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Active tectonics of Erçek Lake Basin and lithostratigraphy of basin deposits (Van, Turkey)

Bülent DOĞAN*

Kocaeli University, Faculty of Engineering, Department of Geological Engineerin, Kocaeli

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Abstract

The Erçek Lake Basin (ELB) is located in the eastern part of Van Lake and has an area of approximately 100 km^2. The eastern section presents gully morphology towards Özalp. Oligo-Miocene and Plio-Quaternary units cover the basement rocks of the study area. Oligo-Miocene units are folded on both the southern and northern parts of ELB. However, in the north of the basin, northward dipping thrust faults generally developed along E-W. In the south, the fold axes differ by a maximum of 30 ° from the E-W to the north. The distribution of the structural elements within the Plio-Quaternary units is rather limited, and these are more prominent in the north of the Erçek Lake. There are a few normal faults in these structural elements. The development of these normal faults occurred as a consequence of the N-S compression in the region and developed in the active tectonic evolution of the region. The Kozluca left lateral strike-slip fault, which also deforms the western margin of Lake Erçek and the intra-lake morphology, is one of the other intra-plate structural elements within the contracted continental crust.

Keywords: *Lithostratigraphy, Active tectonic, Thrust fault, Strike-slip fault.*

Erçek Gölü Havzası çevresinin aktif tektoniği ve havza dolgusunun litostratigrafisi (Van, Türkiye)

Özet

Erçek Gölü havzası (ELB), Van Gölü'nün doğusunda yer alan ve yaklaşık 100 km^2'lik alana sahip ve doğu kesimi de Özalp'e doğru oluk morfolojisinden oluşur. Bu alanda temel kayaçları, hem Oligo-Miyosen, hem de Plio-Kuvaterner yaşlı birimler örter. Erçek gölü havzasının hem güney, hem de kuzeyinde Oligo-Miyosen yaşlı birimler kıvrımlıdır. Ancak havzanın kuzeyinde genel olarak D-B doğrultulu kuzeye eğimli ters faylar da gelişmiştir. Güneyde ise kıvrım eksenleri, D-B'dan kuzeye doğru en fazla 30°

* Bülent DOĞAN, buldogan@yahoo.com, https://orcid.org/0000-0002-6684-2046

lik açı ile sapma gösterir. Yapısal elemanların Plio-Kuvaterner birimler içinde dağılımı ise oldukça sınırlı olup, bunlar da Erçek Gölü havzasının kuzeyinde daha belirgindir. Bu yapısal elamanların içinde az sayıda normal faylar da bulunur. Bu normal faylar bölgenin K-G sıkışması sonucu oluşmuş olup, aktif tektonik evrimi süresince gelişmiştir. Erçek Gölü'nün batı kenarını ve göl içi morfolojisini de deforme eden Kozluca sol yanal doğrultu atımlı fayı da, sıkışan kıtasal kabuktaki diğer levha-içi yapısal unsurlardan biridir.

Anahtar kelimeler: *Litostratigrafi, Aktif tektonik, Ters Fay, Doğrultu-Atımlı fay.*

1. Introduction

Erçek Lake basin (ELB) is bordered with Van Lake basin (VLB) in the west and Erçek-Özalp gully in the east. ELB has an altitude of about 1800 m and an area of 100 km^2. The deepest part of the lake is between 35 and 40 m [1]. Majority of the studies are mainly carried out in VLB, and there are some studies especially on the morphology of ELB [1,2].

The plate movement directions around the VLB and ELB basins are in the N-NW direction with respect to the GPS vectors, which are caused by the northward movement of the Arabian plate [3], (Figure 1a). Different active tectonic sources develop in the region as a result of this movement from about 18 Ma to the present day [4-10]. These tectonic sources made contributions to some deformations in the Plio-Quaternary units especially around the VLB (Figure 1b), [11-13]. Plio-Quaternary geological units around ELB have been defined [14-16].

When the focal mechanisms of the historical earthquakes in the region are checked, it is seen that the mechanisms of the earthquakes are especially thrust and strike-slip faults [17-20]. The tectonic resources in the VLB were active on 23 October 2011 with Mw 7.2 and 9 November 2011 with Mw 5.6 earthquakes [21,22]. These two earthquakes occurred on reverse fault and strike-slip faults respectively in VLB [23]. In addition, there are complex active faults around the ELB, and these active faults have deformed morphology [24]. It is also observed in seismological studies that active faults in the region are different types. It is stated that the reverse fault plane of the 23 October 2011 earthquake is dipped to the north and directed to E-W in the southeast of ELB [25,26]. Focal mechanisms of some earthquakes around ELB were determined and compression was determined in N-S direction and dilatation in E-W direction in the region [27]. In addition, reverse and normal faults in the lake were mapped in both the N-S and E-W oriented seismic reflection sections in the Erçek lake [28,29].

The purpose of this study is to map the distribution of the Plio-Quaternary units around the ELB, and determine the contact relations with units older than Pliocene. Additionally, the morphology of intra-basin and basin margins along with the lake bathymetry was evaluated to explain how the structural elements in the have developed, as the indicators of the state of the active tectonism. In this sense, the investigation of both the Plio-Quaternary units and their contact relations with older units has also enabled the identification of the role of active faults in the development of ELB.

