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Extensional Tectonics and the Geometry of Related Macroscopic Structures: Field Evidence from the Gediz Detachment, Western Turkey

HASAN SÖZBİLİR

Dokuz Eylül University, Faculty of Engineering, Department of Geological Engineering, TR-35100
Bornova, İzmir - TURKEY
(e-mail: hasan.sozbilir@deu.edu.tr)

Abstract: The large-scale, low-angle Gediz detachment fault that constitutes the southern margin of the Gediz graben (also known as the Alaşehir graben) has macroscopic structures of extensional origin, such as folds and back-tilted strata. The folds were formed as antiformal and synformal structures with axes both parallel and perpendicular to the extensional direction in their footwalls and hanging-walls, respectively.

An extension-parallel antiform-synform pair in the footwall of the Gediz detachment, namely the Oyukkıran antiform and the Keserler synform, are recognized south of Dereköy village (Salihli) on the southern margin of the Gediz graben. These are NE–trending domal and basinal structures with a wavelength of 6 km and amplitudes of 1 km. The Oyukkıran antiform is a NE-plunging antiform that exposes granitic rocks (now with cataclastic textures) in its core, with a surrounding cover of Menderes Massif metamorphic rocks, while the Keserler synform has a core of Upper Miocene synextensional sediments that structurally overlie the metamorphic rocks. These corrugations are interpreted as original irregularities of the detachment fault; this interpretation does not require folding after the deposition of the hanging-wall sedimentary sequences.

Three hanging-wall sedimentary sequences, separated from each other by angular unconformities, are redefined in the area. A sequence of Upper Miocene-Lower Pliocene continental sedimentary rocks (SS-II) was deposited in the hanging-wall of the Gediz detachment fault. The sequence is defined as a basal deposit of a supradetachment basin which formed during regional extension in western Anatolia. The SS-II is cut by three basinward-dipping, high-angle normal faults in front of which the SS-III was deposited. The SS-IV comprises the undeformed present-day basin fill of the Gediz graben.

The syn-extensional hanging-wall strata include discontinuous extensional folds which are nearly perpendicular to the extension direction and also to the extension-parallel footwall folds. The extension-perpendicular folds formed as longitudinal drag folds, rollover anticlines and monoclines.

Except for longitudinal extensional folds, rocks in the hanging-wall of the Gediz detachment have been deformed to form back-tilted strata about a horizontal axis which is perpendicular to the extension direction; it is interpreted as an angular unconformity defined by a major change in degree of back-tilted strata, reflecting a change in deformation type - from the supradetachment stage to that of the rift stage in the Gediz graben. The older supradetachment basin formed on the Gediz detachment fault, and its sediments are cut by high-angle normal faults that controlled the formation of the rift basin fill.

Key Words: Geometry, Extensional Structure, Gediz Detachment Fault, Western Turkey

Genişleme Tektoniği ile İlişkili Makroskobik Yapıların Geometrisi: Gediz Sıyrılma Fayından Arazi Verileri, Batı Türkiye

Özet: Gediz grabeninin güney kenarını oluşturan kabuksal ölçekli düşük-açılı Gediz sıyrılma fayı kıvrım ve geriye çarpılmış tabakalar gibi genişleme kökenli makroskobik yapılara sahiptir. Kıvrımlar genişleme doğrultusuna paralel ve dik olacak şekilde sırasıyla taban ve tavan bloğunda oluşmuştur.

Gediz grabeninin güney kenarı üzerindeki Dereköy (Salihli) güneyinde, Gediz sıyrılma fayının taban bloğunda genişleme doğrultusuna paralel Oyukkıran antiformu ve Keserler sinformu saptanmıştır. Bunlar dalga boyu 6 km amplitüdü ise 1 km'ye ulaşan kuzeydoğu doğrultulu dom ve havza benzeri yapılardır. Oyukkıran antiformu çekirdeğinde Menderes metamorfik kayaçlarıyla çevrelenmiş kataklastik dokudaki granitik kayaçların yüzeylediği kuzeydoğuya dalımlı bir antiformu tanımlar. Keserler sinformu ise metamorfik kayaçları yapısal olarak üstleyen genişlemeyle eşyaşlı tortullardan yapılı bir çekirdeğe sahiptir. Bu kırışıklıklar sıyrılma fayının ilksel düzensizlikleri olarak yorumlanmıştır, ve bunların tavan bloğundaki tortul istifin çökeliminden sonra kıvrımlanmaları gerekmez.

Çalışma alanında birbirinden açısal uyumsuzlukla ayrılan üç tavan bloğu tortul istifi yeniden tanımlanmıştır. Üst Miyosen-Alt Pliyosen karasal tortul istifi (SS-II) Gediz sıyrılma fayının tavan bloğunda çökelmiştir. Bu istif Batı

Anadolu'daki bölgesel genişleme sırasında oluşan supradetachment havzasının taban çökeli olarak tanımlanmıştır. SS-II istifi, önünde SS-III istifinin çökeldiği havzaya doğru eğimli üç adet yüksek-açılı normal fayla kesilmiştir. SS-IV istifi Gediz grabeninin deforme olmamış Kuvaterner-Güncel havza dolgusunu oluşturur.

Genişlemeyle eşyaşlı tavan bloğu katmanları genişleme tektoniği sırasında oluşmuş kıvrımlar içerir. Bu kıvrımlar genişleme doğrultultusuna ve genişleme doğrultusuna paralel taban bloğu kıvrımlarına diktir. Genişleme doğrultusuna dik gelişen kıvrımlar sürüme kıvrımları, rollover antiklinaller ve monoklinaller şeklinde oluşmuştur.

Gediz sıyrılma fayının tavan bloğundaki kayalar genişleme doğrultusuna dik yatay eksen etrafında deformasyona uğrayarak geriye çarpılmış tabakalar oluşturmuştur. Geriye doğru çarpılmış tabakalar arasındaki ana eğim derecesi değişikliğiyle ortaya çıkan açısal uyumsuzluk, Gediz grabenindeki supradetachment evreye ait deformasyon tipinden rift evresine değişimi olarak yorumlanmıştır. Daha yaşlı olan supradetachment havzası Gediz sıyrılma fayı üzerinde gelişmiştir ve bu havzanın tortulları rift havzasına ait dolgunun oluşumunu kontrol eden yüksek açılı faylarla kesilmiştir.

Anahtar Sözcükler: Geometri, Genişlemeli Yapı, Gediz Sıyrılma Fayı, Batı Türkiye

Introduction

Much of the research carried out in the extensional terrains of the world has shown that analysis of macroscopic features of hanging-wall and footwall structures provides critical constraints on evolution of three-dimensional detachment fault geometry that can not be determined from the examination of footwall fabrics alone.

Two recent studies done in the Aegean extensional terrain have focused on hanging-wall folds. Koçyiğit *et al.* (1999a) argued that the folds observed in the hanging wall of the Gediz detachment fault formed during N-S-directed compression, while Seyitoğlu *et al.* (2000) contradict that interpretation, suggesting that these folds are products of extensional tectonics. Detailed geological mapping in the area south of Dereköy village (Salihli) shows that not only does the hanging-wall have folded sedimentary strata, but also that the footwall of the Gediz detachment fault is also folded.

The study area is located in the central part of the western Anatolian extensional province (Şengör 1987), where the Bozdağ-Aydın mountain rises along the nearly E-W–trending Gediz and the Büyük Menderes detachment faults to form the two main depressions in western Anatolia, the Gediz and the Büyük Menderes grabens (Figure 1).

The purpose of this paper is to record the geometries of macroscopic features observed in the footwall and the hanging-wall of the Gediz detachment fault. The Gediz detachment fault, formerly named the Karadut detachment fault (Emre 1996), the Çamköy detachment fault (Koçyiğit *et al.* 1999a), and the Gediz detachment (Lips *et al.* 2001), is interpreted as a major low-angle extensional fault that bounds the southern margin of the Gediz graben. In an earlier published map (Emre 1996), many of the structural details - especially about hanging-wall strata and the footwall surface - are absent. The same area has been remapped by the present author over a number of years since 1985. 115 dip measurements from the sedimentary sequences reflect block rotation about a horizontal axis and are used herein for statistical analysis. Dips are utilized in the study of the amount of tilting of the structural blocks using quadrangle-based dip analysis as performed by Lucchitta & Suneson (1993) in the Castaneda Hills-Signal area of west-central Arizona. During the analysis, dips reflecting rotation of blocks are used, while those influenced by drag along faults are not used.

