GEOMETRY AND TECTONIC SIGNIFICANCE OF BUYUK MENDERES DETACHMENT IN THE BASCAYIR AREA, BUYUK MENDERES GRABEN, WESTERN TURKEY

by

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INTRODUCTION

Western Turkey contains well-developed structural features due to the large- scale continental extension (Figure 1). Several E-W trending graben systems, detachment faults and a metamorphic core complex have developed during this extension (Emre and Sozbilir, 1997; Yilmaz *et al.* 2000; Bozkurt, 2001; Seyitoglu *et al.* 2002). The metamorphic core complex, referred as the Menderes Massif, is divided into northern (Gordes), central and southern (Cine) submassifs by two E-W trending grabens (Hetzel *et al.* 1995). These grabens, from north to the south are the Gediz (Alasehir), and Buyuk Menderes grabens.

During the 1990's, field-oriented geological studies in the central Menderes massif, demonstrated the presence of two low-angle normal faults (Figure 2). The normal fault that borders the central Menderes Massif to the north is the Alasehir detachment, a north-dipping low-angle normal fault along the southern margin of the Alasehir (Gediz) Graben (Seyitoglu, Cemen and Tekeli 2000; Gessner *et al*. 2001). It contains ductile (mylonitic) and brittle structures displaying top to the north sense of shear (Isik, Seyitoglu and Cemen, 2003). The normal fault that borders the central Menderes Massif to the south is a south dipping detachment surface along the northern margin of the Buyuk Menderes Graben. This detachment has been named as the Bascayir detachment by Emre and Sozbilir (1997) and Guney detachment by Gessner *et al*. (2001). It is informally named here as the Buyuk Menderes detachment because of its closeness to the Buyuk Menderes Graben. Kinematic indicators along the Buyuk Menderes detachment surface show both top to the north and top to the south sense of shear (Gessner *et al*. 2001 and Isik, Seyitoglu and Cemen, 2003).

The Buyuk Menderes detachment surface contains fault rocks, showing characterictics of ductile and brittle deformation (Hetzel *et al.* 1995 and Gessner *et al.* 2001). In structurally lower levels, these fault rocks grade downward into a ductilely deformed zone where it is referred here as Buyuk Menderes shear zone. This shear zone mainly strikes east- west and dips shallowly to the south. It is defined on the basis of well-developed mylonitic fabrics (Hetzel *et al*. 1995; Gessner *et al*. 2001)

Although the Alasehir (Gediz) detachment has been studied in detail in recent years (Kocyigit, Yusufoglu and Bozkurt 1999; Seyitoglu, Cemen and Tekeli, 2000 and 2002, Gessner *et al*. 2001; Sozbilir, 2002 and Isik, Seyitoglu and Cemen, 2003), the Buyuk Menderes detachment remains relatively unstudied.

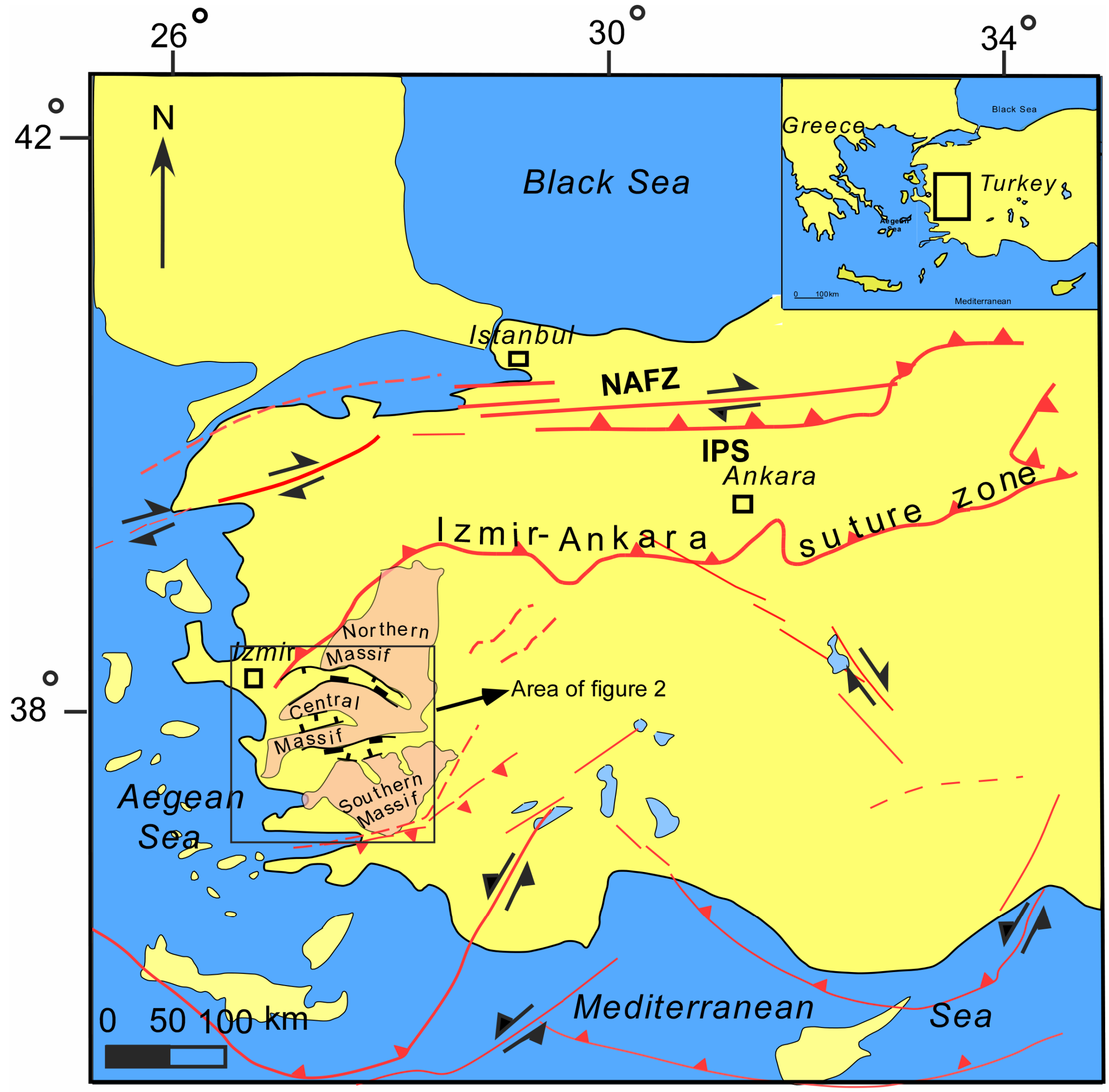


Figure 1. *Map of the western Turkey showing major tectonic features, regions of strong Tertiary extension, and the location of the Menderes Massif Metamorphic Core Complex (modified from Gessner et al. 2001;Ring et al. 2003; Isik et al. 2003). Insert map shows the location of the map in the Aegean region.*

Abbreviations: NAFZ*= North Anatolian Fault zone,* ***IPS****= Intra-pontid suture zone*

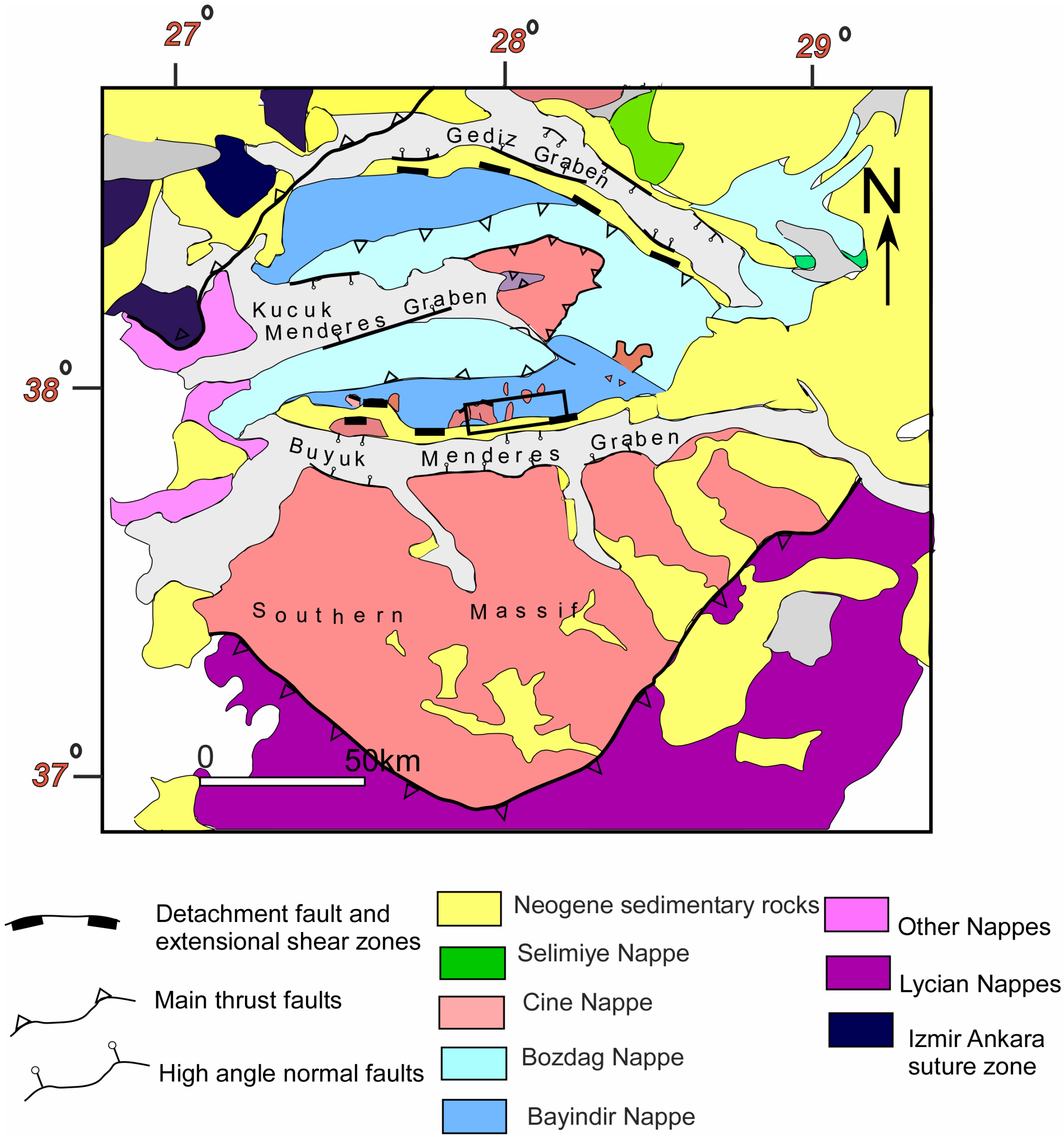


Figure 2. *Simplified geologic map of western Turkey (Modified from, Hetzel et al.1995; Gessner et al. 2001; Isik et al. 2003). The rectangle indicates the location of the study area*

Statement of the Problem

The Buyuk Menderes graben separates the Cine submassif from central Menderes Massif (Figure 1 and Figure 2). It is about 125 km long and 8- 12 km wide. It is bounded by a complex system of normal faults to the north and to the south (Figure 2).

The goal of this thesis is to better understand the structural evolution of the Buyuk Menderes detachment surface, separating the high-grade metamorphic rocks in its upper plate from the ductilely to brittlely deformed medium-grade metamorphic rocks in its lower plate. The upper plate rocks also contain brittlely deformed sedimentary unit. The detachment surface is well exposed in the vicinity of the Bascayir village. Therefore, this area was chosen as the central part of the geological fieldwork for this investigation.

Methods of Investigation

To accomplish the main objectives of this study, a detailed field- work in the vicinity of Bascayir village was carried out during the summers of 2002 and 2003. During the fieldwork, representative samples were collected from the different rock units exposed in the study area. These samples were examined in detail for petrographic and microstructural analysis during the academic year of 2003 and 2004.

Field Mapping and Sampling

1) The geology in an area of 40km^2 along the Buyuk Menderes shear zone has been mapped on a scale of 1/10,000 on the topographic maps provided by the Turkish Mapping Authority. The topographic maps were 1/ 25,000 scale. They were enlarged to 1/10,000 scale. The geologic mapping yields important clues to understand the structural relationship of the upper plate and lower plate rocks of the Buyuk Menderes detachment and to the overall structural characteristics of the detachment.

The detailed mapping in the region also allowed to distinguish deformation structures such as folds, cleavages and foliated structures at different scales. Measurement of fault plane kinematic indicators such as the trend and the plunge of slickenlines and striations were recorded along the fault surface.

2) Over 60 samples were collected from the upper plate and lower plate rocks of the Buyuk Menderes detachment. Most samples were oriented samples to depict the characteristics of the ductile-brittle transition along the Buyuk Menderes shear zone. The foliation and lineation were generally obvious in the field. The Global Positioning System (GPS) locations, including elevation, latitude and longitude values of all observation points were recorded.

3) The critical field relationships were photographed to show mesoscopic features that were too small to show on the geologic map, with 1/10,000 scale.

Laboratory Analysis

1) The oriented samples were cut parallel to the lineation and perpendicular to the foliation. Thin sections were prepared from about 45 samples for examination of microstructures. The analyses of microstructural fabrics were accomplished by using petrographic microscope, with the aim of understanding the occurrence and characteristics of deformation structures and their overprinting relationships.

2) Photographic enhancements of outcrop relationships were made to emphasize the geometric relationship between the outcrop scale structural features. By using photographs, sketches, thin sections, field notes, and the data sets, the characteristics of deformation structures for each type and location were classified.

Geologic Setting

During the 1990's geologic field investigations in the Menderes Massif have been the focus of the numerous studies. These studies have led to a widely accepted conclusion that the Menderes Massif in Turkey is an excellent example of a metamorphic core complex. The southern limit of the Menderes Massif is marked by unmetamorphosed sequence of the Lycian Nappes and the northern border is defined by the Izmir-Ankara suture zone (Figure 2). The Menderes Massif Core complex is composed of the following tectonometamorphic units;

1) High grade Pan African metamorphic rocks, the Core series. Schuiling (1962) first described the gneissic sequence of the core series of the Menderes Massif. Sengor et al. (1984); Dora et al. (1997) and Oberhansli et al. (1997) have pointed out that the core

series are comprised of ductilely deformed high-grade metamorphic rocks. The radiometric age determinations from the core series suggest that its age ranges from 570 Ma to 520 Ma. (Hetzel and Reishmann, 1996)

2) Paleozoic-Mesozoic metasedimentary cover series, Sengor *et al*. (1984); Dora *et al*. (1990) Hetzel *et al*. (1995) have indicated that the cover rocks are composed of greenschist facies mica schist, phyllite, quartzite and marble. Based on the fossil evidences, the age of marbles in the cover series is Cretaceus (Ozer, 1998).

The Menderes Massif is divided into northern (Gordes), central and southern (Cine) submassifs by two E-W trending grabens (Hetzel *et al*. 1995). The Central Menderes Massif is structurally outlined by a zone of gently and systematically arranged north-dipping Alasehir (Gediz) detachment and south- dipping Buyuk Menderes detachment. The deposition of syn-extensional sedimentary units occurred in association with the generation of these detachments (Kocyigit, Yusufoglu and Bozkurt 1999; Yilmaz *et al.* 2000; Seyitoglu, Cemen and Tekeli 2000; and 2002;)

The Alasehir detachment fault is a regional low-angle normal fault that separates an extended upper plate from highly deformed lower plate rocks (Seyitoglu *et al*. 2002). The contact of the lower plate and upper plate rocks along the Alasehir detachment surface is marked by a zone of an extreme shearing and development of fault plane features and kinematic indicators, such as slickensides and striations (Isik, Seyitoglu and Cemen 2003; Bozkurt and Sozbilir 2004). Relatively little has been published about the Buyuk Menderes detachment compared to the Alasehir detachment. Emre and Sozbilir (1997) have suggested that the contact between gneiss klippen (upper plate rocks) and ductilely deformed schists (lower plate rocks) is a low angle normal fault in the form of reactivated thrusts.

Structural Evolution of central Menderes Massif

Hetzel *et al*. (1995) have pointed out that central Menderes Massif contains a dome shaped foliation pattern with a bivergent downdip movement along the northern and southern parts of the central Menderes Massif. Their findings revealed that the northern part of this structural dome is characterized by top to the north and northeast shear sense with shear sense indicators such as, shear bands and c-axis fabrics' orientation. They claimed that the southern part of the central Menderes Massif is characterized by south-southwest shear sense.

Along the northern margin of the Buyuk Menderes graben, Emre and Sozbilir (1997) suggested that the contact between gneiss klippen and metasedimentary cover series is a thrust fault, which had formed due to the contractional regime at Eocene-Oligocene, during the closure of the Tethyan Ocean. They also suggested that this thrust was reactivated as a low-angle normal fault in Miocene.

Lips *et al.* (2001) investigated kinematic indicators of mylonitic rocks along the Buyuk Menderes detachment, and applied Ar ^{40}/Ar^{39} thermochronologic method on these rocks with laser probe experiments. Their combined kinematic analysis data and cooling age of white mica suggest that the northward tectonic transport along the Buyuk Menderes detachment is 36 ± 2 Ma old.

Seyitoglu, Tekeli and Cemen (2000 and 2002) summarized the structural architecture and tectono-sedimentary evolution of Gediz (Alasehir) detachment and associated structures. They divided the fault system into three parts based on the orientation and structural relations. They interpreted that the first fault system was active during the Early –Middle Miocene and first (Alasehir formation) and second sedimentary units (Kursunlu formation) of the graben fill were deposited in the hangingwall of this fault. The Second fault system was developed in the hangingwall of the first system, responsible for the deposition of third sedimentary unit (Sart formation). The rotation of the high angle normal fault was accommodated by isostatic uplift and flexural bending, which developed due to continuous footwall movement on the fault systems (Figure 3).

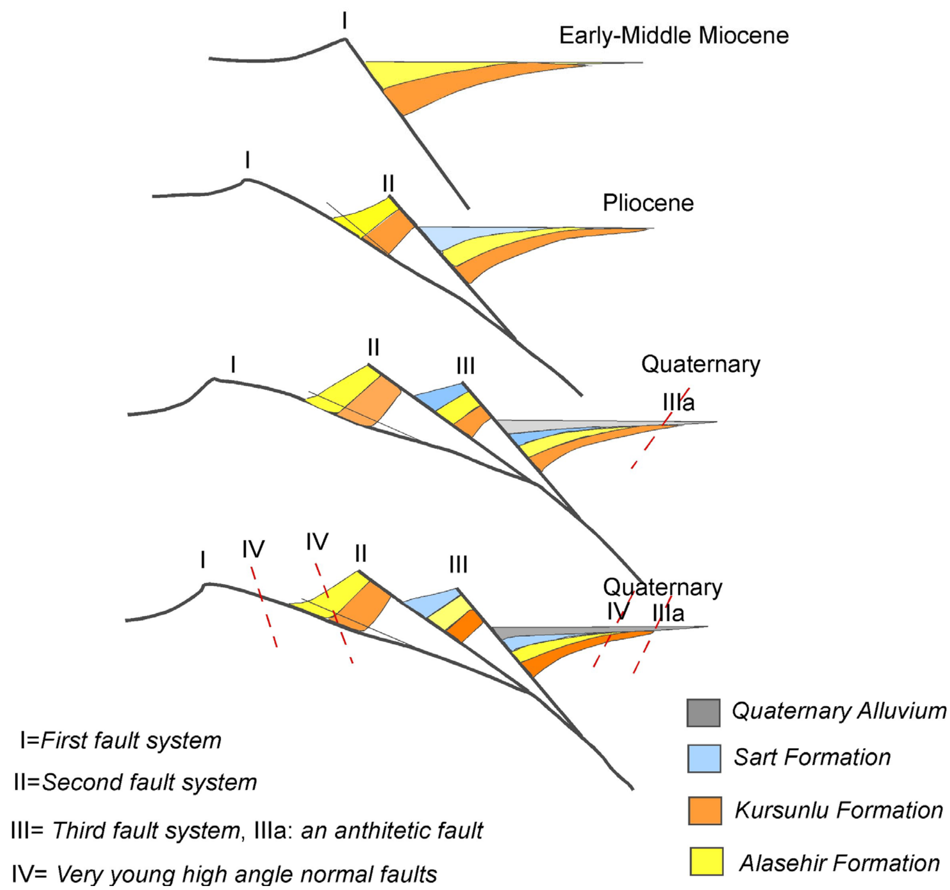


Figure 3. *Tectonosedimentary evolution of Alasehir graben (Seyitoglu, Tekeli and Cemen, 2002).*

Isik, Seyitoglu and Cemen (2003) demonstrated that lower plate plate rocks of the Alasehir detachment have experienced ductile deformation at depth. Subsequently, these ductilely deformed rocks were brought up to the higher crustal levels along Alasehir detachment and overprinted by brittlely deformed rocks. They indicated that Simav detachment fault, located to the north of the Alasehir detachment (Figure 1) show similar deformation characteristics with the Alasehir detachment. The footwall rocks of both detachments contain top to the N-NE shear sense indicators Radiometric data by Isik *et al.* (2002) indicated that the granitoids in the footwall of the Simav detachment is about 22 Ma. . Hetzel (1995) reported the presence of a 20 Ma. old granodiorite along the Alasehir detachment surface. These radiometric ages from the two granodiorite suggest that Cenozoic extension in Western Turkey has started in Early Miocene if the emplacement of these granodiorites is related to the extension in Western Turkey this data may also suggest that the Simav detachment is older that the Alasehir detachment.

Gessner *et al*. (2001) have pointed that several nappe structures in Menderes Massif has thrusted over each other due to the Alpine orogeny (Figure 4). These nappes were named as Menderes nappes. They are arranged from bottom to top as following; 1) the Selimiye nappe, 2) the Cine nappe 3) the Bozdag nappe, and 4) the Bayindir nappe. The Selimiye nappe contains Paleozoic metapelite, metabasite and marble (Schuiling, 1962; Loos and Reischmann, 1999;). The Cine nappe is made up of orthogneiss and paragneiss with intercalated metabasite (Dora *et al*. 1995). The Bozdag nappe is composed of metapelite with intercalated amphibolite, eclogite and marble lenses. The Bayindir nappe contains phyllite, quartzite, marble. Shear sense indicators such as mylonitic shear band foliation and stretching lineation associated with nappe emplacement demonstrate top to the south movement. Gessner *et al.* (2001) have explained the reversal stratigraphy of the Menderes Massif in the Aydin mountains, by southward directed nappe stacking. In this area, Cine nappe was emplaced onto Bayindir nappe. During Cenozoic crustal extension in western Turkey, these faults were reactivated as top to the south brittle shear zone.

