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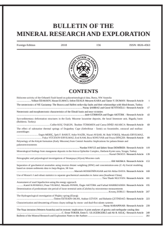

Neotectonic and morphotectonic characteristics of the Elmali basin and near vicinities

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ABSTRACT

Elmalı Basin, which consists of the Elmalı county and some villages, approximately 120 km far from Antalya city, is one of the recent depositional areas in the extensional neotectonic region of southwestern Turkey. The basin provides significant data for the understanding of the geological evolution to record from the basement to recent depositional units. For this reason, these kinds of structures are used to determine the deformations phases for the evolutionary history of basin formation. In the content of the study, following applications have been investigated: (a) mapping of the area and structures in 1/25.000 scale, (b) information about deformation and tectonic activity along the basin margin faults, (c) the distribution of peak ground acceleration (PGA) in case of an earthquake with 6.5 magnitude and (d) morphometric analyzes of the basin to understand the tectonic uplift by using the digital elevation model. The new results combined with existing data imply that the Elmalı Basin has a number of deformation structures and active faults on both western and eastern sites of the basin. Depending on the morphometric indices, western side of the basin created higher uplift ratio compared with the eastern side of the basin.

1. Introduction

The study area Elmalı basin and its near vicinities is the recent depositional area inside the border of Antalya city (Figure 1). In the regional aspect, the area is located on a controversial area where the evolution of Taurus and Isparta Angle have different geological history, the initiation of recent tectonic regime and type of tectonic regime. As it is known from the principals, recent depositional areas are the main target to investigate the tectonic records. In order to understand the recent tectonic and deformational structures, previous discussions are also summarized briefly.

Although the Elmalı basin is located on the II. Degree earthquake zone (AFAD, 1996), there is no active fault according to Map of Active Faults in Turkey (Emre et al., 2013) (Figure 1). Although the lack of active fault in the area, there are historical and instrumental earthquakes around here that is why the study area is in the II. Degree earthquake zone. The most critical point here is that there is no detailed investigation in the study area up to now and probably many geological data are expected to be available because of the existence of recent deposits. Eventually, both the recent sedimentation features and the existence of deformation structures indicate some clues the necessity of detailed investigation in the area during the first field excursion.

In this research, three main objectives are considered. First one is the stratigraphic and tectonic characteristics of the basin fill. 1/25.000 scaled geological map of the study area containing the unit boundaries, boundary relations and deformation structures are examined and mapped. The second objective is to calculate the expected peak ground acceleration (PGA) values derived from a possible earthquake. The values area calculated to provide foreground data for future hazard and risk maps. The last one is the morphometric analyzes to obtain

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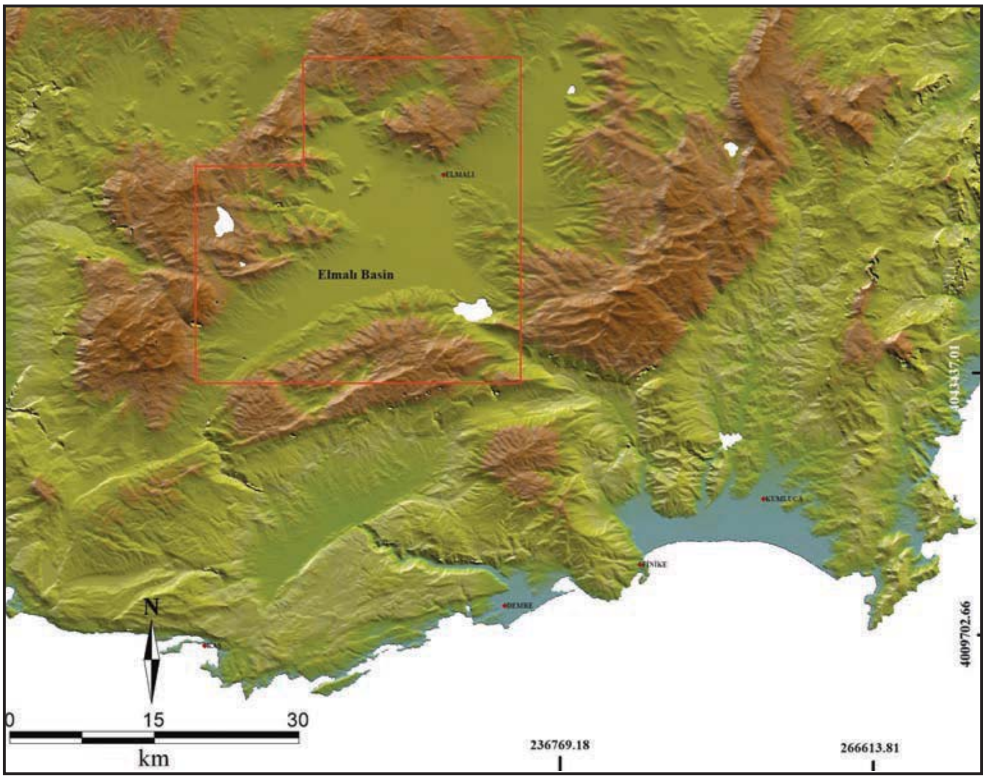


Figure 1- Location map of the study area (red border indicates the target area).

information about the uplift ratio resulted from the tectonic activity of the basin margins by using the digital elevation model.

The Elmalı Basin is a recent depositional area located in the western wings of Isparta Angle, within the western Anatolian extensional neotectonic region. Due to its location and current position, it has great importance to understand the geological evolution of the region (Figure 1).

Studies involving the structural data of the neotectonic period around Elmalı and its vicinities are very limited in the literature. In addition, there are different studies in relation to the paleotectonic evolution of Isparta Angle, especially in the northern part of the basin. Isparta Angle, which is "Λ" shaped morphology, was first described by Blumental (1951, 1963) and two different ideas about the formation of this structure have been put forward. The first one is that it is a structure separating the Taurus into two parts (eastern and western) (Dumont, 1979; Kelling et al., 2005) and another idea claimed that the Taurus mountain formation originates from the twisting of the northward direction to the clockwise and counterclockwise rotation during the Early Paleocene-Early Pliocene (Poisson, 1977; Akay and Uysal, 1985; Kissel and Poisson, 1987; Robertson, 1993; Piper et al., 2002; Poisson et al., 2003).

Moreover, Isparta Angle is issued for controversy about the initiation age of the neotectonic period and the type of recent tectonic regime. A group of scientists think that this structure is still active and deformed by compression regime (Akay and Uysal, 1988; Boray et al., 1985; Barka et al., 1995; Yılmaz et al., 2000; Poisson et al., 2003; Kelling et al., 2005; Alçiçek et al., 2006), on the other hand others argue that it is under the control of the extensional tectonic regime characterized by normal faults (Koçyiğit, 1996; Glover and Robertson, 1998*a*, *b*; Koçyiğit et al., 2000; Koçyiğit and Özacar, 2003; Poisson et al., 2003; Koçyiğit, 2005; Koçyiğit and Deveci, 2007). Previous studies carried out in many basins located inside and outside of Isparta Angle include marine and terrestrial sediments that have deposited in the last phase of the compressional regime. These are Çameli, Acıpayam, Karamanlı, Burdur, Isparta, Senirkent, Dinar, Dombayova–Sandıklı, Karadirek, Sinanpaşa, Haydarlı–Karaadilli, Gelendost, Beyşehir–Yarıkkaya, Şuhut and Akşehir–Afyon (Ercan et al., 1978; Koçyiğit, 1984*a* and 1984*b*; Boray et al., 1985; Karaman, 1986;

Şenel et al., 1989; Price and Scott, 1991; Yağmurlu, 1991; Akgün and Akyol, 1992; Koçyiğit et al., 2000; 2001; Koçyiğit and Özacar, 2003; Alçiçek et al., 2005; Koşun et al., 2009). Without these basins located to the north of Isparta Angle are composed of only terrestrial sediments. The age range of the basin infill varies between Early Miocene and Middle Pliocene (Koçyiğit, 1981; Koçyiğit et al., 2000; Alçiçek vd., 2005; Kelling et al., 2005; Koçyiğit, 2005; Keller and Villari, 1972; Becker-Platen et al., 1977; Besang et al., 1977; Koçyiğit, 1981, 1983, 1984*a*; Ercan et al., 1985: Çevikbaş et al., 1988; Yağmurlu et al., 1997; Erkül et al., 2005; Aldanmaz, 2006). To summarize, there is no complete consensus on the formation mechanism of Isparta Angle and the age of its formation, the types of tectonic regime and its age affecting the region. The circumstance is especially important for the current basins that must be examined and evaluated with the point of view. No detailed mapping of the Elmalı basin, analysis of faults and slip data have been conducted in any of the studies so far. In addition to this, detailed field data about the stratigraphic features of the allochton units, Beydağları autochthonous and nappes in the region (Poisson and Poignant, 1974; Özgül, 1976) and the relationship between Miocene-Recent sediments of some basins in Teke peninsula are given in detail (Brunn et al., 1973; Şenel et al., 1996; Koşun et al., 2009).

Consequently, there are two different ideas about the age of formation for Isparta Angle and the type of recent tectonic regime: (a) The age of Isparta Angle is Late Miocene and the tectonic regime continues without any interruption (Boray et al., 1985; Yağmurlu et al., 1997, Alçiçek et al., 2006; Karaman, 2010); (b) The recent tectonic regime of Isparta Angle are controlled by the extensional forces and the onset age of neotectonic period is Early Quaternary (Koçyiğit, 1996; Glover and Robertson, 1998*b*; Koçyiğit et al., 2000; Koçyiğit and Özacar, 2003; Poisson et al., 2003; Koçyiğit, 2005; Koçyiğit and Deveci, 2007). The types and onset age of the tectonic regime and the deformation phases of the units, which are still controversial in the literature, have been examined based on the deposits around Elmalı basin and significant results have been obtained.

