



Neotectonic Characteristics of the İnönü-Eskişehir Fault System in the Kaymaz (Eskişehir) Region: Influence on the Development of the Mahmudiye-Çifteler-Emirdağ Basin

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Received 26 March 2011; revised typescripts received 06 April 2010 & 27 July 2011; accepted 25 March 2011

Abstract: The İnönü-Eskişehir Fault System (İEFS) is a NW- to WNW-trending zone of active deformation about 15–25 km wide, 400 km long and characterized predominatly by strike-slip faulting. In this study, the Yörükkaracaören (SE of Eskişehir)-Sivrihisar section of the İEFS was investigated. The system consists of three fault zones, namely the Alpu Fault Zone (AFZ), the Eskişehir Fault Zone (EFZ) and the Orhaniye Fault Zone (OFZ) in the study area. The EFZ is made up mostly of N30°W-trending right-lateral strike-slip fault segments with normal components. However, the AFZ and OFZ are composed of E–W-trending normal and NE- to NW-trending strike-slip fault segments.

The Mahmudiye-Çifteler-Emirdağ basin is one of several strike-slip pull-apart basins along the İnönü-Eskişehir Fault System. It is an actively-subsiding NW-trending depression about 25 km wide, 85 km long located between Yörükkaracaören and Emirdağ. It contains two infills. The older and deformed (tilted and folded) infill, which rests with angular unconformity on the erosional surfaces of pre-Miocene metamorphic and non-metamorphic rocks, consists predominatly of lacustrine carbonates. The younger and undeformed basin infill (neotectonic infill) is composed of upper Pliocene–Holocene terrace deposits, alternations of sandstones, lacustrine mudstone to thin limestones and alluvial fans. The two basin infills separated by an angular unconformity, the deformation pattern of the older basin infill and the active bounding strike-slip faults all indicate the superimposed character of the Mahmudiye-Çifteler-Emirdağ pull-apart basin.

Key Words: Kaymaz, İnönü-Eskişehir Fault System, Mahmudiye-Çifteler-Emirdağ basin

İnönü (Eskişehir) Bölgesinde İnönü-Eskişehir Fay Sisteminin Neotektonik Özellikleri: Mahmudiye-Çifteler-Emirdağ Havzası'nın Gelişimine Etkisi

Özet: İnönü-Eskişehir Fay Sistemi (İEFS) yaklaşık 15–25 km genişlikte, 400 km uzunlukta, KB ile BKB gidişli, egemen olarak doğrultu atımlı faylanma ile karakterize edilen aktif bir deformasyon kuşağıdır. Bu çalışma kapsamında, İEFS'nin Yörükkaracaören-Sivrihisar kesimi araştırılmıştır. İEFS, Çalışma alanında, Alpu fay kuşağı (AFK), Eskişehir Fay Kuşağı (EFK) ve Orhaniye fay kuşağı (OFK) olmak üzere üç önemli yapısal öğeden oluşur. Eskişehir Fay Kuşağı, çoğunlukla K30°B gidişli ve normal bileşene sahip sağ yanal doğrultu-atımlı fay segmentleriyle temsil edilir. Bununla beraber AFK ve OFK ise D–B gidişli normal KD ve KB gidişli doğrultu atımlı fay segmentleriyle karakterize edilir.

İnönü-Eskişehir Fay Sistemi boyunca birkaç çek-ayır havza gelişmiştir. Bunlardan biri Mahmudiye-Çifteler-Emirdağ havzasıdır. Bu havza yaklaşık 25 km genişlikte, 85 km uzunlukta ve KB gidişli aktif bir çöküntü alanı olup Yörükkaracaören ile Emirdağ arasında yer alır. Mahmudiye-Çifteler-Emirdağ havzası iki farklı havza dolgusu içerir. Daha yaşlı ve deformasyon geçirmiş (eğimlenmiş ve kıvrımlanmış) olan havza dolgusu, Miyosen öncesi yaşlı metamorfik ve metamorfik olmayan kayaların aşınım yüzeyleri üzerinde açılı uyumsuz olarak bulunur ve başlıca görsel karbonatlardan oluşur. Daha genç ve deformasyon geçirmemiş (yatay konumlu) olan havza dolgusu (yenitektonik dolgu) ise geç Pliyosen–Holosen yaşlı taraça tortulları, kumtaşları, görsel çamurtaşı-ince kireçtaşı ardaşımı ve yelpaze tortullarından oluşur. Birbirinden açılı uyumsuzluk ile ayrılmış iki farklı havza dolgusu, daha yaşlı dolgunun deformasyon türü ve doğrultu atımlı fay karakterindeki aktif havza kenarı fayları gibi veriler Mahmudiye-Çifteler-Emirdağ havzasının üzerlemiş havza özelliğinde olduğunu yansıtmaktadır.

Anahtar Sözcükler: Kaymaz, İnönü-Eskişehir Fay Sistemi, Mahmudiye-Çifteler-Emirdağ havzası

Introduction

Turkey, with its unique geological position and large tectonic structures, can be regarded as a natural laboratory. It owes its shape and structure to several neotectonic regimes which are operating side by side and interacting with each other throughout Turkey. Therefore, the whole of Turkey can be regarded as a Neotectonic region (Koçyiğit 2009). It has been divided into several sub-neotectonic provinces, one of which is central Anatolia. The initiation time of the neotectonic regime varies from place to place. In general, it is accepted that it started in the Late Pliocene (Koçyiğit *et al.* 2001). However, there are several views on the character of the tectonic regime affecting this region in the neotectonic period. According to some workers, the neotectonic regime controlling central Anatolia is compressional (Boray *et al.* 1985; Barka *et al.* 1995). Others have suggested that the western and eastern parts of central Anatolia are being deformed by both tensional and compressional types of neotectonic regime, respectively (Koçyiğit 1984; Koçyiğit & Beyhan 1998; Koçyiğit *et al.* 2000a). Koçyiğit (2009) divided Turkey into five different neotectonic provinces: the Black Sea-Caucasus contractional neotectonic province; the central to North Aegean strike slip neotectonic province; the Northeast to Southeast Anatolian strike-slip neotectonic province; the Southwest Turkey extensional neotectonic province and the Cyprus-South Aegean neotectonic province characterized by active subduction (Figure 1). In terms of plate tectonics, the Anatolian block is bordered to the north by the dextral strike-slip North Anatolian Fault System, to the east by the sinistral strike-slip East Anatolian and the Dead Sea fault systems, by the Aegean shear zone to the west, and the Cyprus subduction zone to the south. In addition to these main structures, the sinistral Central Anatolian Fault System, the dextral Tuzgölü Fault Zone and Eskişehir Fault System, and the west Anatolian graben-horst system are other neotectonic structural elements which shape the Anatolian block (Dirik & Göncüoğlu 1996; Koçyiğit & Beyhan 1998; Dirik 2001; Dirik & Erol 2003; Koçyiğit 2003, 2009; Koçyiğit & Özacar 2003).

Based on the active tectonic regimes and related structures in the Central Anatolian neotectonic province, the İnönü-Eskişehir Fault System (İEFS)

appears to be one of the important neotectonic elements. It runs from Uludağ (Bursa) in the west to Tuzgölü in the east, and separates the southwestern Anatolian extensional province from the northern and eastern Anatolian compressional provinces. It is an active zone of deformation 400 km long and 15–25 km wide, characterized by dextral strike-slip faulting with a considerable normal slip component (Bozkurt 2001; Koçyiğit 2003, 2009). The İEFS is composed of WNW–ESE-trending oblique-slip normal faults, NW–SE-trending right-lateral strike-slip faults and NE–SW-trending left-lateral strike-slip faults. On a regional scale, the İEFS was first studied and mapped by Koçyiğit (1984). The part of İEFS between Uludağ (Bursa) in the west and Sivrihisar in the east was named the Eskişehir fault (McKenzie 1972; Okay 1984; Şengör *et al.* 1985; Barka *et al.* 1995). The Eskişehir fault was then renamed by Şaroğlu *et al.* (1987) the Eskişehir-Bursa fault zone and divided into several sections, such as the İnönü-Dodurga fault zone, Eskişehir fault zone and the Kaymaz fault zone. All these sub-sections were later combined by Altunel and Barka (1998) and renamed the Eskişehir Fault Zone. Some workers (Yaltırak *et al.* 1998; Sakıncı *et al.* 1999) have also interpreted the Eskişehir fault zone as the southeastern extension of the Thrace fault zone, and renamed it as the Thrace-Eskişehir fault zone. Dirik & Erol (2003) stated that the Eskişehir fault zone is probably connected to the Ilıca, Yeniceoba and Cihanbeyli fault zones, which affect the western part of the Tuzgölü basin, and included all these zones within the Eskişehir-Sultanhanı Fault System. The fault planes of this system are well-displayed in the town of İnönü, and so it was called the İnönü-Eskişehir fault zone by Koçyiğit & Özacar (2003). Recently, Özsayın & Dirik (2007) and Koçyiğit (2009) reported that this zone of deformation extends further southeast as far as the southeast of Karapınar County, and renamed it the İnönü-Eskişehir Fault System.

The Mahmudiye-Çifteler-Emirdağ basin is another important structural element of the İEFS. This NW–SE-trending depression is a pull-apart basin about 85 km long and 25 km wide. In terms of neotectonics and seismicity, the Mahmudiye-Çifteler-Emirdağ basin and the segmentation of the İEFS around Kaymaz are the least investigated areas and topics in central Anatolia (Figure 2). Available information

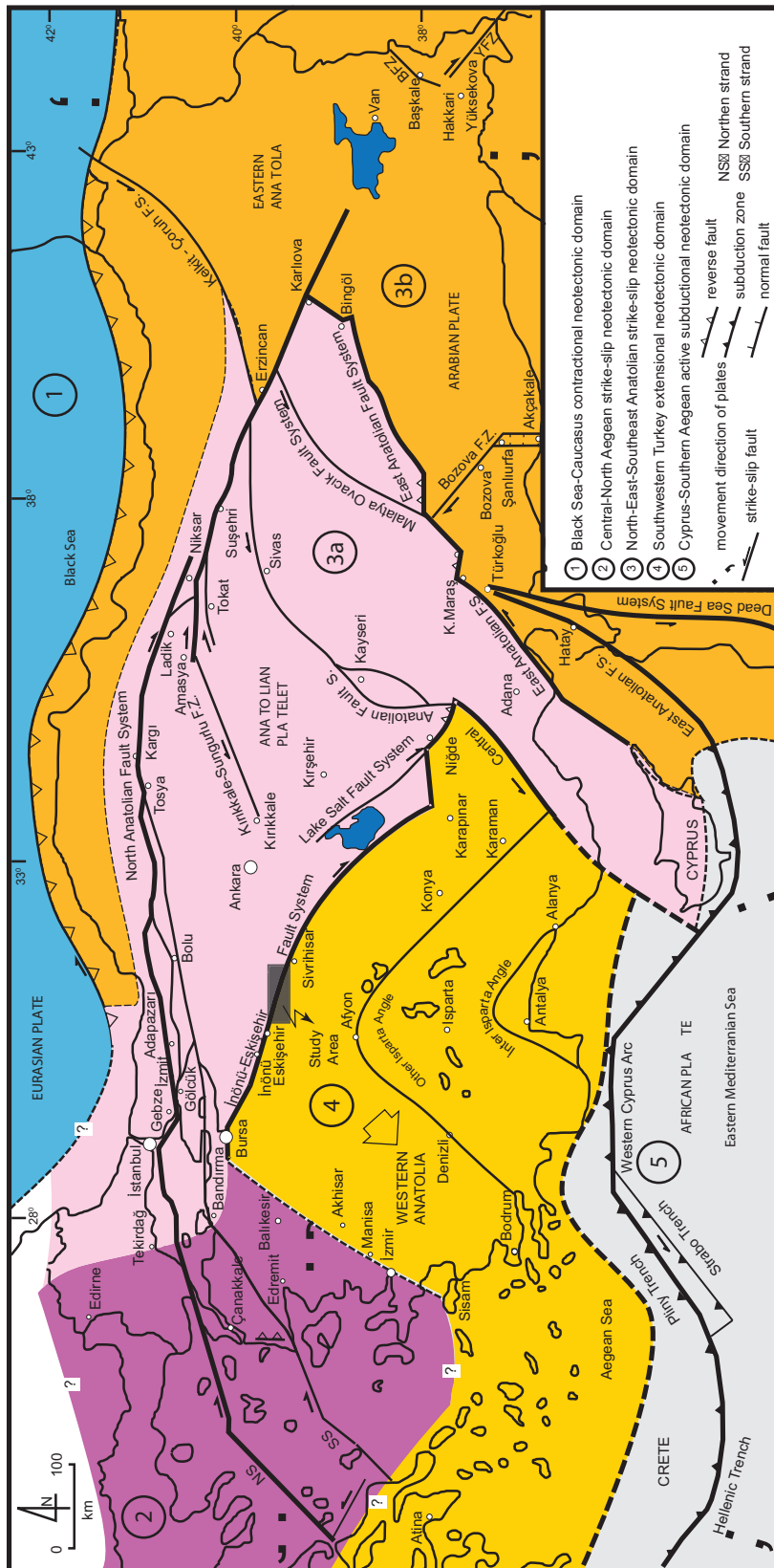


Figure 1. Simplified map showing the neotectonic subdivision of Turkey and its surroundings (Kocyiğit 2009).

about this area is little more than indications of the locations of earthquakes recorded on the map of Turkey. Furthermore, recently published data on the neotectonics and seismicity of Turkey, particularly for central Anatolia, are general approaches, and lack the tangible data required for a detailed neotectonic interpretation (Baran & Gökten 1996, 1999; Koçyiğit 2009; Koçyiğit *et al.* 2000; Gökten *et al.* 2003). Although segments of the Eskişehir fault zone in the study area have been specified (Şaroğlu *et al.* 1987; Koçyiğit 2003), details of these segments and other structures in the study area are missing.

