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Lake Hazar Basin: A Negative Flower Structure on the East Anatolian Fault System (EAFS), SE Turkey

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Abstract: The East Anatolian Fault System (EAFS) is a 30-km-wide, 700-km-long and NE-trending sinistral strike-slip megashear belt between the Anatolian platelet in the northwest and African-Arabian plates in the southeast. It is located between Karlıova County in the NE and Karataş (Adana)-Samandağ (Antakya) in the SW. In the Lake Hazar region, the EAFS consists of five fault zones. These are, from north to south, the Elazığ fault zone, the Uluova fault zone, the Sivrice fault zone, the Adıyaman fault zone and the Lice-Çermik fault zone; in previous studies only the Sivrice fault zone has been reported to be part of the EAFS. The 2–4-km-wide and 180-km-long Sivrice fault zone contains the master fault of the system. It bifurcates into several sub-fault zones and isolated faults resulting in a 5-km-wide, 32-km-long, active lensoidal depression bounded by a series of short to long and curved fault segments with considerable amounts of normal-slip component, particularly on the southern margin. This strike-slip depression was previously reported and interpreted to be a classical pull-apart basin or rhomb-graben basin originating from a left step-over located in the northeastern corner of Lake Hazar. In contrast to this earlier interpretation, our detailed field geological mapping of active faults indicates that there is no any left step-over at the northeast corner of Lake Hazar. In lieu of this, the master fault of the EAFS bifurcates into two sub-strands nearby Kartaldere village in the east which then run in a SW direction across Lake Hazar resulting in two sub-parallel lensoidal depressions separated by an intervening horst. This strike-slip geometry is here termed a negative flower structure. This interpretation is supported by basin-ward curved boundary faults with considerable normal-slip component of movement and by the bathymetry of Lake Hazar.

Back-tilted fault blocks, uplifted and dissected Plio–Quaternary terrace conglomerates, fan-delta deposits and associated syn-sedimentary structures indicate that neotectonic infill of the basin has accumulated under the influence of a strike-slip tectonic regime. The left-lateral strike-slip amount and the vertical throw amount accumulated along the Sivrice fault zone are 9 ± 1 km and 1317 ± 10 m, respectively. These values yield strike- and vertical-slip rates of 4 mm/yr and 0.5 mm/yr, respectively, along the Sivrice fault zone. However, the slip rates along the EAFS must be greater because the EAFS around Lake Hazar consists of five fault zones which all share the slip rate

Key Words: East Anatolian Fault System, Lake Hazar basin, negative flower structure, Turkey

Hazar Gölü Havzası: Doğu Anadolu Fay Sistemi (DAFS) Üzerinde Bir Negatif Çiçek Yapısı, GD Türkiye

Özet: Doğu Anadolu Fay Sistemi (DAFS) kuzeybatıda Anadolu ve güneydoğuda Arap-Afrika levhaları arasında yer alan, ortalama 30 km genişlikte, 700 km uzunlukta ve KD-gidişli, sol yanal doğrultu atımlı büyük bir makaslama kuşağıdır. DAFS kuzeydoğuda Karlıova ilçesi ile güneybatıda Karataş (Adana)–Samandağ (Antakya) arasında yer alır. Hazar Gölü bölgesinde, DAFS beş fay kuşağından oluşur. Bunlar kuzeyden güneye doğru Elazığ, Uluova, Sivrice, Adıyaman ve Lice-Çermik fay kuşaklarıdır. Halbuki önceki çalışmalarda, DAFS, yalnızca Sivrice fay kuşağı olarak tanıtılmıştır. 2–4 km genişliğinde ve 180 km uzunluğundaki Sivrice fay kuşağı DAFS'nin ana fayını içerir ve birkaç alt fay kuşağı ile çok sayıda tekil faya ayrılır; böylece 5 km genişlikte, 32 km uzunlukta, kenarları önemli miktarda normal atım bileşeni olan, kısa ve uzun bir seri fay segmenti ile sınırlanmış, günümüzde büyümesini sürdüren, mercek biçimli bir çöküntü oluşturur. Doğrultu atımlı bu fay çöküntüsü, daha önce, DAFS'nin ana fayının, Hazar gölünün kuzeydoğu köşesinde sola sıçramasıyla oluşmuş, klasik bir çek-ayır havza ya da eşkenar dörtgen biçimli bir graben havzası olarak yorumlanıp rapor edilmiştir. Bu görüşün aksine, aktif fayların ayrıntılı haritalaması ve fayların geometrisi (dağılım biçimi ve birbirleriyle ilişkisi) ana fayın, Hazar Gölü kuzeydoğu köşesinde sola sıçrama yapmadığını açıkça ortaya koymuştur. Bunun yerine, ana fay, daha doğuda yer alan Kartaldere köyü yakınlarında iki alt kola ayrılmakta ve bu iki alt kol güneybatı yönünde Hazar Gölü boyunca güneybatıya doğru devam ederek, birbirinden bir yükselti ile ayrılan, yarı paralel ve mercek biçimli iki çöküntünün oluşumuna yol açmaktadır. Doğrultu atımlı bu yeni geometri burada negatif çiçek yapısı olarak yorumlanıp adlanmıştır. Bu yorum aynı zamanda, önemli miktarda normal atım bileşeni olan ve havzaya doğru iç bükey kenar fayları ve Hazar Gölü'nün batimetrisi tarafından da desteklenmektedir.

Yükseltilmiş ve parçalanmış Pliyo–Kuvaterner yaşlı taraça çakıltaşları, geriye faya doğru eğimlenmiş fay blokları, fay-denetimli yelpaze tortulları ve onların sedimantasyonla yaşıt iç yapıları bu fasiyeslerin doğrultu atımlı bir tektonik rejimin denetiminde çökeldiğini göstermektedir. Sivrice fay kuşağı boyunca birikmiş olan sol yanal doğrultu atım miktarı ve düşey atım miktarı sırayla 9 ± 1 km ve 1317 ± 10 m olarak ölçülmüştür. Bu değerler, Sivrice fay kuşağı üzerindeki yıllık yanal ve düşey kayma hızlarının sırayla 4 mm/yıl ve 0.5 mm/yıl olduğunu gösterir. Ancak, DAFS üzerindeki kayma hızları bu değerlerden çok daha büyüktür, çünkü DAFS, Hazar Gölü bölgesinde, beş fay kuşağından oluşmakta ve kayma hızları yalnız Sivrice fay kuşağı tarafından değil, tüm fay kuşakları tarafından bölüşülmektedir.

Anahtar Sözcükler: Doğu Anadolu Fay Sistemi, Hazar Gölü havzası, negatif çiçek yapısı, Türkiye

Introduction

Strike-slip basins are structural depressions caused by a range of movement complexities along strike-slip fault zones. The general term 'pull-apart basin' in this area was first suggested by Burchfiel & Stewart (1966) based on the term 'Rhombochasm' of Carey (1958). A number of field works have subsequently been carried out on strike-slip basins in California (e.g., Hill & Dibble 1953; Crowell 1974a, b; Harding 1976; Sylvester & Smith 1976; Christie-Blick & Biddle 1985) which have attracted the attention of structural geologists worldwide. In addition during the last 30 years, a number of experimental and field studies have been carried out on the origin and evolutionary history of strike-slip basins (e.g., Ballance & Reading 1980; Rodgers 1980; Schubert 1980; Aydın & Nur 1982, 1985; Mann *et al.* 1983; Biddle & Christie-Blick 1985; Harding 1985; Manspeizer 1985; Koçyiğit 1988, 1989; Ingersoll & Busby 1995; McClay & Dooley 1995; Nilsen & Sylvester 1995; Rahe *et al.* 1998).

Two well-known strike-slip fault systems are the North Anatolian dextral strike-slip fault system and the East Anatolian sinistral strike-slip fault system. The intervening Anatolian platelet has been escaping in WSW direction between these faults towards the easily subductable oceanic crust of the African Plate since Late Pliocene (~ 2.6 Ma) (Hempton 1987; Koçyiğit *et al.* 2001). It has also been suggested that the active tectonics of Turkey is being dominated by the continuing westward escape of an Anatolian block along these same structures (Şengör *et al.* 1985). A number of strike-slip basins of dissimilar geometry have developed on these two strike-slip fault systems including the Sea of Marmara, Adapazarı, Düzce, Bolu, Yeniçağa, Çerkeş-Ilgaz, Tosya, Havza, Niksar, Kazova, Suşehri, Gölova, Erzincan on the NAFS, and the Bingöl, Lake Hazar and Gölbaşı basins on the EAFS (e.g., Aydın & Nur 1982; Hempton *et al.* 1983; Barka & Hancock 1984; Hempton & Dunne 1984; Şengör *et al.* 1985; Crampin & Evans 1986; Koçyiğit, 1988, 1989, 1990, 1996; Tutkun & Hancock 1990; Bozkurt & Koçyiğit 1996; Westaway & Arger 1996; Görür *et al.* 1997; Okay *et al.* 1999).

One of the well-developed strike-slip basins located on the EAFS is the Lake Hazar basin. It was previously studied and interpreted to be a classical pull-apart basin caused by left-stepover of the master fault at the eastern tip of the basin (Hempton & Dunne 1984). In contrast to this latter interpretation, the Lake Hazar basin seems to be a negative flower structure rather than a classic pull-apart basin or rhomb-graben basin or rhombochasm (Burchfiel & Stewart 1966; Robert & Hatcher 1990) based on the bathymetry of Lake Hazar, the strike-slip pattern of margin-boundary faults, and strike-slip complexities developed in and around the Lake Hazar basin. A major aim of the present paper is to present new field data on the origin of the Lake Hazar strike-slip basin and discuss its origin in the light of new field data and previous literature. As in the case of both the NAFS and the EAFS, fault segments comprising these two megashear belts have not been mapped in detail. This situation has lead to a series of misinterpretations of fault geometry, propagation and related basin formation as well as age and slip rate estimates on the fault segments. For this reason, the second aim of this paper is to present new data on total displacement, slip rate and propagation of fault segments together with their detailed field geological map.

Tectonic Setting

Turkey is a seismically active and geologically complicated area within in the Eastern Mediterranean seismic belt

(Figure 1a). The geological complexity is shaped by fold-thrust fault belts, strike-slip faults and related basin formations. These characteristics of mainland Turkey form a natural laboratory for observing deformation during intracontinental convergence and tectonic escape (Dewey *et al.* 1986). This geologically complicated deformation pattern of Turkey has been formed by the demise of the Tethyan seaway, the Bitlis Ocean, between Indian Ocean and Mediterranean Sea, and by continent-continent collision of northerly moving Arabian plate and the Eurasian plate in the Late Serravalian (Şengör & Yılmaz 1981; Dewey *et al.* 1986). These authors accept this as the initiation age of the neotectonic regime in Turkey. After final collision and formation of the Bitlis suture zone, the N–S-directed intracontinental convergence between the Arabian and Eurasian plates continued over a time period of ~9 Ma. This transitional period between the contractional palaeotectonic and the strike-slip neotectonic regimes has resulted in a series of deformations associated with thickening of crust, regional tectonic uplift, E–W-trending folds, thrust to reverse faults, resetting of new drainage system, the disappearance of marine conditions, the development of short to long stratigraphic gaps and predominantly calc-alkaline volcanic activitity (e.g., Şengör & Kidd 1979; Innocenti *et al.* 1980; Dewey *et al.* 1986; Şaroğlu & Yılmaz 1987; Yılmaz *et al.* 1987; Ercan *et al.* 1990; Koçyiğit & Beyhan 1998; Koçyiğit *et al.* 2001). The contractional deformation and development of fold-thrust belts continued until the Late Pliocene, and was then replaced by the emergence of a neotectonic contractional-extensional regime (dominantly strike-slip faulting-related tectonics) evidenced by occurrence of a series of inversions in deformational style, types of geological structures, the nature of sedimentation and basin formation, geochemical characteristics of the volcanic activity (e.g., from calc-alkali nature to dominantly alkali composition), and the nature of seismic activity triggered by formation of two intracontinental transform fault boundaries (North Anatolian dextral strike-slip fault and the East Anatolian sinistral strike-slip fault systems) and west–southwestward escaping Anatolian platelet along these two megashears (e.g., Hempton 1987; Koçyiğit & Beyhan 1998; Yılmaz *et al.* 1998; Koçyiğit *et al.* 2001). Hence the initiation age of strike-slip dominated neotectonism in eastern Turkey is Late Pliocene (Koçyiğit *et al.* 2001).