2. Methodology

The primary and fundamental method is to prepare the detailed geological mapping based on observations in the field and to analyze the fault slip data measured from the fault planes with the TENSOR program (Angelier, 1994). Before doing the field study, the literature survey was completed. Then, 1/25.000 scale geological map of the basin was prepared, the fault and deformation structures were measured and analyzed. In addition, morphometric analyzes are carried out to determine the tectonic effect at the watershed boundaries. In order to perform these analyzes, digital elevation model derived from 1/25.000 scale topographic map was produced by using MapInfo 11.5 and Global Mapper 16.0 programs. To determine of geomorphologic evolution and active tectonic structures of the study area, the relationships between rock resistance and topography has been issued to calculate the morphometric indices “Mountain Front Sinuosity (Smf)”, “Valley floor width-to-height ratios (Vf)” and “Stream length-gradient index (SL)”.

Lastly, the PGA values that would occur in the event of an earthquake with magnitude 6.5 are considered using the attenuation relationship formula proposed by Ulusay et al. (2004). This data also carries the quality of base data for future hazard and risk maps.

3. Geology of the Study Area

3.1. Stratigraphy

There are different types of units representing the age range between from Mesozoic to recent within the study area. As mentioned in previous studies, autochthonous and allochthonous units are the subject of different studies especially outside of the study area (Figure 2). The previous studies are generally related to the nappe tectonics and the formation mechanism of Isparta Angle that have prevailed in the region. In this study, contact relations between the current sediments and older depositions in the basin have been revealed.

The Beydağları carbonate platform is overlaid by two different nappe slices. These are named as Lycian nappes in the northwest and Antalya nappes in the east (Brunn et al., 1971; Poisson, 1977; Gutnic et al., 1979; Robertson, 2000). It has been suggested that the Antalya nappes is emplaced from the southeast part of the Beydağları during the Late Cretaceous and Paleocene (Poisson, 1977; Gutnic et al., 1979; Robertson, 2000) and its origin is related to the closure of the southern branch of Neotethys (Robertson et al., 2003;). It is also suggested that the emplacement of Lycian nappes is during the Late Cretaceous and it is in the same location from Langian to present. Thus, the Lycian nappes are related to the closure of the northern limb of the Neotethys (Poisson, 1977).

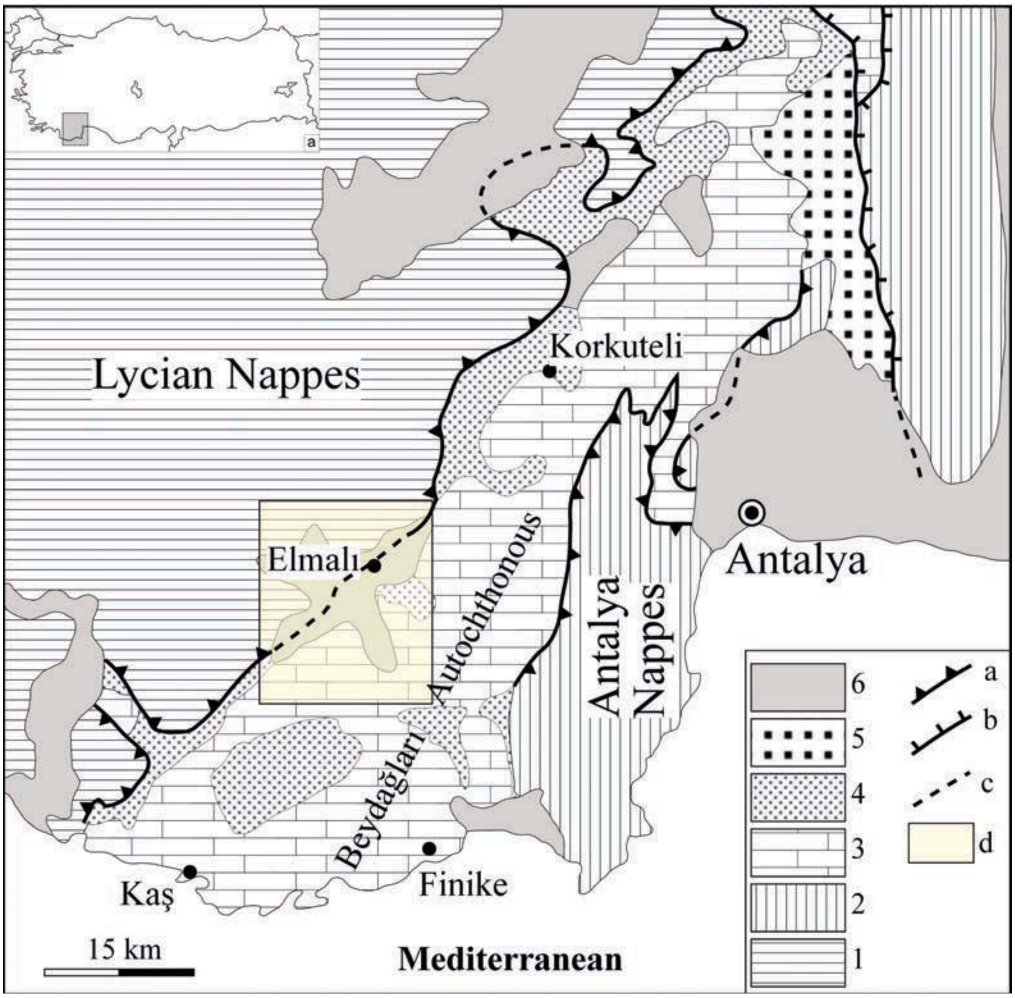


Figure 2- A generalized geological map showing the tectonic units in the study area and surroundings (Hayward, 1982; Meşhur and Akpınar, 1984; Şenel et al., 1992; Aksoy and Aksarı, 2008). 1. Lycian nappes, 2. Antalya nappes, 3. Beydağları autochthonous (Upper Triassic-Oligocene), 4. Beydağları autochthonous (Lower-Middle Miocene), 5. Aksu basin sediments (Lower-Middle Miocene), 6. Plio-Quaternary; a) paleotectonic thrusts, b) Normal faults, c) Possible faults, d) The interested area is shown in figure 3.

Geological features of the Lycian Nappes located in the NW of the Elmalı Basin and also within the boundaries of the study area is subjected to different researches (Hayward, 1982; Aksoy and Aksarı, 2008). According to these studies, Lycian nappes are generally composed of four tectonic slices: Yeşilbarak, Lower, Ophiolite and Upper Nappes. The tectonic slices are separated from each other with low angle thrust faults. The emplacement of Lycian nappes on the Beydağları autochthonous was probably happened in Early Langian, and the reason for emplacement is the shortening in the crust due to compression (Şengör et al., 1984). Studies carried out in the following years emphasize that this last movement of Lycian nappes in the Middle Miocene will not represent crustal compression/contraction and a rootless emplacement has been mentioned (Seyitoğlu et al., 1992; Collins and Robertson, 1998). After the formation of large-scale tectonic events, the development and stratigraphic features of some recent basins have been researched from Miocene to present, but not much information has been obtained in the Elmalı Basin.

The Elmalı Basin located between autochthonous and allochthonous tectonic slices are one of the medium-sized basins on the Teke peninsula, where the recent tectonic regime is controversial. As a result of detailed field excursion, it is seen that a number of units with different ages are located along the margins and within the basin (Figure 3). The uppermost part of the Lycian nappes and the Quaternary sediments were investigated within the scope of the study and their deformations were examined.