During late Pliocene–Recent time, central Anatolia has been slowly deformed (at >20 cm/yr) under two diverse cogenetic neotectonic regimes (Reilinger *et al.* 1997, 2006). Recent GPS studies indicate that there are velocity differences between the east and west parts of central Anatolia, and that deformation in this region is not uniform. The region is being deformed under a compressional regime in the east and an extensional regime in the west (Aktuğ *et al.* 2009). The deformation rate along the İEFS was found from GPS measurements to be 0.15 mm/yr.

The rate in the western sector is 0.1 ustrain/yr and sharply falls to 0.02 ustrain/yr in the east (Kahle *et al.* 1998). Based on geological observations, Koçyiğit (2000) suggested a deformation rate of 0.07–0.13 mm/yr for this system. However, recent dating of terrace deposits yielded 1 mm/yr (Ocakoglu 2007; Ocakoglu & Açikalin 2009).

The İEFS, extending from Uludağ (Bursa) in the west to east of Tuzgölü, played an important role in the tectonic evolution of central Anatolia (Figure 1). This fault system is one of the structural elements formed in association with a compressional regime that influenced the whole of Anatolia in the late Oligocene–early Miocene (Yaltırak *et al.* 1998; Sakıncı *et al.* 1999; Yaltırak 2002). The part of this system in Thrace was activated in the late Oligocene–early Miocene and was cut and displaced dextrally by about 100 km by the North Anatolian Fault System during the Late Miocene–early Pliocene (Okay 2009; Yaltırak *et al.* 1998, 2002; Sakıncı *et al.* 1999). It is also suggested that the system continues towards Thrace characterized by right-lateral slip as a result of pure shearing during the Late Miocene–early Pliocene

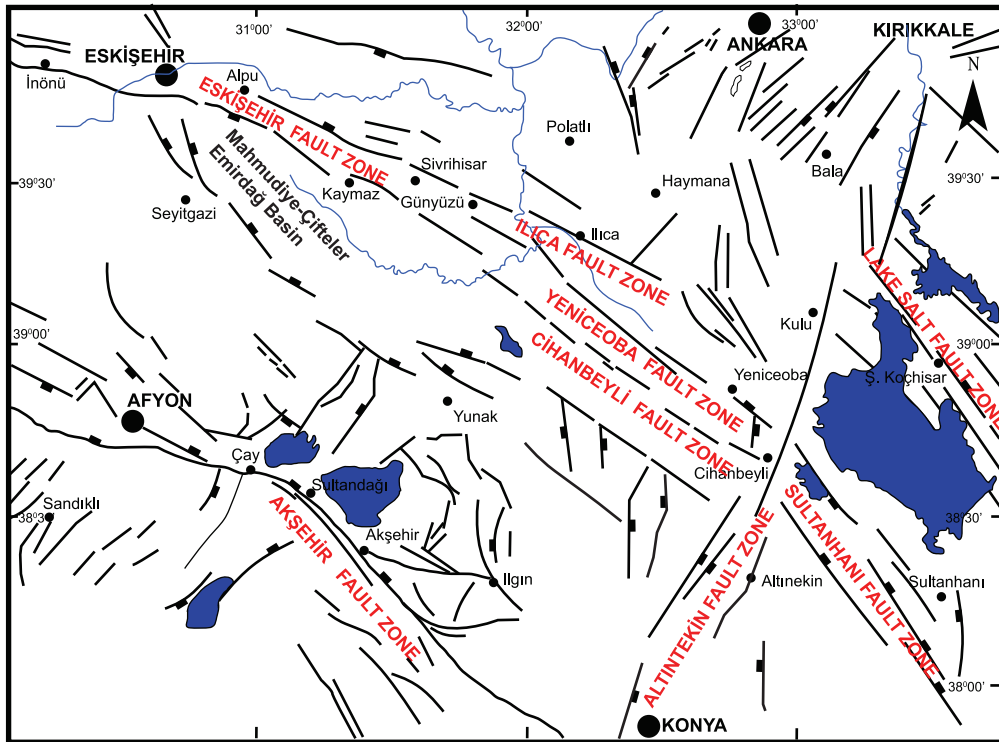


Figure 2. Tectonic map of Central Anatolia and its surroundings (Dirik & Göncüoğlu 1996; Göncüoğlu *et al.* 1996; Dirik 2001; Dirik & Erol 2003; Koçyiğit & Özacar 2003).

(Yaltırak *et al.* 1998; Sakınç *et al.* 1999; Yaltırak 2002; Okay 2009). Recent studies on upper Pliocene–lower Quaternary deposits along the İEFS show that vertical slip in these sediments is around 200 m and fluvial conglomerates deposited by the Porsuk River appear to be elevated by 400 m with respect to the base level of the recent river channel (Koçyiğit 2003). The EFZ is quite a young continental structure and it displays a vertical slip of more than 100 m where it cuts the fluvial sequence of Villafranchian age (post early Pliocene–post early Pleistocene) (Ocakoglu & Açıkalin 2009). Evaluation of available data reveals that the İnönü-Eskişehir Fault System has been active since the Pliocene (Altunel & Barka 1998; Koçyiğit 2003). Recent studies of this system, which is thought to extend towards Thrace, show that the fault is dextral strike-slip, with a normal component (Koçyiğit 2003, 2009; Ocakoglu & Akan 2003; Tokay & Altunel 2005; Ocakoglu *et al.* 2006; Ocakoglu & Açıkalin 2009; Okay 2009).

Based on the literature mentioned above and newly-gathered detailed field data, the present paper aims to explain and interpret: (a) various neotectonic properties of the Yörükkaracaören-Sivrihisar section of the İnönü-Eskişehir Fault System, and (b) the role of the İEFS in the evolutionary history of the Mahmudiye-Çifteler-Emirdağ pull-apart basin.

Stratigraphy

Based on age and lithological to stratigraphical relationships, rocks exposed in the study area were examined under three headings: (1) pre-Miocene rocks, (2) Miocene palaeotectonic basin fill, and (3) neotectonic basin fill (Figure 3). Pre-Miocene rocks are composed of Mesozoic metasedimentary rocks, granitoids, ophiolitic mélangé, and Ilerdian (lower Eocene) shallow marine limestones. Upper Miocene lacustrine limestones are the palaeotectonic basin infill and they overlie the older rocks with angular unconformity. The neotectonic infill is composed of the upper Pliocene–Pleistocene Ilıcabaşı Formation, Holocene fluvial deposits, travertine and alluvial fan deposits (Figure 3).

Older Rocks

Mesozoic and Cenozoic units comprise the basement in the study area. The oldest unit in the region is a

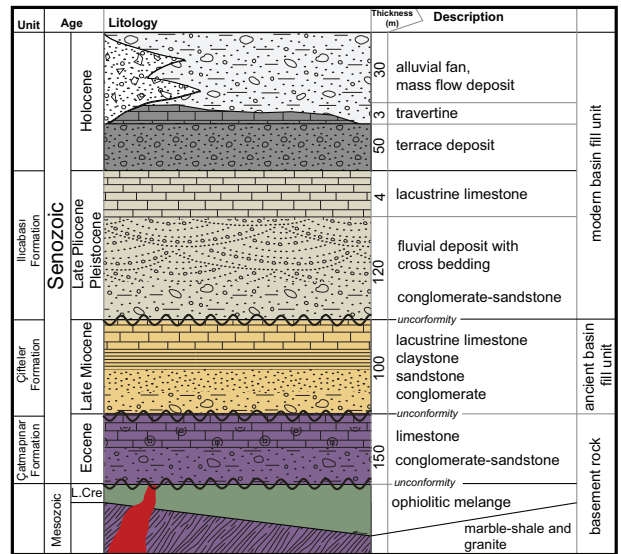


Figure 3. Generalized stratigraphic column of the study area.

marble-schist alternation, which is the product of HP/LT metamorphism of Mesozoic age (Okay 1984; Göncüoğlu *et al.* 2000) (Figure 4). It is extensively exposed along both margins of the Mahmudiye-Çifteler-Emirdağ basin. North of the İEFS, this metasedimentary sequence is cut by granitoids of possible Eocene age. Ophiolitic mélangé, represented mostly by radiolarite and serpentinite, is in tectonic contact with the metasedimentary rocks. The Ilerdian (lower Eocene) Çatmapınar Formation, consisting of nummulite-bearing marine carbonates, rests on the erosional surface of the metamorphic sequence and is widely exposed at the southwest margin of the Mahmudiye-Çifteler-Emirdağ basin (Figure 4).

Palaeotectonic Infill

The Upper Miocene lacustrine limestones (Çifteler Formation) comprise older, deformed basin infill of the Mahmudiye-Çifteler-Emirdağ basin. In the study area the Çifteler Formation is represented by a sandstone-limestone alternation 100 m thick. It is extensively exposed along both sides of the Sakarya River (Figure 4). It also occurs in well-exposed sequences in the area between Sakaryabaşı and Hayruye villages in steep cliffs 15–20 m high on the southern bank of the Sakarya River. Tightly carbonate-cemented, cross-bedded fine-grained sandstones occur at the base, overlain by lacustrine

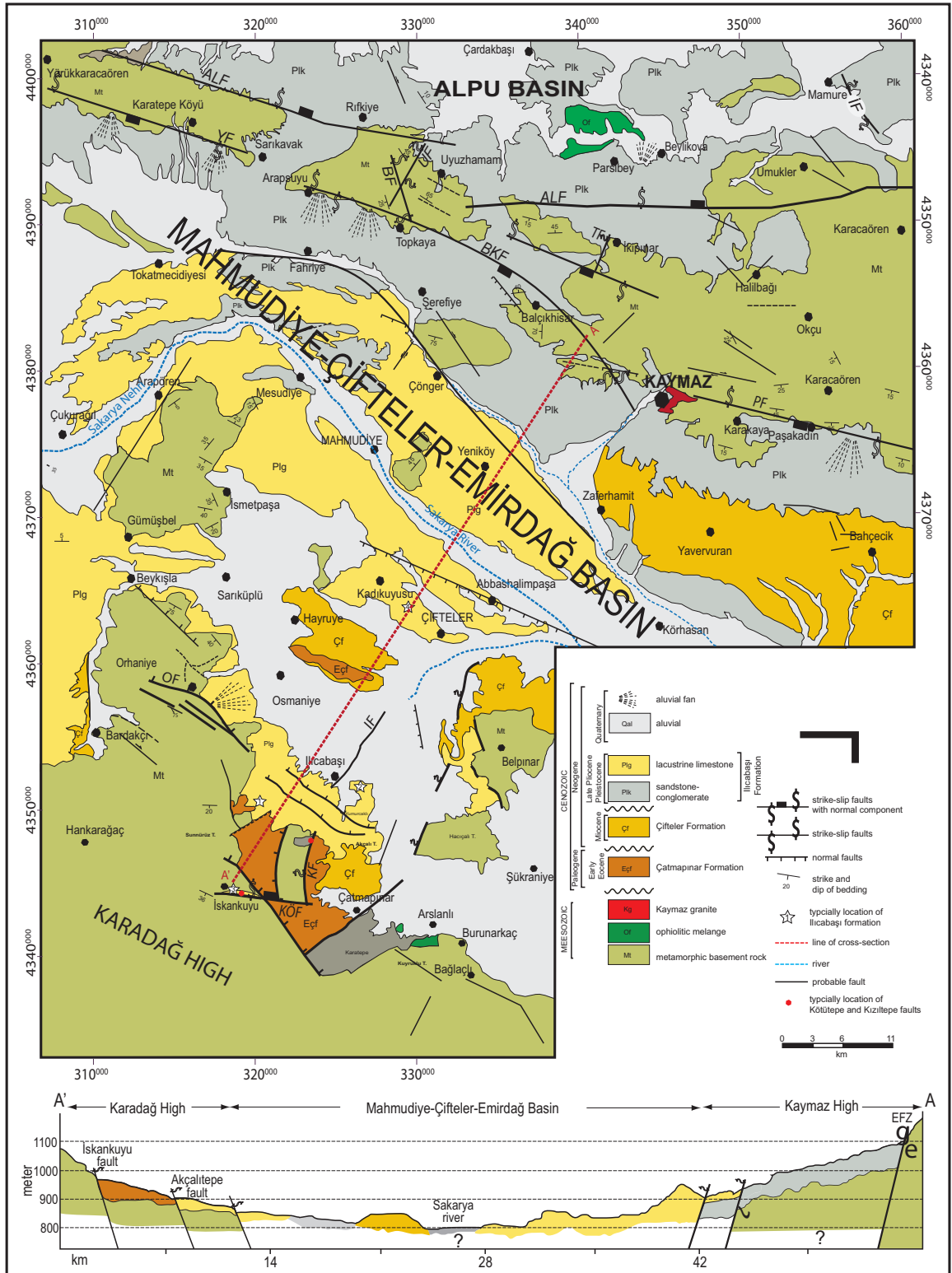


Figure 4. Geological map of the study area. Geological cross-section along the line A-A' YF- Yörükkaracaören fault, BKF- Bardakçı-Kaymaz fault, PF- Paşakadın fault, TF- Tepecik fault, BF- Bardakçı fault, UF- Uyuzhamam fault, ALF- Alpu fault, IF- İncecik fault, OF- Orhaniye fault, KÖF- Kötepe fault, KF- Kızıltepe fault.

white, laminated, thin- to medium-bedded nodular limestones up to 30 m thick. The thin laminations indicate seasonal changes.

