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# Structural features of the Bozdağlar massif to the south of Ilgın and Sarayönü (Konya)

*Ilgın - Sarayönü (Konya) güneyinde Bozdağlar masifinin yapısal özellikleri*

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**Abstract**

The Bozdağlar massif, (NW of Konya), tectonostratigraphically consists of, from bottom to top, autochthonous Upper Permian - Cretaceous Gökçeyurt group, Mesozoic Çayırbağı ophiolite, and Silurian - Mesozoic allochthonous Ladik metamorphites. Upper Miocene - Quaternary rocks consititute neo - autochthonous cover.

Both the autochthonous and allochthonous metamorphites, indicate at least three phases of deformation. The first phase produced recumbent folds under high P/low T metamorphic conditions. The second and the third phases represent post - metamorphic episodes and developed Type 3 ve Type 1 refolded folds. The massif gained its polyphase deformational history and imbricated structures during the Late Cretaceous and following times respectively. The post - orogenic movements during Middle- Late Miocene formed lacustrine basins due to block faultings accompanied with volcanism. At Early Pliocene time, rocks of the massif thrusted over the cover units and finally gravity faultings occurred. All of these movements caused uplift that ranges from 600 to 850 m in the region.

**Key Words:** Bozdağlar massif, Superimposed folds, Dyke swarm, Crenulation cleavage, Kink - band, Neo - tectonics, Block - faulting.

***Öz***

*Bozdağlar masifi (KB Konya), tektonostratigrafik olarak alttan üste doğru otokton, metamorfik Gökçeyurt grubu (Üst Permiyen - Mesozoyik): allokton, Çayırbağı ofiyoliti (Mesozoyik) ve Ladik metamorfitlerinden (Silüriyen - Mesozoyik) oluşur. Üst Miyosen - Kuvaterner yaşlı tortul ve volkanik kayaçlar ise masifin neo - otokton örtü oluşuklarıdır.*

*Masifin hem otokton hem de allokton konumlu kaya birimleri, Alpin hareketlerle üç evreli deformasyona uğrayarak Tip 3 ve Tip 1 türü üstelenmiş kıvrım geometrisi kazanmıştır. İlk evre deformasyona metamorfizma eşlik etmiştir. 2. ve 3. evre deformasyonlar ise metamorfizma sonrası gelişmiştir. Geç Kretase ve sonrasında masif, naplı bir yapı kazanmıştır. Post - orojenik hareketlerle Orta - Geç Miyosen sınırında bölgede, gölsel havzaların oluşumunu sağlayan blok faylanmalar ve bu blok faylanmalara bağlı olarak volkanizma faaliyeti başlamıştır. Erken Pliyosen kabuk sıkışmaları ile de, masife ait kayaçlar örtü oluşukları üzerine bindirmiştir. Geç Pliyosen ve sonrasındaki blok faylanmalarından etkilenen yörenin yüksek kesimlerinde, 600 - 850 m arasında değişen göreli yükselmeler gerçekleşmiştir.*

***Anahtar Sözcükler:*** *Bozdağlar masifi, Çok evreli kıvrımlanma, Dayk kümesi, Buruşma klivajı, Kink bantları, Neotektonik, Blok faylanma.*

## INTRODUCTION

The study area is located between the south of Ilgın and Sarayönü townships, about 35 km northwest of Konya (Figure 1). According to the regional studies, the area is situated between Anatolides and Taurides (Ketin,1966), and it is included in the Afyon -Bolkardağ zone (Okay, 1984), or in the Kütahya-Bolkardağ belt (Özcan et al., 1988). In the study area, there are many studies that are mainly concerned with the stratigraphical problems of the region (Niehoff, 1961; Göğer and Kıral, 1969; Wiesner, 1968; Doğan, 1975; Özcan et al., 1988). Eren (1993a) has investigated the stratigraphical features of the massif, and for the first time, has analyzed the structural features of the area depending on detailed mesoscopic tectonic analyses. Since the stratigraphy of the Bozdağlar massif has been given in detail previously by Özcan et al., (1988) and Eren (1993b), in this paper the stratigraphy of the massif will be summarized and its structural features of the massif, geological and structural maps of the area which are simplified from Eren (1993a) at a scale of 1/25000 will be introduced. The structural data (Figure 1), which are obtained from the detailed field studies, were analyzed using the gometric techniques described by Turner and Jeiss (1963), Ramsay (1967) and Ramsay and Hubert (1987).

## STRATIGRAPHY

In the study area, the rocks of the Bozdağlar massif structurally can be divided into three main units (Figure 2). These comprise, from bottom to top, the autochthonous or parautochthonous Upper Permian-Cretaceous Gökçeyurt group, allochthonous Mesozoic Çayırbağı ophiolite and also allochthonous Silurian-Mesozoic Ladik metamorphites. The Upper Miocene-Quaternary continental sediments and volcanics form the cover of these basement rocks.

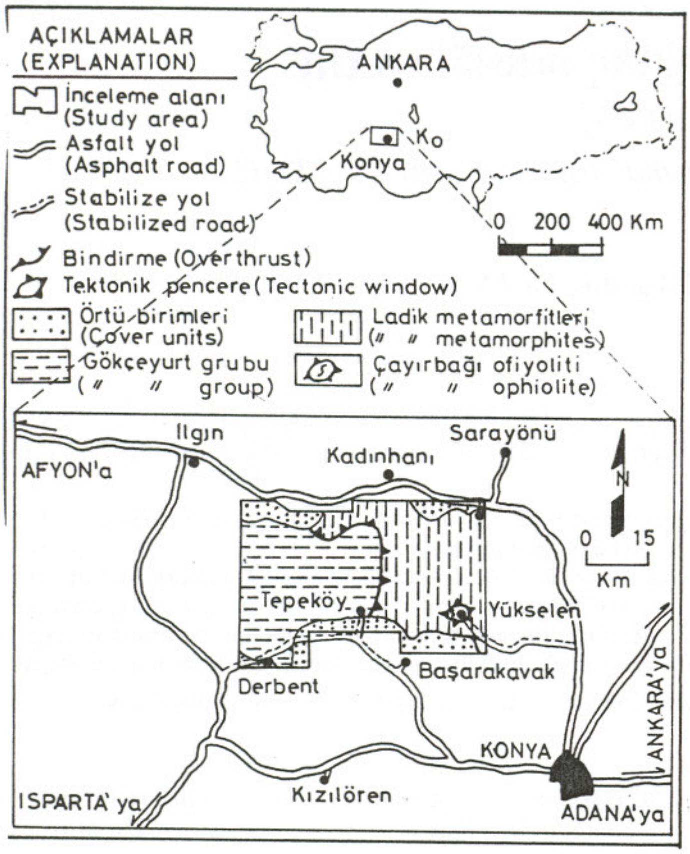



**Figure 1.** Location map.

***Şekil 1.*** *İnceleme alanının yer bulduru haritası.*

The autochthonous Gökçeyurt group consists mainly of lower-grade metamorphic rocks originally representing shallow-marine environment and is subdivided into three formations which are gradational to one another. These are in ascending order, the Upper Permian (Murgabian) Derbent formation composed of metacarbonate, metaquartzite and phyllite, the Upper Permian-Upper Triassic Aladağ formation consisting of alternation of metaclastic and metacarbonate with exotic metacarbonate blocks and rare metabasite intercalations, and the Upper Triassic-Cretaceous Lorasdağı formation which is made up of a thick sequence of metacarbonate rocks with a few interbeds of metachert. The Mesozoic Çayırbağı ophiolite which obducts the Lorasdağı formation around Konya (Özcan et al., 1988), crops out under the Ladik metamorphites in the Yükselen tectonic window, and is composed of serpentinized ultrabasite, gabbro and spilitic basalt. The Ladik metamorphites tectonically overlie the Gökçeyurt group along Tepeköy-Güneypınar thrust and includethe Silurian-Lower Permian aged Sızma, and Upper Permian (?)-Mesozoic Ardıçlı groups which are metamorphosed together. The Sızma group as a Hercynian unit of the massif comprises, in ascending order, Silurian-Lower Carboniferous reefal complex of the Bozdağ formation, the Devonian-Lower Permian Bağrıkurt formation consisting of preflysch, flysch and wild flysch type rocks and Devonian-Lower Permian aged Karadağ metamagmatites, which are related to pre Late Permian continental are development. The Upper Permian (?) to Mesozoic aged post-orogenic Ardıçlı group, which unconformably overlying the Sızma group, is made up of Bahçecik and Ertuğrul formations. These units laterally interfinger to each other and originally reflect continental and mixed-shore environment, respectively.

The Upper Miocene-Lower Pliocene Dilekçi group unconformably rests on the older units and forms the unmetamorphosed cover rocks of the massif. The group includes from base to top, the alluvial fan rocks of the Sille formation, the lacustrine Ulumuhsine formation, the pyroclastic rocks of the Küçümuhsine formation, the lacustrine Ulumuhsine formation, the pyroclastic rocks of the Küçükmuhsine formation, calc-alkali (Keller et al., 1977) rocks of Sulutaş volcanites and alluvial complex of the Yürükler formation. The Upper Pliocene-Quaternary alluvial complex of the Topraklı formation and Recent alluvium are the youngest units of the study area (Figure 2; Eren, 1993a and b).

