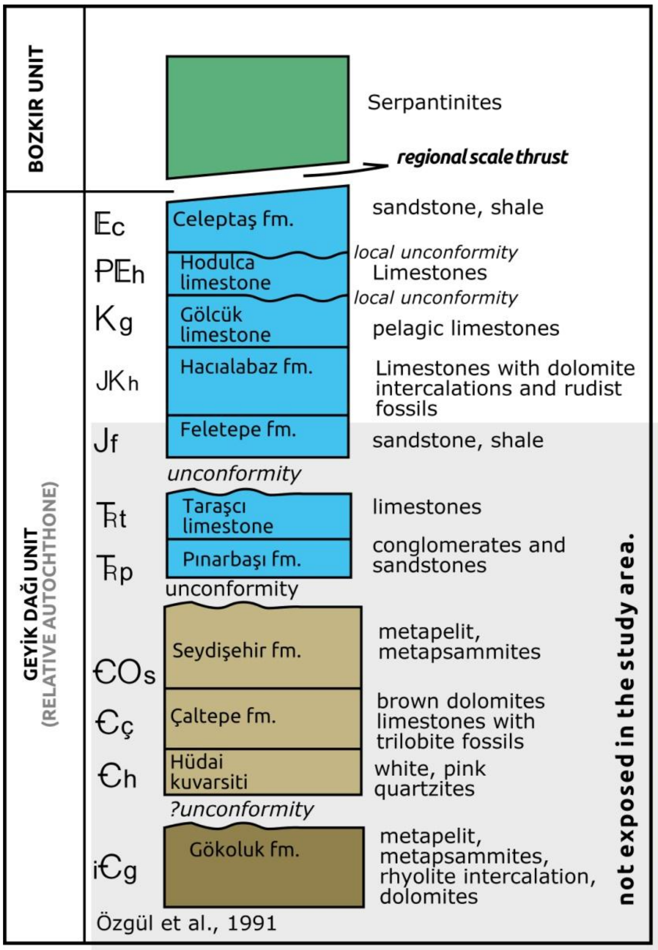

Figure 2.1 Simplified stratigraphic column of the Sultan Mountain autochthon.

Figure 2.2 Photograph showing Pınarbaşı formation composed of platform carbonates that unconformably cover the Cambro-ordovician Seydişehir formation represented by brown sandstone-shale alternation. (03 40 423E; 42 34 904N, 1319 m).

The upper part of the limestone sequence consists of sandstone-shale with nummulite-bearing limestone lenses. The nappes of the Hoyran and Sultan Mountains are found on top of the Lutetian Celeptaş formation.

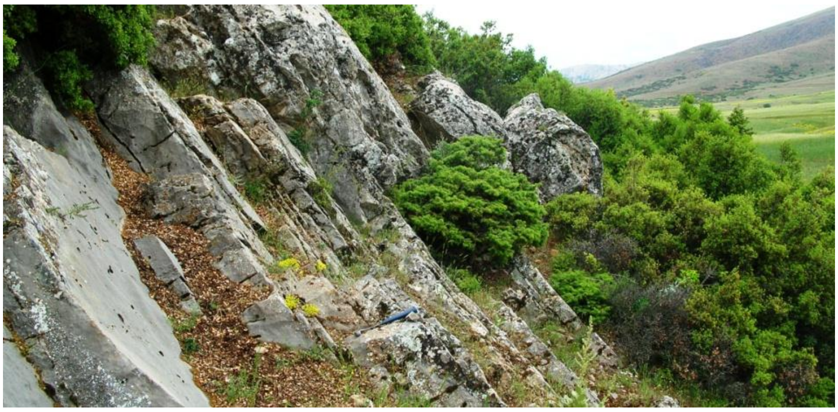

Figure 2.3 Photograph showing the medium-thick bedded limestone (Hacıalabaz formation) with abundant bioclasts and millioid fossils in the Sultan Moutains autochthon to the south of Şarkîkaraağaç (03 58 924E; 42 09 626N, 1190 m).

Due to the this structural relation, the mesoscopic and microscopic structures in the Celeptaş formation provide solid kinematic data related to the emplacement of the nappes. However, in the area between Şarkikaraağaç and Beyşehir Lake the Kızıldağ serpantinites directly overlay the Late Cretaceous limestones and the Celeptaş formation is absent in between. This lackness of the Celeptaş formation might be related to the tectonic slicing of the upper part of the platform related to the odduction of the Kızıldağ ophiolites. Besides this, the contact between the ophiolites and platform sequence is covered by alluvium over large area. For this reason, the Şarkikaraağaç region is less suitable for the kinematic analysis about the Beyşehir-Hoyran nappes.

Figure 2.4 Photographs showing rudist fossils in the Upper Cretaceous Hacıalabaz formation. Top, *Radiolites* sp. [width of view 0,5 m], Bottom left *Bournonia excavata* [width of view is 10 cm] and Bottom right longitudinal section of *Radiolites* sp. (indicated by yellow arrow) [width of view is 20 cm] and lateral section of *Joufia* cf. *cappadociensis* (indicated by red arrow) (03 58 924E; 42 09 626N, 1190 m).

2.2 Stratigraphy of the Anamas Mountains (Geyik Dağı unit)

The Anamas autochthone is represented by platform limestones in the study area (Figure 2.5). To the south of Yenicekale village these platform limestones are in contact with Beyşehir-Hoyran nappes along a NW-SE striking vertical fault (Figure 2.6).

In the study area, the lowermost part of the platform limestones was named as the Hacıalabaz formation (Özgül et al., 1991). The Hacıalabaz formation is represented by beige coloured, medium to thick bedded limestones and rare dolomite beds. These limestones contain abundant rudist shell fragments and milliolid fossils (Figure 2.7). The Gölcük limestone and Hodulca limestone are made up of yellow and beige, micritic limestones. The Hodulca limestone contain planctonic foraminifer in the lower part and nummulite in the upper part. The Celeptaş formation is represented by sandstone-shale alternation, with limestone lenses that contains abundant nummulite fossils (Figure 2.7).

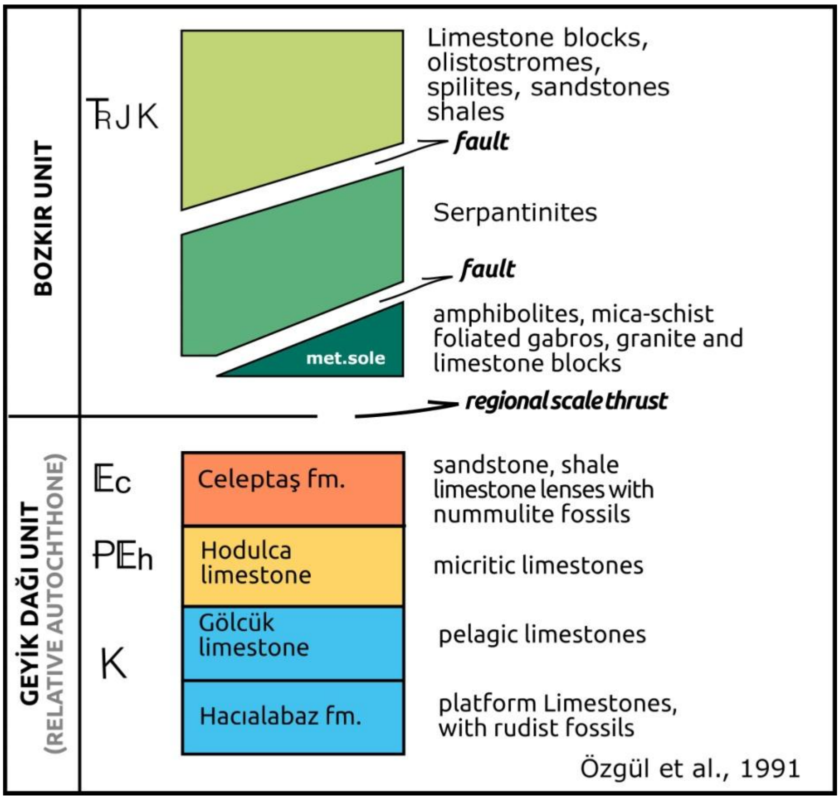

Figure 2.5 Stratigraphic column of the Anamas autochthon and structural position of the Beyşehir-Hoyran nappes around Yenicekale village.