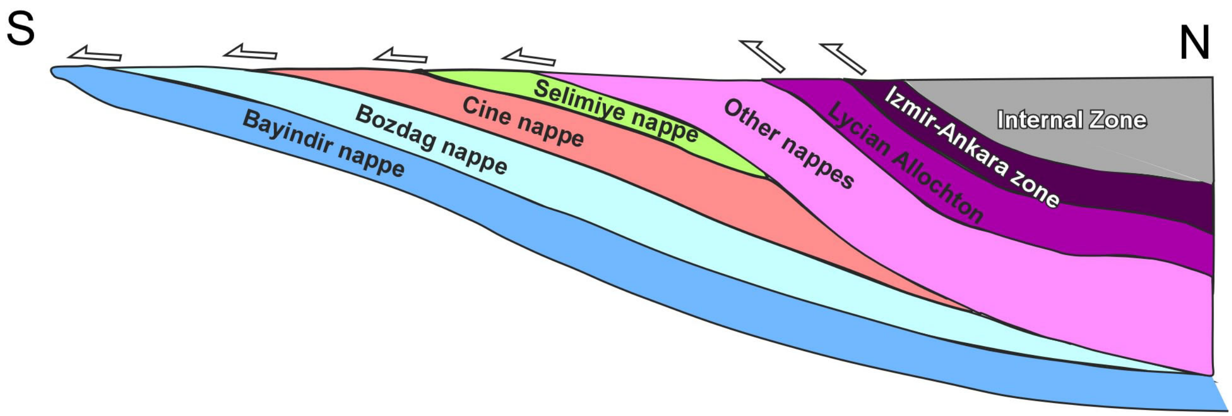


***Figure 4**. Interpretative thrust sequence during deformation of Anatolide belt. See figure 2 for the map view (Gessner et al. 2001)*

Okay (2001) has pointed out the reversal stratigraphy of the Menderes Massif in Aydin mountains. According to Okay (2001), the cover series of the central Menderes massif is the inverted lower limb of southward closing recumbent fold. After the formation of recumbent fold, these cover series rocks were tectonically overlain by gneiss klippen originated from the core of the Menderes Massif (Figure 5).

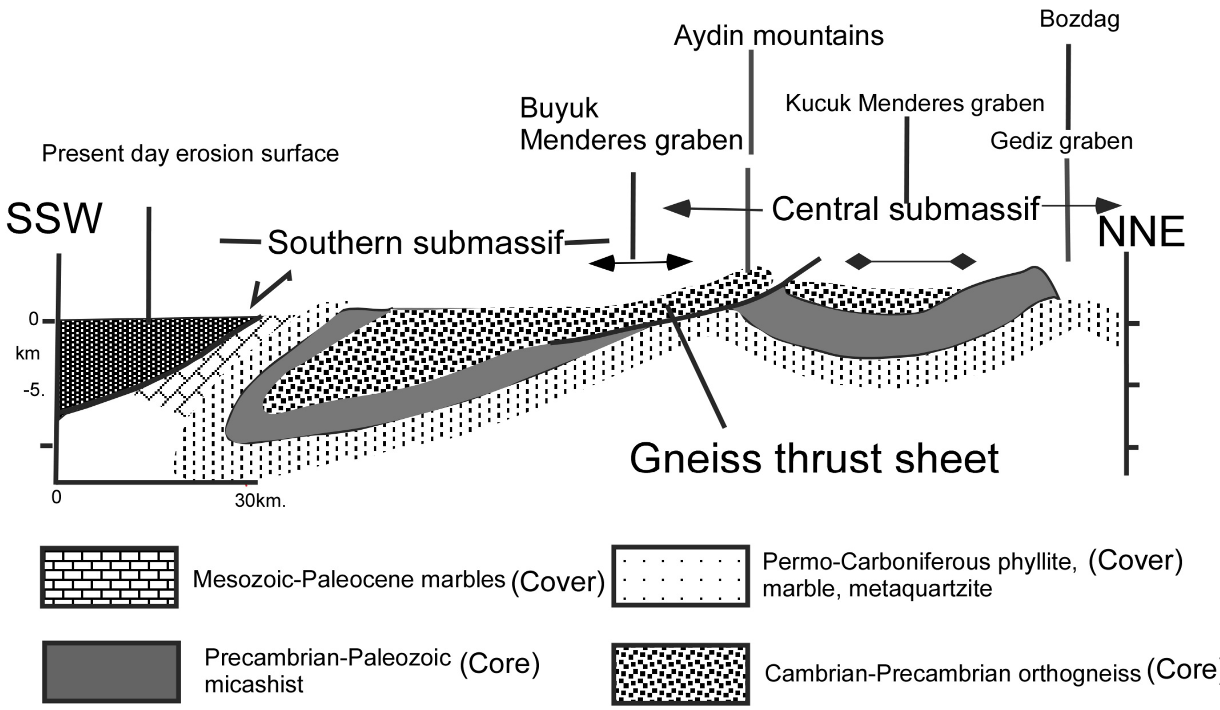
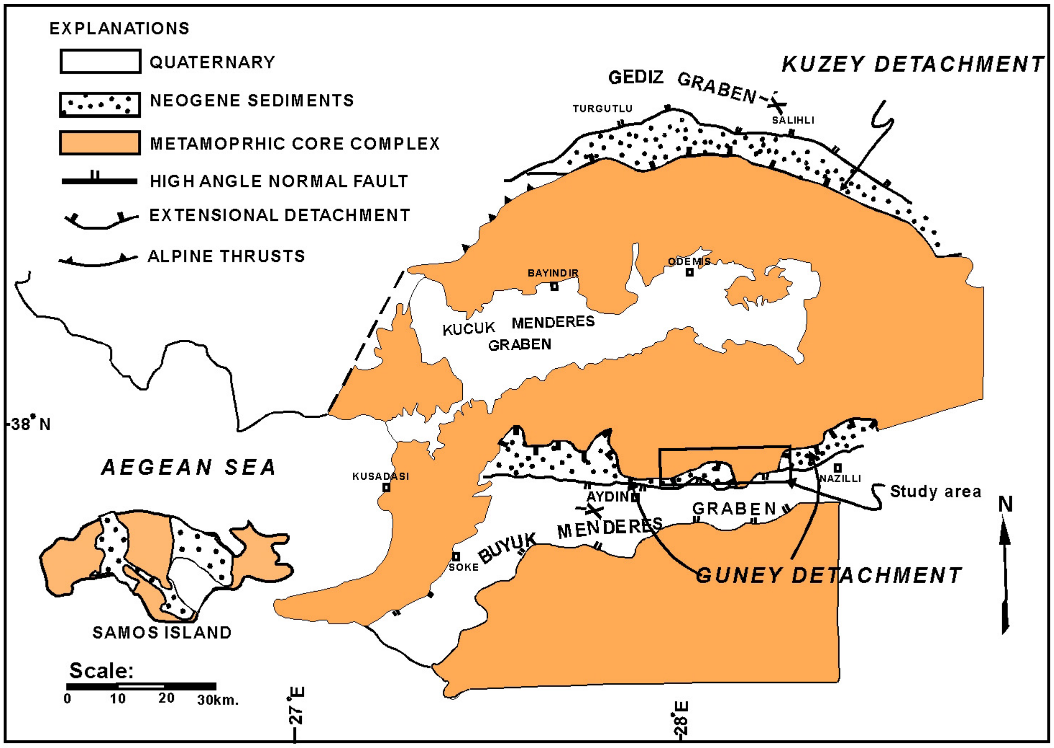
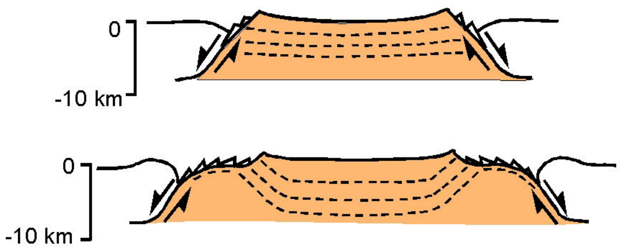


Figure 5. *Simplified North-South crustal scale cross section from the Menderes Massif (Okay, 2001).*

Gessner *et al.* (2001) have indicated that central Menderes Massif is bounded by two symmetrically arranged detachment faults (Figure 13). They named the north-dipping Alasehir detachment as Kuzey (north) detachment and south dipping Buyuk Menderes detachment as Guney (south) detachment. They proposed an active bivergent rolling hinge detachment system for the central Menderes Massif and the existence of syncline structure, formed due to the opposite facing rolling hinges in the footwalls of each of the two detachments (Figure 6).



a)



b)

Figure 6. *a) Geologic map of the Western Anatolia. Note that, metamorphic nappe stacks are undifferentiated. b) Hypothetic model for the evolution of central Menderes Massif (Gessner et al. 2001)*

Timing and Cause of extension in Western Turkey

Although it is widely accepted that Western Turkey as a whole underwent major crustal extension in Cenozoic, the exact timing and origin of the extension in this region is yet to be better understood. Three major models have been proposed to explain the extensional tectonics in western Turkey.

1) Lateral extrusion or tectonic escape model associated with the escape of the Anatolian plate into the Aegean, along boundary faults of the right lateral North Anatolian and left lateral East Anatolian transform faults (Dewey and Sengor 1979; Sengor and Yilmaz 1981; Sengor *et al*. 1985; Cemen, Goncuoglu and Dirik 1999). In this hypothesis, the westward to southwestward escape of the Anatolian plate is responsible for the extensional tectonics regime in western Turkey.

2) The gravitational collapse of the thickened and elevated continental crust with high amount of weight due to the collisional Alpine orogeny in Eocene caused the extensional collapse and thinning of the crust (Dewey, 1988; Seyitoglu and Scott, 1992).

3) The southwestward migration of the Aegean arc created the back-arc extension in Western Turkey (Meulenkamp *et al*. 1988; Okay and Satir, 2000).

Global Positioning system (GPS) studies have provided a detailed view of the present day plate motions in the eastern Mediterranean (McClusky, 2000). The GPS studies confirmed that the Anatolian block moves westward through the North Anatolian Fault (Figure 7). The westward extrusion of the Anatolian block is defined by counterclockwise rotation (Le Pichon and Angelier, 1979; McClusksy *et al*. 2000).

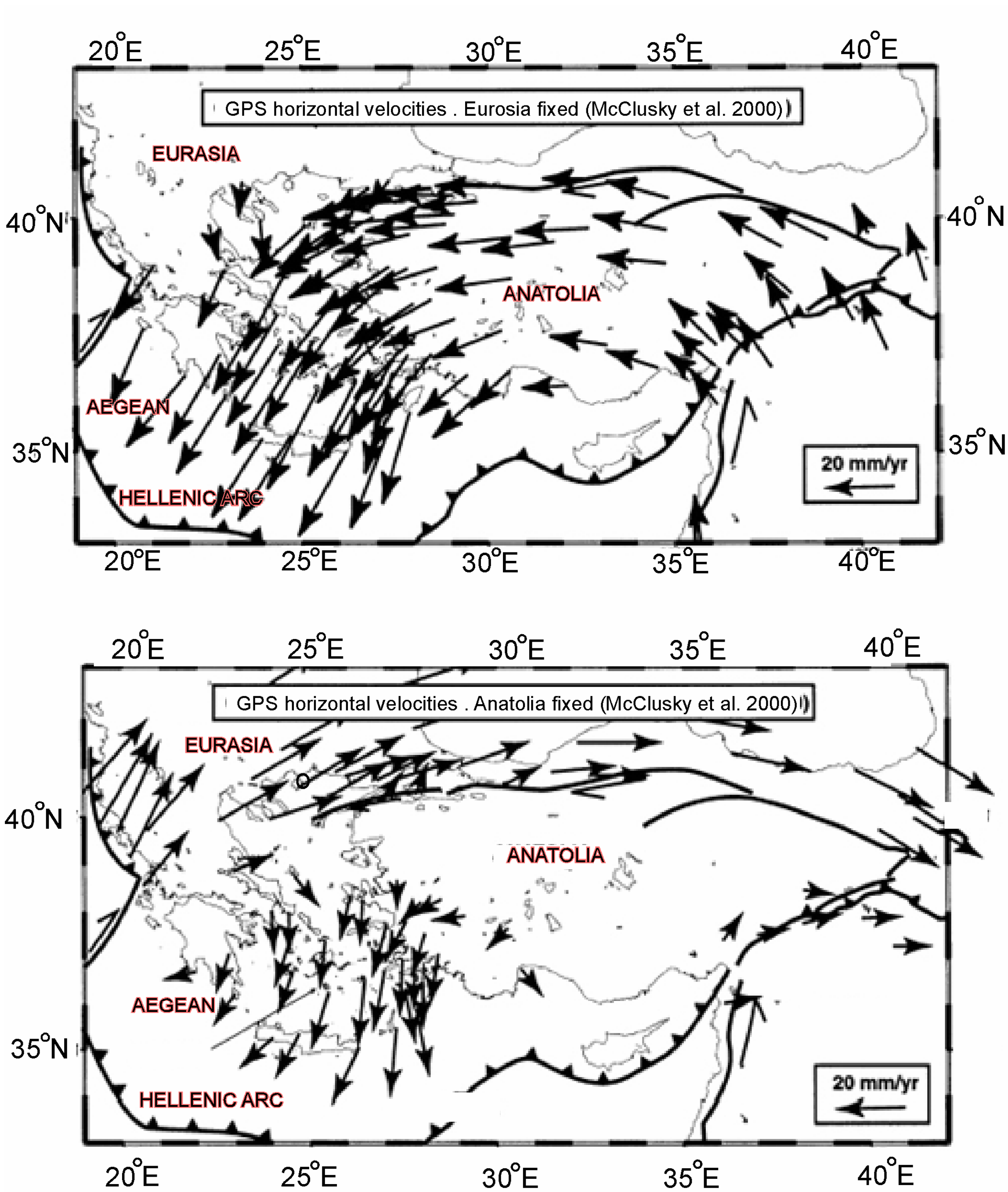


Figure 7. *GPS horizontal velocities, from McClusky et al. (2000)*

a) Eurosia is fixed with respect to Anatolia b) Anatolian plate is fixed.

CHAPTER II

LITERATURE REVIEW

This chapter will involve a brief summary of 1) Major structural features related to the extensional tectonics, such as metamorphic core complexes and associated structures and 2) Shear zones and shear sense indicators

1) Metamorphic Core Complexes and associated structures

Metamorphic core complexes are considered as the major structural features that form during large-scale continental extension. They were first described in the Basin and Range extended terrain of southwestern North America. Davis and Coney (1979) described metamorphic core complexes as

"regions where extensional shear zone on a detachment has drawn up strongly foliated and lineated mylonitized lower plate rocks from the deeper part of the crust to the surface. The mylonite, in turn, is overprinted by strongly brecciated unmetamorphosed carapace of upper plate rocks during uplift. Metamorphic core complexes create asymmetrically dome like structures, which may also be formed due to regional plutonism/magmatism. The intrusions (synextensional magmatism) are the result of thermal uplift, heating the upper crust**"**

Detachment faults play a key role during the exhumation of ductilely deformed rocks and the dip angle of these faults and extension mode characterizes the type of uplift and heat flow (Wernicke, 1982). Lister and Davis (1983) stated that

"The footwall rocks of the detachment faults are uplifted through different levels of metamorphic conditions and deformation types. In most of the metamorphic core complexes the exhumed footwall rocks show the metamorphic conditions of amphibolite

(800ºC/ 8 k bar) or high greenschist faces (500º C/ 6 kbar) due to deformation by non-coaxial laminar flow”

Davis and Lister (1988) recognized the very rapid uplift of lower plate rocks in some of the cordilleran detachment faults. Their thermochronologic data showed that footwall mylonitic gneisses were formed at approximately 12 km at depth and temperatures were as high as 535º C.

There are two main models explaining the development of metamorphic core complexes during a large-scale continental extension.

A) Pure Shear Model

Pure shear extension creates a symmetric structural feature (Figure 8a). According to this model, the crust is thinned and the uplift of the rift shoulders is evenly distributed. During the extension, the asthenosphere creates a bowed up structure due to the isostatic uplift. The detachment zone is associated with a brittle-ductile transition (McKenzie, 1978)

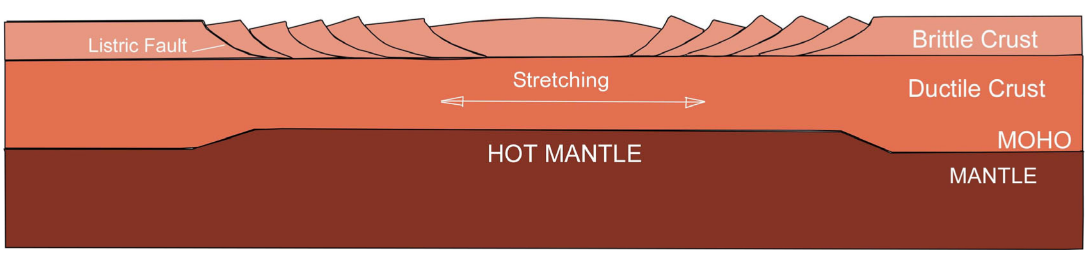


Figure 8. ***Schematic Geologic Models a) Pure Shear Model (Mckenzie, 1978)***

B) Simple Shear Model;

There are two similar simple shear extension models. The first one proposed by Wernicke (1985) requires a large- scale horizontal detachment surface at mid-crustal levels. The second one was proposed by Buck (1988) postulated a steeply dipping fault cutting through the lithosphere (Figure 8b).

In Wernicke's (1985) model, the uplift of the footwall rocks is asymmetric, because the extension is accommodated by a shallow dipping, crustal-scale, low-angle shear zone. Wernicke (1985) has also pointed out that coarse- grained sedimentary fills are deposited in the hangingwall of the subhorizontal detachment. Rotated normal faults and thin fault blocks are associated with the progressively continuing extension (Figure 9).

Buck (1988) and Wernicke and Axen (1988) proposed that high-angle normal faults can rotate to subhorizontal levels during progressive extension because of the upward flexural bending of the footwall rocks of the fault. This process is a sequential process, and it explains recent positions of low- angle normal faults by continuing flexural rotation of the lower plate rocks.

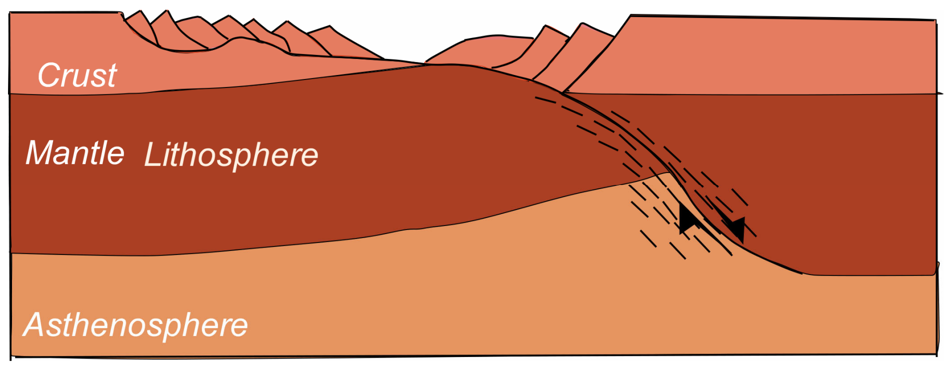


Figure 8b) *Simple Shear Model (Buck et al.1988)*

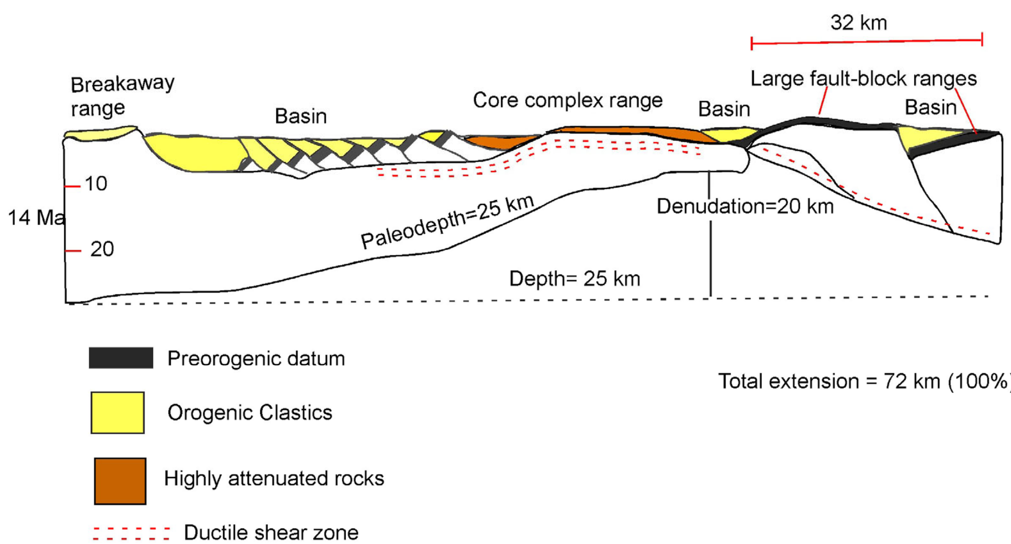


Figure 9. *Model of an extensional simple shear system in the upper crust and middle continental crust (from Wernicke, 1985)*

2) Shear Zones

Shear zones rocks formed of higher strain and deformation when compared with their adjacent rock types (Davis and Reynolds, 1996). Shear zones usually contain structures indicating sense of displacement. They are generally divided into three classes;

1) *Ductile shear zones*: Formed at crustal depths lower than 5- 10 km. The ductile shear zones contain structural features characteristic of high temperature and pressure conditions (Davis and Reynolds, 1996).
2) *Brittle shear zones*: Formed within the 5-10 km. of the earth's surface. Brittle shear zones contain structural features characteristic of brittle deformation such as fracturing and faulting (Davis and Reynolds, 1996).
3) *Brittle-Ductile shear zones*: Both ductilely and brittlely deformed rocks juxtapose along this type of shear zones. When deformation grades from ductile to brittle conditions, it is very possible that ductile structures are overprinted by brittle structures. There can be boudins, porphyroclasts and rock fragments of the brittle rocks, found in the matrix of ductilely deformed rocks (Davis and Reynolds, 1996).

