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A First Record of a Strike-slip Basin in Western Anatolia and Its Tectonic Implication: The Cumaovası Basin

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Abstract: The Cumaovası basin, formerly known as the Çubukludağ Graben, is located at the western end of Gediz and Küçük Menderes grabens in the west Anatolian extensional province. It is 5–17-km wide and 35-km-long, NNE–SSW-trending, asymmetric basin that was formed under the control of strike-slip and oblique-slip normal faults.

The basin contains two different infills that are separated by an angular unconformity: (1) an ancient basin fill consisting of Lower Miocene–Lower Pliocene sequences which accumulated in a fluvio-lacustrine depositional setting, and deformed by NE–SW-trending strike-slip faulting; and (2) a modern basin fill consisting of Plio–Quaternary units that are controlled by synchronous strike-slip and normal faulting. Movement on these faults resulted in deposition of the gently tilted Plio–Pleistocene Görece formation and the recent horizontal alluvium. The Görece formation consists of reddish alluvial fan deposits, while the unconformably overlying recent alluvium is made up of alluvial fan, alluvial plain, and fluvial deposits. Metamorphic rocks of the Menderes Massif and rocks of the Bornova mélange form the basement to the basin fill units.

Structural data from both of the northern and southern margin-bounding faults of the Cumaovası basin are consistent with oblique-slip normal faults with sinistral and dextral strike-slip components. The western margin is bounded by strike-slip faults. The geomorphologic indicators along the western margin of Cumaovası basin and kinematic analysis on the striated fault planes support two senses of movements, each having opposite kinematic indicators. Quantitative indications are presented for the polyphase evolution of the Cumaovası basin, with a change from transpressional to transtensional tectonics, due to an anticlockwise rotation of the stress tensor around vertical axis. The earliest period of evolution is represented by sinistral strike-slip faulting that is documented in outcrops along the Orhanlı Fault Zone. This transpressional regime is inferred to be responsible for the NW–SE shortening associated with NE–SW extension. The younger structural data obtained from the Cumaovası basin support a mixture of normal and strike-slip movement in a transtensional tectonic regime that formed under an approximately N–S extensional direction associated with an approximately E–W compression. This transtensional phase is still ongoing in the region, as indicated by active fault planes and focal mechanisms of shallow earthquakes. The transition from transpressional to transtensional tectonic regime in the Cumaovası basin has been a consequence of local stress field inversion in the region. This local inversion should be taken into account during discussion of the regional tectonics of western Anatolia.

Key Words: Cumaovası strike-slip basin, transpression, transtension, extension, western Anatolia

Batı Anadolu'da Doğrultu-atımlı Havzaya Ait İlk Kayıtlara Bir Örnek: Cumaovası Havzası

Özet: Daha önce Çubukludağ Graben'i olarak bilinen Cumaovası havzası, Batı Anadolu genişleme provensi içerisindeki Gediz ve Küçük Menderes grabenlerinin batı ucunda bulunur. Doğrultu atımlı ve oblik atımlı normal fayların kontrolünde gelişen havza 5–17-km genişliğinde, 35-km uzunluğunda ve yaklaşık KKD–GGB uzanımlı asimetrik bir havzadır.

Havza açısal uyumsuzlukla birbirinden ayrılan iki farklı dolgu ile temsil edilir: (1) eski havza dolgusu flüviyal-gölsel çökelim ortamında biriken ve daha sonra KD–GB-uzanımlı doğrultu atımlı faylarla deforme olan Erken Miyosen–Pliyosen yaşlı istiflerle simgelenir; (2) yeni havza dolgusu doğrultu atım ve normal faylar kontrolünde gelişen Pliyo–Kuvaterner yaşlı birimler içerir. Bu faylardaki hareket Pliyo–Pleyistosen Görece formasyonu ve güncel alüvyonu eğimlendirmiştir. Kırmızı renkli alüvyon yelpazesi çökellerinden oluşan Görece formasyonu, alüvyon yelpazesi, alüvyon düzlüğü ve akarsu kanal çökellerinden oluşan güncel alüvyon birimini uyumsuz olarak üzerler. Menderes Masifi'ne ait metamorfik ve Bornova melanjına ait kayalar havza dolgusu birimlerinin temelini oluşturur.

Cumaovası havzasının kuzey ve güney sınır faylarından elde edilen yapısal veriler oblik atımlı normal faylanmayı karakterize ederken, batı kenarı doğrultu atımlı faylarla sınırlıdır. Cumaovası havzasının batı sınırında topoğrafik haritalar, uydu fotoğrafları ve arazi gözlemleri ile saptanan jeomorfolojik indisler ve fay yüzeylerinde yapılan kinematik analiz çalışmaları iki farklı hareketi destekler niteliktedir. Cumaovası havzasının çok evreli gelişimini gösteren transpresyondan transtensiyona değişen nicel indisler gerilme tensörünün düşey eksen boyunca saat yönünün tersine dönüşü ile ilişkilidir.

Bu evrimin ilk safhası olan sol yönlü doğrultu atımlı faylanma Orhanlı Fay Zonu boyunca gözlenen yüzleklerde bulunur. Bu transpresyon rejimden KB–GD sıkışma ve bununla ilişkili KD–GB açılma gerilmeleri sorumlu görülmektedir. Havzadan elde edilen daha genç yapısal veriler, yaklaşık K–G genişleme ve D–B sıkışma gerilmeleri ile ilişkili transtensiyonal tektonik rejim altında, normal ve doğrultu atımlı hareketin birlikte işlediğini destekler niteliktedir. Aktif fay düzlemleri ve deprem odak mekanizma çözümleri bölgedeki bu transtensiyonal rejimin halen devam ettiğini göstermektedir. Cumaovası havzasında saptanan tektonik rejimin transpresyondan transtansiyona değişimi bölgedeki yersel gerilmenin terslenmesi ile ilişkilidir. Yersel gerilme dağılımındaki bu terslenme Batı Anadolu' nun bölgesel tektoniğini tartışılırken gözardı edilmemelidir.

Anahtar Sözcükler: Cumaovası doğrultu atım havzası, transpresyon, transtansiyon, genişleme, Batı Anadolu

Introduction

Many sedimentary basins of variable sizes are formed under the control of both strike-slip and normal fault systems. These are defined as transtensional basins that have various geometries and complex tectonic and depositional histories. Transtensional basins are most likely to form along oblique-divergent plate boundaries or in transfer and accommodation zones in major rifts and extensional provinces (Christie-Blick & Bilddle 1985; Fauld & Varga 1998). Ingersoll & Busby (1995) defined transtensional basins as those basins formed by extension along strike-slip fault systems. The classic examples of the transtensional basin are the pull-apart basins that are elongated depressions where one strike-slip fault steps over to another strike-slip fault (Aydın & Nur 1982; Christie-Blick & Bilddle 1985). These basins are commonly bounded by large strike-slip fault zones, adjacent to which sediments are strongly deformed. The pull-apart origin of these basins is clearly demonstrated by the character of the basin. Proximal provenance of high energy mass-flow deposits indicate areas of local basement uplift and erosion adjacent to areas with rapid subsidence and deposition features characteristic of a pull-apart origin (Sylvester 1988). However, basins that form where normal or oblique-slip faults splay from large strike-slip faults without a step to another strike-slip fault are best defined as transtensional fault-termination basins (Miall 2000). Fault-termination basins have characteristics of both classic rift and pull-apart (strike-slip) basins (Umhoefer *et al.* 2007). Examples are present in the northern Aegean Sea (Mann 1997; Koukouvelas & Aydın 2002), along ancient strike-slip faults (Olsen & Schlische 1990), and in the southern Gulf of California – an oblique-divergent plate boundary (Dorsey & Umhoefer 2000; Dorsey *et al.* 2001; Umhoefer *et al.* 2007).

A few studies have documented some characteristic structures of strike-slip basins comprising solid structural and sedimentological data (e.g., Crowel 1982; Aydın & Nur 1985; Christie-Blick & Biddle 1985; Nilsen & McLaughlin 1985; Ingersoll 1988; Sylvester 1988; May *et al.* 1993; Campagna & Aydın 1994; Ingersoll & Busby 1995; Nilsen & Sylvester 1995; Dooley & McClay 1997; Rahe *et al.* 1998; Lee & Chough 1999; Ryang & Chough 1999; Barka *et al.* 2000; Miall 2000; Wysocka & Swierczewska 2003). For example, the Ridge basin in southern California is one of the best studied strike-slip basins in the world (Crowel 1982; Nilsen & McLaughlin 1985). It was developed during the Late Miocene–Pliocene time under the control of the dextral San Gabriel Fault, which bounds it to the southwest, while the San Andreas Fault forms its northwest boundary. The Ridge basin is a syncline-like asymmetrical basin filled with up to 14 km of sedimentary sequence. Across the southwestern margin of the basin, there is a thick alluvial fan of deltaic clastics shed from the San Gabriel Fault into the lacustrine sediments (May *et al.* 1993). Another well-defined pull-apart basin is the rhomb-shaped Eumsung basin in Korea (Ryang & Chough 1999). It is approximately 40-km long and 5-km wide. It was formed in an overstep of the sinistral Kongju fault system. On the pull-apart margin of the southwestern part of the Eumsung basin, three alluvial-to-lacustrine systems are recognized: (1) a volcaniclastics-dominated alluvial fan, (2) an alluvial plain dominated by channel shifting within floodplain, and (3) a floodplain and lake. The Lo River basin which is located in Vietnam also demonstrates many of the characteristic structures of a pull-apart basin (Wysocka & Swierczewska 2003). The basin was formed in relation to sinistral transtensional regime through the Red River and Lo River fault zones. It has an alluvial sedimentary fill of 6000-m thickness consisting of three main packages: (1) alluvial fan deposits, (2) gravel- and/or sand-dominated fluvial channel deposits, and (3) alluvial plain deposits. The basin fill was accompanied by syn-depositional tectonism responsible for the development of intraformational folds and local unconformities. These unconformities were e result of transition from transtension to transpression in the basin (Wysocka & Swierczewska 2003).

Most of the strike-slip basins that have been described in Turkey, are related to the North Anatolian and East Anatolian fault zones (e.g., Koçyiğit 1988, 1989, 1990; Westaway & Arger 1996; Barka *et al.* 2000; Koçyiğit & Erol 2001; Şengör *et al.* 2004). The Taşova-Erbaa Basin, as an example, developed along the North Anatolian Fault Zone (Barka *et al.* 2000). It is approximately 65-km long and 15–18-km wide. Barka *et al.* (2000) have mapped numerous extensional and compressional faults which deformed the basin fill. The compressional structures are isolated and associated with master faults, whereas the pervasive extensional faults trend perpendicular to the principal displacement zone of master faults that accommodate secondary pull-apart stretching within the basin.

Although, many studies have concluded that western Anatolia is dominantly characterized by approximately E–W-trending graben-forming high-angle normal faults that developed since the Upper Miocene–Pliocene (the last stage of N–S-extension in the region; e.g., Koçyiğit *et al.* 1999, 2000; Bozkurt & Sözbilir 2004), there are some studies revealing the presence of a number of NE–SW-trending strike-slip faults deforming the western Anatolia crust onshore (Kaya 1981; Genç *et al.* 2001; Kaya *et al.* 2004, 2007; Erkül *et al.* 2005a; Uzel & Sözbilir 2006a) and offsore (Ocakoğlu *et al.* 2004, 2005). The models for the neotectonic evolution of these basins include (summerized in Bozkurt 2003): tectonic escape (Dewey & Şengör 1979; Şengör 1979, 1980, 1982, 1987; Şengör *et al.* 1985; Görür *et al.* 1995), back arc spreading (McKenzie 1978; Le Pichon & Angelier 1979; Jackson & McKenzie 1988; Meulenkamp *et al.* 1994; Okay & Satır 2000), orogenic collapse (Seyitoğlu & Scott 1992; Seyitoğlu *et al.* 1992), episodic two-stage extension model (Sözbilir & Emre 1996; Koçyiğit *et al.* 1999; Bozkurt 2000, 2001a, 2003; Işık & Tekeli 2001; Lips *et al.* 2001; Sözbilir 2001, 2002; Bozkurt & Sözbilir 2004; Koçyiğit 2005), and the velocity differences between the overriding plates (Aegean and Anatolian plates) on the African plate (Doglioni *et al.* 2002; Tokcaer *et al.* 2005).

In this paper, we present the structural features of the NE–SW-trending Cumaovası basin which is located within an intermittently active zone of weakness, the İzmir-Balıkesir Transfer Zone (Figure 1). This study presents structural data collected from the strike-slip faults that bounds the western margin of the basin and the transverse, dip-slip faults to the south and north of the basin. The goal of this study is to resolve the local relative stress axes of various ages in order to understand the deformation history and process of strain transfer in an active, evolving strike-slip basin.

Tectonic Setting

Western Anatolia, the eastern part of the Aegean extensional province, is a seismically active region of N–S continental extension (Bozkurt 2001a). The region is bounded by the North Anatolian Fault Zone to the north and the Aegean-Cyprus Arc to the south (Figure 1). The formation of Pliocene to recent N–S extension in western Anatolia is attributed to tectonic escape-related deformation. This caused westward motion of the Anatolian platelet along its boundary structures; dextral North Anatolian Fault Zone and sinistral East Anatolian Fault Zone (Şengör *et al.* 1985). According to recent GPS measurements, the westward motion changes direction in western Anatolia with an abrupt anticlockwise rotation toward southwest over the Aegean Trench (McClusky *et al.* 2000). The main axis of southwestward motion of western Anatolia is characterized by a transfer zone located between İzmir and Balıkesir, approximately trends N20°E (Sözbilir *et al.* 2003a, b; Erkül *et al.* 2005a). The zone forms the western boundary of the E–W-trending Gediz, Küçük Menderes and Büyük Menderes grabens and accommodated N–S extension during the formation of the grabens. Most of the Quaternary basins included in this zone are bounded by segments of the NE–SW-trending strike-slip faults and E–W-trending normal faults oriented obliquely to the strike-slip faults, and therefore the Quaternary basins lying within the zone have the characteristics of rhomb grabens or strike-slip basins (Uzel & Sözbilir 2005a, 2006b).

The İzmir-Balıkesir Transfer Zone was first identified by Okay & Siyako (1991) as a transform zone of weakness and was interpreted to be the depositional site of the Bornova Flysch Zone during the Late Cretaceous. The Miocene sedimentary basins lying within the zone were described by Kaya (1979, 1981) and Kaya *et al.* (2007). The authors described the region that coincides to this zone as the Akhisar depression and claimed that the structural lines bounding the depression were inherited from pre-Miocene oblique-slip normal faults. Ring *et al.* (1999) rename this feature as a sinistral wrench corridor and propose that the zone was active during the Miocene. They noted that this zone has been sinistrally displaced by ~150 km and that the Vardar-İzmir-Ankara Suture bent to the south along the zone (Figure 1c). Differential extension between the Aegean and the Menderes Massif is indicated by palaeomagnetic data showing an abrupt switch from clockwise rotation on the Aegean (Kissel & Laj 1988) to anticlockwise rotation in western Turkey during the Middle Miocene (Kissel & Laj 1988). The palaeomagnetically determined rotations from Kissel & Laj (1988), have been interpreted by Ring *et al.* (1999) as a sinistral wrench corridor, which is thought to have accommodated differential extension between the Cyclades and western Turkey.

Sözbilir *et al.* (2003a, b) was the first to suggest that the zone is the result of intermittently reactivated basement-involved strike-slip and normal faults. Plio–Quaternary rocks within the NE–SW-trending corridor are primarily broken by multi-orientated faults that have

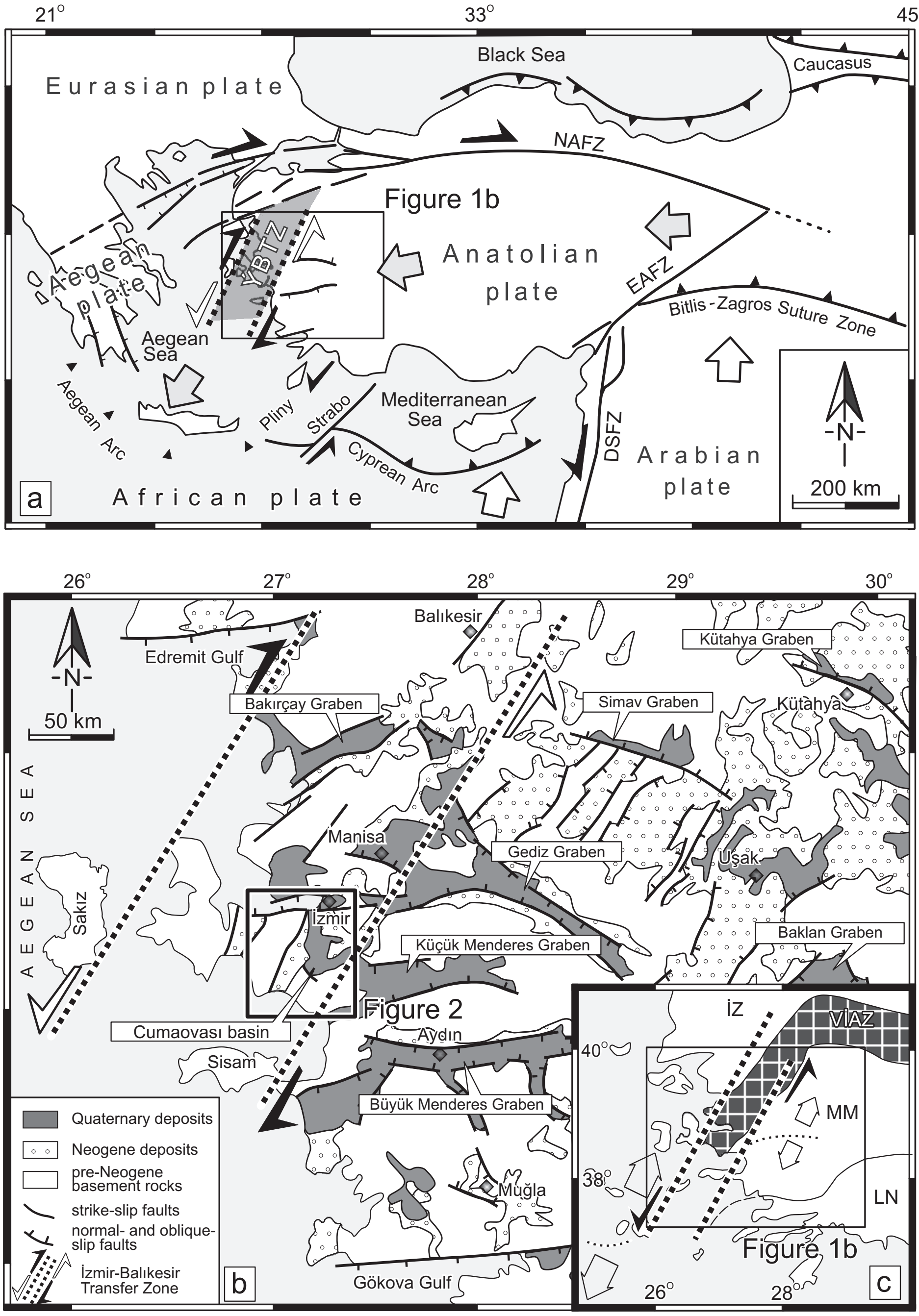

Figure 1. (**a**) A map of the regional tectonic structures of Turkey and surroundings. WAHGS– West Anatolian horst-graben system, NAFZ– North Anatolian Fault Zone, EAFZ– East Anatolian Fault Zone, PST– Pliny-Strabo trench, İBTZ– İzmir-Balıkesir Transfer Zone. Arrows indicate senses of motion relative to the Eurasian plate (modified from Barka 1992, 1999; Bozkurt 2001a). (**b**) Simplified geological map showing the Neogene-Quaternary basins in the western Anatolia with main tectonic lines and distribution of the Neogene–Quaternary deposits (modified from MTA 2002, Geological map of Turkey, scale 1:500 000; Bozkurt 2000, 2001a, b). Inset (**c**) shows a sinistral wrench corridor which abruptly caused a bend of the Vardar-İzmir-Ankara Suture to the south along the İBTZ (modified after Ring *et al.* 1999). Note differential extension between the Aegean and Anatolia. IZ– Internal Zones LN– Lycian Nappes, MM– Menderes Massif, VİAZ– Vardar-İzmir-Ankara Zone.

dextral, sinistral and oblique-slip displacements. The displacements result in subsided and uplifted areas that may form the negative or positive flower structures (Sözbilir *et al.* 2007a, b). Some of the displacement faults can be traced offshore where they have been studied in detail (e.g., Ocakoğlu *et al.* 2004, 2005). Most of these faults are presently active within the İzmir-Balıkesir Transfer Zone of distributed seismicity that is presently considered the transfer zone between Aegean and Anatolia (e.g., Sözbilir *et al.* 2003a, b; Nyst & Teatcher 2004; Uzel & Sözbilir 2005b, 2006a, b).