Stratigraphy of the Southern Sector of the Gediz (Alaşehir) Graben

The Gediz (Alaşehir) graben is situated in the western Anatolian extensional province (Dewey & Şengör (1979), and filled with Miocene to recent sedimentary deposits. The graben fills have formed on the Menderes Massif metamorphic basement (Figure 2), and were described earlier in considerable detail by Seyitoğlu & Scott (1996), Emre (1996), Koçyiğit *et al.* (1999a), and Yılmaz *et al.* (2000). Among these studies, there is no agreement on the names and ages of the lithostratigraphical units (Figure 3). For that reason, in this study, a simple sequence-stratigraphic division is applied to the synextensional sedimentary fill of the Gediz graben rather than the traditional stratigraphic division of Emre (1996), Seyitoğlu & Scott (1996), and Koçyiğit *et al.* (1999a). The sedimentary fill in the local study area is divided into three unconformity-bounded sedimentary packages; four sedimentary sequences have been

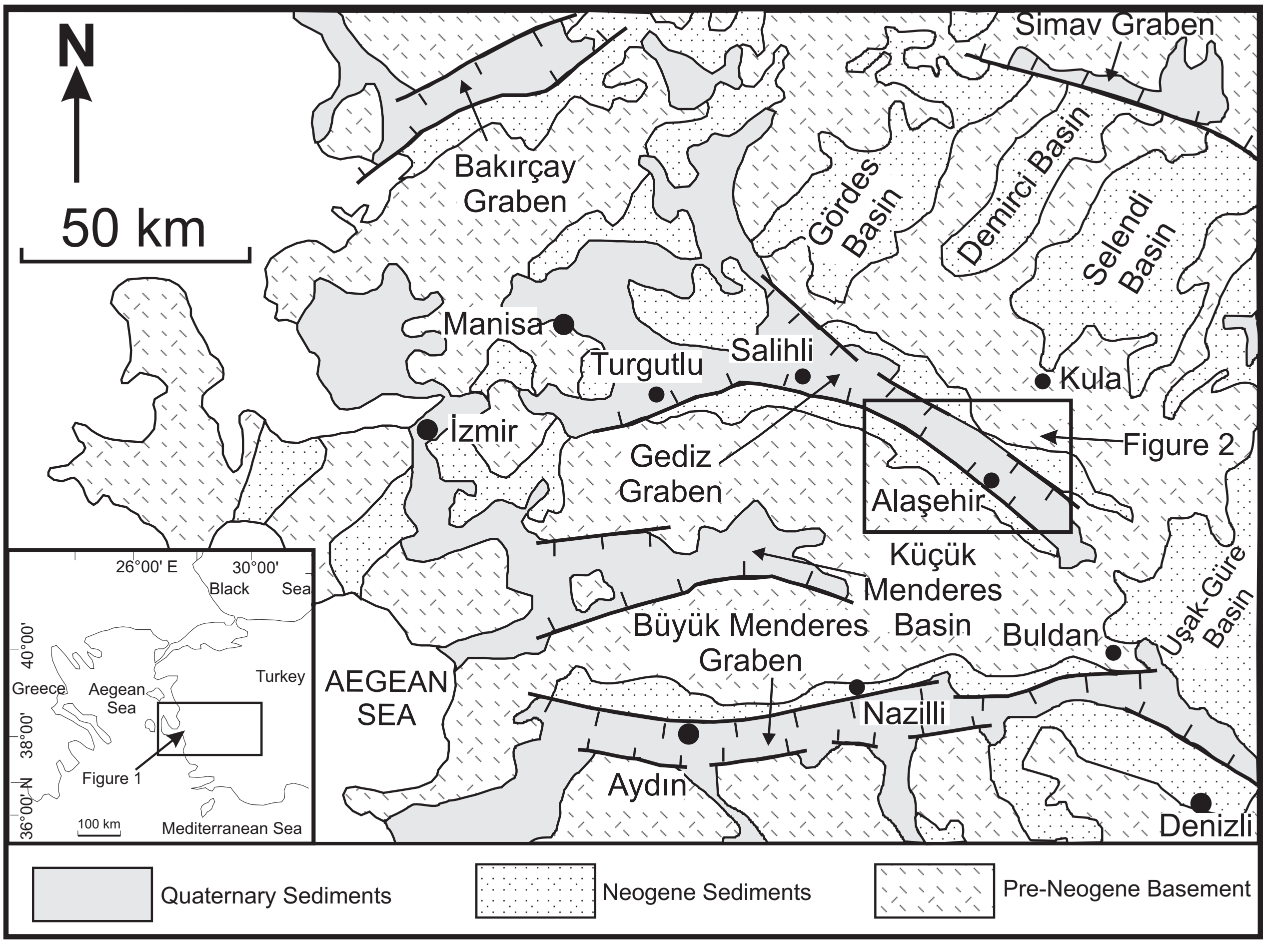

Figure 1. Regional geological map showing the main structural elements of western Anatolia, specifically the Gediz and the Büyük Menderes grabens and surrounding Neogene and Quaternary basins (simplified from Bingöl 1989 and Bozkurt 2000).

documented previously for the whole Gediz graben (Sözbilir 2000; Yılmaz *et al.* 2000). These sequences are briefly described below.

Sedimentary Sequence I (SS-I)

This sequence is the oldest sedimentary unit along the southern margin of the Gediz graben (İztan & Yazman 1990; Yılmaz *et al.* 2000). Outcrops of the sequence are restricted to the area south of Alaşehir (Figure 2). The facies characteristics of the SS-I represent fan delta-lacustrine environments (Cohen *et al.* 1995) that developed in the NE-SW-trending depression (Yılmaz *et al.* 2000). Due to post-depositional faulting, the basin sediments are now found on the shoulders of the Gediz graben as separate outcrops (Figure 2). The age of the SS-I is Early-Middle Miocene on the basis of their sporomorph contents (Ediger *et al.* 1996).

Sedimentary Sequence II (SS-II)

This sequence structurally overlies cataclastic and metamorphic rocks (Figure 4). Stratigraphic relationships with the underlying SS-I have not been found in the study area. This relationship is observed outside the study area, south of Alaşehir, and is interpreted as an unconformable contact (İztan & Yazman 1990; Ediger *et al.* 1996; Yılmaz *et al.* 2000).

The SS-II is divided into two parts: the lower part is a red, coarse-grained lateral alluvial-fan facies, and the upper part has the characteristics of a finer-grained fluvial facies (see Emre 1996; Koçyiğit *et al.* 1999a;

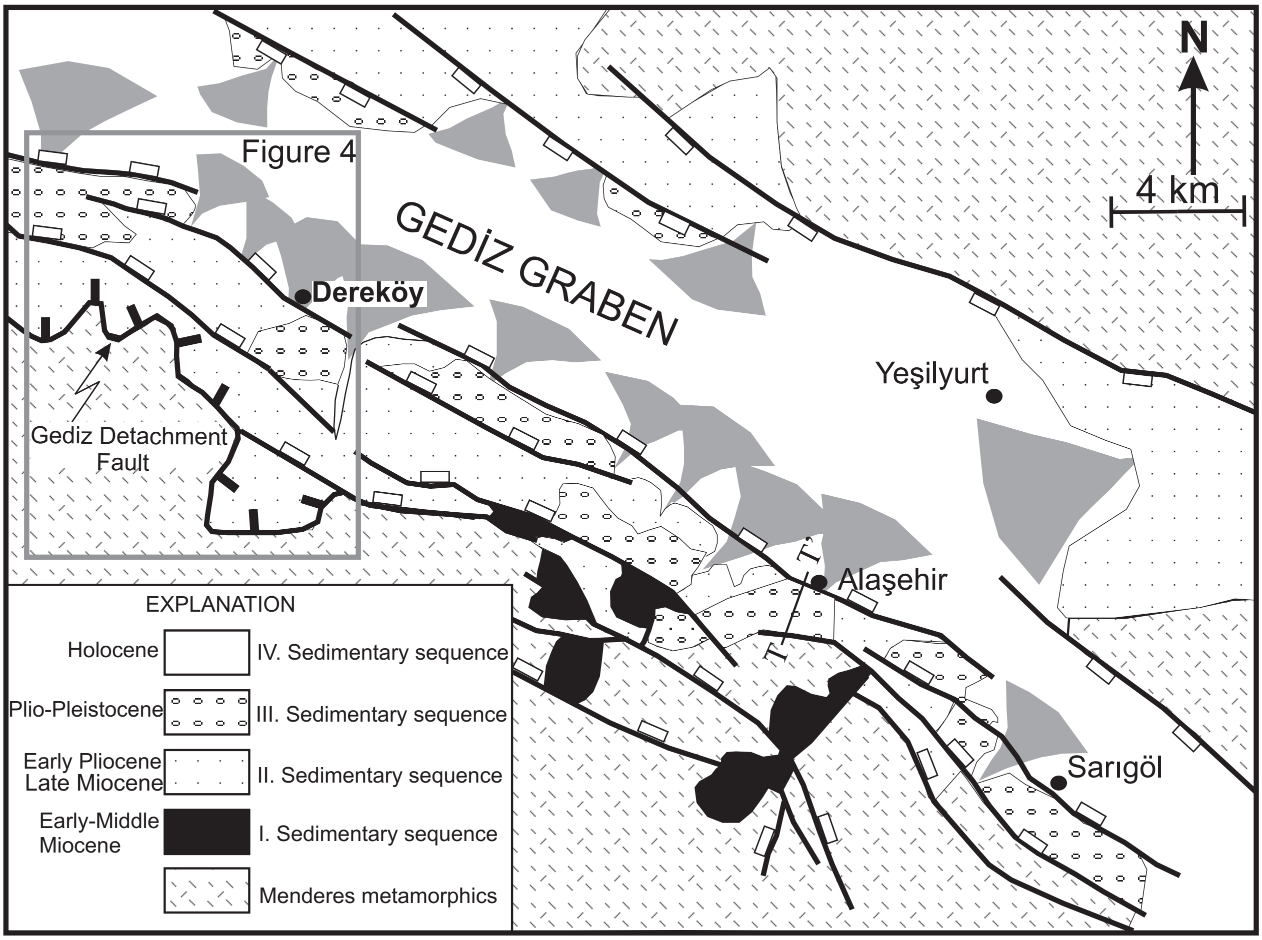

Figure 2. Geological map of the eastern Gediz graben showing the study area in Figure 4 (modified from Koçyiğit *et al*. 1999a and Yılmaz *et al*. 2000). See Figure 1 for location of the map. Line T-T' refers to the location of the cross-section on Figure 10.