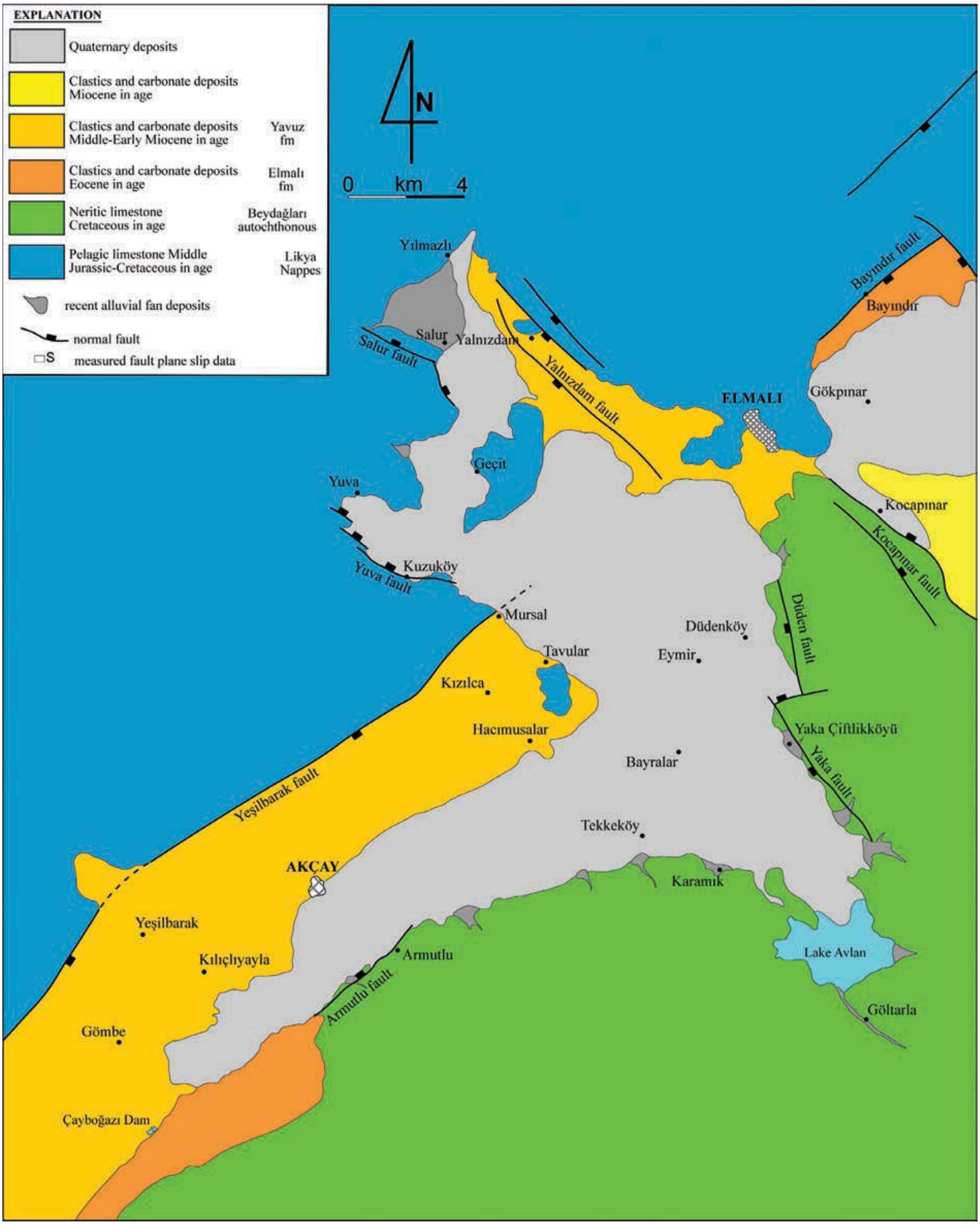


Figure 3- 1/25.000 scale geology map of Elmalı Basin.

The oldest formation of upper nappe is Elmalı formation (Eocene) and named by Önalan (1979). The formation is generally composed of sandstone, claystone and siltstone alternations (Figure 4), and wedge-shaped conglomerate layers at the upper part of the formation.

Yavuz formation is widespread in the area, which is found in the NE and SW parts of the study area (Şenel et al., 1989). The formation consists of clastic limestone in the lower level and claystone, sandstone alternation to the upper level (Figure 5).

Figure 4- Close-up view of the Elmalı formation (looking to NNE).

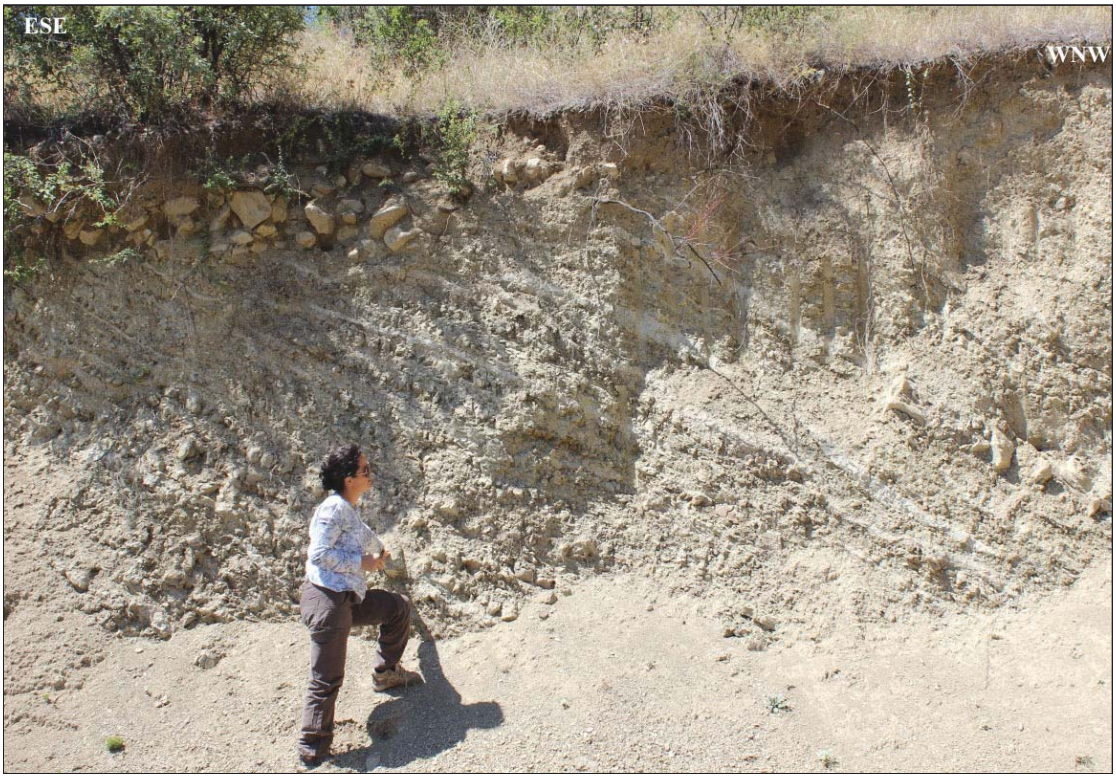


Figure 5- Close up view of Yavuz formation (looking to SSW).

The Elmalı and Yavuz formations belonging to the Yeşilbarak nappe are located along the margins and are also important to identify the recent tectonic regime. Deformation structures related to active basin margin faults and their analysis are presented in the tectonic section. Another formation the Taşkesiği that belongs to the upper nappe is observed along the margins (Figure 6).

The formation consisting of thick massive limestone layers is seen in the north-northwest part of the Elmalı county and shown on the map without being separated by Lycian nappes. Miocene units overlie the gray limestone-clastics alternations of Lycian nappes with unconformably (Figure 7), and the youngest Elmalı basin sediments overlie unconformably on all these units and their deposition is still lasting. Lake Avlan in the southernmost part of the Elmalı Basin shows the water level of the basin and serves the discharge of the water to the south (Figure 8). The relationship of the recent sediments of the Elmalı basin and active faults is presented in the following sections.

Figure 6- Close up view of the Taşkesi formation (looking to S).

Figure 7- Close up view of the Miocene sediments (looking to ENE).

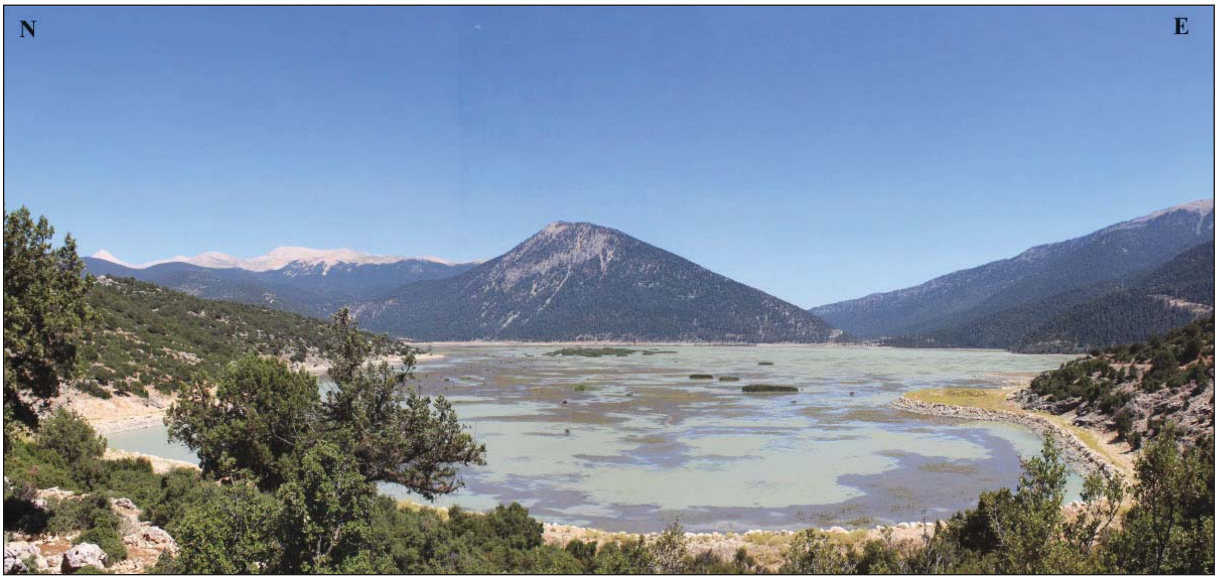


Figure 8- General view of Lake Avlan (looking to E).

3.2. Tectonic Properties

The area is affected under the compressional tectonic regime during the Alpine orogenic process (Colin, 1962; Brunn et al., 1971; Poisson, 1977; Önalan, 1979; Erakman et al., 1982; Akay and Uysal, 1985; Şenel et al., 1987, 1989; Robertson, 1993; Şenel, 1997*a, b, c*), later on it became more complicated after emplacement process of the Antalya nappes on the Beydağları autochthonous during Danian age. In the following phases, the Lycian nappes became active in the Eocene period, and Antalya nappes emplaced in the northwest of the Beydağları autochthonous that finished the nappes activities. The last phase of the Lycian nappes emplacement corresponds to the end of the Middle Miocene (Şenel et al., 1989; Hayward, 1982; Şengör et al., 1984; 1992; Aksoy and Aksarı, 2008). All of the thrusting stages have changed the characters as extensional motions after Upper Miocene and thus the formation of the recent basins started (Şenel, 1997*a, b, c*). One of these basins, Elmalı, is still an active depositional area and the margin faults cut and displace recent deposits accumulated in the basin. The main stress axes have been determined from the paleostress analyses of slip plane data obtained from fault surface. The faults are explained in further part of the text. As it can be seen from the geological map given in figure 3, the active faults in the study area are Düden, Yaka, Yeşilbarak, Yuva, Salur and Yalnızdam faults. These are firstly named and described in this study.