Neotectonic Infill

The upper Pliocene–Pleistocene Ilıcabaşı Formation, Holocene alluvium, fan, and fluvial deposits comprise the young, undeformed infill of the basin. The Ilıcabaşı Formation, which has a key role in understanding the geological evolution of the Mahmudiye–Çifteler–Emirdağ basin, crops out extensively (Figure 4). Localities of type sequences of the formation are the eastern flanks of Karadağ hill (Figure 4, No. 1), south of Ilıcabaşı village (No. 2), east of İskankuyu village (No. 3) and north of Çifteler town (No. 4).

The control of the EFZ on the sedimentation of the Ilıcabaşı Formation is clearly seen. The Ilıcabaşı formation is represented by coarser clastics and swamp deposits in the northern and southern parts in the study area. However, its pebbly fluvial system associated with a fine-grained (flood plain and lacustrine) facies is developed at the centre of the basin (Figure 5a). The lacustrine limestones are particularly prominent in the central part of the basin. The Ilıcabaşı Formation, which is the lowest facies of the neotectonic infill, is composed of materials derived from all surrounding rocks. Its mudstone-carbonate alternation is observed in the northern part of Çifteler. The sequence around

Kaymaz, further north, is characterized by a basal fluvial conglomerate-mudstone alternation, overlain by thin lacustrine limestones up to the top (Figure 5b). Southwest of Belpınar village, a thin level of lacustrine limestone rests on Mesozoic marble with angular unconformity. Southwest of Çifteler, gentle hills are covered by a brittle carbonate deposition. Mammalian fossils such as *Mimomys sp.*, *Canis sp.*, *Vulpes sp.*, *Gazella borbonica*, cf. *Leptobos sp.* identified within the Ilıcabaşı Formation yield a Late Pliocene–Pleistocene age (Saraç 2003).

Alluvial fan deposits in different parts of the study area are generally developed in association with fault morphology. Fans consist mostly of non-cemented or weakly cemented, angular, poorly sorted ophiolite, marble, and granite pebbles, ranging from 2 to 30 cm across. Fans are seen along the western margin of the Mahmudiye–Çifteler–Emirdağ basin, at the southern edges of the Kaymaz uplift from Kaymaz to Sivrihisar, and at the southern edges of the Alpu basin. The alluvial fans developed at the southern margin of the Alpu basin (in the north of the investigated area) are characterized by abundant ophiolite-derived pebbles and gravels, and they seem to be raised from the basin floor (Figure 6a).

Holocene travertines are local occurrences within the fault zones in the study area (Figure 6b). The Uyuzhamam travertine, formed in association with secondary structures in the Alpu Fault Zone, is the most important travertine occurrence in

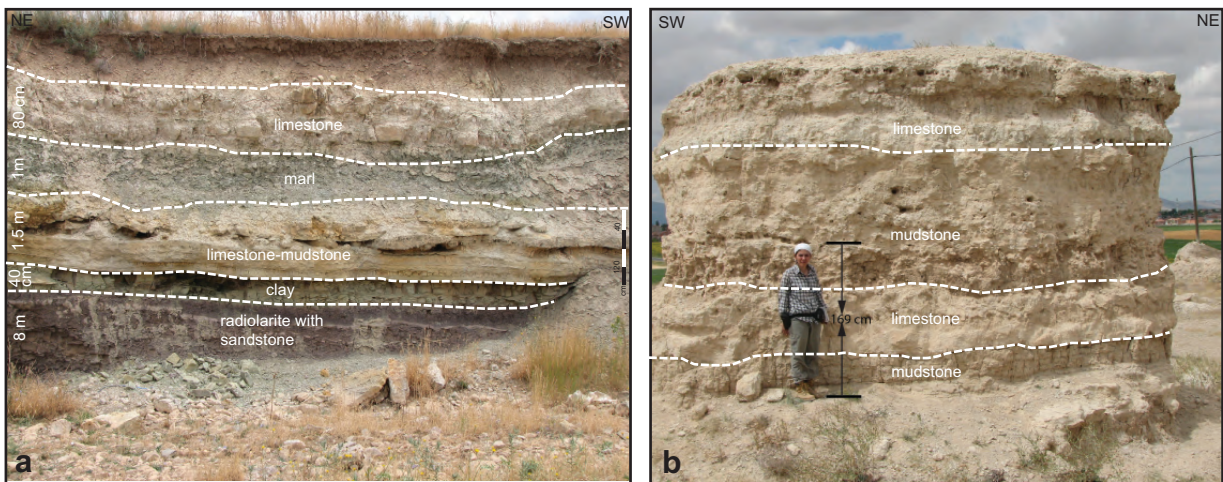


Figure 5. Close-up views of sedimentary successions comprising the Ilıcabaşı formation exposed in the southern (a) and central parts (b) of the basin.

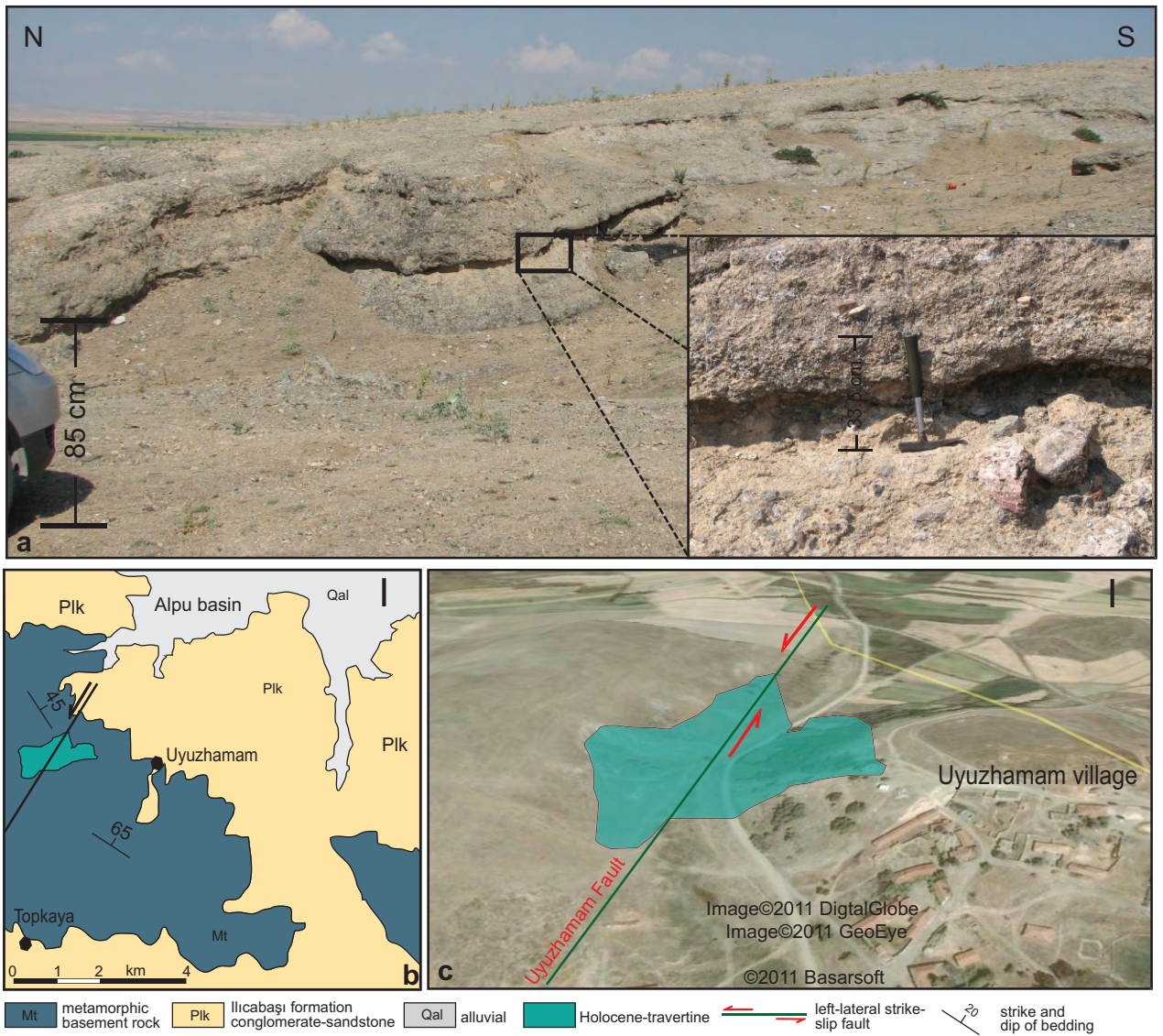


Figure 6. (a) Close-up view of the alluvial fan exposed along the southern margin of the Alpu basin, (b) Geological map of Uyuzhamam village and its neighborhood, and (c) Google Earth image showing recent travertine occurrences.

the investigated area (Figure 6c). Travertines were precipitated from the CaCO_3 -rich water emerging as springs along the left-lateral NE-SW-trending strike-slip Uyuzhamam fault. The old travertine occurrences form quite thick levels on the western block of the fault, but travertine precipitation still continues on the eastern block.

Structural Geology

The İnönü-Eskişehir Fault System was significant in the tectonic evolutionary history of Central Anatolia.

The segmentation of this fault zone around Kaymaz occurred in three different zones. They are, from north to south, the Alpu Fault Zone, the Eskişehir Fault Zone and the Orhaniye Fault Zone. Palaeostress analyses were made by the use of slip vectors measured on the fault slickensides. These analyses are based on a stress-shearing relation developed by Wallace (1951) and Bott (1959). If the slip vector on each slickenside is in the same direction of effective resolved shear stress (Bott 1959), the most suitable stress tensor can be computed from inverse resolving of measured slip vectors (Carey 1974; Angelier 1984).

Angelier's direct inversion method, one of the most frequently used methods in inversion solutions, is based on functions established by a mathematical approach. This technique, using the fault properties, enables calculation of principal stress vectors and F ratio. These properties include character, strike, and dip of the fault and the striae orientations.

Eskişehir Fault Zone (EFZ)

This fault zone is characterized by right-lateral strike-slip faulting with a considerable normal slip component. It extends from Uludağ (Bursa) in the west to Sivrihisar in the east. In the study area, the EFZ trends N25°W from Yörükkaracaören to Kaymaz, where the fault zone significantly shifts to the left and is traceable to Sivrihisar trending about N70°W. Around Sivrihisar, the fault turns to an E–W direction and continues to Yenimehmetli, where it becomes indistinct among young sediments (Figure 2). In the study area, the EFZ has three different segments: the Yörükkaracaören segment (YF), the Bardakçı-Kaymaz segment (BKF), and the Paşakadın segment (PF) (Figures 4 & 7). Along these segments, the EFZ cuts Mesozoic marbles and tectonically juxtaposes them with young units. Furthermore, fault terraces, hanging alluvial fans, morphotectonic

structures, and several kinematic data on the fault slickenside were also observed.

Kinematic data found on the Bardakçı-Kaymaz and Paşakadın segments reveal the character of the fault zone. The Bardakçı-Kaymaz segment is a N25°W-trending right-lateral strike-slip fault, with a normal component, 28 km long (Figures 7 & 8). Along its length, the fault cuts Mesozoic marbles and juxtaposes them with Pleistocene alluvial fan deposits (Figure 4). The kinematic character of this segment was determined by field observations conducted along the full extent of the fault. Hanging fan deposits, offsets in river channels and brecciation are also recorded. Fourteen measurements were taken from fault planes, striae, and deviation angles at three stations along the Bardakçı-Kaymaz segment (Stations 1a, 1b & 2) (Figure 7, Table 1). For palaeostress analysis, the numeric method developed by Angelier (1990, 1994) was used. The palaeostress analyses indicated a localized compression in a NW–SE direction and accordingly a NE–SW-trending extension (Figure 9).