Yılmaz *et al.* 2000). The main lithology in the lower part of the SS-II is a poorly sorted, disorganized boulder breccia and conglomerates having some lenses of pebbly sandstones. A chaotic internal fabric dominates the boulder breccia beds, although intervals showing very crude clast alignments are present. Where intercalated with the pebbly sandstone, beds range from 1 to 2-m-thick. Poorly sorted, disorganized boulder conglomerate is interpreted as a debris flow whose deposition occurred in the proximal part of the alluvial fans. Local crude stratification and imbrication indicate the operation of traction currents toward the middle part of the sequence.

The upper part of the sequence is dominated by sandstone and pebbly sandstone intercalated with cobble conglomerate beds. In the uppermost part of the sequence, cross-bedded sandstone and brown mudstones containing a gastropod fauna of Dacian (Early Pliocene) age are present (Emre 1988). The dated site is shown in Figure 5.

The SS-II is the stratigraphic equivalent of the Kurşunlu formation of Seyitoğlu & Scott (1996). According to those authors, the lower part of the Kurşunlu formation is Early-Middle Miocene in age, based on the Eskihisar sporomorph association. However, recent sporomorph data (Koçyiğit *et al.* 1999b) from equivalent intervals yield an association of Late Serravalian-Early Tortonian age which corresponds to the Yeni Eskihisar palynomorph assemblages of Benda & Meulenkamp (1979). Thus, a Late Miocene-Early Pliocene age is assigned to the SS-II.

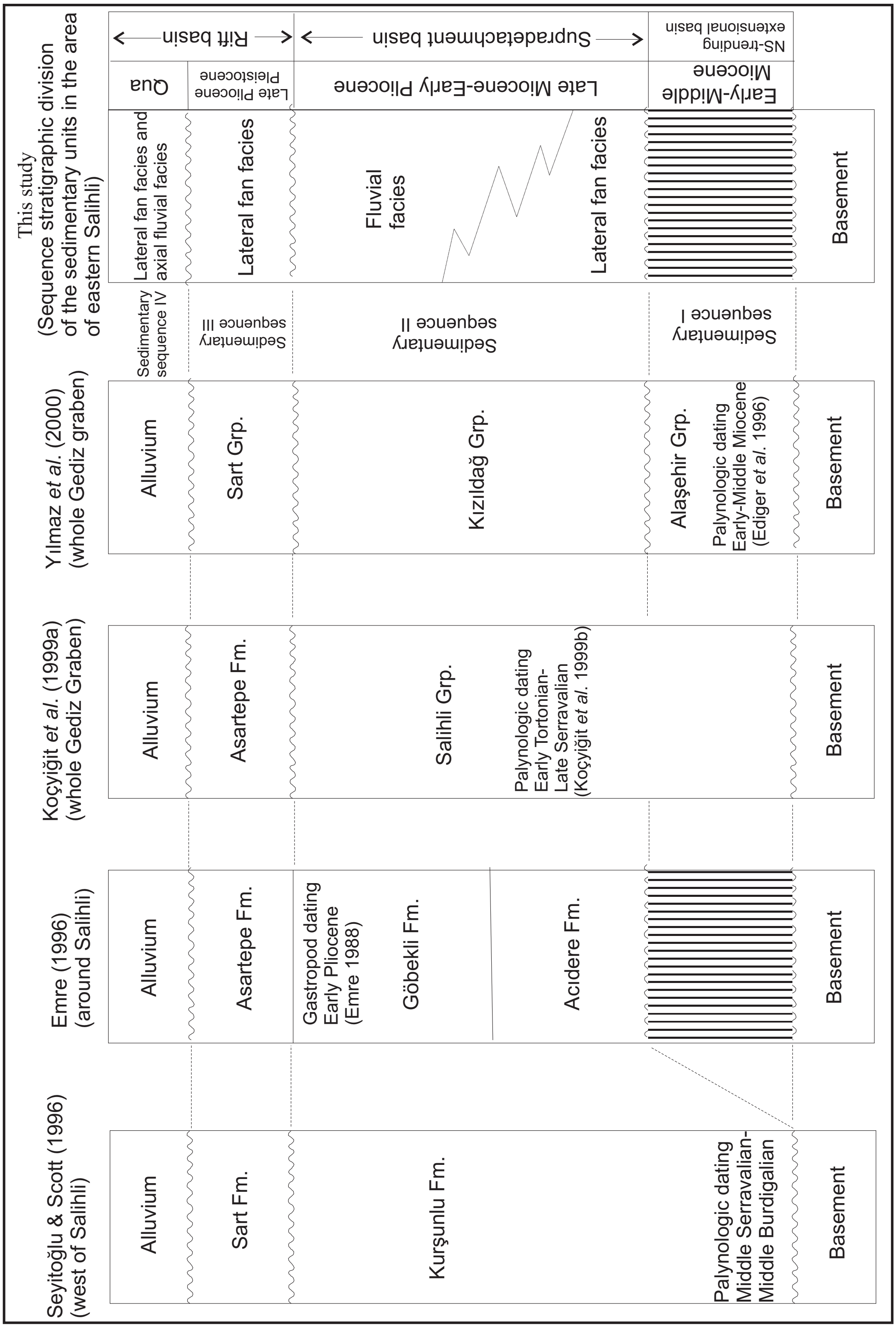

Figure 3. Unconformity-bounded sequence stratigraphic division of the study area and its correlation with previous studies. Note that the dated intervals of the different sequences are indicated.

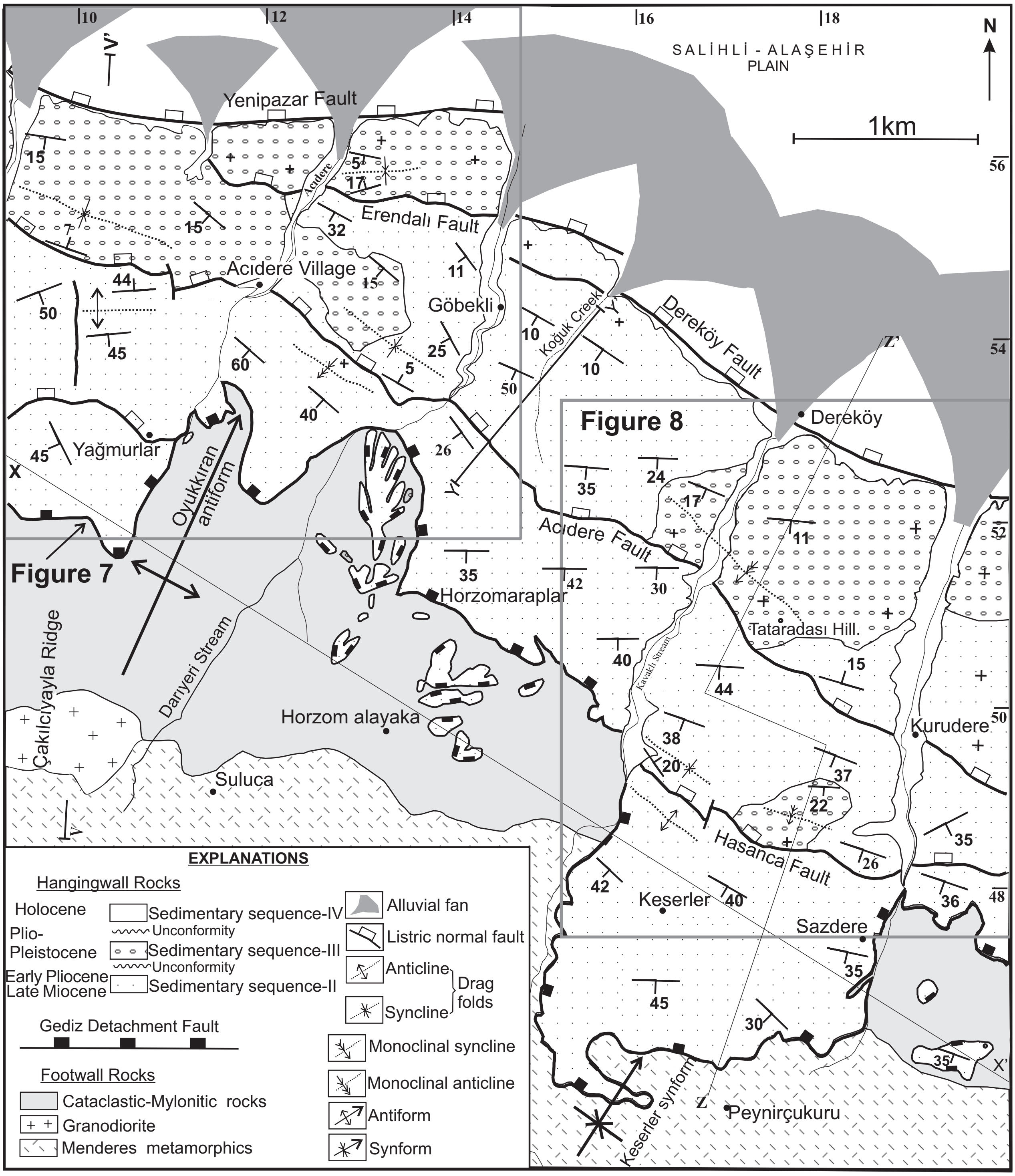

Figure 4. Geological map of the study area (modified from Emre 1996). See Figure 2 for location of the map. Lines X-X', V-V', Z-Z' and Y-Y' refer to the locations of cross-sections on Figures 6 and 9.