2.3 The Beyşehir-Hoyran Nappes (Bozkır unit)

The Beyşehir-Hoyran nappes are represented by sole metamorphics, serpantinites, huge limestone blocks, sandstone-shale melange and spilites as tectonic slices (Figure 2.5, 2.6 and 2.8). The main rock type in the sole metamorphic is amphibolites (Figure 2.12). These amphibolites are dark green and dark gray in colour and show a continous foliation. This foliation is described by preferred orientation of small amphibole crystals. The microphotographs given in Figure 2.10 show this continuous

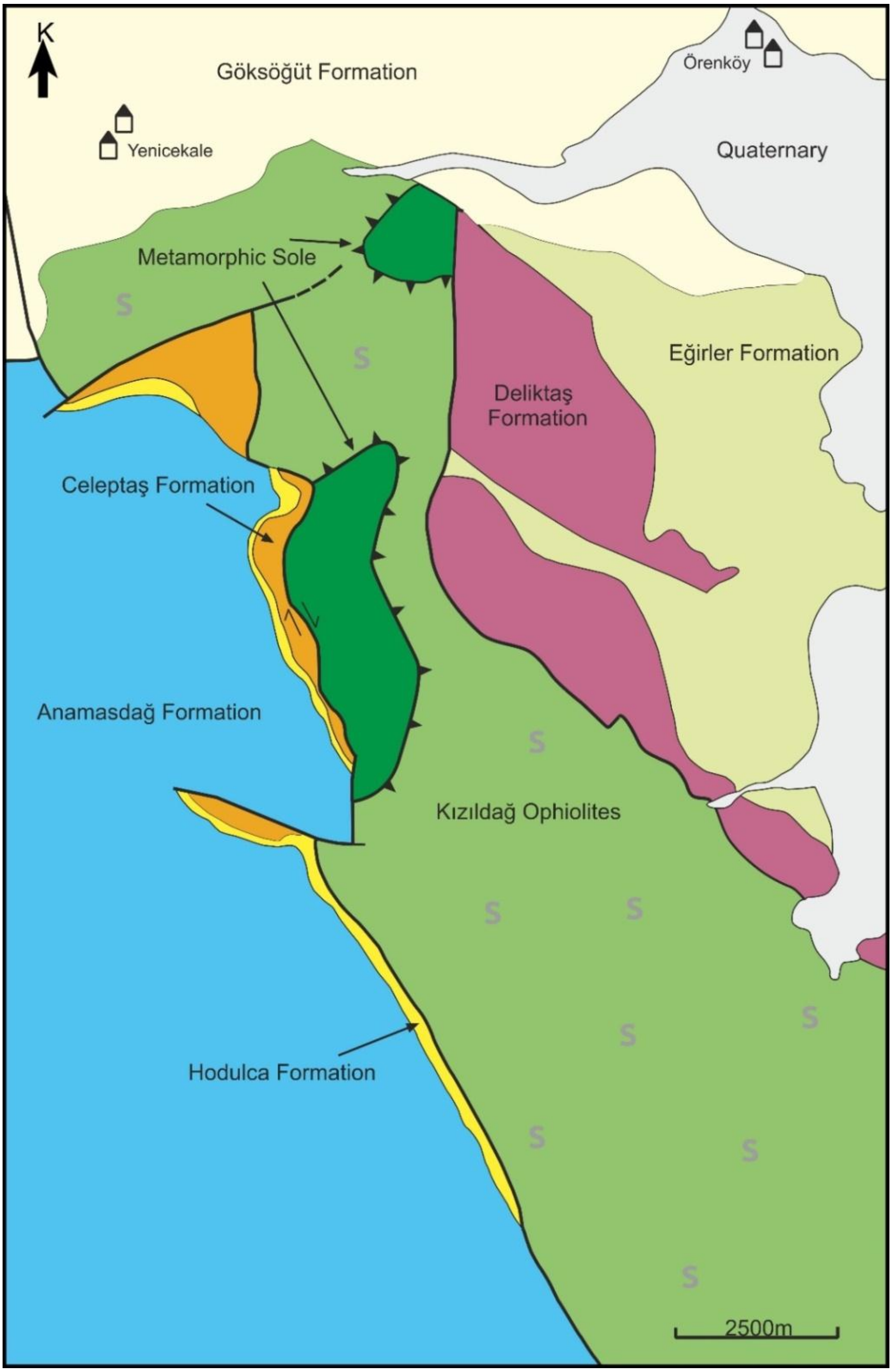

Figure 2.6 Geological map of the study area (modified after Özgül et al., 1991).

Figure 2.7 Photographs showing typical outcrops of the rock units of the Anamas autochthon. Top, medium-thick bedded platform limestones of the Hacıalabaz formation. Middle, rudists shells in these platform limestones. Bottom left, thinly bedded sandstone-shale alternation in the Celeptaş formation, bottom right, photomicrograph showing the sandstones with nummulite fossils (shown with yellow arrow) in the Celeptaş formation.

foliation in these amphibolites. Green amphibole crystals show a strong preferred orientation that form a continuos foliation. The foliated gabbros are found above the amphibolites as thin tectonic slices. In addition to foliated gabbros, the sole metamorphics are also contain strongly sheared serpantinites as thin, discontinuous tectonic slices.

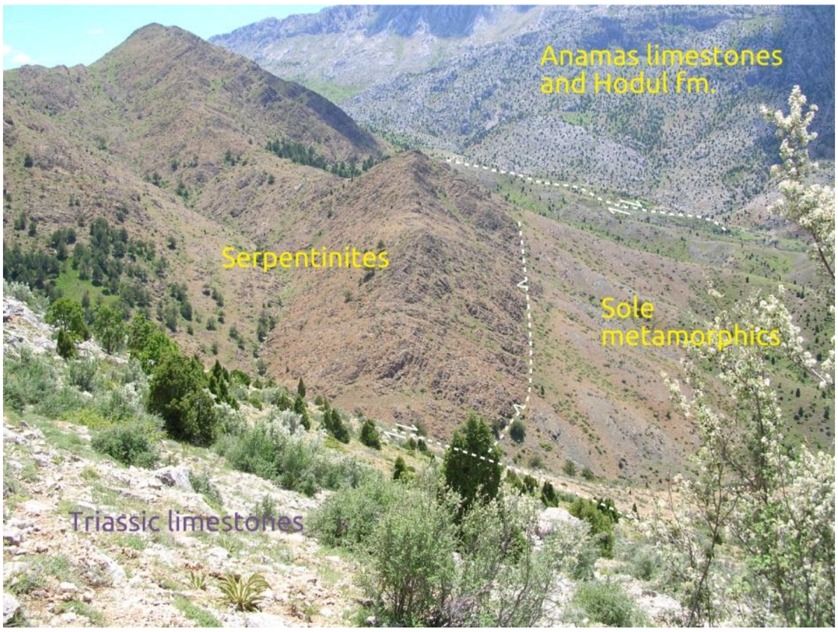

Figure 2.8 Photograph showing the tectonostratigraphic units of the Beyşehir-Hoyran nappes and Anamas autochthon to the south of the Yenicekale village [looking to south].

