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## THE ILICA BRANCH OF THE SOUTHEASTERN ESKİSEHIR FAULT ZONE: AN ACTIVE RIGHT-LATERAL STRIKE-SLIP STRUCTURE IN CENTRAL ANATOLIA, TURKEY

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### ABSTRACT

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The Eskişehir Fault Zone is one of the prominent neotectonic structures of Turkey. It separates the west Anatolian extensional province and the strike-slip induced northwest central Anatolian contractional area in the Anatolian Block. Its southeastern part is generally divided into three branches, namely the Ilca, Yeniceoba, and Cihanbeyli from north to south, respectively. The right lateral strike-slip Ilca branch (IB) is an approximately 100-km-long fault and it is composed of several segments in a northwest-southeast direction. The slickensides, subsidiary fractures, cataclastic zone, fracture-controlled drainage pattern, right lateral stream deflections, deformation in the Quaternary unit observing in the seismic reflection sections, and seismicity of the region all indicate that the IB is an active right lateral strike-slip fault. The IB has also a regional tectonic importance as a boundary fault between the contractional and the extensional regions in central Anatolia considering that it is the southern limit of the contraction-related structures in the west-southwest of Ankara.

### 1. Introduction

The division of the neotectonic provinces of Turkey has been discussed by Şengör (1979, 1980), who proposed dividing them into the North Turkish Province, the East Anatolian Contractual Province, the Central Anatolian “Ova” Province and the West Anatolian Extensional Province (Şengör et al., 1985). The border between the Central Anatolian “Ova” Province and the West Anatolian Extensional Province is evaluated differently. While Şengör et al. (1985) suggest a transition zone, Barka and Reilinger (1997) propose a division according to the recumbent V-shaped borders created by the NW-SE trending Eskişehir and the NE-SW trending Fethiye-Burdur Fault Zones (Figure 1a). Barka and Reilinger (1997) attribute a major role only to the NW part of the Eskişehir Fault Zone (EFZ) because most studies have confirmed the Eskişehir Fault as a short structure around the Eskişehir settlement (Ketin, 1968; Şengör et al., 1985; Şaroğlu et al., 1987), with only one study showing the EFZ as a structure between İnegöl

and central Anatolia in its overall neotectonic map (Koçyiğit, 1991a). Another perspective concerning the EFZ is to extend it from Thrace to central Anatolia during the Early Miocene-Early Pliocene (Yaltırak, 2002). The thermochronological data from the Uludağ massif suggest that the initiation age of the EFZ dates back to Oligocene times (Okay et al., 2008). The regional importance of the EFZ as an eastern border of the West Anatolian Extensional Province has also been emphasized by Koçyiğit and Özcar (2003), especially in light of the normal fault-induced Sultandağ and Çay earthquakes (Taymaz and Tan, 2001; Başokur et al., 2002; Emre et al., 2003).

The northwestern sector of the EFZ is generally better documented than the southeastern sector, though there is no consensus about its structural characteristics. The views can be classified into two groups. One group of researchers suggests that the EFZ’s northwestern sector is composed of active normal faults that overprinted the earlier right lateral strike-slip faults (Yaltırak, 2002; Koçyiğit, 2005;

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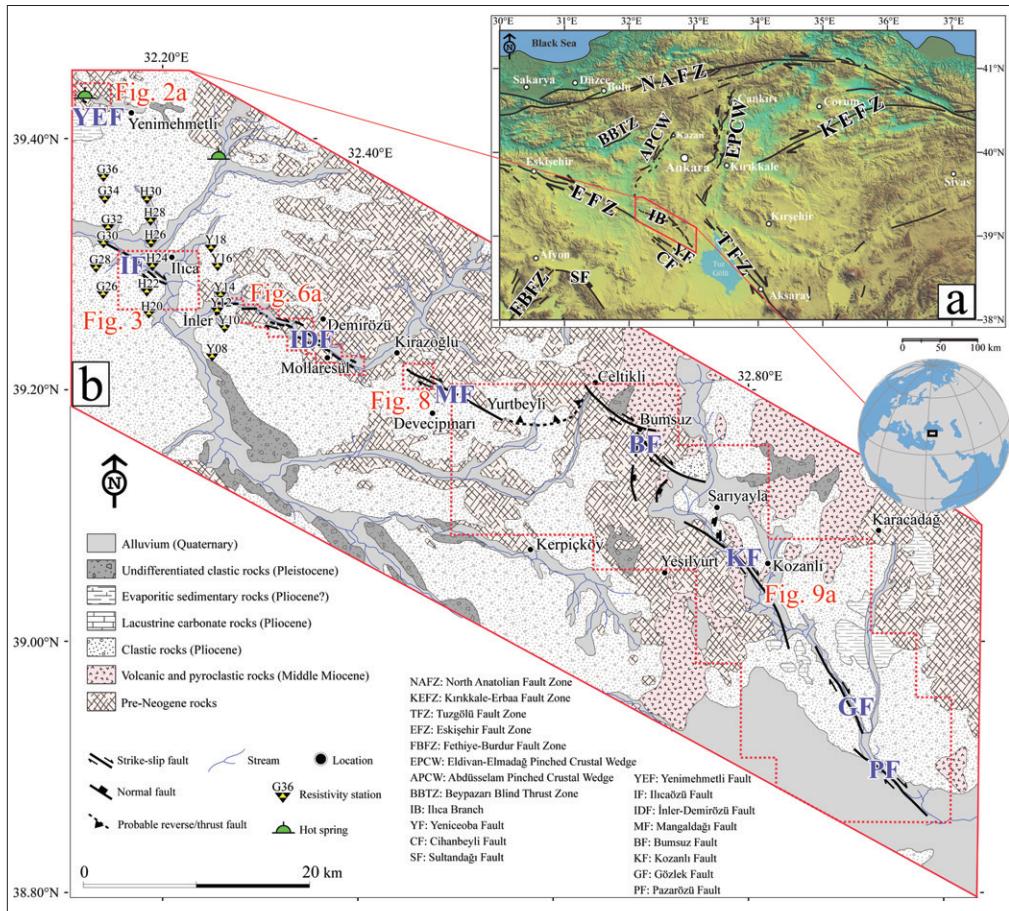


Figure 1- a) Main neotectonic elements of central Anatolia, b) Geological map of the study area (MTA, 2002). Faults were drawn in this study.

Ocakoğlu, 2007). The other group proposes that the strike-slip faults are active structures in the region that superimposed the earlier normal faults (Altunel and Barka, 1998; Seyitoğlu et al., 2010, 2015; Selçuk and Gökten, 2012).