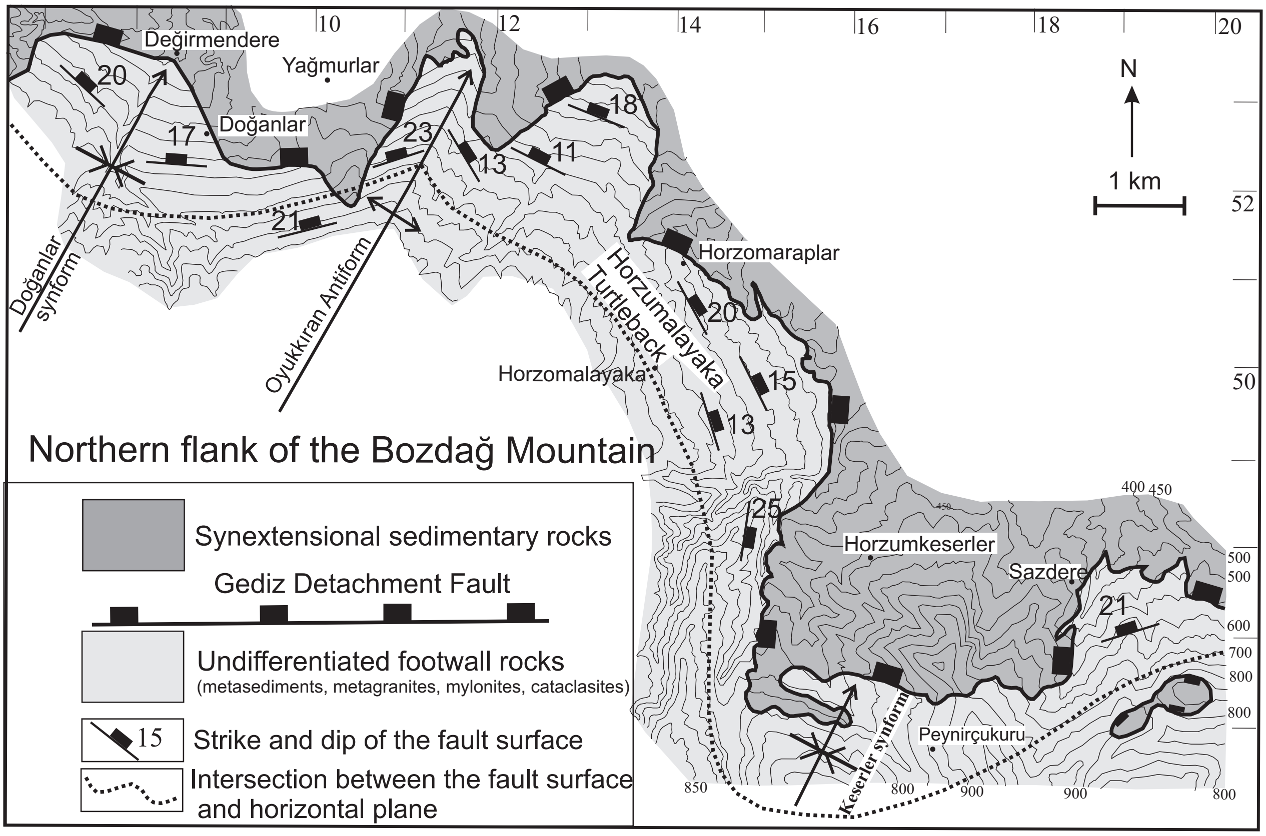

Figure 5. Map showing the corrugated nature of the Gediz detachment surface. Note the present morphology is in accordance with the antiformal-synformal nature of the fault surface. A turtleback-like structure noted by Seyitoğlu et al. (2000) at the eastern limb of the Oyukkıran antiform is indicated.

Sedimentary Sequence III (SS-III)

This sequence formed in front of high-angle normal faults (Hasancatepe fault and Acıdere fault) and rests unconformably on the SS-II. The sequence consists of poorly compacted alluvial-fan deposits that comprise mainly conglomerate and sandstone.

The SS-III is characterized by a succession of a yellowish-brown to gray, poorly sorted alluvial-fan conglomerate and sandstone with subordinate mudstones. The equivalent unit in the Büyük Menderes graben has been dated as Late Pliocene-Pleistocene (Ünay *et al.* 1995).

Sedimentary Sequence IV (SS-IV)

This sequence consists of the fault-controlled, lateral alluvial-fan deposits and the axial fluvial systems of the Alaşehir-Gediz River. The sequence fills the present-day Gediz depression and is juxtaposed with older sedimentary sequences along the Yenipazar and Dereköy faults (Figure 4).

Structural Geology

Four types of major structures occur along the southern margin of the Gediz graben: (1) the Gediz detachment fault; (2) extensional folds in the footwall and the hanging wall of the Gediz detachment, both parallel and perpendicular to the extension direction, respectively; (3) E-W– to NW-SE–trending high-angle normal faults; and (4) a regional unconformity between the SS-II and SS-III.

The Gediz Detachment Fault

The Gediz detachment fault was recently interpreted as a crustal-scale, N-NE–dipping, low-angle breakaway fault that constitutes the southern margin of the Gediz graben

(Hetzel *et al.* 1995; Emre & Sözbilir, 1995; Emre 1996; Koçyiğit *et al.* 1999a; Yılmaz *et al.* 2000; Lips *et al.* 2001; Bozkurt 2001a, b). The structural characteristics of the fault are given in Hetzel *et al.* (1995) and Koçyiğit *et al.* (1999a). The northern flank of Bozdağ Mountain has been interpreted as an exhumed and slightly incised fault surface of the Gediz detachment (Yılmaz *et al.* 2000). The fault juxtaposes Neogene sedimentary rocks in the hanging-wall with mylonitized crystalline basement rocks in the footwall (Figure 4). A zone of penetrative cataclasis extends 50-100 m below the detachment surface in which brittle fabrics overprint ductile fabrics (Hetzel *et al.* 1995; Koçyiğit *et al.* 1999a).

The polished fault plane is exposed between Çakıldoğan and Gölyeri ridge where numerous outcops of the hanging-wall blocks are observed in small patches (Figure 4). The fault plane is also observed east of Sazdere village. The width of the fault scarp reaches 4 km between Karadut and Suluca hill. Between these two places, the detachment surface is curviplanar and contains NE-SW–trending folds that deformed the detachment fault itself (discussed below). Fault-plane measurements suggest that dip angles of the fold limbs are not greater than 25°.

Extensional Folding

Although most folds are associated with contractional regimes, many types of folds have also been reported from extensional basins. In many metamorphic core complexes, in particular, extension-related folds have formed in the hanging-walls and footwalls of normal faults (Mancktelow & Pavlis 1994; Fletcher *et al.* 1995; Schlische 1995).

In most detachment-fault systems, footwall folds defines a basin and dome geometry known as: (1) extension-perpendicular folds and (2) extension-parallel folds. The latter are interpreted to have formed as (1) folding of earlier planar detachment folds (Yin 1991); or (2) as primary fault corrugations (Davis & Lister 1988). The first interpretation requires that the warped detachment-fault geometry be concordant with the attitudes of structures in the upper and lower plates. In contrast, the second interpretation implies that curviplanar detachment-fault geometry is independent of attitude patterns of structures in the upper and lower plates (Yin & Dunn 1992).

Movements on the fault planes of the normal faults result in fault-parallel (longitudinal folds) and fault-normal (transverse folds) folds (Schlische 1995). The axes of these extensional folds form as longitudinal drag and rollover folds to the associated normal faults.