Serpantinites (Kızıldağ ophiolite) are typically olive green colour and have brown weathering colour. Olivine crystals are rarely preserved in serpantinites which contain cromite crsytals as thin layers and isolated grains (Elitok, 2000). Serpantinites show typical web texture in thin sections (Figure 2.9). The sole metamorphics are also contain small tectonic of whether metarhyolite or metachert (Figure 2.11). These siliceous rocks show continuos foliation. This foliation show clos folds (Figure 2.11) and sheath folds.

In addition these metamorphic rocks, within the sole metamorphics, synite/granite is found as thin tectonic slice (Figure 2.12). This granite/syenite is pink in colour, and contain K-feldspar crystals showing radial array, and green coloured amphibole crystals which needle like in shape.

Along the contact between serpantinites and sole metamorphics the recrystallized limestone blocks and tectonic slices have been found. (Figure 2.13). Because of intense deformation these recrystallized limestones do not contain any primary structures or texture that may indicate origin of them.

Figure 2.9 Photographs showing typical outcrops of serpantinites (top, 03 45 730; 42 11 908, 1239 m) and amphibolites (bottom, 03 41 670; 42 14 970, 1392 m) in the Beyşehir-Hoyran nappes and photomicrographs showing the textures of serpantinites (top) and amphibolites (bottom).

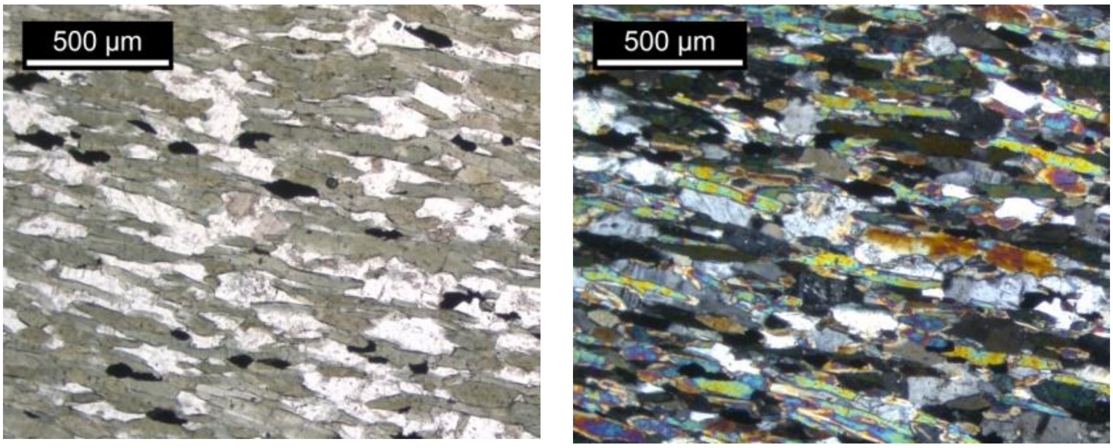

Figure 2.10 Photomicrograph showing continous foliation in the amphibolites in the metamorphic sole. Left, plane polarized light and right, cross-polarized light.

The tectonic slice composed of limestone blocks, sandstone and shale, spilitic volcanites and olistostromal conglomerates is found on the serpantinites and occupies the structurally uppermost position in the Beyşehir-Hoyran nappes. This tectonic slice crop out between Belceğiz and Yenicekale villages in NW-SE direction. Due to the lithological contrast, the trust contact between huge limestone block (The Bakır Dağı limestone, Özgül et al., 1991) and serpantinites can be traced overtly in the field. The limestone blocks contain large megalodont fossils which indicate platform conditions (Figure 2.14). Due to the their white colour and massive internal structure, these limestones were cut to produce marble. The internal structure of this tectonic slice is complex. The olistostromal conglomerates are found close to the limestone blocks that are over 2 km in size. The olistostroms is composed of various limestones and sandstone blocks up to 20 cm set in a coarse, sandy matrix.

Figure 2.11 Photograph shows tightly folded metarhyolite/metachert.

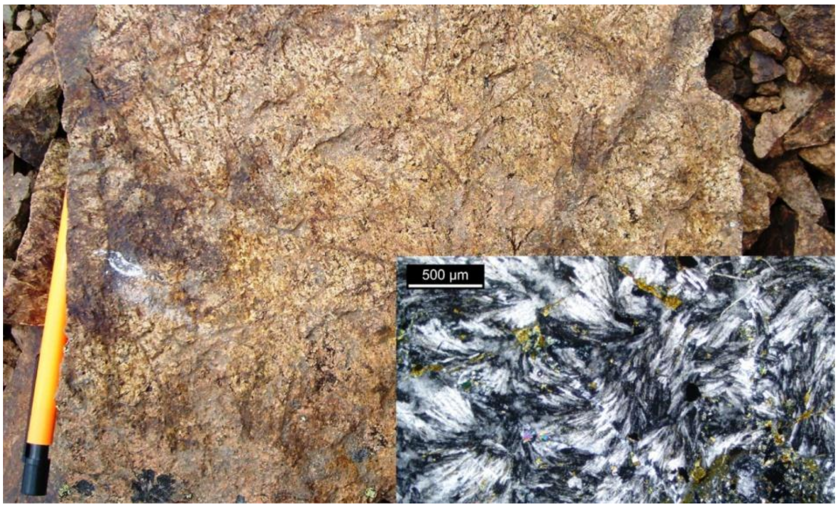

Figure 2.12 Photograph and photomicrograps (inset) showing pink granite/syenite described in the sole metamorphics. Feldspar crystals show a radial array both in thin section and naked eye in the field (03 43 049E; 42 16 259N, 1332 m).

Figure 2.13 Photographs showing recrystallized limestone blocks along the contact zone between metamorphic sole and serpantinites (Yenicekale village).

2.4 Contact Features

In the area between Beyşehir and Hoyran lakes the contact between the Anamas autochthone and tectonic slices of the Bozkır unit (Özgül, 1976) was described as the regional scale thrust (Andrew and Robertson, 2002; Çelik 2006; Elitok, 2000). In the study area the contact relationships of the tectonostratigraphic units are described and discussed below.

The contact relation between the Anamas autochthone and the sole metamorphics is observed overlay around Yenicekale village (Figure 2.8). The sole metamorphics thrust on the Celeptaş formation of the Anamas autochthone. To the southeast (Figure 2.6) of Yenicekale village the fault contact between the Anamas autochthone and serpantinites strike NW-SE and approximately vertical (Figure 2.15).