Within this complex framework, the study area is located at the western termination of the Küçük Menderes Graben, close to the southeastern part of the zone (Figure 1b). Although the basin (formerly known as the Çubukludağ Graben) is cited as a classic example of a graben basin (Genç *et al.* 2001), there remain many unresolved questions about its structural style and history, the complex relationship between active structures and reactivation of ancient structures, and the partitioning of strain.

Stratigraphy of the Cumaovası Basin

The stratigraphy of the study area is considered within three main groups: (1) the basement rock units, (2) Neogene volcano-sedimentary units (ancient basin fill units), and (3) Plio–Quaternary units (modern basin fill units) (Figures 2, 3 & 4). The ancient basin fill is exposed farther away from the modern depression, whereas the modern basin fill is restricted to the interior of the depression. The two basin infills are separated by an angular unconformity (Figure 4).

Basement Rock Units

The basement units consist of Palaeozoic–Mesozoic metamorphic rocks of Menderes Massif and Upper Cretaceous–Palaeocene rocks of Bornova mélange. Detailed descriptions of the basement rocks are beyond the scope of this paper, and the readers are referred to (e.g., Akartuna 1962; Eşder & Şimşek 1975; Kaya 1979, 1981; Başarır & Konuk 1981; Erdoğan 1990; Bozkurt & Oberhänsli 2001; Genç *et al.* 2001) for further reading. However, a brief description of these units will be given below.

The metamorphic rocks of the Menderes Massif are exposed in the southeastern part of the study area around Değirmendere High (Figure 3). The massif consists of schists and marbles with local phyllite intercalations (Dora *et al.* 1990; Güngör 1998; Güngör & Erdoğan 2002). The metamorphic rocks are tectonically overlain by the Bornova mélange (Başarır & Konuk 1981; Erdoğan 1990).

The Bornova mélange (also named as Bornova Flysch Zone by Okay & Siyako 1991) is well-exposed on the Seferihisar High forming the western margin of the Cumaovası basin and on the Değirmendere High to the south (Figure 3). The Bornova mélange is made up of a deformed and locally metamorphosed flysch-like matrix of Maastrichtian–Paleocene age in which blocks of Mesozoic limestones, serpentinites and submarine volcanics occur (Erdoğan 1990). The Menderes Massif and tectonically overlying Bornova mélange are unconformably overlain by the Neogene volcano-sedimantary successions.

Neogene Volcano-sedimentary Units (Ancient Basin-fill Deposits)

The Neogene successions are exposed mainly in the western part of the Cumaovası basin, along a topographic high between the Seferihisar and Değirmendere highs, and in the northern part of the basin, where it is a topographic high between Buca and Kunerlik depressions (Figures 2 & 3). According to Genç *et al.* 2001, the Neogene successions are divided into five major lithostratigraphic units: Çatalca, Karaburun, Ürkmez, Yeniköy and Cumaovası volcanic units (Figure 4). The main lithology in the lower part of the Neogene sequence, the Çatalca formation, is composed of thin-to-thick bedded conglomerates, sandstones, siltstones and shale alternations including lignite lenses. The Çatalca formation is interpreted as a lacustrine-fan delta facies and dated as Lower–Middle Miocene based on the palaentological and palynological studies (Akartuna 1962; Kaya 1979, 1981; Genç *et al.* 2001; Sözbilir *et al.* 2004). Lower–Middle Miocene lacustrine deposits outcrop at various localities in the western Anatolian basins; e.g., Dereköy formation in the Kemalpaşa-Torbalı basin (Sözbilir *et al.* 2004), Soma formation in the Soma basin (İnci 1991, 1998, 2002), Demirci formation in the Demirci basin (İnci 1998; Yılmaz *et al.* 2000), Hacıbekir Group in the Selendi Basin (Seyitoğlu 1997; Ersoy & Helvacı 2007), Hasköy and Başçayır formations in the Büyük Menderes Graben (Sözbilir & Emre 1990; Emre &

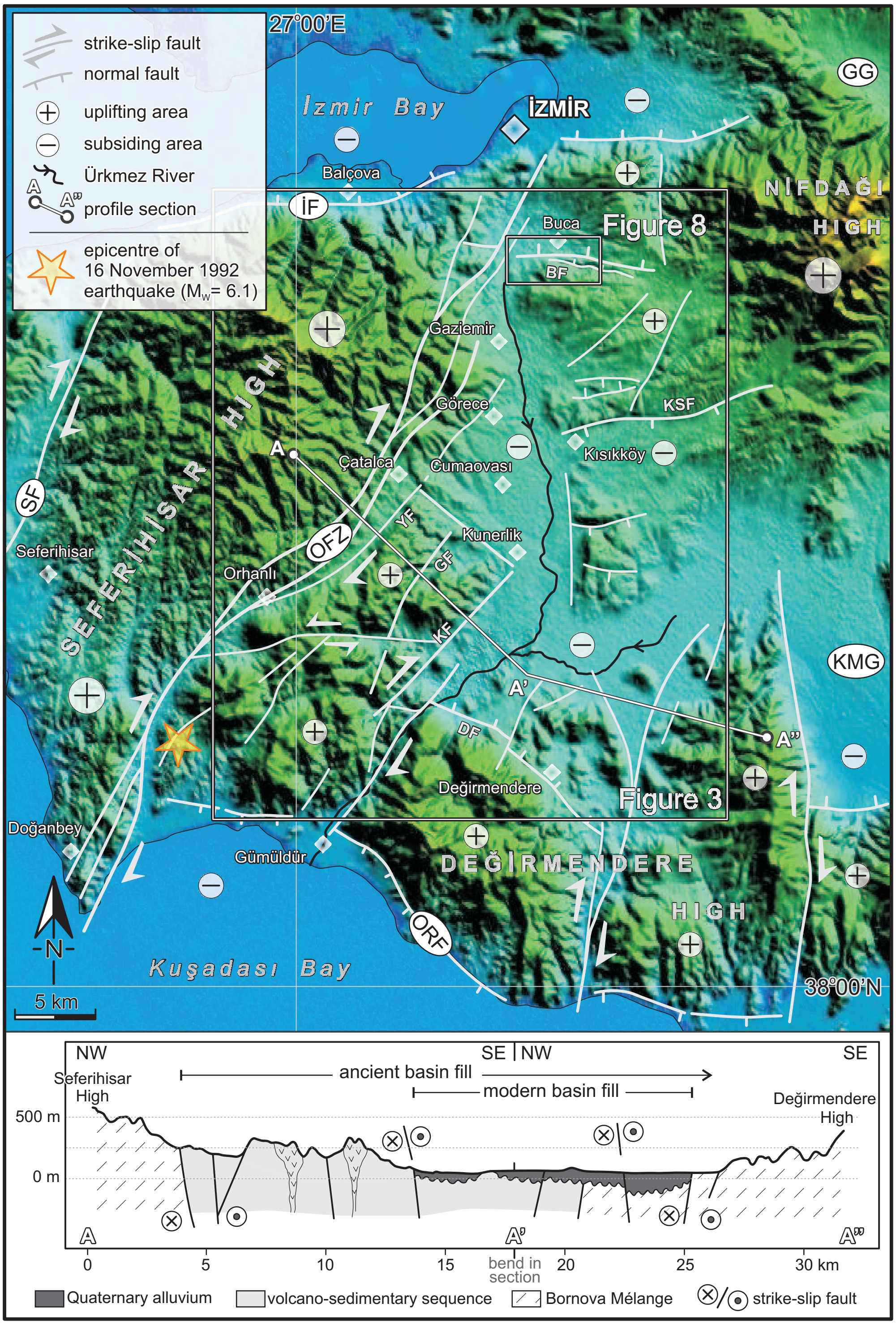

Figure 2. A Landsat image showing fault patterns of the Cumaovası basin. The faults are compiled from Eşder & Şimşek 1975; Genç *et al.* 2001 and this study. DEM adapted from the Global Mapper program (www.globalmapper.com). Note the epicenter of the 16 November 1992 earthquake on the western margin of the Cumaovası basin. The cross section at the bottom of figure shows episodic basin formation, the modern basin fill is superimposed on the ancient basin fill. İF– İzmir fault, SF– Seferihisar fault, OF– Orhanlı Fault Zone, OrF– Ortaköy fault , KMG– Küçük Menderes Graben, GG– Gediz Graben.

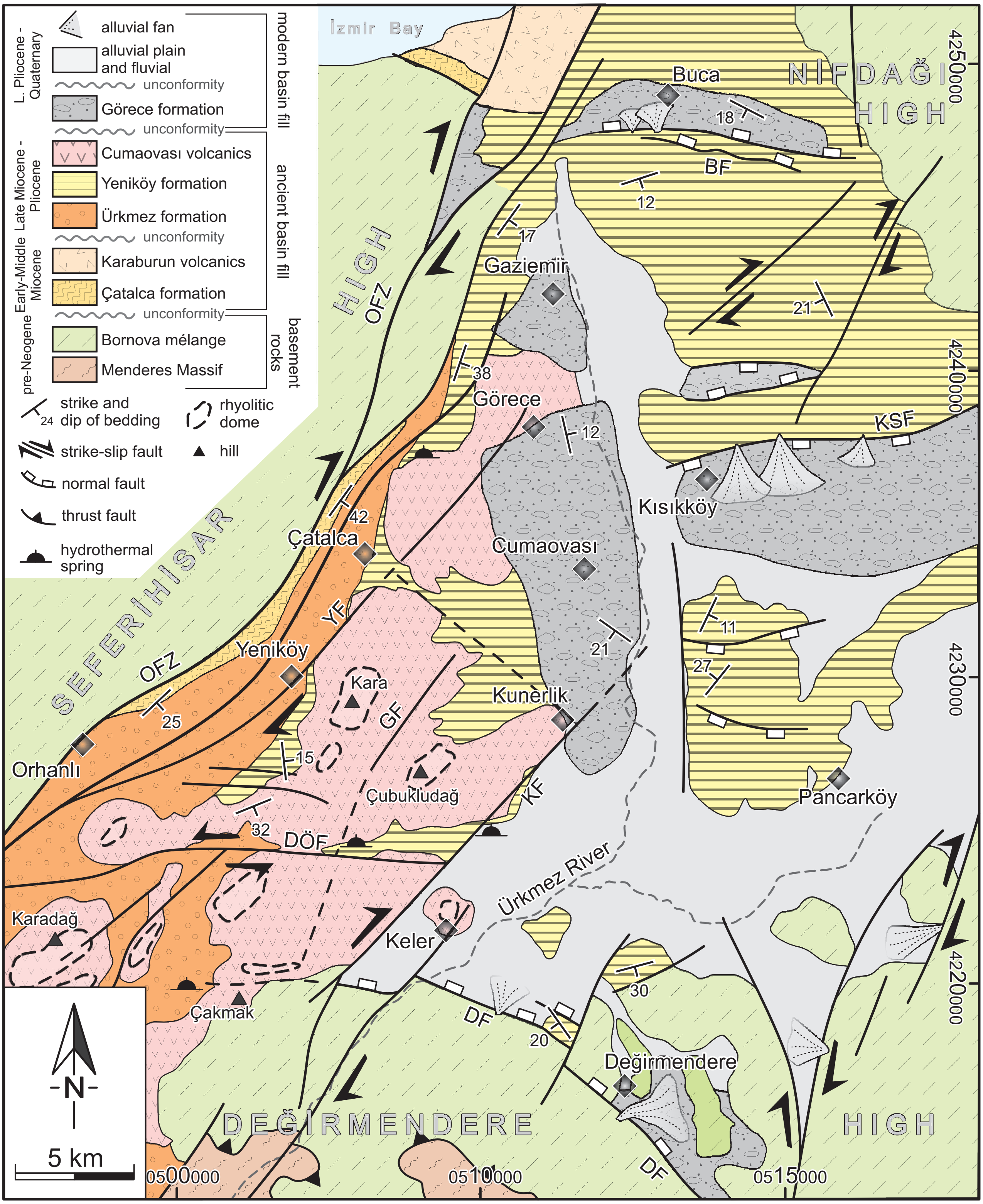

Figure 3. Detailed geological map of the Cumaovası basin. Note the NE–SW-elongation of the rhyolitic dome.

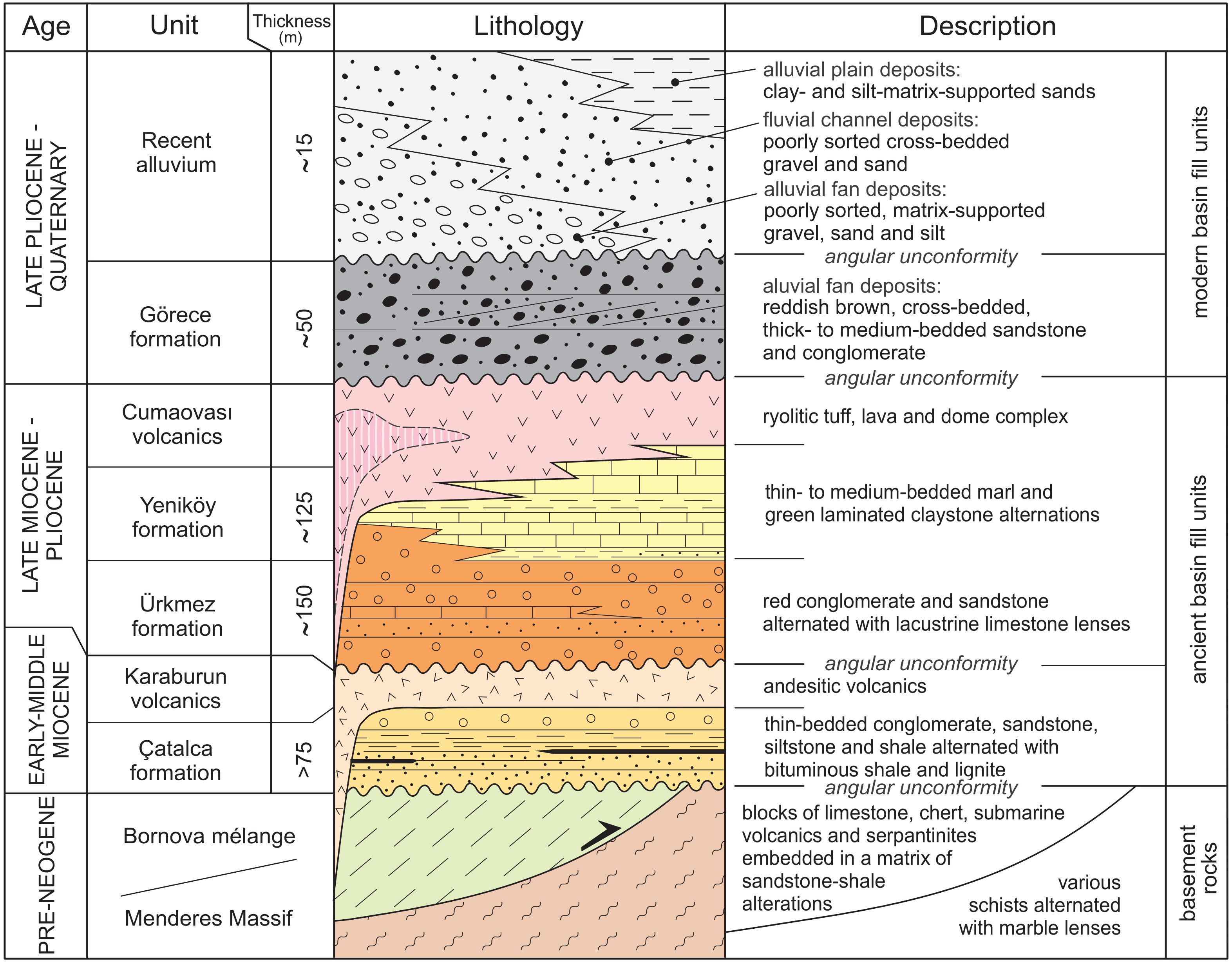

Figure 4. Generalized columnar section of the study area.

Sözbilir 1995; Çemen *et al.* 2006), and Alaşehir Formation in the Gediz Graben (Koçyiğit *et al.* 1999; Yılmaz *et al.* 2000; Sözbilir 2001, 2002; Seyitoğlu *et al.* 2002; Bozkurt & Sözbilir 2004) can be correlated with the Çatalca formation. In the north of the study area, the fine-grained clastics of the Çatalca formation are intercalated with the lavas and tuffs of the Karaburun volcanics. Radiometric datings on the lavas yield ages ranging from about 21 to 15 Ma (Yılmaz 1997).

The middle part of the sequence, the Ürkmez formation (Eşder & Şimşek 1975; Genç *et al.* 2001), is dominated by red conglomerate and sandstone alternation with lacustrine limestone lenses. Upward in the sequence, lithology displays a fining-upward profile where the conglomerates are replaced gradually by fine-grained conglomerates, sandstones and mudstones. According to Genç *et al.* (2001), the Ürkmez formation is of latest Middle(?)–Late Miocene in age and is interpreted as alluvial fan and lateral fan deposits interfingering with low energy lacustrine facies. This clastic rocks are interbedded with lacustrine limestones of the Yeniköy formation in the upper parts of the unit (Eşder & Şimşek 1975; Genç *et al.* 2001). The Yeniköy formation also consist of sandstone, mudstone and claystone alternations with thin lignite seams. Upward, the sequence is dominated by thin- to medium-bedded lacustrine limestones and green laminated claystone alternations. These are interbedded with pyroclastic rocks of the Cumaovası volcanics (Eşder & Şimşek 1975; Özgenç 1978; Genç *et al.* 2001). The outcrops of the Cumaovası volcanics are aligned in the NNE–SSW direction forming 'central volcanics' for the basin. They are exposed around the Karadağ, Dededağ, Karakaya, Kızılcaağaç, Çakmaktepe, Dikmendağı and Çubukludağ hills (Figures 2 & 3). The rhyolitic volcanic rocks of the Cumaovası volcanics yielded 11.5–9 Ma K/Ar ages (Borsi *et al.* 1972; Özgenç 1978; Genç *et al.* 2001). They are mostly rhyolitic pyroclastic rocks and lava flows with local domes. Genç *et al.* (2001) suggested that the Cumaovası volcanics begin with air fall tuffs of about 15 m thickness, forming early products of the volcanic activity. They are overlain by pyroclastic flow deposits, which are commonly composed of fragments of angular lavas within a pumiceous matrix. These are intercalated with rhyolitic lavas, locally included obsidian flows and perlites. The rhyolitic domes are aligned in the NE–SW-direction giving rise to NE–SW-directed hills in plan view (Figure 3). The lava domes are located between Orhanlı Fault Zone and Kunerlik fault, which was responsible for the transtensional opening. This structural origin for the domes is similar to that for the central volcanics previously documented in the NE–SW-trending basins located north of the Gediz Graben (e.g., the Gördes, Demirci, Selendi and Uşak-Güre basins; see Bozkurt 2003 for detail). An ideal pull-apart basin of Crowell (1974) also shows the presence of volcanic products within the centre of the basin. There transtensional forces caused rupture of the centre of the basin and the emplacement of volcanic rocks and shallow intrusions. Thus the strata would pass into volcanoclastics and lava flows, below which diapiric masses of hypabyssal rocks occur. The readers are referred to Genç *et al.* (2001) for detailed description of the ancient basin fill units.