Shear Sense Indicators

Shear sense indicators can be used to determine the sense of shear along the shear zones. By using shear sense indicators, it is possible to interpret the tectonic history of a region. Determination of the shear sense indicators can be made through in both mesoscopic and microscopic scale structural analysis (Davis and Reynolds, 1996). In microscopic scale, the determination of shear sense should be made on thin sections cut parallel to the lineation and perpendicular to the foliation (Passchier and Trouw, 1996).

The following is a short summary of the most common shear sense indicators. Many of these have been used in this study to determine the shear senses along the Buyuk Menderes detachment surface.

A) Ductile Mesoscopic Shear Sense Indicators;

Shear Bands and S-C fabrics,

Davis and Reynolds (1996) defined shear bands as “thin zones of very high strain within the main shear zone”. S-C fabrics are one of the most common shear bands in ductile shear zones (Lister and Snoke, 1984). S surfaces (from the French term for schistosity) represent the foliation, C represent shear bands where there is higher shear strain. S-C surfaces are at high angle to each other (Berthe’ et al.1979). C type shear bands develop in medium grade shear zone, especially in deformed granites, where C type shear bands anastomose around feldspar porphyroclasts (Passchier and Trouw, 1996) (Figure 10).

Folds

In ductilely deformed rocks, folds can also be used for determining the sense of shear by using the vergence of asymmetric intrafolial folds (Davis and Reynolds, 1996). When deformation continues along the shear zone, the hinge of the fold obtains the same orientation with the lineation (Figure 11).

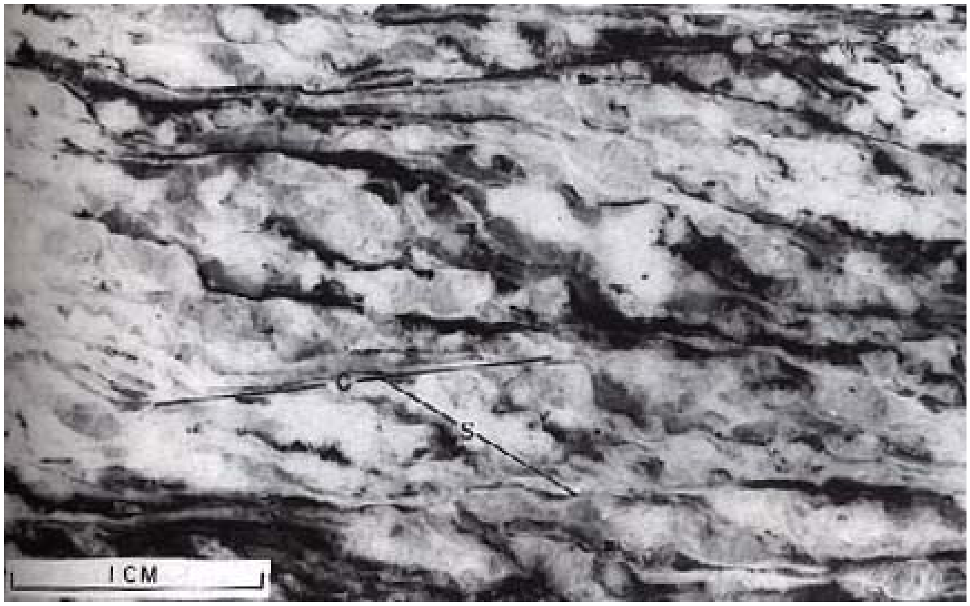


Figure 10. *S-C fabric in Tertiary granodiorite (Davis and Reynolds, 1996)*

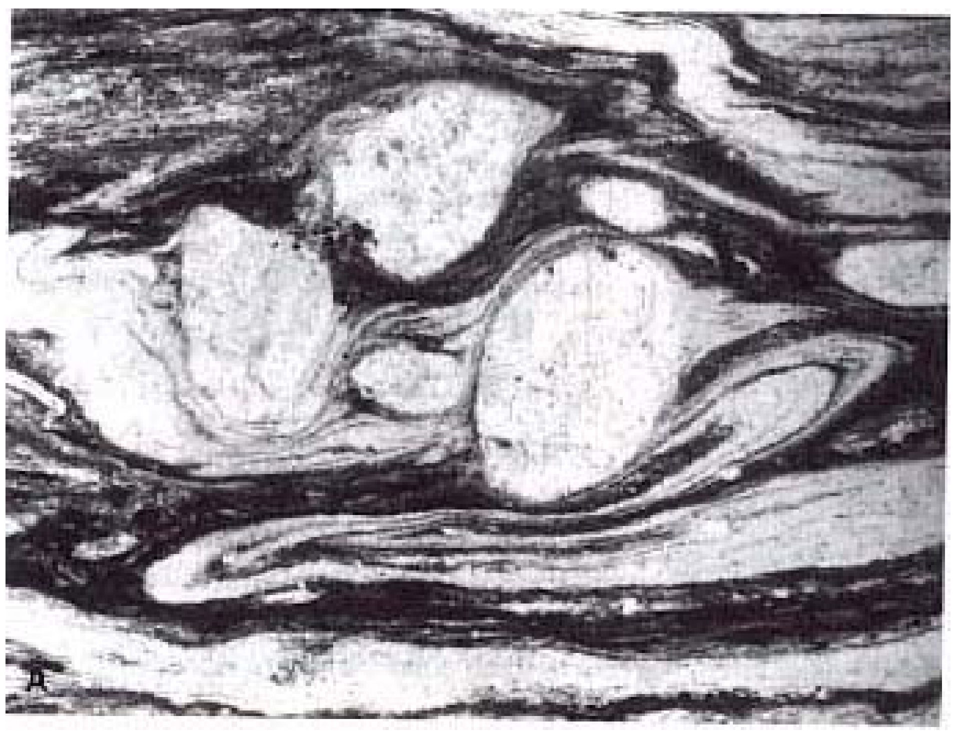


Figure 11. *Asymmetric intrafolial fold in mylonitic granite (Davis and Reynolds, 1996*

Porphyroclasts

Porphyroclasts represent the grains, floating in a less rigid ductilely deformed matrix. Generally, they are interpreted to be the relics from the protolith. Feldspar porphyroclasts are common asymmetric structures developing in the ductile shear zones (Figure 12). Highly attenuated feldspars form tail structures. These tails point the direction of the shear (Passchier, 1994).

There are two types of tails in feldspar porphyroclasts. These tails are σ and φ type tails. In the σ type, tails do not cross the reference plane of shear and represent slow grain rotation (Passchier, 1994) In the φ type tails, tails cross the reference plane of shear and represent fast grain rotation (Passchier, 1994). Passchier and Trouw (1996) stated that highly deformed mica minerals and fine-grained matrix of quartz form the matrix and these minerals usually wrap around the feldspar porphyroclast grains.

B) Brittle Mesoscopic Shear Sense indicators

Passchier and Trouw (1996) pointed out that "in cataclastic rocks, it is hard to define shear sense indicators due to the lack of penetrative deformation". Slickenlines, striations or mineral fibers are used to decipher the sense of movement along the fault surface.

The orientation of the slickenlines can tell the type of displacement on a fault zone. The angle between slickenlines and strike of the fault plane is defined by rake or pitch angle . If this angle ranges from 40 to 70 it can be assumed an oblique displacement during the hangingwall movement.

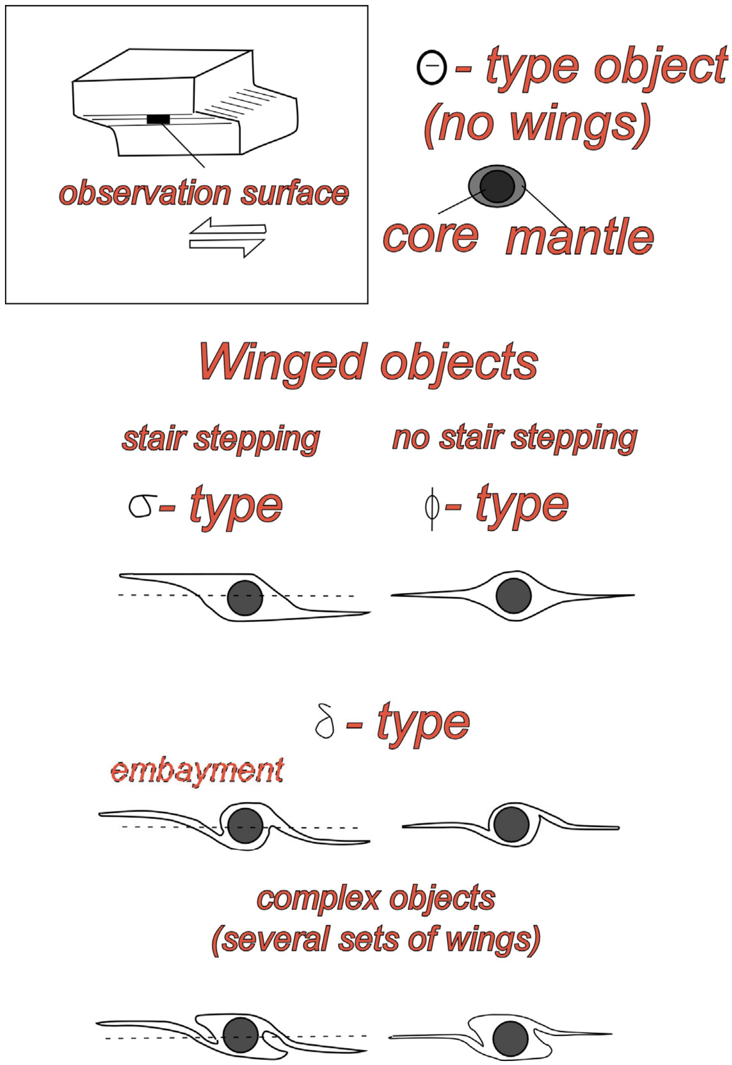


***Figure 12**. Classification of mantled porphyroclasts. Sense of shear is left-lateral (Passchier and Trouw, 1996).*

C) Ductile Microscopic Shear Sense indicators;

In mylonites, the asymmetry of the microstructures is used for determining the sense of shear. Oblique foliation, C and C’ type of shear band cleavages and mica fish are the examples for shear sense indicators, developing in ductilely deformed rocks. (Passchier and Trouw, 1996) (Figure 13 and 14).

Oblique foliation

In oblique foliation, the elongate grains are oblique to the mica-preferred orientation (Passchier and Trouw, 1996). Oblique foliations are common in monomineralic layers of quartz and calcite (Figure 13).

C'type shear bands

C' type shear bands are oblique to the S-plane surfaces, represented by mica minerals such as muscovite and biotite.C' type shear bands are indicative of extreme shearing in mylonitic rocks. The angle between C' type shear band and almost horizontal S-plane is 15°-35. (Passchier and Trouw, 1996) (Figure 13)

Mica Fish

Lister and Snoke (1984) and Passchier and Trouw (1996) pointed out the importance of lozange shape single crystal of mica fish**.** One curved and one planar side in mica fish is used as a shear sense indicator. Trails of small mica fragments, extending into the matrix can be also used as a shear sense indicator (Passchier and Trouw, 1996) (Figure 14).

D) Brittle Microscopic shear sense indicators

Brittlely deformed rocks contain sets of shear fractures showing distinct orientation and movement sense. These oriented fractures are called Reidel Shears. Evans (1990) and Passchier and Trouw (1996). They are named as R, R', P and Y shears and show characteristic orientation and shear sense (Figure 15). Y shear is parallel to the shear zone boundary. In thin sections, it is possible to determine the cross-cutting relationship between these fractures.

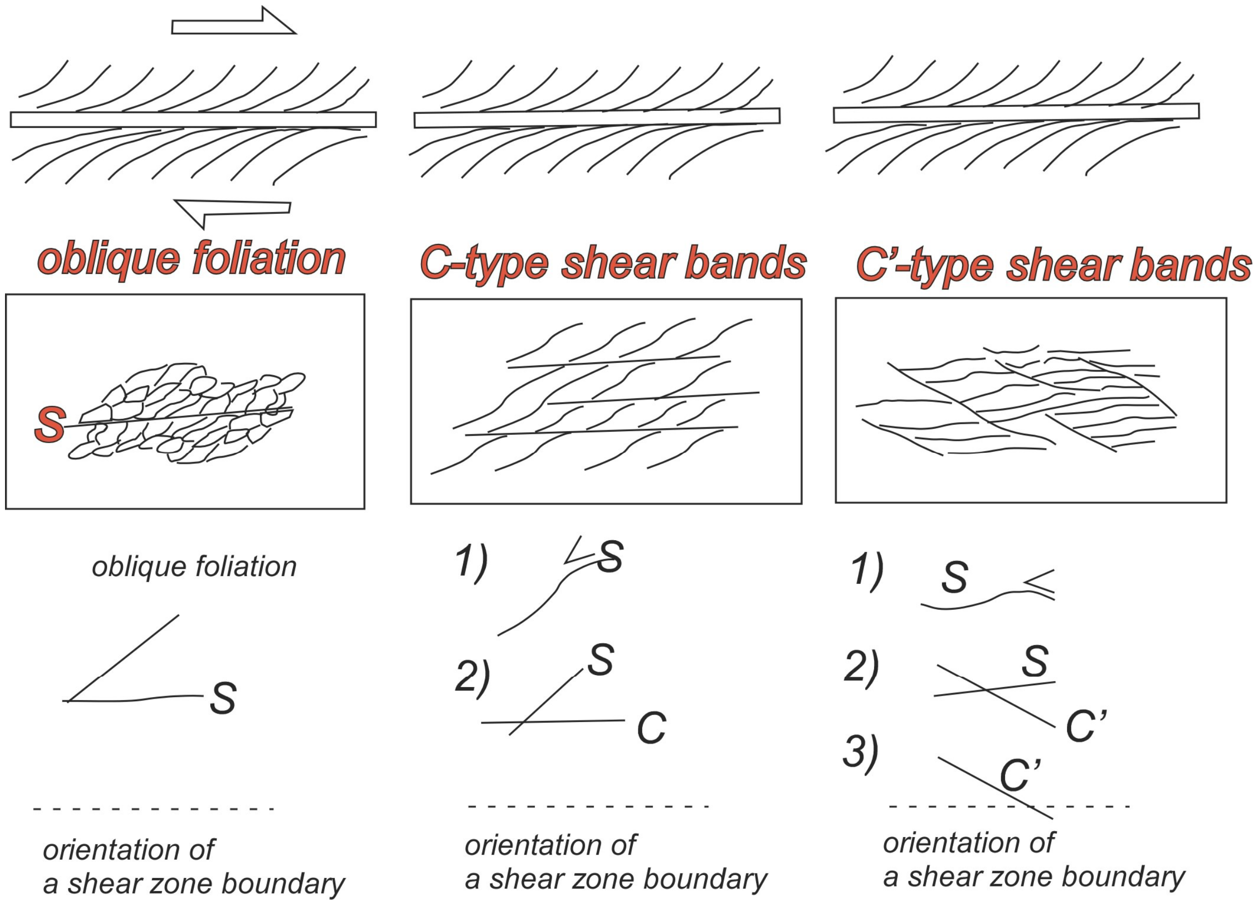


Figure 13. *Three types of foliation pairs are common in ductile shear zones. Elements used to determine the sense of shear are shown below (Passchier and Trouw, 1996).*

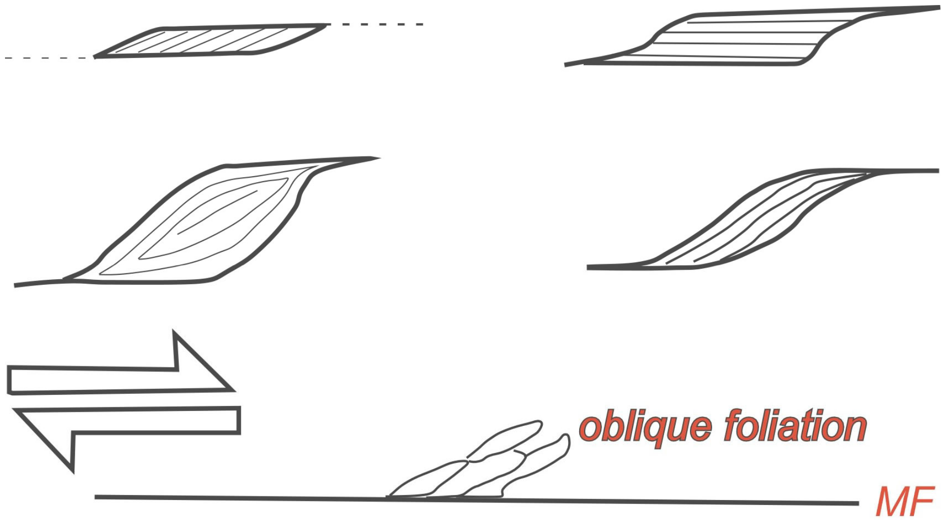


Figure 14. *Schematic drawing of several common types of mica fish. The orientation and relationship with mylonitic foliation is also helpful to determine the sense of shear.*

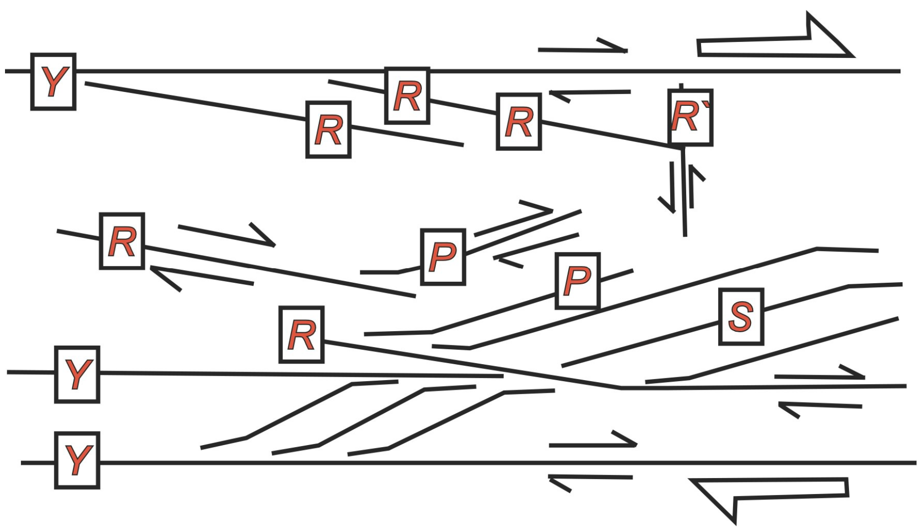


Figure 15*. Schematic diagram showing the characteristic geometry and shear sense of the most common types of Reidel shears.*

CHAPTER III

1) GENERALIZED STRATIGRAPHY OF THE STUDY AREA

In the study area, the Buyuk Menderes detachment fault separates two distinct tectonostratigraphic units, gneiss sequence in its hangingwall and marble intercalated schists in ints footwall (Plate 1). Okay (2001) named the footwall rocks as Goktepe Formation, which contains thick -bedded marbles intercalated with schists. Based on the fossil evidences, such as brachiopods, algae and fusulinid type foraminiferas, Okay (2001) interpreted the age of the Goktepe Formation as Permo-Carboniferous. Recent work conducted by Ozer and Sozbilir (2003), in the eastern part of the study area indicated that the Goktepe Formation contains some rudist fauna; *Hippurites Lapeirusei* (GOLDFUSS), *Hippurites nabresinensis* FUTTERER, *Hippurites cf.colliciatus* WOODWARD. These fossils were found in the thick marbles and the lower part of the Goktepe Formation, indicating that the schist sequence is Santonian-Campanian (Late Cretaceous) in age.

Okay (2001) has suggested that the contact between Permo-Carboniferous, Goktepe formation age unit and the Paragneiss is a thrust fault. However, Ozer and Sozbilir (2003) have interpreted the same contact as extensional detachment fault. Ozer and Sozbilir (2003) have also pointed out that hangingwall rocks of this detachment contain an unconformity surface between sedimentary rocks and gneiss (Figure 16).

The stratigraphy of the study area can be passed through with a long continuous section starting from Kirburun hill (1250 m.) down to the Bascayir village (Plate 1). Along this transect, it is observed that lower plate rocks (marble intercalated schists) are structurally overlain by the upper plate rocks.

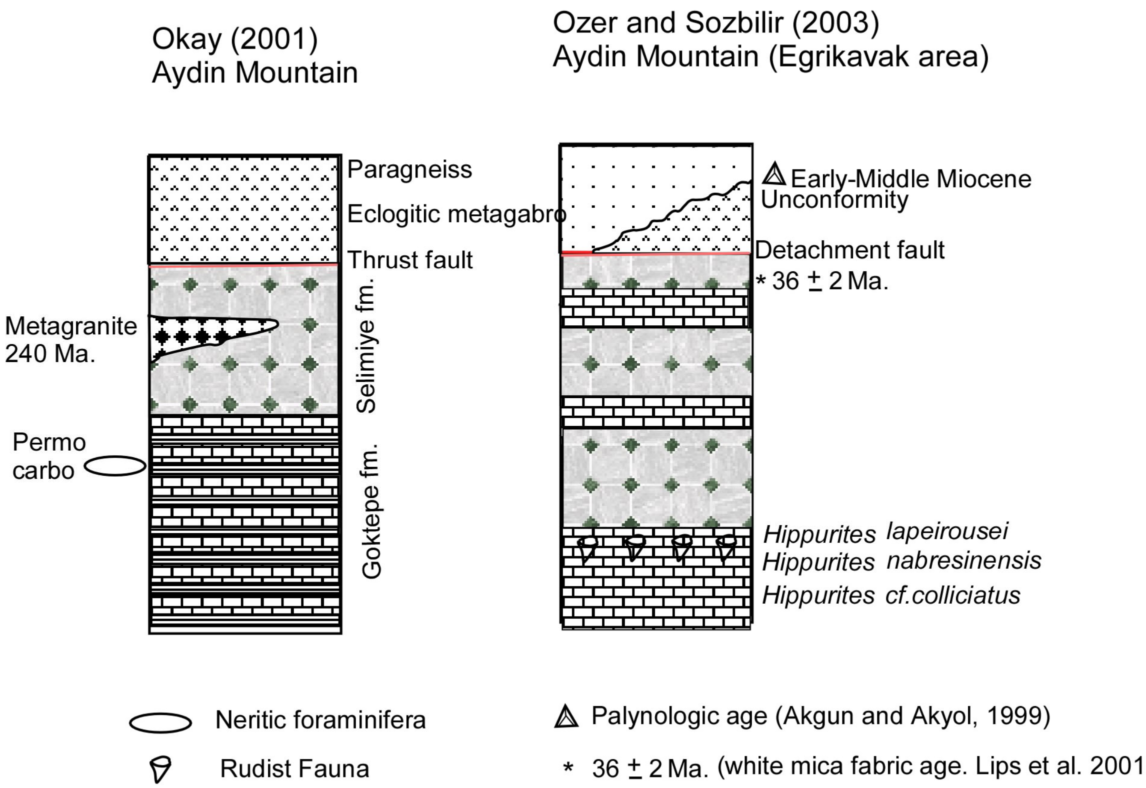


Figure 16. *Comparison and correlation between Okay (2001) and Ozer & Sozbilir's (2003) columnar stratigraphic sections*

Tectonometamorphic units

Aydin Mountains is an E-W trending horst located on the southern part of the central Menderes Massif Metamorphic Core Complex and the northern part of the Buyuk Menderes graben. In the study area, two distinct tectonometamorphic units, lower plate and upper plate rocks, are separated by Buyuk Menderes detachment.