## STRUCTURAL GEOLOGY

The rocks of the Bozdağlar massif gained folded, fractured and nappe structures due to tectonic movements (Figure 3 and 4). The structural features, metamorphism and magmatic activities in the study area, indicate that the rocks of massif are affected by Hercynian and Alpine orogeny and the neotectonic movements. The pre Late Permian aged flysch and wild flysch type rocks (the Bağrıkurt formation) and Karadağ metamagmatics which are related to pre Permian continental arc development, probably represent the activity of Hercynian orogeny (Özcan et al.,1988; Eren, 1993a). However, intensive and polphase Alpine deformations were overprinted and obliterated the Hercynian structures area and made impossisble the structural analyses of them.

In this section, compatible with the strigraphical divisions of the area, firstly the structural analysis of the allochthonous Gökçeyurt Group will be made, then the structural feaures of the Ladik metamorphites will be described, and finally structures which is developed by the Neotectonic movements will be introduced.

### Alpine folds

It is clear from the simplified geological and structural maps of the study area (Figure 3 and 4), both the autochthonous and allochthonous rocks of the massif have undergone polyphase foldings in the map scale. The

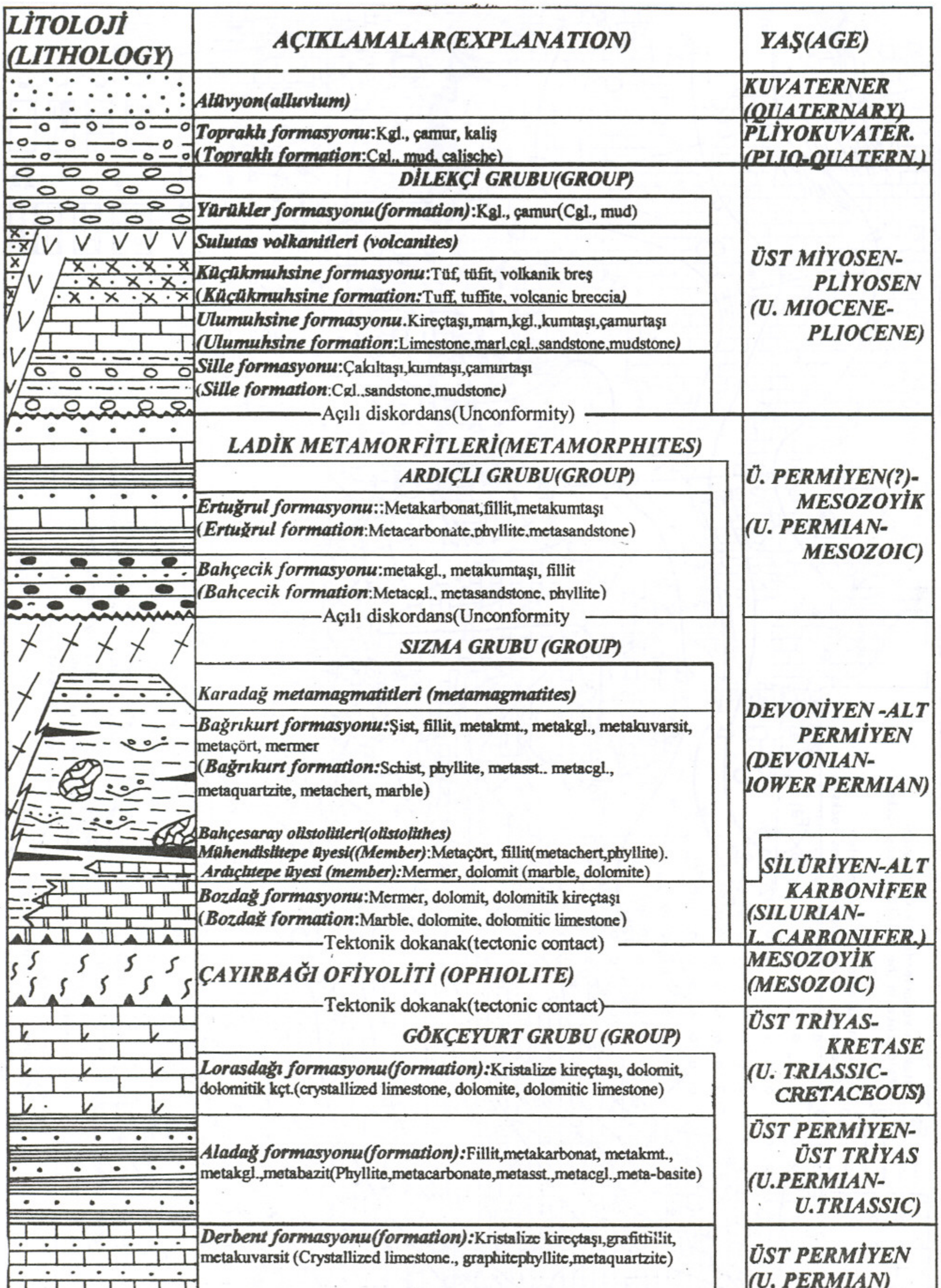
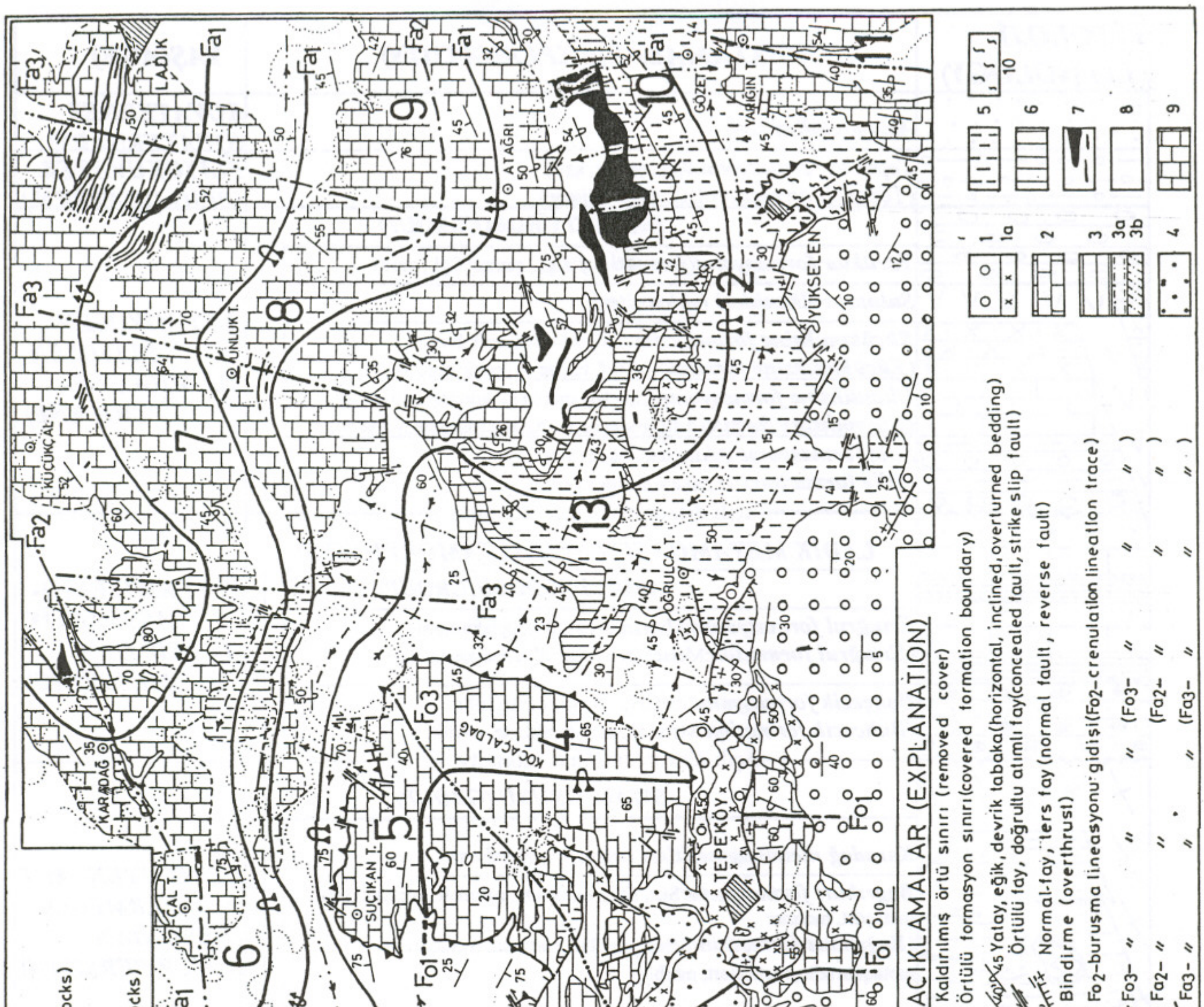