In the study area, the third segment of the Eskişehir Fault Zone is the Paşakadın fault (PF). It steps over to the left around Kaymaz and then extends up to Sivrihisar (Figure 7). The 16-km-long,

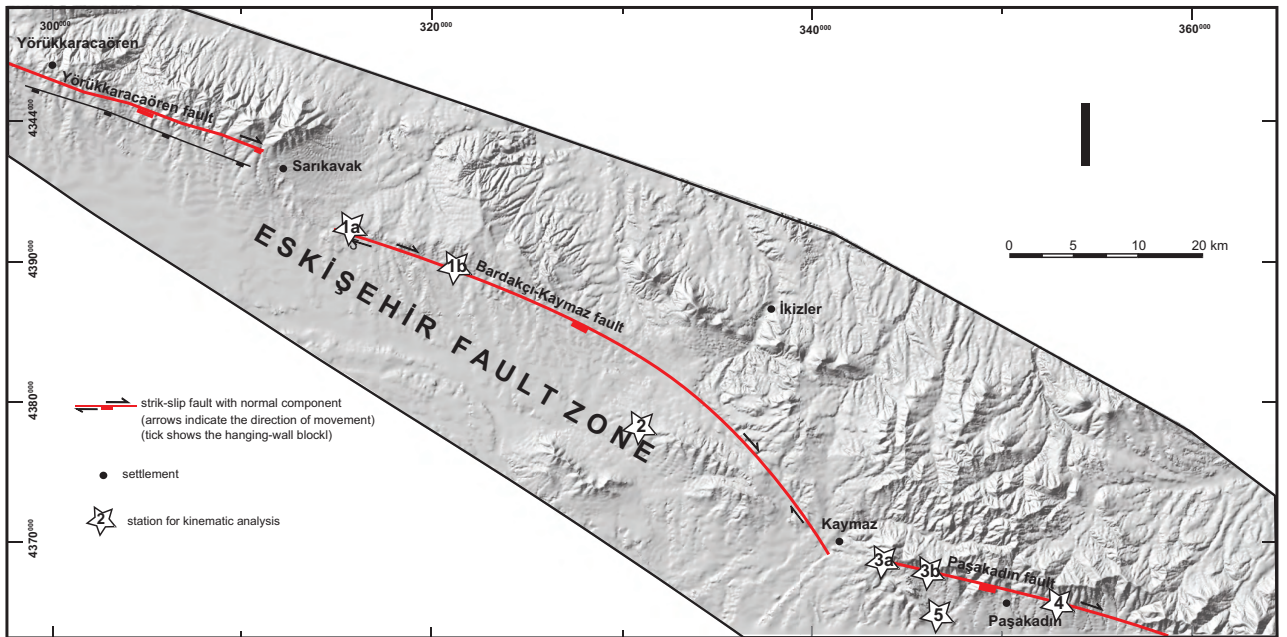


Figure 7. Digital elevation map (DEM) of the Eskişehir Fault Zone.

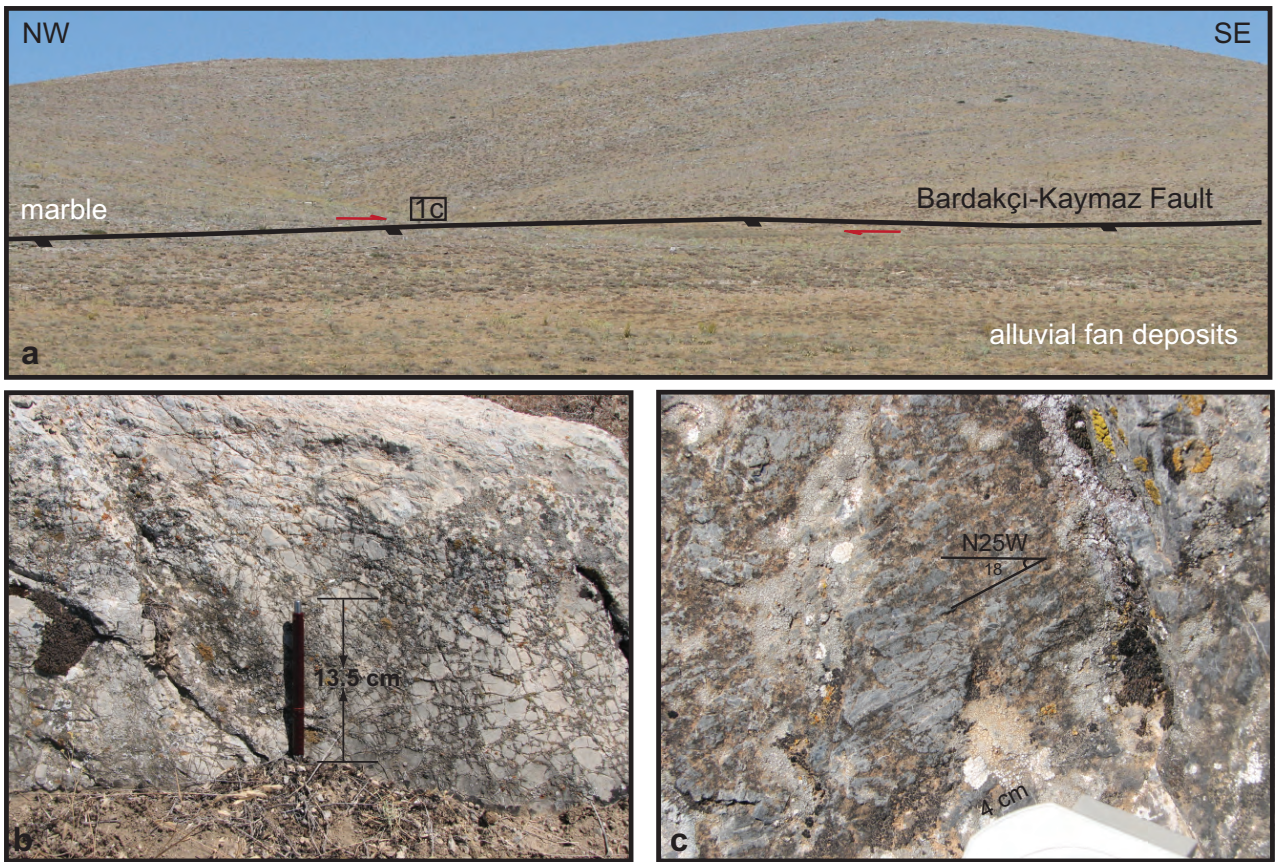


Figure 8. (a) General view of the Bardakçı-Kaymaz fault around Balçıkhisar village, (b) close-up view of the fault breccia in the Sürtopraklık river, and (c) close-up view of the Bardakçı-Kaymaz fault fault slickensides.

N85°W-trending and 65°SW-dipping Paşakadın fault is a right-lateral strike-slip fault with a normal component (Figure 10). It cuts Mesozoic marbles and juxtaposes them with well-cemented alluvial fan deposits. The Paşakadın fault displays some well-developed slickensides in places, on which striae with pitches reaching up to 85° were recorded. They indicate that the dip-slip component changes in places and can be significant (Figure 10). A southward-facing fault escarpment and right-lateral displacements of 200–750 m were measured in the fault-controlled Kocaoğlankaya creek and other southward flowing creeks. These observations indicate that the Paşakadın fault first moved as a dip-slip normal fault, and then as a dextral strike-slip fault. Thirteen measurements were taken from fault slickensides, striae, and deviation angles at three stations along the Paşakadın segment (Station points

3a 3b, 4 & 5) (Figure 7, Table 1). The palaeostress analyses indicate localized NW–SE compression and hence a NE–SW-trending extension (Figure 9).

Alpu Fault Zone (AFZ)

This is another area of active deformation, shaping both the Alpu basin and the Kaymaz uplift. The Alpu, Tepecik (TF), Uyuzhamam (UF), Bardakçı (BF), and İncecik (IF) faults are the main structural components of the Alpu Fault Zone (Figure 11).

The Alpu fault bounds the southern margin of the Alpu Neogene basin (Figure 11). The fault trends ESE from Ağapınar village in the west to the Beylikova region further east. It can be traced as far as Sivrihisar. Further east around Beylikova, it sidesteps. The Alpu fault is characterized by a steep fault scarp and aligned alluvial fans along its foot,

Table 1. Slip-plane data measured from the Eskişehir fault zone and kinematic analysis.

Station	No	Strike (°N)	Dip amount (°)	Rake (°)	Principal Stress Axes	F
1a	1	330	55S	18W	$\sigma_1 = 337^\circ/23^\circ$ $\sigma_2 = 181^\circ/67^\circ$ $\sigma_3 = 076^\circ/02^\circ$	0.527
	2	325	75S	05W		
	3	320	60S	08W		
	4	315	70S	15W		
1b	1	300	45W	70W	$\sigma_1 = 339^\circ/78^\circ$ $\sigma_2 = 140^\circ/11^\circ$ $\sigma_3 = 231^\circ/04^\circ$	0.191
	2	320	55W	75W		
	3	315	50W	80W		
	4	300	50W	75W		
2	1	310	65S	70W	$\sigma_1 = 138^\circ/07^\circ$ $\sigma_2 = 20^\circ/76^\circ$ $\sigma_3 = 230^\circ/12^\circ$	0.524
	2	310	65S	65W		
	3	310	65S	45W		
	4	285	70S	01W		
	5	285	65S	05W		
3a	1	300	85S	80W	$\sigma_1 = 357^\circ/67^\circ$ $\sigma_2 = 126^\circ/15^\circ$ $\sigma_3 = 221^\circ/17^\circ$	0.103
	2	330	65S	75W		
	3	295	78S	82W		
	4	303	76S	62W		
3b	1	150	65S	08W	$\sigma_1 = 357^\circ/07^\circ$ $\sigma_2 = 157^\circ/83^\circ$ $\sigma_3 = 265^\circ/09^\circ$	0.101
	2	320	66S	18W		
4	1	326	85S	25W	$\sigma_1 = 005^\circ/63^\circ$ $\sigma_2 = 186^\circ/27^\circ$ $\sigma_3 = 096^\circ/01^\circ$	0.346
	2	300	89S	01W		
	3	290	50S	89W		
	4	100	85S	89W		
	5	110	75S	80W		
5	1	290	78S	89W	$\sigma_1 = 045^\circ/63^\circ$ $\sigma_2 = 138^\circ/02^\circ$ $\sigma_3 = 229^\circ/29^\circ$	0.342
	2	300	85S	89W		

which have been raised from the basin floor. It is exposed in particular north of Parsipey village and around Beylikova, where significant evidence of the faulting was obtained.

The Tepecik fault (TF), another fault in the Alpu fault zone, is located along the southern edge of the Kaymaz structural high and controls it (Figure 11). The N80°W-trending and 45°SW-dipping Tepecik fault is 13 km long and locally displays well-preserved fault slickensides (6 & 7 in Figure 11). Rakes of slickenlines on the fault slickensides range between 20–30°, revealing the strike-slip nature of the Tepecik fault. Stereographic plots of slip-plane data measured

on these fault slickensides also indicate that the Tepecik fault is a dextral strike-slip fault (Figure 12, Table 2). It cuts the Mesozoic marble-schist alternation and displays a linear fault trace (Figure 13a). A steep fault scarp, sudden break in slope, offset stream beds (e.g., the Kuruçay River, Selvatpınar stream and Kocaoğlankaya River beds) and strips of cataclasites are other morphotectonic criteria for the recognition of the Tepecik fault (Figure 13b).

The Uyuzhamam fault (UF), located between Esenler village to the north and Uyuzhamam village to the south (Figures 4 & 11) trends N25°E, dips at 60° to 85°S and is 8 km long. It is one of the most

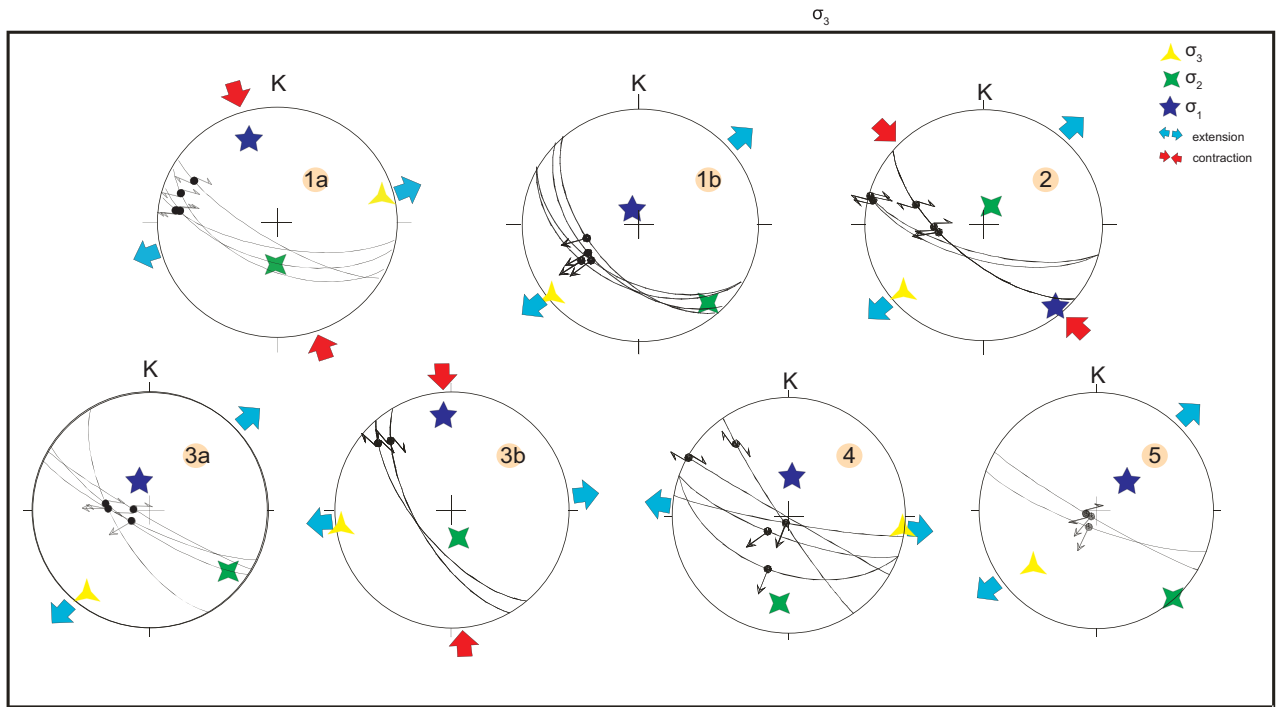


Figure 9. Stereographic plots of slip-plane data measured on slickensides of faults comprising the Eskişehir Fault Zone (1a, 1b and 2 belong to the Bardakçı-Kaymaz fault; 3a, 3b, 4 and 5 belong to the Paşakadın fault).

significant structures controlling the evolution of the study area. The motion took along the Uyuzhamamı fault is recorded on Mesozoic marbles cut by the fault (Figure 14a). Four different rake values were measured on slip planes of this fault. The first two of them are 52°NE and 72°NE (Figure 14b, c), revealing that the Uyuzhamamı fault was an oblique-slip normal fault at the first stage of faulting. The last two rakes on fault slickensides are younger than the others, measure 32°S and 18°N, and indicate the subsequent sinistral strike-slip movement of the Uyuzhamamı fault. The stereographic plot of the slip-plane data measured on the Uyuzhamamı fault slickensides indicates local NW–SE extension in the Alpu area (9 in Figure 12).