Plio–Quaternary Units (Modern Basin-fill Deposits)

The Plio–Quaternary units consist of two terrestrial successions that are separated by an angular unconformity. These are here named, from bottom to top, as the Görece formation and Recent alluvium (Figures 3 & 4).

The Görece Formation, defined in this study, crops out mainly in the middle part of the basin, around the Görece, Kısıkköy, Buca and Değirmendere settlements (Figure 3). The geological map of the area reveals that the unit is mainly exposed along the NE–SW- and E–W-trending faults (Figure 3). The entire sequence is more than 50 m thick and can be divided into three sedimentary facies: matrix-supported massive breccia, massive/poorly stratified conglomerate, and cross-bedded conglomerate with massive sandstone lenses.

The matrix-supported massive breccia facies (FI) is characterized by generally red-coloured, poorly-sorted, medium- to thick-bedded and loosely-cemented conglomerates (Figure 5). It is up to several metres thick. According to a reference section from a unit in the east of the Görece village, clasts range in size from gravel to boulder. Clasts are widely dispersed in the brownish mud matrix and show random orientation. Some units are inversely graded and interlayered with massive/poorly (facies IIA) and cross-bedded conglomerates (facies IIB).

The matrix-supported breccias are interpreted as debris-flow deposits, based on poor sorting, randomly oriented floating clasts, and brownish mud matrix. Deposits with angular clasts larger than 40 cm can be

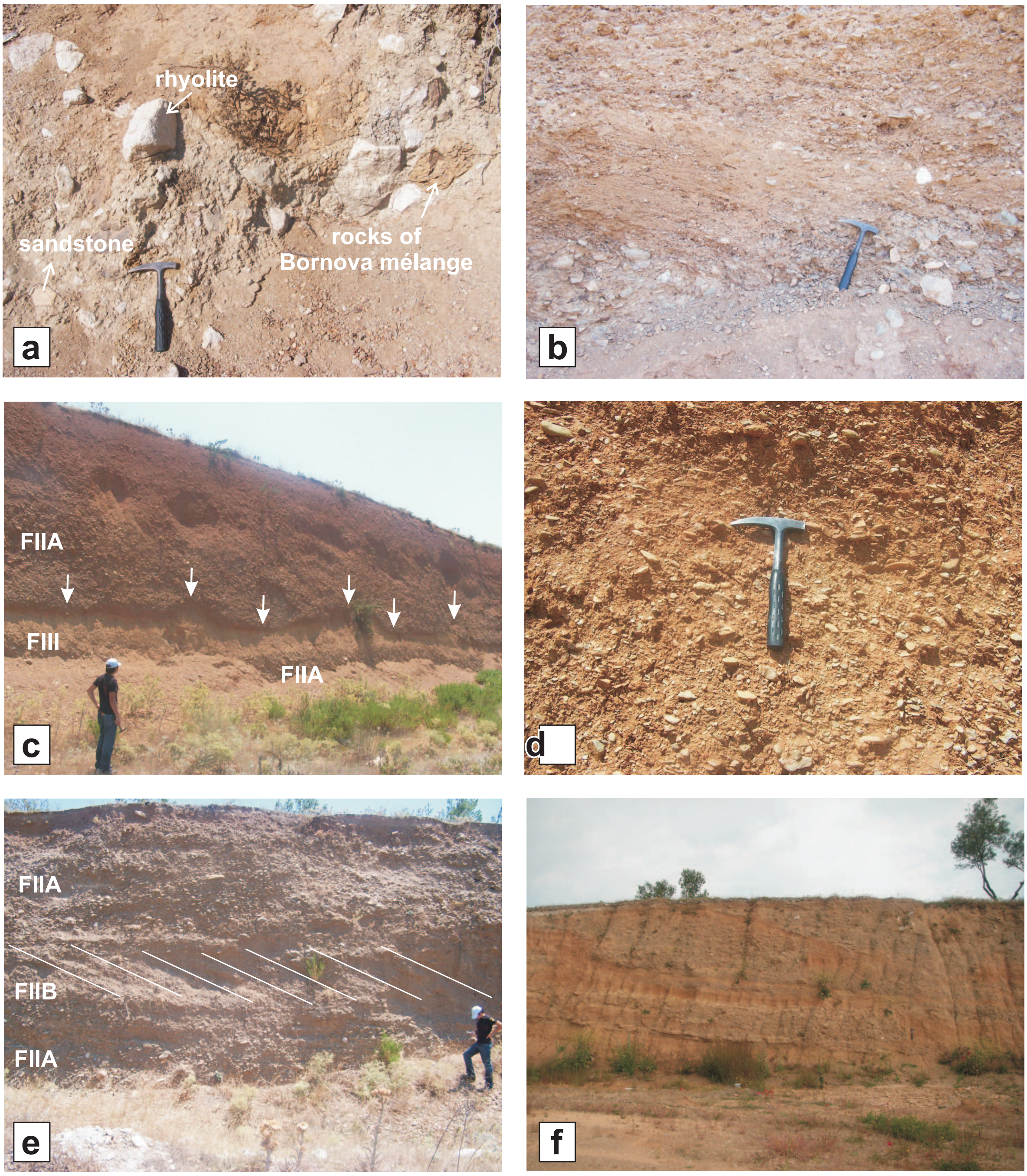

Figure 5. Field photographs showing the main facies characteristics of the Görece formation. (a) Poorly-sorted and disorganised conglomerates (Facies FI); (b) small-scale crossbeds of conglomerates (Facies IIA); (c) an erosional surface between the massive/poorly stratified conglomerates (Facies IIA) and massive sandstones (Facies III); (d) matrix- to clast-supported and poorly-sorted conglomerates with reddish-brown sand matrix (Facies IIA). Note the clasts are oriented to the flow direction; (e) a foreset bed of facies IIB interbedded with the facies IIA; and (f) an alternation of the massive/poorly stratified conglomerates (Facies IIA) and the massive sandstones and the cross-bedded conglomerates (Facies IIB).

interpreted as rockfall deposits. Random orientation and angular shape of clasts may reflect short transport (cf. Miall 1977, 1978; Rust 1978). Based on the facies characteristics and their radial distribution pattern, massive breccias are interpreted as proximal deposits of an alluvial fan (Stanistreet & McCarthy 1993).

The massive/poorly stratified conglomerate facies (FIIA) has either matrix- or clast-supported fabric with poorly- to well-sorted reddish-brown sand and silt matrix (Figure 5). According to a reference section from the unit in the north of the Cumaovası village clasts range in size from granule to boulder (Figure 7). Most clasts show random orientations but some are oriented to the flow direction. The normal and/or inverse grading are usually observed in the sequence. Some units rarely includes stratification and small-scale cross-bedding. The facies are commonly interlayered with cross-bedded conglomerate (facies IIB) and massive sandstone (facies III). Some boundaries with massive sandstones are also erosional.

The clast orientation and imbrications indicate that the gravels were transported as bedload or lag deposits. The mechanism of gravel bedload transport is related to longitudinal bar migration that possibly indicates poorly defined horizontal beds under high flow energy (Miall 1977, 1978; Rust 1978). Based on the facies characteristics and their radial distribution pattern, massive conglomerates are interpreted as proximal deposits of an alluvial fan (Stanistreet & McCarthy 1993).

The cross-bedded conglomerate facies (FIIB) includes planar and trough cross-bedded conglomerates (Figure 5). The foreset angle averages 10° to 40°. The foreset units consist of alternating units of conglomerate, conglomeratic sandstone and sandstone. The combined units are generally up to several metres thick and clast size ranges from gavel to boulder. Most clasts show imbrications that are oriented to the approximately W to E flow direction. Conglomerate layers are commonly fining upward to the sequence and the upper boundary of the cross-beds is usually planar. The trough cross-bedded units commonly show channel geometry. This facies alternates with massive/poorly conglomerate (facies IIA) and massive sandstone (facies III). It is also overlain by massive sandstones with an erosional surface.

This facies was most likely deposited by migration of various gravel bars. The graded upper boundary of the cross-beds supported this basin progradation. In sequence, partly graded units suggest a dispersive pressure during flow (Miall 1977, 1978; Rust 1978). Based on the facies characteristics and their radial distribution pattern, cross-bedded conglomerates are interpreted as middle-distal part deposits of an alluvial fan (Stanistreet & McCarthy 1993).

The massive sandstone facies (FIII) is characterized by massive, poorly to moderately sorted, yellowish red sandstone units which comprise minor amount of conglomerates and siltstone (Figure 5). It is up to 1 m thick and the poorly defined beds usually occur between each massive package. The package includes some isolated pebbly sandstone lenses and layers with a fining upwards trend. Some units contain channel fill conglomerates, and also rarely include organic fragments. This facies is commonly interlayered with massive/poorly stratified (facies IIA) and cross-bedded conglomerates (facies IIB). Its boundary with massive conglomerates is also erosional.

Based on sedimentary and geometric characters, the Görece formation can be considered as an alluvial fan deposition including proximal, middle-distal and alluvial plain parts of the fan system (DeCelles *et al.* 1991; Stanistreet & McCarthy 1993; Nemec & Postma 1993; Blair 1999a, b). It was formed in front of strike-slip (Orhanlı Fault Zone) and normal faults (Buca, Değirmendere and Kısıkköy).

The Görece formation unconformably overlies the ancient basin fill units and is disconformably overlain by recent alluvial deposits. No palaentological data has been acquired from the Görece formation. Close to the study area, Sözbilir *et al.* (2004) defined the Plio–Pleistocene Sütçüler formation in the Kemalpaşa-Torbalı basin, which probably correlates with the Görece formation. Plio–Pleistocene sediments exposed along most of the western Anatolian grabens can also be correlated with the Görece formation (Koçyiğit *et al.* 1999; Yazıcıgil *et al.* 2000; Yılmaz *et al.* 2000; Sarıca 2000; Seyitoğlu *et al.* 2002; Koçyiğit 2005; Rojay *et al.* 2005; Emre & Sözbilir 2007; Ersoy & Helvacı 2007). Its stratigraphic equivalent in the west Anatolian grabens are the Asartepe formation in the south part of the Gediz Graben described in Emre (1996), Aydoğdu formation in Küçük Menderes Graben described in Emre *et al.* (2006), Hüseyinciler formation in Büyük Menderes Graben described in Sarıca (2000) and Yamaçköy formation in Söke area described in Gürer *et al.* (2001); it can be presumed as Plio–Pleistocene in age (Ünay *et al.* 1995; Ünay & de Bruijn 1998).

The Recent alluvium is formed in front of the normal faults (Buca, Kısıkköy and Değirmendere faults) and in the middle part of the basin. The unit consists of alluvial-fan deposits, the alluvial plain deposits and the fluvial

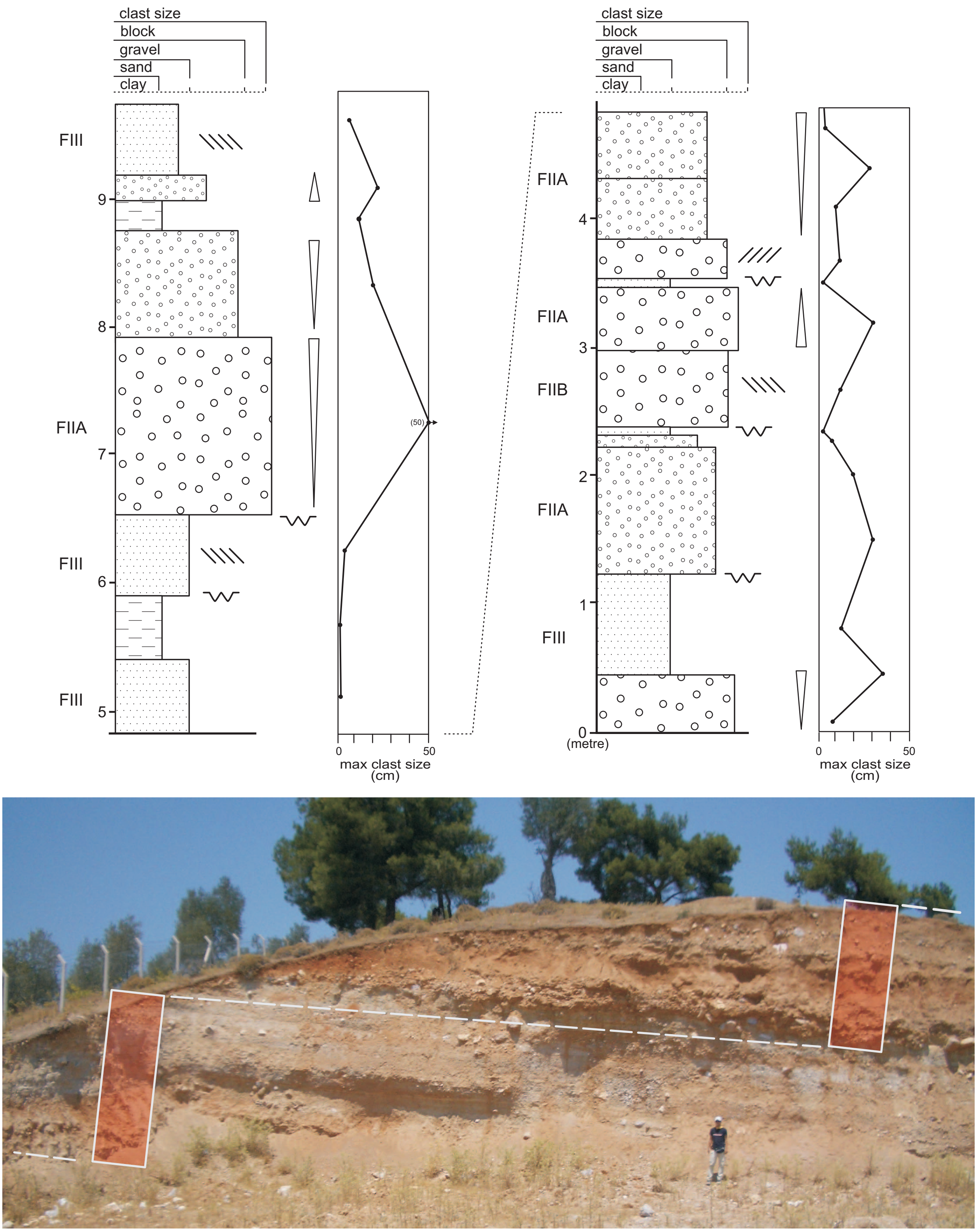

Figure 6. Measured stratigraphic columnar section of the Görece formation along the Cumaovası-İzmir road cut, approximately 2 km WNW of Görece village. The section shows the proximal part of an alluvial fan. See Figure 7 for explanation. The man is 1.80 m tall.

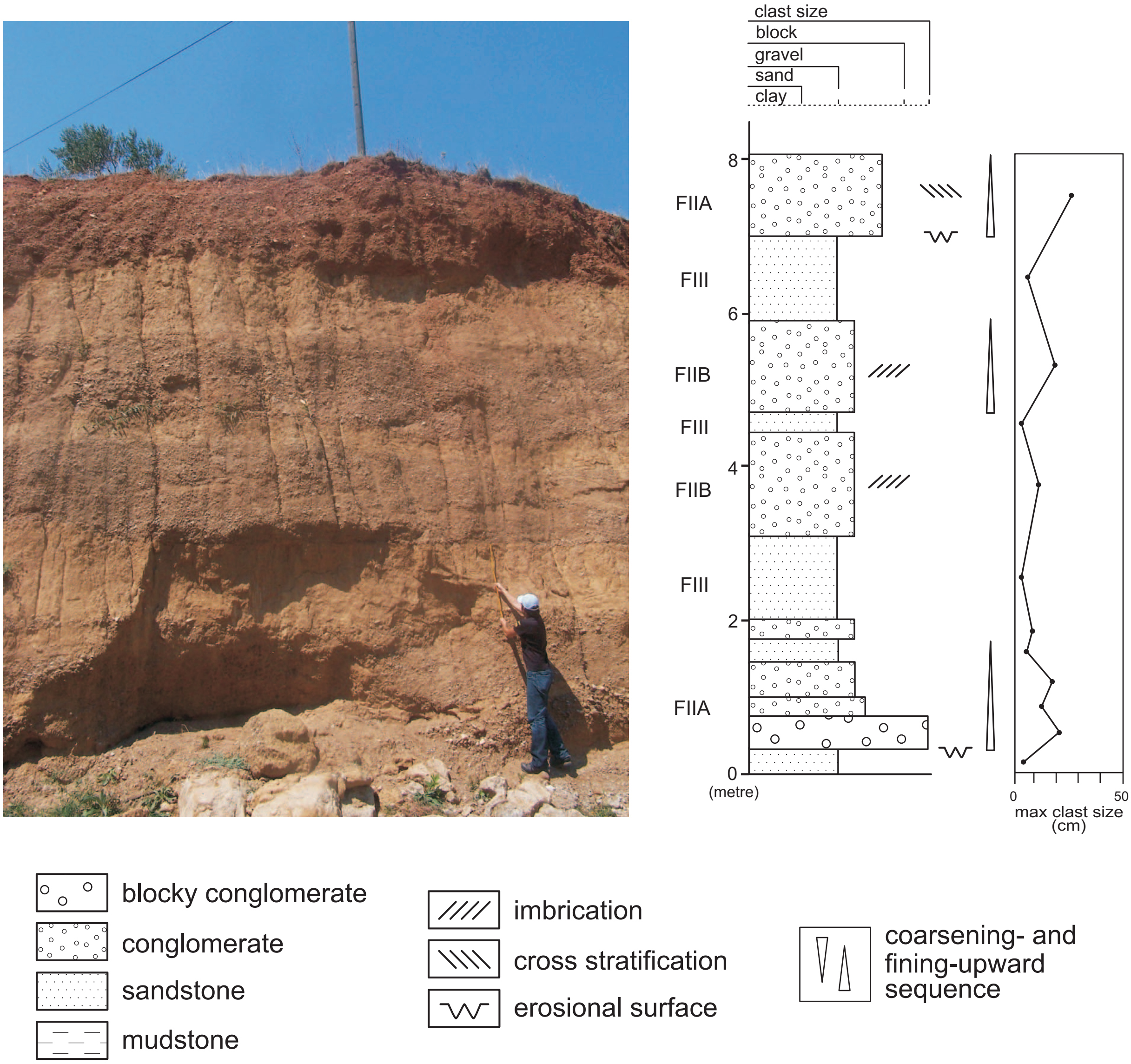

Figure 7. Measured stratigraphic columnar section of the of the Görece formation along the Cumaovası-İzmir road cut, approximately 3 km NW of Cumaovası. The section shows the middle-distal part of an alluvial fan. The man is 1.80 m tall.

deposits. The alluvial-fan deposits crop out around the villages of Buca, Kısıkköy and Değirmendere (Figures 3 & 8). The alluvial-fan deposits are characterized by red-to-grey, unsorted, loosely-cemented, boulder- to pebble-size sediments and controlled by E–W-trending normal faults. The clasts were mainly derived from the limestones of the Bornova mélange and from the Neogene units.

The fan deposits interfinger with alluvial plain and fluvial deposits. The alluvial plain deposits can be followed along the Yobaz River in the Cumaovası plain. The alluvial plain deposits consist of clay and silt, matrix-supported, loosely-cemented sands and organic material-rich mud and clays. The fluvial deposits are characterized by cobble to boulder conglomerates and sands deposited along the river channels in the Cumaovası plain. These are controlled by the present-day drainage system in the region (Figures 2 & 3).