The southeastern sector of the EFZ is composed of three branches: the Ilıca, the Yeniceoba and the Cihanbeyli (Dirik and Erol, 2003). The Yeniceoba and Cihanbeyli branches (Çemen et al., 1999) have been investigated in detail by Özsayın and Dirik (2007), who concluded that the characteristics of the Yeniceoba branch vary from the right lateral strike-slip to the normal fault, while the Cihanbeyli branch has a normal fault character (Özsayın and Dirik, 2007, 2011). The northern Ilıca branch appears on the maps (Koçyiğit, 1991b; Dirik and Erol, 2003) and has been drawn with the help of the right lateral displacements of the streams. However, its structural and geomorphological features have not been studied in detail.

This paper defines the morphotectonic characteristics of the Ilıca branch (IB) by using remote sensing tools together with field data, seismological data and seismic reflection data. Our findings demonstrate that the IB has a right lateral strike-slip character. This result is very important when one considers the strike-slip character of the EFZ's northwestern sector (Seyitoğlu et al., 2015) indicating that the entire EFZ is undoubtedly a strike-slip structure.

## 2. Determination of the Faults Using Remote Sensing and Field Data

We used Google Earth images, SRTM, and ASTER-GDEM data to study the IB of the southeastern EFZ. High spatial resolution satellite images obtained from Google Earth software were mainly used to analyze the subsidiary faults and fractures, as well as morphotectonic features such as stream deflections. SRTM and ASTER-GDEM digital elevation

model (DEM) data were also used to determine the morphotectonic characteristics of the fault segments.

Together with the remote sensing studies, we performed field studies along the IB. We were thus able to observe and collect fault kinematic data from certain parts of the branch.

In this paper, we define the IB of the southeastern sector of the EFZ. It is composed of several faults, including, from northwest to southeast, the Yenimehmetli, İlcaözü, İller-Demirözü, Mangaldağı, Bumsuz, Kozanlı, Gözlek, and Pazarözü faults (Figure 1b).

## 2.1. The Yenimehmetli Fault

The best exposure of this fault is seen in the quarry located between the Yenimehmetli and the Karahamzalı villages, where a major right lateral strike-slip fault surface ( $N70^{\circ}W$ ,  $86^{\circ}SW$ ) with horizontal slickenlines can be observed (Figure 2). Mesozoic limestone in this area is highly fractured;

these shear fractures are concurrent with the right lateral sense of shear that is apparent in the satellite images (Figure 2). The hot spring occurrences (Figure 1b) are one of the indicators of the fault activity in the area as also mentioned by Koçyiğit (1991b).

## 2.2. The İlcaözü Fault

A morphologically sharp contact of approximately 5 km in length is observed between the horizontal Neogene units and the Quaternary deposits near the İlca village (Figures 1b and 3). Although we did not obtain any fault kinematic data during the field studies, the fault is defined based on its morphological expression (Figure 3). The İlcaözü fault is also recognizable in the iso-resistivity sections (Figure 4a and b). These sections, which reflect electrical resistivity of the different soil and rock types near the İlcaözü Fault, have been produced from the unpublished data of the General Directorate of State Hydraulic Works of Turkey.

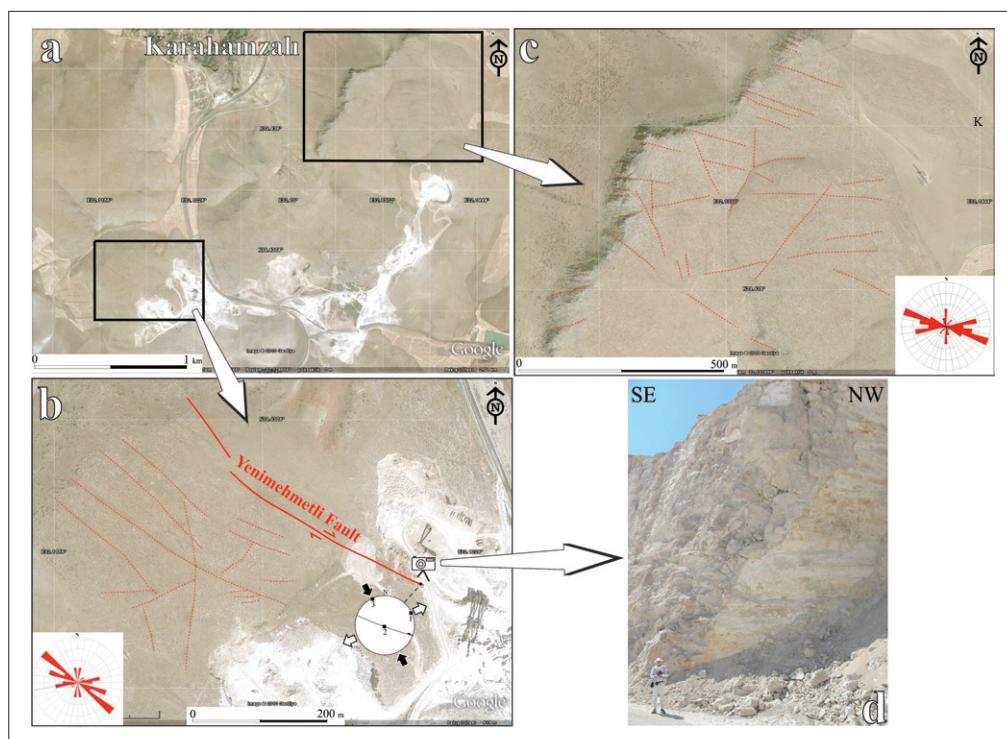


Figure 2- a) Satellite image of the Yenimehmetli fault area. See figure 1b for location, b) Position of the Yenimehmetli fault and the subsidiary fractures. Rose diagram of the fractures is displayed in the left bottom corner. The subsidiary fractures are compatible with the right lateral strike-slip Yenimehmetli fault. White circle is the lower hemisphere equal area stereographic projection of the fault plane. 1, 2, and 3 are the Linked Bingham (Kinematic) axes. Black and white arrows represent shortening and extension direction, respectively, c) Subsidiary fractures on the Mesozoic limestone. Rose diagram of the fractures is displayed in the right bottom corner. The fractures are compatible with the right lateral strike-slip Yenimehmetli fault, d) Strike-slip fault surface of the Yenimehmetli fault.