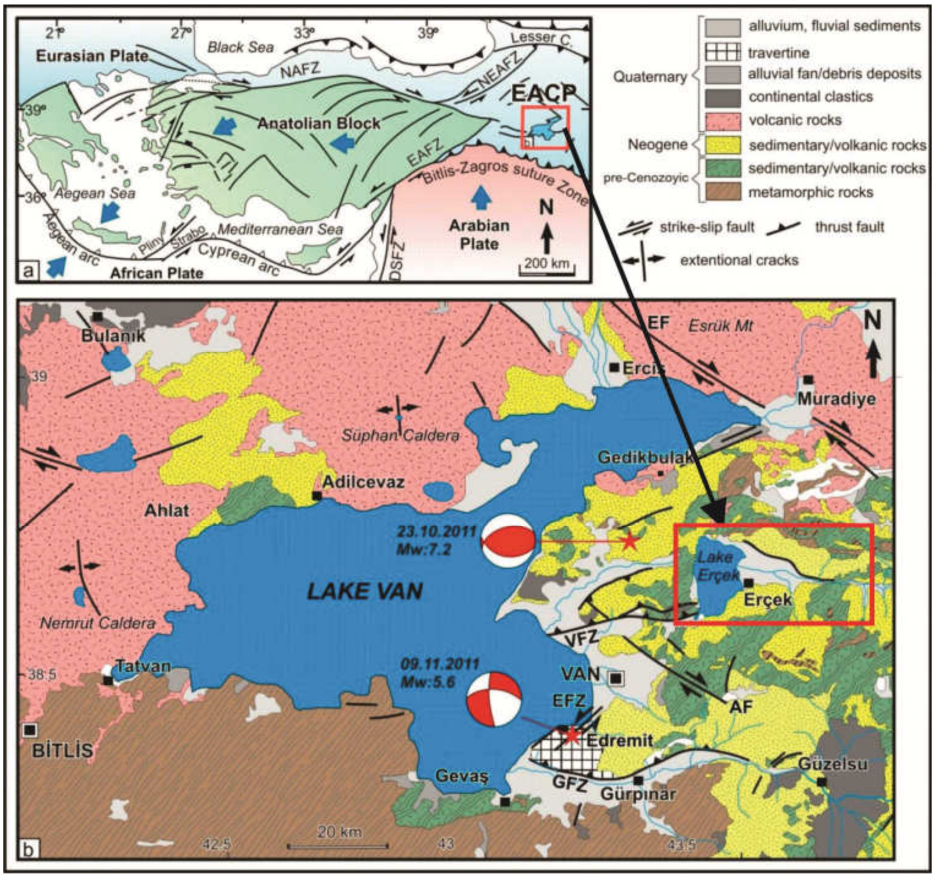

Figure 1. a) Tectonic outline of the eastern Mediterranean area. Abbreviations: EACP, East Anatolian Contractional Province; DSFZ, Dead Sea Fault Zone; EAFZ, East Anatolian Fault Zone; NAFZ, North Anatolian Fault Zone; b) Lake Van Basin and simplified geological map showing the main tectonic structures of the Lake Van Basin and the surrounding area. Abbreviations: GFZ: Gurpinar Fault Zone, AF: Alabayir Fault, VFZ: Van Fault Zone, EFZ: Edremit Fault Zone, EF: Ercis Fault (compiled from [14,30,31]).

2. Material and Method

In the Erçek Lake Basin, Pre-Miocene geological units were considered as the basement rocks. The types of contacts between the basement, Oligo-Miocene and Quaternary units are plotted on 1 / 25.000 scale digital topography maps. In these maps, the watershed of the basin was determined to be used as extend of this study. The structural elements deforming the Neogene and Quaternary units were measured by using geologist compass.

3. Results

In this section, the data obtained in the study area and the sedimentary environments in the Plio-Quaternary period are investigated. In addition, the relevance of the present day morphology of the region to active faults has been assessed, especially for the northern and southern margins of ELB. Also, the structural meaning of the faults observed within the basin stratigraphy has been questioned.

3.1. Lithostratigraphy

Oligo-Miocene (Olm) and Plio-Quaternary geological units unconformably cover the basement rocks in the study area (Figure 2). While the bottom of the base units is composed of ophiolitic rocks up to the section there are clastic and carbonate type rocks which characterize the marine environment. Oligo-Miocene units are composed of mostly sandstone-claystone with minor siltstone contribution. Within these levels, sandy gravel levels with up to a maximum of 30 cm in grain diameter are observed. They are more common in the southern area of ELB than in the north. Because they are usually deposited as fine-grained lithologies, sedimentation environment characterizes the low energy. However, the presence of coarse-grained gravels indicates that the high-energy stream channels were involved in the sedimentation.

