DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

STRUCTURAL ANALYSIS OF THE MENDERES METAMORPHICS, LYCIAN NAPPES AND MELANGE ROCKS OF THE İZMİR-ANKARA ZONE IN AKHİSAR (MANİSA)

by
Ahmad BİLAL

June, 2013

İZMİR

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A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfilment of the Requirements for the Degree of Masters of Science
in Geological Engineering, Applied Geology Program

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June, 2013

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"STRUCTURAL ANALYSIS OF THE MENDERES METAMORPHICS, LYCIAN NAPPES AND MELANGE ROCKS IN THE İZMİR-ANKARA ZONE IN AKHİSAR (MANİSA)"** completed by **AHMAD BİLAL** under supervision of **ASSOC. PROF. DR. TALİP 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.

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Assoc. Prof. Dr. Talip GÜNGÖR

Supervisor

(Jury Member) (Jury Member)

Prof. Dr. Ayşe OKUR

Director

Graduate School of Natural and Applied Sciences

ACKNOWLEDGEMENTS

I would like to express my appreciation to Associate Prof. Dr. Talip GÜNGÖR for his kind supervision and insighful comments throughout the study. This study is supprted by Research Fund of Dokuz Eylül University (2012.KB.FEN.066).

Ahmad BİLAL

STRUCTURAL ANALYSIS OF THE MENDERES METAMORPHICS LYCIAN NAPPES AND MELANGE ROCKS İZMİR – ANKARA ZONES IN AKHİSAR (MANİSA)

ABSTRACT

In the Akhisar region to the northeast of İzmir in west Turkey, the Menderes massif, the Lycian nappes and the Bornova melange of the İzmir-Ankara zone form the main tectonic belts in structurally ascending order. In this region the Menderes massif is represented by massive marbles. The Akhisar nappe of the the Lycian nappes tectonically overlays the Menderes massif and is newly described in this study, and is composed of red and gren metaclastics with conglomerate and rhyolite intercalations and limestone lenses in the lower part, and recrystallized limestones in the upper part. The Bornova melange of the İzmir-Ankara zone tectonically overlays both the Menderes massif and is represented by an ophiolitic complex.

The mafic volcanic rocks found in the Bornova melange are alkaline and subalkaline basalts. Tectonic setting diagrams show that they mostly have affinity with the the ocean-floor basalts, the calc-alkaline basalts and mid-ocean ridge basalts.

The structures in the uppermost part of the Menderes massif and the lower part of the Akhisar nappe are mainly described and studied. Along this zone the kinematic indicators associated with stretching lineation and foliation indicate a top-to-the northeast sense of shear during the emplacement of the Akhisar nappe on the Menderes massif.

Keywords: İzmir-Ankara Zone, Menderes Massif, Lycian Nappes, Bornova Melange, Akhisar Nappe.

AKHİSAR (MANİSA) BÖLGESİNDE MENDERES METAMORFİKLERİ LİKYA NAPLARI VE İZMİR-ANKARA ZONU MELANJ KAYALARININ YAPISAL ANALİZİ

ÖZ

İzmir'in kuzeydoğusunda yeralan Akhisar çevresinde alttan üste Menderes masifi, Likya napları ve İzmir-Ankara zonu'na ait Bornova melanjı ana tektonik kuşakları oluşturur. Menderes masifi bu alanda masif mermerler ile temsil edilmektedir. Likya naplarına ait Akhisar napı bu çalışmada yeni tanımlanmıştır ve altta riyolit, çakıltaşı arakatkıları ve kireçtaşı mercekleri içeren kırmız-yeşil metakumtaşları ve üstte rekristalize kireçtaşlarında meydana gelmektedir. Bornova melanjı ofyolitik karmaşık ile temsil edilmektedir.

Bornova melanjı'nda bulunan mafik volkanitler alkaline ve subalkaline bazaltlardır. Bu bazaltlar okyanus tabanı bazaltları, kalk-alkalin bazaltlar ve okyanus ortası sırt bazaltlarının özelliklerine sahiptir.

Menderes masifi'nin üst bölümünde ve Akhisar napı'nın altında bulunan mezo ve mikro ölçekli yapılar bu çalışmada ayrıntılı incelenmiştir. Bu milonitik fay zonu boyunca oluşan yapraklanma ve lineasyon ile ilişkili kinematik belirteçler Akhisar napı'nın Menderes masifi üzerine yerleşmesi sırasında kuzeydoğuya doğru hareket ettiği göstermektedir.

Anahtar sözcükler: İzmir – Ankara Zonu, Menderes Masifi, Likya Napları, Bornova Karmaşığı, Akhisar Napı.

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CHAPTER ONE
INTRODUCTION

1.1 Location and Accessibility

The Akhisar region is located in the western part of Turkey to the northeast of İzmir (Figure 1.1). The study area includes the villages of Kayaaltı, Sarıçalı and Hasköy around Akhisar. The area is situated in the northwestern part of the Menderes Massif. The Menderes Massif is an extensive metamorphic terrain bordered between the İzmir-Ankara zone and the Lycian nappes in the west Turkey, and is mainly composed of gneissic granites, migmatites and metasedimentary succession ranging from the Early Paleozoic to the Early Tertiary ages. In the study area, the northwestern part of Menderes Massif is represented by a continuous platform sequence.

Akhisar, well-known in the west Anatolia, is located in the Manisa District in west Turkey, and is about 85 km to the northeast of İzmir. The study area is on 1/25000 scale including the topographic sheets of İzmir K19-b1, b2 and b3, and it covers approximately 150 square kilometer. Akhisar with the population of 160 000 is a town in the Manisa District, and is located to the west part of the study area (Figure 1.1).

Both highway and railway connecting the cities of İzmir and Balıkesir pass through the study area in the northeast-southwest direction. There are also minor roads connecting towns and village, and all of them are in use all year-long.

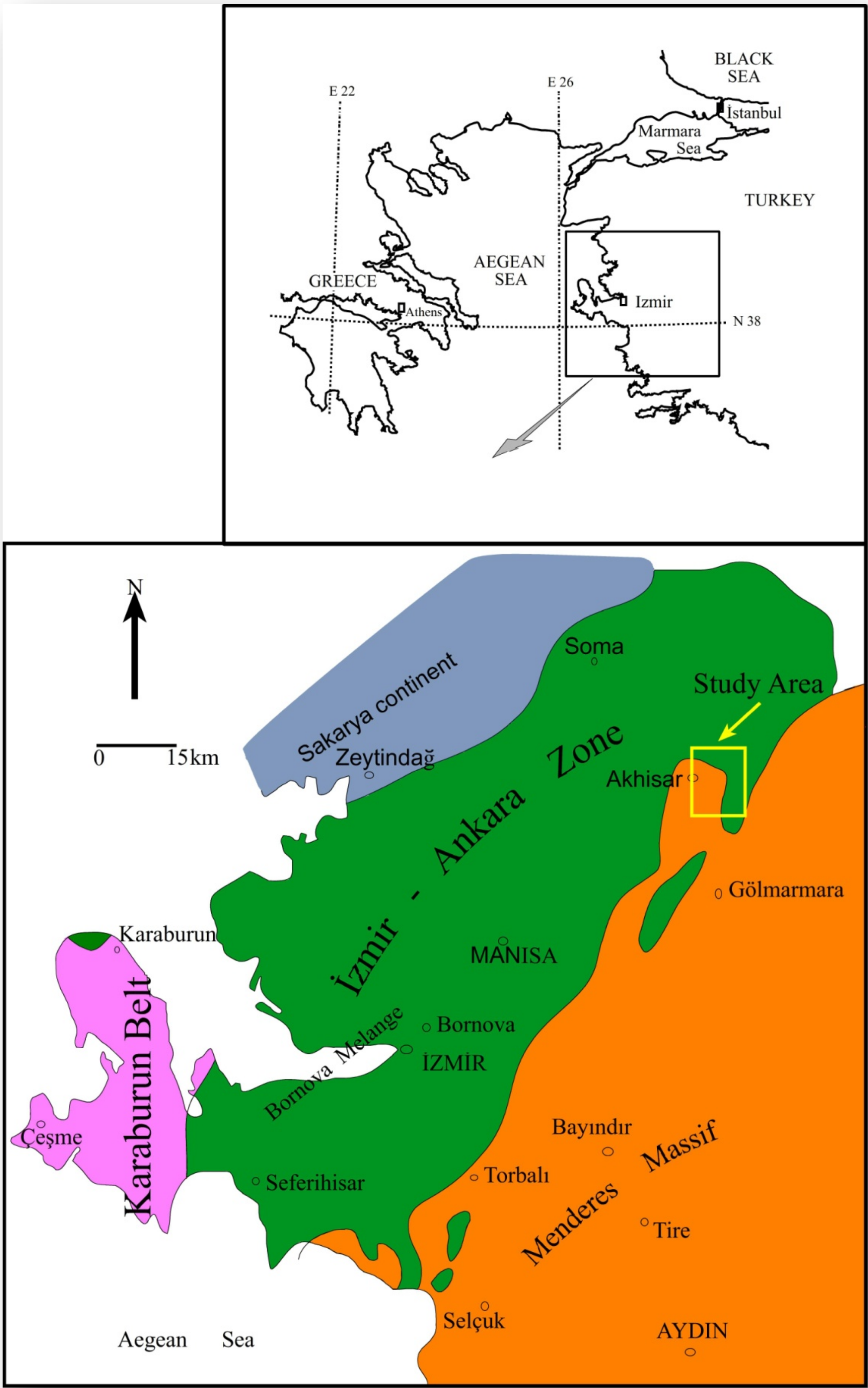

Figure 1.1 Location map of the study area (Erdoğan & Güngör, 1992).

1.2 Objectives and Method of Study

The Menderes massif, Lycian nappes and the İzmir-Ankara zone are the main tectonic terranes in the west Turkey (Figure 1.1). Around the Akhisar, stratigraphy of the Menderes massif was defined by Akdeniz et al. (1979) and Erdoğan and Güngör (1992), however the structural elements of these tectonic belts have not been defined in detail. In the Akhisar region, Menderes massif is represented by the Bayındır formation consisting of micaschists at the top to bottom and Kayaaltı formation made up of platform carbonates at the top (Erdoğan & Güngör, 1992). The Lycian nappes is newly defined in this thesis as a tectonic slice which was previously described as the Hasköy formation on the platform carbonates of the Kayaaltı formation by Erdoğan & Güngör (1992).

The main purpose of this thesis is to describe structural elements and kinematic features of the structures along the boundary between the Menderes massif and the Lycian nappes to the east Akhisar. In addition to this, the geochemical characteristics and tectonic settings of the mafic volcanic rocks found as tectonic slices in the İzmir-Ankara zone in the study area were also considered.

In the tectonic evolution of the west Turkey the emplacement directions of the Lycian nappes and structures in the metamorphic rocks of the Menderes massif play a crucial role. There are many studies focused on these tectonic belts of the west Turkey, however the movement direction of the tectonic slices have not been described clearly yet.

The contact between the Lycian nappes and the Menderes massif in the Akhisar region is the most suitable zone for structural analysis of the tectonic transport direction. Lithology of the both Menderes massif and Lycian nappes are suitable for recording tectonic transport direction and for kinematic analysis. The metaclastic rocks composed of metapelites, metapsammites and metarudites lay in the lower part of the Lycian nappes. The Lycian nappes emplaced along these metaclastics to the top of the platform carbonates of the Menderes massif. Along this relatively ductile unit, the platform sequence of the Lycian nappes thrust above the Menderes massif represented by the regionally metamorphosed rocks. This ductile unit is very suitable for mesoscopic scale structures to form that may be examined for the kinematic analysis of the movement direction of the Lycian nappes.

In this study not only the shear sense indicators in the metaclastics in lower part of the Lycian nappes are examined but also the underlying regionally metacarbonates of the Menderes massif were studied.

Details of the purposes of this thesis are:

1. To study structures along the contact between the Menderes massif and Lycian nappes to figure out the tectonic movement direction of the Lycian nappes.
2. To establish a detailed structural map of the contact between the Menderes massif and Lycian nappes along some sections and then to compare the two tectonic belts.
3. To display deformation of the Lycian nappes by examining mesoscale and microscale structural relation.
4. To compare the structural data obtained from this study in structurally upper part of the Menderes massif and then to display the relation between structural evolutions of the Lycian nappes and Menderes massif.
5. To describe geochemical characteristics and tectonic settings of the mafic volcanic rocks in the İzmir-Ankara zone around Akhisar.

At the beginning of the studies the contact between the Menderes massif and Lycian nappes around Akhisar were examined by field studies to determine the suitable areas for structural analysis. During this stage 1/25 000 scale topographic maps were used. Later along the most suitable areas, detailed observations were done along traverses which extend at suitable direction to tectonic contact. Systematic structural measurements were done in the structurally upper part of the Menderes massif and the lower part of the Lycian nappes. Measurements were done along surfaces parallel to the stretching lineation and perpendicular to the foliation surfaces at each location (Figure 1.2).

The microstructural studies were also carried out syncronously to the field measurements. For these purposes oriented samples were collected in the field. A special notice had been taken during every steps of sample collection. Figure 1.2 explains the preparation of an oriented thin section from an oriented sample.

Samples from the Lycian nappes are mostly collected from metaclastic rocks since the metapelites and metapsammites are the most suitable lithologies for the record of deformation history. They generally preserve earlier structures of the deformation. The metapsammites are found to preserve relatively coarse structures due to their richness in quartz grains. They are suitable for thin section studies. The limestones are found to have weak deformation of memory because of their intendance for recrystallization even under low grade conditions.

When the samples are collected the strike and dip of the foliations and the trend and the plunge of the lineations are drawn on the surface of the sample (Figure 1.2). To avoid mistakes, the location was photographed and simple sketch of the outcrop was drawn on the field notebook.