**Figure 2.** Generalized tectonostratigraphic section of the study area.

***Şekil 2.*** *İnceleme alanının genelleştirilmiş tektonostratigrafik dikme kesiti.*


Fo1
Fo2
Fo3
Fa1
Fa2
Fa3
Otokton kayaçlardaki kıvrım izleri (Fold trace in the autochthonous rocks)
Allokton kayaçlardaki kıvrım izleri (Fold trace in the allochthonous rocks)
ELDEŞ
DERBENT
AKDAĞ
MORBEL T.
AKTEPE
OBAT
TEPEKÖY
SUÇIKAN T.
KOCAÇALDAĞ
KARADAĞ
ÇAL T.
KÜÇÜKÇAL T.
ÜNLÜK T.
ATAĞRI T.
ÖĞRULCA T.
YÜKSELEN
GÖZET T.
LADİK
km
AÇIKLAMALAR (EXPLANATION)
Kaldırılmış örtü sınırı (removed cover)
Örtülü formasyon sınırı (covered formation boundary)
Yatay, eğik, devrik tabaka (horizontal, inclined, overturned bedding)
Örtülü fay, doğrultu atımlı fay (concealed fault, strike slip fault)
Normal-fay, ters fay (normal fault, reverse fault)
Bindirme (overthrust)
Fo2-buruşma lineasyonu gidişi (Fo2-crenulation lineation trace)
Antiklinal eksen izi (anticlinal axial trace)
Senklinal eksen izi (synclinal axial trace)
Devrik antiklinal (overturned anticline)
Devrik senklinal (overturned syncline)

fold axial traces, determined at the map scale, are variable in orientation. In order to analyse geometrical interrelationships amongs the folding phases, both of the two area subdivided into sub-areas by trial and error and on the basis of the axial orientations (Figure 3). In these sub-areas, the measured primary and secondary planar and linear structures were analysed in lower-hemisphere, equal area projections.

**Folds in the autochthonous area**

The fold axial traces determined from the map, show that the autocthonous Gökçeyurt group has undergone at least there phases of folding as designated $Fo_1$, $Fo_2$ and $Fo_3$ (Figure 3). For the geometric analysis, this area is subdivided into five sub-areas.

In the **Eldeş sub-area (1)**, π-poles to the bedding (So) show that $Fo_1$- and $Fo_2$- related $Bo_1$ and $Bo_2$- fold axis trend is N24°W, 20°NW (Figure 5.1). π-poles to the cleavage planes (S1) show that $Bo_2$- fold azimuth is N10°W, 20°NW (Figure 5.2). According to these $Bo_1$ and $Bo_2$ fold hinges are approximately coaxial in the sub-area. The Eldeş sub-area consists of the northwestern continuation of the Akdaş synclinorium, and in this part the structure deformed by $Fo_3$- folding phase. The superposition of the $Fo_3$- fold over the $Fo_1$- folds, created antiformal syncline and synformal anticline structures (Fig. 3). The locus of the measured mesoscopic fold axes (Bso) and the bedding-cleavage intersection lineations ($S_oXS_1$), show that $Bo_1$- and $Bo_2$- fold hinges are

*Şekil 3. İnceleme alanının basitleştirilmiş jeoloji haritası: 1- Sedimanter örtü kayaçları (Üst Miyosen - Pliyosen), 1a- Volkanik örtü kayaçları, 2- Lorasdağı formasyonu (Triyas - Kretase), 3- Aladağ formasyonu (Üst Permiyen - Triyas), 3a- Kırankaya üyesi, 3b- Mekeçal üyesi, 4- Derbent formasyonu (Üst Permiyen), 5- Ertuğrul formasyonu (Permo - Mesozoyik), 6- Bahçecik formasyonu (Permo - Mesozoyik), 7- Karadağ metamagmatitleri (Devoniyen - Alt Permiyen), 8- Bağrıkurt formasyonu (Devoniyen - Alt Permiyen), 9- Bozdağ formasyonu (Silüriyen - Alt Karbonifer), 10- Çayırbağı ofiyoliti (Mesozoyik).*

Figure 3. Simplified geological map of the study area: 1- Sedimentary cover rocks (Upper Miocene - Pliocene), 1a- Volcanic cover rocks, 2- Lorasdağı formation (Triassic - Cretaceous), 3- Aladağ formation (Upper Permian - Triassic), 3a- Kırankaya member, 3b- Mekeçal member, 4- Derbent formation (Upper Permian), 5- Ertuğrul formation (Permo - Mesozoic), 6- Bahçecik formation (Permo - Mesozoic), 7- Karadağ metamagmatics (Devonian - Lower Permian), 8- Bağrıkurt formation (Devonian - Lower Permian), 9- Bozdağ formation (Silurian - Lower Carboniferous), 10- Çayırbağı ophiolite (Mesozoic).

probably deformed by simple shear follevved by flexural slip mechanism of Ramsay (1967) due to $Fo_3$- deformation phase (Fig. 5.3).

In the **Akdağ sub-area (2),** poles to $S_0$ and $S_1$ measurements show that the mean axial orientations are $Bo_1$-=N62°W, 10°SE and $Bo_3$-=N63° E, 40° NE (Figs. 5.4 and 5), respectively. A comparision of the axial trends of the Eldeş and Akdağ sub-areas, demonstrates that $Bo_1$- and $Bo_2$- fold hinges are rotated 40° due to $Fo_3$- folding phase. In this domain, linear tectonic structures are consistent with the map scale trends (Figs. 4, 5, and 6). In the sub-area, the core of the Akdağ synclinorium crops out. the structure has the northwest-southeast trend and the northeast limb of structure is overturned to the southwest. Interference of the $Fo_1$- and $Fo_3$- phase folds created Type 1 dom and basin structures of Ramsay (1967). The southeast limbs of these structures are also overturned to the west-northwest (Fig. 3).

In the **Obatepe sub-area (3),** the great circle girdles of poles to $S_0$ and $S_1$ (Figs. 5, 7 and 8), defines mean axes of $Bo_1$=N40°W, 0° and $Bo_2$=N66W, 18°SE, respectively. $Bo_1$- and $Bo_2$- fold axes are also approximately coaxial and the $Bo_1$- folds are tight to isoclinal with the vergence of to the southwest. The mesoscopic fold hinges and other linear structures, measured in the field, are also consistent with these trends (Fig. 5. 9).

In the **Tepeköy sub-area (4)**, the mean orientation of $Bo_1$- axes as defined by a girdle of bedding ($S_0$) poles is N6°E, 10°NE (Fig. 5.10). Because the metacarbonate rocks of the Lorasdağı formation are widespread in the sub-area, could not have taken sufficient cleavage ($S_1$) measurements for the gometric analysis. In the domain the major map scale structure is the north-south trending Kocaçaldağ structure, and this structure are overturned to the west (Fig. 3). The mesoscopic linear structures show concentration nearly parallel to the main axial orientation (Fig. 5.11), but like the the other subareas show considerable variation due to polyphase folding.

In the **Sıçıkantepe sub-area (5),** a great circle girdle of poles to $S_0$- defines a mean axis of N82°W, 5°SE for $Bo_1$- folds (Fig. 5.12). This axial orientation when compared with the axial orientation of the tepeköy subarea, indicates that $Bo_1$- fold axes have been rotated 80° by the effect of $Bo_3$- folding phase.

All the $S_1$- measurements in the autochthonous area (Fig.5.13), show that axial orientations of $Fo_2$- and $Fo_3$- folds are N65°W, 10°SE and N60°E, 30°NE, respectively. In this area locus of measured mesoscopic cleavage fold hinges (Fig.5.14) belonging to $Fo_2$- folding phase, indicate that these folds are deformed later by