Figure 2.14 Photographs showing the lithologic properties of the tectonic slice consisting of limestone blocks (Bakır Mountain limestone) and melange. Top, contact relation between limestone block and the matrix composed of sandstone, shale and olistostromes. Middle, bivalvia with mogalodontit- type shell (?Megalodon) in the Bakır Mountain limestone. Bottom, olistosromal conglomerates in the melange wrappe the limestone blocks (03 43 806E; 42 14 018N, 1691 m).

Approximately zero rakes of the slickenlines and grooves on fault plane indicate a strike-slip sense of movement. The brittle kinematic indicators along the fault plane show a dextral sense of movement. This dextral strike-slip fault define the Beyşehir-Hoyran nappe which never thrust over the Anamas autochthon (Poissson et al., 2003a, b). the west and southwest of this in fault the study area the Beyşehir-Hoyran nappes are absent on the Anamas autochthone. This structural position and attitude of the fault indicate that this dextral faults represent a lateral-wall in a thrust system (i.e Beyşehir-Hoyran nappe system).

Structural measurements along the contact between limestone blocks of melange and serpantinites define a strike-slip fault (Figure 2.16). The contact between lenage and serpantinites strikes NW-SE between Yenicekale and Ördekçi villages and dip steeply (65-75^0) to NE. Slickenlines and grooves on fault plane indicate the rakes with acute angles (<20^0). This geometric relation shows that the fault between limestone blocks of melange slice and serpantinites has dominantly a strike-slip sense of movement. The kinematic indicators point up a dextral movement same as the fault contact between the Anamas autochthone and Beyşehir-Hoyran nappes.

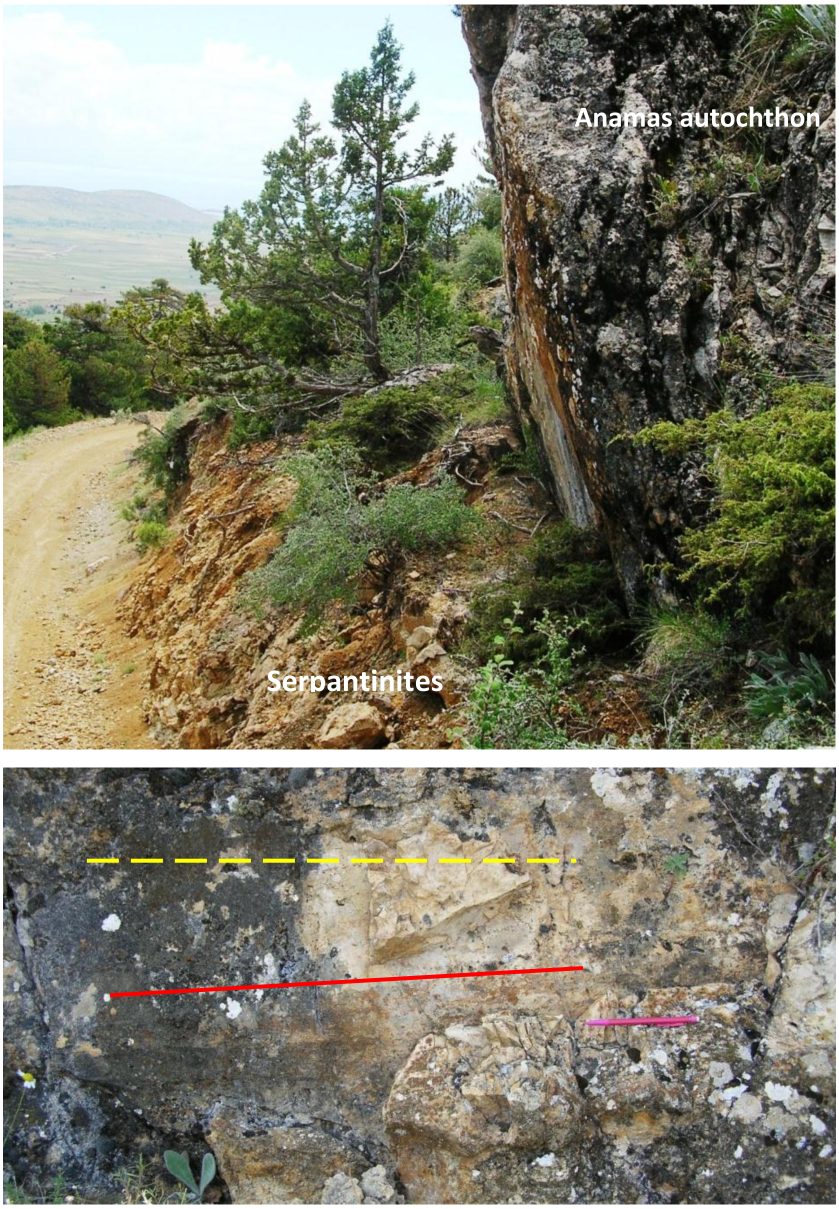

Figure 2.15 Vertical faults located between the platform carbonates of the Anamas autochthon and serpantinites to the northwest of Belceğiz village (top) [looking to southeast]. Slickenlines on the fault plane (bottom). Horizontal slickenlines indicate that fault has a strike-slip sense of movement. Pencil and red line are parallel to the slickenlines. Kinematic data indicates that fault has dextral sense of movement. Dashed yellow line is fault strike, red line is paralel to the slickenlines (03 44 643E; 42 05 920N, 1685 m).

The dextral sense of movements along the faults define that the Beyşehir-Hoyran nappes emplaced presently southeastward on the autochthones of Sultan Mountain and Anamas in the Central Taurides.

Figure 2.16 Photographs showing step fault plane seperate serpantinites of the Beyşehir-Hoyran nappes and Triassic Bakır Mountain limestone (top). Acute rakes of slickenlines (bottom) on fault plane indicate that a dextral strike-slip sense of movement is dominant. Dashed yellow line shows strike of fault and red line is parallel to the slickenlines (03 45 176E; 42 11 615N, 1334 m).

2.5 Kinematic Analysis

Amphibolites, (Figure 2.17) part of the serpantinites of the Beyşehir-Hoyran nappes and the Celeptaş formation that forms the stratigraphically uppermost position the Anamas autochthone provide crucuial data for the kinematic analysis in the Central Taurides (Figure 2.18).

The Beyşehir-Hoyran nappes overthrust the Lutetian Celeptaş formation. The Lutetian is the time for the empacement of Beyşehir-Hoyran nappes in study area. The grains of sandstones in the Celeptaş formation almost completely composed of red chert, serpantinites and mafic volcanics which reflect an ophiolitic source.

Figure 2.17 Field views of metamorphic sole around Yenicekale highland. Photographs showing thin and continous foliation in the amphibolites (top, 03 41 731E; 42 15 279N, 1404 m) and thin foliation in the lower part of the serpantinites (bottom, 03 40 315E; 42 15 268N; 1459 m).

Above all, structure in the sole metamorphics composed mainly of amphibolites and the Celeptaş formation (i.e. along the contact zone of the Anamas autochthone and Beyşehir-Hoyran nappes) were measured to described the emplacement direction of the allachthones. Therefore, during field work, asymmetric structures in the oriented outcrop parallel to the stretching lineation and perpendicular to the foliation were observed to identify direction of nappe movement.

Figure 2.18 Photographs showing lineation structures along the foliation in the metamorphic sole rocks and serpantinites, pencil is 13 cm and parallel to the stretching lineation (03 42 666E; 42 16 369N, 1362 m).