In the laboratory the oriented samples were cut perpendicular to the related foliation and parallel to the stretching or mineral lineation to obtain maximum amount of information about the kinematic indicators (Figure 1.2). These surfaces show structures such as S/C, relation between foliation and porphyroblast/ porphyroclast.

Along the outcrops, the rock samples from the mafic volcanic rocks were collected to make geochemical analysis. Location of these samples indicated on the map presented in pocket on the inside of back cover in this thesis. The stratigraphic sequences of the tectonic terranes in the Akhisar region given in the second chapter were modified after Erdoğan and Güngör (1992). In naming the stratigraphic units previous names used as much as possible. In case of need, the formations were redefined or their stratigraphic relations were reconsidered.

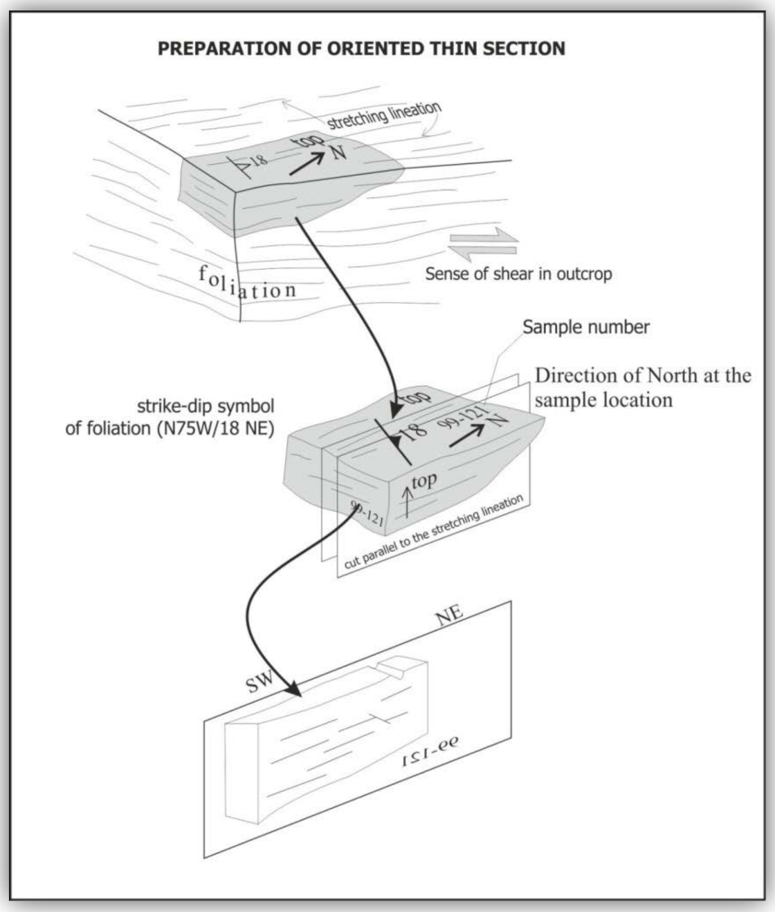

Figure 1.2 Steps for preparation of an oriented thin section.

Figure 1.3 In situ appearance of an oriented sample from rhyolite intercation in the Akhisar nappe, Sarıçalı Village, (0577384; 4298041 UTM 35S).

In regional scale, the boundary relation between the Menderes massif and the İzmir-Ankara zone was studied. After discovering the tectonic slices of the Lycian nappes in the Akhisar region, boundary relation between the Menderes massif and the Lycian nappes were also studied in detail and mapped.

1.3 Layout of this Thesis

Layout of this thesis was arranged according to the rules of the Graduate School of Natural and Applied Sciences of Dokuz Eylül University. This thesis consists of five chapters. The first chapter introduces the location of the study area, and defines objectives and methods used in this study. In addition to that, outlines of the geological setting of the study area and surroundings are defined in the light of the previous studies. In second chapter, lithologic features of the Menderes massif, Lycian nappes and the Izmir-Ankara Zone (Bornova melange) are briefly described after Erdoğan and Güngör (1992) in Akhisar region. The geochemical studies on the mafic volcanic rocks from the Bornova melange in the Akhisar region are presented in the third chapter. In chapter four, the structural elements in the Lycian nappes and the metacarbonate of the Menderes massif of the study area is described. Concluding remarks are given in the last chapter.

1.4 Previous Studies in the Akhisar Region and Surrounding

In the Akhisar region, the Menderes massif, Lycian nappes and the Izmir-Ankara zone (Bornova mélange) crop out. The boundaries between these three tectonic terranes are fault. The Menderes Massif is the structurally lowest and the Bornova melange of the İzmir-Ankara zone is the structurally uppermost unit. The Lycian Nappes are sandwiched between the Menderes Massif and the Bornova melange.

In the study area stratigraphy of the Menderes Massif was documented by Akdeniz et al., (1980) and Erdoğan & Güngör (1992). The stratigraphic sequence of the Menderes Massif starts at the base with the Bayındır formation composed mainly of micaschists with rare lenses of mafic metavolcanic rocks (Erdoğan & Güngör, 1992). These micaschists pass upward into platform carbonates of Triassic-Jurassic age, named as the Kayaaltı formation. Above the massive carbonates of the Kayaaltı formation, the Late Cretaceous Hasköy formation consisting of red and green metaclastics is found along a gradational boundary, however in this thesis the Hasköy formation has been redefined as the Akhisar nappe as a tectonic slice of the Lycian nappes. The structurally lower parts of the Menderes massif composed of high-grade micaschists and gneissic granites of the Neoproterozoic (Candan et al., 2012; Koralay et al., 2012) do not crop out in the study area. In the study area, only the platform carbonates of the Kayaaltı formation crop out structurally below the Bornova melange and the Lycian nappes (the Akhisar nappe).

The Bornova melange of the İzmir-Ankara zone is the structurally uppermost tectononic unit In the Akhisar region, and tectonically overlays the Menderes massif and the Lycian nappes (Erdoğan & Güngör, 1992) (Plate I).

In the regional scale, the Menderes massif is tectonically overlain to the north by the Afyon zone and to the south by the Lycian nappes (Candan et al., 2012). In the northwest, two high-pressure units, the Cycladic complex and overlying the Lycian nappes, as well as the nappes of İzmir-Ankara zone tectonically overlay the Menderes massif.

On the southern flank of the Menderes massif the Lycian nappes is located on the platform carbonates (Brinkman, 1967; Gutnic et al., 1979; Poisson, 1985; Ersoy, 1990; Özkaya, 1991; Güngör & Erdoğan, 2001; Arslan, 2001; Collins & Robertson, 2003; Rimmele et al., 2003; Arslan et al., 2013).

The stratigraphic section of the northern margin of the Menderes massif resembles to that of the Karaburun belt and, before the Maastrichtian these two belts were probably connected to from a single platform (Erdoğan & Güngör, 1992).

The Eocene Başlamış formation is found on the ophiolitic complex of the Bornova melange along the angular unconformity (Akdeniz, 1980; Önoğlu, 1996), and the Neogene conglomerates and volcanic rocks unconformably cover the older tectonostratigraphic units.

CHAPTER TWO
STRATIGRAPHY

The Menderes massif, the Lycian nappes and the Bornova melange of the İzmir-Ankara zone are the main tectonic belts of the west Turkey in structurally ascending order, and they crop out in the Akhisar region (Figures 1.1 & 2.1).

The Menderes massif represented by gnessic granites, gneisses, migmatites, micaschists and massive marbles (e.g. Schuling, 1962; Kröner & Şengör, 1990; Hetzel & Reischmann, 1996; Loos & Reischmann, 1999; Ring et al., 1999; Gessner et al., 2004; Koralay et al., 2001; Candan et al., 2011a, b; Dora et al., 2011) is a vast metmorphic terrane tectonically bounded by the İzmir-Ankara zone and the Lycian nappes. The Menderes massif is the structurally lowest tectonic unit in the study area and is only represented by platform carbonates.

The Lycian belt composed of tectonic slices of platform series and ophiolites is located between the Menderes massif and the Beydağları platforms in the soutwest Turkey. The Lycian nappes with two possible source with respect to the Menderes platform as described below: (1) from the Northern branch of the Neotethys and the northern edge of the Menderes platform, the Lycian nappes thrust southward over the Menderes platform (Dürr 1975; Dürr et al. 1978; Şengör & Yılmaz, 1981; Okay 1989; Collins & Robertson, 1998, 1999, 2003; Rimmele et al. 2003; Ring et al. 1999, 2007; Gessner et al. 2001; Güngör & Erdoğan, 2001) and (2) except for the peridotite slices occupying the structurally highest position, the Lycian nappes originated from the southern edge of the Menderes platform and thrust northward onto the Menderes platform (Poisson, 1985; Özkaya, 1990; Arslan, 2001, Arslan et al., 2013). Between the Menderes and Bey Dağları platforms a narrow, northeast-trending volcanogenic basin was called the Kızılca-Çorakgöl trough by Poisson (1985), theWestern Taurus Trough by Ersoy (1990) and the Alakaya basin by Özkaya (1991).

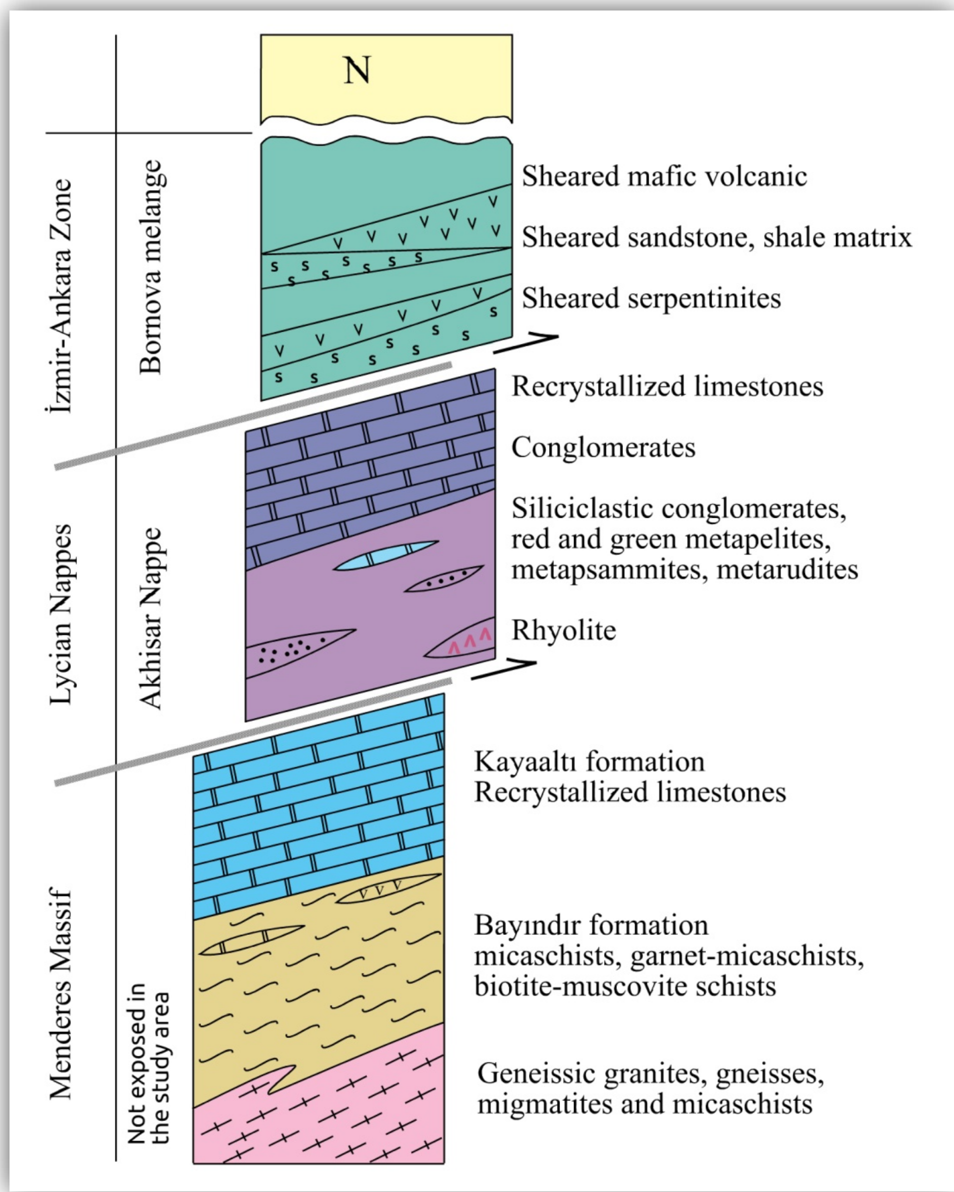

Figure 2.1 Stratigraphy of the tectonostratigraphic units in the Akhisar region.

The Akhisar nappe of the the Lycian nappes tectonically overlays the Menderes massif and they are new describe in the Akhisar region in this study.The Lycian nappes are represented by the Akhisar nappe composed of red and gren metaclastics with conglomerates, rhyolites intercalations and limestone lenses in the lower part, and recrystallized limestones in the upper part (Figure 2.1).

The Bornova melange of the İzmir-Ankara zone tectonically overlays both the Menderes massif and the Akhisar nappe of the Lycian nappes, and forms structurally uppermost tectonic unit in the Akhisar region. The Bornova melange is represented by an ophiolitic complex (Figure 1.1). Internal structure of this complex is completely cut by shear surfaces separating serpentinized peridotites, sheared serpentinites, gabbros, basaltic pillow lavas, red radiolarites and pelagic limestones and sheared sandstone-mudstone matrix.