The present-day neotectonic configuration of Turkey and its neighborhood is shaped mostly by the NAFS and the EAFS. The easternmost tip of the NAFS runs further east of the Karlıova near to the west of Nemrut volcano and is therefore about 1600 km long and a few km to 100 km wide (owing to its wide-spread bifurcation around Sea of Marmara). It runs in an approximately E–W direction across northern Turkey and forms the boundary between the Eurasian plate in the north and the Anatolian platelet in the south. The EAFS is on average 30 km wide, and a 700 km long approximately NE-trending sinistral megashear located between Karlıova in the northeast and Karataş to Samandağ counties in the southwest (Figure 1a) (Arpat & Şaroğlu 1972; Koçyiğit *et al.* 2003). These two megashear belts meet in the Karlıova transform-transform triple junction (Şengör 1980). The active strike-slip deformation and related features, very high seismic activity and the westward migration of activity defined by the occurrence of a succession of devastating earthquakes along the NAFS in the last century has attracted attention of a number of both native and foreign scientists and made it one of the best-known tectonic structures in world. The EAFS is not so well known as the NAFS, although it has similar deformational characteristics and seismicity. A number of detailed geological and seismological works have been carried out on the EAFS (e.g., Arpat & Şaroğlu 1972; Seymen & Aydın 1972; Gülen *et al.* 1987; Şaroğlu *et al.* 1987; Perinçek *et al.* 1987; Tatar 1987; Perinçek & Çemen 1990; Taymaz *et al.* 1991; Herece & Akay 1992; Lyberis *et al.* 1992; Şaroğlu *et al.* 1992; Reilinger *et al.* 1997; Ambraseys & Jackson 1998; Rojay *et al.* 2001; Güneyli 2002; Nalbant *et al.* 2002; Çetin *et al.* 2003; Gürsoy *et al.* 2003; Koçyiğit *et al.* 2003; Ergin *et al.* 2004; Kaya 2004). However, works dealing with strike-slip complexities and basin formation are very limited (e.g., Hempton & Dunne 1984; Muehlberger & Gordon 1987; Westaway & Arger 1996; Koçyiğit 2003). In addition, the NAFS is capable of producing devastating earthquakes with magnitude 7 and greater. With the exception of the Bingöl-Karlıova section, the remainder is in the nature of a seismic gap for at least a time slice of 130 years (Ambraseys & Jackson 1998; Güneyli 2002; Koçyiğit *et al.* 2003; Çetin *et al.* 2003). Such zones are possible sites of future destructive earthquakes. For these reasons, this present paper focuses on strike-slip complexities to the segmentations and basin formation with special emphasize on the origin of the Lake Hazar basin.

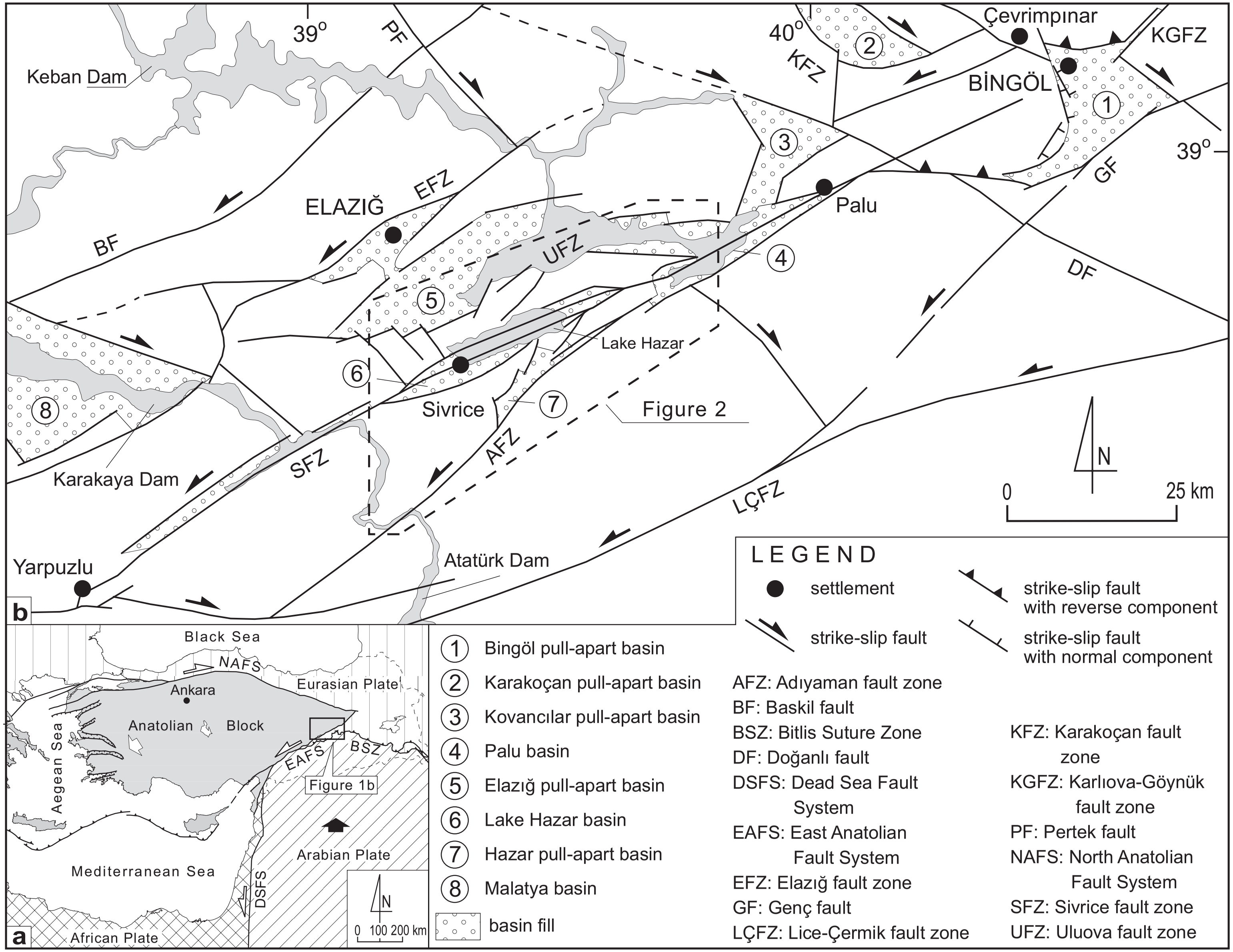

Figure 1. (a) Simplified map showing major plates and their boundary faults in the Eastern Mediterranean region and location of the study area; (b) simplified neotectonic map showing major fault zones and strike-slip basins comprising the East Anatolian Fault System (EAFS) in the Lake Hazar and Bingöl region (After Koçyiğit *et al.* 2003).

Stratigraphy

The pre-Pliocene rocks exposed in the Lake Hazar basin and its neighborhood are here termed basement rocks (Figure 2). They consist of Palaeozoic–Mesozoic Pötürge metamorphics, Jurassic–Lower Cretaceous Guleman ophiolites, Senonian Elazığ igneous rocks, Maastrichtian–Upper Paleocene Hazar and the Middle Eocene Maden Group. Detailed information on the basement rocks may be found in Hempton (1985), Sungurlu *et al.* (1985), Herece & Akay (1992), Aksoy (1993), and Çelik (2003). The Plio–Quaternary basin fill, accumulated under the control of margin-boundary faults of the Lake Hazar basin and are here considered to be neotectonic units (Figure 3). They rest with angular unconformity on the erosional surface of older basement rocks and consist mainly of, from bottom to top, travertines, braided stream deposits, fault terrace deposits, lacustrine deposits, braided stream to delta plain deposits, fan-delta deposits and marsh deposits (Figure 3a). Their various characteristics are described in more detail below (Figures 2 & 3).

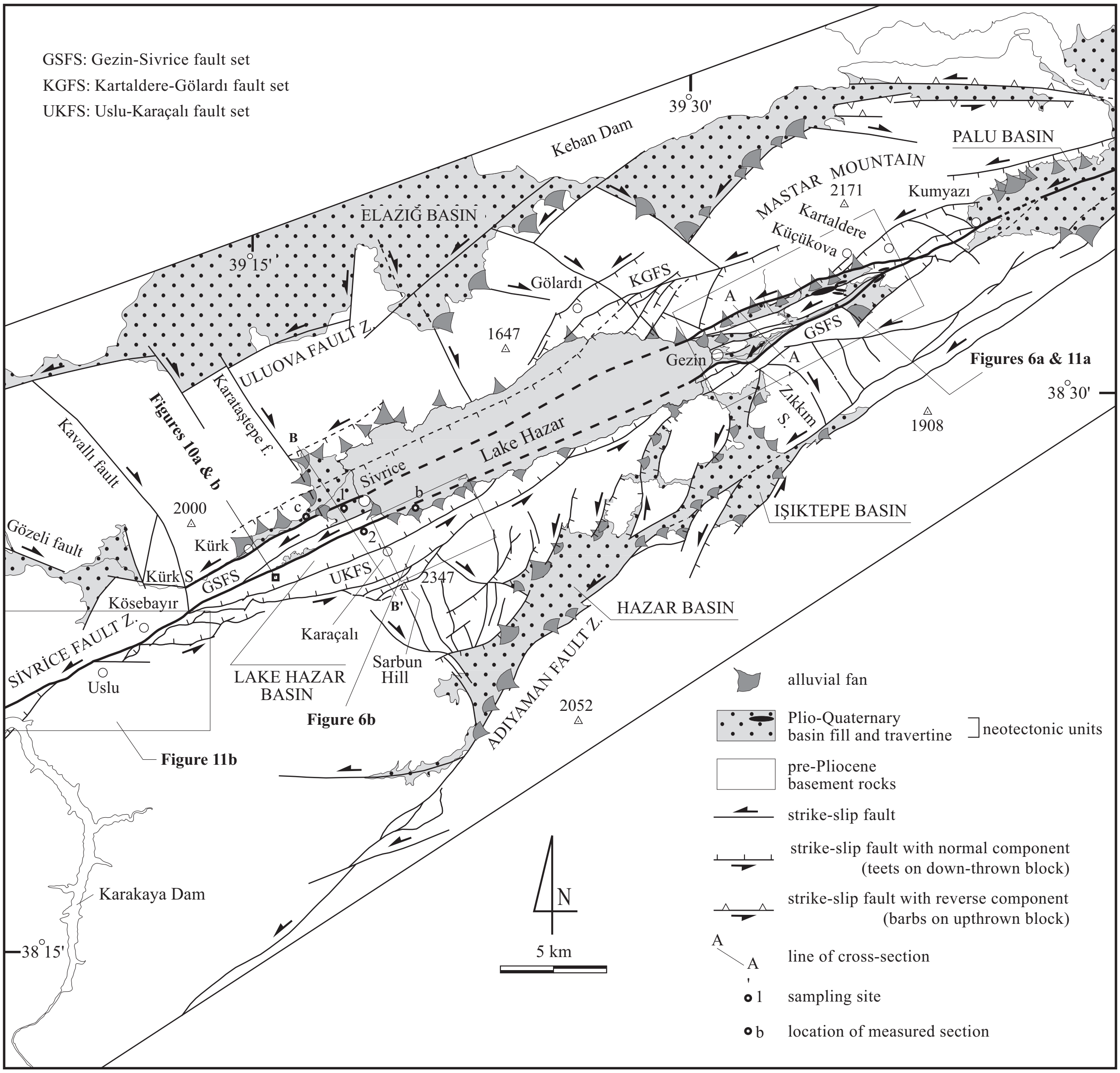

Figure 2. Neotectonic map of the Lake Hazar region.