The İlca Branch of the Southeastern Eskişehir Fault Zone

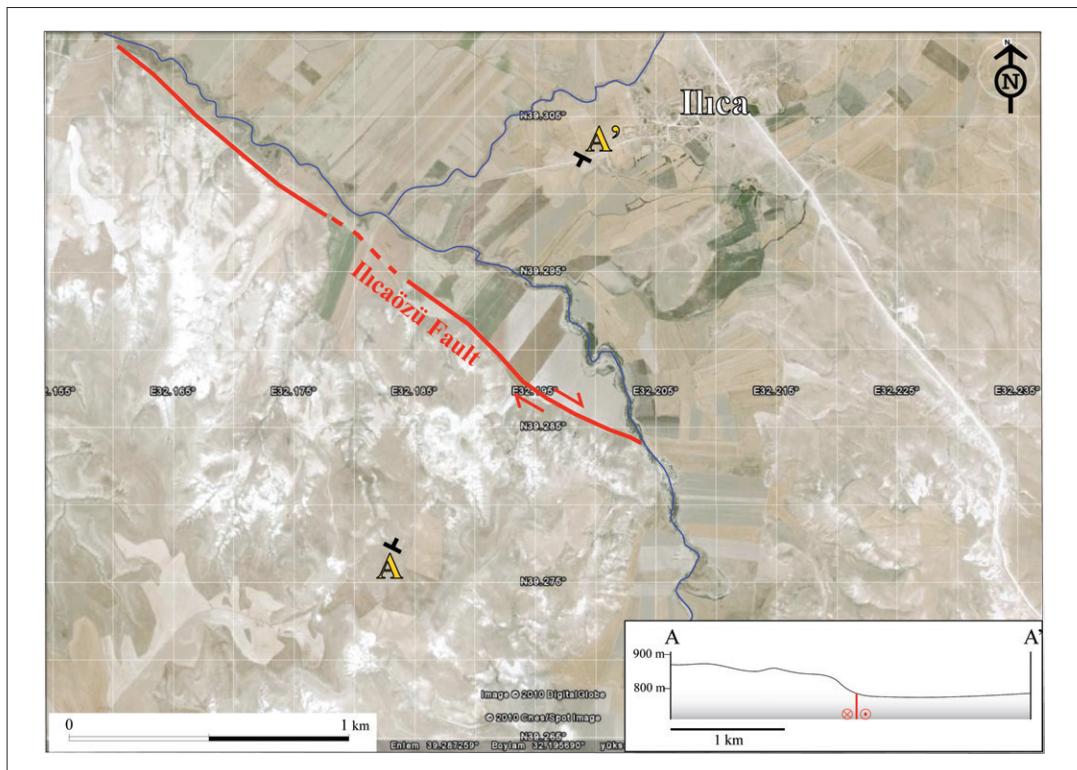


Figure 3- The İlcaözü fault is clearly seen on the satellite image with a morphologically sharp contact between the Neogene and the Quaternary units. See figure 1b for location. A-A' is the section line. The section is displayed in the right bottom corner.

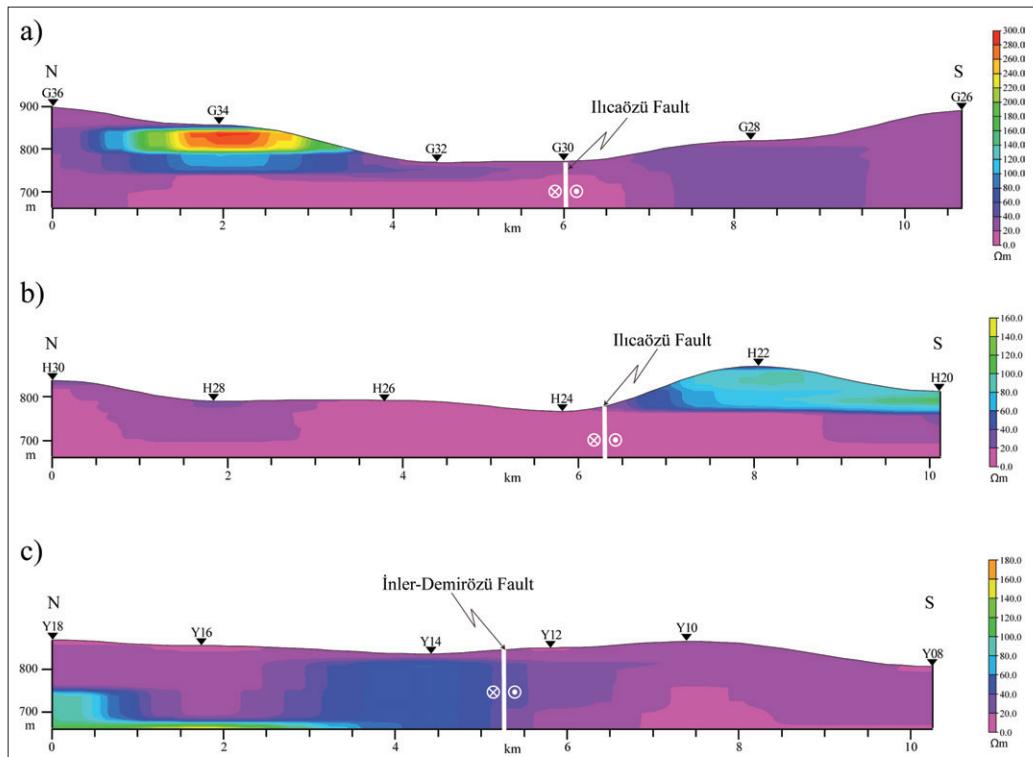


Figure 4- Iso-resistivity cross-sections. See figure 1b for locations of the sections. This unpublished resistivity data is obtained from the General Directorate of State Hydraulic Works of Turkey.

### 2.3. The İnler-Demirözü Fault

Drainage pattern around the IB is dominantly fault/fracture-controlled rectangular type (Figure 5). As a typical example of this drainage style, the most important morphological expression of the İnler-Demirözü fault is the cumulative 14 km right lateral diversion of the Katrancı River (Figures 1b, 5 and 6a). It is difficult to suggest that this diversion is created by the movement on the single fault segment, because the İnler-Demirözü fault is composed of several en echelon segments (Figures 6a and b). The river might be emplaced and followed the trace of the fault segments. On the other hand, the structural data of the right lateral sense of shear obtained from the three locations, the small creeks are diverted right laterally in at least four locations in the range of 75 to 250 meters (Figures 6 and 7a, b, c, d). One of the typical structures along the İnler-Demirözü fault is the cataclastic zone near the road between the Demirözü and Mollaresül villages. This zone can be traced along 100 m and has a width of 20 m (Figures 6 and 7c). It is characterized by crush breccia, which is a cohesive fault rock (Figure 6c). The host rock of the cataclastic zone is dark grey Mesozoic limestone that is highly fractured and crushed. The breccia consists of clasts

and matrix. The clasts are completely derived from the limestone and are a few centimetres in width, while the matrix consists of pulverised materials of the limestone which have attached to the clasts. The cataclastic zone displays fractures with calcite filling, which suggests not only a cataclasis deformation mechanism but also a diffusive mass transfer deformation mechanism. Our structural analysis of the conjugate shear fractures points out that the shortening axis direction is N10°W (Figure 6d). This direction can be correlated with right lateral sense of shearing. The İnler-Demirözü fault can also be observed in the iso-resistivity section (Figure 4c).