3.2.1. Düden fault

The Düden fault is N-S trending, dipping to W, approximately 4 km length normal fault and eastern boundary of the basin. It defines the contact between the basement and Plio-Quaternary deposits and it is the reason for the brecciation of the basement rocks (Figure 9a). The weathering process results the formation of fault clay (Figure 9b) and the slip data in the fault plane are clearly observed due to the well-protected fault slip lines (Figure 9c). The results of the fault slip data analyses; the Düden fault is a normal fault with ~ 85º rake and locally indicates an extensional in NNE-SSW direction. The extensional direction is compatible with Western Anatolia at the regional scale.

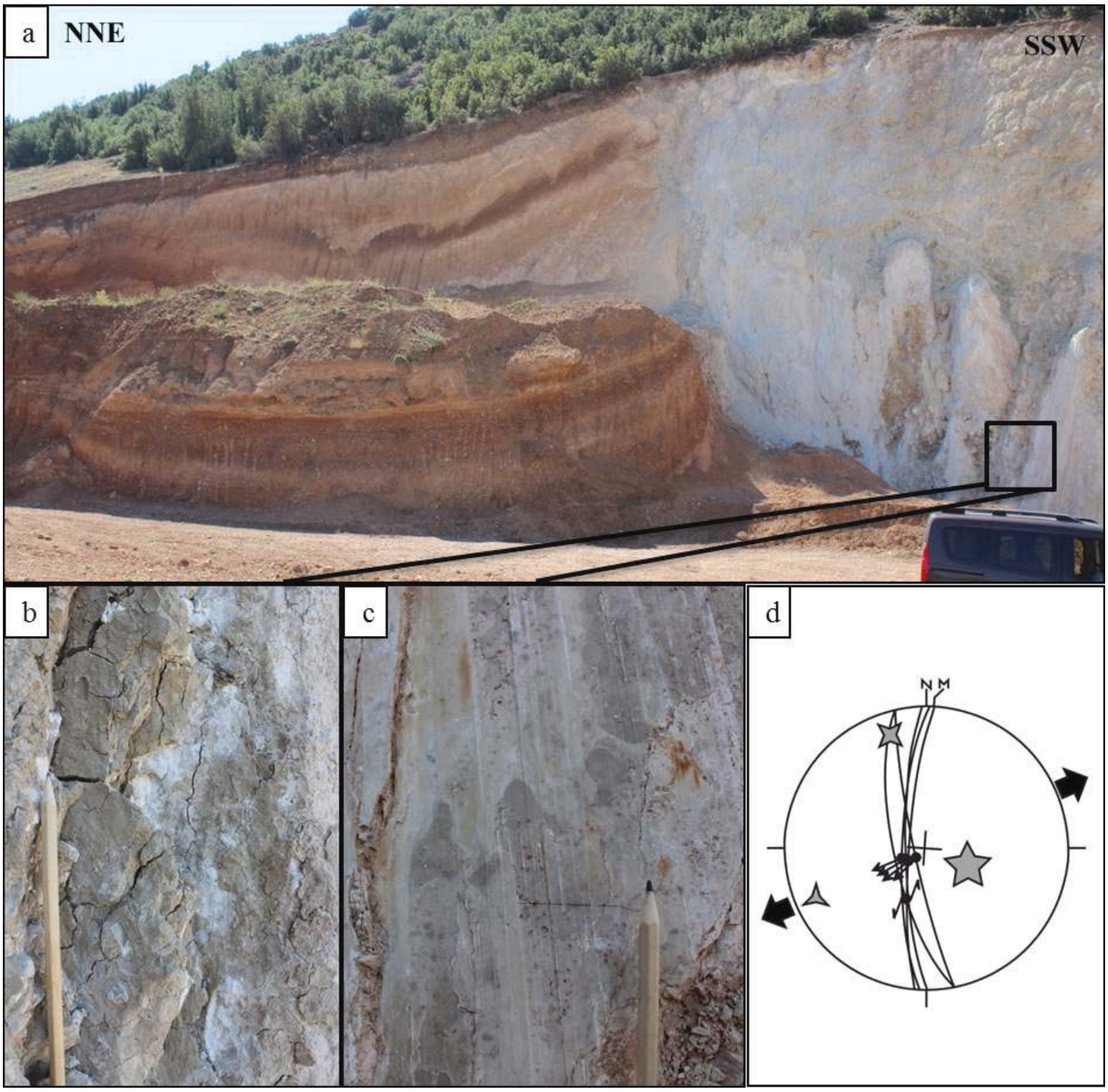


Figure 9- a) The field photograph from the Düden fault is the boundary between the basement and Plio-Quaternary units; b) Close up view of fault clays and slip plane data in the fault zone; c) Close up view of slip lines; d) Paleostress analysis of fault slip data.

3.2.2. Yaka Fault

It is another eastern boundary of the basin. Yaka fault is NNW-SSE trending, 6 km length and located on the east of Yakaçiftlik village. It cuts and displaces the Quaternary units along the eastern margin of the basin and has an important role among the recent structures. Although the Yaka Fault does not have the potential to produce destructive earthquakes, it gives the evidence for the recent activity of the eastern margin of the basin during the Quaternary time. Due to the lack of fine-grained material to record the slip data in the fault zone, a single plane solution is used to stress analyses and a local extension is found in NE-SW direction (Figure 10). The result indicates that the fault is active because it cuts off the recent terrace units and shows a step fault morphology towards the basin.

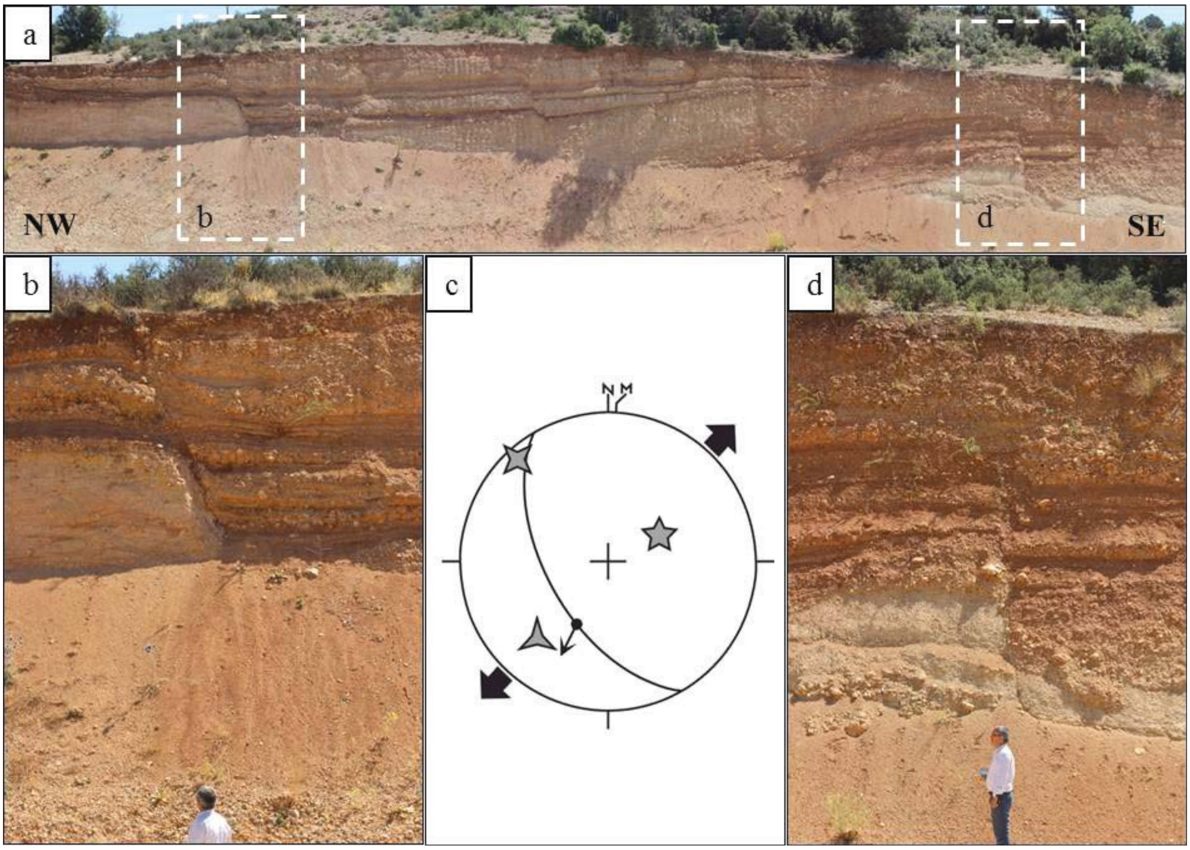


Figure 10- a) General view of the Yaka Fault; b) Close up view of the main branch of the Yaka Fault; c) The paleostress analysis result obtained by using the single plane solution of the Yaka Fault; d) Close up view of second order step like faults of Yaka Fault.

3.2.3. Yeşilbarak Fault

Yeşilbarak Fault is a NE-SW trending, 16 km length normal fault, and NW boundary of the basin (Figure 11a). Although, the Yeşilbarak fault was an important structure between the Lycian nappes and the Beydağları autochthonous during the paleotectonic period (Figure 2), the measured slip data during the neotectonic period and field observations indicate that it is a normal fault displacing the Plio-Quaternary units in the vertical direction. The observation is discussed separately in the discussion part after the morphometric analyzes. Stereographic projection analysis of the slip data (Figure 11b) reveals that the dominant extensional direction is NW-SE.