A) Lower Plate

Mylonitized marble- intercalated schists constitute the lower plate rocks of the study area. The lower plate rocks show a gradation from the highly ductile deformation to brittle deformation. This has been documented along the line of the cross sections of A-A' and B-B`(Plate 2).

In structurally higher levels, brittlely deformed rocks reflecting proximity to the detachment zone overprint these mylonitic features of ductile deformation (Plate 2). Contact between marble and mylonitic schists are usually faulted (Plate 1).

A. 1) General Lithology

Main lithology of the lower plate rocks is foliated micaschists and marbles (Figure 17 and 18). Minerologically, it is dominated by muscovite, biotite, quartz and plagioclase (Figure 19). Some of the micas show undulose extinction and evidence for intracrystaline cataclasis (Goodwin and Wenk, 1990).

Figure 17. *Field Photograph of ductilely deformed schists (lower plate rocks)*

Figure 18. *Field Photograph of mylonitic schist. (Note the folding of mylonitic foliation)*

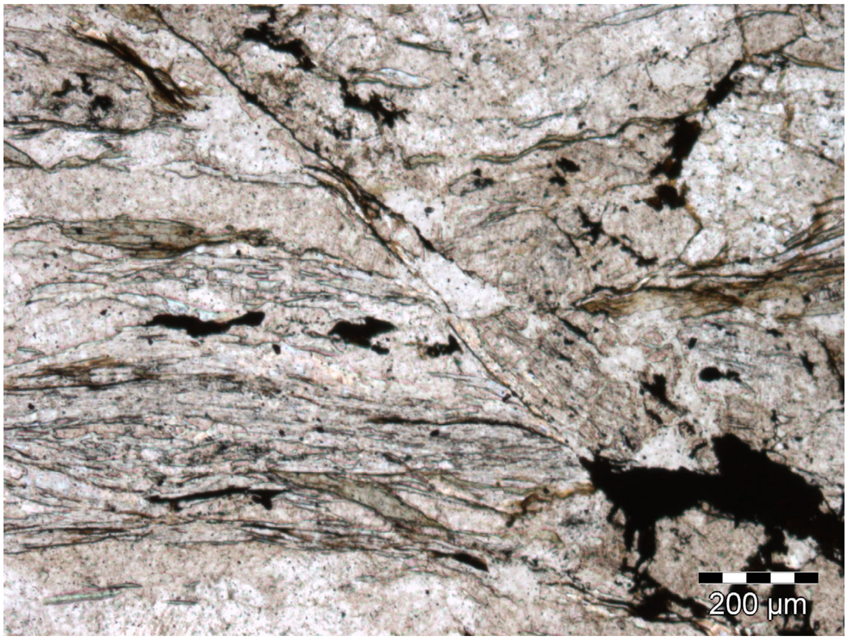


Figure 19. *Photomicrograph of strongly deformed mylonitic schists. The main foliation is almost horizontal and this foliation is cross-cut by fracture.*

B) Upper Plate

The upper plate rocks of the Buyuk Menderes detachment is lithologically heterogeneous, consisting of quartzo-feldspathic gneiss and Early-Miocene rocks of the Haskoy formation.

B.1) Gneiss Sequence

The gneiss sequence is composed of variably mylonitized quartzo-feldspatic gneiss. The main foliation direction is oriented N60W/40NE. Mineralogically, it is composed of K-Feldspar quartz+plagioclase+muscovite+biotite±garnet. Quartz grains are forming elongate domains and polycrystalline ribbons suggesting the occurrence of this mineral under ductile conditions. Feldspar minerals commonly have a reaction rim of biotite and muscovite (Figure 20). In some parts of the thin section, plagioclase is altered into sericite and biotite is altered to the foliation parallel chlorite. Foliations in gneiss sequence are characterized by recrystallized quartz, feldspar and biotite. K-feldspar augens are usually defined by porphyroclasts (Figure 21).

Figure 20. *Photomicrograph of the gneiss. Note that mica minerals wrap around the large feldspar crystals.*

Figure 21. *Outcrop photo of Augen Gneiss. K-Feldspar porphyroclats are ~1 cm. size*

B.2) Haskoy Formation.

The Haskoy is sedimentary rock unit croping out to the east of Bascayir village and is only about 15- 20 m thick (Figure 22). The abrupt truncation of bedding around Bitlar village suggests that this unit is bounded by a low-angle normal fault (Figure 23). A disconformity exists between Haskoy sedimentary unit and gneissic metamorphic rocks. In unconformity surface, the sedimentary rocks contain gneissic clasts.

In the study area, coarse-grained sedimentary deposits were named by Emre and Sozbilir (1997) as "Haskoy unit". This unit is only exposed in the hangingwall (upper plate) of the Buyuk Menderes detachment fault. The Haskoy unit contains the clasts, derived from the footwall and hangingwall rocks of the Buyuk Menderes detachment.

Benda et al. (1974) and Benda and Meulenkamp (1990) assigned an Early-Miocene age to the Haskoy formation based on their pollen analysis of coals collected from the unit. This Haskoy formation overlies the gneiss in the upper plate and is composed of conglemaratic sandstone with typical reddish to brown weathering. It is poorly to moderately sorted, bearing subangular pebble to boulder clasts distributed in the matrix of sandstone and organic-rich claystone. The upper plate is brecciated for ~ 5m above the detachment fault. These evidences suggest that the Haskoy formation was deposited in a basin related to the extensional tectonics in the area and therefore, Haskoy formation represent syn-extensional deposition.

In the northern exit road of Bascayir village, one can note many exposures of the Haskoy unit in a large roadcut. The orientation of bedding plane is ranging from N 40°-50°W/ 15° – 25 NE and N 10°- 40° E / 15°-20° SE. .

***Figure 22**. Looking towards the NE, this is a view of Early-Miocene sedimentary unit Matrix of coarse to granule sized lithic sand forms bedding plane.*

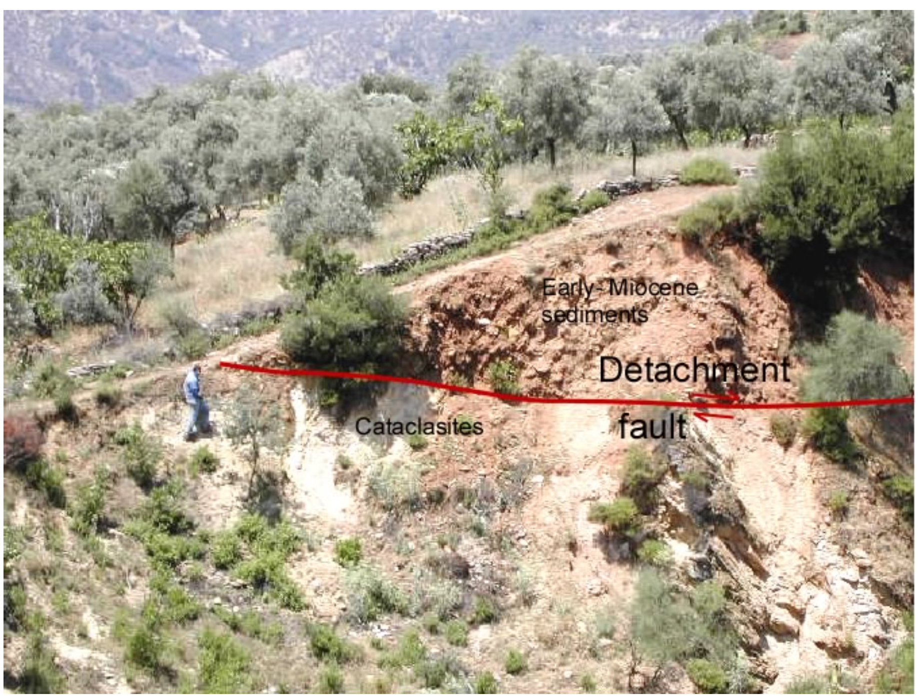


***Figure 23.** The contact between sedimentary unit and lower plate rocks.*

2) STRUCTURAL GEOLOGY

The main structural feature in the study area is the Buyuk Menderes detachment surface. In this chapter, this detachment and other structural features, mapped in the study area will be discussed in detail.

Buyuk Menderes detachment fault

The lower plate of the Buyuk Menderes detachment surface contains mylonitic cover series rocks of the Menderes Massif. The upper plate is made up of ductilely to brittlely deformed core series of the Menderes Massif and a syn-extensional sedimentary rock formation. The reversal of the Menderes Massif stratigraphy in the study area can be explained by 1) Thrust faulting (Nappe structure) Ring et al. 1999 and 2) Southward-closing recumbent fold (Okay 2001).

Excellent exposures of the Buyuk Menderes detachment are located to the south of the Kizilca village (Figure 24). In this locality, the detachment surface strikes N 30°-35° E and dips 20°-24° NW. From Kirburun hill to Kaplan valley the detachment fault strikes more northwesterly (i.e changes counterclockwise to a west northwest orientation) (Figure 25 and Plate I). The orientation of the detachment fault here ranges in strike from ~ N50ºW to N75ºW and dips at ~20º to 25º to SW.

Another good exposure of the detachment surface can be seen around Ahatlar village area (Figure 26). This location provides a scenic NW face of the Buyuk Menderes detachment fault cutting through the landscape (Figure 27). Towards the north one can see the sharp low- angle contact between upper plate rocks (Gneiss) and lower plate rocks (micashists). The continuation of this detachment is in topographically lower position around the Tepecik Hill (Plate I) .The orientation of the detachment fault ranges in strike from N 35º E to N55ºE and dips at ~20º to 30º to SE. At this locality normal displacement is observed along the detachment surface and top to the south transport direction is recorded with mesoscopic shear sense indicators in the field. Buyuk Menderes detachment surface also contains stretching lineation and and striae that plunge approximately between 70° ~ 85° to the SW (Figure 28).

Figure 24. *Exhumed Buyuk Menderes detachment surface, south of Kizilca village*

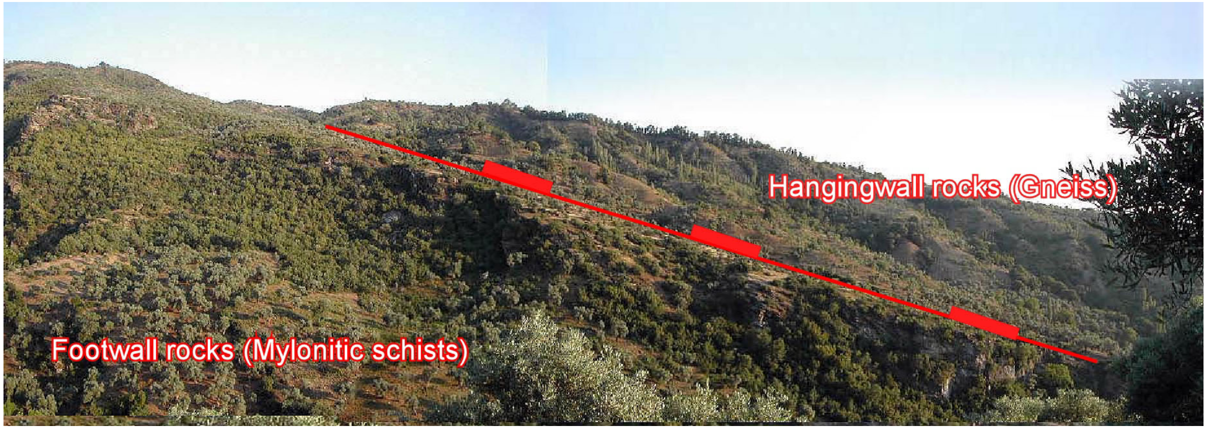


Figure 25. *Photo and interpretive line drawing of a Buyuk Menderes detachment along the Kaplan valley. Displacement along the fault zone is in normal sense with the hangingwall to the SW.*

Figure 26. *Close-up view to the detachment surface, exposed in the Ahatlar village*

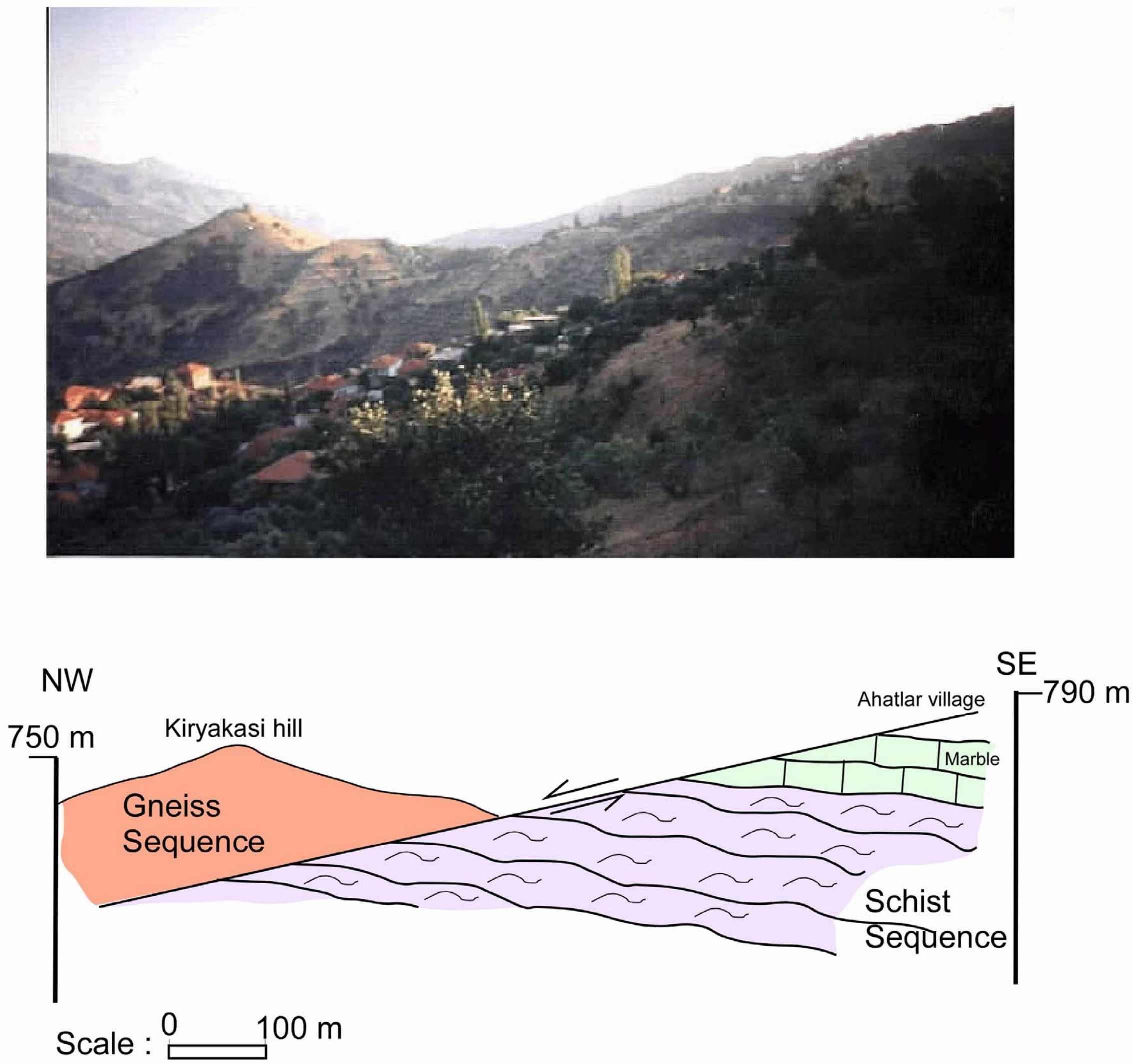


Figure 27. *Field view and cross- section along the Buyuk Menderes detachment fault, showing hangingwall rocks (gneiss) and footwall rocks (marble intercalated schists)*

Figure 28. *Slickenlines on the Buyuk Menderes detachment surface, Ahatlar village*

In the study area, the Buyuk Menderes detachment surface is typically made up of cataclastic rocks. Cataclasites are usually greater than 1 m. wide and they do not have sharp boundaries but may grade into fractured rock adjacent to the fault. Most of the cataclastic rocks are composed of systematically fractured marble unit. The cataclastic marble zone is derived from non-mylonitic marble-intercalated schists of the lower plate.

Low-angle fault exposed west of the Egrikavak area is correlative with the Buyuk Menderes detachment, in Bascayir area. The lack of mylonitic fabric in lower plate rocks to the north can be explained by the northward- shallowing of the regional detachment surface.

In the vicinity of Bitlar village, the Buyuk Menderes detachment places Early Miocene age Haskoy sedimentary unit and gneissic metamorphic rocks of the upper plate over the marble intercalated micaschists of the lower plate. The detachment surface here contains a 4-4.5 km thick brittle zone. The exit road along the northern part of Bascayir village provides an opportunity to reach topographically higher elevations. Along this road, one can see the low- angle normal fault, which is a contact between red colored syn-extensional sedimentary unit and ductilely deformed micashists (Figure 29).

Kinematic indicators of the brittle deformation display southward movement along Buyuk Menderes detachment surface throughout the study area. The similarity in orientation and inferred shear sense of top to the south structures suggest they developed during a single deformational event.

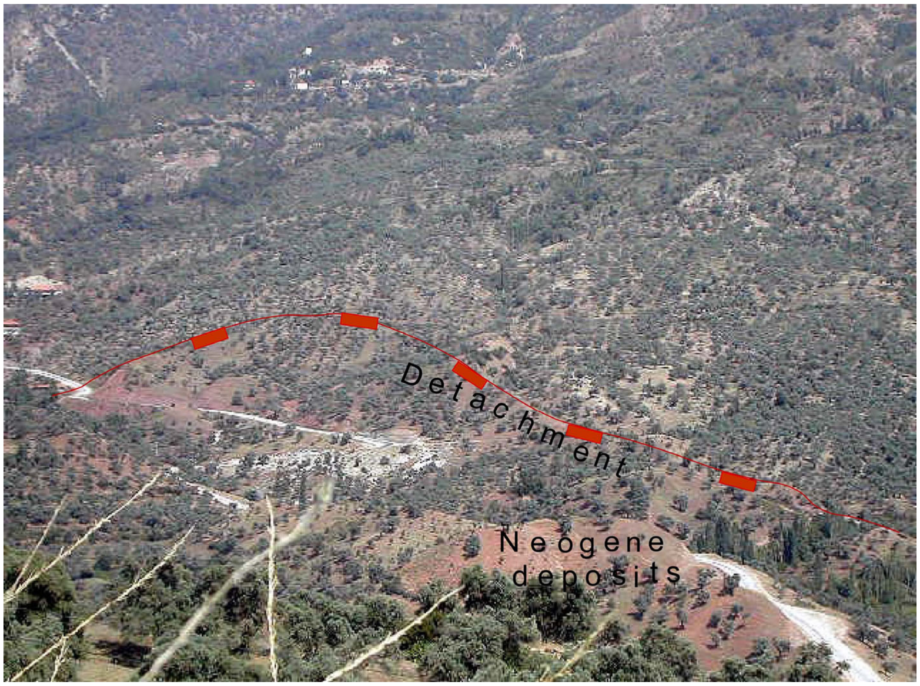


Figure 29. *An overview of the Buyuk Menderes detachment fault, showing the brittlely deformed schists of the footwall and the Neogene sedimentary rocks of the hangingwall*

Other faults

Two moderately dipping normal faults are observed in the study area. One of these faults exposed , in the southern part of the Kizilca village, strikes N 40° E and dips 55° NW.

(Figure 30). This fault has topographically expressed itself with a steep valley. Another fault is located in the northern part of the Gokkiris hill (Plate 1). The zones of marble mark both faults surfaces. These two faults juxtapose marble unit over mylonitic schist.

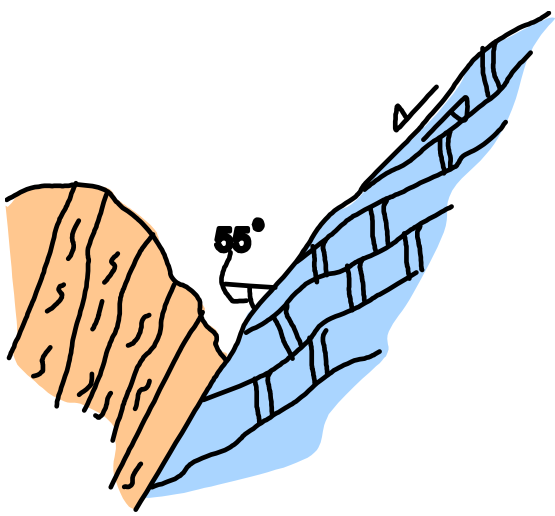


Figure 30. *Moderate angle fault, dipping 55°to NW. Kizilca village.*

CHAPTER IV

KINEMATIC ANALYSIS ALONG THE BUYUK MENDERES SHEAR ZONE

Approximately 45 samples were collected from the mylonitic rocks of the Buyuk Menderes detachment surface (Plate 1). In two locations, rock samples were collected upward along two transects that the detachment surface is cut almost at right angle. Samples were from the exposed lowest elevations of the shear zone towards the detachment surface.