The NNW-trending, steeply dipping (75–85°N) and 8 km long Bardakçı fault (BF) is a right-lateral strike-slip fault with considerable dip-slip component. It is located in Bardakçı village and is conjugate to the Uyuzhamamı fault (Figure 11). The Bardakçı fault cuts Mesozoic marbles intruded by granites (Figure 13d). It displays three sets of superimposed slickenlines which indicate that it has

experienced different phases of motion during its development history (8 in Figure 11 and Figure 14e). These are, in turn, rakes of 50°NNW, 55°SW and 38°SE measured on the Bardakçı fault slickensides. The first and second phases of motions are indicated by the rakes of 50° NNW and 55° SW, which indicate the oblique-slip nature of the fault, i.e., the fault became an oblique-slip normal fault during the first two phases of deformation. The third and youngest phase of motion is indicated by the rake of 38° SE, which implies a dextral strike-slip motion of the fault (8 in Figure 12).

The İncecik fault (İF) is a fault segment 6 km long which trend NW and dips steeply SW. Located ENE of Beylikova in the Alpu basin (Figure 11), it cuts Pleistocene fluvial red clastics and displays well-developed and preserved slickensides including slickenlines with the rakes ranging between 01° and 38° (10 in Figure 11; Figure 15a, b). Stereographic plots of slip-plane data on the Schmidt lower hemisphere net indicate that the İncecik fault is a dextral strike-slip fault developed by an approximately N–S compressive principal stress (10 in Figure 12).

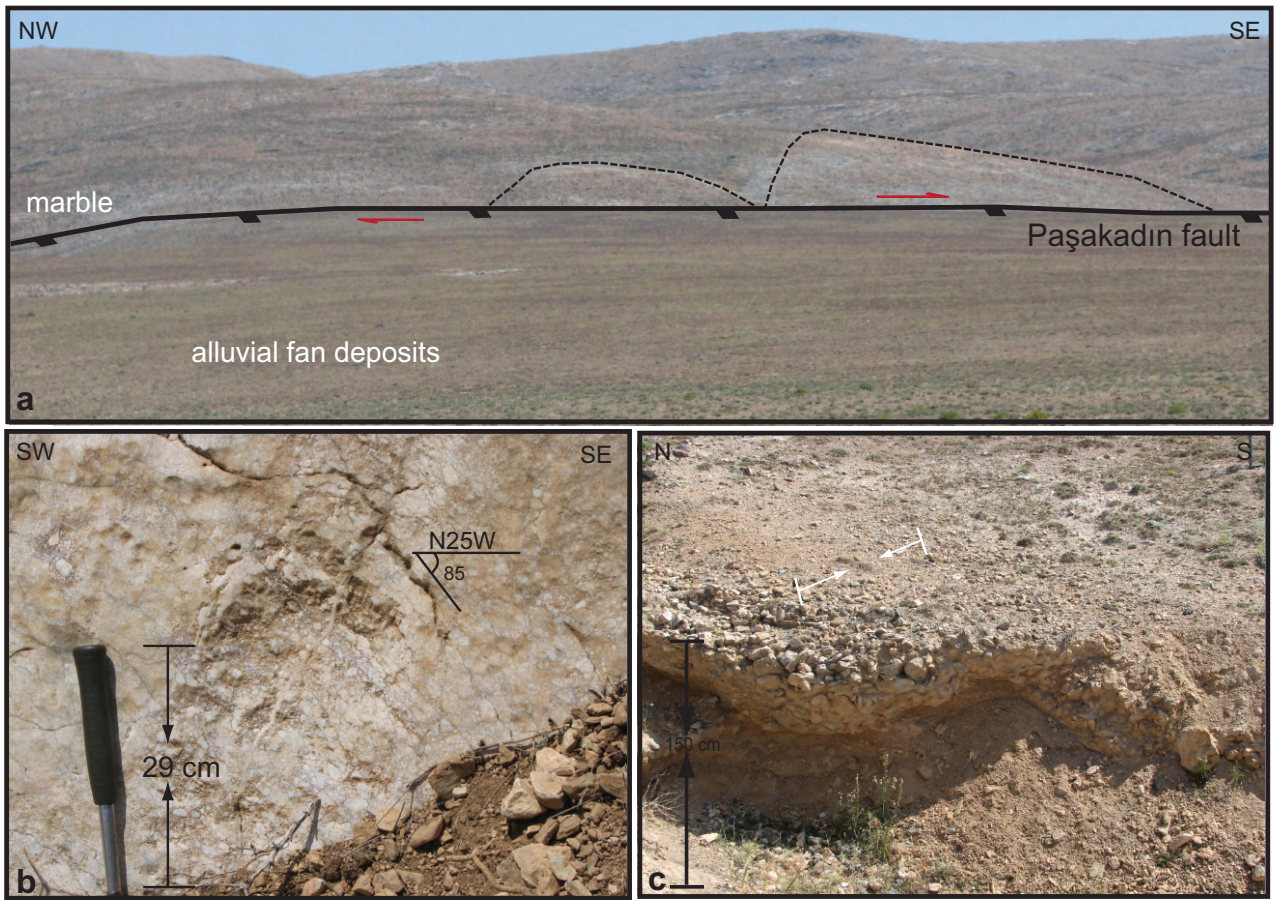


Figure 10. (a) General view of the Paşakadın fault scarp and triangular facets along it, (b) close-up view of the fault slickensides, and (c) the alluvial fan developed along the Paşakadın fault.

Orhaniye Fault Zone (OFZ)

The bounding faults along the south-southwestern margin of the Çifteler-Mahmudiye-Emirdağ basin are here termed the Orhaniye fault zone (Figure 4). It is a NW-trending zone of deformation about 13 km wide and 43 km long, located between Beykışla in the northwest and Arslanlı in the southeast. It consists of numerous structural fault segments of dissimilar trend, length, dip amount and directions, including the Orhaniye, Sakaryabaşı, İskankuyu, Akçalıtepe, Ilıcabaşı, Kötütepe and Kızılkaya faults. Among them, the Orhaniye fault (OF), the Kötütepe (KÖF) and the Kızılkaya faults (KF) are younger ones and well-exposed. These three faults have a key role on the south-southwestern margin of the basin and hence are described in more detail below.

The Orhaniye fault is an oblique-slip normal fault about 15 km long, trending N70°W and dipping

north (38° to 50°) located near Orhaniye settlement (Figure 4). It cuts and tectonically juxtaposes both Mesozoic marbles and upper Pliocene–Pleistocene lacustrine limestones (Figure 16a, b). A line of cold water springs and dense vegetation mark the trace of the fault, which displays well-preserved slickensides in places (Figure 16 c). The slip-plane data measured on slickensides and their stereographic plots on the Schmidt lower hemisphere net indicate that the Orhaniye fault is an oblique-slip normal fault with a considerable strike-slip component (11 in Figure 17, Table 3).

The Kötütepe fault (KÖF), which is an oblique-slip normal fault approximately 10 km long, trending WNW and dipping steeply north (65°), is exposed around İskankuyu village (Figure 4). It cuts and tectonically juxtaposes Mesozoic marble, the lower Eocene Çatmapınar formation and the upper

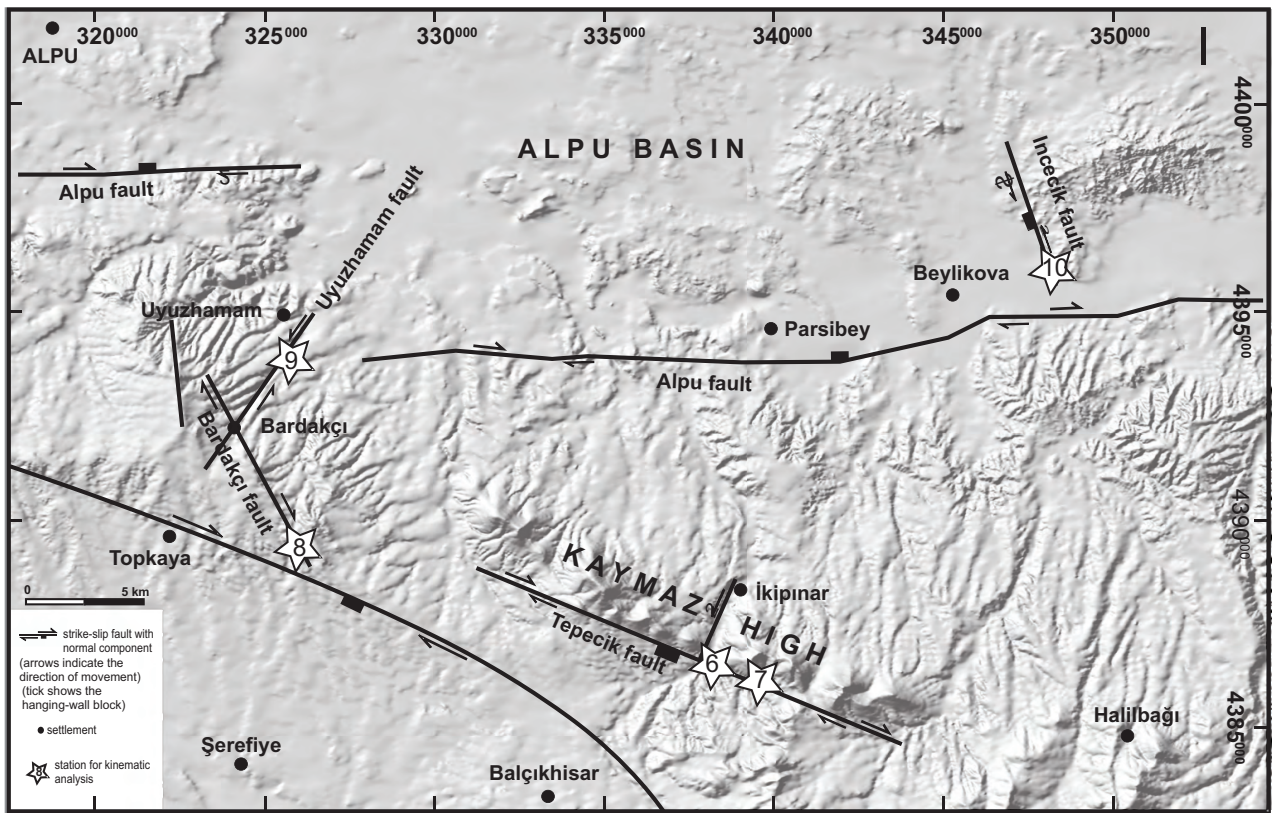


Figure 11. Digital elevation map (DEM) showing faults comprising the Alpu Fault Zone.

Pliocene–Pleistocene Ilıcabaşı formation (Figure 18a). It displays well-preserved slickensides in places (Figure 18b). The slip-plane data measured on the fault slickensides and their stereographic plots on the Schmidt lower hemisphere net indicate that the Kötütepe fault is an oblique-slip normal fault (12 in Figure 17).

The Kızıltepe fault (KF), a sinistral strike-slip fault with a dip-slip normal component approximately 7 km long, trending N–S and dipping west steeply (65°), is exposed on the southern slope of Kızıltepe Hill (Figure 4). The Kızıltepe fault cuts and tectonically juxtaposes Mesozoic marble, the lower Eocene Çatmapınar formation and the upper Pliocene–Pleistocene Ilıcabaşı formation (Figure 4). The well-developed and preserved fault slickensides along the faulted contact between the marble and the Pleistocene deposits can be seen for a distance of 1.5 km (Figure 18c–e). The slip-plane data measured on the fault slickensides and their stereographic plots on the Schmidt lower hemisphere net indicate that the Kızıltepe fault is a sinistral strike-slip fault formed

during a N–S-directed principal stress (13 in Figure 17).