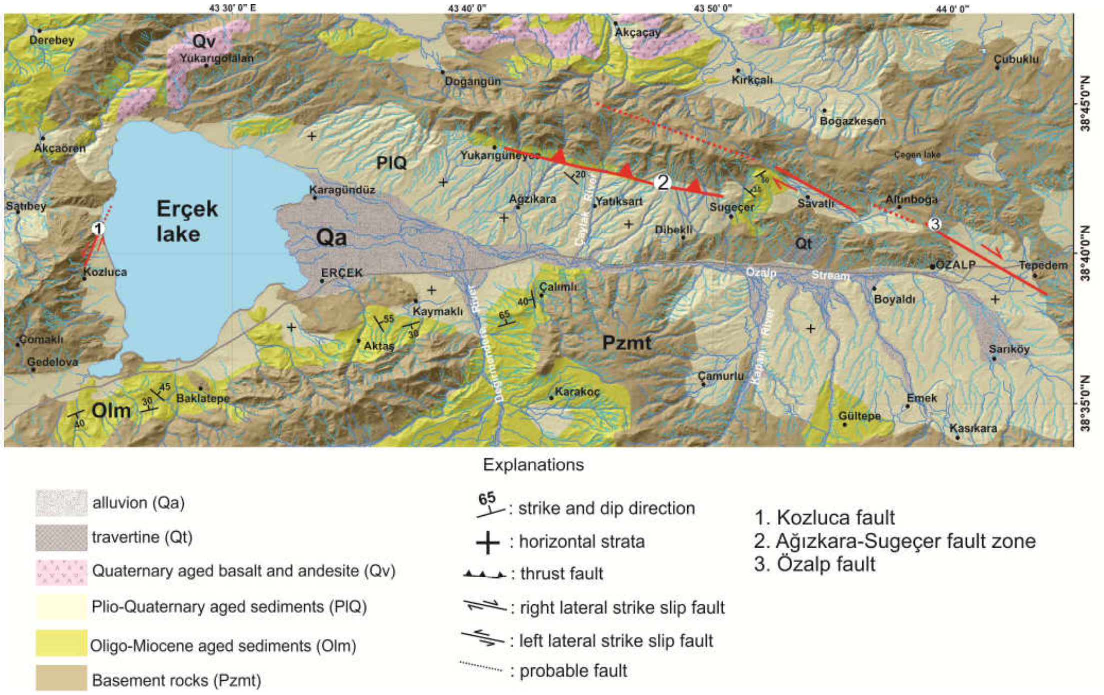

Figure 2. Map of the Neotectonic Period geological units and active faults in the study area (modified from [32]).

These units presenting quite distinctive bedding are light yellow, gray and tones of brown. A similar unit is seen especially in the eastern part of Van Lake. These units named Van formation contain prominent conglomerates in these areas and are accompanied by marine fossiliferous limestones [15]. Oligo-Miocene units, which characterize both the marine and marine active lacustrine environment in the entire Van Lake basin, have been deposited in the remnant sea of the last stage of the Neotethyan Ocean depletion, or in lacustrine areas similar to today's Van Lake environments [15,16]. Volcanic rocks (Qv) are generally Pliocene or younger, and cover a wide area in the Van Lake basin. These rocks are also observed in the study area as intensively fractured basalts and andesites and very few volcano-sediments [33,34].

Another Plio-Quaternary unit in the ELB is the river and alluvial fan deposits (PlQ) which cover wide areas both in the basin and the east of the basin (Figure 3). These units are observed especially between the western edge of Lake Erçek and the high morphology of the western part of the lake and the northern part of the gully between Erçek Lake and Özalp. These units are also observed to the south of the basin and

Erçek-Özalp gully, but they are thinner relative to the northern ones. This unit, which is covered with sedimentary deposits of the youngest rivers in the region, contacts with Oligo-Miocene units as discordance and with an active faulted contact. The bedding at the unit is generally horizontal and has a dipping with deformation close to the fault boundaries. Alluvial fan deposits of PlQ composed of sandy coarse gravel, sand-clay lithologies. Among them, gravels are usually angular and the grain diameter is up to maximum 50 cm. The gravel petrography in the unit consists mainly of ophiolitic rocks in the northern areas and in the south there are limestones and claystone grains derived from Oligo-Miocene units. The other facies within the unit is also formed by stream channels with lithology consisting of well-rounded sandy pebbles.