These samples are labeled as 21, 22, 23, 25 along the transect I and as 11,12, 38, 40 along the transect II. First, the shear sense indicators and other microstructural features along the transect (I) will be described.

Transect I

Sample 21 (Mylonitic schist, GPS: 95190, 01294): This sample is about 35m. below the detachment surface. This rock is mainly composed of quartz, muscovite, biotite and plagioclase minerals. Muscovite and biotite minerals define foliation in the rock. Recrystallized quartz crystals are displaying undulose extinction (Figure 31). This sample does not contain any shear sense indicator.

Sample 22 (Mylonitic schist, GPS: 95355, 01157): Sample 22 is collected about 120m. in the north of sample 21. Foliation in the rock is defined by fine- grained quartz, feldspar and micaceous domains (sericite and muscovite). Opaque minerals are also observed as accessories. It also contains tourmaline crystals, displaying asymmetric porphyroclast feature. These tourmaline crystals can be used as shear sense indicator. Sense of shear is top to the north (Figure 32).

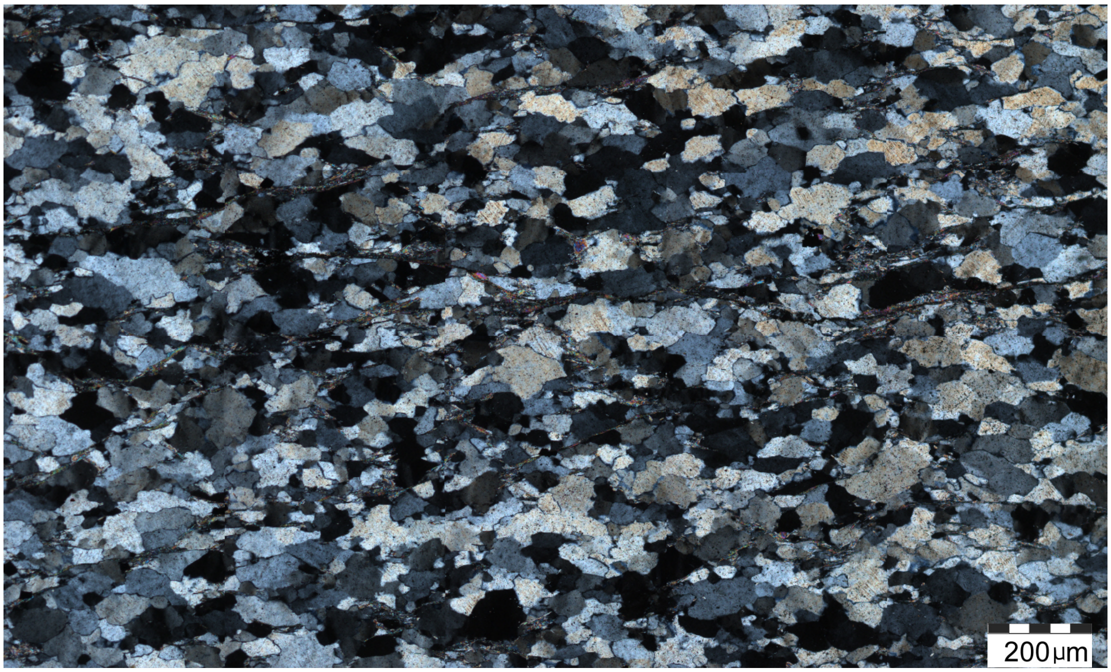


Figure 31. (Sample 21) *Photomicrograph shows the foliation in the quartzschist.*

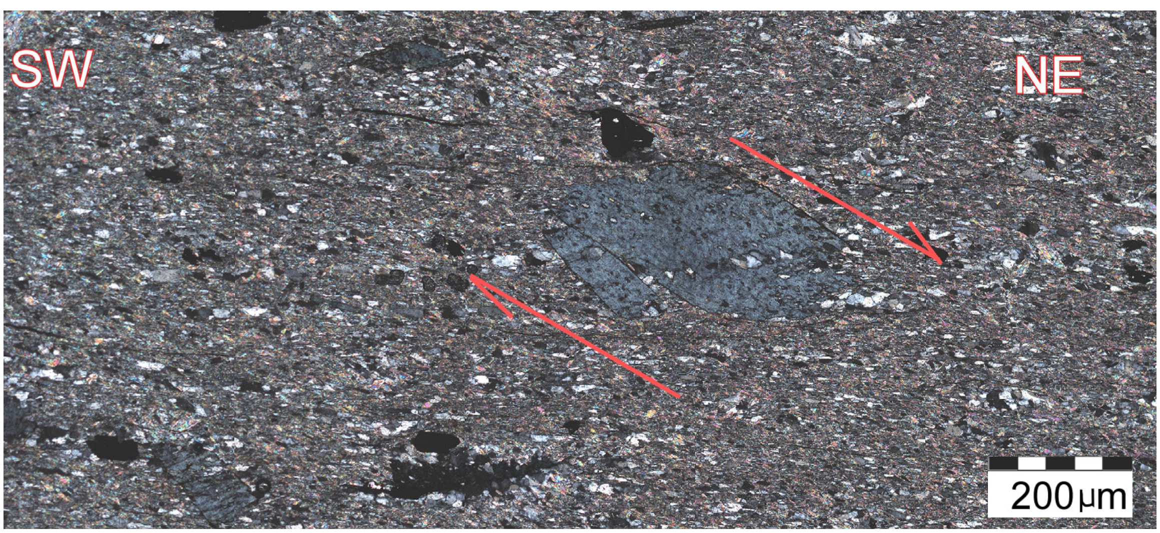


Figure 32*. *(Sample 22) *Photomicrograph depicting asymmetric tourmaline crystal, inferred sense of shear is top to the north.*

Sample 23 (Gniess, GPS: 95264, 00942): This rock is rich in quartz, feldspar, biotite and contains small amount of muscovite minerals. Recrystallized quartz, coarser grained biotite and foliated muscovite minerals define foliation in the rock. Muscovite and biotite grains are also displaying kinking and folding characteristics. Asymmetric mica fish and porphyroclasts suggest that sense of shear is top to the south (Figure 33).

Sample 25 (Augen Gneiss, GPS: 95201, 01070): The whole thin section is composed of the feldspar porphyroclasts of the Augen Gneiss. Quartz and muscovite minerals are observed around the feldspar porphyroclasts (Figure 34). In this sample, it is very hard to determine the sense of shear.

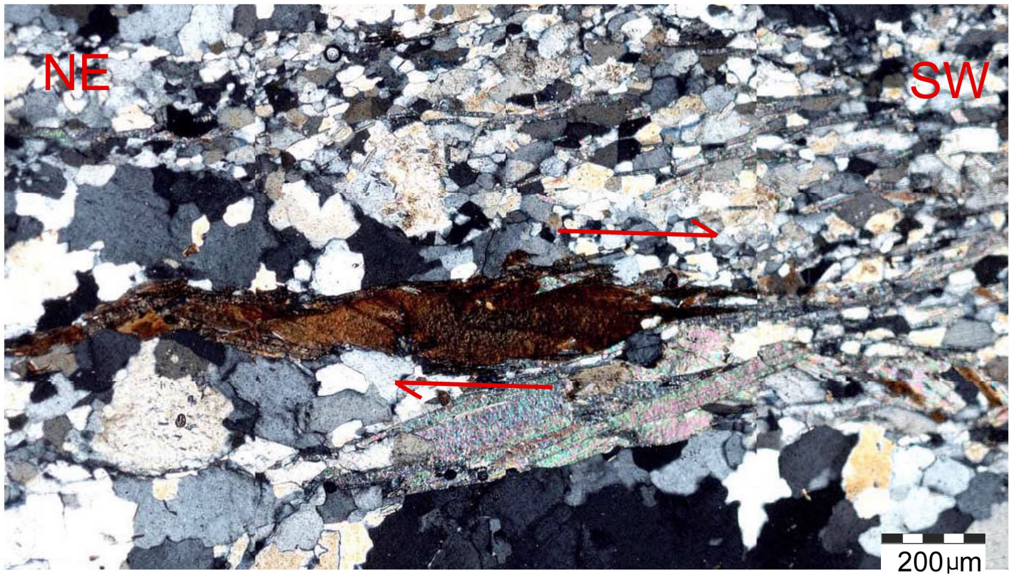


Figure 33. (Sample 23) *Asymmetric mica fish shows the shear sense direction (top to the south). Matrix is composed of recrystallized quartz, showing oblique foliation.*

Figure 34. (Sample 25) *Photomicrograph of the gneiss, composed of large feldspar porphyroclasts, muscovite and quartz.*

Transect II

Sample 11 (Mylonitic Schist, GPS: 94624, 02540): The sample contains quartz, biotite, chlorite, muscovite and feldspar minerals. Chlorite minerals are deflected around coarse-grained feldspar crystals. Main foliation is parallel to the subhorizontal feldspar crystals. The oblique orientation of small quartz grains with respect to main subhorizontal foliation defines the shear sense indicator in this thin section. The sense of shear is top to the north. In the center of the thin section, there is brittlely deformed shear band, cutting through the oblique and main foliation. This suggests that, the rock has deformed brittlely after ductile deformation (Figure 35).

Sample 12 (Mylonitic Schist, GPS: 95067, 03542): The sample is mainly composed of quartz, feldspar, biotite and muscovite minerals. Opaque minerals are accessories. Biotite minerals are altered to chlorite minerals. In thin section, S-C`fabrics are observed, which can be used as shear sense indicators. These fabrics indicate asymmetry in which, C` plane orientation defines shear band surfaces, oblique to shear zone boundary and the S- surfaces. The shear bands usually display anastomosing and wavy structures. Biotite and muscovite grains mainly represent the S surfaces. The angle between S- and C`- surfaces varies between 20º and 35º. S-C' fabrics define the sense of shear top to the north direction. In this sample, there are also rotated porphyroclasts, showing top to the south movement. It is observed that top to the south shear sense is overprinting top to the north sense of shear (Figure 36).

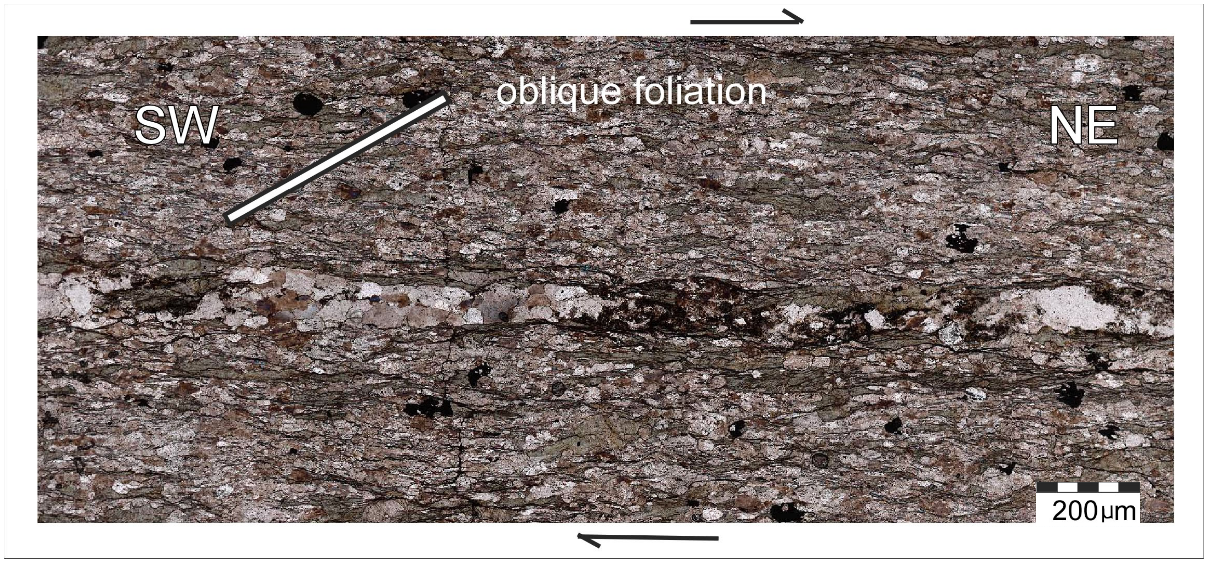


Figure 35 (Sample 11) *Quartz crystals are showing oblique foliation. Main foliation is horizonta, parallel to the feldspar grains.*

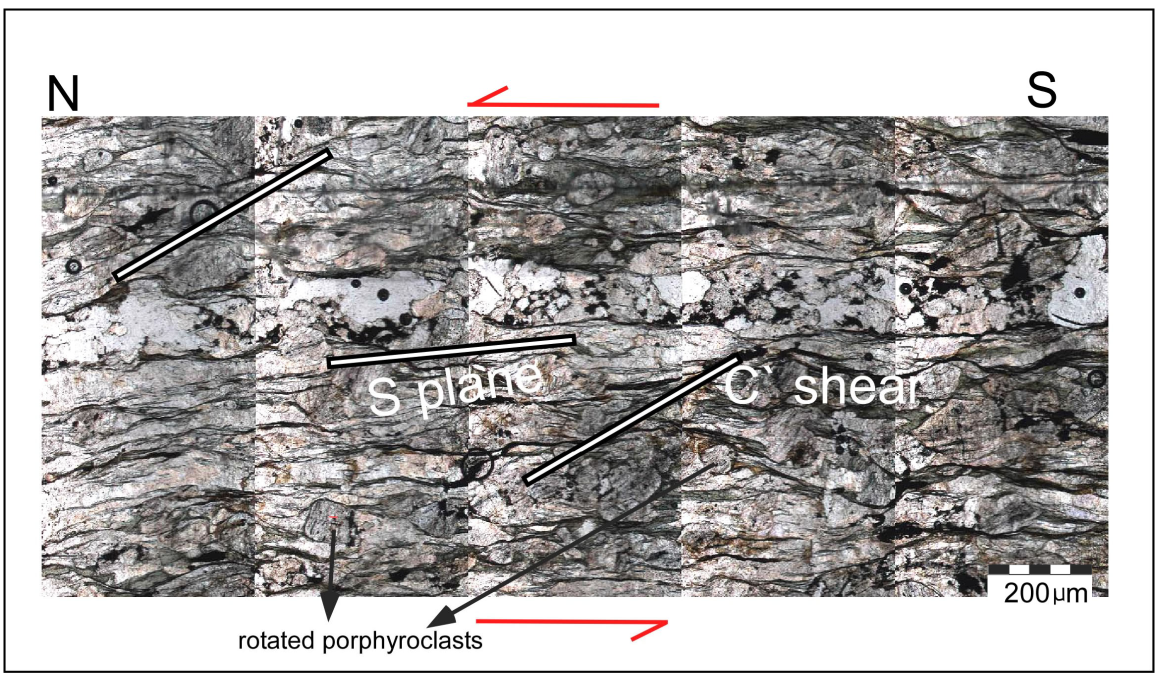


Figure 36 (Sample 12) *S-C' type shear band in mylonites. It is inferred that top to the north sense of shear defined by S-C' shear bans are overprinted by southward rotated porphyroclasts.*

Sample 38 (Mylonitic Schist, GPS: 95046, 02298): The sample is composed of feldpsar, quartz, cholorite, biotite and small amount of calcite and muscovite. Opaq minerals are accessory minerals. S-C' type shear bands suggest that the shear sense is top to the north. Also, small to medium size feldspar porphyroclasts are giving the opposite direction and overprinting top to the north directed shear sense (Figure 37).

Sample 40 (Cataclasite, GPS: 95309, 02448): The rock is showing typical characateristics of granoblastic texture. Minerologically, it is dominated by quartz. Original lithology of the rock is quartzite. In thin sections, it is identified that quartz grains are fractured by systematically arranged fracture sets. Microfracturing has formed grain-size reduction of feldspar and quartz. This suggests that cataclastic rock has developed under brittle deformation (Figure 38).

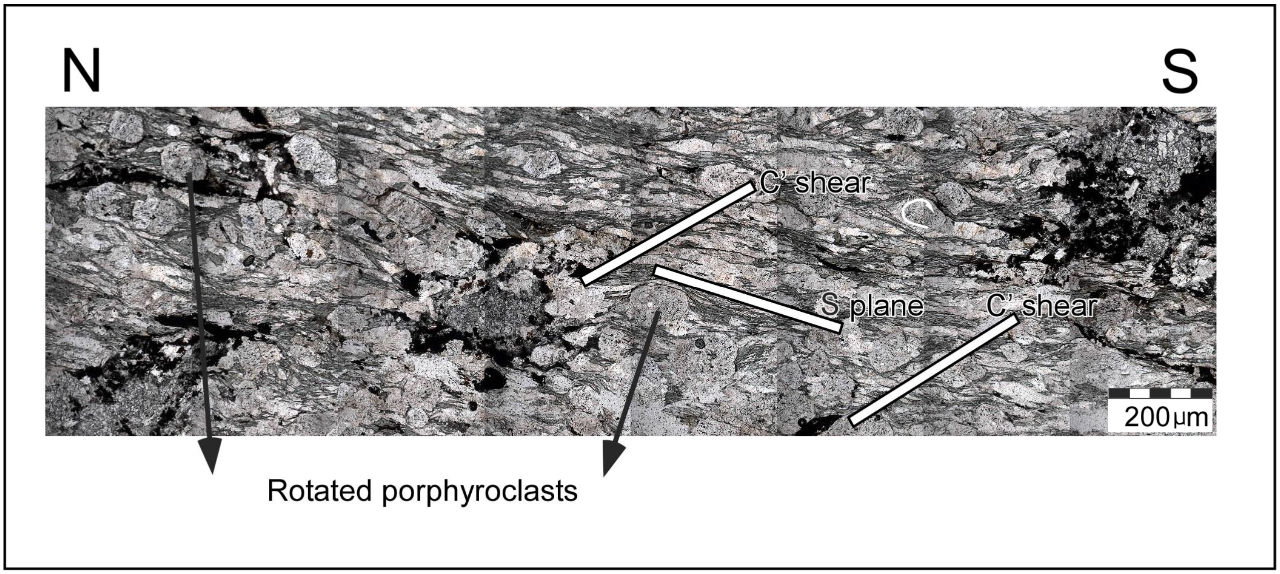


Figure 37. (Sample 38) *Photomicrograph of the mylonitic schist displaying S-C' and rotated porphyroclasts.*

Figure 38. (Sample 40) *Photomicrograph of the cataclastic rock, showing systematically arranged fracture sets*

Thin section analysis of collected samples

In addition to the samples along, transect I and transects II other samples were collected in the study area to identify important microstructural feautures and shear sense indicators along the Buyuk Menderes detachment surface.

Sample 15 (Mylonitic Schists, GPS : 94920, 02200): Minerologically the sample is composed of quartz, feldspar, biotite and muscovite. S-C' features are indicative of shear sense direction. S plane is defined by feldspar crystals whereas C' shear band is defined by biotite . The sense of shear is left lateral, top to the north. In this thin section, there is also brittlely deformed shear band overprinting S-C' fabrics. Brittlely deformed shear band is top to the south directed. This suggests that, top to the south brittle shear sense indicators are overprinting top to the north ductile shear sense indicators (Figure 39).

Sample 6 (Mylonitic Shists, GPS : 96630,00634): Mineralogical composition of the rock sample is biotite, muscovite, feldspar and quartz. In thin section, it is noted that brittle fracturing is commonly arranged in a Reidel System. P and R shears are observed as conjugate, with principal fracture zones intersecting at 60^{o}. Reidel systems or extensional shear bands are very useful tools to determining the sense of shear when they have the sense of shear opposite that of the main shear zone (Reynolds and Lister, 1990). In this case, Reidel shears may be interpreted, as they are the late stage feature that formed after most of the main shear zone fabric. In thin section, brittle fracturing defined by Reidel shear system overprint the top-to the north shear sense indicators (Figure 40).