### 2.4. The Mangaldağı Fault

This fault is separated from the İnler-Demirözü fault with a 1.5-km stepover towards the NE (Figure 1b). The Mangaldağı fault is determined by using satellite images, where a 1.4-km displacement is clearly seen in the anticline of the upper Cretaceous-Paleocene (Türkönal, 1959; Yıldız et al., 2001) limestones (Figure 8a). In addition, many subsidiary fractures (R, R', P, and X) related to the fault are observed on the satellite images (Figure 8b). The orientation of these fractures is concordant with the right lateral strike-slip faulting.

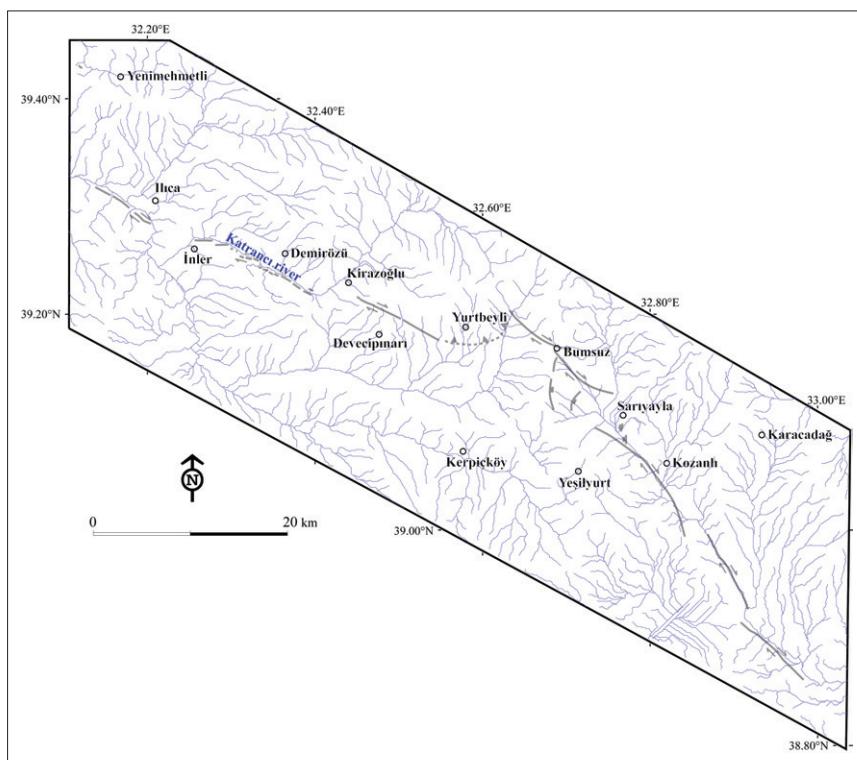


Figure 5- Dominantly fault/fracture-controlled rectangular drainage pattern of the study area.

The İlica Branch of the Southeastern Eskişehir Fault Zone

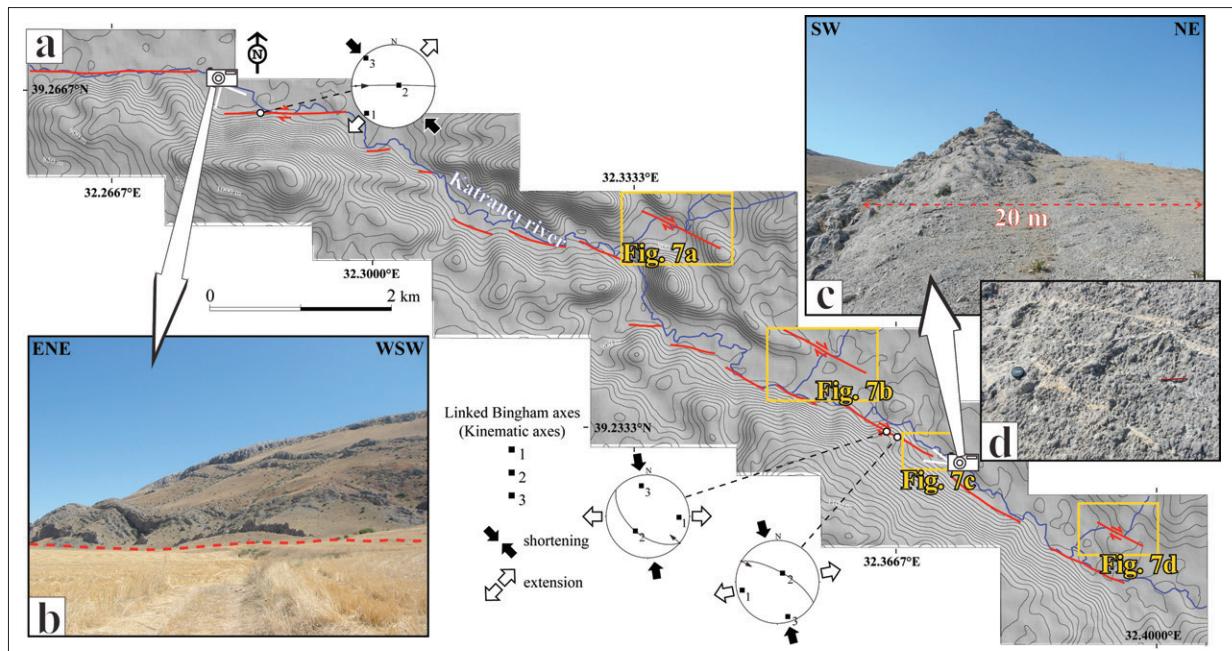


Figure 6- a) Segments of the İlter-Demirözü fault on the ASTER-GDEM shaded relief image. See figure 1b for location. Circles are the lower hemisphere equal area stereographic projection of the fault planes. Black and white arrows represent shortening and extension direction, respectively. Elevation contours were derived from the ASTER-GDEM data. Yellow frames show locations of the stream offsets in figure 7, b) A view from the İlter-Demirözü fault between the Paleocene clastic rocks and the Quaternary units, c) The cataclastic zone on the İlter-Demirözü fault has a width of approximately 20 m, d) A close-up view from the cataclastic zone. Pencil shows the shortening axis direction of N10°W.