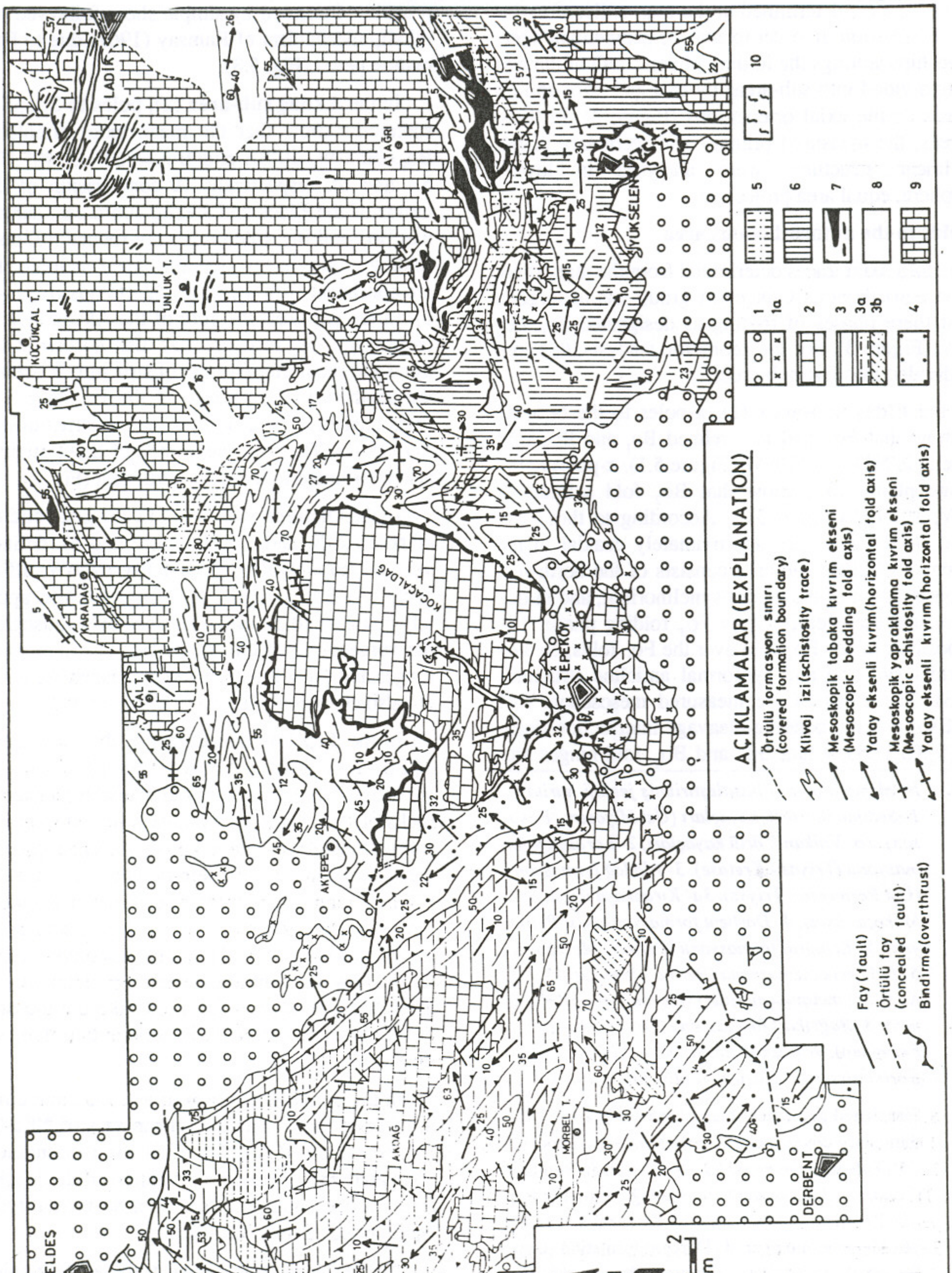



**Figure 4.** Simplified structural map of the study area (Symbols are the same as Figure 3).

***Şekil 4.*** *İnceleme alanının basitleştirilmiş yapısal haritası (Açıklamalar Şekil 3 ile aynı).*

flexural-slip mechanism during $Fo_3$- folding phase. In the area measurements of crenulation hinetions ($L_2$- and $L_3$-) on the $S_1$ cleavage planes show concentration parallel to $Bo_2$-, and $Bo_3$- fold trends (Fig. 5.15).

On the basis of the above geometrical analyses and the field observations, the rocks of autocthonous Upper Permian-Cretaceous Gökçeyurt group have undergone at least three phases of folding, here designated as $Fo_1$-, $Fo_2$- and $Fo_3$- during the Alpine crustal shortening. During the $Fo_1$- folds are tight to isoclinal. A strong and regionallly developed axial planar cleavage, here designated as $S_1$, is observed in these $Fo_1$- folds. With the exception of $Fo_1$- fold hinge zones, the cleavage is parallel to bedding. $Fo_2$- deformation phase produced folds which are coaxial with $Fo_1$- folds. But $Fo_3$- fold are nearly perpendicular to the both. The superposition $Fo_2$- and $Fo_3$- phases of folding uyon $Fo_1$- phase of folding, created Type 3 and Type 1 interference patterens of Ramsay (1967) in the autochthonous, area, respectively. Also, the deformation of $S_1$- cleavage surfaces by $Fo_2$- and $Fo_3$- deformation phases developed $S_2$- and $S_3$- crenulation cleavages.

**Folds in the allocthonous area**

The allochthonous Ladik metamorphites, which are composed of a slice of Hereynian basement rocks (Sızma group) and their post-orogenic cover rocks (Ardıçlı group), have undergone at least three phases of deformation desingnated as $Fa_1$-,$Fa_2$- and $Fa_3$-, due to Alpine orogeny. In the first phase of deformation, the rocks of Ladik metamorphites were folded, metamorphosed and gained regionally developed penetrative cleavage (Eren, 1993a). For the geometric analysis, this area was subdivided into eight sub-areas.

In the **Karadağ sub-areas (6),** which is located west of the most western $Fa_3$- axial trace, poles to $S_0$ and $S_1$- planes (Figs. 5.16 and 17), indicates that axial orientations of $Ba_1$-, $Ba_2$= N78°E, 35°NE and $Ba_2$= E-W,0°, respectively. The axial orientations show that $Ba_1$- and $Ba_2$- fold hinges are nearly coaxial. In the sub-area, measured mesoscopic fold hignes and intersection lineatons (Fig. 5.19), although show variation, are mainly concentrated parallel to this direction. Crenulation lineations, demonstrate that the $S_1$- cleavage surfaces deformed at least twice (Fig. 5.19). In the domain, the east-west trending, tight to isoclinal overturned folds are the main structures. The folds are overturned to the south (Fig.3).

In the **Küçükçaltepe sub-area(7)**, a great cricle of poles to bedding planes defines a mean axis of N6°W, 48°NW (Fig. 5.20.). This orientation is coincident with $Ba_3$- map scale orientation. Also poles to cleavage planes (Fig. 5.21.) indicate that $Ba_3$- has N12°W, 36°NW axial orientation. The locus of the mesascopic linear structures (Fig. 5.22), show that $Ba_1$- and $Ba_2$- linear structures were deformed by flexural-slip mechanism. In the area, measured crenulation axes (Fig. 5.23) concentrated parallel to the east-west and the north-south directions representing $Ba_2$- and $Ba_3$- axial trends, respectively.

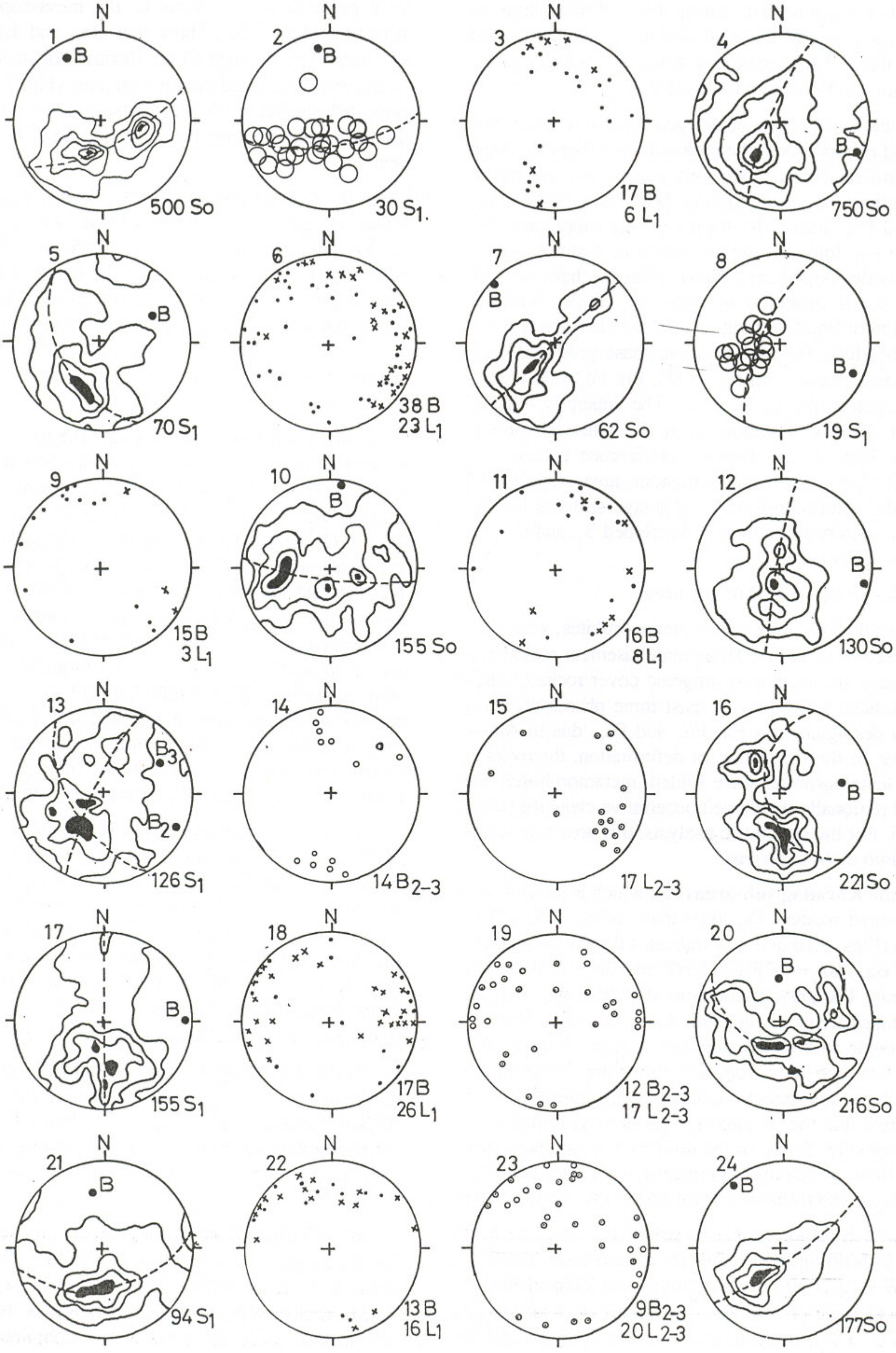
In the **Unluktepe sub-area(8),** $S_0$- and $S_1$- measurements indicate that axial trend of $Ba_1$ is N38°W, 15°NW, and axial trend of $Ba_2$- is N50°W, 15°SE, respectively (Figs. 5.24 and 6.1). In the sub-area measured $Ba_1$-, $Ba_2$- fold hinges are nearly coaxial and mesoscopic linear structures (Fig. 6.2) are very variable in orientation. Crenulation axes are mainly concentrated in the direction of the north-sounth, parallel to the $Ba_3$- fold axial trend (Fig.6.3).

