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Evidence for High-Angle Origin of the Alaşehir Detachment Fault and Layer-Parallel Shortening During Miocene Time in Alaşehir Graben, Western Anatolia

Alaşehir Grabenindeki Alaşehir Sıyrılma Fayının Yüksek Açılı Kökeni ve Miyosen Döneminde Tabaka-Paralel Kısalmaya İlişkin Kanıtlar, Batı Anadolu, Türkiye

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*This paper is respectfully dedicated to geologist **Hakan Ağırbaş**, who is the corresponding author's colleague from İstanbul University with whom he worked for years, on the occasion of the first detailed geological and tectonic mapping in the Alaşehir area between Gökçealan and Tahtacı.*

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Abstract: Western Anatolia is a well-known continental extension province in the world. The most distinctive structural elements of the region are E-W trending grabens. The Alaşehir Graben forms the boundary between the northern and central parts of the Menderes Massif. It trends E-W from Ahmetli to Turgutlu and NW-SE from Salihli to Alaşehir. This paper documents the outcomes of fieldwork along the southern margin of the Alaşehir Graben between the Salihli and Alaşehir areas.

The tectonostratigraphy of the southern margin of the Alaşehir Graben is divided into the footwall and hanging wall of the Alaşehir detachment fault. The footwall comprises the Bayındır and Bozdağ Nappes and the syn-extensional Salihli granitoid intruding the Bayındır Nappe. The hanging wall consists of the Çine Nappe and Neogene-Quaternary sedimentary rocks, and Miocene fills tectonically overlying the Çine Nappe, which is above the Alaşehir detachment fault in the Alaşehir area.

Structural data show three types of master fault sets, including (i) the low-angle Alaşehir detachment fault, which is composed of cataclastic rocks; (ii) low-angle normal faults, which are devoid of any cataclastic rocks; and (iii) Plio-Quaternary high-angle normal faults cutting them. Two different low-angle normal faults were coeval and active during the Miocene, and low-angle normal faults were synthetic and antithetic faults of the Alaşehir detachment fault. Their initial position was high-angle and the original position had 55°-75° dip during the Miocene. In the Salihli and Alaşehir segments, several major fold geometries are defined in the footwall and hanging wall of the Alaşehir detachment fault. The fold axis is NE-trending and plunges mainly northeast in the Salihli segment in the footwall of the Alaşehir detachment fault. The other is ~ E–W-trending and plunges mainly west in the Alaşehir segment in the footwall and hanging wall of the Alaşehir detachment fault. They are associated with extensional structures formed by layer-parallel shortening during the Miocene. The Alaşehir detachment fault, as indicated by the difference in fold axes between the Salihli and Alaşehir segments, was cut and back-rotated by Plio-Quaternary high-angle normal faults and tilted to the south.

Keywords: Alaşehir detachment fault, Alaşehir Graben, fold axis, low- and high-angle normal faults, slickenside, stretching lineation, Western Anatolia.

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Öz: *Batı Anadolu, dünyada iyi bilinen kıtasal gerilmeye sahip bir alanıdır. Bölgenin en belirgin yapısal elemanları D-B doğrultulu grabenlerdir. Alaşehir Grabeni, Menderes Masifi'nin kuzey ve orta kesimleri arasındaki sınırı oluşturur. Ahmetli'den Turgutlu'ya kadar D-B gidişli, Salihli'den Alaşehir'e kadar ise KB-GD gidişlidir. Bu makale, Salihli ve Alaşehir alanları arasındaki Alaşehir Grabeni'nin güney kenarı boyunca yapılan arazi çalışmasının sonuçlarını belgelemektedir.*

Alaşehir Grabeni'nin güney kenarının tektonostratigrafisi Alaşehir sıyrılma fayının taban ve tavan bloğu olarak ikiye ayrılır. Taban bloğu Bayındır ve Bozdağ Naplarını ve Bayındır Napını kesen gerilme ile eşzamanlı Salihli granitoyidinden oluşur. Tavan bloğu Çine Napı ve Neojen-Kuvaterner tortul kayaçlardan oluşur ve Alaşehir bölgesinde Alaşehir sıyrılma fayı üzerinde yer alan Çine Napının üzerinde de Miyosen dolguları tektonik olarak yer almaktadır.

Yapısal veriler, (i) kataklastik kayalardan oluşan düşük-açılı Alaşehir sıyrılma fayı; (ii) kataklastik kayalardan yoksun olan düşük açılı normal faylar; ve (iii) bunları kesen Pliyo-Kuvaterner yüksek açılı normal faylar olmak üzere üç tip ana fay setini göstermektedir. Miyosen'de iki farklı düşük açılı normal fay eş zamanlı ve aktif olup, düşük açılı normal faylar ise Alaşehir ayrılma fayının sintetik ve antitetik faylarıdır. Başlangıç konumları yüksek açılı olup, Miyosen boyunca başlangıç konumlarının eğimleri 55°-75° arasındadır. Salihli ve Alaşehir segmentinde, Alaşehir sıyrılma fayının taban ve tavan bloğunda birçok önemli kıvrım geometrisi tanımlanmıştır. Alaşehir sıyrılma fayının Salihli segmentindeki taban bloğundaki kıvrım ekseni KD gidişlidir ve kuzeydoğuya doğru dalımlıdır. Diğer bir kıvrım ekseni ise Alaşehir sıyrılma fayının Alaşehir segmentinde taban ve tavan bloğunda ~D-B gidişlidir ve batıya doğru dalımlıdır. Bu kıvrımlar Miyosen'de tabaka-paralel kısalma ile oluşan genişlemeye bağlı yapılarla ilişkilidirler. Alaşehir sıyrılma fayı, Salihli ve Alaşehir segmentleri arasındaki kıvrım eksenleri farkından da anlaşılacağı üzere, Pliyo-Kuvaterner yaşlı yüksek-açılı normal faylar tarafından kesilerek geriye doğru döndürülmüş ve güneye doğru eğilmiştir.

Anahtar Kelimeler: *Alaşehir Grabeni, Alaşehir sıyrılma fayı, Batı Anadolu, düşük- ve yüksek-açılı normal faylar, kıvrım ekseni, uzama lineasyonu, fay çizik lineasyonu.*

INTRODUCTION

Western Anatolia is part of the Aegean Extensional Province (AEP), which is an extensional regime driven by the complex convergence of the African and Eurasian plates (Şengör et al., 1985; Jolivet and Brun, 2010) (Figure 1a). There are five hypotheses to explain the tectonic evolution of the AEP. These include (a) the subduction roll-back along the Hellenic arc (c. 60-65 Ma; McKenzie, 1978; Le Pichon and Angelier, 1979, 1981; Mercier, 1981; Jackson and McKenzie, 1988; Meulenkamp et al., 1988, 1994; Kiseel and Laj, 1988; Thomson et al., 1998; Jolivet and Patriat, 1999; Jolivet and Faccenna, 2000; Okay and Satır, 2000; Gessner, et al., 2013; Jolivet et al., 2013), (b) tectonic escape (c. 12-11 Ma; Dewey and Şengör, 1979; Şengör et al., 1985; Şengör, 1987; Yılmaz et al., 2000), (c) orogenic collapse-core complex (c. 29 Ma; Dewey, 1988/Middle Miocene; Seyitoğlu and Scott, 1991, 1992/Early Miocene), (d) different and small convergence rates along the Cyprus trench (c. 30-25 Ma; Doglioni et al., 2002), and (e) episodic two-stage extension, first period: 29–5 Ma, and second period: 5 Ma–recent (Beccaletto and Stenier, 2005; Bozkurt and Rojay, 2005; Koçyiğit et al., 1999). The geology of Western Anatolia is dominated by many grabens that are filled with Miocene to Recent terrestrial clastic rocks, along with volcanic rocks and minor carbonates, as a result of widespread crustal extension that began during the Oligo-Miocene (Bozkurt, 2001; Seyitoğlu and Işık, 2015). There are two groups of Late Cenozoic grabens in western Anatolia, including (a) NNE-SSW-trending basins filled with Lower Miocene and younger siliciclastic, volcanoclastics, and volcanic rocks, and (b) E-W-trending basins filled with Lower Miocene and younger siliciclastic rocks (e.g., Şengör, 1987; Kaya, 1979; Yılmaz et al., 2000; Bozkurt, 2001; Seyitoğlu and Işık, 2015). The NNE-SSW-trending basins comprise the Gördes, Demirci, Uşak-Güre, Selendi, and Baklan grabens that are bounded by high-angle normal faults with strike-slip components (Yılmaz et al., 2000; Bozkurt, 2001, 2003) (Figure 1b). The E-W-trending basins include the Simav, Alaşehir (or Gediz), Küçük Menderes, and Büyük Menderes grabens that are bounded by high-angle to moderately dipping normal faults, which are seismically active (Arpat and Bingöl, 1969; Eyidoğan and Jackson, 1985; Bozkurt, 2001; Çiftçi and Bozkurt, 2009, 2010; Seyitoğlu and Işık, 2015) (Figure 1b). The NNE-SSW-trending grabens form 'hanging grabens' in the footwalls of the E-W-trending grabens and trapped structures and sedimentary rocks from the NNE-SSW-trending grabens are visible in seismic profiles (Yılmaz et al., 2000; Gürer et al., 2001).

Among the E-W-trending grabens, the Alaşehir Graben is the best developed in terms of structural elements and total offset along the graben-bounding structures (e.g., Bozkurt and Sözbilir, 2004; Çiftçi and Bozkurt, 2010). The graben is E-W-trending from Ahmetli to Turgutlu and NW-SE-trending from Salihli to Alaşehir (e.g., Seyitoğlu et al., 2002; Seyitoğlu and Işık, 2015) (Figure 1b).

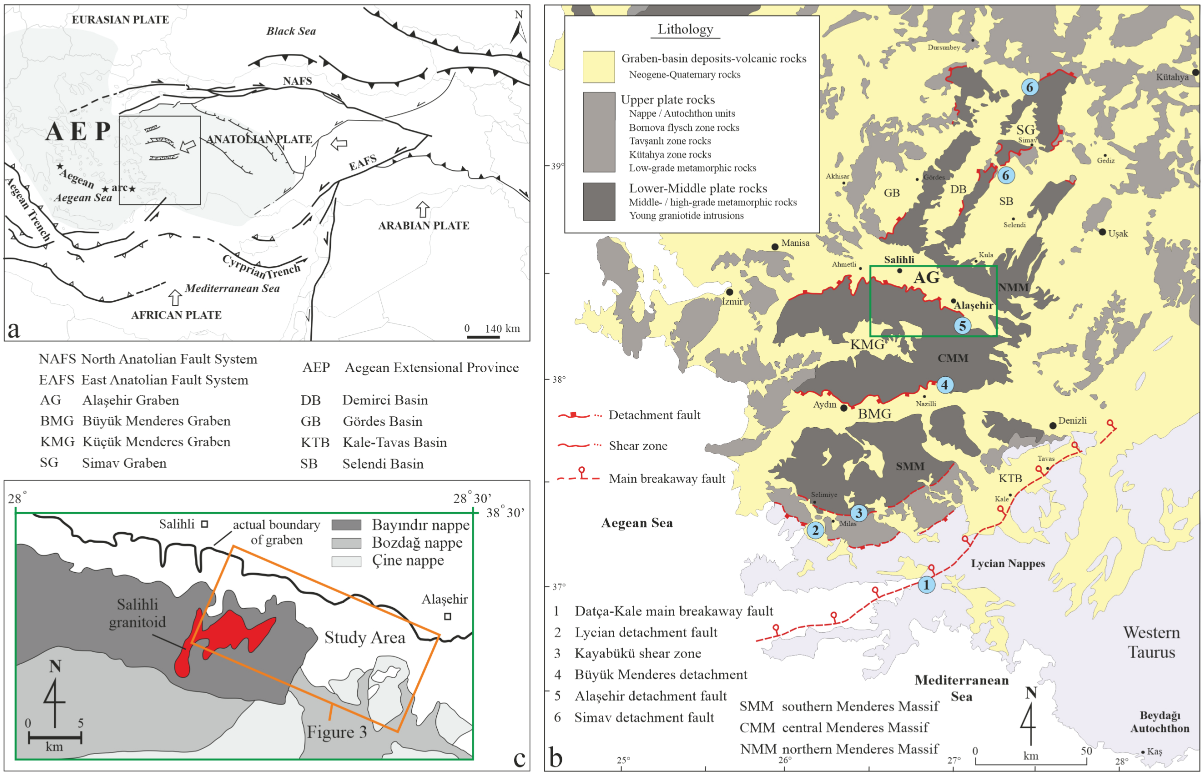

Figure 1. a) Simplified geological map of Western Anatolia showing the Aegean Extensional Province – AEP, (Bozkurt, 2001, 2007), **b)** the distribution of ~E–W-trending grabens and NE–SW-trending basins in the sub-massif of the Menderes Massif (Işık et al., 2003; Seyitoğlu and Işık, 2015) and **c)** the Bayındır-Bozdağ-Çine Nappes of the central sub-massif belonging of the Menderes Massif in the study area (Konak, 2002). The study area is also illustrated on the geological map.

***Şekil 1. a)** Batı Anadolu'nun Ege Genişleme Bölgesi'ni - AEP (Bozkurt, 2001, 2007), **b)** Menderes Masifi'nin alt masifi üzerindeki ~D–B gidişli grabenlerin ve KD–GB gidişli havzaların dağılımını (Işık vd., 2003; Seyitoğlu ve Işık, 2015) ve **c)** çalışma alanındaki Menderes Masifi'ne ait orta masifte yer alan Bayındır-Bozdağ-Çine Naplarını gösteren basitleştirilmiş jeoloji haritası (Konak, 2002). Çalışma alanı jeoloji haritasında da gösterilmiştir.*

The evolution of the Alaşehir Graben has been the focus of much work over the past thirty years (Emre, 1990, 1996; Cohen et al., 1995; Koçyiğit et al., 1999; Yılmaz et al., 2000; Seyitoğlu et al., 2002; Bozkurt and Sözbilir, 2004; Çemen et al., 2005; Purvis and Robertson, 2005; Çiftçi and Bozkurt, 2008; 2009, 2010; Öner and Dilek, 2011; Seyitoğlu and Işık, 2015). However, the development of the Alaşehir Graben has remained controversial, mainly on the basis of tectonic/structural and stratigraphic inferences. Different researchers stated that extension in the Alaşehir Graben was initiated in the latest Oligocene–early Miocene time and formed in two different deformation types; (1) the latest Oligocene–Miocene core-complex formation in the footwall of the present low-angle normal faults, and (2) the post-Miocene actual graben formation as a result of Plio-Quaternary high-angle normal faults (Bozkurt and Sözbilir, 2004; Seyitoğlu and Işık, 2015 and references therein). A major debate has remained unresolved as to whether the two distinct styles developed continuously without a temporal break (Seyitoğlu et al., 2000, 2002, 2004), or episodically, with more than one phase of expansion separated by periods of contraction (Koçyiğit et al., 1999; Yılmaz et al., 2000; Bozkurt and Sözbilir, 2004; Çiftçi and Bozkurt, 2008; 2009, 2010) and tectonic quiescence (Emre, 1990, 1996) during the Pliocene.