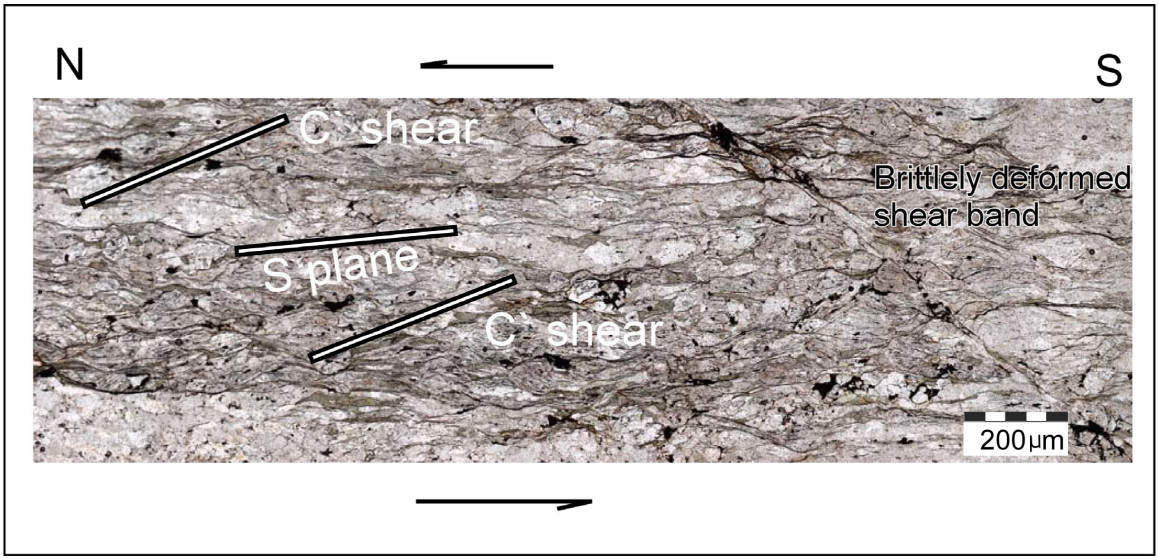


Figure 39. (Sample 15 GPS *) Photomicrograph of the S-C' asymmetric shear band, showing top to the north sense of shear. These ductile features are overprinted by brittle shear band showing top to the south shear sense****.***

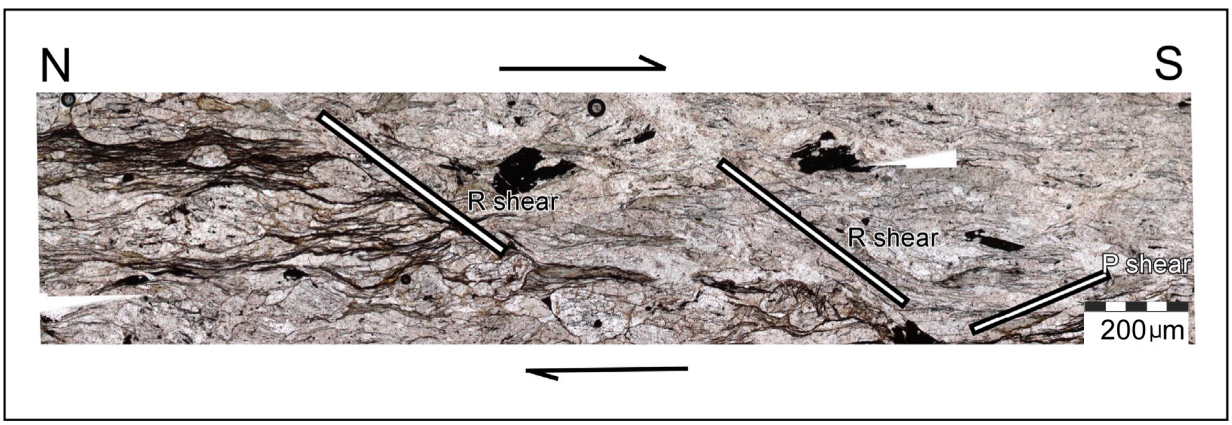


Figure 40*.* ***(Sample 6****) Photomicrograph of Riedel shears with a typical orientation and shear sense.*

The microstructures described above are showing typical crystal-plastic deformation and syn-kinematic recrystallization. The occurrence of feldspar augens and S-C’ structures suggest that the early stages of mylonitization took place moderately at high temperatures (Lister and Snoke, 1984 ; Passchier and Trouw, 1996)

MESOSCOPIC SHEAR SENSE INDICATORS

The study area also contains mesoscopic shear sense indicators, which are used as a tool to determine the shear sense. Mesoscopic kinematic indicators, developed in the mylonitic schists and augen gneisses, include asymmetric K-.feldspar porphyroclasts, asymmetric quartzite and isoclinal folds.

K-feldspar porphyroclasts are locally present in mylonites. The foliation is deflected around these porphyroclasts as well as around feldspar augen (Figure 41). Sigmoidal quartz structures usually were observed in the mylonitic schists (Figure 42). Generally, mesoscopics kinematic indicators show both top- to- the- north and top to the south ductile shear sense. This interpretation is corroborated by microscopic analysis of asymmetric muscovite fish and S-C and S-C’ relations. The existence of these fabrics and textures indicate that deformation within the shear zone is non-coaxial laminar flow, during which the hangingwall of the structure moved down to the south relative to the footwall.

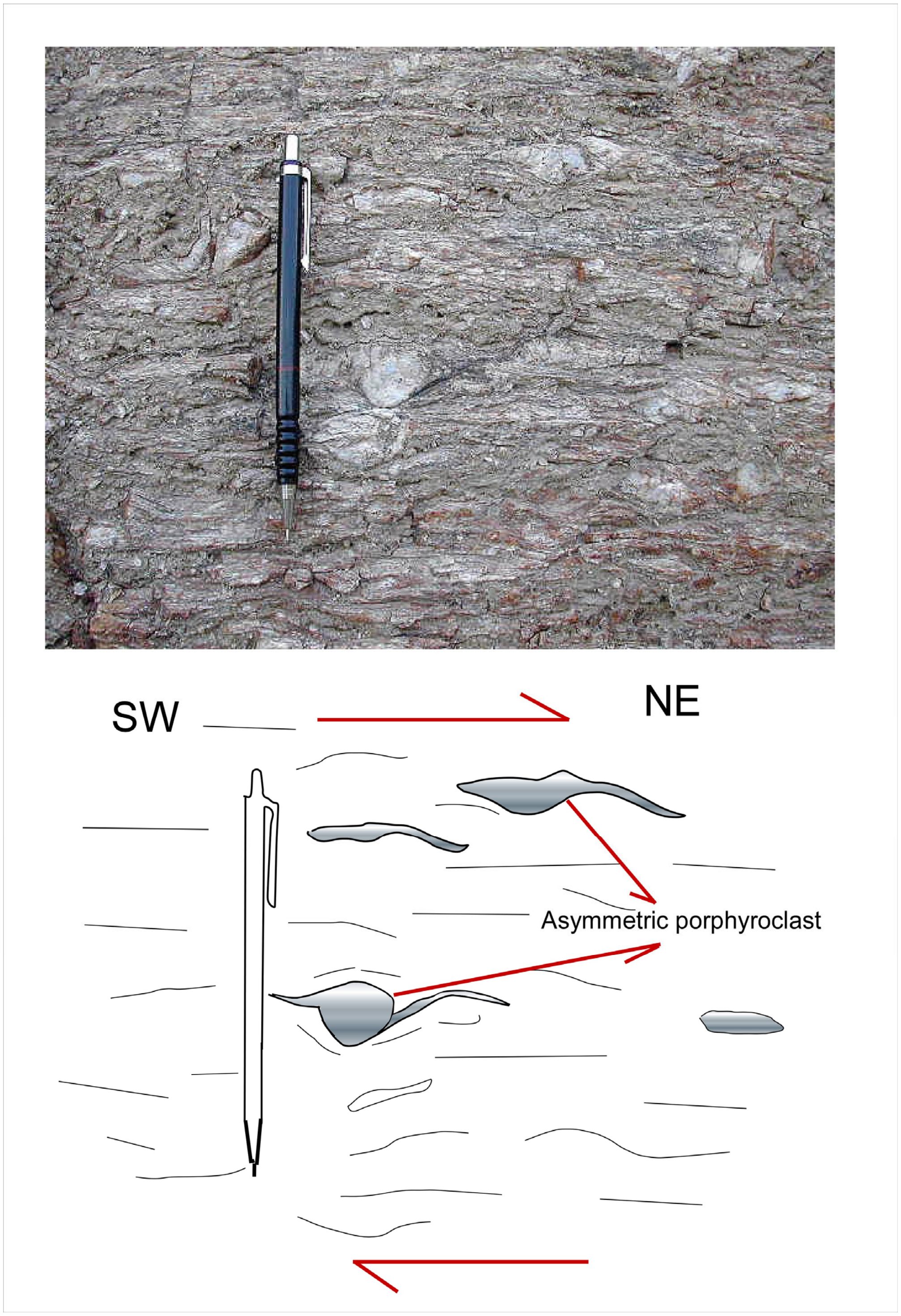


Figure 41. *Asymmetric K-Feldspar porphyroclasts from the Augen gneiss showing the main foliation wraps around the porphyroclasts*

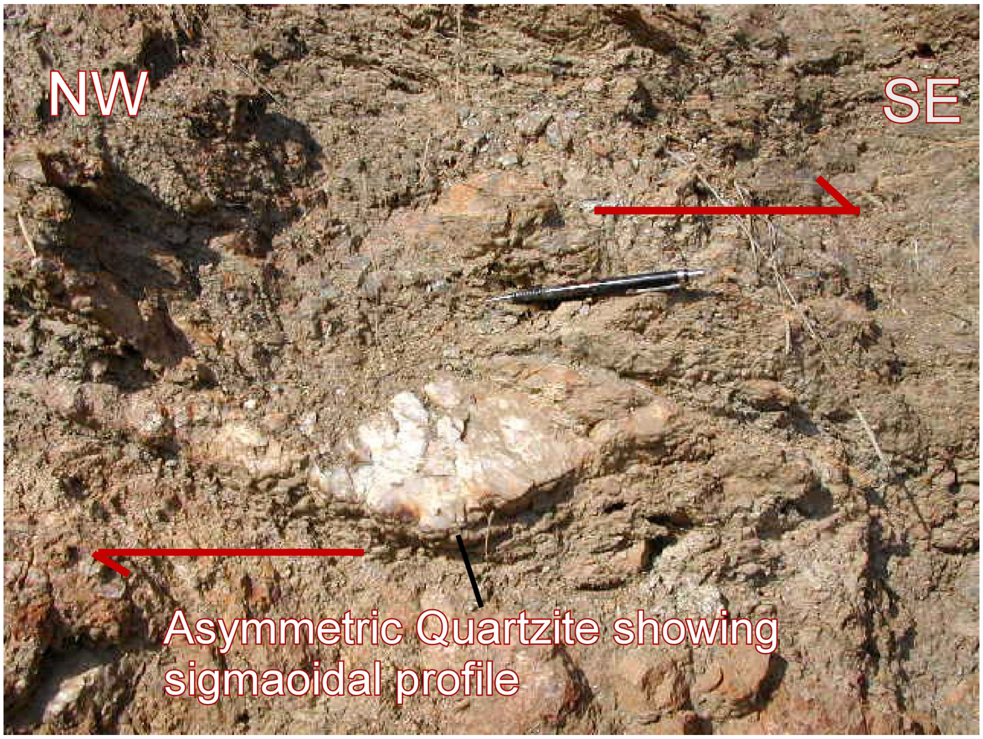


***Figure 42**. Asymmetric Quartzite in micaceous schists, displaying top to the south sense of shear*

Small Scale folds.

Mylonitized micashcists host asymmetric mesoscopic isoclinal folds, north - vergent folds. Rootless isoclinal folds with axial planes dipping to the north, parallel to the regional foliation are exposed along the north-south road through the Tepecik hill (Figure 43). The north-oriented cleavage set and tight folds suggest the northward- tectonic transport.

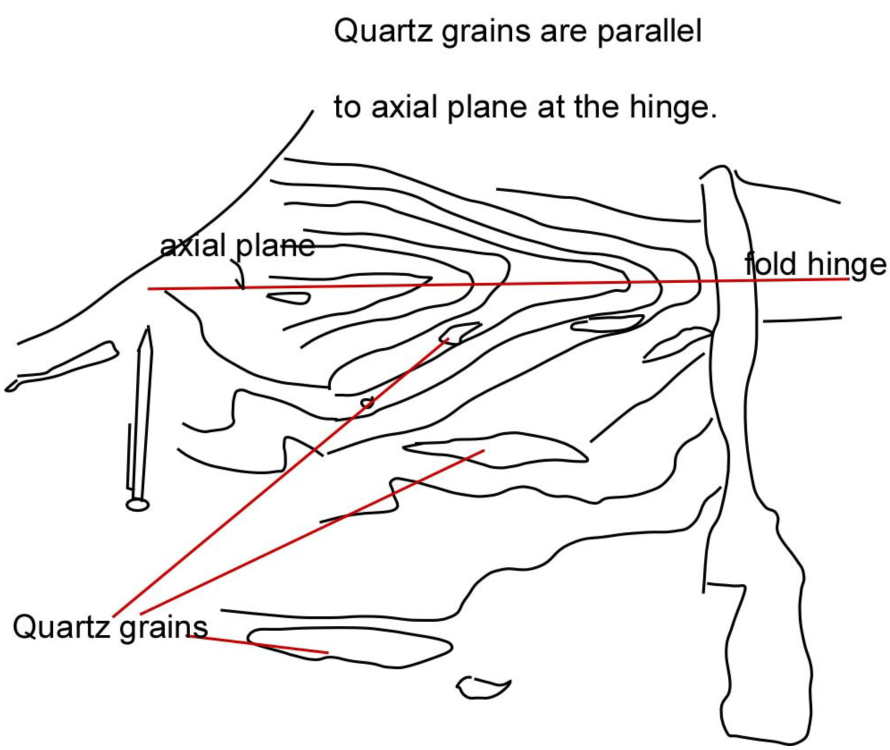


Figure 43. *Micashists show small scale folds in mesozcopic scale. Most of these fold's hinge show the same orientation with the regional foliation*

Overprinting relationships

In metamorphic rocks, deformed rocks and structures representing different metamorphic grades and orientation may overprint each other (Passchier and Trouw, 1996). The overprinting mechanisms are the fundamental consequence of the superposition of different structures and mineral assemblages that differ in age. Overprinting between structures generally shows a clear sequence of timing. (Passchier and Trouw, 1996). The regional tectonic evolution of rock units formed under multiple deformation phases may be explained by identifying the overprinting relationships and deformation phases of the structures (Passchier and Trouw, 1996).

On the basis of kinematic framework and overprinting relationships, structural analysis along the Buyuk Menderes shear zone has identified 2 regionally ductile deformation events (D_1 and D_2) and a southward directed brittle deformation event.

Shear sense indicators for D_1 ductile deformation is northward directed. The age of this deformation event is 36 ± 2 Ma. (Lips et al. 2001). Fabric elements of D_2 generally represent the regional mesoscopic fabrics, which is southward directed. The D_2 deformation band postdates the D_1 deformation bands (Figure 36 and 37). D_1/D_2 geometry of the Buyuk Menderes shear zone is overprinted by a series of structures that formed by brittle deformation, which produced a variety of systemically arranged fracture sets and Reidel shears systems.

This sequence represents the an extensional shear zone stratigraphy and ductile-brittle continuum of deformation during which ductilely deformed fabrics have underwent mylonitization through cataclastisis under decreasing temperature and pressure (Wernicke. 1985).

Kinematic Model

Any model proposed to explain the varied ductile and brittle structures and deformational fabrics exposed on Buyuk Menderes shear zone include the following observations

1) Brittlely extended rocks are juxtaposed against ductilely deformed mylonitic shists, along a low angle cataclastic shear zone.
2) Kinematic indicators show that Buyuk Menderes detachment surface contains top to the north ductile shear sense indicators. These structural features were overprinted by top to the south ductile shear sense indicators, which were in turn overprinted, by brittlely deformed top to the south kinematic indicators. Top to the south brittle features cut through both top to the north and top to the south ductile shear sense indicators.

It is suggested that the geologic relations described above are best explained by multiple deformation along an evolving, crustal-scale, normal- sense displacement zone of simple shear (Wernicke, 1981;Wernicke, 1985). It is also argued that lower plate rocks of Buyuk Menderes detachment were formed at deep crustal levels. These rocks were drawn upward to progressively shallower crustal levels and overprinted by brittle deformation.

CHAPTER V

CONCLUSIONS

The following conclusions were reached regarding the nature of early Miocene extension within the Buyuk Menderes graben.

1) The mechanism accompanying for the observed extension includes low-angle normal faulting. Shallowly dipping, low-angle normal fault floors the extended upper plate.

2) Extensional elements exposed in the Buyuk Menderes shear zone have shown that extension was ductile deformation during the early stage of deformation. D_1 and it is postdated by D_2 ductile deformation.

3) In some areas Buyuk Menderes detachment fault is defined by its topographic expression.

4) In most localities, the brittle fractures truncate ductile fabrics.

5) Brittle deformation is characterized by continuous fractures that propagate across grains and grain boundaries. These fractures cut across grains of different compositions. Individual fractures may originate as shear fractures cross-cutting the ductile extensional shear bands. Brittle deformation, overprinting both D_1 and D_2, is depicted by top-to-the south shear sense in more than 70 percent of the thin sections examined.

6) Deformation features in the Buyuk Menderes shear zone range from ductile-brittle. Ductile features are S-C and S-C` asymmetric structures, schistosity, small-scale folds. Continious fractures and reidel shears define brittle deformation.

7) Detalied microstructural studies on asymmetric quartzite, asymmetric K. Feldspar porphyroclasts, small scale folds and faults show evidence for ductile top to the north and top to the south structures simple shear deformation. Ductile top to the south structures were superimposed on ductile top the north structures.

8) Like many other detachments in Western Turkey (e.g., Alasehir detachment; Isik et al. 2003) Buyuk Menderes detachment fault is characterized by structural zone, where younger brittle-ductile and brittle fabrics overprint early mylonitic fabrics.

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Appendix A: Index microstructural features

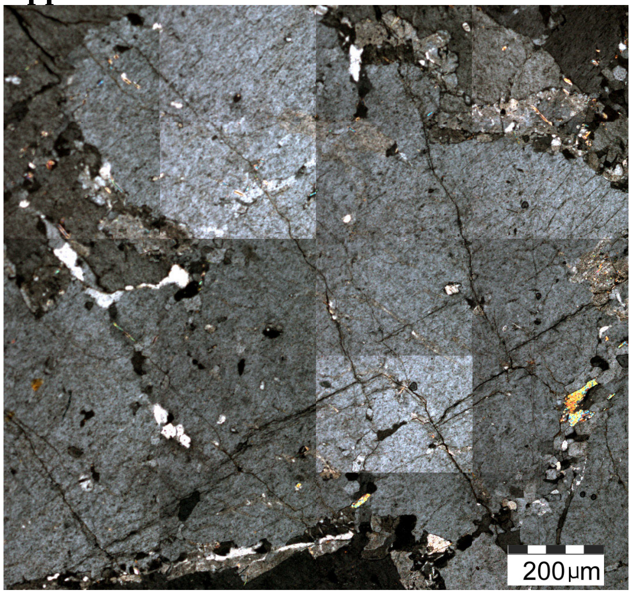


Figure 1. Sample 8. (Augen Gneiss, GPS: 94925, 95688): Photomicrograph of Feldspar crystal showing intracrystalline fractures. Feldspars show the characteristic of brittle fracturing at very low metamorphic grade.below 300º (Passchier and Trouw, 1996).

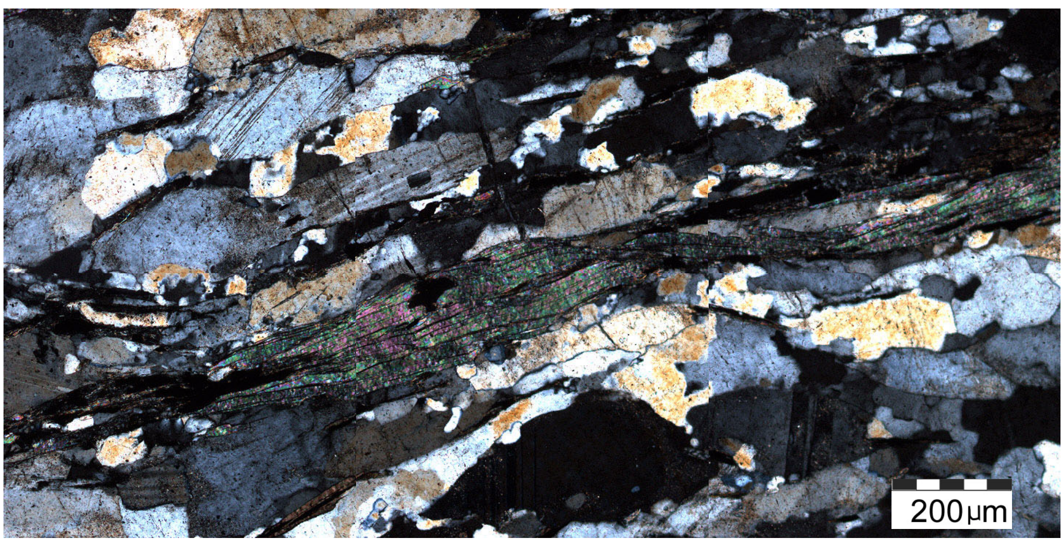


Figure 2. Sample 10. (Mylonitic schist, GPS: 95529, 02648): Muscovite showing kinking and folding features.

Figure 3. Sample 17 (Cataclasite, GPS: 97650, 00056): Photomicrograph of cataclasite, showing microscale fractures and fine- grained crystals are cutting the cataclastic foliations with different orientations.