In the **Atağrıtepe sub-area (9),** The mean orientation of $Ba_1$- or $Ba_2$- fold hinges a defined by a girdle of $So^-$ poles (Fig. 6.4) is N42°E, 12°NE. The mean orientation of $Ba_2$- axes as defined by a girdle of $S_1$- poles in N57°E, O° (Fig.5.6). Comparisions of the axial trends of the Eldeş and Akbağ sub-areas, describe clearly these that the fold hinges have a rotation of 80° due to $Fa_3$- folding phase. $L_2$ and $L_3$ crenulation hinges (Fig. 6.6) are concentrated in the direction the east-notheast and the north-south, pespectively. The prominent structure of th sub-area is Type 3 refolded fold which is developed by th superposition of $Ba_1$- and $Ba_2$- folds. Synformal anticline at the Atağrı hill can be given as an example to this structures. These folds generally are overturned to the south (Fig. 3 and Eren, 1993a).

In the **Gözettepe sub-area (10),** bedding and cleavage measurements (Figs. 6.7 and 8), indicate $Ba_1$-, $Ba_2$=N54°E, 10°NE and $Ba_2$=N70°E, 18°NE axial trends, respectively. $Ba_1$- and $Ba_2$- folds orientations are also nearly coaxial expect 16°. Orientations of mesoscopic linear structures are consistent with the map trends (Fig. 6.9). In the sub-area, the east-west and the north-south directed crenulation axes (Fig. 6.10) are parallel to the $Ba_2$- ve $Ba_3$- fold trends, respectively.

In the **Yarığıntepe sub-area (11),** a great circle girdle of poles to $S_0$- defines a mean axis of N7°W, 30°NW for $Ba_3$- folds (Fig. 6.11). This orientation is consistent with the map scale trend, and belongs to antiformal syncline which is overturned to the west (Figs. 3 and 4).

In the **Yükselen sub-area (12),** the great circle girdles of poles to $S_0$- and $S_1$ (Figs.6.12 and 13) define mean axes of $Ba_1$-, $Ba_2$=N85°E, 38°NE and $Ba_2$=N87°W, 13°SE, respectively, Mesoscopic lineations are also consistent with these orientations, and crenulation hinges


1 B 500 So
2 B 30 $S_1$.
3 17 B 6 $L_1$
4 B 750 So
5 B 70 $S_1$
6 38 B 23 $L_1$
7 B 62 So
8 B 19 $S_1$
9 15 B 3 $L_1$
10 B 155 So
11 16 B 8 $L_1$
12 B 130 So
13 $B_3$ $B_2$ 126 $S_1$
14 14 $B_{2-3}$
15 17 $L_{2-3}$
16 B 221 So
17 B 155 $S_1$
18 17 B 26 $L_1$
19 12 $B_{2-3}$ 17 $L_{2-3}$
20 B 216 So
21 B 94 $S_1$
22 13 B 16 $L_1$
23 9 $B_{2-3}$ 20 $L_{2-3}$
24 B 177 So

are concentrated the west-northwest and the north-sount directions (Figs. 6.14 and 15).

In the **Oğrulcatepe sub-area** (13), poles to $S_0$- indicate $Ba_3$=N9°E, 55°SW and poles to $S_1$- show $Ba_3$=N24°W, 18°NW mean fold axes fold axes orientations (Figs. 6.16, 17). Mesoscopic fold hinges and intersection lineations ($S_0xS_1$) generally concentrated parallel to the directions, but like the other sub-areas show variations. These variatons are due to deformation of linear structures by subsequent folding phases and/or the existence of $Ba_1$-, $Ba_2$- and $Ba_3$- folds in a mesoscopic scale, in the sub-areas.

The fiel observations, the geometric analyses of mesoscopic planar and linear structures, observations of thin sections (Eren, 1993a), and the trends of formations in the map scale, demonstrate that the rocks of allocthonous Ladik metamorphites have undergone at least theree phases of deformation designated here as $Fa_1$-, $Fa_2$- and $Fa_3$-, due to Alpine crustal contraction and shortening. The interference of $Ba_1$- and $Ba_2$- folds produced Type 3 refolded folds and superposition of $Ba_3$- folds upon thees created Type 1 dome and basin structure in the allochthonous area. The major structures are $Ba_1$- related isoclinal folds which are mainly overturned to the south (Figs. 3 and 4). It can be seen form the above geometric analyses made in the autochthonous and the allochthonous area, the deformation history of the both is the same. The comparisions of both map scale trends and the geometrically determined fold axial orientations (Figs. 3,5 and 6), indicate that the tectonic transport in this part of the tauride belt is rotational. According to these, the allochthonous slice has rotated anticlockwise sense relative to the autochthonous area during the thrusting.

As a result of polyphase deformation and folding events, a wide variety of mesoscopic tectonite structures were developed in the allcohthonous area. During $Fa_1$- deformation phase, the rocks of Ladit metamorphites gained regionally developed penetrative cleavage ($S_1$) and metamorphosed at the high pressure/low temperature conditions (Bayiç, 1968; Özcan et al., 1988 and Eren 1993a). $Ba_1$- folds are generally inclined or recumbent isoclinal folds (Plate1. Fig, 1) Where bedding ($S_s$) and cleavage ($S_1$-) planes could be observed in the same outcrop, $S_1$- was parallel or nearly parallel or nearly parallel to bedding planes due to isoclinal folding. Bit at the hinge zones, $S_1$ planes were crossing bedding planes at a high angle (Plate 1, Figs. 2 and 3). Also at the some outcrops cleavage refraction and cleavage fanning could be observed due to differences of competence between the different lithologic layers. At the some locality where deformation was very intense, the bedding transposition was developed. Subsequent $Fa_2$- and $Fa_3$- phases of deformation folded both bedding and cleavage planes (Plate 1, Fig. 4) Superposition of $Ba_1$- upon $Ba_2$- folds created Type 3 ($Ba_1$ // $Ba_2$, $S_1 \perp S_2$; Plate 1, Figs. 5 and 6), and superposition of $Ba_3$- folds upon these developed Type 1 ($Ba_1$ // $Ba_2 \perp Ba_3$, $S_1 \perp S_2 \perp S_3$) interference pattern in the region. As a result of polyphase deformation, $S_2$ and $S_3$- renulation cleavages and $L_2$ and $L_3$- crenulation lineations (Plate 1, Fig. 7; Plate 2, Fig. 1) and monoclinal or conjugate kink bands (Plate 2, Figs. 2 and 3) were formed. Due to repeated folding, early developed linear structures were deformed and had a curved form (Plate 2, Fig. 4). Folds designated as $Ba_2$ and $Ba_3$ are generally open to tight. Cleavage folds which are obverved in the field, are generally zig-zag and box fold style. Both $S_2$ and $S_3$- crenulation cleavages associated with the $Ba_1$ and $Ba_3$- folds display zonal and discrete (Plate 2, Fig. 5) type according to the classification of Gray (1977). The microfolds associated with the crenulation cleavage show both symmetric and asymmetric forms. $Fa_2$- crenulation hinges are perpendicular to $Fa_3$- crenulation hinges and $S_2$- is nearly perpendicular to $S_3$- ($L_2 \perp L_3$, $S_3 \perp S_3$). This geometry results in development Type 1 fold interference pattern defined by the $S_1$- cleavage. At the outcrop scale, $Fa_2$ and $Fa_3$- phases related conjugate kink band axes cross each other orthogonally (Plate 2, Fig. 6) like $L_2$ and $L_3$ crenulation hinges. In the field, the crenulation cleavage widely developed in the metapelitic rocks of the Bağrıkurt and Bahçecik formations. Thin section observations indicate that the spacing of the crenulataion cleavage planes vary also in the same specimen. Where the crenulation cleavage planes spaced widely, the microscopic folds associated with them are open, in contrast, where the cleavage planes closely spaced, the associated microscopic folds are tight to isoclinal. In the crenulated specimens where the deformation is high, the mica minerals which have crystallized during the $Fa_1$- deformation phase, have been brought into subparallel alignment to the crenulation cleavage planes. In addition, in the some asymmetric crenulation cleavage, more inclined limbs of the microfolds enriched with the insoluble dark minerals and this gives a second striped appearance to the rock under the microscope. In the discrete type, the cleavage planes also enriched with teh opaque minerals. Thin section observations failed to show a new metamorphic mineral

**Figure 5.** Point and contour diagrams of the sub-areas of the investigated area: •- fold hinge, x- intersection lineation, Θ- wrinkle lineation, o- cleavage fold hinge. Explanation in text.