The tectonic contact between the Menderes massif, Lycian nappes and Bornova melange is unconformably covered by the Eocene sediments (Önoğlu, 1996) and the volcano-sedimentary Neogene units (Akdeniz, 1980).

In this thesis, the nomenclature of the tectonostratigraphic units in the study area is mainly based on Erdoğan & Güngör (1992) and internal stratigraphy of each tectonostratigraphic units are summarised below. The main distinction of this thesis is to describe the Hasköy formation of Erdoğan & Güngör (1992) as the Akhisar nappe.

2.1 The Menderes Massif

The northern part of the Menderes massif crops out in the Akhisar region and is represented by the Bayındır and Kayaaltı formations (Erdoğan & Güngör, 1992). The Bayındır formation is the stratigraphically lower part of the massif around the study area and is composed of homogeneous micascists. The Kayaaltı formation gradually overlays the Bayındır formation and is made up of platform-type massive limestones. The Bayındır formation and the Neoproterozoic gneissic granites that form the lower part of the Menderes massif do not expose in the study area. For this reason, only the Kayaltı formation is described below.

2.1.1 The Bayındır Formation

In the Akhisar region the Bayındır formation has a thickness more than 2 km, and it crops out to the southeast of Akhisar the outside of study area. The Bayındır formation is composed of muscovite schists, muscovite quartz schists, biotite muscovite schists with white and gray marble lenses. The metamorphic grade in the

Bayındır formation progrades toward the gneissic granites which structurally overlies the Bayındır formation around Demirköprü Dam (Erdoğan and Güngör, 1992).

Around Çömlekçi village the micashist of the Bayındır formation pass gradually upward into the massive limestones of the Kayaaltı formation. Along this gradational zone the lenses of mafic volcanic rocks and limestone lenses are found. The lower boundary of the Bayındır formation does not expose around Akhsiar.

2.1.2 The Kayaaltı Formation

The Kayaaltı formation is composed of marble and micashist alternation, emery bearing massive marbles and dolomitic marbles. Open outcrops of this unit is found around Kayaaltı village to the southeast of Akhisar Erdoğan and Güngör (1992) reported fossils indicating a Liassic age along the lower boundary of the Kayaaltı formation. In the study area the Kayaaltı formation is represented by recrystallized, massive limestones to the east of Akhisar (Plate I). This upper part of the formation also contains poorly preserved rudist fossils.

The lower boundary in the Kayaaltı formation is gradational with the Bayındır formation (Erdoğan and Güngör, 1992) however Akdeniz et al. (1980) described this boundary as an angular unconformity.

2.2 The Lycian Nappes

The Lycian nappes are represented by the Akhisar nappe composed of red and green metaclastic rocks with rhyolite intercalations, limestone lenses and conglomerates intercalations in the lower part and recristallized massive limestones in the upper part (Figure 2.1, Plate I). The Akhisar nappe lithologically resembles to the Karaova formation and Gereme dolomites of the Lycian nappes that crop out to the south of Milas (Arslan, 2001). In the Akhisar area, along the gradational boundary between the red and green metapelites and recrystallized limestones there are limestone layers and intraformational conglomerate interclation (Figures 2.2 and 2.3).

Figure 2.2 Alternation red psammites and pelites in the Akhisar nappe close to the contact of the overlaying limestones.

Figure 2.3 Intraformational conglomerates composed mainly of limestone pebbles in the uppermost part of the detrital part of the Akhisar nappe close to the contact of the overlaying limestones. (Width of photograph is about 75 cm).

However in the lower part of the red and green metaclastics, the siliciclastic conglomerates intercalations around Çamönü village (Plate I, Figure 2.4), and rhyolite intercalations around Seğirdim and Harmandalı villages are found (Figure 2.5).

Figure 2.4 Siliciclastic conglomerate intercalations in the detrital part composed of the lower part of the Akhisar nappe. Width of photograph is about 1 m.

Figure 2.5 Photograph showing deformed rhyolites in the lowermost part of the Akhisar nappe. Pencil is parallel to the stretched feldspar and quartz phenocrysts.

In the area between Sarıçalı and Harmandalı villages the red metapelites and metapsammites, in addition the pale green rhyolite intercalations, contain limestone layers (Plate I). There layers are composed of fine grained, micritic limestones showing continous foliation. The Akhisar nappe tectonically overlays the Kayaaltı formation of the Menderes massif (Figure 2.6). This tectonic contact is observed around Sarıçalı village (Plate I) and mylonitization is prominent along contact zone of both tectonostratigraphic units.

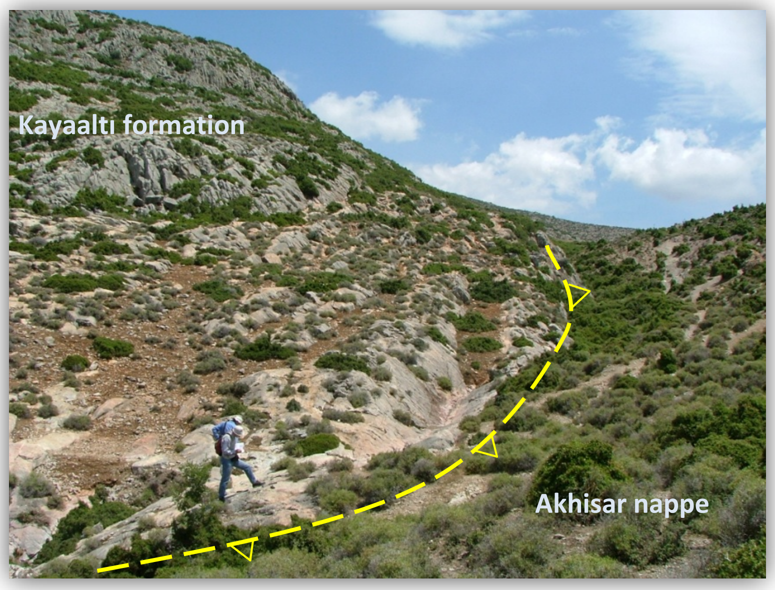

Figure 2.6 Photograph showing the tectonic contact between the Menderes massif and the Akhisar nappe. Northeast of Sarıçalı Village. (05 77 478; 42 98 111 UTM 35 S).

2.3 The Bornova melange

The Bornova melange in the İzmir-Ankara zone is represented by an ophiolitic melange in the Akhisar region (Erdoğan and Güngör, 1992) (Figure 2.1). Internal structure of the Bornova melange is composed of sheared serpentinized peridotites, sheared serpentinites, gabbros, pillow lavas of mafic volcanites, red radiolarites and pelagic limestones, blocks of platform carbonates and sheared mudstone-sandstone matrix in some places (Figure 2.6). The geochemical features of these mafic volcanites are given in chapter 3. This melange tectonically overlays the different stratigraphic units of both the Menderes massif and the Akhisar nappe (Plate I).

The Bornova melage tectonically overlays both the Menderes massif and the Akhisar nappe. These contact relationship is observed in the north of the Durasıl village (Figure 2.7), and in the east of Sarıçalı village (Plate I). Erdoğan and Güngör (1992) reported an age of Berriasian-Turonian from the tectonic slices of the Bornova melange around Akhisar. Lately Sarı (2012) described in detail the Late Maastrihtian-Late Palaeocene age of the micritic limestones and calcerous shales (lenses) in the clastic matrix of the Bornova melage around İzmir.

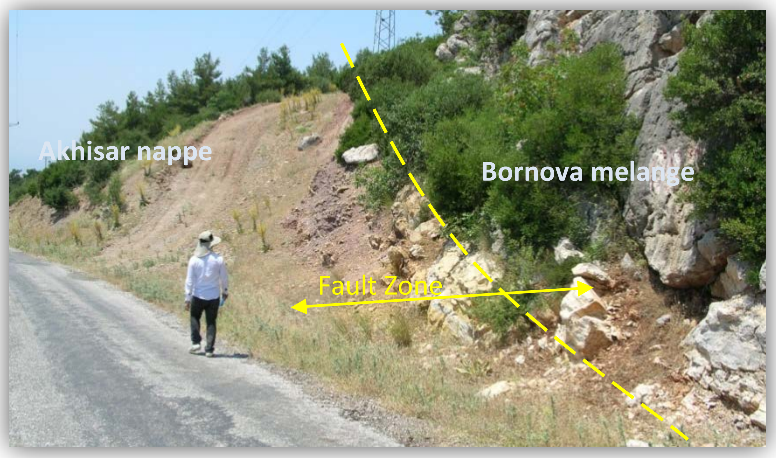

Figure 2.7 Photograph showing the tectonic contact between Akhisar nappe and the Bornova melange. The Bornova melange tectonically overlays the Akhisar nappe along thick cataclastic fault zone. (North of Durasıl Village, Plate I).

Figure 2.8 Photograph showing red radiolarites and limestone block with a strong cataclastic texture in the Bornova melange. (North of Kulaksızlar village, Plate I).

In regions scale the Bornova melage is included into the Bornova flysch zone is represented by a regional olistrome-melage belt located between the İzmir-Ankara.

Tethyan suture the northwest and Menderes massif in the southeast (Okay et al, 2012). In the study area, the Bornova melange represented by unmetamorphosed but strongly deformed flysch type sediments and ophiolitic rocks is the structurally uppermost tectonic slice and overlays the low-grade metamorphic Akhisar nappe and the regionally metamorphic Menderes massif.

The Eocene Başlamış formation (Akdeniz, 1980; Önoğlu, 1996), unconformably cover the ophiolitic melange rocks of the Bornova melange along a basic conglomerates composed mainly of serpentinite pebbles. The Neogene sedimentary and volcanic rocks unconformity cover the Menderes massif, Akhisar nappe and the Bornova melange in and around study area.

The stratigraphy of the matrix and limestone blocks in the Bornova melange were described by Konak (1977), Yağmurlu (1980), Özer & Irtem (1982) around Bornova, and by Erdoğan (1992b) between İzmir and Seferihisar and by Oğuz (1996) in Spil Mountain to the south of Manisa district.

CHAPTER THREE
GEOCHEMISTRY OF MAFIC VOLCANIC ROCKS IN THE BORNOVA MELANGE

3.1 Introduction

In the Akhisar region, the mafic volcanic rocks are found in the Bornova melange of probably Late Campanian-Maastrichtian. The blocky İzmir-Ankara zone tectonically overlays the platform carbonates of the Kayaaltı formation and the Akhisar nappe. The Bornova melange is composed of ophiolitic rocks with complex internal structure cut off by tectonic slices, sheared serpentinized peridotites, serpentinites, gabbros, pillow lavas, red radiolarites and pelagic limestones. Geochemical analyses of 22 samples of mafic volcanic rocks from the Bornova melange have been carried out in this study. Because of scattered setting of the mafic volcanic rocks in the melange the samples were randomly collected, and fresh samples were analysed as much as possible. The samples from Bornova melange were collected in the Akhisar region, where relatively extensive outcrops of the mafic volcanic rocks are found. The locations of these samples are indicated on the map presented in the pocket in the back cover.

The major oxides were analysed by ICP-AES for the Major Oxides, ICP-MS for the trace elements, WST-SEQ for the loss on ignition at 1000^{o} C and ICP-AES for the total calculation. The results of the geochemical analyses is presented in the appendix as table. There is always a problem determining the protolith and tectonic setting of altered and sheared volcanic rocks because of mobility of elements in alteration processes, but the chemical data of the 22 samples from the Bornova melange form a cluster, and do not show very large dispersion that would expected if pronounced mobility occured. Especially, in some samples mobile oxides of SiO_2, CaO, Na_2O and K_2O show variations because of overprinted alteration. In addition to that, in the nomenclature and tectonic discrimination diagrams the relatively immobile trace elements of Ti, Zr, Cr, Mn, P, Nb, Y and Sr were used.

3.2 Mafic Volcanic Rocks of the Bornova Melange

The outcrops of the mafic volcanic rocks scatter in the Bornova melange. Their wide exposures are found around Akhisar, and are indicated by ‘v’ on Plate I. These mafic volcanic rocks are usually fine grained, dark green in colour. Primary porphyritic textures of these mafic volcanic rocks are observed. In thin sections they are represented by spilites composed of plagioclase phenocrysts set in fine grained, dark coloured, chloritic matrix. Spilites are basic and mafic rocks commonly amygdaloidal in texture, in which the primary minerals have been altered. Feldspars are albite in composition and the pyroxenes have been replaced by other minerals and chlorite.

Figure 3.1 Spilitic volcanites in the Bornova melange along road cuts between Akhisar and Gördes.

3.2.1 Nomenclature of the Mafic Volcanites

Major oxides and trace elements compositions of these mafic samples from the Bornova melange of the İzmir-Ankara zone are given in table 1 as appendix, in which SiO_2 ratios varies from %50 to %48, Al_2O_3 from %16.45 to %18.15, Fe_2O_3 from %11.2 to %9.04 and MgO from %4.3 to %6.6.

The results of the geochemical analyses are plotted on related binary and ternary nomenclature diagrams. In the nomenclature diagram devised by Cox, Bell & Pankhurst (1979) of common igneous rocks, based on their silica and alkali contents, the samples of the mafic volcanic rocks from the Bornova melange concentrate in and around the field of basalt (Figure 3.2).