Longitudinal folds have hinges that closely parallel the strike of the fault, but are normal to the extension direction, and are best observed in sections perpendicular to the fault. These folds are classified as the drag folds and rollover folds. Rollover folds form as a result of movement on concave-upward listric faults (Schlische 1995). Drag folds form as a result of the lateral-end upward propagation of faults into regions that have been monoclinally flexed at the fault tips (Hancock & Barka 1987). Field evidence for folding of the footwall and hanging-wall of the Gediz detachment fault are given below:

Footwall Folding in the Gediz Detachment

The fault surface that forms the uppermost part of the footwall in the Gediz detachment has a macroscopic antiformal and synformal structure that have axes parallel to the extension direction (Figure 5). With respect to fault-surface measurements (Figure 5), the surface dips NW east of Oyukkıran ridge, and NE west of the ridge. Such changes in dip direction elucidate the geometry of the Oyukkıran antiform. The axis of the antiform plunges 5° toward N26°E along Oyukkıran ridge. The northwestern and northeastern limbs of the Oyukkıran anticline express the recent morphology of the northern flank of Bozdağ Mountain (Figure 5). The northeastern flank of the Oyukkıran antiform has recently been interpreted as the Horzumalayaka turtleback, similar to the turtleback structures of the Basin and Range province (Seyitoğlu *et al.* 2000). In the southeastern part of the study area, the detachment surface is folded to form the Keserler synform. The core of the synform is occupied by sedimentary sequence II. The Keserler synform has the same orientation as the Oyukkıran antiform (Figure 5). The synextensional granodiorite (Hetzel *et al.* 1995) forms the core of the antiform and SS-II rocks are found in the neighbouring synforms (Figure 6A).

Hanging-wall Folding in the Gediz Detachment

The synextensional sedimentary units that constitute the hanging-wall of the Gediz detachment are cut by three N-

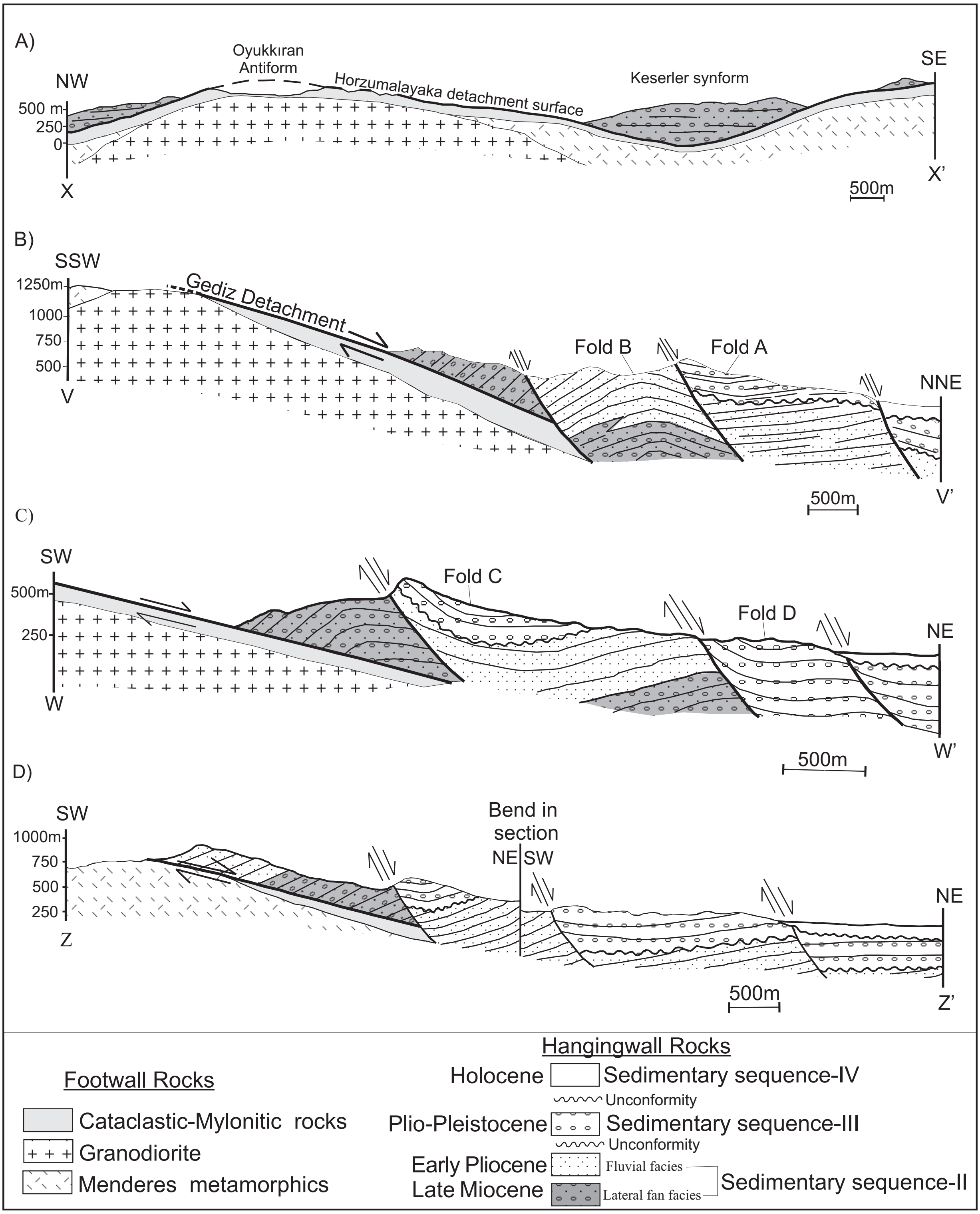

Figure 6. Cross-sections showing the relationship between the extensional folding and faulting in the area (see Figure 4 and Figure 7 for locations of the sections). a) Cross-section normal to the direction of extension. Note the extension-parallel antiformal and synformal structures that formed in the footwall of the Gediz detachment fault. Cross-sections b, c, and d refer to the longitudinal drag folds that formed on or very near the high-angle normal faults.

NE–dipping normal faults (Figure 4). The strata between these faults were rotated during extensional tectonism to form several longitudinal folds. The lengths of the drag folds do not exceed two km, and these formed close to the fault lines (Figure 6). Similar structures have recently been interpreted as extensional folds in a neighbouring area (Seyitoğlu *et al.* 2000), while the same structures have been described as contractional structures (Koçyiğit *et al.* 1999a).

In the vicinity of Asar Hill and Haney Hill near the Acıdere fault line, five drag folds create two anticlines and three synclines in the footwall and hanging-wall of the Acıdere fault, respectively (Figure 7). Fold A is an open syncline with a 5° plunge toward N78°W. The anticline (fold B), located south of Asar Hill, is almost a vertical fold with a 3° plunge toward N83°E and an interlimb angle of 91° . The fold cannot be traced due to a small N-S–trending tear fault. To the north of Haney Hill, another open syncline (fold C) is present, and it plunges 2° toward N53°W. Fold D is also an open syncline related to normal movement along the Erendalı fault. Along the Hasanca fault, an anticline (E) and a syncline (F) are observed 5° and 6° plunges, respectively, toward N64°W (Figure 8). In addition to these drag folds, there are several monoclines with horizontal limbs near the faults (Figures 6, 7 & 8).

A good example of a rollover anticline is observed between the Acıdere fault and the Dereköy fault (Figure 4). The northern limb of the rollover anticline is nearly horizontal, while its southern limb is back-tilted up to 50° toward the fault plane of the Acıdere fault (Figure 9). As seen in Figure 9, rather than simply folding, the hanging-wall of the Acıdere fault more commonly fractured during folding. The presence of a rollover anticline in the hanging-wall of the Acıdere fault suggests that the Acıdere fault is a listric normal fault with a dip of 51° at the surface.

All of the characteristics noted above suggest that the folds, which developed in the hanging-wall of the Gediz detachment fault are similar to the fault-related folds of an extensional setting as defined by Schlische (1995).

High-angle Normal Faults

The supradetachment sequence (SS-II) has been brittlely deformed by high-angle normal faults that strike WNW and are downthrown to the NNE. Four structural blocks between these faults are recognized, and these have been tilted against the fault planes. Because the strata and faults dip in opposite directions, it is inferred that tilting resulted from rotation of the blocks. Rotation here includes actual rotation of blocks along fault planes. The structural characteristics of these faults are given in Emre (1996), Koçyiğit *et al.* (1999a) and Yılmaz *et al.* (2000). They are synthetic to the Gediz detachment fault. The Acıdere fault is the longest normal fault in the area, and is the only fault that has an exposed small fault plane in Acıdere Village. At that locality, the fault plane strikes in N65-71°W with a dip of 51° to the NE. The Yenipazar and the Dereköy faults have fault scarps in front of which several lateral alluvial fans have formed (Figure 4). All sedimentary units have been cut by these youngest high-angle normal faults that developed basinward and that juxtapose the older units with the present-day graben-fill (SS-IV). These faults also cut the Gediz detachment fault at one locality, 1 km south of Alaşehir. At that locality, the Gediz detachment displays a well-developed N–dipping (32°) fault planes, which are cut by a high-angle normal fault (Figure 10). This is also the only locality where the Gediz detachment fault is close to the present-day graben fill.