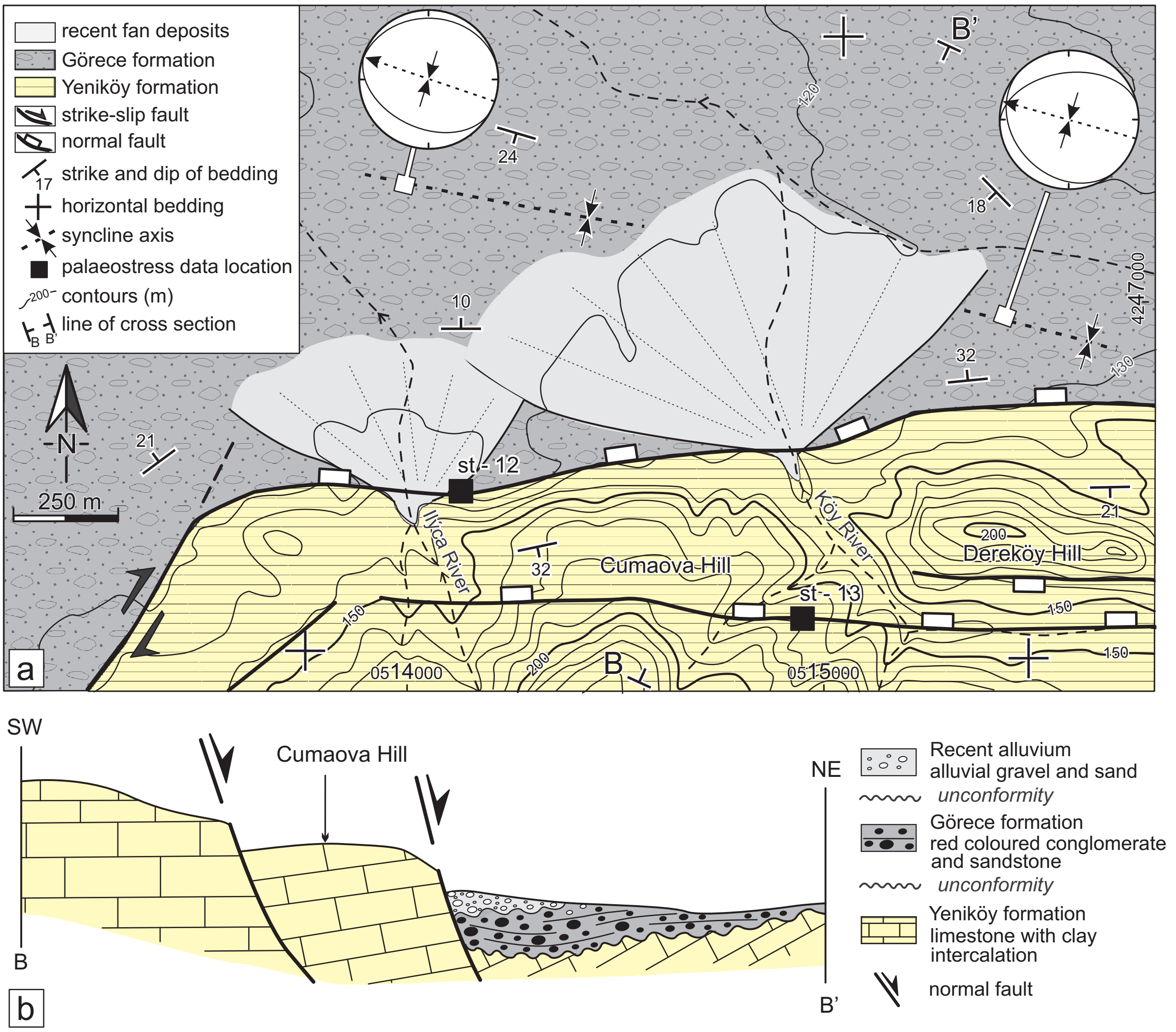

Figure 8. (a) Detailed geological map of the Buca area, and (b) field sketch depicting faulted contact relationship between the ancient basin- fill units (Yeniköy formation) and the modern basin fill units (Görece formation and recent fan deposits). Note the angular unconformity between the Görece formation and recent alluvial fan deposits. Two stereonets indicate attitude of a syncline forming in the hanging wall of the Buca fault.

Structural Geology

Two distinctly oriented fault sets are mapped in the Cumaovası basin (Figures 2, 3 & 8). These are: (1) approximately NE–SW-striking strike-slip faults and (2) approximately E–W-striking normal faults. They bound and control the present tectonic framework and overall geomorphic configuration of the Cumaovası basin. The western part of the Cumaovası basin is bounded by strike-slip faults, whereas the central, southern and northern parts of the basin are bounded by normal faults. All these faults are brittle and the kinematics of faulting are determined by using structural criteria that are well documented in the literature (Hancock 1985; Means 1987; Petit 1987; Stewart & Hancock 1991). Virtually all faults have slickensides with structures indicative of slip direction and in some cases shear sense. Shear direction indicators include striae, grooves, gashes, elongate calcite crystals and riedel shears. In several localities, more than one set of slip lineations on a single fault plane is established. We have also studied the stress field orientations using the observed slip surfaces at 17 stations along the faults where the fault-plane related features are well exposed.

Strike-slip Faults

Numerous strike-slip faults of variable sizes occur at the western margin of the Cumaovası basin. They are mostly dextral-slip faults with normal- and locally reverse-slip components. The fault planes are well-preserved where they cut the pre-Neogene basement rocks and the Neogene rhyolitic lavas and conglomerates. The strike-slip faults that control the drainage pattern of the basin are the Orhanlı Fault Zone and Yeniköy, Deliömer and Kunerlik faults (Figures 2 & 3). Descriptions and kinematic analyses of the faults are given below.

The Orhanlı Fault Zone forms the western margin of the Cumaovası basin, and is also the most prominent structure in the region south of İzmir city (Figures 2, 3 & 10). It bounds the Seferihisar High to the east. It may be traced for about 45 km, between İzmir Bay in the north and Kuşadası Bay in the south. The fault zone includes several dextral fault segments extending mainly in a NE–SW-direction. At st-1, to the northwest of Gaziemir village, the pre-Neogene rocks and the Görece formation are tectonically juxtaposed along the Orhanlı Fault Zone. The fault segments have an overall strike of 10° NE and 48° NE and average dips of about 89° NW and 72° NW, respectively. The main motion along the slip surfaces is dextral strike-slip, however, there is some geomorphological and structural evidence for the presence of an earlier sinistral strike-slip motion. The calculated rake angles for the older sinistral-motion are in the range of 09° to 22° S, whereas for the younger dextral-motion there is a range of 13° to 17° N (Figures 9, 11 & 13).

Three stations (st-2, 3 & 4) on a fault segment lying between Orhanlı village and Gaziemir town also reveal two sets of slickenlines. These show sinistral and dextral strike-slip movements where the rake of slip lines average 10° N (03–18° N) are superimposed by striations with an average rake of 20° S (14–27° S).

There are several well-exposed fault planes trending N35°E and 80° to 86° SE-dipping on limestones of the Bornova mélange to the northeast of the Doğanbey village (st-5). Well-preserved slickenlines on these planes reveal dextral strike-slip faulting with minor normal-slip component and rakes ranging from 20° to 27° S. On some of these fault planes, there is also evidence for older sinistral strike-slip movement with rake angles in the range of 17° to 22° N.

At st-6 to the north of the Çatalca village, the principal displacement fault of the Orhanlı Fault Zone juxtaposes the Bornova mélange rocks with the Ürkmez formation. Here, fault planes show dextral strike-slip faulting with a minor normal-slip component trending approximately N36°E and dipping 68° to 76° SE (where the rakes of slip-lines are in a range of 14° to 22° S). The asymmetric structures show that a dextral shear sense is predominant in the fault zone, consistent with that inferred from tectonic landforms and focal mechanisms for moderate earthquakes occurred along the Orhanlı Fault Zone (Figure 11). On the contrary, a sinistral shear sense is also identified in the same zone, where the rakes of slip-lines are in a range of 09° to 17° N. This discrepancy of shear senses in the same fault zone shows that a slip sense inversion has occurred along the Orhanlı Fault Zone.

To understanding the recent activity of the Orhanlı Fault Zone, morphotectonic features (cf. Lin *et al.* 2002; Maruyama & Lin 2004; Ganas *et al.* 2005) are investigated by interpretation and analysis of 1:25000-scale topographical maps and by detailed field mapping at the 1:25000 scale. Typical tectonic landforms, such as systematically deflected stream channels and ridges, shutter ridges, and fault scarps, are recognized along segments of the Orhanlı Fault Zone. These reveal a major active strike-slip fault zone to the south of İzmir city.

Three representative topographic maps are prepared to show special drainage patterns that developed in the areas along the fault zone (Figure 10). In these areas, most of the southeastward flowing stream channels are deflected dextrally to flow southwestward along the fault traces and then turn their traces again southeastward. However, relatively less sinistrally deflected rivers are also established.

Along the northern part of the fault zone, the Bahçe River and Dana River exhibit approximately 300 m dextral bends (Figure 10b). In the Middle part of the fault zone, the deeply incised Balaban River exhibits a complicated river morphology. Where the river intersects the active fault traces, it presents a hairpin-shaped bend (Figure 10)

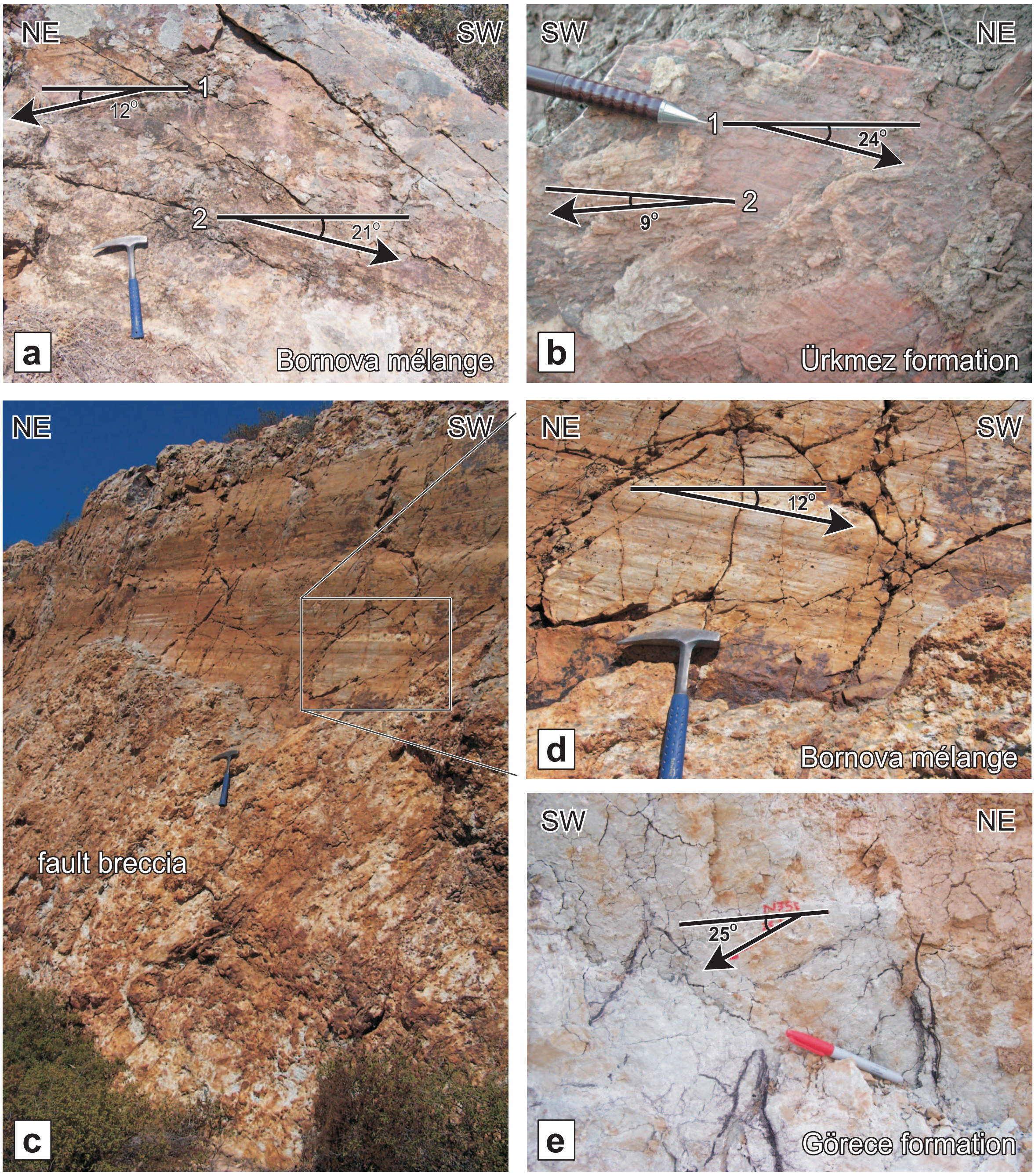

Figure 9. Field photographs showing outcrops of strike-slip faults in the Cumaovası basin. (a) and (b) shows reactivated nature of the Orhanlı Fault Zone. (a) Two striae with different sense of motion developed on the sandstone of the Bornova mélange. Here, sinistral slip occurs on ridge-and-groove and iron-coated slickensides, whereas striae with dextral slip predominantly indicating dextral faulting are superimposed on the same planes. The dextral faults are marked by grooves and clay-gauge; (b) a fault plane with superimposed striae on the conglomerate of the Ürkmez formation. Note the dextral lineations superimposed on the sinistral strike-slip. These crosscutting relations of different kinematic markers give a good relative age determination of both kinematic phases; (c) slip-plane of the Orhanlı Fault Zone indicating nearly horizontal slickensides. Note a thick fault breccia in front of the slickensided fault plane; (d) close-up view of the fault plane, and (e) a slip-plane of the Kunerlik fault indicating nearly horizontal slickensides.

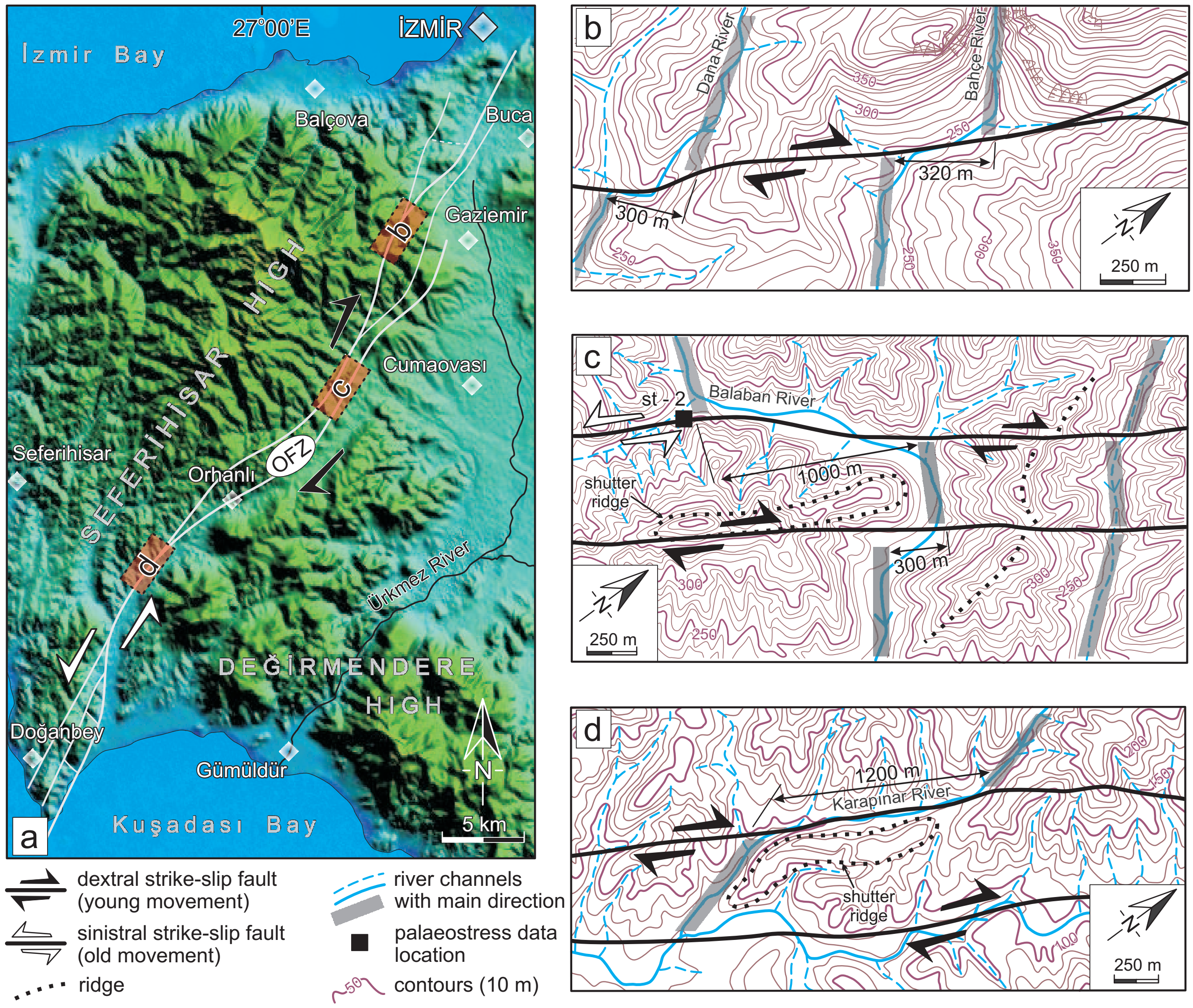

Figure 10. Morphologic and topographic features observed along the Orhanlı Fault Zone. **(a)** Shaded map showing present morphologic features of the Orhanlı Fault Zone. Note a curvilinear principles displacement zone and horsetail splays of en échelon syntethic faults in map view. The locations of the studied areas are also indicated. Three topographic maps in the east side of the figure show the offset patterns of the rivers that cross the Orhanlı Fault Zone; **(b)** a topographic map showing a systematic 300 m dextral offset of the Bahçe River and Dana River. Bold numbers indicate horizontal amount of dextral and sinistral deflections of the rivers; **(c)** a topographic map showing a hairpin-shaped deflection of the Balaban River between two segments of the Orhanlı Fault Zone. When the dextral offset is removed by 300 m to reconstruct the Balaban River prior to dextral offset, a residual sinistral deflection up to 700 m is established; **(d)** a topographic map showing the dextrally deflected Karapınar River. Note a curvilinear shutter ridge between two fault segments of the Orhanlı Fault Zone. The contour interval is 10 m in the topographic maps. Topography redrafted from 1:25 000 topographic maps published by the General Directorate of Military Service.

similar to those observed across the active faults in northwest Indochina (Lacassin *et al.* 1998) and in southwest Japan (Maruyama & Lin 2004). On the hairpin-shaped river, the segments following the active fault trace for 300 m are interpreted to be formed by cumulative dextral offsets (Figure 10c). When 300 m dextral offsets are removed to reconstruct the river morphology prior to dextral faulting, the river channels can not be restored to simple straight morphology but show a sinistral deflection up to 700 m (Figure 10c). Several shutter ridges are also established along the fault zone between Orhanlı Village and Çatalca Village. The Karapınar stream flows southeast into the fault where it is diverted approximately 1200 m to the southwest by a 140 m high shutter ridge. These ridges are aligned parallel to fault segments of the fault zone (Figure 10d). On the basis of their morphological and structural features, it can be interpreted that the early sinistral offsets are later overprinted by dextral offsets. In addition to that, several hot springs occur in the central part of the fault zone, implying that the fault zone provides effectively conduits for the geothermal field. This indicates that the hotsprings in the area are associated with active faults.