The southern margin of the Alaşehir Graben is bounded by the Alaşehir detachment fault[1], which contains cataclastic rocks. This is the surface of the Alaşehir detachment fault, which is exposed for ~150 km from Turgutlu to Alaşehir and dips to the north at a low-angle (10°-20°) (e.g., Emre, 1990, 1996; Işık et al., 2003). There are two different views regarding the tectonic evolution of the Alaşehir detachment fault. One group supports high-angle normal faults with domino-style faulting or listric faulting during the same deformation time as the low-angle detachment surface, which means a single extensional period (e.g., Seyitoğlu et al., 2002). The other group supports cutting relationships between the low-angle detachment surface and high-angle normal faults, which indicates two phases of extension (e.g., Bozkurt and Sözbilir, 2004).

The Alaşehir Graben has key meaning because it includes all the aspects of the geology of Western Anatolia, mainly evidence for distinct structural elements. The detailed stratigraphy and structure of Miocene and post-Miocene grabens in the Alaşehir Graben must be well documented in terms of depositional and extensional or deformational patterns. In this way, it can be determined whether the evolution of extension in the Alaşehir Graben, especially Western Anatolia, is continuous or episodic. In order to contribute to these discussions of the Alaşehir Graben, datasets of Fatih Şen and Hakan Ağırbaş, who worked in the field for three months in the summer of 2003 and prepared their BSc theses in 2004 and 2006 in the Alaşehir Graben (Western Anatolia), are presented. Öner and Dilek (2011) showed that these datasets, which they published by writing an erratum (Öner and Dilek, 2012) to the Geological Society of America Bulletin, belong to Şen (2004) and Ağırbaş (2006) and shared them with the entire earth sciences community. In this paper, the stratigraphy and structure of the Alaşehir Graben were reconstructed with a new perspective by using the stratigraphic and structural datasets of Şen (2004) and Ağırbaş (2006).

GEOLOGICAL FRAMEWORK OF THE ALAŞEHİR GRABEN

The Alaşehir Graben forms the boundary between the northern and central parts of the Menderes

1 The N-facing Alaşehir detachment fault in the Alaşehir Graben in the northern sector corresponds to the S-facing Büyük Menderes detachment fault, developing the Bayındır Nappe and Çine Nappes (Gessner, 2000) in the Büyük Menderes Graben in the southern sector of the Aegean Extensional Province (e.g., Ring et al., 1999; Bozkurt, 2000, 2001; Seyitoğlu and Işık, 2015).

Massif (e.g., Bozkurt and Sözbilir, 2004; Seyitoğlu and Işık, 2015) (Figure 1b). The study area is the northern part of the central sub-massif of the Menderes Massif, which is exposed from Salihli to Alaşehir at the southern margin of the Alaşehir Graben (e.g., Ring et al., 1999; Bozkurt, 2007; Seyitoğlu et al., 2014) (Figure 1b-c). The central sub-massif of the Menderes Massif consists of a nappe pile including the Bayındır, Bozdağ and Çine Nappes that formed during the late Precambrian to early Cambrian and early Cenozoic (e.g., Ring et al. 1999; Dora et al., 2001; Candan et al., 2016) (Fig. 1c). The emplacement of the nappes occurred during the early Eocene (e.g., Gessner, 2000). The Bayındır Nappe is structurally the lowest and consists of schists alternating with paragneiss of greenschist- to amphibolite facies (Dora et al., 2001; Erdoğan and Güngör, 2004). The Bozdağ Nappe is represented by amphibolite facies garnet-mica schists (Gessner et al., 2001). The Çine Nappe consists mainly of amphibolite to granulite facies orthogneisses intruding schist and marble alternating with metabasite (Oberhänsli et al. 1997; Candan et al. 2001).

The Alaşehir Graben formed as a half-graben with an active southern margin during the early to late Miocene, and it evolved into an asymmetric graben as a consequence of younger post-Miocene normal faulting at its northern and southern edges (Çiftçi and Bozkurt, 2009, 2010; Şengör and Bozkurt, 2012). The tectono-stratigraphy of the southern edge of the Alaşehir Graben consists of the Bayındır-Bozdağ-Çine Nappes and syn-extensional Middle Miocene Salihli granitoid (c. 15 Ma; Glodny and Hetzel, 2007) in the footwall of the detachment and Neogene-Quaternary graben fill in the hanging wall of the detachment. These units are separated by the Alaşehir detachment fault (e.g., Seyitoğlu et al., 2002; Bozkurt and Sözbilir, 2004; Seyitoğlu and Işık, 2015) (Figure 2).

There are many inconsistencies in the interpretation of the depositional age of the graben fills, although the Neogene-Quaternary stratigraphy of the Alaşehir Graben has been studied in considerable detail (Figure 2). New names given by the researchers have not been accurately compared with formations mentioned in previous studies due to a lack of detailed mapping. The difficulty of correlation has therefore led to the proposal of several stratigraphic schemes for the graben. It is not obvious whether the correlations are as reliable as suggested due to lateral and vertical facies variations in the fill. Hence, the difficulties of both stratigraphic and structural approaches are even more problematic for the Alaşehir Graben. The graben fills along the southern edge of the Alaşehir Graben can be grouped into three lithological assemblages based on several columnar sections (Figure 2). These include **(a)** Lower-Middle Miocene fills consisting of shale alternating with limestone (Alaşehir Formation, Seyitoğlu et. al., 2002), **(b)** Upper Miocene-Upper Pliocene sandstones and mudstones alternating with conglomerate (Acıdere and Göbekli Formations of Emre, 1990; Kurşunlu Formation of Seyitoğlu et al., 2002 and Çaltılık and Gediz Formations of Çiftçi and Bozkurt, 2009) and **(c)** an unconformably overlying, Plio-Quaternary semi-lithified sandstone and conglomerate (Asartepe Formation of Emre, 1990; Sart Formation of Seyitoğlu et al., 2002 and Kalatepe Formation of Çiftçi and Bozkurt, 2009) (Figure 2).

The faults along the southern edge of the Alaşehir Graben are mainly grouped into three types. **(a)** The E-W-trending, N-dipping (0° to 32°), presently low-angle normal/detachment fault (Allahdiyen fault; Emre, 1990; Karadut fault; Emre, 1996; Emre and Sözbilir, 1997; Çamköy detachment; Koçyiğit et al., 1999; Gediz detachment; Lips et al., 2001; Sözbilir, 2001; Yılmaz et al., 2000; Kuzey detachment; Gessner et al., 2001; Ring et al., 2003 and Alaşehir detachment; Işık et al., 2003).

The footwall of the Alaşehir detachment consists of high-grade metamorphic rocks of the Menderes Massif and the syn-extensional Salihli granitoid intruding them (Emre, 1990; Hetzel et al., 1995a & b; Glodny and Hetzel, 2007; Seyitoğlu and Işık, 2015). They exhibit the effects of ductile and brittle deformation, and are represented by a 60-150 m thick mylonitic and cataclastic zone as a result of the deep-seated part of the fault approaching the surface (e.g. Işık et al., 2003). The Alaşehir detachment fault consists of the Salihli and Alaşehir segments. It has a convex-upward morphology, which was described as a turtleback surface in the Salihli segment (Çemen et al., 2005; Seyitoğlu et al., 2014). Large-scale corrugations are interpreted to have formed nearly NNE-SSW–trending antiform and synform structures in the footwall of the detachment during ongoing movement (Sözbilir, 2001). Low-angle normal faults without cataclastic rocks in the Alaşehir area between Gökçealan and Tahtacı are thought to correspond to the Alaşehir detachment fault, which has turtle-back surfaces at Horzum in the Salihli area (Seyitoğlu et al., 2002, 2014; Bozkurt and Sözbilir, 2004; Çiftçi and Bozkurt, 2009). **(b)** NNE-SSW-trending, E- and W-dipping (85° to 60°) oblique-slip scissor or hinge faults. It is claimed these faults are observed within the approximately NNE-SSW trending stream valleys and are mostly preserved in the Salihli segment of the Alaşehir detachment fault (Öner and Dilek, 2011, 2013). They also have reverse fault components (Öner

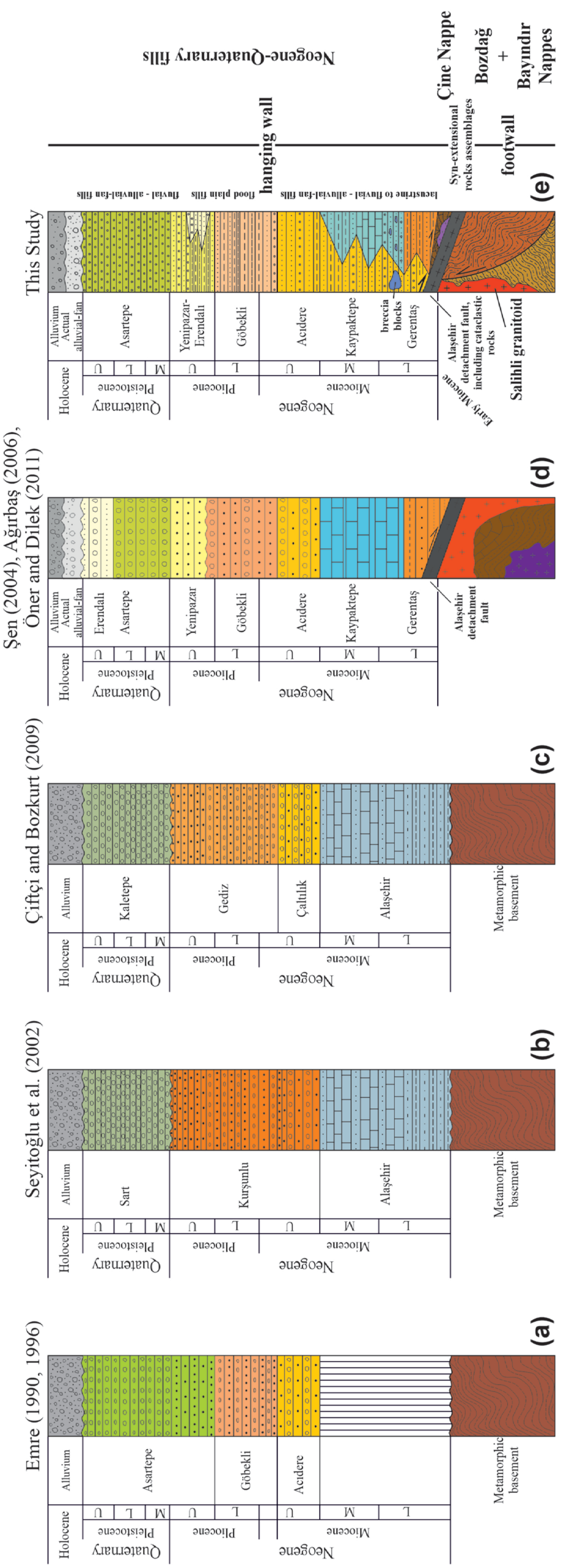

Figure 2. Stratigraphy of the southern margin of the Alaşehir Graben in the study area and its correlation with the most recent literature. **(a)** Emre (1990, 1996), **(b)** Seyitoğlu et al. (2002), **(c)** Çiftçi and Bozkurt (2009), **(d)** Şen (2004), Ağırbaş (2006), Öner and Dilek (2011), **(e)** This study.

Şekil 2. *Alaşehir Grabeni'nin çalışma alanındaki güney kenarının stratigrafisi ve güncel literatür ile ilişkisi.* ***(a)*** *Emre (1990, 1996),* ***(b)*** *Seyitoğlu vd., (2002),* ***(c)*** *Çiftçi ve Bozkurt (2009),* ***(d)*** *Şen (2004), Ağırbaş (2006), Öner ve Dilek (2011),* ***(e)*** *Bu çalışma.*

and Dilek, 2011). **(c)** E-W-trending, N-dipping (≥ 40°) modern graben-bounding normal faults of different sizes with a graben-facing step-like pattern dominated by first-order major and second-order synthetic to antithetic faults (e.g., Bozkurt and Sözbilir, 2004; Çiftçi and Bozkurt, 2009). They juxtapose the Miocene graben fills with either metamorphic rocks of the Menderes Massif or Plio-Quaternary graben fills and separate older rock assemblages from alluvial fan and graben floor fills (e.g., Bozkurt and Sözbilir, 2004). The alluvial fans and alluvium of the Alaşehir Graben are cut by the Yenipazar-Dereköy faults, which are actual graben-bounding normal major faults, and caused the Alaşehir earthquake of 28 March 1969 (M=6.9), which formed a N50°-85°W trending surface rupture 30-35 km in length (Arpat and Bingöl, 1969; Eyidoğan and Jackson, 1985). The Yenipazar-Dereköy faults are synthetic faults of the Keserler fault, which is a major high-angle normal fault in the southern part of the Alaşehir Graben (e.g. Emre, 1990, 1996; Sözbilir, 2001), based on a seismic reflection profile (Çiftçi and Bozkurt, 2009, 2010).

The folds along the southern margin of the Alaşehir Graben are essentially grouped into two types. **(a)** A series of broad E–W-trending broad anticlines and synclines with fold axes sub-parallel to the graben bounding faults, deforming only Miocene fills. Koçyiğit et al. (1999) first reported folds in the Miocene deposits of the Alaşehir Graben and assumed a horizontal position for the Plio-Quaternary fills above an angular unconformity. They attributed the mentioned folds to north-south shortening as a result of a presumed short-lived north-south compression on a regional scale during the Late Miocene to Early Pliocene. Seyitoğlu et al. (2000) attributed these folds to the movement of Miocene fills over listric normal faults, forming drag folds and roll-over anticlines during ongoing extension. The formation of these folds observed in Miocene deposits depends on the movement of the Plio-Quaternary high-angle normal faults, which means that the effects of regional compression are absent (e.g., Seyitoğlu, 1999). **(b)** A series of narrow N-S-trending broad anticlines and synclines with axes sub-perpendicular to the modern graben, deforming only Miocene fills. Çiftçi and Bozkurt (2008) discovered the folds together with minor reverse faults in Lower-Middle Miocene fills in a narrow space in the Alaşehir Graben, and stated that these structures indicate ~N-S direction of compression forming contractional deformation as proposed by Koçyiğit et al. (1999). However, their limited distribution prevents them from being confidently related to regional deformation. Şengör and Bozkurt (2012) stated that these folds are related to extensional structures formed by layer-parallel shortening, as there is no episode of erosion between the superposed structures[2] in the Lower-Middle Miocene fills found by Çiftçi and Bozkurt (2008).

RESULTS OF GEOLOGICAL MAPPING IN THE SOUTHERN MARGIN OF THE ALAŞEHİR GRABEN

Geological mapping and structural analyses were undertaken on the footwall and hanging wall of the Alaşehir detachment fault along the southern edge of the Alaşehir Graben located between Salihli and Alaşehir based on the studies conducted by Şen (2004) and Ağırbaş (2006) in the summer of 2003 (Figure 2e, 3 & 4). The mapping study was carried out without examining

2 Superposed folds are complex folds formed by the superimposition of an early fold set with one or more later fold sets. The resulting fold geometry is referred to as a fold interference pattern. Superposed folds can form during a single deformation event or during different deformation events in a single orogeny (Bhattacharya, 2022). During superposed deformation, an early fold (F_1) can either tighten or open out. Opening out is possible if there is bulk extension across the axial plane of F_1 during the second deformation (F_2). The theoretical model suggests that the rate of opening is largely controlled by the initial tightness of the fold.

previous studies (Şen, 2004; page of 7; Ağırbaş, 2006; page of 12). During the geological mapping studies, rock stratigraphic units were established by tracing contacts. To establish the stratigraphy, the relationship between the unit boundaries was examined and to determine the structural positions of each unit, structural elements (bedding positions, fault planes, fault lineations, extension lineations, foliation planes) were measured from the observation points and recorded on the map using a Brunton brand compass. A minimum of 10 measurements were made per square kilometer. The results of these studies are briefly explained below.