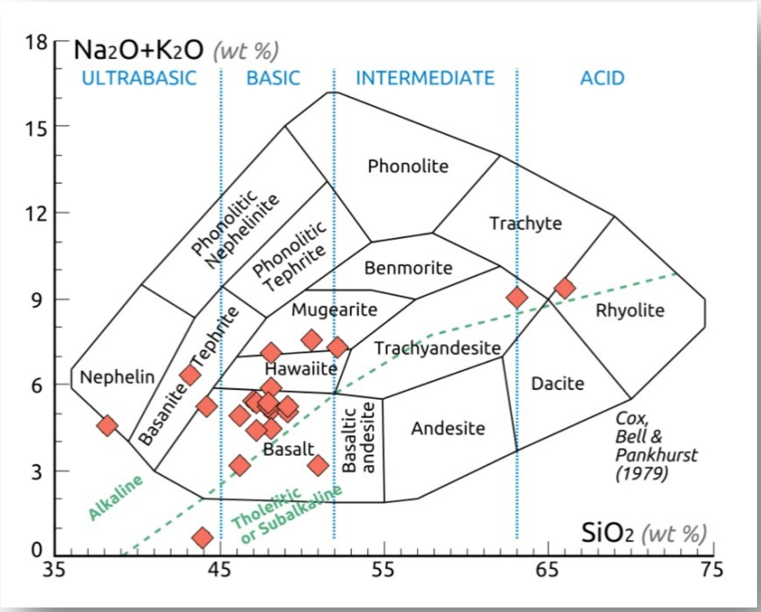

Figure 3.2 Nomenclature diagram of common volcanic rocks based on their silica and alkali contents. Samples from the Bornova melange concentrates mainly on the field of Alkaline basalts.

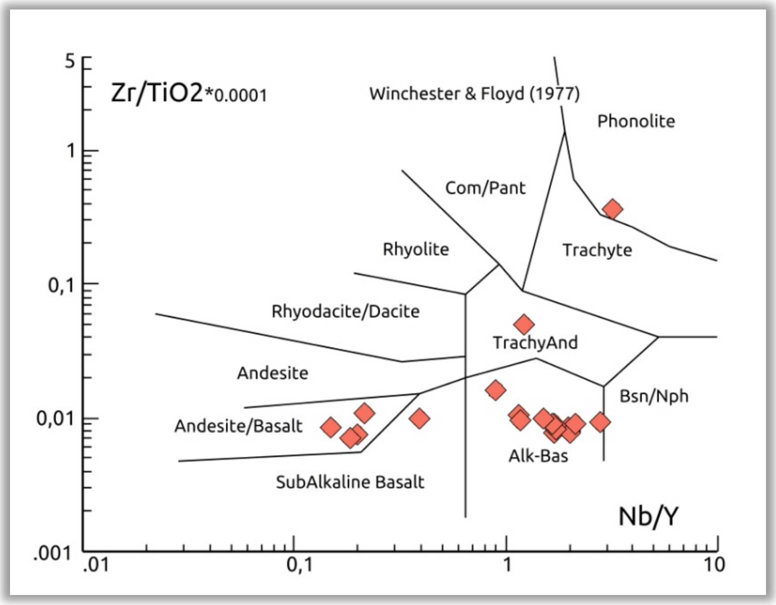

Figure 3.3 Nomenclature diagram of Winchester & Floyd (1977) of the mafic volcanic rocks from the Bornova melange (Akhisar Region). Samples plot on alkaline basalt, subalkaline basalt and andesite/basalt field.

In the diagram of Winchester & Floyd (1977), based on Zr/TiO_2 versus Nb/Y, the samples scatter in the field of alkaline basalt and andesite-basalt (Figure 3.3). The scattered pattern on the graph might be related to the effects of both sea-floor alteration and shearing during the emplacement of slices of the mafic volcanics into the accretionary wedge.

In the another diagram of SiO_2 versus Zr/TiO_2 of Winchester & Floyd (1977), all the samples of the mafic volcanic rocks of the Bornova melenge gather mostly in the field of subalkaline basalt (Figure 3.4).

3.2.2 Character and Tectonic Setting of the Basalts in the Bornova Melange

In order determine major oxides attributes of the mafic volcanic constituents of the Bornova melange, their goechemical data are plot on the total alkalis versus silica diagram of Irvine & Baragar (1971). Except three samples, all the mafic volcanic samples plot in the field of alkaline rocks (Figure 3.5).

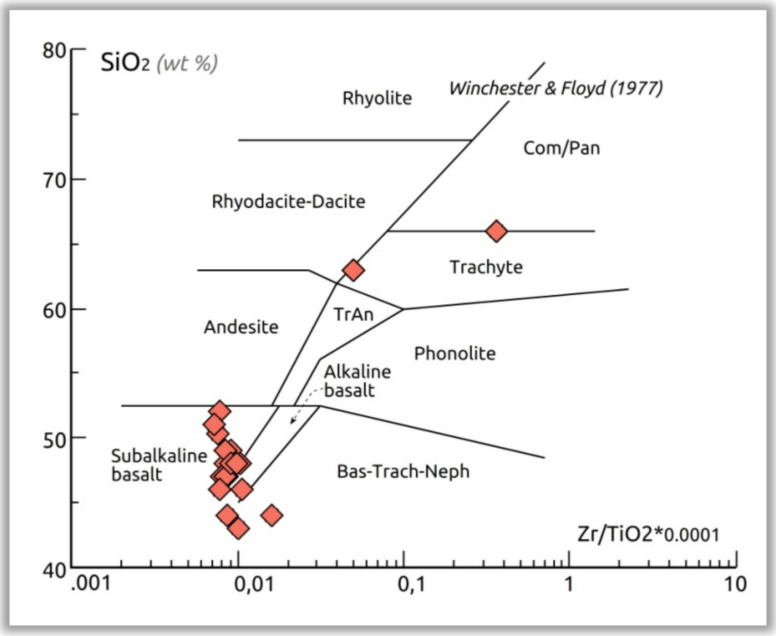

Figure 3.4 Nomenclature diagram of Winchester & Floyd (1977) of the mafic volcanic rocks in the Bornova melange (Akhisar Region). Samples cluster on the fields of subalkaline basalt, alkaline basalt and basanite-trachite-nephelinite.

The tectonic setting of the basalts of the Bornova melange in the Akhisar region is examined by plotting their chemical data on related graphs combined by the elements that are considered to be relatively stable and/or insensitive to hydrothermal proccesses in the temperature range of the greenschist facies. Possible post eruptive alteration and effects of metamorphism on mobility of the elements have discussed in a number of studies, and the elements of Zr, Ti, Mn, P, Nb, Y and Sr are considered as relatively immobile under the conditions of the greenschist facies and are used in this chapter to determine the tectonic setting of the basalts.

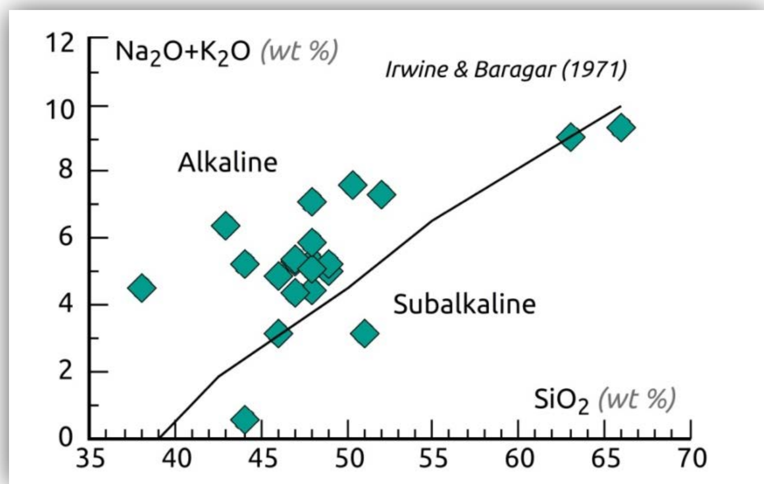

Figure 3.5 Diagram of total alkalis vs SiO_2 showing character of the mafic volcanic rocks from the Bornova melange in the Akhisar region. Three samples plot on the subalkaline field and the other nineteen samples locate on the alkaline field in the diagram of Irvine & Baragar (1971).

Tectonic setting of the basalts in the Bornova melange can be discriminated by variation diagram combined with Ti and Cr by Pearce (1975). Plot of Ti-Cr (ppm) shows that basalts in the Bornova melange have affinity with ocean floor basalts (Figure 3.6).

Ternary diagram (Figure 3.7) combined by Ti/100-Zr-Sr/2 of Pearce & Cann, 1973 shows that tectonic setting of the basalts in the Bornova melange. The mafic volcanic rocks samples mostly concentrates on the ocean-floor basalts and the calc-alkaline basalts.

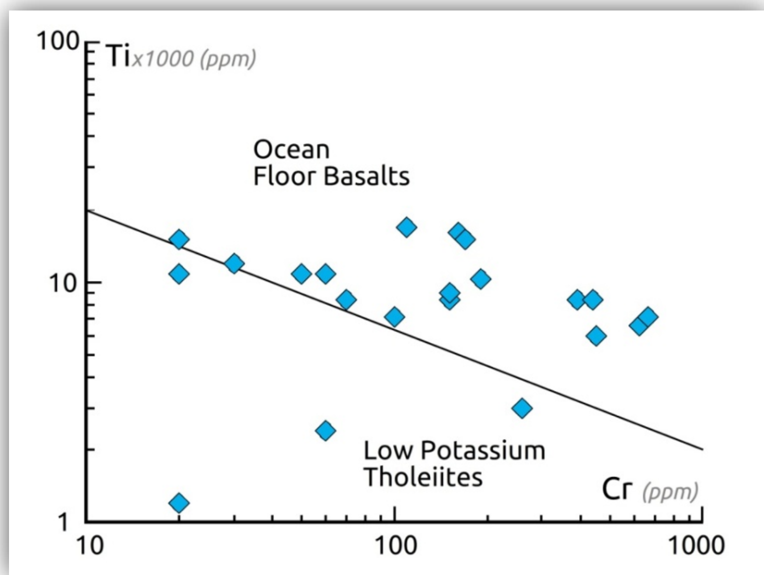

Figure 3.6 Discrimination Pearce (1975) diagram showing tectonic setting of the basalts in the Bornova melange. The most of samples plot on the field of ocean floor basalts.

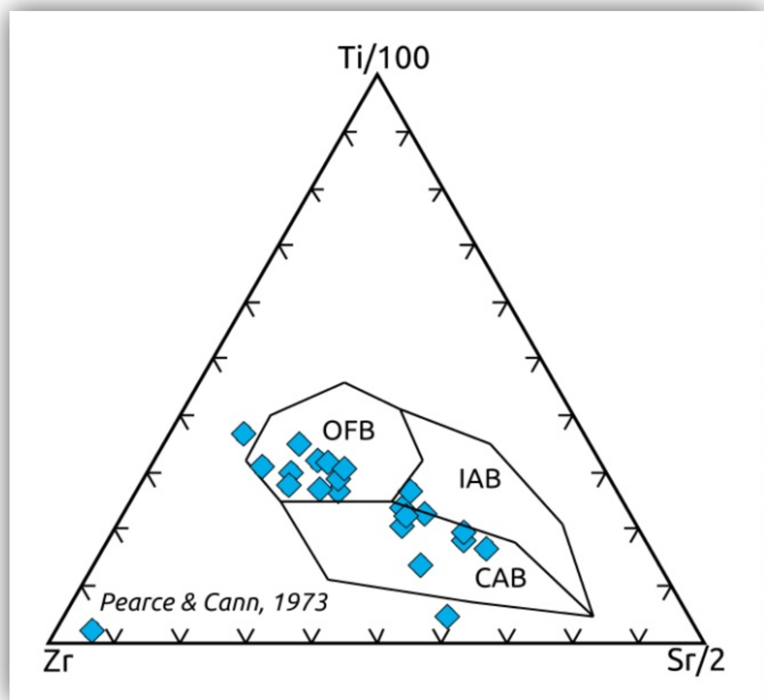

Figure 3.7 Ternary diagram (Pearce & Cann, 1973) showing the tectonic setting of the basalts in the Bornova melange. Samples mostly concentrates on the ocean-floor basalts and the calc-alkaline basalts.

Other discrimation diagram of Ti vs Zr combined by Pearce & Cann (1973) shows that basalts of the Bornova melange plots on the fields of on the ocean-floor basalts and the calc-alkaline basalts (Figure 3.8). The binary diagram of Ti/Cr vs Ni that combined by Beccaluva et al. (1979) indicate that basalts of the Bornova melange mostly have affinity with the mid-ocean ridge basalts (Figure 3.9), and few samples plot on the island arc tholeiites.

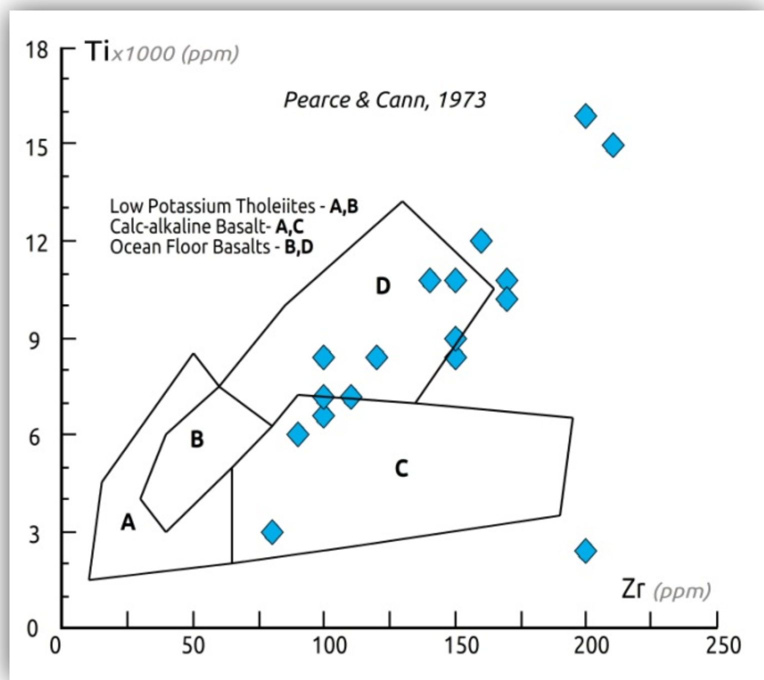

Figure 3.8 Discrimination diagram of Pearce & Cann (1973) shows that basalts of the Bornova melange have affinity with the ocean floor basalts and calc-alkaline basalts.