The Yeniköy Fault is a 200-m-wide, 30-km-long, NE–SW-trending strike-slip fault, running approximately parallel to the Orhanlı Fault Zone (Figures 2, 3 & 10). It is located between the Görece and Ürkmez villages. Northwest of the basin, near Görece, it cuts and tilts the Plio–Quaternery alluvial sediments of the Görece formation. The fault planes indicate a dextral strike-slip faulting with minor normal-slip components. They bound, the morphological high of Çubukludağ, Dededağ ve Karadağ to the east and cut Neogene sandstones, conglomerates and rhyolites. Near the Bahçecik village (st-7), there are a few fault planes indicating a dextral strike-slip faulting with a minor normal- and reverse-slip component. These have fault planes trening in N50°E direction and NW-dipping at 72° to 82°. The slickenlines on the planes shows a rake angle ranging from 03° to 27° S (Figure 13). It can be explained as a synthetic riedel shear (R shear) that has the same shear sense as the Orhanlı Fault Zone.

The Deliömer fault running in a nearly E–W direction is marked by a well-developed fracture zone having a width of >20 m. The fructure zone is composed of nonfoliated cataclasite, fault breccia, and fault planes with nearly horizontal slickenlines. It also displays abundant morphologic features characteristic of strike-slip movement. Abundant striations (plunging 14° SE) generated on the fault plane show a principal strike-slip sense of motion. The fault, as seen in Figure 2, appears as single continuous trace, but a closer view reveals that in fact it is made up of arrays of meso-scale synthetic and antithetic riedel shears forming a narrow damage zone. The shear sense indicators including lineations and riedel shear geometries suggest sinistral strike-slip motion. The Deliömer fault can be interpreted as an antitethic conjugate riedel shear (R') of the Orhanlı Fault Zone (Figures 2 & 3).

The Göllükaya fault is 50-m wide, 20–22-km long, and located between the Cumaovası and Gümüldür villages (Figures 2 & 3). It cuts Neogene sediments and volcanic successions through the Çubukdağ, Dikmendağ and Kızılcaağaç highs. Northwest of Kunerlik village, well-exposed fault planes show dextral strike-slip faulting with nearly horizontal sliplines. Volcanic centres also form along the N–S-trending faults that form structural highs between sub-basins.

The Kunerlik fault is a dextral strike-slip fault and displays abundant morphologic features characteristic of strike-slip faults. It is a 200-m-wide, 20-km-long, N25°E-trending dextral strike-slip fault (Figures 2 & 3). It bounds morphological highs, Çubukludağ, Dikmendağ ve Kızılcaağaç hills, to the east, and cuts Neogene sandstones, conglomerates and rhyolites. Along the Kunerlik, Şaşal and Keler villages, there are several well-exposed fault planes dipping at 76° to 89° SE, where the rakes of slip-lines range from 02° to 12° S (st-9). Around Şaşal village, the Kunerlik fault separates Neogene rhyolites from the recent alluvial unit. To the north (st-8), it cuts and tilts the alluvial fan deposits of Görece formation. Well-preserved slickenlines on the fault planes show dextral strike-slip faulting with rake of sliplines ranging from 0° to 11° NE. The Kunerlik fault is interpreted as an active fault, because it has several fault-parallel-aligned hydrothermal springs (near Şaşal village) and fresh slickensides that cut the Plio–Quaternery to recent sediments.

Normal Faults

Numerous normal faults of variable size were mapped along the northern and southern margins of the Cumaovası basin. The E–W-trending normal faults display well-developed step-like pattern dominated by first- and second-order synthetic fault segments. They are termed, from the north to the south of the study area, Buca, Kısıkköy and Değirmendere faults (Figures 2 & 3).

The Buca fault bounds the morphological high between the Buca and Kısıkköy villages to the north (Figures 2, 3, 8 & 12). It is a 30-m-wide, 8-km-long, approximately E–W-trending normal fault zone, which is located near the Buca village. The fault is characterized by a curvilinear range-front fault trace along which Neogene claystone-limestone alternations and red-coloured alluvial fan deposits of Görece formations are tectonically

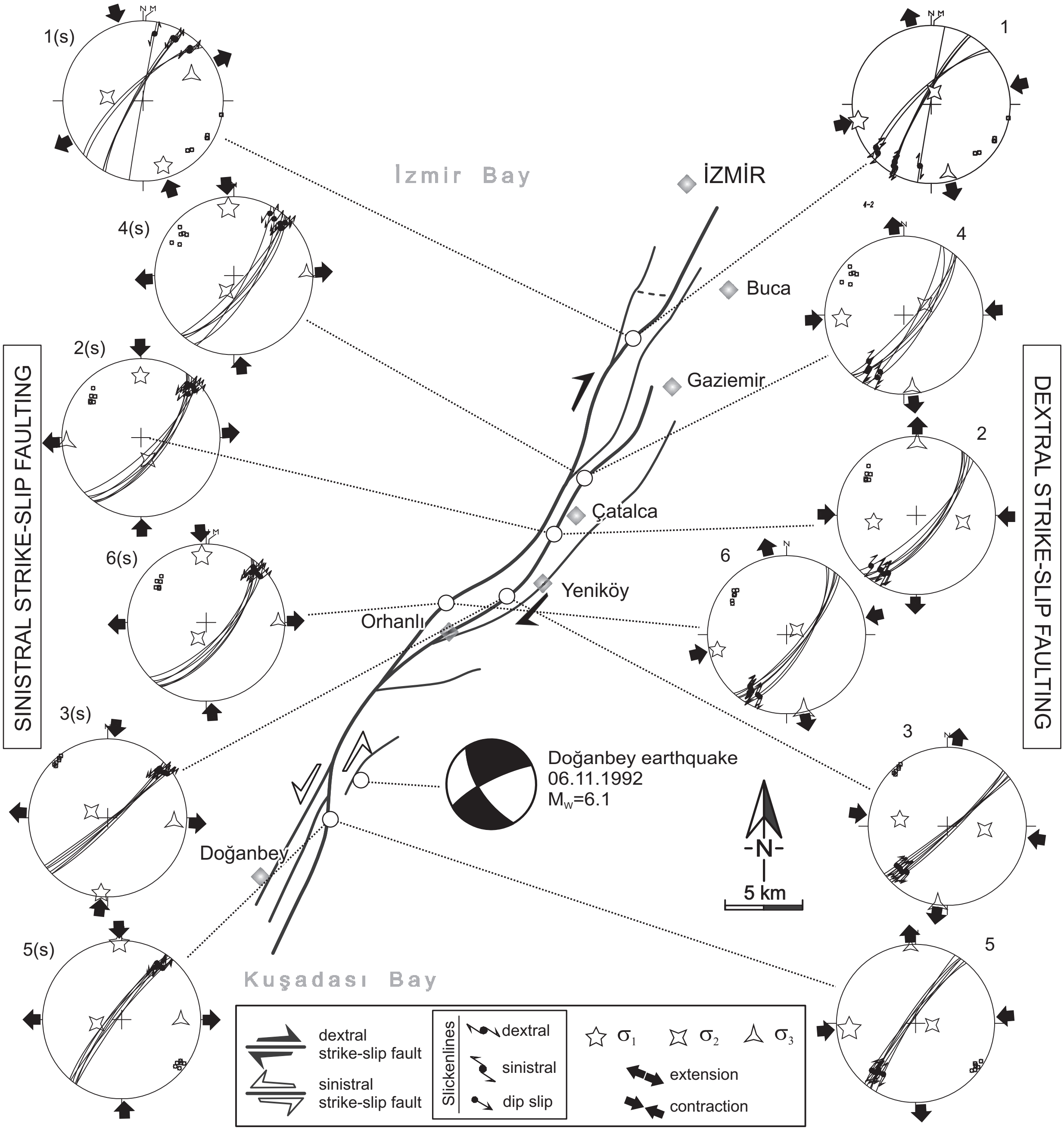

Figure 11. Studied stations on the reactivated segments of the Orhanlı Fault Zone. Kinematic results from the former sinistral strike-slip motion are indicated in the west side of the figure, while the younger dextral strike-slip occurs in the east side of the figure. The location of the 1992-Doğanbey earthquake is also indicated.

juxtaposed. There are also series of actively growing alluvial fans upon these rocks. The Buca fault also displays several well-exposed fault planes and well-preserved slickenlines. Kinematic data on these planes show that the Buca fault is an oblique-slip normal fault with a minor sinistral strike-slip component. The rake of slickenlines ranges from 64° to 89° W.

The syn-extensional sedimentary strata formed in the hanging wall of the Buca fault were rotated to form a WNW–ESE-trending fold. The length of the fold is not

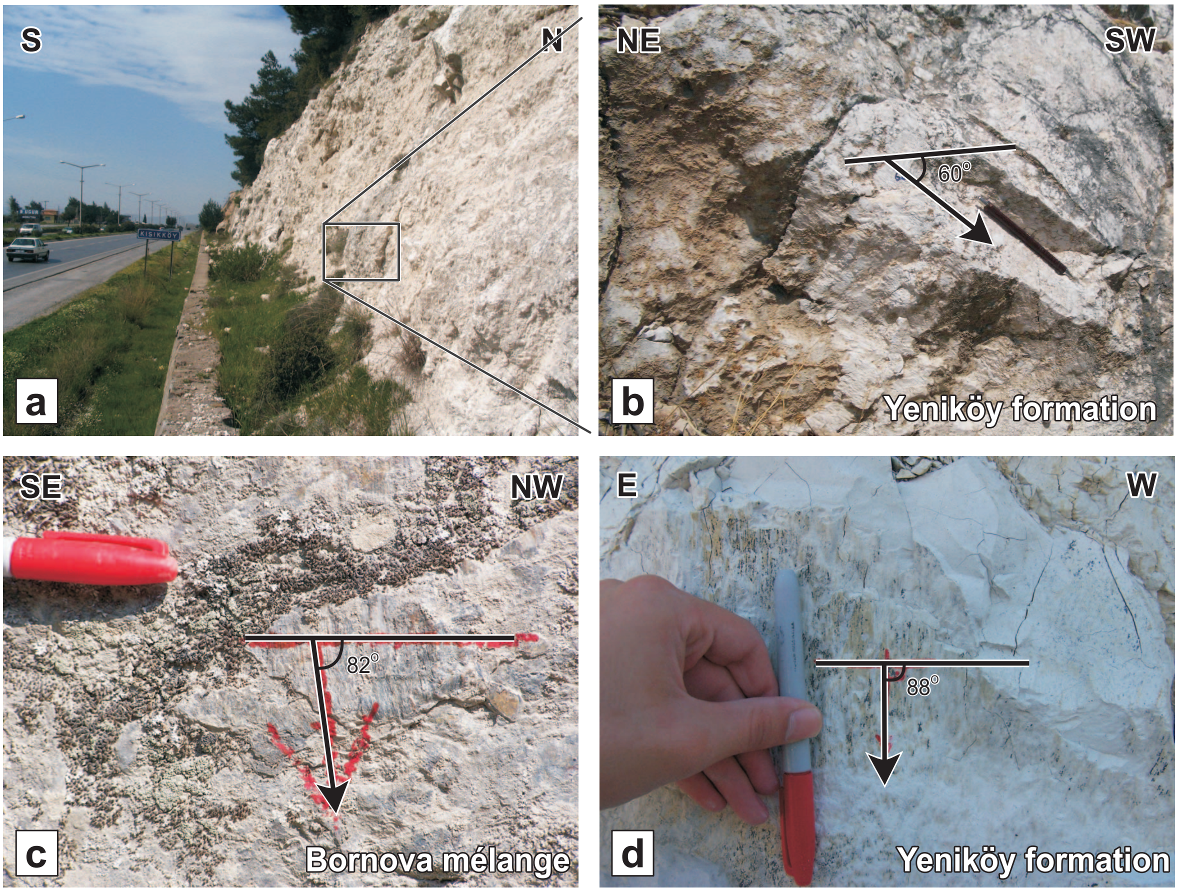

Figure 12. Field photographs showing outcrops of normal faults in the Cumaovası basin. (a) The approximately E–W-trending and southerly-dipping range-front fault, and (b) close-up view of oblique-slip Kısıkköy fault; (c) close-up view of the Değirmendere fault. Note slickensides indicating oblique-slip normal faulting with a minor sinistral strike-slip component; (d) close-up view of the slip-plane of the Buca fault indicating nearly dip-slip.

longer than two kilometres and has formed close to the fault line (Figure 8). The fold is open, almost upright syncline with a fold axes plunging towards N78°W at 07°. The hinge line of the fold is closely parallel to the strike of the Buca fault, but normal to the extension direction. The extension-related folds that have formed in the hanging wall of the normal faults are termed as fault-parallel longitudinal folds (drag folds; Schlische 1995). The axes of these extensional folds form as longitudinal drag to the associated normal faults (Mancktelow & Pavlis 1994; Fletcher *et al.* 1995; Schlische 1995). Drag folds are expected to be formed 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).

The Kısıkköy fault (KF) bounds the morphological high located between the Buca and Kısıkköy villages (Figures 2, 3 & 12). The fault is a 10-m-wide, 6-km-long, approximately E–W-trending oblique-slip normal fault with a minor sinistral strike-slip component. It separates Neogene limestones from red alluvial fan deposits of Görece formations. There are also a series of actively growing alluvial fans aligned parallel to the fault. The well-exposed fault planes are dipping an average of 60° S and the sliplines have rake angles ranging from 51° to 73° E.

The Değirmendere fault (DF) is the southern margin-bounding fault of the Cumaovası basin (Figures 2, 3 & 12). It bounds the Değirmendere high to the north, and is located in the area between the Şaşal and Değirmendere villages. The fault zone displays a well-developed step-like morphology and triangular facets. It cuts pre-Neogene rocks of the Bornova mélange and Neogene sandstone-conglomerates and formed several recent alluvial fans aligned parallel to the fault. Kinematic data show that the Değirmendere fault is an oblique-slip normal fault with a minor sinistral strike-slip component. The fault zone includes fault planes dipping an average of 65° N with rake of sliplines ranging from 63° to 71° NW.

Kinematic Analysis of Fault-slip Data

The inverse analysis of fault-slip data (the orientation and dip of the faults, and sense of slip along them) within the pre-Neogene to Quaternary deposits were used to calculate the principal stress direction responsible for faulting. The fault-slip data are analyzed using the Direct Inversion Method of Angelier (Angelier 1979, 1984, 1994; Angelier *et al.* 1982). The method is based on the assumption that the rigid block displacement is independent and that striations on a fault plane are parallel to the maximum resolved shear stress (τ) applied on this fault. All inversion results include the orientation (plunge and azimuth) of the principal stress axes as well as the 'stress ratio (φ) [$\varphi = (\sigma_2 - \sigma_1)/(\sigma_3 - \sigma_1)$]', a linear quantity describing relative stress magnitudes. The stress axes σ_1, σ_2, and σ_3 correspond to maximum intermediate, and minimum principal stress axes, respectively. In order to understand the kinematic history of the Cumaovası basin, 140 fault-slip data have been analysed from 17 stations (Figure 13 & Table 1). The computed results of the slip data measurements for each fault will be given below.

In the western margin of the basin, we have studied the observed slip surfaces at six localities (st-1–6) along the segments of the Orhanlı Fault Zone where the sinistral strike-slip are superimposed by dextral strike-slip motion. The inverse analysis results of fault-slip measurements for early phase of sinistral strike-slip faulting define steeply plunging σ_2 axes (53° and 76°), but gently plunging σ_3 axes (09° and 32°). The main orientation of σ_1 axis is very variable with an approximately horizontal plunge (10° and 30°). The results suggest that sinistral strike-slip faulting developed under an approximately N–S-trending compression associated with E–W extension. The fault-slip measurements for the later phase of dextral strike-slip faulting define a near horizontal σ_1, approximately 260° trending, and, 10° plunge, whereas σ_3 axes have attitudes of approximately 25°/260°, respectively. The orientation of σ_2 axes is variable with approximately vertical plunging. The results suggest an approximately N–S-directed extension associated with E–W compression (the readers are referred to Table 1 for more details).

The stress field orientations at st-7 along the strike of the Yeniköy Fault suggest a NNE–SSW-directed extension associated with WNW–ESE compression (Figure 13, Table 1). The calculated σ_1 trends 275° and plunges at 14°, whereas σ_2 and σ_3 axes have attitudes of 76°/086° and 02°/185°, respectively.

Fault-slip data from two localities (st-8 and st-9) along the strike of the Kunerlik fault define an approximately vertical $\sigma_{2.}$ plunging at 74–77°, whereas the σ_1 and σ_3 axes are almost horizontal, plunging at 03–07° and 12–15°, and trending 259–106° and 350–198°, respectively. The results suggest that the faulting is consistent with an approximately N–S extension associated with E–W compression.

The fault-slip data collected from st-15 along the Deliömer fault include nearly horizontal σ_1 (18°) trending at 074°, whereas σ_2 and σ_3 axes have attitudes of 72°/239° and 04°/342°, respectively. The results suggest strike-slip faulting in an approximately NW–SE-trending compression associated SW–NE extension.

Seven stress-sites are characterized by tensors with a subvertical σ_1 that are consistent with approximately NW–SE extension (Figure 13). There, the σ_2 and σ_3 axes are subhorizontal, but vary in trend, which makes evaluation of this tensor difficult. These tensors have been collected from stations located along the Buca, Kısıkköy and Değirmendere faults. The computed results of fault-slip measurements along the Buca fault in two localities define a relatively steeply plunging σ_1 axes (53° and 62°), but gently plunging σ_2 axes (03° and 25°). The orientation of the σ_3 axis is very similar for both localities with attitudes of 25°/336° and 27°/341°, respectively. Along the strike of the Kısıkköy fault, the computed results in two localities show remarkable similarities and define an approximately vertical $\sigma_{1,}$ plunging at (65–69°). The σ_2 and σ_3 axes are almost horizontal, plunging at 25–20° and 00–06°, and trending at 205–218° and 114–126°, respectively. In the southern margin of the basin, the stress field orientations using the observed slip

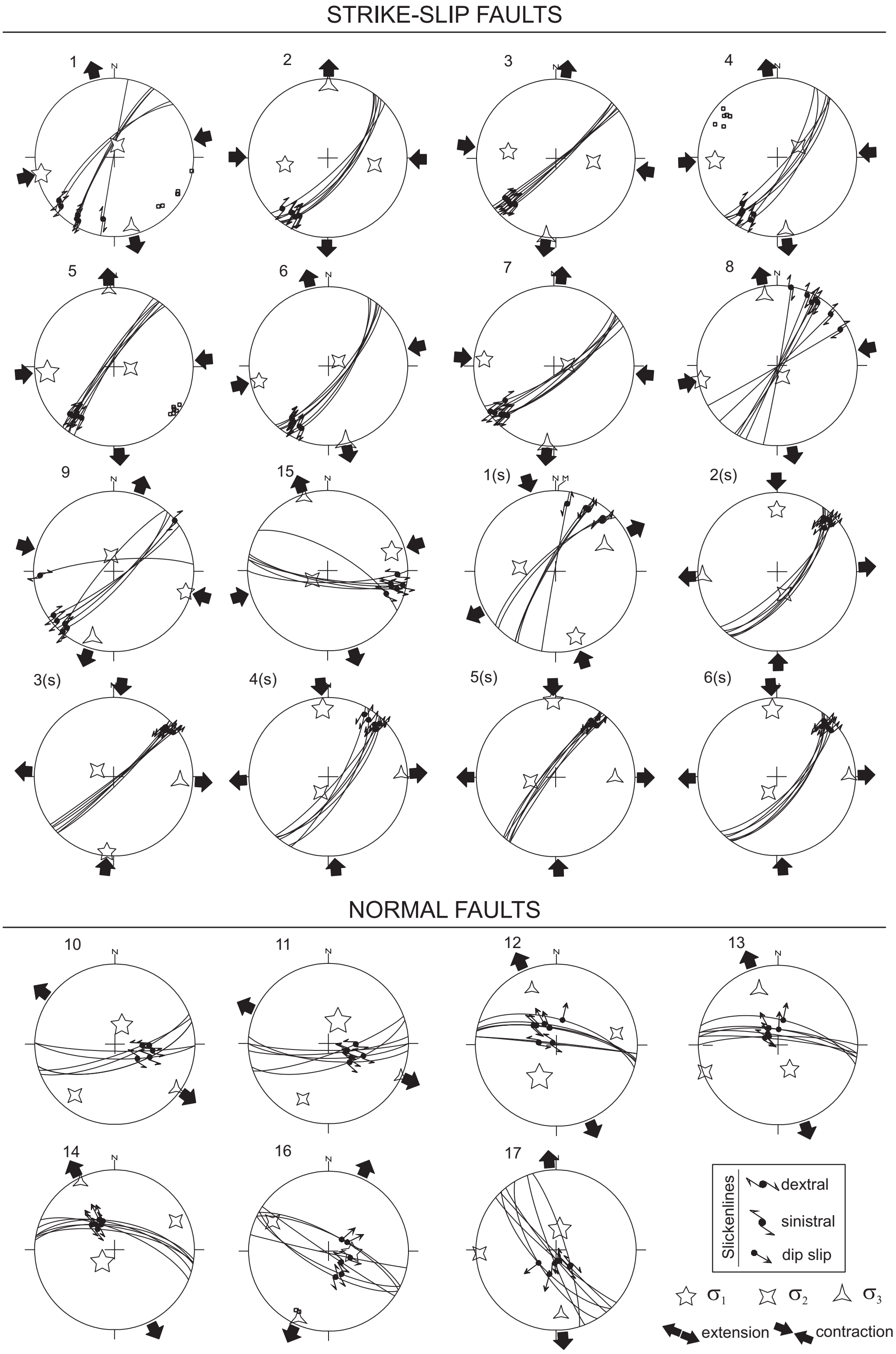

Figure 13. Lower hemisphere equal area projection of the fault planes, slickenlines and stress orientations for the strike-slip and normal faulting.