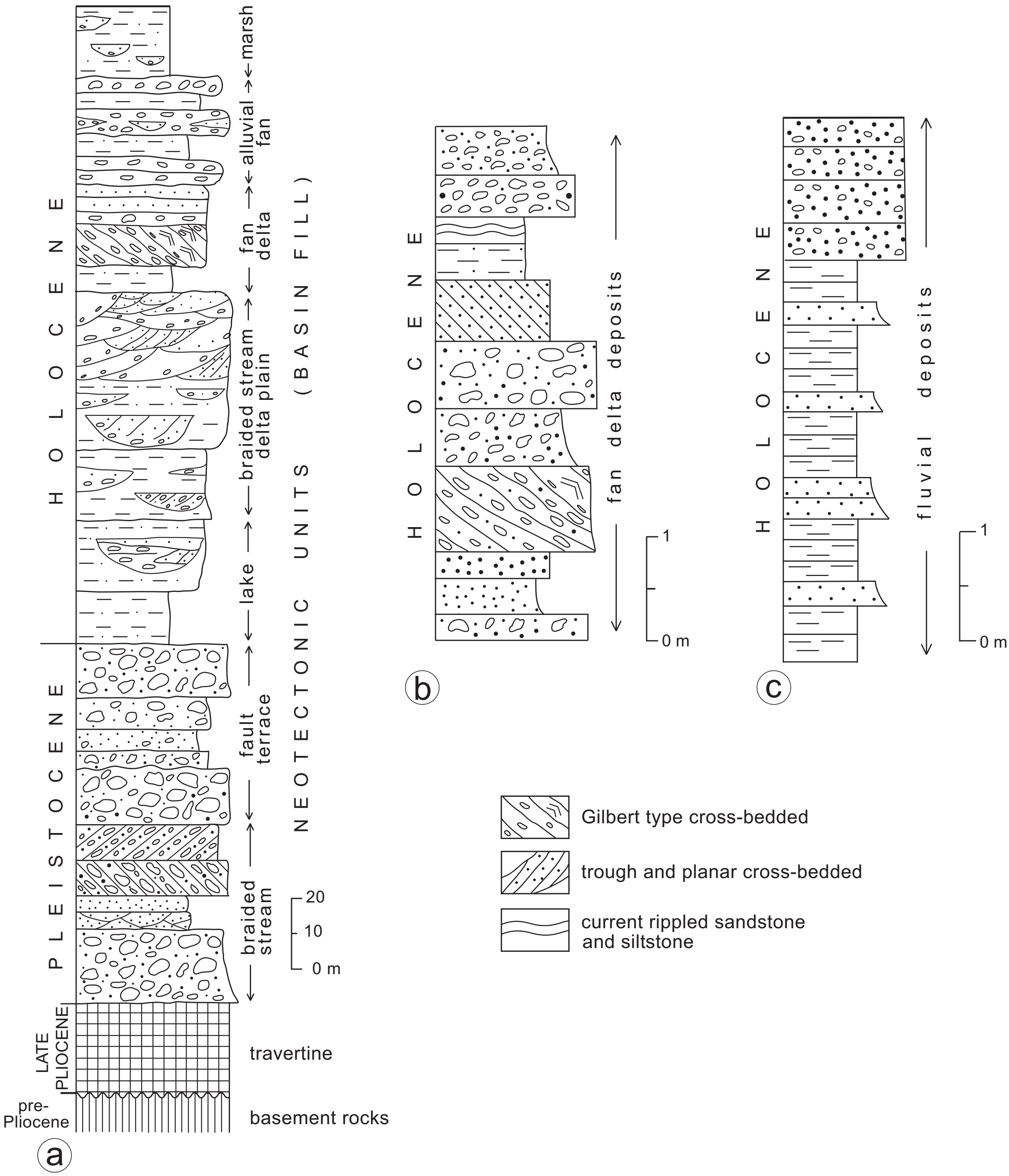

Figure 3. (a) Generalized stratigraphical column of the Lake Hazar basin infill; (b) measured section of fan-delta deposits from the Saklıdere fan-delta on the southwestern corner of the Lake Hazar; (c) measured section of fluvial deposits in the Kürk stream. See Figure 2 for location of b and c.

Travertines

These occur in a series of fault-parallel isolated outcrops ranging from tens of m^2 to a few km^2 in the southwest of Kartaldere village where the master fault of the EAFS bifurcates into two main strands (Figure 2). However, they are more spread on the northern strand than the southern one. Travertines overly unconformably older ophiolitic rocks and occur in terrace and channel types but are not fissure and banded in pattern. They consist of thin and porous laminae and are up to 25 m in total thickness. They are Plio–Quaternary in age; some are still actively growing in a natural response to fault activity.

Fault Terrace Deposits

These mostly occur in an uplifted and perched pattern along the downthrown blocks of the southern margin-boundary faults of the Lake Hazar basin. However, it was not possible to plot them on the map due to the scale of map used during the field geological mapping. Terrace deposits are unsorted and loose to weakly consolidated conglomerates deposited by debris flows. They consist of various-size (boulder-block, cobble, pebble) of angular sediment set in a sandy-silty matrix. They are Plio–Quaternary in age and measure 50 m in thickness.

Fan-Delta Deposits

These are one of the widespread deposits of the basin fill. Fan-delta deposits are products of two different drainage systems: (a) relatively high-angle marginal drainage system or transverse drainage system, and (b) low-angle axial drainage system. Indeed, the main factors controlling both these drainage systems and the delta developments are a slope angle of 3° (Dunne & Hempton 1984) and active faults; the latter are evidenced by the occurrence of soft-sedimentary deformational features in Holocene sediments. The marginal drainage system-dependent fan-deltas are exposed on both the northern and the southern fault-controlled margins of the Lake Hazar basin. However, they are better developed on the southern margin than on the northern one. Fan-deltas observed along the southern margin are small in size and characterized by bottom-set beds, fore-set beds and top-set beds of Gilbert-type cross-beds (Figure 3). Fore-set beds dip 30° towards north into the basin. Beds comprising Gilbert-type cross-beds consist of angular to semi-rounded and imbricate cobbles–pebbles up to 15 cm in diameter which alternate with sinusoidal sand ripples and slumps.

The axial drainage system is represented by running waters flowing in approximately NE- and SW-directions into the Lake Hazar basin. Two of streams comprising this drainage system are the Zıkkım stream located in the northeast and the Kürk stream in the southwest of the basin (Figure 2). The axial drainage system-dependent fan-deltas are characterized by combined mouth bar deposits accumulated at the mouths of these fault-parallel-flowing streams with low slope angle. In general, the drainage basin of the second system is much wider than the first system.

Nearby the source areas of the fault-parallel-flowing Kürk stream, coarse-grained braided river deposits are dominant and consist of thick-bedded, unsorted, rounded to semi-rounded sediments accumulated by debris flows. In general, away from the source area or close to the lake, low-gradient streams comprising the axial drainage system first grade into fan plains and then into straight or slightly sinusoidal isolated distributary channels. In these depositional settings, a delta plain sediment assemblage, composed of braided fan plain and lacustrine coastal facies, is dominant. At the mouth of the distributary channels large, combined, gentle and fine-grained mouth bar sediments are deposited. Current ripples included in the channel deposits indicate transportation from SW to NE. The other widespread lithofacies accompanying to the mouth bar deposits is the fine-grained, dark coloured and organic material-rich marsh facies, which consists of silt, clay and mud. Inside the present-day channels, gravel to rubble bars formed by seasonal floods have accumulated. Alternation of well-sorted finer sand, silt and clay of dissimilar thickness is the diagnostic facies of the distal part of the delta. Consequently, contemporaneous development of two different delta sedimentations along the coastal areas of the Lake Hazar basin implies a tectonic control on the sedimentation.

Alluvial Fans

In the northeastern terrestrial part of the Lake Hazar basin, a number of fault-parallel and diverse-sized alluvial fans occur (Figure 2). The proximal parts of these fans consist of weakly bedded to loose, coarse-grained, unsorted, sand-supported sediments accumulated by debris flows. Clast sizes in these sediments ranges from a few mm to 1 m in diameter. The medial parts of the fans consist of sand-sized and well-bedded sediments. The distal parts of the alluvial fans are characterized by alluvial plain deposits composed of thin-bedded to laminated, finer sand, silt and dark brown clays. The total thickness of the alluvial fans measures 5 m and they are Holocene in age (Figure 3b).

Morphotectonics

The Lake Hazar basin is an about 5-km-wide (maximum), 32-km-long and NE-trending lensoidal depression originated from strike-slip complexities and sinistral strike-slip faulting pattern. It narrows towards its NE and SW tips, and the 20-km-long central part is occupied by Lake Hazar with an average depth of 60 m (Biricik 1993) (Figure 4). However, based on the bathymetric mapping carried out by Huntington (1902) and Biricik (1993), the maximum water depths are 210 m and 89 m, respectively. Lake Hazar is divided into two long, narrow and fault-parallel troughs separated by an intervening sill elevated by the sub-strands of the master fault of the EAFS (Figure 4). In addition, the water surface elevation above sea level is 1240 m. The highest points at both margins of the Lake Hazar basin are the 2347 m high Sarbun Hill at the southern margin and the 2171 m high Mastar Mountain at the northern margin of the basin, i.e., the relief between the deepest point of the basin floor and the highest points at the margins are 1317 m and 1141 m, respectively (Figure 4). The southern margin of the Lake Hazar basin displays a well-developed and basinward-facing step-like morphology due to the considerable amount of normal slip component along the margin-boundary faults. However owing to the high gradient transverse drainage system shaping the southern margin, this morphotectonic pattern is highly dissected (Figures 2 & 5). In particular the southern margin of Lake Hazar basin is surrounded by a thick and weakly consolidated fan-apron deposit formed by coalescence of older isolated fans covering areas of 1–2 km^2. However, the Upper Pliocene–Lower Quaternary deposits are also overlain by a series of fault-parallel, smaller and isolated Holocene fans with apices adjacent to the basin margin-boundary faults. These morphotectonic features suggest that the basin margins have experienced an alternation of quiet and active phases of tectonic activity during the evolution of the Lake Hazar basin. This is also evidenced by the boulder-block conglomerates and finer sandstone, siltstone and mudstone alternations separated by a number of intervening long and short-term erosional gaps. One of the other morphotectonic features shaping particularly the southern margin of the basin is the uplifted and dissected fault terraces bounded by margin-boundary faults displaying northerly facing step-like morphology and slickensides. In places slopes of young fans measure up to 18° as a natural response to the increasing slope and high rate of deposition controlled by the active margin-boundary faults. Accordingly, a series of strike-slip related morphotectonic features are well-exposed along the whole margin of Lake Hazar basin and its neighbourhood. These features include fault-parallel to obliquely orientated pressure ridges, shutter ridges, compressional and releasing types of double bends, lensoidal sag-ponds, long and narrow morphologic troughs, S-shaped deflection to offset stream courses, hanging valleys, beheaded streams and fault valleys (Figure 6a, b).

Sivrice Fault Zone (SFZ)

In and around the Lake Hazar basin, the EAFS was first sub-divided into five major fault zones by Koçyiğit (2003). These are, from north to south, the Elazığ fault zone (EFZ), the Uluova fault zone (UFZ), Sivrice fault zone (SFZ), the Adıyaman fault zone (AFZ) and the Lice-Çermik fault zone (LÇFZ) (Figure 1b). The Lake Hazar basin is located on the central Sivrice fault zone and this paper focuses only on faults comprising the Sivrice fault zone described in detail below.