Stratigraphic Correlation

The tectonostratigraphy of the southern margin of the Alaşehir Graben is represented by the Bayındır-Bozdağ Nappes and the syn-extensional Salihli granitoid intruding the Bayındır Nappe and cataclastic rocks in the footwall of the Alaşehir detachment fault, and the Çine Nappe and the Neogene-Quaternary fills in the hanging wall of the Alaşehir detachment fault based on the geological map and cross-sections (Figure 3 & 4). The Miocene fills were also deposited above the Çine Nappe, which overlies the Alaşehir segment of the Alaşehir detachment fault, and contacts are structural elements comprising low-angle normal faults in the Alaşehir area (Figure 4 & 5).

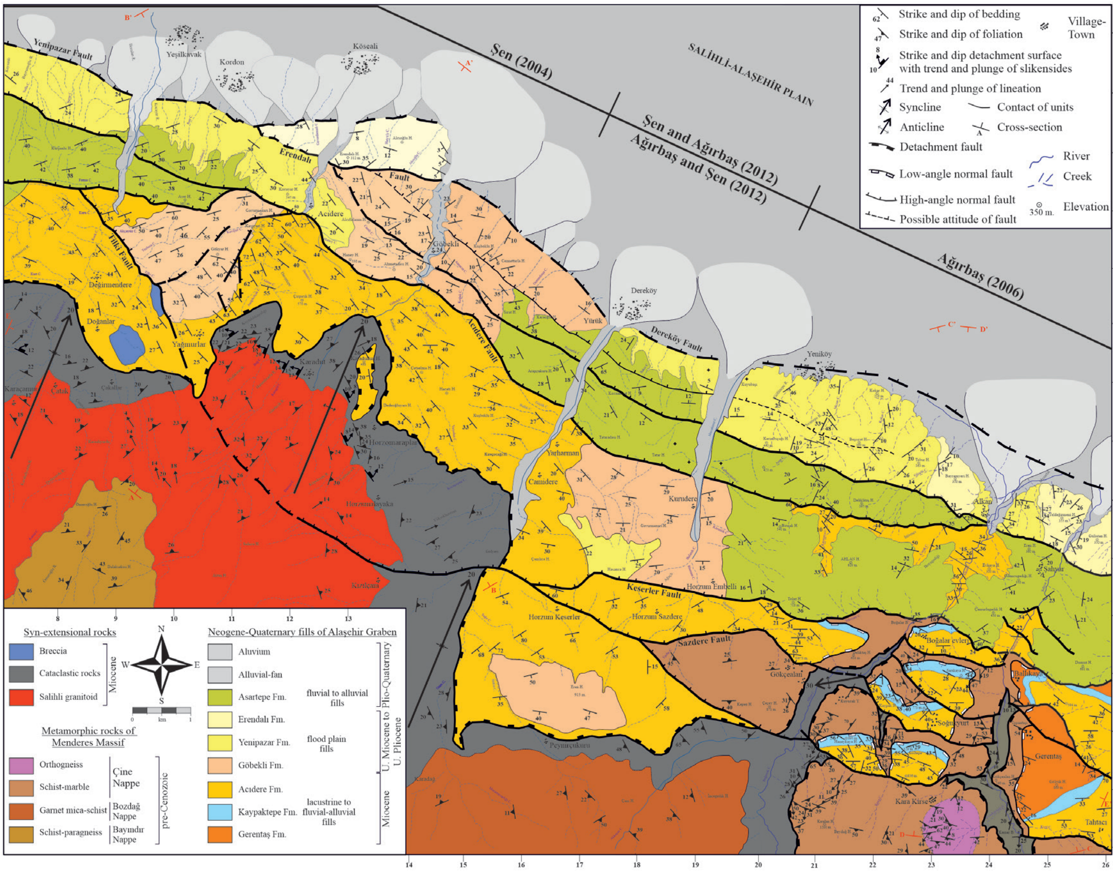

Figure 3. Geological map of the southern margin of the Alaşehir Graben in the area between Karaçamur in the Salihli area and Tahtacı in the Alaşehir area (Şen, 2004; Ağırbaş, 2006; Şen and Ağırbaş, 2012; Ağırbaş and Şen, 2012).

Şekil 3. *Salihli'de Karaçamur ile Alaşehir'de Tahtacı arasında kalan alandaki Alaşehir Grabeni'nin güney kenarının jeolojik haritası (Şen, 2004; Ağırbaş, 2006; Şen ve Ağırbaş, 2012; Ağırbaş ve Şen, 2012).*

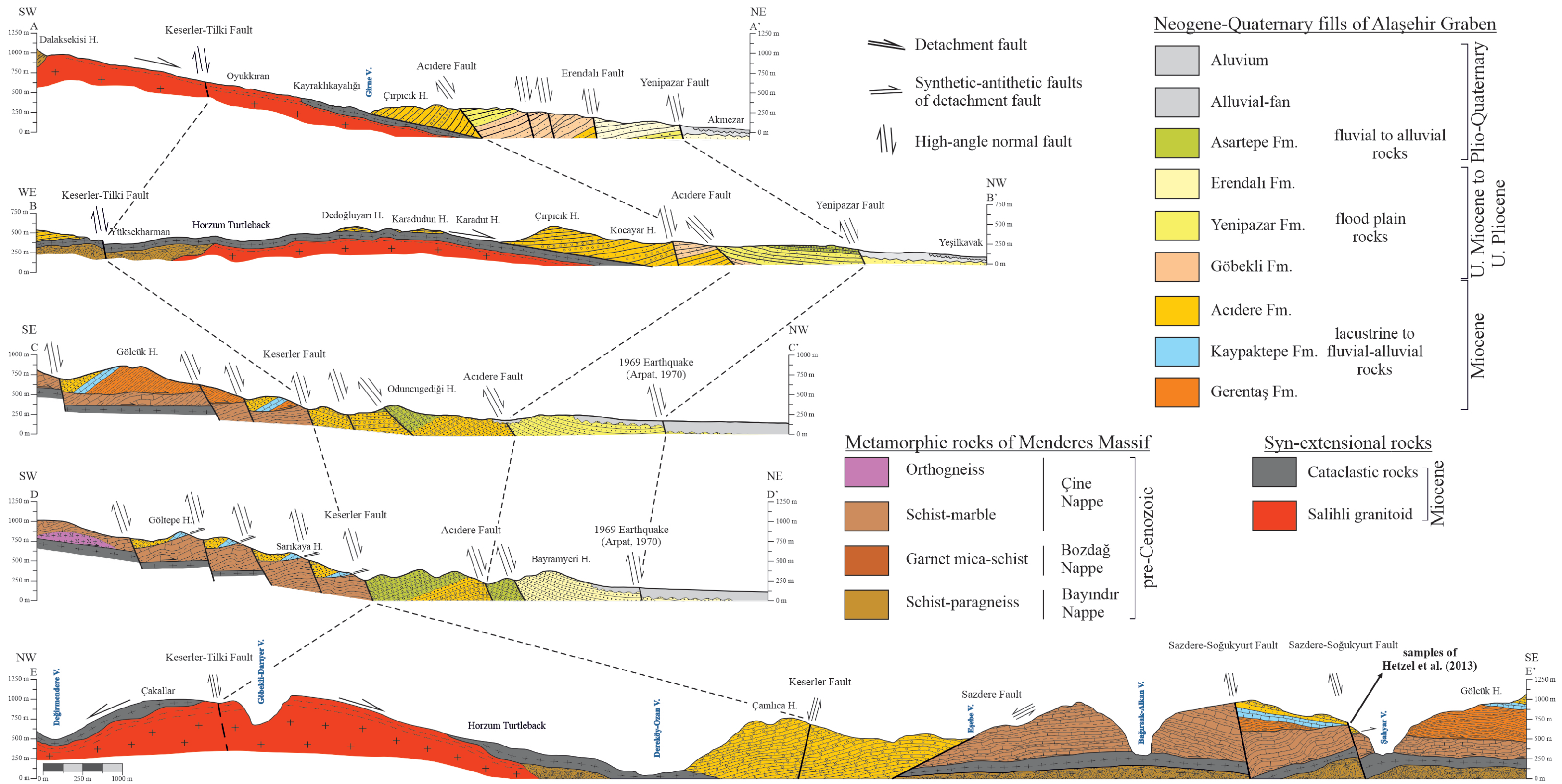

Figure 4. Geological cross-sections of the southern margin of the Alaşehir Graben (Şen, 2004 for A-A' and B-B; Ağırbaş, 2006 for C-C' and D-D', Şen and Ağırbaş (2012) and Ağırbaş and Şen (2012) for E-E' cross-sections). See Figure 3 for the location of cross-sections in the study area. Note that the E-E' section is perpendicular to the other sections and approximately parallel to the Alaşehir Graben.

Şekil 4. Alaşehir Grabeni güney kenarındaki jeolojik kesitler (A-A' ve B-B' için Şen, 2004; C-C' ve D-D' için Ağırbaş, 2006, E-E' kesiti için Şen ve Ağırbaş (2012) ve Ağırbaş ve Şen (2012)' den alınmıştır. Çalışma alanındaki enine kesitlerin konumu için Şekil 3'e bakınız. E-E' kesitinin diğer kesitlere dik ve Alaşehir Grabeni'ne yaklaşık olarak paralel olduğunu unutmayın.

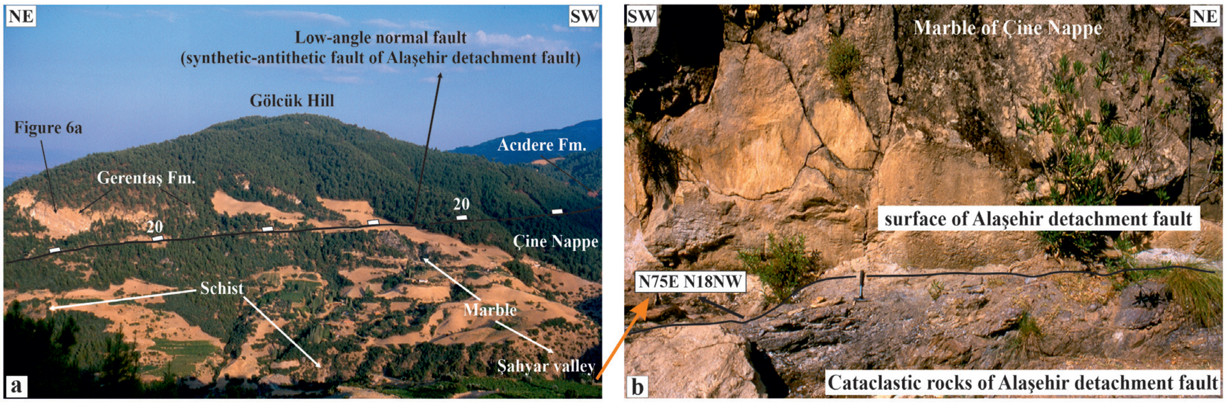

Figure 5. Outcrop views of **(a)** the Gerentaş Formation tectonically overlying the Çine Nappe, which is structurally located above the Alaşehir detachment fault and **(b)** the Çine Nappe located above the Alaşehir detachment fault along the Şahyar valley (35S 0624603/4242398) (Ağırbaş, 2006).

***Şekil 5. (a)** Alaşehir sıyrılma fayı üzerinde yapısal olarak yer alan Çine Napını tektonik olarak örten Gerentaş Formasyonun ve **(b)** Şahyar vadisi boyunca Alaşehir sıyrılma fayı üzerinde yer alan Çine Napı'nın (35S 0624603/4242398) mostra görüntüleri (Ağırbaş, 2006).*

The graben fills (>3000 m: Çiftçi and Bozkurt, 2010; Ağırbaş and Şen, 2012) are mainly exposed along the southern edge of the graben and consist of terrestrial clastic sedimentary rocks and semi-lithified deposits that extend from the Miocene to the Plio-Quaternary without any unconformity (Figure 2e, 6 & 7). They consist of Miocene fills (Gerentaş-Kaypaktepe-Acıdere Formations), Upper Miocene-Upper Pliocene fills (Göbekli-Yenipazar-Erendalı Formations) and Plio-Quaternary fills (Asartepe Formation) (Şen, 2004; Ağırbaş, 2006) (Figure 2e). The nomenclature and contents of the graben fills along the southern margin of the Alaşehir Graben were interpreted by different researchers (e.g., Emre, 1990, 1996; Seyitoğlu et al., 2002; Çiftçi and Bozkurt, 2009; Öner and Dilek, 2011) (Figure 2a & d). The generalized columnar section presented in this paper is the dataset from two BSc theses conducted by Şen (2004) and Ağırbaş (2006).

The Alaşehir Graben sequence begins at the base with the Gerentaş Formation, which consists of red shale alternating with conglomerate-sandstone-mudstone overlain by red mudstone and conglomerate with limestone interbeds of the Kaypaktepe Formation (Ağırbaş, 2006) (Figure 3 & 6). Ağırbaş (2006) stated that the two units correspond to the Alaşehir Formation in previous studies (Seyitoğlu et al., 2002; Çiftçi and Bozkurt, 2009) (Figure 2b & c). They were deposited in a lacustrine and fan-delta depocenter (e.g., Seyitoğlu et al., 2002) tectonically overlying the Çine Nappe, which is structurally located above the Alaşehir segment of the Alaşehir detachment fault (Ağırbaş, 2006) (Figure 3 & 5). Their depositional age is Early-Middle Miocene based on the Eskihisar sporomorph association (Ediger et al., 1996; Şen and Seyitoğlu, 2009). They pass laterally and vertically into alluvial-fan and fluvial deposits consisting of red and gray mudstone-sandstone alternating with conglomerate called the Acıdere Formation of Middle to Upper Miocene age (Ediger et al., 1996; Emre, 1996). However, breccias belonging to the Salihli segment of the Alaşehir detachment fault in the lower beds of this deposit correspond to breccias of the Kaypaktepe Formation (Ağırbaş, 2006) (Figure 6b & e). This result shows that the lower age of the Acıdere

Formation is Lower Miocene, overlying the Bayındır Nappe in the Salihli segment of the Alaşehir detachment fault (Şen, 2004) (Figure 2 & 4). Şen (2004) also defined the Acıdere Formation as corresponding to the Çaltılık Formation (Çiftçi and Bozkurt, 2009) or the lower levels of the Kurşunlu Formation (Seyitoğlu et al., 2002) (Figure 2b, c & e). The Acıdere Formation conformably continues with the Göbekli Formation including light red and gray mudstone, sandstone and conglomerate (Figure 2e). It was deposited in a flood plain (Emre, 1990; Şen, 2004) during the late Miocene to early Pliocene (Emre, 1996; Purvis and Robertson, 2005). It grades vertically into the Yenipazar Formation, which consists of fine-grained clastics of floodplain deposits interbedded with peat laminations that laterally pass into the Erendalı Formation comprising fine- and coarse-grained clastics from channel fills in the floodplain (Şen, 2004; Ağırbaş, 2006; Ağırbaş and Şen, 2012) (Figure 2e & 7). The age is Upper Pliocene (Sarıca, 2000). Şen (2004) stated that the Göbekli-Yenipazar-Erendalı Formations correspond to the Gediz Formation (Çiftçi and Bozkurt, 2009) or the upper levels of the Kurşunlu Formation (Seyitoğlu et al., 2002) (Figure 2b & c) and they correspond to the lower levels of the Asartepe Formation (Emre, 1990, 1996) (Figure 2a) in previous studies. The Yenipazar Formation is conformably overlain by coarse-grained clastics of fluvial to alluvial-fan deposits termed the Asartepe Formation (Şen, 2004; Ağırbaş, 2006) (Figure 2e & 7e). The age is Plio-Quaternary as the upper levels of the Yenipazar Formation are Upper Pliocene according to Sarıca (2000) (Figure 2).