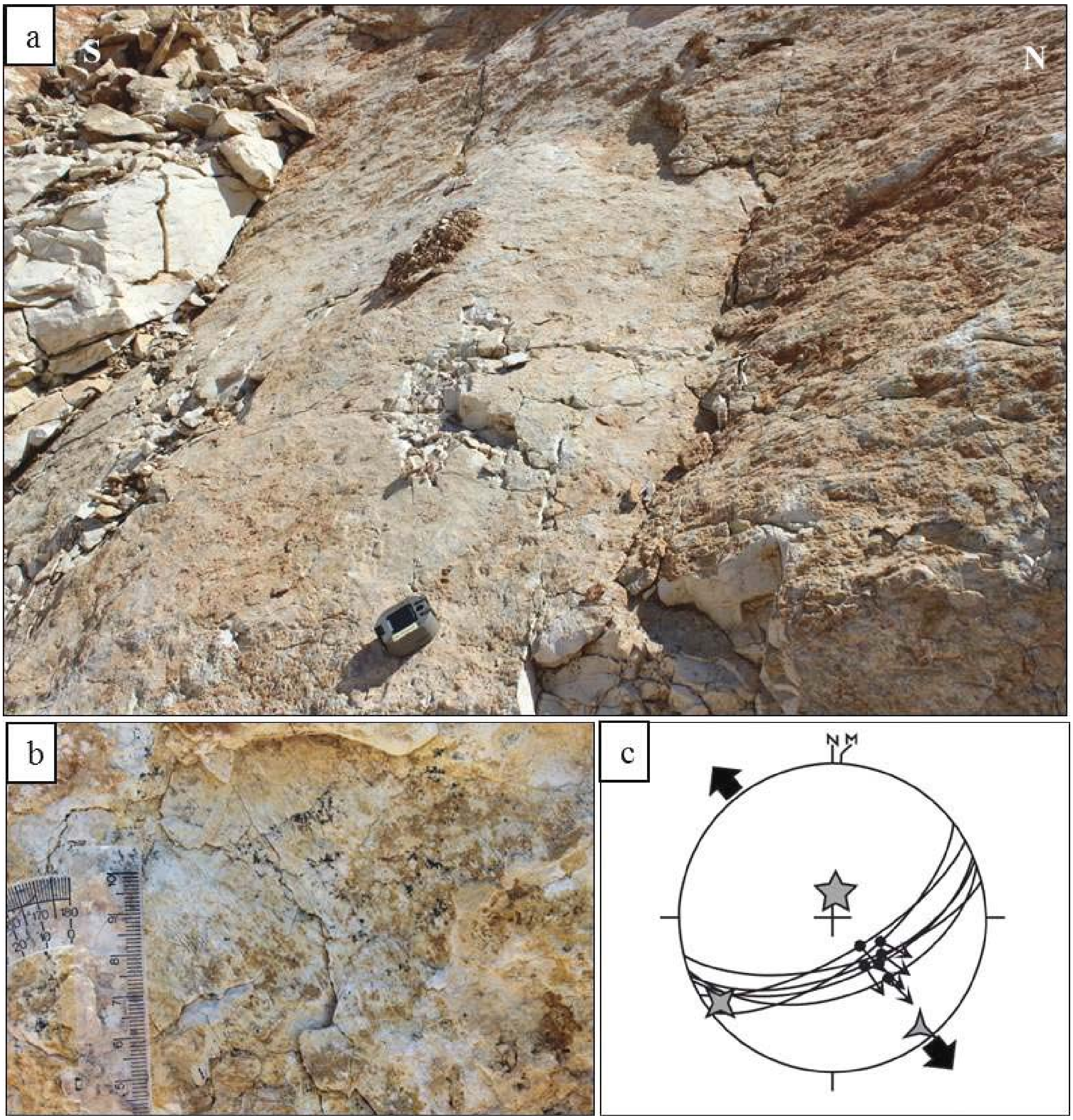


Figure 11- a) General view of Yeşilbarak Fault; b) Close up view of fault slip data; c) Stereographic projection analysis of the Yeşilbarak Fault.

3.2.4. Yuva Fault

Yuva fault that is the northwestern boundary of Elmalı Basin and approximately perpendicular to the Yeşilbarak fault is NW-SE trending, 4 km length and it defines the boundary between basement rocks (pelagic limestone, Likya nappes) and Quaternary units (Figure 12a). Striations on the fault plane is clear after the sloping scree had been removed (Figure 12b). As a result of the slip data analyses, N-S extensional direction is obtained.

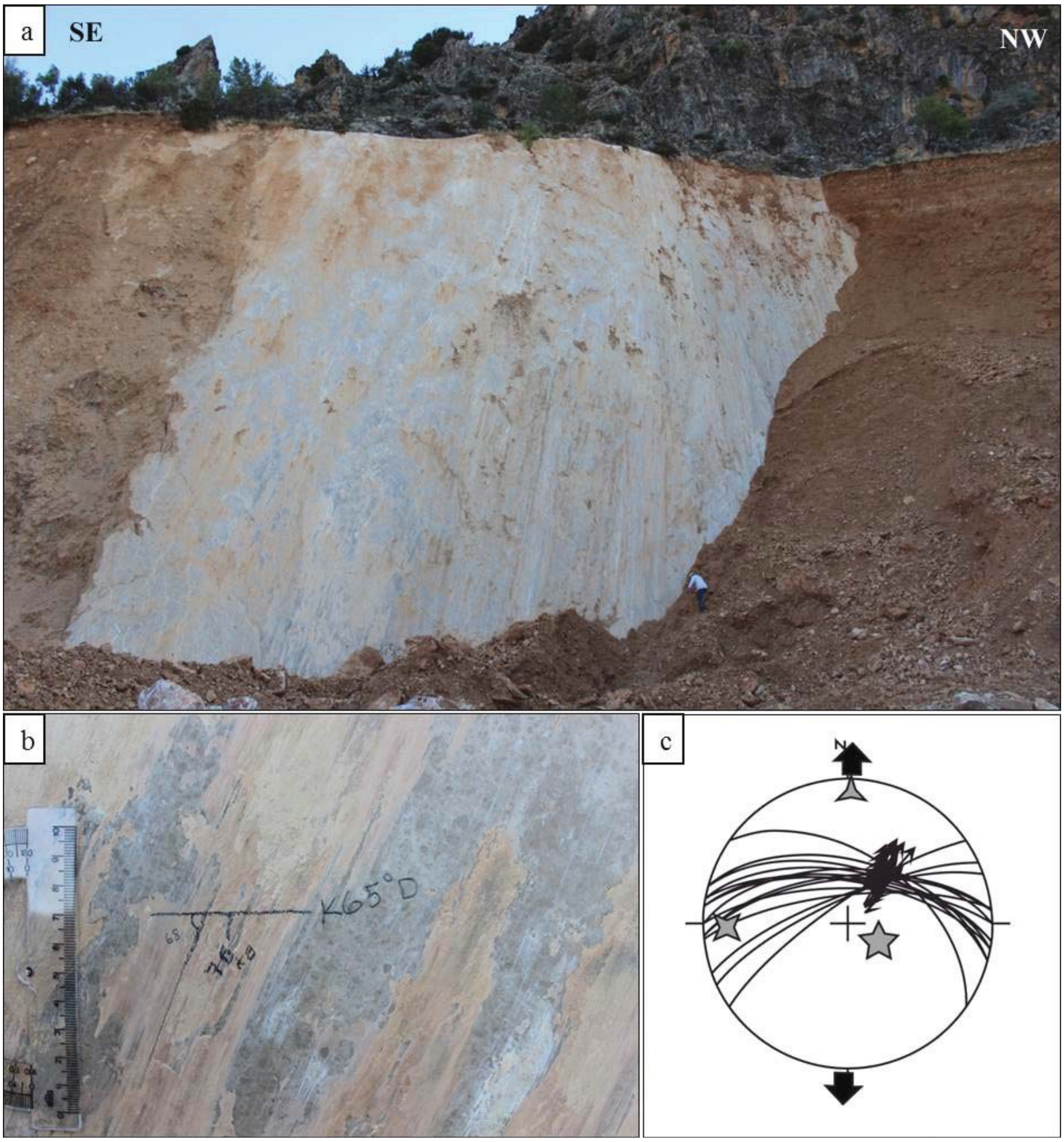


Figure 12- a) General view of Yuva Fault (looking to SW); b) close up view of slip plane data; c) Stereographic projection analysis of the Yeşilbarak Fault.

3.2.5. Salur Fault

Salur fault is NNW-SSE trending, 4 km length, NW boundary of the basin and affects in the initial stage of the basin. The fault is the boundary between Quaternary and basement units (Figure 13). Although the fault plane is observed morphologically, the slip data on the surface cannot be obtained. There is a wide alluvial fan on the hangingwall block and on top of it there is an area of greenhouses due to the sufficient underground water.

Figure 13- General view of Salur fault (looking to NW).

3.2.6. *Yalnızdam Fault*

Yalnizdam fault is NW-SE trending, dipping towards SW, 6 km length normal fault. Step like morphology is identical between the Quaternary and basement units (Figure 14). Even though the trace of fault is observed on the ground surface, slip plane data cannot be found.

Elmalı Basin has been controlled by the active faults having different strike and length. The magnitude of earthquakes and their impact on the settlements that will be caused by some of these faults have been examined in detail below.

Figure 14- General view of Yalnızdam fault (looking to NE).

3.3. Determination of Peak Ground Acceleration

The earthquakes in the Elmalı Basin and its vicinity are examined from 1900 to the present (Figure 15). It is observed that the earthquakes in size 3-4 are common in the region and these earthquakes are distributed in NE-SW direction that is compatible in the general direction of the basin. Coordinate and depth information of them are presented in table 1. The depths of earthquakes are usually shallow and there are no events associated with the crust. The focal mechanism solution of the 4.5 magnitudes in 2010 on the northwestern side of Havran lake indicate that the fault is normal with the lateral component. All of the faults which did not produce an earthquake of destructive magnitude in the instrumental period has the capacity to produce a moderate earthquake. For the reason, it is necessary to consider the probability of an earthquake in hazard maps of the region.