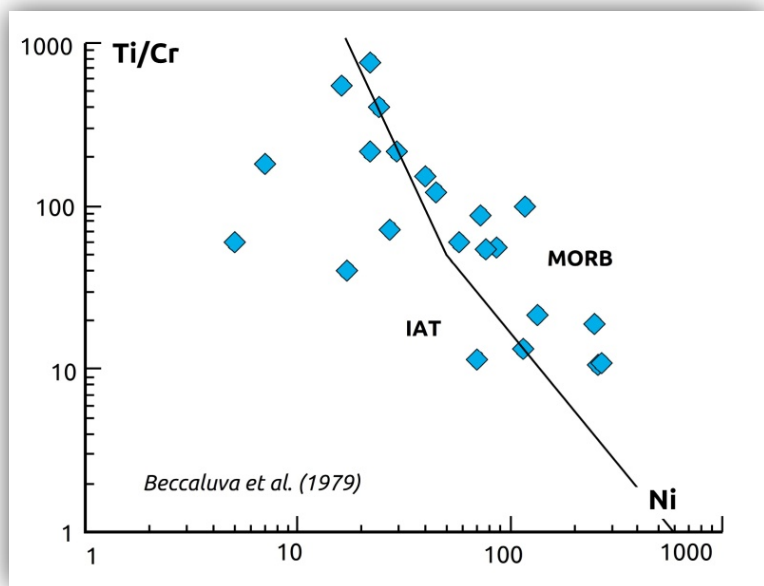

Figure 3.9 Diagram combined by Ti/Cr vs Ni of Beccaluva et al. (1979) showing tectonic setting of the basalt samples from the Bornova melange. The most of the samples plot on the mid-ocean ridge basalts and few samples plot on the Island Arc tholeiites.

However the preceeding diagrams mostly shows that the basalts in the Bornova melange have affinity with the oceanic crust, the foregoing three diagrams indicate that the basalts locate in the fields of within plate basalt, within plate alkaline and tholeiitic basalts (Figures 3.10, 11 and 12). Ternary diagram (Pearce & Cann, 1973) of Ti/100-Zr-3Y samples plot mostly on the within plate basalts (Figure 3.10) and few samples locate on the ocean-floor basalts and volcanic arc basalts. Ternary diagram combined by 2Nb-Zr/4-Y of Meschede (1986) shows that tectonic setting of the basalts of Bornova melange (Figure 3.11). Samples group on two different Fields of within plate alkali/tholeiitic basalts and volcanic arc basalts. Figure 3.12 combined by Zr/Y-Zr by Pearce &Norry (1979) shows that the basalts in the Bornova melange have affinity with the within-plate basalts.

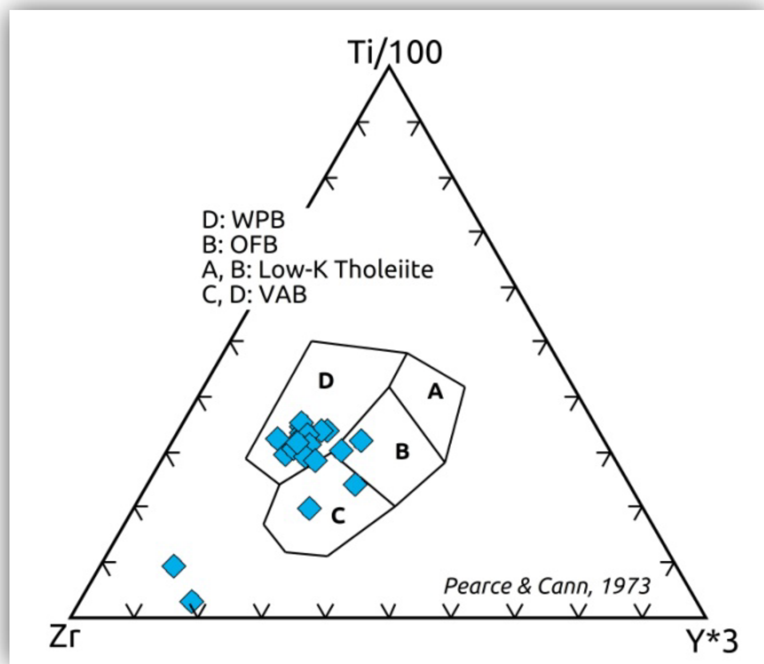

Figure 3.10 Ternary diagram (Pearce & Cann, 1973) showing tectonic setting of the basalts in the Bornova melange. Samples mostly plot on the field of the within plate basalts.

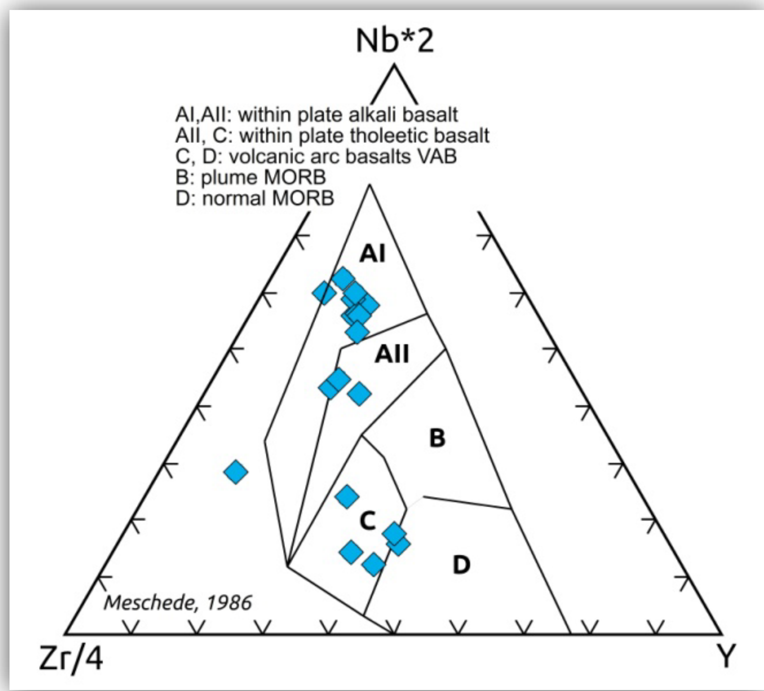

Figure 3.11 Ternary diagram combined by 2Nb-Zr/4-Y of Meschede (1986) showing tectonic setting of the basalts of Bornova melange.

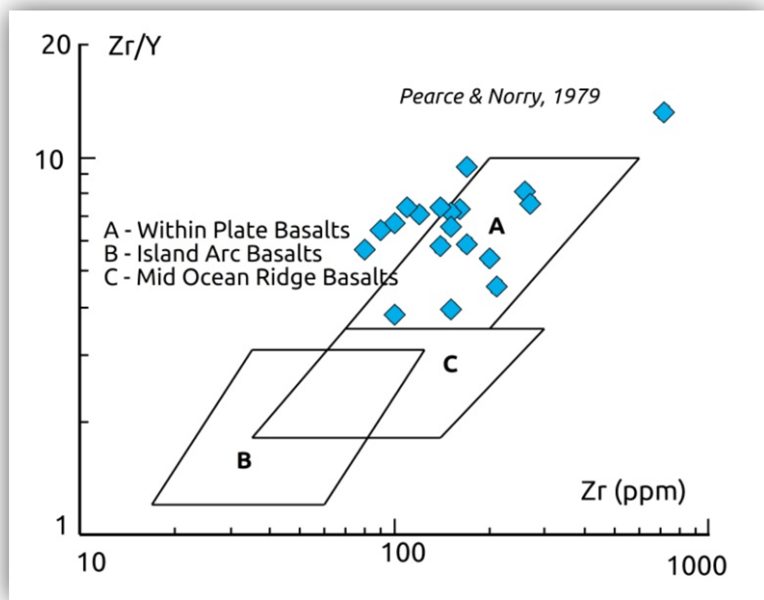

Figure 3.12 Diagram combined by Zr/Y-Zr by Pearce &Norry (1979) Shows that basalts in the Bornova melange have affinity with the within-plate basalts.

CHAPTER FOUR
STRUCTURAL GEOLOGY

This chapter describes the meso- and micro-scale structural elements and kinematic features of the Menderes massif and the overlaying Lycian nappes and the Bornova melange of the İzmir-Ankara zone.

The methology used during the fieldwork includes systematic descriptions and measurements of the mesoscopic structures in outcrops oriented normal to the foliation and parallel to the associated stretching lineation and examination of oriented thin sections (Figures 1.2 and 1.3). Photographs of these meso- and micro-scale planar and linear structures are presented as figures, and orientations of them are given as stereographic plots. Geological map of the Akhisar region is presented as a separate plate (Plate I).

In this chapter the primary and secondary structures which are observed in the uppermost part of the Menderes massif and the lower most part of the Lycian nappes are mainly described. Kinematic indicators that associated with stretching lineation and foliation are determined in the oriented outcrops and in oriented thin sections. The structural evolution of the Menderes massif and the Lycian nappes are discussed on the base of these kinematic indicators.

4.1 Menderes Massif

The Menderes massif is the structurally lowest tectonostratigraphic unit in the Akhisar region, and is represented by recrystallized limestones named as the Kayaltı formation by Erdoğan & Güngör (1992) (Figure 2.1). The Kayaaltı formation is composed of recrystallized platform carbonates (Figure 4.1).

Figure 4.1 Recrystallized limestones of the Kayaaltı formation to the east of Akhisar, East of Seğirdim Village.

The tectonic contact between the Menderes massif and the Lycian nappes is unconformably covered by the flat-lying Neogene volcano sedimentary series.

4.1.1 Secondary Structures

In the uppermost part of the Menderes massif which represented by recrystallized limestones of the Kayaaltı formation, the secondary structures associated with northeast-trending stretching lineation and foliation are as follows:

- Stretching lineation
- Boudin structures and asymmetric boudins of foliation
- Extensional shear bands
- Tension gashes

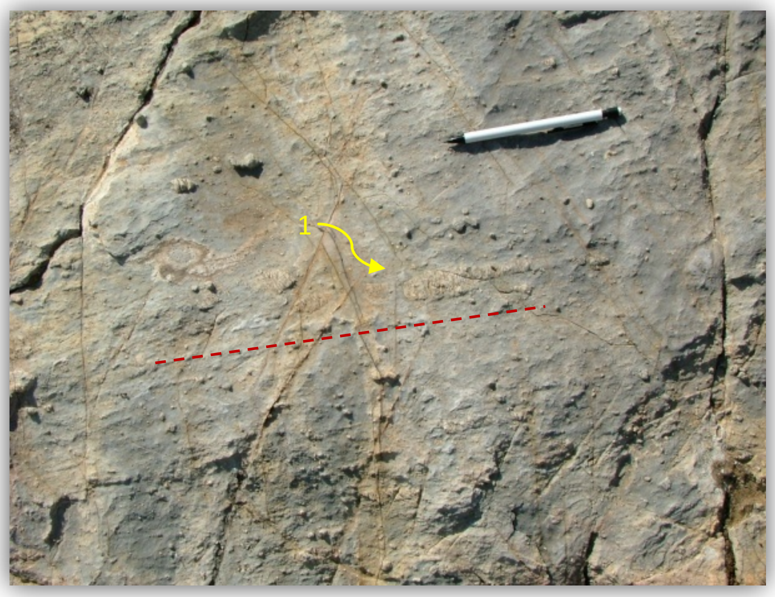

Figure 4.2 Stretching lineation along the foliation planes of the recrystallized limestones of the Kayaaltı formation that represents the structurally upper part of the Menderes massif. Red dashed line is parallel to the stretching lineation diagnosed by stretched dolomite clast (yellow arrow 1). Pencil is 13 centimeters.

The stretching lineation is diagnosed by tiny mica crystals, calcite fibers and clast trains of brittle deformed dolomitic grains (Figures 4.2 and 4.3), in the recrystallized limestones of the Kayaaltı formation.

Along the contact zone between the Menderes massif and the Akhisar nappe the mylonitic parts of each tectonostratigraphic unit clearly display asymmetric structures indicating sense of shear during the emplacement of the Akhisar nappe on the platform carbonates of the Kayaaltı formation.

Isolated boudins of dolomite layers in the mylonitic part of Kayaaltı formation clearly indicate sense of shear related to the nappe emplacement (Figure 4.4).

In the mylonitic marbles of the Kayaaltı formation the dolomitic layers show asymmetric boudins (Figures 4.4, 4.6 and 4.7). The strong asymmetry of the boudins shows a top-NE sense of shear during the emplacement of the Akhisar nappe on the Menderes massif.

Figure 4.3 Stretching lineation along the foliation planes of the recrystallized limestones of the Kayaaltı formation that represents the structurally upper part of the Menderes massif. Red dashed line is parallel to the stretching lineation diagnosed by elongated calcite crystals and calcite fibers yellow (arrow 2). Pencil is 13 centimeters (0578057; 4300709 UTM 35S).

Figure 4.4 Photograph showing the asymmetric boudinage of a dolomite layer in the uppermost part of the Kayaaltı formation. Asymmetry of the boudin clearly indicates a top-NE shear sense. Sarıçalı Village (0577478; 4298111 UTM 35S).