***Şekil 5.*** *İnceleme alanında asalanlara ilişkin nokta ve kontur diyagramları: •- kıvrım ekseni, x- arakesit lineasyonu, Θ- buruşma lineasyonu, o- yapraklanma kıvrım ekseni. Açıklamalar metin içinde.*

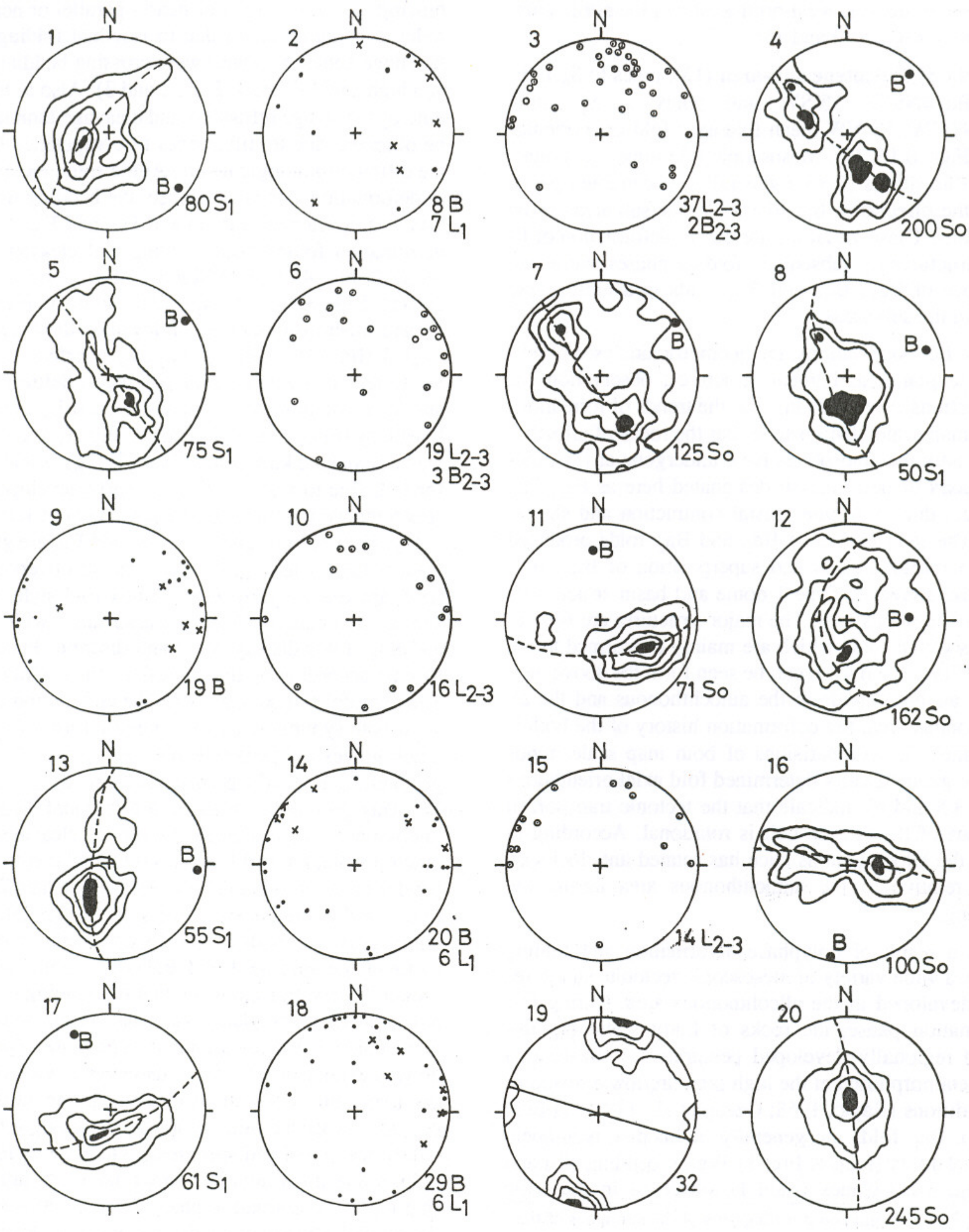



**Figure 6.** Point and contour diagrams of the sub-areas of the investigated area: •- fold hinge, x- intersection lineation, Θ- wrinkle lineation, o- cleavage fold hinge. Explanation are in the text.

***Şekil 6.*** *İnceleme alanında asalanlara ilişkin nokta ve kontur diyagramları: •- kıvrım ekseni, x- arakesit lineasyonu, Θ- buruşma lineasyonu, o- yapraklanma kıvrım ekseni. Açıklamalar metin içinde.*

growth (parallel to the crenulation cleavage planes) occurring during either of the last two generation of folding, that is, $Fa_2$ and $Fa_3$- phases of folding were post-metamorphic in the studied area.

The field observations show that the allochthonous Ladik metamorphites consist of more intensely and widely developed mesoscopic tectonite structures relative to the autochthonous Gökçeyurt group. This demonstrates that the allochthnous rocks were subjected to more deformative movements than the autochthonous rocks. Finally, the field obvervations reveal that the intensity of metamorphism increases from the southwest to the northeast as has been noted earlier by Niehoff (1961).

## Alpine fractures

### Veins and dykes

In the metamorphic rocks of the study area, there are many milky quartz and calcite filled veins, on various scale. But, the most prominent structure is the metamagmatic dyke swarms which crop out in the northeast of the study area (Fig. 3 and 4). The dykes commonly occur in the metacarbonate rocks of the Silurian-Lower Carboniferous Bozdağ Formation and range from 2 to 75 m in width and from 5m to 3 km in lenght. Poles to dyke intrusion planes, show that the average dyke azimuth is N72°W, 90° (Fig. 6.19). In other words, the orientation of the minimum principal compressive stress axis was N15°-20°E, during the intruding time of dykes. The estimated crustal extension amount is between from 5% to 16% averaging 10.5%, in this part of the study area. This extension is related to post Early Carboniferous and pre Late Permian emplacement of Karadağ Metamagmatics. In other words, it belongs to tensionel phase of Hercynian magmatic are evolution (Eren, 1993a).

### Thrusts

After the rocks of the Bozdağlar massif underwent metamorphism and ductile deformation, they were affected by thrusting. The Tepeköy-Güneypınar thrust is the major thrust fault which autcrops in the middle part of the area (Fig. 3). Along the thrust, the rocks of Silurian Lower Permian Ladik metamorphites thrusted over the Upper Permian-Lower Cretaceous Gökçeyurt Group. In the area, the outcrop length of the thrust is 20 km. The dips of thrust planes vary between 25° and 60°. In the north of Kocaçal mountain, the yqhydrothermal milky quartz veins with thickness reaching up to 5 m could be traced along the thrust plane. Around the Aktepe, the measured slickenlines trends vary between N30°E and N50°E, and their plunges are 30° to 35° towards the northeast. In addition, the rocks of Gökçeyurt Group and the Ladik Metamorphites are overturned to the southwest and to the south, respectively. According to these, it can be concluded that its transport direction is from the northeast to the southeast or from the north to the south, in the study area. The other prominent thrust structure that is observed in the southeastern part of the study area is the Yükselen tectonic window in which the mesozoic Çayırbağı ophiolite crops out Underthe Ladik metamorphites. The tectonic window is cut and off-set by northwest-southeast striking a strike slip fault that is concealed beneath the Quaternary alluvium (Figs. 3 and 4). The southastern contact of the window is unconformably overlain by the Upper Miocene-Pliocene cover rocks.

On the basis of age relationships between the units and cross-cutting relationships along the thrusts, this suggests that the thrusting postdates the Early Cretaceous and predates the Late Miocene in the study area. The regional studies indicate the age of thrusting to be Late Cretaceous to Eocene (Şengör and Yılmaz 1981; Özgül, 1984 and Okay, 1984).

## Neotectonic structures

### Folds

The Upper Miocene-Lower Pliocene aged cover rocks, which are widely outcrop in the northwestern and southern part of the study area, show gentle undulations (Eren 1993a). A great circle girdle of poles to bedding planes define a mean axis of N84°E, 50°SW for these undulations (Fig. 6.20). Although these undulations were partly developed by the basement irregularities, the north-south directed horizontal compression during the Neotectonic period was the main deforming agent. these existence of the young thrusts and reverse faults confirm this. So by the effect of under the noth-south directed horizontal compression, the cover rocks have gained the east-west trending doubly plungung fold structures between the Late Miocene and Late Pliocene time (Eren, 1993a).