Besides these, the asymmetric structures in the oriented thin sections studied to be a party to field work.

Amphibolites in sole metamorphics show a characteristic continuous foliation. This foliation is identified by prefered orientation of amphibole crystals (Figure 2.10). Amphibole crystals have an average size of 250 μm, and is diagnosed by strong green plecroism. The lowermost part of serpantinites along the contact with the amphibolites show a prominent foliation with a remarkable linear fabric (Figure 2.18).

The lowermost part of serpantinites and amphibolites, the foliaton planes display a striking stretching lineation diagnosed by preferred orientation of amphiboleand serpantine crystals (Figure 2.18). During the fieldwork trends and plunges the stretching lineation was ststematically measured on the foliation planes in amphibolites and serpantinites.

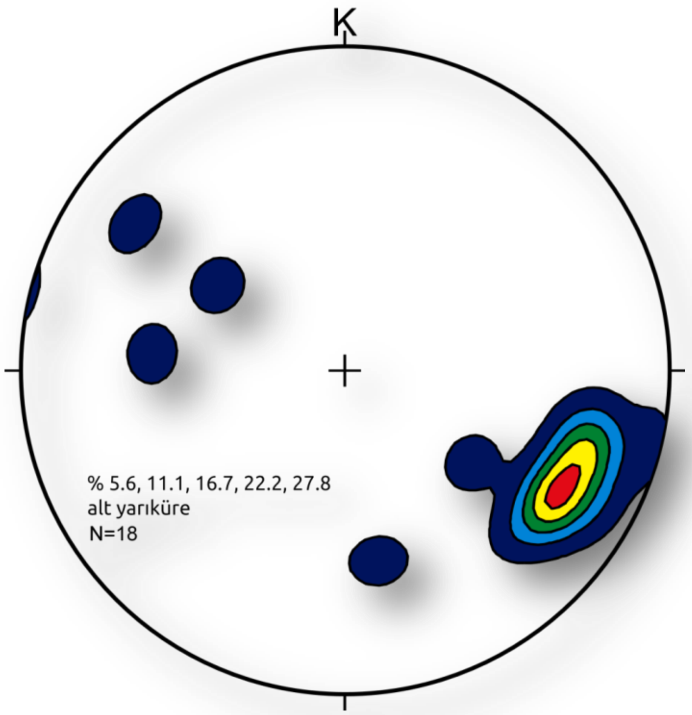

Figure 2.19 Contour diagram of the stretching lineation in the sole metamorphics. Diagram clearly shows that the trend of stretching lineation dominant in NW-SE direction. Lineation has a shallow plunge (25^o) to SE. Trend of the linear fabric indicate that the Beyşehir-Hoyran nappes moved along NW-SE direction.

Trends and plunges of this linear fabric were plotted contoured an stereonet (Figure 2.18). This stereographic plot reveals that the linear fabric has a mean orientation of 120^O/25^O clearly indicate that in the study area. The mean trend of the linear fabric the Beyşehir-Hoyran nappes movedin NW to SE direction while overthrust Anamas and Sultan Mountain autochthon in Central Taurides.

2.6 Mesoscale Kinematic Indicators

During the fieldwork, the asymmetric structures on the oriented outrcops parallel to the stretching lineation and associated foliation were systematically studied. S/C relation in the well foliated amphibolites indicate that upper part was sheared to the right of the outcrop, i.e. top-to-the SE sense of shearing. Sigmoidal shapes of the foliation planes between two cleavage planes are clearly seen on outcrops (Figure 2.20).

Strongly sheared serpantinites with thinly foliation along the lowermost part of the Beyşehir-Hoyran nappes indicate intense deformation and mylonitization around Yenicekale and Madenler villages.

S/C relation in the thinly foliated serpantinites (Figure 2.21) suggests a top-to-the southeast sense of shearing. The foliation planes (S) with moderate dip were cut by approximately flat cleavage planes (C) to form of sigmoids.

Both in the amphibolites and serpantinies with intense deformation the S/C relation consistently indicate a top-to-the southeast shear sense in the Beyşehir-Hoyran nappes. In the intensely sheared serpantinites the asymmetry of sigmoidal porphyroclasts (serpantine sigmoids) also indicate a top-to-the southeast sense of shearing (Figure 2.22) same as the S/C relations suggest.

The kinematic indicators such as S/C relation and sigmoidal porphyroclasts (σ-clasts) coherently indicate a top-southeast shear sense in the Beyşehir-Hoyran nappes in the area between the Hoyran and Beyşehir lakes.

Figure 2.20 Photograph showing S/C structures in thinly foliated amphibolites. In each photo a top-to-the-right sense of shear is clear in the amphibolites. These ductile asymmetric structures indicate that amphibolites was moved to southeast during Lutetian nappe emplacement. Yenicekale Highland (03 41 654E; 42 15 604N; 1436 m).

The structures in the Celeptaş formation specially close to the upper contact with serpantinites and amphibolites derive some data for kinematic analysis related to the empacement of the Beyşehir-Hoyran nappes. In the Yenicekale Pleatau, along the contact zone between the Beyşehir-Hoyran nappes and Celeptaş formation the asymmetry of folds in sandstone-shale alternation with limestone lenses containing nummulites suggests that the overlying nappes moved from northwest to southeast in reference to current geographic directions.

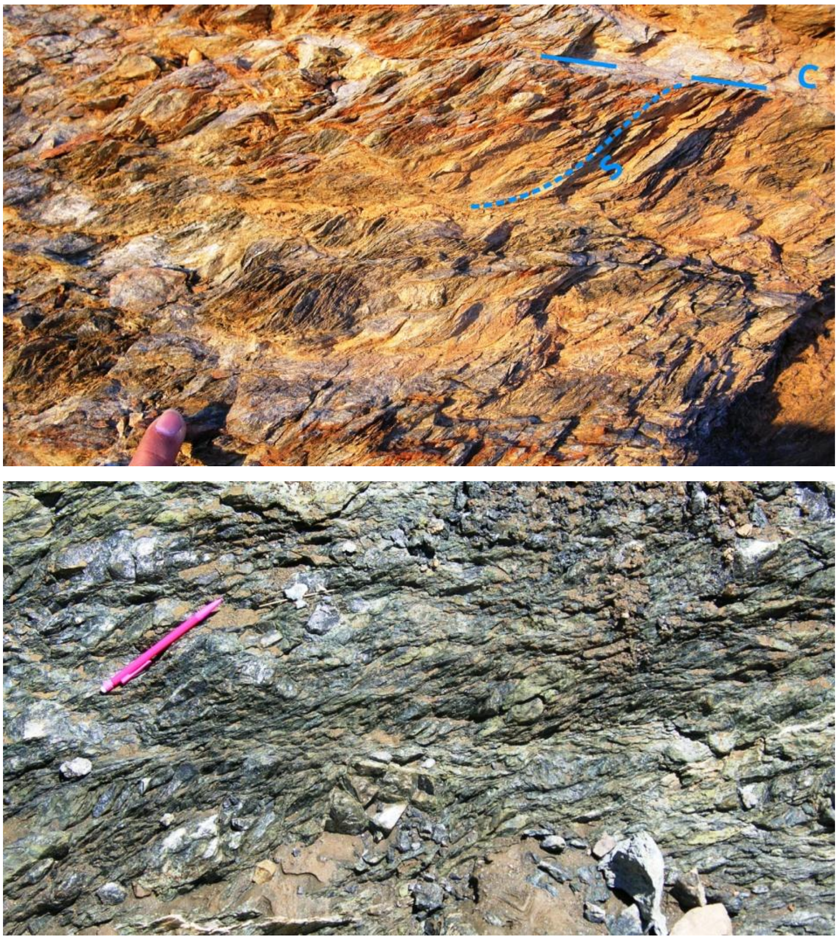

Figure 2.21 Photographs showing S/C structures in serpantinites with continuous foliation. Photos indicate a top-to-the-right sense of shear in the serpantinites. High angle foliation planes (S) was overprinted by approximately horizontal cleavage planes (C). Foliation planes with sigmoidal shapes (top) clearly indicate direction of deformation.