Neotectonic Development of the Mahmudiye-Çifteler-Emirdağ Basin

The neotectonic regime in central Anatolia began after the early Pliocene (Koçyiğit *et al.* 2001). Since then, the eastern half of central Anatolia has been deforming under a compressional neotectonic regime (Koçyiğit 1984; Koçyiğit & Beyhan 1998; Koçyiğit *et al.* 2000, 2001). The N25°W-trending Mahmudiye-Çifteler-Emirdağ basin is an important pull-apart basin developing under the control of this neotectonic regime with its related strike-slip faults. The Mahmudiye-Çifteler-Emirdağ basin is a 25-km-wide, 100-km-long depression with two basin infills separated by an intervening angular unconformity (Figure 19).

The upper Miocene older, deformed basin infill (Çifteler Formation) is exposed in the central and western parts of the Mahmudiye-Çifteler-Emirdağ

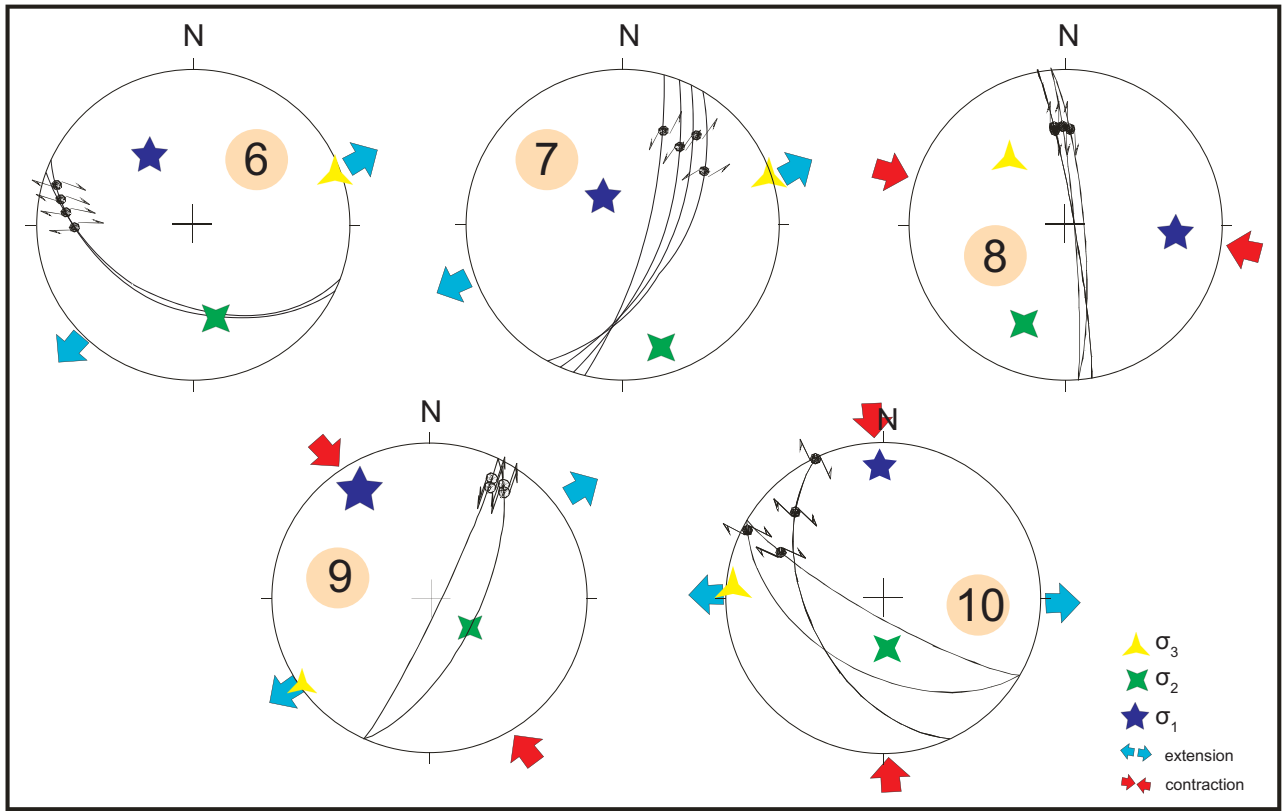


Figure 12. Stereographic plots of slip-plane data measured on fault slickensides of faults comprising the Alpu Fault Zone (6 & 7 on the Tepecik fault, 8 on the Bardakçı Fault, 9 on the Uyuzhamam Fault, and 10 on the İncecik Fault).

Table 2. Slip-plane data measured from the Alpu fault zone and kinematic analysis.

Station	No	Strike (°N)	Dip amount (°)	Rake (°)	Principal Stress Axes	F
6	1	290	45S	20W	$\sigma_1 = 337^\circ/65^\circ$ $\sigma_2 = 170^\circ/21^\circ$ $\sigma_3 = 074^\circ/06^\circ$	0.444
	2	290	45S	30W		
	3	295	45S	10W		
	4	295	45S	15W		
7	1	015	78E	35N	$\sigma_1 = 327^\circ/71^\circ$ $\sigma_2 = 162^\circ/19^\circ$ $\sigma_3 = 071^\circ/05^\circ$	0.770
	2	025	65E	30N		
	3	020	70E	40N		
	4	030	60E	45N		
8	1	175	85E	38S	$\sigma_1 = 098^\circ/28^\circ$ $\sigma_2 = 204^\circ/29^\circ$ $\sigma_3 = 303^\circ/38^\circ$	0.289
	2	180	85E	30S		
	3	172	88E	55S		
	4	178	82E	50S		
9	1	025	85S	18N	$\sigma_1 = 326^\circ/14^\circ$ $\sigma_2 = 138^\circ/58^\circ$ $\sigma_3 = 233^\circ/04^\circ$	0.613
	2	025	85S	15N		
	3	025	85S	20N		
	4	025	65S	18N		
10	1	155	50W	01W	$\sigma_1 = 357^\circ/26^\circ$ $\sigma_2 = 175^\circ/64^\circ$ $\sigma_3 = 266^\circ/01^\circ$	0.253
	2	155	45W	10W		
	3	300	50W	30W		
	4	300	85W	38W		
	5	300	75W	20W		

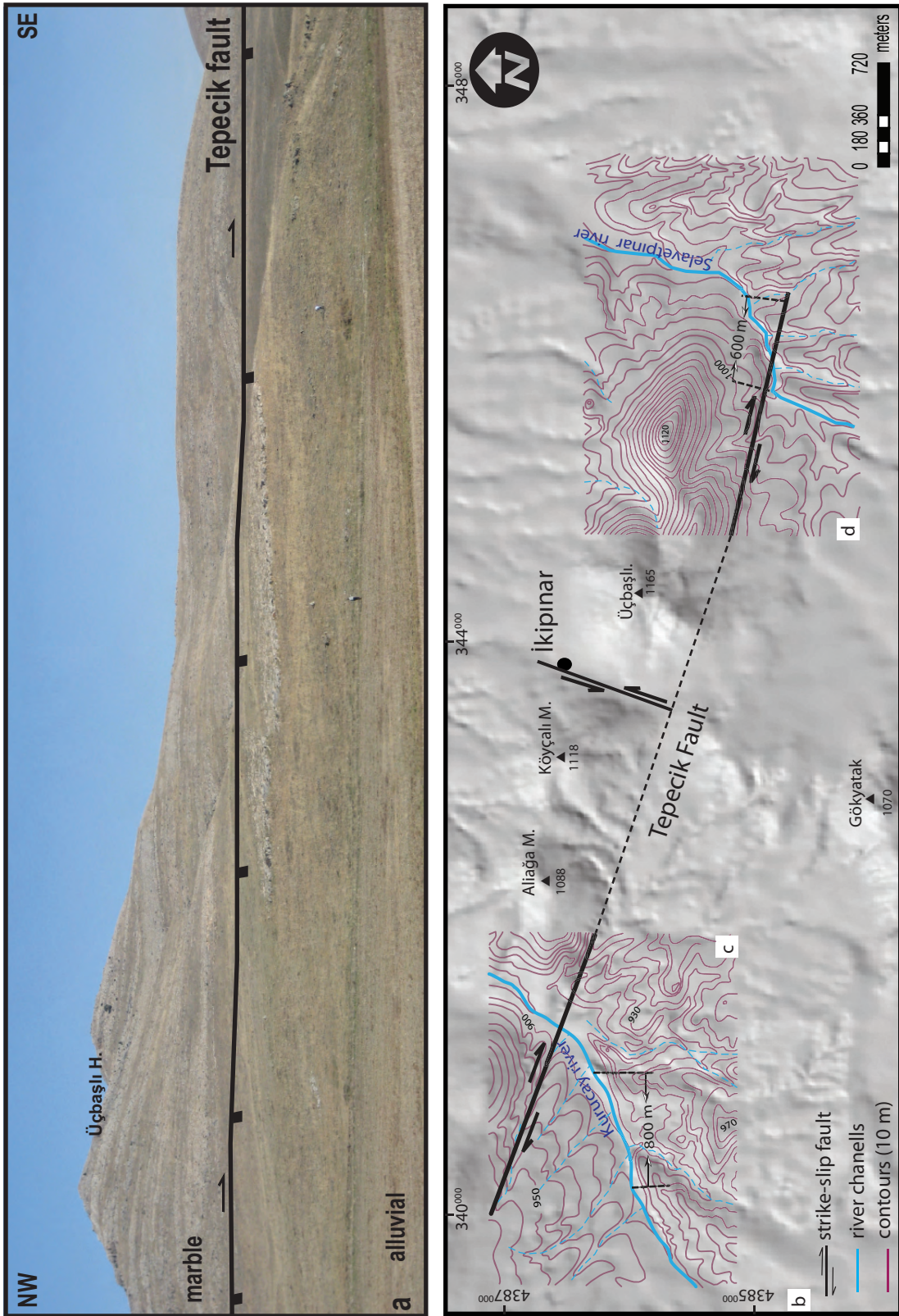


Figure 13. (a) Field photograph showing the right lateral strike-slip Tepecik fault with normal component; (b) Some morphotectonic features observed along the Tepecik Fault (e.g. the Kuruçay River and Selvatpınar stream are cut and offset dextrally by the Tepecik fault by up to 800 m and 600 m respectively).

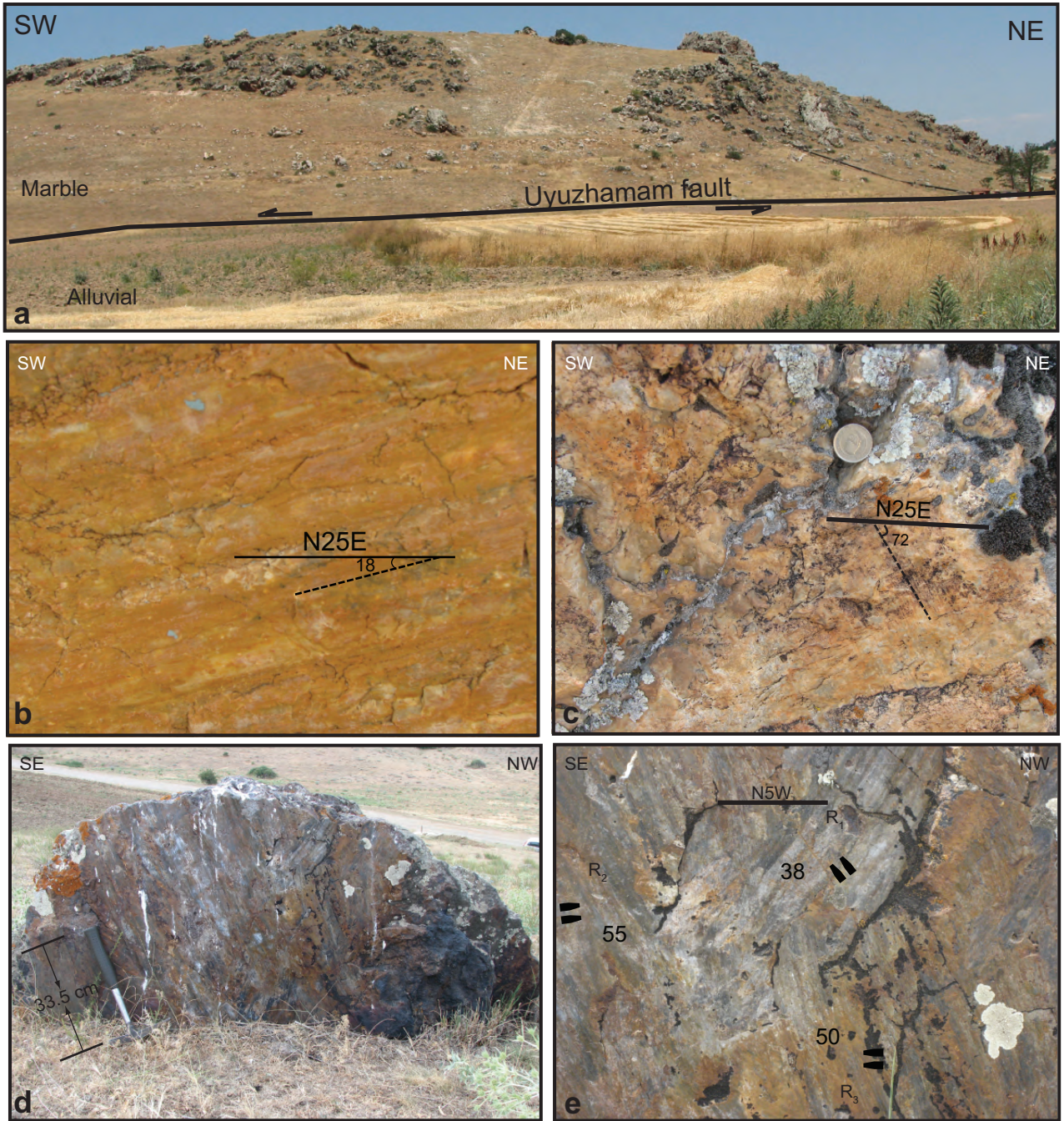


Figure 14. (a) General view of the Uyuzhamam fault cutting Mesozoic marbles, (b) and (c) are close-up views of the Uyuzhamam fault slickensides, (d) view of the Bardakçı fault plane, and (e) close-up view of the Bardakçı fault slickensides with three overprinted slickenlines indicating three phases of motion along the Bardakçı fault.