Faults

Three types of major faults are observed from Salihli to Alaşehir on the southern margin of the Alaşehir Graben.

(a) The southern margin of the Alaşehir Graben is bordered by a predominantly E-W striking, N-dipping and low-angle (8°-20°) Alaşehir detachment fault (Figure 3, 4, 8a & 9a). The Alaşehir detachment fault is represented by the structural juxtaposition of underlying high-grade metamorphic rocks of the Menderes Massif and overlying Miocene fills. The footwall of the Alaşehir detachment fault crops out over an area of ~13 km² and consists of high-grade metamorphic rocks of the Bayındır and Bozdağ Nappes and the syn-extensional Salihli granitoid intruding the Bayındır Nappe. The hanging wall of the Alaşehir detachment fault includes the Çine Nappe and Neogene-Quaternary fills (Figure 3 & 4). The Miocene graben fills that tectonically overlie the Çine Nappe lie above the Alaşehir segment of the Alaşehir detachment fault (Figure 3 & 5). The turtleback surfaces at Horzum in the Salihli segment correspond to the bottom of the Bağırsak-Alkan and Şahyar valleys in the Alaşehir segment of the Alaşehir detachment fault (Figure. 3 & 4).

(b) Low-angle (5°-30°) normal faults have E-W strike and N- and S-dip (Figure 3 & 8b) and crosscut both metamorphic rocks belonging to the Çine Nappe and the Miocene graben fills, except for the Göbekli Formation (Figure 3, 4, 9b, & 10b, c). They are similar to the movement and geometry of the Alaşehir detachment fault that lies beneath the Miocene graben fills; however, these low-angle normal faults differ from the detachment fault because they do not crosscut the Alaşehir detachment fault (Figure 3 & 4). These faults, without cataclastic rocks, are generally observed in NNE-SSW valleys, as in the Kısıkdere valley in the Salihli area and in the Tekedören valley in the Alaşehir area (Figure 9a & 10c). Low-angle normal faults dip to the south in the Haneykaya and Göltepe hills in the Alaşehir area (Figure 3, 4, 8b & 10c). In addition, they do not crosscut the Upper Miocene-Upper Pliocene Göbekli-Yenipazar-Erendalı Formations, representing floodplain deposits (Figure 3, 4, 9b, 10b & c).

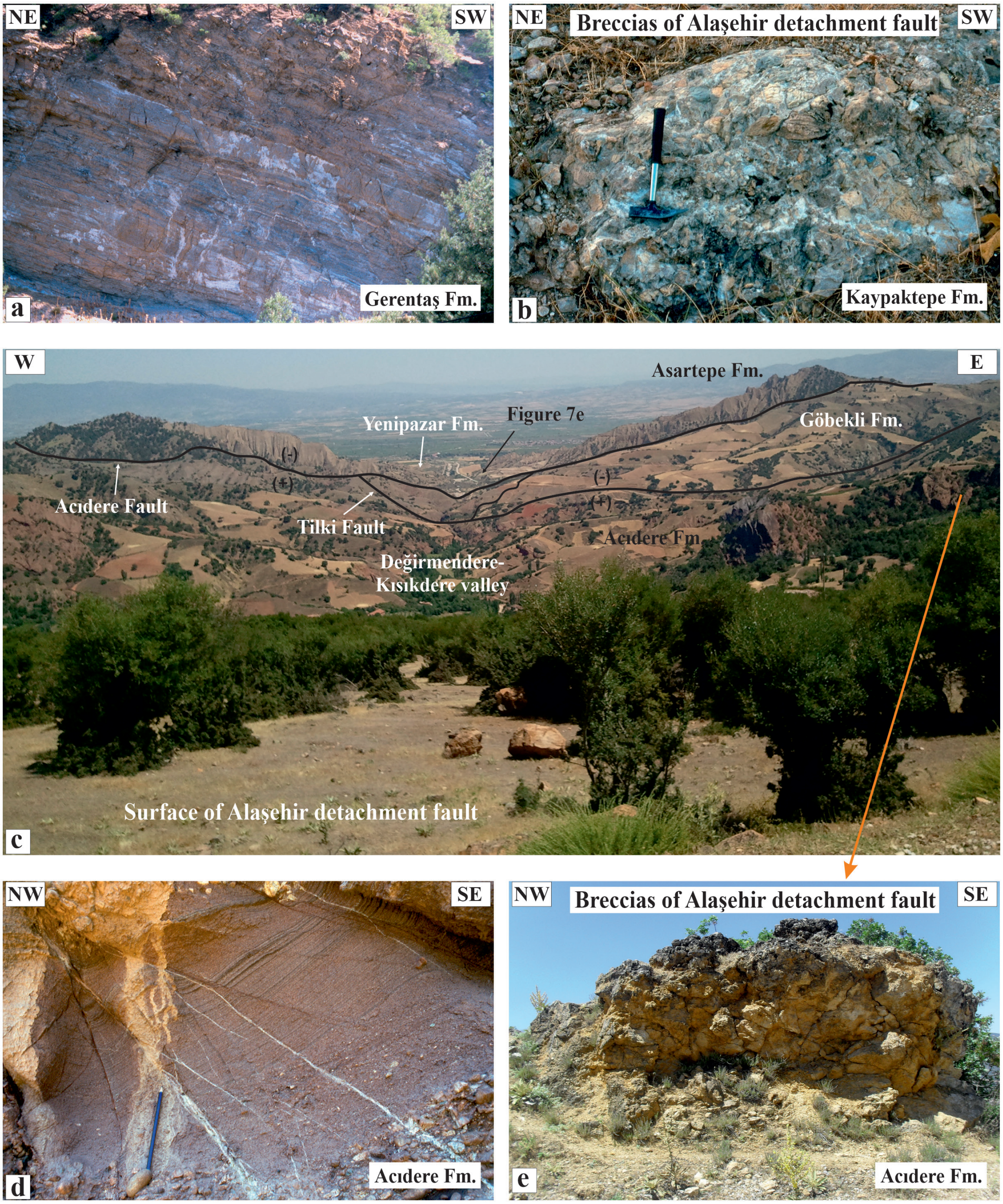

Figure 6. Outcrop views of **a)** shale beds in the Gerentaş Formation in the Alaşehir area, **b)** breccias of the Alaşehir detachment fault in the Kaypaktepe Formation in the Alaşehir area, **c & d)** outcrops of the Acıdere Formation in Salihli and **e)** breccias of the Alaşehir detachment fault in the Acıdere Formation in Salihli (35S 0609204/4252495) (Şen, 2004; Ağırbaş, 2006).

Şekil 6. a) *Gerentaş Formasyonu'nun Alaşehir'deki şeyl tabakalarının,* ***b)*** *Alaşehir'deki Kaypaktepe Formasyonu'ndaki Alaşehir sıyrılma fayı breşlerinin,* ***c ve d)*** *Salihli' deki Acıdere Formasyonu'nun yüzleklerinin ve* ***e)*** *Salihli'deki Acıdere Formasyonu içindeki Alaşehir sıyrılma fayı breşlerinin mostra görüntüleri (35S 0609204/4252495) (Şen, 2004; Ağırbaş, 2006).*

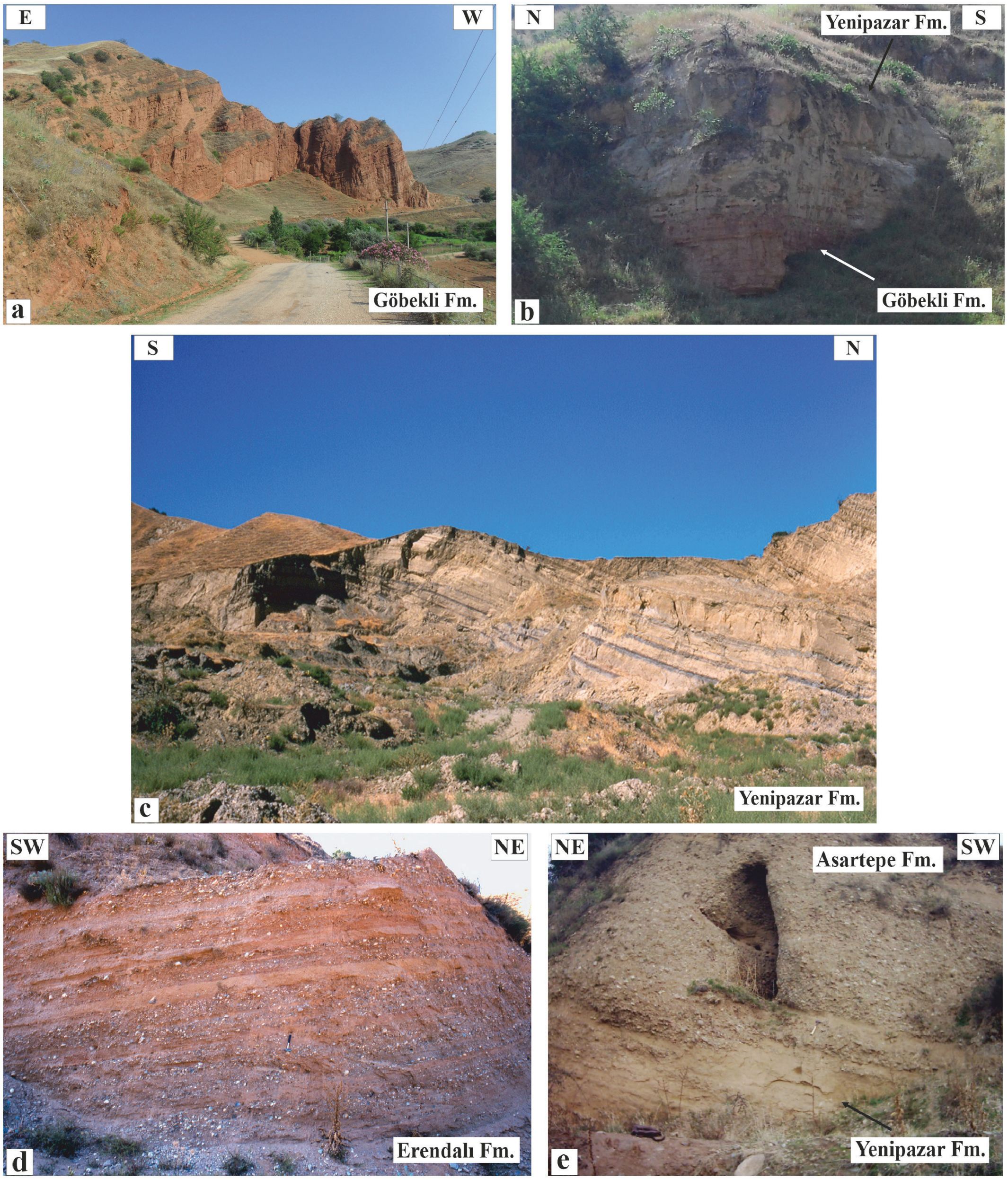

Figure 7. Outcrop views of **(a)** sandstone beds in the Göbekli Formation in Salihli, **b)** the Yenipazar Formation conformably overlying the Göbekli Formation in the Alaşehir area (35S 0615542/4253152), **c)** peat laminations of the Yenipazar Formation in Salihli, **d)** sandstone and conglomerate strata of the Erendalı Formation in Alaşehir and **e)** the Asartepe Formation conformably overlying the Yenipazar Formation in Salihli (35S 609229/4255905) (from Şen, 2004; Ağırbaş, 2006, Şen and Ağırbaş, 2012; Ağırbaş and Şen, 2012).

Şekil 7. a) *Salihli'deki Göbekli Formasyonu'nun kumtaşı tabakalarının,* ***b)*** *Alaşehir'deki Göbekli Formasyonu'nu uyumlu olarak üzerleyen Yenipazar Formasyonu'nun (35S 0615542/4253152),* ***c)*** *Salihli'deki Yenipazar Formasyonu'nun turba laminasyonlarının,* ***d)*** *Alaşehir'deki Erendalı Formasyonu'nun kumtaşı ve konglomera tabakalarının ve* ***e)*** *Salihli'deki Yenipazar Formasyonu'nu uyumlu olarak üzerleyen Asartepe Formasyonu'nun (35S 609229/4255905) mostra görüntüleri (Şen, 2004; Ağırbaş, 2006; Şen ve Ağırbaş, 2012; Ağırbaş ve Şen, 2012).*

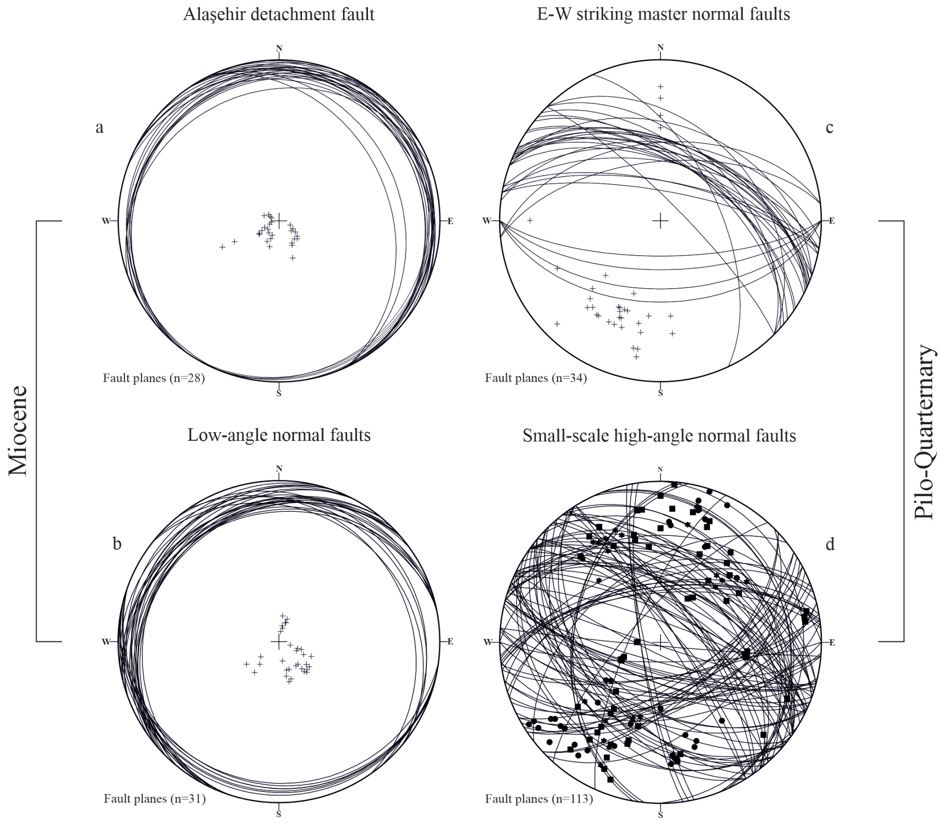

Figure 8. Lower hemisphere equal area projections of various fault types. **a)** Surfaces of the Alaşehir detachment fault, **b)** low-angle normal faults, **c)** E-W striking master high-angle normal faults, **d)** small-scale high-angle normal faults.