In addition to these asymmetric folds, the competent part such as sandstone beds and limestone lenses in the Celeptaş formation overthrust southeastward on surrounding beds to form an internal imbrication (Figure 2.24 and 2.25). In these sandstone-shale alternation Figure 2.24 shows two mesoscopic overthtrust of sandstone beds and Figure 2.25 shows a multiple imbrication of limestone lenses just below the sole metamorphics and intensely sheared serpantinites of the Beyşehir-Hoyran nappes in Yenicekale Plateu. The asymmetry also shows a top-southeast sense of movement in the Celeptaş formation.

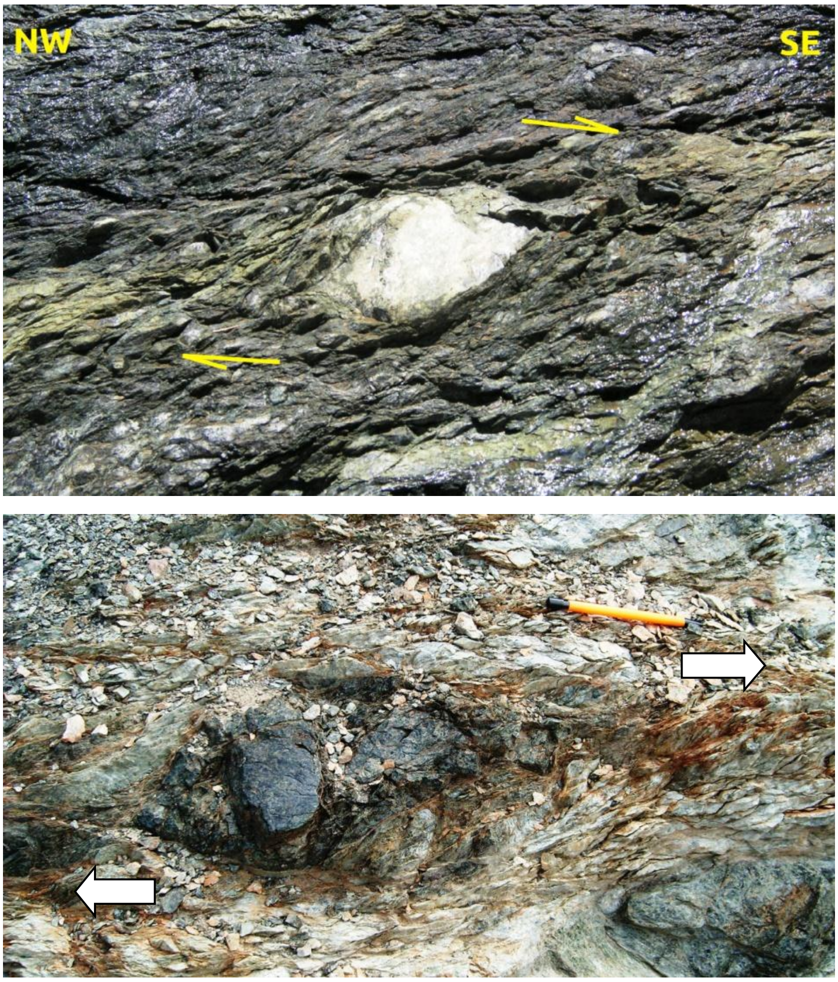

Figure 2.22 Photogpraphs showing sigmoid structures in serpantinites with continuous foliation. Both porphyroclasts with asymmetric tails indicate a top-to-the-right sense of shear in the serpantinites. These structures proof that Beyşehir-Hoyran nappes translation over to the southeast. Yenicekale Highland and Madenler village (03 33 475E; 42 28 522N, 1014 m).

2.7 Microscale Kinematic Indicators

The oriented samples were cut to prepare thin sections oriented parallel to stretching lineation and perpendicular to foliation. The details of the methodology was given in chapter 1. Petrographic and microscale structural features of these rocks are given belows (Figure 2.26 and 2.27). In the oriented thin sections the asymmetric structures such as S/C relation and σ-clast indicate sense of shear in amphibolites of the sole metamorphics.

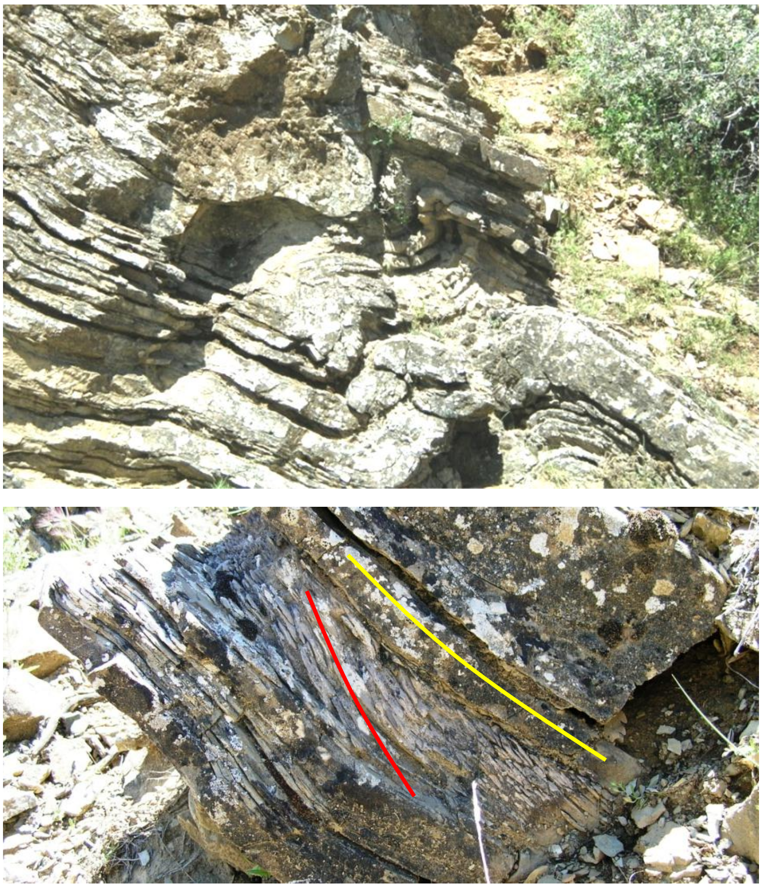

Figure 2.23 Photographs showing an asymmetric mesoscopic fold in red and green sandstone-shale alternation in the Celeptaş formation (top, Yenicekale Highland, width of view is 3m.). Steep cleavage planes in the shale bed on the fold limb (bottom), yellow line is parallel to sandstone layer, red line is parallel to cleavage planes in shale bed (03 41 436E; 42 15 212N, 1354 m).