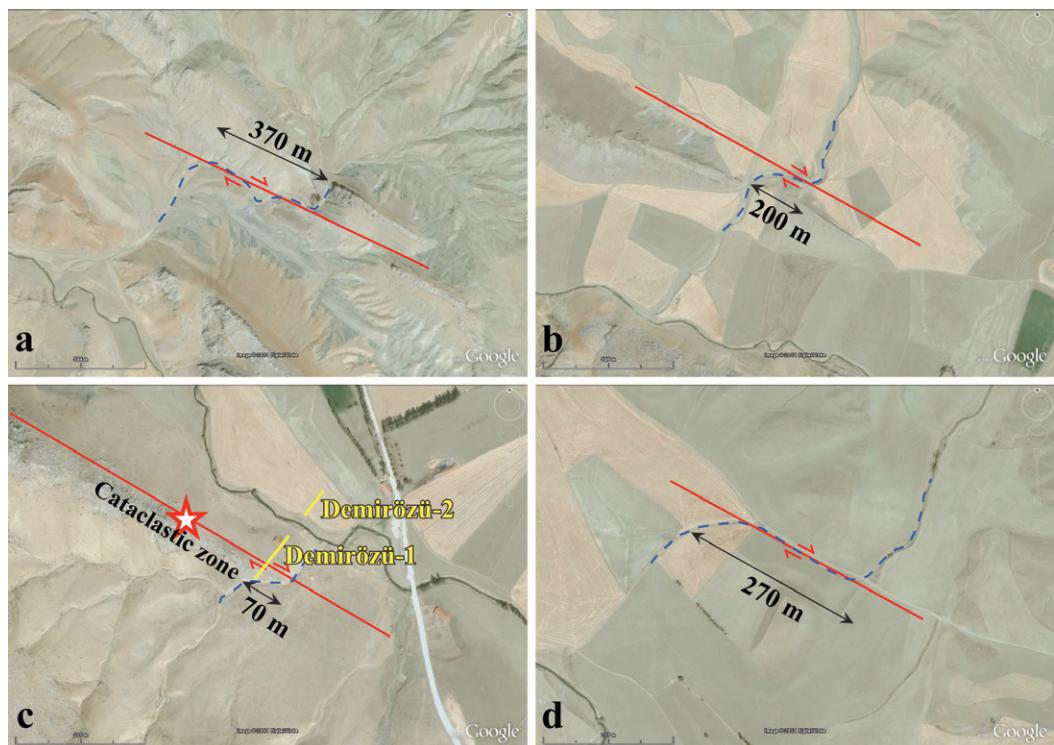


Figure 7- Satellite images related to the İlter-Demirözü fault; a) 370 m stream-channel offset, b) 200 m stream-channel offset, c) 70 m stream-channel offset. The star shows the location of the cataclastic zone. Yellow lines indicate the Demirözü 1 and 2 seismic section lines, d) 270 m stream-channel offset. See figure 6 for locations.

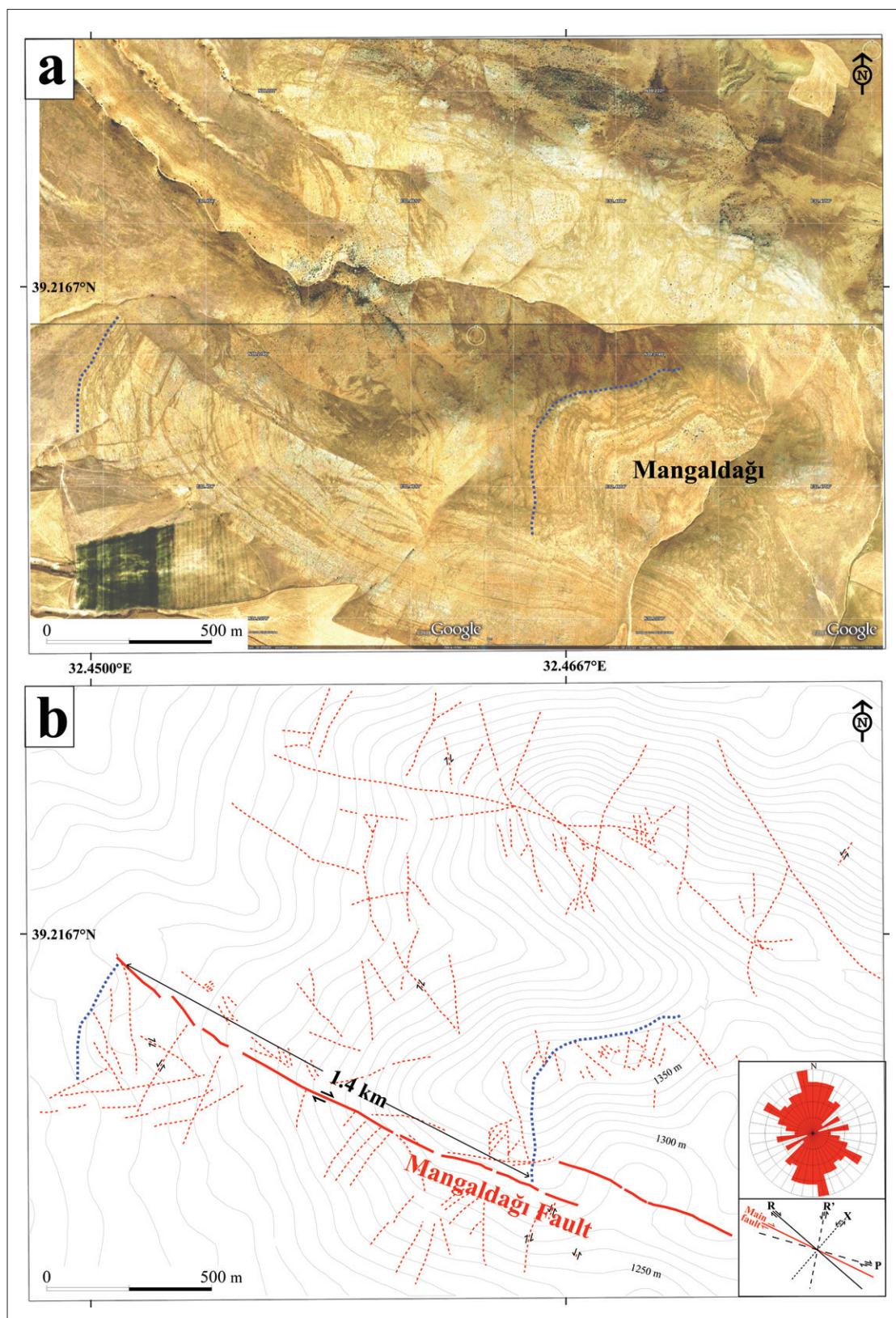


Figure 8- a) Satellite image related to the Mangaldağı fault. Brightness enhancement was applied to the image for better display of the structures, b) Position of the Mangaldağı fault and the subsidiary fractures derived from the satellite image above. 1.4 km displacement is clearly seen in the anticline of the upper Cretaceous-Paleocene limestones. Rose diagram of the fractures and theoretical position of subsidiary fractures (R, R', X, and P) are displayed in the left bottom corner for comparison. The subsidiary fractures are compatible with the right lateral strike-slip Mangaldağı fault.