Figure 4.5 Photograph showing extensional shear reflected by offset of a dolomite layer in the mylonitized limestones in the Kayaaltı formation. Offset of the dolomite layer indicate a top-NE shear sense Sarıçalı Village (0577478; 4298111 UTM 35S).

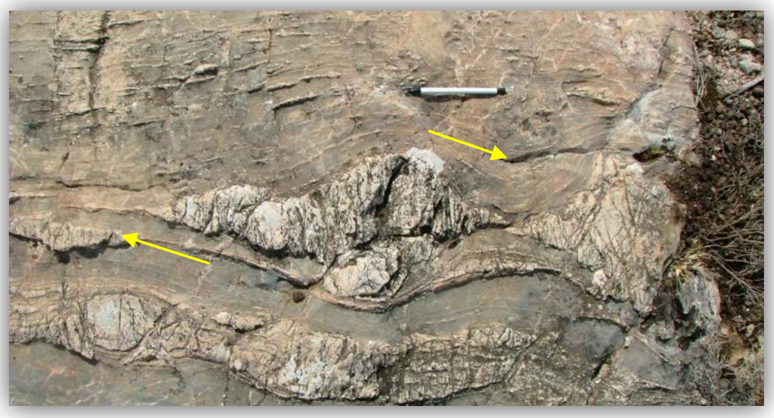

Figure 4.6 Photograph showing asymmetric boudin of a dolomite layer in the mylonitic limestones of the Kayaaltı formation. Asymmetric boudin of yellow dolomite layer show a top-NE shear sense Sarıçalı Village (0577478; 4298111 UTM 35S).

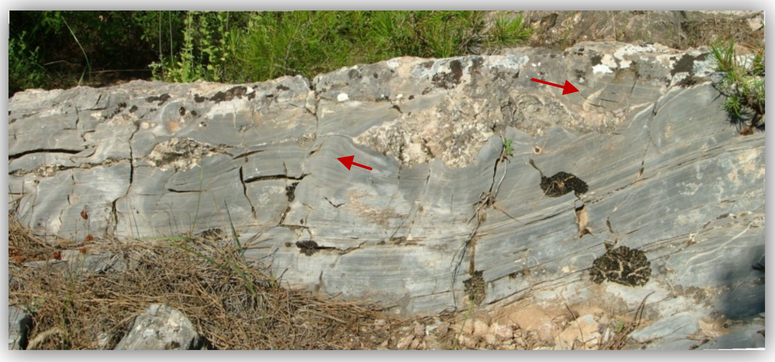

Figure 4.7 Photograph showing asymmetric boudin in the dolomitic layer in mylonitic limestones close to the contact between the Kayaaltı formation and Akhisar Nappe. Strongly stretched and asymmetrically boudinaged dolomite layer shows a top-NE shear sense Harmandalı Village (0578029; 4300899 UTM 35S).

The mylonitic part of the limestone in the Kayaaltı formation also contains tension gashes filled with calcite fibers (Figure 4.8). These tension gashes (mode I cracks) show en-echelon array which indicates a top-NE shear sense and indicate semi-ductile deformation.

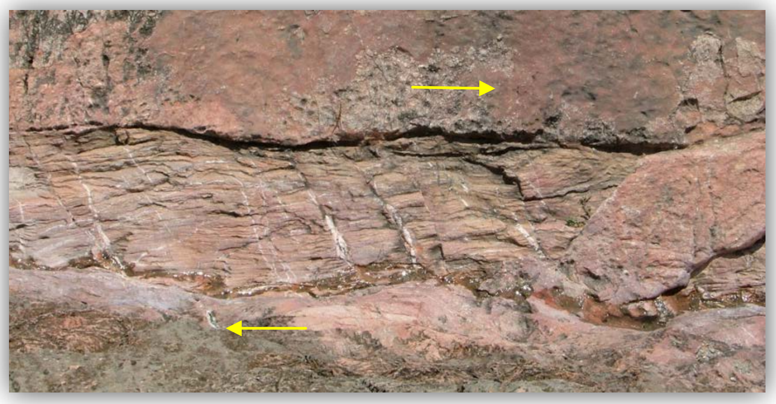

Figure 4.8 Photograph showing en echelon array of tension gashes in the red recrystallized mylonitic limestones of the Kayaaltı formation. Asymmetric array of these tension gashes shows a top-NE shear sense in the recrystallized limestones of the Kayaaltı formation (0577478; 429811 UTM 35S).

4.1.2 Kinematic Features of the Menderes Massif

In the mylonitic part of the Kayaaltı formation the linear fabric trends in northeast direction which indicates the nappe emplacement direction. The asymmetric structures such as asymmetric boudins, en-echelon array of the tension gashes and offset of the dolomite layer associated with the northeast trending stretching lineation indicate a top-to-the northeast sense of shear during emplacement on the Menderes massif.

4.2 Lycian Nappes

In the study area the Lycian nappes are represented by the Akhisar nappe composed of red and green metaclastic rocks with rhyolite intercalations, limestone lenses and conglomerate intercalations in the lower part and recrystallized massif limestones in the upper part (Figure 2.1 and Plate I).

4.2.1 Primary Structures

Bedding planes in the Akhisar nappe can be clearly recognized by conglomerate intercalations and in lenses of limestones (Figures 4.9 and 4.10). The limestones are thinly bedded and are found both along the lower contact of the Akhisar nappe and close to the upper contact with the recrystallized limestones around Akhisar. Thin to medium bedded limestone are approximately NW striking and gently SW dipping around Seğirdim village in the east of Akhisar. The grain supported conglomerate intercalations are composed of red and gray limestone pebbles and sand matrix. The siliciclastic conglomerates that mainly crop out in the east of Çamönü village show thick beds and contain scattered white quartz pebbles in sand matrix (Figure 2.4).

Figure 4.9 Photograph showing intraformational limestone conglomerates in the Akhisar nappe close to the contact between red metaclastics and overlaying recrystallized limestones. Pencil is 13cm.

Figure 4.10 Photograph showing limestone layers in red metapelites close to the contact of the recrystallized limestones forming the upper part of the Akhisar nappe.

4.2.2 Secondary Structures

In strongly brittly deformed red green phyllites of the Akhisar nappe the linear fabrics are defined by stretching lineations, crenulation lineations, axis of mesoscopic folds and long axis of elongated pebbles.These tectonic structures are dominant along the lower boundary of the nappe. Along these contact both the limestones of the Kayaaltı formation and red-green metaclastics with rhyolite interclations show a prominent mylonitization.

In the Akhisar nappe, secondary structures associated with stretching lineation and foliation are follows:

- Asymmetric folds, kink folds and intrafolial folds
- Axial plane foliation, crenulation cleavage
- Extensional shear bands
- Pencil structures, tension gashes
- Asymmetric deformed pebbles
- Sigmoidal fibers in veins
- Pressure shadows
- Semi-brittle shear zone
- Slickenfibers along slickensides

The foliation and cleavage planes are defined by elongation of tiny micas in metapelites and metapsammites of the Akhisar nappe (Figures 4.11, 4.12 and 4.13). The metapelites, metapsammites and recrystallized limestones in the Akhisar nappe have anastomosing foliation in the field however in thin sections they show rough foliation. The rough foliation (Figure 4.12), is defined by thin micaceous cleavage domains showing preferred orientation of elongate grains and phyllosilicates in beards formed around the coarse grains (Gray, 1978) in metapelites and metapsammites. Microlithons exhibit a wide range of preferred orientations of detrital grains from random to strongly oriented. The rough foliation in metapsammites is probably due to the interaction of several deformation mechanisms (Gray, 1978). These are (1) solution transfer (pressure solution) identified by dark seams along cleavage domains and around truncated grains (2) crystallization and/or recrystallization of phyllosilicates along cleavage domains and mica beards around coarse grains(3) rotation and (4) minor grain fracturing.

Along the lower contact the Akhisar nappe show a prominent continous foliation related to mylonitization, however in the most part of the metaclastics the fold axial plane cleavage is common.

The linear fabric in the Akhisar nappe and Menderes massif in the Akhisar region is identified by stretching lineation along foliation (cleavage) plane, crenulation axis, long axis of elongated pebbles, mineral lineation and orientation of fibrous crystals in pressure shadows.

Figure 4.11 Photograph showing rough foliation parallel to the bedding plane in metapsammites of the Akhisar nappe. Çamönü Village.

The asymmetry of shear bands, relationship between foliation and porphyroclasts, S/C relationship, quartz and calcite sigmoids were used to define shear sense during the emplacement of the Akhisar nappe, on to the Menderes massif.

Figure 4.12 Photomicrograph showing rough foliation in the red and green metapsammites of the Akhisar nappe. The rough foliation is identified by elongation of quartz and feldspar grains and mica. Mica Beards around grains. In addition to these, the foliation domains are composed of preferred orientation of tiny phyllosilicates and elongated quartz grains. Width of the view is 2mm.

Figure 4.13 Photograph showing foliation plane in the red and green metapelites of the Akhisar nappe. Pencil is 13cm and parallel to crenulation axis.

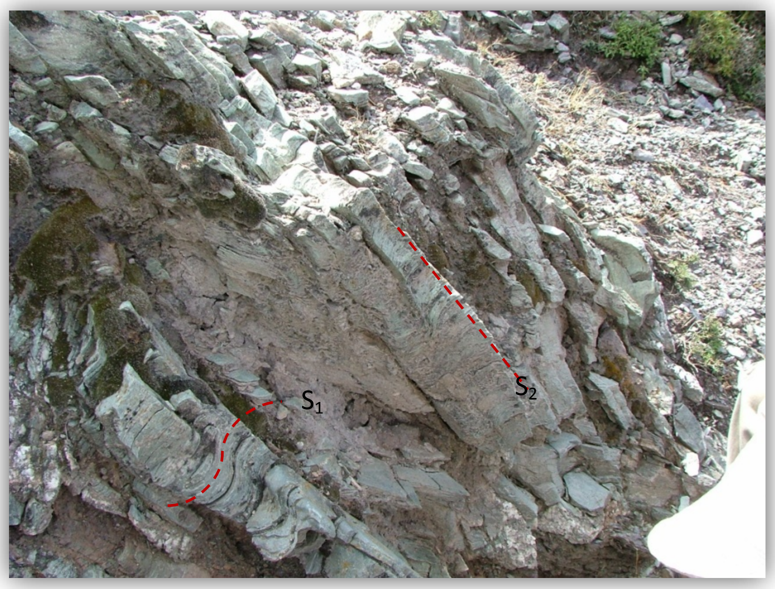

Figure 4.14 Two foliations S_1 and S_2 in the rhyolite intercalations close to the nappe contact of the Akhisar nappe. This two foliations is related to the overturned fold that common along the lower boundary of the Akhisar nappe. Sarıçalı Village (0577384; 4298041 UTM 35S).

The stretching lineation is prominent in the rhyolite intercalations and fine grained, recrystallized limestone layers. In rhyolite elongated feldspar an quartz crystals in green fine grained green matrix define the stretching lineation (Figure 4.15). In gray limestone green lenses stretched calcite crystal, calcite fibers and slickenlines along the continous foliation planes (Figure 4.16).

Figure 4.15 Photograph showing stretching lineation parallel to the red dashed line along the foliation plane in the mylonitic rhyolite intercalations in the red and green metapalites of the Akhisar Nappe. (0577384; 4298041 UTM 35S) Sarıçalı Village.

Figure 4.16 Photograph showing the stretching lineation along the foliation plane in recrystallized limestone lenses in the Akhisar nappe. These limestone lenses show a prominent continous foliation. Pencil is parallel to the stretching lineation, and is 13 centimeters.

In the green metapsmmites quartz fibers filled the mode I cracks (tension gashes) define the stretching direction (Figure 4.17). In some tension gashes the quartz fibers show sigmoids shape which indicate both tension and shear.

Figure 4.17 Stretching lineation along foliation plane and quartz fibers filled mode I cracks in the green metapsammites of the Akhisar nappe. Fibers and stretching lineation are parallel each other.

4.2.3 Kinematic Features of the Akhisar Nappe

The linear fabric in the Akhisar nappe is defined by long axis of stretched pebbles, stretching lineation along foliation planes, axis of mesoscopic folds and crenulation, fibers in the mode I craches. Stereographic plot (Figure 4.18), shows that the linear fabric in the Akhisar nappe has mean orientation of 26/15.

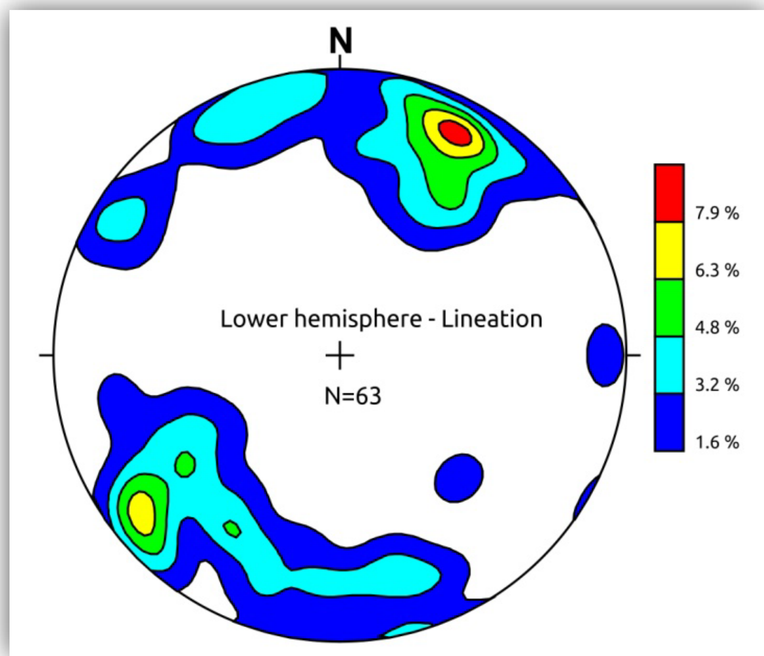

Figure 4.18 Stereographic plot showing the linear fabric in the Akhisar nappe and Menderes massif. Diagram shows that linear fabric has a prominent northeast trend and north-south trends. Dip direction / dip angle.