Table 1. Detailed information about the faults and stress tensors where slickenlines were measured in the Cumaovası basin.

				number	σ_1	σ_2	σ_3	
station	location (N/E)	name of fault	nature of fault	of slip data	dir.°/plung.°	dir.°/plung.°	dir.°/plung.°	ϕ
1	0509166/4243542	Orhanlı Fault Zone (OFZ)	rigth-lateral strike-slip faulting with normal component (young movement)	06	257/06	014/77	166/11	0,315
2	0502125/4230235			06	260/40	098/48	001/09	0,651
3	0501161/4227985			06	278/39	095/51	187/01	0,626
4	0503002/4231540			06	267/22	063/66	173/09	0,579
5	0491554/4216832			06	265/17	096/73	356/03	0,212
6	0501161/4227985			06	258/11	066/78	167/02	0,821
1(s)	0509166/4243542		left-lateral strike-slip faulting with normal component (old movement)	06	163/17	276/53	062/32	0,613
2(s)	0505020/4235053			06	360/23	162/66	267/06	0,716
3(s)	0500175/4227740			06	185/05	291/72	094/17	0,565
4(s)	0505160/4235960			06	355/15	206/72	088/09	0,336
5(s)	0491554/4216832			06	358/04	261/64	090/26	0,434
6(s)	0501161/4227985			06	355/15	206/72	088/09	0,336
7	0506712/4232541	Yeniköy Fault (YF)	rigth-lateral strike-slip faulting with normal component	07	275/14	086/76	185/02	0,688
8	0511195/4227400	Kunerlik fault (KF)	rigth-lateral strike-slip faulting with normal component	07	259/03	154/77	350/12	0,516
9	0507130/4223085			06	106/07	350/74	198/15	0,715
10	0516920/4236950	Kısıkköy fault (KSF)	normal faulting with left-lateral strike-slip component	06	020/69	218/20	126/06	0,320
11	0518440/4237486			06	023/65	205/25	114/00	0,162
12	0514120/4246510	Buca fault (BF)	normal faulting with left-lateral strike-slip component	07	208/53	079/25	336/25	0,080
13	0514950/4246220			06	154/62	250/03	341/27	0,521
14	0519237/4211297	Değrimendere fault (DF)	normal faulting with left-lateral strike-slip component	06	225/73	065/16	333/06	0,220
15	0503916/4225039	Deliömer fault (DÖF)	left-lateral strike-slip faulting with normal component	06	074/18	239/72	342/04	0,252
16	0518485/4227334	conjugate set of faulting	normal faulting with right- and left-lateral strike-slip component	06	094/66	298/22	204/09	0,336
17	0517530/4230680			07	010/68	267/05	175/21	0,316

surfaces along the strike of the Değirmendere fault define a near vertical σ_1, plunging at 73°, whereas σ_2 and σ_3 axes have attitudes of 16°/065° and 06°/333° , respectively (Table 1).

The relatively low value of ϕ derived (0.170 at several stations (st-11, 12 & 14) indicates that the magnitude of σ_1 is much higher than σ_2 and is consistent with the extensional deformation. The calculated ϕ value from the slip surfaces in st-12 is small (0.080) and indicates very high magnitude for σ_1 then σ_2; this is in line with the almost pure N–S extension. However, the calculated high value of ϕ (more than 0.5) at stations located along the western margin of the basin are consistent with strike-slip motion.

With respect to the above results, there are generally two types of faults (strike-slip faults and normal faults) but three different sets of fault-slip data in the Cumaovası basin. The strike-slip faults are steeply dipping and trend approximately NE–SW. Some of them (several segments of the Orhanlı Fault Zone) show clear evidence of early sinistral slip reactivated by later dextral motion. During sinistral motion, the maximum compressive stress (σ_1) was mainly oriented N–S, whereas during dextral slip σ_1 was oriented approximately E–W. The third set of fault-slip data obtained from the normal faults reveal NE–SW, N–S and NW–SE extension. The orientation of principal stress axes for the normal faulting is very similar to an orientation for dextral strike-slip faulting. This indicates that dextral strike-slip faulting and normal faulting likely operated concurrently. Examples of analysis of polyphase deformation have been also performed on the Efes (Dumont *et al.* 1980) and Manisa faults (Bozkurt & Sözbilir 2006).

Age of Faulting

There are three views dealing with the N–S compression that may be responsible for the former sinistral strike-slip motion in the study area: (1) the Bornova Flysch Zone was deposited in a NE–SW-trending sinistral transform fault zone during the Late Cretaceous–Paleocene (Okay *et al.* 1996), (2) there was a wrench-dominated corridor

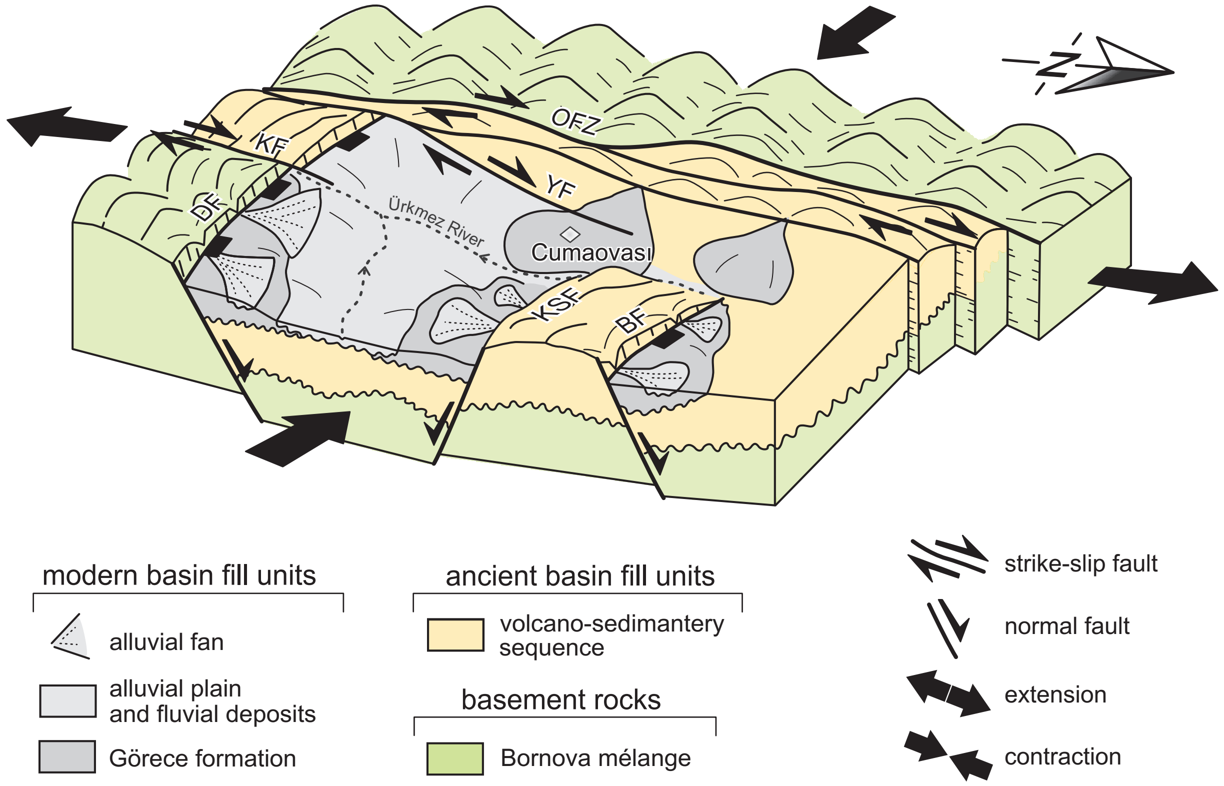

Figure 14. A block diagram showing structural configuration of the Cumaovası Basin.

lying along the Bornova Flysch zone that separated the Aegean region from West Anatolia during the Miocene (Ring *et al.* 1999), and (3) an intervening N–S compressional phase existed during the Early–Middle Pliocene (Koçyiğit *et al.* 1999; Rojay *et al.* 2005; Bozkurt & Sözbilir 2006; Kaya *et al.* 2007; Emre & Sözbilir 2007).

Based on the timing of the E–W and N–S graben evolution in the region, a number of studies (Dumont *et al.* 1980; Şengör *et al.* 1985; Seyitoğlu & Scott 1992; Erinç 1955; Lips *et al.* 2001; Rojay *et al.* 2005; Bozkurt 2001a, 2003; Bozkurt & Sözbilir 2004, 2006) help identify the possible Pliocene compression that may be responsible for strike-slip motion in the study area. According to palaeomagnetic studies, a rotation existed in the region since the Late Miocene (Kissel *et al.* 1986, 1987; Mercier 1981; Westaway 1990; Temiz *et al.* 1998; Rojay *et al.* 2005). A N–S compressional period reflected by strike-slip faulting in the central western Anatolia was accepted as contemporaneous to the intervening compressional phase in the region (Dumont *et al.* 1981; Angelier *et al.* 1981). Kaya *et al.* (2007) documents structural evidence for a compressive phase characterised by a NW–SE-trending dextral wrench-dominated fault zone (the Halitpaşa transpressive zone) which is located in the northwestern continuation of the Gediz Graben. The deformation is Early Pliocene in age according to field relations and mammalian data and is attributed to the known compressive pulse of the Aegean Arc. In addition, the Late Serravalian–late Early Pliocene is presumed to be the time of N–S compression in the Gediz Graben region (Koçyiğit *et al.* 1999). Based on the principle stress direction, anticlockwise rotation is observed from N–S compression to E–W compression. This indicates that the palaeostress field seems to be changed by major tectonic events; probably related to the dextral movement on the North Anatolian Fault Zone. According to Rojay *et al.* (2005), one compressional period, multidirectional extensional periods (three successive deformational phases), and a possible counterclockwise rotation for the post-Miocene period have been developed in the Küçük Menderes Graben. According to Angelier *et al.* (1982) both extension and compression took place during Miocene times and at least three compressional events occurred in western Anatolia. The first event, between the Aquitanian and Burdigalian formed NW–SE compressive structures in the Lycian molasse basin (Sözbilir 2005). The second compressional event produced numerous folds, thrusts and strike-slip faults in the Miocene near İzmir, with compression varing from E–W to NW–SE and occurring during Langian–Tortonian times. The last important NE–SW compressional event occurred at the end of the Miocene.

The Cumaovası basin is characterized by episodic tectonic activity, where superposed transpressional and transtensional deformation occurred. The sinistral offset is consistent with that recorded in the pre-Neogene basement rocks (st-5). It has been proposed that strike-slip faulting was active during the Late Miocene as the basin was divided into sub-basins by NE–SW-trending volcanic domes. The radiometric ages (11.5–9 Ma K/Ar ages) obtained from samples of rhyolitic lavas are coeval with the strike-slip tectonism (Borsi *et al.* 1972). Structural evidence for the Pliocene compression phase is established at st-2, 3, 4 and 6, where the Ürkmez formation deformed by a reactivated strike-slip fault segment of the Orhanlı Fault Zone. We believe that transpressional deformation had ceased prior to deposition of the Plio–Pleistocene Görece formation. The structural observations show that the dextral strike-slip fabrics were overprinted on sinistral ones which formed during a previous deformation phase. During the Late Miocene–Early Pliocene compression phase, the entire Aegean and Anatolian region was affected (Mercier 1981). Some workers consider that the subduction along the Aegean trench is closely related to the compression phase referred to above. The presence of two sets of striations on the slip surfaces suggest that the fault is a reactivated structure. Slip sense should have changed over time from sinistral to dextral movements. The latter episode of dextral strike-slip deformation phase coincides with a regional change in stress regime that occurred during the Plio–Quaternary as a response to the onset of westward tectonic escape of Anatolia along the NAF and EAF (Dewey & Şengör 1979; Şengör *et al.* 1985; Şengör 1987). The switch to NE–SW extension in the Late Pliocene relates to a regional change in stress direction throughout in the Aegean region. Strike-slip faults as well as normal faults developed, suggesting that the later palaeostress field was a transtension one. Relative ages are inferred from cross-cutting relationships between successive striae on the same fault plane and from geomorphological evidence along the fault zone. During this time interval the transtensional Cumaovası basin developed, in which Plio–Quaternary sediments were deposited. The Plio–Quaternary transtensional deformation has also been described along the İzmir-Balıkesir Transfer Zone within several basins (e.g., Kemalpaşa-Torbalı basin in Sözbilir *et al.* 2004; Bigadiç basin in Erkül *et al.* 2005a, b).

Kissel *et al.* (1987) stated that major differential block rotations occurred between the Karaburun Peninsula and the area immediately NE of İzmir. For the İzmir area, the most striking feature is that the Karaburun Peninsula west of the Gülbahçe fault appears to have rotated clockwise since the Late Miocene (Kissel *et al.* 1987; Orbay *et al.* 2000). On the other hand, Kissel *et al.* (1987) documented that the area immediately north and east of İzmir shows anticlockwise rotation. Aktuğ & Kılıçoğlu (2006) have established a GPS monitoring network in 2001 to investigates active deformation around İzmir. Their results show E–W shortening between the Karaburun Peninsula and the northern part of İzmir Bay. According to these authors, this stress regime is related to dextral faulting and clockwise rotation around Karaburun Peninsula. These results suggest that the dextral slip of the fault has mainly accommodated the E–W shortening associated with N–S extensional forces during actual regime.

Discussion and Conclusion

For over 30 years, earth scientists have conducted field-oriented studies in western Anatolia and these studies revealed that the deformation in the brittle upper crust is accompanied by the normal faults and related basins since Miocene time. However, recent earthquakes occurring to the south of İzmir Bay region indicate that strike-slip motion in this region is the major cause of such seismic events (1992, Doğanbey $M_W = 6.0$; 2003, Urla $M_W = 5.7$; and 2005, Sığacık $M_W = 5.4\text{-}5.8$, see Benetatos *et al.* 2006 and Aktar *et al.* 2007 for detailed descriptions of the seismic events). Field-oriented geological studies also support a strike-slip dominated zone of weakness (the İzmir-Balıkesir Transfer Zone) that may responsible for the listed earthquakes. Within the zone, the structure and kinematics of the Cumaovası basin are documented. We found that the central and northern parts of the Cumaovası basin are shaped by normal faults while western part of basin is deformed by major strike-slip faults. As such, this study is the first detailed field-based investigation of active strike-slip faults in Western Anatolia.

Based on stratigraphical, sedimentological and structural data, we describe the Cumaovası basin as a strike-slip basin because: (1) it is an asymmetric basin which is bounded by strike-slip and normal faults synchronously, (2) the basin fill is longitudinally and laterally asymmetric; and (3) the basin fill is generally characterized by abrupt facies changes and multiple basin margin sources (Figure 14). The normal fault population strikes approximately E–W, whereas the strike-slip population has a clear pattern with a predominant NE–SW orientation. The regionally significant one, the Orhanlı Fault Zone, has distinctive sinistral and dextral strike-slip geomorphic features including deflected river channels, offset ridges, shutter ridges, and fault scarps. The geomorphic evidence suggests that the Orhanlı Fault Zone is active. The recent activity is also indicated by a moderate magnitude seismic event (the 6 November 1992 earthquake; Tan & Taymaz 2001) and by the presence of several hot springs located along the fault zone. Alternatively, previous geological studies interpret the Orhanlı (Tuzla) Fault Zone as a thrust fault, dextral strike-slip fault and sinistral strike-slip fault by Eşder & Şimşek (1975), Emre & Barka (2000) and Genç *et al.* (2001), respectively. Our kinematic analyses on the striated fault planes suggest two sense of movements with opposite kinematic indicators. The earlier sinistral strike-slip movement is overprinted by the subsequent dextral strike-slip markers. Geomorphologic indicators such as the offset of river channels and pressure ridges also support two different movement along the Orhanlı Fault Zone.

According to Seyitoğlu & Scott (1992), the region underwent a single tectonic period since the Late Oligocene–Early Miocene. As an alternative interpretation, we suggest the possibility of a stress regime that changed with time. A total of 140 measurements of striated fault planes from 17 sites along both strike-slip and normal faults were collected in pre-Neogene basement in Neogene sediments and volcanites, as well as in Plio–Quaternary sediments. Field data and kinematic analyses along these major faults show that the strike-slip and normal faulting are developed synchronously. Kinematic data derived using the Angelier method indicate that the first movement in the region was related to approximately E–W extension associated with N–S-directed compression. On the other hand, the later stage of activity is consistent with approximately N–S extension associated with E–W-directed compression. This transtensional phase is still ongoing in the region, as indicated by active fault planes and focal mechanisms of shallow earthquakes. These successive events of extension and compression may be related to the westward escape and southwestward motion of western Anatolia along the North Anatolian Fault Zone and then the Aegean-Cyprus subduction zone.

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References

AKARTUNA, M. 1962. İzmir-Torbalı-Seferihisar-Urla bölgesi jeolojisi hakkında [Geology of İzmir-Torbalı-Seferihisar-Urla region]. *Mineral Research and Exploration Institute (MTA) of Turkey Bulletin* **59**, 1–18.

AKTAR, M., KARABULUT, H., ÖZALAYBEY, S. & CHILDS, D. 2007. A conjugate strike-slip fault system within the extensional tectonics of Western Turkey. *Geophysical Journal International* **171**, 1363–1375.

AKTUĞ, B. & KILIÇOĞLU, A. 2006. Recent crustal deformation of İzmir, western Anatolia and surrounding regions as deduced from repeated GPS measurements and strain field. *Journal of Geodynamics* **41**, 471–484.

ANGELIER, J. 1979. Determination of the mean principal directions of stress for a given fault population. *Tectonophysics* **56**, 17–26.

ANGELIER, J. 1984. Tectonic analysis of fault slip data sets. *Journal of Geophysical Research* **80**, 5835–5848.