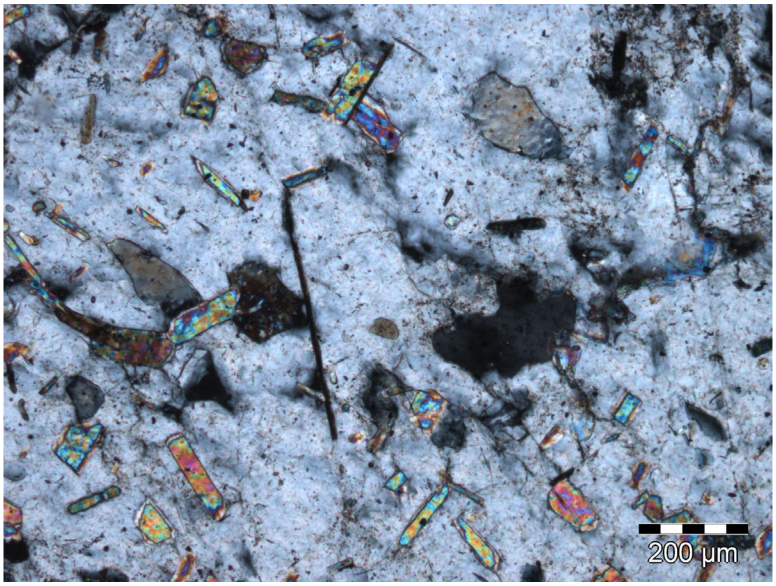


Figure 4*. Sample 9 (Neogene sedimentary unit, GPS: 95190, 02052) Photomicrograph of the Haskoy sedimentary formation. Muscovite, feldspar and, quartz particles are distributed in matrix.*

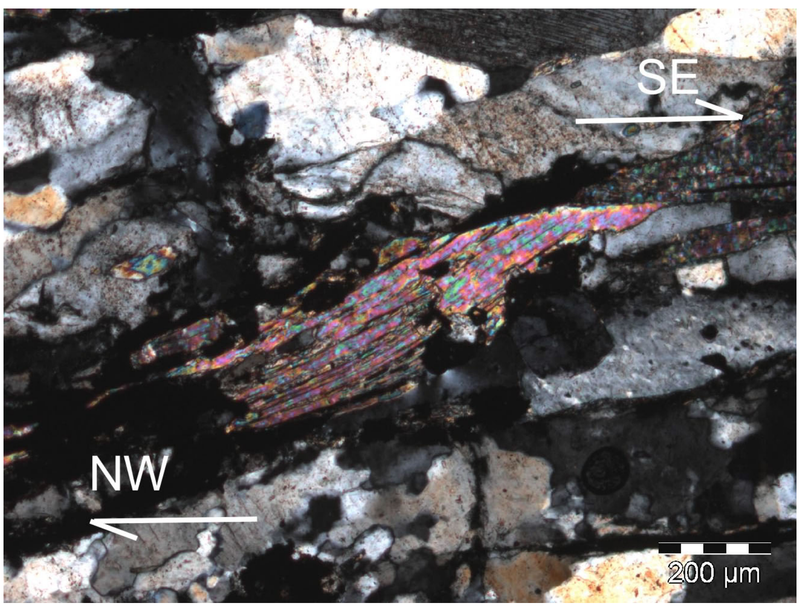


Figure 5. Sample 10 (Mylonitic schists, GPS 95529, 02648): The rock is composed of muscovite, biotite, feldspar and quartz. Asymmetric mica fish has developed in the rock during mylonitization. Inferred sense of shear is top to the south

Appendix B: Mesoscopic shear sense indicators;

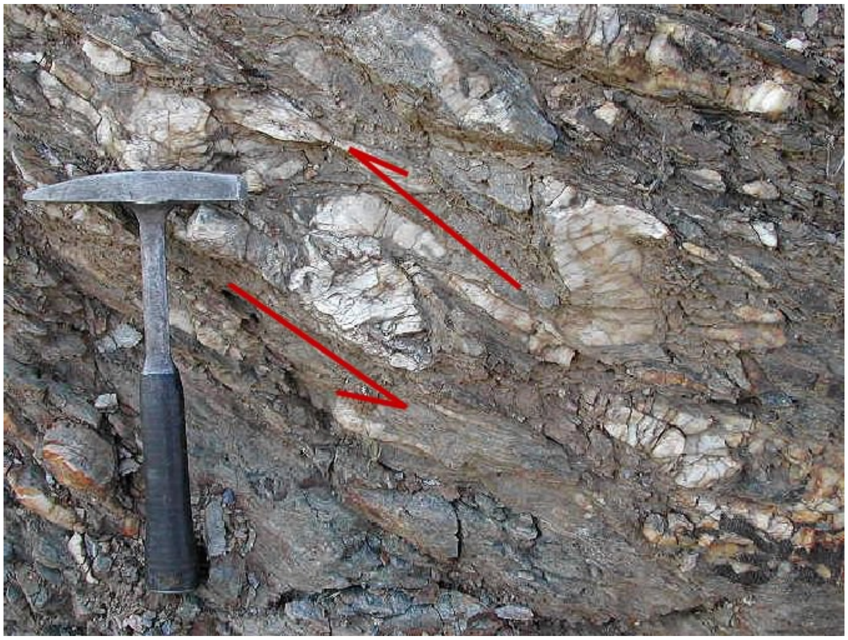


Figure 6. (GPS: 89424, 99927) Asymmetrical S-fold in mylonites formed by left lateral movement.

Figure 7. (GPS: 90489, 01365): S -type fold in mylonitic schists.

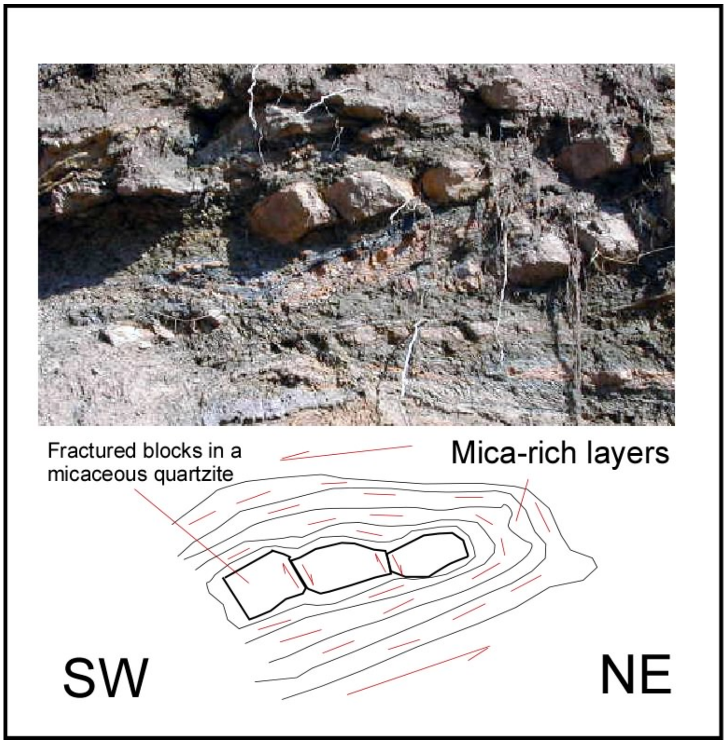


Figure 8. (GPS: 95774, 02030): Brittle shear sense indicator, domino faulting in mylonites. Inferred sense of is shear is top to the south, same orientation with Buyuk Menderes detachment fault.

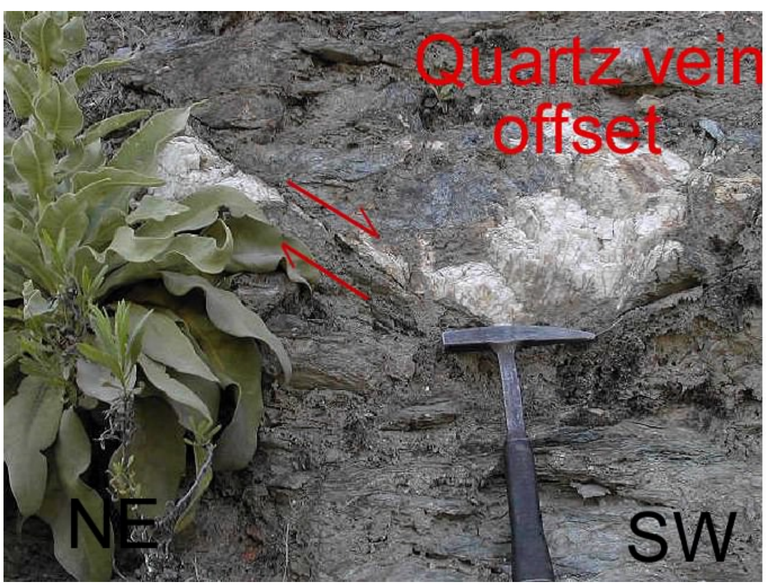


Figure 9*. (GPS: 89424, 99923): Quartz vein in mylonites. It is offset by small-scale fault*

Figure 10. (GPS: 96325, 99213): Outcrop photo of the foliated Gneiss (upper plate rocks).

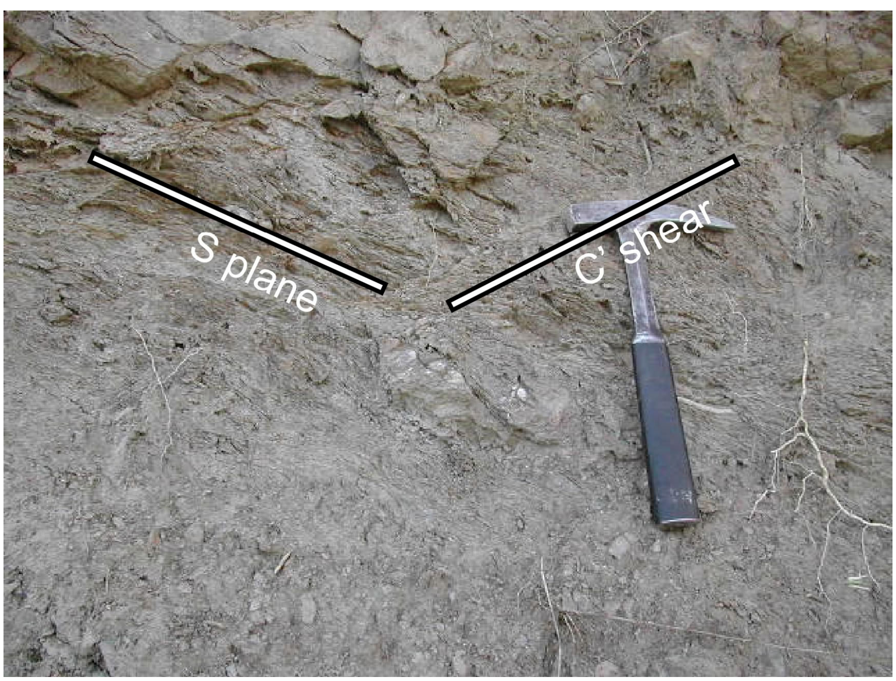


Figure 11. (GPS: 95095, 03365): S-C' type shear band in mylonites.

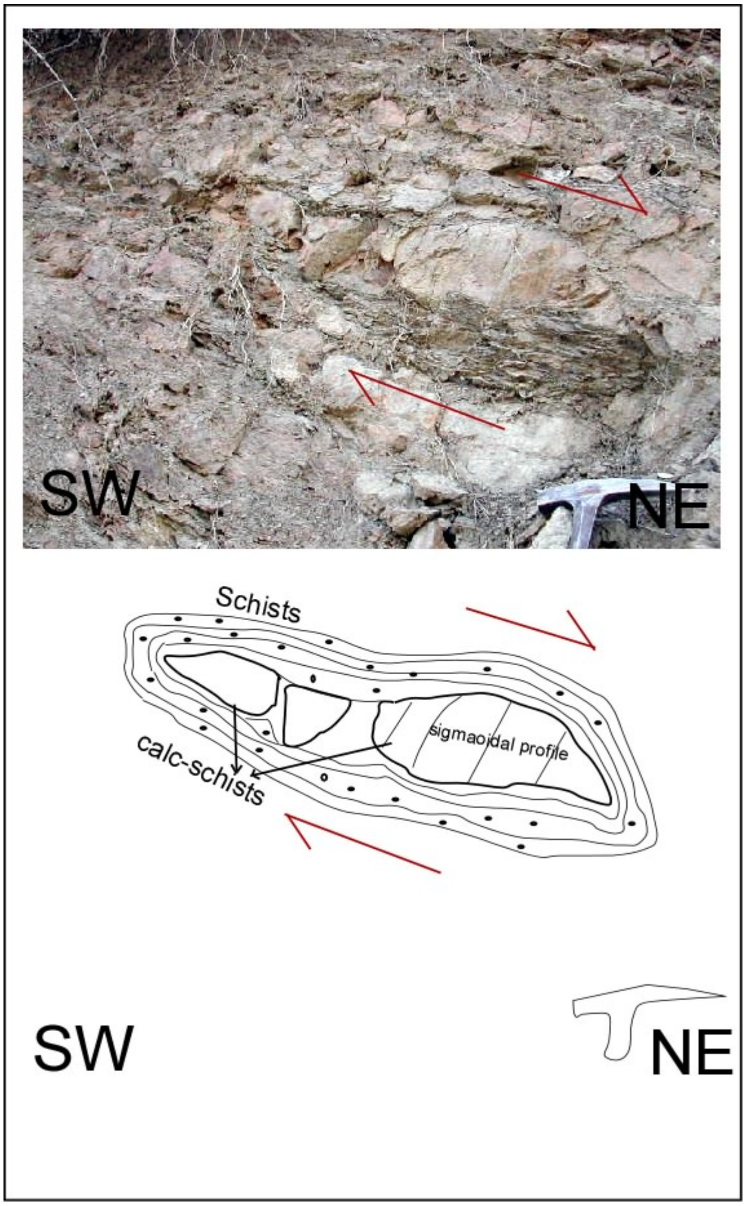


Figure 12. (GPS: 95067, 03542) Calcareous material in mylonites having sigmoidal profile. Inferred sense of shear top to the north.

Appendix C: Field-view of the Buyuk Menderes detachment surface

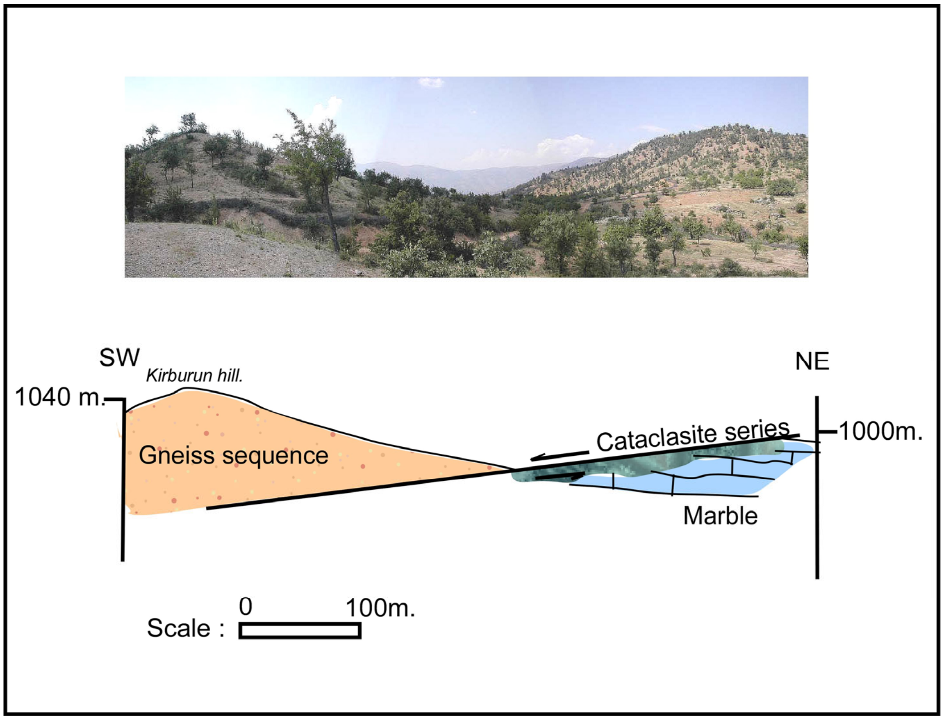


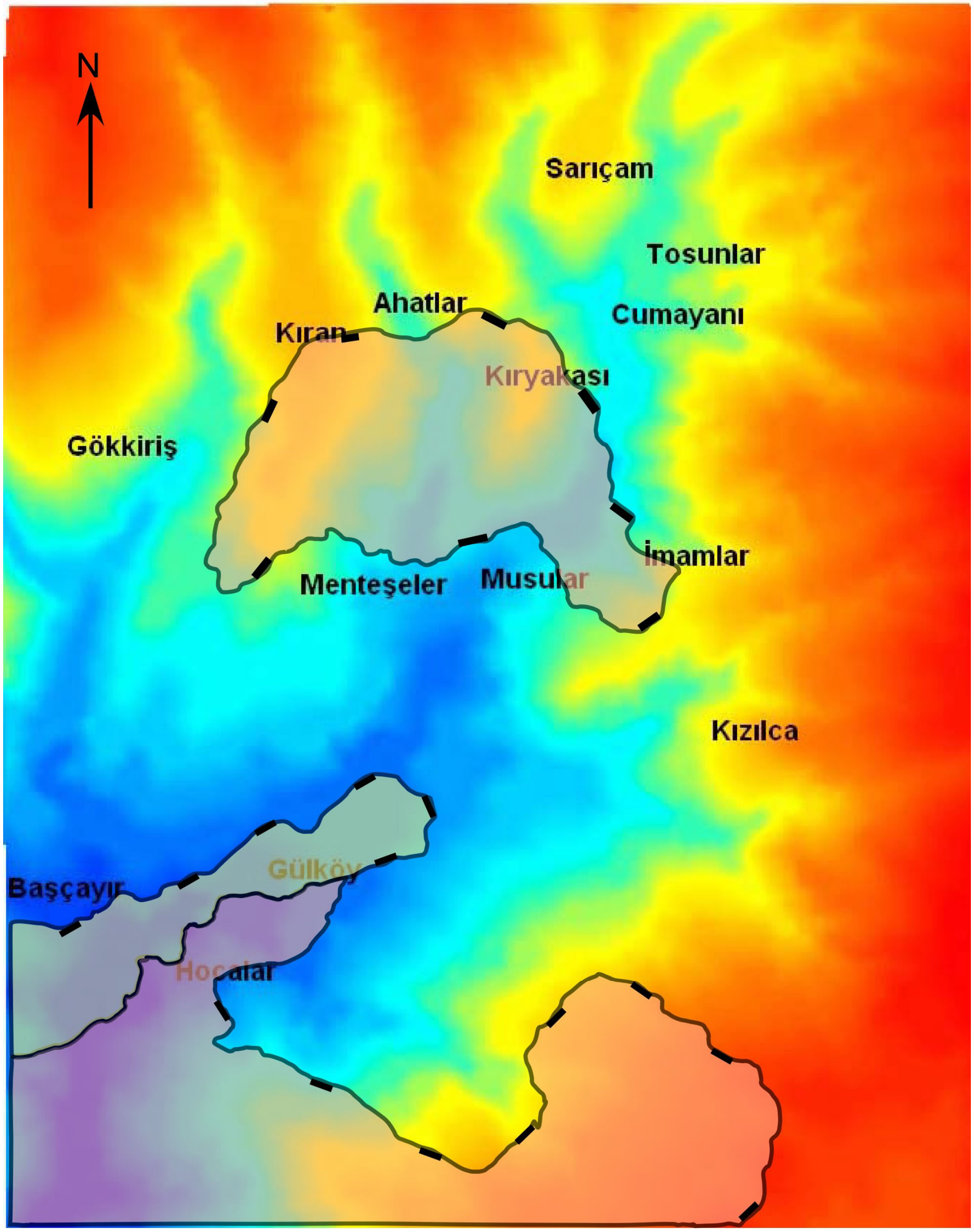
Figure 13. (GPS: 96325, 99213): Photo and cross-section showing of a typical low-angle normal fault, exposed at location of Kirburun hill. In this location, detachment surface strikes 35º to NS and dips 23º towards SW

Figure 14. (GPS: 95646, 02364): Field view of Buyuk Menderes detachment surface, separating red colored-Haskoy formation from cataclasites.

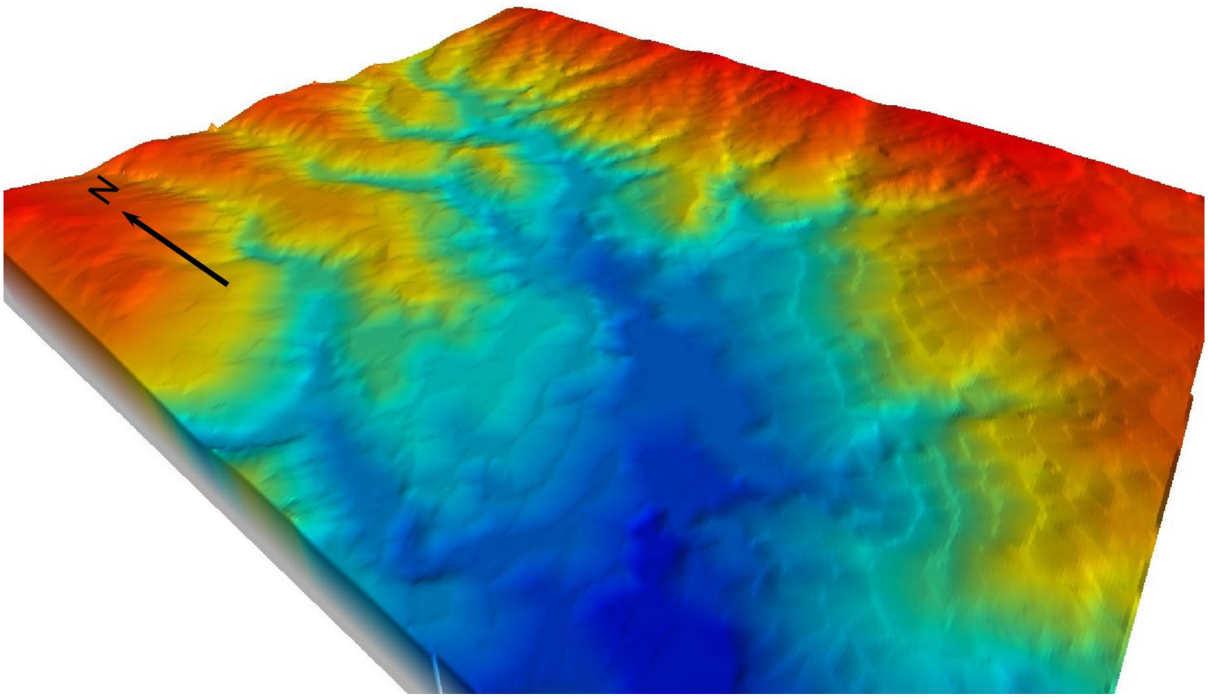
Figure 15. (GPS: 95309, 02448): Outcrop photo of the cataclastic shear zone, north of Bascayir village.