Şekil 8. *Farklı fay türlerinin alt yarım küre eşit alan izdüşümleri.* ***a)*** *Alaşehir sıyrılma fayının yüzeyleri,* ***b)*** *düşük-açılı normal faylar,* ***c)*** *D-B doğrultulu ana yüksek-açılı normal faylar,* ***d)*** *küçük ölçekli yüksek-açılı normal faylar.*

(c) The third fault type is high-angle normal faults, which are approximately E-W trending and 40°-75° dipping (Figure 3, 4, 8c, d &10b, d). They crosscut the footwall and hanging wall of the Alaşehir detachment fault. They continue from Salihli to Alaşehir. Shorter segments are nearly 3-15 km in length (Figure 3 & 4). The master high-angle faults are the Keserler-Acıdere faults in the south and the Yenipazar-Erendalı-Dereköy faults in the north (Figure 3 & 4). They have both synthetic-antithetic and conjugate faults. Synthetic and antithetic faults related to high-angle faults range in size from several meters to a few centimeters (Figure 10d). The high-angle Keserler normal fault crosscuts high-grade metamorphic rocks of the Menderes Massif and cataclastic rocks of the Alaşehir detachment fault (Figure 3 & 4). The Keserler fault in Alaşehir extends to the Kaymaktutan and Tilkidere valley and continues with the high-angle Acıdere normal fault in Salihli (Figure 3 & 4). The Acıdere fault, located between the Keserler fault and the Yenipazar-Dereköy fault, is nearly 13 km long and roughly parallel to the NW-SE Alaşehir Graben. It juxtaposes older fills (Acıdere-Göbekli Formations) with younger fills (Yenipazar-Erendalı and Asartepe Formations) (Figure 3 & 4).

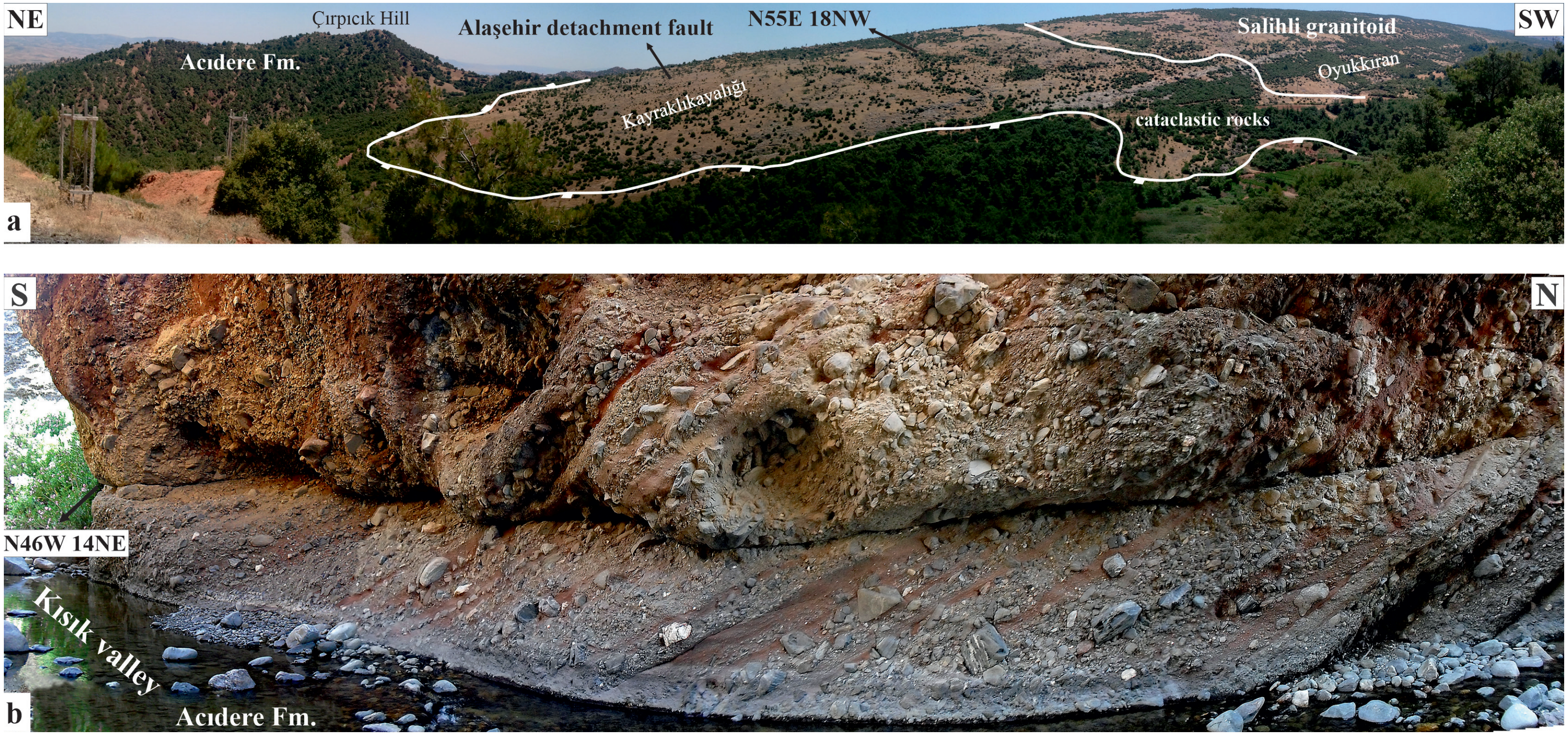

Figure 9. Photographs illustrating some different fault types observed in the Alaşehir Graben in the Salihli area. **a)** the Alaşehir detachment fault and its relationship to the Acıdere Formation, **b)** low-angle normal fault crosscutting the Acıdere formation in Kısıkdere valley in the Salihli area (Şen, 2004). See Figure 3 for the locations of the photos.

Şekil 9. *Salihli' deki Alaşehir Grabeni'nde gözlenen bazı farklı fay tiplerini gösteren fotoğraflar.* ***a)*** *Alaşehir sıyrılma fayı ve Acıdere Formasyonu ile ilişkisini gösteren saha fotoğrafı,* ***b)*** *Salihli mevkii Kısıkdere vadisinde Acıdere Formasyonu'nu kesen düşük-açılı normal fayı gösteren saha fotoğrafı (Şen, 2004). Fotoğrafların konumları için Şekil 3'e bakınız.*

Folds

Several folds are defined in the footwall and hanging wall of the Alaşehir detachment fault, which consists of two segments of the Salihli and Alaşehir segments (Figure 3, 11 & 12). The measurements obtained from foliations on the surface of the Alaşehir detachment fault in the Salihli segment show that the β axis is N20°E trending and 20° NE plunging with stretching lineations plunging to the northeast and northwest. Slickensides on the Alaşehir detachment fault plunge to both northwest and northeast into fold limbs, corresponding to this fold axis (Figure 11a, b & 12a, c). Measurements taken from high-grade metamorphic rocks belonging to the Bayındır and Bozdağ Nappes located ~ 150 meters beneath the Salihli segment of the Alaşehir detachment fault show that the β axis is N10°E trending and 8° NE plunging (Figure 11c & 12d). This indicates that the Salihli segment of the Alaşehir detachment fault is folded, with the axes of the folds being NE-directed and plunging mainly eastward at angles of 8°-20°. Looking at the geological map by Şen (2004), the fold axes are located along the NNE-SSW trending Değirmendere-Yeşilkavak, Darıyer-Göbekli and Ozan-Dereköy valleys (Figure 3).

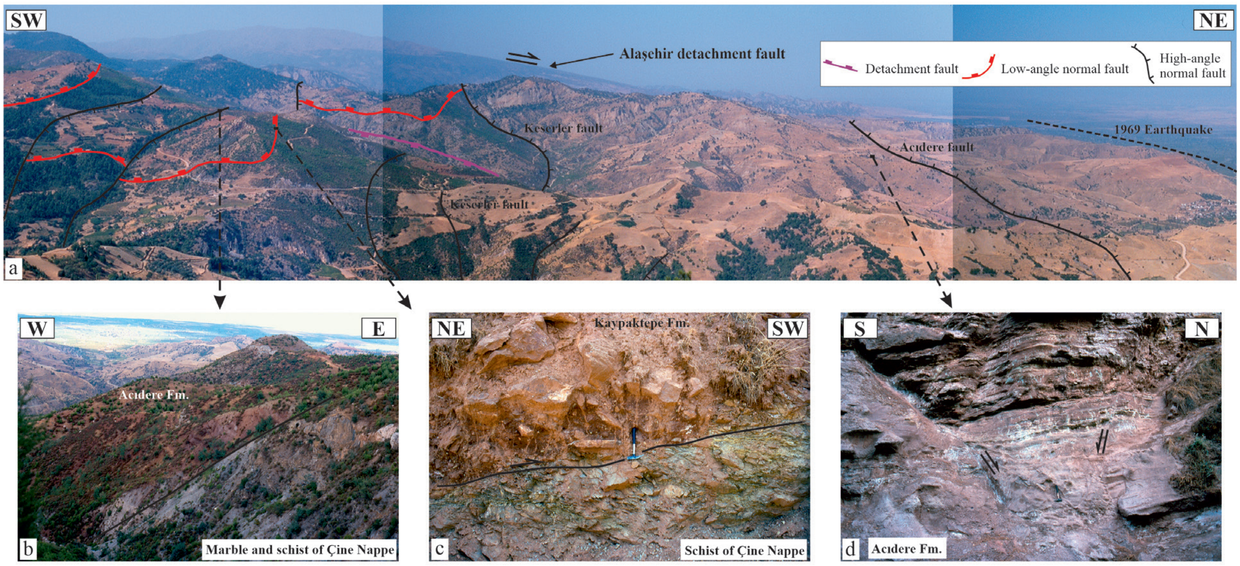

Figure 10. Some different fault types observed in the Alaşehir Graben in the Alaşehir area. **a)** the relationship between the Alaşehir detachment fault with low-angle normal faults and high-angle normal faults, **b)** photo displaying a high-angle normal fault between the Acıdere Formation and marble and schist of the Çine Nappe in Bağırsak-Alkan valley, **c)** a low-angle normal fault between the Kaypaktepe Formation and the Çine Nappe in the Bağırsak-Alkan valley, and **d)** synthetic and antithetic faults of E-W striking major normal faults crosscutting the Acıdere Formation in the Çorak valley (Ağırbaş, 2006). See Figure 3 for the locations of the photos.

Şekil 10. *Alaşehir bölgesinde Alaşehir Grabeni'nde gözlenen bazı farklı fay tiplerini gösteren fotoğraflar.* ***a)*** *Alaşehir sıyrılma fayı ile düşük-açılı normal faylar ve yüksek-açılı normal faylar arasındaki ilişkiyi gösteren arazi fotoğrafı,* ***b)*** *Bağırsak-Alkan vadisinde Acıdere Formasyonu ile Çine Napının mermer ve şistleri arasındaki yüksek-açılı normal fayı gösteren fotoğraf,* ***c)*** *Bağırsak-Alkan vadisinde Kaypaktepe Formasyonu ile Çine Napı arasındaki düşük-açılı normal fayı gösteren fotoğraf, ve* ***d)*** *Çorak vadisinde Acıdere Formasyonunu kesen D-B doğrultulu majör yüksek-açılı normal fayların sintetik ve antitetik faylarını gösteren fotoğraf (Ağırbaş, 2006). Fotoğrafların konumları için Şekil 3'e bakınız.*

The measurements obtained from foliations on the surface of the detachment fault in the Alaşehir segment of the Alaşehir detachment fault show the β axis is N80°E trending and 30° SW plunging with stretching lineations plunging to the northwest and southwest. Slickensides on the Alaşehir segment of the Alaşehir detachment fault plunge to the northwest and southwest into fold limbs, following this fold axis (Figure 11d & 12e, g). Measurements taken from high-grade metamorphic rocks belonging to the Çine Nappe above the Alaşehir detachment fault show that there are two different folds, implying that the β_1 axis trends N8°W and plunges 12° SE and the β_2 axis trends N62°E and plunges 26° SW (Figure 12h). Kink bands in the orto-gneisses intruding the schist and marble intercalations of the Çine Nappe and in the shale beds of the Gerentaş Formation in the hanging wall of the Alaşehir detachment fault show that the β axis trends N85°E and plunges 25° SW, corresponding to ~ E–W-trending folds (Figure 11e, f & 12i). It is understood that the β_1 axis in the Çine Nappe overlying the Alaşehir detachment fault belongs to pre-Miocene time (Figure 12h). This is evidence that the Alaşehir segment of the Alaşehir detachment fault is folded, with the axes of the folds being NE-directed and plunging mainly westward at angles of 26°-30°. Looking at the geological map by Ağırbaş (2006), the fold axes are located along the NNE-SSW-trending Alkan-Bağırsak and Şahyar valleys (Figure 3).

The difference in the axis of the fold in the Salihli and Alaşehir segments indicates that it may have been caused by back-rotation and tilting to the south of the footwall and hanging wall of the Alaşehir detachment. The folds are cross-cut by Plio-Quaternary high-angle normal faults (Figure 3 & 4).

Reorienting a Tilted Plane to its Horizontal Position - Tectonic Readjustment

This simple geological problem is the process of reorienting a tilted layer or fault to its previous orientation, which is done by regressing in time for structures that are the same age and have experienced the same deformation (Ketin and Canıtez, 1979; Figure 10-22, pages of 169-179). In order to do this, the great circle and the pole of a layer with a given strike and dip (N42°W, 52°SW) are plotted on the stereographic net (Figure 13a), and then pole d is marked on the E-W line of the projection net. Since the pole of the layer is located in the center of the net when the layer is horizontal, D_0 is obtained by moving D to the center. In this case, D_0 is the tilted version of D which is horizontal and its great circle is located on the periphery of the stereographic net (Figure 13a). Considering a linear element (L) on the layer, its reorientation to horizontal will be L_0 (Figure 13a).

Synthetic and antithetic faults are terms used to define minor faults connected with a master fault. They are coeval; however, antithetic faults develop shortly after synthetic faulting. Antithetic and synthetic faults, which merge deeply with the major fault, crosscut each other (Ketin and Canıtez, 1979; page of 206; Önalan, 2000; page of 302).