A Regional Unconformity

As suggested by Lucchitta & Suneson (1993), plotting dip measurements taken from syntectonic sedimentary deposits is a simple and useful technique for recognizing regional unconformities between synextensional sedimentary sequences. Hundreds of dips were measured in the tilted four structural blocks of the area. The quadrangle-based analyses show that dip values define two main structural groups of dips from the southern margin of the Gediz graben (Figure 11). The first structural group comprises dips of the Upper Miocene-Lower Pliocene sediments (S-II); the mean of these dips is 35°. Another structural group includes a sedimentary succession of Upper Pliocene-Pleistocene age (S-III), and has a mean dip of 17°. This data suggests that block rotation and movements on the Gediz detachment fault started after deposition of SS-II. The younger block rotation should be related to movements along high-angle normal faults during the Late Pleistocene.

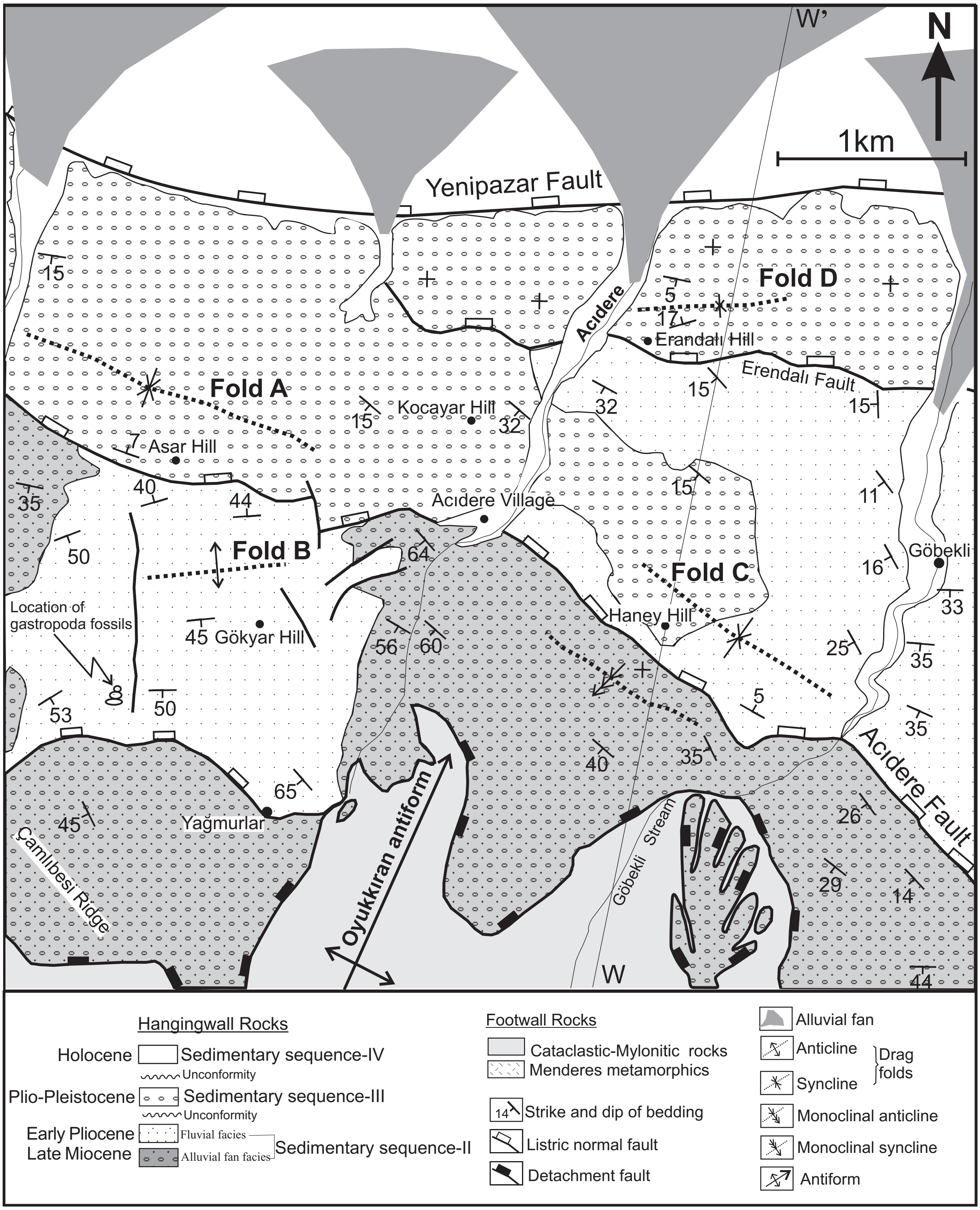

Figure 7. Detailed geological map of the area around Acıdere village. Note the fold axes are nearly parallel to the strikes of the high-angle normal faults. Location of a dated (Dacian) site in the upper part of the SS-II is indicated. See Figure 4 for location of the map.

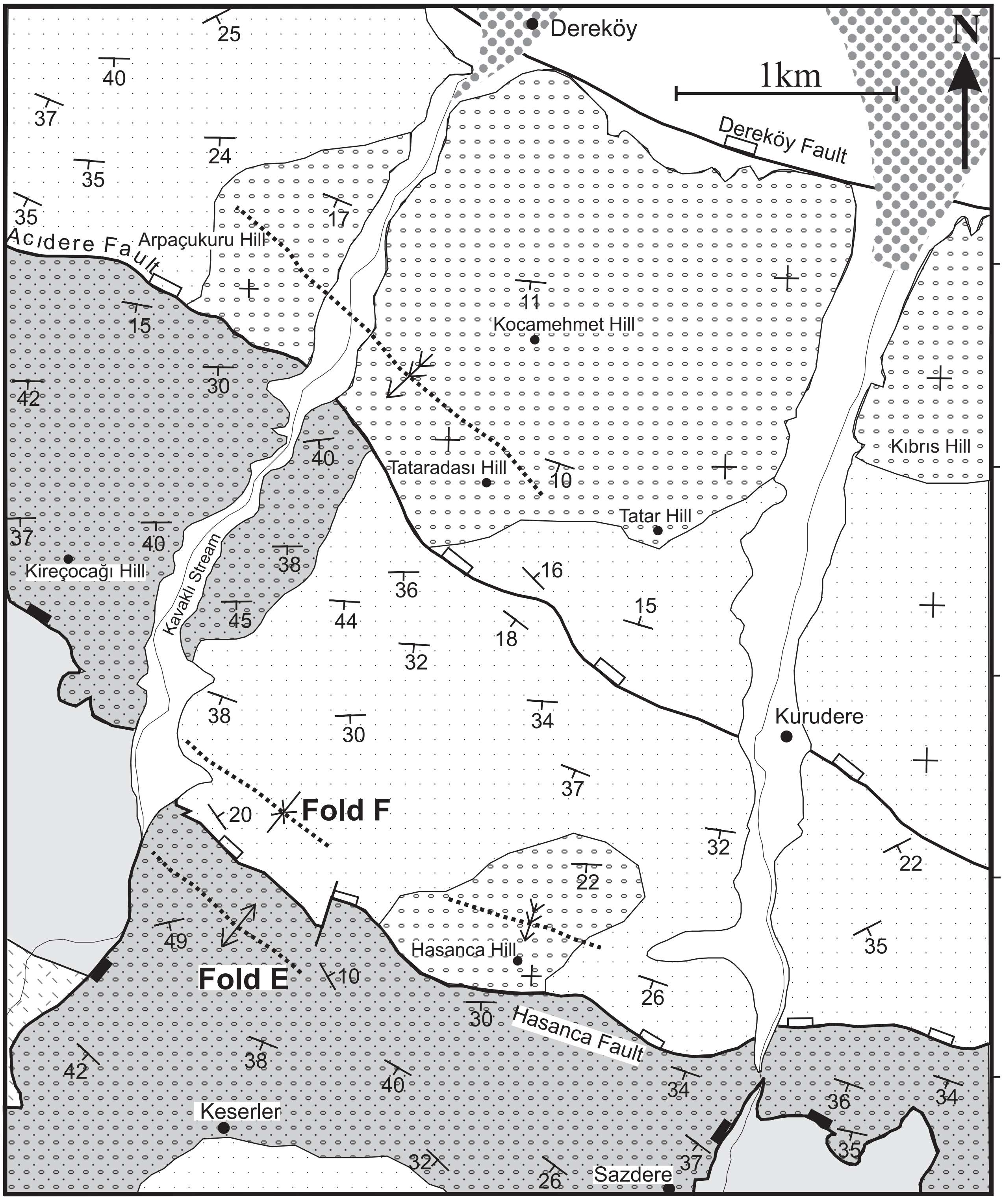

Figure 8. Detailed geological map of the area south of Dereköy village. Note the presence of longitudinal monoclinal synclines in front of the high-angle normal faults. See Figure 4 for location of the map. See Figure 7 for explanation.