This is a 2–6-km-wide, 180-km-long and NE-trending sinistral strike-slip fault zone located between Palu County in the northeast and Yarpuzlu County in the southwest (Figure 1b). The SFZ also contains the master fault of the EAFS, and consists of three fault sets (Gezin-Sivrice fault set, Kartaldere-Gölardı fault set, Uslu-Karaçalı fault set) and a number of isolated faults of dissimilar size, nature and lengths (Figure 2). It also contains a number of short and obliquely-orientated fault segments in the nature of R and R' (Figure 7) although these fault segments were not mapped because of their scale. The SFZ is also seismically very active as evidenced by both the 3 May 1874 ground rupture-forming historical earthquake sourced from the reactivation of the

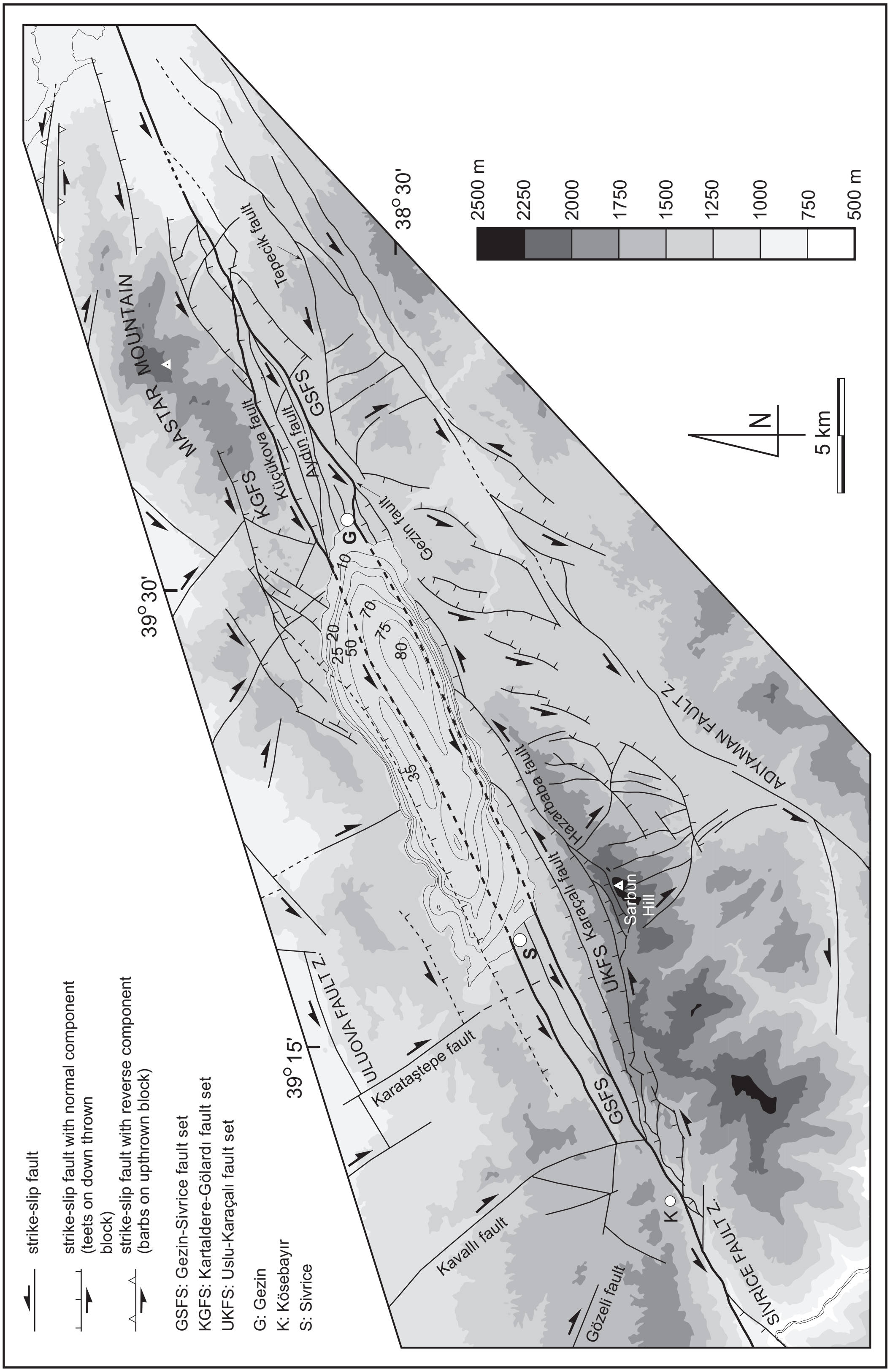

Figure 4. Simplified neotectonic and bathymetric maps of the Lake Hazar basin.

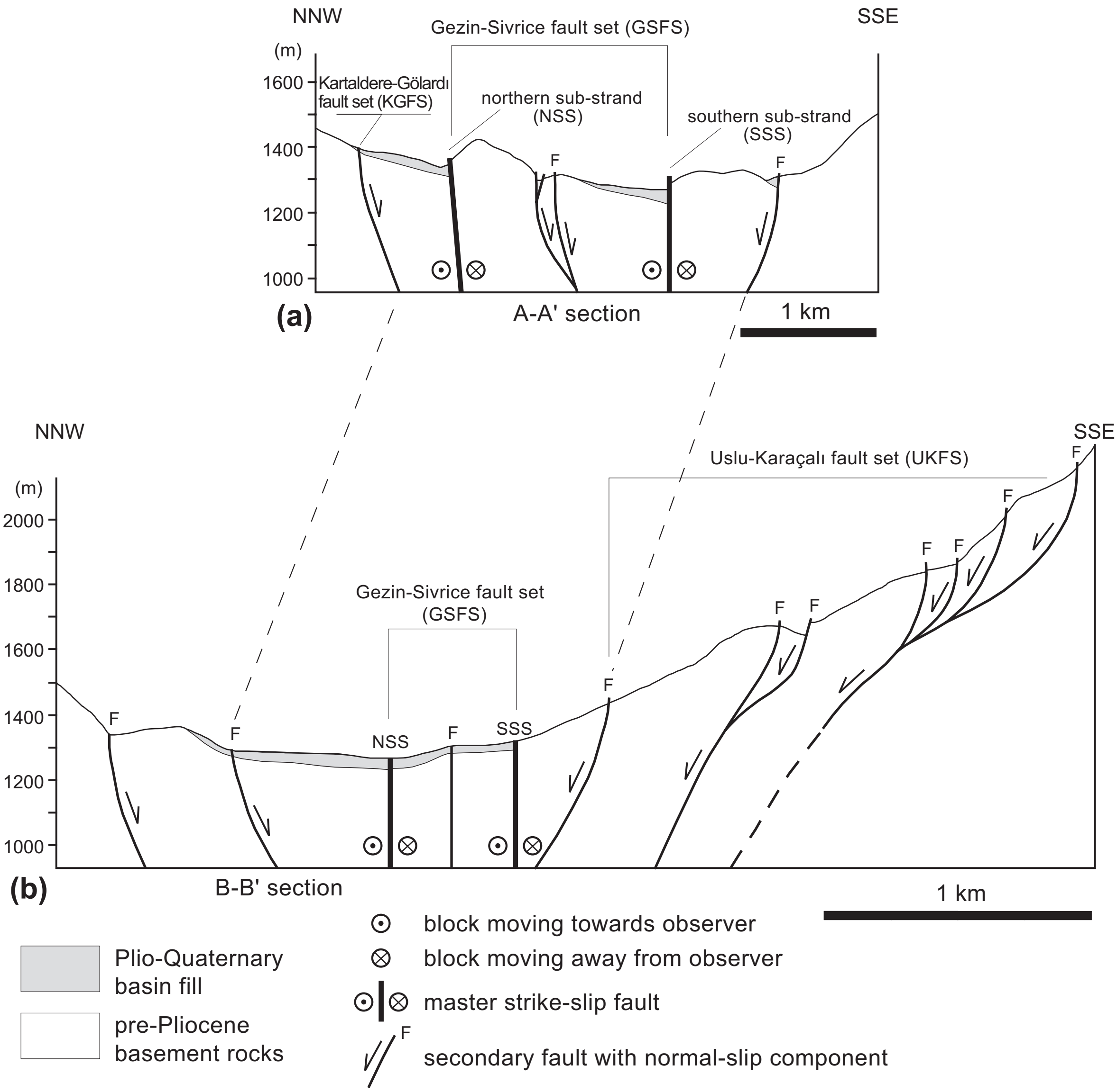

Figure 5. Geological cross sections showing typical step-like topography of the (a) northeastern and (b) southwestern margins and related negative flower structure of the Lake Hazar basin.

Palu-Gezin section of the master fault (Ambraseys & Jackson 1998; Güneyli 2002), and the occurrence of seismicity-induced soft-sedimentary deformational features, such as the asymmetric folds, small-scale normal faults, sand intrusions, water escape or load structures, cycloids, flame-like structures, stretched and segmented clayey silt beds deformed into irregular waveforms and surrounded by very fine-grained sands (Hempton & Dewey 1983). These soft-sedimentary deformation features occur as intercalations within a Holocene sedimentary package, and are separated by several undeformed (regularly-bedded) sedimentary horizons of dissimilar thickness in the distal part of a fan-apron deposit near the northeastern coastal plain of the Lake Hazar basin. Such kinds of young soft sedimentary deformational features have recently been attributed to ground rupture-forming historical earthquakes (Hempton & Dewey 1983; Vanneste *et al.* 1999).

Figure 6. (a) Field photograph showing some of well-exposed strike-slip faulting related morphotectonic features. P– pressure ridge, t– morphotectonic trough (northeastern terrestrial tip of the Lake Hazar basin, view to S); (b) field photograph showing step-like morphology, basinward-facing steep fault scarp and S-shaped bended and deflected stream course (Salık stream bed) indicating an active sinistral strike-slip faulting in the Lake Hazar region (southern margin of the Lake Hazar basin, view to S). See Figure 2 for locations of field photographs.

Gezin-Sivrice Fault Set (GSFS). This is the 2–4-km-wide, 180-km-long and NE-trending sinistral strike-slip fault set located between Palu in the northeast and Yarpuzlu in the southwest (Figure 1b). The GSFS consists of a series of parallel and sub-parallel fault segments (Figure 6a). The most significant fault segment is the master fault of the EAFS. It enters into the area of investigation in Palu in the northeast and runs in a SW direction up to 1 km southwest of the village of Kartaldere, where it bifurcates into two sub-strands, namely the southern sub-strand and the northern sub-strand (Figures 2, 6a & 8). The northern sub-strand follows the same direction and enters into Lake Hazar 1 km north of the town of Gezin, and continues across Lake Hazar up to the north of Sivrice County, where it reappears on land; finally it runs in the same direction up to near east of Kösebayır village, where it meets the Kavallı isolated fault and terminates (Figures 2 & 4). Older basement rocks such as the Jurassic–Lower Cretaceous Guleman ophiolite and the Upper Cretaceous–Paleocene Hazar Complex are tectonically juxtaposed with the Plio–Quaternary basin fill along its length and it also cuts across basin fill, in places. Structural analysis of the growth faults measured at station 1 (Figure 2) formed in tectonically controlled basin fill reveals a localized extension in a ENE–WSW direction (Figure 9a).