### Faults

The considerations of faults associated with the Neotectonic movements showed three main periods of faulting in the study area. These are, 1-The Middle to Upper Pliocene aged normal faulting, 2-Reverse and thrust faulting which are continued up to Early Pliocene, 3-Normal faulting that postdates the Early Pliocene and continues up to Quaternary time. The lithologic characters and geological evolution of the Upper Pliocene-Lower Pliocene Dilekçi group (Eren, 1993a), indicate the existence of the block faulting (as a growth faulting)

## PLATE I

**Figure 1.** $Fa_1$ recumbent, isoclinal fold in recrystallized limestone (Ertuğrul formation, 500 m west of the Yükselen village).

**Figure 2.** Mesoscopic $Fa_1$ fold and axial - $S_1$ plane cleavage in calc - phyllite (Bahçecik formation, 3 km northeast of teh Yükselen village).

**Figure 3.** Recumbent $Fa_1$ fold and cleavage - bedding relationship in phyllite - metasandstone alternations (Ertuğrul formation, 3 km southeast of Atağrı T.).

**Figure 4.** $Fa_2$ cleavage ($S_1$) folds in calc - phyllite (Ertuğrul formation, 3 km southeast of the Atağrı T.).

**Figure 5.** Intrafolial $Fa_1$ fold refolded by open $Fa_2$ fold in marble (Bozdağ formation).

**Figure 6.** Type 3 refolded fold in metasandstone (Ertuğrul formation).

**Figure 7.** $S_2$ crenulation cleavage and $L_2$ wrinkle lineations in phyllite (Bahçecik formation, 2 km northwest of the Yükselen village).

## *LEVHA I*

***Şekil 1.*** *Rekristalize kireçtaşlarında izlenen $Fa_1$ evresine ilişkin yatık izoklinal bir kıvrım (Ertuğrul formasyonu, Yükselen kasabasının 500 m batısı).*

***Şekil 2.*** *Kalkfillitlerde izlenen mesoskopik $Ba_1$ tabaka (So) kıvrımlarında gelişmiş $S_1$ eksen düzlemi klivajları (Bahçecik formasyonu, Yükselen'in 3 km kuzeydoğusu).*

***Şekil 3.*** *Fillit - metakumtaşı ardalanmasında izlenen $Ba_1$ yatık mesoskopik bir kıvrımın eksen bölgesinde tabaka (So) ve klivaj ($S_1$) ilişkisi (Ertuğrul formasyonu, Atağrı T.'nin 3 km güneydoğusu).*

***Şekil 4.*** *Kalkfillitlerde $Ba_2$ evresiyle ilişkili klivaj ($S_1$) kıvrımları (Ertuğrul formasyonu, Atağrı T.'nin 3 km güneydoğusu).*

***Şekil 5.*** *$Ba_1$ ve $Ba_2$ evrelerinin girişimi ile oluşmuş Tip 3 türü kıvrım girişimi yapısı (Bantlı mermer, Bozdağ formasyonu).*

***Şekil 6.*** *Metakumtaşlarında gözlenen mesoskopik Tip 3 türü kıvrım (Ertuğrul formasyonu).*

***Şekil 7.*** *Fillitlerdeki yapraklanma ($S_1$) düzlemlerinin deformasyonu sonucu oluşmuş buruşma klivajı ($S_2$) ve lineasyonları ($L_2$), Bahçecik formasyonu, Yükselen'in 2 km kuzeybatısı.*

## PLATE II

**Figure 1.** Asymetric crenulation cleavages and folded bouding in graphite - phyllite and metasiltstone alternations (Bağrıkurt formation, acetate negative film).

**Figure 2.** Monoclinal kink - bands and zigzag folds in calc - phyllite (Ertuğrul formation, 5 km northeast of the Oğrulca T.).

**Figure 3.** Conjugate kink folds in phyllite (Bahçecik formation, 2.5 km northwest of the Yükselen village).

**Figure 4.** Deformed $Fa_1$ fold axis in metasandstone, Ertuğrul formation.

**Figure 5.** Asymetric and discrete crenulation cleavages in phyllite (Bahçecik formation, acetate negative film).

**Figure 6.** Perpendicularly developed $Fa_2$ and $Fa_3$ phases related kink axes in metasandstone (Bahçecik formation, 2 km northwest of the Yükselen village).

## *LEVHA II*

***Şekil 1.*** *Grafitfillit - metasiltaşı içinde izlenen asimetrik buruşma klivajı ve kıvrımlanmış budinajlar (Bağrıkurt formasyon, asetat negatif film).*

***Şekil 2.*** *Kalk - fillitlerde izlenen monoklinal kink bantları ve zigzag kıvrımlar (Ertuğrul formasyonu, Oğrulca T.'nin 5 km kuzeydoğusu).*

***Şekil 3.*** *Fillitlerde gözlenen kesişen kink kıvrımları (Bahçecik formasyonu, Yükselen'in 2.5 km kuzeybatısı).*

***Şekil 4.*** *$Ba_1$ evresine ilişkin deforma olmuş kıvrım ekseni ve çizgisellikler ($L_1$), Ertuğrul formasyonu.*

***Şekil 5.*** *Fillitlerde izlenen ayrık buruşma klivajları (Bahçecik formasyonu, asetat negatif film).*

***Şekil 6.*** *Metakumtaşlarında $Fa_2$ ve $Fa_3$ evresiyle ilişkili ve birbirine dik gelişmiş kink eksenleri (Bahçecik formasyonu, Yükselen'in 2 km kuzeybatısı).*