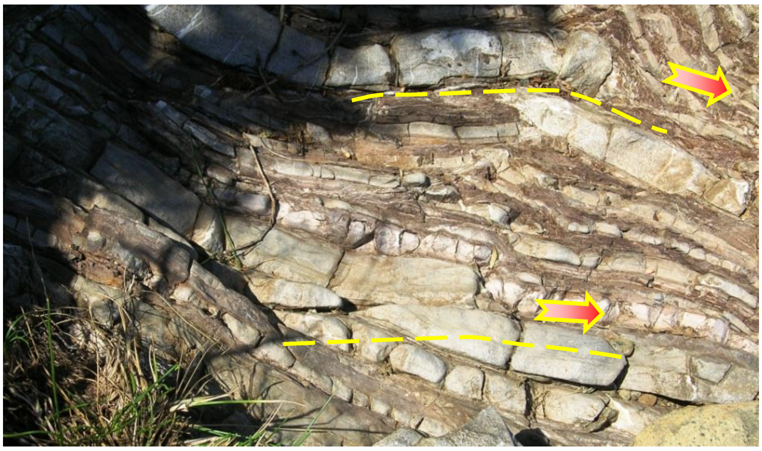

Figure 2.24 Photograph showing imbrication in the sandstone-shale alternation in the Celeptaş formation by mesoscopic reverse faults (yellow dashed lines). Sense of movement of the hanging walls of these faults indicate a southeast movement. Yenicekale Hihgland.

Figure 2.25 Photograph showing deformation of the limestones lenses with nummulite fossils in the Celeptaş formation. Slicing and imbrication of the limestone lenses by mesoscopic thrusts clearly indicate a top-to-the-right sense of shear. This outcrop located just below the sole metamorphics point out that sole metamorphics and the Celeptaş formation moved together to the southeast during emplacement of the of the Beyşehir-Hoyran nappes.

Figure 2.26 show two examples of S/C relation in thinly foliated amphibolites. In both microphotographs approximately flat foliation planes (S) were deformed by moderately dipping cleavage planes. Asymmetry of the S/C relation clearly indicate a top-to-the right sense of shear, i.e. top-southeast shear sense. σ-clast in amphibolites also show a top-southeast shear sense in amphibolite (Figure 2.27).

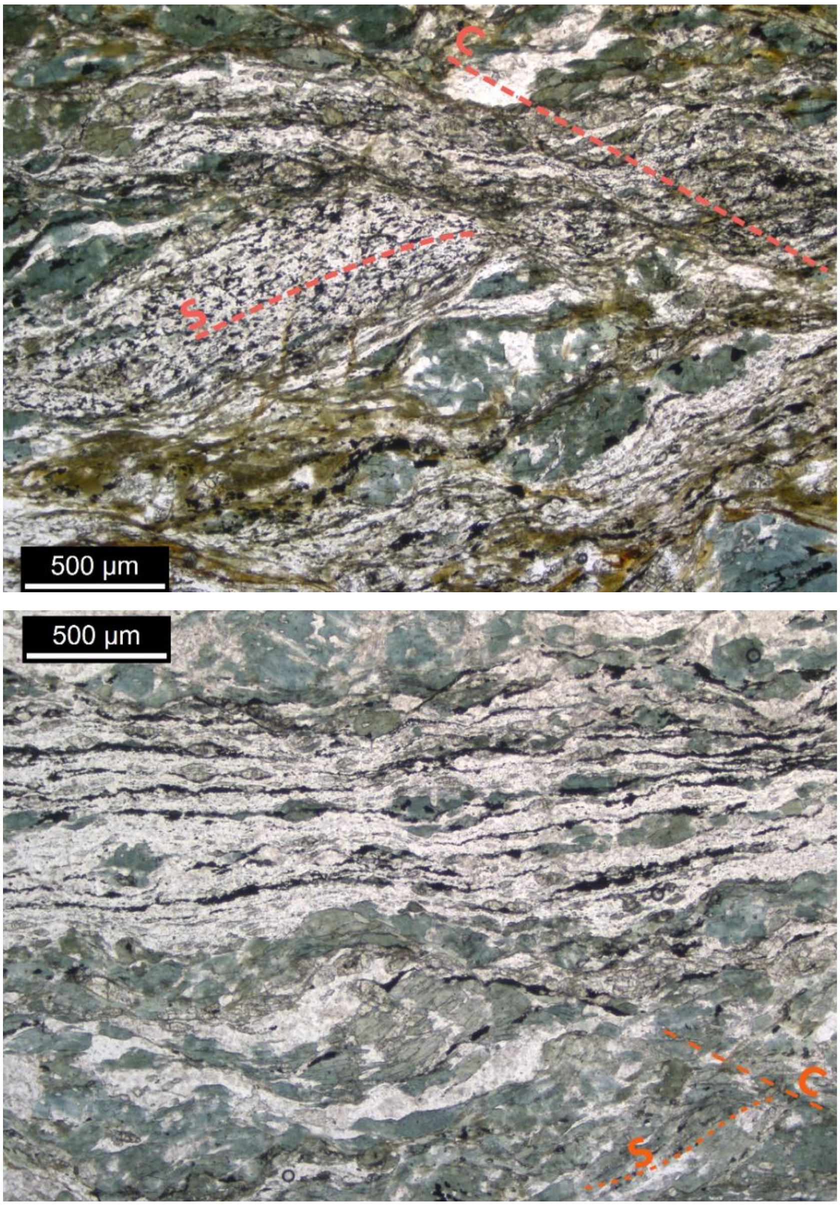

Figure 2.26 Photomicrographs of thin sections of amphibolites in the sole metamorphics showing S/C relationships. Asymmetry of these structures indicate a top-to-the-right, i.e. top-southeast, sense of shear. S indicates foliation, C indicates cleavage planes.

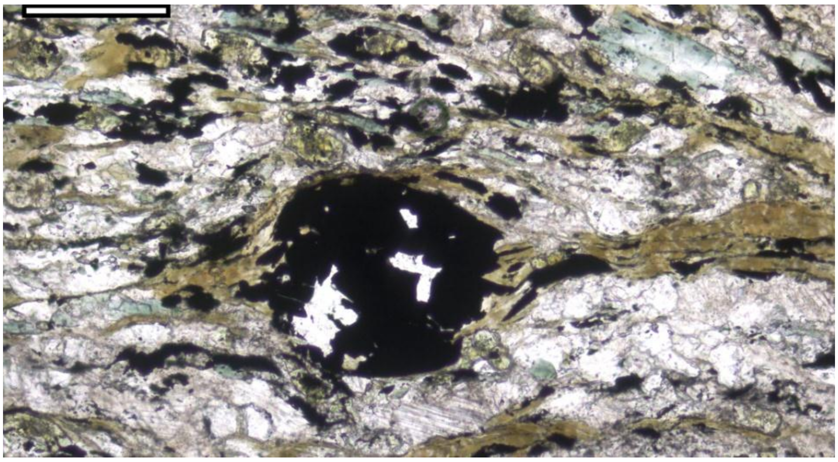

Figure 2.27 Photomicrograph showing asymmetic tails composed of chlorite crystals around the opaque mineral indicate a top-to-the-right, i.e. top-southeast, sense of shear. Scale bar is 200 μm.