Contour diagram of foliation in the Akhisar nappe shows a folding of foliation. The NW-trending axes of these folds are approximately perpendicular to the stretching lineation.

The linear fabric and associated asymmetric structures such as deformed quartz pebbles (Figure 4.20, 4.21), S/C relationship, quartz and calcite sigmoids indicate a top-to the northeast sense of shear in the Akhisar nappe.

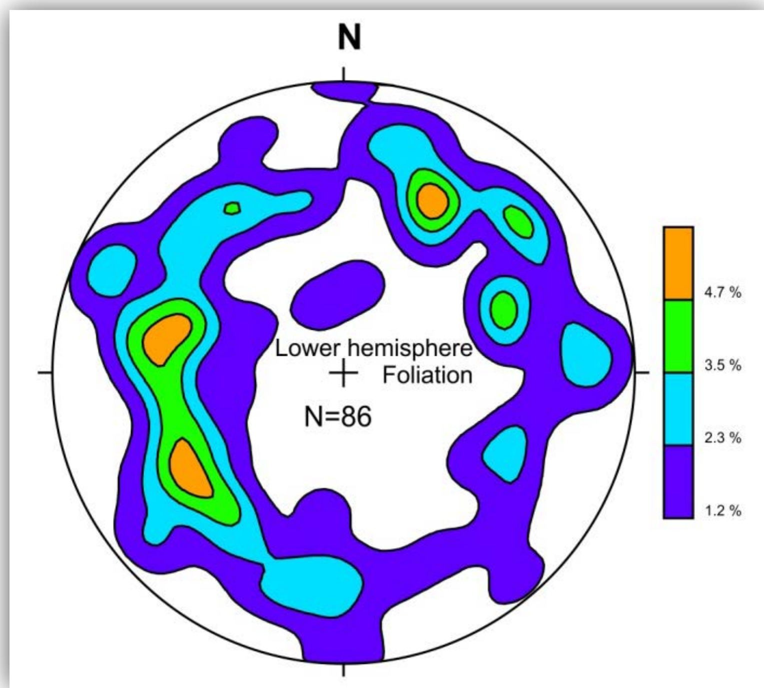

Figure 4.19 Contour diagram of the foliation in the Akhisar nappe. Dip direction/dip angle. Dip directions of the foliation shows a NE-trending fold of foliation.

Figure 4.20 Asymmetrically deformed quartz pebble. Asymmetric foliation indicate a top-NE sigma sense of shear. Çamönü village.

Figure 4.21 Photograph showing asymmetric deformed quartz pebble indicate a top-NE sense of shear in the surface parallel to the stretching lineation and perpendicular to the foliation. Çamönü village.

The mesoscopic scale overturned folds (Figure 4.22), along the lower contact of the Akhisar nappe are common. Along these folds the northeast trending stretching lineation also folded and it is perpendicular to the fold axis.

Figure 4.22 Photographs showing overturned folds in the red and green metapsammites in the Akhisar nappe. Asymmetry of the folds shows a top-NE sense of rotation. Sarıçalı village (0577341; 4298021 UTM 35S).

Figure 4.23 Overturned fold in green metapsammites. So: Bedding plane, S1: Fold axial plane cleavage.

Asymmetric structures such as ∂- calsts, quartz and calcite sigmoids and S/C relationship in the oriented thin sections (Figure 4.24a, b, c and d), clearly show a top-to-the northeast sense of shear in the rhyolite intercalations and red-green metapelites, metapsmmites of the Akhisar nappe.

The linear fabric and associated asymmetric structures consistently show a top-to-the northeast sense of shear in the mylonitic zone along the contact between the Akhisar nappe and the underlying Menderes massif. These mylonitic zone possible formed during Neotethys closure (Şengör & Yılmaz, 1981), and collision. The kinematic analysis including extensive field work and many measured structural elements nearly introduces the direction of the nappe movement.

The Eocene-Oligosen (Akdeniz, 1980; Önoğlu, 1996), and Neogene sedimentary and volcanic rocks are in post-tectonic facies and cover the Bornova melange, Akhisar nappe and Menderes massif.

Brittle normal faults cut the Akhisar nappe. SW dipping brittle normal fault that cut the recrystallized limestones of the Akhisar nappe is observed in the south Akhisar.

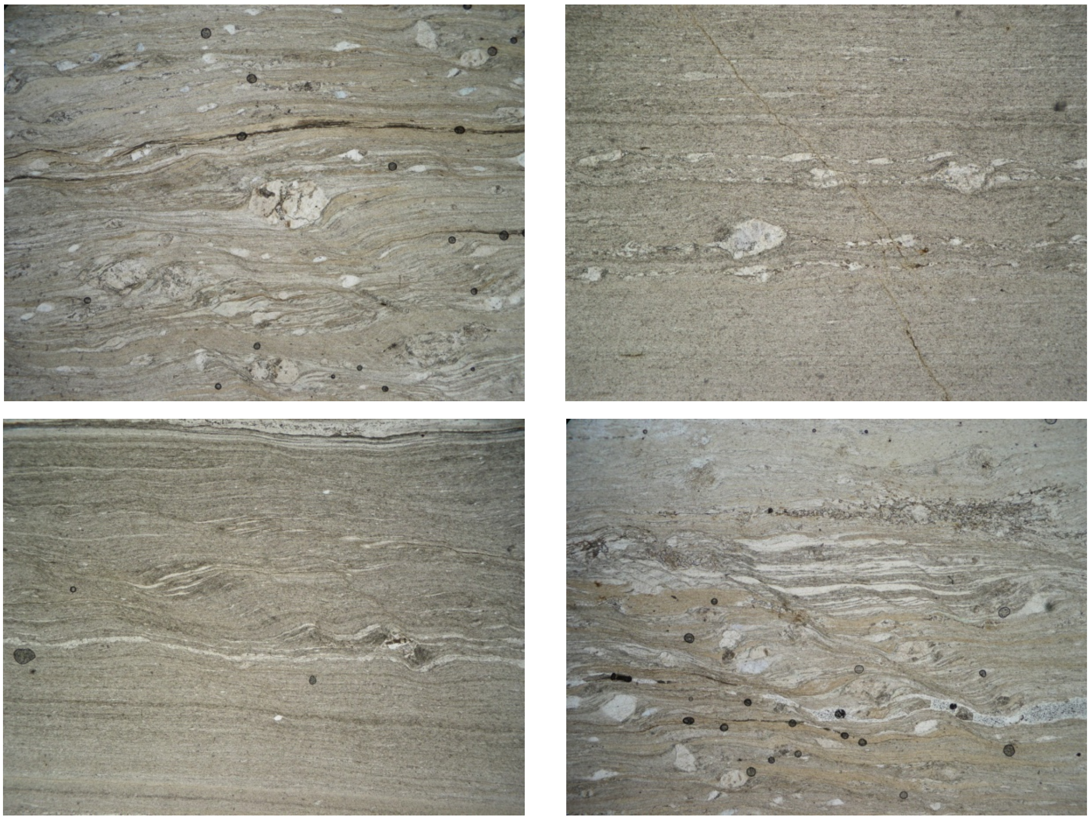

Figure 4.24 Photomicrographs of oriented thin sections from metapelites and metapsammites. (a) s-clasts, (b) sigma clasts and detached q-veinletts, (c,d) S/C relations consistently indicate a top-NE sense of shear along the lower boundary of the Akhisar nappe. (Width of fotograph is about 2mm).

Figure 4.25 Photograph showing active dextral oblique fault cut the recrystallized limestones of the Akhisar nappe.

4.3 The Bornova Melange

The Bornova melange overlays the Akhisar nappe and the Menderes massif along an approximately that tectonic contact (Plate I). The Bornova melange is made up of tectonic slices of sheared serpentinites, gabbros, blocks of platform carbonates, radiolarian cherts, mafic spilitic basalts and sheared matrix of sandstone and shale. The sheared internal structure of the Bornova melange shows a chaotic anastomosing foliation represented by shear fractures (Figure 4.26).

Shear surfaces form an anostomosing foliation in the Bornova melange. Tectonic slices enveloped by shear surface were brittly deformed and they also show rootless folds (Figure 4.27).

Figure 4.26 Photograph showing sheared sandstone shale matrix of the Bornova melange.

Figure 4.27 Rootless folds tectonic slice composed of radiolarian cherts in the radiolarian cherts in the Bornova melange.

CHAPTER FIVE
CONCLUSIONS

The Menderes Massif, Lycian nappes and Bornova melange which form the main tectonic belts of the west Turkey expose in the Akhisar region.

The Menderes Massif that forms the structurally lowest tectonic terrane is reperesented by massive marbles named as the Kayaaltı formation.

The Lycian nappes is represented by the Akhisar nappe composed of red and gren metaclastics with conglomerate and rhyolite intercalations and limestone lenses in the lower part, and recrystallized limestones in the upper part. The Akhisar nappe tectonically overlays the Kayaaltı formation along a low-angle fault zone that provides mesoscopic and microscopic structures for the kinematic analysis.

The İzmir-Ankara zone is represented by the Bornova melange that tectonically overlays both the Menderes massif and the Akhisar nappe. The Bornova melange is composed of sheared serpentinized peridotites, sheared serpentinites, gabbros, pillow lavas of mafic volcanites, red radiolarites and pelagic limestones, blocks of platform carbonates and sheared mudstone-sandstone matrix in some places. The mafic volcanic rocks found in the Bornova melange are alkaline and subalkaline basalts. Tectonic setting diagrams show that they mostly have affinity with the the ocean-floor basalts, the calc-alkaline basalts and mid-ocean ridge basalts.

The meso- and microscale structures in the uppermost part of the Menderes massif and the lower part of the Akhisar nappe are mainly described and studied. Along this mylonitic fault zone the kinematic indicators associated with stretching lineation and foliation indicate a top-to-the northeast sense of shear during the emplacement of the Akhisar nappe on the Menderes massif.

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APPENDIX

Table Results of geochemical analysis of the mafic volcanic rocks in the Bornova melange.

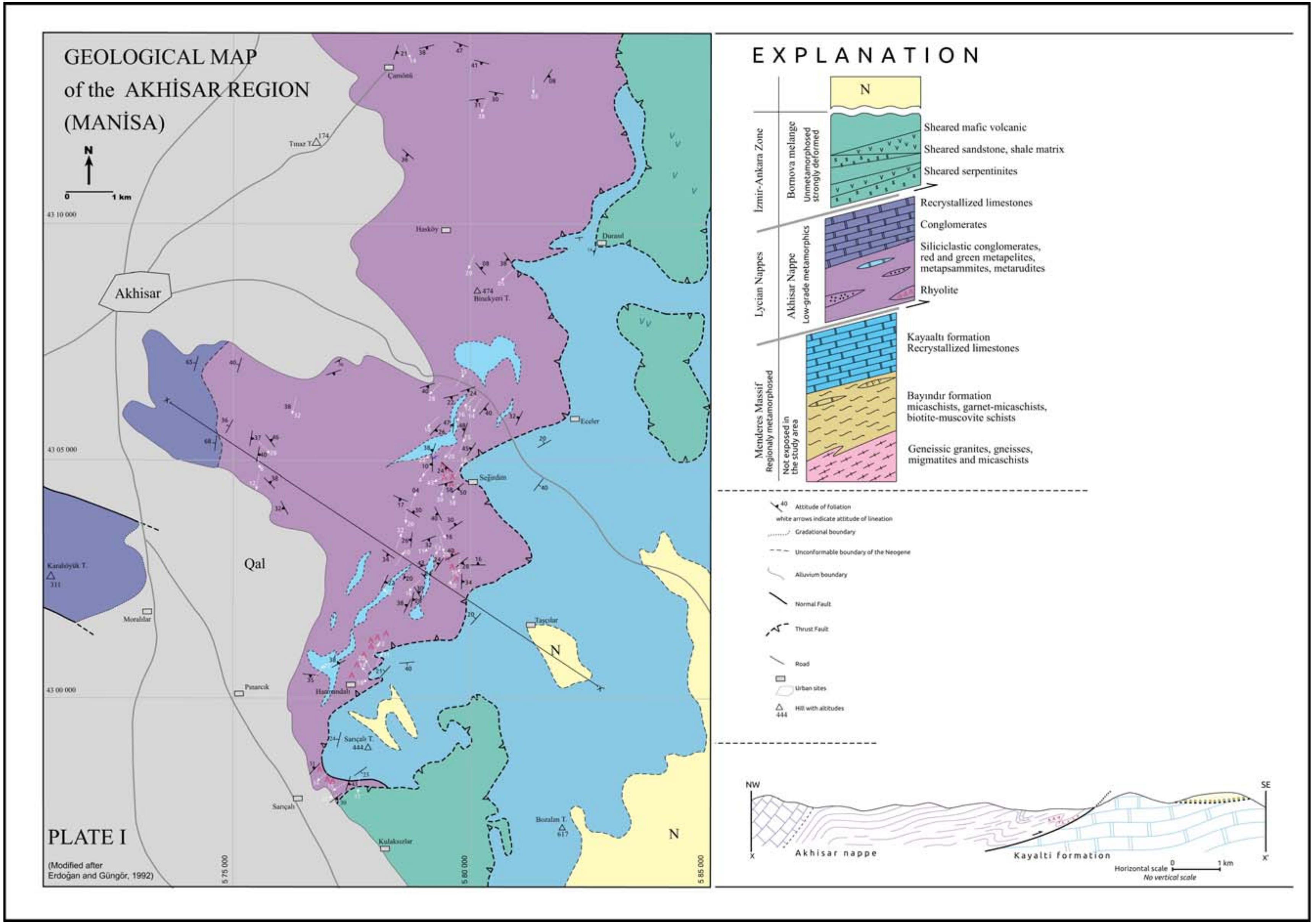
SAMPLE DESCRIPTION	Ag ppm	Ba ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Dy ppm	Er ppm	Eu ppm	Ga ppm
1	<1	72	19.2	38.3	160	1.79	41	6.62	4.45	1.58	17.7
2	<1	89.8	17.5	47	170	3.41	29	7.27	5.08	1.66	20.6
3	<1	131	80	33.4	20	0.55	18	5.94	3.21	2.41	16.7
4	<1	100.5	57	7.5	60	0.28	15	2.84	1.9	1.2	13.1
5	<1	181.5	66.9	35.3	110	1.68	36	6.51	3.74	2.45	21.4
6	<1	154.5	52.4	41.4	70	7.03	15	3.21	1.84	1.36	17.7
7	<1	446	67.4	41.6	30	4	42	3.97	2.22	1.74	19
8	<1	287	65.4	47.7	20	9.56	23	3.92	2.19	1.83	18.7
9	<1	115.5	41.4	55.2	620	0.27	54	2.91	1.66	1.26	11.9
10	<1	119	53.4	28.8	50	0.16	23	4.37	2.48	1.84	18.9
11	<1	1840	71.9	21.4	60	17	40	1.9	0.95	1.34	18.9
12	<1	229	41.6	42	150	1.16	76	3.2	1.84	1.37	13.6
13	<1	34.5	14.6	51.3	390	0.17	58	4.81	3.02	1.19	13.6
14	<1	164	38.8	64.9	440	1.19	62	6.07	3.93	1.87	17.5
15	<1	177	57.8	35	50	0.46	34	3.63	2.03	1.66	17.7
16	<1	113.5	40.8	57.5	660	0.27	56	2.96	1.65	1.21	12.1
17	<1	287	34.4	35.5	450	0.08	47	2.51	1.45	1.07	14.2
18	<1	293	77.6	29.8	150	3.41	52	4.34	2.57	1.93	18
19	<1	907	76.7	37.2	260	0.84	93	3.01	1.55	1.58	14.3
20	<1	238	47.7	10.7	100	1.35	36	3.12	1.6	1.37	13.1
21	<1	513	181	25.9	20	1.76	<5	9.96	6.23	0.71	33
22	<1	76.6	36.6	38.8	190	0.81	49	5.71	3.44	1.72	23