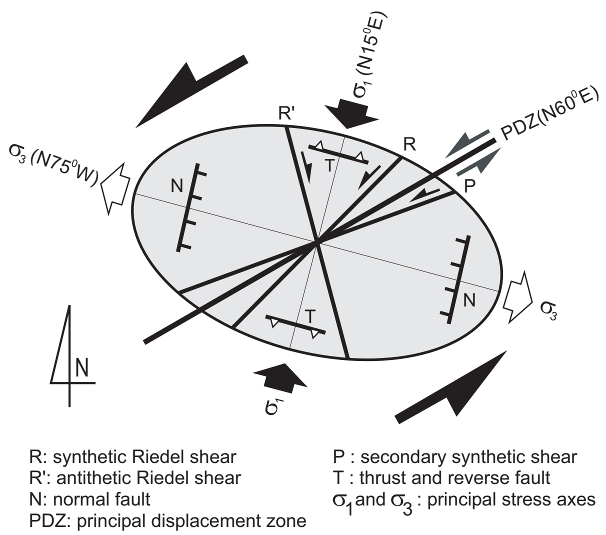

Figure 7. Plan view of geometric relations between structures (Ramsay 1967) formed during a simple shear deformation history with shear parallel to the Sivrice fault zone.

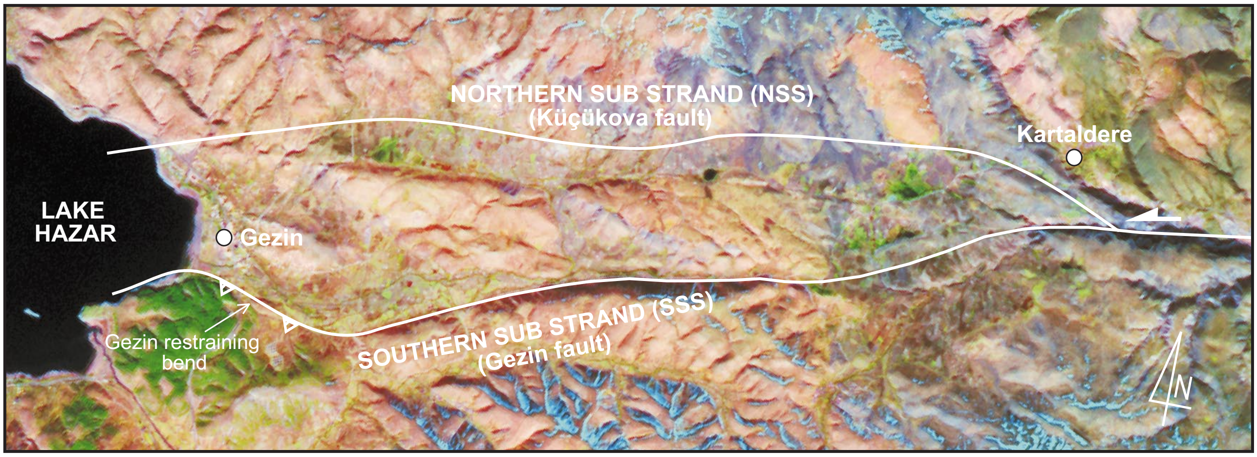

Figure 8. General views of the sub-strands of the master fault and a well-developed restraining bend (Gezin restraining bend) in the northeastern part of the Lake Hazar basin on the ASTER image.

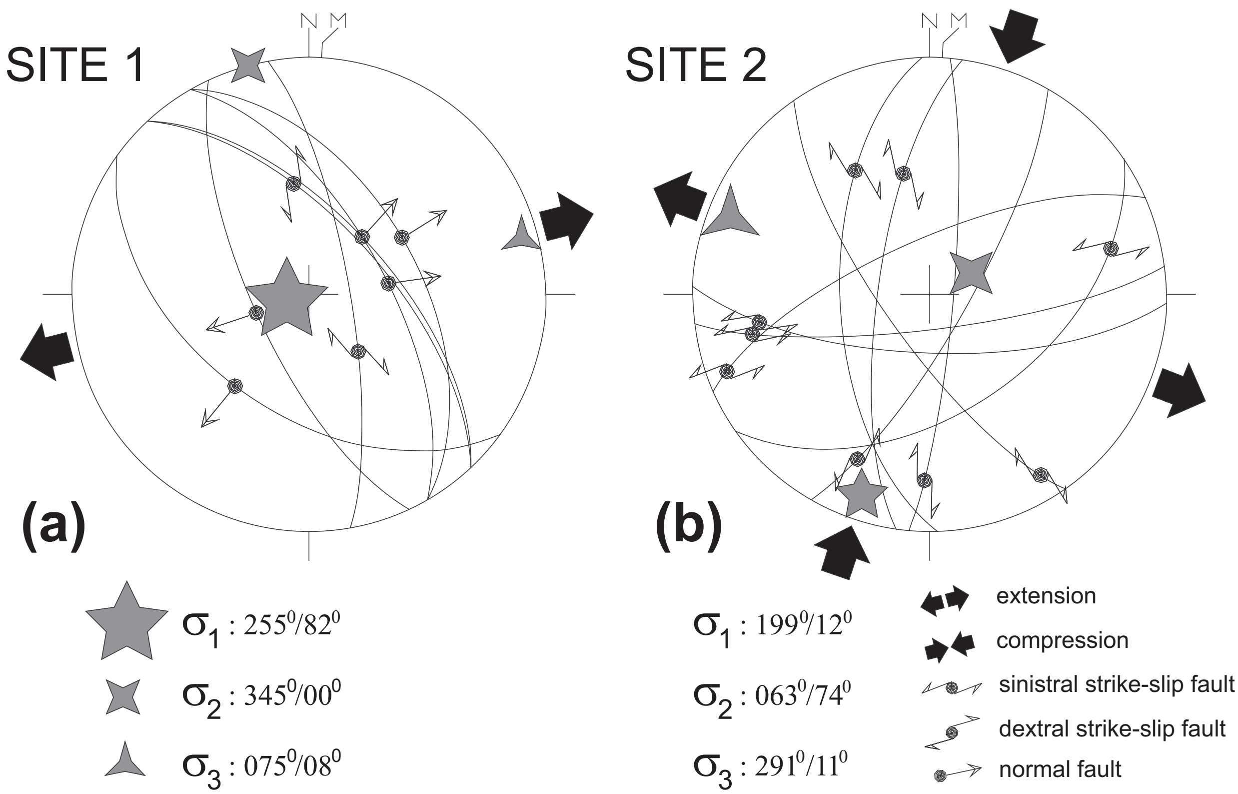

Figure 9. Lower hemisphere, equal area projection of principal stress axes constructed from fault-slip data using the Inversion Method (Angelier 1994). Fault-slip data from basin infill deposits in site 1 (a) and Jurassic–Upper Cretaceous ophiolitic rocks in site 2 (b). See Figure 2 for locations.

The southern sub-strand runs in a SW direction for 8 km distance, then results in a 2-km-long contractional double bend, namely the Gezin restraining bend, near to the SSE of the town of Gezin (Figure 8) where it enters into Lake Hazar and runs in a SW direction up to 0.7 km south of Sivrice County. It then reappears on land and follows the same direction in and outside of the study area (Figures 2 and 4). The northeastern section of the southern sub-strand was previously termed to be the 'Sivrice-Sincik fault' by Herece & Akay (1992) and the 'Gezin Fault' by Güneyli (2002) and Çetin *et al.* (2003). In the northeast, it tectonically juxtaposes the Hazar complex with the basin fill, while it cuts through the Guleman ophiolites and Maden Group in the southwest. Palaeostress analysis of slip-plane data obtained on slickensides preserved on ophiolitic rocks along the fault reveals localized NNE–SSW contraction (station 2 in Figure 2; Figure 9b).

Kartaldere–Gölardı Fault Set (KGFS). This is an about 4-km-wide, 22-km-long and N60°E-trending fault set located around the villages of Kartaldere and Gölardı (Figure 2). SSE of Gölardı, the KGFS bends slightly south and bifurcates into a series of parallel, sub-parallel and curved fault segments resulting in a horsetail structure and basinward-facing step-like morphology associated with the evolution of the Lake Hazar basin. The northern sub-strand and the KGFS determine and shape the northeastern part of the Lake Hazar basin (Figure 2).

Uslu–Karaçalı Fault Set (UKFS). This is the 4-km-wide, 25-km-long fault set located between Uslu village in the southwest and 5 km southwest of the town of Gezin in the northeast (Figure 2). The UKFS consists of a number of diverse-sized, northwesterly curved to steeply dipping fault segments. Along the south–southwest margin of the Lake Hazar basin, these fault segments display a back-tilted and basin-ward facing step-like morphology and well-preserved slickensides with a rake of up to 25° suggesting a considerable normal-slip component (Figures 6b & 10a, b). The UKFS occurs within the basement rocks, and shapes the south–southwestern margin of the Lake Hazar basin.

There are also a series of short (5 km) and long (18 km), and approximately NW-trending isolated faults in the nature of secondary right-lateral strike-slip faults (R'). They mostly occur along the northwestern margin of the Lake Hazar basin and divide this section of the basin into a series of southwesterly-tilted blocks. Two of these isolated fault segments are the Karataştepe and the Kavallı faults (Figure 2).

Age, Displacement and Slip Rate on the Sivrice Fault Zone

The sedimentary fill accumulated under the control of margin-boundary faults of the Lake Hazar basin consists mostly of weakly consolidated to loose fault terrace deposits, fan-delta deposits, travertines and alluvial fans. They are nearly flat-lying and rest with angular unconformity on an erosional surface of deformed (folded and reverse faulted) basement rocks of pre-Late

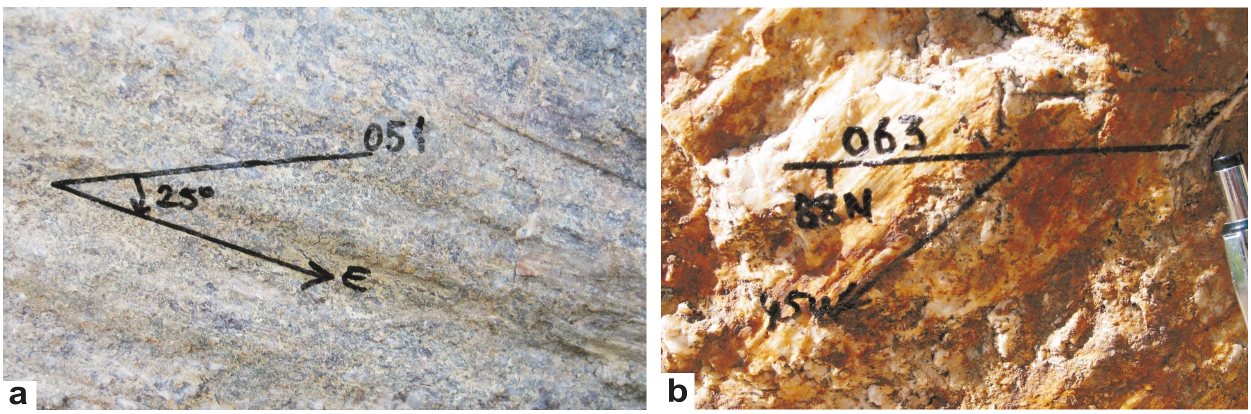

Figure 10. Field photographs showing close-up views of slickensides with a rake of up to 25° on the fault segments comprising the Uslu-Karaçalı fault set. See Figure 2 for locations of field photographs.

Pliocene age (Kerey & Türkmen 1991; Aksoy 1993; Çelik 2003). Therefore, the age of the neotectonic fill of the Lake Hazar basin must be younger than Middle Pliocene, possibly Plio–Quaternary.