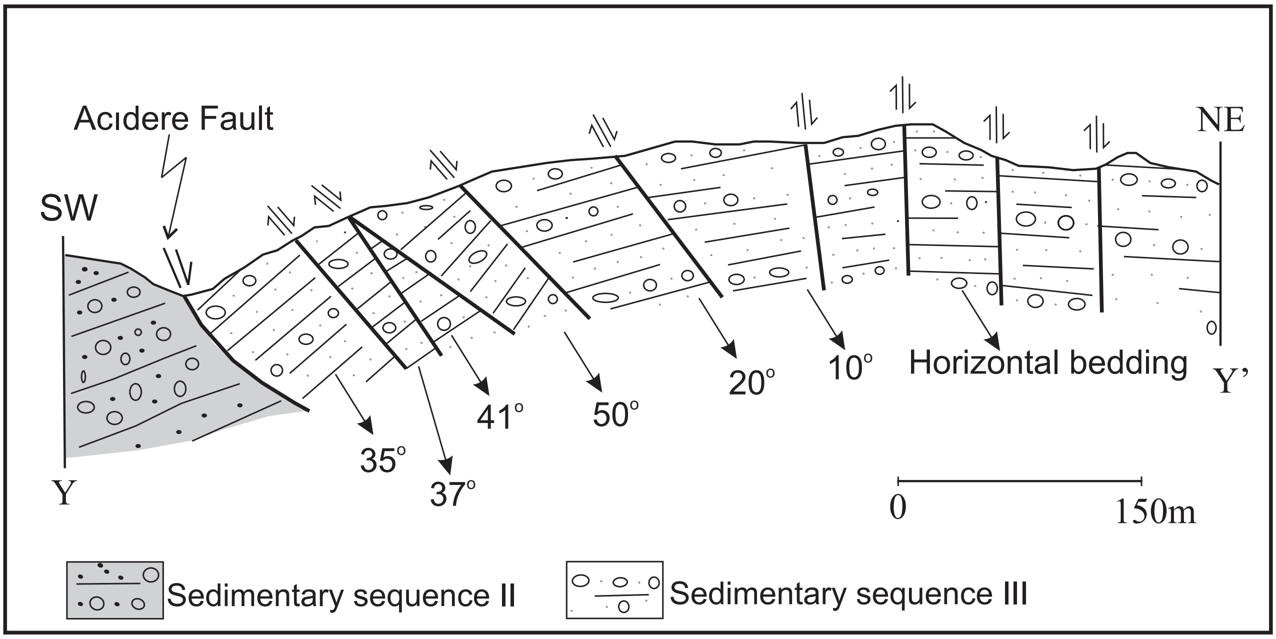

Figure 9. Schematic cross-section showing the rollover anticline that developed on the hanging wall of the Acıdere fault. Exposure on the western bank of the Koğuk creek. See Figure 4 for location of the section.

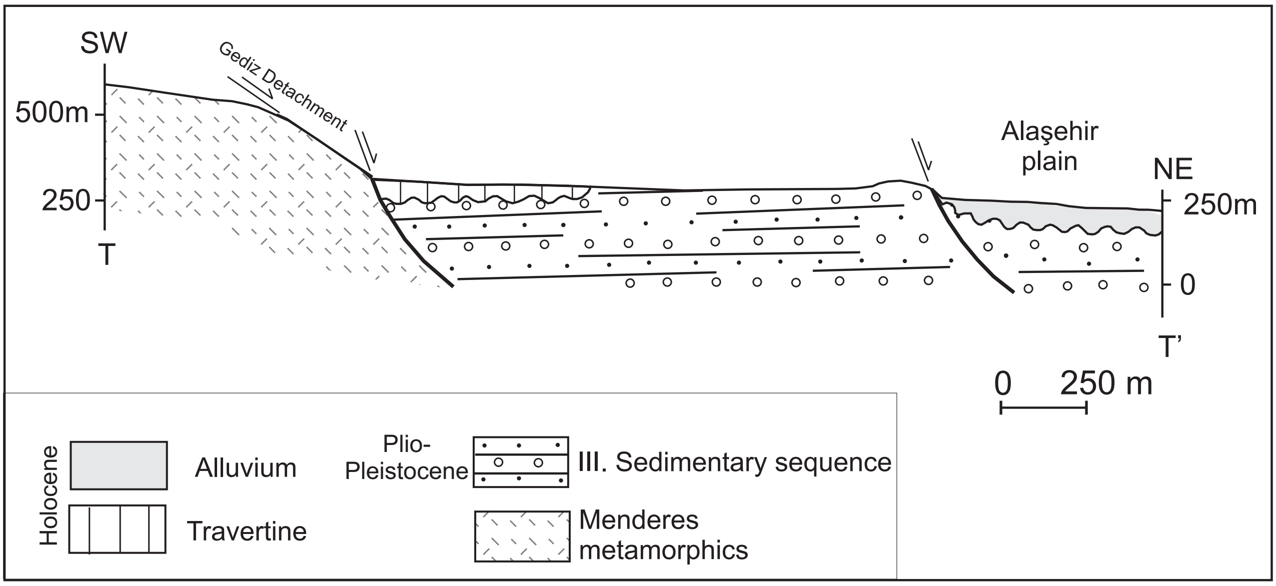

Figure 10. Cross-section showing cross-cutting relationships between the low-angle Gediz detachment fault and the high-angle normal fault. See Figure 2 for location of the section.

Discussion and Conclusion

The Gediz graben is located within the western Anatolian extensional province, a region characterized by N-S extension acommodated by nearly E-W–trending normal fault systems and N-S–trending oblique to strike-slip faults (Koçyiğit 1984). One result of this tectonic activity is the Gediz detachment fault from beneath which the Menderes metamorphic core complex was exhumed. The half-graben geometry formed in Late Miocene to Early

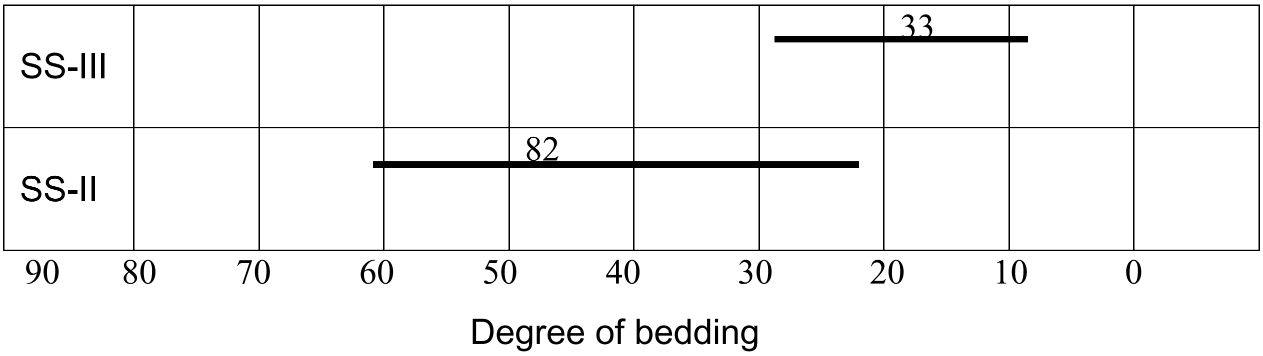

Figure 11. Dip data grouped by quadrangle showing where significant changes in the dip values of sedimentary sequences occur. The diagram shows the number of measurements (82 and 33) and dip intervals of the bedding (bold lines).

Pliocene time, coeval with the breakaway of this regional, N-NE dipping detachment fault. In contrast to previous studies (Seyitoğlu & Scott 1996; Koçyiğit *et al.* 1999a), the older SS-I is not present in the study area, but outside the area to the south of Alaşehir. The stratigraphic equivalent of the SS-I is also observed in the Büyük Menderes graben (e.g., the Hasköy unit of Sözbilir & Emre 1990; Unit I of Cohen *et al.* 1995; Unit A of Bozkurt 2000). Moreover, personal field observations in different parts of the Büyük Menderes graben suggest