If the Plio-Quaternary high-angle normal faults, cutting the Alaşehir detachment fault and the low-angle normal faults, are reversed, their initial position when they formed during the Miocene can be easily found before the folding of the Alaşehir detachment fault. Six datasets, including the surfaces of the Alaşehir detachment fault, low-angle normal faults, and high-angle normal faults together with their synthetic and antithetic faults in the Salihli and Alaşehir segments, were plotted onto the stereographic net (Figure 13b; Table 1). With the re-orientation of high-angle normal faults to horizontal on the stereographic net, the Alaşehir detachment fault and low-angle normal faults appear to have been high-angle faults during the Miocene (Figure 13c). In addition, the beds of lacustrine and fluvial/alluvial fan fills were plotted as a control mechanism, and they appear to have had a horizontal position during the Miocene (Figure 13c). Thus, the initial position of the Alaşehir detachment fault and the low-angle normal faults was high angle (Figure 14)

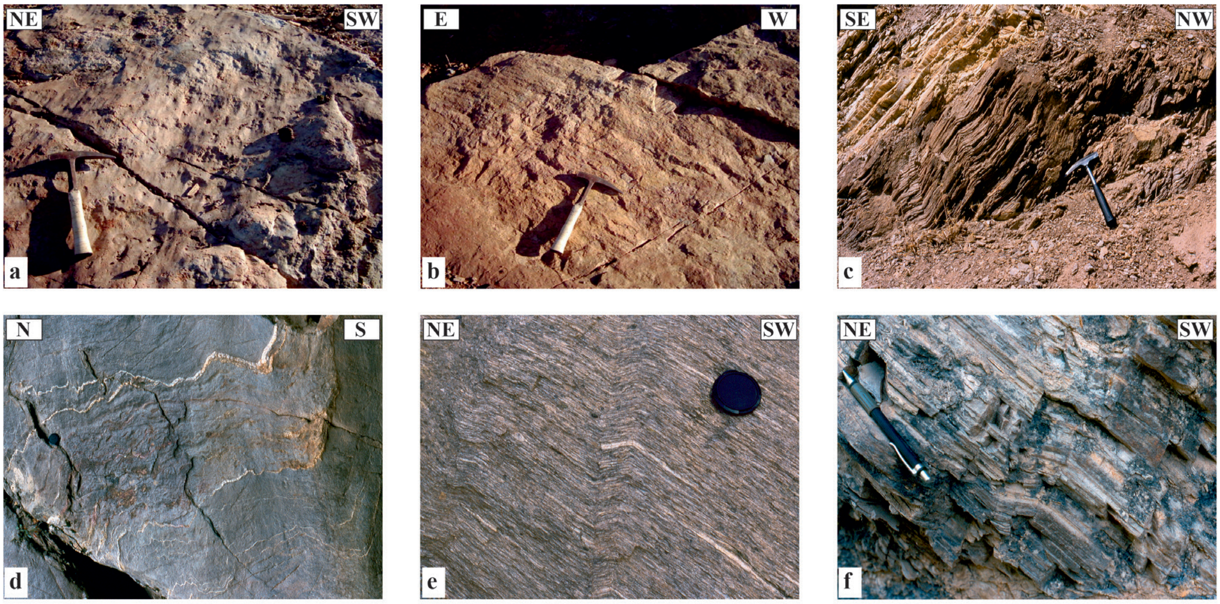

Figure 11. The footwall and hanging wall of the Alaşehir detachment fault in the Alaşehir Graben. **a & b)** Photos displaying slickensides and grooves of the Alaşehir detachment fault in Oyukkıran and Köpektepe ridge, respectively. **c)** Fold structures in the Bayındır nappe located in the footwall of the Alaşehir detachment fault. **d)**. Fold structures in the Alaşehir detachment fault in Bağırsak-Alkan valley (35S 0620158/4244339). **e)** Kink bands of the Çine Nappe in the hanging wall of the Alaşehir detachment fault in Gökçealan hill. **f)** Kink bands in the shale beds of the Gerentaş Formation in the hanging wall of the Alaşehir detachment fault in Gölcük hill (Şen, 2004; Ağırbaş, 2006). See Figure 3 for the location of photos of the structural elements.

Şekil 11. *Alaşehir Grabeni'ndeki Alaşehir sıyrılma fayının taban ve tavan bloklarını gösteren fotoğraflar.* ***a-b)*** *Alaşehir sıyrılma fayının Oyukkıran ve Köpektepe sırtındaki fay çizikleri ve oluk izlerini gösteren fotoğraflar.* ***c)*** *Alaşehir sıyrılma fayı tabanında yer alan Bayındır Napı'ndaki kıvrım yapılarını gösteren fotoğraf.* ***d)****. Bağırsak-Alkan vadisinde Alaşehir sıyrılma fayındaki kıvrım yapılarını gösteren fotoğraf (35S 0620158/4244339).* ***e)*** *Gökçealan tepesindeki Alaşehir sıyrılma fayının tavan bloğundaki Çine Napı'ndaki kink bantlarını gösteren fotoğraf.* ***f)*** *Gölcük tepesindeki Alaşehir sıyrılma fayının tavan bloğundaki Gerentaş Formasyonu'nun şeyl tabakalarındaki kink bantlarını gösteren fotoğraf(Şen, 2004; Ağırbaş, 2006). Yapısal elemanlara ait olan fotoğrafların yerleri için Şekil 3'e bakınız.*

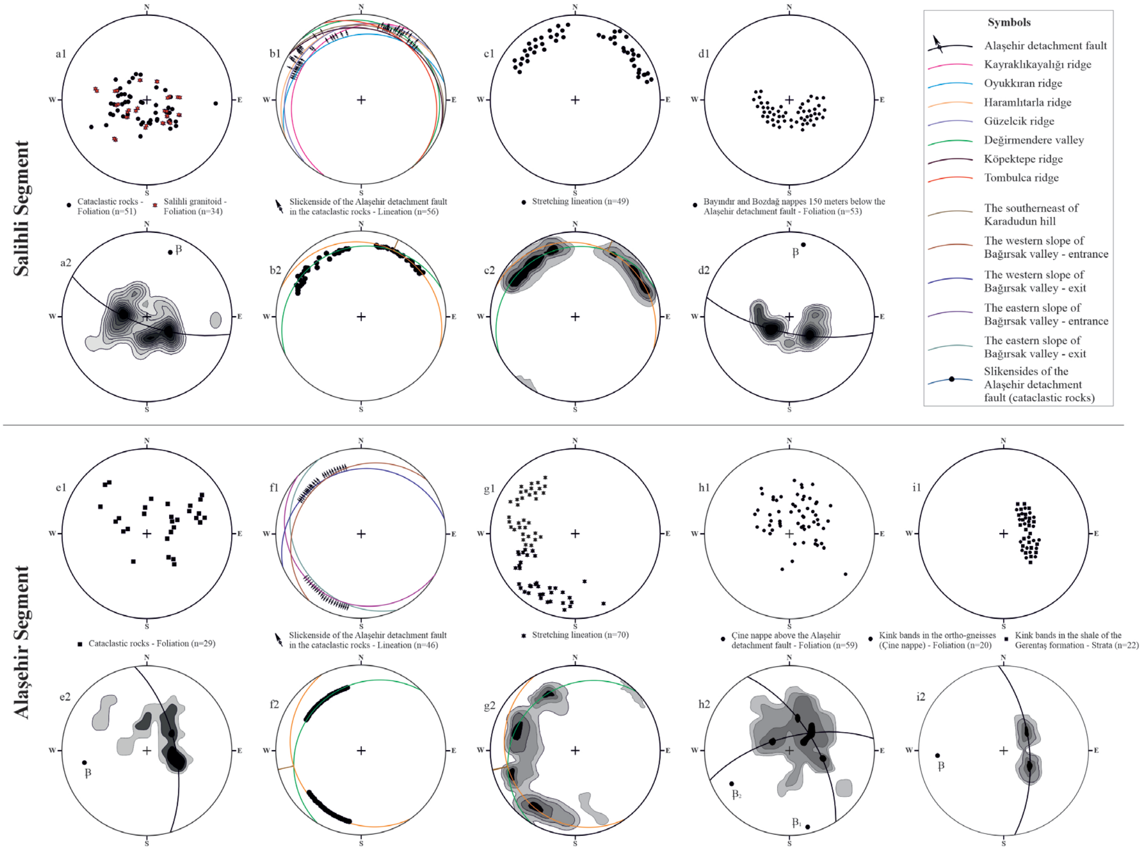

Figure 12. Lower hemisphere equal area projections illustrating fold structures in the footwall and hanging wall of the Alaşehir detachment fault on the Salihli and Alaşehir segments. Pole (**a1**) and contour (**a2**) diagrams of foliations in the detachment fault. (**b1-2**) Surface of the detachment fault with slickensides. Pole (**c1**) and contour (**c2**) diagrams of stretching lineations in the detachment fault. Pole (**d1**) and contour (d2) diagrams of foliations in the Bayındır and Bozdağ Nappes 150 meters below the detachment fault. Pole (**e1**) and contour (**e2**) diagrams of foliations in the detachment fault. (**f1-2**) Surface of the detachment fault with slickensides. Pole (**g1**) and contour (**g2**) diagrams of stretching lineations in the detachment fault. Pole (**h1**) and contour (**h2**) diagrams of foliations from the Çine Nappe in the hanging wall detachment fault. Pole (**i1**) and contour (**i2**) diagrams of foliations belonging to kink bands in the ortho-gneisses of the Çine Nappe and in the shale of the Gerentaş Formation in the hanging wall of the detachment fault. Note that the β axis is NE trending and NE plunging on the Salihli segment and the β axis is ~ E–W-trending and SW plunging on the Alaşehir segment in the Alaşehir detachment fault (Şen, 2004; Ağırbaş, 2006). n = number of data points

Şekil 12. *Salihli ve Alaşehir segmentindeki Alaşehir sıyrılma fayının taban ve tavan bloğundaki kıvrım yapılarını gösteren alt yarımküre eşit alan izdüşümleri. Sıyrılma fayındaki yapraklanmaların nokta **(a1)** ve kontur **(a2)** diyagramları. **(b1-2)** fay çizik lineasyonlarının olduğu sıyrılma fay düzlemlerinin nokta ve kontur diyagramları. Sıyrılma fayındaki uzama lineasyonların nokta **(c1)** ve kontur **(c2)** diyagramları. Sıyrılma fayının 150 metre altındaki Bayındır ve Bozdağ Napları'ndaki yapraklanmaların nokta **(d1)** ve kontur **(d2)** diyagramları. Sıyrılma fayındaki yapraklanmaların nokta **(e1)** ve kontur **(e2)** diyagramları. **(f1-2)** fay çizik lineasyonlarının olduğu sıyrılma fay düzlemlerinin nokta ve kontur diyagramları. Sıyrılma fayındaki uzama lineasyonların nokta **(g1)** ve kontur **(g2)** diyagramları. Sıyrılma fayındaki Çine Napı'ndaki yapraklanmaların nokta **(h1)** ve kontur **(h2)** diyagramları. Sıyrılma fayının tavan bloğundaki Çine Napı'ndaki ortognayslarda ve Gerentaş Formasyonunun şeylindeki kink bantlarına ait foliasyonların nokta **(i1)** ve kontur **(i2)** diyagramları. Alaşehir sıyrılma fayında β ekseninin Salihli segmentinde KD gidişli ve KD dalımlı ve β ekseninin Alaşehir segmentinde ~ D–B gidişli ve GB dalımlı olduğuna dikkat ediniz (Şen, 2004; Ağırbaş, 2006). n = veri sayısı noktası*

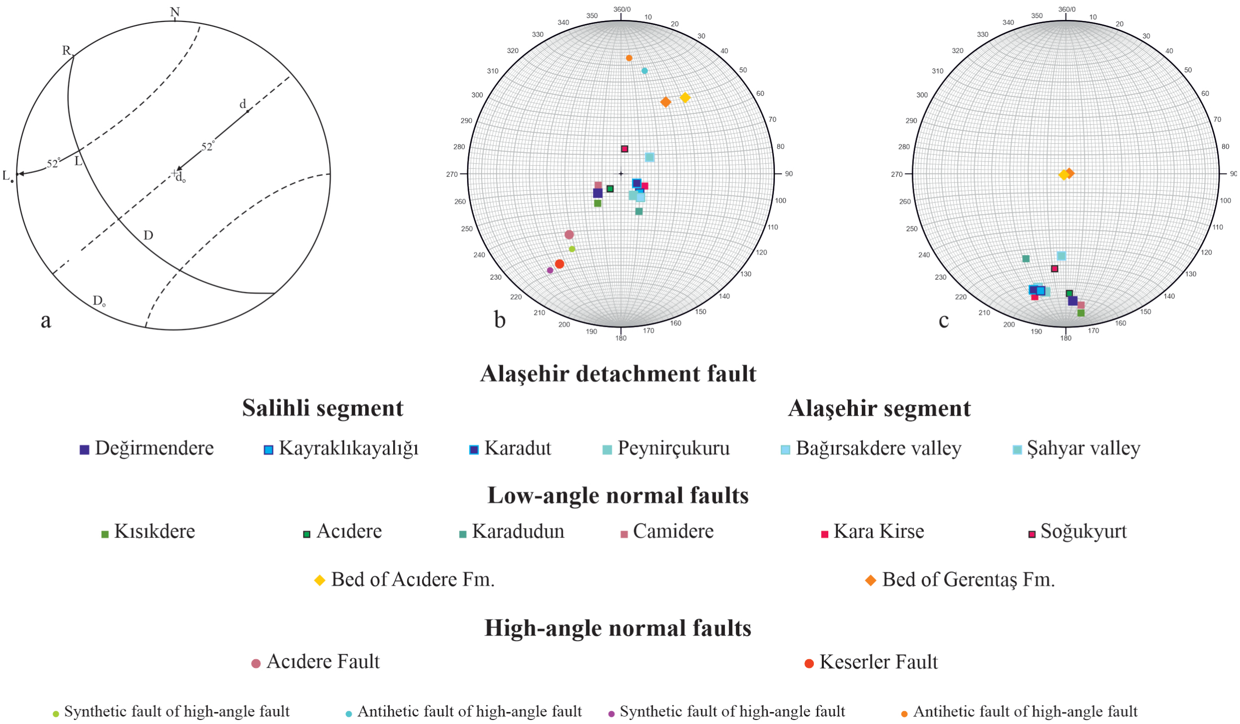

Figure 13. Figures illustrating **a)** re-orientation of a tilted plane to its horizontal position (Ketin and Canıtez, 1979), **b & c)** Schmidt lower hemisphere equal-area projections of Alaşehir detachment fault and low-angle normal faults to apply the tectonic reorganization.

Şekil 13. a) *Eğik bir düzlemin yatay konumuna yeniden yönlendirilmesini (Ketin ve Canıtez, 1979),* ***b*** *ve* ***c)*** *Alaşehir sıyrılma fayının ve düşük-açılı normal fayların tektonik düzeltmeyi uygulamak için Schmidt alt yarımküre eşit alan izdüşümlerini gösteren şekiller.*

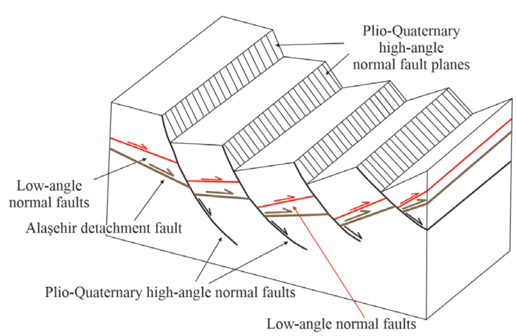

Figure 14. Block diagram explaining the southward back-rotation, tilting, and decreasing dip of the Miocene faults as a result of the Plio-Quaternary high-angle faults cutting the Alaşehir detachment fault and synthetic and antithetic faults (Ağırbaş, 2006; page of 85).