In previous works (Arpat & Şaroğlu 1972, 1975; Hempton 1985; Herece & Akay 1992; Turan 1993; Turan & Gürocak 1997; Özdemir & İnceöz 2003) it has been reported that the total left-lateral displacement accumulated on the master strand of the Sivrice fault zone ranges from 9 km to 27 km, based on both the structural and geomorphological markers such as offset formation boundaries and drainage systems. In the present study it has been observed and measured to be 6.5 to 9 km, respectively, based on the offset formation boundaries in the west and east of the Lake Hazar basin (Figure 11). The 9 km total displacement was accumulated during the Plio–Quaternary (~2.6 Ma) and yields a left-lateral slip rate of approximately 4 mm/yr. Of course, the slip rate along the Sivrice fault zone may be significantly greater than this value, because it represents the slip rate on the master strand only; the SFZ consists of a number of parallel to sub-parallel secondary fault segments that also share slip along the Sivrice fault zone (Figures 2 & 4).

In the same way, the faults comprising the SFZ are not entirely pure strike-slip in nature. This is evidenced by the negative flower structure nature of the Lake Hazar basin and its particularly southern margin-boundary faults displaying step-like morphology and slickensides with slip lines raking at 25° and also indicating a normal component (Figures 6b & 11). As has been explained in foregoing chapters, this is also supported by the great elevation difference (1317 and 1141 m, respectively) between the floor of the Lake Hazar basin and peaks of its both margins. Consequently, the total vertical displacement along the SFZ is 1317 m, and yields a vertical slip rate of ~ 0.4 to 0.5 mm/ yr.

Discussion and Conclusions

In general, the Lake Hazar basin is a ~5-km-wide, 32-km-long and NE-trending strike-slip basin located between Kartaldere in the NE and Kösebayır in the SW (Figure 2). Its northeastern and southwestern parts are terrestrial, but its central part is occupied by waters of Lake Hazar. The main bulk of the basin is located on two sub-strands of the master fault of the EAFS. The northeastern part of the northern sub-strand and the southwestern part of the southern sub-strand were previously termed as the offset parts of a single master fault by Hempton & Dunne (1984) (Figure12a). They have also interpreted this geometrical relationship to be a strike-slip complexity in the nature of a left step-over, on which the Lake Hazar basin has nucleated and developed into a classical pull-apart basin (Figure 12). In contrast to their observation and interpretation, the fault geometry obtained by our detailed field geological mapping of active faults, and from the bathymetric map (Biricik 1993) of Lake Hazar indicate that the master fault of the EAFS bifurcates into two sub-strands 1 km southwest of Kartaldere (Figure (8), and they run without resulting in any left step-over across Lake Hazar up to Kösebayır village in the west (Figures 2, 4 & 13 a). In this new frame, the Lake Hazar basin seems to be a fault wedge type of pull-apart basin originated from subsidence of an intervening block bounded by two sub-strands of the master fault (Crowell 1974a). Thus, the Lake Hazar basin has originally nucleated on these two sub-strands of the master fault, and evolved into its present-day configuration in terms of both the sub-strands and the other subordinate fault segments with considerable normal-slip components (Figures 5, 6b & 13). Hence the Lake Hazar basin is a negative flower structure (Figures 5 & 13) rather than a classical pull-apart basin or rhomb graben basin (Figure 12).

Around the Lake Hazar basin, the EAFS is about 75 km in width, and consists of one isolated fault and five fault zones. These are, from north to south, the Baskil fault (BF), the Elazığ fault zone (EFZ), the Uluova fault zone (UFZ), the Sivrice fault zone (SFZ), the Adıyaman fault zone (AFZ) and the Lice-Çermik fault zone (LÇFZ) (Figure 1). Based on the structural markers (offset formation boundaries), the total left-lateral strike-slip amount accumulated on the master strand of the EAFS was observed and measured as 9 ± 1 km. This value yields a slip rate of about 4 mm/yr but the slip rate along the EAFS must be greater than this because it is shared by the other four fault zones and one isolated fault comprising the EAFS (Figure 1). In the same way, at both margins of the Lake Hazar basin, the faults comprising the EAFS are not entirely pure strike-slip in nature. This is evidenced by the negative flower structure nature of the Lake Hazar basin, and its southern margin-boundary faults (SFZ) displaying step-like morphology and

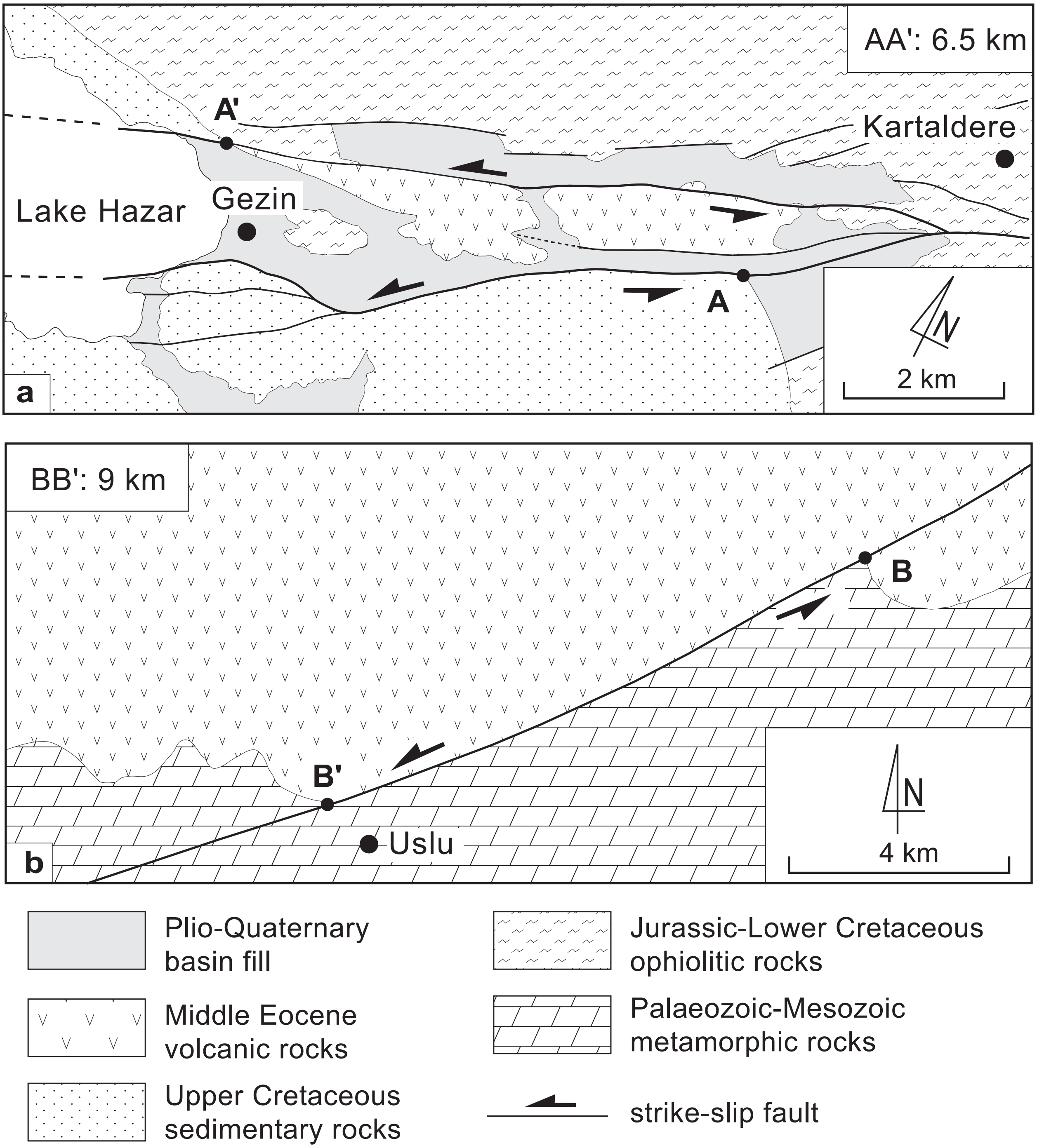

Figure 11. (a) Geological map showing the tectonic juxtaposition between the Plio–Quaternary basin infill and older basement rocks, and total displacement (A–A'= 6.5 km) accumulated along the two sub-strands of the SFZ; (b) geological map showing the left-lateral offset (B–B'= 9 km) along the master fault of the Sivrice fault zone. See Figure 2 for locations.

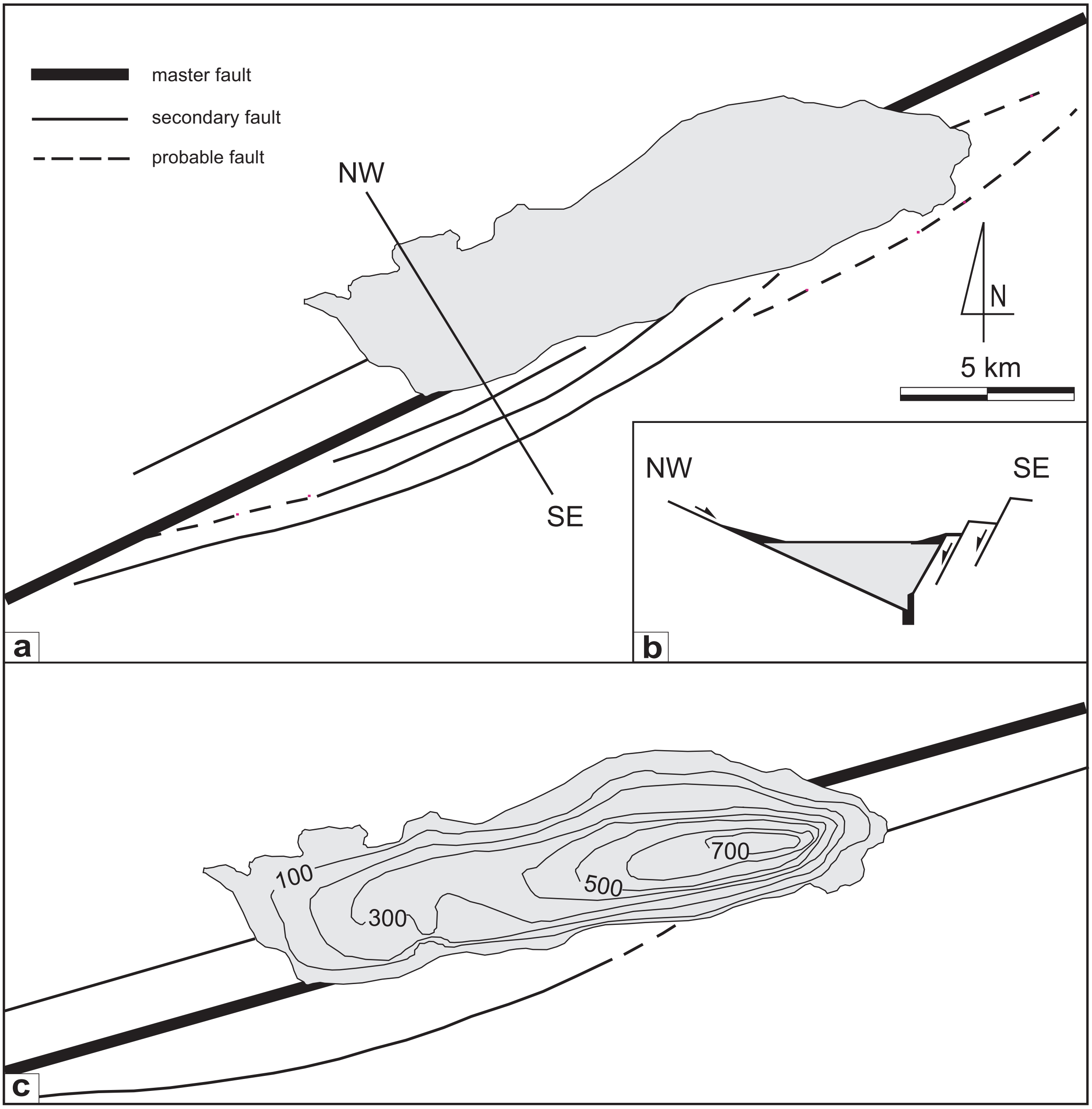

Figure 12. (a) Map showing faults which control the structure of the Lake Hazar basin (Hempton & Dunne 1984); (b) schematic NW–SE cross-section of the basin; (c) neotectonic and bathymetric map of the Lake Hazar basin (Huntington 1902).

slickensides with slip lines making a rake of 25° (Figures 6b & 11). Based on the great elevation difference (1317 and 1141 m, respectively) between the floor of the Lake Hazar basin and peaks on both margins, the total vertical displacement along the SFZ is estimated as 1317 ± 10 m. This value yields a vertical slip rate of ~ 0.4 to 0.5 mm/yr on the Sivrice fault zone alone.