basin. It consists of a sandstone-limestone alternation deposited in a fluvio-lacustrine setting. The Çifteler Formation has been elevated, dissected into blocks and became an erosional source area for the younger

basin infill (Ilıcabaşı Formation) just before its deposition. The lower part of the Plio-Quaternary Ilıcabaşı Formation comprises conglomerates containing pebbles derived directly from the

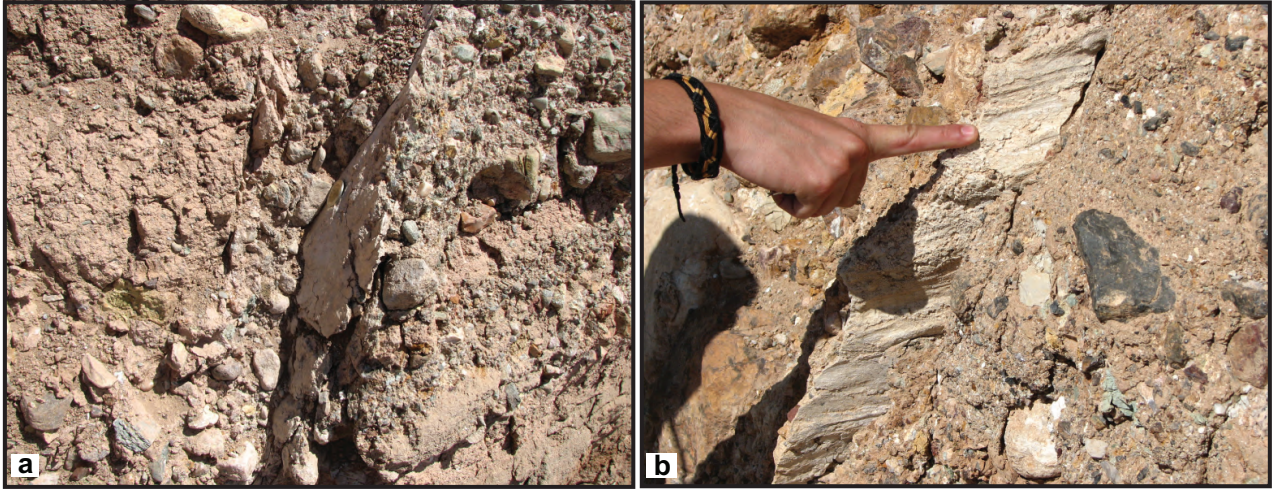


Figure 15. Alpu Fault Zone; (a, b) close-up views of the fault slickensides with nearly horizontal slickenlines.



Figure 16. (a) General view of the Orhaniye fault along which Mesozoic marbles are tectonically juxtaposed with the upper Pliocene–Pleistocene Ilıcabaşı Formation, (b) close-up view of intensely deformed (folded) marble, and (c) close-up view of the Orhaniye fault slickensides.

underlying older and deformed Çifteler Formation. These younger and undeformed (almost horizontal) basin infill (neotectonic infill) basal conglomerates grade up into sandstones which are then succeeded by a sandstone and limestone alternation deposited in a

lacustrine environment. The presence of two different basin infills, separated by an angular unconformity and the style of tilting and folding of the older basin infill all indicate the superimposed character of the Mahmudiye-Çifteler-Emirdağ strike-slip basin.

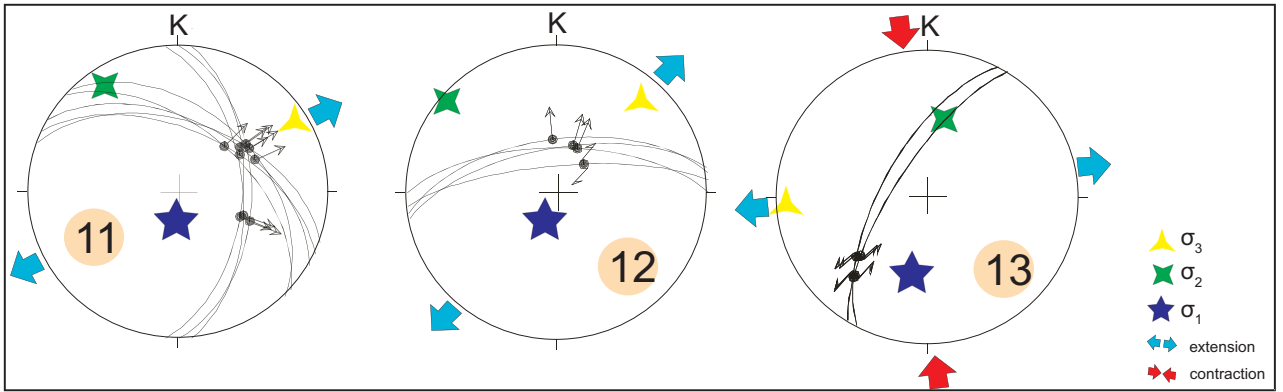


Figure 17. Stereographic plots of slip-plane data measured on slickensides of the faults comprising the Orhaniye Fault Zone (11 on the Orhaniye fault, 12 on the Kötütepe fault, and 13 on the Kızıltepe Fault).

Table 3. Slip-plane data measured from the Orhaniye fault zone and kinematic analysis.

Station	No	Strike (°N)	Dip amount (°)	Rake (°)	Principal Stress Axes	F
11	1	290	50N	65S	$\sigma_1 = 185^\circ/74^\circ$ $\sigma_2 = 326^\circ/13^\circ$ $\sigma_3 = 048^\circ/10^\circ$	0.196
	2	180	50E	75S		
	3	300	50N	75S		
	4	315	44N	84S		
	5	312	54N	89S		
	6	300	50N	65S		
	7	295	55N	75S		
	8	175	55E	75S		
	9	185	55E	80S		
12	1	085	75N	75E	$\sigma_1 = 204/72^\circ$ $\sigma_2 = 310/05^\circ$ $\sigma_3 = 041^\circ/17^\circ$	0.373
	2	090	65N	80E		
	3	080	65N	78E		
	4	082	60N	89E		
13	1	028	65W	30S	$\sigma_1 = 171^\circ/34^\circ$, $\sigma_2 = 001^\circ/46^\circ$ $\sigma_3 = 261^\circ/00^\circ$	0.315
	2	032	72W	42S		

The Orhaniye, İskankuyu and Kötütepe faults, which affected the development of the Mahmudiye-Çifteler-Emirdağ basin during late Pliocene–early post-Pleistocene time, influenced the deposition of the Ilıcabaşı Formation. The basin deepened and water level in the environment was gradually raised owing to the motion along these faults. This is also indicated by the sequence characteristics of the Ilıcabaşı Formation, such as basal clastics and overlying lacustrine carbonates, which reveal that the fluvial conditions prevailing early in the basin evolution, were later supplanted by lacustrine conditions. The Plio–Quaternary basin development

and its sedimentation were also controlled by the Sakaryabaşı fault set, the Akçalı tepe fault, and the Kızılkaya fault. These faults have produced 0.11 mm/yr of deformation at the basin margins in Plio–Quaternary time, occurring along the step-like normal faults comprising the northwestern hanging wall blocks, where the elevation of the basin floor is 900 m above sea level. The dip-slip amounts, which do not exceed 10 m for each fault, decrease in a zone close to the bounding faults due to the bending of hanging-wall blocks. These faults become listric at depth.

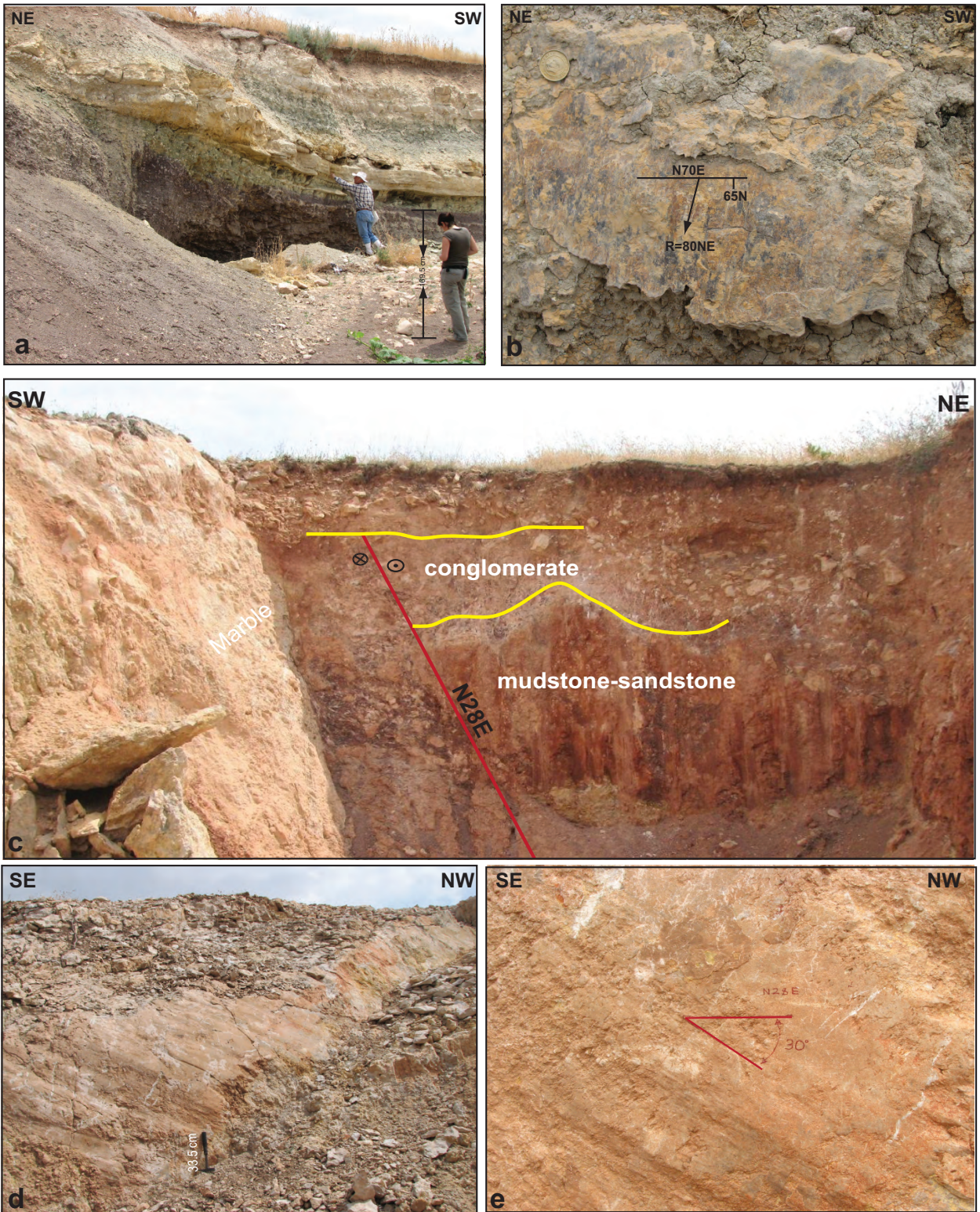


Figure 18. (a) Close-up view of the upper Pliocene–Pleistocene lacustrine and swamp deposits of Ilıcabaşı formation, (b) close-up view of the Kötütepe fault slickensides, (c) close-up view of the faulted contact (Kızıltepe fault) between Mesozoic marble and Pleistocene deposits, and (d, e) close-up views of the Kızıltepe fault slickensides.