To sum up, amphibolites, serpantinites and sandstone-shale alternation of the Celeptaş formation exhibit asymmetric structures such as S/C relations, σ-clasts, fold and faults associated with a southeast-trending stretching lineation. Asymmetry of these structures clearly indicate a top-southeast shear sense during emplacement of the Beyşehir-Hoyran nappes onto the autochthonous of Sultan Mountains and Anamas in the area between the lakes Hoyran and Beyşehir in Central Taurides.

CHAPTER THREE
DISCUSSION AND CONCLUSIONS

The study area is located on the northeastern part of the Isparta Angle which is main macroscopic structure of the Central Taurides. Although the Isparta Angle form main structure of the Central Taurides, the kinematic analysis of the nappes in the area is very limited. The Isparta Angle was tectonically assembled by the Lycian, Hoyran-Beyşehir-Hadim and Antalya allochthons on the Beydağları and Anamas-Akseki autochthons from the Latest Cretaceous to the Late Pliocene (Şengör and Yılmaz, 1981; Özgül, 1984; Poisson et al., 2003; Robertson et al., 2003). The proposed tectonic models for the Isparta Angle come up with the internal stratigraphy, tectonic position, metamorphic grade and current attitudes of the boundaries of tectonostratigraphic units in the lack of kinematic analysis (Güngör, 2013).

Şengör and Yılmaz (1981) identified southward ophiolite obduction from the northern branch of the Neotethys on the Anatolide-Tauride block during the Late Cretaceous-Middle Eocene. Okay et al., (2001) and Moix et al., (2008) confirm the southward movement of the nappes along the Central Taurides.

The alternative tectonic model was mainly based on the Antalya nappes and defined the latest Cretaceous-Middle Eocene closure of the Pamphylian or the Isparta Angle Ocean basin due to the east-west compression (Poisson et al., 1984 and 2003, Robertson, 1993).

The study area is located to the northeastern part of the Isparta Angle (Figure 3.1) and comprises the Anamas and Sultan Dağları autochthons and Beyşehir-Hoyran allachthons. The stratigraphic records of the autochthons show that the Beyşehir-Hoyran nappes were emplaced during Lutetian (Middle Eocene). The Lutetian Celeptaş formation is composed of sandstone-shale alternation with nummulite-bearing limestone lenses and is found on the top of the progressive platform carbonates of the autochthons. The Beyşehir-Hoyran nappes is the another tectonic component of the Isparta Angle and form a bend parallel to the bending of Isparta Angle (Blumental, 1947; Özgül 1976 and 1984; Poisson et al., 2003). The Oligocene rocks are in post-tectonic facies (molasse) and unconformably cover Beyşehir-Hoyran nappes in the eastern part of the Isparta Angle.

Systematic structural measurements in the Beyşehir-Hoyran nappes and Celeptaş formation indicate that the linear structures and associated shear sense indicators are consistent in both autochtones and allochthous. In the area between the Lakes of Hoyran and Beyşehir, the meso- and micro-structures related to the Lutetian nappe emplacement clearly suggest a top-SE shear sense.

This kinematic data obtained from the study area disagree with the tectonic models put forward the southward nappe translation that crossed over the Anatolide-Tauride platform (Şengör and Yılmaz, 1981; Özgül, 1984; Moix et al., 2008).

Previous paleomagnetic data show that east part of the Isparta Angle was subjected to about 40^{o} clockwise rotation (Kissel and Poisson, 1986, 1987; Kissel et al., 1993; Piper et al., 2002) from Eocene onward. In consideration of the foregoing paleomagnetic data the current attitude of the linear fabric in Beyşehir-Hoyran nappes and the Celeptaş formation should be corrected to Eocene position. Thus, the Eocene attitude of the linear fabric can be restored to E-W trend associated with top-E shear sense. This sense of shear related to the emplacement of the Beyşehir-Hoyran nappes is consistent to those in the Sultan Mountains described by Güngör (2013). During the mid-Eocene nappe movement the Beyşehir-Hoyran nappes never crossed over the Anamas-Akseki autochtone (Poisson et al., 2003a, b; Robertson et al., 2003), and the dextral strike-slip fault between the Anamas autochtone and the Beyşehir-Hoyran nappes supports this tectonic relation of allochthones and autochtone in the east part of the Isparta Angle.

Conclusions

The following are the main conclusions of this study:

1. The Beyşehir-Hoyran Nappes, Sultan Mountain Nappes and Anamas autochthone form the main tectonostratigraphic unit of the Central Taurides.

2. Anamas autochtone represented by Anamasdağ, Hodul and Celeptaş formations occupies structurally lowest tectonic position in the study area. The Anamasdağ formation is composed of gray, fossiliferous limestones. The Hodul formation consists of beige, micritic limestones. The Celeptaş formation is made up of sandstone-shale alternation with nummulite-bearing limestone lenses.

3. Sultan Mountains nappes comprise in ascending order the Çimendere unit and Akşehir, Doğanhisar and Çay nappes Güngör (2013). The structurally lowest unit i.e. the relative autochthone is the Çimendere units composed of mostly metapelites and metasammites with brown dolomites, trilobite-bearing limestone lenses and mafic volcanic intercalations. The Akşehir nappe tectonically overlays the Çimendere units and is represented by quartzites, limestone, dolomite, metapelite and recrystallized limestone. The Doğanhisar nappe overlays both Akşehir nappe and Çimendere unit consisted of schists, quartzites, recrystallized limestones and metapelites in the lower parts, and quartzites limestones and metapelites and metasammites in the upper parts. The Çay nappe occupying the structurally uppermost position is represented by limestones, metapelites, dolomites in the lower parts, and limestones and serpantinites, peridotite in the upper parts. The Beyşehir-Hoyran nappes overlay the Sultan Mountain nappes.

4. Beyşehir-Hoyran nappes comprise two main units in the study area; These are the Kızıldağ ophiolite with metamorphic sole, and the melange with huge limestone blocks. The metamorphic sole is mainly composed of amphibolites

and thin tectonic slices of foliated gabbros, granite and quartz schists. The Kızıldağ ophiolite is represented by serpantinites. The metamorphic sole rocks show a prominent foliation with a lineation provide us meso- and micro-scale stuctures for the kinematic analysis.

5. The meso- and micro-scale stuctures in the metamorphic sole of the Beyşehir-Hoyran nappes and Triassic limestones were studied to desribe dieaction of the shear sense. The contact relation between the Beyşehir-Hoyran nappes and the Anamas autochtone were also studied and redefined. In the most of the previous studies, these contacts were described as thrust faults, however new structural data obtained during this study show that these contacts are strike-slip faults. The dextral strike-slip fault between the Anamas autochthone and the Kızıldağ ophiolite represents a lateral wall in a thrust system.

6. Kinematic indicators such as S/C relation and s-clasts associated with stretching lineation and foliation shows a top-SE shear sense during the Lutetian nappe emplacements. This top-SE sense of shear is restored to approximately a top-E shear sense in consideration of the palaeomagnetic data indicating 40^o clockwise rotation of the east part of the Isparta Angle.

7. In the light of this study, the Lutetian movement direction of the Beyşehir - Hoyran nappes in the study area is similar to that in the Sultan Mountains as described by Güngör (2013).

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