Şekil 14. *Alaşehir sıyrılma fayı ile sintetik ve antitetik fayları kesen Pliyo-Kuvaterner yüksek-açılı faylar sonucu Miyosen faylarının güneye doğru geriye dönmesini, eğilmesini ve eğiminin azalmasını açıklayan blok diyagram (Ağırbaş, 2006, 85. sayfa).*

Table 1. List of faults with tectonic readjustment.
Çizelge 1. *Tektonik düzeltme yapılan temsili fayların listesi.*

	Segments	Location	Position	Coordinates
Surfaces of Alaşehir detachment fault	**Salihli segment**	Değirmendere	N38W 12NE	35 S 608045 / 4252944
		Kayraklıkayalığı	N55E 10NW	35 S 611217 / 4252757
		Karadut	N30E 13NW	35 S 612819 / 4252705
	Alaşehir segment	Peynirçukuru	N28E 14NW	35 S 616462 / 4245440
		Bağırsak valley	N50E 20NW	34 S 620699 / 4245644
		Şahyar valley	N30W 35SW	35 S 624002 / 4244986
Low-angle normal faults	**Salihli segment**	Kısıkdere	N46W 14NE	35 S 608686 / 4254485
		Acıdere	N54W 6NE	34 S 612091 / 4253915
		Karadudun	N65E 10NW	35 S 617650 / 4253043
	Alaşehir segment	Camidere	N26W 12NE	35 S 616236 / 4250626
		Karakirse	N82W 4SW	35 S 622181 / 4247371
		Soğukyurt	N28E 14NW	35 S 623182 / 4245612
Strike and dip bedding	**Salihli segment**	Acıdere Formation	N60W 40SW	35 S 608504 / 4254297
		Acıdere Formation	N60W 40SW	35 S 610488 / 4252384
		Acıdere Formation	N60W 40SW	35 S 613769 / 4252321
	Alaşehir segment	Acıdere Formation	N60W 40SW	35 S 616453 / 4250546
		Gerentaş Formation	N64W 38SW	35 S 624448 / 4244690
		Gerentaş Formation	N64W 38SW	35 S 624584 / 4244216
High-angle normal faults	**Salihli segment**	Acıdere fault	N62W 50NE	35 S 611888 / 4254488
		Synthetic fault	N56W 58NE	35 S 613053 / 4255237
		Antihetic fault	N78W 64SW	35 S 611040 / 4254061
	Alaşehir segment	Keserler fault	N56W 45NE	35 S 623091 / 4247764
		Synthetic fault	N54W 40NE	35 S 623231 / 4249682
		Antihetic fault	N85W 70SW	35 S 624698 / 4246939

DISCUSSION

Stratigraphy and Fault Types in The Alaşehir Graben

The tectono-stratigraphy of the southern margin of the Alaşehir Graben consists of the Bayındır and Bozdağ Nappes, the syn-extensional Salihli granitoid intruding the Bayındır Nappe, the cataclastic rocks in the footwall, the Çine Nappe and the Neogene-Quaternary fills in the hanging wall of the Alaşehir detachment fault on the basis of the geological map and cross-sections (Figure 2 &5).

Three different types of master faults occur from Salihli to Alaşehir along the southern edge of the Alaşehir Graben (Figure 3,4 & 8). These include **(a)** an E-W striking, N-dipping and low-angle (8°-20°) normal fault termed the Alaşehir detachment fault bordered by the southern margin of the Alaşehir Graben; **(b)** E-W striking, N-/S-dipping and low-angle (5°-30°) normal faults crosscutting the high-grade metamorphic rocks of the Çine Nappe and Miocene graben-fills; and **(c)** E-W striking, N-/S-dipping and high-angle (40°-75°) normal faults crosscutting the footwall and hanging wall of the Alaşehir detachment (Figure 8). High-angle normal faults are youngest compared to the Alaşehir detachment fault and low-angle normal faults according to field observations (Figure 3 & 4). Low-angle normal faults are similar in character and geometry to the Alaşehir detachment fault; however, they differ from the Alaşehir detachment fault in that they do not cut it. They also do not cut the Upper Miocene-Lower Pliocene Göbekli Formation and the younger formations (Figure 3, 4 & 9b).

The last movement of the Alaşehir detachment fault was late Messinian according to the frictional age of its footwall (c. 6-5.5 Ma; Lips et al., 2001). This age is also consistent with the nature of the low-angle normal faults crosscutting the Miocene fills, except for the Upper Miocene-Lower Pliocene Göbekli Formation consisting of floodplain deposits (Figs. 3, 4, 5a, 9b & 10a, c). This means that the Alaşehir detachment fault and low-angle normal faults were coeval. It is possible to see that the Alaşehir detachment fault and low-angle normal faults were high-angle normal faults during the Miocene based on tectonic reorganization (Figure 13b & c). Synthetic and antithetic faults merge with the master fault; however, they do not cut the main fault, just as they cut each other. Therefore, low-angle normal faults, which are devoid of cataclastic rocks, were synthetic and antithetic faults of the Alaşehir detachment fault during the early to earliest late Miocene. They are crosscut by Plio-Quaternary high-normal faults and have become low-angle as a result of back-rotation and tilting to the south (Figure 3, 4, 13c &14).

Several researchers reported that the initial position of the Alaşehir detachment fault was low angle from the time of graben formation and that it is cut by high-angle normal faults that are younger to the north (Emre, 1990, 1996; Hetzel et al., 1995a, b; Emre and Sözbilir, 1997; Sözbilir, 2001; Purvis and Robertson, 2005; Öner and Dilek, 2011). However, its original position was a high-angle normal fault during the Miocene according to the tectonic reorganization (Figure 13b & c). Öner and Dilek (2011) reported that low- and high-angle normal faults are crosscut by each other in the Kısıkdere valley in the Salihli area and low-angle normal faults are synthetic and antithetic faults of master high-angle normal faults. However, low-angle normal faults do not cut the Upper Miocene to Plio-Quaternary fills (Göbekli-Yenipazar-Erendalı-Asartepe Formations) (Figure 3 & 4) and low-angle normal faults are synthetic and antithetic faults of the Alaşehir detachment fault (Figure 13b-c & 14). Furthermore, the accommodation faults first proposed by Emre (1990 & 1996) were interpreted as scissor/hinge faults crosscutting all rocks in NNE-SSW trending valleys (Öner and Dilek, 2011 & 2013). Small-scale reverse faults crosscutting the Lower-Upper Miocene Acıdere Formation in the village of Yağmurlar (35S 0609906/4252770) were suggested to be evidence of scissor/hinge faults (Öner and Dilek, 2011; Figure 13B, page of 2134). These faults, which do not cross-cut the post-Upper Miocene fills, are examples of reverse faults found southeast of Alaşehir by Çiftçi and Bozkurt (2008). These reverse faults do not show the contraction phase of the Alaşehir Graben as stated by Koçyiğit et al. (1999). They represent extensional structures formed by layer-parallel shortening during the Miocene, as explained by Şengör and Bozkurt (2012).

The detachment fault, originally a high-angle normal fault, have been reduced in angle by isostatic rebound (Buck, 1988; Wernicke and Axen, 1988). New high-angle normal faults, which develop in the hanging wall of the detachment faults, take over the task of the detachment as it cannot cope with the extensional regime (Buck, 1988; Wernicke and Axen, 1988; Manning and Bartley, 1994). This means that the movement should end on the rotating first fault and the primary throw on faults formed before rotation remains unchanged during the ongoing extensional regime (Axen and Bartley, 1997). This mechanism is defined as a flexural rotation/rolling hinge model adapted to the Alaşehir detachment fault (e.g., Seyitoğlu et al., 2002; Demircioğlu et al., 2010; Seyitoğlu and Işık, 2015).

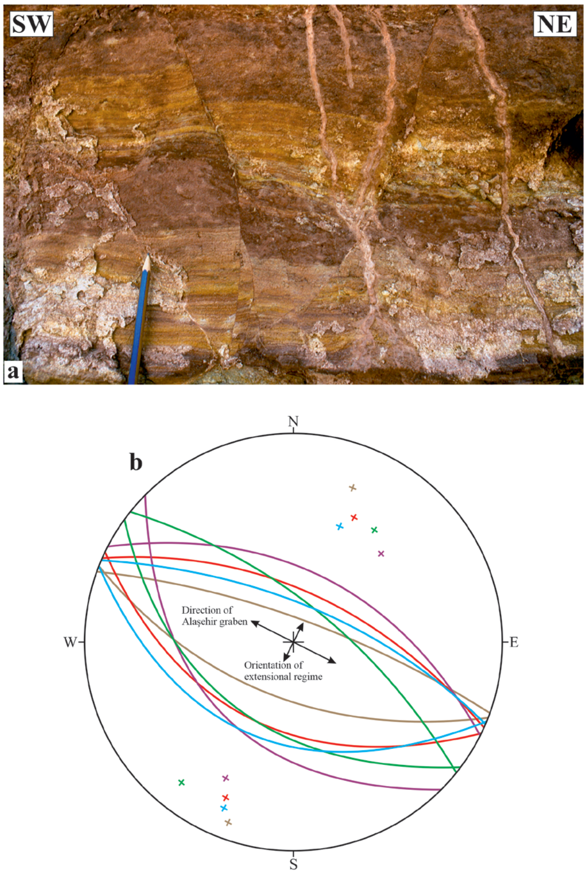

Figure 15. Figures illustrating small-scale high-angle normal faults that cut the Acıdere Formation **(a)** and lower hemisphere equal area projections of these faults to find the orientation of an extensional regime for the Alaşehir Graben during the Plio-Quaternary **(b)** (Ağırbaş, 2006).

Şekil 15. *Acıdere Formasyonu'nu kesen küçük-ölçekli yüksek-açılı normal fayları gösteren şekiller. Alaşehir Grabeni'ne ait Pliyo-Kuvaterner'de genişlemeli bir rejimin oryantasyonunu bulan bu fayların **(a)** ve alt yarım küre eşit alan izdüşümleri **(b)** (Ağırbaş, 2006).*

Seyitoğlu et al. (2002) emphasized that there is activation on the rotated low-angle fault around Kara Kirse and Soğukyurt in Alaşehir (Figure 3 & 4). The mentioned low-angle normal fault cuts the Kurşunlu Formation, corresponding to the Acıdere-Göbekli-Yenipazar-Erendalı Formations in Figure 2e, and the low-angle normal fault between the Menderes Massif and the Miocene fills was defined as the Alaşehir detachment fault in Figure 3. Hetzel et al. (2013) reported that this fault was dated to the Late Miocene to Late Pliocene (K-Ar ages of 10.6 to 3.5 Ma). According to this observation and dating, as the Alaşehir detachment fault rotated and became low angle activity continued, different from the original flexural rotation/rolling hinge model, and field data illustrate that this caused exposure of a larger amount of metamorphic rocks belonging to the Menderes Massif. It is understood that there was activity on the rotated low-angle fault as a result of low-angle normal faults crosscutting the Kurşunlu Formation with activity on these low-angle normal faults occurring after its deposition. Therefore, this difference is defined as the Alaşehir type rolling hinge model, and this model clarifies the extensional tectonic regime continuing from the early Miocene to Quaternary without major disruption on the basis of apatite and zircon fission track ages (c. 8.70-1.75 Ma, apatite fission track, Gessner et al., 2001; c. 8.5-0.80 Ma, apatite fission track and c. 21-2 Ma, zircon fission track, Buscher et al., 2013). There are several assumptions regarding this situation. First of all, the low-angle normal fault between the metamorphic rocks and the Miocene fills in the Alaşehir area is defined as the Alaşehir detachment fault, which has turtleback surfaces in the Salihli area. However, the Alaşehir segment of the Alaşehir detachment fault lies at the base of NE-SW oriented valleys, including the Bağırsak-Alkan and Şahyar valleys (Figure 3, 4, 5 & 11d). Secondly, the low-angle normal faults in the Alaşehir area represent the Alaşehir detachment fault between the Çine Nappe and the Miocene sedimentary rocks. The Çine Nappe, which overlies the Alaşehir detachment fault in the Alaşehir segment of the Alaşehir detachment fault, is tectonically overlain by the Miocene graben fills (Figure 3, 4 & 5). Thirdly, it is concluded that the rotated low-angle faults cut the Kurşunlu Formation, corresponding to the Acıdere-Göbekli-Yenipazar-Erendalı Formations in Figure 2e. However, they only crosscut the Lower-Upper Miocene Acıdere Formation (Figure 3, 4 & 9b), and this observation is consistent with the sedimentological evolution of other fills. The Upper Miocene-Upper Pliocene Göbekli-Yenipazar-Erendalı Formations represent floodplain fills (Emre, 1990, 1996) and quiescence of the extensional event in the Alaşehir Graben (Şen, 2004; Ağırbaş, 2006; Şen, 2016). In summary, the last tectonic activity on the Alaşehir detachment fault was in the late Miocene, as noted by Lips et al. (2001). Plio-Quaternary thermal ages (c. 3.10-1.75 Ma, apatite fission track, Gessner et al., 2001; c. 3.50-0.80 Ma, apatite fission track and c. 3.5-2.0 Ma, zircon fission track, Buscher et al., 2013; c. 3.50-3.20 Ma; Hetzel et al., 2013) show that the footwall and hanging wall of the Alaşehir detachment fault were exhumed under the control of Plio-Quaternary high-angle normal faults. For example, it is possible to see master high-angle normal faults surrounding the dated low-angle normal fault (c. 9.2 Ma and 3.20 Ma) to the west of Şahyar valley in the Alaşehir area in Hetzel et al. (2013) (Figure 3 & 4e).

The Alaşehir detachment fault is cut by high-angle normal faults and gained a low angle by tilting, based on mapping studies in the Alaşehir area (Bozkurt and Sözbilir, 2004; Çiftçi and Bozkurt, 2008, 2009, 2010). The rotated low-angle normal faults in the aforementioned studies, defined as the Alaşehir detachment fault, are synthetic and antithetic faults of the Alaşehir detachment fault based on the map of Ağırbaş (2006) (Figure 3, 4 & 13b, c). That is, the fault they rotated is not the Alaşehir detachment fault.

Fold Types in The Alaşehir Graben

The studies by Şen (2004) and Ağırbaş (2006) defined a set of major folds in the footwall and hanging wall of the Alaşehir detachment fault. These folds lie along NNE-SSW trending valleys. They were interpreted differently by several researchers (Sözbilir, 2001; Çemen et al., 2005; Seyitoğlu et al., 2014; Öner and Dilek, 2011, 2013).