SAMPLE	Gd	Hf	Ho	La	Lu	Mo	Nb	Nd	Ni	Pb	Pr
DESCRIPTION	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	6.05	5.1	1.42	6.9	0.68	<2	7.3	14	117	<5	2.98
2	6.53	5.2	1.57	6.8	0.74	<2	6.8	15.4	72	<5	3.14
3	7.91	6.3	1.12	39.2	0.36	2	36.9	37.6	22	5	9.78
4	3.34	3.7	0.62	31.2	0.29	<2	50.6	22	7	<5	6.28
5	7.85	6.1	1.26	31.6	0.46	<2	42.2	32.3	40	8	8.4
6	4.11	2.8	0.62	27.9	0.23	3	33.8	21.3	45	<5	5.88
7	4.88	3.5	0.79	36.7	0.28	<2	44.2	26.5	24	<5	7.55
8	5.08	3.5	0.76	34.7	0.29	<2	42.5	26.4	16	<5	7.38
9	3.64	2.5	0.57	21.7	0.21	<2	25.2	17	257	<5	4.76
10	5.66	3.5	0.86	30.3	0.33	<2	40.3	24.6	29	<5	6.71
11	3.62	5	0.33	38.7	0.13	3	11.9	28.9	17	65	8.18
12	3.95	2.8	0.63	20.3	0.23	<2	29.8	18.1	86	<5	4.91
13	5.03	2.5	0.99	6.7	0.4	<2	4.8	11.5	134	5	2.5
14	6.38	3.6	1.27	16.3	0.5	<2	8.1	22.2	251	9	5.4
15	4.6	3.2	0.71	30.8	0.26	<2	38.6	23.2	22	5	6.52
16	3.62	2.4	0.56	21.2	0.21	<2	25.7	16.9	269	<5	4.63
17	3.09	2.2	0.49	18.6	0.18	<2	23.1	14.6	115	<5	3.96
18	5.58	3.4	0.85	40.7	0.33	<2	34.4	30.6	58	<5	8.67
19	4.54	2	0.53	39.6	0.22	2	12.5	31.3	70	5	8.46
20	4.17	2.7	0.57	25.2	0.22	<2	31.9	20.7	27	<5	5.33
21	9.99	15.6	1.98	96.7	1	<2	176.5	63.6	<5	<5	19
22	6.07	4.1	1.11	16.2	0.48	<2	11.3	20.7	77	<5	4.82

SAMPLE DESCRIPTION	Rb ppm	Sm ppm	Sn ppm	Sr ppm	Ta ppm	Tb ppm	Th ppm	Tl ppm	Tm ppm	U ppm	V ppm
1	13.5	4.45	2	189.5	0.6	0.98	0.66	<0.5	0.67	0.44	287
2	35.9	4.8	2	92.8	0.6	1.05	0.57	<0.5	0.77	0.39	357
3	28.5	7.85	2	630	2.7	1.02	4.2	<0.5	0.44	1.42	190
4	1.7	3.9	1	249	3.5	0.45	6.39	<0.5	0.3	1.02	128
5	38.4	7.1	2	247	3.1	1.09	5.05	<0.5	0.52	1.12	241
6	7.4	4.09	1	296	2.4	0.55	5.02	<0.5	0.26	0.97	241
7	69	5.01	1	185	3	0.65	6.28	<0.5	0.35	1.19	341
8	17.3	4.91	1	438	2.9	0.67	5.8	<0.5	0.33	2.33	289
9	27.8	3.4	1	395	1.8	0.49	3.73	<0.5	0.25	0.76	201
10	5.2	5.01	1	182	2.8	0.74	5.22	<0.5	0.37	0.59	314
11	308	5.23	2	632	0.9	0.39	44.1	3.4	0.16	23.4	80
12	9.4	3.72	1	171.5	2.1	0.56	3.87	<0.5	0.28	3.07	258
13	2.6	3.49	1	265	0.4	0.74	0.5	<0.5	0.46	0.15	247
14	31.9	5.23	2	140	0.6	0.93	2.76	<0.5	0.58	0.69	169
15	5.2	4.41	1	211	2.6	0.61	4.81	<0.5	0.31	0.99	280
16	28.4	3.32	1	398	1.8	0.49	3.34	<0.5	0.25	0.71	219
17	14.9	2.9	1	421	1.6	0.43	2.98	<0.5	0.22	0.5	232
18	80.9	5.46	1	187	2.1	0.72	4.75	<0.5	0.36	1.14	238
19	14	5.66	1	218	0.5	0.55	5.88	<0.5	0.23	1.86	275
20	34.5	4.11	1	277	2	0.56	3.39	<0.5	0.25	1.37	212
21	92.7	11.05	5	83.2	10.9	1.6	22.9	<0.5	0.99	4.58	10
22	3.7	5.07	2	112.5	0.8	0.92	3.1	<0.5	0.52	1.33	281

SAMPLE	W	Y	Yb	Zn	Zr	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O
DESCRIPTION	ppm	ppm	ppm	ppm	ppm	%	%	%	%	%	%
1	42	37.2	4.31	112	200	50.4	16.45	11.15	1.63	4.25	7.03
2	12	46.2	4.66	153	210	47.9	15.5	13.35	2.27	5.63	4.22
3	31	32.2	2.4	119	260	48.3	11.85	8.95	11.4	1.65	4.34
4	34	17.6	1.81	27	170	48.1	15.45	3.53	13.25	0.12	7.02
5	15	35.6	3.02	101	270	47.7	15.65	10.1	4.38	9.1	2.65
6	44	17.3	1.5	57	120	47	16.9	8.44	9.79	5.56	4.01
7	12	21.5	1.92	104	160	46.5	15.65	10.85	6.52	4.05	3.63
8	78	21.1	1.87	93	150	46.8	16.4	10.5	7.07	4.62	4.71
9	29	15.4	1.42	69	100	49	14.15	8.65	8.43	9.1	4.25
10	13	23.5	2.09	94	140	51.8	18.05	8.05	1.69	5.05	7.09
11	46	9.8	0.85	67	200	63.4	16.2	4.13	1.52	2.18	4.06
12	26	16.9	1.54	71	120	43.9	16.4	6.96	10.5	5.47	4.75
13	36	26.4	2.62	70	100	51	13.8	8.39	9.08	8.95	3.08
14	18	38.3	3.34	153	150	46.4	15.2	9.39	8.38	4.23	3.89
15	76	19	1.68	73	140	46	17.2	7.39	14	3.07	2.85
16	34	15.4	1.36	70	100	49.3	14.6	8.5	8.58	9.12	4.36
17	46	13.6	1.2	57	90	47.8	14.8	6.78	12.8	6.84	4.09
18	9	23.3	2.18	86	150	43.3	14.95	10.9	9.11	4.17	3.16
19	13	14.3	1.38	74	80	44.1	13.3	8.52	12.75	4.9	0.01
20	36	15.4	1.44	45	110	38.4	12.4	5.45	20.3	0.51	3.26
21	241	54.8	6.41	145	720	65.5	15.45	3.47	0.32	1.08	3.54
22	36	29.4	3.14	88	170	47.6	18.15	9.04	5.4	6.64	5.8

SAMPLE	K2O	Cr2O3	TiO2	MnO	P2O5	SrO	BaO	LOI	Total
DESCRIPTION	%	%	%	%	%	%	%	%	%
1	0.54	0.02	2.65	0.1	0.32	0.02	0.01	3.45	98.02
2	0.99	0.02	2.51	0.16	0.29	0.01	0.01	5.28	98.14
3	1.03	<0.01	2.5	0.19	0.62	0.08	0.01	8.93	99.85
4	0.07	0.01	1.82	0.06	0.45	0.03	0.01	10.9	100.82
5	1.83	0.01	2.76	0.35	0.53	0.03	0.02	5.05	100.16
6	0.35	0.01	1.44	0.13	0.29	0.04	0.02	5.84	99.82
7	1.73	<0.01	1.95	0.28	0.36	0.02	0.05	7.77	99.36
8	0.74	<0.01	1.78	0.16	0.36	0.06	0.03	6.81	100.04
9	0.81	0.08	1.12	0.15	0.2	0.05	0.01	4.25	100.25
10	0.2	0.01	1.88	0.15	0.4	0.02	0.01	4.28	98.68
11	4.95	0.01	0.42	0.09	0.29	0.08	0.22	3.05	100.6
12	0.47	0.02	1.39	0.15	0.31	0.02	0.03	8.82	99.19
13	0.12	0.05	1.37	0.33	0.19	0.03	<0.01	3.57	99.96
14	0.96	0.06	1.43	1.14	0.22	0.02	0.02	8.29	99.63
15	0.3	<0.01	1.76	0.11	0.44	0.03	0.02	7.08	100.25
16	0.85	0.09	1.16	0.15	0.25	0.05	0.01	4.3	101.32
17	0.98	0.06	1.01	0.11	0.23	0.06	0.03	5.42	101.01
18	3.23	0.02	1.54	0.13	0.43	0.03	0.03	8.21	99.21
19	0.64	0.04	0.53	0.13	0.24	0.03	0.11	15.6	100.9
20	1.26	0.01	1.21	0.06	0.47	0.03	0.03	17.95	101.34
21	5.84	<0.01	0.24	0.08	0.03	0.01	0.06	2.62	98.24
22	0.11	0.03	1.67	0.14	0.31	0.01	0.01	6.17	101.08



GEOLOGICAL MAP
of the AKHİSAR REGION
(MANİSA)
N
0 1 km
43 10 000
43 05 000
43 00 000
5 75 000
5 80 000
5 85 000
Akhisar
Qal
N
Çamönü
Tmaz T. 174
Hasköy
Durasıl
Binekyeri T. 474
Eceler
Seğirdim
Karaköyük T. 311
Moralılar
Taşçılar
Pınarcık
Hacımmdalı
Sarıçalı T. 444
Sarıçalı
Kulaksızlar
Bozalan T. 617
PLATE I
(Modified after
Erdoğan and Güngör, 1992)
EXPLANATION
N
İzmir-Ankara Zone
Bornova melange
Unmetamorphosed strongly deformed
Sheared mafic volcanic
Sheared sandstone, shale matrix
Sheared serpentinites
Lycian Nappes
Akhisar Nappe
Low-grade metamorphics
Recrystallized limestones
Conglomerates
Siliciclastic conglomerates,
red and green metapelites,
metapsammites, metarudites
Rhyolite
Menderes Massif
Regionaly metamorphosed
Not exposed in the study area
Kayaaltı formation
Recrystallized limestones
Bayındır formation
micaschists, garnet-micaschists,
biotite-muscovite schists
Geneissic granites, gneisses,
migmatites and micaschists
Attitude of foliation
white arrows indicate attitude of lineation
Gradational boundary
Unconformable boundary of the Neogene
Alluvium boundary
Normal Fault
Thrust Fault
Road
Urban sites
Hill with altitudes
NW
SE
X
X'
Akhisar nappe
Kayalti formation
Horizontal scale 0 1 km
No vertical scale