**PLATE I**
***LEVHA I***

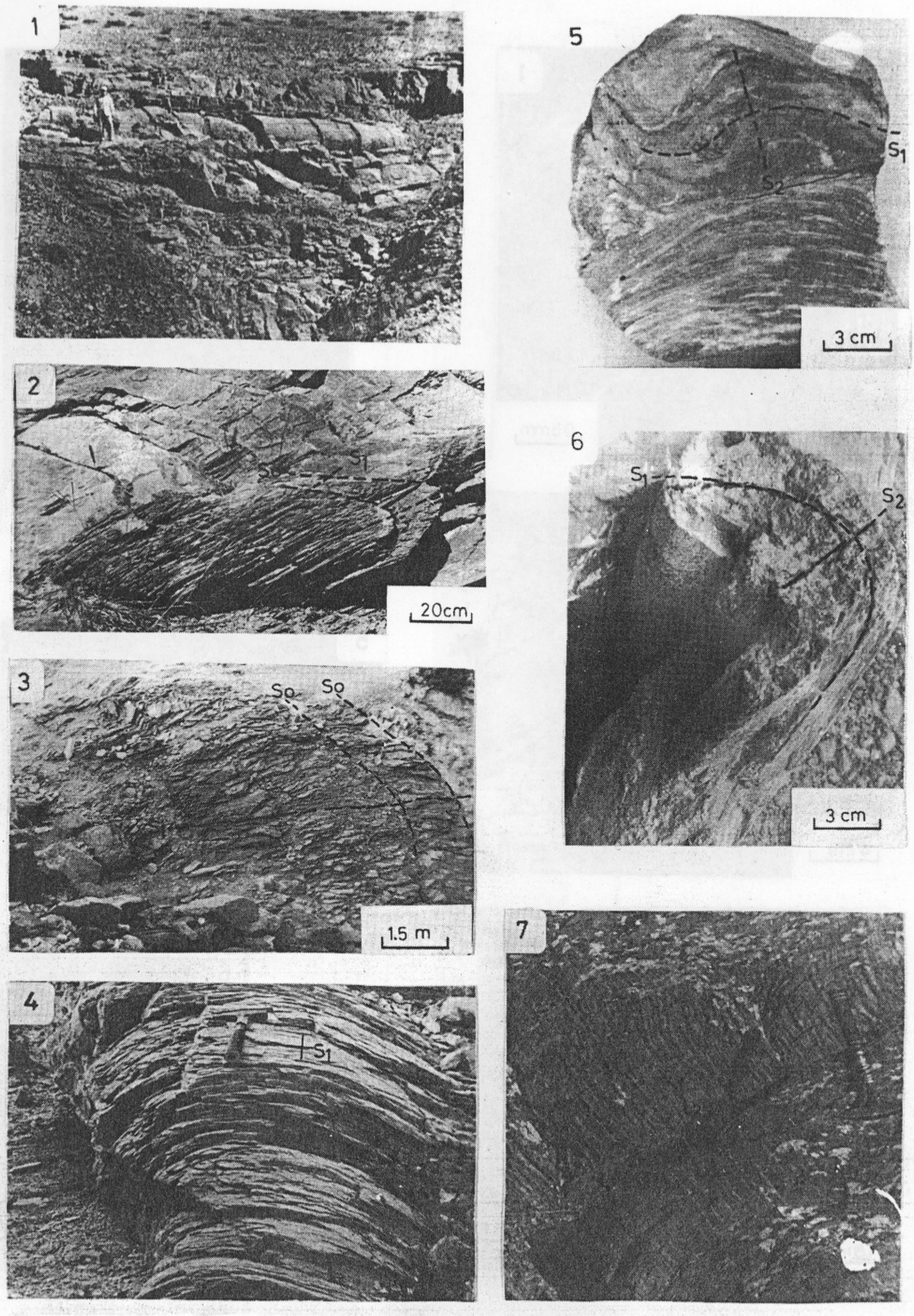
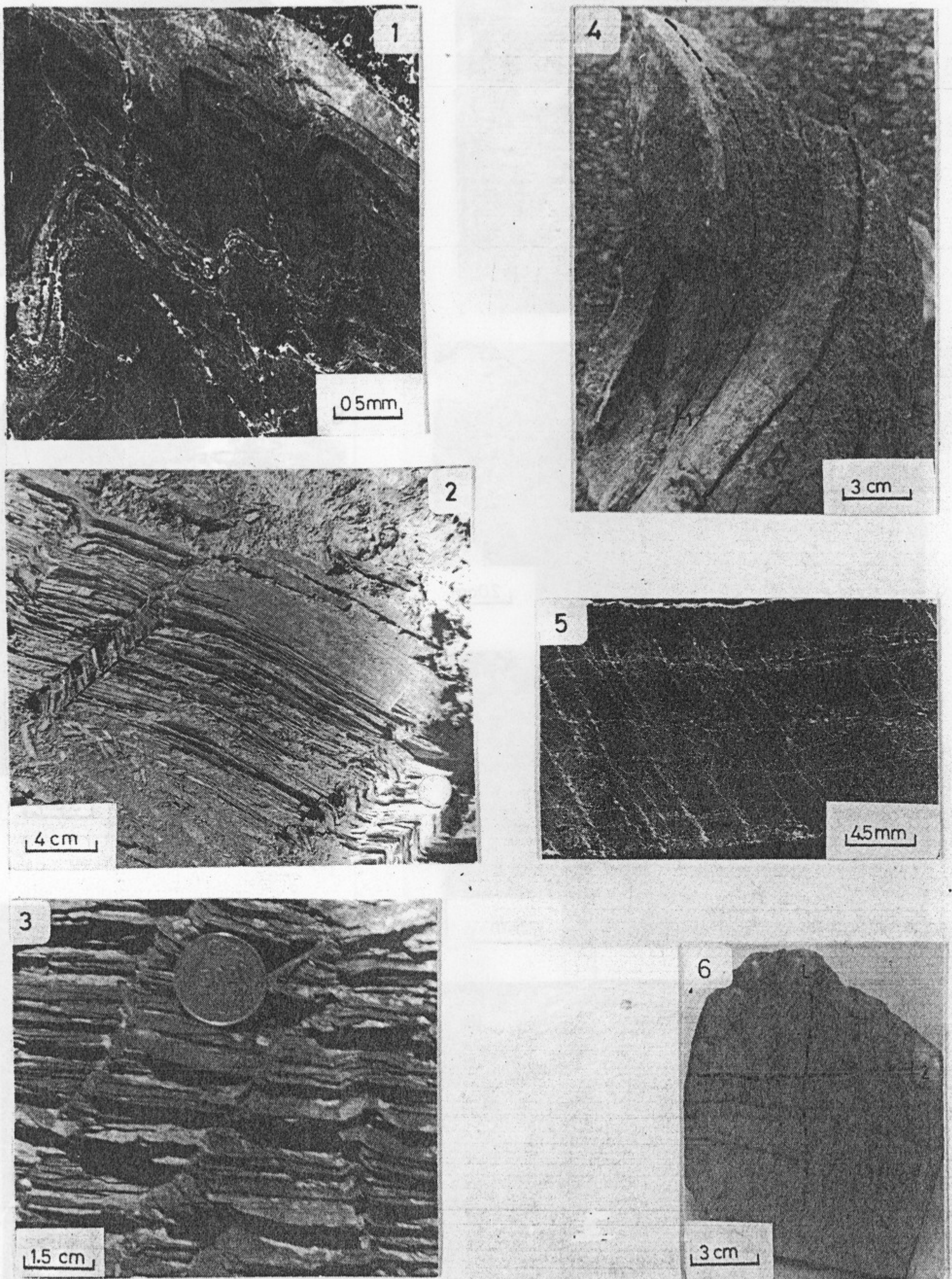


**PLATE I**
*LEVHA I*



during the Middle and Late Miocene times. As a result of these block faulting, alluvial fans and closed lacustrine basins were formed in the region. Also, the Upper Miocene-Lower Pliocene aged trending contact between the rocks of the massif and continental cover rocks (Figs. 3 and 4). This indicate that volcanic activity has mainly developed along the shore of old Konya lake (Roberts, 1982). In the region the young overthrusts which are related to the neotectonic movements, are observed in the northern and western of Tepeköy (Figs. 3 and 4), and in the vicinity of Sille villages, west of Konya (Eren, 1993a). They have transported the rocks of the massif at least 5 km from the north and have emplaced them over the Upper Miocene-Lower Pliocene aged cover rocks. Thrust planes mainly trend the east-west direction and dip 20° to 40° to the north. The thrusting is mainly over the 15-3 Ma aged (Besang et al., 1977) volcanic rocks. In the vicinity of the thrusts, bedding planes of lacustrine limestone have inclined up to 90°. These thrusts are also covered stratigraphically with the lacustrine deposits (Eren, 1993a). This demonstrates that the thrusting was coeval with the deposition of the Dilekçi group, and ended prior to the Late Pliocene time. The Lower Pliocene aged alluvial fan rocks (Yürükler formation; Eren, 1993b) as a the uppermost unit of the Dilekçi group, show that the block faultings have also occurred during the Late Pliocene time. The observed faults also located between at the margins of massif and the cover rocks, and their dips are between 60°- 90°. This probably indicates the rejuvenation of the older normal faults.

The base of lacustrine deposist of the cover unit exposed at an elevation of about 1820 m on the south side of the Tepeköy and Yükselen villages. However, the same rocks exposed at an elevation of between 1000 and 1050 m, at the margins of the massif. This indicates that there is and uplift that ranges from 600 to 850 m in the study area, since the Pliocene time. Besides this, the drilling holes on Konya plain, over 400 m deep, have failed to intercept the base of cover rocks (Ö. Hamarat, 1995, personal communication), and this probably reveal that the range of uplift is from 1200 to 1300 m in the region, since the Late Miocene time.

## CONCLUSIONS

In the present study the rocks of the Bozdağlar massif to the south Ilgın and Sarayönü townships are subdivided into two areas according to their structural settings. Then, these areas are subdivided into twenty three sub-areas and all the measured primary and secondary planar and linear structures analyzed geometrically. As a result, it has shown that both the autochthonous Gökçeyurt group and the allochthonous Ladik metamorphites have been subjected to at least three phases of deformation and ductile folding by the Alpine crustal shortening. These to at least three phases of deformation and ductile folding by the Alpine crustal shortening. These intense and polyphase Alpine deformation overprinted and obliterated the Hercynian structures of Sızma group. The first phase of folding ($F_1$) prodeced isoclinal, recumbent folds and a regionally developed penetrative cleavage ($S_1$) under high P/low T metamorphic conditions. The $S_1$ penetrative cleavage has developed axial planar to these folds. The $F_2$- and $F_3$- phases of folding represent post-metamorphic deformations. $F_2$- folds are tight to open and an $S_2$- crenulation cleavage exists, axial planar to $F_2$- folds. The $F_1$- and $F_2$- fold hinges are nearly parallel and superposition of these folds developed Type 3 (Ramsay, 1967) fold interference pattern both in mesoscopic and the map scale. $F_3$- folds are also open and an $S_3$- crenulation cleavage is recognized axial planar to $F_3$- folds. $F_2$- and $F_3$- fold hinges are nearly orthogonal. This geometry results in development Type 1 fold interference pattern. Both the $F_2$- and $F_3$- phases of folding also are developed widespread conjufate kink bands on $S_1$- surfaces. On the outcrop scale, $F_2$- and $F_3$- phase are related kink axes cross each other orthogonally, such as $L_2$- and $L_3$- crenulation hinges. It is believed that the massif gained its present polyphase deformational history and thrust structures by syn and post metamorphic movements acting during the Late Cretaceous and onwards, respectively. In the area, the vergence of folds is mainly to the south and to the southwest, and this indicates that the direction of tectonic transport is from the north to the south or from the northeast to the southwest. A comparision of the autocthonous and allocthonous area shows that the tectonic transport is rotational in the anticlockwise sense.

The dayk swarms of Karadağ metamagmatics which are intruded into the rocks of the Sızma group after the Early Carboniferous but prior to the Late Permian time, reveal that there is about 10.5% crustal extension, in the northwestern part of the study area.

After the Alpine crustal shortening, the study area was affected by post-orogenic movements. During the post-orogenic movements, at Middle-Late Miocene, fresh-water lacustrine basins were formed by block faultings accompanied with volcanism. Then, the young thrusting, which caused transportation of the massif rocks over the cover rocks at least 5 km from the north to the south, was developed, prior to the Late Pliocene time. Finally, gravity faulting has occurred. As a result, the amount of uplift by the post-orogenic faulting varies between 1200 to 1300 m in the region.

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