## 2.5. The Bumsuz, Kozanlı, Gözlek and Pazarözü Faults

The Bumsuz fault is recognized by the sharp topographical differences between the Çeltikli and Bumsuz villages (Figures 1b and 9a) and also shown on the active fault map of Turkey (Emre et al., 2011). A shear zone and the strike-slip fault surfaces are observed on the Bumsuz fault (Figure 9b). The morphological features disappear at the north end of the Samsam Lake, but at the south of the lake, surface expressions are visible on the Kozanlı fault. Samsam Lake is located on the releasing stepover between the Bumsuz and the Kozanlı faults (Figure 9a). At the southeast end of the Kozanlı fault, a small lake called Gökgöl has formed due to the blocking of the stream drainage by the restraining stepover between the Kozanlı and the Gözlek faults (Figure 9a). The Gözlek stream continues along the Gözlek fault, and the fault creates a releasing offset with the Pazarözü

fault (Figure 9a). The IB, in the eastern sector of the EFZ, reaches the Tuzgölü plain following the Pazarözü fault.

## 3. Seismic Reflection Studies

The seismic reflection studies were performed on the İnler-Demirözü fault, where a well-developed cataclastic zone was observed (Figure 7c).

### 3.1. Data Acquisition

We shot two seismic reflection profiles in the İnler-Demirözü area (Figure 7c). The field-spread of Line Demirözü-1 was conducted using a regular ‘Walk-Away’ technique. Forty-eight vertical geophones (14 Hz) were planted with a 2-m group-interval (CDP interval was 2 m). The shot interval was 4 m. A total of 25 hammer-shots were performed with 3 vertical stacks. The first shot station was located 1 m ahead

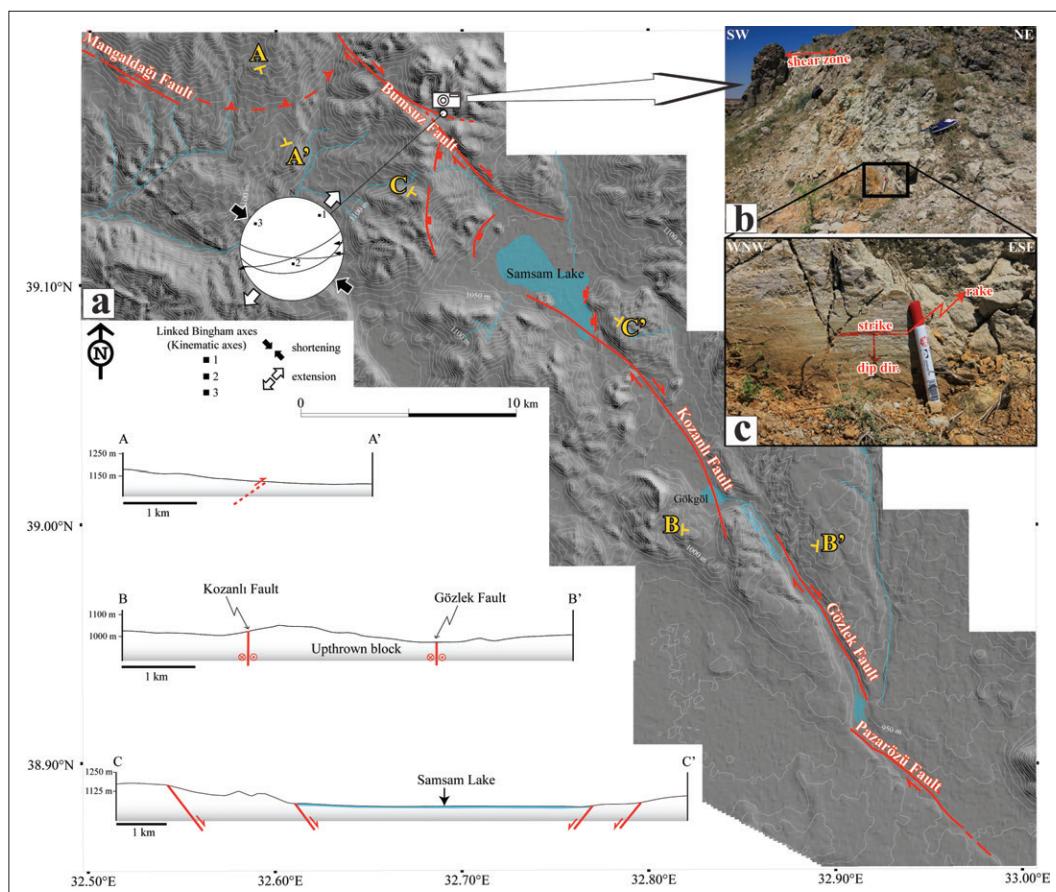


Figure 9- a) The Mangaldağı, Bumsuz, Kozanlı, Gözlek, and Pazarözü faults on the SRTM shaded relief image. A-A', B-B', and C-C' are the section lines. The sections are displayed in the left bottom side. The white circle is the lower hemisphere equal area stereographic projection of the fault planes. Black and white arrows represent shortening and extension direction, respectively. See figure 1b for location and text for explanation, b) The shear zone on the Bumsuz fault, c) A strike-slip fault surface from the shear zone.

of the first geophone station. The field-spread of Line Demirözü-2 was a special application of the ‘Walk-Away’ technique designed to cross the creek. Forty-eight vertical geophones (14 Hz) were planted at a 1-m group-interval (CDP interval was 0.5 m), with a shot interval of 2 m. A total of 25 hammer-shots were performed with 3 vertical stacks. The first shot station was located 70 m ahead of the first geophone station. For both profiles, the sampling interval was 0.5 ms, and the recording time was 2 s.

### 3.2. Data Processing

Data processing included many steps: (1) geometry definition; (2) band-pass trapezoidal filter: 1-5-90-100 Hertz; (3) time-powered gain application (power: 0.5 seconds); (4) trace editing; (5) ground-roll muting; (6) CDP-sort; (7) velocity analysis: CVS Interactive; (8) stack; (9) band-pass trapezoidal filter: 1-5-90-100 Hertz; (10) time-powered gain application (power: 0.5 seconds); (11) horizontal smoothing (weights: 0.25, 0.5, 1, 0.5, 0.25); and (12) time-to-depth conversion ( $t = 140$  ms,  $v = 1600$  m/s). While processing Line Demirözü-1, to consider the irregular topography, a static correction was applied.