Figure 16. (GPS: 97450, 02000). Field view of the moderate-angle normal fault around Kizilca village. Fault surface is made up of marbles. The orientation of the fault is N 40º E/ 55º NW

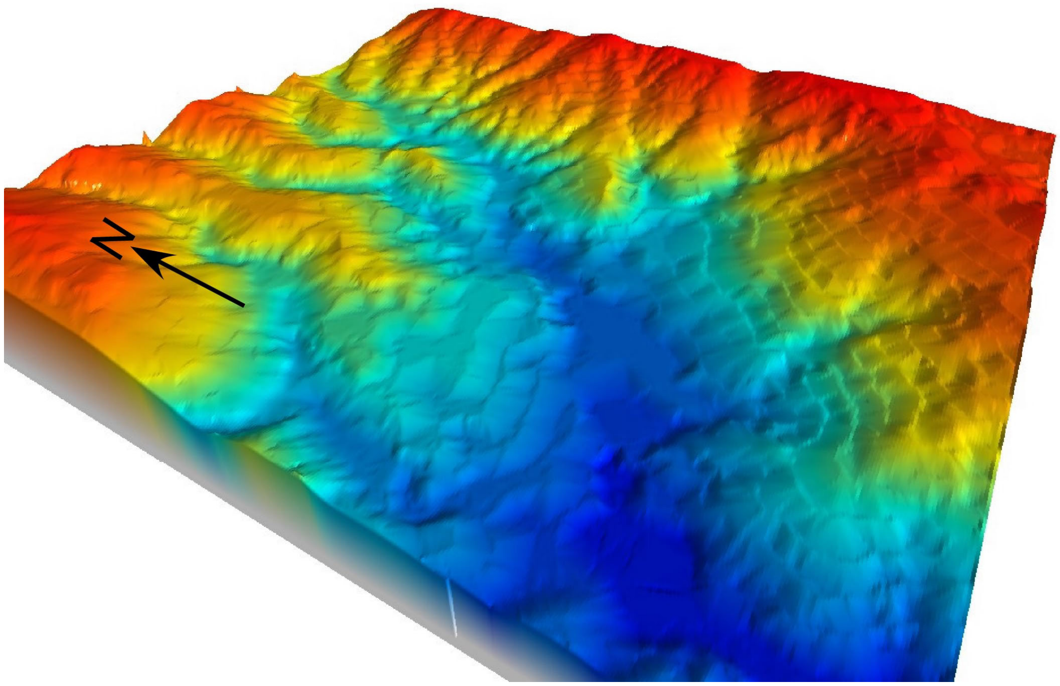
Appendix D: DEM of the study area



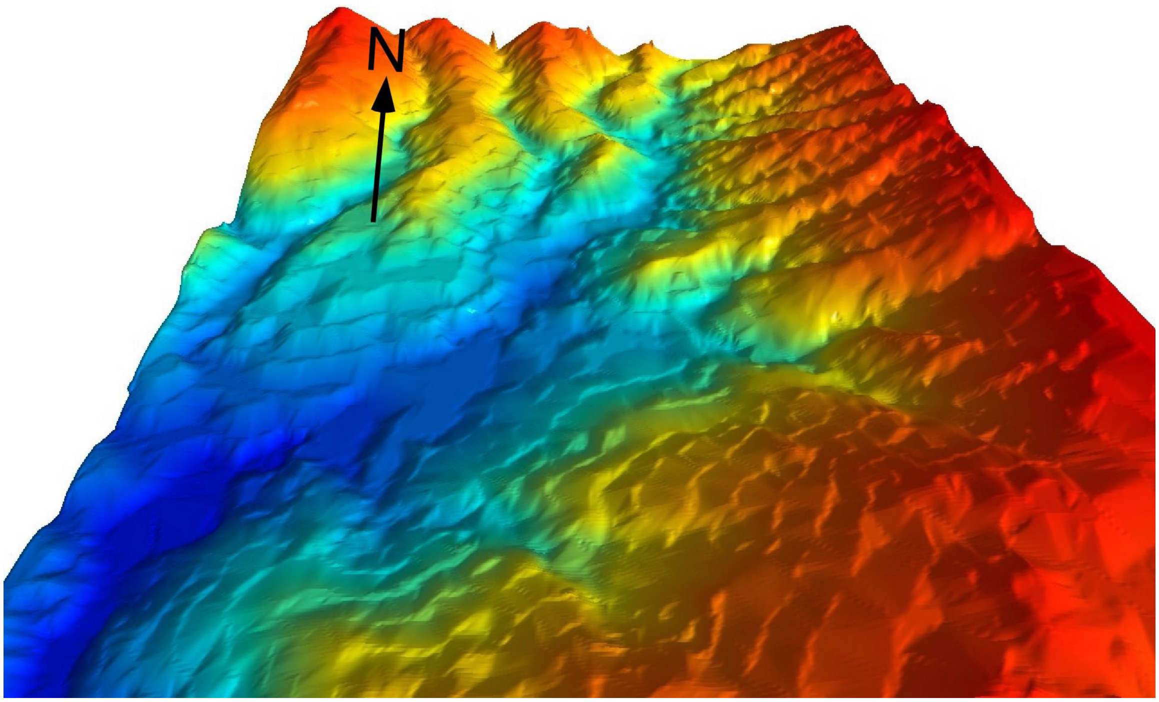
DEM (Digital Elevation Model) of the study area



3-D_1 Multi-Image

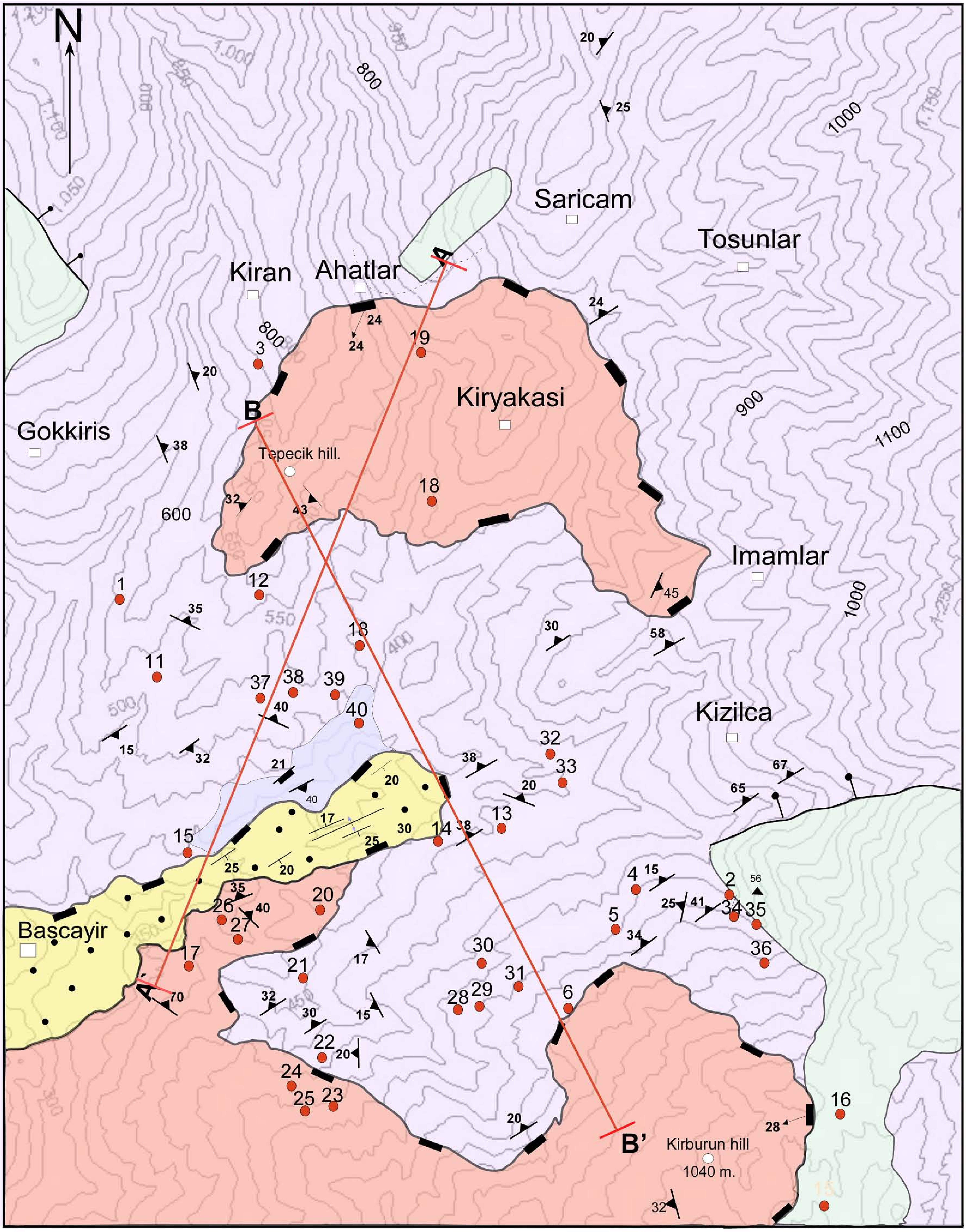


3-D_2 Multi-Image



3-D_3 Multi-Image

Plate I Geologic Map of the Study Area



Hangingwall rocks — **Early Miocene Sedimentary Unit**

Unconformity

Gneissic sequence

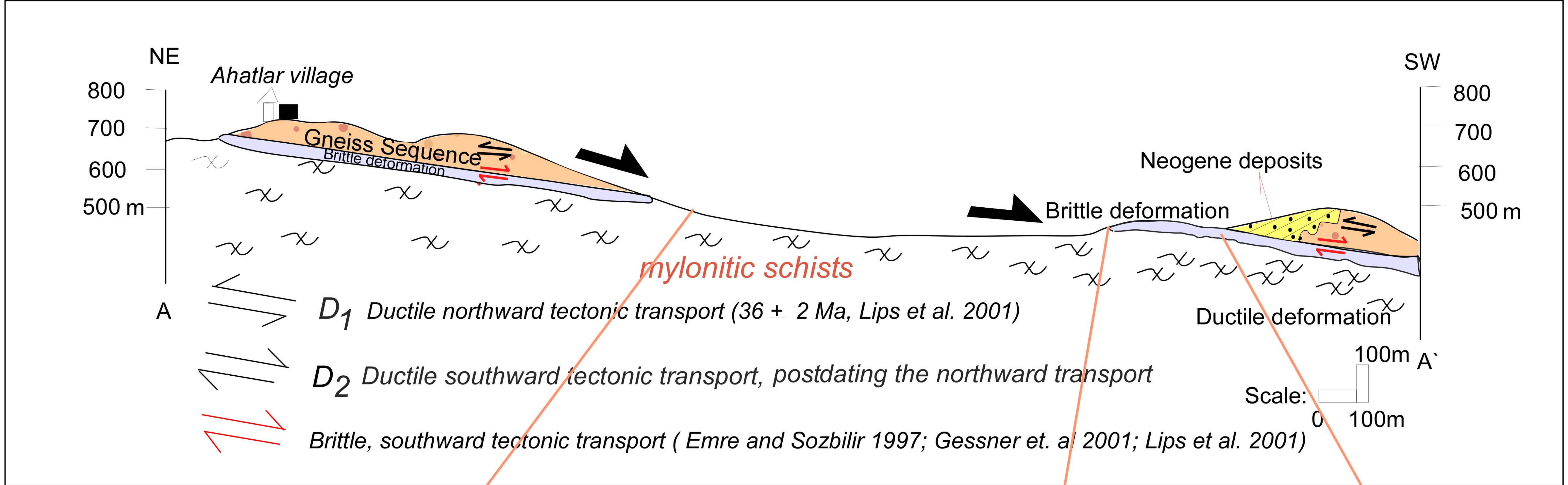
Buyuk Menderes detachment fault

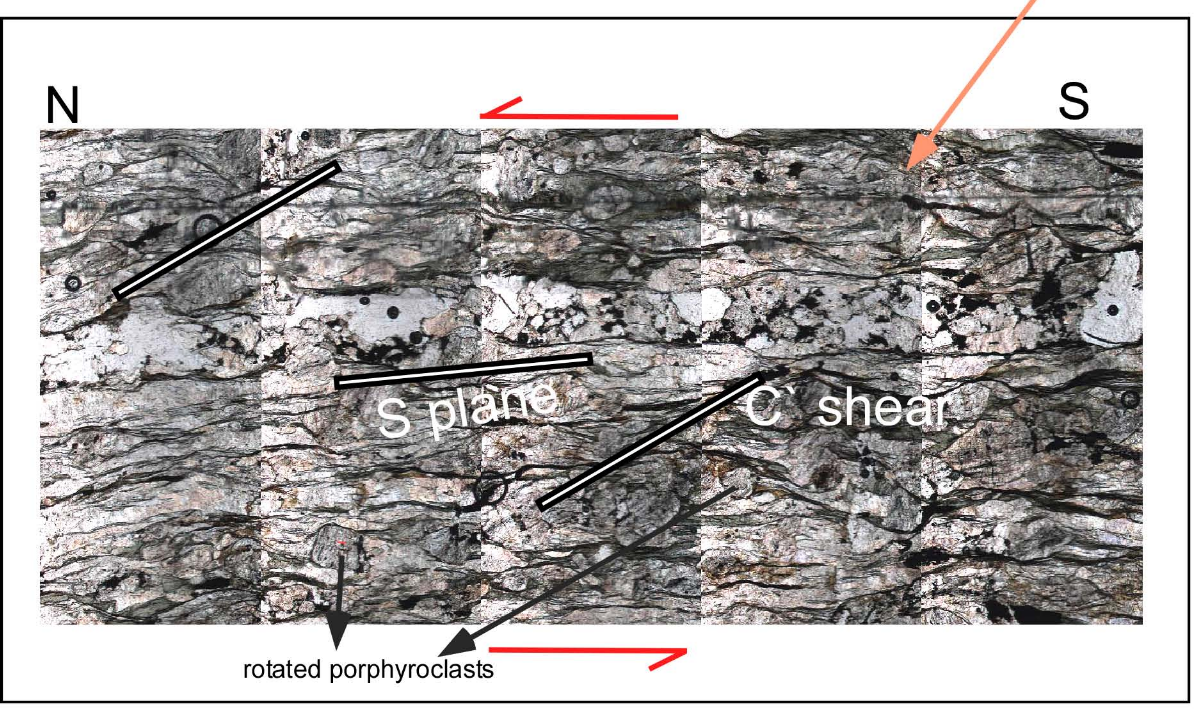
Footwall rocks — **Footwall rocks (contains cataclastic marbles and schists)**

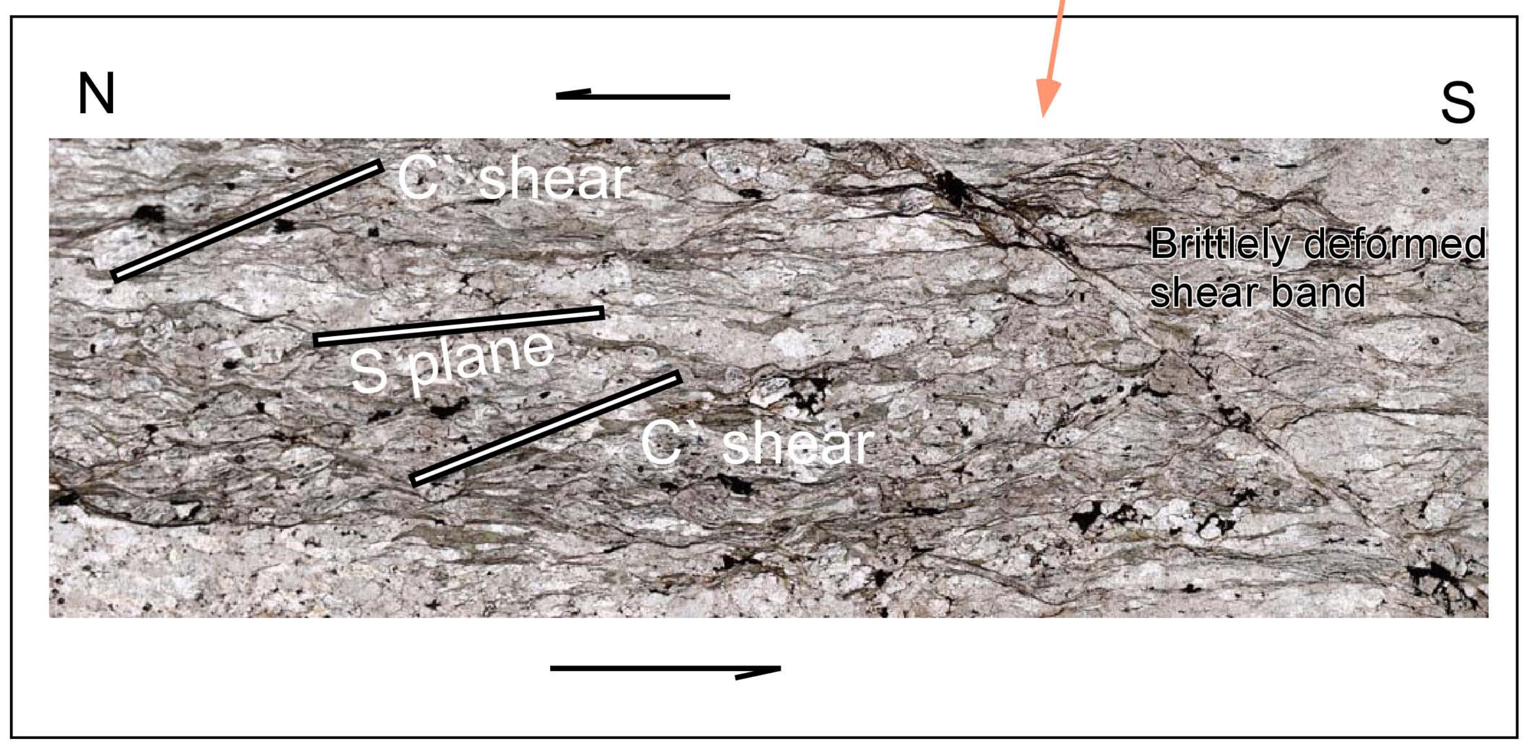
Scale: 0 200m.

7 Stretching lineation; 500 Topographic contours; 34 Mylonitic Foliation; High-angle normal fault

25 Cataclastic Foliation; Sample Location; 20 Strike and dip of the bedding plane; A A' Section line



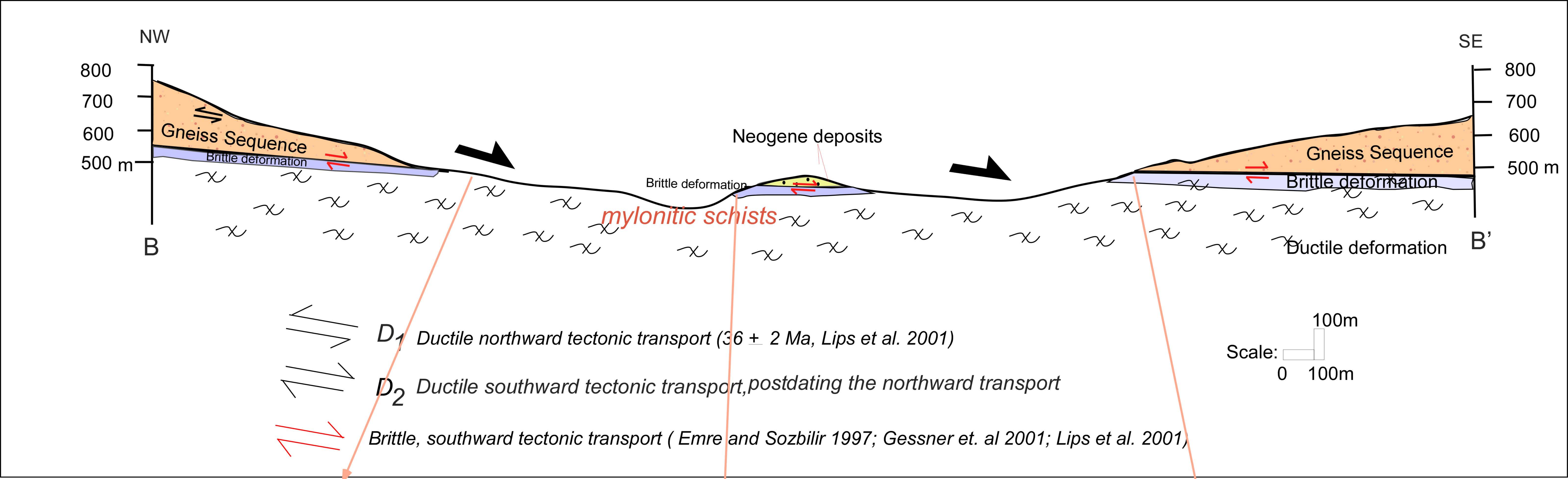




C'type shear band cleavage transecting the main foliation in micaschits. Left lateral shear sense indicates top to the north. Rotated porphyroclasts suggest top to the south movement and overprinting earlier stage top to the north shear sense

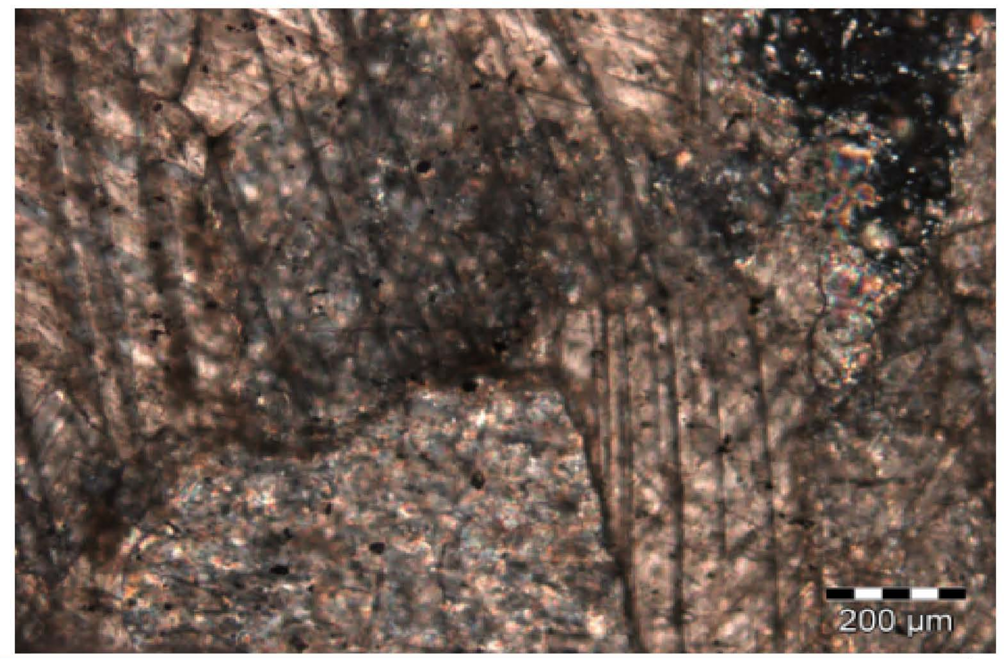
C'type shear band and cleavage in mylonite, indicating left lateral shear sense.Fracture is cutting through the asymmetric shear band, overprinting ductile deformation.

Cataclastic material made up of mylonitic rock fragments and feldspar porphryoclasts. Fractures are commonly filled with iron-oxide.



Mylonitized micashists. Biotite minerals wrap around garnet porphyroclast. Intracrystalline fractures in garnet porphyroclast suggets that the mineral has experienced brittle conditions at last stage of the deformation.

Outcrop photo of the Buyuk Menderes detachment surface. Brittlely deformed rocks are overprinting ductilely deformed rocks.



Brittlely deformed marble along the detachment surface. Fractures are cutting the cataclastic foliation.

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