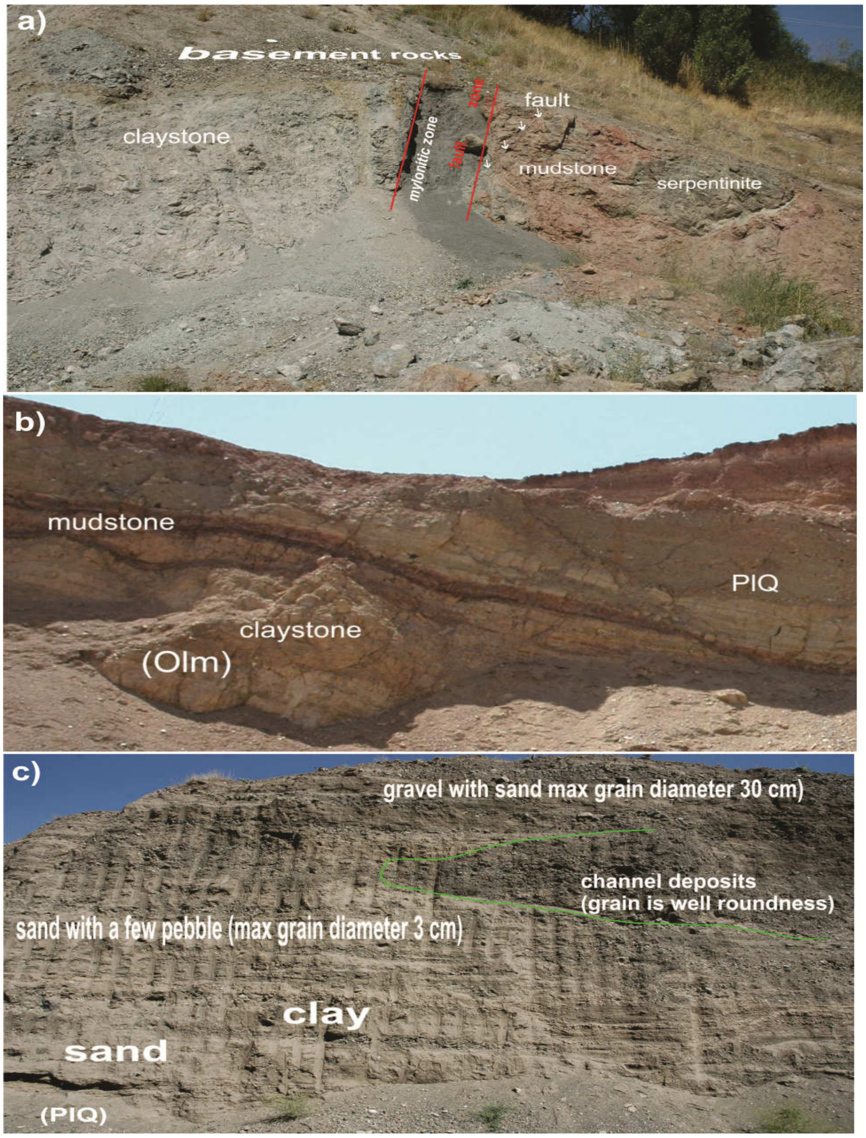

Figure 3. Lithostratigraphic view of the a) basement rocks b) Oligo-Miocene c) Plio-Quaternary geological units in ELB.

In these pebbles, the imbrication is well developed and it is understood that the grains are derived from the base rocks in both the northern and southern directions. Another facies of the alluvial fan deposits in the study area is represented by the distal part of the fan consisting of sand, clay and silt. During the deposition of these sediments that settled further from the source, the energy is lower than in other environments.

3.2. Morphotectonic Settings

During the sedimentation of Plio-Quaternary sediments, which covers a wide region in the study area, active faults in the region changed morphology in terms of topographic values of the watershed lines. The study area consists of both the 15x16 km ELB and the eastern gully with a 25 x 2 km area. The northeastern and western parts of the ELB have a higher morphology and slope angle, while the slope angle is particularly lower in the south, southeast and northwest areas (Figure 4).

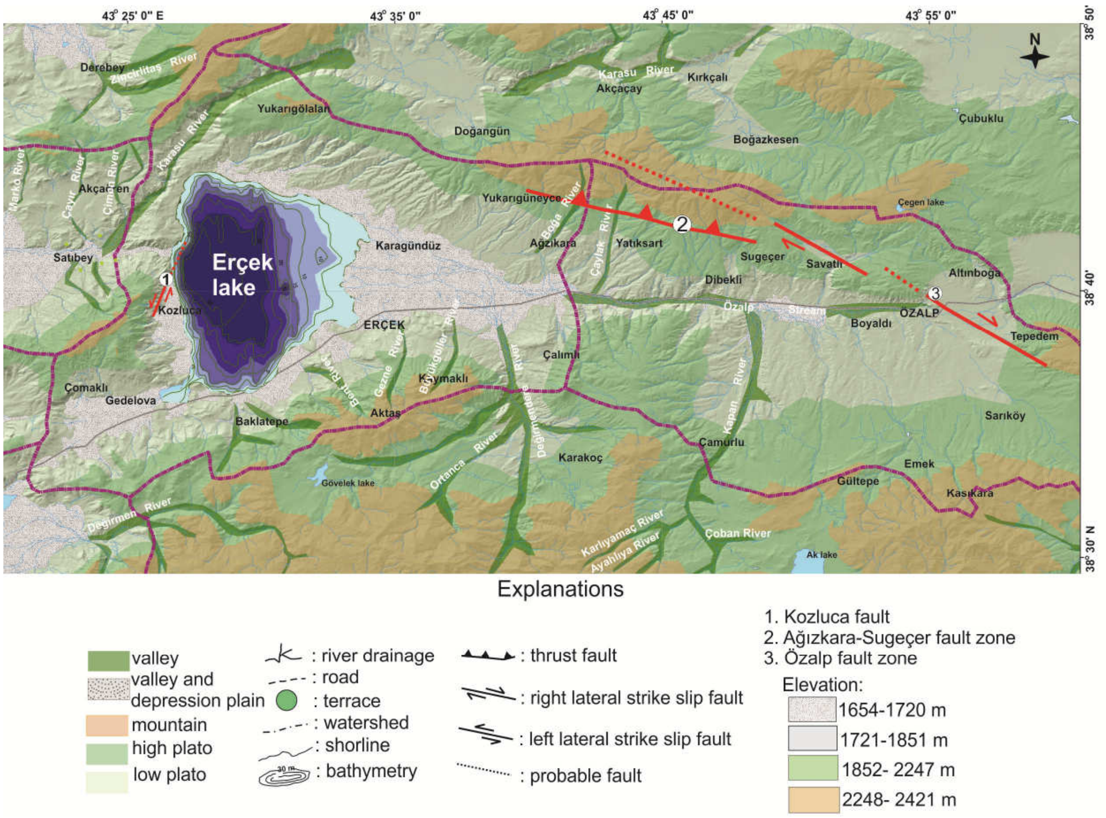

Figure 4. The appearance of active faults together with the morphological elements of the ELB and gully located to the east of lake (Erçek Lake bathymetry map was taken from [1]).