### 3.3. Interpretation of the Seismic Sections

The southwest end of the Demirözü-1 seismic section corresponds to the cataclastic zone observed from the surface. This part of the seismic section is

highly deformed and fractured by the fault segments (Figure 10a). The main fault zone producing the apparent positive flower structures is located in the middle of the Demirözü-1 seismic section, which corresponds to the location between the cataclastic zone and the Katrancı River in the field. All of the faults in this seismic section are clearly affected within the top 50 m from the surface, which confirms the recent activity of the İnler-Demirözü fault (Figure 10a). The Demirözü-2 seismic section is the northeast continuation of the Demirözü-1 (Figure 10b) and is relatively less deformed. On both sides of the Katrancı River, only small strike-slip fault segments buried under the recent alluvium can be observed (Figure 10b).

### 4. Seismicity of the İlica Branch

On the basis of an earthquake catalogue prepared by KOERI for the instrumental period since 1900, the IB (shown in Figure 11) has a lesser seismic activity rate than its surroundings, such as the Bala region (Esat et al., 2014). However, the seismicity map clearly shows that the IB produced significant seismic activity ( $3 \leq M < 5$ ), especially in its northwestern and southeastern tips (Figure 11). Although the seismicity along the IB shows some clustering characteristics from place to place, it is generally distributed along the strike. In order to identify the fault geometry, a focal mechanism solution analysis was implemented using digital records of some recent earthquakes.

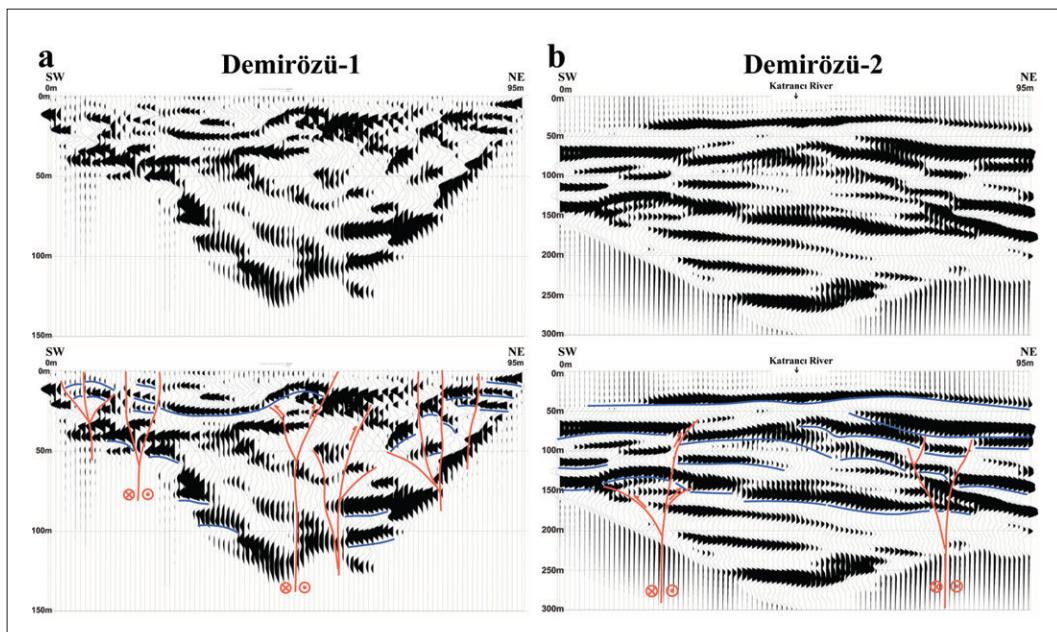


Figure 10- Seismic reflection sections from (a) Demirözü-1 and (b) Demirözü-2 section lines. Above, uninterpreted; below, interpreted. See text for explanation and figure 7c for location.