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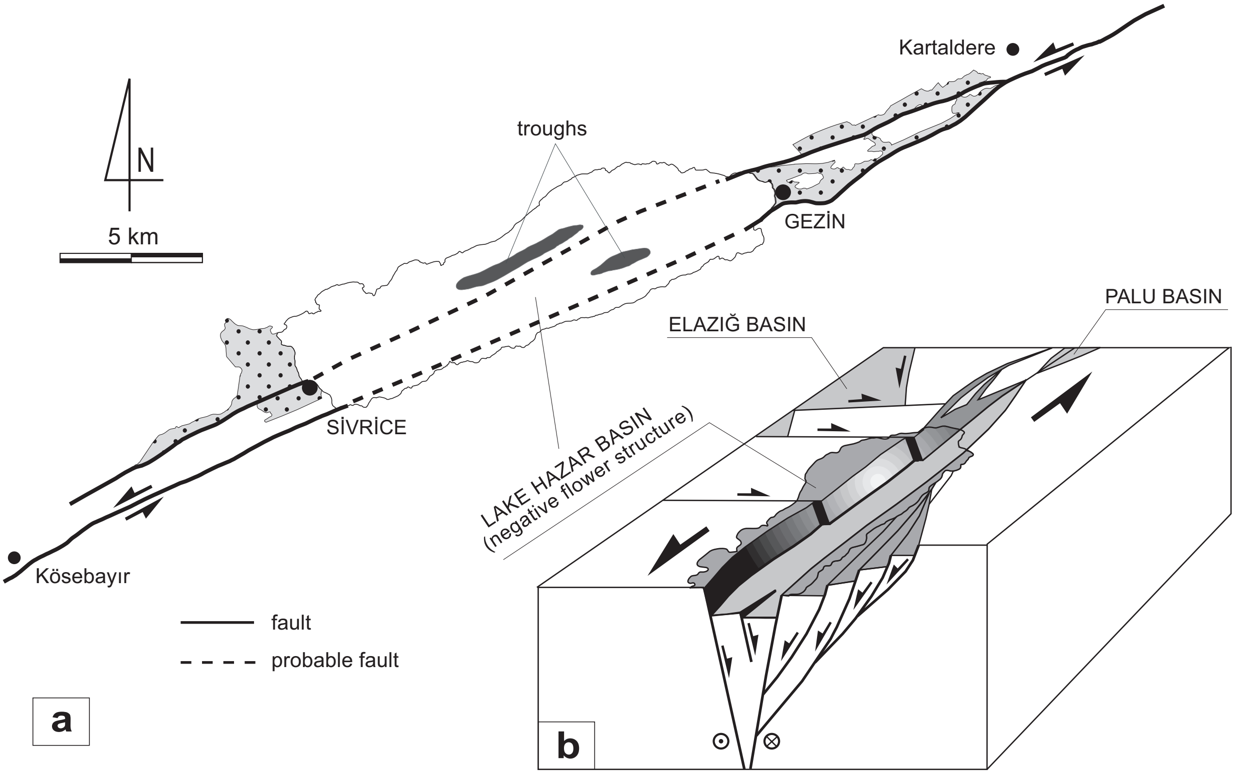

Figure 13. (a) Map showing the master fault and its sub-strands which control the negative flower structure of the Lake-Hazar basin; (b) sketch block diagram illustrating the structural evolution of the active Lake Hazar basin. Arrows show the relative motion senses on the fault segments.

References

AKSOY, E. 1993. Elazığ batı ve güneyinin genel jeolojik özellikleri [General geological characteristics of western and southern Elazığ region]. *Turkish Journal of Earth Sciences* **2**, 113–123 [in Turkish with English abstract].

AMBRASEYS, N.N. & JACKSON, J.A. 1998. Faulting associated with historical and recent earthquakes in the Eastern Mediterranean region. *Geophysical Journal International* **133**, 390–406.

ANGELIER, J. 1994. Faults slip analysis and palaeostress reconstruction. *In*: HANCOCK, P.L. (ed), *Continental Deformation*. Pergamon, Oxford, 53–101.

ARPAT, E. & ŞAROĞLU, F. 1972. The East Anatolian Fault System: thoughts on its development. *Mineral Research and Exploration Institute (MTA) of Turkey Bulletin* **78**, 33–39.

ARPAT, E. & ŞAROĞLU, F. 1975. Some significant recent tectonic events in Turkey. *Geological Society of Turkey Bulletin* **18**, 91–101 [in Turkish with English abstract].

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 Publication **37**, 35–44.

BALLANCE, P.F. & READING, H.G. 1980. *Sedimentation in Oblique-slip Mobile Zones*. International Association of Sedimentologists, Special Publication **4**.

BARKA, A. & HANCOCK, P.L.1984. Neotectonic deformation patterns in the convex-northwards arc of the North Anatolian Fault Zone. *In:* DIXON, J.E. & ROBERTSON A.H.F. (eds), *The Geological Evolution of the Eastern Mediterranean.* Geological Society, London, Special Publications **17**, 763–774.

BIDDLE, K.T. & CHRISTIE-BLICK, N. 1985. *Strike-slip Faulting and Basin Formation*. Society of Economic Paleontologists and Mineralogists, Special Publication **37**.

BIRİCİK, A.S. 1993. Hazar (Gölcük) Gölü depresyonu (Elazığ) [Hazar (Gölcük) Lake depression (Elazığ)]. *Türkiye Coğrafya Dergisi* **28**, 45–63 [in Turkish].

BOZKURT, E. & KOÇYİĞİT, A. 1996. The Kazova basin: an active negative flower structure on the Almus Fault Zone, a splay fault system of the North Anatolian Fault Zone, Turkey. *Tectonophysics* **265**, 239–254.

BURCHFIEL, B.C. & STEWART, J. 1966. 'Pull-apart' origin of the central segment of Death Valley, California. *Geological Society of America Bulletin* **77**, 439–442.

CAREY, S.W. 1958. A tectonic approach to continental drift. *In:* CAREY, S.W. (convenor), *Continental Drift – A Symposium, Hobart, University of Tasmania*, 177–355.

ÇELİK, H. 2003. *Mastar Dağı (Elazığ GD'su) Çevresinin Stratigrafik ve Tektonik Özellikleri [Stratigraphical and Tectonic Characteristics of Master Mountain and Adjacent Area (SE of Elazığ)]*. PhD Thesis, Fırat University [in Turkish with English abstract, unpublished].

ÇETİN, H., GÜNEYLİ, H. & MAYER, L. 2003. Palaeoseismology of the Palu-Lake Hazar segment of the East Anatolian Fault Zone, Turkey. *Tectonophysics* **374**, 163–197.

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.

CRAMPIN, S. & EVANS, R. 1986. Neotectonics of the Marmara region. *Journal of the Geological Society, London* **143**, 343–348.

CROWELL, J.C. 1974a. 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. 1974b. Sedimentation along the San Andreas fault, California. *In*: DOTT, R.H. & SHAVER, R.H. (eds), *Modern and Ancient Geosynclinal Sedimentation*. Society of Economic Paleontologists and Mineralogists, Special Publications **19**, 292–303.

DEWEY, J.F., HEMPTON, M.R., KIDD, W.S.F., ŞAROĞLU, F. & ŞENGÖR, A.M.C. 1986. Shortening of continental lithosphere: the neotectonics of Eastern Anatolia – a young collision zone. *In*: COWARD, M.P. & RIES, A.C. (eds), *Collisional Tectonics*. Geological Society, London, Special Publications **19**, 3–36.

DUNNE, L. & HEMPTON, M.R. 1984. Deltaic sedimentation in the Lake Hazar pull-apart basin, south-eastern Turkey. *Sedimentology* **31**, 401–412.

ERCAN, T., FUJITANI, T., MADSUDA, J.I., NOTSUT, K., TOKEL, S. & UI, T. 1990. Doğu ve Güneydoğu Anadolu Neojen–Kuvaterner volkaniklerine ilişkin yeni Jeokimyasal, radiometrik ve izotopik verilerin yorumu [Interpretation of new geochemical, radiometric and isotopic data from Neogene–Quaternary volcanics of east-southeast Anatolia]. *Mineral Research and Exploration Institute (MTA) of Turkey Bulletin* **110**, 143–164 [in Turkish with English abstract].

ERGİN, M., AKTAR, M. & EYİDOĞAN, H. 2004. Present-day seismicity and seismotectonics of the Cilician Basin: Eastern Mediterranian Region of Turkey. *Bulletin of the Seismological Society of America* **94**, 930–939.

GÖRÜR, N., ÇAĞATAY, M.N., SAKINÇ, M., SÜMENGEN, M., ŞENTÜRK, K., YALTIRAK, C. & TCHAPALYGA, A.1997. Origin of the Sea of Marmara as deduced from Neogene to Quaternary palaeogeographic evolution of its frame. *International Geology Review* **39**, 342–352.

GÜLEN, L., BARKA, A. & TOKSÖZ, M.N. 1987. Continental collision and related complex deformation; Maraş triple junction and surrounding structures in SE Turkey. *Hacettepe University, Earth Sciences* **14**, 319–336.

GÜNEYLİ, H. 2002. *Doğu Anadolu Fay Sistemi, Palu-Hazar Gölü Segmentinin Neotektoniği ve Palaeosismolojisi [Neotectonics and Palaeoseismology of Palu-Lake Hazar Segment of East Anatolian Fault System]*. PhD Thesis, Çukurova University [in Turkish with English abstract, unpublished].

GÜRSOY, H., TATAR, O., PIPER, J.D.A., HEIMANN, A. & MESCI, L. 2003. Neotectonic deformation linking the East Anatolian and Karataş-Osmaniye intracontinental transform fault zones in the Gulf of İskenderun, southern Turkey, deduced from palaeomagnetic study of the Ceyhan-Osmaniye volcanics. *Tectonics* **22**, Art. No. 1067

HARDING, T.P. 1976. Tectonic significance and hydrocarbon trapping consequences of sequential folding synchronous with San Andreas faulting, San Joaquin Valley, California. *American Association of Petroleum Geologists Bulletin* **60**, 356–378.

HARDING, T.P. 1985. Seismic characteristics and identification of negative flower structures, positive flower structures, and positive structural inversion. *American Association of Petroleum Geologists Bulletin* **63**, 1016–1058.

HEMPTON, M.R. 1985. Structure and deformation history of the Bitlis suture near Lake Hazar, southeastern Turkey. *Geological Society of American Bulletin* **96**, 233–243.

HEMPTON, M.R. 1987. Constraints on Arabian plate motion and extensional history of Red Sea. *Tectonics* **6**, 687–705.

HEMPTON, M.R. & DEWEY, J.F. 1983. Earthquake-induced deformational structures in young lacustrine sediments, East Anatolian Fault, Southeast Turkey. *Tectonophysics* **98**, T7–T14.

HEMPTON, M.R. & DUNNE, L.A. 1984. Sedimentation in pull-apart basins: active examples in eastern Turkey. *Journal of Geology* **92**, 513–530.

HEMPTON, M.R., DUNNE, L.A. & DEWEY, J.F. 1983. Sedimentation in active strike-slip basin, Southeastern Turkey. *Journal of Geology* **91**, 401–412.