The Erçek Lake, which is more than 35 m in depth, is also affected by active faults in the region and western margin bathymetry has a higher slope angle than the other margins of the lake (see Figure 4). Accordingly, there is a difference in the topographic slope angles from the watershed of the ELB to the basin and to the long axis of Erçek-Özalp gully. According to this, the highest topographic slope angle from the watershed to the axis of the basin between the Yukarıgölalan and Yukarıgüneyce villages of the lake is around 40°, while the same value is 70° between the Yukarıgüneyce and Sugeçer villages. To the east, the highest slope angle is 65° in the southwestern part of the fault, depending on the Ozalp fault zone around Tepedem - Savatlı - Doğangün, while this value is 50° in the north east. The western margin of the ELB and the bathymetry to the west of the lake area are similar at high slope angles, and the highest slope angle from the western watershed to the axis of the lake is 80°. The E-W direction zoning of the Kozluca fault means that the western edge of Erçek Lake is also affected by active deformation. Therefore, when the deepest area of the Erçek Lake (35 m) is taken as the center; the bathymetry contours from the western edge of the lake to the east are very close together (Figure 4). In addition, the Plio-Quaternary sediments in the region also have higher elevations in areas where active fault morphology is present. When the main valleys in the region and the Holocene sediments in the valleys are evaluated; in the valleys cut by the faults located around the ELB, river channel sediments associated with fault-related stepping are also deposited in accordance with the block elevation. The Plio-Quaternary sediments in the Çaylak and Boğa River valleys north of the ELB are at most 2300 m elevation and 2180 m elevation at Bent, Gezne, Büyükgöller, Değirmendere and Kapan rivers in the south. Watershed around ELB has the highest values especially in the western and north-east of the lake. Accordingly, the development of the ELB is mainly associated with the Ağızkara-Sugeçer fault zone (Figure 5).