ANGELIER, J. 1994. Fault slip analysis and paleostress reconstruction. *In:* HANCOCK, P.L. (ed), *Continental Deformation*. Pergamon Press, Oxford, 53–100.

ANGELIER, J., DUMONT, J.F., KARAMANDERESI, İ.H., POISSON, A., ŞIMŞEK, Ş. & UYSAL, Ş. 1981. Analyses of fault mechanisms and expansion of southwestern Anatolia since the Late Miocene. *Tectonophysics* **79**, 11–19.

ANGELIER, J., TARANTOLA, B., VALETTE, S. & MANOUSSIS. A. 1982. Inversion of field data in fault tectonics to obtain the regional stress–1. Single phase fault populations: a new method of computing the stress tensor. *Geophysical Journal of Royal Astronomic Society* **69**, 607–621.

AYDIN, A. & NUR, A. 1982. Evolution of pull-apart basins and their scale independence. *Tectonics* **1**, 91–105.

AYDIN, A. & NUR, A. 1985. The types and role of step-overs in strike-slip tectonics. *In:* BIDDLE, K.T. & CHRISTIE-BLICK, N. (eds), *Strike-Slip Faulting and Basin Formation*. Society of Economic Paleontologists and Mineralogists Special Publications **37**, 35–44.

BARKA, A.A. 1992. The North Anatolian Fault Zone. *Annales Tectonicae* **6**, 164–195.

BARKA, A.A. 1999. The 17 August 1999 İzmit earthquake. *Science* **285**, 1858–1859.

BARKA, A.A., AKYÜZ, H.S, COHEN H.A. & WATCHORN, F. 2000. Tectonic evolution of the Niksar and Taşova-Erbaa pull-apart basins, North Anatolian Fault Zone: their significance for the motion of the Anatolian Block. *Tectonophysics* **322**, 243–64.

BAŞARIR, E. & KONUK, Y.T. 1981. Gümüldür yöresinin kristalin temeli ve allokton birimleri [Crystalline basement and allochthon units of Gümüldür region]. *Geological Society of Turkey Bulletin* **24**, 1–6 [in Turkish with English abstract].

BENETATOS, C., KIRATZI, A., GANAS, A., ZIAZIA, A., PLESSA, A. & DRAKATOS, G. 2006. Strike-slip motions in the Gulf of Sığacık (western Anatolia): properties of the 17 October 2005 earthquake seismic sequence. *Tectonophysics* **426**, 263–279.

BLAIR, T.C. 1999a. Cause of dominance by sheetflood vs debris-flow processes on two adjoining fans, Death Valley, California. *Sedimentology* **46**, 1015–1028.

BLAIR, T.C. 1999b. Sedimentology and progressive tectonic unconformities of the sheetflood-dominated Hell's Gate alluvial fan, Death Valley, California. *Sedimentary Geology* **132**, 233–262.

BORSI, S., FERRARA, G., INNOCENTI, F. & MAZZUOLI, R. 1972. Geochronology and petrology of recent volcanics in the eastern Aegean sea (west Anatolia and Leovos Island). *Bulletin of Volcanology* **36**, 473–496.

BOZKURT, E. 2000. Timing of extension on the Büyük Menderes Graben, western Turkey, and its tectonic implications. *In:* BOZKURT E., WINCHESTER J.A. & PIPER J.D.A. (eds), *Tectonics and Magmatism in Turkey and The Surrounding Area*. Geological Society, London, Special Publications **173**, 385–403.

BOZKURT, E. 2001a. Neotectonics of Turkey – a synthesis. *Geodinamica Acta* **14**, 3–30.

BOZKURT, E. 2001b. Late Alpine evolution of the central Menderes Massif, western Anatolia, Turkey. *International Journal of Earth Sciences* 89, 728–744.

BOZKURT, E. 2003. Origin of NE-trending basins in western Turkey. *Geodinamica Acta* 16, 61–81.

BOZKURT, E. & OBERHÄNSLI, R. 2001. Menderes Massif (Western Turkey): structural, metamorphic and magmatic evolution: a synthesis. *International Journal of Earth Sciences* 89, 679–708.

BOZKURT, E. & SÖZBİLİR, H. 2004. Tectonic evolution of the Gediz Graben: field evidence for an episodic, two extension in western Turkey. *Geological Magazine* 141, 63–79.

BOZKURT, E. & SÖZBİLİR, H. 2006. Evolution of the large-scale active Manisa Fault, Southwest Turkey: implications on fault development and regional tectonics. *Geodinamica Acta* 19, 427–453.

CAMPAGNA, D.J. & AYDIN, A. 1994. Basin genesis associated with strike-slip faulting in the Basin and Range, southeastern Nevada. *Tectonics* 13/2, 327–341.

ÇEMEN, İ., CATLOS, E.J., GÖĞÜŞ, O. & ÖZERDEM C. 2006. Postcollisional extensional tectonics and exhumation of the Menderes Massif in the Western Anatolia extended terrane, Turkey. *In:* DILEK, Y. & PAVLIDES, S. (eds), *Postcollisional Tectonics and Magmatism in the Mediterranean Region and Asia*. The Geological Society of America, Special Publications 409, 353–379.

CHRISTIE-BLICK, N. & BIDDLE, K.T. 1985. Deformation and basin formation along strike-slip faults. *In:* BIDDLE, K.T. & CHRISTIE-BLICK, N. (eds), *Strike-Slip Faulting and Basin Formation*. Society of Economic Paleontologists and Mineralogists Special Publications 37, 1–34.

CROWELL, J.C. 1974. Origin of late Cenozoic basins in southern California. *In:* DICKINSON W.R. (ed), *Tectonics and Sedimentation*. Society of Economic Paleontologists and Mineralogists Special Publications 22, 190–204.

CROWELL, J.C. 1982. The tectonics of Ridge Basin, southern California. *In:* CROWELL, J.C. & LINK, M.H. (eds), *Geologic History of Ridge Basin Southern California, Los Angeles.* Society of Economic Paleontologists and Mineralogists, Special Publications 22, 25–41.

DECELLES, P.G., GRAY, M.B., COLE, R.B., PEQUERA, N., PIVNIK, D.A., RIDGWAY, K.D. & SRIVASTAVA, P. 1991. Controls on synorogenic alluvial-fan architecture, Beartooth Conglomerate, Wyoming and Montana. *Sedimentology* 38, 567–590.

DEWEY, J.F. & ŞENGÖR, A.M.C. 1979. Aegean and surrounding regions: complex multiple and continuum tectonics in a convergent zone. *Geological Society of America Bulletin* 90, 84–92.

DOGLIONI, C., AGOSTINI, S., CRESPI, M., INNOCENTI, F., MARETTI, P., RIGUIZZI, F. & SAVAŞÇIN, Y. 2002. On the extension in western Anatolia and the Aegean sea. *Journal Virtual Explorer* 7, 117–131.

DOOLEY, T. & MCCLAY, K. 1997. Analog modeling of pull-apart basins. *American Association of Petroleum Geologists Bulletin* 81, 1804–1843.

DORA, O., KUN, N. & CANDAN, O. 1990. Metamorphic history and geotectonic evolution of the Menderes Massif. *Proceedings of International Earth Sciences Congress on Aegean Regions*, 102–115.

DORSEY, R.J. & UMHOEFER, P.J. 2000. Tectonic and eustatic controls on sequence stratigraphy of the Pliocene Loreto basin, Baja California Sur, Mexico. *Geological Society of America Bulletin* 112, 177–199.

DORSEY, R.J., UMHOEFER, P.J. & Mayer, L. 2001. Pliocene stratigraphic evolution of northeastern Carmen Island, Gulf of California: implications for oblique-rifting tectonics. *Sedimentary Geology* 144, 97–123.

DUMONT, J.F., UYSAL, S. & ŞIMŞEK, Ş. 1981. Superposition des jeux sur une faille et succession des événments néotectoniques: L'exemple d'Ephése (Turquie). *Compte Rendu Sommaire des séances de la Société Géologique de France* 1, 22–24.

DUMONT, J.F., UYSAL, S., ŞIMŞEK, Ş., KARAMANDERESİ, İ.H. & LETOUZEY, J. 1980. Formation of the grabens in southwestern Anatolia. *Mineral Research and Exploration Institute (MTA) of Turkey Bulletin* 92, 7–18 [English edition].

EMRE, Ö. & BARKA, A. 2000. Active faults between Gediz Graben and Aegean Sea (İzmir region). *In: Proceedings of Seismicity of western Anatolia Symposium*. Dokuz Eylül University Publications, 131–132 [in Turkish with English abstract].

EMRE, T. 1996. Gediz Graben'nin tektonik evrimi [Geology and tectonics of Gediz Graben]. *Turkish Journal of Earth Sciences* 5, 171–185 [in Turkish with English abstract].

EMRE, T. & SÖZBİLİR, H. 1995. Field evidence for metamorphic core complex, detachment faulting and accomodation faults in the Gediz and Büyük Menderes grabes, western Anatolia. *In: Proceedings International Earth Sciences Colloquium on the Aegen Region, İzmir*, 73–93.

EMRE, T. & SÖZBİLİR, H. 2007. Tectonic evolution of the Kiraz Basin, Küçük Menderes Graben: evidence for compression/uplift-related basin formation overprinted by extensional tectonics in West Anatolia. *Turkish Journal of Earth Sciences* 16, 441–470.

EMRE, T., SÖZBİLİR, H. & GÖKÇEN, N. 2006. Kiraz-Beydağ çevresinin Neojen Kuvaterner stratigrafisi, Küçük Menderes Grabeni, Batı Anadolu [Neogene Quaternary stratigraphy of Kiraz-Beydağ area]. *Mineral Research and Exploration Institute (MTA) of Turkey Bulletin* 132, 1–32 [in Turkish with English abstract].

ERDOĞAN, B. 1990. İzmir-Ankara Zonu'nun, İzmir ile Seferihisar arasındaki bölgede stratigrafik özellikleri ve tektonik evrimi [Stratigraphic features and tectonic evolution of the İzmir-Ankara Zone located between İzmir and Seferihisar]. *Turkish Association of Petroleum Geologists (TPJD) Bulletin* 2, 1–20 [in Turkish].

ERİNÇ, S. 1955. Die morduologischen Entwicklungsstadien der Küçükmenderes Masse. *Rewiew of the Geographical Enstitute of the University of İstanbul* 2, 93–95.

ERKÜL, F., HELVACI, C. & SÖZBİLİR, H. 2005a. Evidence for two episodes of volcanism in the Bigadic borate basin and tectonic implications for western Turkey. *Geological Journal* 40, 1–16.

ERKÜL, F., HELVACI, C. & SÖZBİLİR, H. 2005b. Stratigraphy and geochronology of the Early Miocene volcanics in the Bigadiç borate basin, western Turkey. *Turkish Journal of Earth Sciences* **14**, 227–253.

ERSOY, Y. & HELVACI, C. 2007. Stratigraphy and geochemical features of the Early Miocene bimodal (ultrapotassic and calc-alkaline) volcanic activity within the NE-trending Selendi Basin, Western Anatolia, Turkey. *Turkish Journal of Earth Sciences* **16**, 117–139.

EŞDER, T. & ŞIMŞEK, Ş. 1975. Geology of İzmir (Seferihisar) geothermal area western Anatolia of Turkey determination of rezervoirs by means of gradient driling. *In: Proceedings of 2nd UN. Symposium*, San Francisco, 349–361.

FAULD, J.E. & VARGA, R.J. 1998. The role of accommodation zones and transfer zones in the regional segmentation of extended terranes. *In:* FAULD, J.E. & STEWART, J.H. (eds), *Accommodation Zones and Transfer Zones: The Regional Segmentation of The Basin and Range Province*. The Geological Society of America Special Paper **323**, 1–46.

FLETCHER, J.M., BARTLEY, J.M., MARTIN, M.W., GLAZNER, A.F. & WALKER, J.D. 1995. Large-magnitude continental extension, an example from the central Mojave metamorphic core complex. *Geological Society of America Bulletin* **107**, 1468–1483.

GANAS, A., PAVLIDES, S. & KARASTATHIS, V. 2005. DEM-based morphometry of range-front escarpments in Attica, central Greece, and its relation to fault slip rates. *Geomorphology* **65**, 301–319.

GENÇ, Ş.C., ALTUNKAYNAK, Ş., KARACIK, Z. & YILMAZ, Y. 2001. The Çubukludağ Graben, Karaburun peninsula: it's tectonic significance in the Neogene geological evolution of the western Anatolia. *Geodinamica Acta* **14**, 45–55.

GÖRÜR, N., ŞENGÖR, A.M.C., SAKINÇ, M., TÜYSÜZ, O., AKKÖK, R., YIĞITBAŞ, E., OKTAY, F.Y., BARKA, A., SARICA, N., ECEVİTOĞLU, B., DEMİRBAĞ, E., ERSOY, S., ALGAN, O., GÜNEYSU, C. & AYKOL, A. 1995. Rift formation in the Gökova region, southwest Anatolia: implications for the opening of the Aegean Sea. *Geological Magazine* **132**, 637–50.

GÜNGÖR, T. 1998. *Stratigraphy and Tectonic Evolution of the Menderes Massif in the Söke-Selçuk Region*. PhD Thesis, Dokuz Eylül University, İzmir, Turkey [unpublished].

GÜNGÖR, T. & ERDOĞAN, B. 2002. Tectonic significance of mafic volcanic rocks in a Mesozoic sequence of the Menderes Massif, west Turkey. *International Journal of Earth Sciences* **91**, 386–397.

GÜRER, Ö.F, BOZCU, M., YILMAZ, K. & YILMAZ, Y. 2001. Neogene basin development around Söke-Kuşadası (western Anatolia) and its bearing on tectonic development of the Aegean region. *Geodinamica Acta* **14**, 57–69.

HANCOCK, P.L. 1985. Brittle microtectonics: principles and practice. *Journal of Structural Geology* **7**, 437–457.

HANCOCK, P.L & BARKA, A.A. 1987. Kinematic indicators on active normal faults in western Turkey. *Journal of Structural Geology* **9**, 419–427.

İNCI, U. 1991. Miocene alluvial fan-alkaline playa lignite-trona bearing deposits from an inverted basin in Anatolia: sedimentology and tectonic controls on deposition. *Sedimentary Geology* **71**, 73–97.

İNCI, U. 1998. Lignite and carbonate deposition in Middle Lignite sequence of the Soma Formation from Soma coalfield, western Turkey. *International Journal of Coal Geology* **37**, 287–313.

İNCI, U. 2002. Depositional evolution of coal successions in the Soma coalfield, western Turkey. *International Journal of Coal Geology* **51**, 1–29.

INGERSOLL, R.V. 1988. Tectonics of Sedimentary Basins. *Geological Society of America Bulletin* **100**, 1704–1719.

INGERSOLL, R.V. & BUSBY, C.J. 1995. Tectonics of sedimentary basins. *In:* BUSBY, C.J. & INGERSOLL, R.V. (eds), *Tectonics of Sedimentary Basins*. Blackwell Science, 1–51.

IŞIK, V. & TEKELİ, O. 2001. Late orogenic crustal extension in the northern Menderes Massif (western Turkey): evidence for metamorphic core complex formation. *International Journal of Earth Sciences* **89**, 757–765.

JACKSON, J. & MCKENZIE, D. 1988. The relationship between plate motions and seismic moment tensors, and the rates of active deformation in the Mediterranean and Middle East. *Geophysical Journal of the Royal Astronomical Society* **93**, 45–73.

KAYA, O. 1979. Ortadoğu Ege çöküntüsünün (Neojen) stratigrafisi ve tektoniği [Neogene Stratigraphy and tectonics of the middle-east Aegean depression]. *Geological Society of Turkey Bulletin* **22**, 35–58 [in Turkish with English abstract].

KAYA, O. 1981. Miocene reference section for the coastal parts of West Anatolia. *Newsletters on Stratigraphy* **10**, 164–191.

KAYA, O., ÜNAY, E., GÖKTAŞ, F. & SARAÇ, G. 2007. Early Miocene stratigraphy of Central West Anatolia, Turkey: implications for the tectonic evolution of the Eastern Aegean area. *Geological Journal* **42**, 85–109.

KAYA, O., ÜNAY, E., SARAÇ, G., EICHHORN, S., HASSENRÜCK, S., KNAPPE, A., PEKDEĞER, A. & MAYDA, S. 2004. Halitpaşa transpressive zone: implications for an Early Pliocene compressional phase in central western Anatolia, Turkey. *Turkish Journal of Earth Sciences* **13**, 1–13.

KISSEL, C. & LAJ, C. 1988. The Tertiary geodynamic evolution of the Aegean Arc: a palaeomagnetic reconstruction. *Tectonophysics* **146**, 183–201.

KISSEL, C., LAJ, C., POISSON, A., SAVASCIN, Y., SIMEAKIS, K. & MERCIER, J.L. 1986. Paleomagnetic evidence for Neogene rotational deformations in the Aegean domain. *Tectonics* **5**, 783–796.

KISSEL, C., LAJ, C., ŞENGÖR, A.M.C. & POISSON A. 1987. Paleomagnetic evidence for rotation in opposite senses of adjacent blocks in northeastern Aegea and western Anatolia. *Geophysical Research Letters* **9**, 907–910.

KOÇYİĞİT, A. 1988. Tectonic setting of the Geyve basin: age and total offset of the Geyve fault zone, East Marmara, Turkey. *Journal of Pure and Applied Sciences* **21**, 81–104.

KOÇYİĞİT, A. 1989. Suşehri basin: an active fault-wedge basin on the North Anatolian Fault Zone, Turkey. *Tectonophysics* **167**, 13–29.

Koçyiğit, A. 1990. Tectonic setting of the Gölova basin: total offset of the North Anatolian fault zone, E. Pontides, Turkey. *Annales Tectonicae* **4**, 155–170.

Koçyiğit, A. 2005. The Denizli graben-horst System and the eastern limit of western Anatolian continental extension: basin fill, structure, deformational mode, throw amount and episodic evolutionary history, SW Turkey. *Geodinamica Acta* **18**, 167–208.

Koçyiğit, A. & Erol, B. 2001. A tectonic escape structure: Erciyes pull-apart basin, Kayseri, central Anatolia, Turkey. *Geodinamica Acta* **14**, 133–145.

Koçyiğit, A., Ünay, E. & Saraç, G. 2000. Episodic graben formation and extensional neotectonic regime in west central Anatolia and the Isparta Angle: a key study in the Akşehir-Afyon Graben, Turkey. *In:* Bozkurt, E., Winchester, J.A. & Piper, J.D.A. (eds), *Tectonics and Magmatism in Turkey and the Surrounding Area*. Geological Society, London, Special Publications **173**, 405–421.

Koçyiğit, A., Yusufoğlu, H. & Bozkurt, E. 1999. Evidence from the Gediz Graben for episodic two-stage extension in western Turkey. *Journal of the Geological Society, London* **156**, 605–616.

Koukouvelas, I.K. & Aydin, A. 2002. Fault structure and related basins of the North Aegean Sea and its surroundings. *Tectonics* **21**, 1046.

Lacassin, R., Replumaz, A. & Leloup, P.H. 1998. Hairpin river loops and slip-sense inversion on southeast Asian strike-slip faults. *Geology* **26**, 703–706.

Le Pichon, X. & Angelier, J. 1979. The Aegean arc and trench system: a key to the neotectonic evolution of the eastern Mediterranean area. *Tectonophysics* **60**, 1–42.

Lee, S.H. & Chough, S.K. 1999. Progressive changes in sedimentary facies and stratal patterns along the strike-slip margin, northeastern Jinan Basin (Cretaceous), southwest Korea: implications for differential subsidence. *Sedimentary Geology* **123**, 81–102.

Lin, A., Fu, B., Kano, B., Maruyama, T & Guo, J. 2002. Late Quaternary dextral displacement along active faults in the Yanqi Basin, southeastern Tian Shan, northwest China. *Tectonophysics* **354**, 157–178.