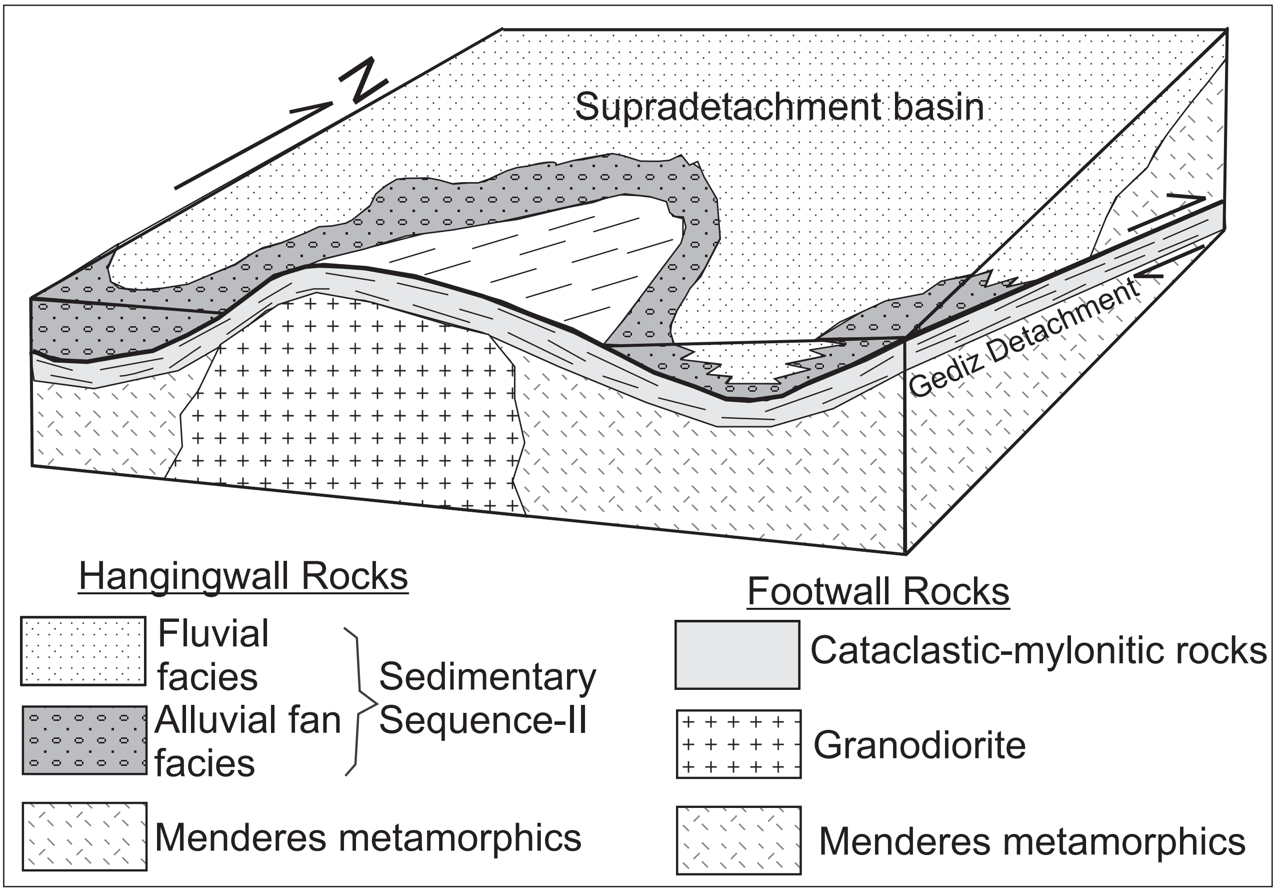

Figure 12. Schematic block diagram of the three-dimensional geometry of the Gediz detachment fault and related supradetachment basin. Note that the basal sequence of the supradetachment basin is controlled by the domal and basinal structures of the Gediz detachment fault.

that the basin in which the SS-I formed is a NE-SW-trending half graben. Some data that give rise to this conclusion are: (1) in the Buldan horst, lateral alluvial fan - fan delta deposits of the oldest sequence reach up to 700 m in thickness, (2) while to the west, around Nazilli, the thickness decreases to 60 m, (3) farther west, to the north of İncirliova, organic-rich lacustrine shales of the SS-I rest directly on the Menderes metamorphic rocks.

The Gediz graben contains an Upper Miocene to Early Pliocene supradetachment sedimentary succession (SS-II) that records the unroofing of the Menderes metamorphic core complex (Figure 12). The SS-II has been divided into lower and upper parts. The lower part consists of polylithological, boulder breccia and conglomerate with red sandy matrix and red sandstones. The lower SS-II is interpreted as proximal alluvial-fan deposits related to the initial opening of the supradetachment basin. Deposition of the supradetachment sequence (SS-II) began during the Late Serravalian-Early Tortonian, or Late Miocene, and ended about Dacian (Early Pliocene). The younger SS-III appears to have formed under the control of the high-angle normal faults.

In the area south of Dereköy village, there are mesoscopic structures – including drag folds, rollover anticlines and back-tilted strata – in the hanging-wall synextensional sedimentary deposits, and domal and basinal structures in the footwall of the Gediz detachment (Figure 13).

The Gediz detachment fault is curviplanar along the northern flank of Bozdağ Mountain. Corrugations in the brittle detachment record shortening normal to the extension direction in the brittle regime, and it appears that synextensional folding occurred during active displacement across the brittle-ductile fault zone in the Menderes metamorphic core complex.

As seen in Figure 13, folds that developed in the footwall of the Gediz detachment have the plunging axes of antiformal and synformal structures that parallel the extension direction of western Anatolia. In contrast, the folds that developed in the synextensional sedimentary sequences have the nearly horizontal axes of drag folds that are perpendicular to the extension direction. Drag folds are longitudinal folds that are generally restricted to the region adjacent to the high-angle fault surface.

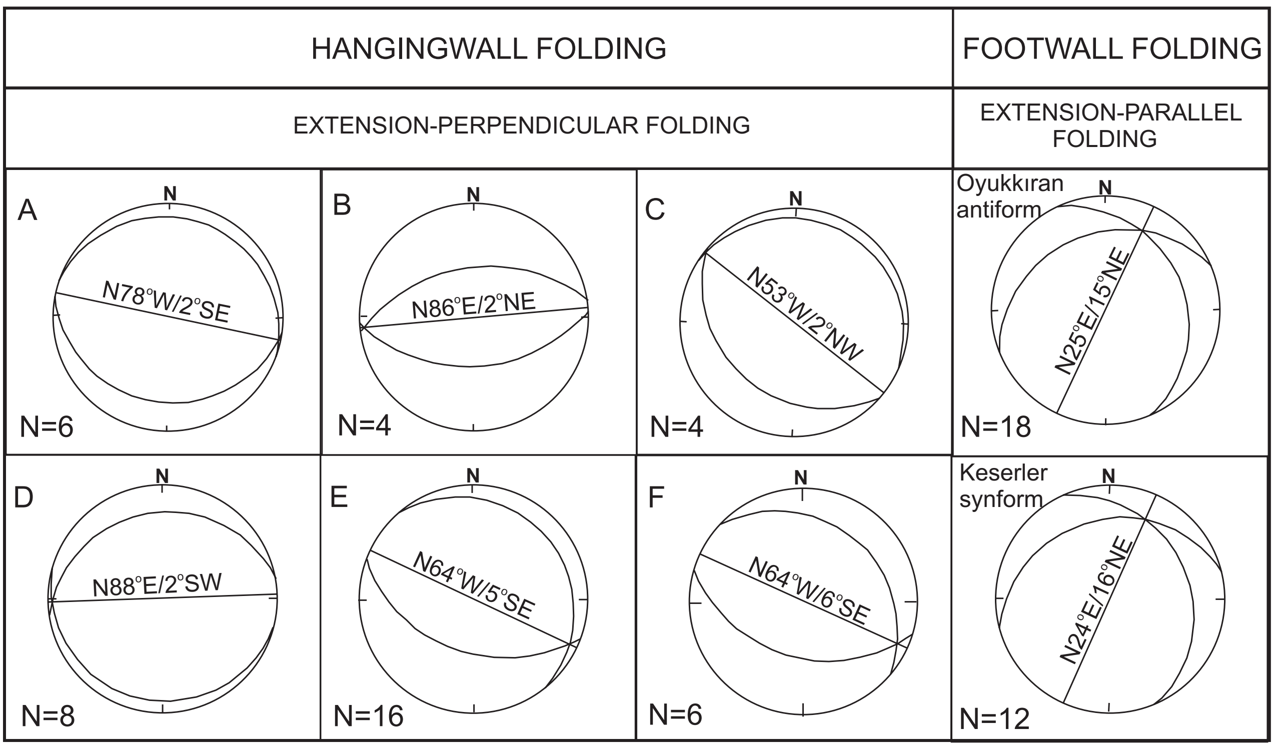

Figure 13. Lower-hemisphere stereonets showing orientations of grouped folds axes that are oriented both parallel and perpendicular to the direction of extension. Note the axes of hanging-wall folds are approximately normal to the footwall folds.

Synclines or monoclinal synclines form in the hanging-walls of high-angle normal faults; anticlines or monoclinal anticlines occur in the footwalls.

Rocks in the hanging wall of the Gediz detachment were deformed to form back-tilted strata around a horizontal axis – which is younger than and perpendicular to the antiformal-synformal corrugation of the Gediz detachment. The first rotation of the blocks started after deposition of the S-II, and before deposition of the S-III, between Early and Late Pliocene. Dips of the S-II produced by rotation of blocks along the footwall-bounding Gediz detachment have a mean dip of 22° However, field data from 1 km south of Alaşehir yielded an extensional detachment with a dip-slip, 32°N–dipping fault plane which was cut later by a high-angle normal fault. The truncation of a low-angle fault by a high-angle fault along the Gediz graben is best explained by a two-stage model for Late Cenozoic extensional province in western Anatolia (Koçyiğit *et al.* 1999a). Syntectonic Upper Pliocene-Pleistocene strata (S-III) were deposited in the trough formed by the rotation of these blocks. After deposition of the S-III, block rotation with a mean dip of 17° developed about an E-W-trending horizontal axis at the end of the Pleistocene.

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