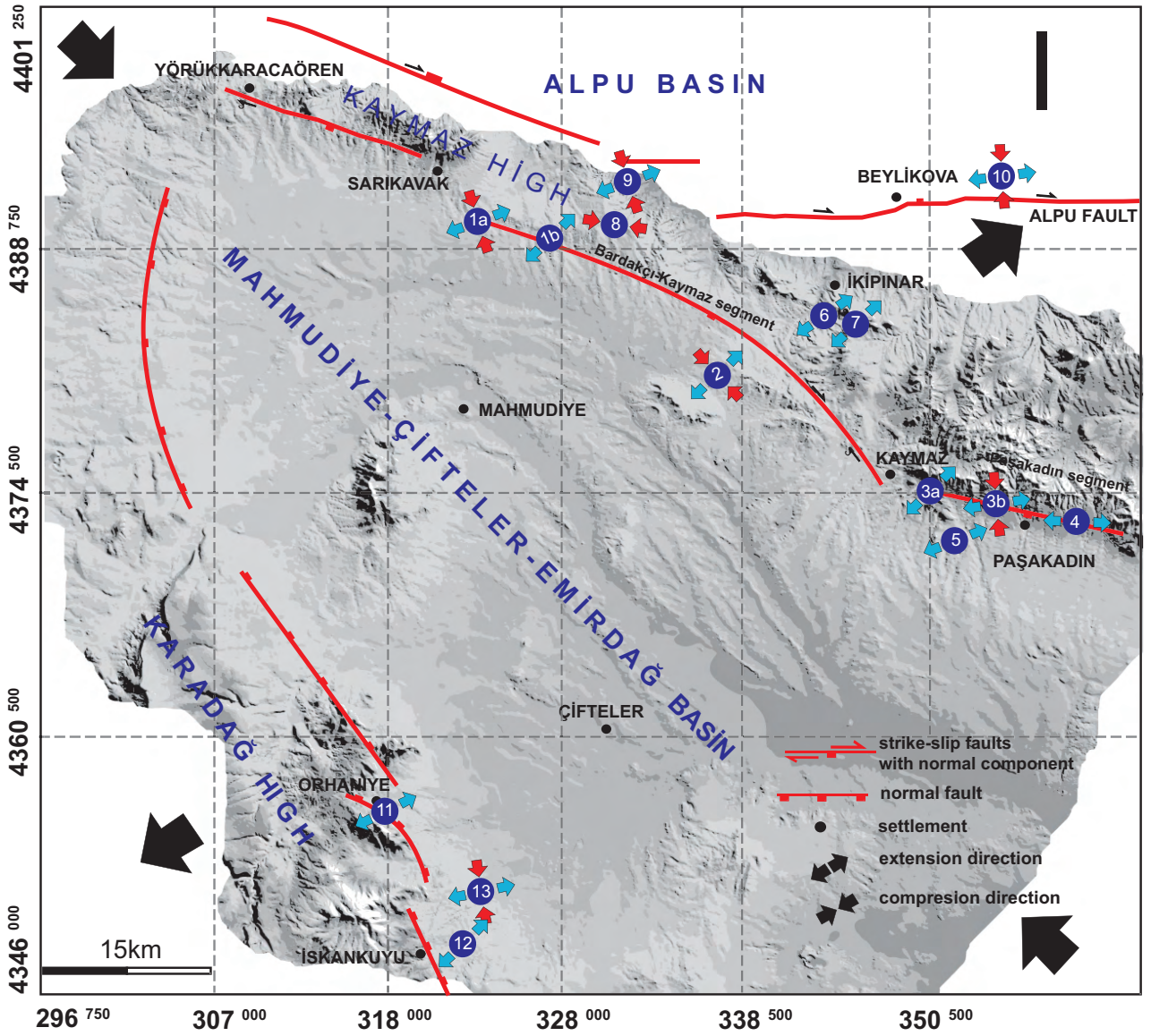


Figure 19. DEM showing general outline of the Mahmudiye-Çifteler-Emirdağ basin. Numbers 1 through 13 are sites of fault slickensides (large red and blue arrows indicate local compression and extension directions respectively).

Southeast of the Çifteler-Mahmudiye-Emirdağ basin, the Yeniceoba and Cihanbeyli fault zones run parallel to the general trend of the İnönü-Eskişehir Fault System. In general, on earlier neotectonic maps of the region, the Yeniceoba and Cihanbeyli fault zones are shown to be the eastward continuation of the İnönü-Eskişehir Fault Zone (Koçyiğit 1991; Koçyiğit *et al.* 1995; Dirik & Göncüoğlu 1996; Dirik 2001; Dirik & Erol 2003; Koçyiğit & Özacar 2003). However, we observed that the Yeniceoba and the

Cihanbeyli fault zones are located further south and are connected to the İnönü-Eskişehir Fault Zone by an intervening transfer fault trending NNW-SSE along the Çıralıözü creek to the east of the study area, as seen in the Ankara sheet of the 1/500,000 scale geological map of Turkey (Erentöz 1963). Consequently, these two fault zones do not extend to the southern end of the Çifteler-Mahmudiye-Emirdağ basin. However, they have a significant role in the development of basins in southern Central

Anatolia. Their possible influence on basins will be described in the chapter of discussion, below.

Discussion and Conclusions

Detailed field studies have been carried out on the Yeniceoba, Cihanbeyli, and Sultanhanı sections of the İnönü-Eskişehir Fault System (Özsayın & Dirik 2007; Akıl 2008; Koçyiğit 2009). Although some previous studies also dealt with the general characteristics of the İnönü-Eskişehir Fault System (Şaroğlu 1987; Barka *et al.* 1995; Koçyiğit *et al.* 2000), detailed structural analysis of the segments comprising the İEFS around Kaymaz Town has not been previously attempted. Based on detailed field geological mapping carried out around Kaymaz, it has been determined that the İEFS is composed of three fault zones: the Alpu (AFZ), Eskişehir (EFZ) and Orhaniye fault zones (OFZ). Differing ideas about the character of the EFZ have been proposed: (1) it is a normal fault with strike-slip component (Yaltırak 2002), and (2) it is a strike-slip fault system with considerable amount of normal component (Koçyiğit 2005). However, in the the present study, it was also determined that the EFZ is a right-lateral strike-slip fault with a normal component. Localized compressional occurs along the EFZ around Kaymaz Town due to the 1.5-km-long left step-over. The strain rate along the EFZ, at 1–2 mm/y (Altunel & Barka 1998), is also significant with regard to earthquake prediction. Koçyiğit (2005) suggested a vertical displacement of 0.07–0.13 mm/yr along the zone, and a strain rate of 1 mm/yr along the EFZ was determined by Ocakoğlu & Açıkalın (2009). In the present study, based on both the late Pliocene–Pleistocene (Saraç 2003) age of basin infill and the right-lateral offsets (125 to 750 m) observed and measured along the stream beds, a strain-rate of 0.44 mm/yr has been calculated. Palaeostress analyses of slip-plane data measured along the Bardakçı Uyuzhamam and Alpu faults which comprise the EFZ indicate a NNW–SSE principal compressive stress has been operating.

The Mahmudiye-Çifteler-Emirdağ basin, previously described as the Çifteler-Akgöl graben (Koçyiğit 2003), is one of the most significant structural components of the İEFS. The western part of this basin is controlled by dip-slip and oblique-slip normal faults, trending NW–SE in the studied

area. They control Pleistocene clastics and lacustrine carbonates accumulated in the basin. Some other faults occurring along the margins of the basin cut the lacustrine carbonates comprising the upper horizons of the Ilıcınar Formation. Two basin infills separated by an intervening angular unconformity and the tilted to folded deformation pattern of older infill reveal an episodic evolutionary history for the Mahmudiye-Çifteler-Emirdağ basin.

The study area is being currently governed by a compressional NNW–SSE-directed stress. The field data indicate that the Yörükkaracaören and the Bardakçı-Kaymaz segments of the Eskişehir Fault Zone are right-lateral strike-slip faults with a normal dip-slip component active during the Plio–Quaternary neotectonic period. The Paşakadın fault caused a localized compressional area owing to the left stepping-over near Kaymaz. The difference in strain-rates along the bounding faults may have played a key role in the development of the Mahmudiye-Çifteler-Emirdağ basin. In general, the long axis of this parallelogram-shaped basin extends NE–SW. The Yeniceoba and the Cihanbeyli fault zones are shown to be the southeastern continuation of the İEFS on the previous neotectonic map of the region (Dirik 1991; Koçyiğit 1991; Koçyiğit *et al.* 1995; Dirik & Göncüoğlu 1996; Dirik & Erol 2003; Koçyiğit & Özacar 2003). However, these two fault zones are connected to the EFZ by an intervening and NNW–SSE-trending transverse structure in the far east of the study area, and thus they only indirectly affect the southeast section of the Mahmudiye-Çifteler-Emirdağ basin (Figure 20). Consequently, the basin does not fit the classical geometry of the pull-apart basins developed along the short step-overs of strike-slip faults (Mann *et al.* 1983). Parallel right-lateral strike-slip faults occur in the north and south of the region but the dip-slip and the oblique-slip normal faults trend NW–SE and control the western part of the basin. They fit well with the classical pattern or geometry of pull-apart basins. In this frame, both the E–W active stretching and the young strike-slip fault-controlled sedimentation in the study area can be attributed to a current pull-apart mechanism in the region. As a result, we propose that the Mahmudiye-Çifteler-Emirdağ basin can be kinematically considered as a pull-apart basin.

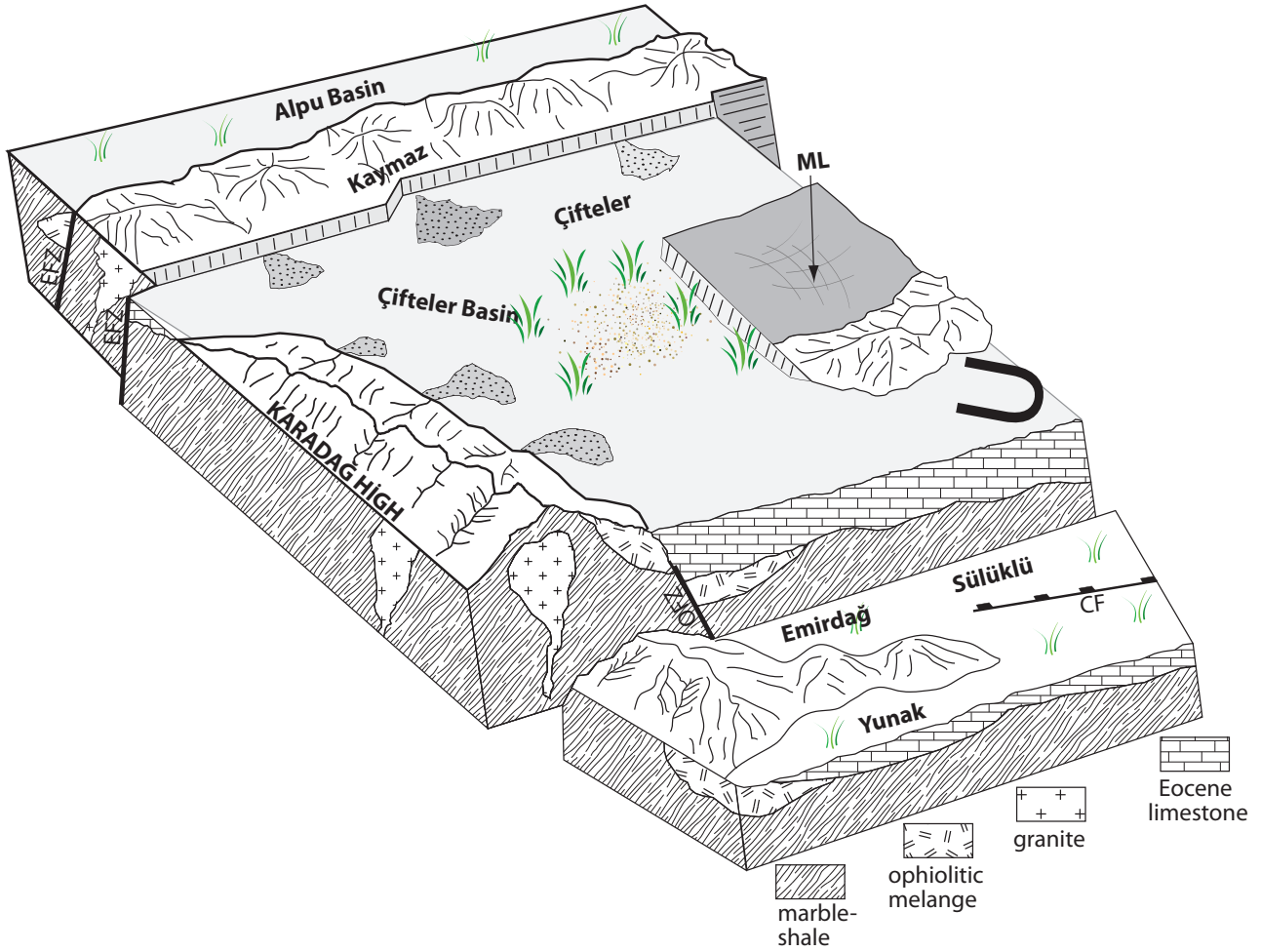


Figure 20. Sketched block diagram depicting Late Pliocene configuration of the Çifteler-Mahmudiye-Emirdağ basin (EFZ- Eskişehir Fault Zone, OFZ-Orhaniye Fault Zone).

Acknowledgement

This paper comprises part of the PhD Thesis of the first author which was supported by the Ankara University Research Fund (Project No: 20050745-013HBP). The authors are grateful to Ali Koçyiğit

(Middle East Technical University of Turkey), whose comments substantially improved the manuscript. The authors also thank the referees of the paper for their constructive criticisms.

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