Although any destructive earthquake did not happen recently, the probable earthquake magnitude sourced from the margin boundary faults are calculated Ms=6.3 for the Yeşilbarak fault, Ms=5 for the 4 km Yuva fault, Ms=6.3 for the Yuva and Düden faults and Ms=5.4 for the 7 km Yalnızdam fault (Aydan et al., 2002).

The presence of settlements in and around the Elmalı Basin increases the probable damage and loss of life in case of a medium-sized earthquake. For this reason, the peak ground acceleration values that would occur randomly in different units in the Elmalı basin and the values were calculated for Ms=6.5. The

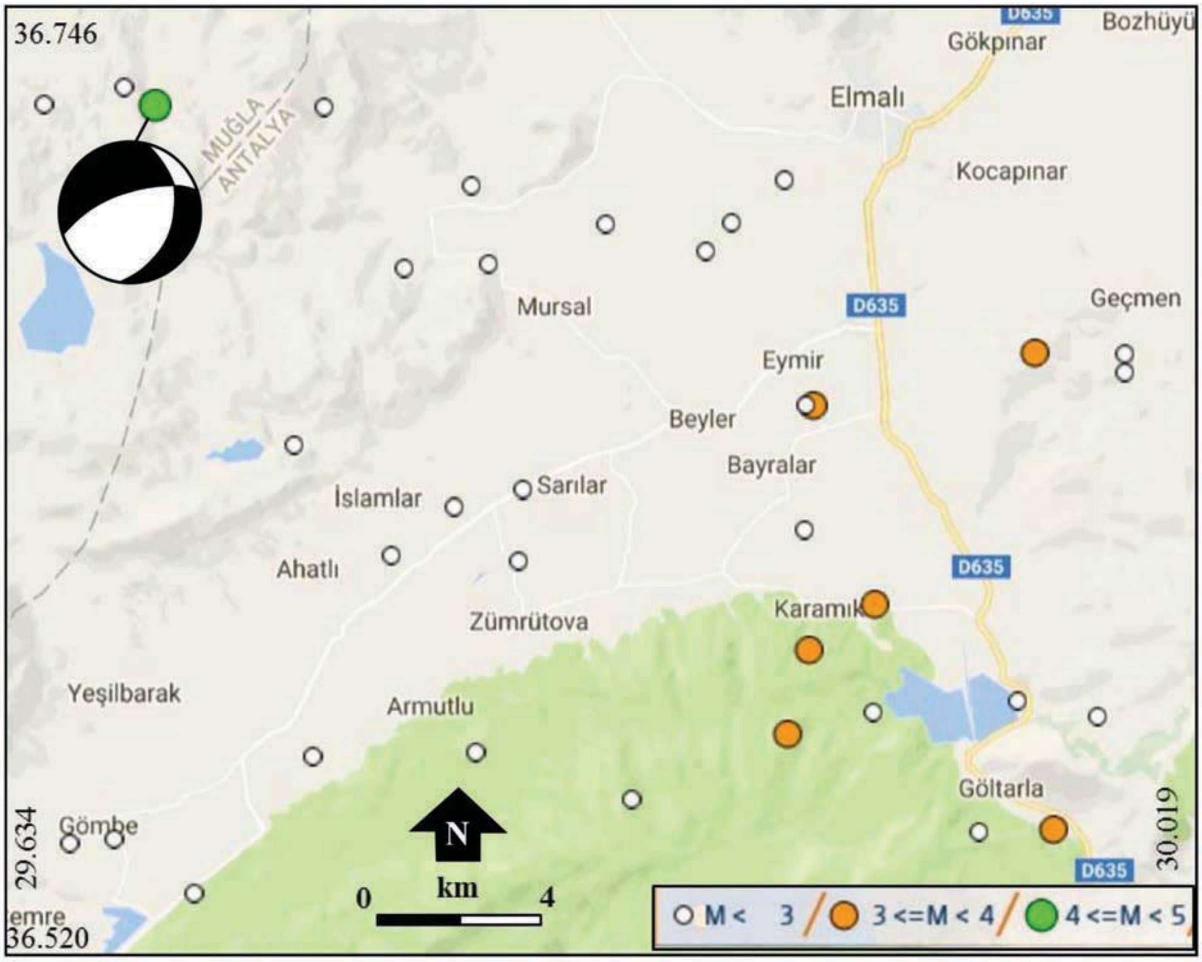


Figure 15- Distribution of recent earthquakes in Elmalı Basin and surrounding areas from 1900 to present (earthquakes from KOERI (2017) and AFAD (2017) catalogs).

Table 1- List of earthquakes between 01/01/1900 - 13/02/2017, 36.520 - 36.746 N and 29.634 - 30.019 E coordinate range, with a magnitude between 0 <= M <10. The earthquake in orange color is shown in figure 15 with focal mechanism solutions.

Date (UTC)	Latitude	Longitude	Depth	Magnitude type	Magnitude	Location
30/12/2016 06:37:39	36.6343	29.8063	7	ML	1.6	ANTALYA-ELMALI
30/03/2016 20:27:57	36.733	29.7428	7	ML	1	ANTALYA-ELMALI
18/09/2015 04:39:56	36.6695	29.999	7.01	ML	1.9	ANTALYA-ELMALI
13/06/2015 03:45:03	36.6958	29.865	7	ML	1.1	ANTALYA-ELMALI
03/05/2015 21:32:27	36.5445	29.6755	7.03	ML	1.5	ANTALYA-KAŞ
04/04/2015 04:37:54	36.624	29.8965	7.09	ML	1.6	ANTALYA-ELMALI
16/08/2014 18:45:44	36.5433	29.661	6.92	ML	1.4	ANTALYA-KAŞ
01/07/2014 11:21:49	36.668	29.97	49.8	Mw	3.5	ANTALYA-ELMALI
23/04/2014 16:12:35	36.5656	29.7388	7.52	ML	1.4	ANTALYA-ELMALI
16/04/2014 00:43:31	36.5761	29.9901	62.27	ML	2.3	ANTALYA-ELMALI
06/04/2014 02:01:26	36.6563	29.8971	7	ML	1.8	ANTALYA-ELMALI
18/11/2013 20:52:19	36.6457	29.733	6.99	Ml	2.1	ANTALYA-ELMALI
04/09/2013 11:29:16	36.577	29.9183	6.97	Ml	2.2	ANTALYA-ELMALI
06/08/2013 20:16:39	36.5463	29.9523	6.88	Ml	2.2	ANTALYA-ELMALI
13/03/2013 01:06:54	36.5303	29.701	7.22	Ml	1.9	ANTALYA-KAŞ
09/03/2013 23:07:57	36.5802	29.9647	7	Ml	2	ANTALYA-ELMALI
11/01/2013 07:26:34	36.7028	29.8327	6.99	Ml	2.6	ANTALYA-ELMALI
10/01/2013 03:34:27	36.5668	29.7912	6.9	Ml	2.9	ANTALYA-ELMALI
27/02/2011 05:22:15	36.6177	29.7642	7	Md	2.4	ANTALYA-ELMALI
14/07/2010 08:12:14	36.7143	29.8898	7	Md	2.5	ANTALYA-ELMALI
31/05/2010 17:55:21	36.5547	29.841	7.14	Md	2.7	ANTALYA-ELMALI
27/05/2010 00:16:00	36.738	29.6785	7	Md	2.7	MUGLA-FETHİYE
26/05/2010 18:57:14	36.6912	29.7683	7	Md	2.5	ANTALYA-ELMALI
26/05/2010 18:35:59	36.6302	29.7845	7	Md	2.6	ANTALYA-ELMALI
26/05/2010 17:53:17	36.6925	29.7952	7	Md	2.6	ANTALYA-ELMALI
26/05/2010 15:29:26	36.6162	29.8048	7	Md	2.6	ANTALYA-ELMALI
26/05/2010 15:14:13	36.703	29.8733	7	Md	2.6	ANTALYA-ELMALI
26/05/2010 14:37:11	36.5915	29.8978	30	Md	3.1	ANTALYA-ELMALI
26/05/2010 14:22:21	36.7312	29.6883	20.66	Ml	4.5	ANTALYA-ELMALI
02/07/2009 07:05:40	36.6035	29.9187	6.68	Md	3	ANTALYA-ELMALI
09/11/2008 12:55:57	36.6645	29.999	6.43	Md	2.8	ANTALYA-ELMALI
07/03/2008 10:44:13	36.6545	29.8992	6.84	Md	3.3	ANTALYA-ELMALI
07/02/2007 06:25:13	36.5455	29.9759	28.93	Md	3.4	ANTALYA-ELMALI
05/10/2005 10:56:49	36.5701	29.891	30.1	Md	3.6	ANTALYA-ELMALI
28/07/2005 23:48:30	36.7126	29.7899	2.44	Md	2.8	ANTALYA-ELMALI
28/12/2004 00:01:20	36.7334	29.6528	9.29	Md	2.8	MUĞLA-FETHİYE

magnitude value has been converted from Ms to Mw based on the formula given below (Aydan et al., 2002) (Figure 16).

$$M_w = 0.6798M_s + 2.0402$$

$M_w = 6.5$ is calculated.