Lips, A.L.W., Cassard, D., Sözbilir, H., Yilmaz, H. & Wijbrans, J. 2001. Multistage exhumation of the Menderes Massif, western Anatolia (Turkey). *International Journal of Earth Sciences* **89**, 781–792.

Mancktelow, N.S. & Pavlis, T.L. 1994. Fold-fault relationships in low-angle detachment systems. *Tectonics* **13**, 668–685.

Mann, P. 1997. Model for the formation of large, transtensional basins in zones of tectonic escape. *Geology* **25**, 211–214.

Maruyama, T. & Lin, A. 2004. Slip sense inversion on active strike-slip faults in southwest Japan and its implications for Cenozoic tectonic evolution. *Tectonophysics* **383**, 45–70.

May, S. M., Ehman, K.D., Gray, G.G. & Crowell, J.C. 1993. A new angle on the tectonic evolution of the Ridge Basin, a 'strike-slip' basin in southern California. *Geological Society America Bulletin* **105**, 1357–1372.

McClusky, S., Balassanian, S., Barka, A. A., Demir, C., Ergintav, S., Georgiev, I., Gürkan, O., Hamburger, H., Hurst, K., Kahle, H.G., Kastens, K., Kekelidze, G., King, R., Kotzev, V., Lenk, O., Mahmoud, S., Mishin, A., Nadariya, M., Ouzounis, A., Paradissis, D., Peter, Y., Prilepin, M., Reilinger, R. E., Şanli, İ., Seeger, H., Tealeb, A., Toksöz, M. N. & Veis, G. 2000. Global Positioning System constraints on plate kinematics and dynamics in the Eastern Mediterranean and Caucasus. *Journal of Geophysical Research* **105**, 5695–5720.

McKenzie, D.P. 1978. Active tectonics of the Alpine–Himalayan belt: the Aegean Sea and surrounding regions. *Geophysical Journal of the Royal Astronomical Society* **55**, 217–254.

Means, W.D. 1987. A newly recognized type of slickenside striation. *Journal of Structural Geology* **9**, 585–90.

Mercier, J.L. 1981. Extensional compressional tectonics associated with the Aegean Arc: Comparison with the Andean Cordillera of south Peru-North Bolivia. *Philosophical Transactions of the Royal Society of London* **300**, 337–357.

Meulenkamp, J.E., Van Der Zwaan, G.J. & Van Wamel, W.A. 1994. On Late Miocene to recent vertical motions in the Cretan segment of the Hellenic arc. *Tectonophysics* **234**, 53–72.

Miall, A.D. 1977. A review of the braided river depositional environment. *Earth Sciences Review* **13**, 1–62.

Miall, A.D. 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. *Canadian Society of Petroleum Geologists* **5**, 597–604.

Miall, A.D. 2000. *Principles of Sedimentary Basin Analysis*. Springer, Berlin, **616**.

Nemec, W. & Postma, G. 1993. Queternary alluvial fans in soutwestern Crete: sedimentation processes and geomorphic evolution. *In:* Marzo, M. & Puigde Fabrega, C. (eds), *Alluvial sedimentation*. International Association of Sedimentologists, Special Publication **17**, 235–276.

Nilsen, T.H. & McLaughlin, R.J. 1985. Comparison of tectonic framework and depositional patterns of the Hornelen strike-slip basin of Norway and Ridge and Little Sulphur Creek strike-slip basins of Californian. *In:* Biddle, K.T. & Christie-blick, N. (eds), *Strike-Slip Faulting and Basin Formation*. Society of Economic Paleontologists and Mineralogists Special Publications **37**, 80–103.

Nilsen, T.H. & Sylvester, A.G. 1995. Strike-slip basins. *In:* Busby, C.J. & Ingersoll, R.V. (eds), *Tectonics of Sedimentary Basins*. Blackwell, Cambridge, 425–457.

Nyst, M. & Teatcher, W. 2004. New constrains on the active tectonic deformation of the Aegean. *Journal of Geophysical Research* **109**, 1–23.

Ocakoğlu, N., Demirbağ, E. & Kuşcu İ. 2004. Neotectonic structures in the area offshore of Alaçatı, Doğanbey and Kuşadası (western Turkey): evidence of strike-slip faulting in the Aegean extensional province. *Tectonophysics* **391**, 67–83.

Ocakoğlu, N., Demirbağ, E. & Kuşcu, İ. 2005. Neotectonic structures in İzmir Gulf and surrounding regions (western Turkey): evidences of strike-slip faulting with compression in the Aegean extensional regime. *Marine Geology* **219**, 155–171.

OKAY, A.İ. & SATIR, M. 2000. Coeval plutonism and metamorphism core complex in northwest Turkey. *Geological Magazine* **137**, 495–516.

OKAY, A.İ., SATIR M., MALUSKI, H., SIYAKO, M., MONIE, P., METZGER, R. & AKYÜZ, S. 1996. Paleo- and Neo-Tethyan events in northwest Turkey: geological and geochronological constraints. *In*: YIN, A. & HARRISON, M. (eds), *Tectonics of Asia*. Cambridge University Press, Cambridge, 420–441.

OKAY, A.İ. & SIYAKO, M. 1991. The new position of the İzmir-Ankara Neo-Tethyan Suture between İzmir and Balıkesir. *In: Proceedings of the Ozan Sungurlu Symposium*, 333–355.

OLSEN, P.E. & SCHLISCHE, R.W. 1990. Transtensional arm of the early Mesozoic Fundy rift basin: penecontemporaneous faulting and sedimentation. *Geology* **18**, 695–698.

ORBAY, N., SANVER, M., TAPIRDAMAZ, C., HISARLI, M, İŞSEVEN, T. & ÖZÇEP, F. 2000. Karaburun Yarımadasının paleomağnetizması ve tektonik evrimi [Paleomagnetism and tectonic evolution of the Karaburun Peninsula]. *In: Proceedings of Seismicity of western Anatolia Symposium,* Dokuz Eylül University Publications, 59–67 [in Turkish with English abstract].

ÖZGENÇ, İ. 1978. Cumaovası (İzmir) asit volkanitlerde saptanan iki ekstrüzyon aşaması arasındaki göreceli yaş ilişkisi [Relative age relationships between two extrusion phases of Cumaovası acidic volcanics (İzmir)]. *Geological Society of Turkey Bulletin* **21**, 31–34 [in Turkish with English abstract].

PETIT, J.P. 1987. Criteria for the sense of movement on fault surfaces in brittle rocks. *Journal of Structural Geology* **9**, 597–608.

RAHE, B., FERRILL, D.A. & MORRIS, A.R. 1998. Physical analog modeling of pull-apart basin evolution. *Tectonophysics* **285**, 21–40.

RING, U., SUSANNE, L. & MATTHIAS, B. 1999. Structural analysis of a complex nappe sequence and late orogenic basins from the Agean Island of Samos, Greece. *Journal of Structural Geology* **21**, 1575–1601.

ROJAY, B., TOPRAK, V., DEMİRCİ, C. & SÜZEN, L. 2005. Plio–Quaternary evolution of the Küçük Menderes Graben Southwestern Anatolia, Turkey. *Geodinamica Acta* **18**, 317–331.

RUST, B.R. 1978. Depositional models for braided alluvium. *In:* MIALL, A.D. (ed), *Fluvial Sedimentology*. Canadanian Society of Petroleum Geologists Memoir **5**, 605–625.

RYANG, W.H. & CHOUGH, S.K. 1999. Alluvial-to-lacustrine systems in a pullapart margin: southwestern Eumsung Basin (Cretaceous), Korea. *Sedimentary Geology* **127**, 31–47.

SARICA, N. 2000. The Plio–Pleistocene age of Büyük Menderes and Gediz grabens and their tectonic significance on N–S extensional tectonics in West Anatolia: mammalian evidence from the continental deposits. *Geological Journal* **35**, 1–24.

SCHLISCHE, R.W. 1995. Geometry and origin of fault-related folds in extensional settings. *American Association of Petroleum Geologists Bulletin* **79**, 1661–1678.

ŞENGÖR, A.M.C. 1979. The North Anatolian Transform Fault: its age, offset and tectonic significance. *Journal of the Geological Society, London* **136**, 269–282.

ŞENGÖR, A.M.C. 1980. *Türkiye'nin Neotektoniğinin Esasları [Fundamentals of Neotectonics of Turkey]*. Geological Society of Turkey, Conference Series **2** [in Turkish].

ŞENGÖR, A.M.C. 1982. Ege'nin neotektonik evrimini yöneten etkenler [The effects controlling neotectonic evolution of the Aegean]. *Congress of the Geological Society of Turkey*, 59–72.

ŞENGÖR, A.M.C. 1987. Cross-faults and differential stretching of hanging walls in regions of low-angle normal faulting: examples from western Turkey. *In:* COWARD, M.P., DEWEY, J.F. & HANCOCK, P.L. (eds), *Continental Extensional Tectonics*. Geological Society, London, Special Publications **28**, 575–589.

ŞENGÖR, A.M.C., GÖRÜR, N. & ŞAROĞLU, F. 1985. Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. *In*: BIDDLE, K. & CHRISTIE-BLICK, N. (eds), *Strike-Slip Deformation, Basin Formation and Sedimentation*. Society of Economic Paleontologists and Mineralogists, Special Publications **37**, 227–264.

ŞENGÖR, A.M.C., TÜYSÜZ, O., İMREN, C., SAKINÇ, M., EYİDOĞAN, H., GÖRÜR, N., LE PICHON, X., & RANGIN, C. 2004. The North Anatolian Fault: a new look. *Annual Reviews of Earth and Planetary Science* **33**, 1–75.

SEYİTOĞLU, G. 1997. Late Cenozoic tectono-sedimentary development of the Selendi and Uşak-Güre basins: a contribution to the discussion on the development of east-west and north trending basins in western Anatolia. *Geological Magazine* **134**, 163–175.

SEYİTOĞLU, G. & SCOTT, B.C. 1992. Late Cenozoic volcanic evolution of the northeastern Aegean region. *Journal of Volcanology and Geothermal Research* **54**, 157–176.

SEYİTOĞLU, G., SCOTT, B.C. & RUNDLE, C.C. 1992. Timing of Cenozoic extensional tectonics in west Turkey. *Journal of the Geological Society, London* **149**, 533–538.

SEYİTOĞLU, G., TEKELİ, O., ÇEMEN, İ., ŞEN, Ş. & IŞIK, V. 2002. The role of the flexural rotation/rolling hinge model in the tectonic evolution of the Alaşehir Graben, western Turkey. *Geological Magazine* **139**, 15–26.

SÖZBİLİR, H. 2001. Extensional tectonics and the geometry of related macroscopic structures: field evidence from the Gediz detachment, western Turkey. *Turkish Journal of Earth Sciences* **10**, 51–67.

SÖZBİLİR, H. 2002. Geometry and origin of folding in the Neogene sediments of the Gediz Graben, western Anatolia, Turkey. *Geodinamica Acta* **15**, 277–288.

SÖZBİLİR, H. 2005. Oligo–Miocene extension in the Lycian Orogen: evidence from the Lycian molasse basin, SW Turkey. *Geodinamica Acta* **18**, 255–282.

SÖZBİLİR, H. & EMRE, T. 1990. Neogene stratigraphy and structure of the northern rim of the Büyük Menderes Graben. *In:* SAVAŞÇIN, M.Y. & ERONAT, A.H. (eds), *Proceedings of International Earth Science Colloquium on the Aegean Region* **2**, 314–322.

SÖZBİLİR, H. & EMRE, T. 1996. Supra-detachment basin and rift basin developed during the neotectonic evolution of the Menderes Massif. *Geological Congress of Turkey, Ankara, Abstracts*, 300–301.

Sözbilir, H., Erkül, F. & Sümer, Ö. 2003a. Gümüldür (İzmir) ve Bigadiç (Balıkesir) arasında uzanan Miyosen sonrası yaşlı KD-Doğrultulu accommodation zonuna ait saha verileri, Batı Anadolu [Field evidence for post-Miocene NE-trending accomodation zone lying between Gümüldür (İzmir) and Bigadiç (Balıkesir), west Anatolia]. *Geological Congress of Turkey, Ankara, Abstracts*, 85–86.

Sözbilir, H., Helvaci, C., Sümer, Ö., Uzel, B., Ersoy, Y., Erkül, F., Tatar, S. & Oskay, M. 2007b. Batı Anadolu'da tortullaşmayla yaşıt ve tortullaşma sonrası doğrultu atım tektoniğine ait arazi verileri: Miyosen yaşlı volkanosedimanter istifinden örnekler, Çeşme Yarımadası, İzmir [Field evidence for syn-to post-sedimentary strike-slip tectonics: examples from the Miocene volcano-sedimentary units, Çeşme Peninsula, İzmir]. *30th Geology Symposium, Adana, Abstracts,* 189–190.

Sözbilir, H., İnci, U., Erkül, F. & Sümer, Ö. 2003b. An active intermitten transform zone accommodating N–S extension in Western Anatolia and its relation to the North Anatolian Fault System. *International Workshop on the North Anatolian, East Anatolian and Dead Sea Fault Systems: Recent Progress in Tectonics and Paleoseismology, and Field Training Course in Paleoseismology, Ankara. Poster Session,* 2/2.

Sözbilir, H., Sari, B. Akgün, F., Gökçen, N., Akkiraz, S., Sümer, Ö. & Erkül, F. 2004. First example of a transtensional supradetachment basin in western Anatolia: The Kemalpaşa-Torbalı Basin, Turkey. *32nd Internatinonal Geological Congress, Italy, Abstracts* **2**, p. 894.

Sözbilir, H., Sümer, Ö., Uzel, B., Özkaymak, Ç., Ersoy, Y., Erkül, F., İnci, U. & Helvaci, C. 2007a. Batı Anadolu'da İzmir-Balıkesir Transfer Zonu içinde kalan aktif doğrultu-atımlı faylarla sınırlı havzaların jeolojik özellikleri [Geological features of strike-slip basins located within the İzmir-Balıkesir Transfer Zone, western Anatolia]. *11th Active Tectonics Research Group Meeting, Abstracts,* p. 42.

Stanistreet, I.G. & McCarthy, T.S. 1993. The Okavango Fan and the classification of subaerial fan systems. *Sedimentary Geology* **85**, 115–133.

Stewart, I.S. & Hancock, P.L. 1991. Scales of structural heterogeneity within neotectonic normal fault zones in the Aegean region. *Journal of Structural Geology* **13**, 191 204.

Sylvester, A. G. 1988. Strike-slip faults. *Geological Society of America Bulletin* **100**, 1666–1703.

Tan, O. & Taymaz, T. 2001. Source parametres of November 6, 1992 Doganbey (İzmir) earthquake (M_w=6.0) obtained from inversion of teleseismic body-waveforms. *In: Proceedings of 4th International Turkish Geology Symposium: Work in Progress on the Geology of Turkey and Its Surroundings*, Çukurova University Publications, p. 171.

Temiz, H., Gürsoy, H. & Tatar, O. 1998. Kinematics of Late Pliocene–Quaternary normal faulting in the south-eastern end of the Gediz Graben, western Anatolia, Turkey. *International Geology Review* **40**, 638–646.

Tokcaer, M., Agostini, S. & Savaşçin, M.Y. 2005. Geotectonic setting, origin and emplacement model of the youngest Kula Volcanics in western Anatolia. *Turkish Journal of Earth Sciences* **14**, 145–166.

Umhoefer, P., Schwennicke, T., Del Margo, M.T., Ruiz-Geraldo, G., Ingle, J.C. & Mcintosh, W. 2007. Transtensional fault-termination basins: an important basin type illustrated by the Pliocene San Jose Island basin and related basins in the southern Gulf of California, Mexico. *Basin Research* **19**, 297–322.

Uzel, B. & Sözbilir, H. 2005a. First record of Quaternary pull-apart basin in western Analolia: the Cumaovası basin, İzmir-Turkey. *International Earth Sciences Colloquium on the Aegen Region, İzmir, Abstracts,* p. 119.

Uzel, B. & Sözbilir, H. 2005b. Batı Anadolu' daki transtansiyonel ortama ait yapısal veriler: Kuvaterner yaşlı Cumaovası havzasından bir örnek [Structural evidences for transtensional tectonic setting in western Anatolia: An example from Quaternary Cumaovası Basin]. *Geological Congress of Turkey, Ankara, Abstracts,* 52–53.

Uzel, B. & Sözbilir, H. 2006a. Orhanlı (Tuzla) Fay Zonu' ndaki jeolojik-jeomorfolojik belirteçler ve odak mekanizma çözümünün karşılaştırılması: Batı Anadolu'da KD-uzanımlı doğrultu atımlı fayların reaktivasyonu [Comparsion between geologic-geomorphologic indicators and focal mechanism solutions along the Orhanlı (Tuzla) Fault Zone: Reactivation of NE-trending strike-slip faults in western Anatolia]. *Geological Congress of Turkey, Ankara, Abstracts,* 79–80.

Uzel, B. & Sözbilir, H. 2006b. Batı Anadolu'da normal faylar ve doğrultu atımlı fayların birlikte işlediği havzalara bir örnek: Cumaovası çek-ayır havzası, İzmir [An example of basins which developed under the control of normal faults and strike-slip faults: Cumaovası pull-apart basin, İzmir]. *10th Meeting of Active Tectonics Research Group, Abstracts,* p. 93.

Ünay, E. & De Bruijn H. 1998. Plio–Pleistocene rodents and lagomorphs from Anatolia. *The Dawn of the Quaternary*, Mededelingen Nederlands Instituut voor Toegepaste Geowettenschappen **60**, 431–467.

Ünay, E., Göktaş. F., Hakyemez, H., Y., Avşar, M. & Şan, Ö. 1995. Büyük Menderes Grabeni'nin kuzey kenarındaki çökellerin Arvicolidae (Rodentia, Mammalia) faunasına dayalı olarak yaşlandırılması [Dating of sediments located at the northern margin of the Büyük Menderes Graben based on Arvicolidae (Rodentia, Mammalia) fauna]. *Geological Society of Turkey Bulletin* **38**, 75–80.

Westaway, R. 1990. Block rotation in western Turkey: 1. Observational evidence. *Journal of Geophysical Research* **95**, 19857–19884.

Westaway, R. & Arger, J. 1996. The Gölbaşı Basin, southeastern Turkey: a complex discontinuity in a major strike-slip fault zone. *Journal of the Geological Society, London* **153**, 729–743.

Wysocka, A. & Swierczewska, A. 2003. Alluvial deposits from the strike-slip fault Lo River Basin (Oligocene/Miocene), Red River Fault Zone, north-western Vietnam. *Journal of Asian Earth Sciences* **21**, 1097–1112.

Yazicigil, H., Doyuran, V., Karahanoğlu, N., Çamur, Z., Toprak, V., Rojay, B., Yilmaz, K., Şakiyan, J., Süzen, L., Yeşilnacar, E., Gündoğgu, A., Pusatli, T. & Tuzcu, B. 2000. *Revize Hidrojeolojik Etüdler Kapsamında K. Menderes Havzasının Yeraltısularının incelenmesi ve Yönetimi [Revised Hydrogeological Investigation of Ground Waters of the K. Menderes Basin].* ODTU-DSİ project, 7 volumes [in Turkish, unpublished].

Yilmaz, Y. 1997. Geology of western Anatolia. *In:* Schindler, C. & Pfister, M. (eds), *Active Tectonics of Northwestern Anatolia–The Marmara Polyproject*, vdf Hochschulverlag AG an der ETH Zürich, 31–53.

Yilmaz, Y., Genç, S.C., Gürer, O.F., Bozcu M., Yilmaz K., Karacik Z., Altunkaynak, Ş. & Elmas A. 2000. When did the western Anatolian grabens begin to develop? *In:* Bozkurt, E., Winchester, J.A. & Piper, J.D.A. (eds), *Tectonics and Magmatism in Turkey and the Surrounding Area.* Geological Society, London, Special Publications **173**, 353–384.

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