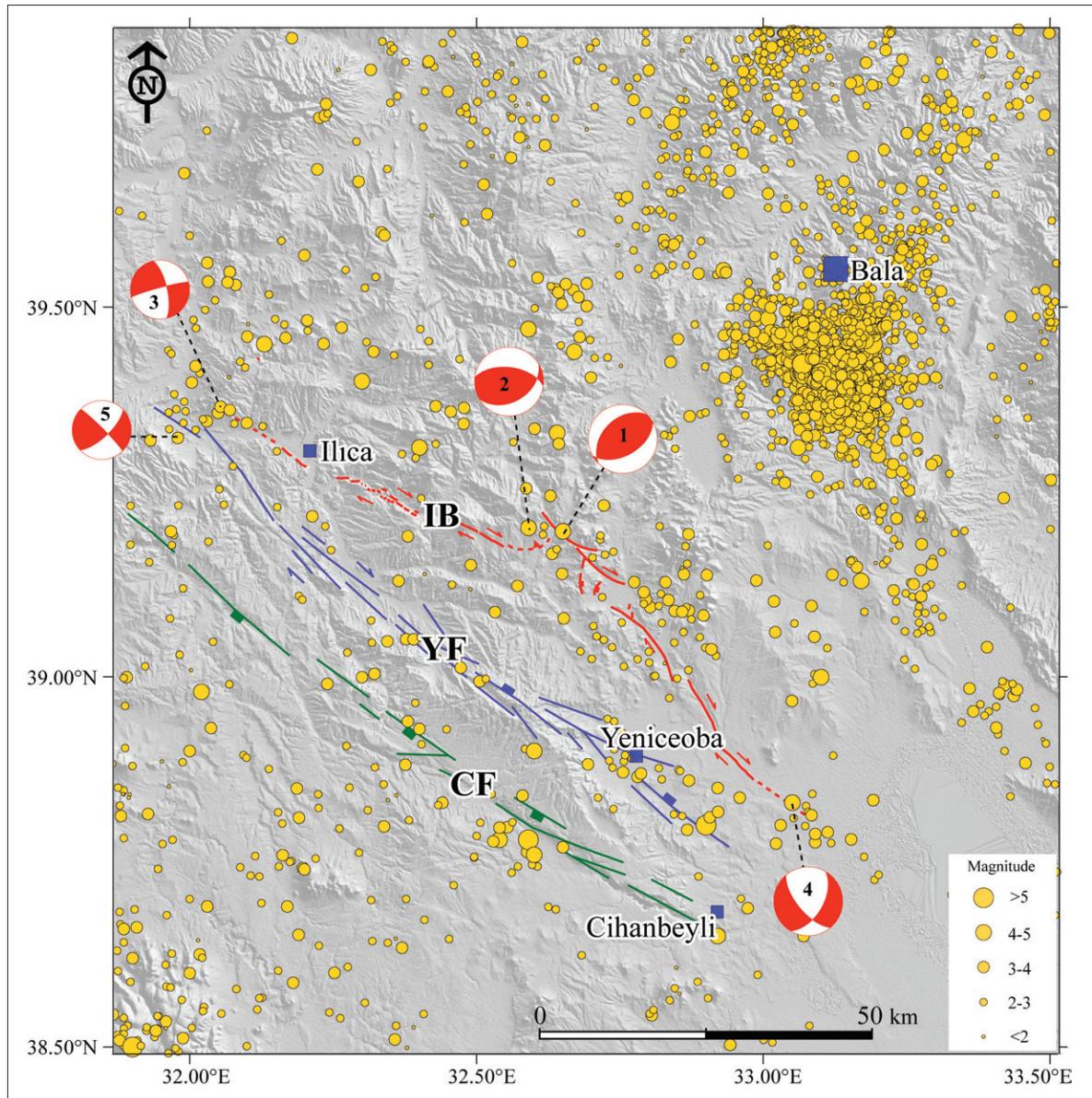


Figure 11- Earthquake distribution in the southeastern Eskişehir Fault Zone. Red line represents the İlica branch (IB). Blue and green lines show Yeniceoba (YF) and Cihanbeyli (CF) faults, respectively (Özsayın and Dirik, 2007). Epicentral data were obtained from the Kandilli Observatory and Earthquake Research Institute (KOERI) of Turkey's catalogue for instrumental period. Parameters of the focal mechanism solutions are given in table 1.

To compute the focal mechanism solutions of the events, we used the FPFIT program (Reasenberg and Oppenheimer, 1985), which computes double-couple fault plane solutions from P-wave first motion data using a grid search method. The focal mechanism solutions of the three earthquakes (06.03.2006,  $M = 3.1$ ; 13.12.2007,  $M = 4.9$  and 29.05.2010,  $M = 3.1$ ) located in both tips of the fault represent a typical strike-slip fault geometry, which is compatible with the IB (Figure 11 and table 1). Moreover, the focal mechanism solutions of the two sequential earthquakes (07.02.2004,  $M = 4.2$  and 08.02.2004,  $M = 4.4$ ) are in

the middle of the IB indicate thrust faulting (Figure 11 and table 1). This thrust faulting is expected in this area because these two earthquakes were located on the restraining stepover between the Mangaldağı and the Bumsuz faults, where the IB changes direction nearly  $30^\circ$  (Figures 9 and 11).

## 5. Discussion and Conclusions

In this study, the right lateral strike-slip IB was defined via remote sensing, field observations, seismology, and seismic reflection studies.

Table 1- Parameters of the focal mechanism solutions.

No	Date (dd/mm/yyyy)	Time (GMT)	Lat. N (°)	Lon. E (°)	Depth (km)	Mag.	Nodal Planes			P		T	
							Str.1(°) Str.2(°)	Dip1(°) Dip2(°)	Rake1(°) Rake2(°)	Azi. (°)	Plunge (°)	Azi. (°)	Plunge (°)
1	07/02/2004	19:26:19.20	39.1928	32.6547	2.0	4.2	60 225	50 41	100 78	143	5	23	81
2	08/02/2004	09:27:54.30	39.2037	32.5905	10.0	4.4	60 277	40 56	60 113	351	8	238	69
3	06/03/2006	20:18:35.85	39.3628	32.0570	17.2	3.1	255 347	85 70	-20 -175	209	18	303	10
4	13/12/2007	18:06:18.70	38.8267	33.0507	5.0	4.9	140 30	65 54	-140 -31	360	45	263	6
5	29/05/2010	13:47:12.07	39.3162	31.9940	7.2	3.1	315 47	85 70	160 5	3	10	269	18

The IB is considered as one of the three branches of the southeastern EFZ, and it is the southern limit of the contractional structures (i.e. folds, blind thrust faults, and pinched wedge structures) located between Kazan and Yenimehmetli (W and SW of Ankara) (Esat and Seyitoğlu, 2010; Esat, 2011). The IB is composed of several right lateral strike-slip faults and their corresponding segments. This is an important conclusion when we consider about the different views on the character of the EFZ. Some studies describe the EFZ as İnönü-Eskişehir Fault System (Özsayın and Dirik, 2007, 2011) which runs from Bursa to the west of Tuzgölü. In these studies, the Eskişehir, İlica, Yeniceoba, and Cihanbeyli branches constitute the İnönü-Eskişehir Fault System. Eskişehir and İlica branches have right lateral strike-slip character, but Yeniceoba and Cihanbeyli branches are determined as normal fault with right lateral strike-slip component and pure normal fault, respectively (Özsayın and Dirik, 2007, 2011). Apart from this, other researchers define the active faults in western part of the EFZ between İnönü and Eskişehir as normal faults (Yalıtrak, 2002; Koçyiğit, 2005; Ocakoğlu, 2007). The recent study (Seyitoğlu et al., 2015), however, suggest that the active faults in this area have a N60W trending right lateral strike-slip character. Faults in the area between the east of Eskişehir and the IB are also mapped as right lateral strike-slip faults with normal components by Selçuk and Gökten (2012). These results together with our observations about the nature of IB are demonstrated that the EFZ is dominantly a right lateral strike-slip zone. Thus, the Yeniceoba and Cihanbeyli branches, which assumed to be the southeastern parts of the EFZ, could be considered as independent faults from the EFZ due to their normal fault nature, even if they appear to be morphologically related to the EFZ.

The triangle shaped area bounded with the NAFZ, KEFZ, and EFZ is under the influence of NW-SE contraction and it is defined as a neotectonic region called “NW central Anatolian contractional area”. The EFZ is a boundary structure between this contractional area and the west Anatolian extensional province (Esat and Seyitoğlu, 2010; Esat, 2011). The IB, eastern continuation of the EFZ, is the southern limit of the contractional structures which lie between immediately W and SW of Ankara, as also mentioned above. These structures are not observed south of the branch (Figure 1a; Esat, 2011). Consequently, the IB has an important meaning for the regional geology, considering its role as an eastern boundary between the contractional and the extensional regions in central Anatolia. Moreover, the seismic activity and the morphotectonic features also show that the IB is an active structure. Therefore, it should be taken into consideration for the earthquake risk assessment of the capital city Ankara and its surroundings together with the Yeniceoba and Cihanbeyli faults that described by earlier studies.

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