According to Çemen et al. (2005) and Seyitoğlu et al. (2014), convex-upward surfaces observed in the footwall of the Alaşehir detachment fault located between Horzumaraplar and Horzumalayka are interpreted as turtleback surfaces, called the ‘’Horzum Turtleback’’. There are two basic conditions for the formation of this geometry. The Alaşehir detachment fault formed under the control of the rolling hinge mechanism. It was also active after the formation of high-angle normal faults that are part of the synthetic and antithetic hanging wall detachment fault and syn-extensional magmatic body intruding the mid-crustal relay ramp between Salihli and Alaşehir segments. However, the fold axes obtained from the surfaces of the Alaşehir detachment fault in the Salihli and Alaşehir segments are different from each other. The fold axis has N20°E trend and 20° NE plunge in the Salihli segment on the footwall of the Alaşehir detachment fault. The fold axis has N80°E trend and 30° SW plunge in the Alaşehir segment on the footwall of the Alaşehir detachment fault, corresponding to that the fold axis has N85°E trend and 25° SW plunge in the Alaşehir segment on the hanging wall of the Alaşehir detachment fault (Figure 11 & 12). This means that the Alaşehir detachment fault was rotated by cutting with Plio-Quaternary high-angle faults (Figure 4 & 14). In addition, the measured stratigraphic record of the Upper Miocene-Lower Pliocene Göbekli Formation indicates that the Alaşehir detachment fault was not active during the floodplain fill deposition (Şen, 2004, 2016). This determination supports the view that the last movement of the Alaşehir detachment fault was in late Messinian time, as stated by other researchers (c. 6-5.5 Ma; Lips et al., 2001; Gessner et al., 2001; Heineke et al., 2019). Therefore, the Alaşehir detachment fault was inactive before it was cut by high-angle normal faults, and these folds or turtle-back surfaces occurred without the need for formation of relay ramps on the Alaşehir detachment fault when it was active from the earliest early Miocene to the latest late Miocene.

Sözbilir (2001) reported extension-parallel antiform and synform structures, known as the Oyukkıran antiform and Keserler synform, on the footwall of the Alaşehir detachment fault in the Salihli segment, similar to folds found in the study by Şen (2004). According to the researcher, these corrugations were formed as original irregularities of the Alaşehir detachment fault and did not require folding after the deposition of Miocene fills in the hanging wall. Nevertheless, these folds with β axis N20°E trend and 20° NE plunge on the Salihli segment are equivalent to folds with β axis N80°E trend and 30° SW plunge on the Alaşehir segment in the footwall of the Alaşehir detachment fault, corresponding to the fold axis in the Lower-Middle Miocene strata in the hanging wall of the Alaşehir detachment fault (Figure 11 & 12). These folds can be seen in the footwall and in the hanging wall of the Alaşehir detachment fault in the Salihli and Alaşehir segments. Thus, the primary irregularities stated by Sözbilir (2001) are invalid for the Alaşehir detachment fault.

Öner and Dilek (2011, 2013) stated that the accommodation faults first proposed by Emre (1990, 1996) were interpreted as scissor or hinge faults crosscutting all units in NNE-SSW trending valleys. However, there are no structural data associated with them, such as planes, slickensides and grooves of the scissor-hinge faults, which have a component of oblique-slip movement, along the bottom and slopes of NNE-SSW trending valleys (Şen, 2004; Ağırbaş, 2006) (Figure 3 & 4). Small-scale reverse faults crosscutting the Lower-Upper Miocene Acıdere Formation in the village of Yağmurlar (35S 0609906/4252770) were reported as evidence for scissor or hinge faults (Öner and Dilek, 2011; Figure 13B, page of 2134). However, these faults do not cut post-Miocene fills (Şen, 2004; Ağırbaş, 2006) (Figure 2 & 3). They are part of the small-scale reverse faults cutting the Miocene fills found by Çiftçi and Bozkurt (2008) in the hanging wall of the Alaşehir detachment fault in the Alaşehir segment. The NNE-SSW trending scissor or hinge faults crosscutting structural elements with all units of the Alaşehir Graben are non-existent structures in the study area. As a corollary, the hypotheses put forward by the aforementioned researchers regarding the formation of structures representing these valleys are invalid.

In newly-opened road cuts in the Alaşehir area, outside of the study area, Çiftçi and Bozkurt (2008) reported that fold axes are generally oriented E–W and plunge mainly westward at angles < 20° in shale-sandstone beds of the Alaşehir Formation, corresponding to the Lower-Middle Miocene Gerentaş and Kaypaktepe Formations. The researchers noted that these folds and small-scale north-verging reverse faults are representative of NNE–SSW-oriented shortening, as suggested by Koçyiğit et al. (1999). They are associated with extensional structures formed by layer-parallel shortening according to Şengör and Bozkurt (2012), who note that nowhere is there an erosional episode between the superimposed structures. Our own later observations in the company of geologist Hakan Ağırbaş indicate that there are no erosional planes between these structures in the village of Osmaniye in the Alaşehir area and they correspond to small-scale reverse faults crosscutting the Lower-Upper Miocene Acıdere Formation in the village of Yağmurlar in the Salihli area. The superposed structures are also not present in the Upper Miocene-Lower Pliocene Göbekli Formation. Thus, they are related to layer-parallel shortening during the Miocene instead of the contractional stage during the Pliocene as stated by Koçyiğit et al. (1999).

Seyitoğlu et al. (2000) stated the folds found by Koçyiğit et al. (1999) mobilized the Miocene sedimentary rocks over listric normal faults, forming folds, drag folds and rollover anticlines during ongoing extension. In this context, the formation of these folds observed in the Miocene fills depends on the movement of the Plio-Quaternary high-angle normal faults. Therefore, the folds found by Çiftçi and Bozkurt (2008) are different from the drag folds and rollover anticlines with origin identified by Seyitoğlu et al. (2000). E–W trending and < 20° W plunging folds on a local scale found by Çiftçi and Bozkurt (2008) are compatible with ~ E–W trending and ~ 30° W plunging folds in the footwall and hanging wall of the Alaşehir detachment fault on the Alaşehir segment, corresponding to the N20°E trending and 20° NE plunging folds in the footwall of the Alaşehir detachment fault on the Salihli segment discovered in the study by Şen (2004) and Ağırbaş (2006) (Figure 12). They are part of the extensional structures formed by layer-parallel shortening during the Miocene. The small-scale reverse faults crosscutting the Lower-Upper Miocene Acıdere Formation in the hanging wall of the detachment fault on the Salihli segment indicate that this event occurred during the late Miocene because they do not cut the Upper Miocene-Lower Pliocene Göbekli Formation. This means that the extensional tectonic regime under the control of the Alaşehir detachment fault ended during deposition of the Upper Miocene-Lower Pliocene Göbekli Formation, with a monotonous sequence which repeats and is not tectonically mobile, after the first 140 meters from the stratigraphic bottom (Şen, 2004 & 2016).

Overall, the inconsistency of the fold axis on the Salihli and Alaşehir segments shows that the Alaşehir detachment fault was cut and back-rotated and tilted to the south by Plio-Quaternary high-angle normal faults. This is proof that the Alaşehir detachment fault was inactive during this time. The Plio-Quaternary thermal ages obtained from the footwall of the Alaşehir detachment fault (c. 3.10-1.75 Ma, apatite fission track, Gessner et al., 2001; c. 3.50-0.80 Ma, apatite fission track and c. 3.5-2.0 Ma, zircon fission track, Buscher et al., 2013; c. 3.50-3.20 Ma; Hetzel et al., 2013) represent exhumation of the Miocene graben with high-angle normal faults. Therefore, the data obtained by Şen (2004) and Ağırbaş (2006) rule out the flexural rotation-rolling hinge model for the Alaşehir detachment fault proposed by Gessner et al. (2001) and Seyitoğlu et al. (2002, 2014). In this context, Işık et al. (2003) found that the extensional direction of the Alaşehir Graben was NE-SW during the Miocene to the present, based on the stretching lineations on the Horzum Turtleback surfaces found by Çemen et al. (2005). However, the Horzum Turtleback at Horzum represents the fold limb and the NE-SW direction is the orientation of the extensional regime during the Plio-Quaternary time (Ağırbaş, 2006) (Figure 15).

If the model generated from the data presented in this study is evaluated on the scale of Western Anatolia, the late Miocene time of the last movement of the Alaşehir detachment fault (c. 6-5.5 Ma; Lips et al., 2001; Gessner et al., 2001; Heineke et al., 2019) corresponds to the time of the final motion of the Büyük Menderes detachment fault (c. 5.5-5 Ma; Wölfler et al., 2017; Heineke et al., 2019). Doğan (2020) found extensional thrust fault and fold sets affecting the Plio-Quaternary semi-lithified sandstone and conglomerate beds in the Söke-Kuşadası Basin, which is considered to be the western extension of the Büyük Menderes Graben. The Plio-Quaternary thrust faults and folds in the Büyük Menderes Graben are part of the extensional structures in the Alaşehir Graben, which were formed by layer-parallel shortening during the Miocene. Such structures are more common during the early phases of extensional events (e.g., Şengör and Bozkurt, 2012). This is further support for the two-stage extensional model, consisting of Miocene and Plio-Quaternary extensional phases in Western Anatolia.

CONCLUSIONS

In this paper, data were presented from the southern margin of the Alaşehir Graben in the BSc theses of Şen (2004) and Ağırbaş (2006) that provide an explanation of its tectonic evolution.

The Alaşehir detachment fault and the low-angle normal faults were coeval and the low-angle normal faults were structural elements of the synthetic and antithetic faults of the Alaşehir detachment fault during the Miocene. Their initial position was high angle and the original position of the high angles had 55°-75° dip during the Miocene.

Several major fold geometries defined in the footwall and hanging wall of the Alaşehir detachment fault are located along NNE-SSW trending valleys. The fold axis is NE-trending and plunges mainly northeastward in the Salihli segment in the footwall of the Alaşehir detachment fault. The other is ~E–W-trending and plunges mainly westward in the Alaşehir segment in both the footwall and hanging wall of the Alaşehir detachment fault. They are associated with extensional structures formed by layer-parallel shortening during the Miocene. The Alaşehir detachment fault was cut and back-rotated by Plio-Quaternary high-angle normal faults and tilted to the south, as shown by the difference in fold axes between the Salihli and Alaşehir segments. Therefore, the flexural rotation-rolling hinge model does not work for the Alaşehir detachment fault as it does not reflect the nature of the Alaşehir Graben.

GENİŞLETİLMİŞ ÖZET

Batı Anadolu, dünyada iyi bilinen kıtasal gerilmeye sahip bir alandır. Bölgenin en belirgin yapısal elemanları D-B doğrultulu grabenlerdir (örn., Bozkurt, 2001, Bozkurt ve Sözbilir, 2004; Seyitoğlu ve Işık, 2015). Alaşehir Grabeni, Menderes Masifi'nin kuzey ve orta kesimleri arasındaki sınırı oluşturur. Ahmetli'den Turgutlu'ya kadar D-B gidişli, Salihli'den Alaşehir'e kadar ise KB-GD gidişlidir. Çalışma alanı, Alaşehir Grabeni'nin güney kenarında Salihli'den Alaşehir'e kadar yüzeyleyen Menderes Masifi'nin orta masifinin kuzey kesimidir (örn., Ring vd., 1999; Bozkurt, 2007; Seyitoğlu vd., 2014). Bu makale, Alaşehir Grabeni'nin güney kenarı boyunca 2003 yaz döneminde üç ay süren, Şen (2004) ve Ağırbaş (2006) tarafından yapılan iki bitirme tezinin veri setinin sonuçlarını belgelemektedir.

Bu çalışma, Alaşehir Grabeni'nin güney kenarının tektonostratigrafisi Bayındır ve Bozdağ Napları, Bayındır Napını kesen gerilme ile eşzamanlı Salihli granitoyidi ve Alaşehir sıyrılma fayının taban bloğundaki kataklastik kayaçlar ile, ve Çine Napı ve Neojen-Kuvaterner dolguları ise Alaşehir sıyrılma fayının tavan bloğu ile temsil edildiğine; ayrıca, Alaşehir bölgesinde Alaşehir sıyrılma fayı üzerinde kalan Çine Napının üzerinde tektonik olarak Miyosen dolgularının olduğuna dair saha kanıtı sağlamaktadır (Şen, 2004; Ağırbaş, 2006).

Graben dolguları esas olarak grabenin güney kenarı boyunca yüzeylenir ve Miyosen'den Pliyo-Kuvarterner'e kadar herhangi bir zaman boşluğu olmadan çökelen karasal kırıntılı tortul kayaçlar ve yarı taşlaşmış çökellerden oluşur. Alaşehir Grabeni'ne ait olan sedimanter kayaçlar Miyosen dolguları (Gerentaş-Kaypaktepe-Acıdere Formasyonları), Üst Miyosen-Üst Pliyosen dolguları (Göbekli-Yenipazar-Erendalı Formasyonları) ve Pliyo-Kuvaterner dolgularından (Asartepe Formasyonu) *oluşmaktadır (Şen, 2004; Ağırbaş, 2006; Ağırbaş and Şen, 2012).*

Yapısal veriler, (i) kataklastik kayalardan oluşan düşük-açılı Alaşehir sıyrılma fayı; (ii) kataklastik kayalardan yoksun olan düşük açılı normal faylar; ve (iii) bunları kesen Pliyo-Kuvaterner yüksek açılı normal faylar olmak üzere üç tip ana fay takımı olduğunu göstermektedir. İki farklı düşük açılı normal faylar aynı dönemde oluşan fay takımlarıdır ve Miyosen sırasında aktiftir ve kataklastik kayaçlardan yoksun olan düşük-açılı normal faylar ise Alaşehir sıyrılma fayının Miyosen dönemindeki sintetik ve antitetik faylarıdır. Yapılan tektonik düzeltmeye göre, bu faylar Miyosen sırasındaki ilksel konumları yüksek açılı olup, yüksek açıların başlangıç konumları 55°-75° eğimlidir. Pliyo-Kuvaterner yaşlı yüksek-açılı normal faylar Miyosen yaşlı fayları keserek rotasyonun etkisiyle düşük-açılı normal faylar haline gelmişlerdir.

Alaşehir sıyrılma fayının Salihli ve Alaşehir segmentlerinde taban ve tavan blokunda kıvrımlar tanımlanmıştır. Alaşehir sıyrılma fayının taban bloğunun Salihli segmentinde, β kıvrım ekseni K20°D gidişli ve 20°KD dalımlı olup kuzeydoğu ve kuzeybatıya dalımlı uzama ile fay çizik lineasyonlarına sahiptir ve bu kıvrım eksen konumu ise Alaşehir sıyrılma fayı altındaki metamorfik kayaçlarda K10°D gidişli ve 8°KD dalımlı β kıvrım eksenine karşılık gelir. Alaşehir sıyrılma fayının taban bloğunun Alaşehir segmentinde, β kıvrım ekseni K80°D gidişli ve 30°GB dalımlı olup kuzeybatı ve güneybatıya dalımlı uzama ile fay çizik lineasyonlarına sahiptir ve bu kıvrım eksen konumu Alaşehir sıyrılma fayının üstünde yer alan Çine Napındaki metamorfik kayaçlarda K62°D gidişli ve 26°GB dalımlı β kıvrım eksenine karşılık gelir. Alaşehir segmentindeki Alaşehir sıyrılma fayının tavan bloğunda yer alan Çine Napı ve Miyosen dolgularındaki kink bantlarına ait β kıvrım ekseninin K85°D gidişli ve 25°GB dalımlı ve aynı segmentte ~ D–B gidişli kıvrımlara uygun olduğunu gösterir. Alaşehir sıyrılma fayının taban ve tavan bloğundaki kayaç gruplarındaki bu kıvrımlar Miyosen sırasında tabaka-paralel kısalma ile oluşan genişlemeye bağlı yapılarla ilişkilidirler. Alaşehir sıyrılma fayı, Salihli ve Alaşehir segmentleri arasındaki kıvrım eksenleri farkından da anlaşılacağı üzere, Pliyo-Kuvaterner yaşlı yüksek-açılı normal faylar tarafından kesilerek geriye doğru döndürülmüş ve güneye doğru eğilmiştir.

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