Then, peak ground acceleration (PGA) values that will occur as a result of such earthquake will be calculated by using the following formula.

$$PGA=2.18\ e^{0.0218(33.3M_W - Re + 7.8427S_A + 18.9282S_B}$$

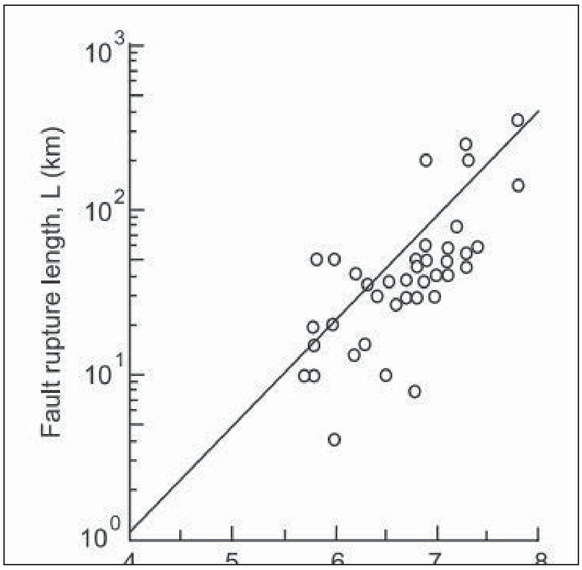


Figure 16- The relationship between Ms and surface rupture (Aydan et al., 2002).

S_A and S_B the values defining the rock or soil types (Ulusay et al., 2004). Where;

$S_A = S_B = 0$ basement rocks (hard rock),

$S_A = 1$ and $S_B = 0$ soil (Miocene units)

$S_A = 0$ and $S_B = 1$ loose units (Plio-Quaternary and alluvial deposits)

Re = the distance between fault and control points

According to the distribution of PGA values, PGA=0.35 g for recent basin fill, PGA=0.27 g for Miocene units and PGA=0.23 g for basement rocks. The closets settlements are chosen as control points. Briefly, PGA values indicate that if a moderate earthquake happens around the Elmalı basin, the result can be harmful for the people.

4. Morphometric Analyses of Elmalı Basin

Morphometry is defined as the quantitative measurement of the landscape. Morphometric analyzes are especially carried out in order to reveal the geomorphological features along the river basins. The geomorphological features of the basin are calculated by using digital elevation model and the obtained results are transformed into morphometric indices to be meaningful for tectonics. Each parameter sets a different characteristic of the basin and determines its impact on basin development (Schumm, 1986; Keller and Pinter, 1996). In this study, the valley floor width to valley height ratio (Vf), mountain front sinuosity (Smf) and the stream length-gradient index (SL) are calculated to determine whether the formation of the Elmalı Basin is tectonically controlled or not. The indices are determined for 4 different valleys (A, B, C, D) and for Smf value (1, 2, 3) for 3 different mountain front areas (Figure 17).

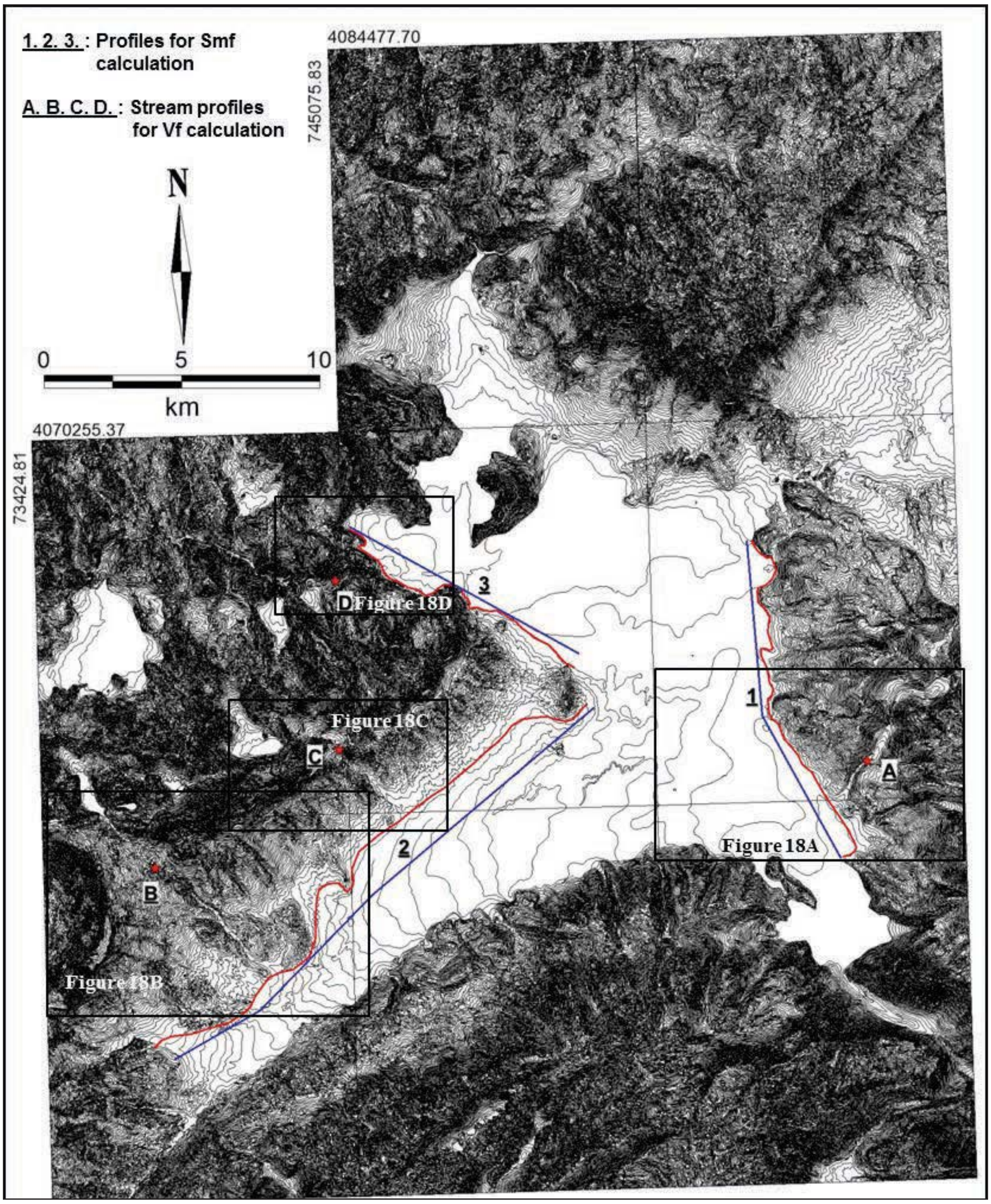


Figure 17- Map showing the contours of the study area and the locations of morphometric indices. Vf for A, B, C and D; Smf indices for 1, 2 and 3 are calculated.

4.1. The Valley Floor Width to Valley Height Ratio (Vf)

The index provides a distinction between the relatively high Vf value for wide valley floor and the low Vf value for V-shaped valleys. Low Vf values generally indicate that there is a significant relationship between deep valley and the tectonic effect, which is associated with elevated and actively digging valleys, while high Vf values indicate relatively low tectonic effect due to the relationship with low upward rate (Bull and McFadden, 1977; Rockwell et al., 1984; Keller and Pinter, 1996). The determined Vf value ranges and their results are given in table 2.

Table 2- Vf values ranges and their meanings.

Range of values	Identifications
Vf ≤ 0.5	High tectonic activity
1 < Vf < 0.5	Moderate tectonic activity
Vf ≥ 1	Low tectonic activity

The Vf value is calculated using the following formula;

$$Vf = 2Vfw/[(Eld - Esc) + (Erd - Esc)]$$

where;

Vf: **T**he **V**alley **F**loor width to **V**alley **H**eight ratio

Vfw: the width of the valley floor

Eld: elevations of the left-hand valley

Erd: elevations of the right-hand valley

Esc: the elevation of the stream channel or valley floor

For the Elmalı Basin, Vf calculations were made in the Akarca (A), Çayır (B), Gavurçay (C) and Değirmen (D) sub-basins respectively.

The calculated values along the profiles taken perpendicular to the A, B, C and D stream valleys with a range from 0.09 to 0.75 (Figure 18, Table 3). The Akarca stream flowing towards the SW in the footwall block of Yaka fault, which controls the eastern part of the basin; the Çayır and Gavurçay streams flowing towards the east in the footwall block of Yeşilbarak Fault, which controls the western part of the basin; and Değirmenderesi stream in the footwall block of Yuva fault indicate that the Vf values are dominantly lower than 0.5. Vf values are plotted along the streams, it increases as move away from the basin, revealing that the tectonic effect increases in the basin (Table 3).