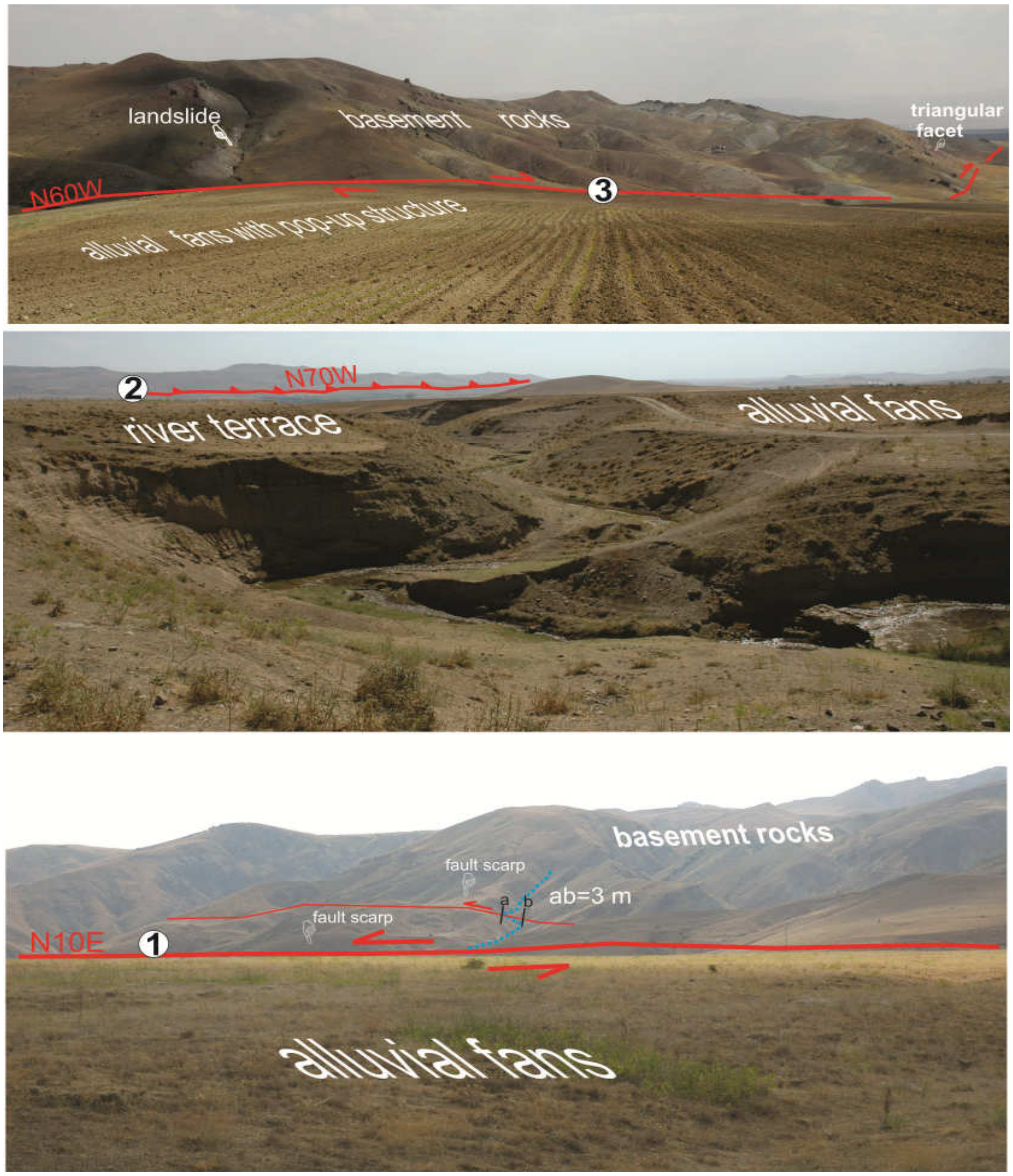

Figure 5. The appearance of the basement rock, Plio-Quaternary alluvial fans, current stream terraces along with all the fault zones and the morphotectonic elements in the immediate vicinity of the ELB (1,2,3 numbers indicate the fault names, see Fig. 2,3 for details).

3.3. Structural Geology

The active structural elements in the region, in particular their geometry in the Neogene and Quaternary stratigraphy, and their developments are discussed in this section. It is seen that reverse faults predominate primarily in both the basement rocks and the younger geological units of the region. The study area, which is located about 110 km north of the Bitlis-Zagros Suture Zone providing collision for Anatolian and Arabian Plates, is also a lake basin (ELB) [1,9,42]. The best recent example for the active collision is the 23 October 2011 Mw 7.1 Van earthquake [35-37]. The surface rupture caused by this earthquake was observed in limited areas compared to the seismogenic zone, indicating that the rupture plane is a blind reverse fault. This means that the active faults that cut Plio-Quaternary sediments in ELB and Van Lake basin in the region are very limited on the surface. However, blind thrust fault planes are the most dominant tectonic regime as the compression intra-plate, as are the faults observed in both the base rocks and the Oligo-Miocene units of the region. The best example of the existence of compression is different kinds of faulting on a concrete block resulted by 23 October 2011 *Mw* 7.1 Van earthquake [36]. Accordingly, the entire region is affected by the N-S compression of the main tectonic source. With this compression, intra-plate strike-slip and normal faults are observed both in the Van Lake basin and around the ELB. Besides, especially in Oligo-Miocene units, many folds compatible with active compressional deformation have developed.

These folds are also other structural elements explaining that compression in the region is generally N-S oriented. One of the most prominent structural data of the Ağızkara-Sugeçer fault is that the Oligo-Miocene units in the hanging-wall block of the fault gain an average of 20° beneath the ophiolitic base rocks along the plane, to the north. Thus, a monocline-like fold was formed within Oligo-Miocene units in the hanging-wall block of the fault (Figure 6a). The minimum lateral length of the Kozluca fault, which is observed at the western margin of the ELB, is 4 km and the lateral offsets on the surface are very clear. In addition, due to blind faulting, the lateral offsets are clearly observed in the Oligo-Miocene units (Figure 6b). The Kozluca fault is one of the causative elements in the formation of ELB. Additionally, the Ağızkara-Sugeçer fault zone with a length of at least 18 km on the northeastern edge of the ELB is a reverse fault with northward dipping and N70° - 80° W strike. To the south of this basin, no faulting is observed on either morphology or stratigraphy. Approximately 2 km east of the Özalp district, the N40°- 55° W right-lateral strike-slip Özalp fault zone generated deformation elements in both Oligo-Miocene and Plio-Quaternary sediments. It is stated that the reverse and normal faults observed in the sediments within Erçek Lake are also observed on all margins of the lake (Figure 6c). In addition, it is understood that most of the active deformation of focal mechanisms belonging to some earthquakes around the ELB are reverse faults forming N-S directional compression. The active tectonic elements around the ELB are concentrated in the lake and the western edge of the lake, and no structural elements are observed in the southern land of the lake. The earthquake activity also supports these deformations in and around ELB. Especially the presence of earthquakes with $M \geq 4$ in the vicinity of the basin indicates that the faults that are sources of the structures shown in Figure 6 are active (Figure 7).