HERECE, E. & AKAY, E. 1992. Karlıova-Çelikhan arasında Doğu Anadolu fayı [East Anatolian Fault between Karlıova and Çelikhan]. *Abstracts, 9th Petroleum Congress of Turkey,* 361–372.

HILL, M.L. & DIBBLE, T.W. 1953. San Andreas, Garlock and Big Pine faults, California. *Geological Society of America Bulletin* **64**, 443–458.

HUNTINGTON, E. 1902. The valley of the upper Euphrates River and its people. *Geological Society of America Bulletin* **34**, 301–318.

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.

INNOCENTI, F., PISA, R., MAZZUOLI, C., PASQUARE, G., SERRI, G. & VILLARI, L. 1980. Geology of the volcanic area north of Lake Van (Turkey). *Geological Rundschau* **69**, 292–322.

KEREY, İ.E. & TÜRKMEN, İ. 1991. Palu formasyonunun (Pliyosen–Kuvaterner) sedimentolojik özellikleri, Elazığ doğusu [Sedimentology of Palu formation (Pliocene–Quaternary), east of Elazığ]. *Geological Society of Turkey Bulletin* **34**, 21–26 [in Turkish with English abstract].

KAYA, A. 2004. Gezin (Maden-Elazığ) çevresinin jeolojisi [Geology of Gezin region (Maden-Elazığ)]. *Pamukkale Üniversitesi, Mühendislik Bilimleri Dergisi* **10**, 41–50 [in Turkish with English abstract].

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

KOÇYIĞIT, 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* **IV**, 155–170.

KOÇYIĞIT, A. 1996. Superimposed basins and their relations to recent strike-slip fault zone: a case study of the Refahiye superimposed basin adjacent the North Anatolian transform fault, northwestern Turkey. *International Geology Review* **38**, 701–713.

KOÇYIĞIT, A. 2003. Segmentation and near future seismicity of the East Anatolian Fault System. *Abstracts, International Workshop on the North Anatolian, East Anatolian and Dead Sea Fault System: Recent Progress in Tectonics and Palaeoseismology*, 31 August to 12 September 2003, METU (Ankara, Turkey), p. 7.

KOÇYIĞIT, A. & BEYHAN, A. 1998. A new intracontinental transcurrent structure: the Central Anatolian Fault Zone, Turkey. *Tectonophysics* **284**, 317–336.

KOÇYIĞIT, A., AKSOY, E. & İNCEÖZ, M. 2003. *Basic Neotectonic Characteristics of the Sivrice Fault Zone in the Sivrice-Palu area, East Anatolian Fault System (EAFS), Turkey*. Excursion Guide Book, International Workshop on the North Anatolian, East Anatolian and Dead Sea Fault Systems: Recent Progress in Tectonics and Palaeoseismology, 31 August to 12 September 2003, METU (Ankara, Turkey).

KOÇYIĞIT, A., YILMAZ, A., ADAMIA S. & KULOSHVILI, S. 2001. Neotectonics of East Anatolian Plateau (Turkey) and Lesser Caucasus: implication for transition from thrusting to strike-slip faulting. *Geodinamica Acta* **14**, 177–195.

LYBERISS, N., YÜRÜR, T., CHOROWICZ, J., KASAPOĞLU, E. & GÜNDOĞDU, N. 1992. The East Anatolian Fault: an oblique collision belt. *Tectonophysics* **204**, 1–15

MANSPEIZER, W. 1985. The Dead Sea Rift: Impact of climate and tectonism on Pleistocene and Holocene sedimentation. *In:* BIDDLE, K.T. & CHRISTIE-BLICK, N. (eds), *Strike-Slip Faulting and Basin Formation*. Society of Economic Paleontologists and Mineralogists, Special Publications **37**, 143–158.

MANN, P., HEMPTON, M.R., BRADLEY, D.C. & BURKE, K. 1983. Development of pull-apart basins. *Journal of Geology* **91**, 529–554.

MCCLAY, K. & DOOLEY, T. 1995. Analogue models of pull-apart basins. *Geology* **23**, 711–714.

MUEHLBERGER, W.R. & GORDON, M.B. 1987. Observation on the complexity of the East Anatolian Fault, Turkey. *Journal of Structural Geology* **9**, 899–903

NALBANT, S., MCCLUSKY, J., STEACY, S. & BARKA, A. 2002. Stress accumulation and increased seismic risk in eastern Turkey. *Earth and Planetary Science Letters* **195**, 291–298.

NILSEN, T.H. & SYLVESTER, A.G. 1995. Strike-slip basins. *In:* BUSBY, C.J. & INGERSOLL, R.V. (eds), *Tectonics of Sedimentary Basins.* Blackwell Science Publications, 425–457.

OKAY, A., DEMİRBAŞ, E., KURT, H., OKAY, N. & KUŞÇU İ. 1999. An active deep marine strike-slip basin along the North Anatolian Fault in Turkey. *Tectonics* **18**, 129–148.

ÖZDEMİR, M.A & İNCEÖZ, M. 2003. Doğu Anadolu Fay Zonunda (Karlıova-Türkoğlu arasında) akarsu ötelenmelerinin tektonik verilerle karşılaştırılması [Comparison of river offsets and tectonic data along the East Anatolian Fault Zone in the area between Karlıova and Türkoğlu]. *Afyon Kocatepe Üniversitesi Sosyal Bilimler Dergisi* **V**, 89–114 [in Turkish with English abstract].

PERİNÇEK, D. & ÇEMEN, İ. 1990. The structural relationship between the East Anatolian and Dead Sea fault zones in southeastern Turkey. *Tectonophysics* **172**, 331–340.

PERİNÇEK, D., GÜNAY, Y. & KOZLU, H. 1987. New observations on strike-slip faults in East and Southeast Anatolia. *The Seventh Biannual Petroleum Congress of Turkish Association of Petroleum Geologists, Ankara, Proceedings,* 89–103.

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

RAMSAY, J.G. 1967. *Folding and Fracturing of Rocks*. McGraw-Hill Book, New York.

REILINGER, R.E., MCCLUSKY, S.C., ORAL, M.B., KING, R.W. & TOKSÖZ, M.N. 1997. Global Positioning System measurements of present-day crustal movements in the Arabia-Africa-Eurasian plate collision zone. *Journal of Geophysical Research* **102**, 9983–9999.

ROBERT, D. & HATCHER, J.R. 1990. *Structural Geology*. Merrill Publishing Company, London.

RODGERS, D.A. 1980. Analysis of pull-apart basin development produced by en echelon strike-slip faults. *In:* BALLANCE, P.F. & READING, H.G. (eds), *Sedimentation in Oblique-slip Mobile Zones*. International Association of Sedimentologists, Special Publications **4**, 27–41.

ROJAY, B., HEIMANN, A. & TOPRAK, V. 2001. Neotectonic and volcanic characteristics of the Karasu fault zone (Anatolia, Turkey): the transition zone between the Dead Sea transform and the East Anatolian fault zone. *Geodinamica Acta* **14**, 197–212.

SCHUBERT, C. 1980. Late Cenozoic pull-apart basins, Bocono fault zone, Venezuelan Andes. *Journal of Structural Geology* **2**, 463–468.

ŞAROĞLU, F. & YILMAZ Y. 1987. Doğu Anadolu'da Neotektonik dönemdeki jeolojik evrim ve havza modelleri [Geological evolution and basin models of East Anatolia during neotectonic period]. *Mineral Research and Exploration Institute (MTA) Bulletin of Turkey* **107**, 73–94 [in Turkish with English abstract].

ŞAROĞLU, F., EMRE, Ö. & BORAY, A. 1987. *Türkiye'nin Diri Fayları ve Depremsellikleri [Active Faults of Turkey and Their Earthquake Potential]*. Mineral Research and Exploration Institute (MTA) of Turkey Report no. **8174** [in Turkish, unpublished].

ŞAROĞLU, F., EMRE, Ö. & KUŞÇU, İ. 1992. The East Anatolian Fault Zone of Turkey. *Annales Tectonicae* **6**, 99–125.

SEYMEN, İ. & AYDIN, A. 1972. Bingöl deprem fayı ve bunun Kuzey Anadolu Fay Zonu ile ilişkisi [Bingöl earthquake fault and its relation to North Anatolian Fault Zone]. *Mineral Research and Exploration Institute (MTA) of Turkey Bulletin* **79**, 1–8 [in Turkish with English abstract].

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

ŞENGÖR, A.M.C. & KIDD, W.S.F. 1979. Post-collisional tectonics of the Turkish-Iranian plateau and a comparison with Tibet. *Tectonophysics* **55**, 361–376.

ŞENGÖR, A.M.C. & YILMAZ, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics* **75**, 181–241.

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.T. & CHRISTIE-BLICK, N. (eds), *Strike-Slip Faulting and Basin Formation.* Society of Economic Paleontologists and Mineralogists, Special Publications **37**, 227–264.

SUNGURLU, O., PERİNÇEK, D., KURT, G., TUNA, E., DÜLGER, S., ÇELİKDEMİR, E. & NAZ, H. 1985. Elazığ-Hazar-Palu alanının jeolojisi [Geology of Elazığ-Hazar-Palu area]. *Petrol İşleri Genel Müdürlüğü Dergisi* **29**, 83–191 [in Turkish with English abstract].

SYLVESTER, A.G. & SMITH, R.R.1976. Tectonic transpression and basement-controlled deformation in San Andreas fault zone, Salton Trough, California. *American Association of Petroleum Geologists Bulletin* **30**, 2081–2102

TATAR, Y. 1987. Elazığ bölgesinin genel tektonik yapıları ve Landsat fotoğrafları üzerine yapılan bazı gözlemler [Structures of Elazığ region and observations on Landsat images]. *Hacettepe University*, *Yerbilimleri* **14**, 295–308.

TAYMAZ, T., EYİDOĞAN, H. & JACKSON, J. 1991. Source parameters of large earthquakes in the East Anatolian Fault Zone (Turkey). *Geophysical Journal International* **106**, 537–550

TURAN, M. 1993. Elazığ yakın civarındaki bazı önemli tektonik yapılar ve bunların bölgenin jeolojik evrimindeki yeri [Tectonic structures around Elazığ and their significance in the geologic evolution of the region]. *Proccedings, A. Suat Erk Jeoloji Simpozyumu (2–5 Eylül 1991, Ankara),* 193–204 [in Turkish with English abstract].

TURAN, M. & GÜROCAK, Z. 1997. Sivrice (Elazığ) civarında Doğu Anadolu Fay Zonu'nun tektonik özellikleri [Tectonic characteristics of East Anatolian Fault Zone around Sivrice (Elazığ)]. *Proceedings, 20. Yıl Jeoloji Sempozyumu*, *Selçuk Üniversitesi Mühendislik-Mimarlık Fakültesi Jeoloji Mühendisliği Bölümü*, 465–477 [in Turkish with English abstract].

TUTKUN, S.Z. & HANCOCK, P.L. 1990. Tectonic landforms expressing strain at the Karlıova continental triple junction (E Turkey). *Annales Tectonicae* **IV**, 182–195.

VANNESTE, K., MEGHRAOUI, M. & CAMBELBEECK, T. 1999. Late Quaternary earthquake-related deformation along the Belgian portion of the Feldbiss Fault, Lower Rhine Graben System. *Tectonophysics* **309**, 57–79.

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.

YILMAZ, Y., ŞAROĞLU, F. & GÜNER, Y. 1987. Initiation of the neomagmatism in East Anatolia. *Tectonophysics* **134**, 177–194.

YILMAZ, Y., GÜNER, Y. & ŞAROĞLU, F. 1998. Geology of the Quaternary volcanic centres of the East Anatolia. *Journal of Volcanology and Geothermal Research* **85**, 173–210.

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