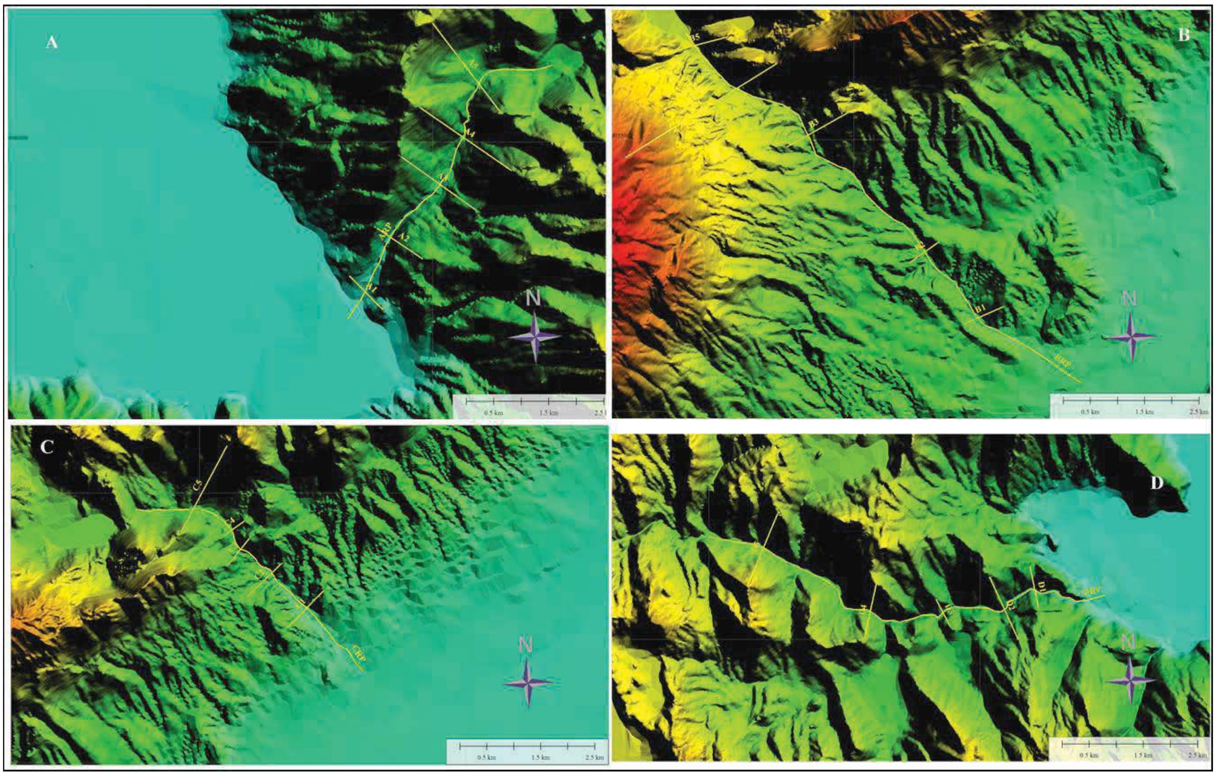
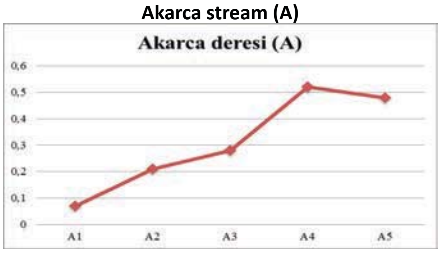
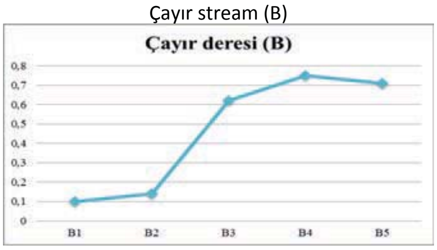
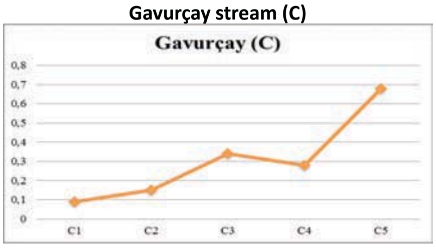
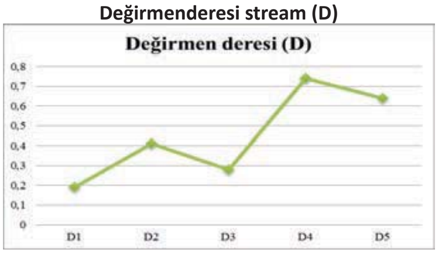


Figure 18- Digital elevation models (A1-A5 and B1-B5) showing stream profiles (RP) and a cross-section taken is perpendicular to the valleys with morphometric analysis.

Table 3- Calculated Vf values and the graphs to indicate the changes in the basin.

Profile name		Vf	Towards the basin center
A			Akarca stream (A) 
	A1	0,07	
	A2	0,21	
	A3	0,28	
	A4	0,52	
	A5	0,48	
B			Çayır stream (B) 
	B1	0,10	
	B2	0,14	
	B3	0,62	
	B4	0,75	
	B5	0,71	
C			Gavurçay stream (C) 
	C1	0,09	
	C2	0,15	
	C3	0,34	
	C4	0,28	
	C5	0,68	
D			Değirmenderesi stream (D) 
	D1	0,19	
	D2	0,41	
	D3	0,28	
	D4	0,74	
	D5	0,64	

4.2. Mountain Front Sinuosity (Smf)

The Mountain front sinuosity (Smf) is used to define the effect of tectonics in the basin development processes and compared with the Vf value (Rockwell et al., 1984; Silva et al., 2003). The low values of the Smf indices, one of the effective methods used for the determination of tectonic activity, indicate high tectonic effect while the high values indicate the low tectonic effect and increased erosion effect. The meaning of the Smf results are shown in table 4. Smf value is calculated by the following formula;

Table 4- Smf values and their meanings.

Range of values	Identifications
Smf = 1	High tectonic activity
Smf > 1	Low tectonic activity

$$Smf = Lmf / Ls$$

where,

Lmf = the total length of the mountain front (red lines in figure 17)

Ls = the straight line length of the mountain front along the Lmf (blue lines in figure 17).

The Smf value for the **1**, **2** and **3** mountain fronts are calculated (Figure 17, Table 5). As is evident from the Smf values, the degree of tectonic activity is clearly obtained at the basin margins, suggesting that the tectonic activity at the different edges of the basin has a similar rate.

Table 5- Calculated mountain front sinuosity (Smf) (for location look at figure 17).

Profile name	Smf
1	1.18
2	1.12
3	1.17

4.3. The Stream Length-Gradient Index (SL)

The Stream Length-Gradient Index (SL) is calculated to assess the relationship between possible tectonic activity, rock resistance and topography along a valley (Hack, 1973; Keller and Pinter, 2002). The range of values and their representations in the literature for the SL value are listed in table 6. The index is calculated by the following formula;

$$SL=(\Delta H/\Delta L)L$$

where;

ΔH: the change in elevation of the reach,

ΔL: the length of the reach,

L: the total length from midpoint of the reach of interest upstream to the highest point on the channel

Table 6- SL value ranges and media properties they represent.

Range of values	Identifications
$SL \geq 500$	The existence of high resistant rocks and/or high tectonic activity
$300 \leq SL < 500$	The existence of moderate resistant rocks and/or moderate tectonic activity
$SL < 300$	The existence of low resistant rocks and/or low tectonic activity

SL values were calculated for A, B, C and D drainages where Vf values were calculated (Figure 17, Table 7). The results of the analysis show that the tectonic activity in the study area is moderate.

Table 7- Calculated SL values.

Stream profiles for SL	SL
A	329
B	401
C	335
D	341

The results of the morphometric analysis based on digital elevation model in the study area reveal the effectiveness of tectonic activity along the valley profiles. The most important point to be emphasized here is that, considering the age of the units, the rate of rising is not high, but the effect of tectonic activity appears in the region.

5. Discussion and Conclusion

The Elmalı Basin which is located about 120 km far from Antalya is a recent depositional basin, forming under the control of NE-SW trending normal faults and it is between the neritic limestones of the allochthonous Lycian and the autochthonous Beydağları nappes. Some previous scientific studies related to the paleotectonic evolution of nappes tectonism is not the main topic of this study but they are summarized inhere. Besides, the main aims of the study;

- detailed geological mapping and stratigraphic properties of Quaternary tectonic activity of the basin,
- analysis of the slip plane data was performed and the effective stress distributions were determined,
- peak ground acceleration values on the different soil types due to a moderate earthquake were calculated and
- morphometric indices were calculated in order to determine the relationship between tectonics and morphology.

According to the Turkey Active Fault Map (Emre et al., 2013), which was renovated in 2013, no active faults bounding the Elmalı Basin are observed. However, the active faults have been determined and mapped as a result of the detailed field study, which cut and displaced the recent deposits. These are Düden, Yaka, Yeşilbarak, Yuva, Salur and Yalnızdam faults and the results of measurement and analysis of fault slip data, the dominant characters of them are normal faulting. Slip plane data belonging to the NW-SE trending Salur fault between the basement and recent units and NW-SE trending Yalnızdam fault between Miocene and recent deposits could not be observed during the field study. On the other hand, fault planes and slip plane data ENE-WSW extensional direction in N-S trending Düden fault, NE-SW extensional direction in NW-SE trending Yaka fault, NW-SE extensional direction in NE-SW trending Yeşilbarak fault and N-S extensional direction in E-W trending Yuva fault were measured and analyzed. These data prove Quaternary activity of the faults. Paleostress analyses from the active fault in the study area is compatible with the regional extensional direction in Western Anatolia which is the approximately N-S direction. Some incompatibilities for the regional extension direction are the results of uneven fault traces and some local anomalies. In addition, there is no moderate or destructive earthquake during the instrumental period so no focal mechanism solution in the study area. Despite that the extensional tectonic regime has many evidences for the normal faulting in the study area.

The lack of devastating earthquake in and near the basin does not mean that a destructive earthquake will not affect the settlement in the area. For the reason, peak ground acceleration (PGA) values are calculated based on 20 km distance and Mw=6.5 magnitude earthquake. The PGA values emerge; 0.35 g for recent basin fill, 0.27 g for Miocene units and 0.23 g for the basement. It is obvious that the damage will be increased in the settlements villages around the basin. As general conclusion based on the earthquake potential of the area is that the slip rate of the study area is slow.

Geomorphological analyzes are carried out in order to determine the effect of tectonism in the formation of the Elmalı Basin and its structures within the scope of this study. The most important effect on the formation of surface morphology is stream pattern, which shows significant features depending on tectonic movements. In this study, three different parameters are used. These are the Vf, the Smf and the SL. Both Vf and Smf values indicate that the western margin of Elmalı basin is more active than the eastern margin. According to Vf, Smf and SL analyze made in 4 different sub-basins, the basins are asymmetric and younger basins.

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