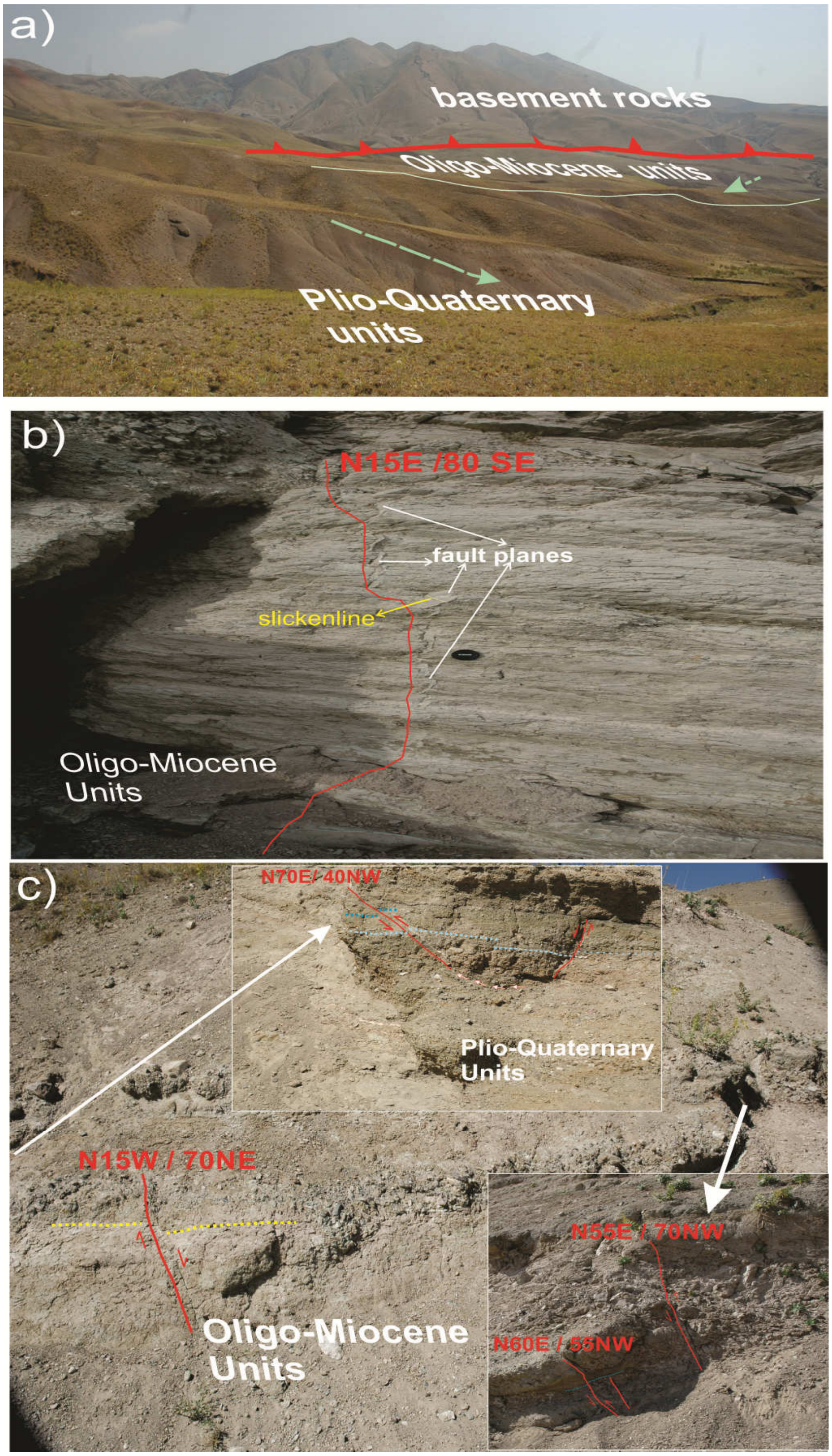

Figure 6. a) a northward inclined view of Oligo-Miocene units over the Plio-Quaternary units in the Ağzıkara-Sugeçer Fault zone (dashed lines indicate layer dip direction) b) Kozluca fault trace, yellow colored slickenline compatible with left-lateral movement c) The appearance of normal faults along with the reverse fault effective deformation indicating deformation of the geological units at different ages in the region (the yellow arrows show the changes of dip direction of the unit).

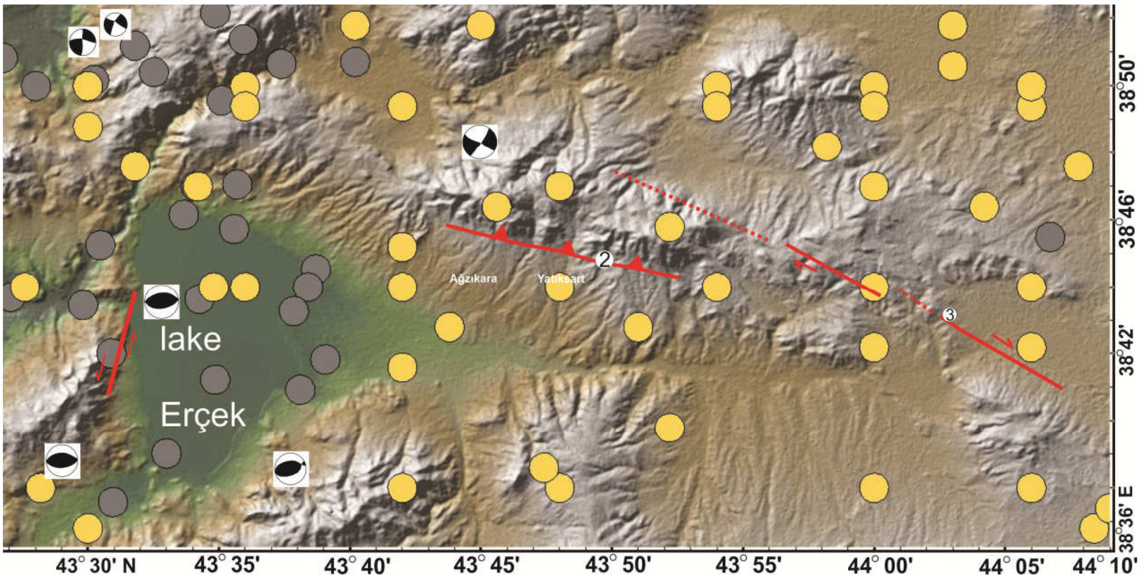

Figure 7. The epicentral distribution of earthquakes at Erçek Lake and surroundings, the yellow (from USGS-United States Geological Survey) and gray (from EMSC-Eastern Mediterranean Seismological Center) points are M ≥ 4 earthquakes along with the fault mechanisms of some earthquakes [27].

4. Discussion and Conclusion

Active faults around both Van Lake and ELB have been mapped in very different types and locations in some studies [38-40]. Accordingly, it should be argued which tectonic sources within the Van Lake basins are effective in basin formation. In addition, the active faulting occurring as blind fault type in the whole region restricted the length of surface rupture observed on the surface. With Mw 7.1 earthquake on October 23, 2011, approximately 20% of the seismogenic strike-slip plane length could be traced on the surface. The mean thrust offset along the fractured fault plane is 4 m around the seismogenic zone, while the surface value is about 10-15 cm [18,19,21,36,41].

The collision tectonics, which started after the subduction tectonism, where the reverse faults were dominant, which allowed the oceanic lithosphere to be delaminated in the region, became as effective as the day-to-day. This allows the deformation elements to form more intensively within the ELB than within the Oligo-Miocene units. The deformational structures in the Oligo-Miocene units more prominent than the Plio-Quaternary have made possible today's active deformation structures of the Van Lake basin as blind. The same situation is also observed in ELB basin. The depression formation, which is defined for the general of the Eastern Anatolian region, takes place as the ramp basins, and there are pull-apart basins developed by strike-slip faulting among the ramp basins. In addition, for the whole Eastern Anatolia, the presence of the extension is mentioned [10,20,41].

The faults near ELB are explained in detail in this study. Accordingly, faults around Van Lake basins consist of reverse faults associated with Bitlis-Zagros suture zone and continental- continental collision. During this collision, both strike-slip and normal faults in the region have been effective in the deformation of the ELB crust. It is stated that normal faults, which are also found in the structural elements around Van Lake in the west of the study area, are generally perpendicular to reverse faults. In this study, the presence of such faults around the ELB has also been identified (see Figure 6c). In addition to being a tectonic basin with faults controlled mainly from the northern margin of ELB, it was indicated that the drainage area around this depression occurred during the last ice age [1].

It is stated that the ELB occurred as ramp basin controlled by Ilıkaynak reverse fault at the northern edge and by the Kozluca normal fault at the western edge [42]. In the ELB, the north margin is a reverse fault, as observed on the surface, and the western margin is a depression bounded by left lateral strike-slip fault. During the tectonic deformation of this depression, the transtensional component of the Kozluca fault at the western edge of the ELB is quite effective. This component also allowed the western edge of Ercek Lake to have a higher slope angle than the eastern edge. In the northern margin, the reverse faulting, which provided the compression of the ELB crust, has enabled the tectonic formation of the whole depression from Oligo-Miocene to present (Figure 8).

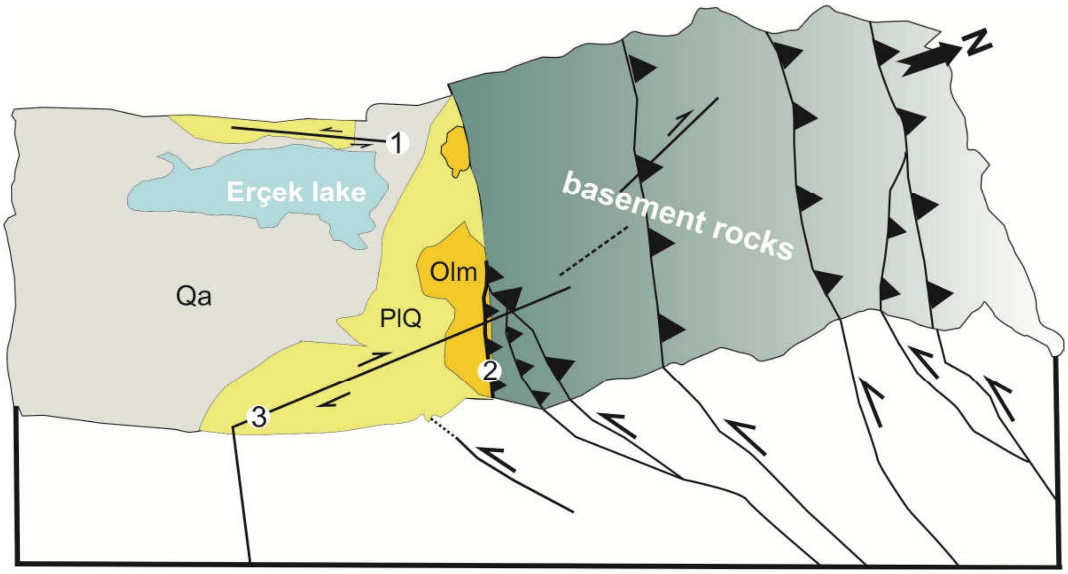

Figure 8. Primary reverse faults involved in the tectonic development of ELB and block diagram showing the strike-slip faults developed along with the reverse faults due to compressed crust.

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